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APPENDIX A
BASIN POINT OF CONTACT AND MAILING ADDRESS

APPENDIX A

Contact information for Plan Manager and GSA Mailing Address (Reg. § 354.6):

MGA's plan manager is:

Sierra Ryan, Water Resources Planner
County of Santa Cruz Environmental Health
Health Services Agency
701 Ocean Street **|** Room 312 | 831.454.3133
Sierra.Ryan@santacruzcounty.us
www.midcountygroundwater.org

MGA mailing address is:

Santa Cruz Mid-County Groundwater Agency
c/o Soquel Creek Water District
Attention: Board Secretary
5180 Soquel Drive
Soquel, CA 95073

APPENDIX B

SUMMARY OF PUBLIC COMMENTS RECEIVED ON THE DRAFT GSP AND RESPONSES

APPENDIX B – COMMENTS RECIEVED

Draft Groundwater Sustainability Plan – Public Comments Received		
ID and Commenter	Document Type and Date	Separate Attachments
1. The Nature Conservancy	Letter dated 9/9/2019	Attachments A, B, C, D & E
2. NOAA - National Marine Fisheries Service	Letter dated 9/10/2019	
3. California Department of Fish and Wildlife	Letter dated 9/12/2019	
4. Audubon California; Clean Water Action and Clean Water Fund; Local Government Commission; The Nature Conservancy; Union of Concerned Scientists	Letter dated 9/19/2019	Appendix A
5. Jerome Paul	Letter dated 9/19/2019[1]	
6. Soquel Creek Water District	Letter dated 9/19/2019	
7. Becky Steinbruner	Email 8/14/2019	
8. Becky Steinbruner	Email 8/28/2019	
9. Becky Steinbruner	Email 8/29/2019	
10. Ramona Andre	Email 9/14/2019	
11. Richard Andre	Email 9/14/2019	
12. Cliff Bixler	Email 9/16/2019	
13. Larry Freeman	Email 9/16/2019	Attachment
14. Becky Steinbruner	Email 9/17/2019	
15. Scott McGilvray	Email 9/18/2019	2 Attachments
16. Linda Wilshusen	Email 9/18/2019	
17. Debra Wirkman	Email 9/18/2019	
18. Tom Butler	Email 9/19/2019	
19. Douglas Deitch	Email 9/19/2019	13 Attachments
20. Douglas Deitch	Email 9/19/2019	2 Attachments
21. Erica Stanojevic	Email 9/19/2019	Attachment
22. Becky Steinbruner	Email 9/19/2019	
23. Becky Steinbruner	Comment Card dated 1/17/2019[2]	
24. Becky Steinbruner	Comment Card dated 1/17/2019[2]	
25. Becky Steinbruner	Comment Card dated 1/18/2019[2]	
26. Craig	Comment Card dated 7/20/2019	
27. Becky Steinbruner	Comment Card dated 7/22/2019	
28. Becky Steinbruner	Comment Card dated 7/22/2019	
29. Becky Steinbruner	Comment Card dated 7/22/2019	
30. Michael M.	Comment Card undated[2]	
31. Becky Steinbruner	Oral Comment 9/19/2019	
[1] Draft GSP comment letter hand delivered at 9/19/2019 MGA Board Meeting during another agenda item. [2]Draft GSP comment cards were not produced and available until the July 18, 2019 MGA Board meeting		

See Draft Groundwater Sustainability Plan Public Comments here.

Draft Groundwater Sustainability Plan – Public Comments & Responses

Comment Theme	Main point(s)	Comment ID[1]	Comments Resulting in GSP changes
Beneficial Users	Concerns regarding adequate representation	1, 4, 27	1, 4, 27
	Disadvantaged Communities	2, 4	2, 4
Committees	Composition of Committees	1, 4, 22, 27	1, 4, 22, 27
	GSP Advisory Committee did not develop its own recommendations for MGA board (rubber stamp)	27	27
Document Presentation	Document organization is confusing, lack of Table of Contents	8, 27	
Fees/Raftelis	Private Pumper Future Fees & Raftelis White Paper	25, 28	25, 28
GW Modeling	Pumping, modeling and groundwater levels	29	29
	Water Budget/climate change	4, 6	4, 6
Mapping	Add elements to maps	1, 3, 4	1, 3, 4
Monitoring	Stream gage monitoring cost critique	13	13
	Stream monitoring text review and proposed technique	1, 2, 3, 4, 13	1, 2, 3, 4, 13
	Monitoring network	1, 2, 3, 4, 6, 31	10, 11, 12, 18, 26, 30, 31
Outreach	July & August 2019 GSP oral presentation criticisms	9, 10, 26	
	Communications and Engagement Plan	4	4
Projects & Mgmt. Actions	Support Pure Water Soquel (PWS)	12, 18	
	Oppose PWS	10, 11, 26	
	Questions about projects and management actions	5, 15, 25, 30	5, 15,
	Criticism of project analysis	5, 15	
	Clarify project description	13, 16	13, 16
	Clarify project costs or assumptions for ASR	16	16
	Fails to adequately assess project alternatives	5, 15, 21, 23, 24	5, 15, 21, 23, 24
Public Comment	Public comments on Draft GSP should be made available to the public verbatim	22, 23, 31	
	Extend public comment period by 60-days (Nov. 8)	21	
Overall	GSP is inadequate	5, 21	21
	State should manage Basin	19, 20	
	Basin boundary concerns	1, 22	1
	Typos/corrections	13	13
References	References not available; lack of citations	1, 2, 4, 8, 14, 16, 21, 27	1, 2, 4, 8, 14, 16, 21, 27

[1] ID from comment table included in *Compiled Comments on the Draft GSP* found here or www.midcountygroundwater.org/sites/default/files/uploads/Draft_GSP_Public_Comments_2019-1004.pdf

Comment Theme	Main point(s)	Comment ID[1]	Comments Resulting in GSP changes
Surface Water Sustainable Management Criteria	Poor correlation between stream flow and GW levels	1, 2, 3, 4, 6	1, 2, 3, 4, 6
	Limitations in existing GW & SW monitoring network	1, 2, 6	1, 2, 6
	Concerns regarding stream flow estimate and Basin impacts	2, 4, 6	2, 4, 6
	Groundwater Dependent Ecosystems (GDE) definition criteria/resources used and GDE management	1, 4	1, 4
	Effects on Environmental Beneficial Users & GDE	1, 4, 6	1, 4, 6
	Concerns re SW & GW modeling adequacy/calibration	1, 2, 6	1, 2, 6
Water Quality	Water quality comments	7, 8, 10, 11 12, 14, 18, 17, 26 30	7, 8, 10, 11 12, 14, 18, 17, 26, 30

Continued

[1] ID from comment table included in *Compiled Comments on the Draft GSP* found here or www.midcountygroundwater.org/sites/default/files/uploads/Draft_GSP_Public_Comments_2019-1004.pdf

APPENDIX C

SUMMARY LIST OF PUBLIC MEETINGS AND OUTREACH

APPENDIX C

List of Public Meetings and Outreach

Topic	Detail
Public Meetings	• 12 private well owner/stakeholder meetings between May 2014 and June 2018 • 6 informational sessions between October 2017 and April 2019 • 2-hour community drop-in sessions every other month since 2016 • 20 GSP Advisory committee meetings between October 2017 and June 2019 • 2 GSP Workshops and 1 GSP Q&A Session planned between July 2019 and August 2019 • 37 MGA, SAGMC, BIG, GSA FC meetings between February 2014 and November 2019
Postcard Mailings and letters	• June 2019 – GSP Survey and Plan update to all Basin residents and owners • March 2018 – GSP update to private well owners and small water systems • June 2017 – GSP update meeting to private well owners and small water systems • January 2017 - GSP update meeting to Basin agricultural and commercial pumpers • December 2015 – GSP update meeting to private well owners
Survey	• June 2019 - GSP outreach mechanism and to inform future MGA outreach efforts • Nov 2017 to May 2018 - Private well owner outreach to inform GSP planning process
Email List-Serve	• Monthly E-newsletter to approximately 650 unique email addresses, including interested parties
Brochure	Targeted at rural users mailed to all private well owners and small water systems
Open House	3 GSP Open House events during Draft GSP public comment period
Road Signs	4 message boards placed at prominent thoroughfares before meetings and events
Public MGA Board Meetings	37 public Board meetings between February 2014 and November 2019 for MGA, and predecessor agencies
GSP Advisory Committee	Total of 20 monthly public meetings from October 2017 through June 2019
Surface Water-Groundwater Working Group	4 Surface Water Working Group meetings consisting of GSP Advisory Committee participants, resource agencies, local planning agencies, and environmental groups.
Tabling and Presentations	Connecting the Drops, Water Harvest Festival, presentations and conferences
Website	midcountygroundwater.org
Miscellaneous	Newspaper articles/editorials, social media through partner agencies, handouts, tour, tabling events

APPENDIX 1-A

SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY JOINT EXERCISE OF POWERS AGREEMENT

Also available at:

http://www.midcountygroundwater.org/sites/default/files/uploads/Signed%20JPA%20Effective%20March%2017%202016.pdf

JOINT EXERCISE OF POWERS AGREEMENT

by and among

CENTRAL WATER DISTRICT

CITY OF SANTA CRUZ

COUNTY OF SANTA CRUZ

and

SOQUEL CREEK WATER DISTRICT

creating the

SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY

March 17, 2016

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JOINT EXERCISE OF POWERS AGREEMENT
OF THE SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY

This **Joint Exercise of Powers Agreement ("Agreement")** is made and entered into as of March 17, 2016 ("Effective Date"), by and among the Central Water District, the City of Santa Cruz, the County of Santa Cruz, and the Soquel Creek Water District, sometimes referred to herein individually as a "**Member**" and collectively as the "**Members**" for purposes of forming the Santa Cruz Mid-County Groundwater Agency ("**Agency**") and setting forth the terms pursuant to which the Agency shall operate. Capitalized defined terms used herein shall have the meanings given to them in Article 1 of this Agreement.

RECITALS

A. Each of the Members is a local agency, as defined by the Sustainable Groundwater Management Act of 2014 ("**SGMA**"), duly organized and existing under and by virtue of the laws of the State of California, and each Member can exercise powers related to groundwater management.

B. SGMA requires designation of a groundwater sustainability agency ("**GSA**") by June 30, 2017, for groundwater basins designated by the California Department of Water Resources ("**DWR**") as medium- and high-priority basins.

C. SGMA requires adoption of a groundwater sustainability plan ("**GSP**") by January 31, 2020, for all medium- and high-priority basins identified as being subject to critical conditions of overdraft.

D. Each of the Members either extracts groundwater from or regulates land use activities overlying a common groundwater basin located within the mid-county coastal region of the County of Santa Cruz. This Basin includes all or part of four basins identified in DWR's Bulletin Number 118, including the following basins (designated by the name of the basin and number assigned to it in DWR-Bulletin No. 118): Soquel Valley (3-1), West Santa Cruz Terrace (3-26), Santa Cruz Purisima Formation (3-21), and Pajaro Valley Basin (3-2). All or some of these basins have been designated as medium or high priority basins. Through the Agency, the Members provided modifications to the Bulletin-118 boundaries as allowed by Title 23 of the California Code of Regulations to create a new consolidated basin called the "Santa Cruz Mid-County Groundwater Basin" with 3-1 as the number for the consolidated basin under DWR Bulletin No. 118 (hereafter "**Basin**").

E. The Members intend for the Agency to develop a GSP and manage the Basin pursuant to SGMA.

F. Under SGMA, a combination of local agencies may form a GSA through a joint powers agreement.

G. The Members have determined that the sustainable management of the Basin pursuant to SGMA may best be achieved through the cooperation of the Members operating through a joint powers agency.

H. The Joint Exercise of Powers Act of 2000 ("Act") authorizes the Members to create a joint powers authority, to jointly exercise any power common to the Members, and to exercise additional powers granted under the Act.

I. The Act, including the Marks-Roos Local Bond Pooling Act of 1985 (Government Code sections 6584, *et seq.*), authorizes an entity created pursuant to the Act to issue bonds, and under certain circumstances, to purchase bonds issued by, or to make loans to, the Members for financing public capital improvements, working capital, liability and other insurance needs or projects whenever doing so results in significant public benefits, as determined by the Members. The Act further authorizes and empowers a joint powers authority to sell bonds so issued or purchased to public or private purchasers at public or negotiated sales.

J. The Members have a history of collaborating on groundwater management issues in the Santa Cruz Mid-County Groundwater Basin, originally with a joint powers agreement formed in 1995 by the Soquel Creek Water District and the Central Water District, which was subsequently amended in August of 2015 to include the City of Santa Cruz and the County of Santa Cruz, to form the Soquel-Aptos Groundwater Management Committee.

K. The Members agree that by approving the creation of the Santa Cruz Mid-County Groundwater Agency they are withdrawing from and disbanding the joint powers agency formed as a result of earlier joint powers agreements originally creating the Basin Implementation Group as subsequently amended to create the Soquel-Aptos Groundwater Management Committee.

L. Based on the foregoing legal authority, the Members desire to create a joint powers authority for the purpose of taking all actions deemed necessary by the joint powers authority to ensure sustainable management of the Basin as required by SGMA.

M. The governing board of each Member has determined it to be in the Member's best interest and in the public interest that this Agreement be executed.

TERMS OF AGREEMENT

In consideration of the mutual promises and covenants herein contained, the Members agree as follows:

ARTICLE 1
DEFINITIONS

The following terms have the following meanings for purposes of this Agreement:

1.1 "Act" means the Joint Exercise of Powers Act, set forth in Chapter 5 of Division 7 of Title 1 of the Government Code, sections 6500, *et seq.*, including all laws supplemental thereto.

1.2 "Agreement" has the meaning assigned thereto in the Preamble.

1.3 "Auditor" means the auditor of the financial affairs of the Agency appointed by the Board of Directors pursuant to Section 14.3 of this Agreement.

1.4 "Agency" has the meaning assigned thereto in the Preamble.

1.5 "Basin" has the meaning assigned thereto in Recital D.

1.6 "Board of Directors" or "Board" means the governing body of the Agency as established by Article 6 of this Agreement.

1.7 "Bylaws" means the bylaws, if any, adopted by the Board of Directors pursuant to Article 11 of this Agreement to govern the day-to-day operations of the Agency.

1.8 "Director" and "Alternate Director" mean a director or alternate director appointed pursuant to Sections 6.3 and 6.4 of this Agreement. "Member Director" is a Director or Alternate Director appointed by and representing a Member agency pursuant to Section 6.1.1 of this agreement.

1.9 "DWR" has the meaning assigned thereto in Recital B.

1.10 "GSA" has the meaning assigned thereto in Recital B.

1.11 "GSP" has the meaning assigned thereto in Recital C.

1.12 "Member" means each party to this Agreement that satisfies the requirements of Section 5.1 of this Agreement, including any new members as may be authorized by the Board, pursuant to Section 5.2 of this Agreement.

1.13 "Officer(s)" means the Chair, Vice Chair, Secretary, or Treasurer of the Agency to be appointed by the Board of Directors pursuant to Section 7.1 of this Agreement.

1.14 "SGMA" has the meaning assigned thereto in Recital A.

1.15 "State" means the State of California.

ARTICLE 2
CREATION OF THE AGENCY

2.1 Creation of a Joint Powers Authority. There is hereby created pursuant to the Act a joint powers authority, which will be a public entity separate from the Members to this Agreement, and shall be known as the Santa Cruz Mid-County Joint Powers Agency ("**Agency**"). Within 30 days after the Effective Date of this Agreement and after any amendment, the Agency shall cause a notice of this Agreement or amendment to be prepared and filed with the office of the California Secretary of State containing the information required by Government Code section 6503.5. Within 10 days after the Effective Date of this Agreement, the Agency shall cause a statement of the information concerning the Agency, required by Government Code section 53051, to be filed with the office of the California Secretary of State and with the County Clerk for the County of Santa Cruz, setting forth the facts required to be stated pursuant to Government Code section 53051(a).

2.2 Purpose of the Agency. Each Member to this Agreement has in common the power to study, plan, develop, finance, acquire, construct, maintain, repair, manage, operate, control, and govern the water supply and water management within the Basin, either alone or in cooperation with other public or private non-member entities, and each is a local agency eligible to serve as a GSA within the Basin, either alone or jointly through a joint powers agreement as provided for by SGMA. The purpose of this Agency is to serve as the GSA for the Basin and to develop, adopt, and implement the GSP for the Basin pursuant to SGMA and other applicable provisions of law.

ARTICLE 3
TERM

This Agreement shall become effective upon execution by each of the Members and shall remain in effect until terminated pursuant to the provisions of Article 17 (Withdrawal of Members) of this Agreement.

ARTICLE 4
POWERS

The Agency shall possess the power in its own name to exercise any and all common powers of its Members reasonably related to the purposes of the Agency, including but not limited to the following powers, together with such other powers as are expressly set forth in the Act and in SGMA. For purposes of Government Code section 6509, the powers of the Agency shall be exercised subject to the restrictions upon the manner of exercising such powers as are imposed on the County of Santa Cruz, and in the event of the withdrawal of the County of Santa Cruz as a Member under this Agreement, then the manner of exercising the Agency's powers shall be those restrictions imposed on the City of Santa Cruz.

4.1 To exercise all powers afforded to a GSA pursuant to and as permitted by SGMA.

4.2 To develop, adopt and implement the GSP pursuant to SGMA.

4.3 To adopt rules, regulations, policies, bylaws and procedures governing the operation of the Agency and adoption and implementation of the GSP.

4.4 To obtain rights, permits and other authorizations for or pertaining to implementation of the GSP.

4.5 To perform other ancillary tasks relating to the operation of the Agency pursuant to SGMA, including without limitation, environmental review, engineering, and design.

4.6 To make and enter into all contracts necessary to the full exercise of the Agency's power.

4.7 To employ, designate or otherwise contract for the services of agents, officers, employees, attorneys, engineers, planners, financial consultants, technical specialists, advisors, and independent contractors.

4.8 To exercise jointly the common powers of the Members, as directed by the Board, in developing and implementing a GSP for the Basin.

4.9 To investigate legislation and proposed legislation affecting the Basin and to make appearances regarding such matters.

4.10 To cooperate and to act in conjunction and contract with the United States, the State of California or any agency thereof, counties, municipalities, public and private corporations of any kind (including without limitation, investor-owned utilities), and individuals, or any of them, for any and all purposes necessary or convenient for the full exercise of the powers of the Agency.

4.11 To incur debts, liabilities or obligations, to issue bonds, notes, certificates of participation, guarantees, equipment leases, reimbursement obligations and other indebtedness, and, to the extent provided for in a duly adopted Agency to impose assessments, groundwater extraction fees or other charges, and other means of financing the Agency as provided in Chapter 8 of SGMA commencing at Section 10730 of the Water Code.

4.12 To collect and monitor data on the extraction of groundwater from, and the quality of groundwater in, the Basin.

4.13 To establish and administer a conjunctive use program for the purposes of maintaining sustainable yields in the Basin consistent with the requirements of SGMA.

4.14 To exchange and distribute water.

4.15 To regulate groundwater extractions as permitted by SGMA.

4.16 To impose groundwater extraction fees as permitted by SGMA.

4.17 To spread, sink and inject water into the Basin.

4.18 To store, transport, recapture, recycle, purify, treat or otherwise manage and control water for beneficial use.

4.19 To apply for, accept and receive licenses, permits, water rights, approvals, agreements, grants, loans, contributions, donations or other aid from any agency of the United States, the State of California, or other public agencies or private persons or entities necessary for the Agency's purposes.

4.20 To develop and facilitate market-based solutions for the use and management of water rights.

4.21 To acquire property and other assets by grant, lease, purchase, bequest, devise, gift or eminent domain, and to hold, enjoy, lease or sell, or otherwise dispose of, property, including real property, water rights, and personal property, necessary for the full exercise of the Agency's powers.

4.22 To sue and be sued in its own name.

4.23 To provide for the prosecution of, defense of, or other participation in actions or proceedings at law or in public hearings in which the Members, pursuant to this Agreement, may have an interest and may employ counsel and other expert assistance for these purposes.

4.24 To exercise the common powers of its Members to develop, collect, provide, and disseminate information that furthers the purposes of the Agency, including but not limited to the operation of the Agency and adoption and implementation of the GSP to the Members, legislative, administrative, and judicial bodies, as well the public generally.

4.25 To accumulate operating and reserve funds for the purposes herein stated.

4.26 To invest money that is not required for the immediate necessities of the Agency, as the Agency determines is advisable, in the same manner and upon the same conditions as Members, pursuant to Government Code section 53601, as it now exists or may hereafter be amended.

4.27 To undertake any investigations, studies, and matters of general administration.

4.28 To perform all other acts necessary or proper to carry out fully the purposes of this Agreement.

ARTICLE 5
MEMBERSHIP

5.1 Members. The Members of the Agency shall be the Central Water District, the City of Santa Cruz, the County of Santa Cruz, and the Soquel Creek Water District, as long as they have not, pursuant to the provisions hereof, withdrawn from this Agreement.

5.2 New Members. Any public agency (as defined by the Act) that is not a Member on the Effective Date of this Agreement may become a Member upon: (a) the approval of the Board of Directors by a supermajority of at least seventy-five (75%) of the votes held among all Directors as specified in Article 9 (Member Voting); (b) payment of a pro rata share of all previously incurred costs that the Board of Directors determines have resulted in benefit to the public agency, and are appropriate for assessment on the public agency; and (c) execution of a written agreement subjecting the public agency to the terms and conditions of this Agreement.

ARTICLE 6
BOARD OF DIRECTORS AND OFFICERS

6.1 Formation of the Board of Directors. The Agency shall be governed by a Board of Directors ("**Board**"). The Board shall consist of eleven (11) Directors consisting of the following representatives who shall be appointed in the manner set forth in Section 6.3:

6.1.1 Two representatives appointed by the governing board of each of the following public agency Members: the Central Water District, the City of Santa Cruz, the County of Santa Cruz, and the Soquel Creek Water District.

6.1.2 Three representatives of private well owners within the boundaries of the Agency.

6.2 Duties of the Board of Directors. The business and affairs of the Agency, and all of its powers, including without limitation all powers set forth in Article 4 (Powers), are reserved to and shall be exercised by and through the Board of Directors, except as may be expressly delegated to the staff or others pursuant to this Agreement, Bylaws, or by specific action of the Board of Directors.

6.3 Appointment of Directors. The Directors shall be appointed as follows:

6.3.1 The two representatives from the Central Water District shall be appointed by resolution of the Central Water District Board of Directors.

6.3.2 The two representatives from the City of Santa Cruz shall be appointed by resolution of the City of Santa Cruz City Council.

6.3.3 The two representatives from the County of Santa Cruz shall be appointed by resolution of the County of Santa Cruz Board of Supervisors.

6.3.4 The two representatives from the Soquel Creek Water District shall be appointed by resolution of the Soquel Creek Water District Board of Directors.

6.3.5 The three representatives of private well owners shall be appointed by majority vote of the eight public agency Member Directors. The procedures for nominating the private well owners shall be set forth in the Bylaws.

6.4 Alternate Directors. Each Member may have one Alternate to act as a substitute Director for either of the Member's Directors. One Alternate shall also be appointed to act as a substitute Director for any of the three Directors representing private well owners. All Alternates shall be appointed in the same manner as set forth in Section 6.3. Alternate Directors shall have no vote, and shall not participate in any discussions or deliberations of the Board unless appearing as a substitute for a Director due to absence or conflict of interest. If the Director is not present, or if the Director has a conflict of interest which precludes participation by the Director in any decision-making process of the Board, the Alternate Director appointed to act in his/her place shall assume all rights of the Director, and shall have the authority to act in his/her absence, including casting votes on matters before the Board. Each Alternate Director shall be appointed prior to the third meeting of the Board. Alternates are strongly encouraged to attend all Board meetings and stay informed on current issues before the Board.

6.5 Requirements. Each Member's Directors and Alternate Director shall be appointed by resolution of that Member's governing body to serve for a term of four years except, for the purpose of establishing staggered terms, one of the initially-appointed Directors of each Member shall, as designated by the Member, serve an initial term of two years. A Member's Director or Alternate Director may be removed during his or her term or reappointed for multiple terms at the pleasure of the Member that appointed him or her. A Director representing private well owners may be removed or reappointed in the same manner as he or she was appointed as set forth in Section 6.3. No individual Director may be removed in any other manner, including by the affirmative vote of the other Directors.

6.6 Vacancies. A vacancy on the Board of Directors shall occur when a Director resigns or at the end of the Director's term as set forth in Section 6.5. For Member Directors, a vacancy shall also occur when he or she is removed by his or her appointing Member. For Directors representing private well owners, a vacancy shall also occur when the Director is removed as set forth in Section 6.5. Upon the vacancy of a Director, the Alternate Director shall serve as Director until a new Director is appointed as set forth in Section 6.3 unless the Alternate is already serving as a substitute Director in the event of a prior vacancy, in which case, the seat shall remain vacant until a replacement Director is appointed as set forth in Section 6.3. Members shall provide notice of any changes in Director or Alternate Director positions to the Board of Directors or its designee in writing and signed by an authorized representative of the Member.

ARTICLE 7
OFFICERS

7.1 Officers. Officers of the Agency shall be a Chair, Vice Chair, Secretary, and Treasurer. The Treasurer shall be appointed consistent with the provisions of Section 14.3. The Vice Chair, or in the Vice Chair's absence, the Secretary, shall exercise all powers of the Chair in the Chair's absence or inability to act.

7.2 Appointment of Officers. Officers shall be elected annually by, and serve at the pleasure of, the Board of Directors. Officers shall be elected at the first Board meeting, and thereafter at the first Board meeting following January 1st of each year, or as duly continued by the Board. An Officer may serve for multiple consecutive terms, with no term limit. Any Officer may resign at any time upon written notice to the Board, and may be removed and replaced by a simple majority vote of the Board.

7.3 Principal Office. The principal office of the Agency shall be established by the Board of Directors, and may thereafter be changed by a simple majority vote of the Board.

ARTICLE 8
DIRECTOR MEETINGS

8.1 Initial Meeting. The initial meeting of the Board of Directors shall be held in the County of Santa Cruz, California, within thirty (30) days of the Effective Date of this Agreement.

8.2 Time and Place. The Board of Directors shall meet at least quarterly, at a date, time and place set by the Board within the jurisdictional boundaries of one or more of the Members, and at such other times as may be determined by the Board.

8.3 Special Meetings. Special meetings of the Board of Directors may be called by the Chair or by a simple majority of Directors, in accordance with the provisions of Government Code section 54956.

8.4 Conduct. All meetings of the Board of Directors, including special meetings, shall be noticed, held, and conducted in accordance with the Ralph M. Brown Act (Government Code sections 54950, *et seq.*). The Board may use teleconferencing in connection with any meeting in conformance with and to the extent authorized by applicable law.

8.5 Local Conflict of Interest Code. The Board of Directors shall adopt a local conflict of interest code pursuant to the provisions of the Political Reform Act of 1974 (Government Code sections 81000, *et seq.*)

ARTICLE 9
MEMBER VOTING

9.1 Quorum. A quorum of any meeting of the Board of Directors shall consist of an absolute majority of Directors plus one Director. In the absence of a quorum, any meeting of the Directors may be adjourned by a vote of the simple majority of Directors present, but no other business may be transacted. For purposes of this Article, a Director shall be deemed present if the Director appears at the meeting in person or participates telephonically, provided that the telephone appearance is consistent with the requirements of the Ralph M. Brown Act.

9.2 Director Votes. Voting by the Board of Directors shall be made on the basis of one vote for each Director. A Director, or an Alternate Director when acting in the absence of his or her Director, may vote on all matters of Agency business unless disqualified because of a conflict of interest pursuant to California law or the local conflict of interest code adopted by the Board of Directors.

9.3 Affirmative Decisions of the Board of Directors. Except as otherwise specified in this Agreement, all affirmative decisions of the Board of Directors shall require the affirmative vote of a simple majority of all appointed Directors participating in voting on a matter of Agency business, provided that if a Director is disqualified from voting on a matter before the Board because of a conflict of interest, that Director shall be excluded from the calculation of the total number of Directors that constitute a majority. Notwithstanding the foregoing, a unanimous vote of all Member Directors participating in voting shall be required to approve any of the following: (i) any capital expenditure that is estimated to cost $100,000 or more; (ii) the annual budget; (iii) the GSP for the Basin or any amendment thereto; (iv) the levying of assessments or fees; (v) issuance of indebtedness; or (vi) any stipulation to resolve litigation concerning groundwater rights within or groundwater management for the Basin.

ARTICLE 10
AGENCY ADMINISTRATION, MANAGEMENT AND OPERATION

The Board of Directors may select and implement an approach to Agency administration and management that is appropriate to the circumstances and adapted to the GSA's needs as they may evolve over time. Details of the Board's decision on Agency administration, management and operation shall be incorporated into the GSA's bylaws and reviewed and revised as needed using the established process for revising the GSA's bylaws.

ARTICLE 11
BYLAWS

The Board of Directors shall cause to be drafted, approve, and amend Bylaws of the Agency to govern the day-to-day operations of the Agency. The Bylaws shall be adopted at or before the first anniversary of the Board's first meeting.

ARTICLE 12
ADVISORY COMMITTEES

The Board of Directors may from time to time appoint one or more advisory committees or establish standing or ad hoc committees to assist in carrying out the purposes and objectives of the Agency. The Board shall determine the purpose and need for such committees and the necessary qualifications for individuals appointed to them.

ARTICLE 13
OPERATION OF COMMITTEES

Each committee shall include a Director as the chair thereof. Other members of each committee may be constituted by such individuals approved by the Board of Directors for participation on the committee. However, no committee or participant on such committee shall have any authority to act on behalf of the Agency except as duly authorized by the Board.

ARTICLE 14
ACCOUNTING PRACTICES

14.1 General. The Board of Directors shall establish and maintain such funds and accounts as may be required by generally accepted public agency accounting practices. The Agency shall maintain strict accountability of all funds and a report of all receipts and disbursements of the Agency.

14.2 Fiscal Year. Unless the Board of Directors decides otherwise, the fiscal year for the Agency shall run concurrent with the calendar year.

14.3 Appointment of Treasurer and Auditor; Duties. The Treasurer and Auditor shall be appointed in the manner, and shall perform such duties and responsibilities, specified in Sections 6505.5 and 6505.6 of the Act.

ARTICLE 15
BUDGET AND EXPENSES

15.1 Budget. Within 120 after the first meeting of the Board of Directors, and thereafter prior to the commencement of each fiscal year, the Board shall adopt a budget for the Agency for the ensuing fiscal year no later than June 30^{th} . In the event that a budget is not so approved, the prior year's budget shall be deemed approved for the ensuing fiscal year, and any groundwater extraction fee or assessment(s) of contributions of Members, or both, approved by the Board during the prior fiscal year shall again be assessed in the same amount and terms for the ensuing fiscal year.

15.2 Agency Funding and Contributions. For the purpose of funding the expenses and ongoing operations of the Agency, the Board of Directors shall maintain a funding account in connection with the annual budget process. The Board of Directors may fund the Agency and the GSP as provided in Chapter 8 of SGMA, commencing with Section 10730 of the Water Code, and may also issue assessments for contributions by the Members in the amount and frequency determined necessary by the Board. Such Member contributions shall be paid by each Member to the Agency within 30 days of assessment by the Board.

15.3 Return of Contributions. In accordance with Government Code section 6512.1, repayment or return to the Members of all or any part of any contributions made by Members and any revenues by the Agency may be directed by the Board of Directors at such time and upon such terms as the Board of Directors may decide; provided that (1) any distributions shall be made in proportion to the contributions paid by each Member to the Agency, and (2) any capital contribution paid by a Member voluntarily, and without obligation to make such capital contribution pursuant to Section 15.2, shall be returned to the contributing Member, together with accrued interests at the annual rate published as the yield of the Local Agency Investment Fund administered by the California State Treasurer, before any other return of contributions to the Members is made. The Agency shall hold title to all funds and property acquired by the Agency during the term of this Agreement.

15.4 Issuance of Indebtedness. The Agency may issue bonds, notes or other forms of indebtedness, as permitted under Section 4.11, provided such issuance be approved at a meeting of the Board of Directors by unanimous vote of the Member Directors as specified in Article 9 (Member Voting).

ARTICLE 16
LIABILITIES

16.1 Liability. In accordance with Government Code section 6507, the debt, liabilities and obligations of the Agency shall be the debts, liabilities and obligations of the Agency alone, and not the Members.

16.2 Indemnity. Funds of the Agency may be used to defend, indemnify, and hold harmless the Agency, each Member, each Director, and any officers, agents and employees of the Agency for their actions taken within the course and scope of their duties while acting on behalf of the Agency. Other than for gross negligence or intentional acts, to the fullest extent permitted by law, the Agency agrees to save, indemnify, defend and hold harmless each Member from any liability, claims, suits, actions, arbitration proceedings, administrative proceedings, regulatory proceedings, losses, expenses or costs of any kind, whether actual, alleged or threatened, including attorney's fees and costs, court costs, interest, defense costs, and expert witness fees, where the same arise out of, or are in any way attributable, in whole or in part, to negligent acts or omissions of the Agency or its employees, officers or agents or the employees, officers or agents of any Member, while acting within the course and scope of a Member relationship with the Agency.

ARTICLE 17
WITHDRAWAL OF MEMBERS

17.1 Unilateral Withdrawal. Subject to the Dispute Resolution provisions set forth in Section 18.9, a Member may unilaterally withdraw from this Agreement without causing or requiring termination of this Agreement, effective upon 30 days written notice to the Board of Directors or its designee.

17.2 Rescission or Termination of Agency. This Agreement may be rescinded and the Agency terminated by unanimous written consent of all Members, except during the outstanding term of any Agency indebtedness.

17.3 Effect of Withdrawal or Termination. Upon termination of this Agreement or unilateral withdrawal, a Member shall remain obligated to pay its share of all debts, liabilities and obligations of the Agency required of the Member pursuant to terms of this Agreement, and that were incurred or accrued prior to the effective date of such termination or withdrawal, including without limitation those debts, liabilities and obligations pursuant to Sections 4.11 and 15.4. Any Member who withdraws from the Agency shall have no right to participate in the business and affairs of the Agency or to exercise any rights of a Member under this Agreement or the Act, but shall continue to share in distributions from the Agency on the same basis as if such Member had not withdrawn, provided that a Member that has withdrawn from the Agency shall not receive distributions in excess of the contributions made to the Agency while a Member. The right to share in distributions granted under this Section 17.3 shall be in lieu of any right the withdrawn Member may have to receive a distribution or payment of the fair value of the Member's interest in the Agency.

17.4 Return of Contribution. Upon termination of this Agreement, any surplus money on-hand shall be returned to the Members in proportion to their contributions made. The Board of Directors shall first offer any property, works, rights and interests of the Agency for sale to the Members on terms and conditions determined by the Board of Directors. If no such sale to Members is consummated, the Board of Directors shall offer the property, works, rights, and interest of the Agency for sale to any non-member for good and adequate consideration. The net proceeds from any sale shall be distributed among the Members in proportion to their contributions made.

ARTICLE 18
MISCELLANEOUS PROVISIONS

18.1 No Predetermination or Irretrievable Commitment of Resources. Nothing herein shall constitute a determination by the Agency or any of its Members that any action shall be undertaken, or that any unconditional or irretrievable commitment of resources shall be made, until such time as the required compliance with all local, state, or federal laws, including without limitation the California Environmental Quality Act, National Environmental Policy Act, or permit requirements, as applicable, has been completed.

18.2 Notices. Notices to a Director or Member hereunder shall be sufficient if delivered to the respective Director or clerk of the Member agency and addressed to the Director or clerk of the Member agency. Delivery may be accomplished by U.S. Postal Service, private mail service or electronic mail.

18.3 Amendments to Agreement. This Agreement may be amended or modified at any time only by subsequent written agreement approved and executed by all of the Members.

18.4 Agreement Complete. The foregoing constitutes the full and complete Agreement of the Members. This Agreement supersedes all prior agreements and understandings, whether in writing or oral, related to the subject matter of this Agreement that are not set forth in writing herein.

18.5 Severability. Should any part, term or provision of this Agreement be decided by a court of competent jurisdiction to be illegal or in conflict with any applicable federal law or any law of the State of California, or otherwise be rendered unenforceable or ineffectual, the validity of the remaining parts, terms, or provisions hereof shall not be affected thereby, provided however, that if the remaining parts, terms, or provisions do not comply with the Act, this Agreement shall terminate.

18.6 Withdrawal by Operation of Law. Should the participation of any Member to this Agreement be decided by the courts to be illegal or in excess of that Member's authority or in conflict with any law, the validity of the Agreement as to the remaining Members shall not be affected thereby.

18.7 Assignment. The rights and duties of the Members may not be assigned or delegated without the written consent of all other Members. Any attempt to assign or delegate such rights or duties in contravention of this Agreement shall be null and void.

18.8 Binding on Successors. This Agreement shall inure to the benefit of, and be binding upon, the successors and assigns of the Members.

18.9 Dispute Resolution. In the event that any dispute arises among the Members relating to (i) this Agreement, (ii) the rights and obligations arising from this Agreement, or (iii) or a Member proposing to withdraw from membership in the Agency, the aggrieved Member or Member proposing to withdraw from membership shall provide written notice to the other Members of the controversy or proposal to withdraw from membership. Within thirty (30) days thereafter, the Members shall attempt in good faith to resolve the controversy through informal means. If the Members cannot agree upon a resolution of the controversy within thirty (30) days from the providing of written notice specified above, the dispute shall be submitted to mediation prior to commencement of any legal action or prior to withdraw of a Member proposing to withdraw from membership. The mediation shall be no less than a full day (unless agreed otherwise among the Members) and the cost of mediation shall be paid in equal proportion among the Members. The mediator shall be either voluntarily agreed to or appointed by the Superior Court upon a suit and motion for appointment of a neutral mediator. Upon completion of mediation, if the controversy has not been resolved, any Member may exercise all rights to bring a legal action relating to the controversy or (except where such controversy relates to withdrawal of a Member's obligations upon withdrawal) withdraw from membership as otherwise authorized pursuant to this Agreement.

18.10 Counterparts. This Agreement may be executed in counterparts, each of which shall be deemed an original.

18.11 Singular Includes Plural. Whenever used in this Agreement, the singular form of any term includes the plural form and the plural form includes the singular form.

18.12 Member Authorization. The legislative bodies of the Members have each authorized execution of this Agreement, as evidenced by their respective signatures below.

IN WITNESS WHEREOF, the Members hereto have executed this Agreement by authorized officials thereof.

CENTRAL WATER DISTRICT

By: [signature]

Title: Board President -CWD

APPROVED AS TO FORM:

By: [signature]

Title: District Counsel

CITY OF SANTA CRUZ

By: [signature]

Title: City Manager

2-23-16

APPROVED AS TO FORM:

By: [signature]

Title: Anthony P. Condotti City Attorney

COUNTY OF SANTA CRUZ

By: [signature]

Title: County Administrative Officer

APPROVED AS TO FORM:

By: [signature]

Title: County Counsel

SOQUEL CREEK WATER DISTRICT

By: Bruce Daniels

Title: President, Board

APPROVED AS TO FORM:

By: [signature]

Title: District Counsel

APPENDIX 2-A

SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY
COMMUNICATIONS & ENGAGEMENT PLAN

Santa Cruz Mid-County Groundwater Agency Communication & Engagement Plan

Background

Santa Cruz Mid-County's main drinking water supply is groundwater. As a result of decades of past over-pumping, streams do not always have enough water to support fish and wildlife, we have seawater contamination in some private coastal production wells, and the danger of seawater contamination spreading inland to contaminate more water supply wells. We need to work together to ensure a sustainable water supply now and for the future. The Santa Cruz Mid-County Groundwater Agency (MGA) is developing a Groundwater Sustainability Plan (GSP) to ensure a sustainable water supply supporting environmental and human needs, in compliance with the Sustainable Groundwater Management Act of 2014 (SGMA).

Communication Goals

1. Public understanding of the challenges facing groundwater supplies.
2. Public support for practical water supply solutions.
3. Engaged stakeholders who provide input and guidance to develop the Groundwater Sustainability Plan (GSP).
4. Increase public awareness of the need to protect local groundwater resources and increase groundwater levels.

Objectives

Through public meetings, workshops, events, online engagement, and print materials the public will understand:

1. Where we get our water in the Mid-County basin.
2. The nature of groundwater and its relationship to water supply and environmental values.
3. The problems that threaten our groundwater supplies.
4. Possible solutions to managing our groundwater supplies.
5. The state's mandate for a plan to ensure groundwater sustainability by 2020, and attainment by 2040 (SGMA).
6. The role of Santa Cruz Mid-County Groundwater Agency to prepare and implement the GSP.

Audiences/stakeholders

- Basin water users/rate payers.
- Basin landowners/taxpayers.
- Land and ecosystem managers.

Audiences/stakeholders contact strategies:

1) Basin Water Users
    a. City of Santa Cruz Water customers (small portion of total supply)
       How to contact: Bill inserts, presentations to community groups, social media, e-newsletters, press releases, and community parties.

    b. Central Water District (all)
       How to contact: Bill inserts, e-newsletters, press releases, and community parties.

    c. Soquel Creek Water District (SqCWD) customers (all)
       How to contact: Bill inserts and carrier routes, presentations to community groups, social media, e-newsletters, press releases, and community parties.

    d. Private well residential users and small water systems (all)
       How to contact: postcards, presentations to community groups, road signs, small water system quarterly meetings, partnering with RCD, press releases and community parties.

    e. Commercial/institutional/agricultural well users (all)
       How to contact: direct calls, press releases, partnering with RCD, presentations to industry groups.

2) Non-profits: Email lists, presentations to Boards/Councils
3) Government agencies: Presentations to Councils, Boards, and Advisory Committees

Category of Interest	Examples of Stakeholder Groups	Engagement purpose
General Public	• School Boards • Basin Residents	Inform to improve public awareness of sustainable groundwater management
Land Use	• City of Santa Cruz Planning • City of Capitola Planning • County Planning • LAFCO • AMBAG	Consult and involve to ensure land use policies are supporting GSPs, and GSP reflects projected population and development
Private users	• Private domestic pumpers • Soquel High School • Cabrillo College • Seascape Golf Course • Small community systems	Inform and involve to avoid negative impact to these users, and to inform about the need and basis for possible future fees

Urban/ Agriculture users	• Soquel Creek Water District • Central Water District • City of Santa Cruz Water Department • Resource Conservation District of Santa Cruz County • Farm Bureau • Vintners association • Cannabis Licensing Division	Collaborate to ensure sustainable management of groundwater, and to inform about the need and basis for possible future fees
Environmental and Ecosystem	• Federal and State agencies (Fish and Wildlife) • Wetland managers • Environmental groups	Inform and involve to sustain vital groundwater dependent ecosystems
Economic Development	• Chambers of Commerce, SC Business Council; business sectors such as real estate, developers, tourism • Elected officials (Board of Supervisors, City Council members) • State Assembly members • State Senators	Inform and involve to support a stable economy
Human right to water	• Disadvantaged Communities • Environmental Justice Groups • Human Service non-profits (Human Care Alliance etc.)	Inform and involve to provide a safe and secure groundwater supplies to DACs
Integrated Water Management	• Regional water management groups (IRWM regions) • Flood agencies	Inform, involve and collaborate to improve regional sustainability

Audience Survey and Mapping

Organizational stakeholders identified through the interested parties list are already engaged in the process through the MGA partner agencies and receiving email information from the MGA. A survey is available for private well owners at https://www.surveymonkey.com/r/MGAwellowner. The MGA is also planning a baseline phone survey in late 2018 to identify the level of knowledge and interest of the community in the MGA to inform future outreach.

Key stakeholder groups have also been engaged through membership in the GSP Advisory Committee. Advisory Committee members represent diverse social, cultural, economic, technical, and organizational backgrounds, and provide outreach to the stakeholder interest groups they represent.

Key Messages

1) The MGA and its partner agencies must get the Mid-County groundwater basin up to protective levels to prevent seawater intrusion.
2) We are working toward a strategy to bring the basin into sustainability without compromising human or environmental health.
3) Water conservation must continue.

4) Conservation alone will not restore the groundwater basin.
5) MGA and its member agencies have used conservation and water production management strategies to protect groundwater supplies from depletion and seawater intrusion. We need to examine alternative water sources to develop a supplemental water supply to achieve sustainability.
6) To be successful, management efforts and supplemental water supply efforts will require beneficiaries to support funding mechanisms.

Define sustainability:
The use of groundwater to meet our needs without harming the environment or jeopardizing future water supply reliability.

Venues for Engaging

Partnerships to develop consistent groundwater messaging:
The water agencies and partners within and around the Mid-County Basin have been working together closely on joint messaging and outreach strategies around water issues since the early 2000s. The primary mechanism for this effort is the Water Conservation Coalition (WCC) of Santa Cruz County (www. Watersavingtips.org). MGA partner agencies collaborate to develop narrative messages that inform the public about the need for groundwater basin restoration.

Partnerships with existing outreach and youth engagement programs:
The WCC has produced educational booklets for elementary schools, maintains a website with information on water purveyors and rebates, jointly pays for a high school and college level video contest about water in the county, sponsors programs like adult learning classes at Cabrillo College, classroom presentations, and educational campaigns including newspaper ads and bus ads. The Coalition has been featuring information on groundwater hydrology and SGMA at recent tabling events in partnership with the MGA and other GSAs in the region.

Additional outreach to local schools within the basin is done by staff from the Soquel Creek Water District and the City of Santa Cruz. Outreach includes shows at school assemblies, field trips, and in-class presentations that include building a model water system and learning about jobs in the water industry. Starting in Fall 2018, outreach will include 6-8th grade education about water supply systems which includes groundwater generally and the MGA specifically. More information can be found at https://www.soquelcreekwater.org/schools/school-programs.

Social Media:

- MGA e-newsletter
- City of Santa Cruz Water Supply Advisory Committee (WSAC) e-newsletter
- SqCWD e-newsletter and Facebook page
- County and City Water Department Facebook pages
- County supervisor email lists and Facebook pages
- Nextdoor

Informational brochures and handouts: *Sharing and Sustaining Mid-County Groundwater*, *Who Cares About Groundwater?,* Postcards, 2-page information factsheet handout.

Community Groups:

- Parent Teacher Associations
- Public Meetings
- Civic Organizations (e.g. Rotary, Lions, League of Women Voters, etc.)
- Farm Bureau
- Chambers of Commerce and other business organizations/sectors.

Website:

1) Background and basic information about the problem, SGMA, the MGA, and the GSP
2) Projects that have been implemented or are being prepared (recharge, water transfers, see also *Water Supply Augmentation Options for the Santa Cruz Mid-County Groundwater Basin*)
3) Identify gaps in information that we are presenting (how much recharge makes it to aquifer)

Stakeholder Meetings, Community Events:

- At least 2 workshops per year.
- Fun neighborhood events to engage folks that may not come to a meeting.
- Participation at tabling events like Earth Day, the County Fair, and Farmer's Markets either as the MGA or in partnership with the Water Conservation Coalition.
- Connecting the Drops.

Educational Videos and Infographics:

- Soquel Creek has invested in some very good graphical videos.
- Our interest right now is to do a series of short (1-3 minute) videos each covering a simple topic relating to the MGA (see list below for possibilities).
- Develop interactive groundwater games (aquifers, infiltration, supplemental supplies) for use at community events.

Phased Approach Implementation Timeline

The Mid-County Agency has prepared a 3-phase approach to outreach.

Phase 1: Ongoing Efforts

- MGA Website, www.midcountygroundwater.org (regular updates)
- Key press releases and social media information (ongoing as needed)
- Public meetings/workshops (ongoing)
- MGA Drop-Ins (ongoing bi-monthly)
- Mailings (ongoing as needed)
- MGA E-blast (ongoing monthly)
- Recording meetings and having them online

Phase 2: July 1-October 31, 2018.

Purpose: Name recognition, basic information about what the MGA is, what we are doing, and why (both state regulations and the problem):

a. Joint powers of different agencies working together to ensure a sustainable water supply now and for the future.
b. State mandate to write, implement, and monitor a GSP

c. Critical overdraft (stream flow is affected, seawater intrusion impacts basin groundwater supply.)

MGA Considerations and Work to Date:

a. Around the world, 70% of coastal groundwater aquifers have already been ruined by seawater contamination.
b. Locally we have avoided seawater contamination to our municipal supplies through price adjustments, water conservation, and groundwater management, but seawater contamination is on is already onshore at Soquel Point and La Selva Beach.
c. Projected climate change impacts on local rainfall patterns and hotter temperatures will require additional tools to continue to protect our coastal groundwater aquifers.
d. Since its creation in 2016, MGA has used innovative technologies like SkyTEM, DualEM to better understand subsurface geology and aid in planning projects that enhance our water supplies and protect our coastal groundwater from seawater intrusion.

Tasks for Phase 2:

1) Review draft stakeholder engagement plan, make suggestions. Include more text about leveraging existing programs, add the survey (benefits messaging and support), multiple phased approach to outreach.
2) Contract with survey company to provide us with a baseline of outreach priorities.
3) Possible survey questions:
   - *Have you heard about the MGA and if so, what do you know about it?*
   - *Do you know we have groundwater issue?*
   - *Do you think you can conserve more?*
     i. *Do you think more conservation can solve our problem?*
     ii. *Is your water consumption metered?*
     iii. *Do you know how much water your household uses per person/day?*
     iv. *Did your water usage changed in response to drought conditions?*
     v. *Has your water usage gone up since the State drought ended in 2017?*
   - *Do you have a strong feeling about supplemental supplies?:*
     i. *Desalination*
     ii. *River transfers (Explain if needed)*
     iii. *Stormwater infiltration (explain if needed)*
     iv. *Recycled water (explain if needed)*
   - *What would you be willing to pay to keep your groundwater supply sustainable?:*
     i. *A $20-50 annual fee for monitoring and basin management)?*
     ii. *A $50-100 annual fee to share costs to develop additional water supply projects?*
     iii. *A $100-200 annual fee for restoration and environmental stewardship?*
   - *Who do you trust for information on water issues?:*
     i. *Specific individual or agency (please name)*
     ii. *Local county/city governments (please name)*
     iii. *Local water providers (please name)*
     iv. *State water agencies (please name)*
     v. *UCSC research scientists (please name)*
     vi. *Others (please name)*

- *How do you get information about local issues?:*
    i. *Local daily/weekly newspapers (please name)*
    ii. *Radio (please name)*
    iii. *Websites (please name)*
    iv. *Social Media (please name)*
    v. *Other (please name)*

4) Design and print a table cloth, stickers, and 2 banners.
5) Finish the "Who cares about groundwater?" brochure/postcard.
6) Hire RogueMark Studies or similar to create story graphics/graphic recording of SkyTEM meeting and the June Stakeholder meeting.
7) Hold stakeholder meeting in June 2018 and periodically through GSP roll out in late 2019/early 2020 similar to past meetings.
8) Create a participatory group of two to four students, called Student Sustainable Groundwater Liaisons, who can observe and occasionally participate in the MGA Board and Advisory Committee meetings. Their role will be to provide us with some guidance on how to engage with youth, provide input to the GSP, and work to inform students that there are careers and other roles in local water governance that benefit from new, young participants. (Students would be recruited from local high schools, Cabrillo College, UCSC, or CSUMB if they have a connection to the MGA area. We would solicit recruitment assistance from teachers and career counselors interested in enriching student experiences through practical work experience.)

Phase 3: November 1, 2018-December 31, 2019

Purpose: to foster trust in GSP process and ultimately support for approval of the plan. Teach people about supplemental water supply and how we pay for it. Provide an opportunity for meaningful input.

Tasks for Phase 3:

1) Create simple infographics for use in e-newsletter, MGA Board meetings, and general public outreach (need to decide topics from list below or others based on survey results).
2) Create videos (need to decide topics from list below or others based on survey results).
3) Hold stakeholder outreach meetings to allow for meaningful input to key GSP sections and document public concerns. Individual stations for GSP topic areas with question and comment cards, note pad, bullet points.
4) Use existing water related meetings and relationships to amplify MGA messages.
5) Decide how to target messages based on survey results.

Infographic/Video concepts – will decide which are needed based on survey results and input from executive team.

- Seawater intrusion/protective levels (already a good video available)
- Conjunctive Use
- Need for supplemental supply
- Growth vs water use
- One water/ All water is recycled – careful what you put down the drain
- Surface water/groundwater levels/groundwater dependent ecosystems/ streamflow (could include data or be conceptual)

- Storage
- Groundwater level
- SGMA process
- GSP content
- Data displays:
  - groundwater production and rainfall over time,
  - water that could be created from various projects,
  - implementation costs,
  - streamflow
  - land use
  - water use and population
  - water quality

Phase 4: January 1, 2020- ongoing

Purpose: Roll out of the final plan, informational meetings, press releases, GSP completion celebration.

Work with Student Sustainable Groundwater Liaisons to improve engagement with local high schools and colleges.

Evaluation and Assessment

By taking a phased approach to outreach, we allow ourselves opportunities to assess to the program and evaluate how our plan is performing against our goals and objectives by asking:

- What worked well
- What didn't work as planned
- Meeting recaps with next steps
- What are the gaps in citizen knowledge that we should focus our outreach towards?

APPENDIX 2-B

SANTA CRUZ MID-COUNTY BASIN GROUNDWATER FLOW MODEL: WATER USE ESTIMATES AND RETURN FLOW IMPLEMENTATION (TASK 2) MEMORANDUM

1814 Franklin St, Suite 501
Oakland, CA 94612

TECHNICAL MEMORANDUM

To: John Ricker and Ron Duncan

From: Georgina King and Cameron Tana

Date: March 31, 2017

Subject: Santa Cruz Mid-County Basin Groundwater Flow Model: Water Use Estimates and Return Flow Implementation (Task 2)

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List of Tables

1.0 INTRODUCTION

This technical memorandum documents the methodologies used for estimating the non-municipal water use component of consumptive use in the basin for input into the Santa Cruz Mid-County basin groundwater model that simulates conditions for Water Years 1985-2015. The components of consumptive use are water use and return flow. Water use estimates are required to estimate groundwater pumping where pumping is not metered or recorded. Water use estimates are also required to estimate return flow, the water used but then returned to the watershed. Watershed processes simulated by the Precipitation Runoff Modeling System (PRMS) will be integrated into the groundwater-surface water model using GSFLOW. An introductory discussion of the approach for estimates for return flow are also discussed in this memorandum.

Municipal pumping within the basin is metered, but for most areas without municipal supplies the amount of water use is not metered or recorded. For these non-metered areas, the amount of water use is estimated based on land use. The estimates for non-municipal domestic water use is described in this memorandum. The methodology for estimating institutional, recreational, and agricultural irrigation water use based on crop type and climate is also described in this memorandum. These estimates of water use will be used to define non-municipal pumping in the model.

The technical memorandum describes a number of assumptions for water use and return flow that will be incorporated into the Mid-County Groundwater Basin groundwater model. The sensitivity of these assumptions will be tested by the model. However, the amount of non-municipal domestic, institutional, recreational, and agricultural water use is small and likely less sensitive compared to some of the other model inputs, such as precipitation, and outputs, such as evapotranspiration.

2.0 NON-MUNICIPAL DOMESTIC WATER USE

2.1 NON-MUNICIPAL DOMESTIC WATER USE METHODOLOGY

For purposes of the groundwater model, non-municipal water use is considered use that is supplied by non-municipal sources of groundwater. Community water systems are included in the non-municipal water use estimate where metered data are not available. Non-municipal water use estimates are used for two purposes: to provide a volume for groundwater extraction where metered data are not available, and to estimate the amount of non-municipal use return flow from septic tanks and landscape irrigation as a proportion of the water used at each residence. Commercial water use is not considered in this estimate because according to Santa Cruz County's (the County's) 1994 land use dataset, there is no significant commercial land use, other than agriculture-related activities, in areas that do not receive municipal water supply.

To estimate the amount of non-municipal domestic water use within the model domain, two sources of data are used. The primary data source is the County's building footprint geographical information systems (GIS) layer that is used to identify individual residential buildings. The second data source, used to supplement the building footprints, is land use data from Santa Cruz County identifying residential parcels.
Santa Cruz County developed the building footprint layer from aerial photograph interpretation using photographs from 2003 and 2007. We applied a filter to exclude buildings that are not classed as habitable structures and have footprints that are less than 500 square feet in area. Residential buildings served by the City of Santa Cruz, Soquel Creek Water District (SqCWD), Central Water District (CWD), City of Watsonville, and Scotts Valley Water District were also excluded. To identify residential buildings served by the list of agencies above, a layer of municipal metered parcels was intersected with the building footprints. All residential building footprints falling within the metered parcel layer or that were part of a multi-parcel residential complex that included one metered parcel were excluded following the assumption that these residences are supplied water by an overlying water supply agency.[1]

Because the building footprint data comprises only residential buildings as of 2007, and because some buildings may have been missed in the County's building footprint layer due to tree cover, we also identified residential parcels that do not receive municipal supply and did not have an identified building footprint from Santa Cruz County's land use dataset. Residential parcels added to the dataset were selected using land use codes listed in Appendix A. Residential parcels not receiving municipal water were identified based on the layer of metered parcels. In order to determine the number of non-municipal water use residential buildings as of 2014, we assumed that each residential parcel without an identified building footprint had one building unless the land use description for the parcel specifically included the number of additional residences.

Table 1 shows the number of non-municipal water use residential buildings as of 2014 in the full model domain and within the Santa Cruz Mid-County Basin. The table also breaks down the number of non-municipal water use homes that are on septic and sewer. Sewered areas are those areas which are connected to sewer lines. The sewer spatial data was provided by the County and SqCWD. It is assumed that those homes not connected to the sewer are on septic systems.

[1] Central Water District does provide water to a few residences that also have private wells; those wells are seasonal and/or not reliable sources of drinking water (Bracamonte, 2016). Therefore, this small amount of private water use is not accounted for in the model. This same assumption was made for other areas supplied municipal water by other agencies.

Table 1: Summary of Non-Municipal Water Use Residential Building Count

Data Source	Number of Non-Municipal Water Use Homes on Septic Systems		Number of Non-Municipal Water Use Homes on Sewer		Total Number of Non-Municipal Water Use Homes	
	Model Area	Mid-County Groundwater Basin	Model Area	Mid-County Groundwater Basin	Model Area	Mid-County Groundwater Basin
Santa Cruz County Building Footprints	4,333	1,728	409	331	**4,742**	**2,059**
Santa Cruz County Land Use Residential Parcels Without Building Footprints	736	326	0	0	**736**	**326**
Total	**5,069**	**2,054**	**409**	**331**	**5,478**	**2,385**

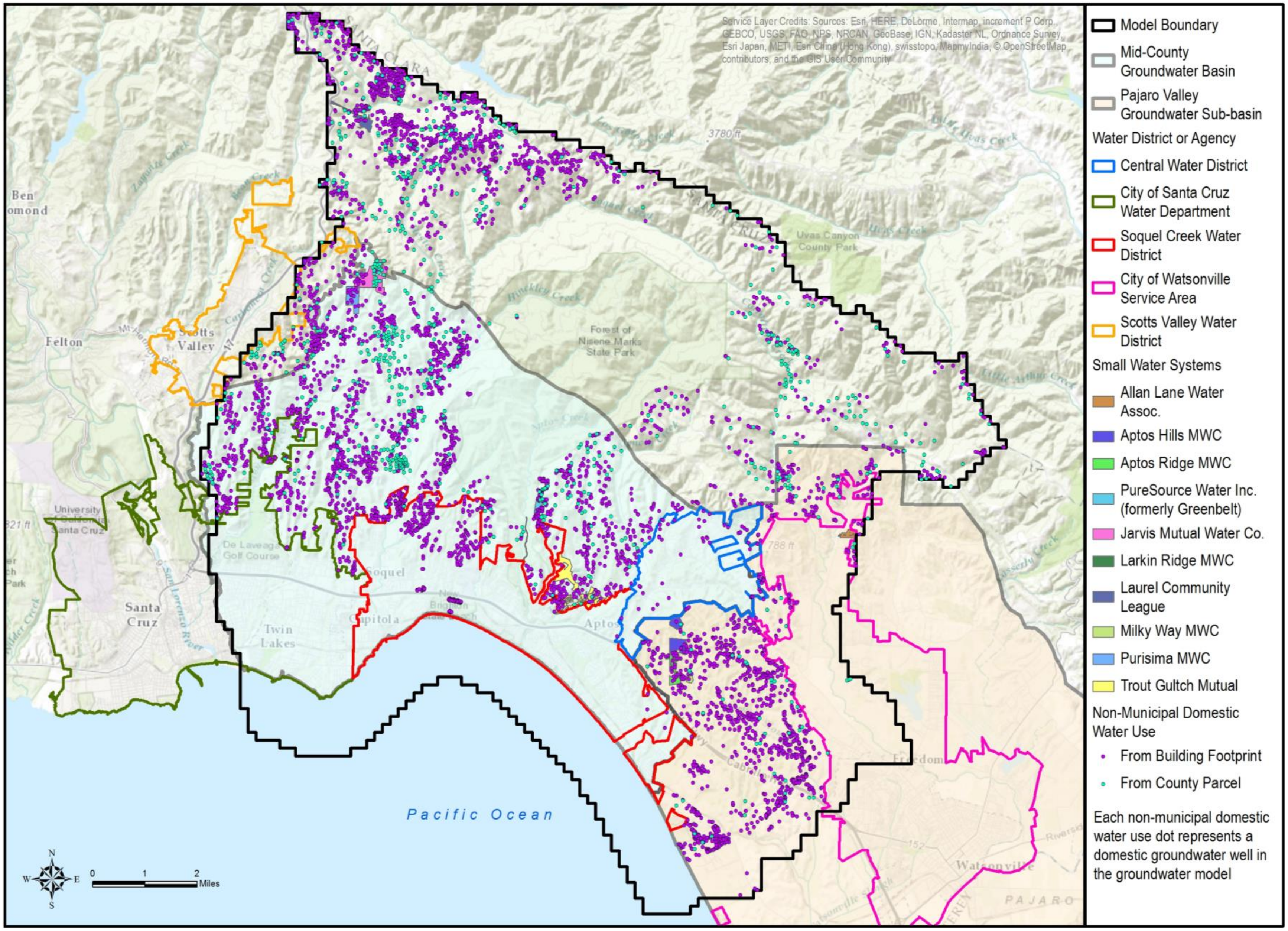

Figure 1: Non-Municipal Water Use Building Footprints and Residential Parcels

2.2 NON-MUNICIPAL DOMESTIC WATER USE FACTOR

An annual water use factor was developed to apply to the total number of non-municipal water use residences to obtain annual volumes of non-municipal groundwater pumped within the model area. The water use factor for 2015 was based on an evaluation of water use in 2015 by small water systems within and in close proximity to the model area (Table 2). From these data provided by the County, it was observed that water use per connection is greater for the larger of the small water systems in the Pajaro Valley Groundwater Sub-basin (Table 2). Based on this, the average 2015 water use factor for small water systems in the Pajaro Valley Groundwater Sub-basin is 0.50 acre-feet per year, and in the Mid-County Groundwater Basin (and remaining area within the model) it is 0.23 acre-feet per year (Table 2). These factors are applied to the non-municipal domestic dataset for Water Year 2015 according to the groundwater basin the water use falls in.

Table 2: Groundwater Pumped by Small Water Systems in 2015

Small System Name	Connections	2015 Use (gallons)	2015 Use / Connection (gallons)	2015 Water Use Factor (AFY)
Allan Lane Water Association	***16***	***4,326,708***	***270,419***	***0.83***
Aptos Hills Mutual Water Co.	***11***	***2,514,698***	***228,609***	***0.70***
Aptos Ridge Mutual Water Co.	***16***	***3,375,425***	***210,964***	***0.65***
Larkin Ridge Mutual Water Co.	***5***	***329,270***	***65,854***	***0.20***
Milky Way Mutual Water Co.	***9***	***420,975***	***46,775***	***0.14***
Trout Gulch Mutual	186	13,754,865	73,951	0.23
Purisima Mutual Water Co.	14	1,767,174	126,227	0.39
PureSource Water Inc.	80	5,315,289	66,441	0.20
Jarvis Mutual Water Co.	36	2,143,690	59,547	0.18
Laurel Community League	24	1,283,012	53,459	0.16
Average All				**0.37**
Average Mid-County Basin				**0.23**
Average Pajaro Valley Sub-basin				**0.50**

Five top small water systems in the table (in bold italics) are located in the Pajaro Valley Groundwater Sub-basin.

The water use factor was assumed to have been higher in years prior to 2015 because water conservation was not practiced to the extent that it is in the most recent years as evidenced by water use metered at several systems with data from 2013 through 2015 (Table 3). Based on this, percentage of water conserved between 2013 and 2015 in Pajaro Valley Groundwater Sub-basin was 20%, and in the Mid-County Groundwater Basin (and remaining area within the model) it was 34% (Table 2). These factors are applied to the 2015 water use factor to arrive at a water use factor for 2013. Water Year 2014's water use factor was assumed to be the mean of 2013 and 215 factors.

The water use factors are increased incrementally from 2013 backwards to the start of the model period. For the non-Pajaro Valley Groundwater Sub-basin areas, the period from 1989 through 2004 is assigned a water use factor 0.44 acre-feet per year based on Wolcott (1999), with a higher factor before that period and a declining factor since that period. For the Pajaro Valley Groundwater Sub-basin, a Proposition 218 service charge study by PVWMA estimated a water use factor of 0.59 acre-feet per year for 2009 based on small water system usage. This water use factor is the same as that estimated for 2015 based on 20% conservation of 2015 use, and thus was applied from 2009 through 2013. The water use factors prior to 2009 were increased incrementally over the same periods as the non-Pajaro Valley Groundwater Sub-basin factors. Table 4 provides the annual water use factors used to estimate historical non-municipal water use for the model area and for the Mid-County Groundwater Basin, as a subset of the model area.

Table 3: Observed Conservation from 2013 through 2015 for Small Water System with Metered Records

Small Water System	July – December Usage (AFY)			Conservation % 2013 – 2015
	2013	2014	2015	WUF (AFY)
Aptos Hills Mutual Water Co.	4.3	6.5	3.5	17%
Aptos Ridge Mutual Water Co.	9.0	3.5	6.9	23%
Trout Gulch Mutual	36.0	24.3	21.7	40%
PureSource Water Inc.	11.7	7.9	8.6	27%
Jarvis Mutual Water Co.	6.2	5.1	2.2	65%
Laurel Community League	2.0	2.0	1.9	4%
Average All				**29%**
Average Mid-County Basin				**34%**
Average Pajaro Valley Sub-basin				**20%**

Table 4: Summary of Non-Municipal Water Use Factors

Water Year	Non-Pajaro Valley Groundwater Sub-Basin (AFY)	Non-Pajaro Valley Groundwater Sub-Basin (AFY)
1985	0.46	0.62
1986	0.46	0.62
1987	0.46	0.62
1988	0.46	0.62
1989	0.44	0.62
1990	0.44	0.62
1991	0.44	0.62
1992	0.44	0.62
1993	0.44	0.62
1994	0.44	0.62
1995	0.44	0.62
1996	0.44	0.62
1997	0.44	0.62
1998	0.44	0.62
1999	0.44	0.62
2000	0.44	0.62
2001	0.44	0.62
2002	0.44	0.62
2003	0.44	0.62
2004	0.44	0.62
2005	0.41	0.61
2006	0.41	0.61
2007	0.41	0.61
2008	0.41	0.61
2009	0.38	0.59
2010	0.38	0.59
2011	0.38	0.59
2012	0.38	0.59
2013	0.35	0.59
2014	0.29	0.54
2015	0.23	0.5

2.3 NON-MUNICIPAL DOMESTIC WATER USE ESTIMATE

To estimate the annual non-municipal water use for all simulated years of the model period, the number of non-municipal residences was extrapolated from the count of residential buildings for 2014 obtained from Santa Cruz County building footprints and residential parcels. The number of buildings was assumed to increase or decrease in proportion to the increase or decrease in the County's unincorporated population relative to 2014's population (Table 5). Spatial distribution of water use was maintained consistent to the distribution for 2014.

Table 5 shows that estimates of annual non-municipal residential groundwater use in the model area have ranged from approximately 2,751 acre-feet in 1985 to a maximum of 3,223 acre-feet in 2000, subsequently falling to a minimum of 2,418 acre-feet in 2015. A subset of non-municipal estimates of groundwater use for the Santa Cruz Mid-County Basin are included in Table 5.

2.4 MONTHLY VARIATION OF NON-MUNICIPAL DOMESTIC WATER USE

Pumping will be applied to the model in monthly stress periods because municipal pumping for Water Years 1985-2015 is recorded on a monthly basis. Monthly variation of non-municipal domestic water use is assumed to result from variation in outdoor water use. Outdoor water use is assumed to average 30% of total domestic water use (Johnson *et al*., 2004). The variation of outdoor water use by month will be estimated from the variation of potential evapotranspiration (PET) minus actual evapotranspiration of rainfall as calculated by an initial simulation of watershed processes by PRMS.

Table 5: Estimated Non-Municipal Domestic Water Use based on Number of Residential Buildings and Population Change

Water Year	Unincorporated Population % of 2014	Estimated Number of Non-Municipal Supplied Residential Buildings		Non-Municipal Domestic Water Use (AFY)	
		Model Area	Mid-County Groundwater Basin	Model Area	Mid-County Groundwater Basin
1985	90.1%	4,938	2,147	2,880	988
1986	92.1%	5,046	2,194	2,943	1,009
1987	94.0%	5,148	2,239	3,003	1,030
1988	94.8%	5,194	2,259	3,029	1,039
1989	96.5%	5,289	2,300	3,060	1,012
1990	98.3%	5,383	2,341	3,115	1,030
1991	97.3%	5,329	2,317	3,084	1,019
1992	97.8%	5,357	2,330	3,100	1,025
1993	98.5%	5,398	2,347	3,124	1,033
1994	99.3%	5,439	2,365	3,147	1,041
1995	99.6%	5,456	2,372	3,157	1,044
1996	100.2%	5,489	2,387	3,176	1,050
1997	99.5%	5,449	2,370	3,153	1,043
1998	100.1%	5,483	2,384	3,173	1,049
1999	100.7%	5,518	2,399	3,193	1,056
2000	101.7%	5,570	2,422	3,223	1,066
2001	100.4%	5,500	2,392	3,183	1,052
2002	99.9%	5,472	2,379	3,166	1,047
2003	99.1%	5,429	2,361	3,142	1,039
2004	98.0%	5,368	2,334	3,106	1,027
2005	96.7%	5,298	2,304	2,988	945
2006	96.5%	5,287	2,299	2,982	943
2007	96.2%	5,270	2,292	2,973	940
2008	96.8%	5,305	2,307	2,992	946
2009	97.3%	5,333	2,319	2,882	881
2010	97.8%	5,360	2,331	2,897	886
2011	97.9%	5,364	2,332	2,899	886
2012	98.4%	5,392	2,344	2,914	891
2013	99.3%	5,439	2,365	2,900	824
2014	***100.0%***	***5,478***	***2,382***	2,660	689
2015	100.8%	5,520	2,400	2,418	552
			Average	**3,021**	**970**

Note: estimates based on estimated 2014 residential building/parcel count and 2014 unincorporated population

3.0 Institutional Non-Municipal Water Use

Non-municipal, non-agricultural water use that is excluded from non-municipal domestic water use, because it cannot be accounted for by using residential buildings or parcels, is considered institutional non-municipal water use. This is water use by institutions or facilities within the model area that pump their own groundwater primarily for large scale irrigation of recreational turf.

The only small water system in the model area with available and consistent historical usage records is from Trout Gulch Mutual, where data are available from 2008 through 2015. This usage is included as institutional use because it is not supplied by municipal water and does not need to be estimated based on residential building footprints or parcels. Pumping for Trout Gulch Mutual prior to 2008 was assumed to be the same as its 2008 pumping. Estimates of pumping by other small water systems who do not have available and well-documented multi-year records of usage were developed by using the building footprints, parcels and water use factors described in Section 2.0.

Table 6 lists the non-municipal and non-agricultural water use institutions/facilities and provides their estimated water use. Estimates of water use are from a number of sources as referenced in the table. Figure 2 shows the locations of these institutions within the model area.

3.1 Calculation of Irrigation Use

Some of the institutions use privately pumped groundwater to irrigate recreational turf in addition to potable supply for their institutions. Table 6 identifies areas of irrigation for these institutions. The amount of groundwater pumped for outdoor use based on the turf acreage provided will be estimated based on potential evapotranspiration (PET) minus rainfall evapotranspiration (ET demand) calculated by an initial simulation of watershed processes by PRMS that accounts for climatic conditions during the 1985-2015 model period. ET calculated by PRMS is for generalized plant cover, while the estimated irrigation for turf is based on crop evapotranspiration specific to turf (ET_c). ET_c is estimated by multiplying turfgrass' crop coefficient (K_c) by ET demand calculated by PRMS adjusted for the generalized crop coefficient applied in PRMS. Values of K_c for turf vary by month and are listed in Table 7. An irrigation inefficiency of 10-20% will be added to irrigation demand to estimate the pumping needed to meet this demand. Although PRMS calculates soil moisture that could affect irrigation demand, to avoid iterative calculation of irrigation demand using the model, we will estimate irrigation demand based only on ET_c minus actual evapotranspiration of rainfall calculated by PRMS adjusted for crop coefficients.

Table 6 also shows a preliminary estimate for outdoor water use at these areas prior to running the model using average monthly reference potential evapotranspiration (ET_o) from CIMIS Station No. 209 (Watsonville West II), and no irrigation between November and March to account for a typical rainy season. Based on the preliminary estimates, the preliminary water use factor for irrigation is approximately 1.8 acre-feet/acre. As reference, Wolcott (1999) used a similar factor of 1.7 acre-feet/acre.

Estimates by Kennedy (2015) for water use are also shown in Table 6 with notes where there are discrepancies from the preliminary estimates calculated based on the assumptions above.

Table 6: Estimated Groundwater Pumped by Institutions/Facilities in the Model Area

Institution/ Facility	Year	Area of Irrigated Turf (acres)	Preliminary Outdoor Water Use (AFY)	Indoor Water Use (AFY)	Preliminary Pumped Groundwater (AFY)	Kennedy Estimates of Total Water Pumped (AFY)/Comments on Current Status
Aptos High School		2.2	4.0[1]	9.3[3]	13.3	
KOA		-			11 estimate	26.7 - seems high
Monterey Bay Academy	2015	uncertain	577[8]	18[3]	595[6]	
Renaissance High School		1.8	3.2[1]	2.0[3]	5.3	1.7
7th Day Adventist Conference*		-	-	8.0[2]	8.0	11.0 / County confirms no current irrigation
Cabrillo College*	2014	12.7	22.9[1]	55.1	78.0[6]	95
Enchanted Valley*		-	-	5.4[2]	5.4	5 (rounded down)
Kennolyn Camp*		-		Included in non-municipal water use estimate		9
Land of Medicine Buddha*		-	-	1.7[2]	1.7	2 (rounded up)
Mountain Elementary School*		1.9	3.5[1]	1.5[1]	5.0	County has 0.02AFY reported pumping – this seems low given they irrigate turf
Seascape Golf Course*		136.1	108[6]	MS	108[6]	232 / County permit for 108 AFY
Seascape Greens*		11.5	20.6[1]	MS	20.6	Not included
Soquel High School*		6.4	11.5[1]	MS	11.5	Not included
St. Clare's Retreat Home*		-	-	2	2	Not included
Trout Gulch Mutual *	Ave 2008 –2014	-	20.4[7]	47.5[7]	67.9[5]	67.1
Total Model					**932.7**	
***Total Mid-County Groundwater Basin**					**308.1**	

* = Mid-County Groundwater Basin
MS = municipal supply
[1] Irrigated area multiplied by water use factor of 1.8 acre-feet/acre
[2] Wolcott (1999) Appendix E
[3] Using per capita rates and other assumptions for schools from Wolcott (1999) Appendix E
[4] HydroMetrics (2015)
[5] Trout Gulch Mutual's pumping records
[6] Santa Cruz County records
[7] Based on 30/70 Outdoor/Indoor usage
[8] Difference between groundwater pumped and indoor use

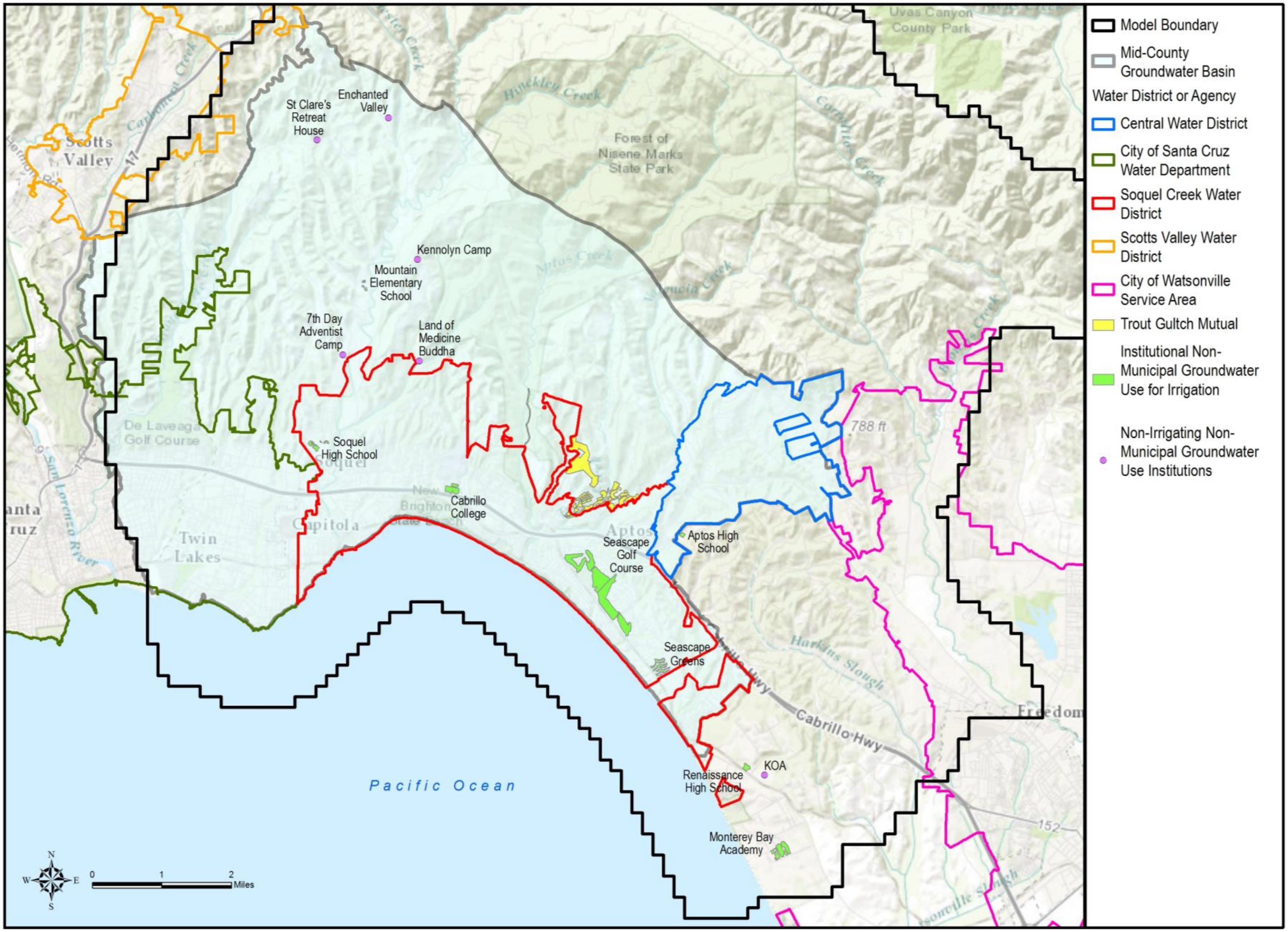

Figure 2: Non-Municipal Groundwater Use Institutions

4.0 Agricultural Water Use

4.1 Agricultural Irrigation Use Methodology

An estimate of the amount of agricultural irrigation applied in the groundwater model is estimated based on crop evapotranspiration (ET_c). The amount of groundwater pumped for agricultural use will be estimated based on potential evapotranspiration (PET) minus rainfall evapotranspiration calculated by an initial simulation of watershed processes by PRMS that accounts for climatic conditions during the 1985-2015 model period as described in the previous section. For agriculture, crop coefficient (K_c) is affected by crop type, stage of growth, soil moisture, the health of the plants, and cultural practices. Values for K_c (unitless) are primarily those used in the PVWMA groundwater model developed by the USGS (Hanson *et al.*, 2014). Exceptions to Pajaro Valley K_c are coefficients for apple orchards, vineyards, pastures, and nurseries/greenhouses.

Apple orchards within the Mid-County Groundwater Basin are mostly well-established and require limited irrigation. We assumed only irrigation in the warmer months of April through October. The Pajaro Valley model April through October K_c values were reduced until the annual water demand approximated measured water use used in the CWD model for apple orchards (HydroMetrics WRI and Kennedy/Jenks, 2014). This same approach of reducing monthly K_c based on measured water use for the CWD model was taken for all vineyards (irrigated April through September) and pastures (irrigated April through November) in the model. The Pajaro Valley model used a K_c value of 0.1 for all 12 months for nurseries/greenhouses. A review of published papers on crop coefficients indicated that the coefficient should be much higher. Therefore we have assumed a K_c of 0.8 for all months for nurseries/greenhouses. The monthly K_c to be used in the GSFLOW model for each crop type are summarized in Table 7.

Table 7: Monthly Crop Coefficients (K_c)

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Turf (Urban)	0.56	0.56	0.56	0.73	0.73	0.73	0.73	0.7	0.62	0.56	0.56	0.56
Vegetable Row Crops	0.61	0.61	0.61	0.92	0.71	0.6	1.04	0.92	0.59	1	0.85	0.61
Strawberry	0.62	0.62	0.62	0.86	0.66	0.58	1.01	0.9	0.56	1.06	0.86	0.62
MGB Deciduous (Orchards)	0	0	0	0.025	0.075	0.1	0.125	0.15	0.15	0.025	0	0
Non-MGB Deciduous (Orchards)	0.03	0.03	0.03	0.1	0.3	0.4	0.5	0.6	0.6	0.1	0.03	0.03
Subtropical	0.56	0.56	0.56	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.56
Vines/Grapes	0	0	0	0.17	0.22	0.23	0.23	0.22	0.12	0	0	0
Pasture	0	0	0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0
Grains (Field Crops)	0.25	0.25	0.25	1.17	0.87	0.17	0.17	0.17	0.17	0.17	0.17	0.25
Nurseries/Greenhouses	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Raspberries/ Blackberries/Blueberries	0.16	0.16	0.16	0.51	0.75	0.78	0.78	0.75	0.45	0.25	0.2	0.16
Semi-agriculture	0.31	0.31	0.31	0.62	0.74	0.7	0.7	0.53	0.34	0.27	0.27	0.31

Coefficients are unitless
Sources of data: PVWMA Groundwater Model (Hanson *et al.*, 2014) and HydroMetrics WRI & Kennedy/Jenks (2014)

There are some apple orchards and pastures in the model that have been identified by the County as dry farmed and therefore no irrigation demand is estimated for those areas.

Annual agricultural demand is estimated by summing the product of the monthly crop coefficients (K_c), a monthly reference evapotranspiration (ET_o) that is measured at a nearby CIMIS station, and the crop acreage:

$$Agricultural\ Demand\ (acre - feet) = K_c\ (unitless) \times ET_o(feet) \times crop\ area\ (acres)$$

4.2 Preliminary Agricultural Irrigation Demand Estimate

Using the methodology described in the section above, Table 8 summarizes the crops, their 2014 acreages, and preliminary estimates for water demand for 2014 based on monthly reference crop evapotranspiration (ET_o) in 2014 from CIMIS Station No. 209 (Watsonville West II. The acreages and locations of crops were obtained primarily from PVWMA, which maps crop coverages at least annually. Current aerial photographs were used to supplement crop locations and types in areas to the west of the data provided by PVWMA. The County also provided some field verification and identified some areas within the Mid-County Groundwater Basin that are dry farmed.

The locations of horse and cattle related operations were identified through an internet search and confirmed by aerial photographs. Figure 3 shows the 2014 distribution of crops by type within the model area. Some of the agricultural demand in the model area is met by water supplied by CWD, as indicated in Table 8.

For the water demand from livestock related agriculture, horses are estimated by head count instead of acreage. It was assumed that horse boarding, breeding, and training facilities use 30 gallons per horse per day[2]. The number of horses at each facility was estimated by counting the number of stalls from aerial photographs. The one cattle ranch that we have identified has been excluded because it appears small based on aerial photographs. Water use data for the one egg ranch within the model area was provided by CWD.

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[2] Horses require on average 10 gallons per day for direct consumption. We assumed 20 gallons per day per horse additional water use for other activities at the facility such as cleaning and dust control. Assuming 35 horses, a total water use of 30 gallons per day per head is also the Barn Boarding Stable's 2005-2015 average metered records from CWD.

Table 8: Summary of 2014 Agricultural Water Demand

Crop/Activity	Unirrigated Acreage (acres)		Irrigated Acreage (acres)		Estimated 2014 Water Demand by Supply (AFY)		Estimated 2014 Water Demand by Area (AFY)	
	Model Area	Mid-County Groundwater Basin	Model Area	Mid-County Groundwater Basin	Private Supply	CWD Supply	Model Area	Mid-County Groundwater Basin
Deciduous (Apple Orchards)	89	89	1,515	350	1,185	10	1,195	81
Strawberries	-	-	653	0	1,706	0	1,706	0
Vegetable Row Crop	-	-	652	88	1,705	33	1,738	235
Nurseries/Flowers/Tropical Plants	-	-	566	27	1,555	0	1,555	74
Raspberries and Blackberries	-	-	520	0	912	0	912	0
Vine/Grapes	-	-	280	186	115	10	125	83
Fallow	-	-	206	0	0	0	0	0
Pasture	33	33	205	74	440	0	440	160
Greenhouse	-	-	75	3	206	0	206	8
Other Agriculture	-	-	31	0	54	0	54	0
Bamboo	-	-	30	30	0	13	13	13
Ag. Unknown	-	-	4	1	6	0	6	3
Olive Orchard (similar to apple orchard demand)	-	-	1	1	0	0.2	0.2	0.2
Citrus	-	-	22	22	48	0	48	48
Horses	-	-	-	-	13.7	0.3	14	7
Egg Ranch	-	-	-	-	0	2	2	2
Total Crops and Livestock	**122**	**122**	**4,759**	**784**	**7,946**	**69**	**8,015**	**715**

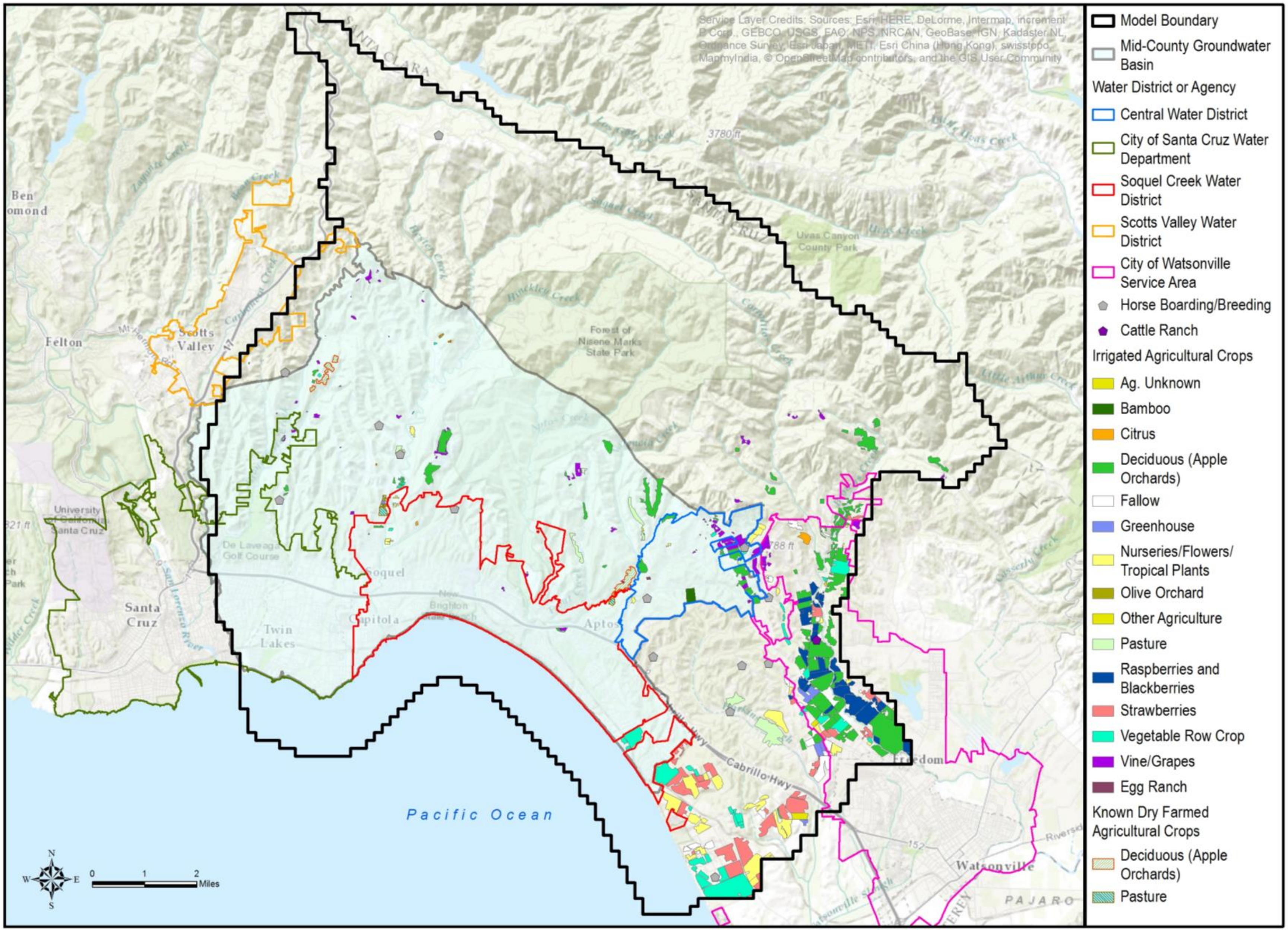

Figure 3: 2014 Agriculture in the Model Area

5.0 IMPLEMENTING NON-MUNICIPAL PUMPING IN MODEL

All non-municipal domestic and institutional, and agricultural water use is assumed to be supplied by privately pumped groundwater. This pumping will be aggregated and estimated for each applicable model cell; specific wells will not be explicitly simulated in the model. The pumping estimates will be added to the Multi-Node Well (MNW2) package file as multi-layer wells screened from the top layer to the lowest likely layer of production for the grid cell. Pumping will be distributed to layers by the model based on simulated layer transmissivity. If the shallowest layers become dry in the model, pumping is distributed to lower saturated layers so that all of the estimated pumping is included in the model's water budget.

6.0 SIMULATING RETURN FLOW COMPONENTS

There are a number of return flow components that will be included in the groundwater model. This memorandum introduces these components and how we propose to estimate them. The final estimates and resultant model input will be discussed in the memorandum documenting the integrated GSFLOW model.

In general, return flow components include:

1. System losses: water, sewer and septic systems,
2. The inefficient portion of municipal and non-municipal domestic and institutional irrigation (outdoor applied water), and
3. The inefficient portion of agricultural irrigation.

A phased approach is planned for implementing return flow components in the GSFLOW model. Initially, all return flow components will be added in GSFLOW's UZF package, which is applied below the root zone (Table 9). The US Geological Survey recently added this capability to UZF under its joint funding agreement with SqCWD. Using only the single package that is integral to GSFLOW will expedite model results that will allow MGA and members evaluate groundwater management alternatives and supplemental supply options by early 2017. However, adding return flow components to UZF will preclude calculation of near surface runoff of the return flow components to surface water.

Future work will continue use of UZF for simulating return flow from water and sewer system losses, and septic systems, which is assumed to occur below the soil root zone. However, there is an option to simulate return flow from the inefficient portions of irrigation using the newly developed Water Use Module (WUM) for PRMS, which adds water to the near surface capillary zone (Table 9). This module effectively allows for the inefficient portions of return flow near surface runoff to surface water as well as groundwater recharge. The need to implement WUM will be evaluated in 2017 when the model will be used to analyze relative impacts from various water use classifications under a County Proposition 1 grant.

Table 9: Summary of Packages Used to Simulate Return Flow in the Model

Return Flow Component	Package used in Model Implementation	
	Initial (2016)	Future Option (2017)
Water system losses	UZF	UZF
Sewer losses	UZF	UZF
Septic system losses	UZF	UZF
Municipal & non-municipal irrigation	UZF	WUM
Agricultural irrigation	UZF	WUM

The following sections describe our proposed approach for simulating the different return flow components using UZF only for this first phase of return flow implementation.

6.1 WATER SYSTEM LOSSES

Water system losses will be calculated as percentage of estimated deliveries to each service area and applied in UZF to model cells overlying those service areas.

For the Central Water District (CWD) model, the system loss percentage for CWD was varied over time based on unaccounted water losses by fiscal year through 2009 (HydroMetrics WRI and Kennedy/Jenks, 2014). The approximate range of CWD system loss estimated for the CWD model for 1984-2009 was 4-14%. This percentage will be updated for fiscal years through 2015.

For the CWD model, the system loss percentage for Soquel Creek Water District (SqCWD) was estimated as 7% which was confirmed through a SqCWD water audit for 2010-2013 (Mead, 2014) . The Cities of Santa Cruz and Watsonville water system losses will be 7.5% and 6%, respectively, per their 2015 Urban Water Management Plans (UWMP)

6.2 WASTEWATER RETURN FLOWS

Wastewater return flows will be based on indoor use that becomes wastewater. Indoor use has generally been assumed to be 70% of total water use (Johnson et al., 2004 and USEPA, 2008) and 90% of indoor water use is assumed to become wastewater. There are a range of available estimates for this value with measurements at mountain residences in Colorado indicating approximately 81% (Stennard et al, 2010) and California Department of Water Resources (1983) estimating 98%.

For wastewater return flows from sewer losses in sewered areas, the same loss percentage of 7% used in the CWD model based on the SqCWD system loss percentage will be applied to model cells overlying all sewered areas. These sewer losses will be added in UZF to infiltrate below the root zone.

All of indoor water use that becomes wastewater for septic systems will be also be added in UZF below the root zone for model cells in unsewered areas. Although there has been research indicating additional evapotranspiration from septic systems than surrounding areas (Stannard et al., 2010), typical leachfield depth in Santa Cruz County is 4 to 50 feet and County staff has rarely observed increased vegetation overlying or nearby leachfields that would indicate root zone evapotransporation from septic systems (Ricker, 2016).

Santa Cruz County has observed that the percentage of indoor use is influenced by overall water use and climatic conditions (Ricker, personal communication). In years of drought, such as from 2013 – 2015, water conservation is practiced to a greater extent by the public. Outdoor use is usually the first place where water use is cut, thus the percentage of indoor use is greater in those years than years when the overall water use is higher. For the period through 2013, the percentage of indoor use in the model will be 70% and will increase to 75% for 2014, and to 80% for 2015.

6.3 IRRIGATION RETURN FLOWS

The portion of water from irrigation that returns to the watershed as runoff or groundwater recharge is the inefficient portion of irrigation. The amount of water applied in UZF is just the inefficient irrigation calculated in the model cell because UZF represents what is below the capillary zone where the crop's evapotranspiration demand is met. The inefficiency factor, or the percentage of crop ET demand that does not evapotranspirate, will range from 10% (Todd, 2014) to 20% (Johnson et al., 2004).

7.0 Calculating Return Flow Components

Calculation of return flow components depends on water source and wastewater destination in addition to type of water use. The following sections describe our proposed approach for calculating the different return flow components.

7.1 Municipal Return Flow

Figure 4 illustrates how we plan to estimate return flows from municipally supplied water including system losses and wastewater return flows discussed above as well as irrigation return flows. From available water supply records, we will distribute return flows spatially based on land use and service areas. Municipal water use for the Cities of Santa Cruz and Watsonville includes both surface water and groundwater. Land use factors affecting municipal return flow include defining areas of large-scale irrigation versus primarily residential and commercial use where irrigation is at a smaller scale. Figure 5 shows the locations of municipal service areas and various land use categories used for different applied water types.

To estimate the amount of residential and commercial water use for each municipal service area, water system losses as described above and water used for large-scale irrigation will be subtracted from the amount of water supplied to each service area. The amount of irrigation applied will vary monthly based on local potential evapotranspiration (Figure 4). Return flow comprised of the inefficient portion of outdoor use, sewer losses in sewered areas, and septic system leakage will be distributed to model cells overlying those service areas. Areas that are not supplied water, such as open space and undeveloped land will be excluded.

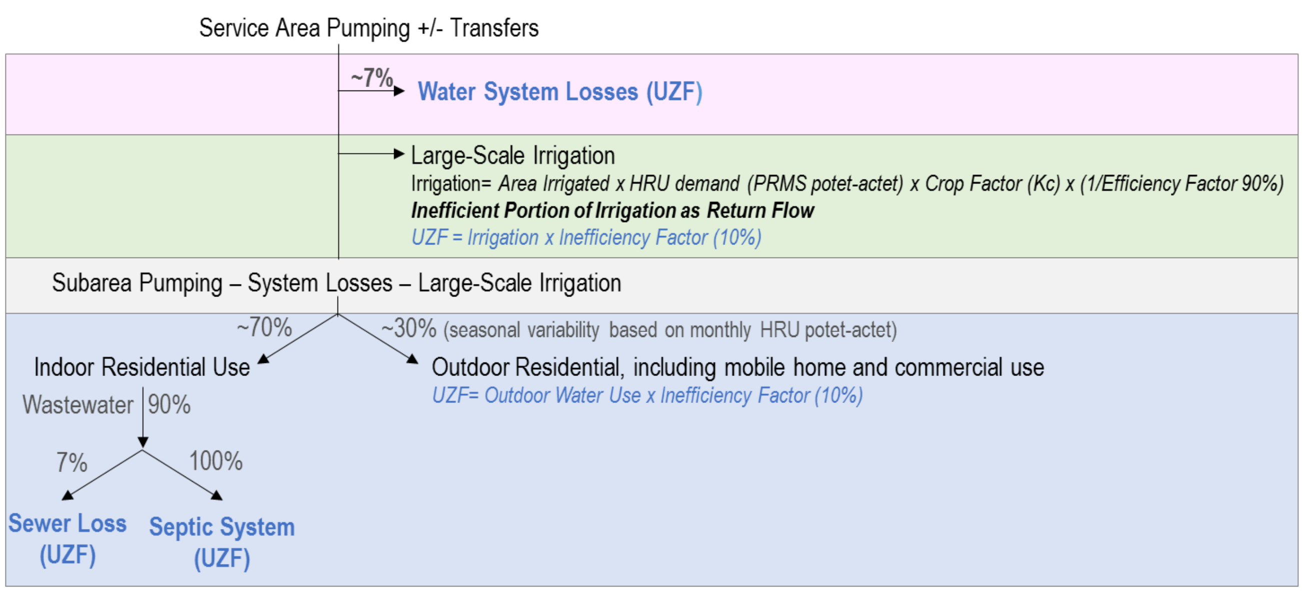

Figure 4: Approach to Estimating Municipal Return Flow

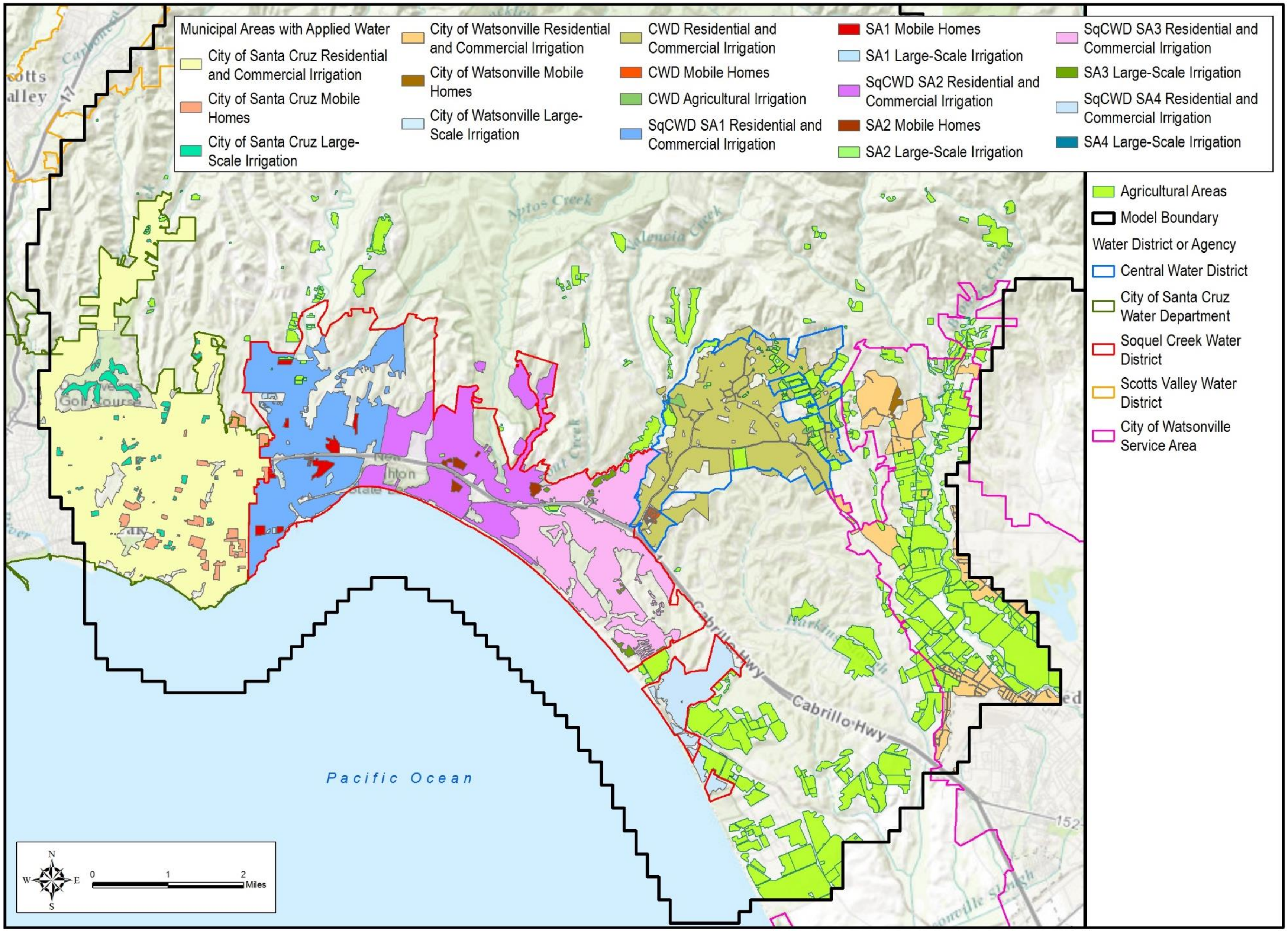

Figure 5: Municipal Applied Water Areas

Return flow represented by the inefficient portion of large-scale irrigation of sports fields and parks will also be applied to model cells that overlie those irrigated areas. Estimates of large-scale irrigation will rely on irrigation demand as estimated by the difference between capillary zone PET and actual rainfall ET simulated by PRMS, the area of the cell being irrigated, a crop factor, and irrigation inefficiency.

7.2 NON-MUNICIPAL DOMESTIC RETURN FLOW

The inefficient portion of non-municipal outdoor domestic use will be applied in the model using the non-municipal domestic water use described earlier in this technical memorandum. Figure 6 shows approximately 30% of total domestic water use will be assumed for outdoor use based on the average outdoor water use for 1985-2013, and a portion of this outdoor use, based on an inefficiency factor, will be applied to cells overlying the areas identified in this memo as having non-municipal domestic water use. The percentage of outdoor water use is assumed to decrease for 2014-2015 to achieve recent conservation as described in Section 6.2, and will vary monthly to simulate changing seasonal demands. Figure 6 also shows the wastewater return flow of indoor use from septic systems as described above.

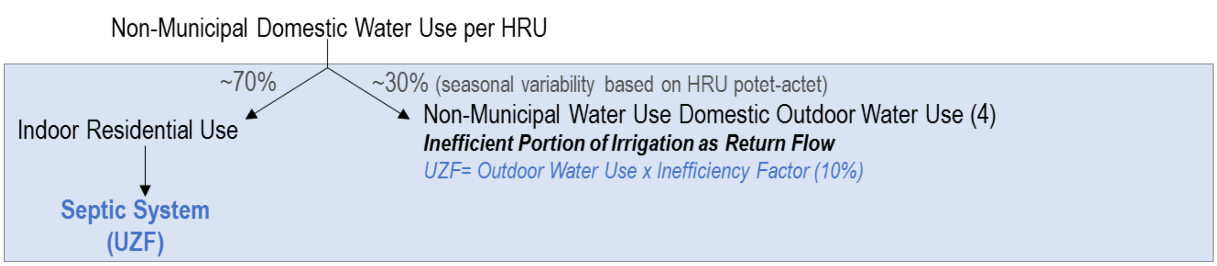

Figure 6: Approach for Estimating Non-Municipal Domestic Return Flow

7.3 INSTITUTIONAL NON-MUNICIPAL IRRIGATION RETURN FLOW

Similar to municipal large-scale irrigation, the inefficient portion of municipal institutional irrigation will be applied to model cells that overlie institutional irrigated areas (Figure 2), and will represent a proportion of applied water based on an assumed inefficiency factor. The calculation of return flow for each model cell is shown in Figure 7.

7.4 AGRICULTURAL IRRIGATION RETURN FLOW

The inefficient portion of agricultural irrigation to apply in the model will be based on the difference between PRMS estimated PET and actual ET (irrigation demand), the area of the cell being irrigated, a specific crop factor, and irrigation inefficiency (Figure 7).

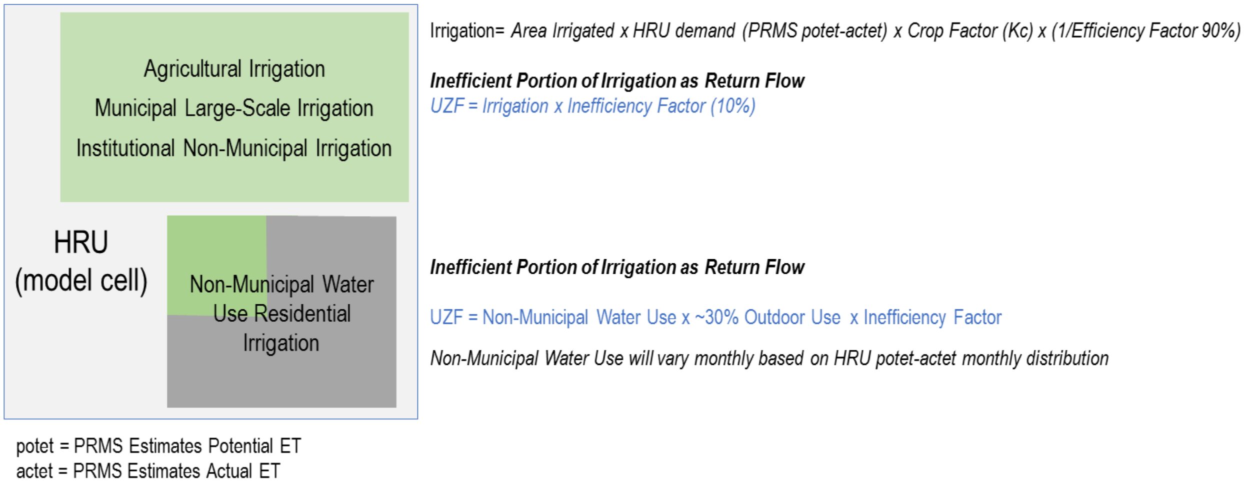

Figure 7: Return Flow Estimate Approach from Irrigation per Model Cell

8.0 SENSITIVITY OF WATER USE AND RETURN FLOW ASSUMPTIONS

This technical memorandum describes a number of assumptions for water use and return flow that will be incorporated into the Mid-County Groundwater Basin groundwater model. These assumptions can be tested with sensitivity runs using the model that test the effect of changing the assumptions on model predictions. However, when making any changes, the model calibration to groundwater level data and streamflow must be checked and the model potentially will need to be re-calibrated based on the changes. Only a calibrated model should be used to assess changes to model predictions.

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Appendix A

List of Santa Cruz County land use codes used to identify non-municipal water use residential parcels. Those in bold are codes that did not contain residential building footprints.

010-LOT/RESIDENTIAL ZONE
015-LOT/MISC RES IMPS
016-BUILDING IN PROGRESS
020-SINGLE RESIDENCE
021-CONDOMINIUM UNIT
023-NON-CONFORMING RES
024-SFR W/ SECONDARY USE
025-AFFORDABLE HOUSING
027-TOWNHOUSE
028-SFR + SECOND UNIT
029-SFR + GRANNY UNIT
030-SINGLE DUPLEX
031-TWO SFRS/1 APN
032-3 OR 4 UNITS/2+ BLDGS
033-TRIPLEX
034-FOUR-PLEX
040-VACANT APARTMENT LOT
041-5 - 10 UNITS
042-11 - 20 UNITS
043-21 - 40 UNITS
044-41 - 60 UNITS
045-60 - 100 UNITS
046-OVER 100 UNITS
050-LOT/RURAL ZONE
051-1-4.9 ACRE/RURAL
052-5-19.9 ACRE/RURAL
053-20- 49.9 ACRE/RURAL
054-50- 99.9 ACRE/RURAL
055-100-199.9 ACRE/RURAL
05B-MISC IMPS 1-4.9 ACRE
05C-MISC IMPS 5-19.9 ACRE
05D-MISC IMPS 20-49.9 ACRE
05F-MISC IMPS 100-199.9 ACR

060-HOMESITE/< 1 ACRE
061-HOMESITE/1-4.9 ACRES
062-HOMESITE/5-19.9 ACRE
063-HOMESITE/20-49.9 ACRES
064-HOMESITE/50-99.9 ACRES
065-HOMESITE/100-199.99 ACRE
068-RURAL DWELLINGS/1 APN
070-MOTEL/UNDER 20 UNITS
071-MOTEL/20 TO 49 UNITS
072-MOTEL/50 + UNITS
074-RESORT MOTEL
080-HOTEL
085-BED AND BREAKFAST
262-NURSERY W/ RES
411-ORCHARD/RESIDENCE
421-VINEYARD/RESIDENCE
431-BERRY FARM/RESIDENCE
432-BERRY FARM/MISC IMPS
451-VEGIE FARM/RESIDENCE
480-POULTRY RANCH
490-DIVERSIFIED FARM
500-TPZ/NO RESIDENCE
501-TPZ/RESIDENCE
511-CLCA/RESIDENCE
520-OSE/NO RESIDENCE
521-OSE/RESIDENCE
711-OTHER CHURCH PROPERTY

APPENDIX 2-C

MUNICIPAL RETURN FLOW MEMORANDUM

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TECHNICAL MEMORANDUM

DATE: August 28, 2019

TO: Santa Cruz Mid-County Groundwater Agency

FROM: Georgina King and Cameron Tana

PROJECT: Santa Cruz Mid-County Basin Groundwater Model

SUBJECT: Municipal Return Flow

SERVICE AREA WATER SUPPLY

Water supplied or delivered to the various municipal service areas in the model is the source of water from which different components of return flow are estimated.

Individual municipal return flow components estimated are:

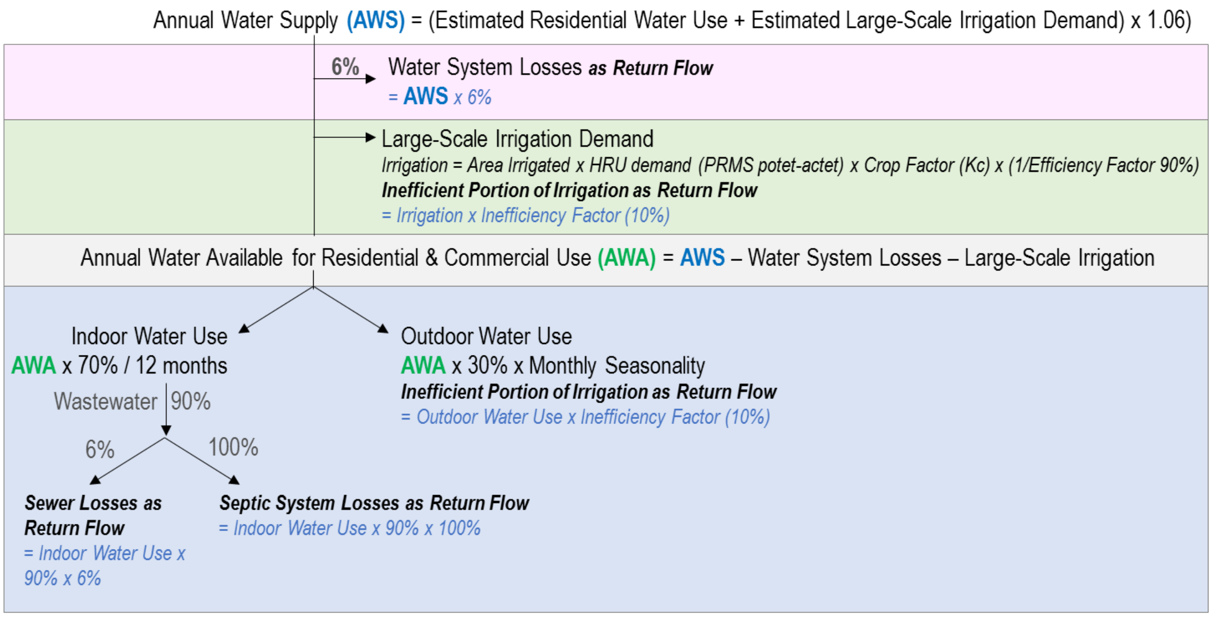
1. Water system losses,
2. Large-scale landscape/field irrigation,
3. Small-scale landscape irrigation (residential and commercial), and
4. Sewer system losses, and septic tank leakage.

The amount of water supplied to each service area is obtained from readily available data provided by the four municipal water agencies in the model area: City of Santa Cruz, Soquel Creek Water District (SqCWD), Central Water District (CWD), and City of Watsonville. If monthly data are not available, annual data are used.

Annual data are used for the Cities of Watsonville and Santa Cruz. Both these municipalities deliver water to customers from both groundwater and surface water sources. Both CWD and SqCWD are able to provide monthly water supply data from well production records as groundwater is their sole source of water.

City of Watsonville

The City of Watsonville was not able to provide readily available water delivery data for the portion of their service area within the model. Their annual water supply (AWS) is estimated as the sum of residential water use and large-scale landscape irrigation, plus 6% to account for water system losses of that water (City of Watsonville, 2016). As an estimate of residential water use, building counts, similar to the approach taken for private water use, are used to estimate annual residential water use to supply areas. The amount of large-scale landscape irrigation is estimated based on irrigated area, water demand, turf crop factor and irrigation inefficiency. The top two rows of Figure 1 show the calculations for estimating AWS for those portions of the City of Watsonville service area within the model.



Monthly Seasonality =Monthly HRU potet-actet / Annual HRU potet-actet

Figure 1: City of Watsonville Return Flow Calculations

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City of Santa Cruz

As no delivery data are readily available that are specific to the model area, the City of Santa Cruz provided its entire service area annual consumption data from 1983 – 2015 for its different use types. The amount of water delivered to users in the model area was determined from the percentage of each use type within the model area compared to the entire service area (Table 1). The General Plan land use was used to determine relative land use percentages in the model area. As the City of Santa Cruz's consumption data are generated at meters, 7.5% assumed for water losses (WSC, 2016) was added to the consumption data to estimate AWS within their service area in the model. The top line of Figure 2 shows the calculations to estimate AWS.

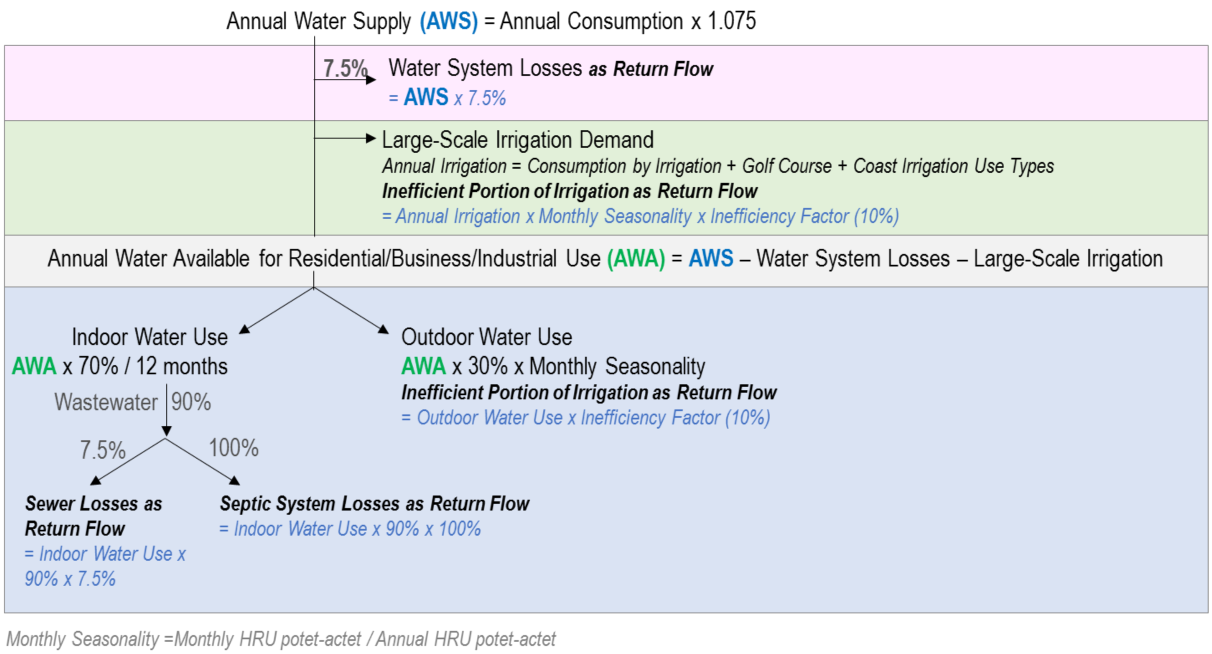

Figure 2: City of Santa Cruz Return Flow Calculations

Table 1: Percentage of All City of Santa Cruz Water Use Types within Model Area

Use Type	Percentage of Total City Land Use within Model Area
Single Family Residential	49%
Multiple Residential	50%
Business	55%
Industrial	34%
Municipal	33%
Irrigation (Large-Scale)	38%
Golf Course Irrigation	100%
Coast Irrigation	55%
Other (Construction & Hydrants)	38% (but negligible return flow assumed)

Central Water District

Groundwater pumped from CWD wells is delivered to both residential/commercial and agricultural customers. The amount of water available for residential/commercial purposes is estimated as the difference between the amount pumped and the amount supplied for agriculture, as shown on Figure 3. Water losses from 1985-1999 are 12%, from 2000-2007 are 7%, and from 2008-2016 are 4%. CWD system loss varies over time based on unaccounted water losses recorded by CWD each fiscal year.

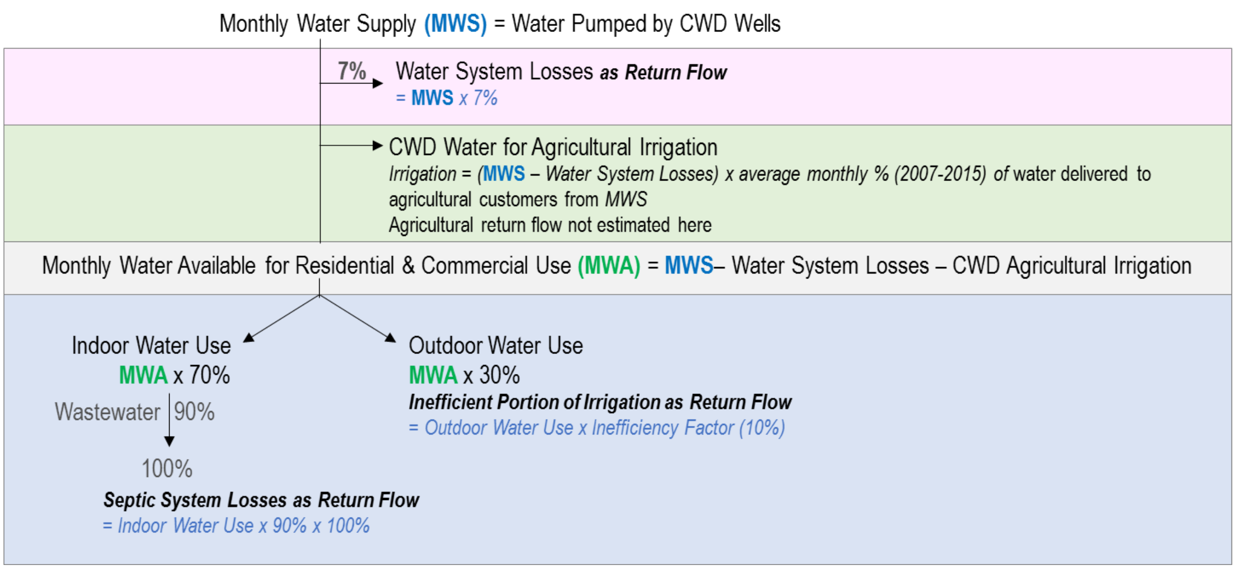

Figure 3: Central Water District Return Flow Calculations

Soquel Creek Water District

Water delivered to each of their four service areas (SA) is determined from the amount of groundwater pumped within each SA plus factoring in transfers that occur between service areas. Delivery data for each SA compared to groundwater pumped within each SA from 2014-2016 was used to estimate the average transfer from SA1 to SA2, SA3 to SA2, and SA3 to SA4. Table 2 summarizes the transfers used to estimate water delivered to each SA that is then used to estimate various components of return flow. The top line on Figure 4 shows the calculation to estimate monthly water supply to each SA. A water loss percentage of 7% is assumed from groundwater pumped (WSC, 2016).

Table 2: Summary of SqCWD Service Area Transfers between 2014 and 2016

Transfer From/To	Percent of Groundwater Produced in Originating Service Area
SA1 to SA2	8.5%
SA 3 to SA2	1.7%
SA3 to SA4	14.3%

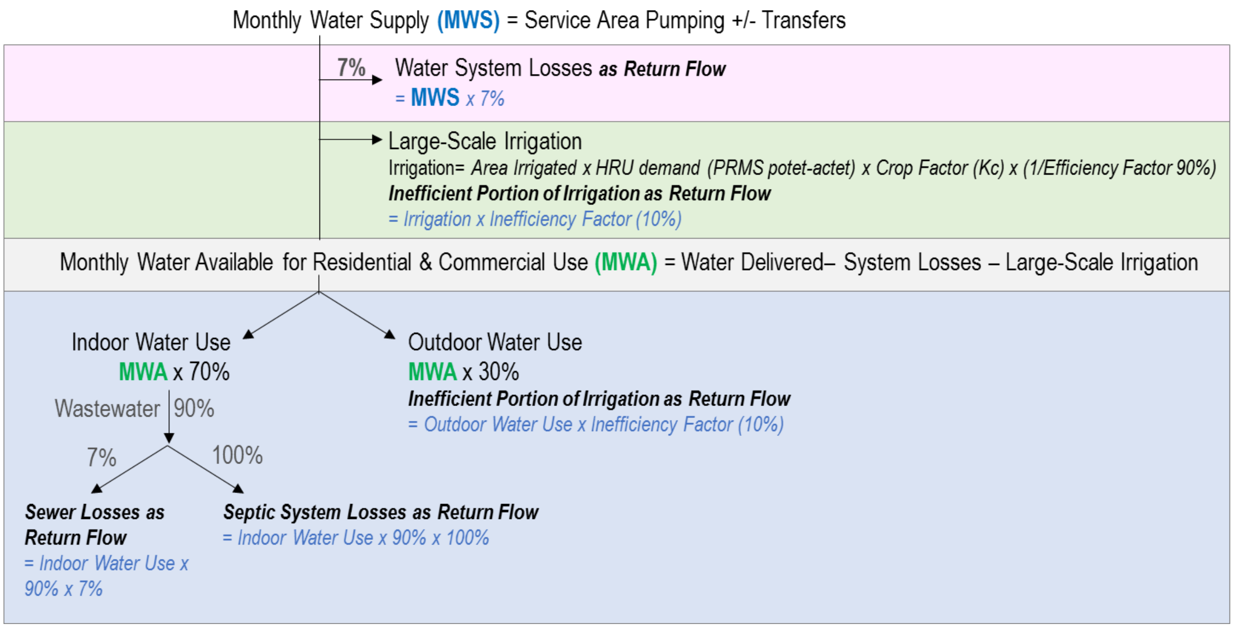

Figure 4: Soquel Creek Water District Return Flow Calculations

RETURN FLOW ESTIMATES

Different municipal water uses have their own proportion of water that percolates into the ground as return flow. Water system losses from both the water distribution and sewer systems are considered return flow. Water system losses are subtracted from water supply and thereafter, any water required to meet large-scale irrigation demand is subtracted from the supply. This leaves an amount of water that can be used for residential/commercial indoor and outdoor use. Assumed indoor and outdoor use is 70% and 30%, respectively. We assume 90% of indoor use becomes wastewater. For areas not connected to sewers, it is further assumed that 100% of wastewater percolates from septic systems into the unsaturated zone as return flow.

Inefficiencies in both residential irrigation (outdoor use) and large-scale irrigation result in an assumed return flow of 10% of the applied water. For the Cities of Santa Cruz and Watsonville, CWD, and SqCWD, Figure 1 through Figure 4, respectively, illustrate the methods for estimating each municipality’s return flow estimates. Summaries by water year of each component of return flow are provided in Table 3 through Table 6. The last column of these tables provides the percentage of the total water supply that comprises return flow.

The return flow estimates are applied to the model cells based on the ratio of the area of the model cell that receives municipal water for residential /commercial use compared to the entire service area. Figure 5 shows the location of the residential/commercial and large-landscape irrigation areas within each service area. Figure 6 shows the location of sewered and unsewered (septic tank) areas. Both figures also show model cell boundaries for the municipal water uses.

HOW WATER DELIVERED IS APPLIED TO MODEL CELLS FOR EACH MONTHLY MODEL STRESS PERIOD

For CWD and SqCWD, where monthly data are available, the deliveries to each service area are obtained from the service area pumping +/- any transfers, as described above. For the Cities of Watsonville and Santa Cruz, where annual data are only available, the amount of water applied to each model cell is distributed differently for indoor residential and irrigation use. Monthly indoor use is estimated as 70% of annual water delivered divided by 12 months. Monthly outdoor residential/commercial and large-scale irrigation use are based on irrigation demand (difference between monthly PRMS modeled potential ET (potet) and actual ET (actet)).

- For the City of Santa Cruz, where the water use type was 100% irrigation, the annual volume is distributed to months based on the ratio of monthly to annual irrigation demand for each model cell. For the outdoor portion of residential and commercial water use, the same ratio of monthly to annual irrigation demand for each model cell is used to distribute the annual volumes to monthly volumes.
- For the City of Watsonville, the amount of water to apply to each model cell for either large-scale or residential irrigation is distributed to months based on the ratio of monthly to annual irrigation demand for each model cell.

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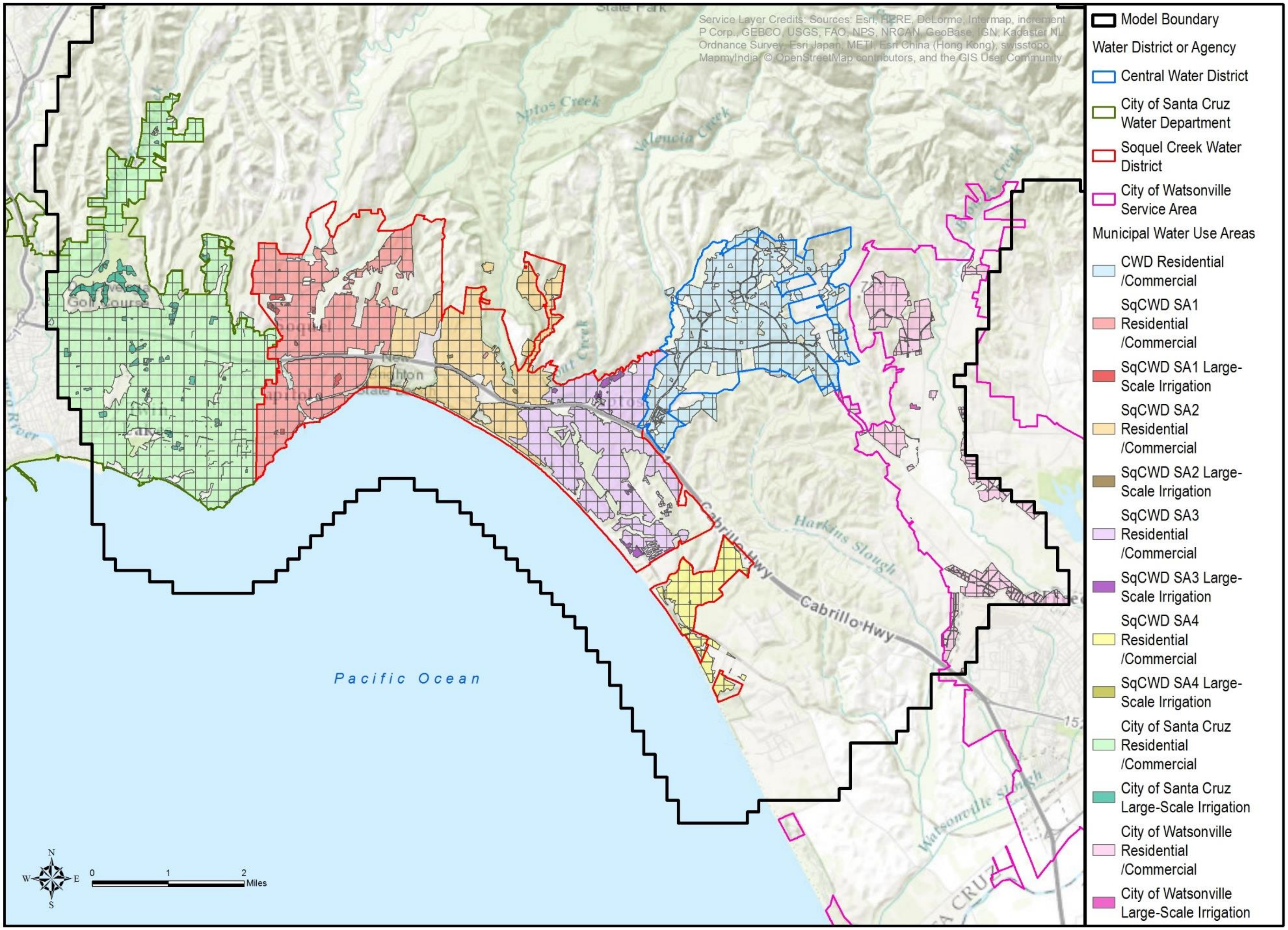

Figure 5: Residential/Commercial and Large-Scale Irrigation Areas within Municipal Service Area

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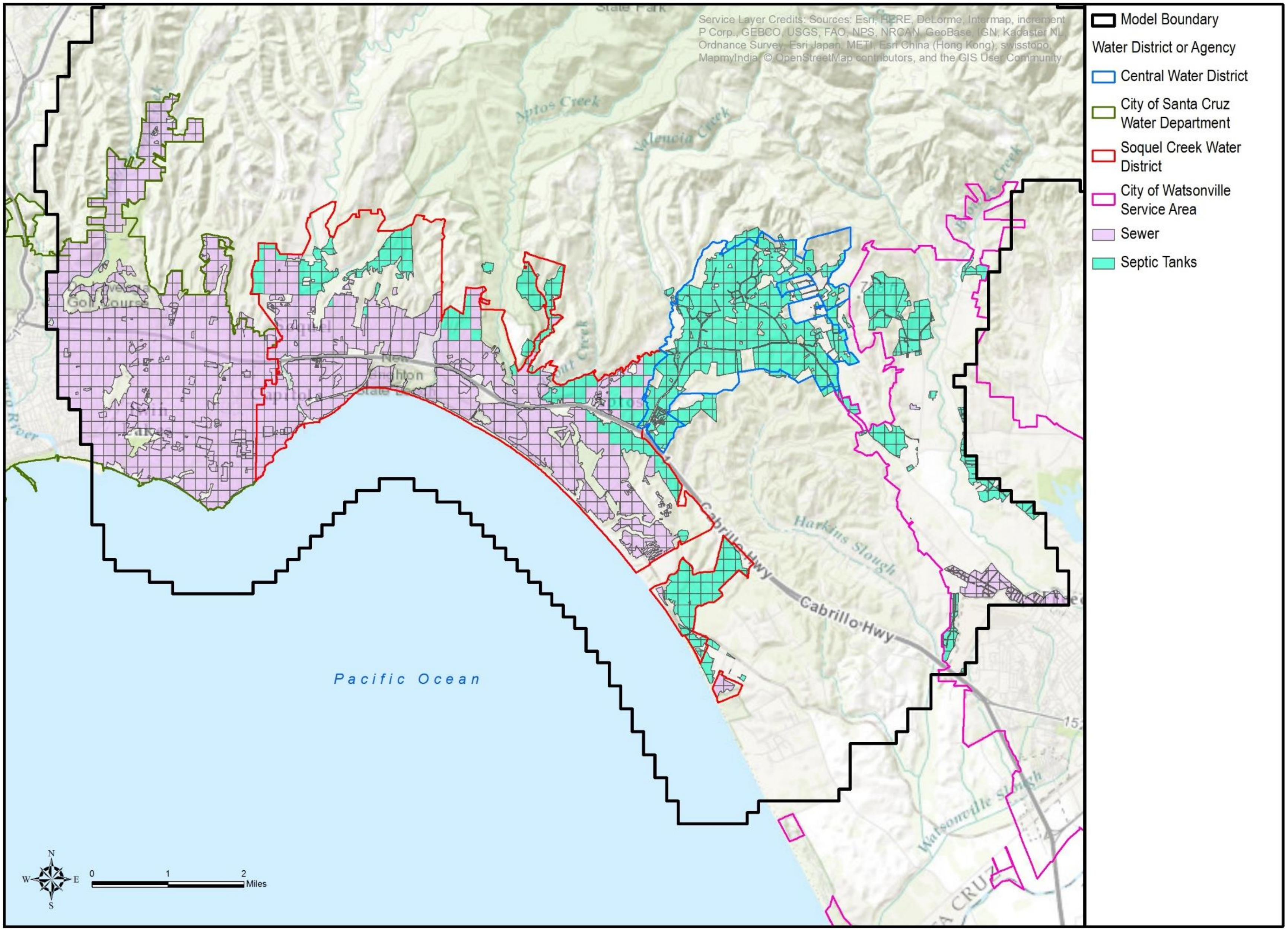

Figure 6: Municipal Sewered and Septic Tank Areas

Table 3: City of Watsonville Return Flow Estimates

Water Year	Water Supply to Service Area in Model, acre-feet	Return Flow in acre-feet						Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Large-Scale Landscape Irrigation	Small-Scale Landscape Irrigation	Sewer Losses	Septic Systems	Total Return Flow	
1985	478.1	28.7	0.3	14.2	6.5	206.8	227.9	47.7%
1986	497.3	29.8	0.3	14.8	6.7	215.2	237.1	47.7%
1987	511.9	30.7	0.3	15.3	6.9	221.6	244.1	47.7%
1988	529.1	31.7	0.3	15.8	7.2	229.1	252.3	47.7%
1989	543.1	32.6	0.3	16.2	7.4	235.2	259.0	47.7%
1990	561.0	33.7	0.3	16.7	7.6	243.0	267.6	47.7%
1991	577.5	34.6	0.3	17.2	7.8	250.2	275.5	47.7%
1992	596.8	35.8	0.3	17.8	8.1	258.6	284.8	47.7%
1993	614.0	36.8	0.3	18.3	8.3	266.1	293.0	47.7%
1994	633.2	38.0	0.3	18.9	8.6	274.4	302.2	47.7%
1995	650.5	39.0	0.3	19.4	8.8	282.0	310.5	47.7%
1996	708.8	42.5	0.3	21.2	9.6	307.4	338.5	47.7%
1997	724.8	43.5	0.3	21.7	9.8	314.3	346.1	47.7%
1998	742.7	44.6	0.3	22.2	10.1	322.1	354.7	47.8%
1999	766.0	46.0	0.3	22.9	10.4	332.2	365.8	47.8%
2000	816.4	49.0	0.3	24.4	11.1	354.2	390.0	47.8%
2001	823.0	49.4	0.3	24.6	11.2	357.1	393.1	47.8%
2002	819.0	49.1	0.3	24.5	11.1	355.3	391.2	47.8%
2003	828.3	49.7	0.3	24.8	11.2	359.4	395.7	47.8%
2004	850.9	51.1	0.3	25.4	11.5	369.2	406.5	47.8%
2005	843.1	50.6	0.3	25.2	11.4	365.8	402.7	47.8%
2006	860.6	51.6	0.3	25.7	11.7	373.5	411.2	47.8%
2007	868.5	52.1	0.3	26.0	11.8	376.9	414.9	47.8%
2008	872.4	52.3	0.3	26.1	11.8	378.6	416.8	47.8%
2009	850.2	51.0	0.3	25.4	11.5	368.9	406.2	47.8%
2010	852.1	51.1	0.3	25.5	11.6	369.7	407.1	47.8%
2011	858.4	51.5	0.3	25.7	11.6	372.5	410.1	47.8%
2012	861.6	51.7	0.3	25.8	11.7	373.9	411.6	47.8%
2013	866.0	52.0	0.3	25.9	11.8	375.8	413.7	47.8%
2014	798.0	47.9	0.3	23.9	10.8	346.2	381.2	47.8%
2015	744.0	44.6	0.3	22.2	10.1	322.7	355.3	47.8%
Average	727.3	43.6	0.3	21.7	9.9	315.4	347.3	47.7%

Table 4: City of Santa Cruz Return Flow Estimates

Water Year	Water Supply to Service Area in Model, acre-feet	Return Flow in acre-feet					Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Large-Scale Landscape Irrigation	Small-Scale Landscape Irrigation	Sewer Losses	Total Return Flow	
1985	6,593.7	461.6	72.1	162.3	238.6	934.6	14.2%
1986	6,663.3	466.4	68.7	165.3	243.0	943.4	14.2%
1987	6,941.7	485.9	84.4	168.3	247.4	986.1	14.2%
1988	6,258.3	438.1	77.5	151.3	222.5	889.4	14.2%
1989	5,749.4	402.5	61.8	141.9	208.6	814.7	14.2%
1990	5,209.9	364.7	55.0	126.8	186.4	732.9	14.1%
1991	4,891.0	342.4	53.1	120.3	176.8	692.6	14.2%
1992	5,419.7	379.4	57.6	133.7	196.5	767.2	14.2%
1993	5,455.4	381.9	47.1	137.9	202.8	769.7	14.1%
1994	5,648.9	395.4	47.4	143.2	210.5	796.4	14.1%
1995	5,777.5	404.4	47.1	147.0	216.1	814.6	14.1%
1996	6,143.6	430.1	51.7	155.8	229.0	866.6	14.1%
1997	6,633.3	464.3	64.7	165.5	243.2	937.7	14.1%
1998	5,887.4	412.1	43.9	151.0	221.9	828.9	14.1%
1999	6,192.2	433.5	52.4	156.9	230.7	873.4	14.1%
2000	6,183.4	432.8	51.5	157.0	230.7	872.0	14.1%
2001	6,255.6	437.9	63.6	155.4	228.4	885.2	14.2%
2002	6,072.7	425.1	62.4	150.5	221.3	859.4	14.2%
2003	6,072.7	425.1	69.6	148.4	218.2	861.4	14.2%
2004	6,191.6	433.4	75.0	150.1	220.6	879.2	14.2%
2005	5,780.4	404.6	58.0	143.7	211.3	817.6	14.1%
2006	5,579.3	390.6	62.6	136.8	201.0	790.9	14.2%
2007	5,477.2	383.4	54.7	136.3	200.4	774.8	14.1%
2008	5,537.2	387.6	60.7	136.1	200.1	784.6	14.2%
2009	4,840.5	338.8	44.0	121.7	178.9	683.5	14.1%
2010	4,764.2	333.5	41.4	120.4	177.0	672.4	14.1%
2011	4,569.3	319.8	36.8	116.4	171.1	644.2	14.1%
2012	4,870.7	341.0	47.2	121.7	178.8	688.7	14.1%
2013	5,078.7	355.5	54.5	125.3	184.1	719.4	14.2%
2014	4,083.1	285.8	35.7	103.1	151.6	576.3	14.1%
2015	3,837.2	268.6	42.4	94.3	138.6	543.9	14.2%
Average	5,634.2	394.4	56.3	140.1	206.0	796.8	14.1%

Table 5: Soquel Creek Water District Return Flow Estimates

Water Year	Water Supply to Service Area in Model, acre-feet	Return Flow in acre-feet						Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Large-Scale Landscape Irrigation	Small-Scale Landscape Irrigation	Sewer Losses	Septic Systems	Total Return Flow	
1985	4,318.5	302.3	13.2	116.5	135.8	559.0	1,126.8	26.1%
1986	4,272.5	299.1	10.3	116.1	137.1	529.0	1,091.6	25.5%
1987	5,234.6	366.4	13.8	141.9	163.7	708.1	1,393.9	26.6%
1988	4,858.7	340.1	14.8	131.1	151.0	658.1	1,295.2	26.7%
1989	4,797.2	335.8	12.7	130.0	149.0	664.8	1,292.3	26.9%
1990	4,818.5	337.3	13.3	130.5	150.6	649.1	1,280.7	26.6%
1991	4,703.0	329.2	10.4	128.1	148.1	634.4	1,250.3	26.6%
1992	4,908.3	343.6	13.9	132.8	152.6	672.0	1,314.9	26.8%
1993	4,863.2	340.4	11.6	132.2	152.2	665.2	1,301.7	26.8%
1994	5,089.3	356.2	10.4	138.9	159.4	706.7	1,371.6	27.0%
1995	4,854.9	339.8	9.9	132.5	153.5	650.6	1,286.3	26.5%
1996	5,183.2	362.8	12.7	140.8	163.4	688.0	1,367.7	26.4%
1997	5,570.8	390.0	14.7	151.0	174.1	755.0	1,484.8	26.7%
1998	4,966.1	347.6	7.8	136.2	157.8	670.0	1,319.4	26.6%
1999	5,211.5	364.8	8.2	142.9	165.0	712.3	1,393.2	26.7%
2000	5,270.8	369.0	9.9	144.1	166.6	712.7	1,402.2	26.6%
2001	5,174.7	362.2	9.7	141.5	164.3	688.2	1,365.9	26.4%
2002	5,375.8	376.3	9.6	147.1	172.6	689.3	1,394.9	25.9%
2003	5,331.8	373.2	11.1	145.4	171.4	667.7	1,368.9	25.7%
2004	5,372.0	376.0	13.0	146.0	172.8	659.2	1,367.0	25.4%
2005	4,543.8	318.1	7.3	124.6	147.2	566.2	1,163.4	25.6%
2006	4,548.6	318.4	10.2	123.9	144.5	591.7	1,188.7	26.1%
2007	4,625.8	323.8	12.0	125.5	144.9	623.6	1,229.7	26.6%
2008	4,557.0	319.0	12.6	123.4	141.7	625.9	1,222.6	26.8%
2009	4,162.1	291.3	12.5	112.4	131.6	529.8	1,077.6	25.9%
2010	3,932.5	275.3	10.3	106.6	127.5	461.6	981.3	25.0%
2011	4,011.2	280.8	8.7	109.3	131.0	467.1	997.0	24.9%
2012	4,159.1	291.1	12.7	112.2	134.0	487.8	1,037.9	25.0%
2013	4,217.5	295.2	19.2	111.9	132.2	509.1	1,067.6	25.3%
2014	3,702.9	259.2	20.0	97.3	115.6	432.6	924.7	25.0%
2015	3,153.9	220.8	22.4	81.3	96.9	355.8	777.2	24.6%
Average	4,702.9	329.2	12.2	127.5	148.6	612.6	1,230.2	26.1%

Table 6: Central Water District Return Flow Estimates

Water Year	Water Supply to Service Area in Model*, acre-feet	Return Flow in acre-feet				Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Small-Scale Landscape Irrigation	Septic Systems	Total Return Flow	
1985	352.9	27.5	9.8	205.0	242.3	68.7%
1986	363.0	28.3	10.0	210.9	249.2	68.7%
1987	399.4	31.1	11.1	232.1	274.2	68.6%
1988	393.2	30.6	10.9	228.4	270.0	68.6%
1989	363.2	28.4	10.0	210.9	249.4	68.7%
1990	387.1	30.1	10.7	224.9	265.7	68.6%
1991	383.9	29.8	10.6	223.1	263.5	68.6%
1992	417.5	32.7	11.5	242.5	286.7	68.7%
1993	429.6	33.7	11.9	249.4	295.0	68.7%
1994	431.2	33.7	11.9	250.4	296.1	68.7%
1995	409.5	32.2	11.3	237.7	281.2	68.7%
1996	469.4	36.8	13.0	272.5	322.3	68.7%
1997	539.5	42.3	14.9	313.2	370.4	68.7%
1998	476.0	37.4	13.2	276.3	326.9	68.7%
1999	479.9	37.7	13.3	278.6	329.6	68.7%
2000	489.2	38.3	13.5	284.1	335.9	68.7%
2001	496.7	39.0	13.7	288.4	341.1	68.7%
2002	529.1	41.5	14.6	307.2	363.3	68.7%
2003	519.3	40.8	14.4	301.5	356.7	68.7%
2004	565.6	44.3	15.6	328.4	388.4	68.7%
2005	456.9	36.0	12.6	265.2	313.8	68.7%
2006	483.1	38.1	13.3	280.3	331.8	68.7%
2007	532.3	41.7	14.7	309.1	365.5	68.7%
2008	520.0	40.9	14.4	301.9	357.1	68.7%
2009	530.4	41.6	14.7	307.9	364.2	68.7%
2010	428.8	33.6	11.9	248.9	294.4	68.7%
2011	434.4	34.1	12.0	252.2	298.3	68.7%
2012	479.3	37.5	13.3	278.4	329.1	68.7%
2013	501.2	39.1	13.9	291.1	344.1	68.7%
2014	452.3	35.0	12.5	262.9	310.4	68.6%
2015	352.7	27.4	9.8	204.9	242.1	68.6%
Average	453.8	35.5	12.5	263.5	311.6	68.7%

* This column is water supply for residential/commercial use only, and does not include water delivered for agricultural use.

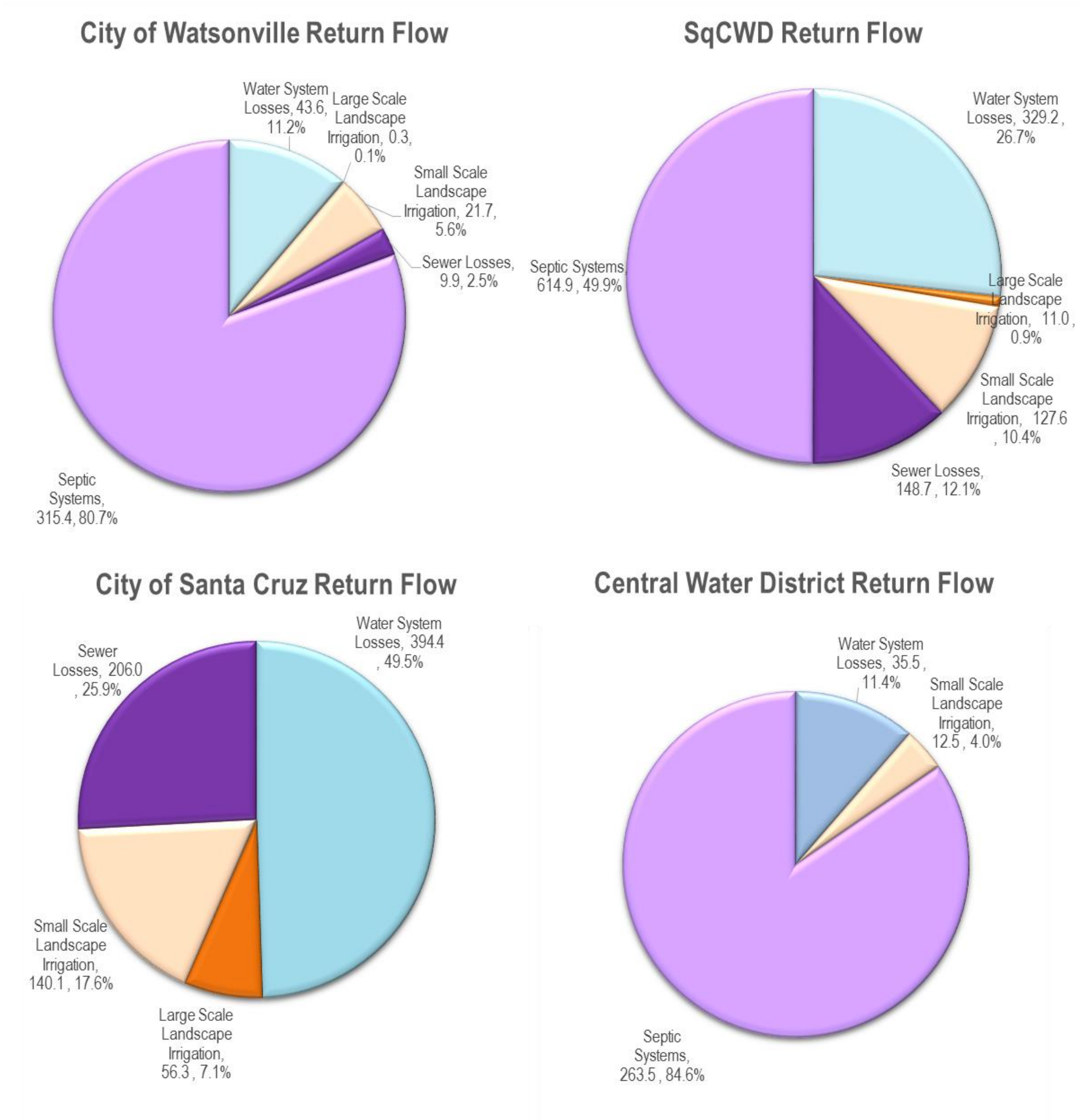

Figure 7: Municipal Return Flow Pie Charts (in acre-feet per year)

APPENDIX 2-D

SOQUEL-APTOS GROUNDWATERFLOW MODEL: SUBSURFACE MODEL (TASK 3) MEMORANDUM

1814 Franklin St, Suite 501
Oakland, CA 94612

TECHNICAL MEMORANDUM

To: Ron Duncan

From: Sean Culkin P.G., C. Hg.
Mike Cloud, P.G.
Cameron Tana, P.E.

Date: November 24, 2015

Subject: Soquel-Aptos Groundwater Flow Model: Subsurface Model Construction (Task 3)

1.0 INTRODUCTION

This technical memorandum documents the completed and ongoing activities to develop the conceptual model, hydrostratigraphy, and subsurface boundary conditions for construction of the groundwater flow model of the Soquel-Aptos groundwater basin (basin). Subsequent technical memoranda on model construction will document the development of the watershed model, land use analysis for water use and return flow, integration of the watershed model with the groundwater model using GSFLOW, and the incorporation of code to simulate seawater intrusion. After the model is constructed and calibrated, the model will be used by the Soquel-Aptos Groundwater Management Committee (SAGMC) to evaluate long-term options for raising groundwater elevations in the basin and eliminating overdraft.

The modeling effort documented in this technical memorandum identifies the model extent and boundaries, as well as translates the Purisima Formation and Aromas Red Sands conceptual model into groundwater model layers. The conceptual model for the basin has been reported in detail in the *Groundwater Assessment of Alternative Conjunctive Use Scenarios, Technical Memorandum 2: Hydrogeologic Conceptual Model* (Johnson *et al*., 2004).

The groundwater component of the groundwater flow model will be built using the U.S. Geological Survey's (USGS) MODFLOW software for groundwater modeling applications. This MODFLOW groundwater flow model will be integrated with a watershed model using the USGS's Precipitation-Runoff Modeling System (PRMS) to create a USGS GSFLOW model.

2.0 DATA COMPILATION

For developing the model stratigraphy, a set of 67 available down-hole electrical resistivity logs (e-logs) were compiled for wells/borings drilled into the Purisima Formation in central Santa Cruz County. These e-logs are from public and private wells, as well as oil and gas wells. Available surface geologic and gravity anomaly maps from USGS, and seafloor maps were also used to update the conceptual basin stratigraphy.

Data for boundary condition development are primarily in the form of monitoring well groundwater elevation data from City of Santa Cruz, Soquel Creek Water District (SqCWD), Central Water District (CWD), and Pajaro Valley Water Management Agency (PVWMA) wells within the basin model domain. Groundwater elevation data from City of Santa Cruz, SqCWD, and CWD are reported by HydroMetrics WRI annually, and updated data from selected PVWMA wells near the southeastern boundary of the model were obtained by request from that agency.

3.0 DOMAIN EXTENT AND MODEL HYDROSTRATIGRAPHY

The lateral extent of the basin model domain is similar to the domain of the previously-constructed PRMS model (HydroMetrics WRI, 2011). The domain covers watersheds that may recharge the aquifers pumped in the area managed by SAGMC. The western boundary of the model is the boundary between the Carbonara Creek and Branciforte Creek watersheds approximately parallel to California State Route 17 from the City of Santa Cruz in the south to Redwood Estates in the north. Outcrops of granite and metamorphic rocks along Carbonara Creek indicate that there is no connectivity of groundwater flow into or out of water-bearing units of the basin along this margin.

The northern watershed boundary of the model approximately follows Summit Road and Loma Prieta Avenue for a distance of about 17 miles along a northwest to southeast alignment. Unlike the previous PRMS model, the oceanic southern boundary of the model has been extended approximately one mile offshore, parallel to the coastline. This allows for adequate contact of outcropping Purisima and Aromas Formation units with the seafloor, in order to simulate saltwater-freshwater interactions such as seawater intrusion.

The eastern boundary of the model follows the eastern boundary of the Corralitos Creek watershed. The extent of the southeastern boundary of the basin model has also been revised from the previous PRMS boundary, in that it extends beyond Buena Vista Drive in Watsonville nearly one-half mile. This boundary is approximately the same as the southeastern boundary of the groundwater model previously developed for CWD covering the Aromas area (HydroMetrics WRI and Kennedy/Jenks, 2014), and it limits the extent of the Pajaro Valley basin included in the groundwater model. It is expected that PVWMA will manage the rest of the Pajaro Valley basin excluded from this model, which will be used for management by SAGMC for the area to the west. As much as is practicable, the selected boundaries are intended to coincide with known hydrologic boundaries. Figure 1 shows the active extent of the groundwater model domain.

Vertically, the groundwater model domain includes surficial alluvium and the more extensive regional hydrostratigraphic units. Earlier reports for the SqCWD had correlated several distinct stratigraphic intervals in this area (Luhdorff & Scalmanini, 1984). Johnson *et al.* (2004) more accurately defined and partitioned these intervals as aquifer or aquitard units. These hydrostratigraphic units were named the Purisima AA aquifer, A aquifer, B aquitard, BC aquifer, D aquitard, DEF aquifer, and F aquifer or, TpAA through TpF for short. The TpAA is the lowermost unit in the Purisima and the TpF is the uppermost unit (Figure 2). Underlying the sedimentary units in this area is a granitic basement complex, except in areas underlain by an undefined Tertiary unit referred to as the Tu unit by Johnson et al. (2004) or the Santa Margarita by others. South of the Zayante Fault (Figure 1), each unit outcrops at the ground surface. The TpAA outcrops primarily in the western portion of the groundwater basin and the TpF outcrops in the east. The units outcrop in this pattern because the Purisima Formation shallowly dips in a southeast direction towards the Pajaro Valley. Outcrop patterns were later projected across the basin and into Monterey Bay (SqCWD and CWD, 2007). In the southeastern portion of the model, the Purisima Formation is overlain by a unit known as the Aromas Red Sands (labeled as Qua and Qa on Figure 2), which is the shallowest water-bearing unit in this area. This unit of poorly consolidated interbedded fluvial, marine, and aeolian material

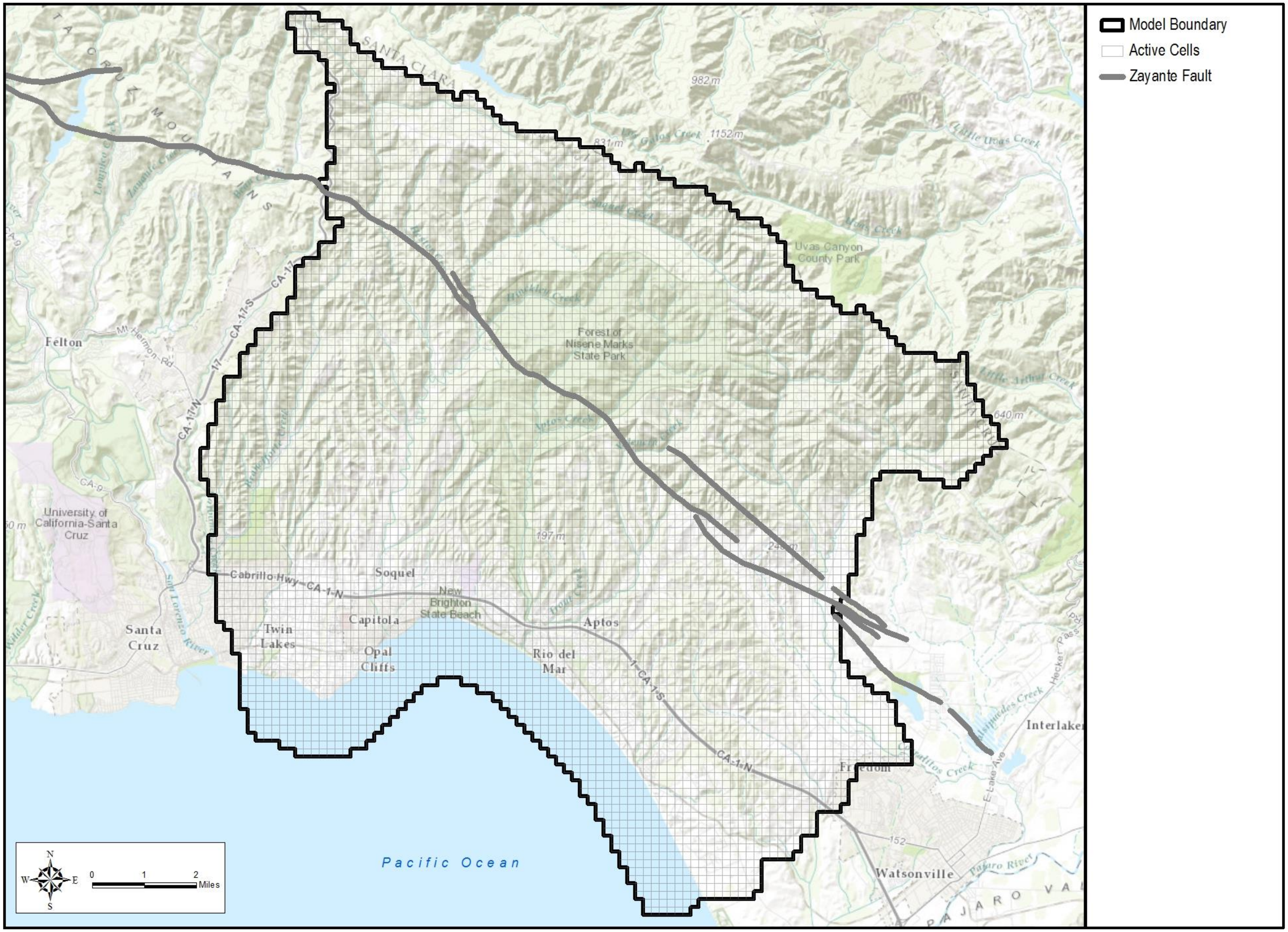

Figure 1: Basin Model Domain Extent

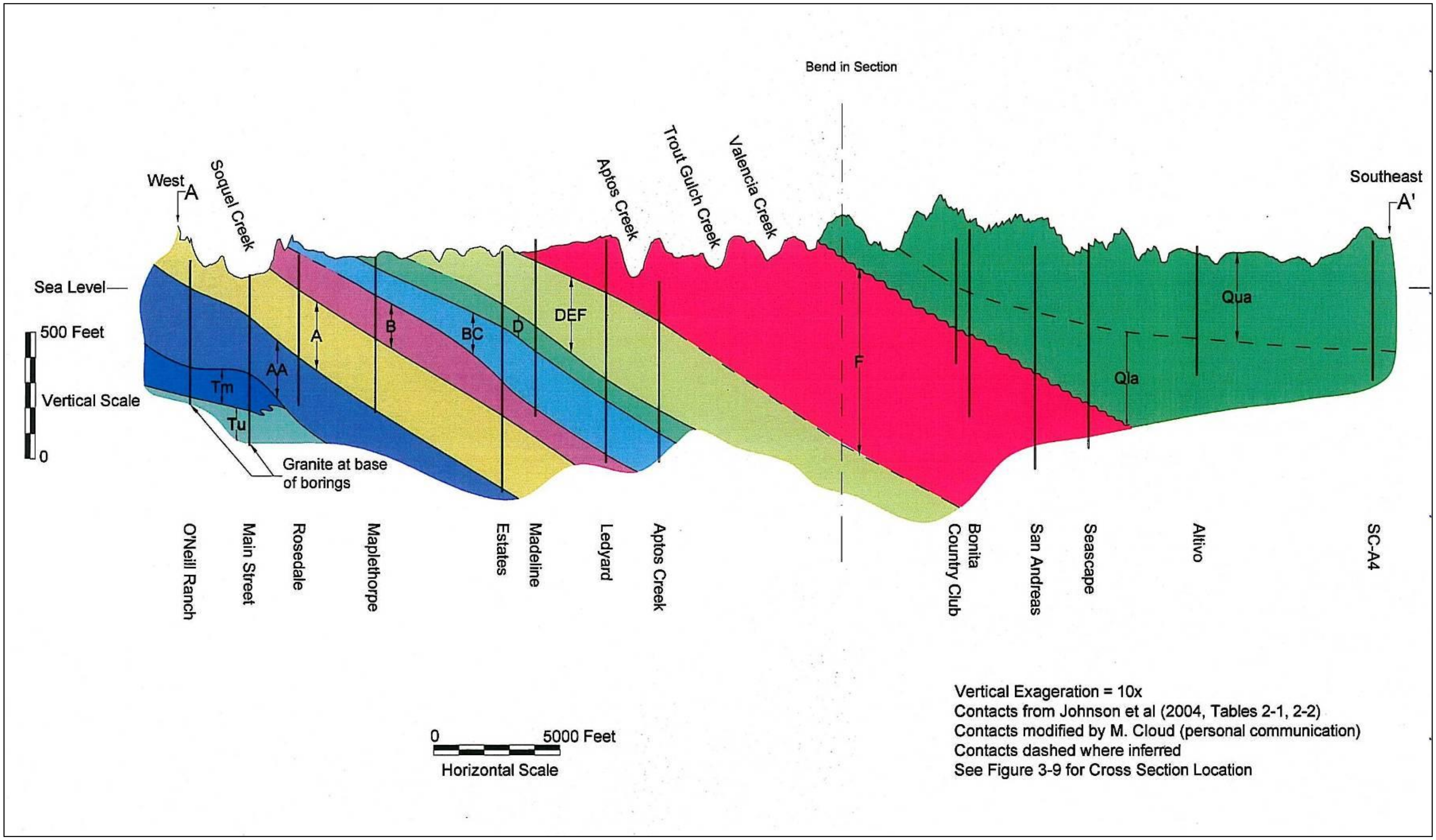

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Figure 2: Generalized Hydrostratigraphic Cross-Section

overlays the Purisima Formation in the hills and coastal terraces east and southeast of Aptos. A large portion of this unit may be unsaturated, especially where the groundwater table is drawn down to near sea level (Johnson *et. al.*, 2004).

The groundwater model domain encompasses the Aromas Red Sands, the units of the Purisima Formation, and the underlying undifferentiated tertiary deposits. The granitic basement rock of the basin constitutes the base of the groundwater model. To simplify the groundwater model, Purisima Formation units were reduced from the original seven e-log hydrostratigraphic units defined by Johnson et al. (2004) down to six groundwater model layers by combining the DEF and F aquifer units. The laterally-extensive model layers are considered to be either aquifers or aquitards. Aquifer units are those zones dominated with sandstone and aquitards are the zones dominated by mudstone. Table 1 summarizes the hydrostratigraphic units applied in the groundwater model (see also Appendix A). Detailed descriptions of the Aromas Red Sands and Purisima Formation aquifer and aquitard units are available in previous documents (Johnson et. al., 2004; HydroMetrics WRI, 2011).

Table 1: Groundwater Model Hydrostratigraphic Unit Summary

Unit Name (Geologic Unit)	Model Layer	Unit Type
Stream Alluvium	1-9[1]	Stream-associated water-bearing surficial alluvium
Terrace Deposits	1-9[1]	Alluvial terrace deposits near coast
Aromas Red Sands	2	Interbedded sand, silt, and clay deposits
Purisima TpDEF, TpF	3	Aquifer
Purisima TpD	4	Aquitard
Purisima TpBC	5	Aquifer
Purisima TpB	6	Aquitard
Purisima TpA	7	Aquifer
Purisima TpAA	8	Aquifer
Tu[2]	9	Aquifer

[1]Alluvium and terrace deposits assigned to various model layers as described in sections below
[2]Tu unit includes all non-Purisima water-bearing units between base of TpAA Aquifer and top of granitic model base.

Another noteworthy feature of the model domain is the Zayante Fault, which is a northwest-southeast trending fault that runs through the groundwater model domain (Figure 1). North of this fault, the Purisima Formation consists of a number of steeply dipping and folded materials which are offset from Purisima Formation units south of the fault (Johnson et al., 2004). The Purisima Formation materials north of the fault are not well defined as hydrostratigraphic units like they are south of the fault. The material properties of the groundwater model layers north of this fault will likely reflect this lack of differentiation. The area north of the Zayante Fault was retained in the model domain due to the watershed's necessary contribution to the surface water and near-surface flow component of the GSFLOW model. This fault also likely acts as a barrier to deeper groundwater flow between the folded units of the Glenwood Syncline north of the fault and units of the Purisima and Aromas south of the fault (Johnson *et al.*, 2004).

4.0 CONCEPTUAL MODEL METHODOLOGY

In general, the conceptual model as it pertains to the basin groundwater model will follow the conceptual model outlined in the Johnson et. al. report (2004); recent work building upon this model is described in the sections below. As documented in previous studies (Luhdorff & Scalmanini, 1984), the Purisima Formation dips shallowly to the southeast. In the eastern region of the basin, the bedding has a consistent dip of 3 to 4 degrees to the east. West of Soquel Creek, the dip shallows to 2 to 3 degrees to the east. The dip of the Purisima beds appears to mimic the underlying granitic basement structure, suggesting that the Purisima Formation may have been deposited horizontally on the granitic basement, then tilted by the uplift of the basement rock.

HydroMetrics WRI recently updated the Central Water District's (CWD) groundwater model (HydroMetrics WRI and Kennedy/Jenks, 2014). This model covers most of the Aromas area and has layers representing the Aromas Red Sands, TpF unit, and TpDEF unit. Where applicable, the conceptual model of the CWD model will be merged into the larger basin model. For example, the hydrostratigraphic contact between the Aromas Red Sands and Purisima Formation is extracted from the CWD model for use in the larger basin model.

4.1 STRATIGRAPHIC ANALYSIS

HydroMetrics WRI made various assumptions and simplifications during the evaluation of the Purisima Formation stratigraphy and structure for the basin groundwater model. A summary of some of the primary assumptions are as follows:

1) Individual Purisima units tend to maintain relatively constant thicknesses across the groundwater basin.
2) The angle and dip direction of the Purisima Formation units generally reflects the underlying basement structure.
3) The regional gravity anomaly distribution (USGS, 2004) reflects the basement structure.
4) Faults were not used to explain structure unless there was compelling evidence or need for them. No faults other than the Zayante fault are known to significantly offset the hydrostratigraphy such that groundwater flow across the fault zone is impeded. Therefore, we assumed that any other faults are not barriers to groundwater flow.
5) A cemented zone within the lower TpB Aquitard unit is visible in resistivity logs as a spike in resistivity across a large area of the model domain, and is also identifiable in local surface outcrops. As such, the base of the TpB Aquitard is used as a reference elevation surface to aid in defining the hydrostratigraphy of overlying and underlying units within the Purisima Formation.

As in previous analyses (Luhdorff & Scalmanini, 1984), the e-log signatures from different boreholes were compared to identify specific stratigraphic intervals in the Purisima Formation. If individual sedimentary beds are laterally extensive, the same layered sequence of the sedimentary units can be identified at multiple locations. By correlating the elevation of specific intervals from borehole to borehole, the structure of the bedding layers is determined.

Most of the bedding layers can be readily correlated from borehole to borehole. Units TpB through TpF have very distinct e-log signatures, which facilitates correlation between boreholes because they consist of a mixture of sandstone and mudstone beds. The distinctive TpA/TpB contact, which is readily identifiable on every e-log that encounters it, was used as a reference point for stratigraphic analysis. The base of the Purisima Formation is clearly identified on e-logs for sufficiently deep boreholes. The structure of the granitic basement of the model domain was also identifiable in boreholes, gravity anomaly studies, and regional outcrops, which were used to develop inform the basement structure of the model. An example stratigraphic column summarizing the conceptual hydrostratigraphy developed from this investigation is show on Figure 3, and unit thicknesses are summarized in Table 2. Details of the granitic basement structure are shown in Figure 4 through Figure 6, the elevation of the base of individual units, as well as borehole locations used in part to define the base of each unit, are shown on Figure 7 through Figure 14, and the stratigraphic picks made from borehole logs are tabulated in Appendix A.

The TpA and TpAA units have an assumed combined thickness of 600 feet. These units do not have lithologically consistent internal sedimentary layers and therefore it is difficult to identify the contact surface between them in the boring logs and e-logs. As such, both the TpA and TpAA units are assigned a uniform thickness of 300 feet each over most of the model domain. Where the contact between these units is detectable in e-logs, primarily in the southwestern portion of the model domain, they are assigned variable thicknesses, with the thickness of the TpA varying between approximately 200 and 300 feet, and the thickness of the TpAA varying between approximately 300 and 400 feet; generally maintaining the total combined thickness of 600 feet.

The Tu unit is assumed to constitute all the sediments where the granitic basement is lower than the base of the Purisima Formation (i.e. lower than the TpAA). As such, it's thickness is variable between approximately 10 and 3,000 feet. This unit is generally found in the western portion of the basin and pinches out where the base of the Purisima intersects the granitic basement. East of the pinch-out margin of the Tu, the base of the Purisima Formation sits directly on top of the granitic basement. The base of the TpAA generally follows the structure of the granitic basement, but where necessary, the thickness of the TpAA was adjusted to that it met the interpolated granitic basement surface. As such, the thickness of the TpAA and the combined thickness of 600 feet for the TpA and TpAA has some local variation from 300 feet and 600 feet respectively east of the Tu to accommodate the granitic basement structure, but the TpAA generally maintains a thickness of approximately 300 feet.

One significant geologic feature observed in the stratigraphic analysis is a granitic structural high near the western boundary of the model domain, south of the Zayante Fault. West of this structural high, the elevation of the granitic basement dips steeply towards the northwest into a trough.

The location and structure of the granitic high is shown in Figure 4. This figure shows granite elevation contours developed as a part of this analysis, as well as surficial geologic data (USGS, 1997). The western boundary of the model domain is aligned with the watershed boundary shown in the figure, and the strike of the granitic high is shown as the "Granitic Divide" line. The structure of the granitic basement is supported by gravity anomaly surveys of the area (USGS, 2004), from which granite elevation contours can also be inferred (Figure 5).

The structure of the granitic basement in the western area of the model domain has also been documented by Todd Engineers (1997) and ETIC Engineering (2006) in groundwater modeling technical studies of the area. Figure 6 presents a cross-section from a previous modeling study (Kennedy/Jenks, 2015) that crosses the western edge of the model domain. In this figure, the granitic structural trough is evident in the area of the model domain boundary near Carbonera Creek, and the eastward-dipping Purisima Formation is shown to be underlain by geologic units usually associated with the Santa Margarita Basin to the west. As modeling progresses, different material properties may be assigned to the sediments west of the granite high to differentiate them from the Tu unit that dips towards the east beneath the Purisima Formation, since the Tu west of the divide may be more closely associated with westward-dipping stratigraphic units of the adjacent Santa Margarita Basin. Boundary conditions in this area will also be modified to represent groundwater flow conditions out of the Soquel-Aptos Basin.

The highest density of available e-log data is in the coastal terrace area of mid Santa Cruz County, where most urban development has occurred and depth to groundwater is the shallowest. Available e-logs in the inland, hilly areas of the Purisima Formation are sparse, which makes correlation more difficult. Appendix A shows the depth and elevation of each geologic contact in the logs the overlying Aromas Red Sands down to the granitic basement. This Appendix also includes estimated contact depths/elevations where they could be reliably estimated.

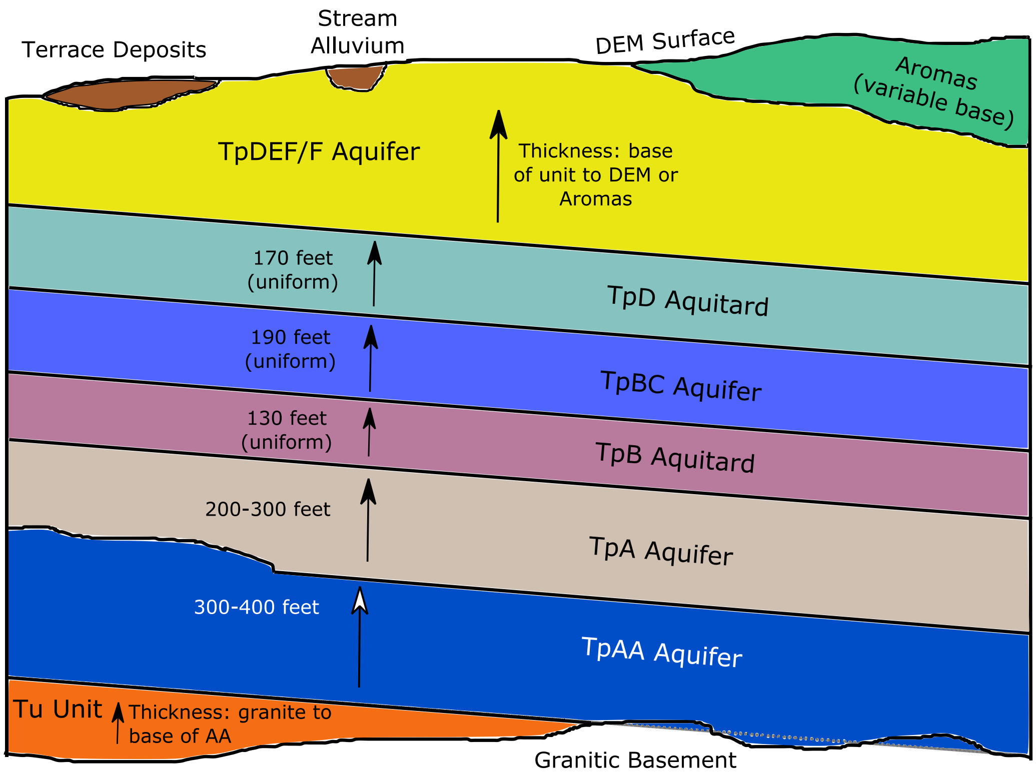

Figure 3: Example Stratigraphic Column of Model Hydrostratigraphy

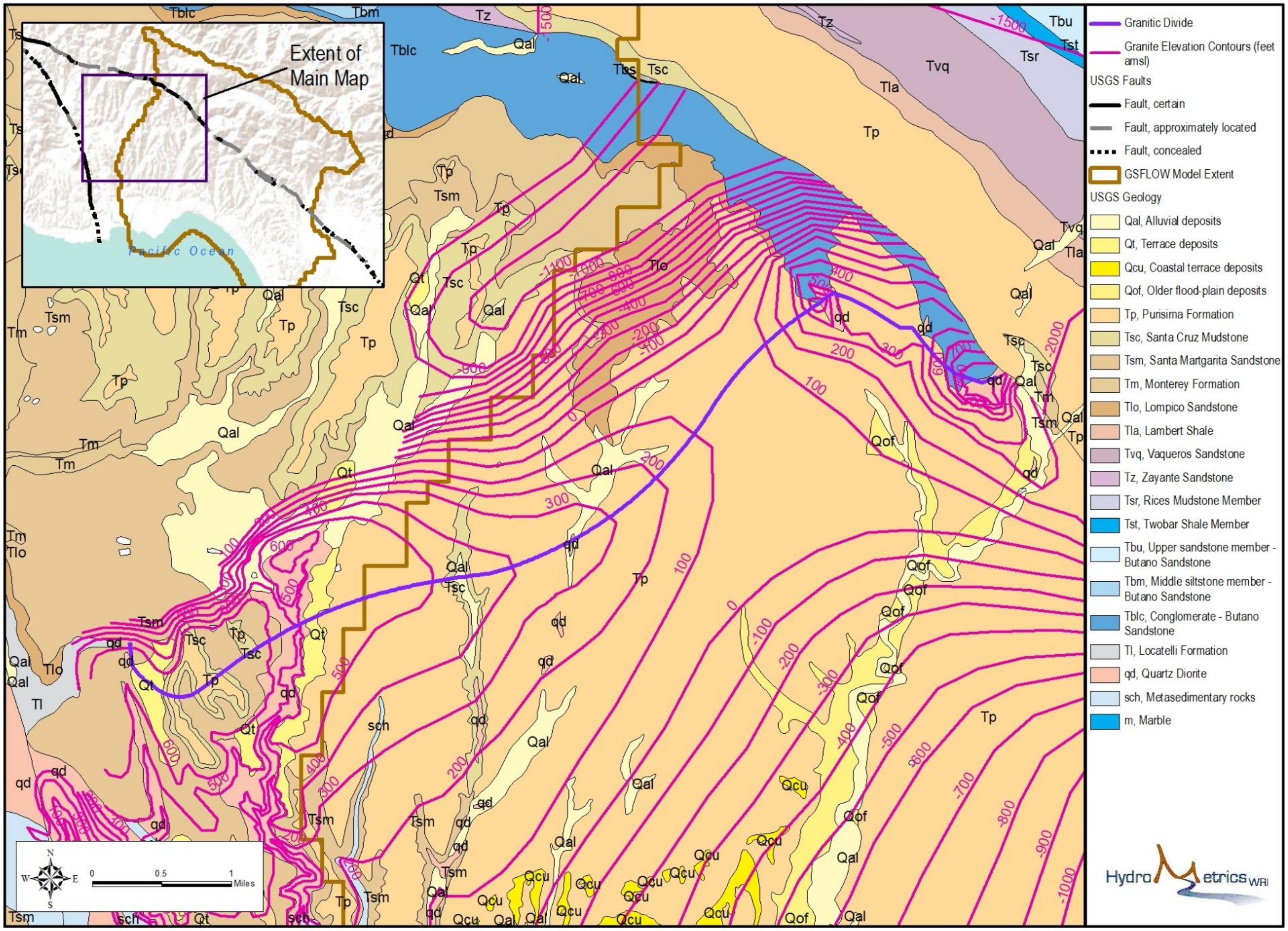

Figure 4: Structure of Granitic Basement Elevation, Western Area of Model Domain

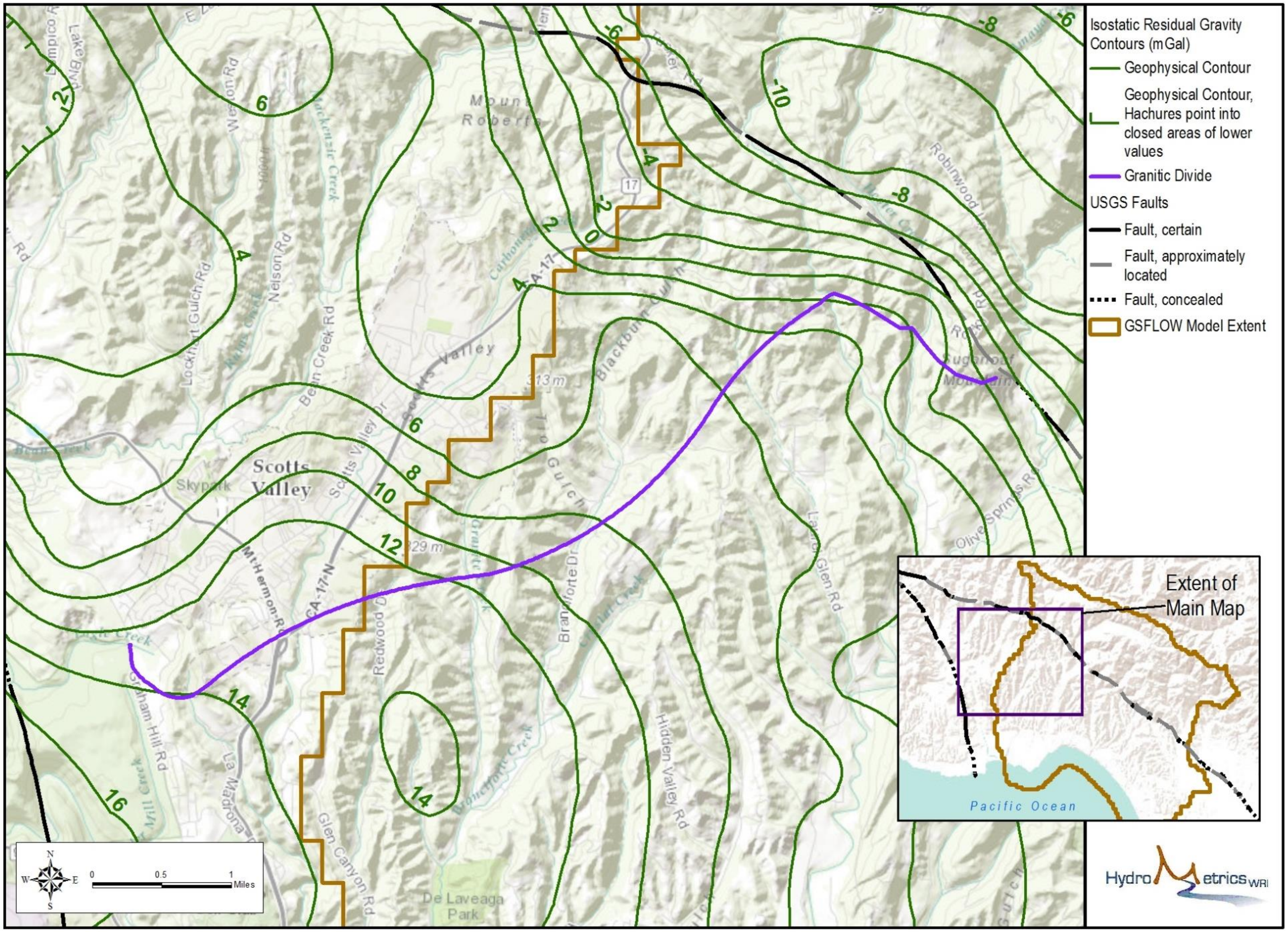

Figure 5: Gravity Anomaly Contours, Western Area of Model Domain

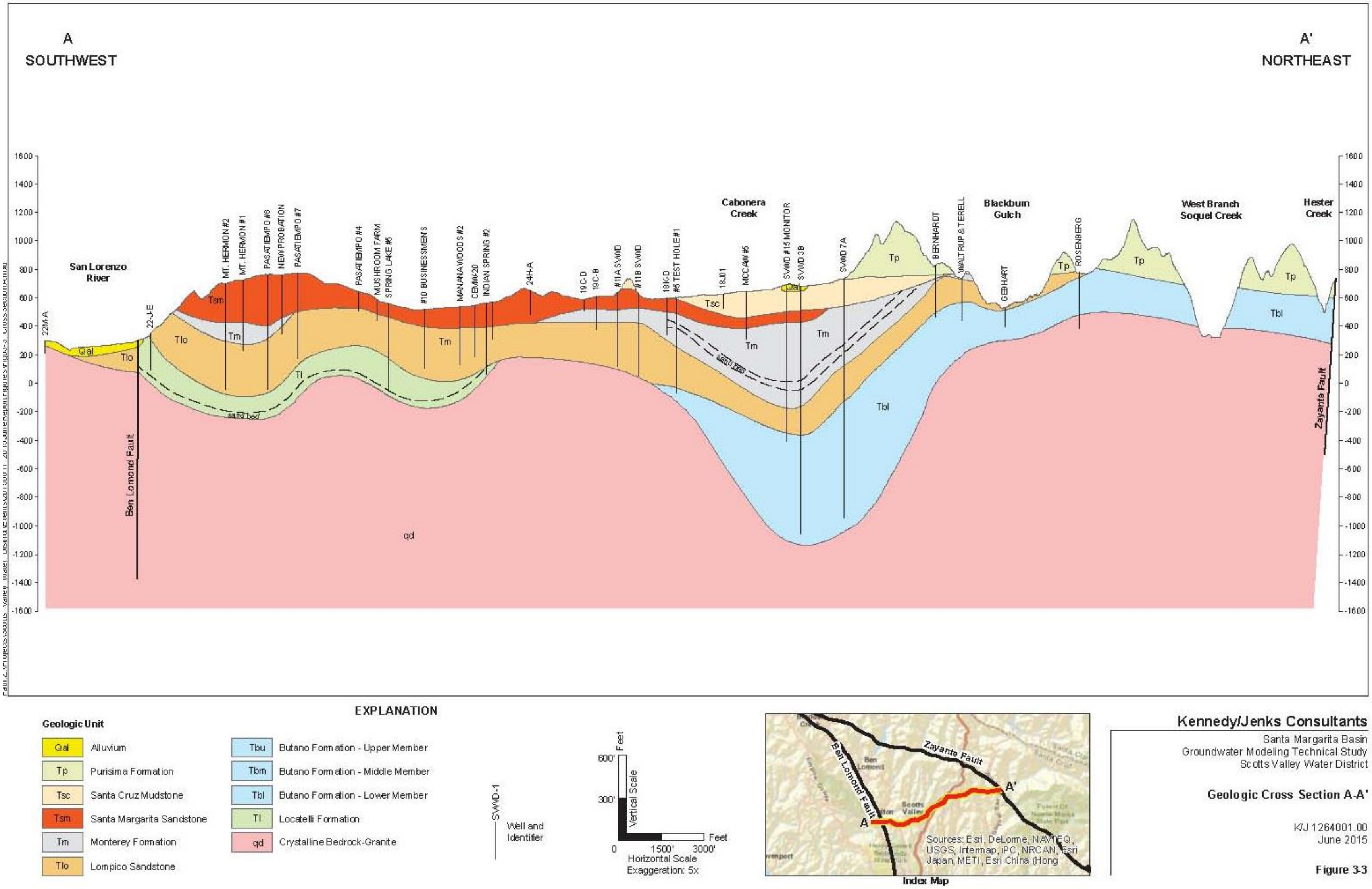

Figure 6: Cross-Section Near Western Boundary of Model Domain (from Kennedy/Jenks Consultants, 2015)

Table 2: Model Hydrostratigraphic Unit Thicknesses

Unit Name	Thickness
Stream Alluvium	Uniform (20 feet)
Terrace Deposits	Uniform (50 feet)
Aromas Red Sands	Variable (approximately 10 to 1,000 feet - consistent with CWD model)
Purisima TpDEF, TpF	Variable (base of Aromas to top of D Aquitard)
Purisima TpD	Uniform (170 feet)
Purisima TpBC	Uniform (190 Feet)
Purisima TpB	Uniform (130 feet)
Purisima TpA	Variable (approximately 200 to 300 feet)
Purisima TpAA	Variable (approximately 300 to 400 feet)
Tu	Variable (approximately 10 to 3,000 feet - distance from base of Purisima to top of granitic basement)

4.2 Model Geometry and Grid

The groundwater model domain consists of 135 rows and 105 columns of uniformly-sized grid cells. Only the grid cells contained within the area shown on Figure 1 will actively simulate groundwater flow. The size of each grid cell is 800 feet by 800 feet. The selection of an 800-foot uniform grid cell size followed an analysis that showed this resolution would sufficiently capture surface elevation features for the hydrologic response units (HRU) of the PRMS watershed model. For GSFLOW models, the USGS recommends using HRUs in PRMS that match the size and dimensions of the MODFLOW grid cells.

4.3 Groundwater Model Layers

The hydrostratigraphy of much of the groundwater model domain was developed using three reference elevations: the land surface, the base of the Purisima TpB aquitard (i.e. the identifiable basal TpB marker unit), and the top of the granitic basement. The land surface was defined using a digital elevation model (DEM) interpolated to the 800-foot uniform groundwater grid spacing. The bottom of the Purisima TpB aquitard and the top of the granitic basement were developed by manually picking the depths of these surfaces from borehole logs, as described in the sections above. The structure of the granitic basement was also informed by regional gravity anomaly maps. Top of the granitic basement and base of the Purisima TpB aquitard elevations as intersected by boreholes were hand-contoured over the groundwater model domain south of the Zayante Fault, and revised using GIS software to ensure the outcrop patterns of each surface were consistent with the previously mapped and reported outcrop patterns of the region (Johnson et al., 2004 and SqCWD and CWD, 2007). North of the Zayante Fault, the granite and bottom of the Purisima TpB aquitard surfaces were extended uniformly and perpendicular to the general trend and dip of the fault because Purisima Formation layers are not well defined north of the fault and differentiation of the layers likely will not be simulated.

The contact elevations between each hydrogeologic unit in the model are mapped on Figure 7 through Figure 14, along with applicable borehole control points estimated from available e-logs. The bottom of the Purisima TpB aquitard was interpolated to the uniform grid spacing of the groundwater model via kriging within the Surfer® software program. The Purisima TpB aquitard elevations are used as a reference surface for defining the depths of the other Purisima Formation units. Thicknesses were assigned to aquifer and aquitard units based on the e-log analysis described in the previous section (see Table 2). The bottom elevations of the DEF/F aquifer, D aquitard, and BC aquifer layers are determined by adding the uniform thicknesses to the B aquitard bottom elevations, while the bottom elevations of the AA aquifer layer are determined by subtracting the total A/AA thickness of 600 feet from the B aquitard bottom elevations. This combined A/AA unit is subdivided into two units of generally uniform, but locally variable thickness as described in the section above.

The Tu unit model layer, which combines any units below the Purisima Formation and above the granitic basement into one model layer, extends from the base of the TpAA aquifer model layer to the top of the granitic basement. Where granitic basement meets the base of the Purisima Formation in the eastern part of the domain, the Tu unit is inactive. Additionally, the Tu unit was made inactive within the model domain east of the limit shown in Figure 7, based on the assumed pinch-out margin of the Tu. As such, the bottom of the model is represented by the base of the Tu with elevations of the granitic basement west of the pinchout margin as shown in Figure 7. The bottom of the model is represented by the base of the AA aquifer with elevations of the granitic basement east of this margin as shown in Figure 9.

The depth of the bottom of the Aromas model layer is also variable over parts of the model domain. This surface contact was interpolated from the base of the deepest Aromas layer in the CWD model to the 800-foot uniform model grid. Model elevations in the CWD model (HydroMetrics WRI and Kennedy/Jenks, 2014) were based on Johnson (2006). This surface was contoured, and the contours were extended beyond the CWD model domain to areas of the Aromas Red Sands that are outside of that domain, but within the basin wide model domain. The CWD model domain shown on Figure 14. The distance between the top of the D aquitard layer to either the land surface or the bottom of the Aromas layer was assigned as the same thickness of the DEF/F aquifer layer.

Model layer contact surfaces were assigned to the model grid using the Groundwater Modeling System (GMS) software package, where layer thicknesses were determined according to the variable or uniform thickness between the reference surfaces of the base of the B aquitard and the granitic basement. The top of all model layers were cropped to the DEM land surface, and inactivated where those layers artificially extended above the land surface according to the imposed dip and interpolation method. Therefore, thicknesses of layers as they outcrop are less than the uniform thicknesses shown in Table 2. The result is an outcrop map that reasonably approximates available maps of surface units. Some simplification was applied to the model grid so that disconnected islands of active cells, usually in upland areas within a given hydrostratigraphic unit, were minimized. Where the granitic basement surface was interpolated to extend close to DEM surface (within approximately 10 feet), all model layers were inactivated to represent the no-flow areas where granite outcrops to the surface.

Figure 15 shows the extent of the outcropping model layers representing the Aromas and Purisima units and location of cross-sections A-A′, B-B′, and C-C′. Figure 16 through Figure 18 show the simulated model layers along these cross-section lines. Cross-section A-A′ runs roughly parallel to California State Route 1, and shows that the southeasterly-dipping Purisima units are well-represented in the groundwater model domain. The variable thickness of the Aromas layer is also evident, as is the pinch-out of the Tu layer where the Purisima Formation extends to the granitic basement in the western portion of the model domain. Cross-section B-B′ runs roughly parallel to Soquel Creek, and shows an area where the model grid is inactive due a surface outcrop of granite, Cross-section C-C′ runs parallel to the model domain's southern offshore boundary, showing a similar dip direction as in cross-section A-A′, and the geologic units that outcrop to the ocean floor along that line.

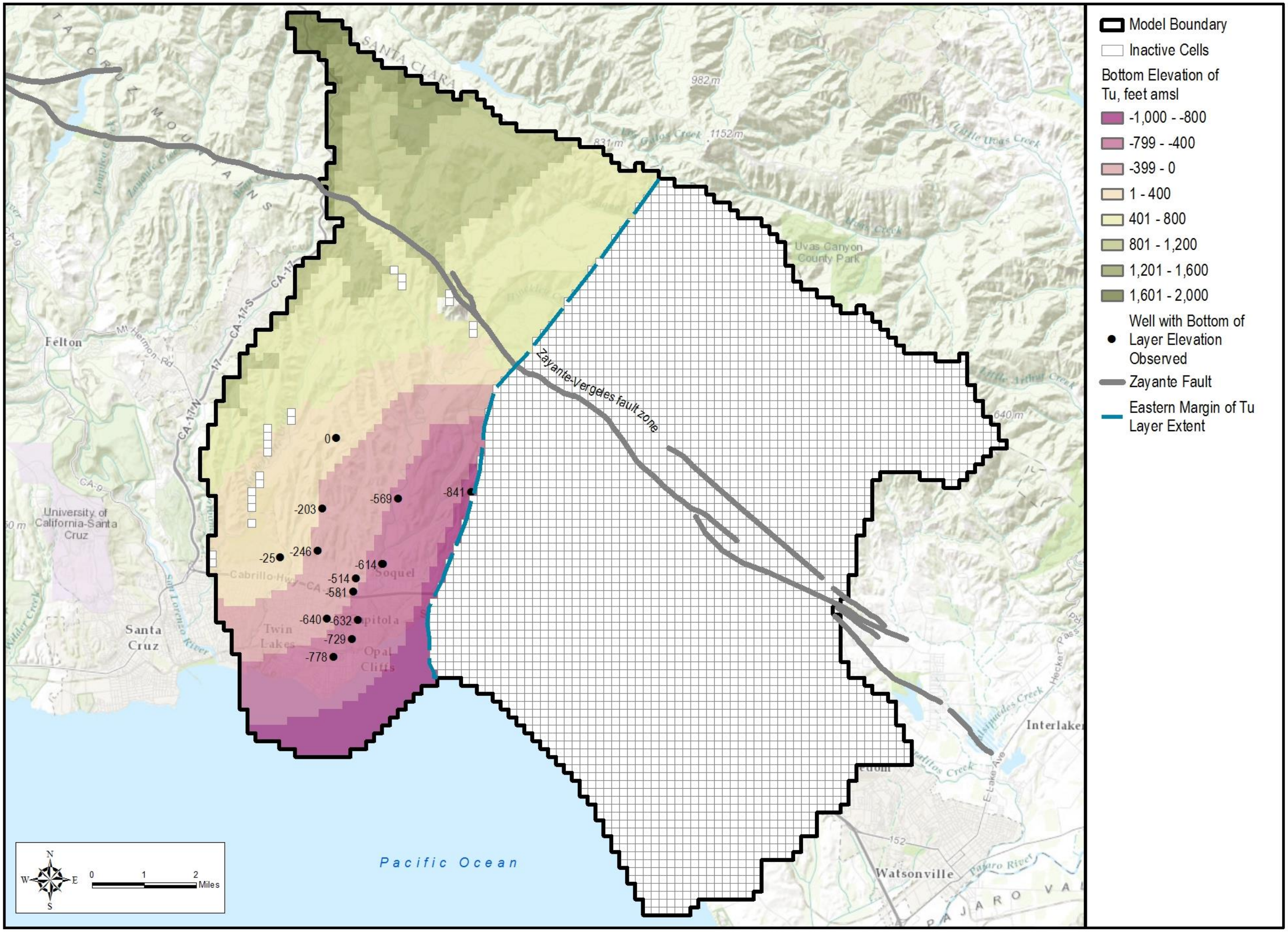

Figure 7: Base of Tu Unit Elevations in Model

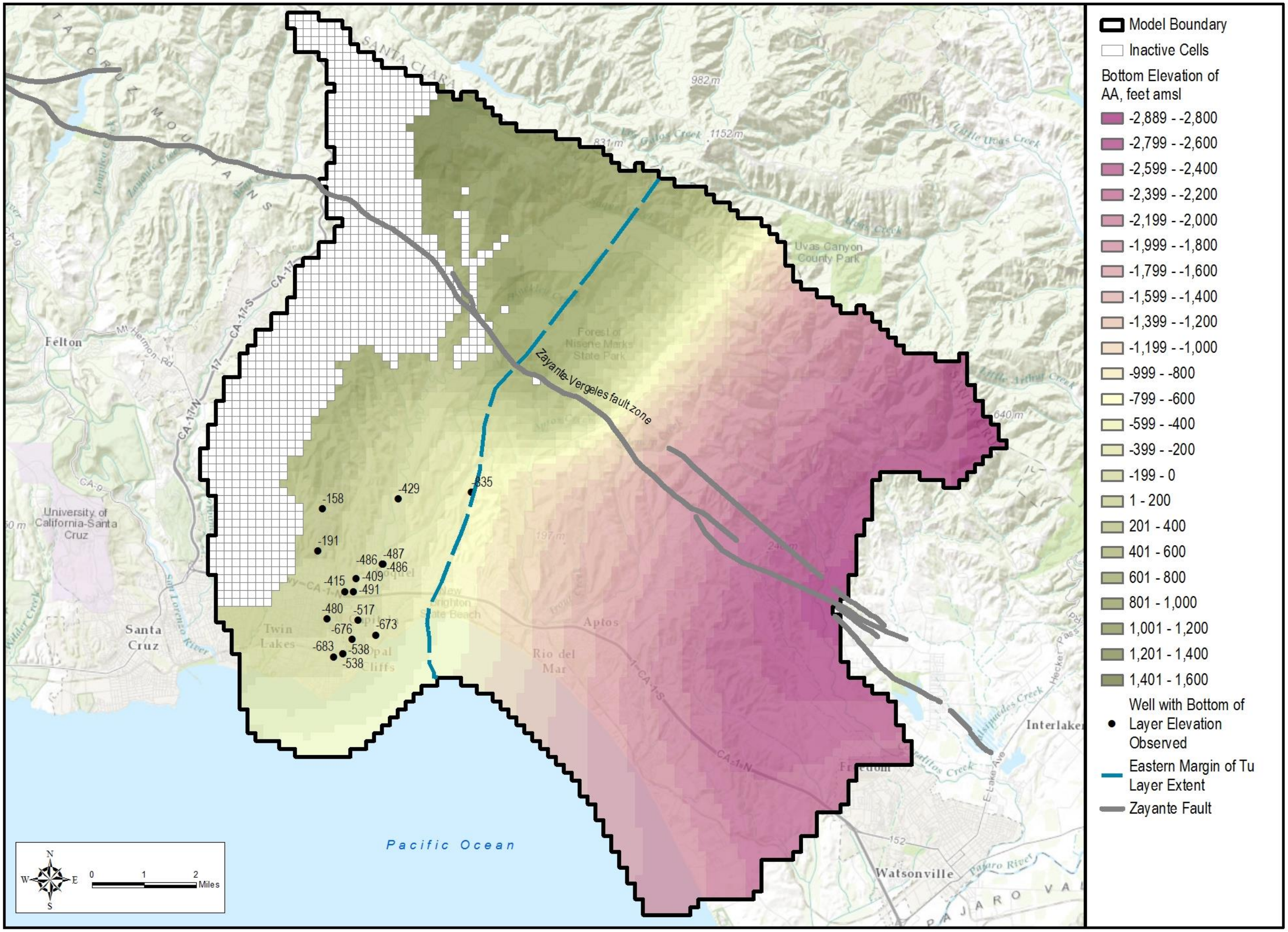

Figure 8: Base of TpAA Unit Elevations in Model

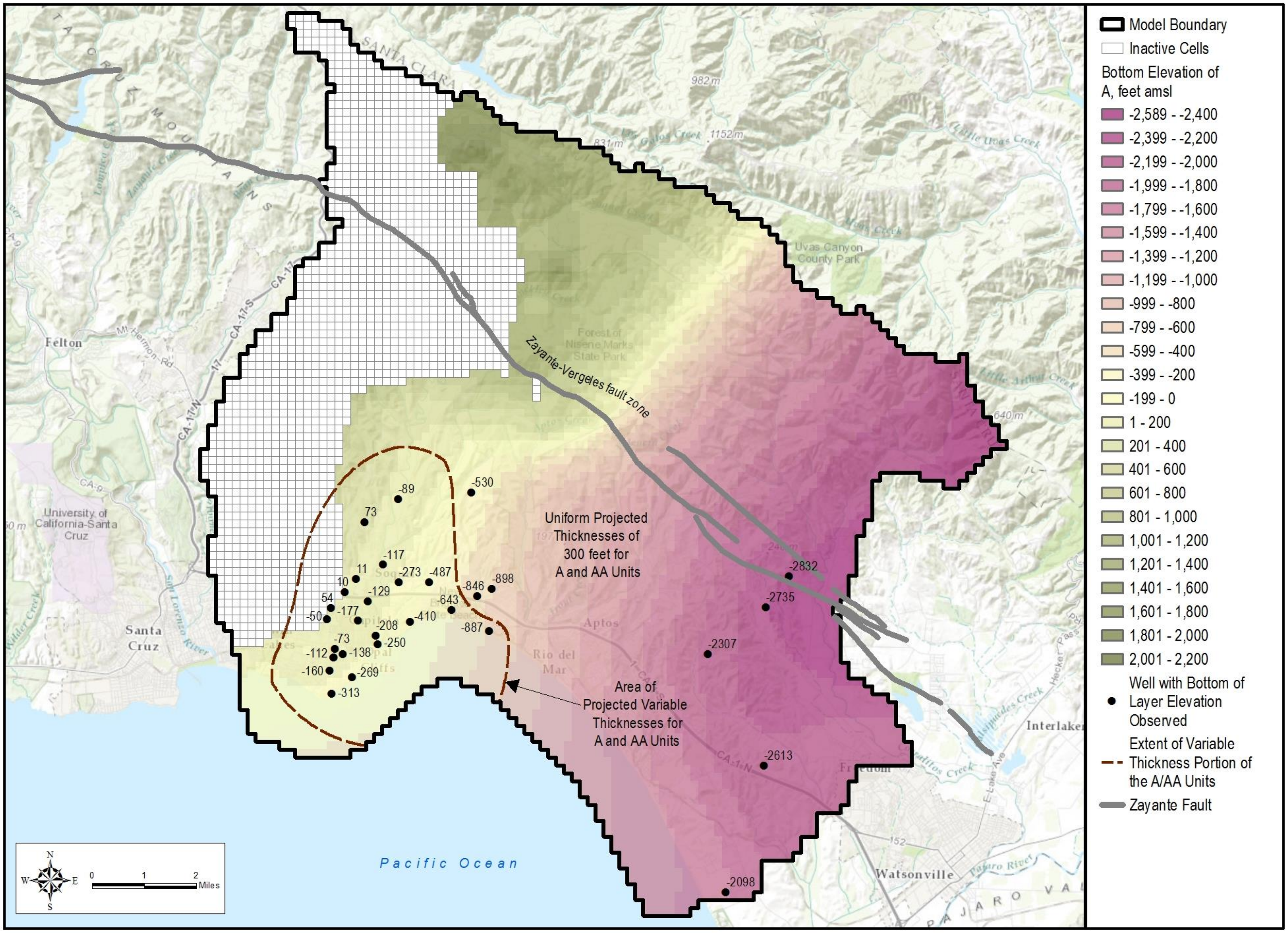

Figure 9: Base of TpA Unit Elevations in Model

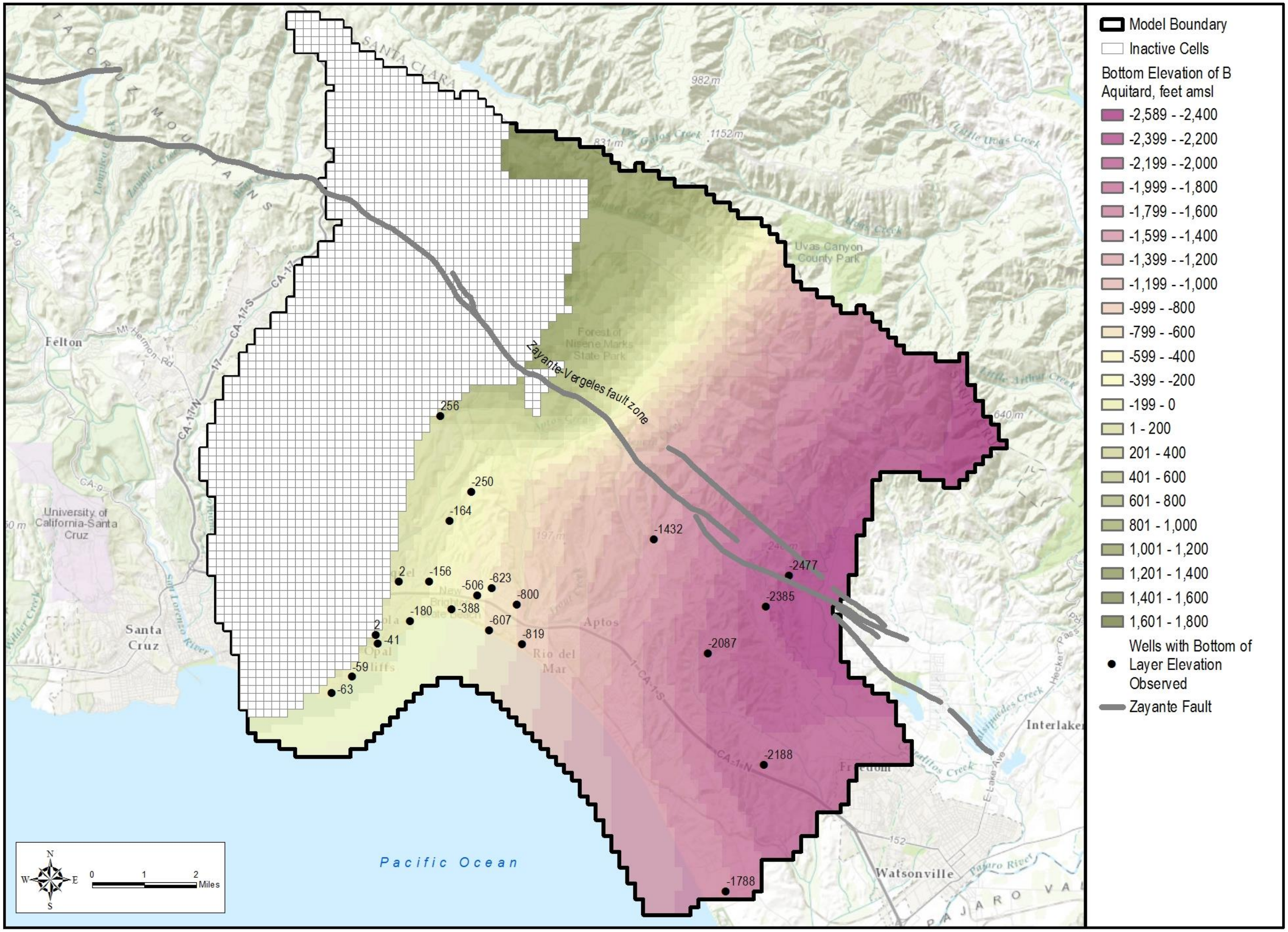

Figure 10: Base of TpB Aquitard Elevations in Model

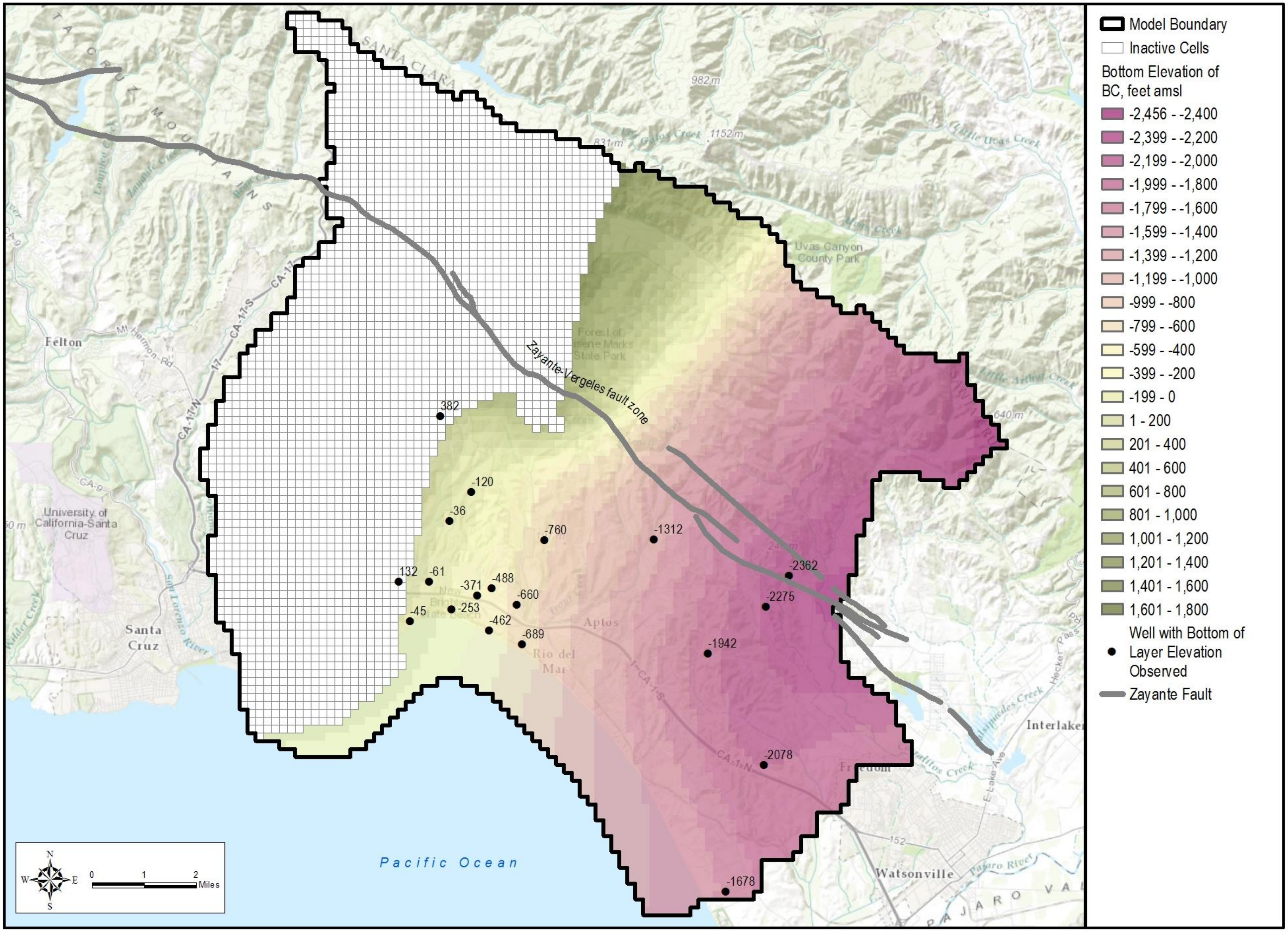

Figure 11: Base of TpBC Unit Elevations in Model

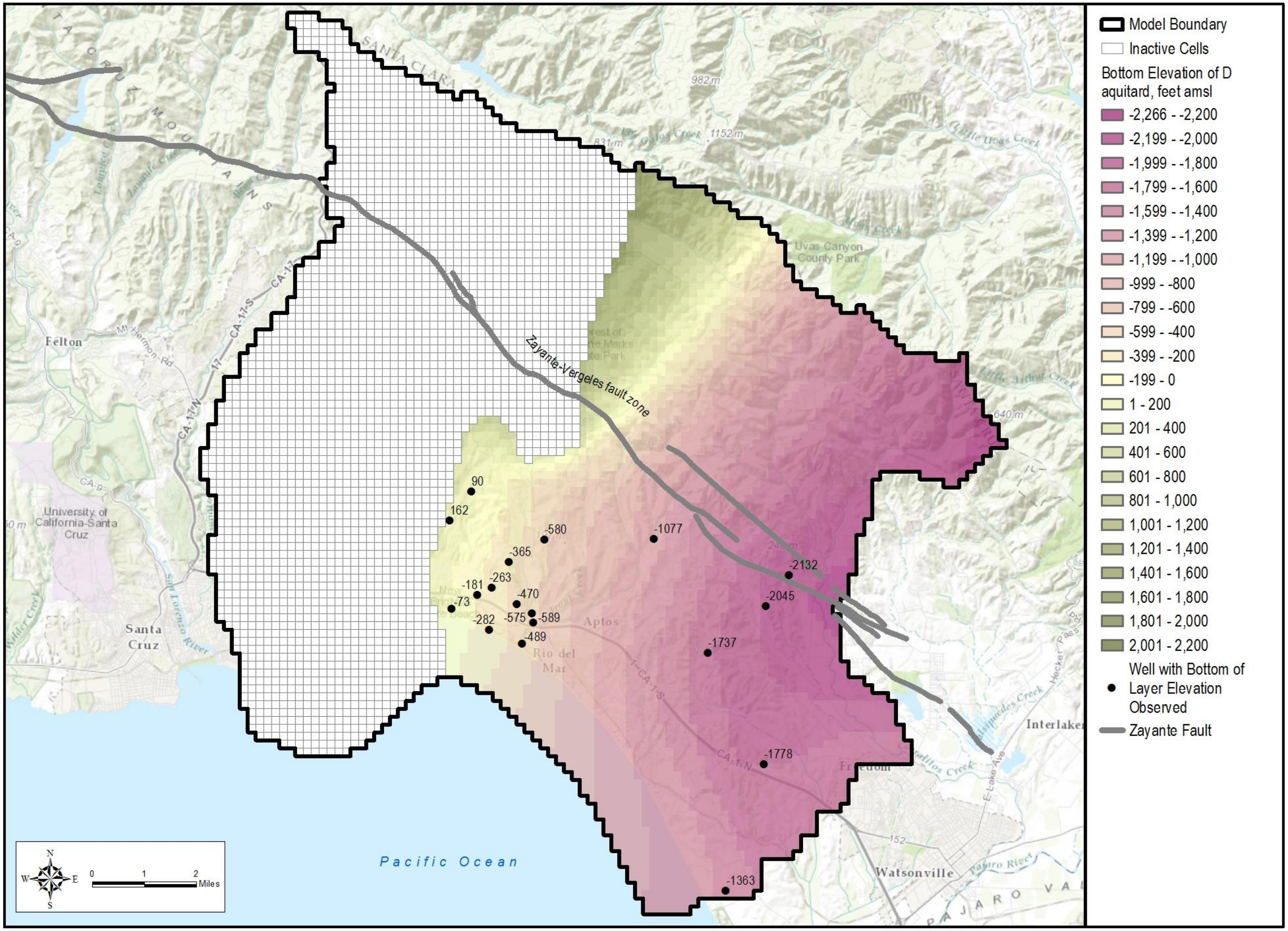

Figure 12: Base of TpD Aquitard Elevations in Model

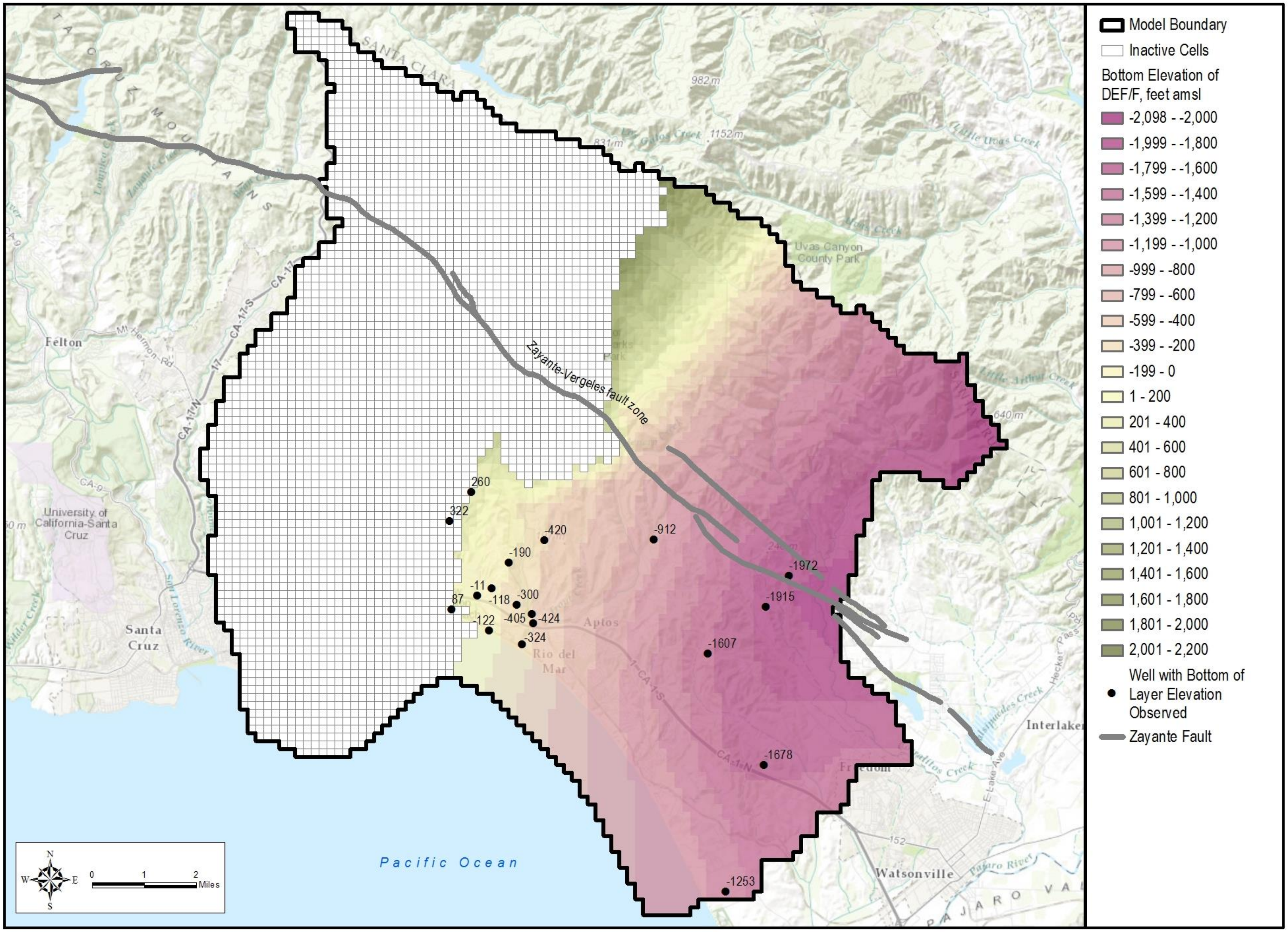

Figure 13: Base of TpDEF/F Unit Elevations in Model

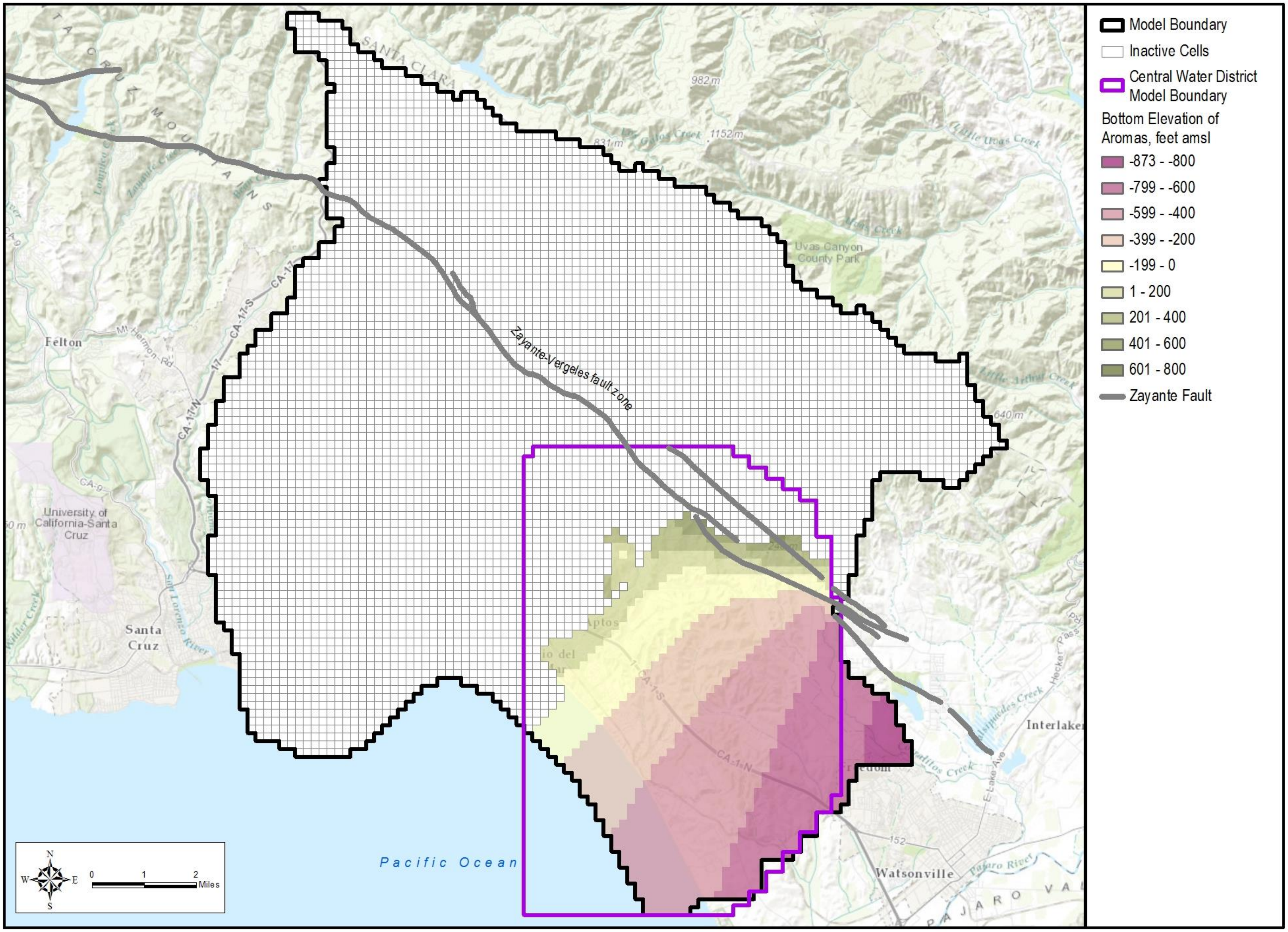

Figure 14: Base of Aromas Red Sands Elevations in Model

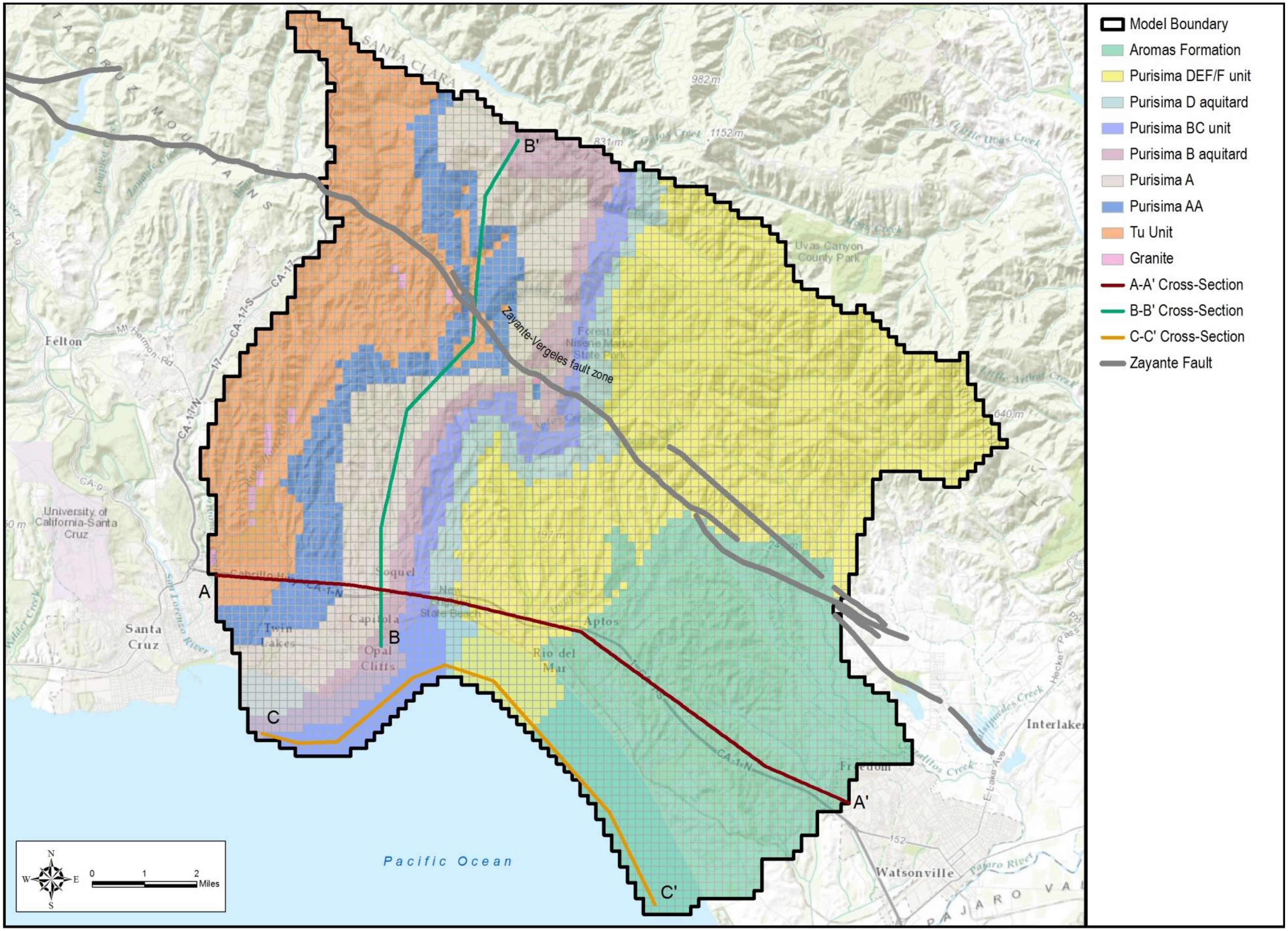

Figure 15: Simulated Aromas and Purisima Outcrop Extents

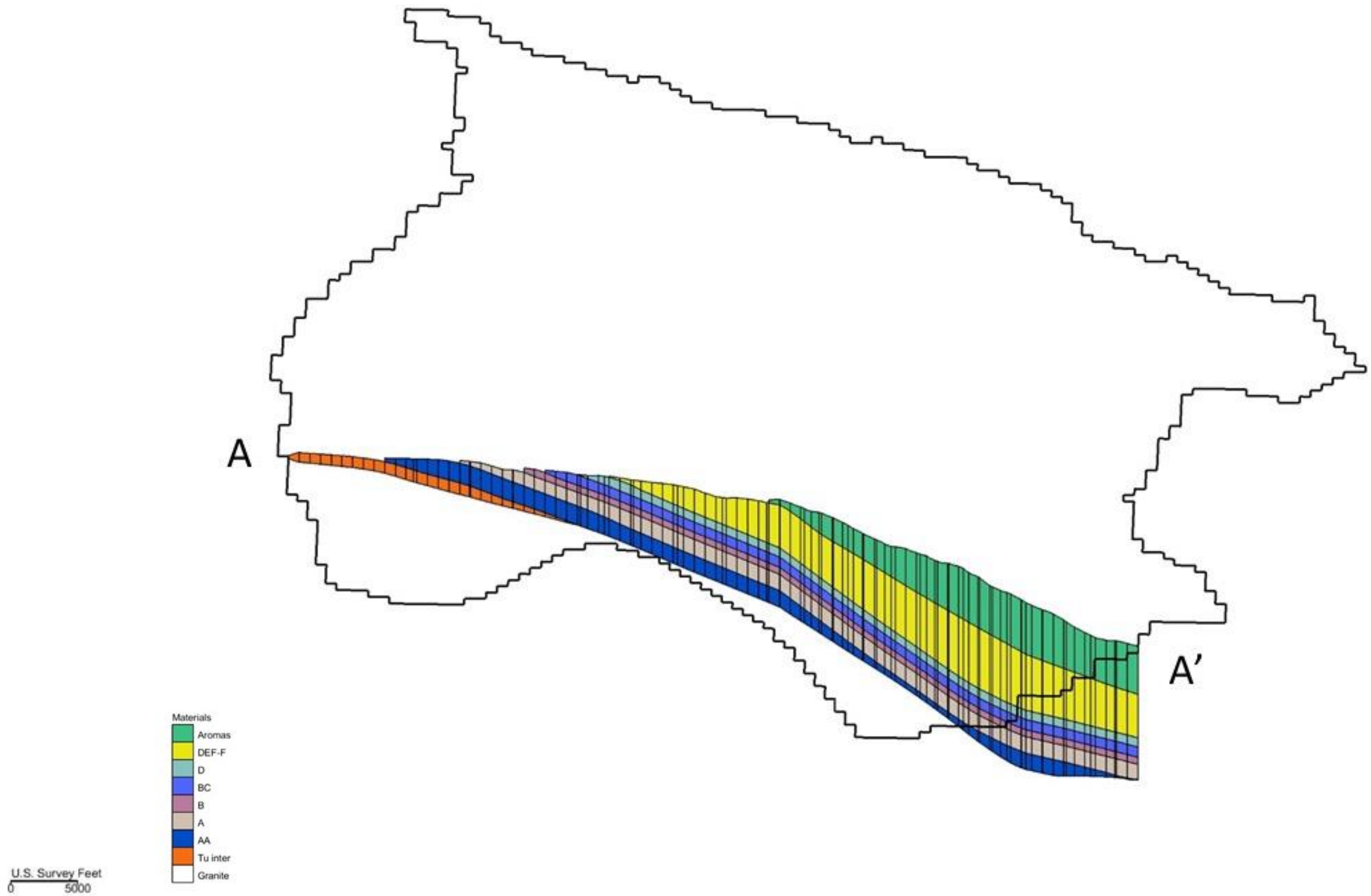

Figure 16: Simulated Cross-Section A-A'

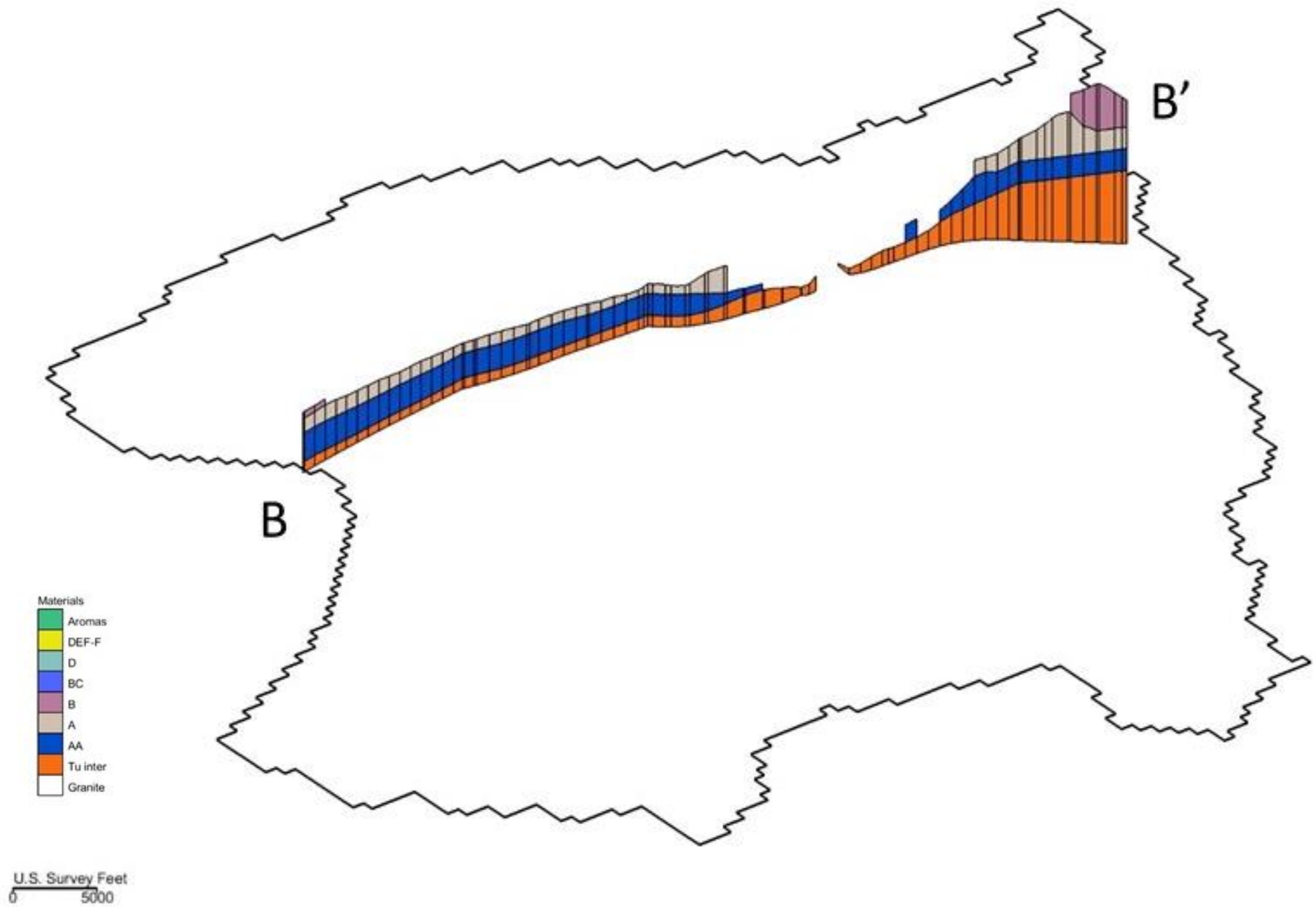

Figure 17: Simulated Cross-Section B-B′

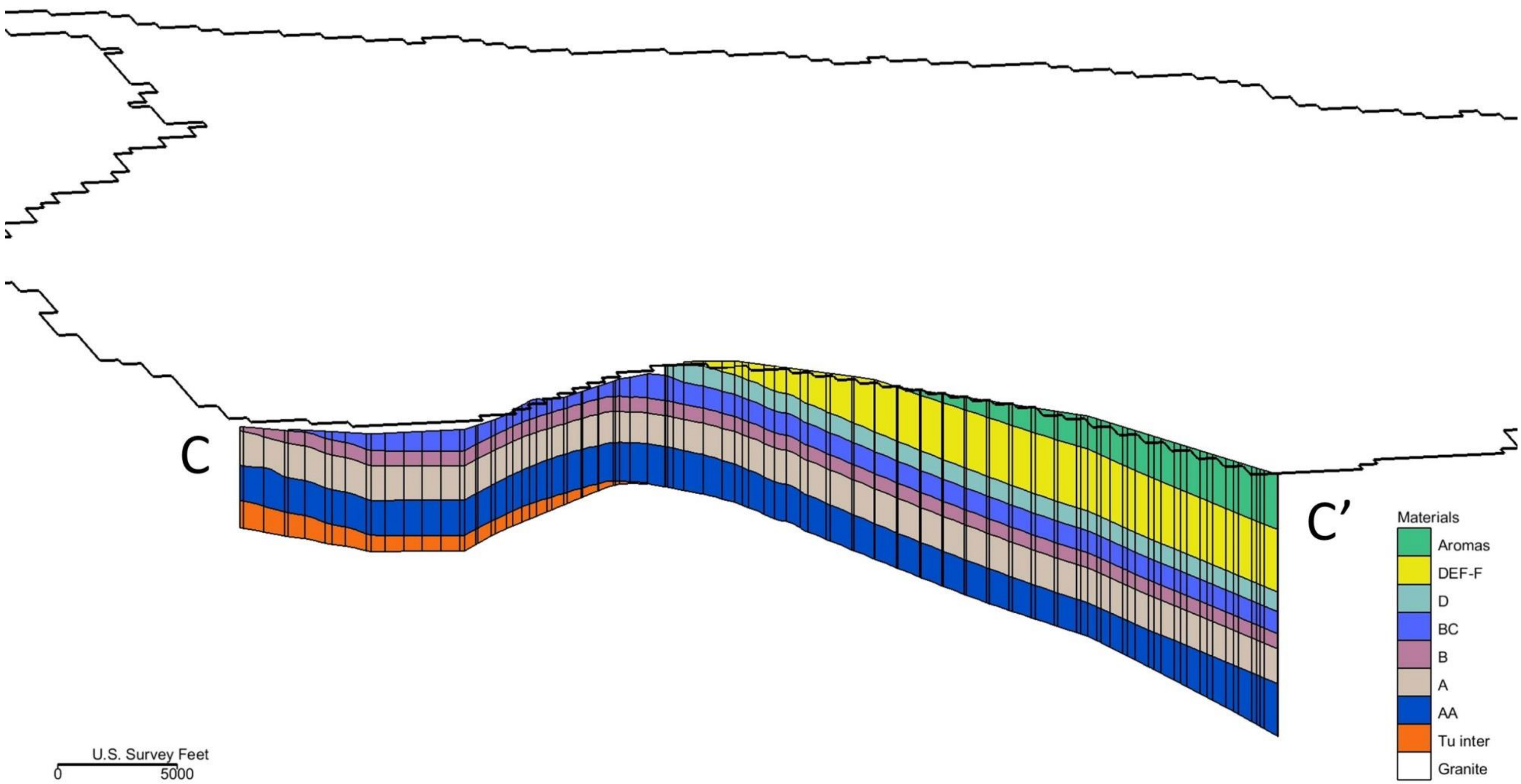

Figure 18: Simulated Cross-Section C-C′

4.4 EXTENT AND DEFINITION OF SIMULATED ALLUVIAL MATERIAL

In addition to the Aromas Red Sands and Purisima Formation, alluvial material associated with streambed deposits and coastal terrace deposits are defined within the model domain. Streambed sand and gravel deposits may be of relatively higher-permeability material than the surrounding surficial geology, so they are considered necessary to represent the groundwater-surface water interactions that occur in the integrated GSFLOW model. Terrace deposits consist of unconsolidated sediments formed by surf erosion in periods of high sea levels during the Pleistocene epoch. While they may yield only relatively minor quantities of groundwater to wells, they were added to the model to accommodate their potential for affecting recharge to the underlying aquifer units. The simulated thicknesses of these alluvial materials is simplified to be uniform wherever they exist within the model domain.

Because the Aromas and Purisima Formation outcrop over the extent of the model domain, the ground surface is defined by various model layers. The alluvium may be found overlying any of these outcropping model layers; therefore the alluvium cannot be defined as a single layer within the model. Rather, alluvium will be assigned to whatever model layer overlies the regional aquifers where that alluvium is identified to exist. The exact material properties of the alluvium will be documented in a future technical memorandum. To accommodate the alluvium thickness, the top-of-layer elevations of the underlying units are revised by subtracting the alluvium thickness from the interpolated DEM surface. Figure 19 and Figure 20 show the simulated extents of active streambed alluvium and terrace deposit materials within the model domain, respectively. The streambed alluvial areas are congruent with the anticipated extent of stream cells developed for the PRMS component of the model. The extent of terrace deposits was inferred from existing USGS surficial geology maps.

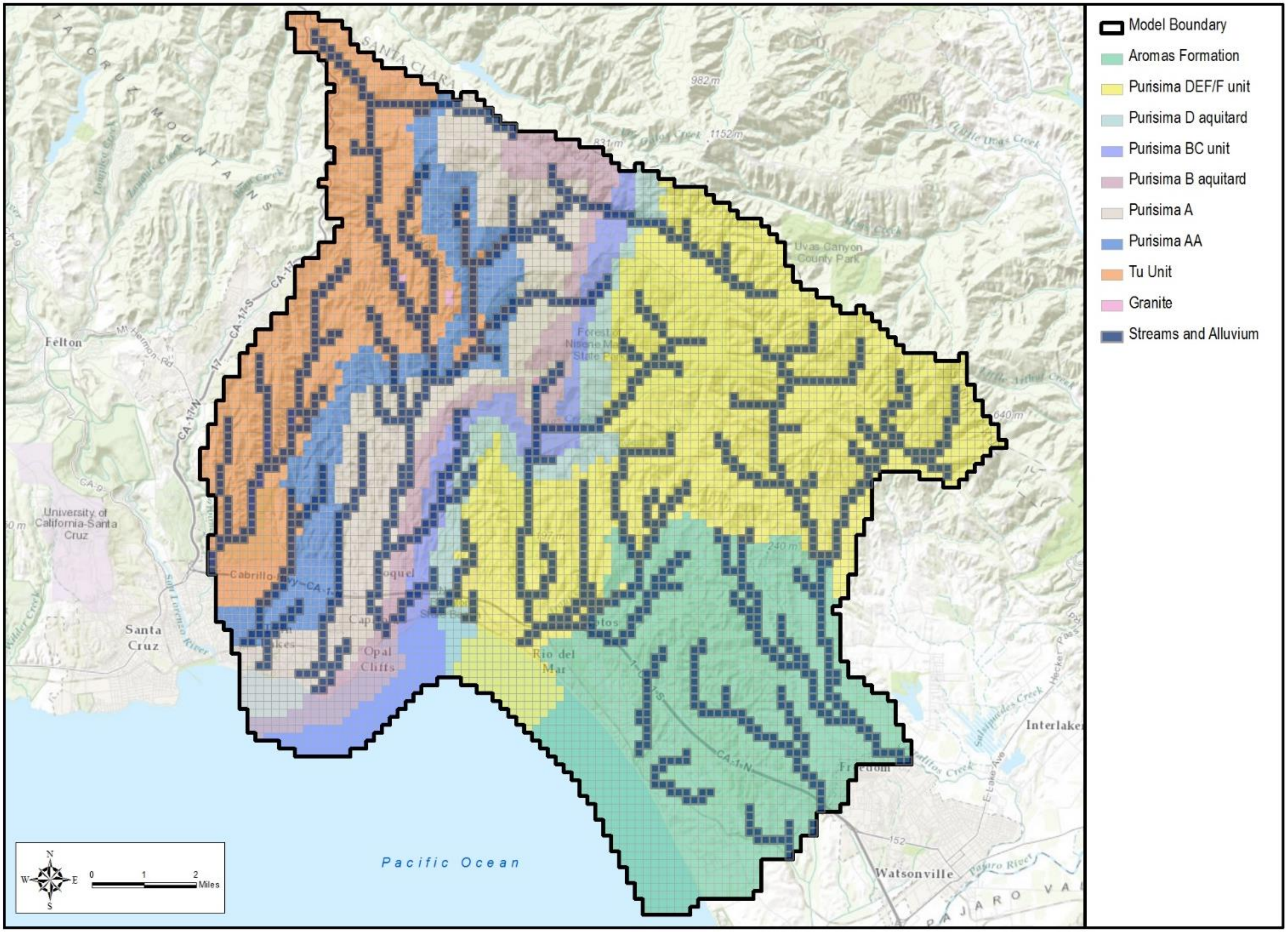

Figure 19: Simulated Extent of Streambed Alluvium

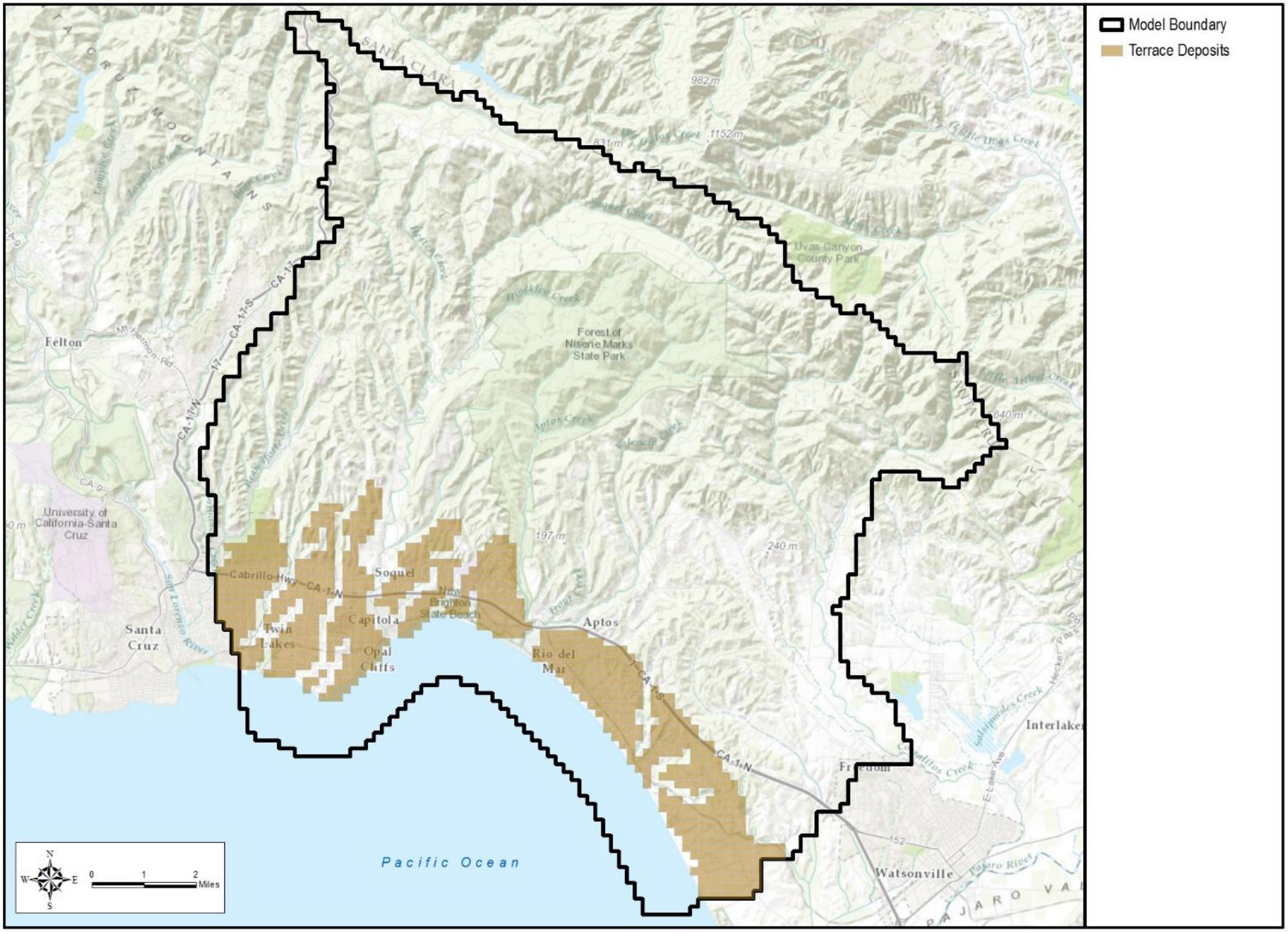

Figure 20: Simulated Extent of Terrace Deposits

Assigning streambed alluvium to various model layers was complicated by areas where streams cross simulated outcrop boundaries. In order to allow for hydraulic connectivity in these streambed units, additional layering was necessary to ensure that flow within the streambed units is not impeded by an effective boundary created where adjacent stream cells are assigned to different model layers. Figure 21 shows a diagram outlining the stream alluvial layering approach within the groundwater model where streams cross outcrop boundaries. In these instances, an additional vertical layer of alluvium is added to create a stack of cells connecting the alluvium overlapping the different outcropping aquifers. Minimal vertical anisotropy applied to the alluvial cells will facilitate a continuous flow path laterally out of the upstream alluvial cell, downward or upward through the stacked alluvial cells, and then laterally in the downstream direction through the alluvium. Without this additional layering, no lateral flow would occur in the alluvial cells of streams that cross outcrop boundaries.

As developed for PRMS, simulated streamflow may occur between adjacent stream cells, but also between cells that overlay diagonally-aligned model cells. However, groundwater flow is not simulated between diagonally-aligned model cells. As such, "bridge" streambed alluvium cells were defined to maintain lateral hydraulic connectivity between model cells representing the alluvium of a diagonally-flowing stream, with a continuous flow path maintained using stacking of two or more layers at the bridge cell as described above. Figure 22 demonstrates the process by which these additional bridge cells were defined, including cases where the stream crosses an outcrop boundary, as described above.

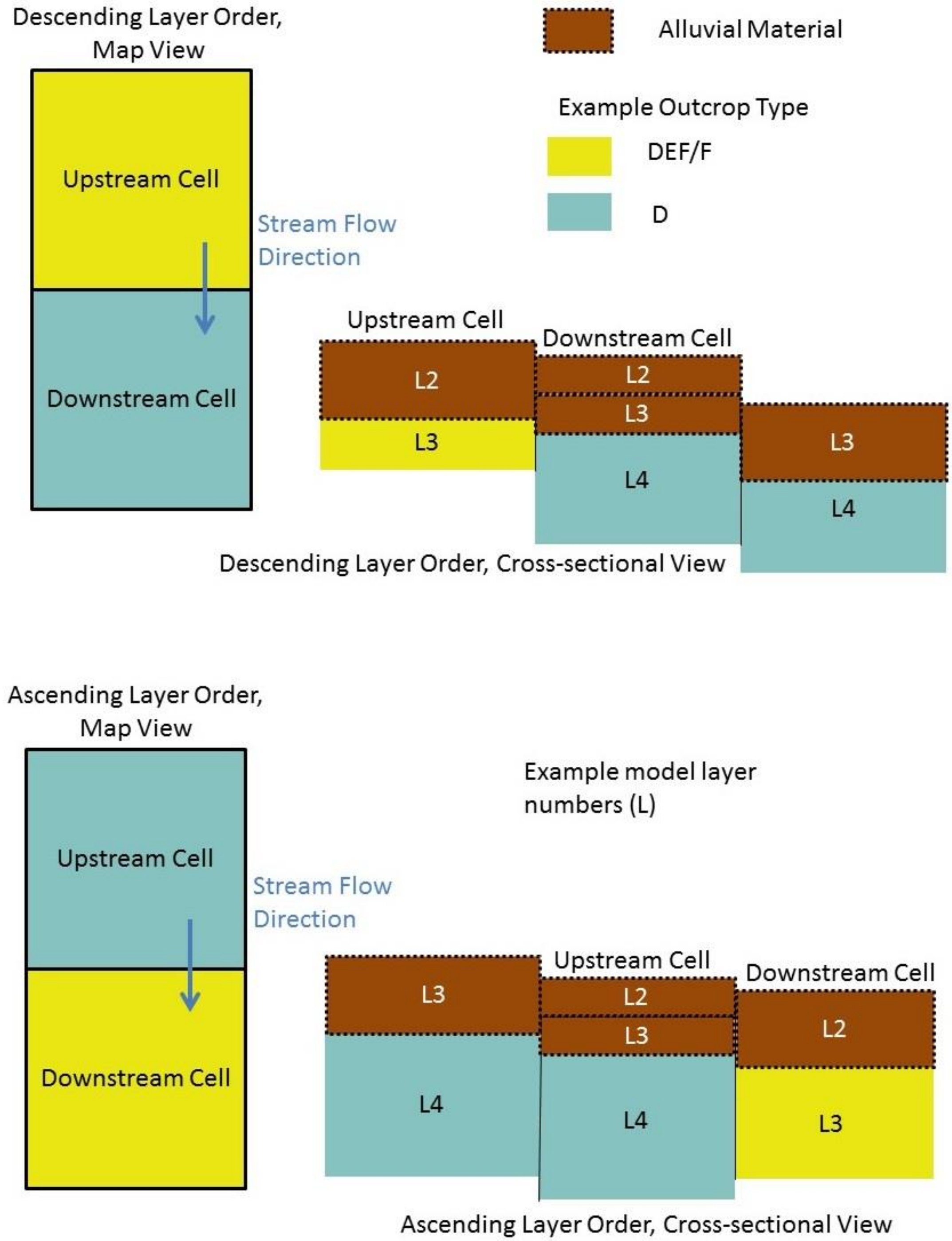

Figure 21: Example Stream Alluvium Layer Assignment

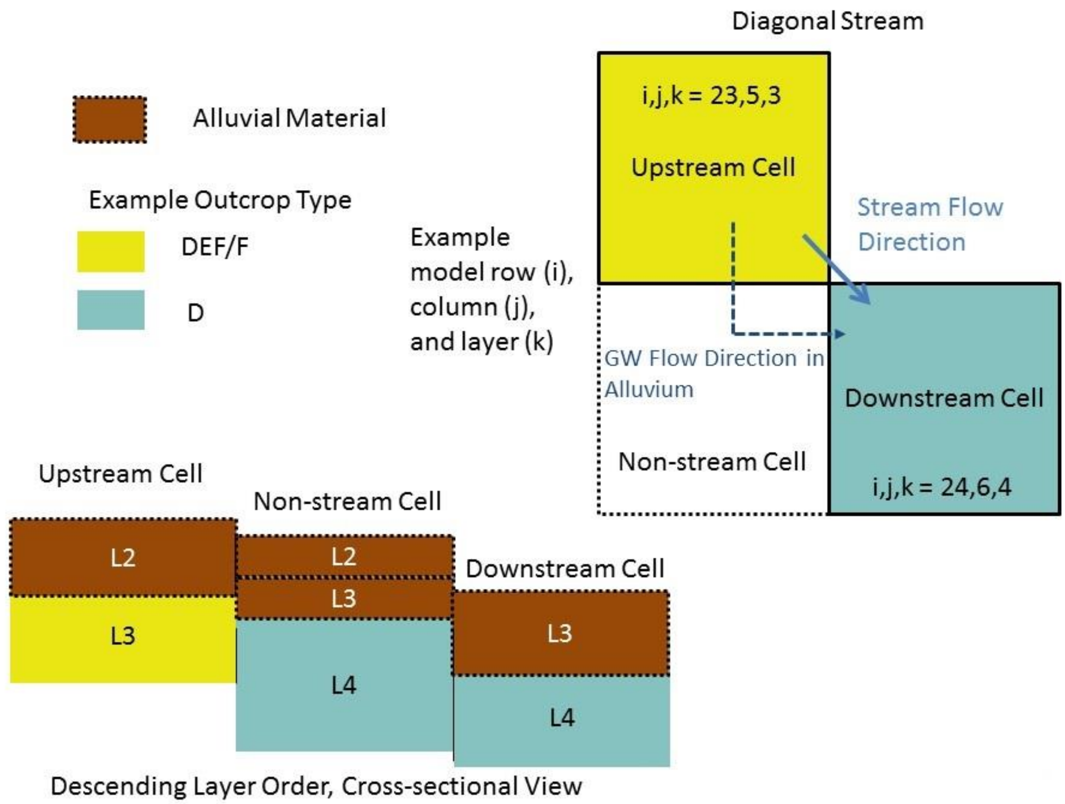

Figure 22: Example Stream Alluvium Layer Assignment for Diagonally-aligned Streams

5.0 Boundary Conditions

Model boundaries have been selected so that they generally follow existing watershed boundaries or other hydraulic boundaries within the model domain. As such, the northern, western, and eastern edges of the model will be assigned no-flow boundary conditions. The extent and type of anticipated boundary conditions is shown on Figure 23.

Active Aromas or Purisima model cells that outcrop beyond the coastline will be assigned as general head boundary (GHB) cells where the simulated head value is equivalent to mean sea level similar to the CWD model (HydroMetrics WRI and Kennedy/Jenks, 2014). Conductance will be estimated as model construction and calibration proceeds. Conductance values will also be varied spatially to account for changes in seafloor sediment type and thickness.

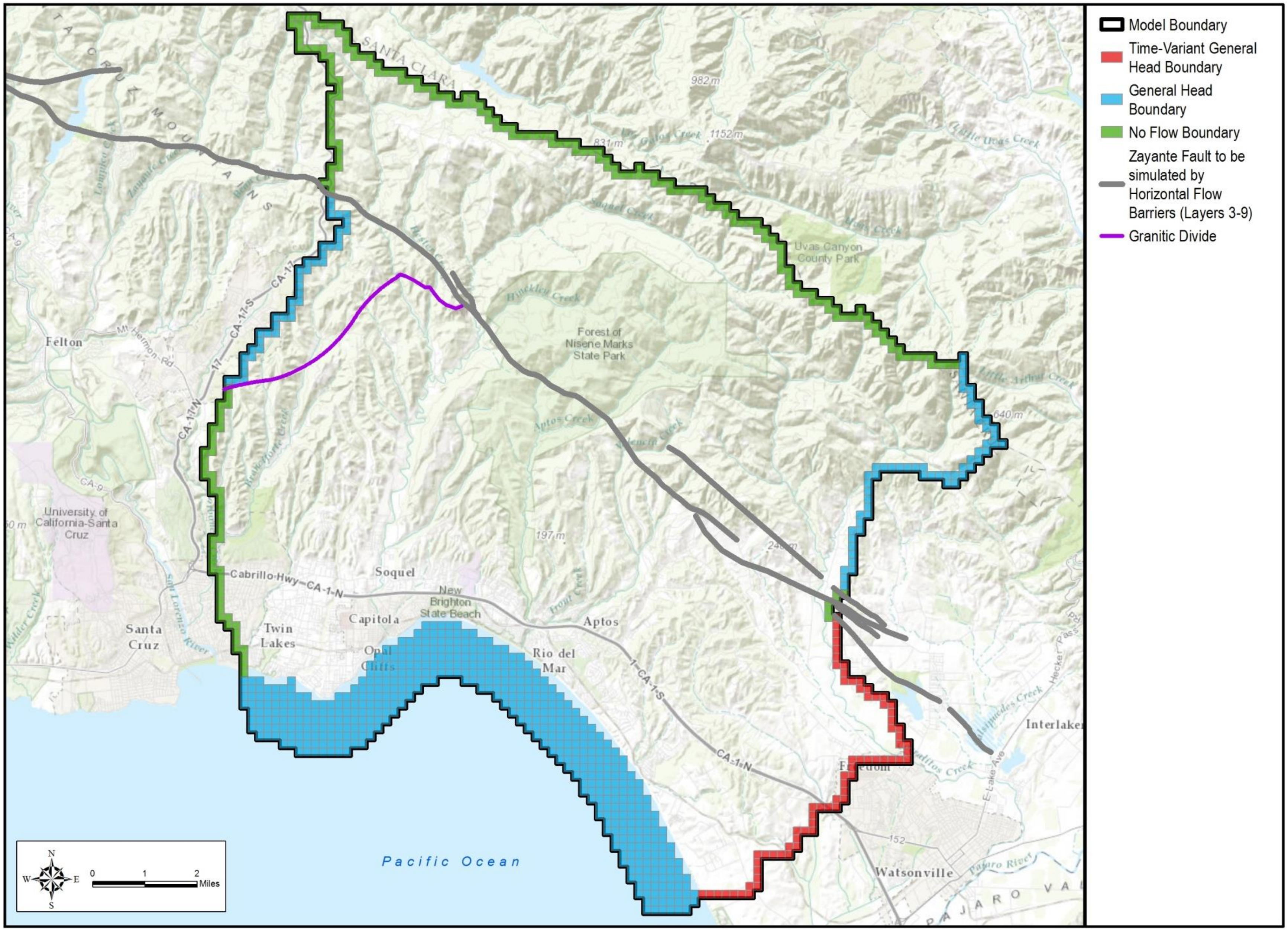

Figure 23: Generalized groundwater model boundary conditions.

The Zayante Fault will be represented by the horizontal flow barrier (HFB) package. Implementing these flow barriers between cells north and south of the fault will provide resistance to flow between the well-defined Purisima unit layers south of the fault and the undefined Purisima Formation north of the fault as described in section 4.3. HFB conductance will be estimated during model calibration.

The area of the model north of the Zayante Fault is within the watershed area of the Soquel-Aptos Basin, and will receive surface water in the form of precipitation and streamflow. However, groundwater flow from infiltration into the simulated undifferentiated Purisima units north of the fault will be impeded by the fault HFB. In order to avoid mounding and unreasonably high groundwater levels in this area, an additional GHB will be applied to the eastern boundary of the model north of the fault. The head and conductance along this boundary will be varied as model work progresses to maintain reasonable groundwater head elevations north of the Zayante Fault. It is unlikely that model calibration will be sensitive to this boundary condition, as the majority of pumping wells and groundwater calibration targets will be south of the fault.

Groundwater modeling studies of the Santa Margarita Basin and Scotts Valley area (Todd Engineers, 1997; ETIC Engineering, 2006; Kennedy/Jenks Consultants, 2015) indicate that groundwater flow west of the granitic structural divide shown on Figure 4, Figure 5, and Figure 23 within the aquifer units below the Purisima Formation is directed roughly westward, away from the Soquel-Aptos Basin. As such, assigning a no flow boundary west of this structural divide may result in unreasonable mounding and flow directions to occur in the thick portion of the simulated Tu unit west of the divide. It may also be problematic to inactivate model cells west of the structural divide as at the surface, this area is still within the Soquel-Aptos watershed and contains steams that necessarily contribute flow to model domain. To accommodate this feature of the hydrostratigraphy, a GHB will be applied to the western boundary of the model between the intersection of the granitic structural divide with the western model boundary and the Zayante Fault, which is also the northern boundary of the Santa Margarita Basin. This will induce westward groundwater flow out of the model domain west of the structural divide and maintain reasonable groundwater elevations within the Tu unit in this area.

The southeastern boundary is the only boundary that does not intersect a watershed or naturally-occurring hydraulic barrier. Rather, it is similar to the southeastern boundary of the CWD model in the coastal plain area of the City of Watsonville. Model cells representing this boundary will be defined as GHB cells via similar method as was applied to the CWD model (Hydrometrics WRI and Kennedy/Jenks, 2014). In the CWD model, a GHB boundary with transient heads estimated for the entire boundary length was developed based on groundwater elevation data provided by PVWMA. As groundwater data in this area are relatively limited, the transient heads were assigned to three separate segments of the boundary according to a function for seasonally-fluctuating groundwater elevations that was fit to historical water level data at the PVWMA wells. Historical lateral groundwater gradients were used to apply a generalized spatial trend to each segment of the boundary (Hydrometrics WRI and Kennedy/Jenks, 2014). These interpolated time series extend through 2012 for the CWD model, and will be updated to extend through 2015 to be applied to the basin wide model. The CWD model did not extend vertically into the Purisima along this southeastern boundary, and groundwater level data from PVMWA wells in this area are limited to the Aromas Formation. To account for this, a consistent vertical gradient will be estimated, and transient and spatial head data will be interpolated according to the gradient at GHB cells in the underlying Purisima layers along the boundary in the basin wide groundwater model. Where necessary, the extent of each boundary segment, the function applied to develop transient head conditions, or the vertical gradient will be adjusted as model construction and calibration proceeds. Figure 24 shows the area of the southeastern model boundary, the wells used to define the spatial variability of the boundary in the CWD model, as well as other PVMWA wells in the vicinity that may be used as sources of groundwater elevation data to define the boundary heads. Pumping from the City of Watsonville also occurs in this area, and will be explicitly defined by pumping wells in the model. City of Watsonville wells that fall within the model domain are also shown in Figure 24. Future changes to pumping at other City of Watsonville wells will need to be simulated by adjusting the boundary condition.

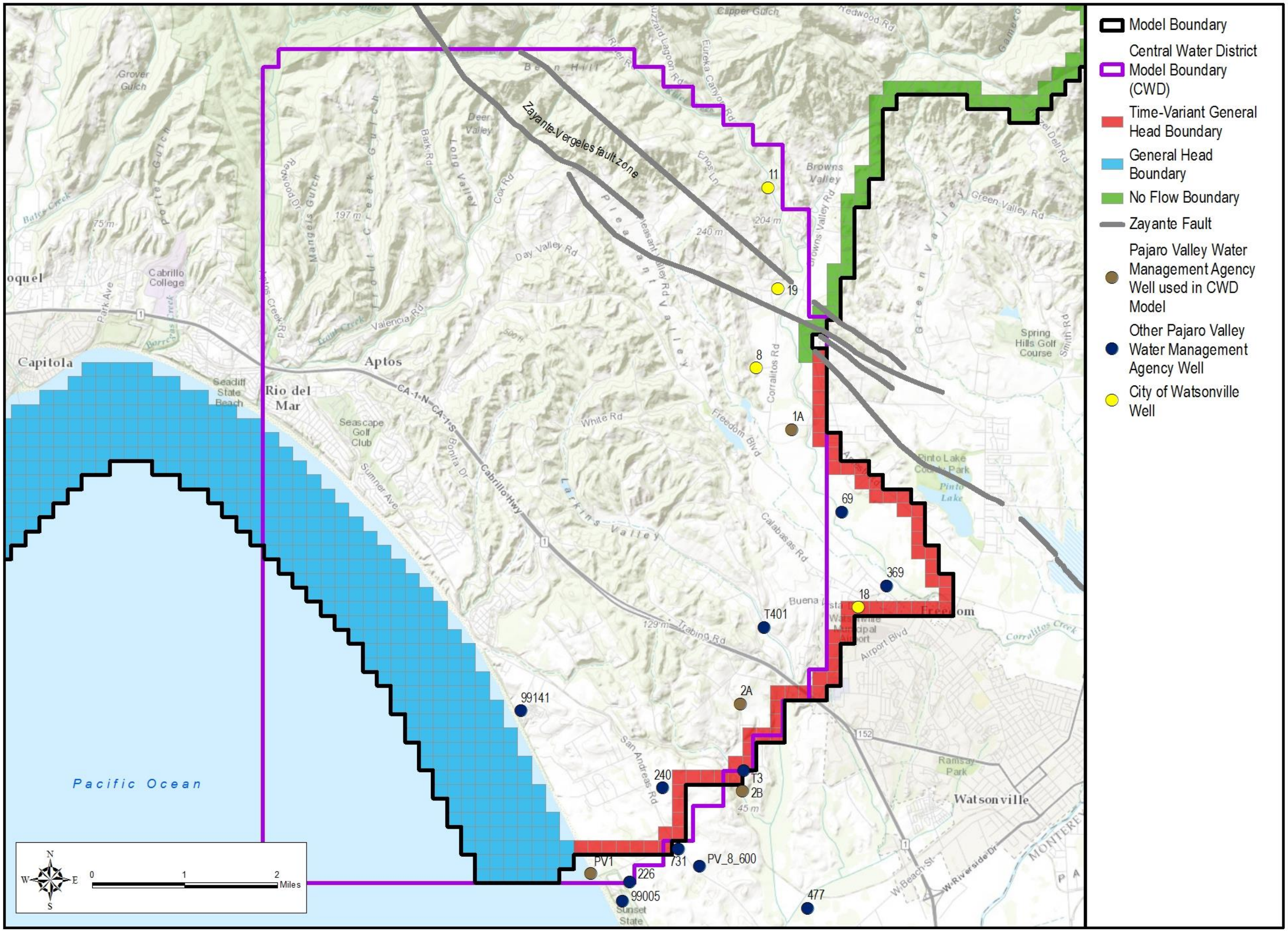

Figure 24: Southeastern Model Boundary

There may also be the need for boundary conditions in layer 9, the deepest active layer, to the west. As discussed in section 4.1, sediments in this layer west of the granitic high shown in Figure 4 may be more closely associated with the Santa Margarita basin and a boundary condition representing this association may need to be added. This will be evaluated as modeling proceeds.

6.0 NEXT STEPS

This memorandum will be reviewed by the model Technical Advisory Committee (TAC) and a meeting with the TAC and SAGMC member staff will be held by November 17, 2015 to discuss the memorandum and subsurface model construction. The next draft memorandums that will be produced are:

- A memorandum on estimates for non-agency water use and basinwide return flow (Task 2). This memorandum will be first reviewed by the SAGMC subcommittee on estimating private water use.
- A memorandum on construction of the PRMS watershed model (Task 2)

The above two memorandums will be provided to the TAC for review in advance of a meeting by early December 2015. Any necessary changes to the model setup based on TAC comments will be made and the model components discussed in the three memorandums will be integrated into a GSFLOW model. After integration, the following memorandums will mark project milestones.

- GSFLOW Integration (February 2016)
- Model Calibration (May 2016)
- Model Simulations of Groundwater Management Alternatives (July 2016)
- Integration of Seawater Interface Package and Seawater Intrusion Simulation (October 2016)

7.0 References

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Appendix A: List of Stratigraphic Unit Elevation Data

Well or Borehole	Elevation Interpolated from E-Log (feet above mean sea level)						
	Bottom Tu / top of Granite	Bottom TpAA	Bottom TpA	Bottom TpB	Bottom TpBC	Bottom TpD	Bottom TpDEF/F
Aptos Creek	--	--	--	--	--	-588.78	-423.78
Aptos School	--	--	--	--	--	--	--
Austrian Way	--	--	--	--	--	-365	-190
Cornwell	--	--	73	328	--	--	--
Estates	--	--	-845.7	-505.7	-370.7	-180.7	-10.7
Ledyard	--	--	--	-799.59	-659.59	-469.59	-299.59
Madeline	--	--	-897.92	-622.92	-487.92	-262.92	-117.92
Main St.	-614.5	-486.5	-116.5	--	--	--	--
Monte Toyon Test	--	--	--	--	-760	-580	-420
Opal #5 (Garnet)	--	-673	-208	2	--	--	--
Rosedale	--	--	--	2	132	--	--
T. Hopkins	--	--	--	--	--	-574.51	-404.51
Tannery	--	--	-486.48	-156.48	-61.48	--	--
O'Neill Test	-514	-409	11	256	--	--	--
SC-1A,B (Prospect)	--	--	-249.67	-40.67	--	--	--
SC-3A,B,C (Escalona)	--	--	-410	-180	-45	--	--
SC-5A,B,C,D,E (New Brighton)	--	--	-643	-388	-253	-73	87
SC-8A,B,C,D,E,F	--	--	--	-819.36	-689.36	-489.36	-324.36

Well or Borehole	Elevation Interpolated from E-Log (feet above mean sea level)						
	Bottom Tu / top of Granite	Bottom TpAA	Bottom TpA	Bottom TpB	Bottom TpBC	Bottom TpD	Bottom TpDEF/F
(Aptos Crk)							
SC-9A,B,C,D,E (Seacliff)	--	--	-887	-607	-462	-282	-122
SC-10AA,A (Cherryvale)	-568.75	-428.75	-88.75	--	--	--	--
SC-11A,B,C,D	-841	-835	-530	-250	-120	90	260
SC-12	--	--	--	-1432	-1312	-1077	-912
SC-18A	-614	-486	--	--	--	--	--
SC-18AA	-614	-486	--	--	--	--	--
SC-22 Tu	-632	-517	-177	--	--	--	--
Rosedale	--	--	-273	--	--	--	--
Foster-Gamble	--	--	--	-164	-36	162	322
Anderson	0	--	-50	--	--	--	--
65GHR	--	--	--	256	382	--	--
Auto Plaza Drive	--	--	-129	--	--	--	--
Axford Rd	-640	-480	-50	--	--	--	--
Beltz #4	--	--	-73	--	--	--	--
Beltz #6 (TH-3)	--	-538	-138	--	--	--	--
Beltz #7 (TH-2)	--	--	-112	--	--	--	--
Beltz #8 (TH-3)	--	-538	--	--	--	--	--
Beltz #9 (TH-1)	--	--	-160	--	--	--	--

Well or Borehole	Elevation Interpolated from E-Log (feet above mean sea level)						
	Bottom Tu / top of Granite	Bottom TpAA	Bottom TpA	Bottom TpB	Bottom TpBC	Bottom TpD	Bottom TpDEF/F
Coffey Lane	--	--	54	--	--	--	--
Beltz #12 Cory St	--	-415	10	--	--	--	--
Delaveaga Test	-25	15	--	--	--	--	--
Pleasure Pt A,B,C	--	--	-268.72	-58.72	--	--	--
SC TH-1 (57)	-581	-491	--	--	--	--	--
SC TH-2 (57)	-729	-676	--	--	--	--	--
SC TH-3 (57)	-119	-64	--	--	--	--	--
Thurber Lane Pump Sta	-246	-191	--	--	--	--	--
Thurber Lane (North)	-203	-158	--	--	--	--	--
Santa Margarita Test (TH-2)	-778	-683	-112	--	--	--	--
Soquel Point	--	--	-313	-63	--	--	--
Blake (O&G)	-2153	--	-2098	-1788	-1678	-1363	-1253
Carpenter (O&G)	-2748	--	-2613	-2188	-2078	-1778	-1678
J.H. Blake (O&G)	--	--	-2832	-2477	-2362	-2132	-1972
Light (O&G)	--	--	-2735	-2385	-2275	-2045	-1915
Pierce (O&G)	--	--	-2307	-2087	-1942	-1737	-1607
Leonardich (O&G)	--	--	--	-2645	-2530	-2300	-2165
Dicicco	--	--	--	-2470	-2340	-1950	-1820

Note: “-- “ indicates data for given stratigraphic interval is unavailable at that well or borehole

APPENDIX 2-E

SANTA CRUZ MID-COUNTY BASIN CONCEPTUAL MODEL UPDATE MEMORANDUM

1814 Franklin St, Suite 501
Oakland, CA 94612

TECHNICAL MEMORANDUM

To: Ron Duncan

From: Sean Culkin, Cameron Tana

Date: March 31, 2017

Subject: Santa Cruz Mid-County Basin Conceptual Model Update

1. Introduction

In November 2015, HydroMetrics Water Resources Inc. (HydroMetrics WRI) prepared the *Soquel-Aptos Groundwater Flow Model: Subsurface Construction (Task 3)* technical memorandum (HydroMetrics WRI, 2015). This memorandum documented the development of the conceptual model, the hydrostratigraphy, and the subsurface boundary conditions for the Santa Cruz Mid-County Basin (Mid-County Basin or the basin) groundwater-surface water model (the model). In August 2016, HydroMetrics WRI submitted the *Santa Cruz Mid-County Basin Groundwater Model Boundaries Update* technical memorandum (HydroMetrics WRI, 2016), which is an addendum to the initial conceptual model document. Since August 2016, HydroMetrics WRI has made progress calibrating the surface water and groundwater components of the model, and as developed an integrated groundwater-surface water model using the GSFLOW model code.

This document serves as an addendum to both previous memorandums, and summarizes additional recent changes to the model. Calibration efforts have yielded insights into groundwater elevation distribution and dynamics within the basin that were not satisfactorily represented by the previously-presented conceptual model. Therefore, the changes to the conceptual model documented here have been incorporated into the simulated hydrostratigraphy of the basin to allow for a more comprehensive calibration to basinwide groundwater elevations.

2. Conceptual Model Changes

This section describes two general conceptual model changes applied to the basin and the model.

2.1. Fault Distribution within the Basin

Previous descriptions of the basin include one major fault, the Zayante Fault, which roughly bisects the model domain along a northwest-southeast trending line (Figure 1). This fault divides all layers of the groundwater model, including layers representing the Aromas Formation, Purisima Formation, and the composite hydrostratigraphic unit between the base of the Purisima Formation and the granitic base of the basin (HydroMetrics WRI, 2015). Following basin boundary modification in 2016, the Zayante Fault is also currently the northern boundary of the Santa Cruz Mid-County Basin. North of the Zayante Fault, there are no groundwater elevation observation points that have been added to the model, and the hydrostratigraphy of the area is considered to be "undifferentiated." South of the Zayante Fault, groundwater level observations can be evaluated in each aquifer or aquitard layer, which are each simulated by individual model layers.

Within the basin, relatively high seasonal or annual average groundwater elevations of 100 feet or more above mean sea level (MSL) exist at observation well locations clustered south of the Zayante Fault. Farther south of the fault in coastal areas, average groundwater elevations are closer to MSL, or below MSL in cases where groundwater has been depressed by pumping wells. Additionally, lateral groundwater gradients are relatively flatter in coastal areas than inland areas. This trend results in an area of relatively steep lateral groundwater gradients approximately 1.5 miles south of the Zayante Fault, as shown in groundwater elevation maps produced for the previous Central Water District (CWD) model (Figure 2). This trend is especially prevalent in units of the Purisima Formation (model layers 3 through 7), but general trends of higher-to-lower groundwater elevations from inland to coastal areas is observed throughout the basin.

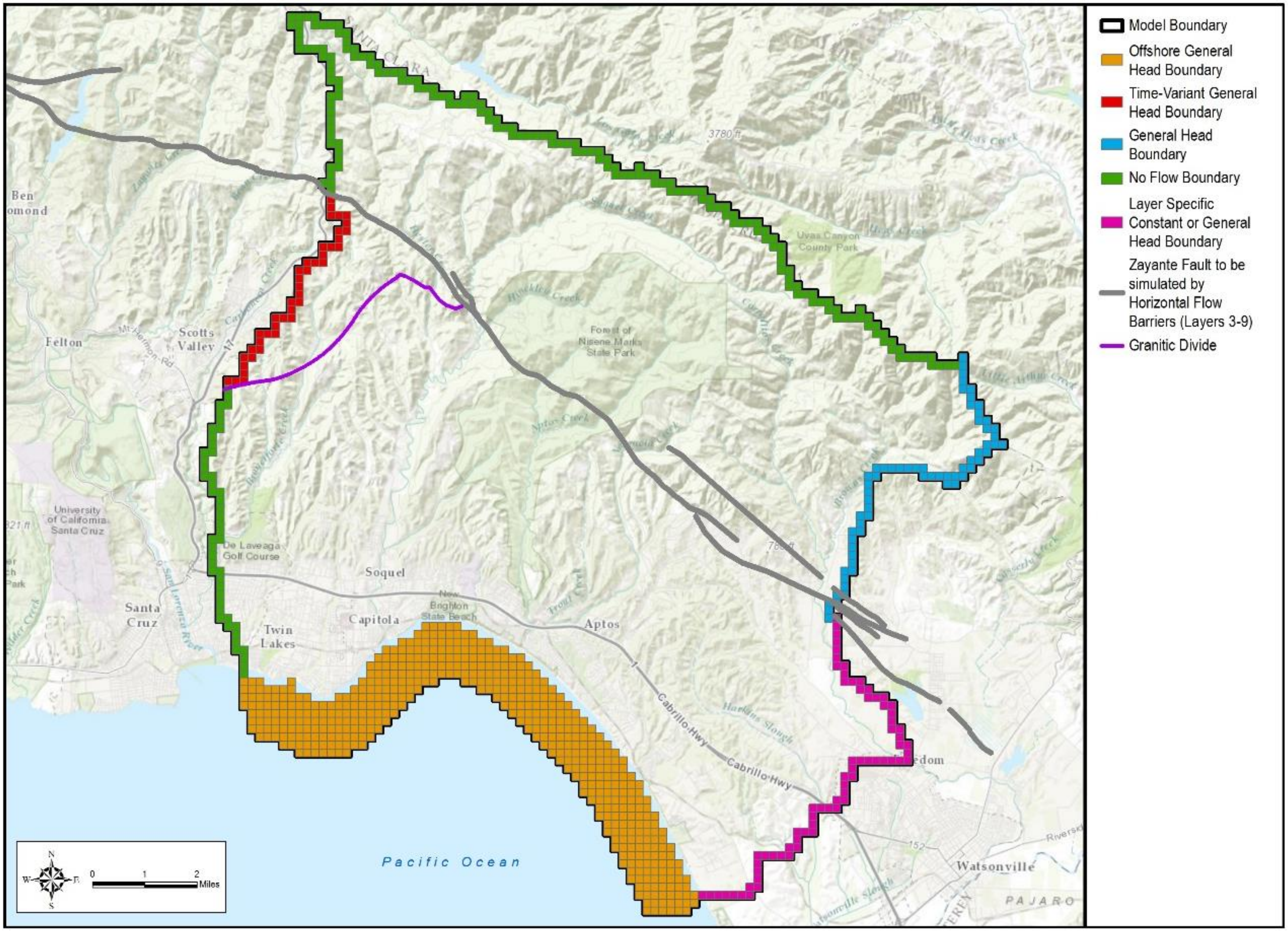

Figure 1: Summary of Model Domain Area and Boundaries (HydroMetrics WRI, 2015)

A similar area of steep lateral gradients was also evident in results from the groundwater model prepared for the CWD, documented in *Aromas and Purisima Basin Management Technical Study, Santa Cruz Integrated Regional Water Management Planning Grant Task 4* (HydroMetrics WRI, 2014). Figure 2 shows an example of simulated groundwater elevation contours in the Purisima formation with an area of steep groundwater gradient in the CWD service area south of the Zayante Fault. One step taken to achieve this simulated gradient in the calibration of the CWD model was to apply a relatively high range of hydraulic conductivity, where low conductivity areas result in steeper gradients by resisting lateral groundwater flow. Figure 3 shows the distribution of hydraulic conductivity values applied to the Purisima Formation in the CWD model, ranging over four to five orders of magnitude.

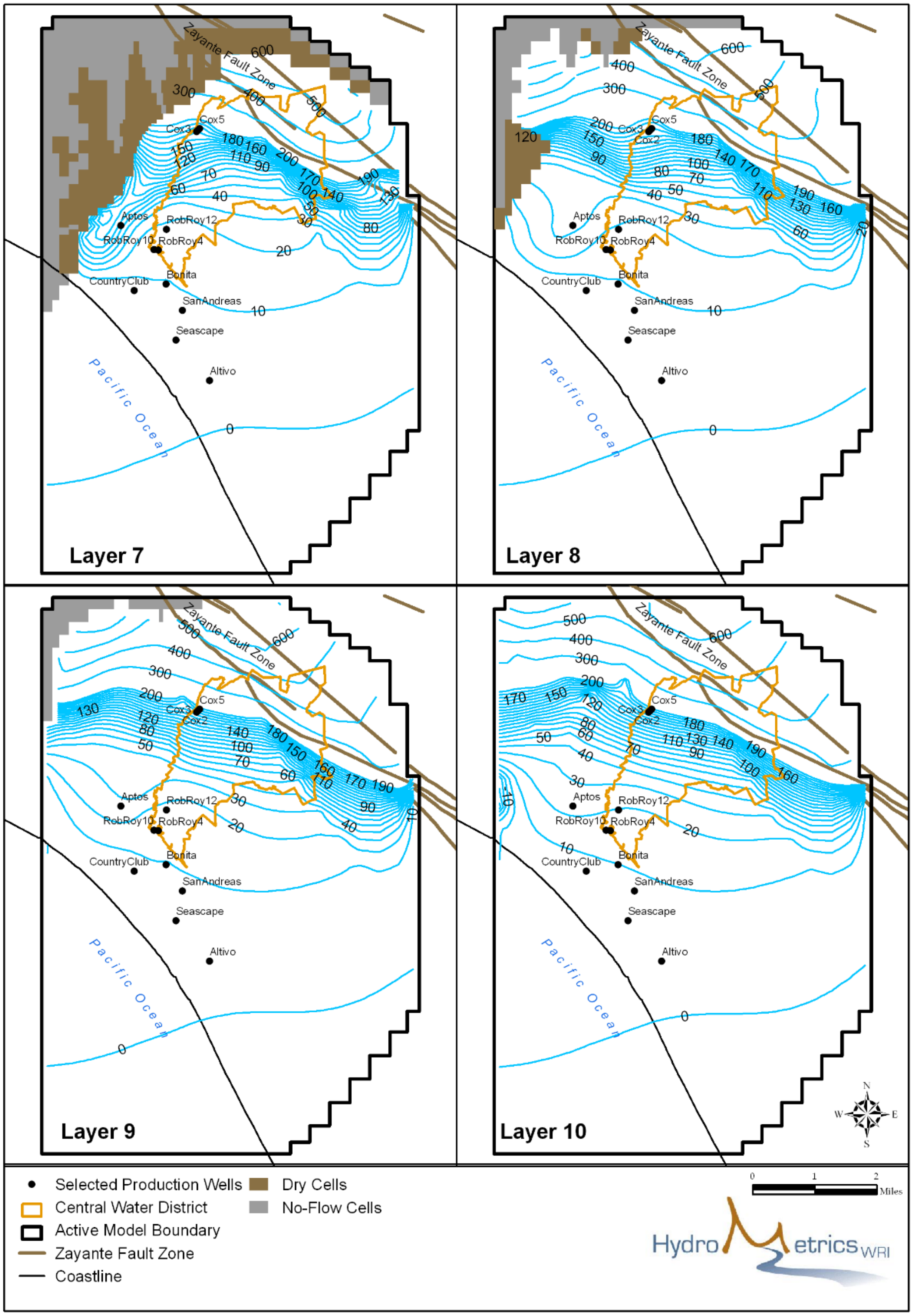

Figure 2: Simulated Groundwater Elevations (feet MSL) in Purisima Formation (HydroMetrics WRI, 2014)

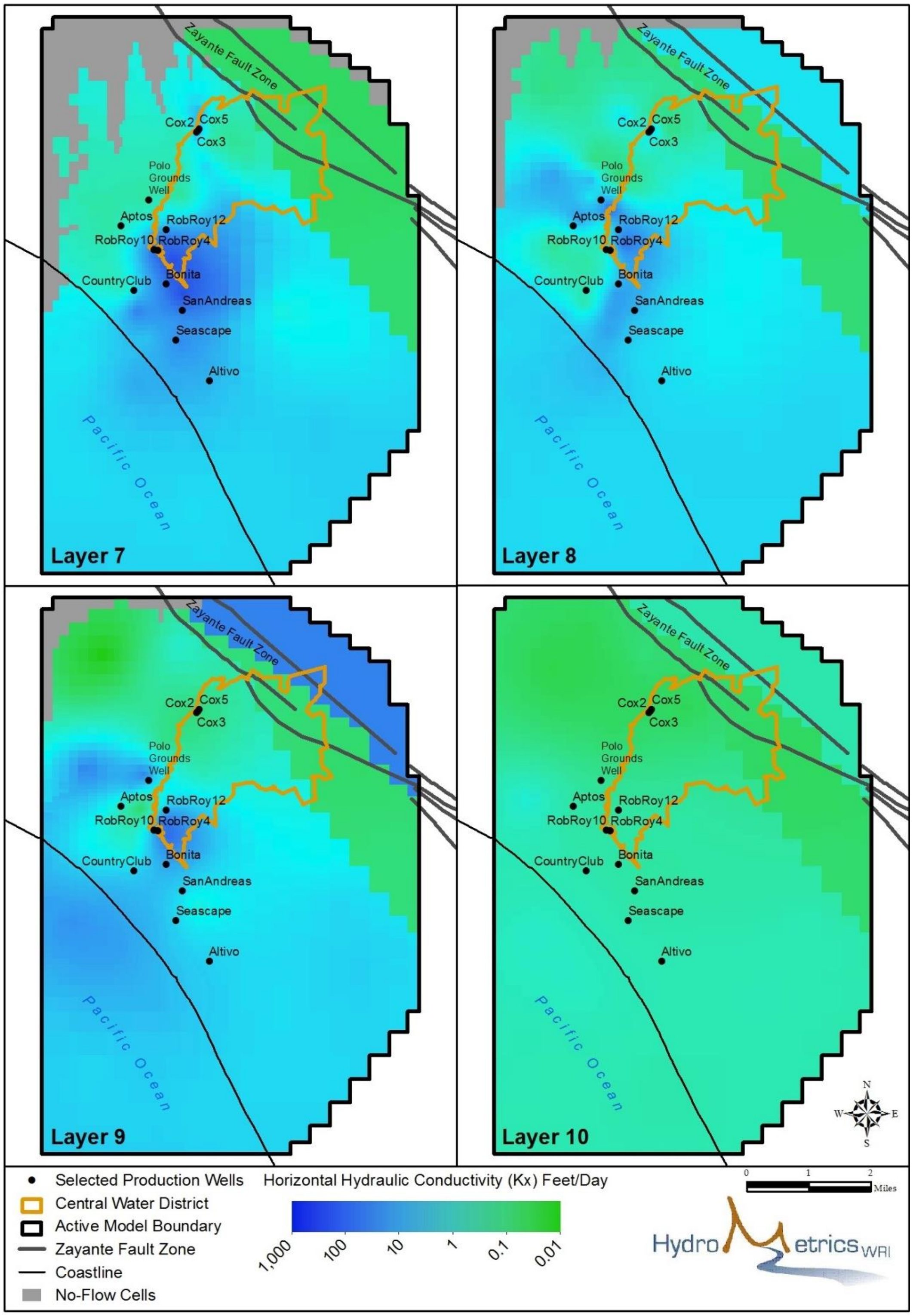

Figure 3: Horizontal Hydraulic Conductivity for Purisima Formation (HydroMetrics WRI, 2014)

To investigate alternatives to applying a large hydraulic conductivity range to simulated Purisima Formation layers within the Mid-County Basin model, HydroMetrics WRI investigated the potential for additional faulting in this area of the basin. Often, faulting can act as a barrier to groundwater flow due to lower conductivity clays within the fault, or by causing an abrupt change in formation conductivity across the fault. This can facilitate large changes in groundwater elevation on either side of the fault. Discussions with former Santa Cruz County geologist Mike Cloud led to our review of a U.S. Geological Survey (USGS) report of earthquakes and faults within the greater San Francisco Bay Area, including Santa Cruz county (USGS, 2004). This investigation indicates that, based on seismic activity in the area, there is evidence of some faulting south of the Zayante Fault within the domain of the Mid-County Model. HydroMetrics WRI has projected the location of the faults mapped by the USGS as shown in Figure 4. Although the mapped extent of this additional faulting is relatively limited in the USGS report, it generally corresponds with the area of steep groundwater gradients observed in the Mid-County Basin.

Academic thesis work performed in the 1950s has also yielded some evidence of additional faulting in this area of the basin. Alexander (1953) observed deformation of the marine terraces near Capitola between Aptos and Rio del Mar. This axis of deformation appears to have an east-west alignment similar to faulting found in the USGS report and inferred from regional groundwater elevation gradients.

Based on these studies and lines of evidence, HydroMetrics WRI added a second fault generally aligned with the data shown in the USGS report. This second fault is tentatively named the Aptos Fault. The simulated Aptos Fault is south of the Zayante Fault, and follows a similar northwest-southeast trend. For modeling purposes, the Aptos Fault extends through all Purisima Formation model layers, and extends from approximately the western outcrop of the Purisima Formation through the USGS-mapped fault zones. The location of the simulated fault in relation to the Zayante and USGS-mapped faults is shown in Figure 4.

Adding the Aptos Fault results in improved model fit to observed groundwater elevations north and south of the fault. HydroMetrics WRI will maintain this hydraulic flow barrier within the model domain through calibration of the model; the final conductance, position, and extent of the simulated fault will be presented in the report of final model calibration. We believe that based on the evidence available, a hydraulic flow barrier is preferable and more consistent with regional geology than assigning other hydraulic parameters such as hydraulic conductivity to achieve model calibration.

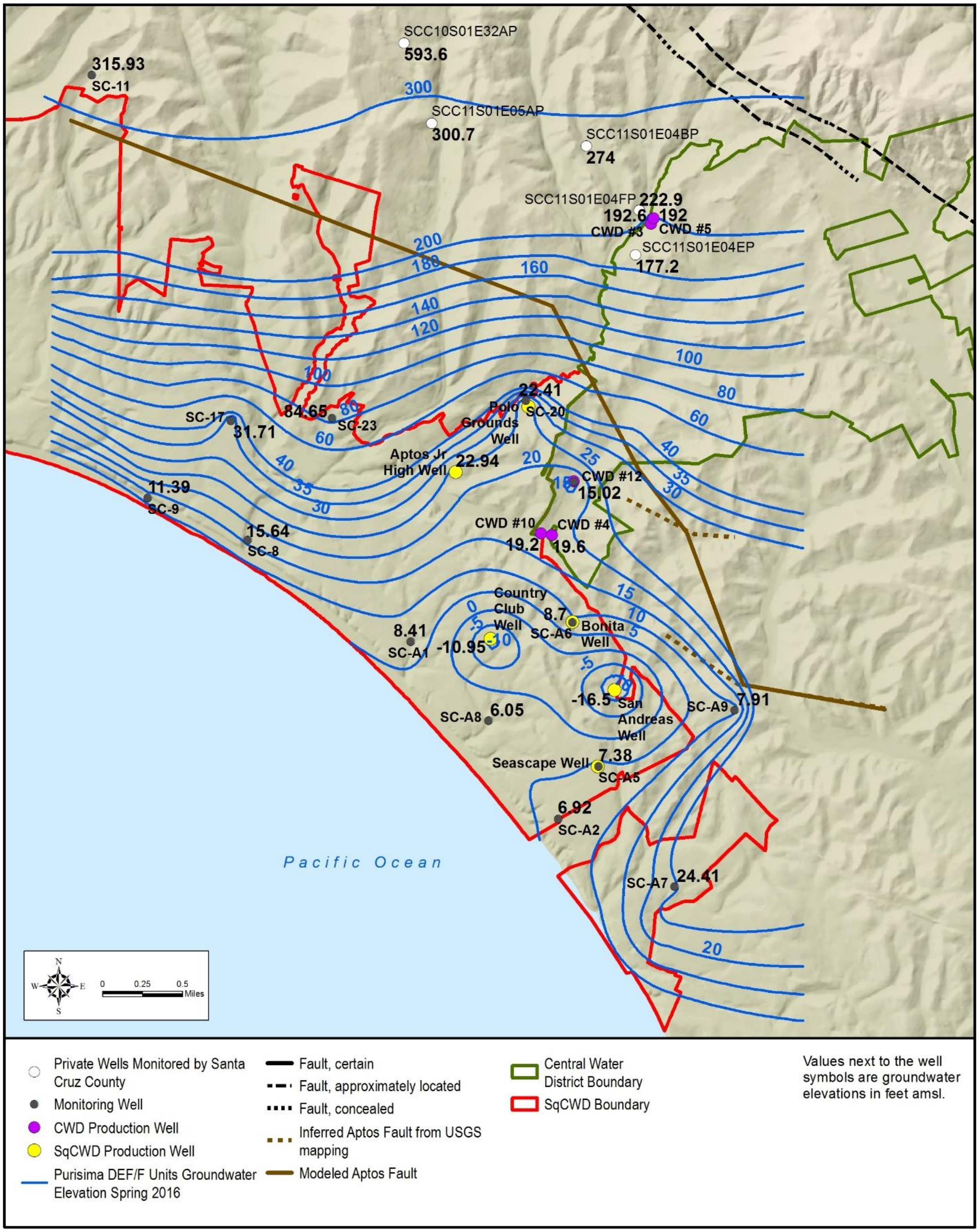

Figure 4: Faulting and Groundwater Elevations in the Aptos Area of the Santa Cruz Mid-County Basin

2.2. Pajaro Area Boundary Condition

The Mid-County Basin model contains a general head boundary (GHB) north of the Zayante Fault along the eastern boundary of the model domain near the service area of Pajaro Valley Water Management Agency (PVWMA; see blue line on Figure 1). This boundary is intended to allow an outlet for groundwater to flow east out of Mid-County Basin into the Pajaro Basin per the conceptual model of the shared boundary area (HydroMetrics WRI, 2015).

Few groundwater monitoring locations or estimates of groundwater elevation north of the Zayante Fault are available. However, through calibration we determined that assigning a relatively low general head value to this GHB boundary as described in the previous memo resulted in simulated heads north of the fault that are too low to maintain the relatively high heads observed south of the Zayante fault in the Purisima Formation. Reviewing the CWD model boundary conditions indicates that constant head conditions were applied to that model north of the Zayante Fault corresponding with Ryder Gulch (Figure 5). The head values applied to this boundary condition in the CWD model are relatively high, and exceed 200 feet MSL, corresponding with the relatively high elevation of discharging streams in this area.

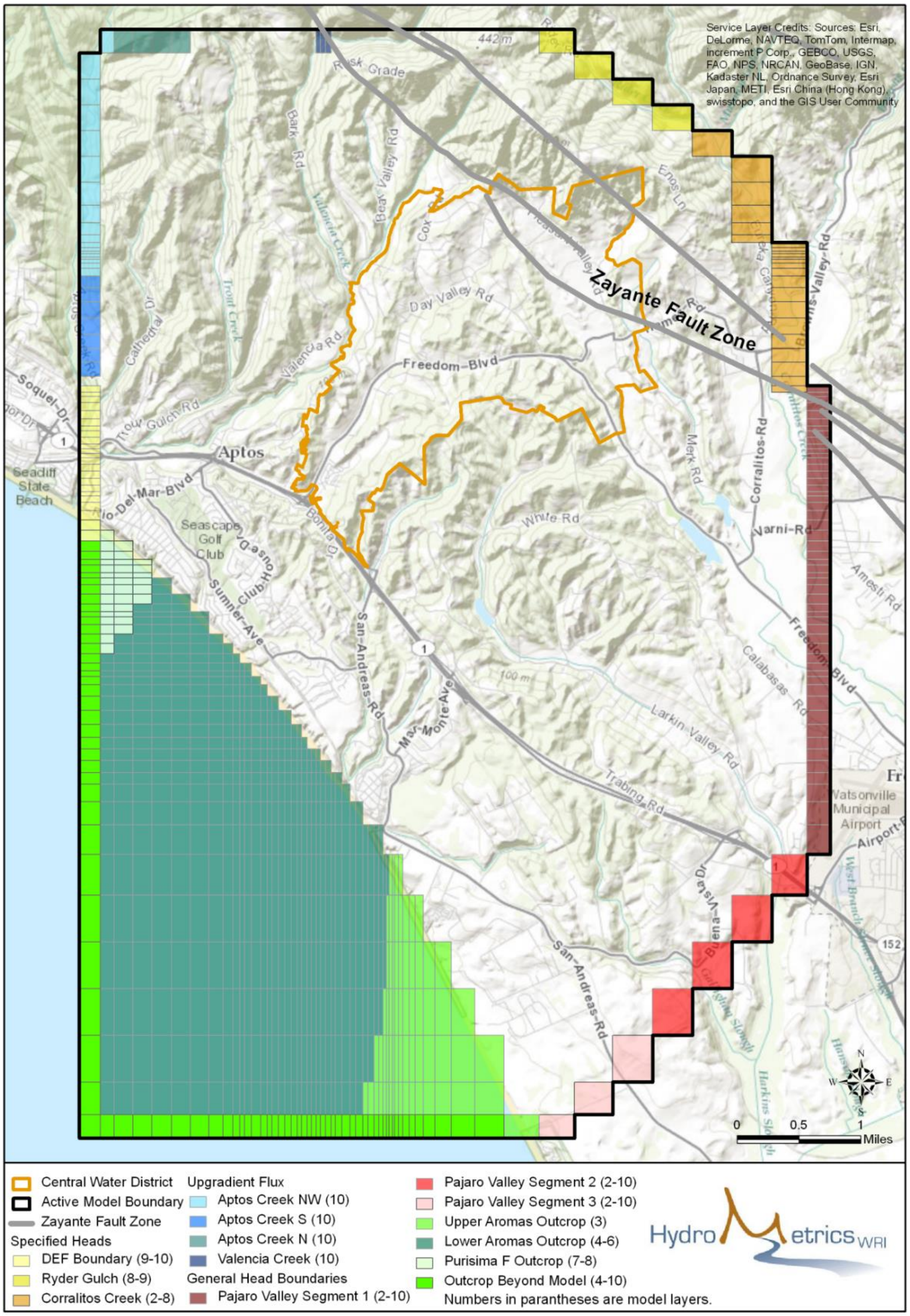

Figure 5: CWD Model Boundary Conditions (HydroMetrics WRI, 2014)

The GHB boundary of the Mid-County model has been updated to reflect higher general heads, consistent with previous modeling efforts. This has resulted in a more reasonable simulated groundwater elevation change across the Zayante Fault and has contributed to more accurately represented groundwater elevations at observation points south of the Zayante Fault. The final configuration of this boundary that results in the best fit to observed data will be presented following final calibration.

3. References

Alexander, C.S., 1953. The marine and stream terraces of the Capitola-Watsonville area. University of California Publications in Geography, v.10, p. 144.

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APPENDIX 2-F
SANTA CRUZ MID-COUNTY BASIN MODEL INTEGRATION AND CALIBRATION

September 6, 2019

Santa Cruz Mid-County Basin Model Integration and Calibration

SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY

GSP REVIEW DRAFT

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1 BACKGROUND

This report documents the calibration of the integrated surface water-groundwater model ("the model") of the Santa Cruz Mid-County Basin ("the Basin"). It also documents the linkages between the surface and groundwater processes within the model. The model simulates groundwater and surface water processes for a calibration period from Water Year 1984 through 2015, and will be used to project future Basin conditions to evaluate water management scenarios. These scenarios will support groundwater management alternatives for the Santa Cruz Mid-County Groundwater Agency (MGA), Pure Water Soquel (PWS) advanced purified groundwater replenishment, City of Santa Cruz aquifer storage and recovery (ASR) projects, and other water supply alternatives. This report follows and builds upon previous model documentation regarding conceptual model development and model input development referenced throughout the report.

The MGA provided funding for most of the model development, including calibration, but some tasks documented in this report were funded by Santa Cruz County's Prop 1 grant for counties with stressed basins. The tasks funded by the County's grant are identified in the report.

2 MODEL SOFTWARE SUMMARY

As documented in previous memoranda (HydroMetrics WRI, 2015; HydroMetrics WRI, 2016a), the model is built using the U.S. Geological Survey's (USGS) GSFLOW software, which is an integrated watershed-groundwater model (Makstrom *et al.*, 2008). USGS release 1.2.2 (Regan *et al.*, 2018) is used for the model. Figure 1 summarizes the relationship between groundwater and surface water processes implemented within GSFLOW. GSFLOW integrates the Precipitation-Runoff Modeling System (PRMS) watershed model code (Leavesley *et al.*, 1983) with the MODFLOW groundwater model code. PRMS simulates watershed flows (Region 1 on Figure 1), while MODFLOW simulates flow beneath the base of the soil zone within the three-dimensional aquifer system (Region 3). The MODFLOW Streamflow-Routing (SFR) package simulates flows in streams (Region 2).

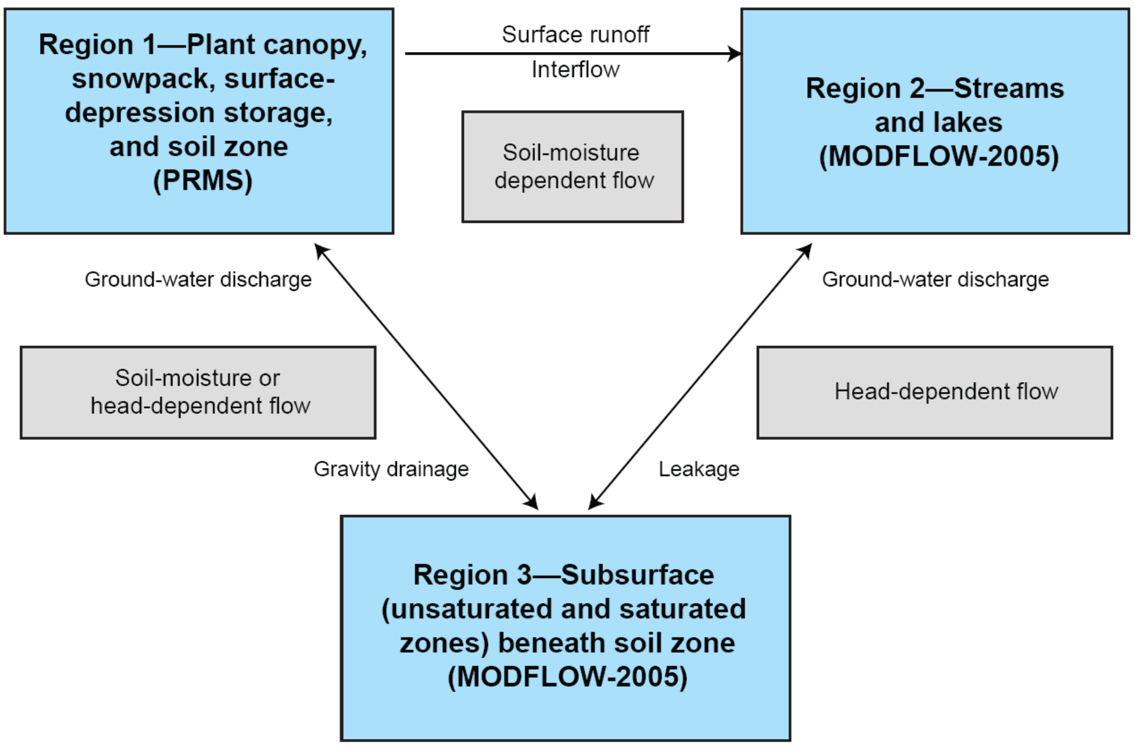
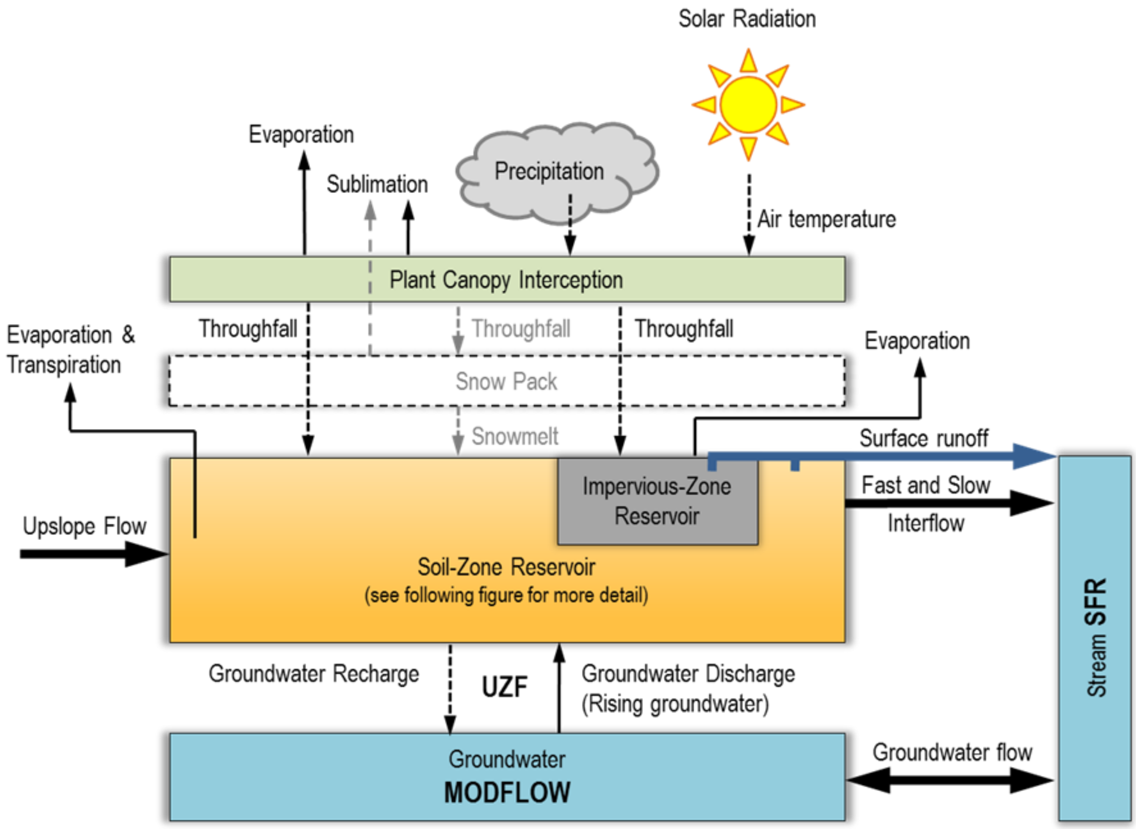


Figure 1. Diagram of Flow Exchange within GSFLOW Calculations Processes (Markstrom et. al., 2008)

Figure 2 provides more detail about watershed flows simulated by PRMS and the flows that integrate PRMS and MODFLOW in GSFLOW. PRMS uses climate inputs of precipitation and temperature, and simulates evapotranspiration, runoff and infiltration.

Figure 3 shows the different flow types in the soil-zone reservoir that are associated with parameters requiring calibration. The MODFLOW Unsaturated-Zone Flow (UZF) package is required to simulate groundwater recharge and discharge between the soil zone and the groundwater table. The MODFLOW SFR package receives runoff from PRMS and also calculates flows between streams and groundwater.



Elements and text in light gray are part of GSFLOW but were not used in the model

Figure 2. Summary of Watershed and Climate Inputs for GSFLOW

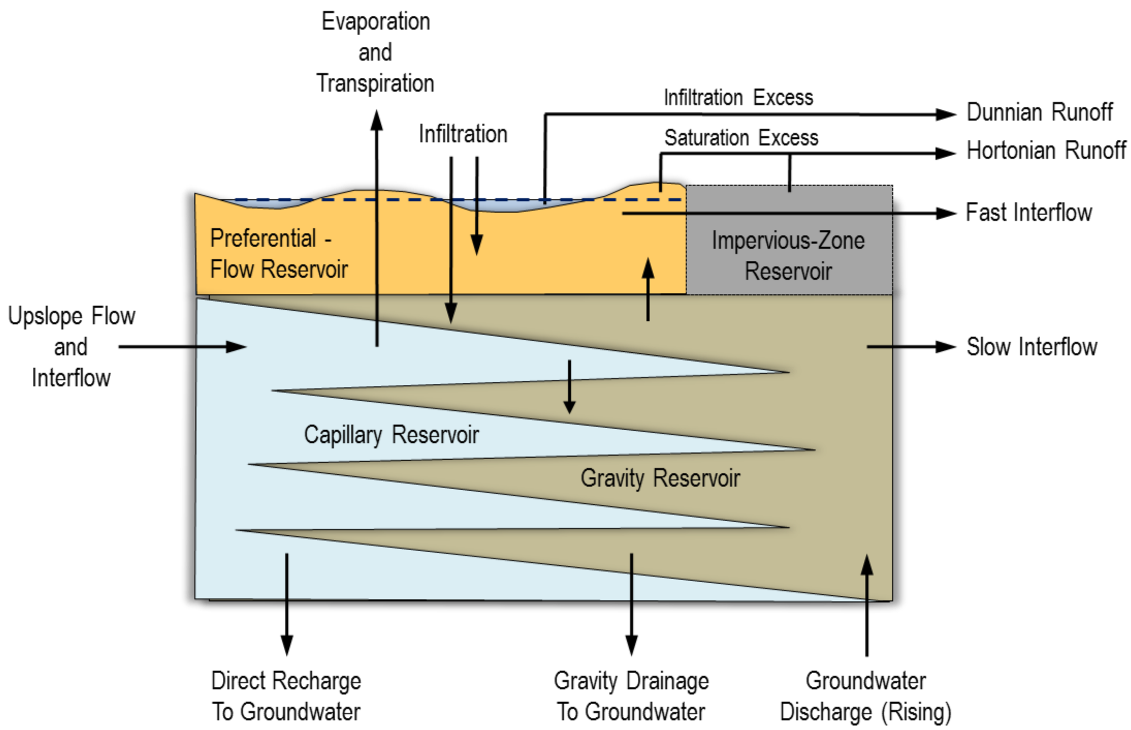


Figure 3. Soil-Zone Reservoirs Inflows and Outflows

3 MODEL CONSTRUCTION

This section summarizes the construction of the Santa Cruz Mid-County Basin groundwater-surface water model ("the model").

3.1 Model Domain

As described in the *Santa Cruz Mid-County Basin Groundwater Flow Model: Precipitation-Runoff Modeling System Setup (Task 2)* memorandum (HydroMetrics WRI, 2016), the model domain covers the watershed area that potentially contributes flow to the stacked aquifer units of the Santa Cruz Mid-County Basin. This includes the Basin area along with portions of adjacent basins including the Santa Margarita Basin, the Purisima Highlands Subbasin, and the Pajaro Valley Subbasin (Figure 4). The western boundary of the model domain is the boundary of the Carbonara Creek and Branciforte Creek watersheds, which approximates the westernmost outcrop of the major aquifers in the Santa Cruz Mid-County Basin. The northern watershed boundary of the model approximately follows Summit Road and Loma Prieta Avenue for a distance of about 17 miles along a northwest to southeast alignment. The eastern boundary of the model follows the eastern boundary of the Corralitos Creek watershed. This boundary is farther east than necessary for encompassing the entire area that likely contributes flow to the Santa Cruz Mid-County Basin; but using this boundary allows the model to include the Corralitos Creek stream gauge at Freedom (Figure 5) which is the only active gauge on Corralitos Creek.

The southern boundary of the model extends approximately one mile offshore, parallel to the coastline. This allows for contact of outcropping Purisima and Aromas Formation units with the seafloor that serves as a density corrected head boundary condition and a potential source of seawater intrusion. The one mile offshore length is also longer than the cross-sectional models that were originally designed to evaluate protective groundwater elevations. Offshore distances of up to 3,500 feet ensured that the simulated freshwater-salt water interface did not intersect the end of the model (HydroMetrics LLC, 2009)

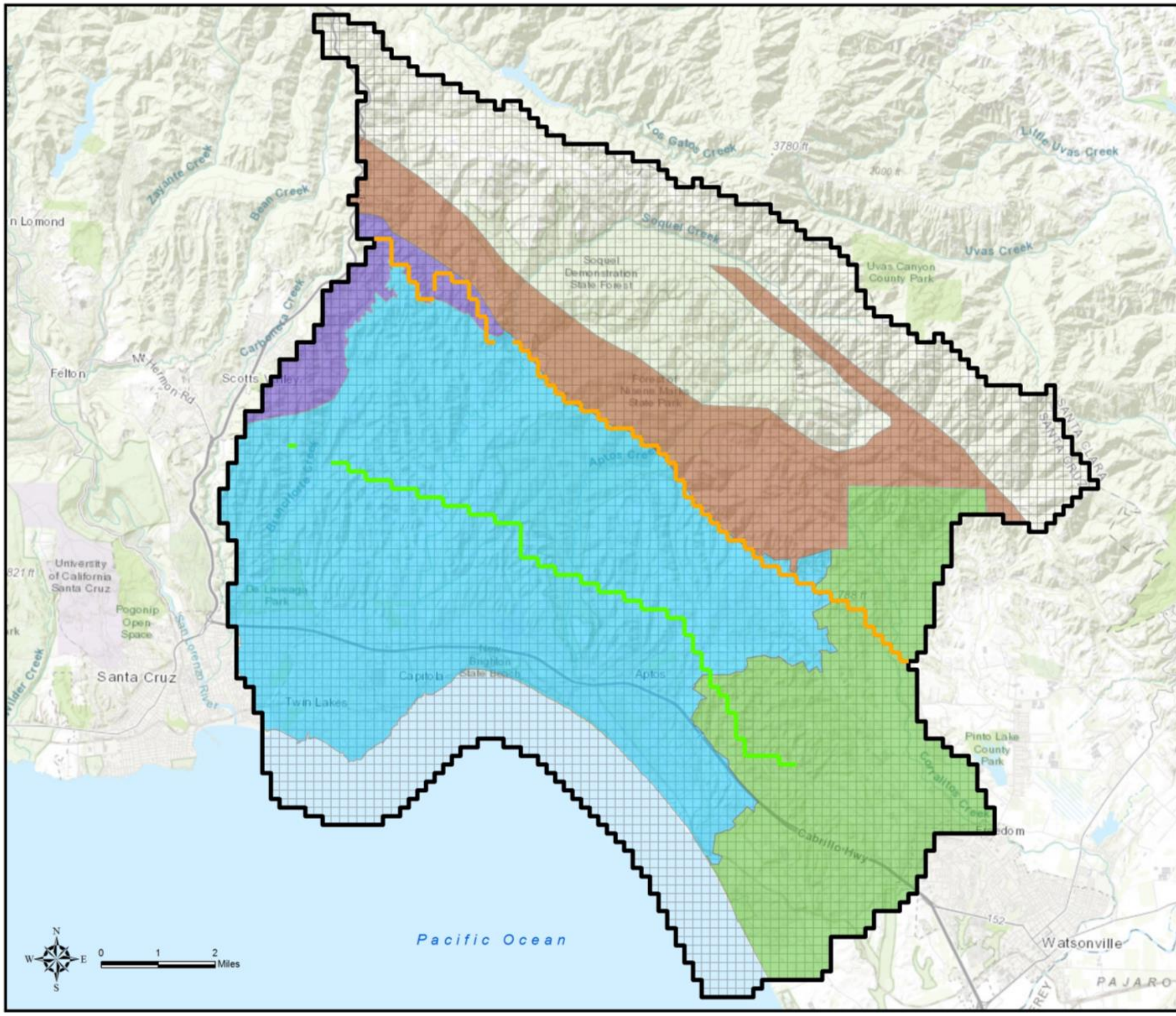


Figure 4. Model Domain, Santa Cruz Mid-County Basin and Adjacent Basin

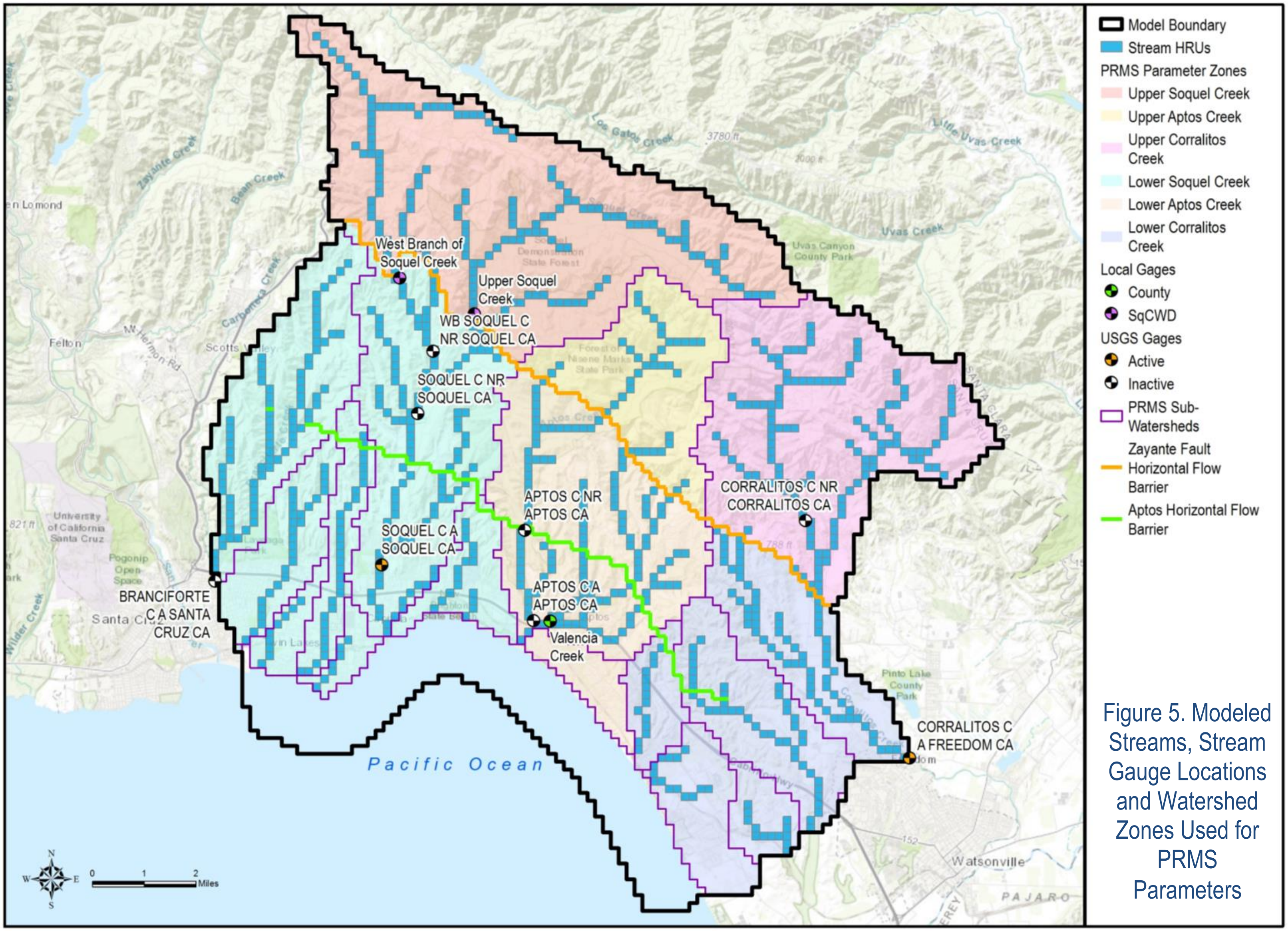


Figure 5. Modeled Streams, Stream Gauge Locations and Watershed Zones Used for PRMS Parameters

3.2 Model Discretization

Both the MODFLOW portion and the PRMS portion of GSFLOW must be discretized. As described previously (HydroMetrics WRI, 2016a), PRMS requires that the model area be divided into discrete units that are assigned physical characteristics such as slope, aspect, elevation, vegetation type, soil type, land use, and precipitation. These units are called hydrologic response units (HRU). Daily water and energy balances are calculated for each HRU, and the sum of these area weighted responses for all HRUs results in the daily watershed response for the model area.

The US Geological Survey recommends that the discretization of PRMS HRUs match the discretization of MODFLOW model cells. Therefore, the model has been discretized into a uniform rectilinear grid of 800 by 800 foot HRUs that overlay a groundwater model grid including 135 rows and 105 columns of cells with the same dimensions. A grid size of 800 feet is the largest grid size that best preserved finer scale elevation distributions across the study area (HydroMetrics WRI, 2016a).

Figure 5 illustrates how stream reaches were assigned to model HRUs and the MODFLOW SFR package.

3.3 Model Layering

The layering of the MODFLOW model follows the conceptual model of stacked aquifer units in the Basin described in previous documents, notably the *Soquel-Aptos Groundwater Flow Model: Subsurface Model Construction (Task 3)* technical memorandum (HydroMetrics WRI, 2015). This conceptual model draws heavily on work by Johnson *et al.* in the *Technical Memorandum 2: Hydrogeologic Conceptual Model* (2004), as well as input from former Santa Cruz County geologist, Mike Cloud.

Model layers 2 through 9 represent the stacked hydrostratigraphic units of the Santa Cruz Mid-County Basin. Model layer 2 primarily represents the Aromas Red Sands Formation. Model layers 3-8 primarily represent aquifer and aquitard units of the Purisima Formation. Model layer 9 represents the unit underlying the Purisima Formation, referred to by Johnson *et al.* (2004) as the Tu unit. Table 1 shows the relationship between model layers and hydrostratigraphic units. Plate 1 shows thicknesses of model layers for aquifer units and Figure 6 shows thicknesses of model layers for aquitard units. These figures also illustrate how the model layer outcrops pinch out to the west.

Stream alluvium and Terrace Deposits are represented in model layers 1-8 overlying the layers of the aquifer and aquitard units where they outcrop.

Table 1. Model Layers and Hydrostratigraphic Units

Model Layers	Hydrostratigraphic Unit	Aquifer/Aquitard
1-8	Stream Alluvium	N/A
1-8	Terrace Deposits	N/A
2	Aromas Red Sands	Aquifer
3	Purisima F and DEF	Aquifer
4	Purisima D	Aquitard
5	Purisima BC	Aquifer
6	Purisima B	Aquitard
7	Purisima A	Aquifer
8	Purisima AA	Aquifer
9	Tu	Aquifer

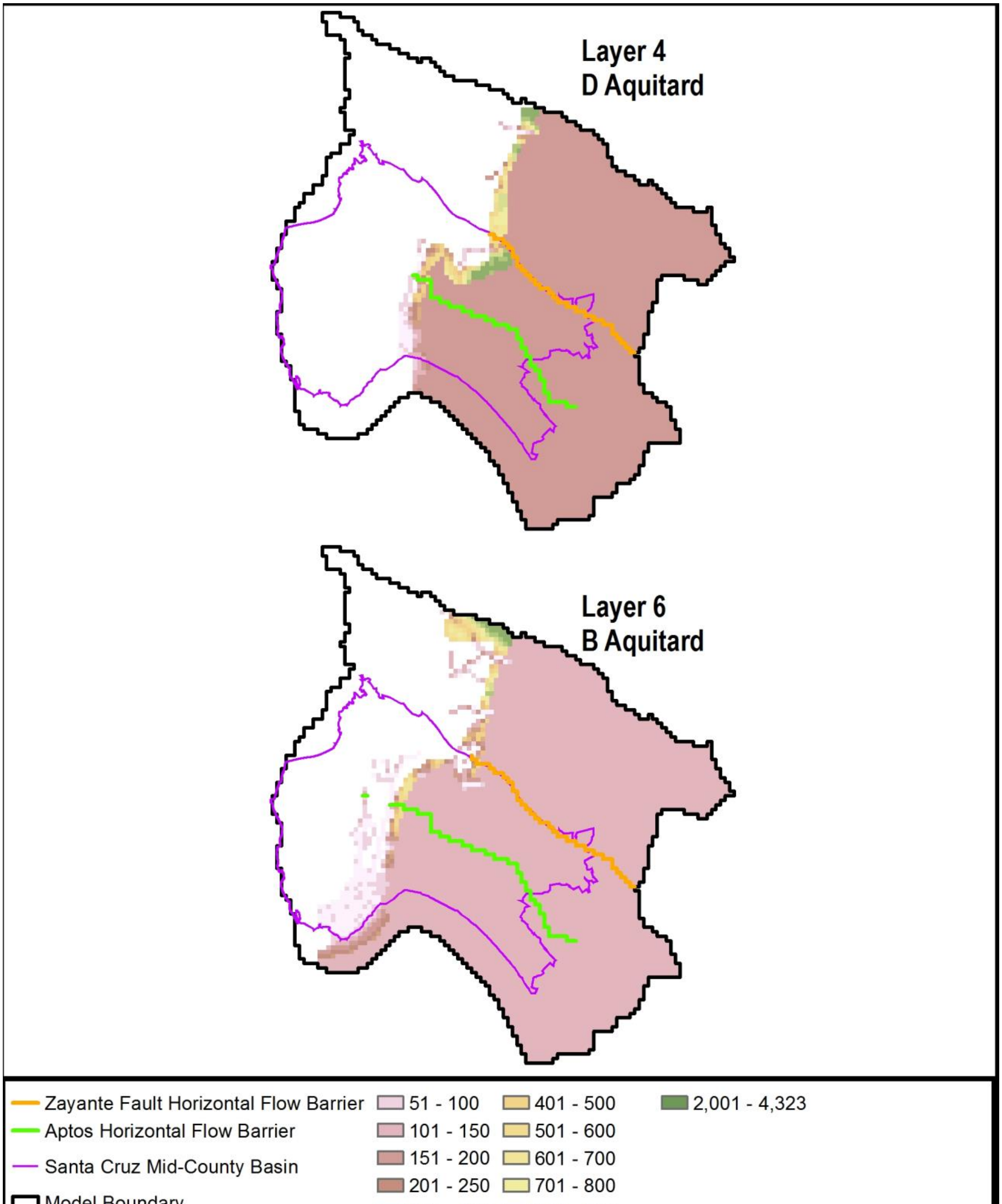


Figure 6. Model Layer Thicknesses of Aquitard Units

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3.4 PRMS Modules Used to Calculate Watershed Flows

PRMS uses different modules to simulate various water and energy processes in the watershed. The modules selected for the Santa Cruz Mid-County Basin GSFLOW model were based on the availability of data and appropriateness for local conditions. Modules used are summarized in Table 2.

Table 2: PRMS Modules used to Calculate Watershed Flows in Santa Cruz Mid-County Basin GSFLOW Model

Module Name	Module Description
basin	Defines shared watershed-wide and HRU physical parameters and variables
cascade	Determines computational order of the HRUs and groundwater reservoirs for routing flow downslope
soltab	Computes potential solar radiation and sunlight hours for each HRU for each day of the year
temp_laps	Distributes maximum and minimum temperatures to each HRU using temperature data measured at least two temperature stations at different elevations, based on an estimated lapse rate between pairs of stations
precip_1sta	Determines the form of precipitation and distributes it to each HRU using on the basis of a measured value of precipitation and parameters used to account for elevation, spatial variation, topography, gauge location, and deficiencies in gauge catch
ddsolrad	Distributes solar radiation to each HRU and estimates missing solar radiation data using a maximum temperature per degree-day relation
transp_tindex	Computes transpiration using a temperature index that is the cumulative sum of daily maximum temperature for each HRU after the model reaches the transpiration starting month. The period of transpiration for each HRU ends when the simulation reaches the month specified
potet_pt	Computes the potential evapotranspiration by using the Priestley-Taylor formulation (Priestley and Taylor, 1972). Revised formulation in GSFLOW 1.2.2 (Regan *et al.*, 2018) used instead of Jensen-Haise formulation used in previous versions of the Basin model because Priestley-Taylor more appropriate for hotter temperatures of future climate scenarios (Milly and Dunne, 2011)
intcp	Computes volume of intercepted precipitation, evaporation from intercepted precipitation, and throughfall that reaches the soil or snowpack
srunoff_smidx	Computes surface runoff and infiltration for each HRU using a non-linear variable-source-area method allowing for cascading flow
soilzone	Computes inflows to and outflows from soil zone of each HRU and includes inflows from infiltration, groundwater, and upslope HRUs, and outflows to gravity drainage, interflow, and surface runoff to downslope HRUs

3.5 MODFLOW Packages Used to Calculate Groundwater Flows

MODFLOW uses modular packages for simulating different aspects of groundwater flow. The MODFLOW packages selected for the Santa Cruz Mid-County Basin GSFLOW model were based on GSFLOW requirements and consistency with the conceptual model for the Basin.

Table 3. MODFLOW Packages used to Calculate Groundwater Flows in Santa Cruz Mid-County Basin GSFLOW Model

Package Name	Package Input Use
Basic (BAS)	Defines active cells and initial heads
Discretization (DIS)	Defines model discretization and layer elevations
Upstream Weighted Flows (UPW)	Defines groundwater flow parameters
Newton-Raphson Solver (NWT)	Defines numerical solver settings
Multi-Node Well (MNW2)	Defines pumping and recharge by well and package calculates well flows by layer
Stream Flow Routing (SFR)	Defines stream routing and package calculates stream flows based on runoff and groundwater interaction
Time-Variant Specified Head (CHD)	Defines transient specified heads
General Head Boundary (GHB)	Defines head dependent boundaries with associated conductance
Horizontal Flow Barrier (HFB)	Defines low conductance resulting from Zayante Fault and faulting in Aptos area
Unsaturated Zone Flow (UZF)	Defines parameters from flow from soil zone to groundwater

3.5.1 Specified Head Boundary Condition Assignment (CHD)

Specified head boundary conditions were used to simulate the interaction between the Santa Cruz Mid-County Basin and the adjacent Pajaro Valley. HydroMetrics WRI (2015) described how head values for the Constant Head (CHD) package were assigned to layers 2 and 3, representing the Aromas Red Sands and Purisima F and DEF units, along the boundary with the Pajaro Valley Subbasin south of the Zayante Fault. This boundary does not represent a naturally-occurring hydraulic barrier. Transient specified heads were based on available PVWMA groundwater level data, with added seasonal variation. This was the same approach used to develop a similar boundary condition for the Central Water District (CWD) groundwater model (HydroMetrics WRI and Kennedy Jenks, 2014). Plate 2 shows average specified heads for this boundary condition.

3.5.2 General Head Boundary (GHB) Condition Head Assignment

General head boundaries (GHB) simulate flows between the Basin and the ocean, flows between the model and the adjacent Santa Margarita Basin, and flows between the model and the adjacent Pajaro Valley Subbasin. Plate 2 shows the location of the GHB cells in different model layers. GHB conditions are assigned along the western model boundary in the following locations:

- The western model boundary in the Santa Margarita Basin;
- The eastern boundary in the Pajaro Valley Subbasin north of the Zayante Fault;
- The southeastern boundary in the Pajaro Valley Subbasin south of the Zayante Fault for layers 5, 7, and 8 representing Purisima BC, A, and AA aquifer units;
- The offshore model boundary; and
- Offshore cells within the model domain where model layers outcrop below Monterey Bay.

Heads assigned to the western boundary in the Santa Margarita Basin are based on long-term groundwater level trend data from Scotts Valley Water District wells as described in HydroMetrics WRI (2016b). Heads assigned to the eastern boundary north of the Zayante Fault are based on groundwater level used in the CWD model corresponding with the relatively high elevation of discharging streams in the Ryder Gulch watershed as described in HydroMetrics WRI (2017a).

Heads for the southeastern boundary condition in the Purisima BC, A, and AA aquifer units are based on the head of the nearest offshore general head boundary cell. There are little available data in these deeper units and limited pumping or other stress in the Pajaro Valley Subbasin. Therefore, the heads reflect the nearest boundary condition of Monterey Bay.

Heads assigned for the offshore boundary condition at the edge of the model assume that groundwater is fully saline one mile offshore. The heads therefore are the density corrected freshwater equivalent heads based on the average depth below sea level of the model cell.

The heads assigned for the general head boundary condition where model cells outcrop are based on the saline water of Monterey Bay overlying the outcrop. The heads therefore are the density corrected freshwater equivalent heads based on the depth below sea level of the top of the model cell. Plate 2 shows heads assigned to the general head boundaries by layer.

3.5.3 Horizontal Flow Barriers (HFBs) for Faulting

Horizontal flow barrier boundaries represent faulting that reduce horizontal groundwater flow. The Zayante Fault is well mapped on geologic maps and defines the northern boundary of the Basin. Less well mapped is faulting in the Aptos area, but as discussed in HydroMetrics WRI (2017a), evidence of faulting south of the Zayante Fault and steep groundwater gradients support the implementation of a horizontal flow barrier through the Aptos area as shown on Plate 2.

3.5.4 Unsaturated-Zone Flow (UZF)

GSFLOW requires use of the MODFLOW UZF package, which simulates groundwater flow within the unsaturated zone (Hughes *et al.*, 2012). However, the version of the calibrated model presented herein does not explicitly simulate unsaturated zone flow. The infiltration to groundwater as calculated by GSFLOW is applied directly to the saturated zone of the groundwater flow domain. Observations made during calibration, as well as investigations of the connectivity of shallow and deep groundwater within the Basin (HydroMetrics WRI, 2017b), indicated that there was sufficient disconnect between unsaturated parts of the groundwater model, such as stream alluvium and Terrace Deposits, and the productive groundwater aquifers of the Aromas Red Sands, Purisima, and Tu units such that simulating unsaturated flow is not critical for achieving acceptable calibration. Removing unsaturated zone flow from the model process also significantly reduces computational time and resources, which was beneficial to the calibration process requiring large numbers of model runs.

The US Geological Survey also modified the UZF package to allow specification of return flow to be added to the subsurface below the soil zone, which is applied directly the saturated zone for the calibrated model. This was a critical modification for simulating septic return flows. This modification is available in GSFLOW release 1.2.2 (Regan *et al*., 2018).

4 MODEL INPUT DATA

This section describes the hydrologic and geologic data used in the model calibration process.

4.1 Precipitation and Recharge

Recharge to the groundwater portion of the model is controlled by processes within GSFLOW as summarized in Figure 2 and Figure 3, as well as the GSFLOW documentation (Markstrom *et al*., 2008).

Precipitation is spatially distributed across the GSFLOW model domain using the precip_1sta module in PRMS. This module uses a combination of spatial and temporal data is used from DAYMET, a database of gridded daily weather parameters for North America. Using this module, DAYMET's mean monthly precipitation distributions (Thornton *et al*., 1997; Thornton *et al*., 2014) are used to spatially distribute daily precipitation values observed at the National Weather Service (NWS) Santa Cruz Cooperative Observer Network (COOP) and Watsonville Water Works weather stations to the model HRUs. Figure 7 illustrates the spatial distribution of DAYMET mean annual precipitation across the model domain, and also shows the areas where simulated rainfall is based on daily values at the Watsonville Water Works station or the Santa Cruz station.

Temperature is spatially distributed across the GSFLOW model domain using the temp_laps module in PRMS. This module assigns temperature data to different elevations. Observed daily minimum and maximum temperatures from the Santa Cruz Co-op station are used for a lower elevation station. Daily temperature values from DAYMET are used to represent temperatures at a location near the ridgeline for upper elevation temperatures.

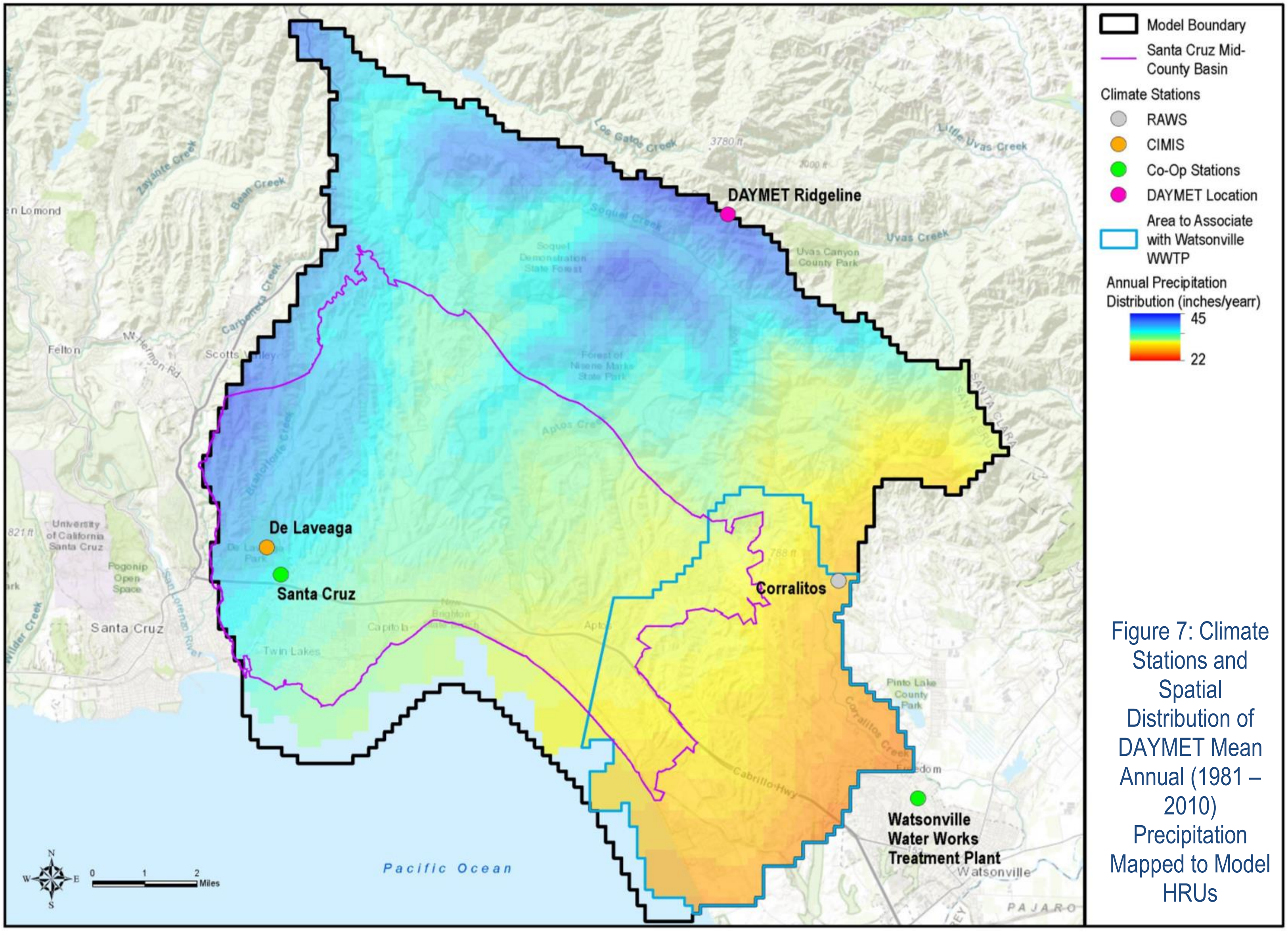


Figure 7: Climate Stations and Spatial Distribution of DAYMET Mean Annual (1981 – 2010) Precipitation Mapped to Model HRUs

4.2 Watershed Parameter Data

Data inputs to the PRMS component of the model include spatial data related to the physical environment such as elevation, slope, aspect, geology, soil type, land use, and vegetation type and density. As described in detail in HydroMetrics WRI (2016a), the following GIS datasets are mapped to HRUs:

- 10 meter resolution digital elevation model (DEM), with derived slope and aspect (National Elevation Dataset, 2015),
- USGS National Hydrography Dataset (NHD)) for streams and creeks,
- LANDFIRE vegetation type and density distributions (LANDFIRE, 2010), and
- SSURGO soils data of percent sand, silt, clay, and available water holding capacity (USDA, 2012).
- Percent impervious from the 2011 National Land Cover Database (Homer et al., 2015)

Maps showing the distribution across the model for most of these datasets are included in HydroMetrics WRI (2016a). Additional mapped distributions for vegetation type (Figure 8), summer vegetation density (Figure 9), winter vegetation density (Figure 10), and percent impervious (Figure 11) are provided in this report for completeness.

HRU-to-HRU connections, PRMS cascade parameters, and stream locations were computed from the DEM using the Cascade Routing Tool (CRT) (Henson *et al.*, 2013). CRT was iteratively executed to optimize stream locations and connections relative to NHD streamlines. Sub-watersheds were delineated according to stream gauge locations and primary tributary confluences and attributed to model stream cells with stream segment and reach identifiers used in the MODFLOW SFR package (Figure 5).

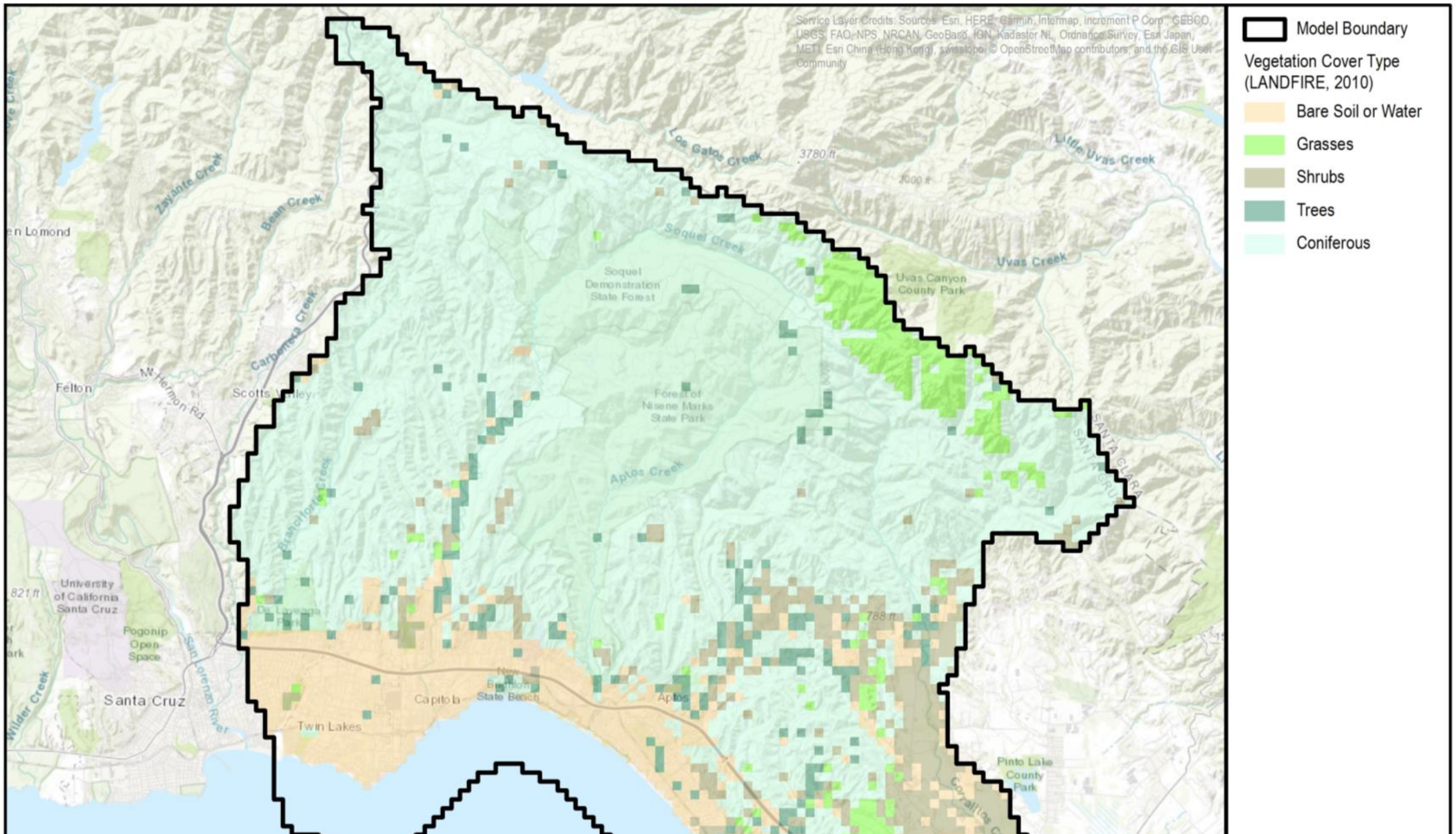


Figure 8: Vegetation Type Distribution Mapped to Model HRUs

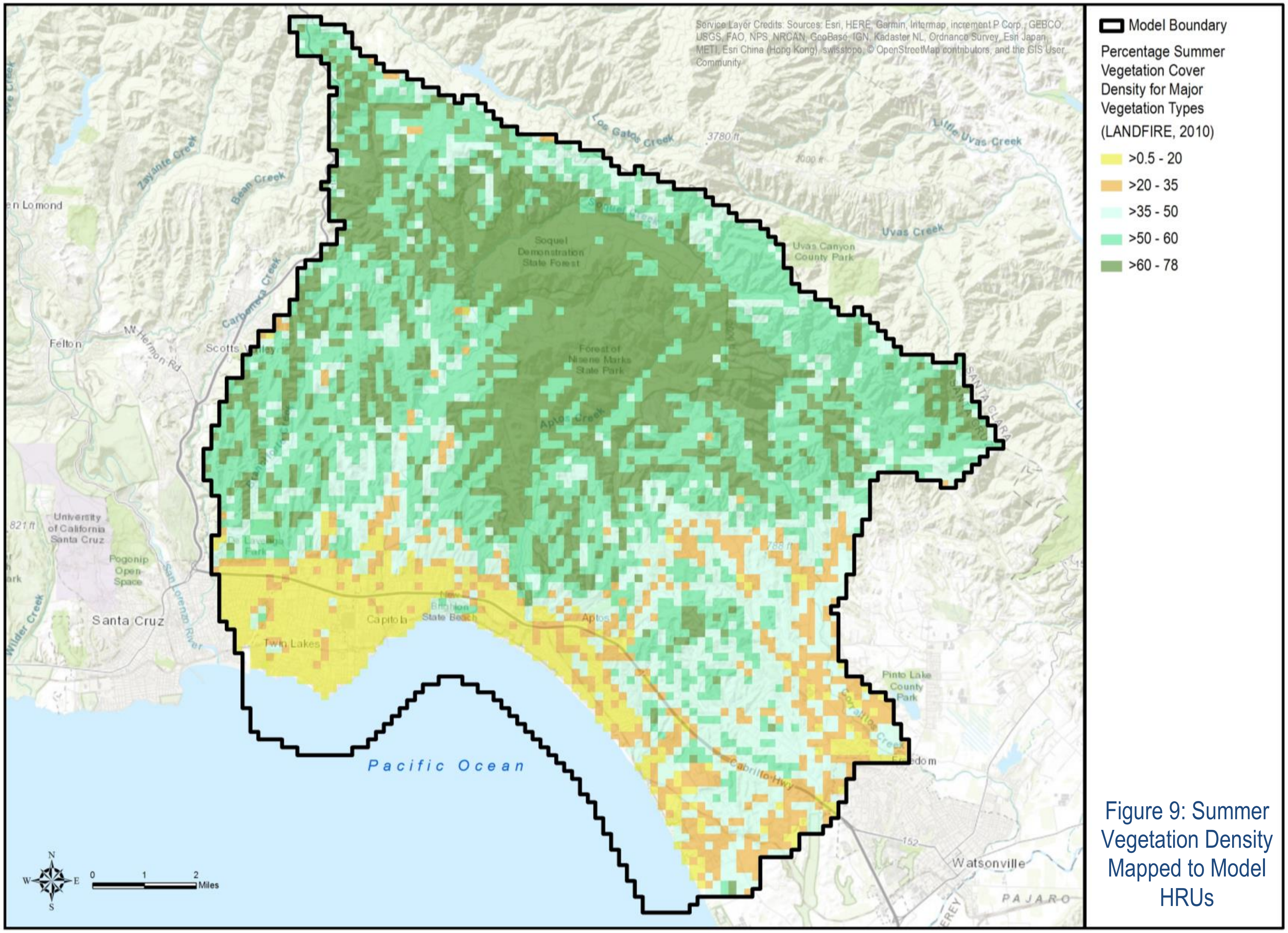


Figure 9: Summer Vegetation Density Mapped to Model HRUs

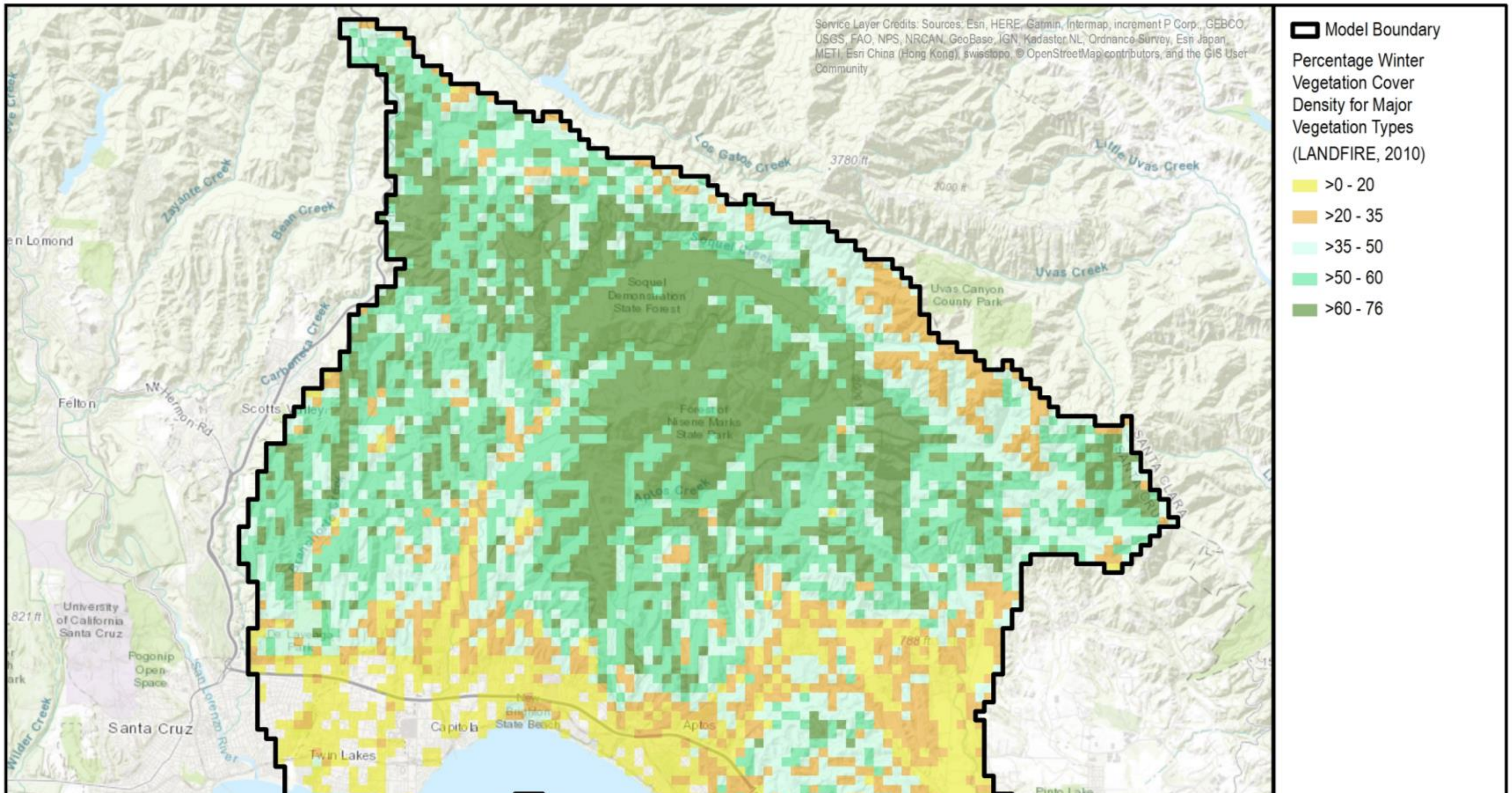


Figure 10: Winter Vegetation Density Distribution Mapped to Model HRUs

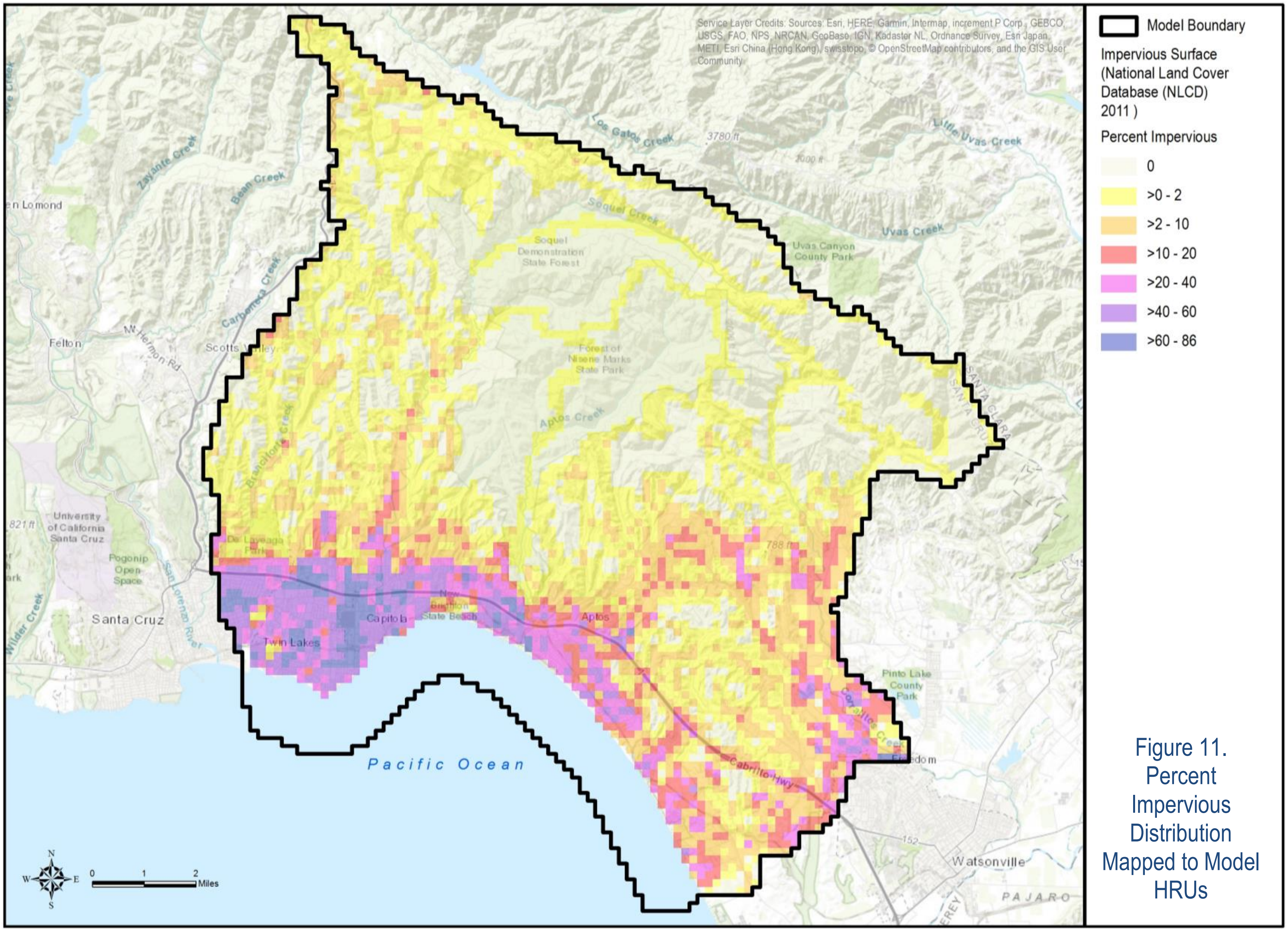


Figure 11. Percent Impervious Distribution Mapped to Model HRUs

4.3 Pumping Well Data

Groundwater pumping is implemented with the Multi-Node Well (MNW2) MODFLOW package. The MNW2 package calculates flow into the well from various model layers based on actual screen elevations. Where available for municipal wells, screened interval elevations are entered in the MNW2 package. An exception to this this is where Soquel Creek Water District (SqCWD) are screened within both the Aromas Red Sands and Purisima F unit. In this case we assigned all pumping to layer 3, representing the Purisima F unit, to simulate a confined aquifer response observed near the coast. As described in the *Santa Cruz Mid-County Basin Groundwater Flow Model: Water Use Estimates and Return Flow Implementation* memorandum (HydroMetrics WRI, 2017c), most non-municipal pumping is based on land use for a model cell, not actual, identified well locations. Table 4 lists the municipal wells explicitly simulated in the model. Non-municipal pumping is assigned to the layer representing the shallowest aquifer unit that is not outcropping at the estimated well location. Plate 3 shows simulated pumping well locations by model layer for each aquifer unit.

Table 4. Municipal Wells in Model Domain

Well Name	Agency	Pumping Data Range (Water Year)	Aquifer Unit in Model[1]
Beltz #12	City of Santa Cruz	1984-2016	AA, Tu
Beltz #1	City of Santa Cruz	1984-2015	A
Beltz #7	City of Santa Cruz	1984-2015	A, AA
Beltz #10	City of Santa Cruz	1984-2016	A, AA
Beltz #9	City of Santa Cruz	1984-2016	A
Beltz #4	City of Santa Cruz	1985-2015	A
Beltz #8	City of Santa Cruz	1984-2016	A, AA
CWD-2	CWD	1985-2002	DEF/F
CWD-3	CWD	1985-2014	DEF/F
CWD-5	CWD	1985-2014	DEF/F
CWD-4	CWD	1985-2016	Aromas, DEF/F
CWD-10	CWD	1985-2016	Aromas, DEF/F
CWD-12	CWD	1986-2016	Aromas, DEF/F
Cliff Well	SqCWD	1984-1986	DEF/F
O'Neill Ranch Well	SqCWD	2015-2016	AA, Tu
Opal Well #1	SqCWD	1984-2000	A
Polo Grounds Well	SqCWD	1985-2016	DEF/F
Tannery Well II	SqCWD	2002-2016	A, AA
Aptos Jr High Well	SqCWD	1985-2016	DEF/F

Well Name	Agency	Pumping Data Range (Water Year)	Aquifer Unit in Model[1]
Monterey Well	SqCWD	1984-2015	A
T-Hopkins Well	SqCWD	1990-2016	DEF/F
Ledyard Well	SqCWD	1986-2016	BC
Aptos Creek Well	SqCWD	1984-2016	DEF/F, BC
Estates Well	SqCWD	1986-2016	BC, A
Madeline Well #2	SqCWD	1984-2015	BC
Main Street Well	SqCWD	1988-2016	AA, Tu
Rosedale 2 Well	SqCWD	1984-2016	A, AA
Tannery Well	SqCWD	1984-2000	A, AA
Maplethorpe Well	SqCWD	1984-2015	A, AA
Garnet Well	SqCWD	1996-2016	A
Sells Well	SqCWD	1984-2015	Aromas
Altivo Well	SqCWD	1984-2015	Aromas
Bonita Well	SqCWD	1984-2016	DEF/F
Seascape Well	SqCWD	1984-2015	DEF/F
San Andreas Well	SqCWD	1992-2016	DEF/F
Country Club Well	SqCWD	1985-2016	DEF/F

[1]See *Soquel-Aptos Groundwater Flow Model: Subsurface Model Construction* (HydroMetrics WRI, 2015) for detailed model layer description.

Groundwater pumping volumes are based on a number of sources. Municipal pumping within the Basin is metered, and historical records have been supplied by the primary municipal pumping agencies. For non-metered areas, the amount of water use is estimated based on land use. The estimates for non-municipal domestic water use, including the methodology for estimating institutional, recreational, and agricultural irrigation water use, is described in detail in the *Santa Cruz Mid-County Basin Groundwater Flow Model: Water Use Estimates and Return Flow Implementation* memorandum (HydroMetrics WRI, 2017c).

Pumping data applied to the model are generally grouped into the following categories:

- Municipal pumping for the calibration period of October 1984 through October 2015 were obtained from SqCWD, the City of Santa Cruz, and CWD. Pumping from Watsonville or Pajaro Valley Water Management Agency (PVWMA) wells near the southeastern boundary of the model was not explicitly simulated in the model as the specified head boundary condition incorporates the effects of that pumping.

- Pumping for private water use was based on a count of residential buildings per model cell (HydroMetrics WRI, 2017c)

- Institutional water use was estimated or recorded at specific properties (HydroMetrics WRI, 2017c).

- Agricultural pumping was calculated based on crop demand and evapotranspiration demand (HydroMetrics WRI, 2017c). Evapotranspiration demand is calculated by PRMS for the 1984-2015 period as the difference between potential evapotranspiration and actual evapotranspiration from rainfall.

Figure 12 shows the simulated pumping flows by use type within the Santa Cruz Mid-County Basin (MCB) and in the model domain outside the Basin.

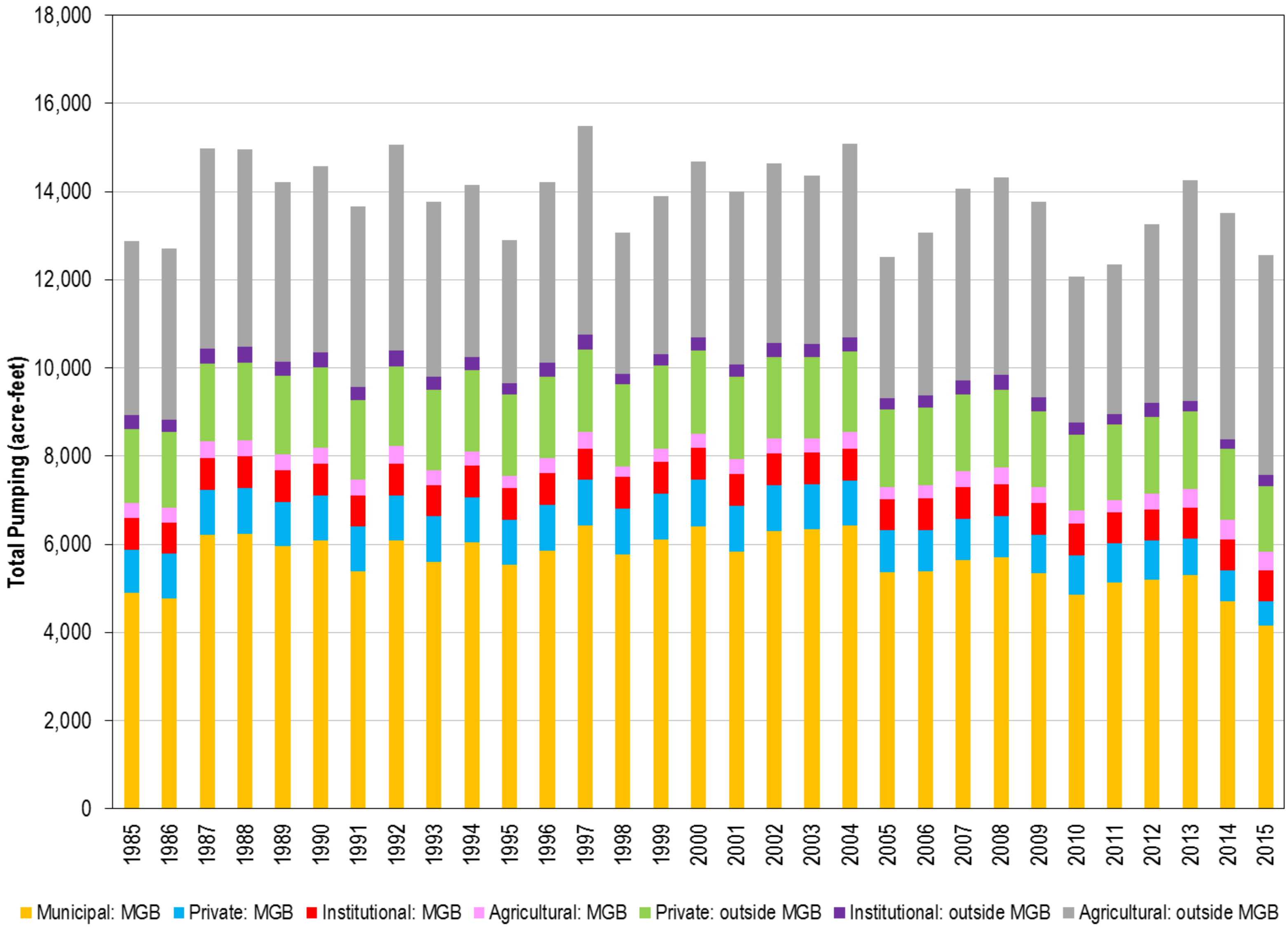


Figure 12. Simulated Groundwater Pumping by Use Type and Location

4.4 Return Flow Data

Return flow is implemented with the UZF package described in Section 3.5.4. There are a number of return flow components included in the groundwater model, as described below.

1. Return flow from system losses, which are losses from water, sewer and septic systems. Water system losses are estimated as a percentage of estimated deliveries to each service area and applied in UZF to model cells overlying those service areas. Details on the approach used to estimate municipal return flow estimates are provided in Appendix A. Municipal areas with system losses are City of Santa Cruz, CWD, SqCWD, and City of Watsonville. Sewer and septic system losses are estimated as a proportion of indoor water use overlying sewered and non-sewered areas, respectively, and applied in UZF to model cells underlying those areas. Indoor use is assumed to be 70% of total water use, and 90% of indoor water use is assumed to become wastewater (HydroMetrics WRI, 2017c). For wastewater return flows in sewered areas, return flows from sewer losses are assumed to be the same percentage used for system losses and losses area applied to model cells overlying sewered areas. For non-sewered areas, it was assumed 90% of wastewater becomes return flow through leakage from septic systems.

2. Return flow from the inefficient portion of municipal and non-municipal domestic and institutional irrigation. Return flow represented by the inefficient portion (10%) of large-scale irrigation of sports fields and parks in both municipal areas and for institutional use outside of municipal served areas is applied to model cells that overlie those irrigated areas. Large-scale irrigation demand is estimated as the difference between capillary zone PET and actual rainfall ET simulated by PRMS, the area being irrigated, and a crop factor. For return flow from non-municipal domestic irrigation, the inefficient portion (10%) of outdoor domestic use is applied in the model using the non-municipal domestic water use described in *Santa Cruz Mid-County Basin Groundwater Flow Model: Water Use Estimates and Return Flow Implementation* memorandum (HydroMetrics WRI, 2017c). It is assumed that approximately 30% of total domestic water use is outdoor use.

3. Return flow from the inefficient portion of agricultural irrigation. It was assumed that the return flow from agricultural irrigation is 10% of agricultural pumping or demand, described in Section 4.3. As described in the *Santa Cruz Mid-County Basin Groundwater Flow Model: Water Use Estimates and Return Flow Implementation* memorandum (HydroMetrics WRI, 2017c), agricultural return

flow is applied in UZF to model cells overlying areas with mapped irrigated agriculture.

Figure 13 shows return flows by use type within the Santa Cruz Mid-County Groundwater Basin (MGB) and in the model domain outside the Basin. The largest component of return flow in the model is from private groundwater use, which includes both the inefficient portion of landscape irrigation and leakage from septic systems. The second greatest component of return flow in the model is from municipal uses. This category includes system losses and the inefficient portion of domestic and large-scale landscape irrigation. Within the Mid-County Basin, return flow from municipal use is greater than from private use.

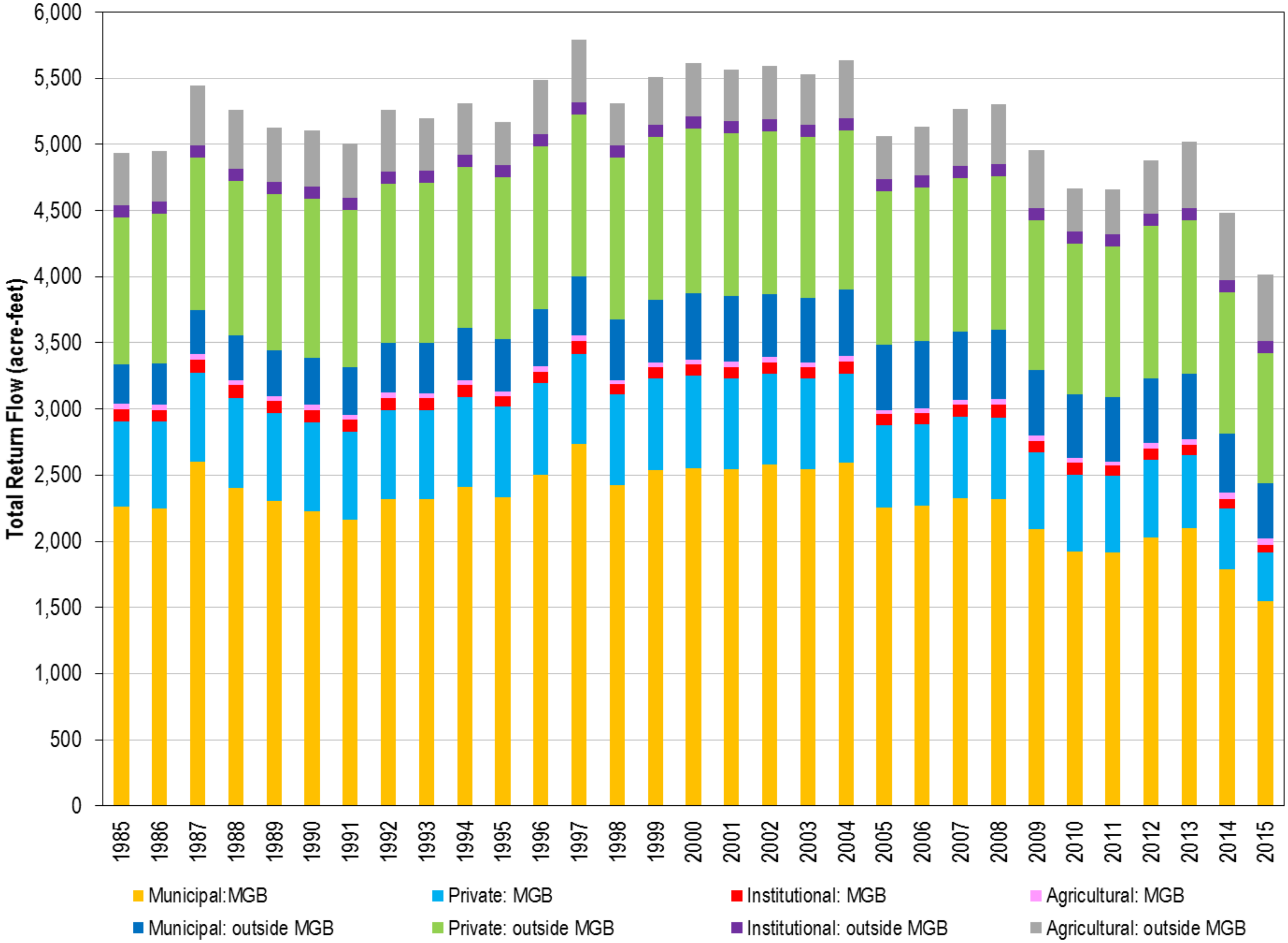


Figure 13: Simulated Return Flow by Use Type and Location

5 CALIBRATION TARGET DATA

This section describes the nature and source of observed data used to compare against simulated results during the calibration process.

5.1 Climate Calibration Targets

The first step in calibrating watershed processes is to calibrate how climate data are translated to available water in the watershed. The available water is the precipitation, less evapotranspiration. Target data that are calibrated in this step are solar radiation and potential evapotranspiration. Solar radiation data are measured at the De Laveaga CIMIS and Corralitos RAWS stations (Figure 7). Calibration target data for potential evapotranspiration at these stations are calculated based on solar radiation, temperature, humidity, and wind speed using the ASCE standard Penmen- Monteith equation for a grass reference surface (ASCE-EWRI, 2005).

5.2 Streamflow Calibration Targets

Streamflow data from eleven stream gauges within the model domain are available for use as calibration targets. Observed daily streamflow values are compared against simulated streamflow values at these gauges during the calibration process. Where data are not available at a gauge for the entire calibration period, synthetic data are produced based on linear regressions from double-mass curves.

Double-mass curves are generated between gauges with incomplete records and one of the two gauges with complete records for the concurrent data period. Linear regression equations are developed for each of the double-mass curves. Double-mass curves are extrapolated to the entire model calibration period based on the linear regression equation. Additional detail on this approach can be found in the *Estimation of Deep Groundwater Recharge Using a Precipitation-Runoff Watershed Model* report (HydroMetrics WRI, 2011)

Table 5 lists the gauges used for calibration of streamflow within the model. The location of these gauges is shown in Figure 5.

Table 5: Summary of Gauge Locations used as Calibration Targets

Gauge Name	Date Range of Available Data	Source of Data
West Branch	1984-2016	SqCWD
Upper Soquel Creek	10/1/1983 - 1/30/1986 11/21/1986 – present[1]	SqCWD
West Branch Soquel Creek near Soquel	10/1/1958 – 10/6/1972[2]	USGS[3]
Soquel Creek near Soquel	10/1/1968 – 9/30/1972[2]	USGS
Soquel Creek at Soquel	5/1/1951 – present	USGS
Aptos Creek near Aptos	10/1/1971 – 9/30/1985[2]	USGS
Aptos Creek at Aptos	10/1/1958 – 10/6/1972	USGS
Valencia Creek	10/1/2008 - 12/31/2009	Santa Cruz Co.
Branciforte Creek at Santa Cruz[4]	Estimated for model period[2]	USGS
Corralitos Creek near Corralitos	10/1/1957 – 10/11/1972[2]	USGS
Corralitos Creek at Freedom	10/1/1956 – present	USGS

[1] Data available intermittently
[2] Estimated for model period based on linear regressions from double-mass curves generated between gauges with incomplete records and one of the two gauges with complete records for overlapped data
[3] U.S. Geological Survey
[4] Part of watershed for gauge outside model domain

5.3 Groundwater Elevation Calibration Targets

5.3.1 Targets in Model Layers Representing Basin Aquifer Units

Groundwater elevations have been measured at a number of production and monitoring wells in the Purisima Formation and Aromas Red Sands within the model domain throughout the calibration period. A total of 121 individual monitoring locations were identified within the model domain, and groundwater level data from those wells were added to the model as calibration targets in model layers representing the Purisima Formation and Aromas Red Sands after excluding observations determined to be anomalous or unreliable. Observations from wells that are screened across multiple model layers are input into the model as composite water levels that are weighted by layer transmissivity according to the percentage of screened interval in each layer. Table 6 lists the wells used as groundwater level calibration targets in Basin aquifer units within the model. Plate 4 shows the location of these wells used as calibration targets within each aquifer layer of the model. Most calibration targets are south of the Aptos area horizontal flow barrier where it is modeled. There are no calibration targets north of the Zayante Fault.

Table 6. Wells used as Groundwater Elevation Calibration Targets in Basin Aquifer Units

Well Name	Associated Agency	Model Layer(s)[1]	Water Year Range of Calibration Data[2]
30th Ave-1	City of Santa Cruz	Tu	2013-2015
30th Ave-2	City of Santa Cruz	AA	2013-2015
Auto Plaza Deep	City of Santa Cruz	AA	2010-2015
Auto Plaza Medium	City of Santa Cruz	AA	2010-2015
Auto Plaza Shallow	City of Santa Cruz	A	2010-2015
Beltz #2	City of Santa Cruz	A	2004-2015
Beltz #6	City of Santa Cruz	A	2004-2015
Beltz #7 Deep	City of Santa Cruz	Tu	2013-2015
Beltz # 7 Test Well	City of Santa Cruz	Tu	2004-2015
Coffee Lane Park Deep	City of Santa Cruz	AA	2010-2015
Coffee Lane Park Shallow	City of Santa Cruz	AA	2010-2015
Corcoran Lagoon Deep	City of Santa Cruz	AA	2004-2015
Corcoran Lagoon Medium	City of Santa Cruz	A	2004-2015
Corcoran Lagoon Shallow	City of Santa Cruz	B Aquitard-A	2004-2015
Cory Street-4	City of Santa Cruz	Tu	2014-2015
Cory Street Deep	City of Santa Cruz	AA	2010-2015
Cory Street Medium	City of Santa Cruz	AA	2010-2015
Cory Street Shallow	City of Santa Cruz	A-AA	2010-2015
Moran Lake Deep	City of Santa Cruz	A	2004-2015
Moran Lake Medium	City of Santa Cruz	A	2004-2015
Moran Lake Shallow	City of Santa Cruz	A	2004-2015
Pleasure Point Deep	City of Santa Cruz	AA	2000-2015
Pleasure Point Medium	City of Santa Cruz	A	2000-2015
Pleasure Point Shallow	City of Santa Cruz	A	1989-2015
Schwan Lake	City of Santa Cruz	A	2004-2015
Soquel Point Deep	City of Santa Cruz	A-AA	2004-2015
Soquel Point Medium	City of Santa Cruz	A	2004-2015
Soquel Point Shallow	City of Santa Cruz	A	2004-2015
Thurber Ln Deep	City of Santa Cruz	Tu	2008-2015
Black	CWD	Aromas	1985-2014
Cox-3	CWD	DEF/F	1985-2015
CWD-B	CWD	Aromas	2006-2015
CWD-C	CWD	DEF/F	2006-2015
Altivo	SqCWD	Aromas	1984-2015
Bonita	SqCWD	Aromas-DEF/F	1984-2015

Well Name	Associated Agency	Model Layer(s)[1]	Water Year Range of Calibration Data[2]
Country Club	SqCWD	Aromas-DEF/F	1984-2015
Rob Roy-4	SqCWD	Aromas-DEF/F	1985-2015
San Andreas	SqCWD	Aromas-DEF/F	1992-2015
SC-10AAA	SqCWD	AA	1986-2015
SC-10AAR	SqCWD	AA	1986-2015
SC-11A-R	SqCWD	A	2006-2015
SC-11B	SqCWD	BC	2006-2013
SC-11C	SqCWD	D Aquitard-BC	2006-2013
SC-11D-R	SqCWD	DEF/F-D Aquitard	2006-2013
SC-11RB	SqCWD	BC	2014-2015
SC-13A	SqCWD	Tu	1995-2015
SC-14A	SqCWD	A-AA	1986-2015
SC-14B	SqCWD	BC-B Aquitard	1986-2015
SC-15A	SqCWD	AA	2006-2015
SC-15B	SqCWD	A	2006-2015
SC-16A	SqCWD	B Aquitard-A	1986-2015
SC-16B	SqCWD	D Aquitard-BC	2016-2015
SC-17A	SqCWD	B Aquitard-A	1986-2015
SC-17B	SqCWD	D Aquitard-BC	1986-2015
SC-17C	SqCWD	DEF/F-D Aquitard	2007-2015
SC-18AAR	SqCWD	Tu	1999-2017
SC-18A-R	SqCWD	AA	1999-2015
SC-19	SqCWD	DEF/F	2007-2015
SC-1A	SqCWD	A-AA	1986-2015
SC-20A	SqCWD	DEF/F	2010-2015
SC-21A	SqCWD	A-AA	2012-2015
SC-21AA	SqCWD	AA	2012-2015
SC-21AAA	SqCWD	Tu	2012-2015
SC-22A	SqCWD	A-AA	2013-2015
SC-22AAA	SqCWD	Tu	2012-2015
SC-23A	SqCWD	D Aquitard-BC	2014-2015
SC-23C	SqCWD	DEF/F	2014-2015
SC-3A-R	SqCWD	A-AA	1986-2009
SC-3B-R	SqCWD	BC-B Aquitard	1986-2005
SC-3C-R	SqCWD	BC	1990-2015
SC-5A-R	SqCWD	A-AA	1986-2015

Well Name	Associated Agency	Model Layer(s)[1]	Water Year Range of Calibration Data[2]
SC-5C-R	SqCWD	BC	1986-2015
SC-5D	SqCWD	D Aquitard-BC	1986-2000
SC-5RB	SqCWD	B Aquitard	2003-2015
SC-8A	SqCWD	A	1986-1992
SC-8B	SqCWD	BC-B Aquitard	1986-1992
SC-8RA	SqCWD	A	1996-2015
SC-8RB	SqCWD	BC	1996-2015
SC-8RD	SqCWD	D Aquitard	1996-2015
SC-9A-R	SqCWD	A	1986-2012
SC-9C-R	SqCWD	BC	1986-2012
SC-9E-R	SqCWD	DEF/F-D Aquitard	1988-2012
SC-A1B	SqCWD	DEF/F	1989-2015
SC-A1D	SqCWD	DEF/F	1989-2015
SC-A2A-R	SqCWD	DEF/F	1989-2015
SC-A2C-R	SqCWD	Aromas	1989-2015
SC-A3A	SqCWD	Aromas	1989-2015
SC-A4A	SqCWD	Aromas	2002-2015
SC-A4B	SqCWD	Aromas	2002-2015
SC-A5A	SqCWD	DEF/F	1994-2015
SC-A5C	SqCWD	Aromas	2002-2015
SC-A6A	SqCWD	DEF/F	2004-2015
SC-A7B	SqCWD	Aromas	2004-2015
SC-A7C	SqCWD	Aromas	2004-2015
SC-A8A	SqCWD	DEF/F	2008-2015
SC-A8C	SqCWD	Aromas	2008-2015
SC-A9A	SqCWD	DEF/F	2014-2015
SC-A9B	SqCWD	Aromas	2014
Seascape	SqCWD	Aromas	1986-2015
Sells	SqCWD	Aromas	1984-2015
01E04BP	Private	DEF/F	2009-2015
01E04DP	Private	Aromas	2009-2014
01E04EP	Private	DEF/F	2009-2015
01E04FP	Private	DEF/F	2009-2015
01E05AP	Private	DEF/F	2008-2015
01E06AS	Private	DEF/F	2009
01E08AS	Private	DEF/F	2008-2011

Well Name	Associated Agency	Model Layer(s)[1]	Water Year Range of Calibration Data[2]
01E08BS	Private	DEF/F	2008-2012
01E09AP	Private	DEF/F	2009-2013
01E09BP	Private	DEF/F	2009-2010
01E15AS	Private	Aromas	2008-2015
01E22AS	Private	Aromas	2009-2011
01E22BS	Private	Aromas	2009-2015
01W06AS	Private	Tu	2009-2015
01W06BS	Private	Tu	2009-2015
01W06DP	Private	Tu	2011-2015
01W14BP	Private	Tu	2008-2015
01W15AP	Private	Tu	2008-2015
01W22AS	Private	Tu	2008-2015
01W30AP	Private	Tu	2008-2015
01W32AS	Private	Tu	2009-2015

[1] See *Soquel-Aptos Groundwater Flow Model: Subsurface Model Construction* (HydroMetrics WRI, 2015) for detailed model layer descriptions
[2] Water year

5.3.2 Targets for Shallow Groundwater along Soquel Creek

As part of a scope for Santa Cruz County's Prop 1 grant for Counties with Stressed Basins, additional calibration was performed including shallow groundwater levels along Soquel Creek as targets. The purpose of this calibration is to improve simulation of stream-aquifer interaction along Soquel Creek to inform development of sustainability management criteria for streamflow depletion from pumping, including use of shallow groundwater levels as groundwater level proxies. Table 7 lists the shallow wells along Soquel Creek used as groundwater elevation targets. Figure 14 shows the locations of these shallow wells.

Table 7. Shallow Wells along Soquel Creek used as Groundwater Elevation Calibration Targets

Well Name	Associated Agency	Model Layer(s)[1]	Water Year Range of Calibration Data[2]
Simons	SqCWD	Alluvium overlying A	2002-2011
Balogh	SqCWD	Alluvium overlying A	2002-2015
Main St SW-1	SqCWD	Alluvium overlying A	2001-2015
Wharf Road SW	SqCWD	Alluvium overlying A	2013-2015
Nob Hil SW 2I	SqCWD	Alluvium overlying A	2001-2015

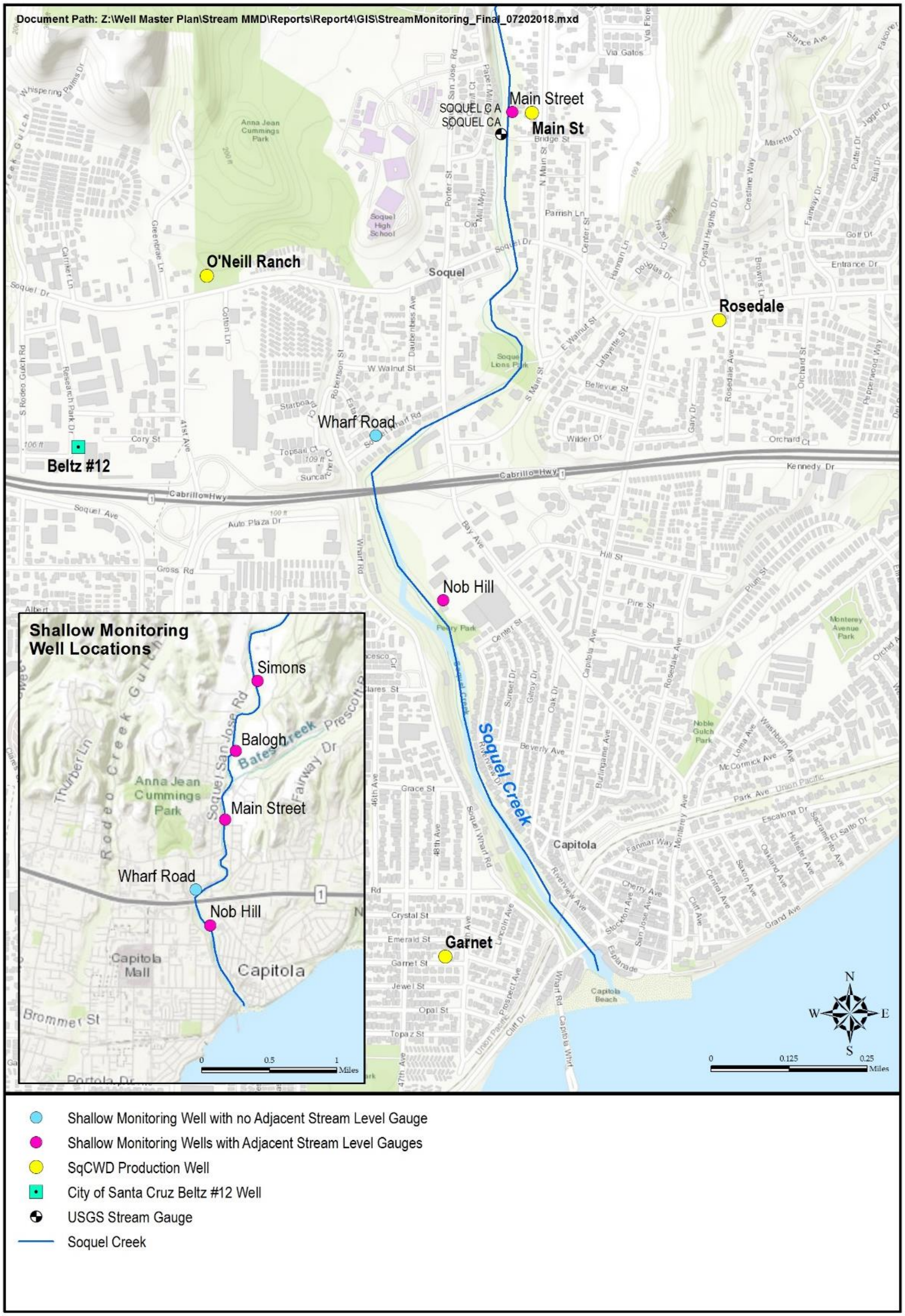


Figure 14. Locations of Shallow Groundwater Elevation Targets along Soquel Creek

These groundwater level targets are located in model layer 6 representing alluvium underlying Soquel Creek and overlying the Purisima A unit. Previous studies (LKA and LSCE, 2003) indicated that at least the Main St SW-1 is screened in the Purisima Formation, but the vertical gradient observed between the shallow groundwater levels and deeper Purisima Formation groundwater levels observed at monitoring well SC-18A justifies simulating the shallow wells in the model layer directly beneath Soquel Creek. Therefore, the model is calibrated to simulate the vertical connection of Soquel Creek to underlying Purisima Formation. The model does not simulate the horizontal connection of Soquel Creek to shallow wells along the Creek as the distance between the Creek and wells are less than the model cell width of 800 feet as shown in Figure 15.

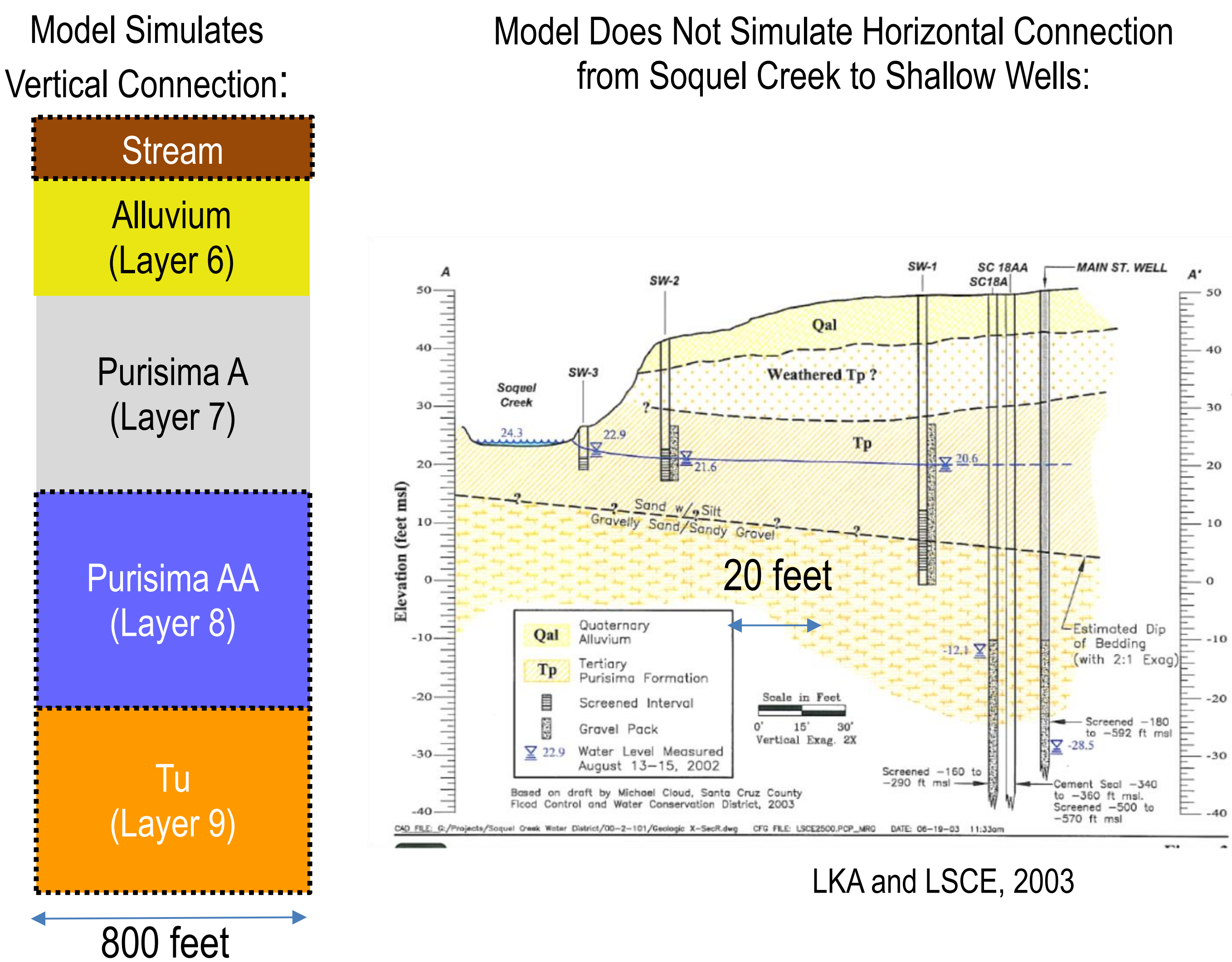


Figure 15. Model Simulation of Vertical Connection between Stream-Aquifers

6 CALIBRATION PROCESS

Calibrating the Basin model involves successive attempts to match simulated output to calibration targets during the calibration period. Simulated climate, streamflow and groundwater elevation data are compared to observed values, and surface and groundwater parameters are adjusted between model runs to improve the fit of simulated to observed values.

Preliminary work calibrating the model involved using separate models. One model calibrated climate and surface water flow using only the PRMS watershed model. A second model calibrated groundwater-only flow using the MODFLOW model. A major factor contributing to this decision was the relative model run times of the separate model packages compared to the integrated GSFLOW model. Separate models used to calibrate different datasets were as follows:

1. PRMS only runs for Water Years 1985-2015 to calibrate to climate output of solar radiation and potential evapotranspiration. Solar radiation and potential evapotranspiration calculations remain consistent when run as part of GSFLOW.

2. GSFLOW runs for Water Years 1992-1995 to calibrate to streamflow. Streamflow calibrated to PRMS only runs did not remain consistent when run as part of GSFLOW due to simulation of groundwater discharge to the soil zone in GSFLOW. The US Geological Survey recommended calibrating to a shorter time period to reduce run times. Water Years 1992-1995 includes variation in climate that makes it appropriate for calibrating streamflow under different climate conditions.

3. MODFLOW only runs for Water Years 1985-2015. When an acceptably-calibrated model fit to streamflow observations was achieved, a GSFLOW run for Water Years 1985-2015 was run to estimate recharge and a corresponding MODFLOW-only model using the recharge estimates was created to change groundwater parameters to achieve calibration to groundwater observations to understand model sensitivities and develop strategies for calibrating to groundwater levels.

4. GSFLOW runs for Water Years 1992-1995 to recalibrate to streamflow again. Changes to groundwater parameters did not change streamflow calibration substantially, but streamflow calibration was adjusted for consistency.

5. GSFLOW runs for Water Years 1985-2015. There are some differences in groundwater results provided by MODFLOW only and GSFLOW runs so final calibration to groundwater levels was based on GSFLOW runs. Further adjustment of climate or watershed parameters was not necessary as part of this calibration.

6. Under the scope for Santa Cruz County's Prop 1 grant. GSFLOW runs for Water Years 1985-2015 to calibrate to shallow groundwater levels along Soquel Creek while maintaining streamflow calibration and calibration in underlying Purisima Formation aquifer units.

7 MODEL CALIBRATION

This section presents the model calibration that includes calibrating to climate, streamflow, and groundwater level targets.

7.1 Climate Calibration

PRMS solar radiation and potential evapotranspiration parameters were first calibrated to measured solar radiation (SR) and calculated potential evapotranspiration (PET) at the Delaveaga CIMIS and Corralitos RAWS stations (HydroMetrics WRI, 2016a). PRMS calculates solar radiation using the ddsolrad module where the parameters are slope and intercept of the maximum temperature per degree day linear relationship. Monthly parameters (dday_intcp and dday_slope) are calibrated (Table 8) to monthly averages of solar radiation (Figure 16 and Figure 17). Based on calibrated solar radiation, monthly coefficients (pt_alpha) for the Priestly-Taylor equation (Table 8) are adjusted to calibrate simulated potential evapotranspiration to average potential evapotranspiration at the stations (Figure 18 and Figure 19). The Priestly-Taylor equation requires relative humidity so average monthly relative humidity from the Santa Cruz Co-op station is used (Table 8).

Table 8. Monthly Parameters for Solar Radiation and Potential Evapotranspiration

Parameter Name	dday_intcp	dday_slope	hum_pct	pt_alpha
Parameter Description	Intercept in temperature degree-day relation	Slope in temperature degree-day relation	Monthly relative humidity percent	Monthly adjustment factor used in Priestly-Taylor PET calculations
January	-13.6453	0.2715	75	0.9116
February	-20.0454	0.3977	72	0.7988
March	-26.6630	0.5290	70	0.7668
April	-34.9496	0.6562	70	0.78520
May	-44.0930	0.7574	72	0.7383
June	-54.5417	0.8769	75	0.7574
July	-54.1731	0.8449	80	0.7514
August	-49.4067	0.7701	82	0.7531
September	-39.2594	0.6358	75	0.7731
October	-28.2960	0.4917	70	0.8563
November	-15.3850	0.3092	70	0.9507
December	-11.2614	0.2698	76	0.9002

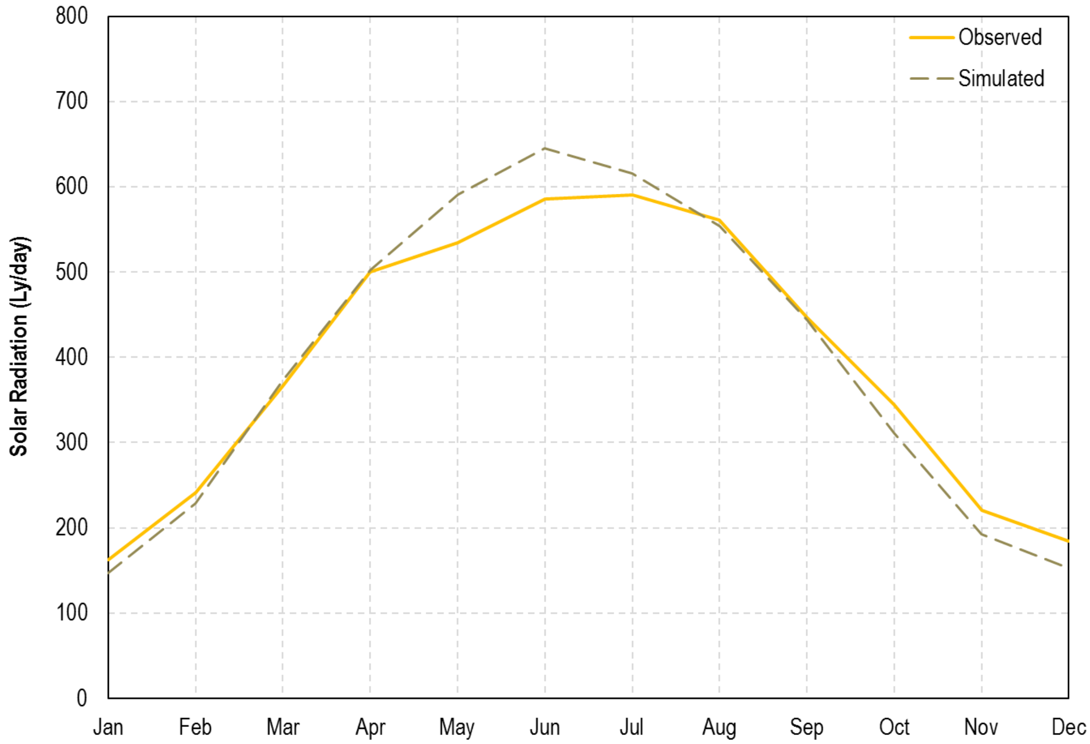


Figure 16. Calibration of Solar Radiation at de Lavega CIMIS Station

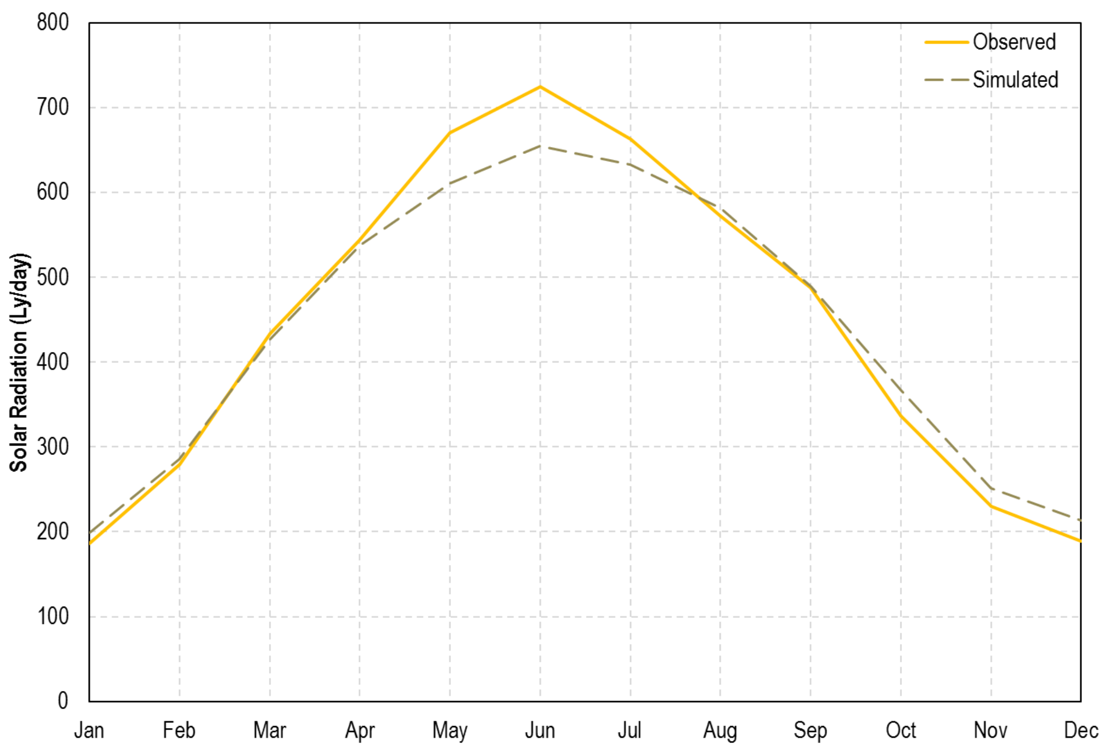


Figure 17. Calibration of Solar Radiation at Corralitos RAWS Station

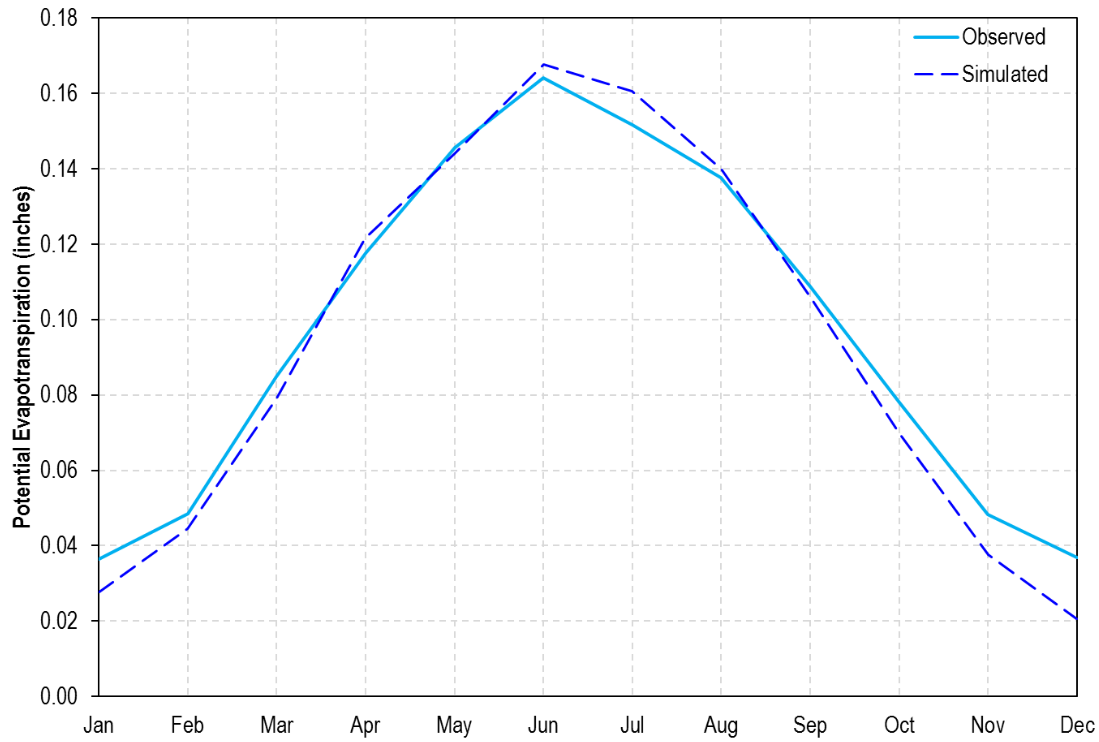


Figure 18. Calibration of Potential Evapotranspiration at de Lavega CIMIS Station

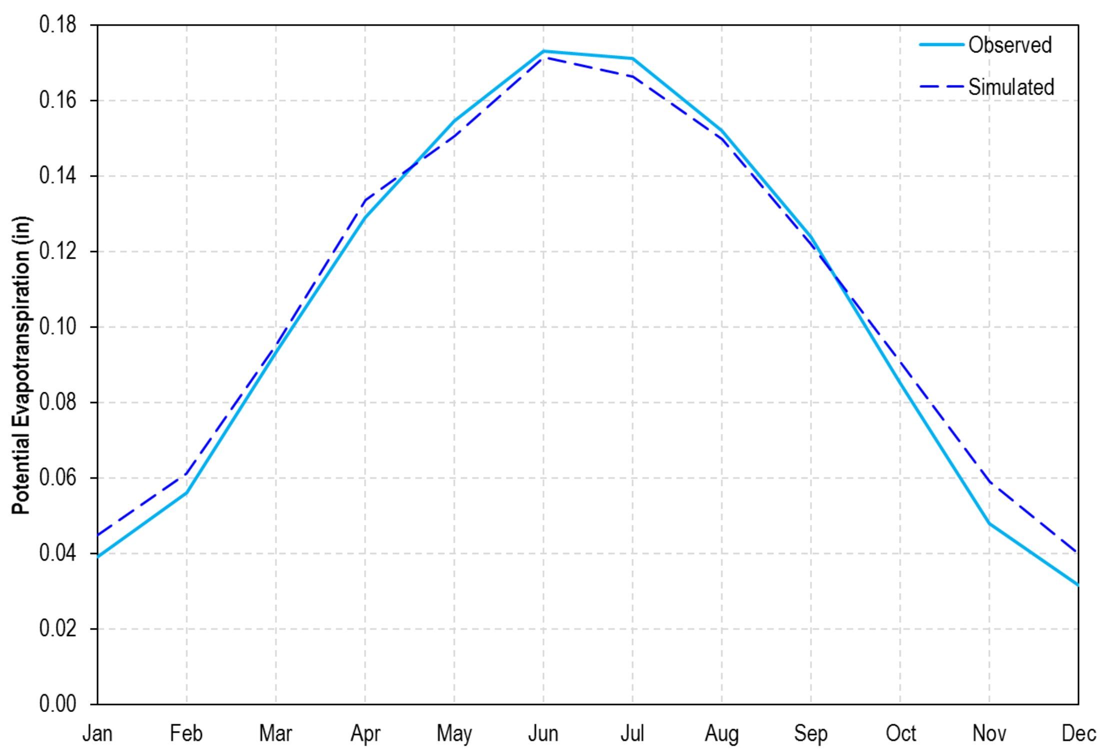


Figure 19. Calibration of Potential Evapotranspiration at Corralitos RAWS Station

7.2 Surface Water Calibration

Calibration of the surface water component of the model with the GSFLOW run simulating Water Years 1992-1995 compares GSFLOW model MODFLOW GAGE package output at stream gauges with daily observations at the stream gauge. Watershed parameters were adjusted to improve the match between simulated output and observations.

7.2.1 Watershed Parameters by Zone

Watershed parameters were adjusted by zones for Soquel Creek, Aptos Creek, and Corralitos Creek upstream and downstream of Zayante Fault, which is the northern boundary of the Basin (Figure 5). Gauges on these creeks can be sorted into upstream and downstream gauges with the simulated streamflow at the upstream gauges primarily affected by parameters in its watershed upstream of Zayante Fault and simulated streamflow at the downstream gauges affected by parameters at both zones in the watershed. The watershed parameters affect the streamflows shown in Figure 22.

Some parameters represent the soil zone reservoir volumes and other parameters represent coefficients for empirical equations describing flows to and from soil zone reservoirs. Table 9 describes the watershed parameters and provides their calibrated values.

The capillary zone capacities soil_moist_max and soil_rechr_max have spatial variation within each PRMS parameter zone based on calculations using the SSUGRO soils dataset for the previous PRMS recharge dataset (HydroMetrics WRI, 2011). Zone based factors multiplying spatial variation within the zones are used for calibration. Figure 20 shows the calibrated results of this multiplication.

In general, parameters representing flows from the soil zone are on the low end of the expected range while parameters representing soil moisture capacities (sat_threshold, soil_moist_max, and soil_rechr_max) are relatively high. This facilitates soil zone only slowly releasing water to streams and groundwater to calibrate slow recession curves observed at stream gauges in the watersheds.

Table 9. Watershed Parameters by Zone

Parameter Name	Parameter Description	Associated Flow	Upper Soquel	Lower Soquel	Upper Aptos	Lower Aptos	Upper Corralitos	Lower Corralitos
fastcoef_lin	Coefficient to route preferential-flow storage down slope	fast interflow	0.023	0.443	0.012	0.010	0.389	0.910
fastcoef_sq	Coefficient to route preferential-flow storage down slope	fast interflow	0.003	0.028	0.000	0.315	0.790	0.818
gwflow_coef	Groundwater routing coefficient	Groundwater Flow	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06
gwsink_coef	Groundwater sink coefficient	Groundwater sink	1	1	1	1	1	1
imperv_stor_max	Maximum impervious area retention storage for each HRU	Hortonian Surface Flow	0	0.490	0.126	1	1	1
pref_flow_den	Preferential-flow pore density	Preferential flow	0.1064	0.0912	0.0841	0.2107	1E-05	1E-05
sat_threshold	Soil saturation threshold, above field-capacity threshold	gravity and preferential flow	11.31	250.72	38.20	184.35	7.27	6.96
slowcoef_lin	Coefficient to route gravity-flow storage down slope	slow interflow	0.0023	1.341E-05	0.0143	0.0009	5.146E-05	0.0012
slowcoef_sq	Coefficient to route gravity-flow storage down slope	slow interflow	0.0204	0.000	0.000	0.0041	0.0034	0.1746
smidx_coef	Coefficient in non-linear contributing area lgorithm	Hortonian Surface Flow	0.0011	0.0010	0.0010	0.0023	0.0010	0.0010
smidx_exp	Exponent in non-linear contributing area algorithm	Hortonian Surface Flow	0.1934	0.1	0.2005	0.1271	0.1	0.1

Parameter Name	Parameter Description	Associated Flow	Upper Soquel	Lower Soquel	Upper Aptos	Lower Aptos	Upper Corralitos	Lower Corralitos
soil_moist_max	Maximum available water holding capacity of soil profile. Soil profile is surface to bottom of rooting zone	NA	21.5	8.5	13.3	20.0	24	24
soil_rechr_max	Maximum value for soil recharge zone (upper portion of soil moisture zone where losses occur as both evaporation and transpiration)	NA	13	7.25	9.71	0.67	9.27	13
soil2gw_max	Maximum amount of the capillary reservoir excess that is routed directly to the GWR for each HRU	Direct Recharge	1.98E-05	0.0025	0.0015	0.0414	0.2337	0.0005
ssr2gw_rate	Coefficient in equation used to route water from the subsurface reservoirs to the groundwater reservoirs	Gravity Drainage	2.5909	0.0045	3.9344	0.1350	0.0203	0.2560
ssr2gw_exp	Coefficient in equation used to route water from the subsurface reservoirs to the groundwater reservoirs	Gravity Drainage	0.0079	0.0162	0.0005	0.0010	0.0102	0.2993

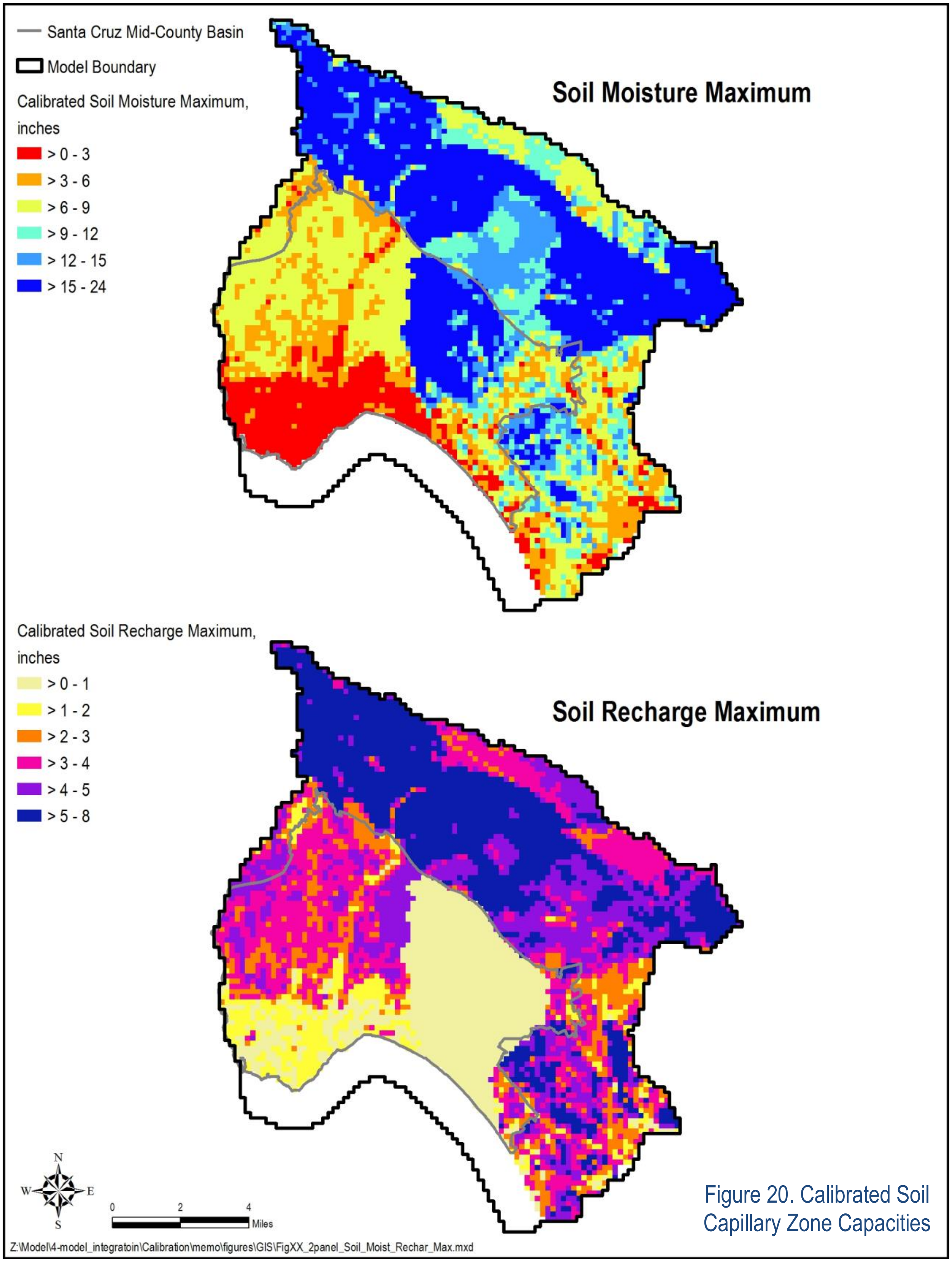


Figure 20. Calibrated Soil Capillary Zone Capacities

7.2.2 MODFLOW SFR Streambed Hydraulic Conductivity

As part of the streamflow calibration with GSFLOW, hydraulic conductivities for streambeds in the MODFLOW SFR package controlling flows between streams and groundwater were calibrated. Figure 21 shows the calibrated streambed hydraulic conductivities by SFR segment. For uniform streambed thickness of 3.28 feet, hydraulic conductivities of 3 x 10^{-}-^{3} feet per day are used for all streams except along lower Soquel Creek where shallow groundwater levels are available for calibration. Values of streambed hydraulic conductivity are relatively low throughout the watershed to facilitate simulation of slow recession curves controlled by soil retention of precipitation.

As calibrated for the Santa Cruz County Prop 1 grant scope, streambed hydraulic conductivities along Soquel Creek are higher (7 x 10^{-2} to 0.3 feet per day) where shallow groundwater level data are available. The data show connection between the shallow groundwater and Soquel Creek because the difference between shallow groundwater and stream stages is relatively small. Therefore, based on these available data, the model simulates more groundwater interaction with the stream for this area than what is simulated for the rest of the model. Simulating a relationship between shallow groundwater levels and flows between groundwater and streams is consistent with use of shallow groundwater levels as groundwater level proxies for streamflow depletion. However, data quantifying flows between the stream and shallow groundwater are not available for calibration so there is high uncertainty of the magnitude of simulated flows between stream and aquifer calculated by the model.

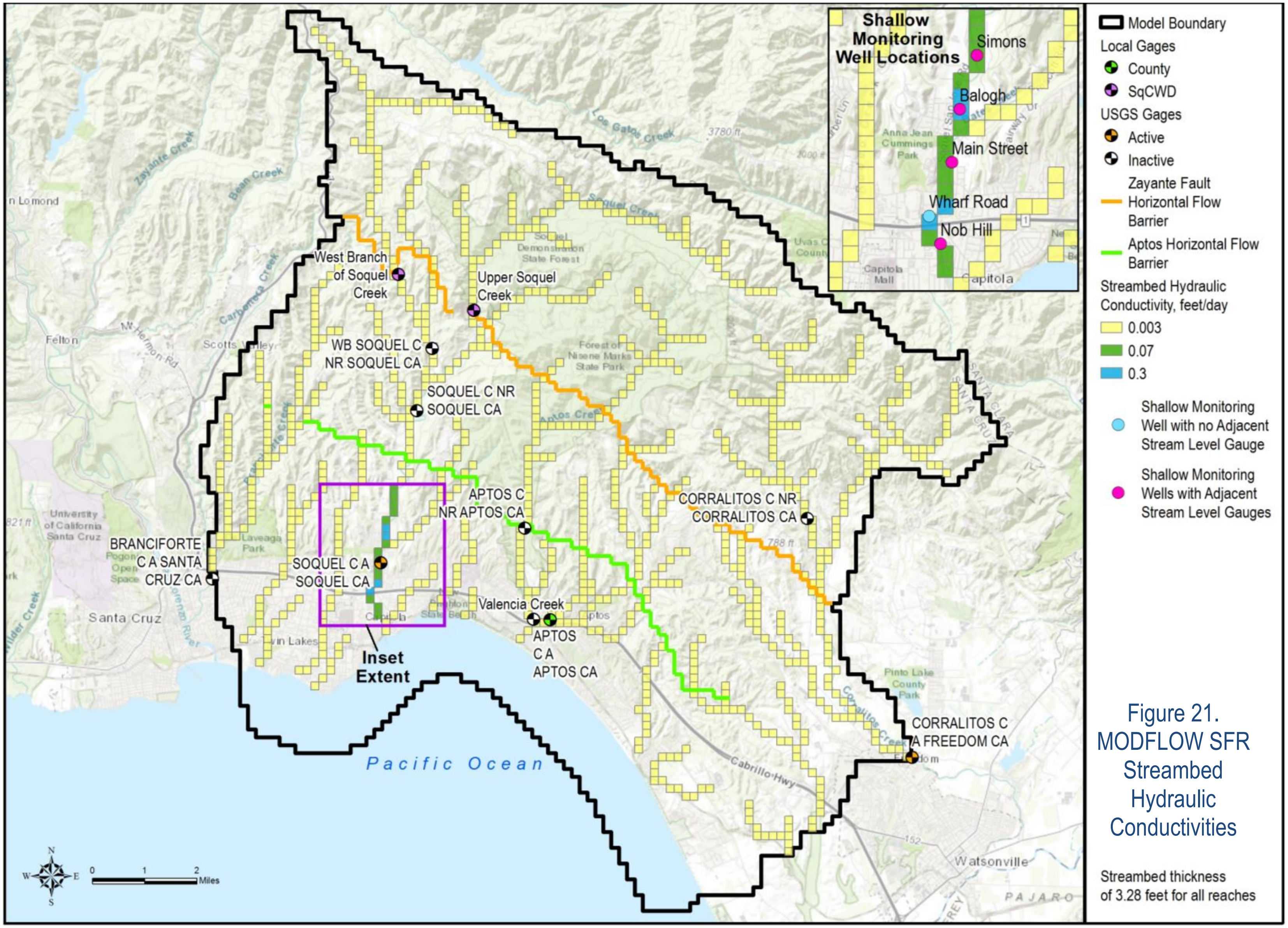


Figure 21. MODFLOW SFR Streambed Hydraulic Conductivities

7.2.2.1 Streamflow Calibration Results

Streamflow calibration results did not change substantially between the second step of streamflow calibration using GSFLOW for Water Years 1992-1995 and final calibration of GSFLOW for Water Years 1985-2015 that calibrated to shallow groundwater levels along Soquel Creek.

Measured streamflows were reasonably simulated at the two stream gauges with the most complete record of data: Soquel Creek at Soquel Gauge and Corralitos Creek at Freedom Gauge (see HydroMetrics WRI, 2016a for preliminary calibration results for PET and streamflow). Figure 22 shows simulated and observed streamflow for the two gauges over time.

Figure 23 and Figure 24 present observed *versus* simulated daily streamflow for calibration targets at the stream gauges with the most complete record of data. Results from an unbiased model (*i.e*., a perfectly-calibrated model) will align with the 45-degree line plotted on the figures. These plots demonstrate good and relatively unbiased calibration over the majority of streamflow ranges observed in the data, with some divergence in the simulated daily flows at very low (<1 cubic feet per second [cfs]) flow rates.

Goodness of fit between the simulated and observed streamflow was initially only assessed at annual time steps for preliminary model simulations, and was further evaluated at monthly and daily time steps using the Nash-Sutcliffe statistic (Nash and Sutcliffe, 1970). As a more quantitative measure of how well the model predicted streamflow, the Nash-Sutcliffe goodness of fit (NS) statistic was calculated for each of the gauges. This statistic has been used previously in other PRMS models to evaluate the performance of the PRMS calibration (Hay et al., 2006; Dudley, 2008; Viger *et al*., 2010). The NS statistic provides a measure of whether the PRMS model is a better predictor of annual streamflows than the average streamflow.

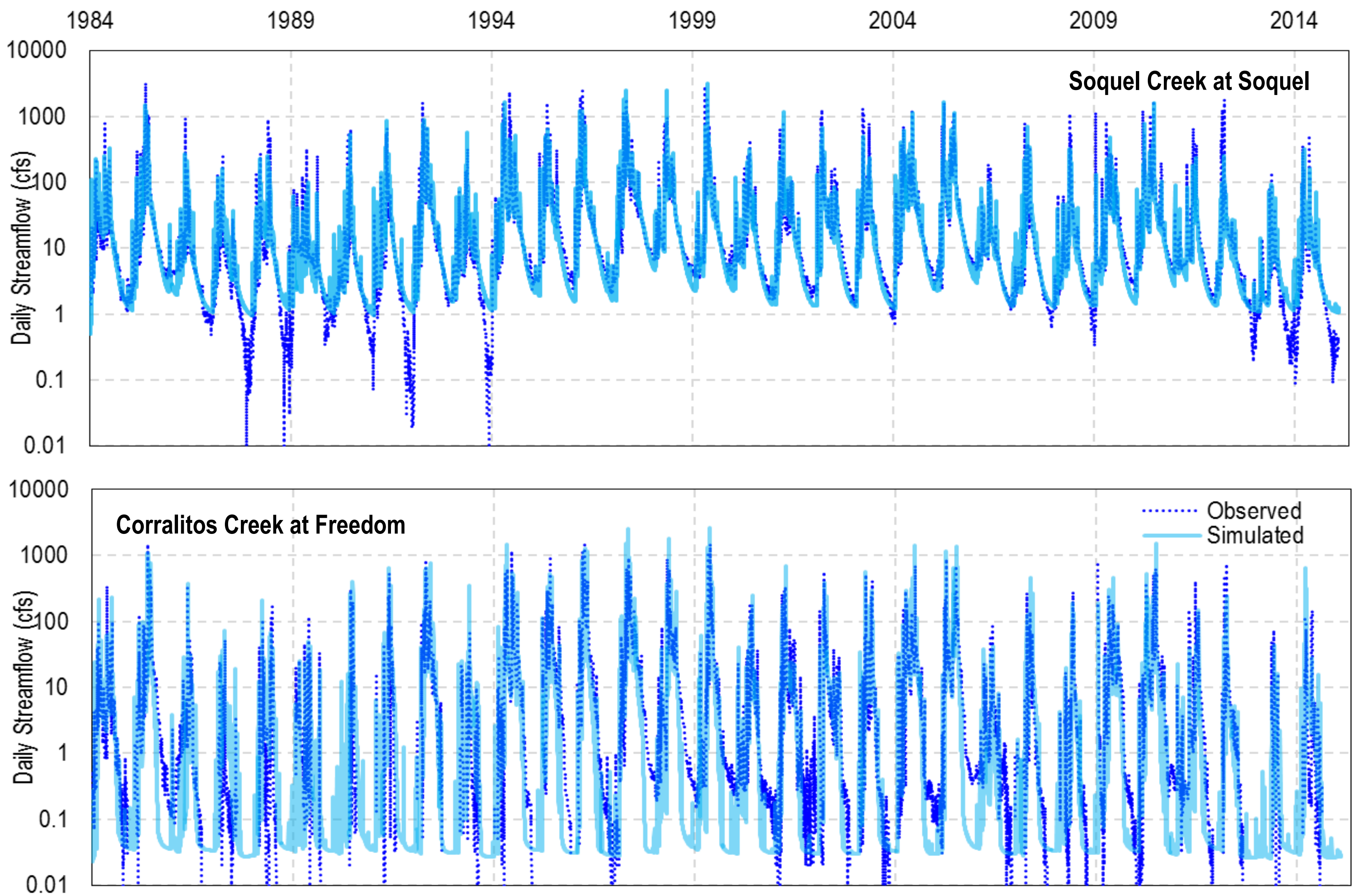


Figure 22. Simulated and Observed Streamflow: Soquel Creek at Soquel and Corralitos Creek at Freedom Gauges

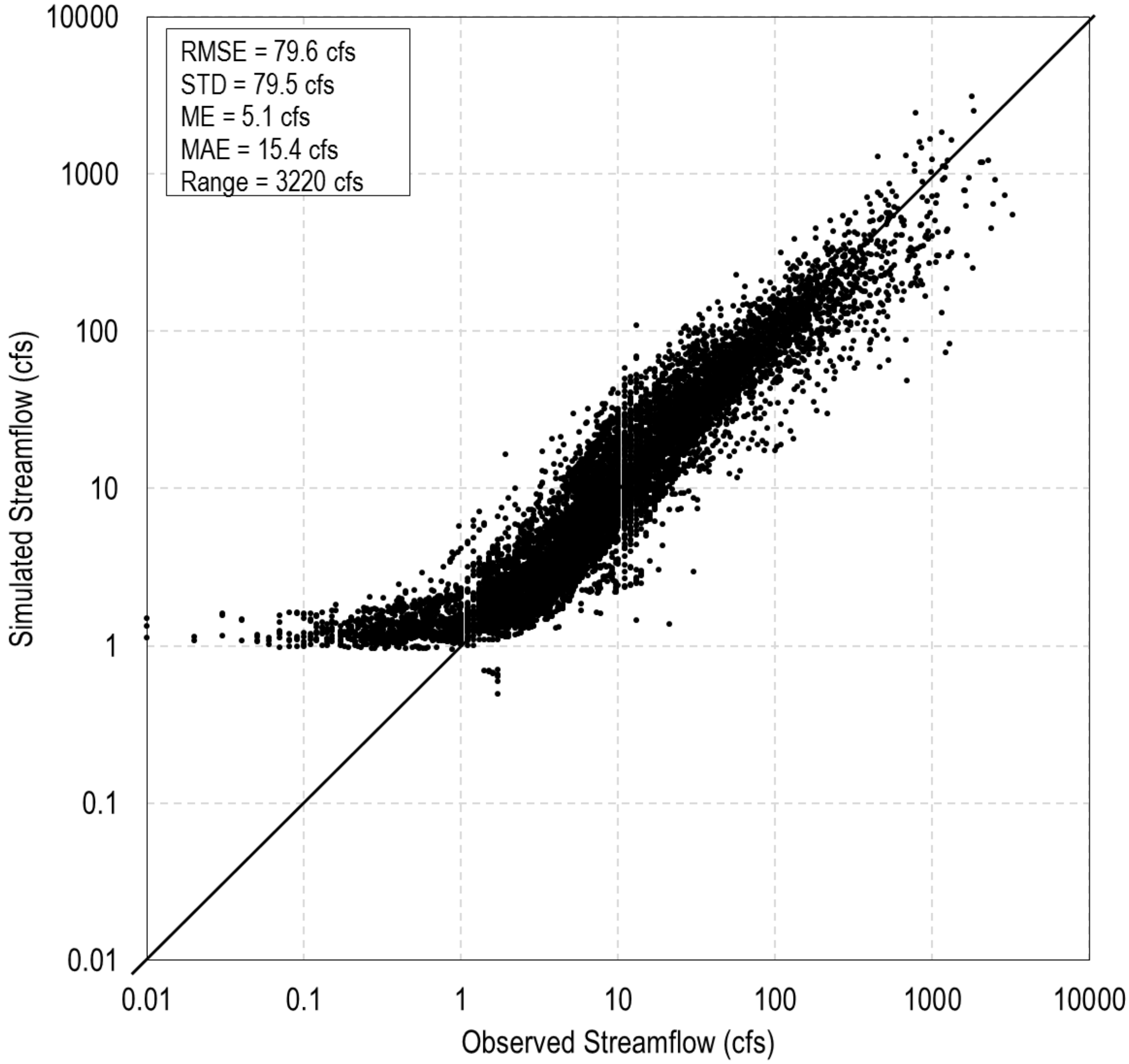


Figure 23. Soquel at Soquel Gauge Observed vs. Simulated Daily Streamflow

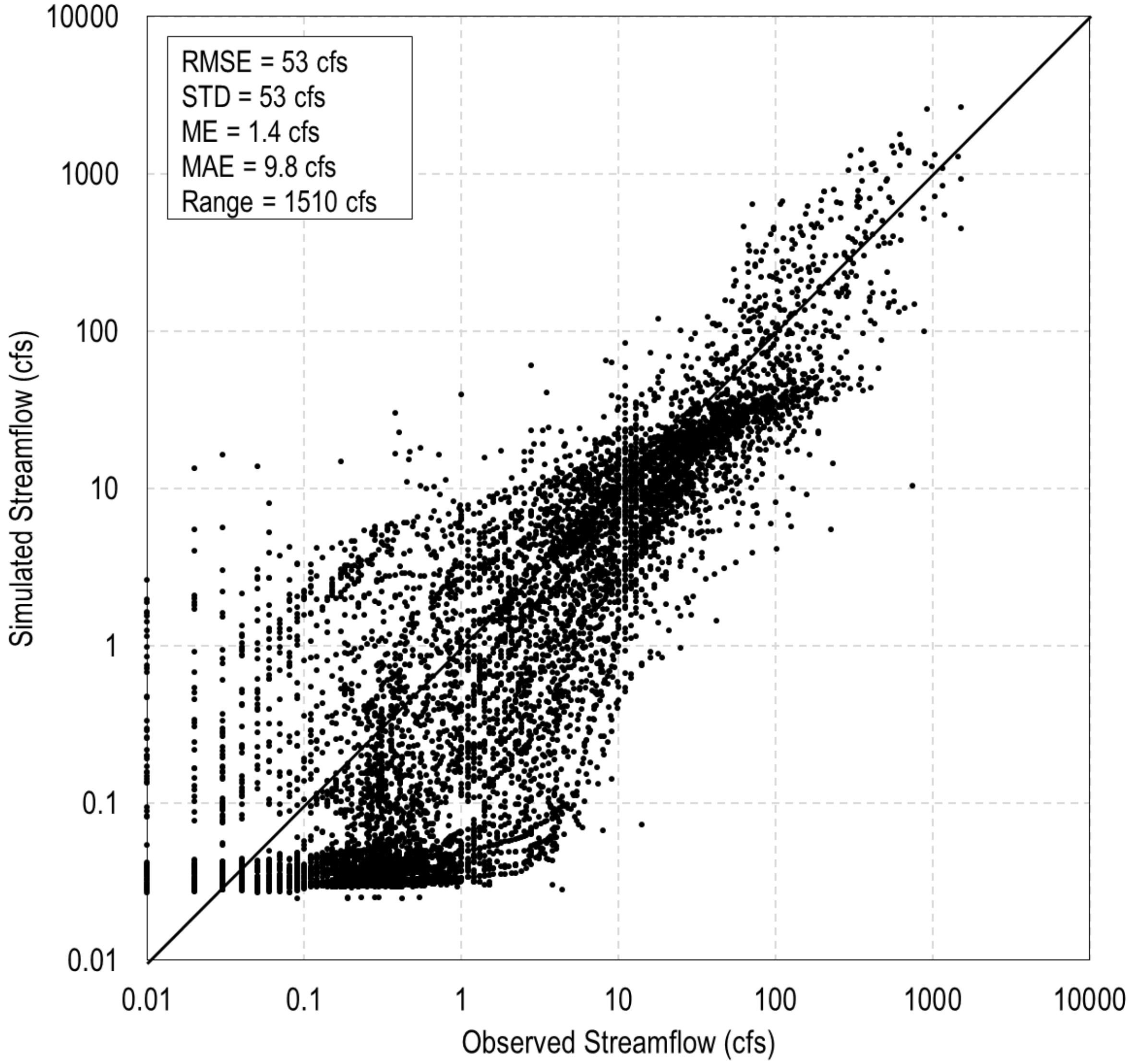


Figure 24. Corralitos at Freedom Gauge Observed vs. Simulated Daily Streamflow

The NS value is calculated for each water year as follows (Moriasi et al., 2007; Nash and Sutcliffe, 1970):

$$NS = 1.0 - \sum_{n=1}^{ndays} (MSD_n - SIM_n)^2 / \sum_{n=1}^{ndays} (MSD_n - MN_n)^2$$

where MSD = measured daily runoff values,

SIM = simulated daily runoff values,

MN = average of the measured values, and

n = the number of values out of a total of n days (ndays).

An NS value of one indicates a perfect fit between observed and simulated. A value of zero indicates that predicting annual streamflows with the PRMS model is as good as using the average value of all the observed data. Any value above zero is considered acceptable, and indicates that predicting annual streamflows with the PRMS model is better than using the average value of all the observed data. Figure 25 and Figure 26 present Nash-Sutcliffe results for stream gauges with the most complete record of data. Based on the NS charts presented for the Soquel at Soquel Gauge and the Corralitos at Freedom Gauge in Figure 25 and Figure 26, it can be inferred that predicting annual streamflows with the current PRMS model is better than using the average value of all the observed data.

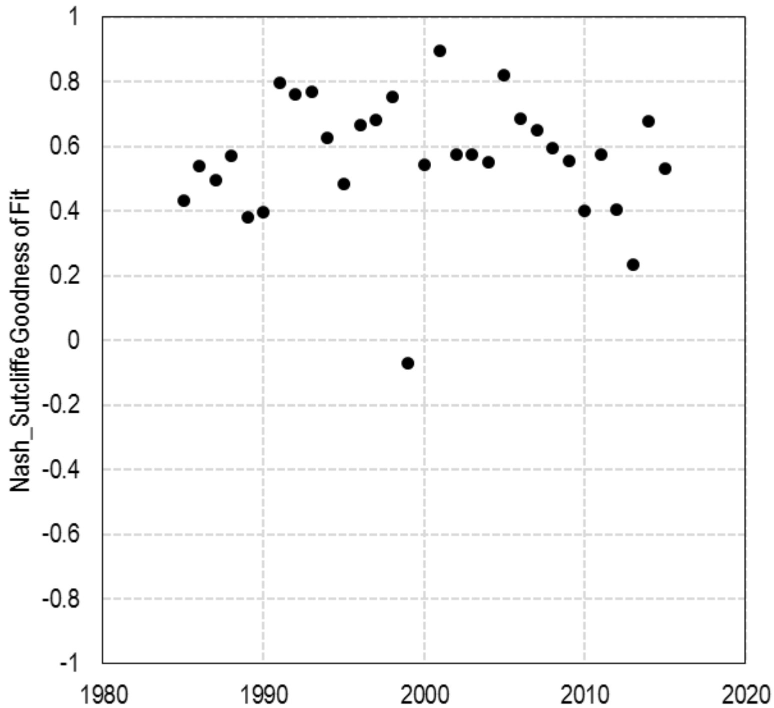


Figure 25. Nash-Sutcliffe Goodness of Fit, Soquel at Soquel Gauge

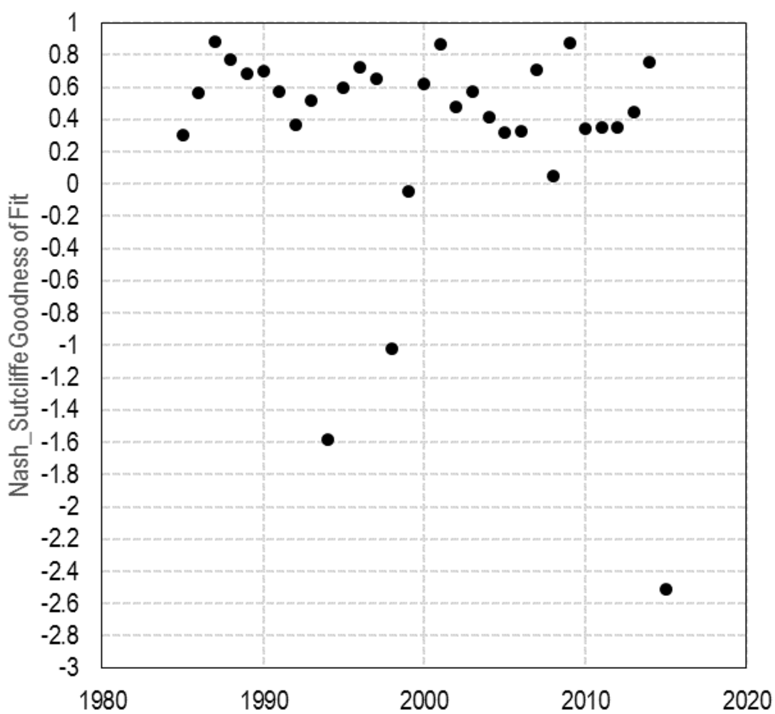


Figure 26. Nash-Sutcliffe Goodness of Fit, Corralitos at Freedom Gauge

7.3 Groundwater Calibration

The primary groundwater model parameters adjusted during calibration were as follows:

- The horizontal and vertical components of hydraulic conductivity (Kh and Kz, respectively.
- Storage parameters specific storage (Ss) and specific yield (Sy).
- GHB conductances of the offshore, seafloor, Santa Margarita Basin, and southeastern GHBs.
- Fault conductances for both the Zayante Fault and Aptos-area faulting, as represented by conductance values within the horizontal flow barrier (HFB) package in MODFLOW.

7.3.1 Groundwater Parameters Distributed by Pilot Point Method

A pilot point approach was taken to distribute the Kh, Kz, Ss, and Sy aquifer properties within the Basin model during calibration. This approach is documented by John Doherty (2003), and is similar to the approach used for the CWD groundwater model (HydroMetrics, 2014b).

The pilot point methodology estimates aquifer properties at specific points within the model domain, and interpolates the values between those points over the entire domain. Pilot points are generally placed where more calibration target data are available; in this Basin model, points clustered near the coastal well areas. Points were also distributed between pumping wells and outflow boundaries, and in areas to eliminate large spatial gaps between points. Pilot points for Kh, Kz, Ss, Sy were co-located, and their distribution in each model layer is presented on Plate 5 and Figure 27.

Plate 6 through Plate 9 show the distribution for calibrated horizontal and vertical hydraulic conductivity, specific storage and specific yield for each model layer. Plate 8 shows the approximate maximum area that is confined where the specific storage aquifer property applies. Plate 9 shows the approximate maximum area that is unconfined where the specific yield aquifer property applies.

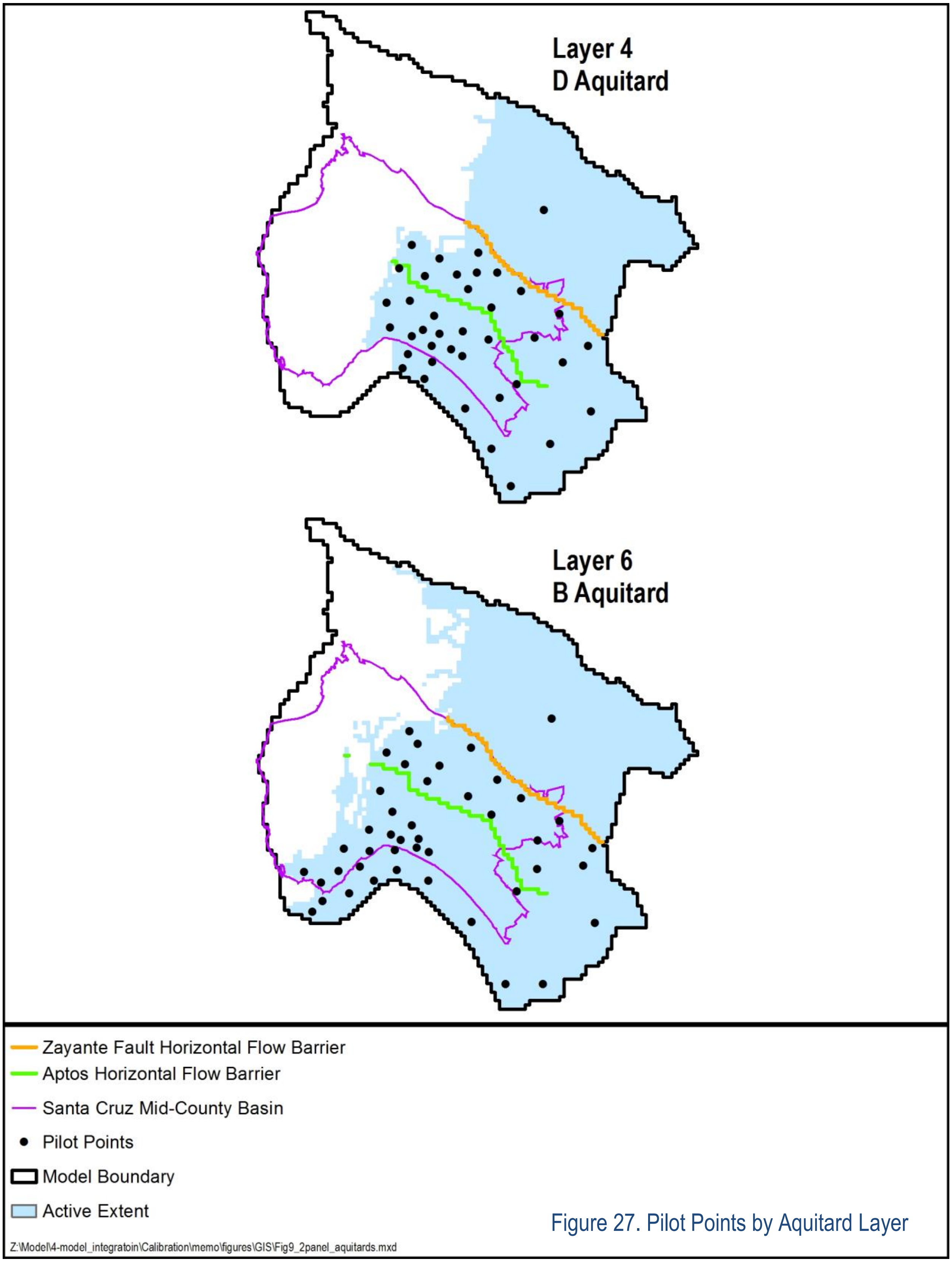


Figure 27. Pilot Points by Aquitard Layer

7.3.2 Hydraulic Properties by Basin Aquifer and Aquitard Layers

The following describes calibrated hydraulic properties by layer, focusing on the area where calibration targets exist. This area includes parts of Santa Cruz Mid-County Basin and Pajaro Valley Subbasin for the Aromas Red Sands Formation (model layer 2), south of the modeled Aptos area fault for the Purisima Formation (model layers 3-8), and the area providing municipal supply in the Tu unit (model layer 9).

- The Aromas Red Sands Formation (model layer 2) generally has higher horizontal hydraulic conductivity than other layers, though hydraulic conductivity in the Santa Cruz Mid-County Basin is generally lower than the Pajaro Valley Subbasin. Specific yield is modeled as relatively homogenous in this layer.

- The harmonic average of calibrated vertical hydraulic conductivity for Aromas Red Sands Formation and Purisima F aquifer units (model layers 2 and 3) that controls vertical flow between the layers is relatively high compared to vertical conductivity in other layers consistent with lack of a well-defined aquitard between the Aromas Red Sands and Purisima Formations.

- The Purisima F Unit (the eastern portion of model layer 3) has higher horizontal hydraulic conductivity than the Purisima DEF Unit (the western portion of model layer 3). The Purisima F Unit area has relatively high specific storage consistent with fast recovery observed at the SqCWD and CWD Rob Roy wells in the area. The Purisima DEF unit area has low specific yield in an area simulated as unconfined; however the DEF unit is more likely confined in this area and the combination of F and DEF units in the model make it difficult to simulate the confined response in the DEF Unit.

- Vertical hydraulic conductivity of the Purisima D Unit (model layer 4) is low consistent with this well-defined hydrostratigraphic unit being an aquitard.

- The Purisima BC Unit (model layer 5) has relatively low horizontal hydraulic conductivity and low specific storage consistent with the low yield and larger drawdowns of the aquifer.

- Vertical hydraulic conductivity of the Purisima B Unit (model layer 6) is low consistent with this well-defined hydrostratigraphic unit being an aquitard.

- The Purisima A Unit (model layer 7) has larger onshore areas of relatively high hydraulic conductivity (> 5 feet/day) compared to layers representing the Purisima Formation DEF, BC, and AA units, consistent with this unit having the largest number of productive wells in the Purisima. There is high hydraulic conductivity offshore to increase the connection with the offshore boundary condition. Specific storage along the coast is low to better match the groundwater level response at coastal monitoring wells to pumping.

- The Purisima AA Unit (model layer 8) has lower horizontal hydraulic conductivity than the Purisima A unit onshore in the Western Purisima area where the two units are pumped, but also has high hydraulic conductivity offshore in the west to increase the connection with where Purisima A unit outcrops. Horizontal hydraulic conductivity is high where Purisima AA unit outcrops inland. Specific storage is relatively high, especially for areas south of the horizontal flow barrier representing Aptos area faulting.

- Vertical hydraulic conductivities of the Purisima A and AA Units (model layers 7 and 8) controlling flow between the aquifer units are higher than for the Purisima D and B units (model layers 4 and 6) representing well defined aquitards. The vertical hydraulic conductivities offshore are high to connect the AA Unit with offshore outcrop that only occurs in the A Unit. In order to calibrate observed response in shallow groundwater levels to deeper Purisima Formation pumping, Purisima A unit vertical hydraulic conductivity is relatively high underlying Soquel Creek.

- The Tu Unit (model layer 9) has high horizontal hydraulic conductivity where SqCWD and City wells pump in the unit with moderate conductivities west to the approximate outcrop of the Santa Margarita Formation. The limited area of moderate and high conductivities is consistent with the apparent limits to recharge supplying the SqCWD and City wells in the unit. The vertical conductivity of the Tu Unit is very low to provide minimal connection between the Tu and the Purisima Formation. Specific storage is low to better match drawdown responses to pumping.

- Properties in areas without calibration data, such as north of the Zayante Fault and in most layers between the Zayante Fault and the HFB representing Aptos area faulting, are simulated as homogenous. Values in these areas are assigned to simulate water budget that facilitates calibration where data are available.

Hydraulic properties for the model were not calibrated to estimates for hydraulic properties obtained from pumping tests at wells in the Basin. The purpose of the Basin model is to simulate regional aquifer response to groundwater use and management in the Basin and therefore calibrating to static groundwater levels at monitoring wells is more appropriate for that purpose. Pumping tests typically provide near-well data for the response at the pumping well to pumping at the same well and therefore are more representative of conditions at the well and the immediately vicinity of the well. For reference, Appendix B provides a comparison of modeled hydraulic properties near wells with pumping test data with estimates of properties from the pumping test data.

7.3.3 Hydraulic Properties for Stream Alluvium and Terrace Deposit

Model cells underlying stream alluvium and representing overlying Terrace Deposits are mostly homogenous with high hydraulic conductivities (Kx=50 feet per day and Kz=0.1 feet per day) and relatively high specific yield of 0.15. These properties were mostly not adjusted during calibration except for two exceptions. Specific yield in the stream alluvium where shallow monitoring wells along Soquel Creek are located were lowered to 0.015 to simulate observed response to seasonal pumping cycles. Hydraulic conductivity was lowered (Kx=1 feet per day and $Kz=1x10^{-4}$ feet per day) for Terrace Deposit in model layers 6 and 7 to reduce vertical recharge into the Purisima Formation from these western areas.

7.3.4 Boundary Condition Calibration

Plate 10 presents calibrated estimates of GHB conductance by aquifer layer. Conductance is the hydraulic conductivity multiplied by cross-sectional area of flow divided by distance to boundary, which represent's the GHB's ability to transmit flow. Most of the GHB conductances represent the conceptual model for the GHB and did not require much adjustment during calibration. These GHBs include the offshore GHBs at the model boundaries, the Pajaro Valley Subbasin GHBs on each side of the Zayante Fault, and the Santa Margarita Basin GHBs.

- GHBs at the model boundary one mile offshore have very high conductances because it is assumed that groundwater is full strength seawater at the location.
- GHBs along the side boundaries that connect the shore out to the boundary one mile offshore have very low conductance to emphasize the effect of GHBs one mile offshore and for outcrops under the Bay.
- GHBs in the Pajaro Valley Subbasin south of Zayante Fault have low conductance to reflect the distance to the offshore location defining the GHB head.
- GHBs in the Pajaro Valley Subbasin north of Zayante Fault have low conductance to reflect stream conductance within Ryder Gulch that defines the GHB head.
- GHBs in the Santa Margarita Basin have high conductance to better represent nearby observations of groundwater levels.

The GHBs with conductances adjusted most in calibration were the GHBs representing offshore outcrops of aquifer units underneath Monterey Bay.

- GHBs in the Aromas Red Sands Formation (model layer 2) have low conductances for a limited connection between onshore groundwater levels with the offshore boundary. Since brackish groundwater occurs in part of the Aromas Red Sands Formation, implementation of the SWI2 seawater intrusion package may improve simulation of onshore groundwater levels in model layer 2 given presence of the freshwater-seawater interface onshore.

- GHBs in the Purisima DEF/F and BC Units (model layers 3 and 5) have low conductances for a limited connection between onshore groundwater levels with the offshore boundary. Since brackish groundwater occurs in part of the the Purisima F unit, implementation of the SWI2 seawater intrusion package may improve simulation of onshore groundwater levels in this area of model layer 3 given presence of the freshwater-seawater interface onshore.

- GHBs in the Purisima A Unit (model layer 7) have high conductances for a greater connection between onshore groundwater levels with the offshore boundary.

Plate 10 also presents calibrated estimates of horizontal flow barrier (HFB) leakance by aquifer layer to represent faulting. Leakance, or the HFB hydraulic characteristic, is equivalent to the hydraulic conductivity of the HFB divided by HFB width that represents the HFB's ability to transmit flow. In general, leakances for the HFB representing faulting in the Aptos area are lower than leakances for the Zayante Fault. Groundwater level data show a large gradient across the Aptos area, while some amount of flow across the Zayante Fault is necessary for the water budget.

7.3.5 Calibration of Groundwater Elevations in Basin Aquifer Units

Groundwater model calibration is commonly evaluated by comparing simulated groundwater levels to observed groundwater levels that make up the groundwater calibration targets as described in the sections above. Hydrographs of simulated groundwater elevations should generally match the trends and fluctuations observed in measured hydrographs. Selected hydrographs showing both observed and simulated groundwater elevations are provided in Appendix C. The hydrographs included in Appendix C were selected to represent different areas and aquifers within the model. Also, monitoring wells separated from production wells are prioritized to represent regional aquifer response to pumping. The hydrographs demonstrate that the model is accurately simulating historical hydrologic trends and response to pumping within the major aquifers of interest in the Basin, particularly at coastal monitoring wells where groundwater levels are evaluated against protective elevations to assess risk of seawater intrusion. Figure 28 through Figure 31 show hydrographs for the coastal monitoring wells that are representative monitoring points in the GSP with groundwater elevations used as proxies for seawater intrusion. The calibration supports use of model results at these wells from simulations of future conditions for comparison to the proxies to evaluate whether sustainability is achieved for the seawater intrusion indicator.

Areas where model fit is less accurate typically fall in to two categories:

- Areas where calibration target wells exhibit a confined response to pumping but fall within areas where the layer in which they are screened are unconfined within the model. This is a limitation in the vertical discretization of the model, as in Layer 3, which is a combination of the DEF and F units of the Purisima.

- Inland areas of the model where calibration target density and associated parameter pilot point density is low. These wells are often private wells with little information in areas relatively far from areas where protective groundwater elevations have been determined.

In general, the accuracy of the model to groundwater conditions within the protected aquifers, especially in regions near the coast, will make this model a robust platform for future predictive scenario of management alternatives and other groundwater infrastructure projects within the Basin.

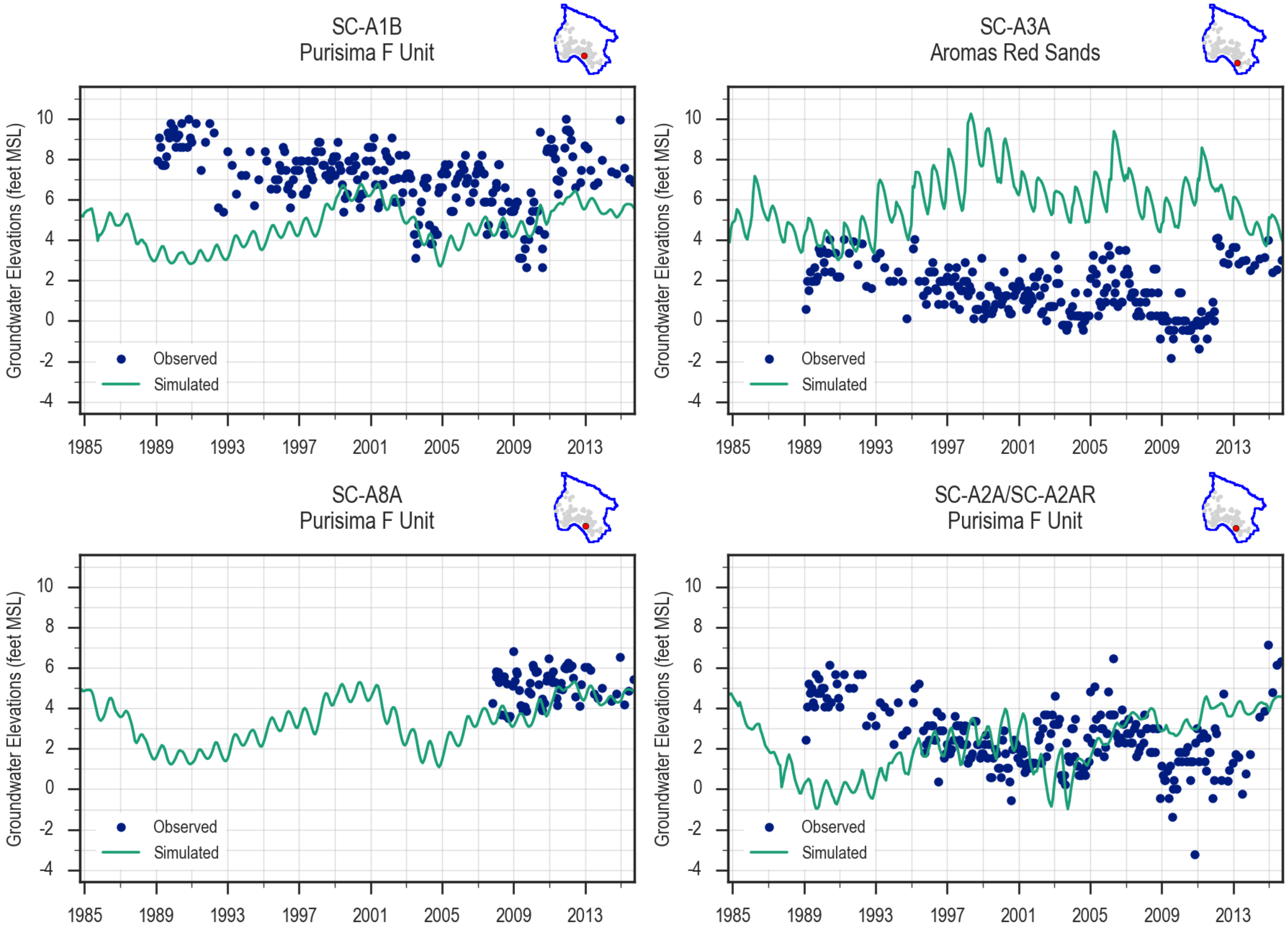


Figure 28. Calibration Hydrographs at Coastal Monitoring Wells in Aromas and Purisima F Units

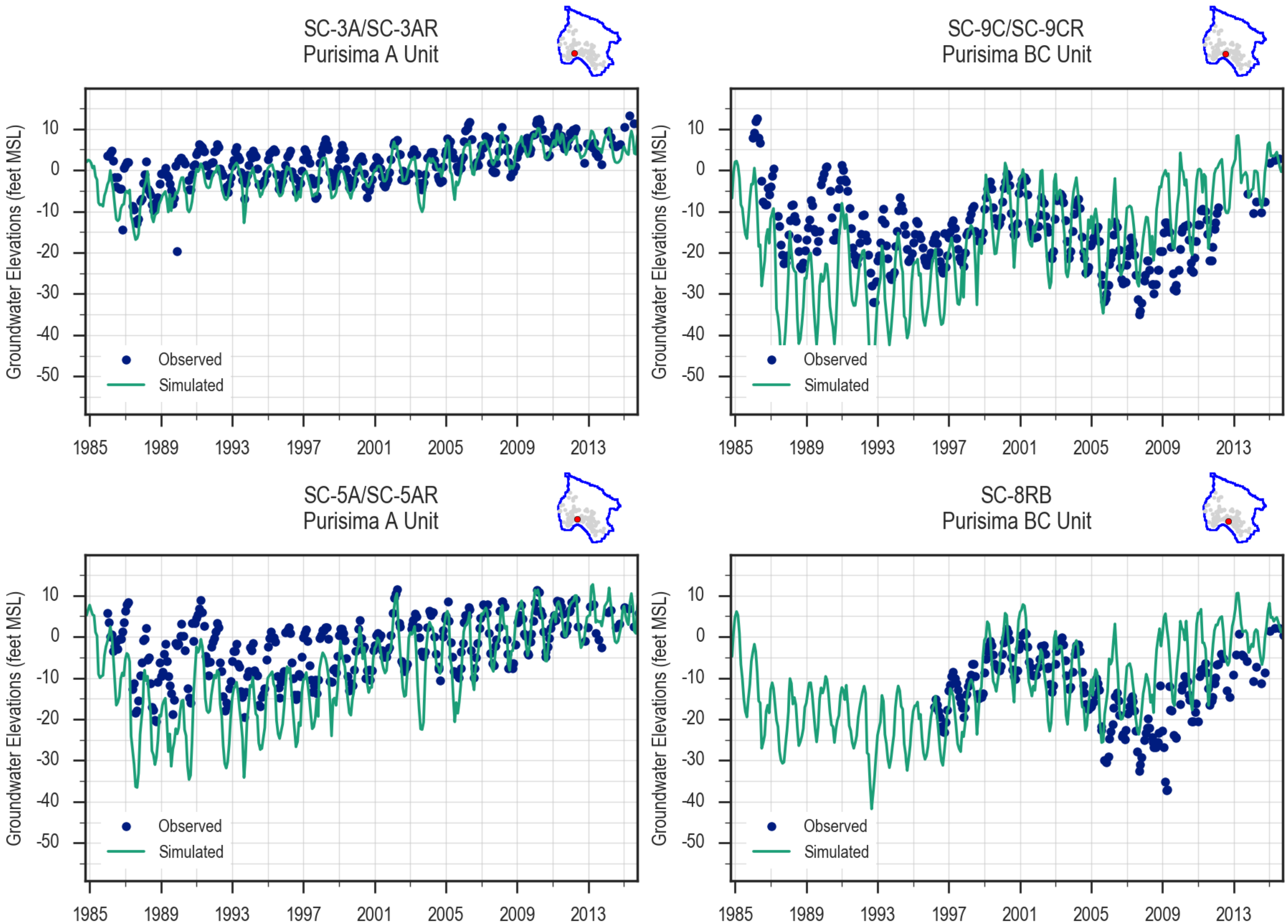


Figure 29. Calibration Hydrographs at Coastal Monitoring Wells in Purisima BC and A Units

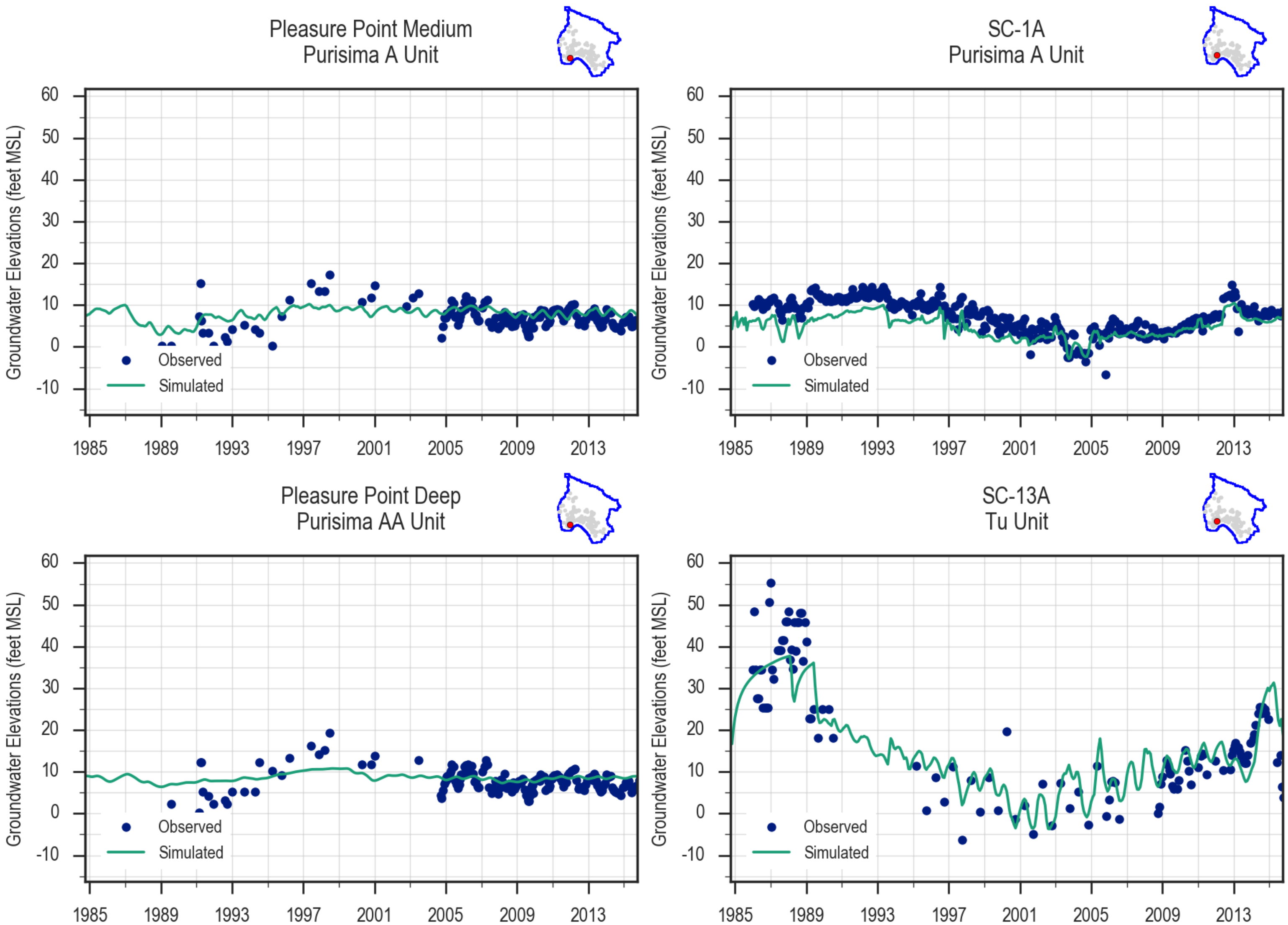


Figure 30. Calibration Hydrographs at Coastal Monitoring Wells in Purisima A and AA Units and Tu Unit

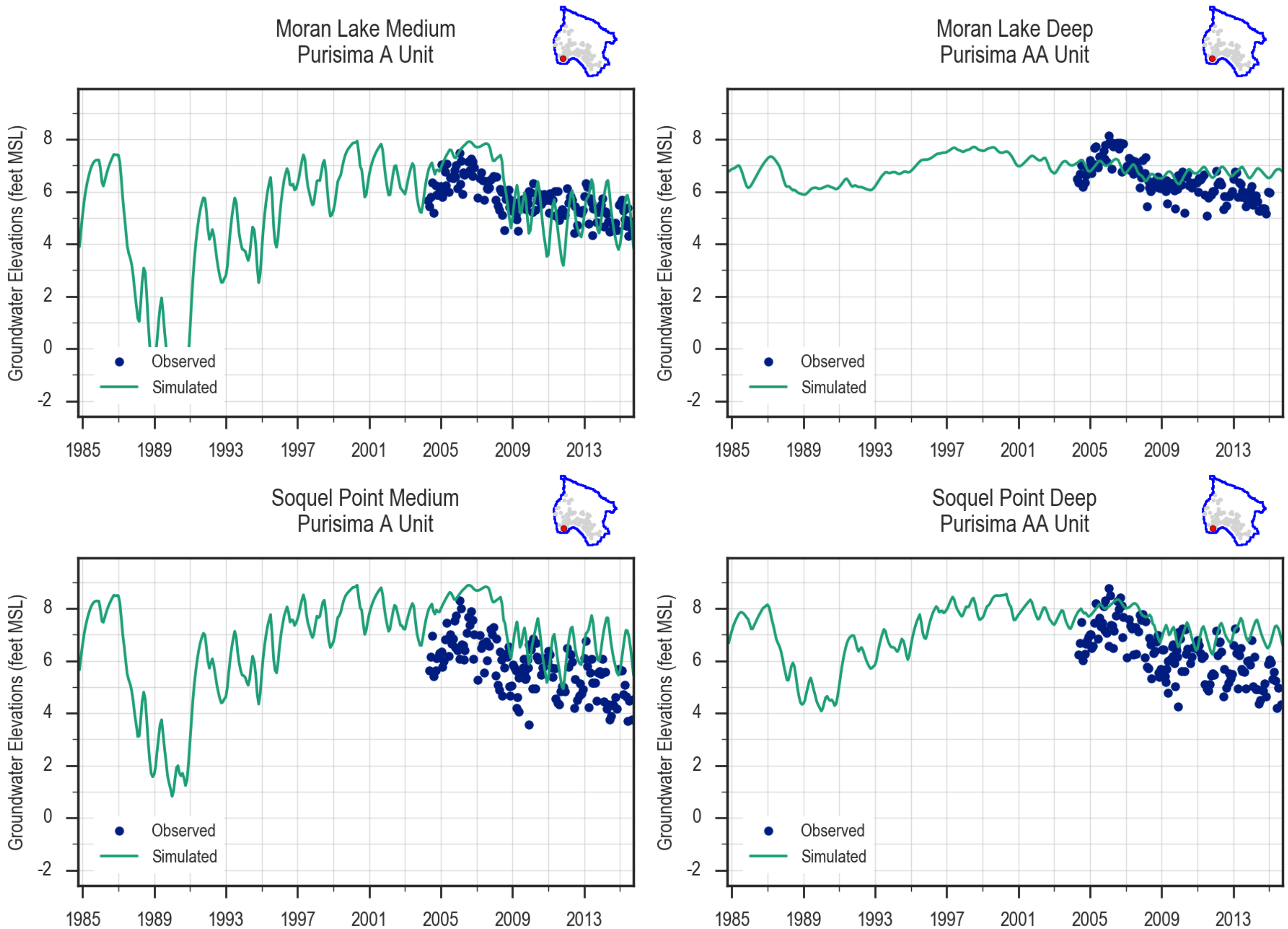


Figure 31. Calibration Hydrographs at Coastal Monitoring Wells in Purisima A and AA Units

Various graphical and statistical methods can be used to demonstrate the magnitude and potential bias of the calibration errors. Figure 32 shows simulated groundwater elevations plotted against observed groundwater elevations for the entire calibration period. Results from an unbiased model will scatter around a 45º line, shown as a solid black line on this graph. If the model has a bias such as exaggerating or underestimating groundwater level differences, the results will diverge from this 45º line. The distribution of data points on Figure 32 show that they cluster along the 45º line, indicating that the model results are not biased towards overestimating or underestimating average groundwater level differences.

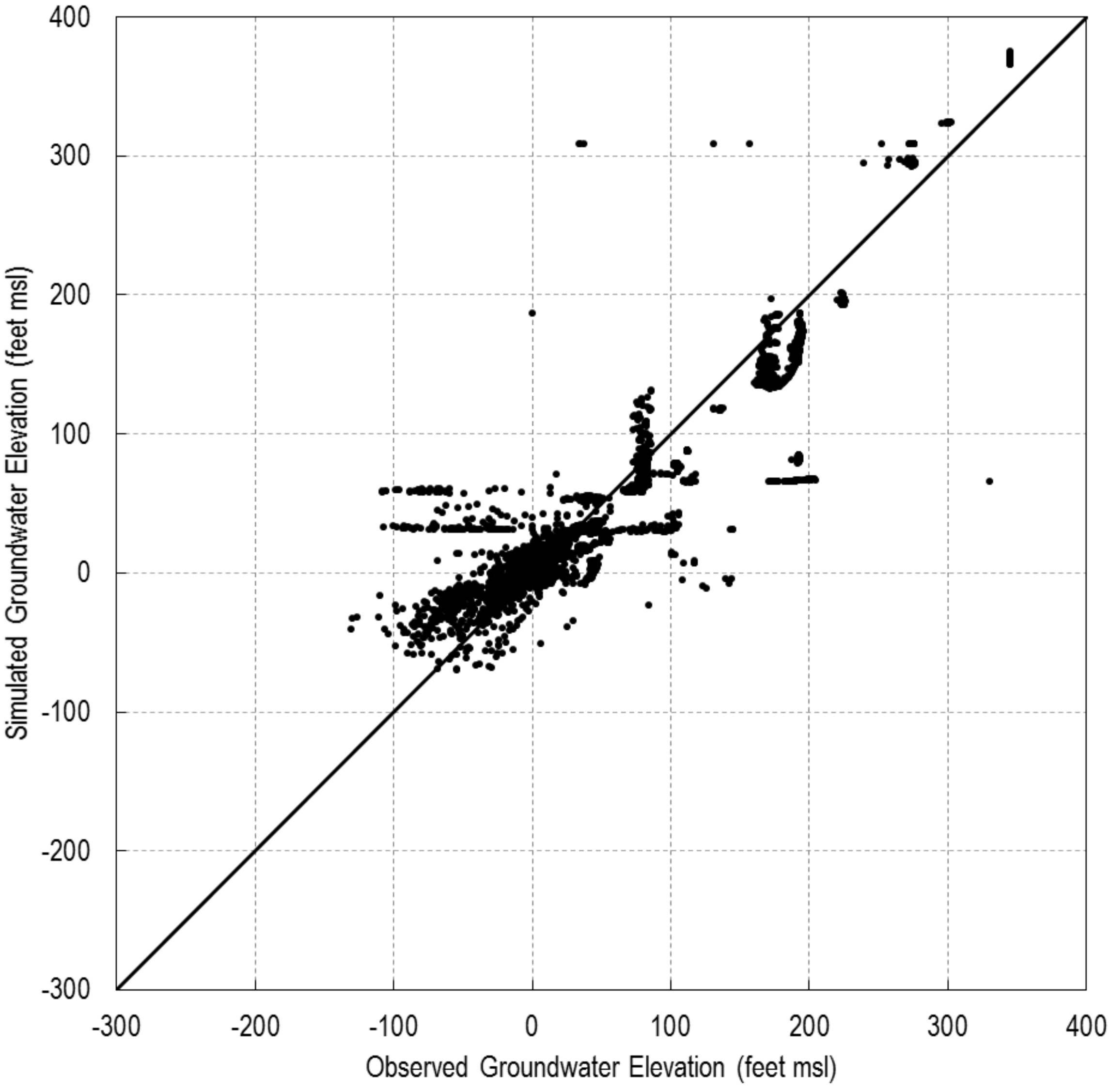


Figure 32. Observed vs. Simulated Groundwater Elevations from Groundwater Calibration Targets in Model

Table 10 includes various statistical measures of calibration accuracy. The four statistical measures used to evaluate calibration are the mean error (ME), the mean absolute error (MAE), the standard deviation of the errors (STD), and the root mean squared error (RMSE). The mean error is the average error between measured and simulated groundwater elevations for all data on Figure 32.

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(h_m - h_s\right)_i$$

Where h_m is the measured groundwater elevation, h_s is the simulated groundwater elevation, and n is the number of observations.

The mean absolute error is the average of the absolute differences between measured and simulated groundwater elevations.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|h_m - h_s\right|_i$$

The standard deviation of the errors is one measure of the spread of the errors around the 45º line in Figure 32. The population standard deviation is used for these calculations.

$$STD = \sqrt{\frac{n\sum_{i=1}^{n}\left(h_m - h_s\right)_i^2 - \left(\sum_{i=1}^{n}\left(h_m - h_s\right)\right)_i^2}{n^2}}$$

The RMSE is similar to the standard deviation of the error. It also measures the spread of the errors around the 45º line in Figure 32, and is calculated as the square root of the average squared errors.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(h_m - h_s\right)_i^2}$$

As a measure of successful model calibration, Anderson and Woessner (1992) state that the ratio of the spread of the errors to the total head range in the system should be small to ensure that the errors are only a small part of the overall model response. As a general rule, the RMSE should be less than 10% of the total head range in the model. The RMSE of 22.13 feet is approximately 2.3% of the total head range of 983.60 feet. A second general rule that is occasionally used is that the mean absolute error should be less than 5% of the total head range in the model. The mean absolute error of 10.17 feet is approximately 1.0% of the total head range. Therefore, on average, the model errors are within an acceptable range.

Table 10. Statistical Measures of Model Calibration

Statistical Measure	Abbreviation	Measure Value	Ratio of Measure to the Range of Observed Values
Root Mean Square Error	RMSE	22.13	2.3%
Standard Deviation	STD	22.09	2.2%
Mean Error	ME	1.29	0.1%
Mean Absolute Error	MAE	10.17	1.0%
Range of Observed Values	Range	983.60	

7.3.6 Groundwater Elevation Calibration in Shallow Wells along Soquel Creek

Under Santa Cruz County's Prop 1 grant, the model was calibrated to shallow groundwater elevations along Soquel Creek in order to support use of the model to evaluate streamflow depletion from pumping. The purpose of this focused calibration is for the model to simulate the long-term trends where shallow aquifer response to deeper pumping is observed. This is primarily achieved by adjusting hydraulic parameters that control the vertical connection between the stream, the layer representing shallow alluvium, and the deeper Purisima Formation units (Figure 15). The main hydraulic parameters controlling this connection is streambed hydraulic conductivity (Section 7.2.2) and Purisima Formation vertical conductivity (Section 7.3.2).

In order to show the vertical connection, hydrographs of simulated results and observations at shallow wells are shown with hydrographs of simulated results in underlying Purisima Formation layers. As described in Section 7.3.5 , the model is calibrated to simulate response to pumping in the Purisima Formation. Figure 33 shows the hydrographs of the upstream Simons and Balogh shallow wells where observed shallow groundwater levels do not show the long term trend of a response to Basin pumping simulated in the underlying Purisima A unit. The model is calibrated also to not simulate a shallow aquifer response to pumping.

The Main Street shallow well is adjacent to the Main Street production well that is screened in the deeper Purisima AA unit and Tu unit. Figure 34 shows a muted response at the Main Street shallow wells to pumping compared to the response simulated in the Purisima AA unit, but observed groundwater levels at the Main Street shallow well do follow the long-term trend of groundwater level recovery from 2001 to 2011, then a brief increase in drawdown in 2012-2013, with increased pumping from the Main Street well and a rebound thereafter.

Figure 35 shows similar simulation of long-term trends at the Nob Hill shallow well.

These shallow monitoring wells are representative monitoring points in the GSP with groundwater elevations used as proxies for the streamflow depletion sustainable management criteria. The basis for the use of these proxies is that the higher shallow groundwater levels indicate greater groundwater flow to streams, and lower shallow groundwater levels indicate less groundwater flow to streams based on the apparent connection between stream stages and shallow groundwater levels. The model is calibrated to simulate the observed shallow groundwater elevations in response to groundwater levels and pumping in deeper Purisima units. The calibration supports use of model results for simulations of future conditions at these wells. The results can be compared to groundwater level proxies for evaluating whether sustainability is achieved for the depletion of interconnected surface water indicator. Therefore, the model can be used to evaluate effects of projects and management actions in the deeper Purisima units on shallow groundwater levels for comparison to the groundwater level proxies.

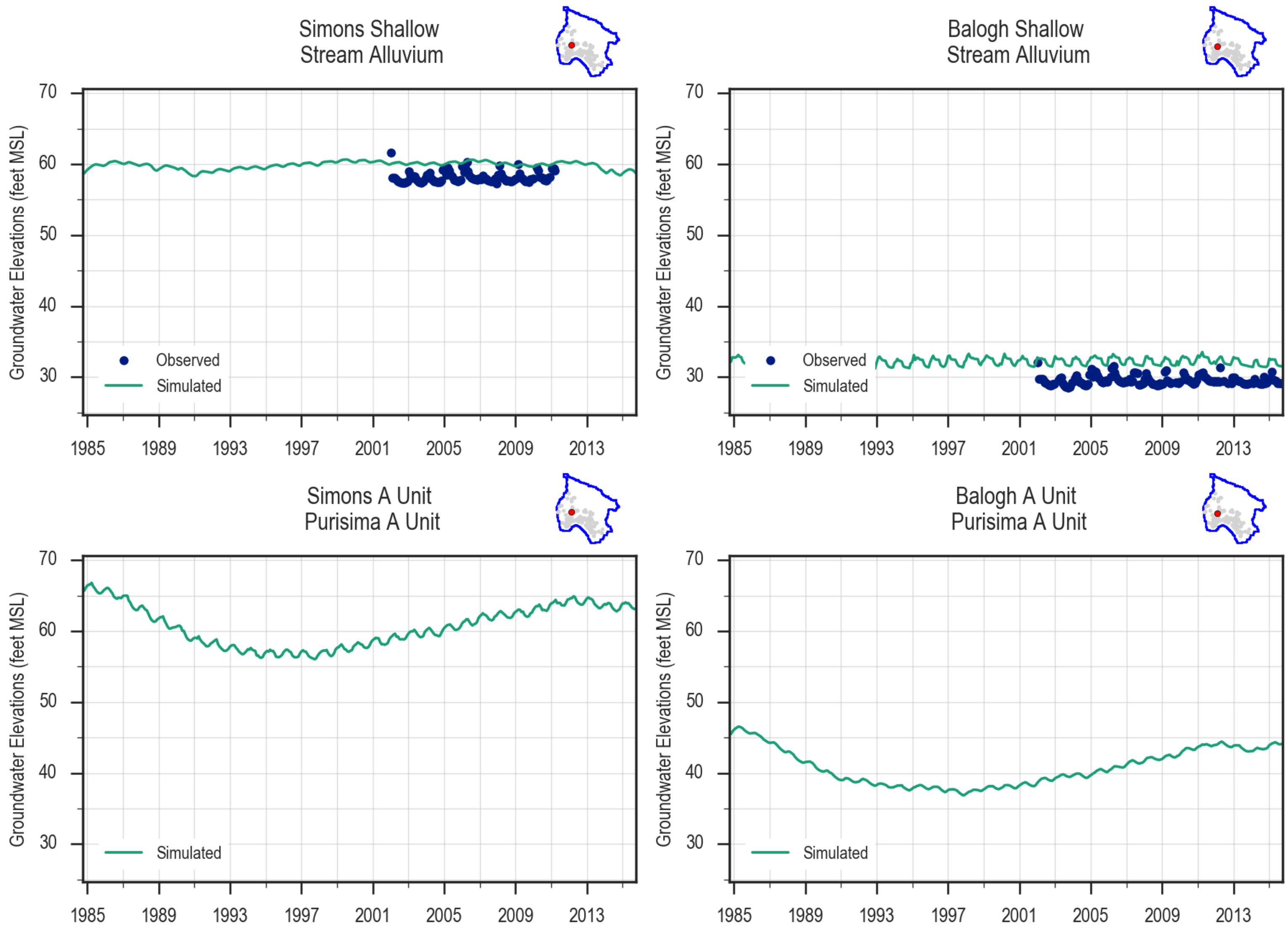


Figure 33. Calibration Hydrographs at Simons and Balogh Shallow Wells and Underlying Purisima A Unit

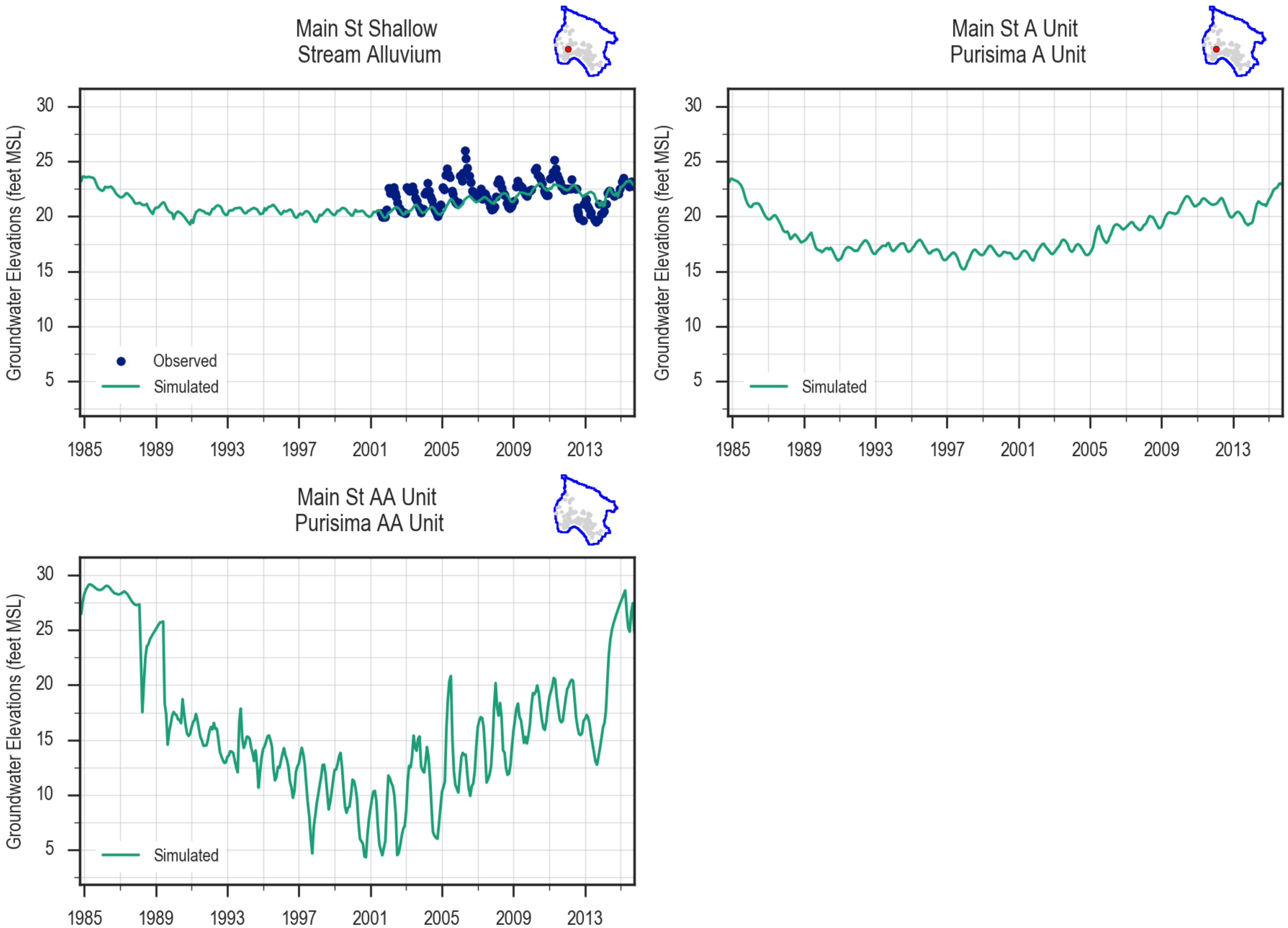


Figure 34. Calibration Hydrographs at Main St. SW 1 and Underlying Purisima A and AA Units

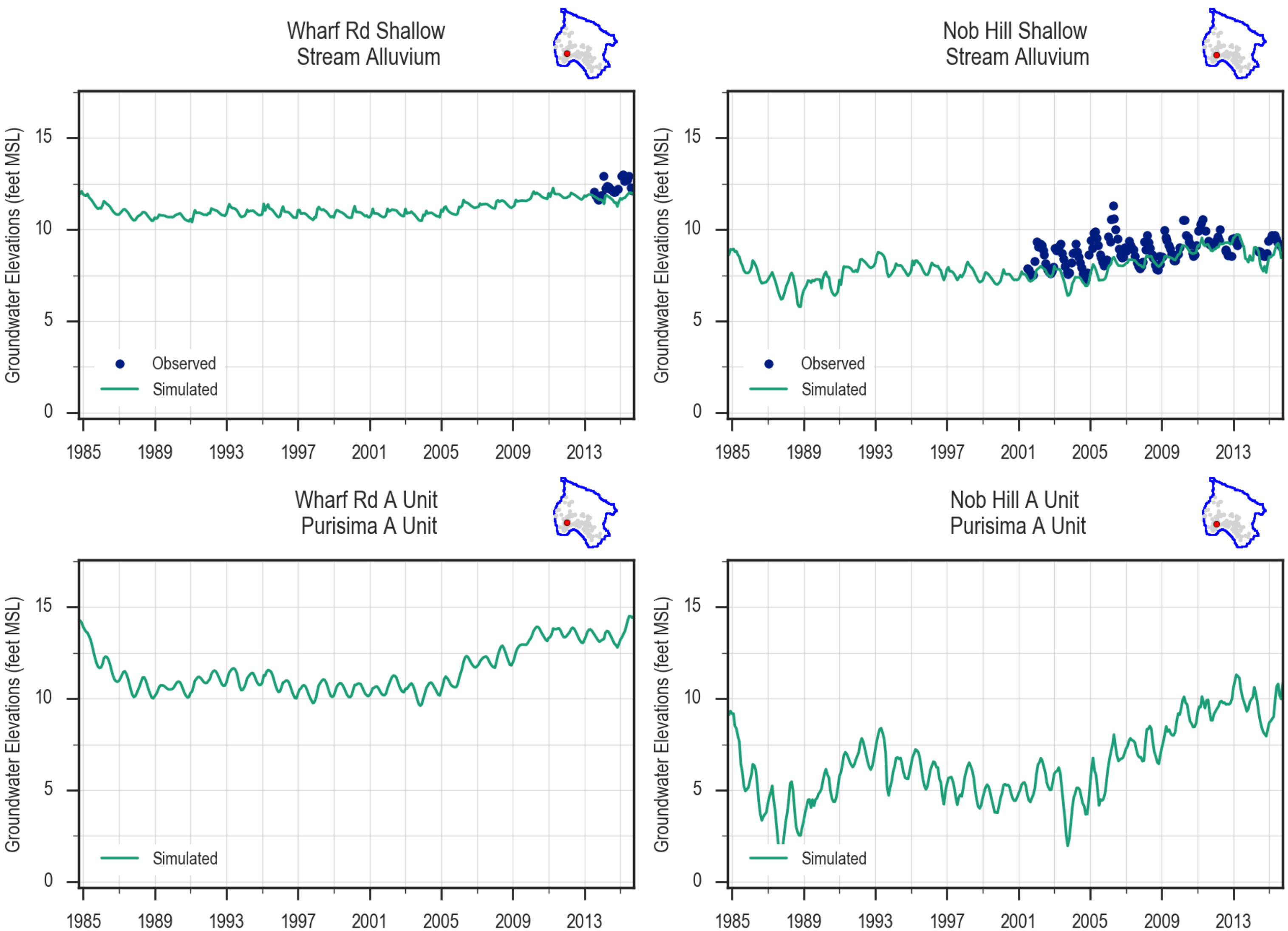


Figure 35. Hydrographs at Wharf Rd. and Nob Hill Shallow Wells and Underlying Purisima A Unit

8 RESULTS FOR CALIBRATED MODEL

8.1 Groundwater Elevation Contours

Plate 11 through Plate 14 show simulated groundwater elevations within each aquifer layer of the model at September 1994 and March 2015. September 1994 is a representative time for when groundwater elevations are low throughout the Basin. March 2015 is the representative time for when groundwater elevations are high throughout the Basin. Plate 11 and Plate 13 show groundwater elevations for these time periods. These maps show the simulated regional groundwater directions and gradients within the Basin by aquifer.

- The Aromas Red Sands Formation (model layer 2) generally shows flow toward the coast within the Basin but the 10 foot above mean sea level (amsl) contour moves toward the coast over time as pumping decreases.
- The Purisima F unit portion (eastern part of layer in Basin) of model layer 3 shows flat gradient of 0-10 feet amsl near the coast, but pumping depressions near the coast are eliminated over time. Inland contours move farther inland over time as pumping at the inland Rob Roy wells, Aptos Jr. High well, and Polo Grounds wells come online.
- The Purisima DEF unit portion (western part of layer) of model layer 3 shows increased pumping depressions over time as pumping shifted from the Aptos Creek well also screened in the BC unit to T. Hopkins well screened only in the DEF time.
- The Purisima BC unit (model layer 5) shows a large pumping depression below sea level that lessens over time such that groundwater elevations rise to and above sea level at the coast.
- The Purisima A unit (model layer 7) shows pumping depressions below sea level that lessen over time such that groundwater elevations rise to and above sea level at the coast.
- The Purisima AA unit (model layer 8) shows a small pumping depression that lessens over time.
- The Tu unit (model layer 9) shows larger pumping depressions in the fall and less in the spring. Spring 2015 is prior to Tu pumping being increased with new wells at Beltz #12 and O'Neill Ranch in summer and fall 2015.

Plate 12 and Plate 14 show the areas that are dry, unconfined, and confined for each aquifer layer of the model. The confined area is where specific storage (Plate 10) applies and the unconfined area is where specific yield (Plate 9) applies. The Aromas Red Sands Formation (model layer 2) is mostly unconfined within the Basin so confined response to pumping that is sometimes observed in the Basin is not well simulated, which is why some wells that may be screened across both the Aromas Red Sands Formation and Purisima F unit (model layer 3) are simulated as pumping from model layer 3 only. Much of the Purisima DEF unit area, western portion of model layer 3, is unconfined, and the model does not simulate the confined response to pumping in this area. Adding more layer discretization to these areas would be necessary to better simulate the confined response that is observed.

8.2 Surface Water Budget

In this sub-section, the surface water budget of the Basin is described. The surface water budget is described for the watershed and for the stream system within the Basin. The watershed budget is based on model results for how precipitation is apportioned. The stream system budget describes inflows and outflows to streams in the Basin.

For the watershed budget, the model simulates annual precipitation over the calibration period in the Basin as ranging from less than 16 inches to over 65 inches (1990 and 1998 respectively). On average, the model simulates 66% of precipitation that lands on the Basin as evaporated or transpired without reaching a surface water body. The model simulates another 27% as overland flow that eventually enters streams and creeks within the Basin. Five percent of precipitation is simulated to percolate beyond the root zone and enters the underlying aquifer as unsaturated zone flow (UZF) recharge, Terrace Deposits recharge, or stream alluvium recharge. The remaining portion (2%) reflects the net change in soil moisture stored in the soil layer over the Basin area. In most years this value is negative, reflecting gaining soil moisture conditions. However, in some years this value is positive, reflecting decreasing moisture in the soil layer. Typically this occurs during relatively dry years following a wet period, as evapotranspiration (ET) receives larger contributions from the soil layer during the drier year. The precipitation budget over time is presented in Figure 36.

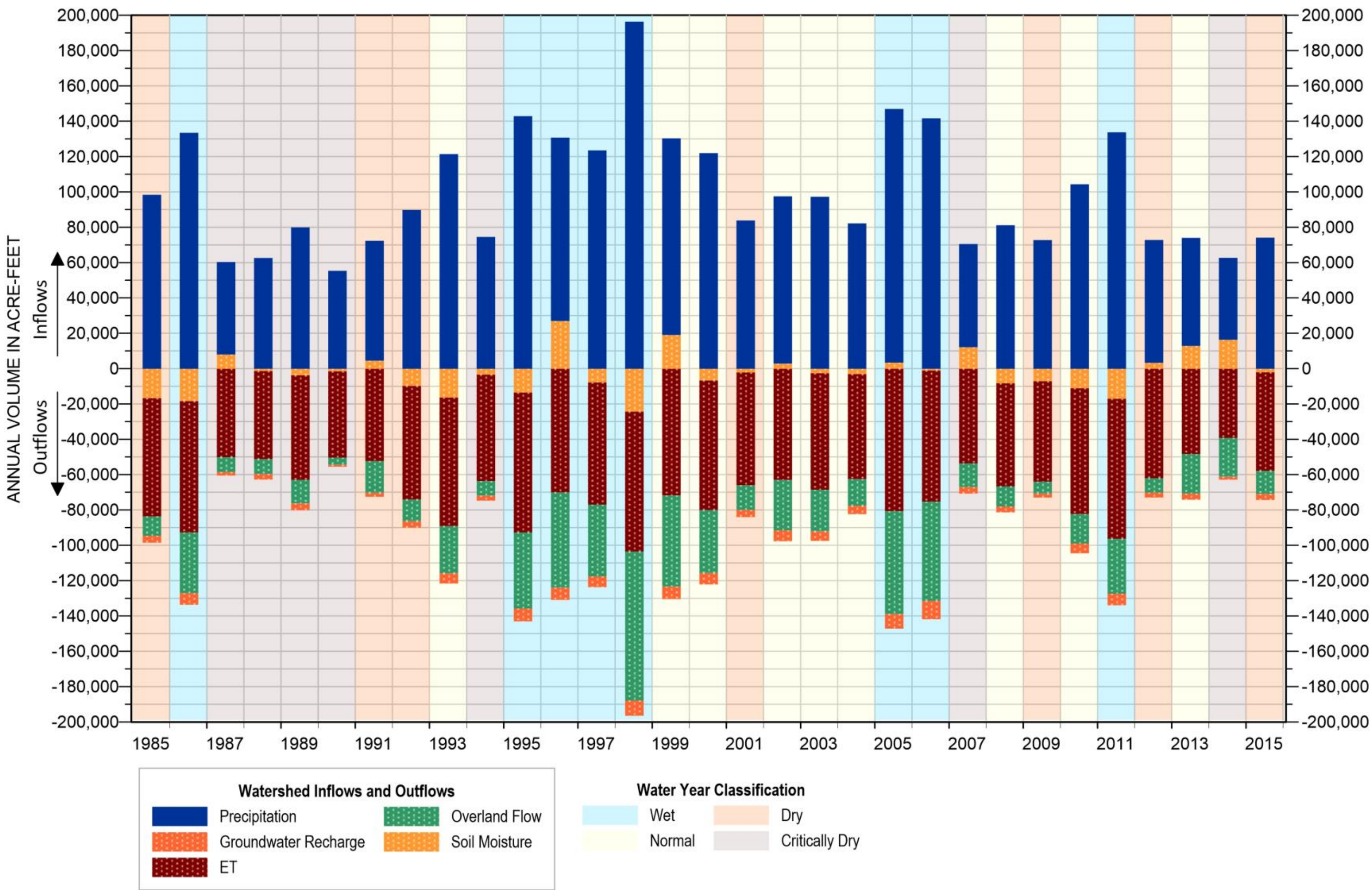


Figure 36. Annual Watershed Budget for Santa Cruz Mid-County Basin

For the stream system budget, the model simulates around 56% of inflow to the Basin's surface water system occurs due to overland flow entering streams and rivers within the Basin. The model simulates an additional 26% as entering the Basin from the area overlying Purisima Highlands Subbasin to the north. Primary water bodies supplying this inflow include Soquel Creek, Hester Creek, Hinckley Creek, and Aptos Creek. The model simulates 16% as entering from the adjacent Santa Margarita Basin, primarily from Branciforte and Granite Creeks. The remaining 3% of inflow to the surface water system is from net inflow from groundwater to streams (2%) and a few small creeks entering from the Pajaro Valley Subbasin (1%).

Surface water outflows in the model are dominated by outflow to ocean (89%). Nine percent leaves the Basin via Carbonara Creek, which enters the area overlying the Santa Cruz Terrace Subbasin just north of the City of Santa Cruz. The remaining 2% comprises minor amounts of surface water flowing into the Pajaro Valley Subbasin and Santa Margarita Basin, and small soil moisture fluctuations in the soil layer. The historical stream system water budget is presented in Figure 37.

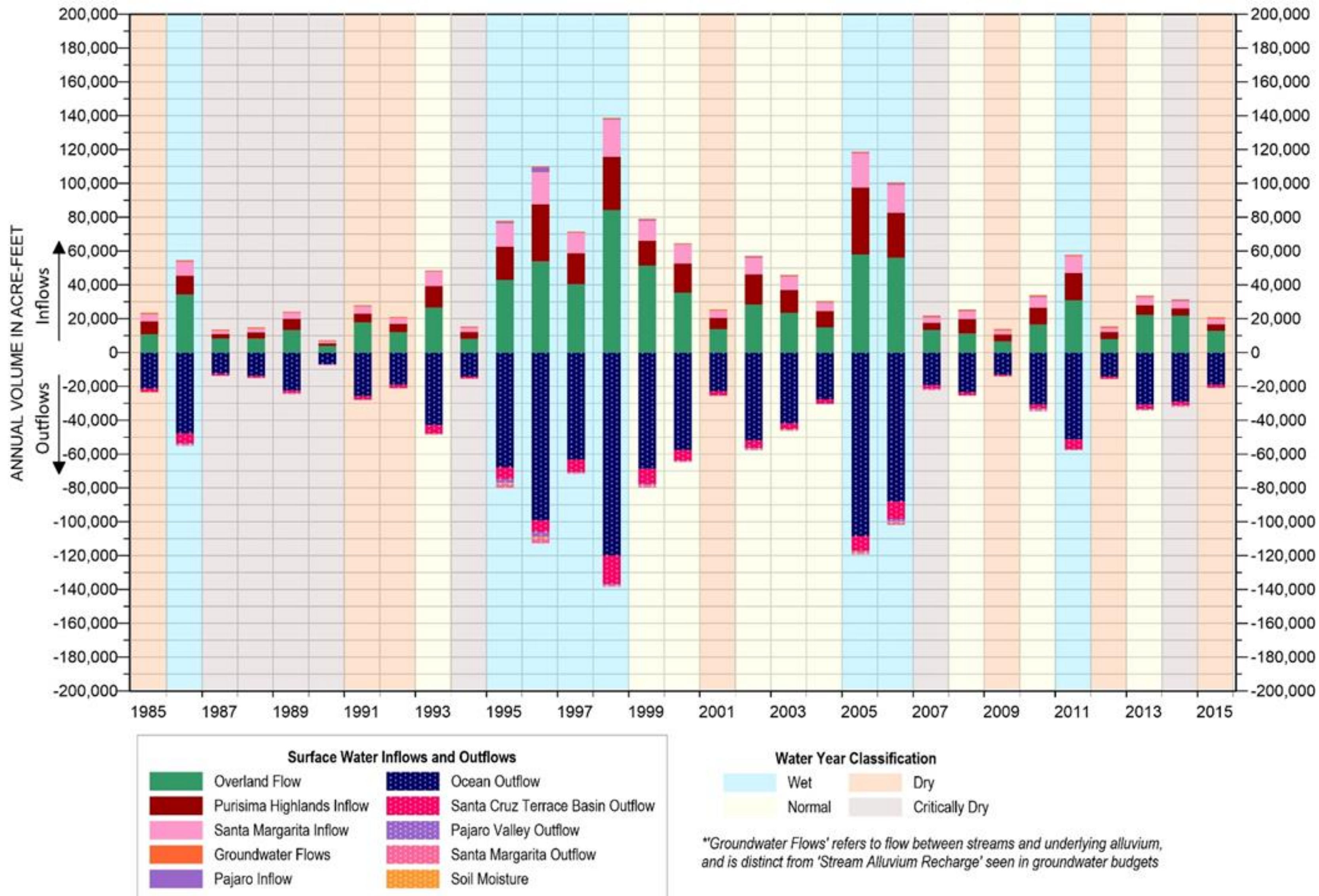


Figure 37. Annual Stream System Budget for Santa Cruz Mid-County Basin

8.3 Groundwater Budget

In this section, the groundwater budget of the Basin is described. Components of the groundwater budget are discussed in the subsections below. The groundwater budget discussion and associated charts separate the areas north and south of the horizontal flow barrier (HFB) representing Aptos area faulting because the groundwater budget south of this HFB Fault is more instructive for evaluating seawater intrusion, which is the sustainability indicator that has driven designation of the Basin as being in critical overdraft. In addition, the majority of pumping in the Basin, including all of the municipal pumping, occurs south of the Aptos area faulting (Figure 12) and most of the calibration data are from south of the Aptos area faulting (Plate 4).

Figure 38 and Figure 39 show the annual groundwater budget either side of the HFB representing Aptos area faulting, within the Basin. As discussed earlier, there are limited pumping activities north of the Aptos area faulting, with the majority of Basin pumping occurring south of Aptosarea faulting. The water budget north of the Aptos area faulting mainly comprises natural areal recharge (included as “UZF Recharge” on figures), stream recharge (shown as “Stream Alluvium” on figures), inflows from Purisima Highlands Subbasin, and outflows to Pajaro Valley Subbasin. Groundwater flows across basin boundaries south of the Aptos area faulting are not as substantial part of the water budget as they are north of the Aptos area faulting. Instead the water budget south of the Aptos area faulting in the Basin is influenced mostly by groundwater pumping, areal recharge, stream recharge, and flows offshore.

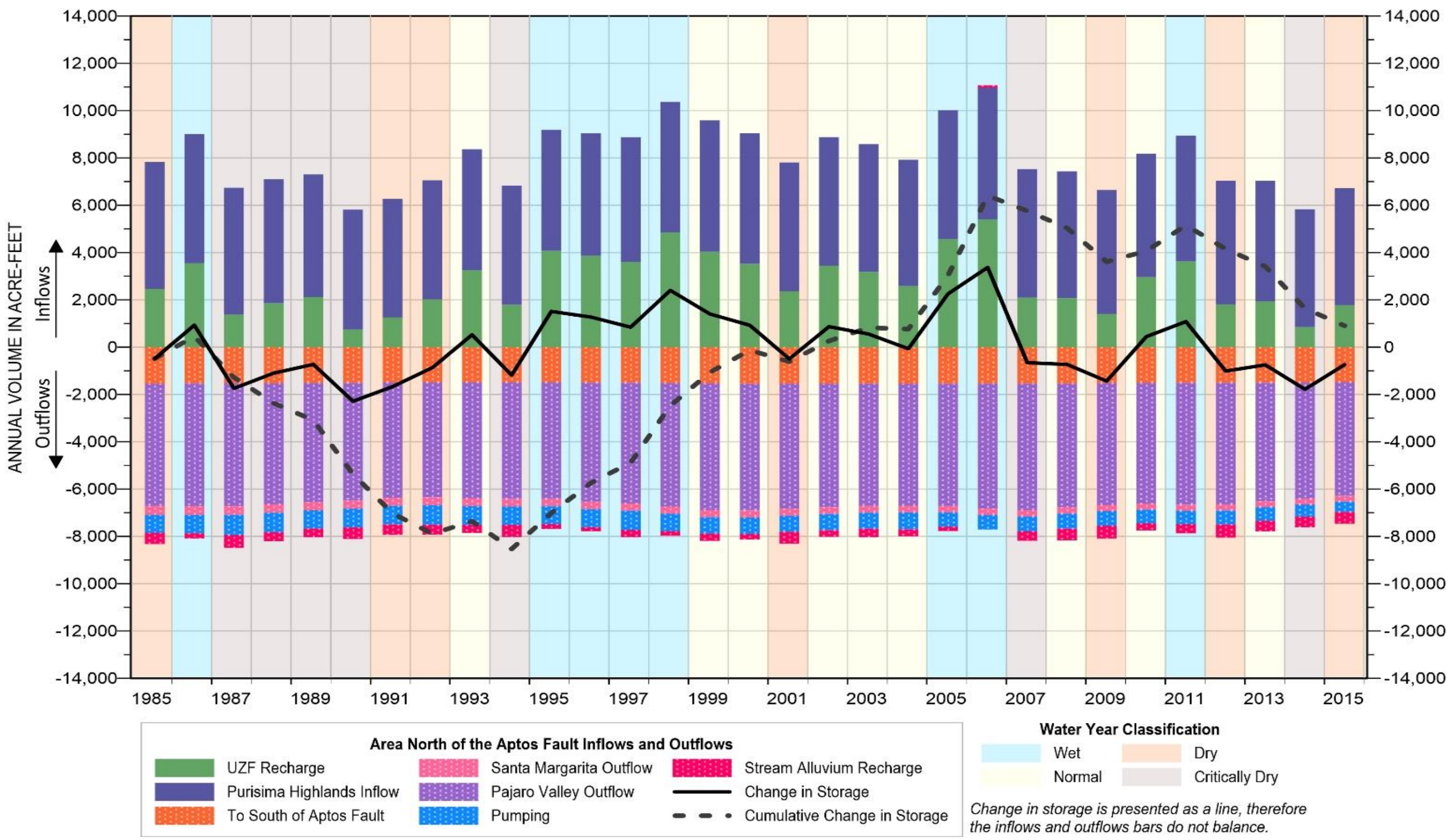


Figure 38. Annual Groundwater Budget in Santa Cruz Mid-County Basin, North of HFB for Aptos Faulting

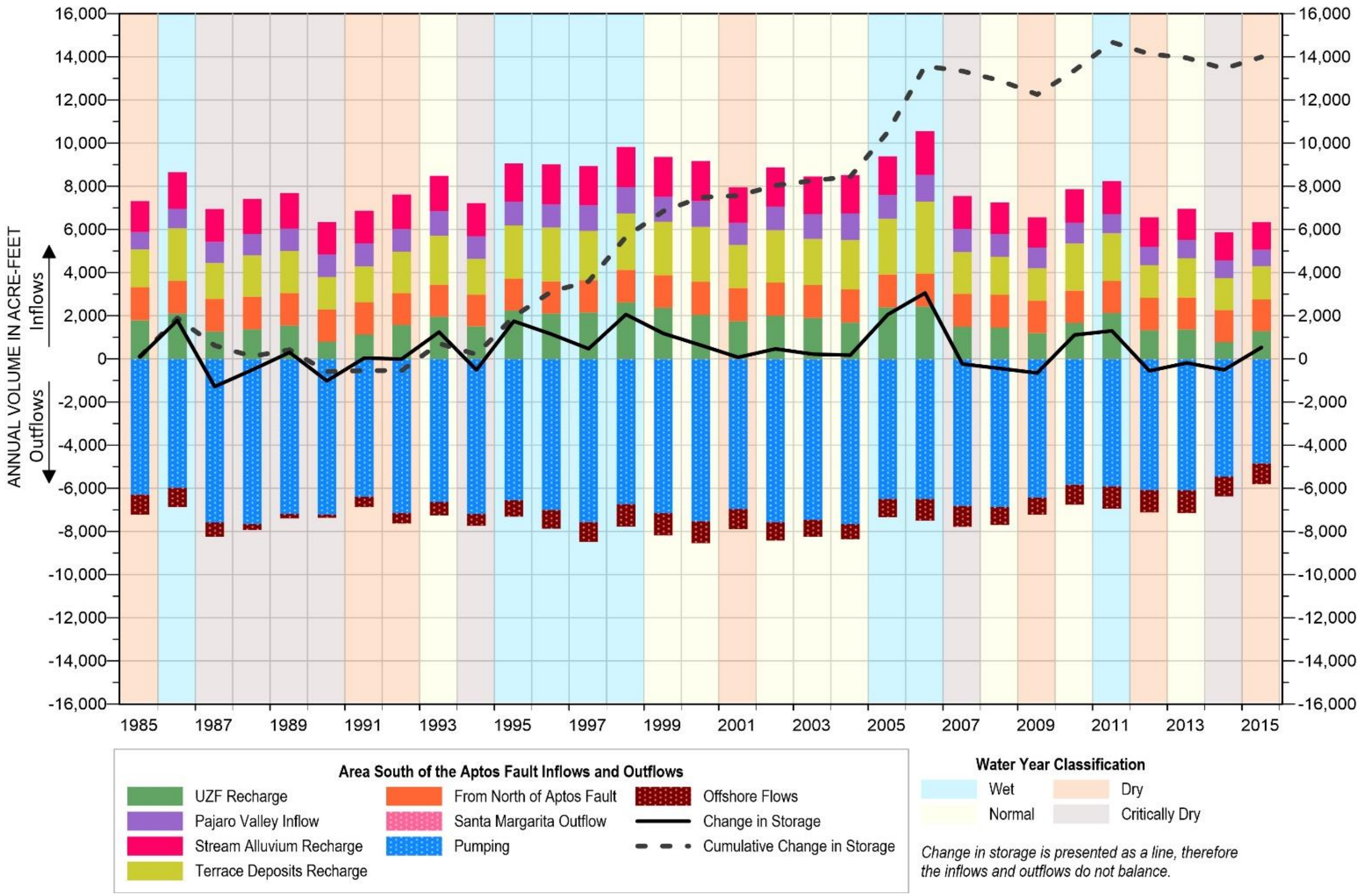


Figure 39. Annual Groundwater Budget in Santa Cruz Mid-County Basin, South of HFB for Aptos Faulting

8.3.1 Flows within Basin Boundaries

8.3.1.1 UZF recharge

This component of the groundwater budget includes components of areal recharge calculated by PRMS from climate inputs (direct recharge and gravity drainage in Figure 3) and return flows that are described in Section 4.4. These flows are always inflows to the Basin.

UZF recharge varies with climatic conditions. UZF recharge is greater north of the HFB representing Aptos area faulting than south of the HFB, but this is partly because recharge to Terrace Deposits is calculated separately from UZF recharge (see subsection below).

8.3.1.2 Flows between Alluvium to Aquifers and Aquitards of the Basin

The groundwater budget is calculated for layers representing the stacked aquifer and aquitard units of the Basin. Aromas Red Sands, Purisima Formation units, and Tu unit. Therefore, the water budget includes flows from overlying cells representing stream alluvium and Terrace Deposits (Figure 40).

Flow from stream alluvium is an important component of the Basin's groundwater budget and includes both streambed recharge and areal recharge through these areas. The volumes shown on the water budget charts represent net flows from stream alluvium to underlying aquifer and aquitard layers. There are areas and months where groundwater from the aquifers and aquitards flow into the stream alluvium, but overall the annual net flow is from stream alluvium to underlying stacked units of the Basin. Meanwhile, the surface water budget (Figure 37) shows net groundwater discharge from stream alluvium to streams. Thus, the stream alluvium is a net source of water for both streams and the underlying stacked aquifer and aquitard units of the Basin.

South of the Aptos area faulting, flow from alluvium includes flow from Terrace Deposits overlying the layers. This is a type of areal recharge to the coastal areas of the Basin and are always inflows.

Appendix D includes the annual water budget for each model layer in the Basin.

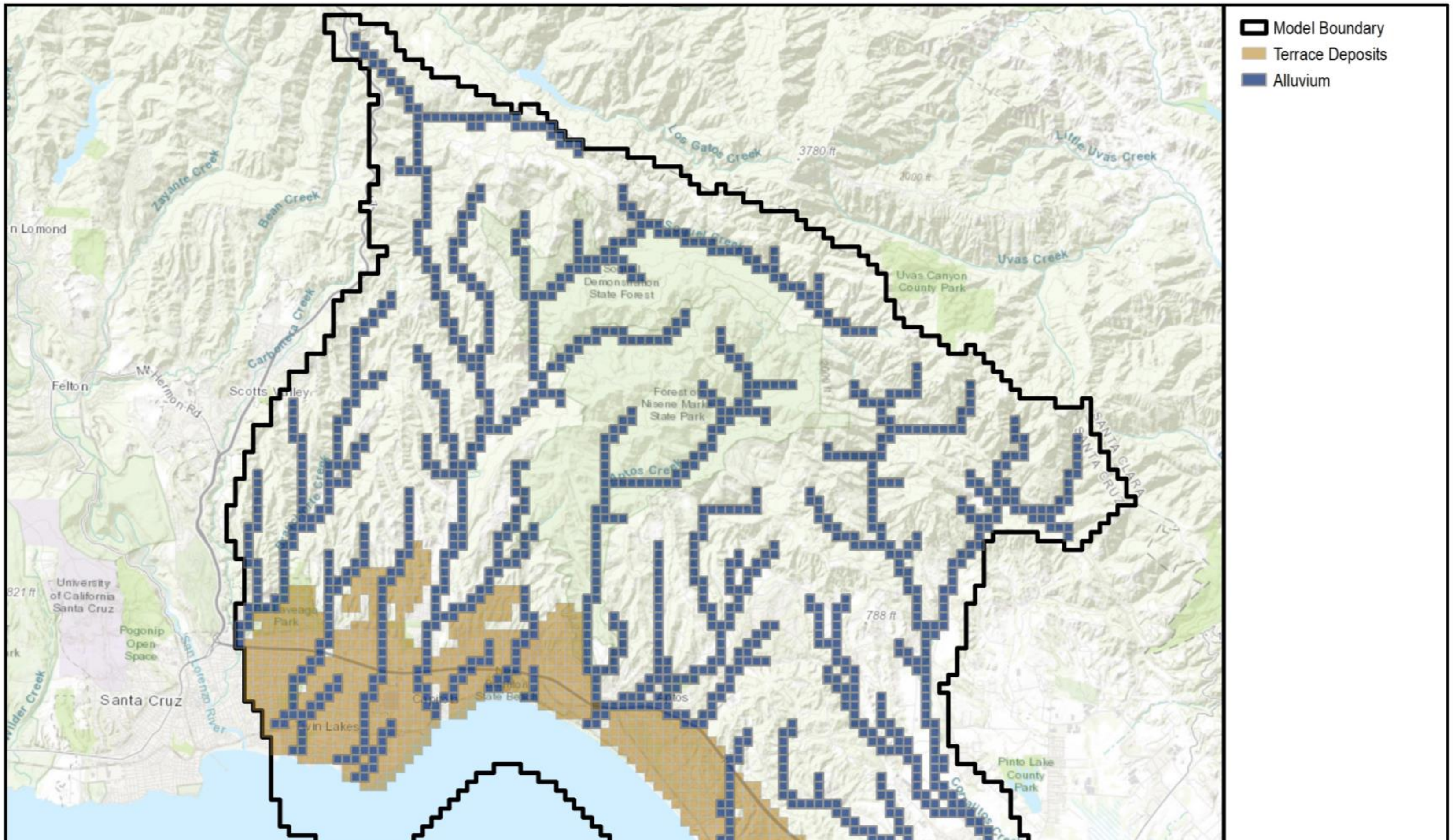


Figure 40. Location of Stream Alluvium and Terrace Deposits

8.3.1.3 Groundwater Pumping

Groundwater pumping is described in Section 4.3. Simulated groundwater pumping is less than the estimates for non-municipal pumping input into the model because pumping at wells in a model cell are turned off if the model cell goes dry.

8.3.2 Flows Across Basin Boundaries

8.3.2.1 Flows between other Basins

Groundwater flow occurs between the Basin and adjacent basins: Purisima Highlands, Pajaro Valley, and Santa Margarita Basins. Substantial inflows occur from Purisima Highlands across the Zayante Fault representing the northern boundary of the Basin. The inflow is relatively constant compared to other inflow components such as UZF recharge and flows from alluvium.

Relatively small flows occur north of HFB representing Aptos area faulting between the Basin and Santa Margarita Basin. These flows only occur in model layer 9 (Tu unit). The basin boundary with Santa Margarita Basin occurs in an area of model layer 9 that is separated from the high conductivity area of model layer 9 representing the Tu unit pumped by the City of Santa Cruz and SqCWD.

Substantial outflows occur from the Basin to the Pajaro Valley Subbasin, but mostly north of the HFB representing Aptos area faulting. This is consistent with observations of high groundwater levels to the northwest and lower groundwater levels in Pajaro Valley near the coast. The model layer with the largest amount of this type of outflow is model layer 3, which represents both the Purisima F and DEF units which are not significantly pumped by pumpers in Pajaro Valley. The model layer with the second largest amount of outflow is model layer 2, representing the Aromas Red Sands, which is the primary aquifer for pumpers in Pajaro Valley.

South of the HFB representing Aptos area faulting, there is net inflow from the Pajaro Valley Subbasin. This is primarily due to the geometry of the basin boundary, which is based on the administrative boundary of Pajaro Valley Water Management Agency (PVWMA). PVWMA covers the area inland of SqCWD Service Areas III and IV so inland groundwater flow to SqCWD production wells in those areas towards the coast is inflow into the Mid-County Basin.

8.3.2.2 Offshore Flows

An important component of the groundwater budget for evaluating groundwater sustainability are flows between the Basin and the ocean (offshore) because seawater intrusion is the sustainability indicator that is the basis for the Basin's overdraft condition. This flow only occurs south of Aptos area faulting. The water budget south the HFB reprenting of Aptosarea faulting (Figure 39) is more instructive for evaluating these flows than the water budget for the entire Basin. Net outflows (negative in the water budget charts) of some magnitude is required to prevent seawater intrusion. Net inflows (positive in the water budget charts) are indicative of flow conditions that will eventually result in seawater intrusion.

Figure 39 shows Basin net offshore outflows and Figure 41 shows the net offshore outflows by layer with the y-axis reversed. Figure 41 shows there has been net inflow in model layers 3 (Purisima F/DEF) and 7 (Purisima A) indicating the high risk of seawater intrusion into these aquifer units historically. Although inflows from the ocean have decreased more recently, inflows still indicate seawater intrusion risk. Net outflows simulated in the Purisima BC and Purisima A aquifer units where seawater intrusion risk has been identified have increased over time. However, water budget results should not be the primary model results for evaluating seawater intrusion because freshwater outflow offshore may not be enough to prevent denser seawater from intruding. In addition, net flows representing flows across the entire coastal boundary may not represent the localized risk near pumping centers. The primary model results for evaluating seawater intrusion should be simulated groundwater levels at coastal monitoring wells compared to established protective elevations.

8.3.3 Change of Groundwater in Storage

Figure 42 shows the cumulative groundwater in storage change for each model layer as well as the entire Basin. Figure 42 depicts that the loss of groundwater in storage in the Basin early in the period was mainly governed by the groundwater in storage loss in model layers 3 (Purisima F/DEF) and 7 (Purisima A); where the majority of Basin pumping occurs. Figure 43 and Figure 44 show the cumulative groundwater in storage change for each model layer in the Basin north and south of the HFB representing Aptos area faulting respectively. The same conclusion can be drawn on these figures as from Figure 42 which is that the loss of groundwater in storage was governed by the loss of storage in model layers 3 and 7, south of the Aptos area faulting where the most pumping occurs in the basin (Figure 39).

An important note is that a reduction of groundwater in storage is not the reason behind the critical overdraft conditions in the Basin. The cause has been the risk of seawater intrusion, which has been due to low groundwater levels near the coast in specific aquifer units. Figure 38 and Figure 39 show that offshore flows are a small part of the water budget compared to changes in groundwater in storage, but offshore flows are what indicate seawater intrusion risk.

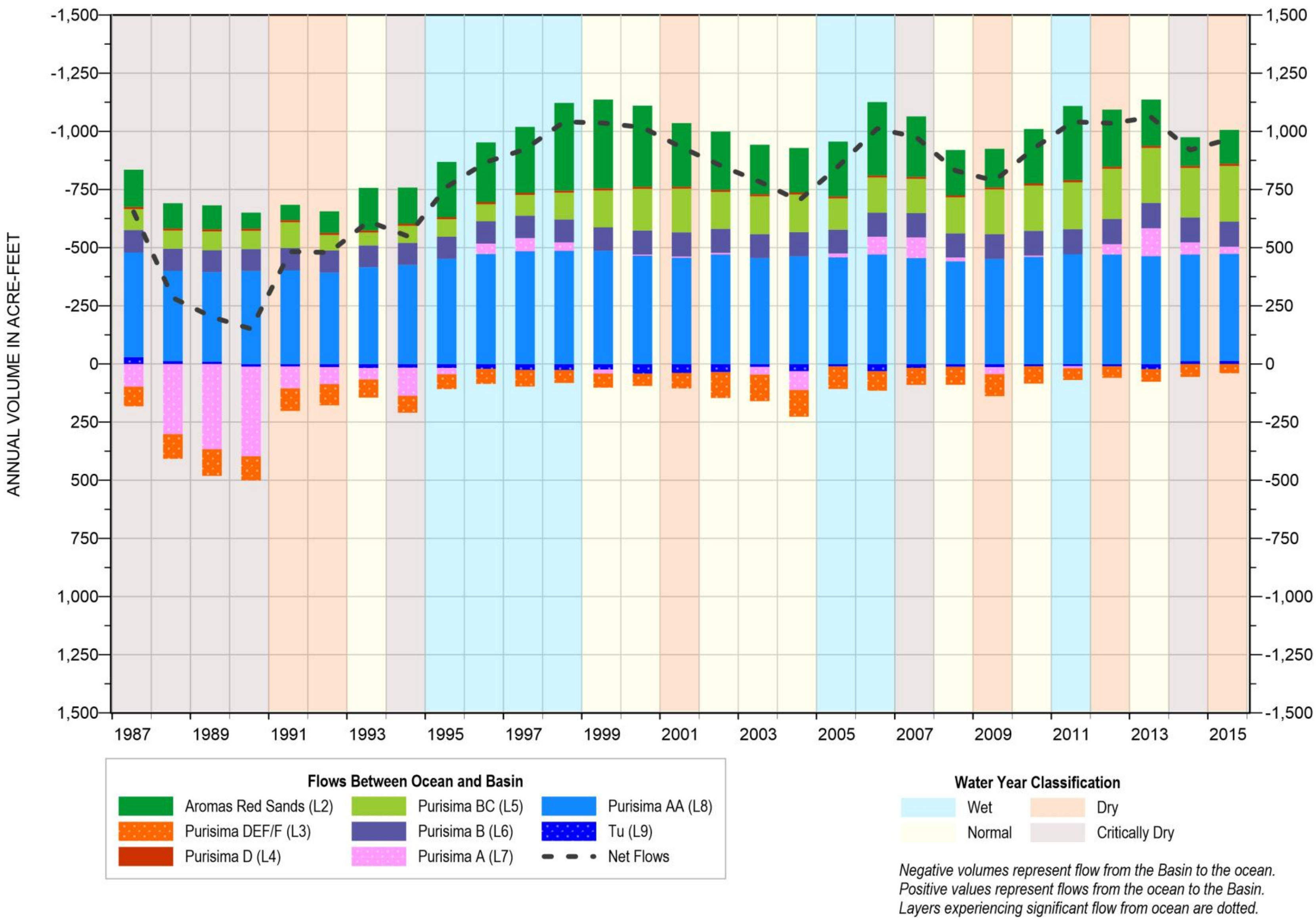


Figure 41. Offshore Groundwater Flow to Mid-County Basin for each Model Layer

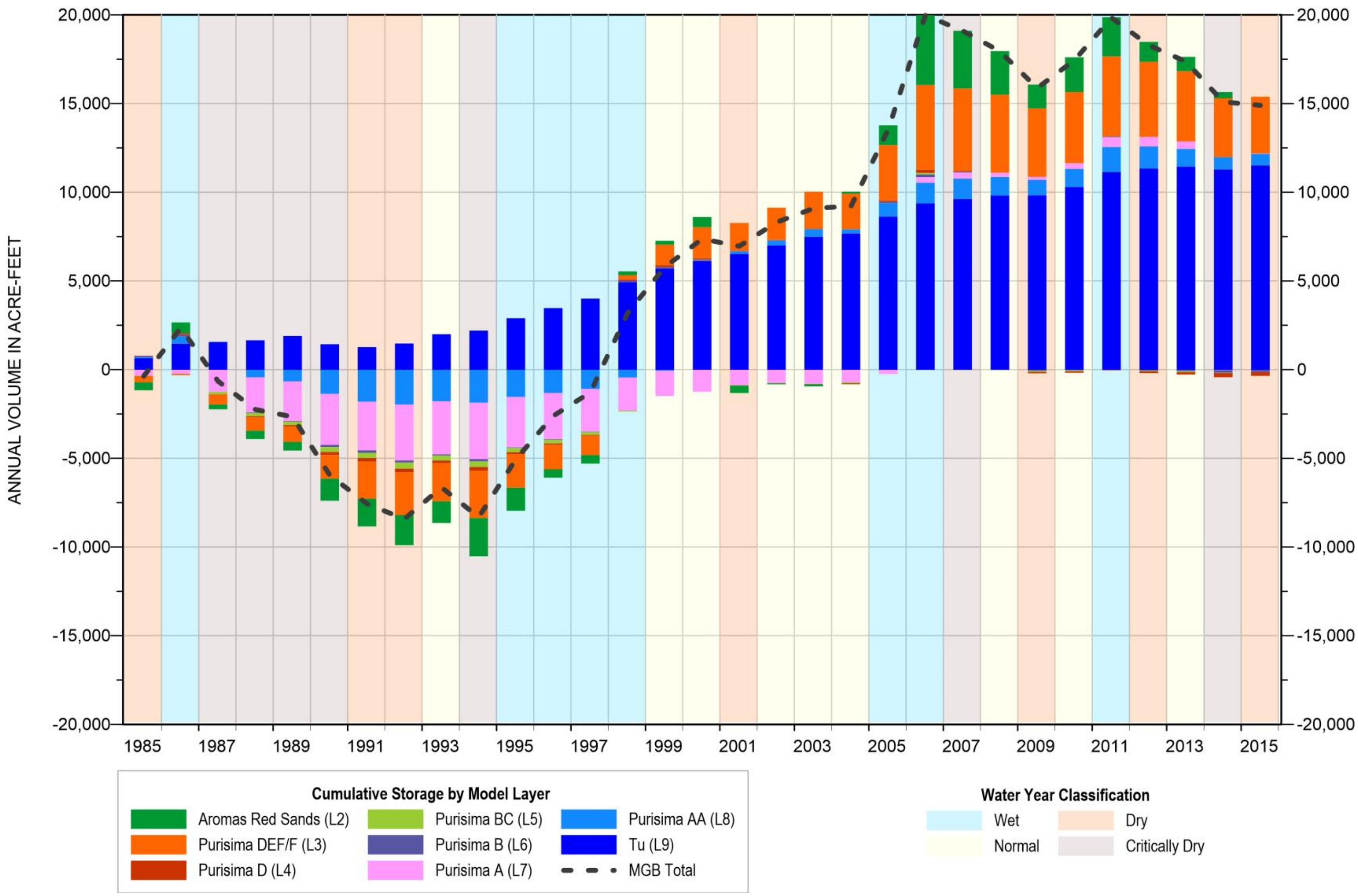


Figure 42. Cumulative Change in Storage Change in Mid-County Basin

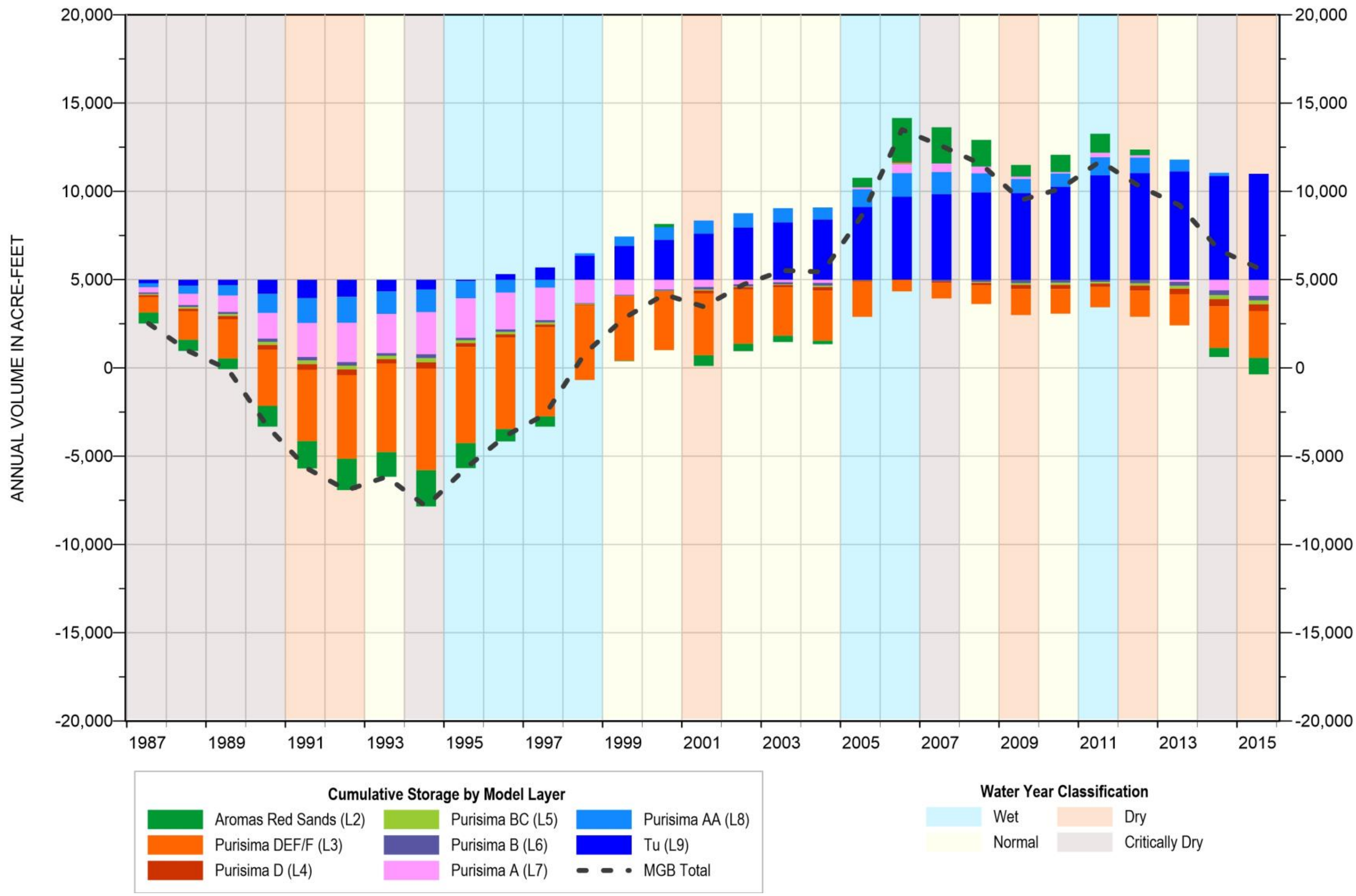


Figure 43. Cumulative Change in Storage in Mid-County Basin; North of HFB for Aptos Faulting

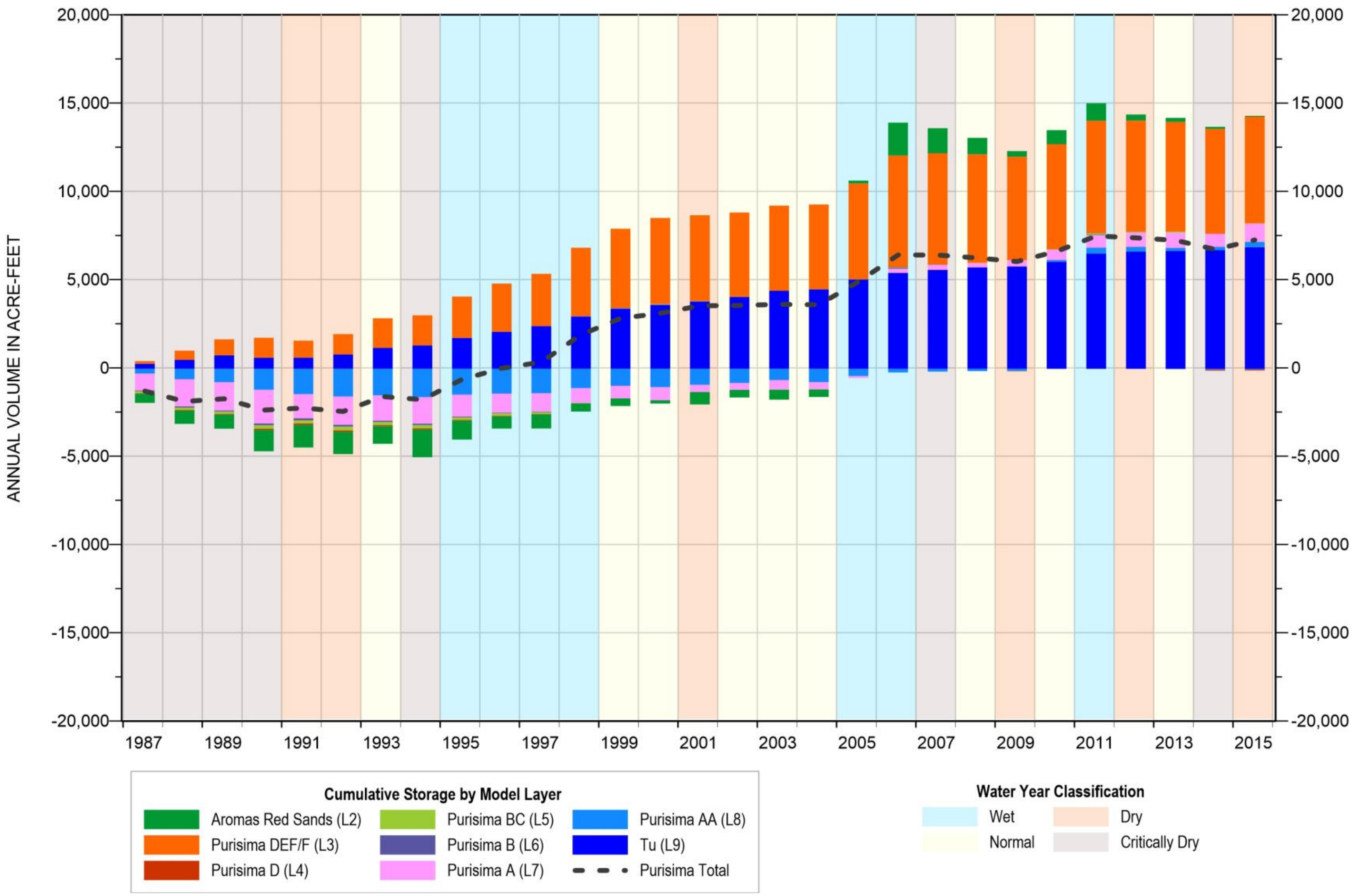


Figure 44. Cumulative Change in Storage in Mid-County Basin, South of HFB for Aptos Area Faulting

8.4 Stream-Aquifer Interactions

The model is used to evaluate stream-aquifer interactions in several ways including identifying where streams are interconnected with groundwater, where shallow pumping may affect streamflows, and estimating groundwater contributions to streamflow. The development of these evaluations were undertaken for Santa Cruz County's Prop 1 grant for stressed basins.

8.4.1 Interconnected Streams with Groundwater

The sustainability indicator in the Groundwater Sustainability Plan (GSP) related to surface water is depletion of interconnected surface water caused by groundwater use. Interconnected surface water is defined in DWR's regulations for GSPs as "surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer." The model is used to identify how often streams in the Basin are connected with groundwater in the underlying aquifer representing stream alluvium based on output from the model's stream (SFR) package. Figure 45 shows that Soquel Creek is simulated as connected to groundwater more than other streams in the Basin and streams overlying the Purisima F unit and Aromas Red Sands such as Valencia Creek are mostly simulated as not connected to groundwater, which is consistent with the conceptual understanding for the Basin

8.4.2 Depth to Groundwater

In order to identify where shallow pumping wells are more likely to exist and contribute to streamflow depletion in the Basin, Figure 46 shows modeled depth to the water table in March 2015. March 2015 is the representative time for when groundwater levels are high throughout the Basin.

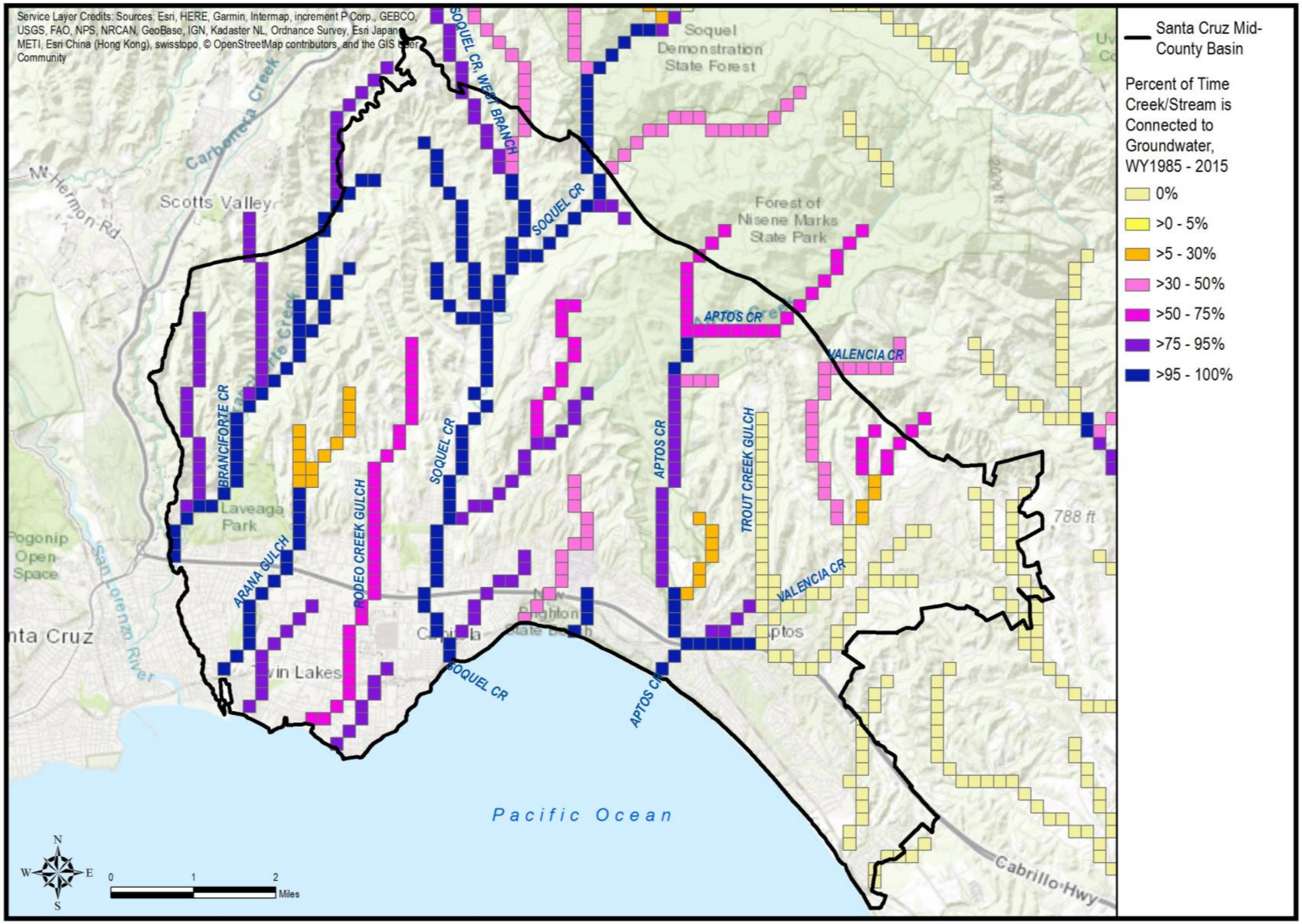
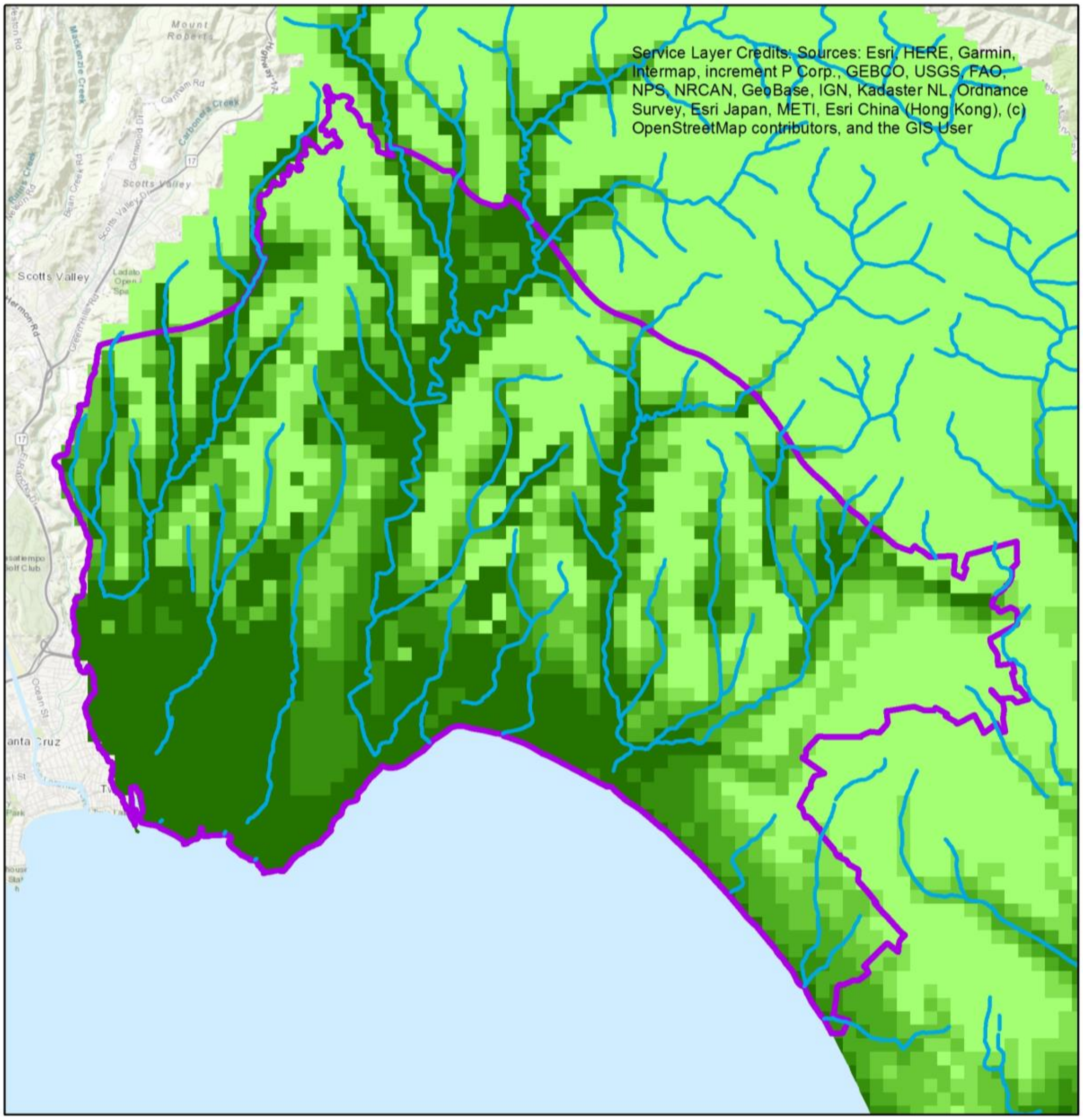


Figure 45. Percent of Time Surface Water and Groundwater are Connected



EXPLANATION

Depth to Water, feet below ground surface

- <50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 250
- >250
- Santa Cruz Mid-County Basin
- Streams

N

0 1 2 3 4

Miles

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Figure 46. Depth to Shallowest Groundwater in March 2015

8.4.3 Groundwater Contribution to Soquel Creek Flow

Based on the calibration of shallow groundwater levels along Soquel Creek (Section 7.3.6), the model is used to estimate groundwater contribution to Soquel Creek where calibration data are available and vertical connection between stream and underlying aquifers is higher than the rest of the model. Figure 47 and Figure 48 show the groundwater contribution to Soquel Creek for the minimum flow month in each year to provide an estimate of the groundwater contribution when streamflow depletions are most likely to result in significant and unreasonable conditions. Figure 47 shows the stretch from Moores Gulch to Bates Creek where the Simons and Balogh shallow wells are located (Figure 21). Figure 48 shows the stretch downstream of Bates Creek where the Main Street, Wharf Road, and Nob Hill shallow wells are located. Most of the streamflow is simulated to come from upstream. Groundwater contribution to streamflow along these stretches is less than 0.5 cfs consistent with estimates from previous studies that streamflow depletion has not been observed because depletion of up to 0.5 cfs cannot be observed from the data (Johnson et al., 2004). As described previously, more precise data for groundwater contribution to streamflow are not available for calibration. Therefore, the model could estimate groundwater contribution of any value from 0 to 0.5 cfs and be consistent with the conclusion from Johnson et al., 2004, which indicates the uncertainty of these groundwater contribution flow estimates.

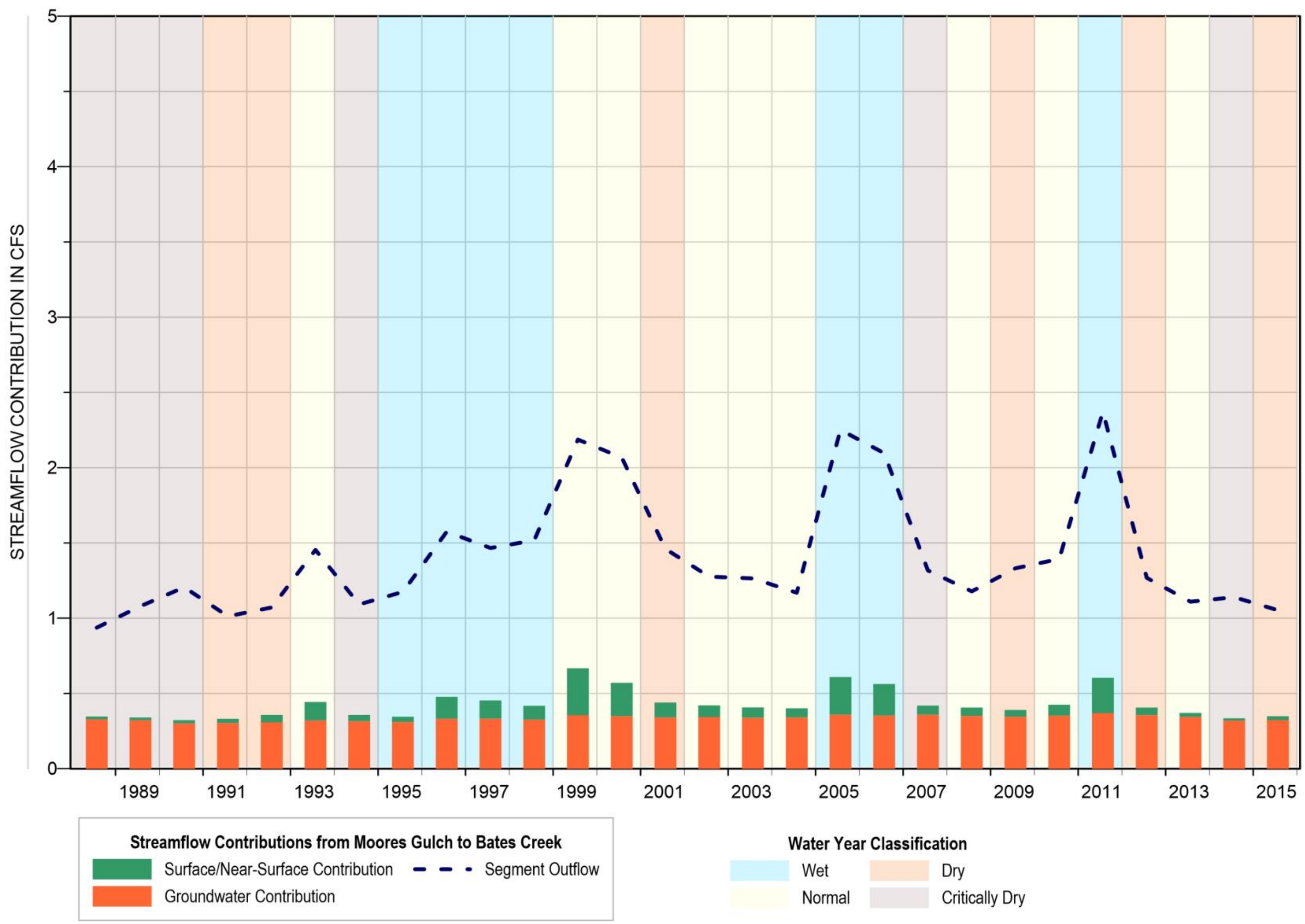

Figure 47. Simulated Minimum Monthly Flows from Moores Gulch to Bates Creek

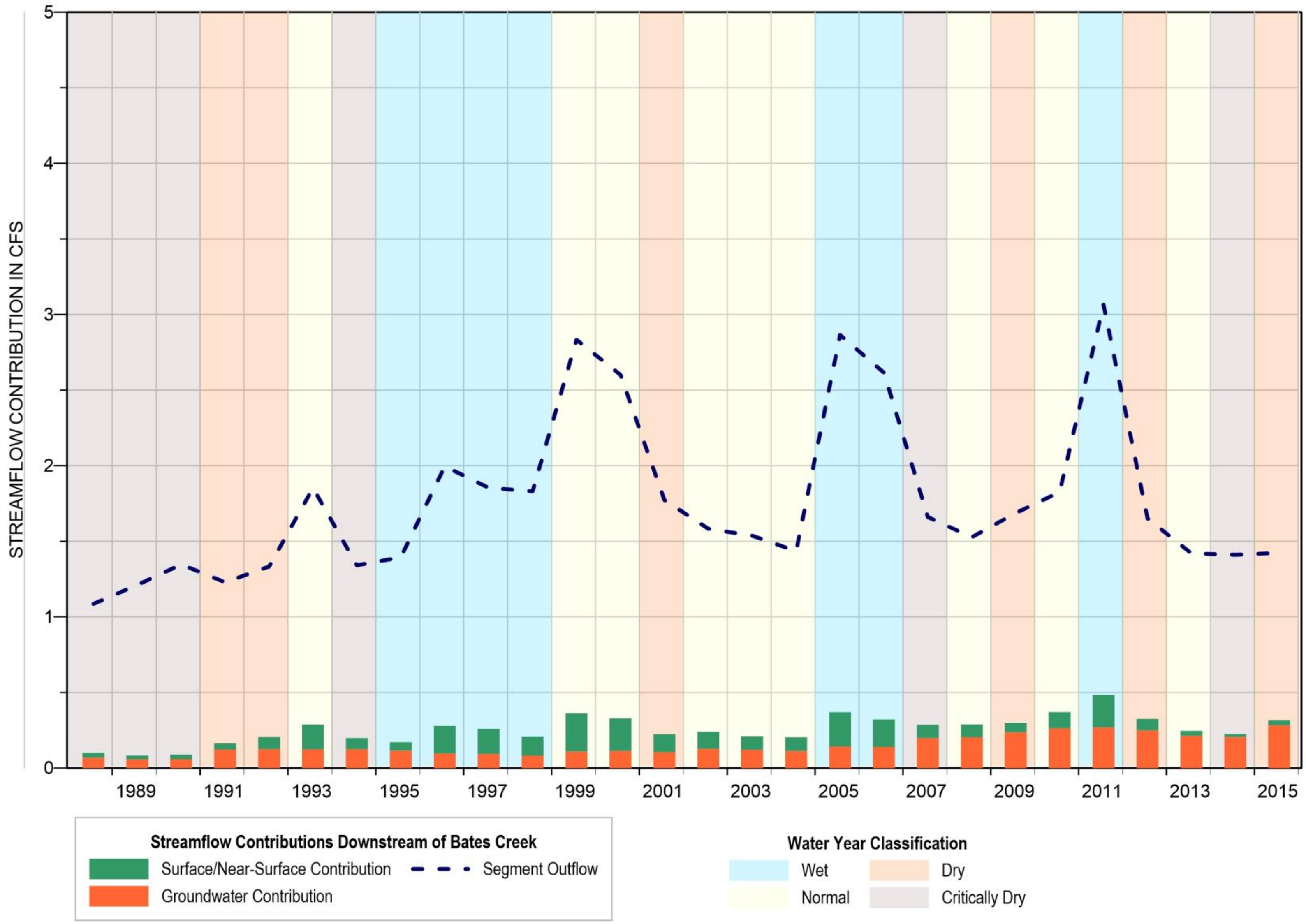

Figure 48. Simulated Minimum Monthly Flows Downstream of Bates Creek

9 SENSITIVITY RUNS

Several sensitivity runs were conducted to evaluate effects of different water use types and assumptions on sustainability for the Basin. The results of these runs are compared to the results of the calibration run described above to evaluate these effects. Sensitivity runs included a run to support development of the streamflow depletion sustainable management criteria:

- Remove all Basin pumping and associated return flow to estimate streamflow depletion in Soquel Creek from Basin groundwater use.

The following sensitivity runs were also performed as part of the scope for Santa Cruz County's Prop 1 grant.

- Remove inland pumping and associated return flow to evaluate effects of inland groundwater use.
- Re-assign non-municipal pumping underneath stream alluvium and Terrace deposit cells to overlying alluvium and Terrace deposit cells to evaluate potential effects of shallow pumping on streamflow.
- Remove non-municipal pumping in lower Soquel Creek and Bates Creek Valleys to evaluate effects of non-municipal pumpers on Soquel Creek streamflow.
- Reduce septic return flow assuming 50% return flow in septic areas instead of 90% currently assumed.

The sensitivity of sustainability to these changes is evaluated by comparing model results to the calibration run. Model results that are compared include:

- Groundwater levels at coastal monitoring wells that are representative monitoring points with groundwater elevation proxies for seawater intrusion in the GSP;
- Groundwater levels at shallow wells along Soquel Creek that are representative monitoring points with groundwater elevation proxies for seawater intrusion in the GSP; and
- Differences in groundwater contribution to streamflow in Soquel Creek watershed during the month with minimum streamflow for each year.

- These sensitivity runs change model output beyond what is calibrated and therefore the results include substantial uncertainty.

9.1 Estimate of Streamflow Depletion from Basin Groundwater Use

In order to establish sustainable management criteria for streamflow depletion, the model is used to estimate historical streamflow depletion in Soquel Creek from Basin groundwater use. This estimate is based on a sensitivity run that removes all Basin pumping and associated return flow over the calibration period. Pumping and return flow simulated for the Basin and removed for this sensitivity run are shown in Figure 12 and Figure 13, respectively. The estimate of streamflow depletion from historical Basin groundwater use is based on the difference in groundwater contributions to streamflow in the Soquel Creek watershed between the sensitivity run and the calibration run. As described previously, the model is not calibrated to precise estimates of flows between groundwater and streams, so estimates of streamflow depletion from the model have high uncertainty. Additionally, sensitivity runs provide estimates of streamflow depletion resulting from groundwater use and incorporating other assumptions. It is important to note that these estimates represent conditions that have not occurred historically and are therefore uncalibrated to any data, which introduces additional uncertainty.

Figure 49 shows the groundwater and surface/near-surface contributions for Soquel Creek watershed in the minimum flow month for each water year of the calibration run. As in Section 8.4.3, the minimum flow month for each year is evaluated because these are the months when streamflow depletions are most likely to result in significant and unreasonable conditions. With all of Basin pumping removed, the increase in total streamflow for the watershed in these minimum flow months are almost all due to higher contributions from groundwater. Removing all Basin pumping in the model results in an increased groundwater contribution to Soquel Creek of up to 1.4 cfs. Therefore, the estimate of historical streamflow depletion based on the model is 1.4 cfs.

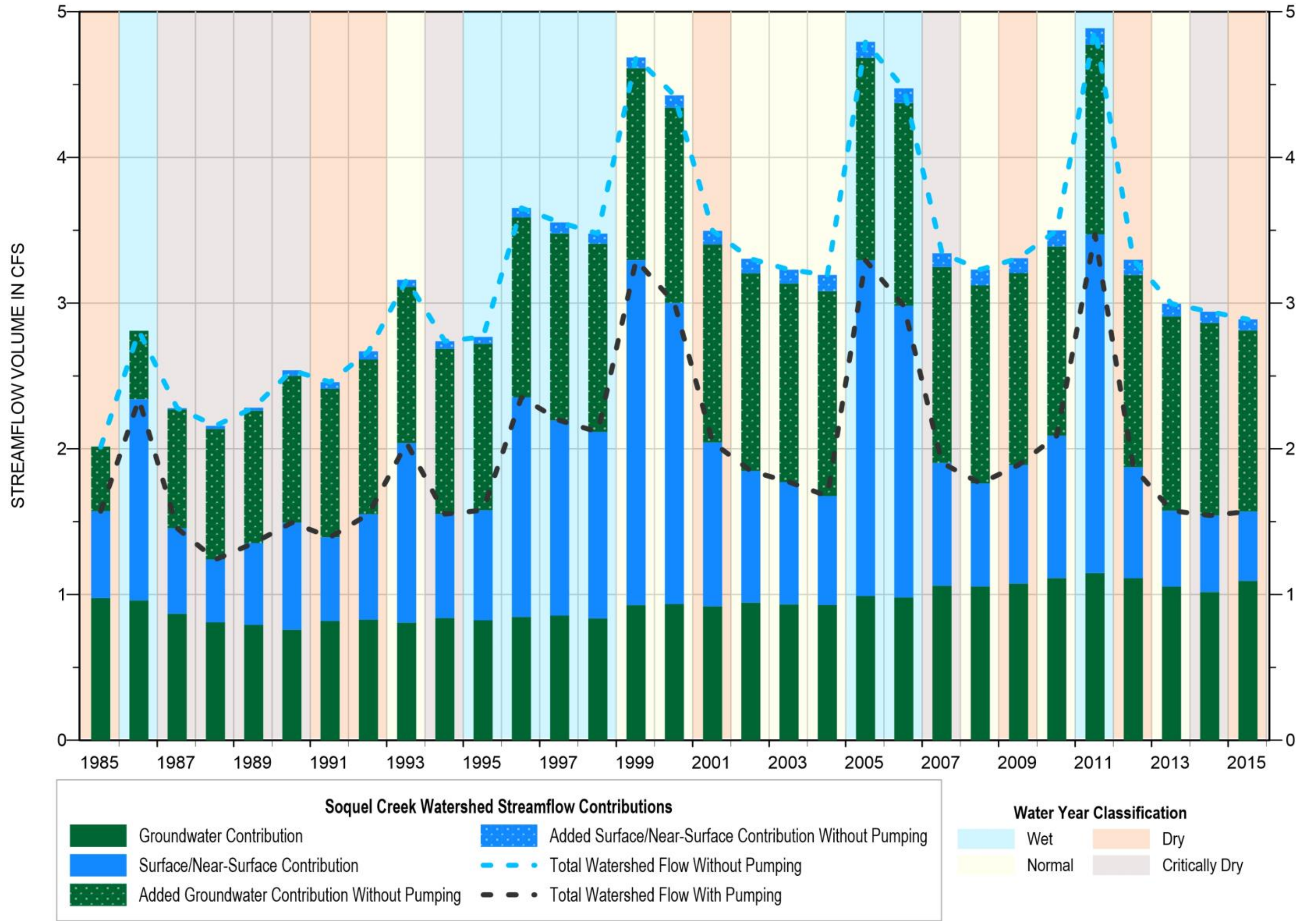

Figure 49. Simulated Contributions to Soquel Creek Watershed Streamflow in Minimum Flow Month with and without Historical Pumping

9.2 Effects of Inland Groundwater Use

For this sensitivity run, inland pumping and associated return flow was removed from the area shown in Figure 50 where groundwater elevations are estimated by the model to be above 50 feet msl. The average decrease in pumping is approximately 1,000 acre-feet per year and the average decrease in return flow is approximately 400 acre-feet per year.

This sensitivity run indicates that inland groundwater use has minimal effect on Basin sustainability. At coastal monitoring wells that are representative monitoring points for seawater intrusion, Figure 51 and Figure 52 show that the increase in groundwater levels resulting from removal of the inland groundwater use is very slight.

Sensitivity of streamflow depletion to inland groundwater use is larger than sensitivity related to seawater intrusion, but still small. At shallow wells along Soquel Creek that are representative monitoring points for streamflow depletion, there are small increases in groundwater levels with removal of the inland groundwater use (Figure 53). Based on the increase in groundwater contribution to streamflow resulting from this groundwater use removal during months with minimum streamflow, the model estimates streamflow depletion effects of this inland pumping as up to 0.1 cfs (Figure 54).

9.3 Effects of Pumping from Shallow Groundwater

In the calibrated model, non-municipal pumping is assumed to occur in the shallowest Basin aquifer unit in the Aromas Red Sands and Purisima Formation, not the stream alluvium and Terrace deposits. For this sensitivity run, non-municipal pumping assumed to occur from Basin aquifer units underlying stream alluvium and Terrace Deposits shown in Figure 40 is moved up to extract from the stream alluvium and Terrace Deposits instead. Approximately 30 acre-feet per year of pumping is moved up to the Terrace Deposits and approximately 250 acre-feet per year is moved up to the stream alluvium.

The run tests the sensitivity of streamflow depletion along Soquel Creek to shallow pumping. Moving pumping to the stream alluvium results in decreases in shallow groundwater levels along Soquel Creek as shown in Figure 53. Based on the decrease in groundwater contribution to streamflow resulting from moving pumping to shallow alluvium and Terrace Deposits during months with minimum streamflow months, the model estimates streamflow depletion effects of potential shallow pumping as approximately 0.1 cfs (Figure 54).

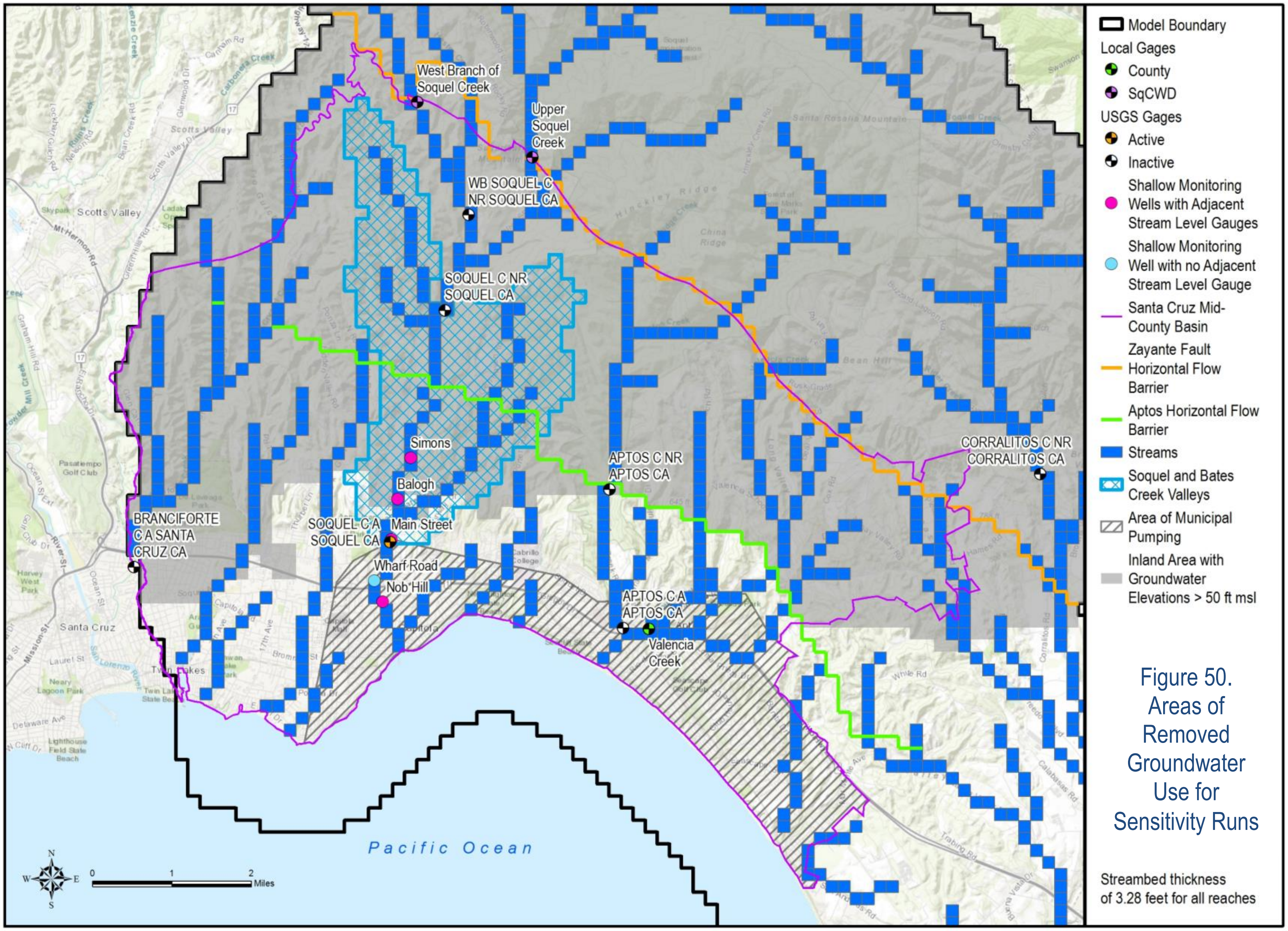

Figure 50. Areas of Removed Groundwater Use for Sensitivity Runs

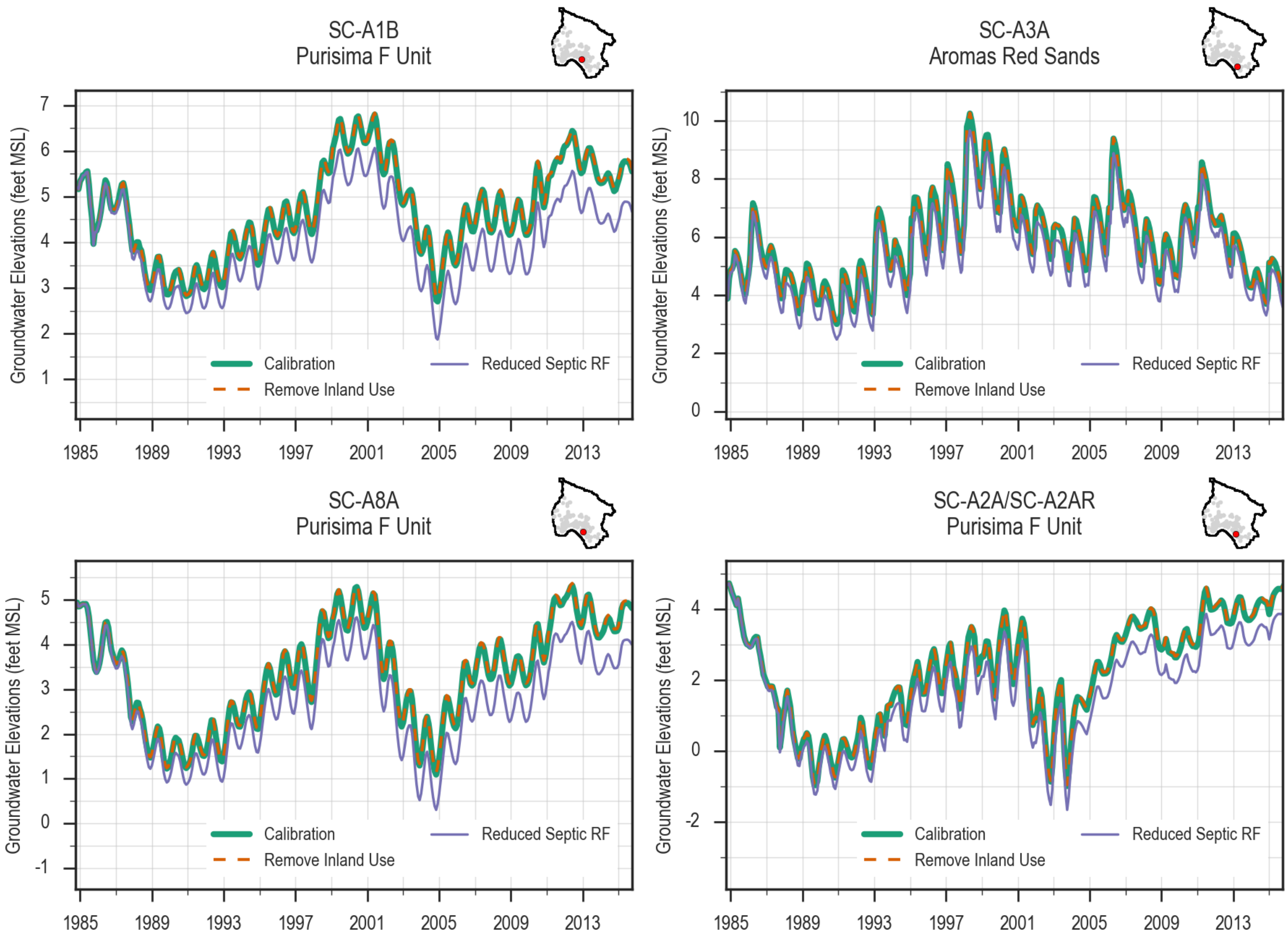

Figure 51. Sensitivity Hydrographs at Coastal Monitoring Wells in Aromas and Purisima F Units

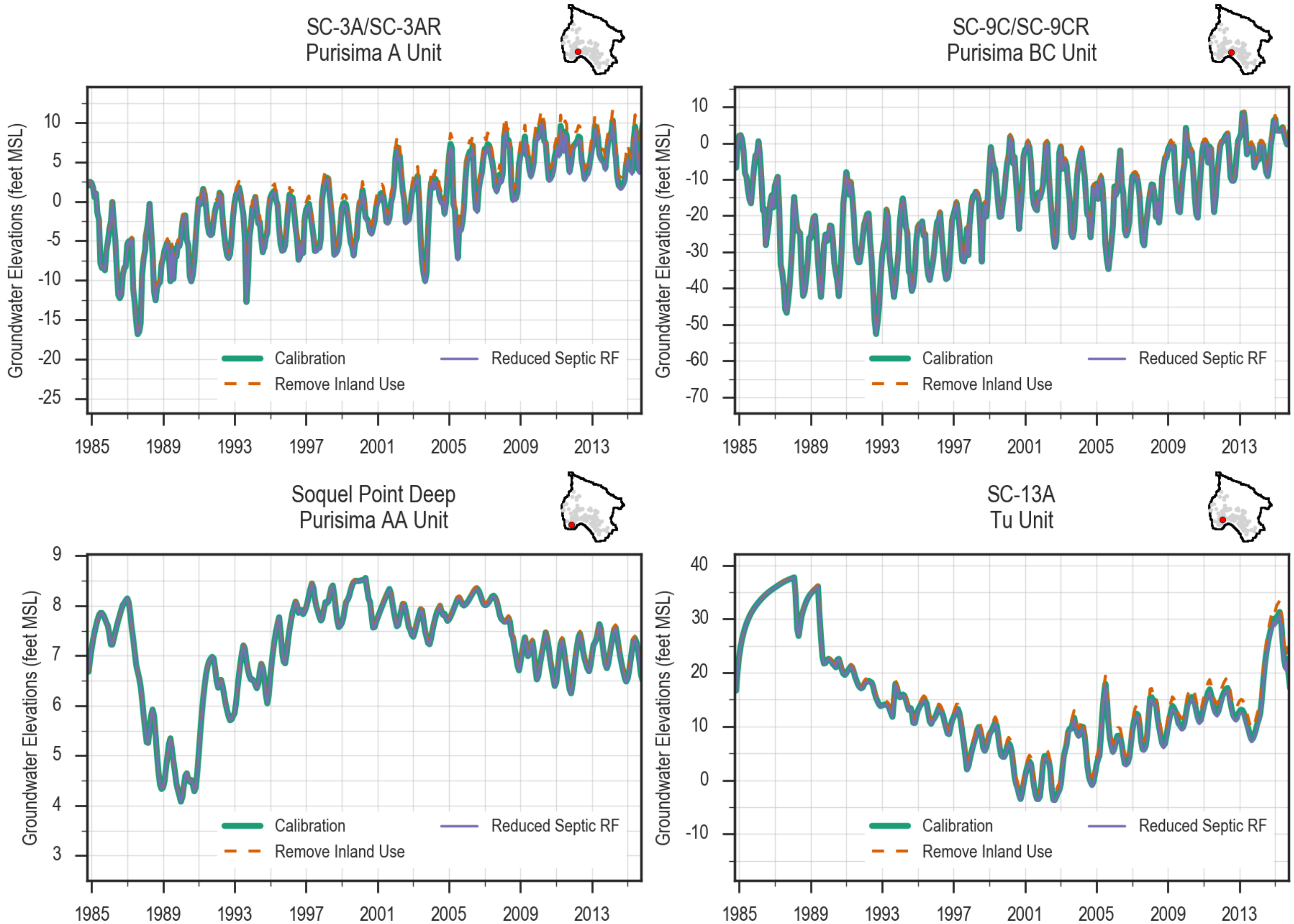

Figure 52. Sensitivity Hydrographs at Coastal Monitoring Wells in Purisima and Tu Units

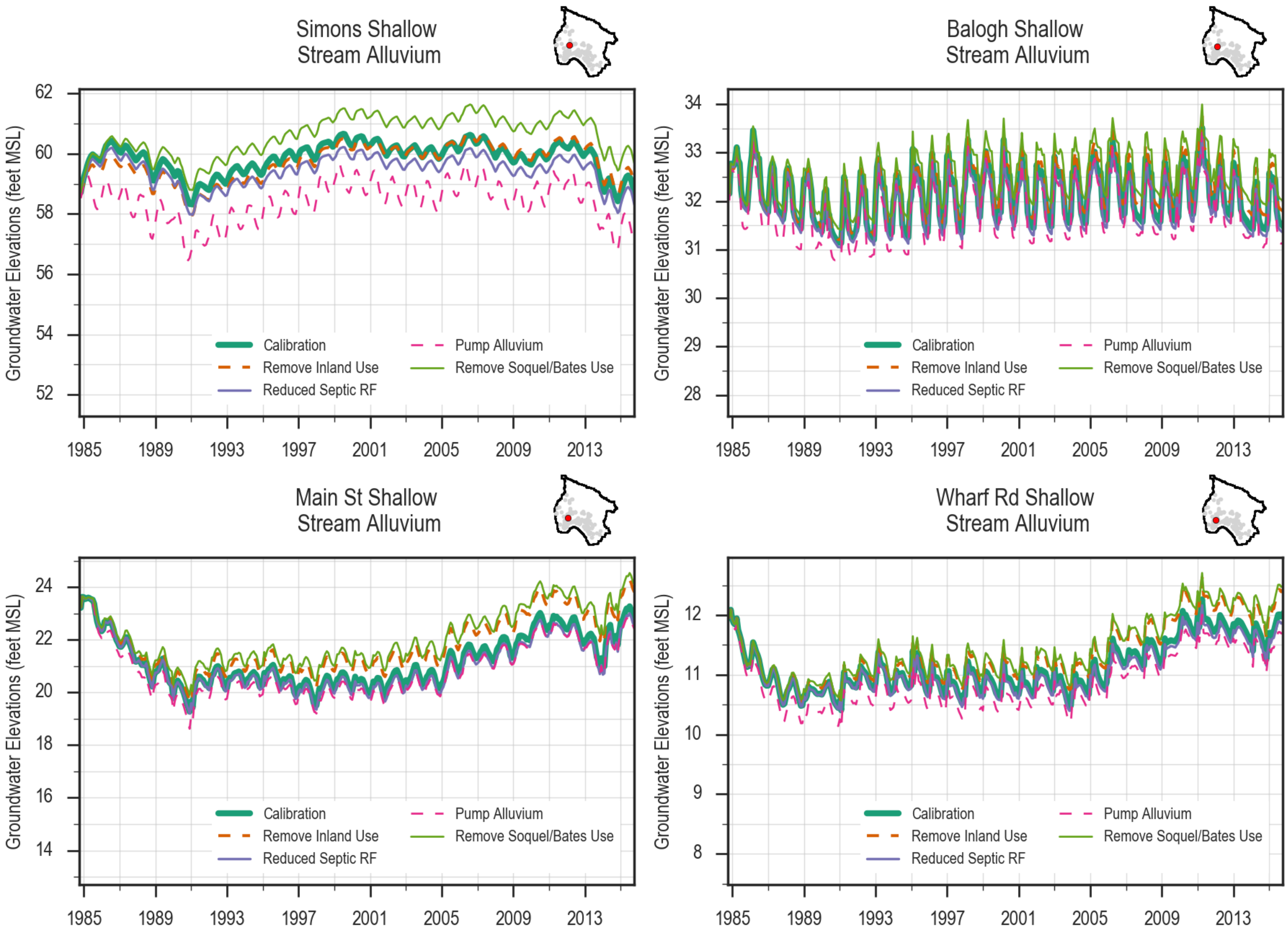

Figure 53. Sensitivity Hydrographs at Shallow Wells along Soquel Creek

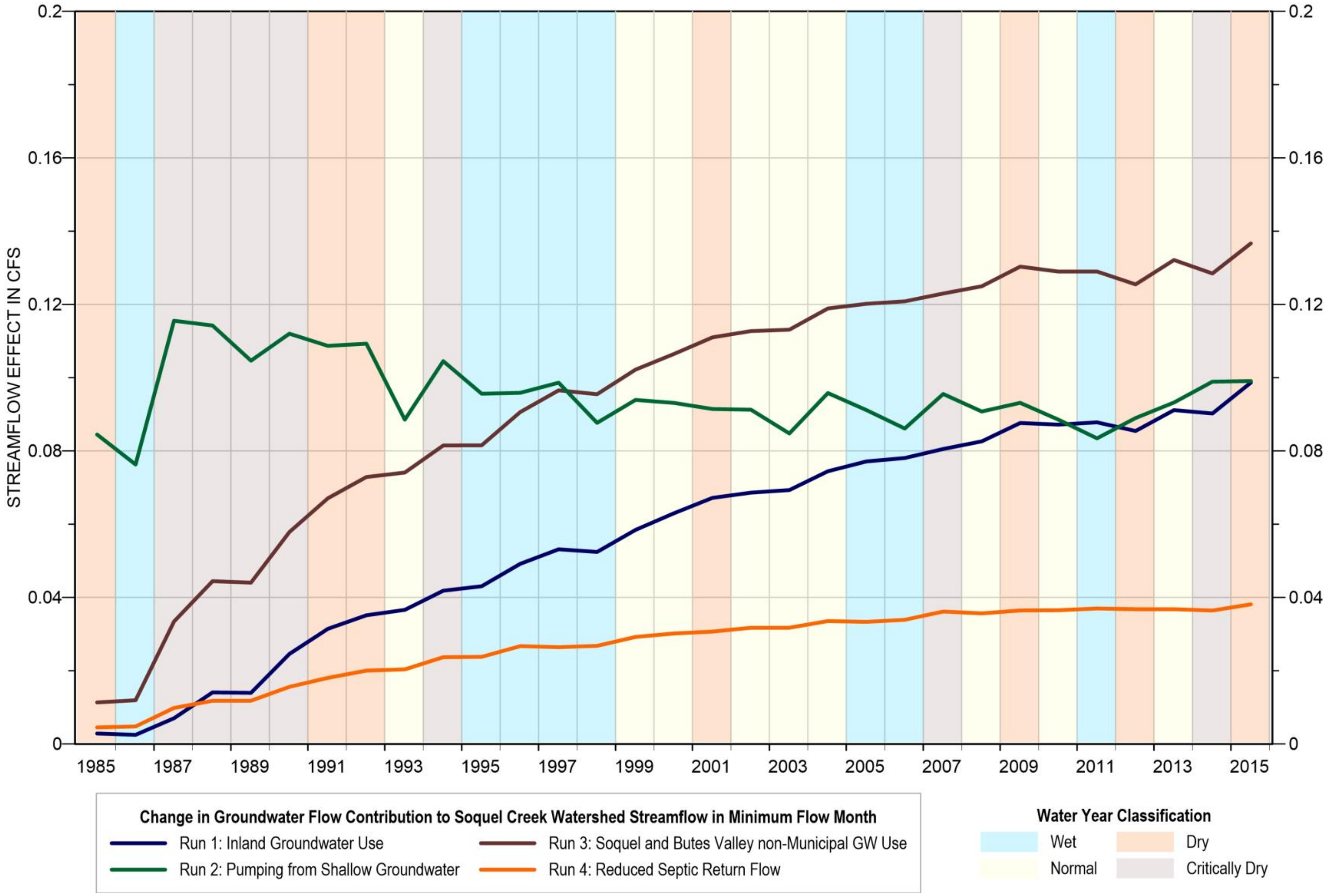

Figure 54. Sensitivity of Stream Depletion Effects

9.4 Effects of Pumping from Soquel Creek and Bates Creek Valleys

For this sensitivity run, non-municipal pumping was removed from Soquel Creek and Bates Creek Valleys, for the area shown on Figure 50. The run tests the sensitivity of streamflow depletion along Soquel Creek to shallow pumping. The average decrease in pumping was approximately 370 acre-feet per year.

As expected, groundwater use in the Soquel Creek and Bates Creek Valleys shows a larger effect on streamflow than other sensitivity runs except the run that removed all Basin groundwater use. At the shallow wells along Soquel Creek, there are small increases in groundwater levels with removal of inland groundwater use (Figure 53). Based on the decrease in groundwater contribution to streamflow resulting from removing pumping in this area during the months with minimum, the model estimates streamflow depletion effects of potential shallow pumping as up to 0.15 cfs (Figure 54).

9.5 Effects of Reduced Septic Return Flow

In the calibrated model, 90% of indoor use in septic areas are assumed to become return flow. The model adds the return flow volumes as recharge below the soil zone to the UZF package. For this sensitivity run, it is assumed that only 50% of indoor use in septic areas are assumed to become return flow to test the effect of the septic return flow assumption. The approximately 45% reduction in septic return flow results in an average decrease in return flow of 300 acre-feet per year.

This sensitivity run indicates that the septic return flow assumption has a small effect on model evaluation of Basin sustainability. At coastal monitoring wells that are representative monitoring points for seawater intrusion, Figure 51 shows the decrease in groundwater levels resulting from reduction of septic return flow is up to 1 foot in the Purisima F unit and Aromas Red Sands where there are septic areas near the coast. There is almost no effect of the assumption in the deeper Purisima and Tu unit.

Sensitivity of streamflow depletion to the assumption for septic return flow is very small. At shallow wells along Soquel Creek that are representative monitoring points for streamflow depletion, there are very small decreases in groundwater levels with reduction of septic return flows. Based on the decrease in groundwater contribution to streamflow during the minimum streamflow months resulting from this removal, the model estimates streamflow depletion effects of this assumption as less than 0.05 cfs.

10 SIMULATING SEAWATER INTERFACE

We previously recommended to implement the MODFLOW SWI2 package (Bakker et al., 2013) in the model to be able to simulate movement of the seawater interface and evaluate potential effects of projects and management actions on the seawater interface. The SWI2 package has not been implemented in the model as it is not necessary for the GSP to simulate the seawater interface because groundwater elevation proxies are being used for the seawater intrusion sustainable management criteria. Model results of groundwater elevations can be used to compare to those groundwater elevation proxies to evaluate the benefits of projects and management actions for preventing undesirable results in seawater intrusion.

We are now recommending that the SWI2 package not be implemented in the model for two reasons.

1. The effort to overcome challenges in implementing the SWI2 package would not be cost-effective given that it is not necessary for evaluating Basin sustainability;
2. Implementing the SWI2 package would not answer the questions from the GSP Advisory Committee about movement of the seawater interface related to the use of five year groundwater elevation averages for seawater intrusion sustainability management criteria.

10.1 Challenges for Implementation of SWI2 package in Santa Cruz Mid-County Basin Model

SWI2 stability and convergence of the solution is highly dependent on having the 3-dimensional representation of the initial salt water interface surface properly and adequately defined over the entire model domain. Defining the current seawater interface configuration poses challenges given current data gaps in the understanding of the interface over the entire model domain. For example, the SKYTEM survey identifying salty water in aquifer units offshore could not be extended onshore over most of the model area and an understanding of how salinity concentrations change with depth in the deeper aquifers is limited both by the lack of deep well data covering the near coastal areas and the limitation on the depth of investigation of the SKYTEM survey. Because the shape of the interface in the lower aquifers is not well understood or constrained, this creates a challenge in representing and modeling the 3-dimensional interface.

10.2 Model Evaluation of Five Year Groundwater Elevation Averages for Seawater Intrusion Sustainability Management Criteria

A GSP Advisory Committee helped develop sustainability management criteria for the GSP. The main questions that arose from the Committee on the movement of the seawater interface were related to the appropriateness of using a five year average as groundwater elevation proxies for seawater intrusion sustainability management criteria. Using a five year average allows for time periods when groundwater elevations are lower than the criteria even if they are offset by times when groundwater elevations are higher than the criteria. The GSP provides sufficient rationale for why the five year average is appropriate, but the MGA may want to evaluate further during GSP implementation.

The SWI2 package cannot be used for this evaluation as it only simulates the movement of a sharp interface. Part of the concern of using the five year average is that time periods of lower groundwater elevations will allow seawater to intrude and even as higher groundwater elevations push out the average location of the interface, salty water will remain inland. Simulating only the sharp interface will not simulate this potential spreading of salty water as groundwater elevations vary.

One potential alternative to implementing the SWI2 package is to use two-dimensional cross-sectional models with the SEAWAT package (Langevin et al., 2008) similar to the models previously used to estimate the protective elevations (HydroMetrics LLC, 2009) used as groundwater level proxies for seawater intrusion sustainable management criteria. SEAWAT represents advection and dispersion of salinity fronts needed to address this issue. In addition, developing a two-dimensional representation of the interface will be simpler than developing a three-dimensional representation. Output from the Mid-County Basin GSFLOW model simulations of projects and management actions can be used as boundary condition inputs to the cross-sectional models to represent expected changes in coastal groundwater elevations over time under the GSP.

11 CONCLUSIONS

This report describes the development and calibration of the integrated surface water-groundwater model of the Santa Cruz Mid-County Basin, which has been used to develop sustainability management criteria and to project future Basin conditions for evaluating water management scenarios during GSP implementation. The GSFLOW model was constructed to evaluate seawater intrusion, simulate groundwater and surface water processes, and is calibrated to groundwater level and streamflow data for the period from Water Year 1984 through 2015.

The PRMS portion of the model is calibrated to measured streamflow and allows for estimation of recharge to Basin aquifers and aquitard units. Groundwater aquifer properties have been calibrated to observed groundwater levels for most coastal groundwater wells. The calibrated model can be used to evaluate groundwater management projects with the primary goal of preventing seawater intrusion. Groundwater level calibration also supports evaluating groundwater level responses to projects in areas where observation data show past responses to municipal pumping (i.e. south of the simulated horizontal flow barrier (HFB) representing Aptos area faulting).

Calibration to shallow groundwater levels along Soquel Creek supports using the model to simulate shallow groundwater level responses to groundwater management projects for evaluating sustainability of streamflow depletion. The model is not calibrated to precise estimates of flows between groundwater and streams, so estimates of streamflow depletion from the model have high uncertainty. Additionally, sensitivity runs provide estimates of streamflow depletion resulting from groundwater use and incorporating other assumptions. It is important to note that these estimates represent conditions that have not occurred historically and are therefore uncalibrated to any data, which introduces additional uncertainty.

The remainder of the model area does not have the benefit of measured shallow groundwater data from which to calibrate the model and therefore the simulation of shallow groundwater and stream-aquifer interactions is much more uncertain than in areas with shallow monitoring wells.

The current model is not recommended for evaluating responses in the Purisima DEF unit due to limitations associated with the current vertical discretization of model layers in this area, which prevents simulation of the observed confined aquifer response. The current model is also not recommended for evaluating responses to pumping or managed recharge north of Aptos area faulting as there lacks measured groundwater level data showing past responses to regional pumping.

The use of the model in evaluating proposed projects should be with respect to protective groundwater elevation for preventing seawater intrusion and whether or not a project recovers and maintains groundwater levels at protective elevations. The model can also be used to evaluate effects of projects on meeting sustainability criteria for streamflow depletion by predicting shallow groundwater levels along Soquel Creek. The model can also be used to evaluate groundwater level effects of projects throughout the area south of the Aptos area faulting, such as at existing or planned well locations.

The model should not be used to define a single number that any project or combination of projects needs to supply to achieve sustainability, as the ability to prevent seawater intrusion and avoid other undesirable results depends on the specifics of each project. The model can be used to define a single number for planning purposes, but it will be based on specific assumptions for projects and management actions to achieve sustainability.

The water budgets calculated by the model can be used for groundwater sustainability planning, but it must be understood that there are significant differences for the portions of the basin north and south of the Aptos area faulting. It is also important to understand that even components of the water budget that make up a small percentage of the total budget, such as offshore outflows which regulate seawater intrusion, can actually have greater importance on basin sustainability than other water budget components with larger volumes.

The following is a list of recommendations for future improvements of the model:

- Consider splitting layer 3 to separately simulate the Purisima DEF and F units which have different observed confined and unconfined aquifer responses in some areas of the model

- Calibrate inland groundwater levels after five years of data become available from representative monitoring points.

- Calibrate shallow groundwater levels along additional creeks after five years of data become available from representative monitoring points.

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13 ACRONYMS & ABBREVIATIONS

AFY................acre-feet per year
ASR................aquifer storage and recovery
amsl................above mean sea level
bgs..................below ground surface
cfs...................cubic feet per second
cfs...................cublic feet per second
COOP.............Cooperative Observer Network
CRT................Cascade Routing Tool
CWD..............Central Water District
DEM...............digital elevation model
GHB...............general head boundary
GIS.................geographic information systems
HFB................horizontal flow barrier
HRU...............hydrologic response unit
Kh...................horizontal hydraulic conductivity
Kv...................vertical hydraulic conductivity
MAE...............mean absolute error
ME..................mean error
MGA ....Mid-County Groundwater Agency
MGB ....Mid-County Groundwater Basin
MNW2...........Multi-Node Well
NHD...............National Hydrography Dataset
NS ....Nash-Sutcliffe goodness of fit
NWS...............National Weather Service
PET ....potential evapotranspiration
PRMS.............Precipitation-Runoff Modeling System
PVWMA.........Pajaro Valley Water Management Agency
PWS ....Pure Water Soquel
RMSE.............root mean squared error
SFR ....Streamflow-Routing
SWI................Seawater Interface
SqCWD..........Soquel Creek Water District
SR...................solar radiation
Ss....................specific storage
STD................standard deviation

Sy ....specific yield
USGS .............U.S. Geological Survey
UZF................Unsaturated-Zone Flow

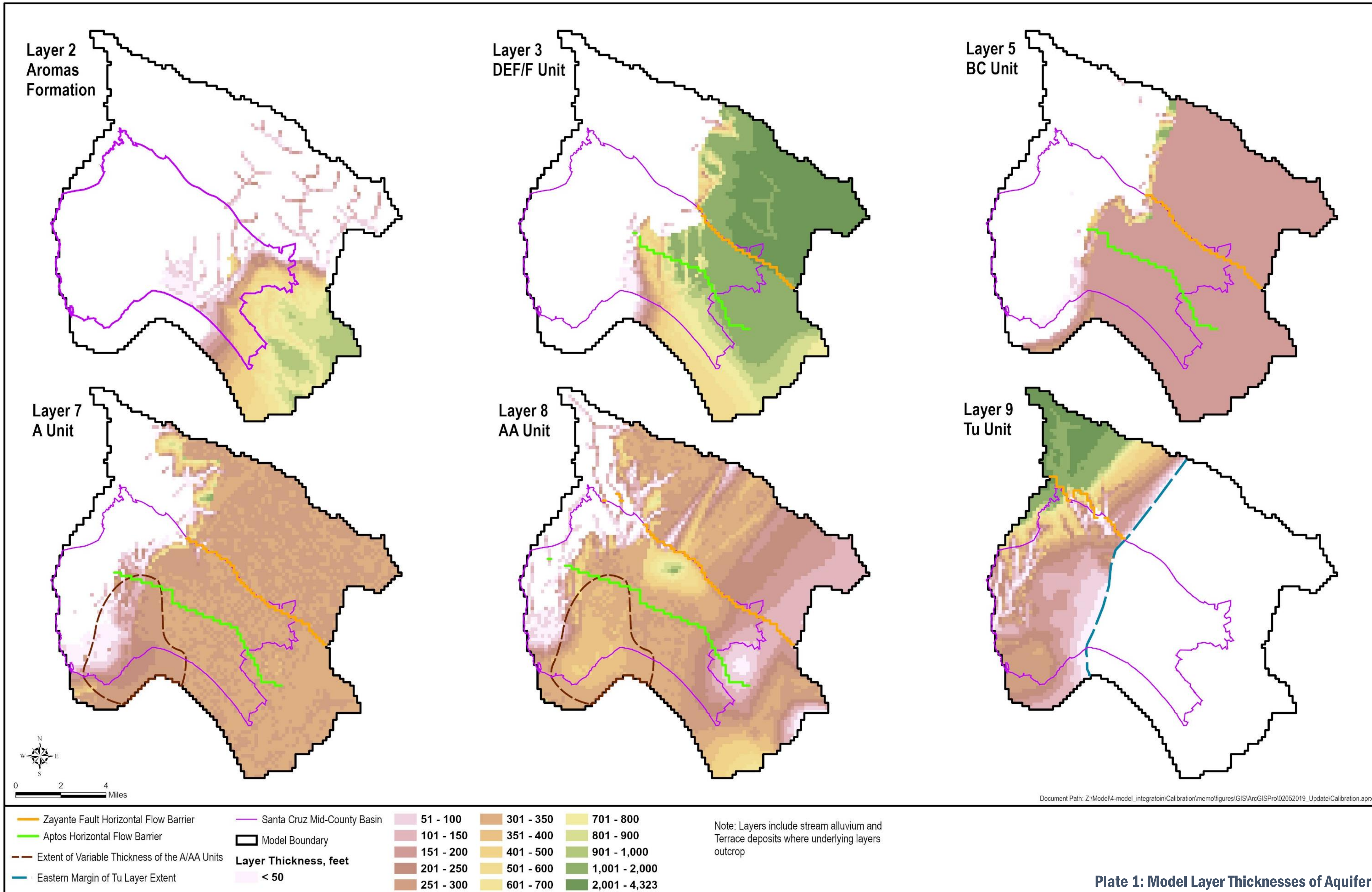


Plate 1: Model Layer Thicknesses of Aquifer

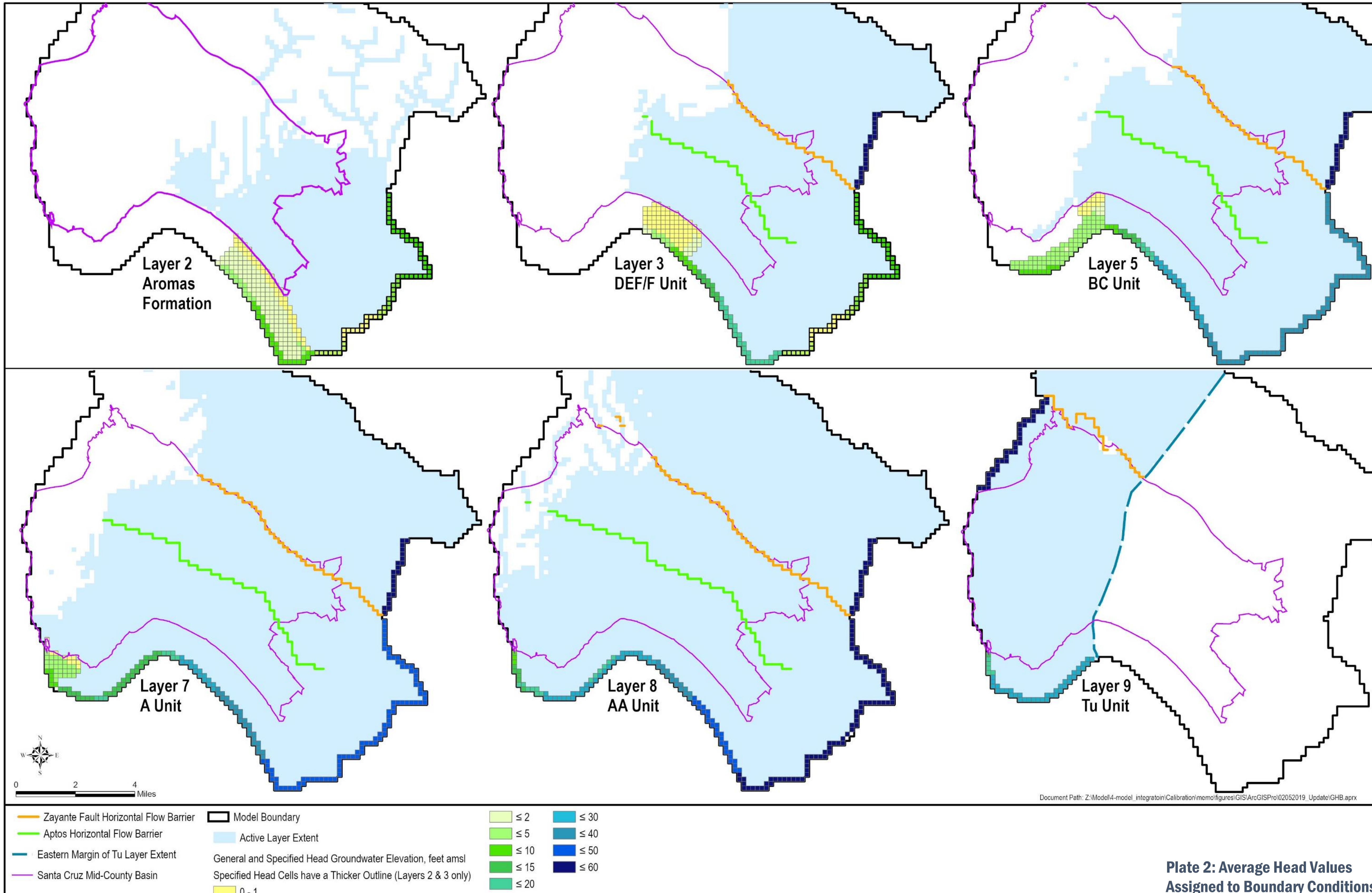


Plate 2: Average Head Values Assigned to Boundary Conditions

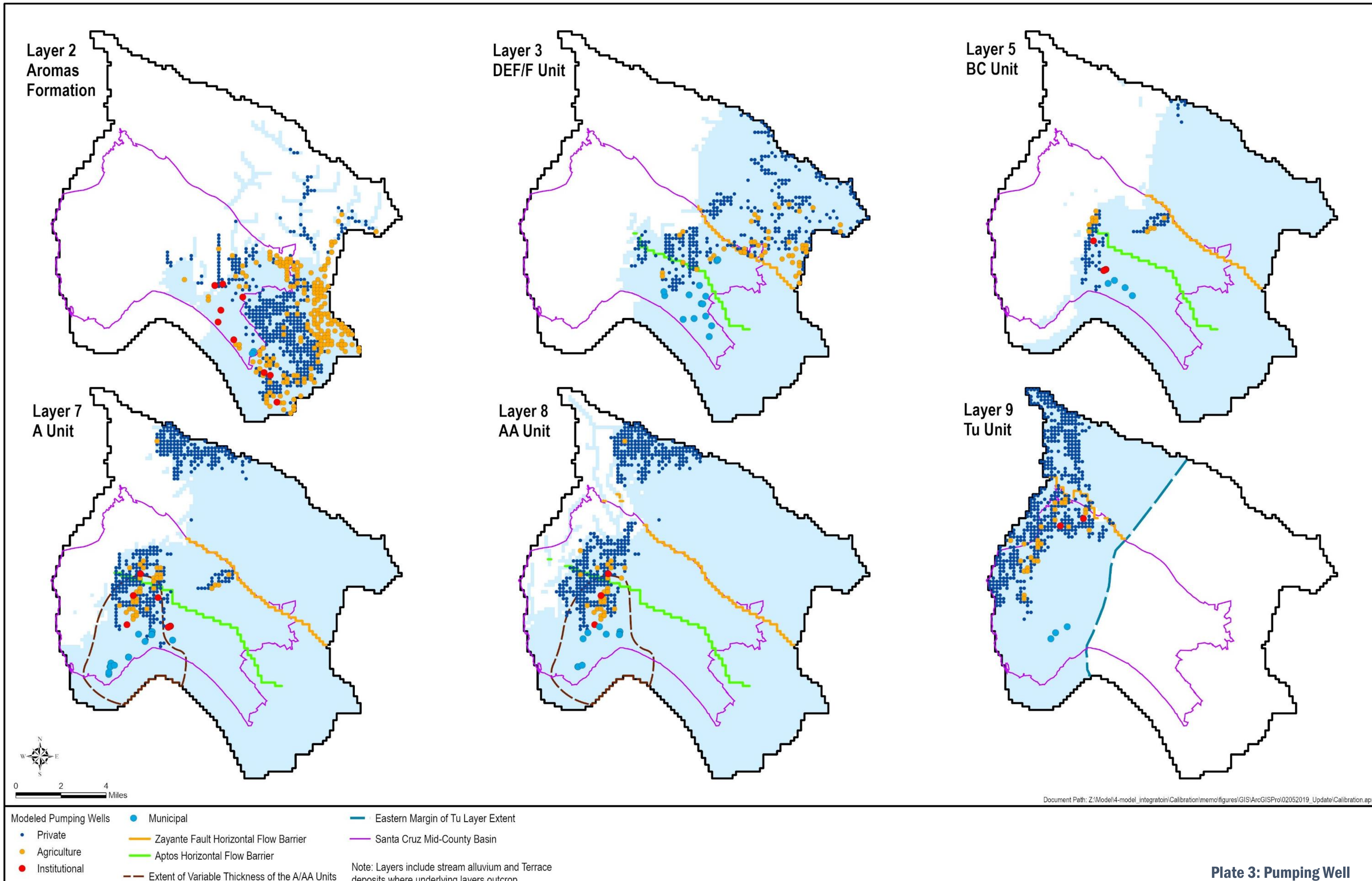


Plate 3: Pumping Well Locations by Model Layer

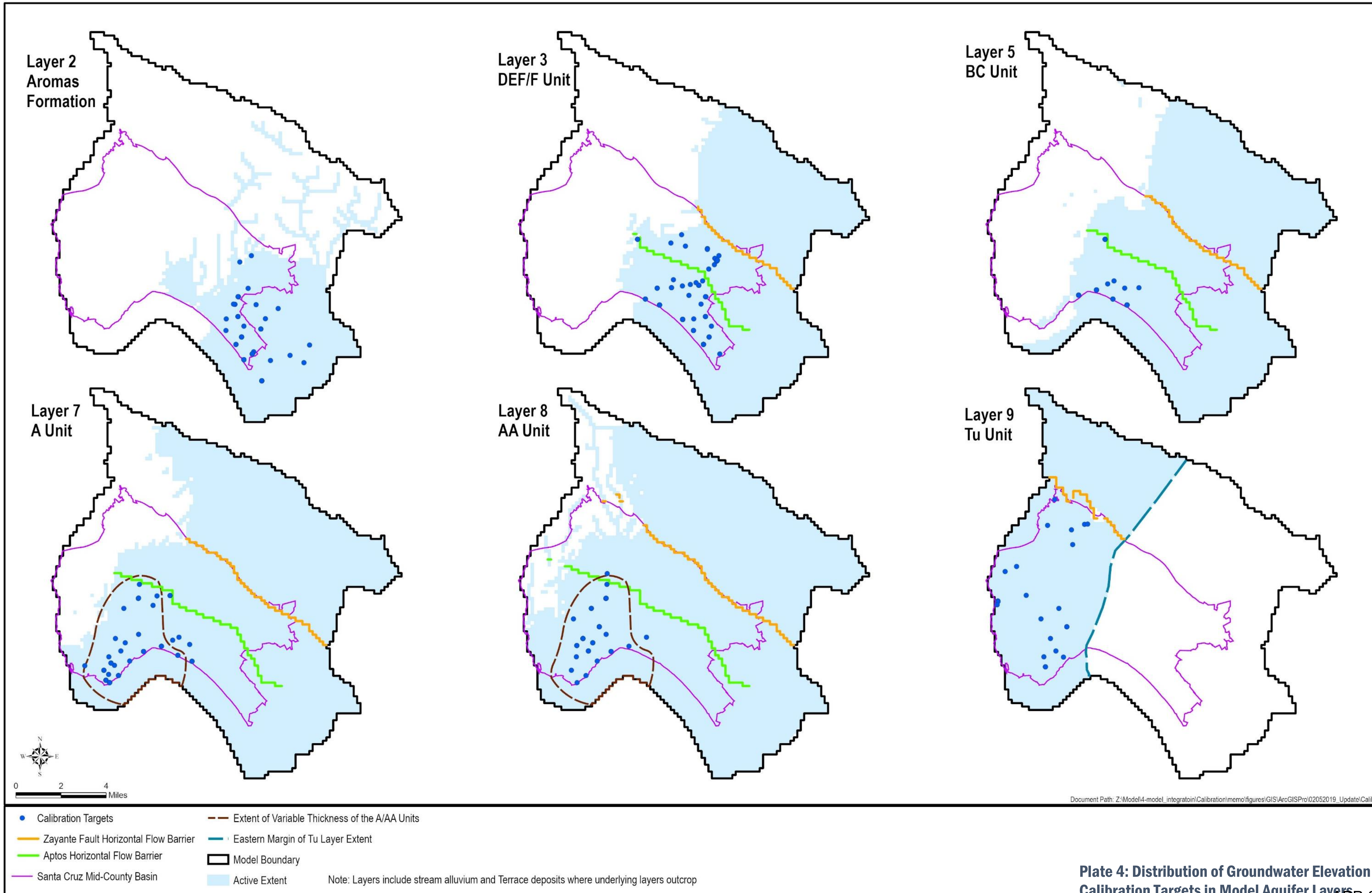


Plate 4: Distribution of Groundwater Elevation Calibration Targets in Model Aquifer Layers

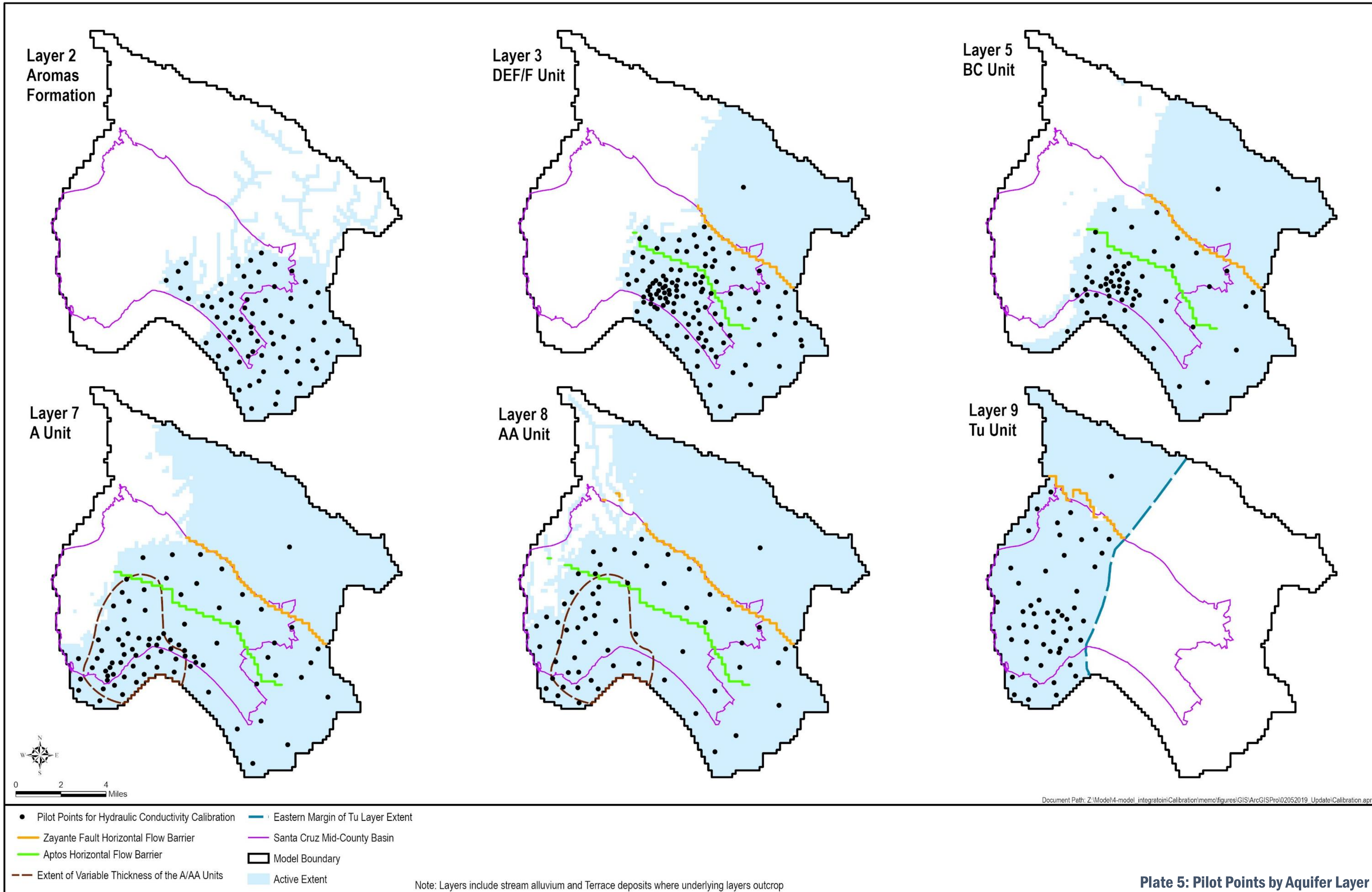


Plate 5: Pilot Points by Aquifer Layer

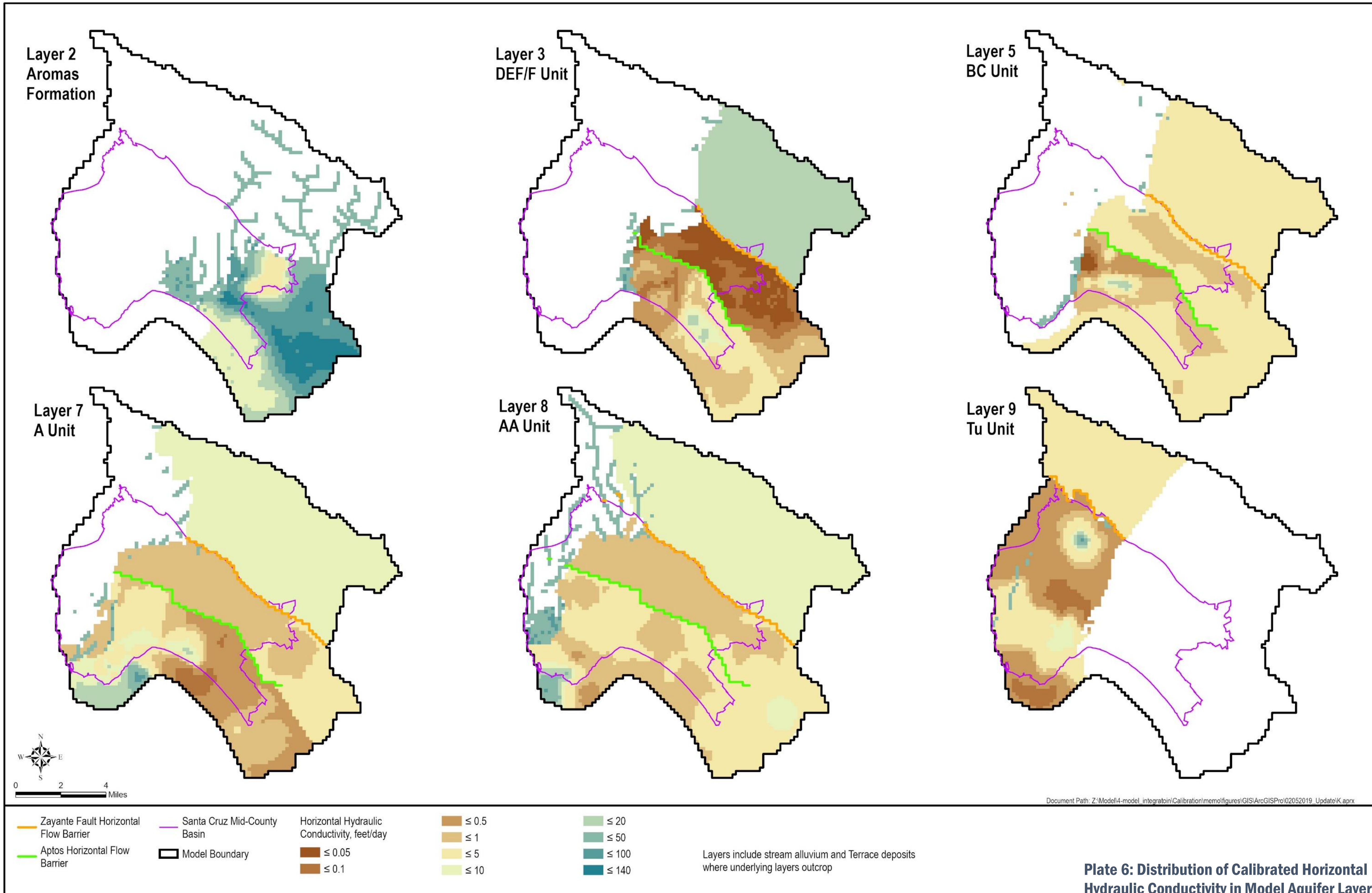


Plate 6: Distribution of Calibrated Horizontal Hydraulic Conductivity in Model Aquifer Layers

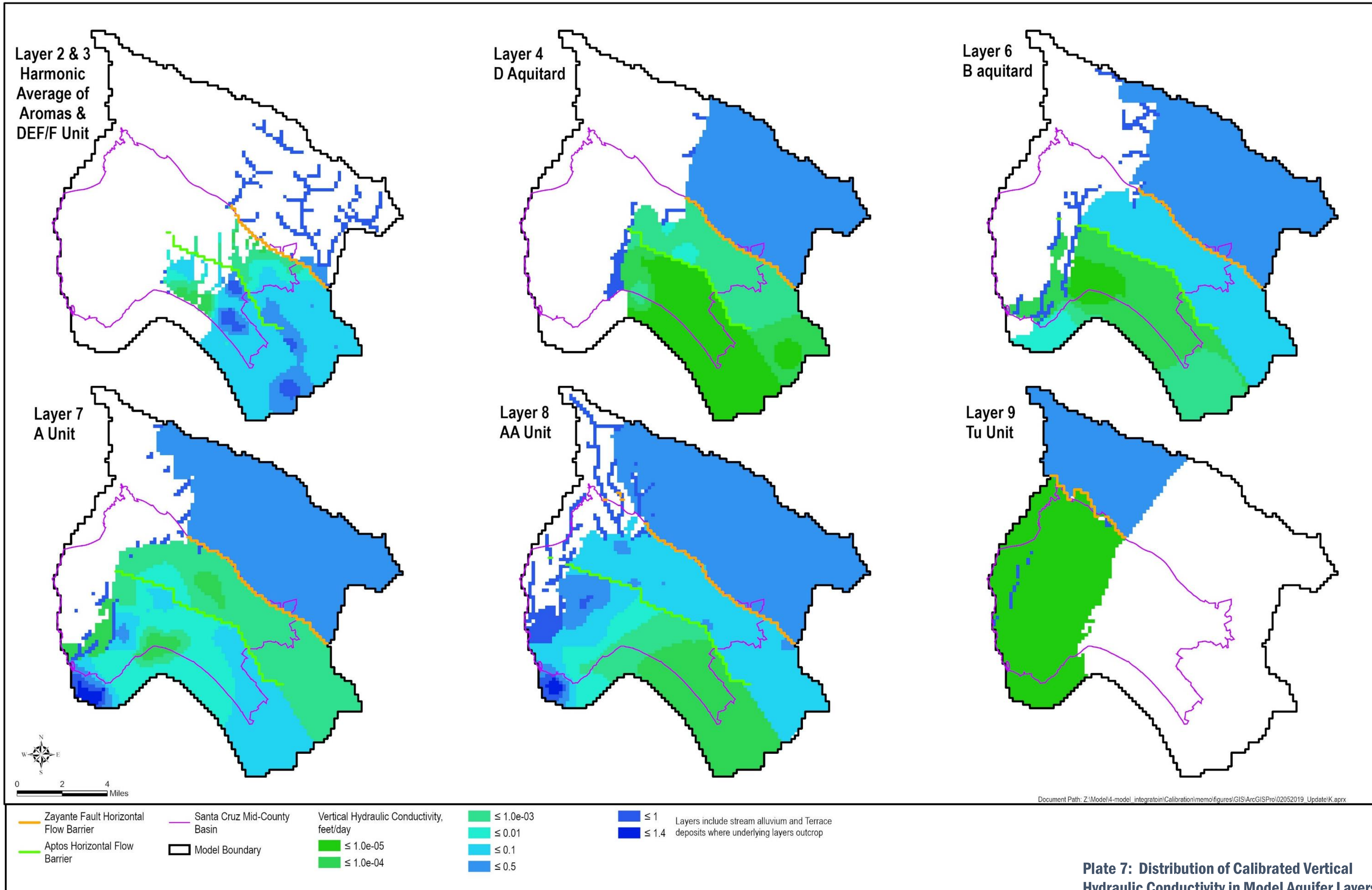


Plate 7: Distribution of Calibrated Vertical Hydraulic Conductivity in Model Aquifer Layers

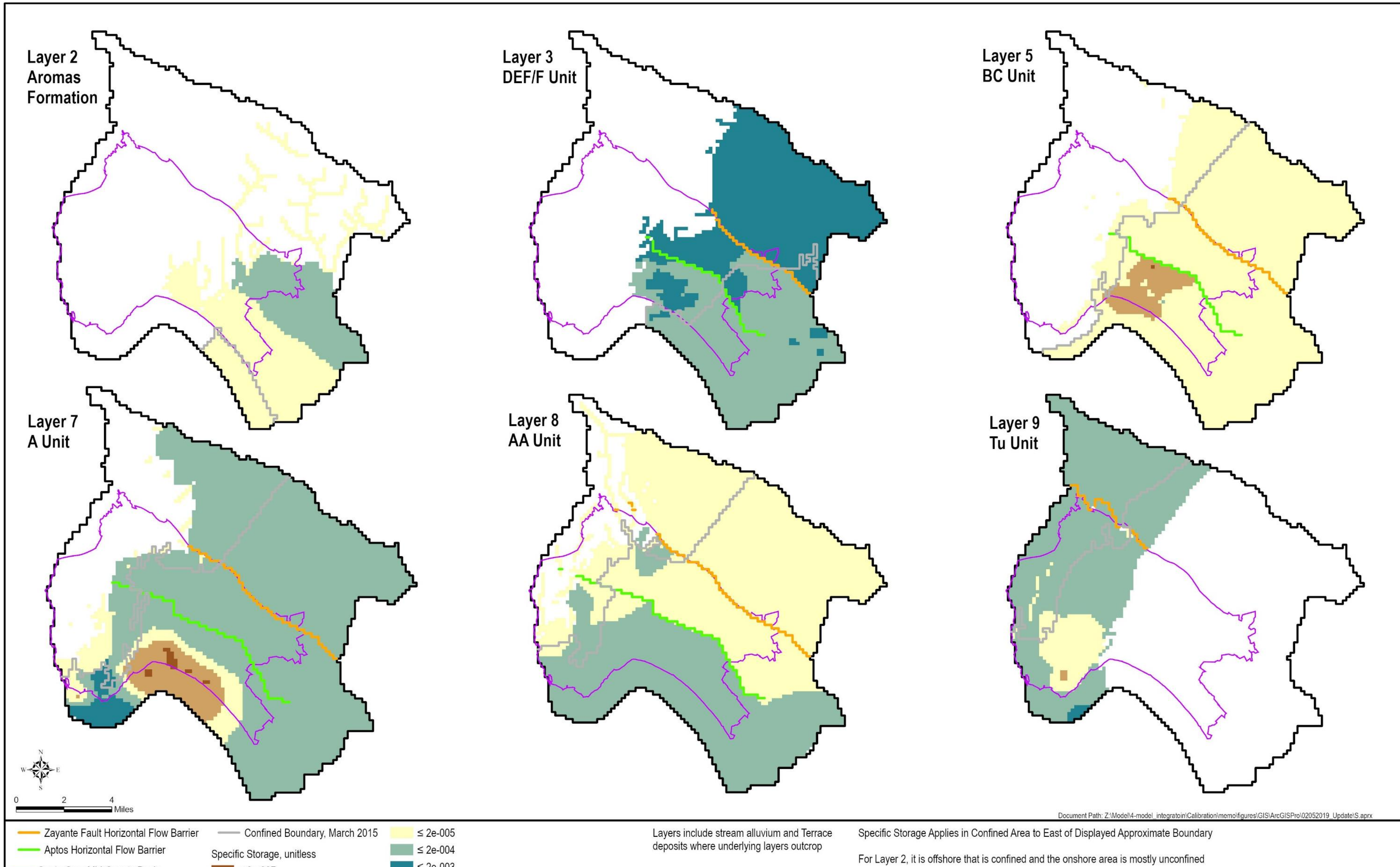


Plate 8: Distribution of Calibrated Specific Storage in Model Aquifer Layers

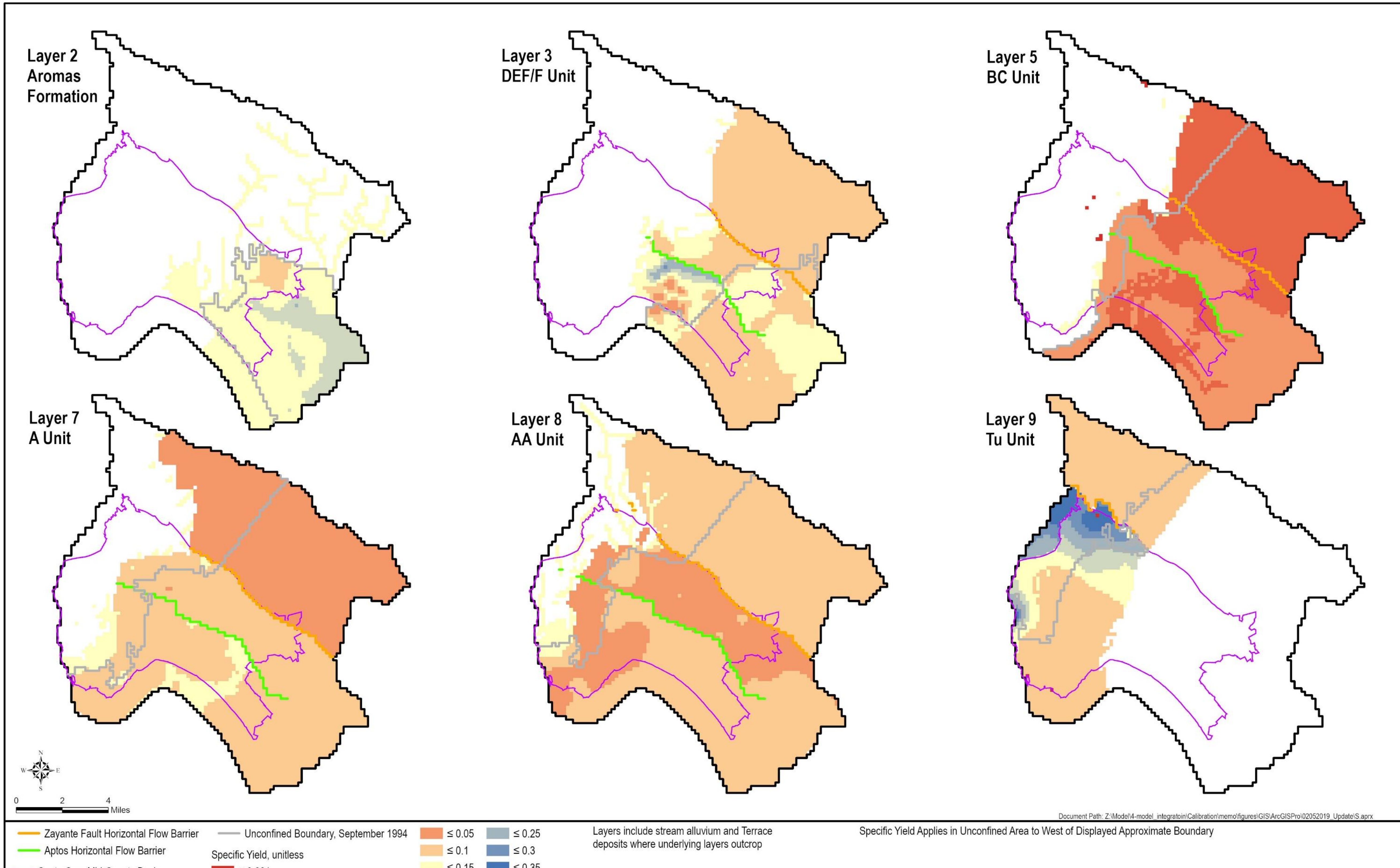


Plate 9: Distribution of Calibrated Specific Yield in Model Aquifer Layers

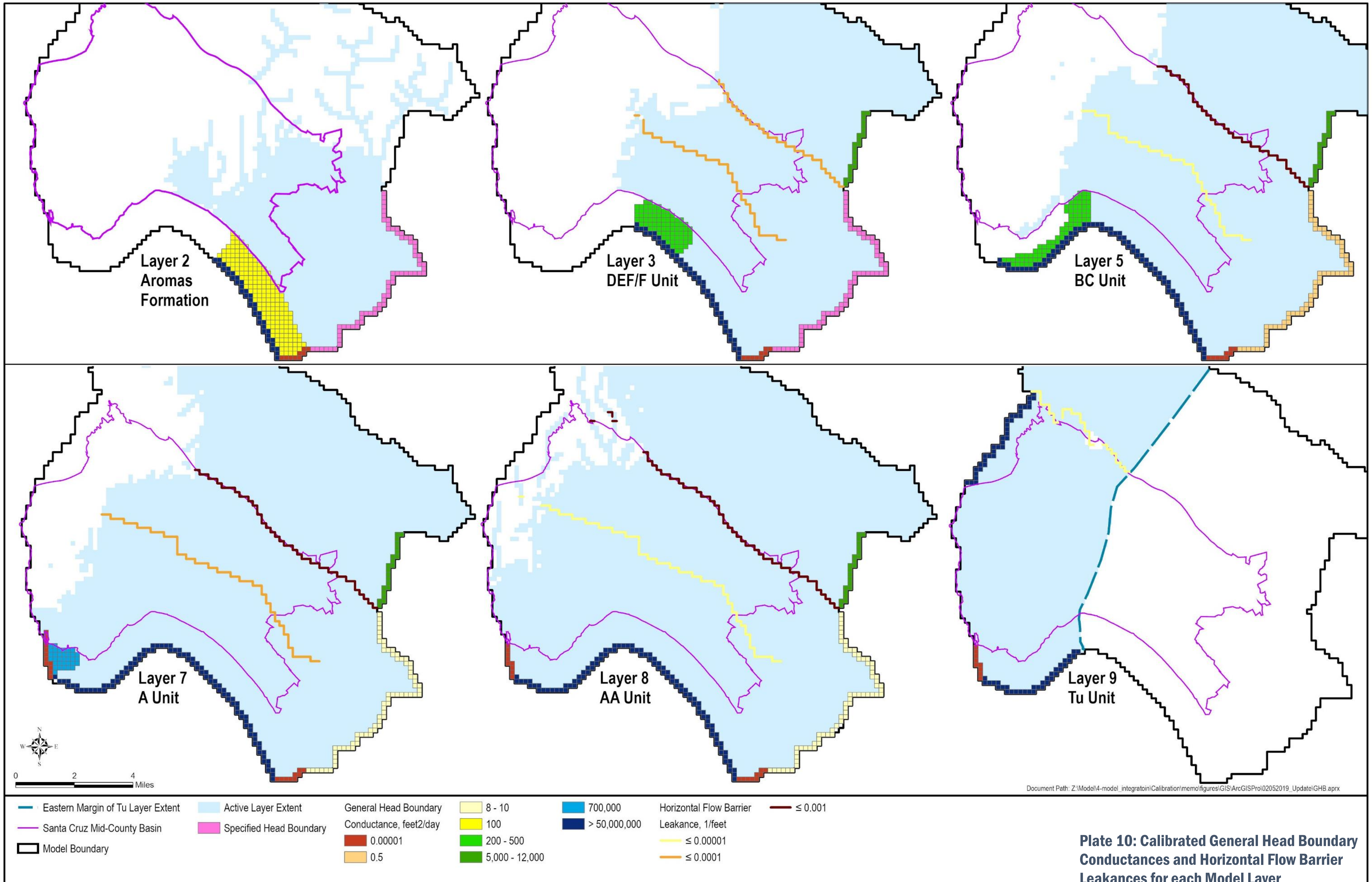


Plate 10: Calibrated General Head Boundary Conductances and Horizontal Flow Barrier Leakances for each Model Layer

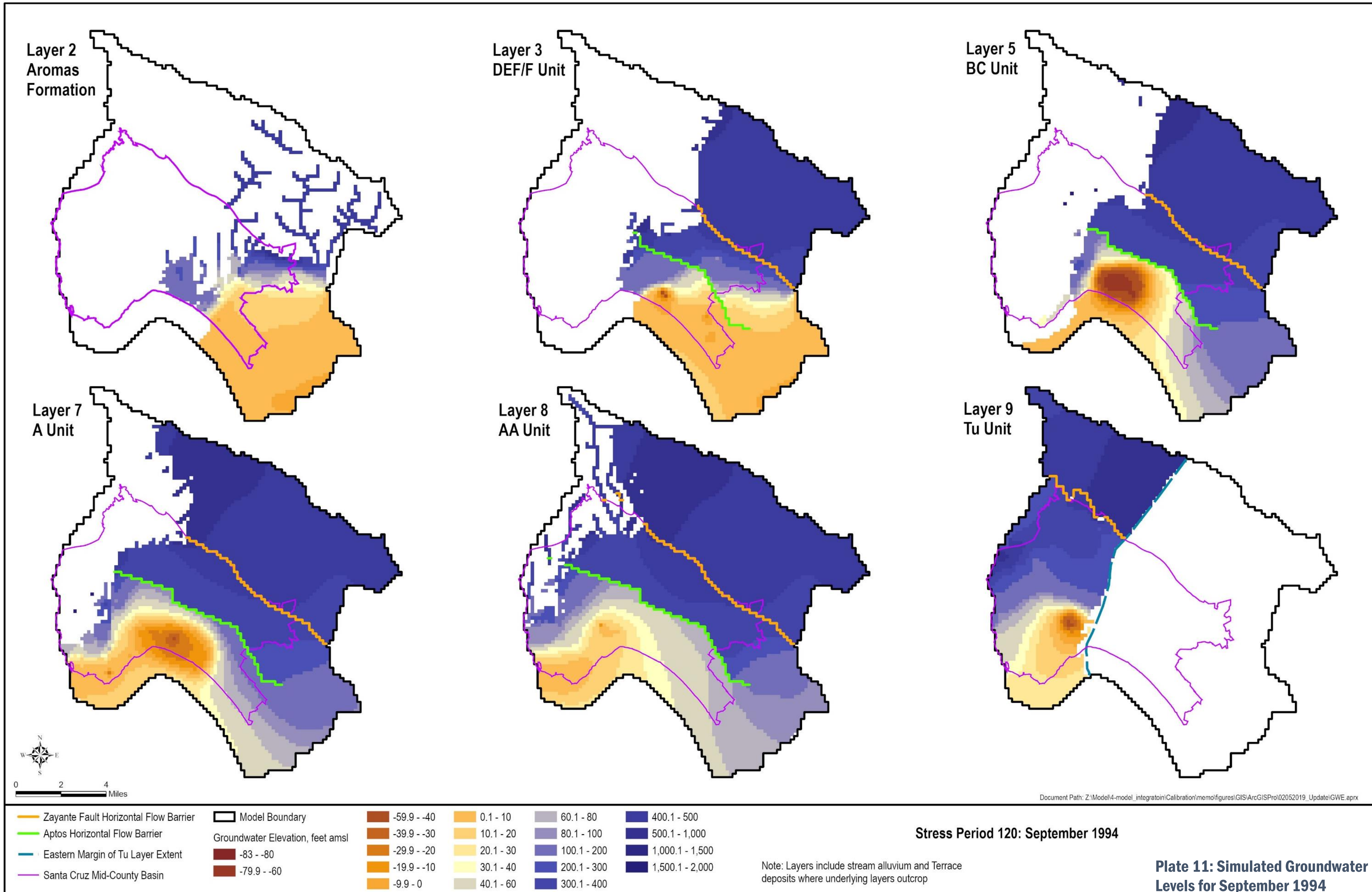
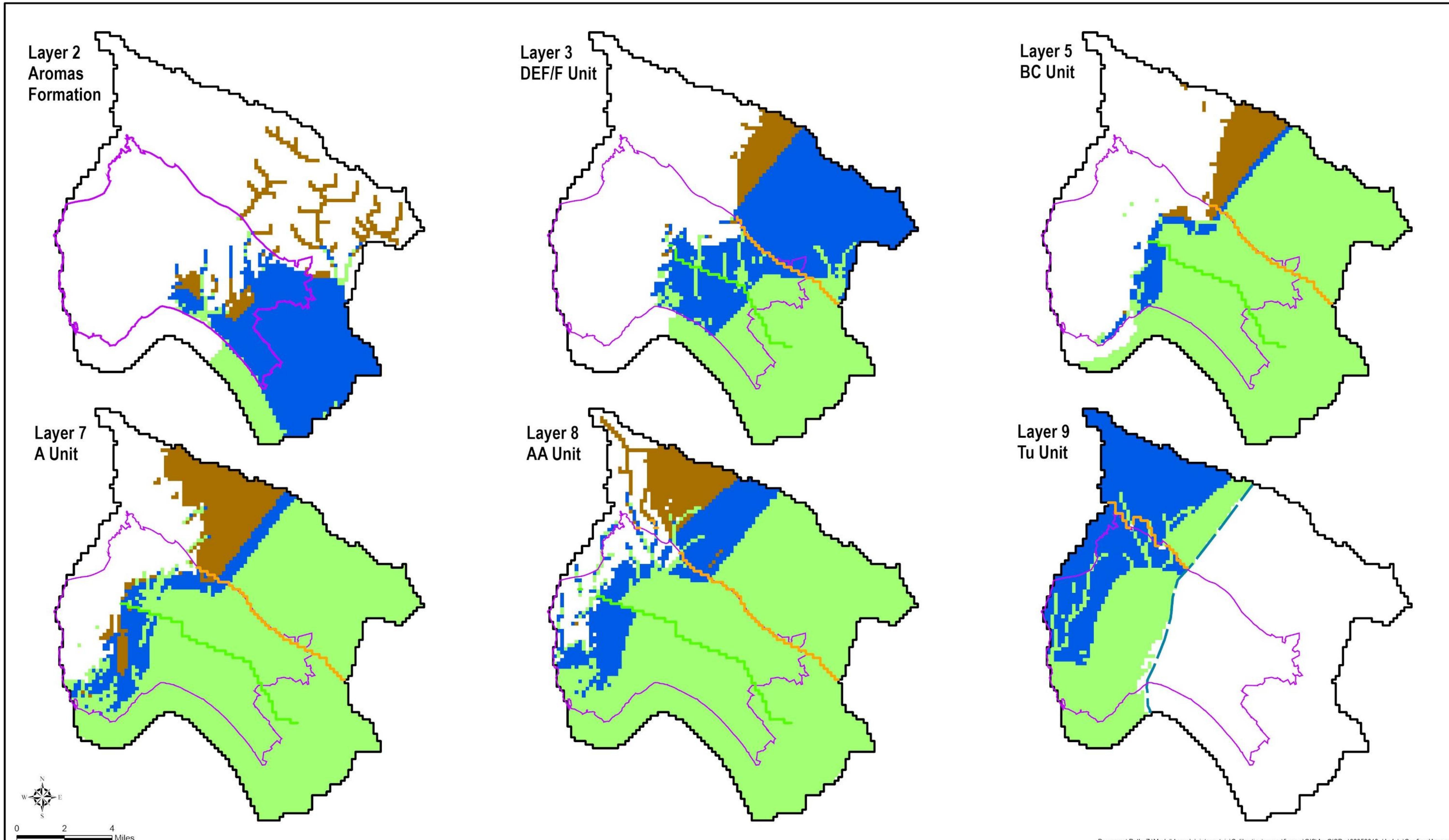


Plate 11: Simulated Groundwater Levels for September 1994



Zayante Fault Horizontal Flow Barrier
Aptos Horizontal Flow Barrier
Eastern Margin of Tu Layer Extent
Santa Cruz Mid-County Basin
Model Boundary
Dry
Unconfined
Confined

Note: Layers include stream alluvium and Terrace deposits where underlying layers outcrop

Stress Period 120: September 1994

Plate 12: Simulated Dry, Unconfined and Confined Areas for September 1994

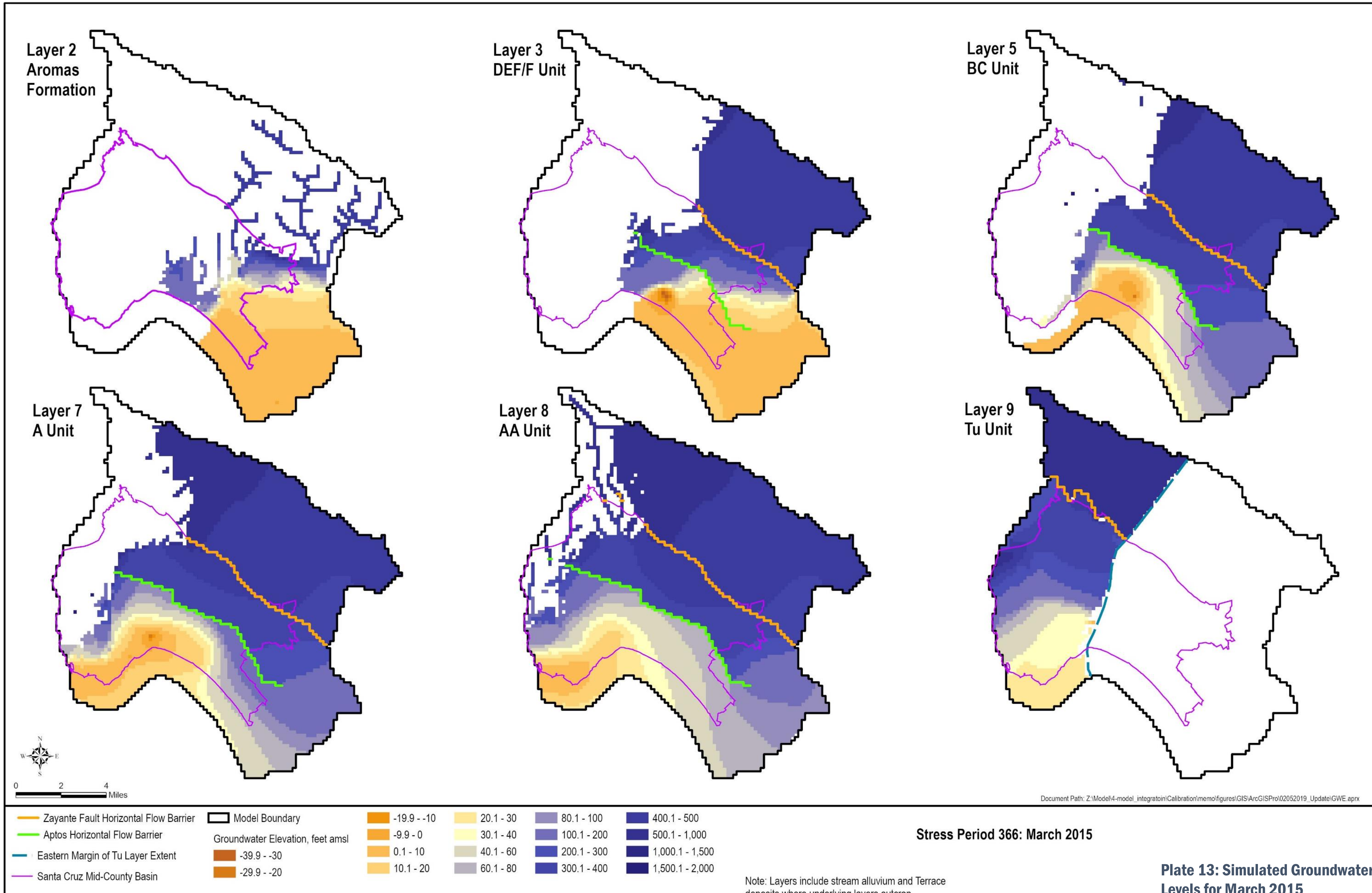
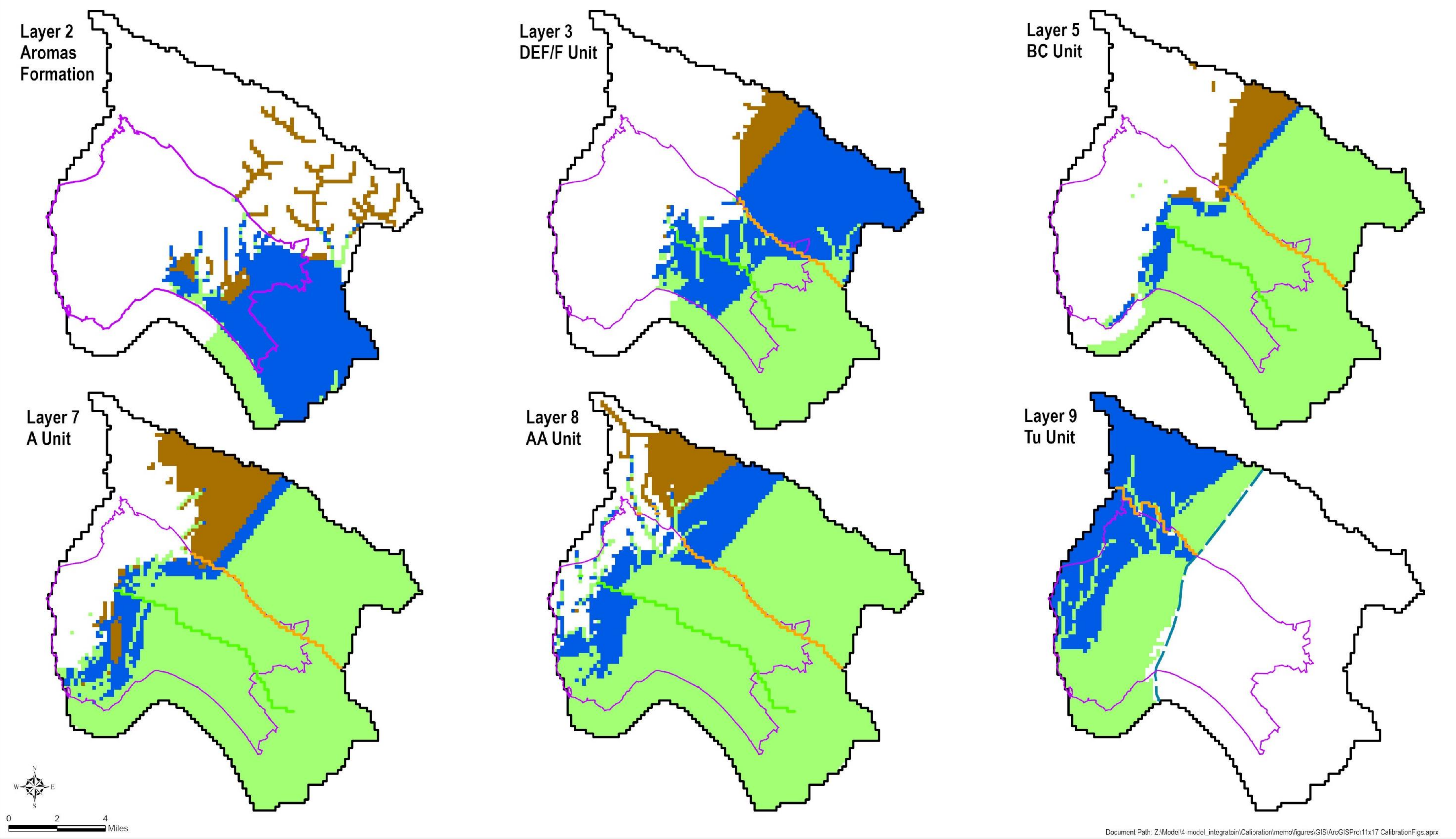


Plate 13: Simulated Groundwater Levels for March 2015



Zayante Fault Horizontal Flow Barrier
Aptos Horizontal Flow Barrier
Eastern Margin of Tu Layer Extent
Santa Cruz Mid-County Basin
Model Boundary
Dry
Unconfined
Confined

Note: Layers include stream alluvium and Terrace deposits where underlying layers outcrop

Stress Period 366: March 2015

Plate 14: Simulated Dry, Unconfined and Confined Areas for March 2015

Appendix A

Municipal Return Flow Estimate Approach

TECHNICAL MEMORANDUM

DATE: August 28, 2019

TO: Santa Cruz Mid-County Groundwater Agency

FROM: Georgina King and Cameron Tana

PROJECT: Santa Cruz Mid-County Basin Groundwater Model

SUBJECT: Municipal Return Flow

SERVICE AREA WATER SUPPLY

Water supplied or delivered to the various municipal service areas in the model is the source of water from which different components of return flow are estimated.

Individual municipal return flow components estimated are:

1. Water system losses,
2. Large-scale landscape/field irrigation,
3. Small-scale landscape irrigation (residential and commercial), and
4. Sewer system losses, and septic tank leakage.

The amount of water supplied to each service area is obtained from readily available data provided by the four municipal water agencies in the model area: City of Santa Cruz, Soquel Creek Water District (SqCWD), Central Water District (CWD), and City of Watsonville. If monthly data are not available, annual data are used.

Annual data are used for the Cities of Watsonville and Santa Cruz. Both these municipalities deliver water to customers from both groundwater and surface water sources. Both CWD and SqCWD are able to provide monthly water supply data from well production records as groundwater is their sole source of water.

City of Watsonville

The City of Watsonville was not able to provide readily available water delivery data for the portion of their service area within the model. Their annual water supply (AWS) is estimated as the sum of residential water use and large-scale landscape irrigation, plus 6% to account for water system losses of that water (City of Watsonville, 2016). As an estimate of residential water use, building counts, similar to the approach taken for private water use, are used to estimate annual residential water use to supply areas. The amount of large-scale landscape irrigation is estimated based on irrigated area, water demand, turf crop factor and irrigation inefficiency. The top two rows of Figure 1 show the calculations for estimating AWS for those portions of the City of Watsonville service area within the model.

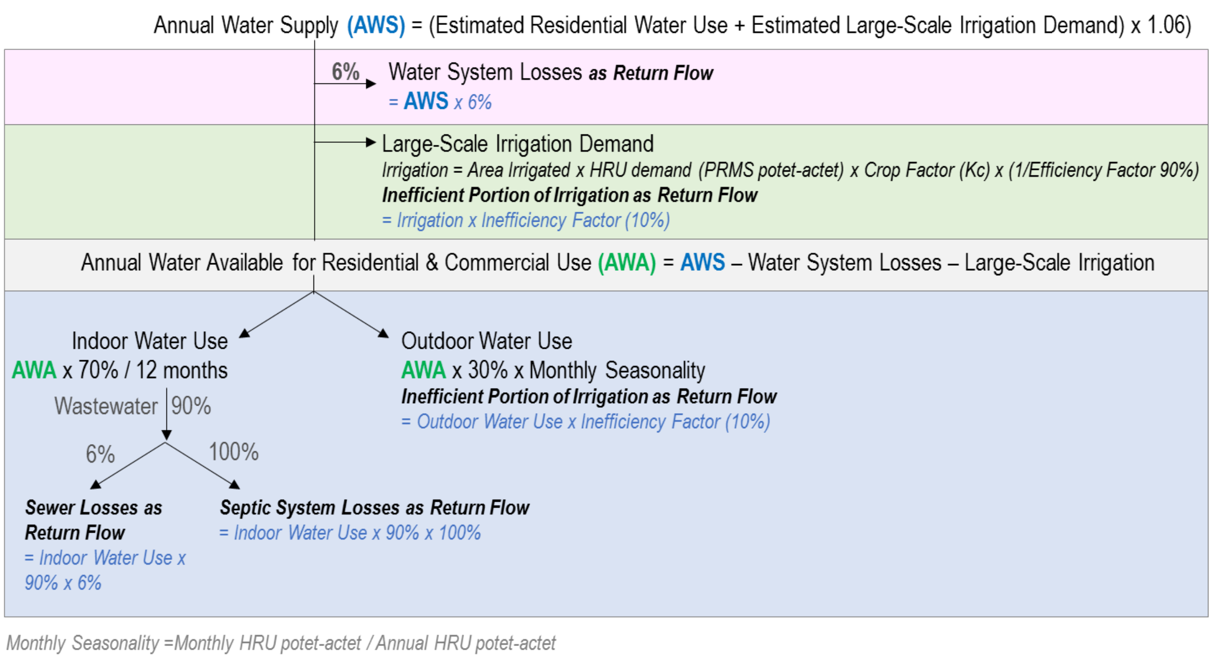


Figure 1: City of Watsonville Return Flow Calculations

City of Santa Cruz

As no delivery data are readily available that are specific to the model area, the City of Santa Cruz provided its entire service area annual consumption data from 1983 – 2015 for its different use types. The amount of water delivered to users in the model area was determined from the percentage of each use type within the model area compared to the entire service area (Table 1). The General Plan land use was used to determine relative land use percentages in the model area. As the City of Santa Cruz's consumption data are generated at meters, 7.5% assumed for water losses (WSC, 2016) was added to the consumption data to estimate AWS within their service area in the model. The top line of Figure 2 shows the calculations to estimate AWS.

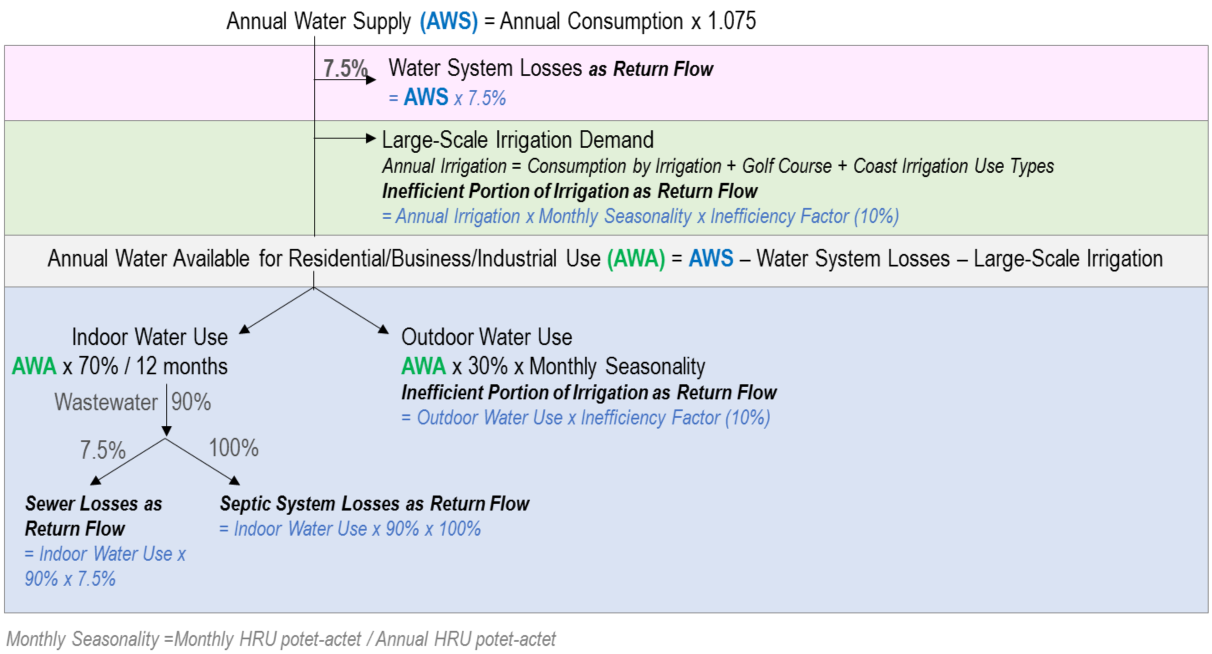


Figure 2: City of Santa Cruz Return Flow Calculations

Table 1: Percentage of All City of Santa Cruz Water Use Types within Model Area

Use Type	Percentage of Total City Land Use within Model Area
Single Family Residential	49%
Multiple Residential	50%
Business	55%
Industrial	34%
Municipal	33%
Irrigation (Large-Scale)	38%
Golf Course Irrigation	100%
Coast Irrigation	55%
Other (Construction & Hydrants)	38% (but negligible return flow assumed)

Central Water District

Groundwater pumped from CWD wells is delivered to both residential/commercial and agricultural customers. The amount of water available for residential/commercial purposes is estimated as the difference between the amount pumped and the amount supplied for agriculture, as shown on Figure 3. Water losses from 1985-1999 are 12%, from 2000-2007 are 7%, and from 2008-2016 are 4%. CWD system loss varies over time based on unaccounted water losses recorded by CWD each fiscal year.

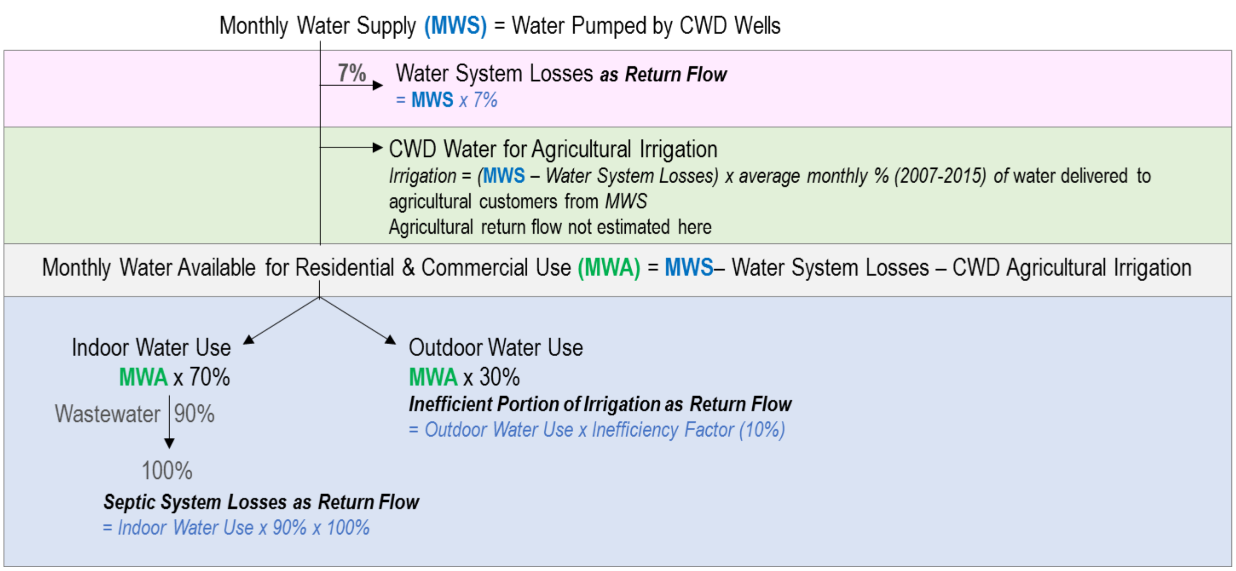


Figure 3: Central Water District Return Flow Calculations

Soquel Creek Water District

Water delivered to each of their four service areas (SA) is determined from the amount of groundwater pumped within each SA plus factoring in transfers that occur between service areas. Delivery data for each SA compared to groundwater pumped within each SA from 2014-2016 was used to estimate the average transfer from SA1 to SA2, SA3 to SA2, and SA3 to SA4. Table 2 summarizes the transfers used to estimate water delivered to each SA that is then used to estimate various components of return flow. The top line on Figure 4 shows the calculation to estimate monthly water supply to each SA. A water loss percentage of 7% is assumed from groundwater pumped (WSC, 2016).

Table 2: Summary of SqCWD Service Area Transfers between 2014 and 2016

Transfer From/To	Percent of Groundwater Produced in Originating Service Area
SA1 to SA2	8.5%
SA 3 to SA2	1.7%
SA3 to SA4	14.3%

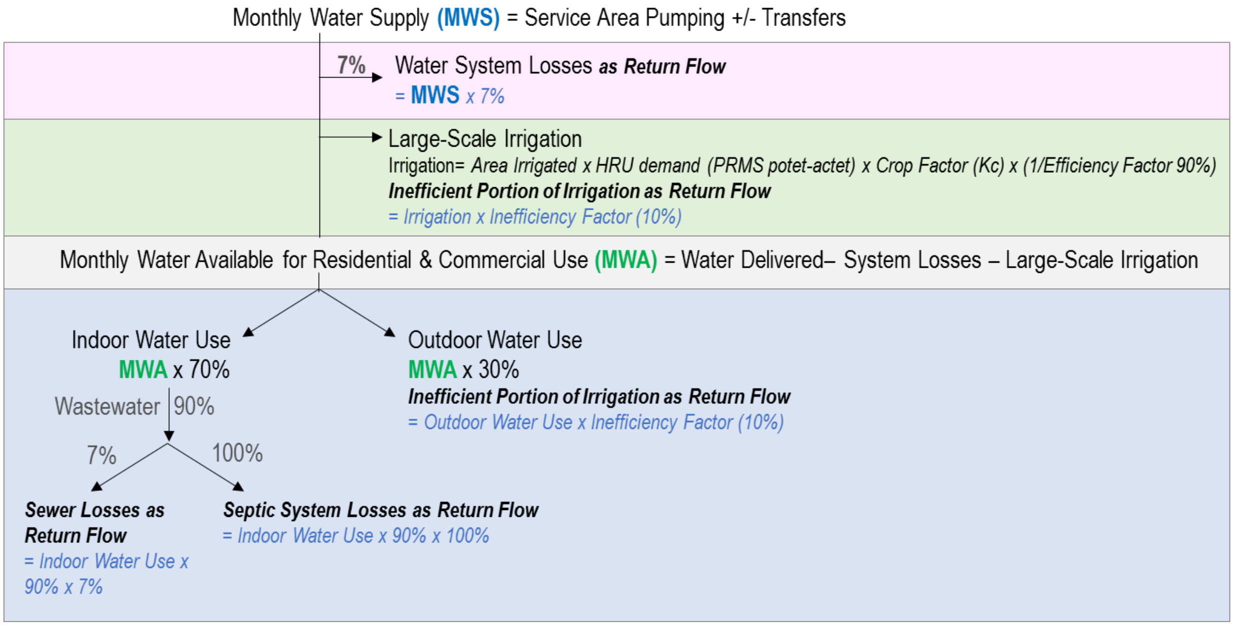


Figure 4: Soquel Creek Water District Return Flow Calculations

RETURN FLOW ESTIMATES

Different municipal water uses have their own proportion of water that percolates into the ground as return flow. Water system losses from both the water distribution and sewer systems are considered return flow. Water system losses are subtracted from water supply and thereafter, any water required to meet large-scale irrigation demand is subtracted from the supply. This leaves an amount of water that can be used for residential/commercial indoor and outdoor use. Assumed indoor and outdoor use is 70% and 30%, respectively. We assume 90% of indoor use becomes wastewater. For areas not connected to sewers, it is further assumed that 100% of wastewater percolates from septic systems into the unsaturated zone as return flow.

Inefficiencies in both residential irrigation (outdoor use) and large-scale irrigation result in an assumed return flow of 10% of the applied water. For the Cities of Santa Cruz and Watsonville, CWD, and SqCWD, Figure 1 through Figure 4, respectively, illustrate the methods for estimating each municipality’s return flow estimates. Summaries by water year of each component of return flow are provided in Table 3 through Table 6. The last column of these tables provides the percentage of the total water supply that comprises return flow.

The return flow estimates are applied to the model cells based on the ratio of the area of the model cell that receives municipal water for residential /commercial use compared to the entire service area. Figure 5 shows the location of the residential/commercial and large-landscape irrigation areas within each service area. Figure 6 shows the location of sewered and unsewered (septic tank) areas. Both figures also show model cell boundaries for the municipal water uses.

HOW WATER DELIVERED IS APPLIED TO MODEL CELLS FOR EACH MONTHLY MODEL STRESS PERIOD

For CWD and SqCWD, where monthly data are available, the deliveries to each service area are obtained from the service area pumping +/- any transfers, as described above. For the Cities of Watsonville and Santa Cruz, where annual data are only available, the amount of water applied to each model cell is distributed differently for indoor residential and irrigation use. Monthly indoor use is estimated as 70% of annual water delivered divided by 12 months. Monthly outdoor residential/commercial and large-scale irrigation use are based on irrigation demand (difference between monthly PRMS modeled potential ET (potet) and actual ET (actet)).

- For the City of Santa Cruz, where the water use type was 100% irrigation, the annual volume is distributed to months based on the ratio of monthly to annual irrigation demand for each model cell. For the outdoor portion of residential and commercial water use, the same ratio of monthly to annual irrigation demand for each model cell is used to distribute the annual volumes to monthly volumes.
- For the City of Watsonville, the amount of water to apply to each model cell for either large-scale or residential irrigation is distributed to months based on the ratio of monthly to annual irrigation demand for each model cell.

REFERENCES

City of Santa Cruz Water Department, 2016, City of Santa Cruz Water Department 2015 Urban Water Management Plan. August 2016.

City of Watsonville, 2016 City of Watsonville 2015 Urban Water Management Plan.

Water Systems Consulting, Inc., 2016, Soquel Creek Water District 2015 Urban Water Management Plan. Prepared for Soquel Creek Water District, June 2016.

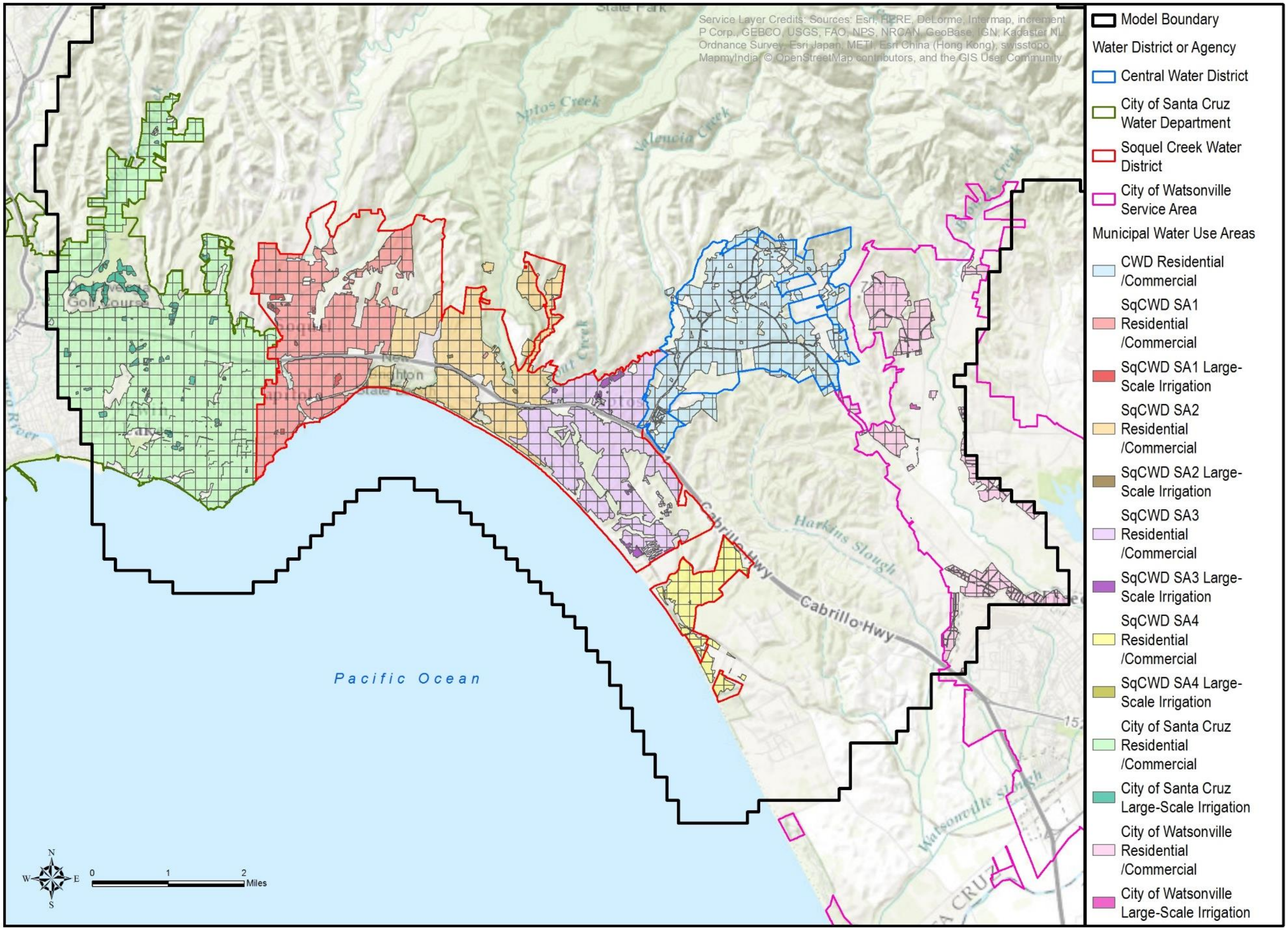


Figure 5: Residential/Commercial and Large-Scale Irrigation Areas within Municipal Service Area

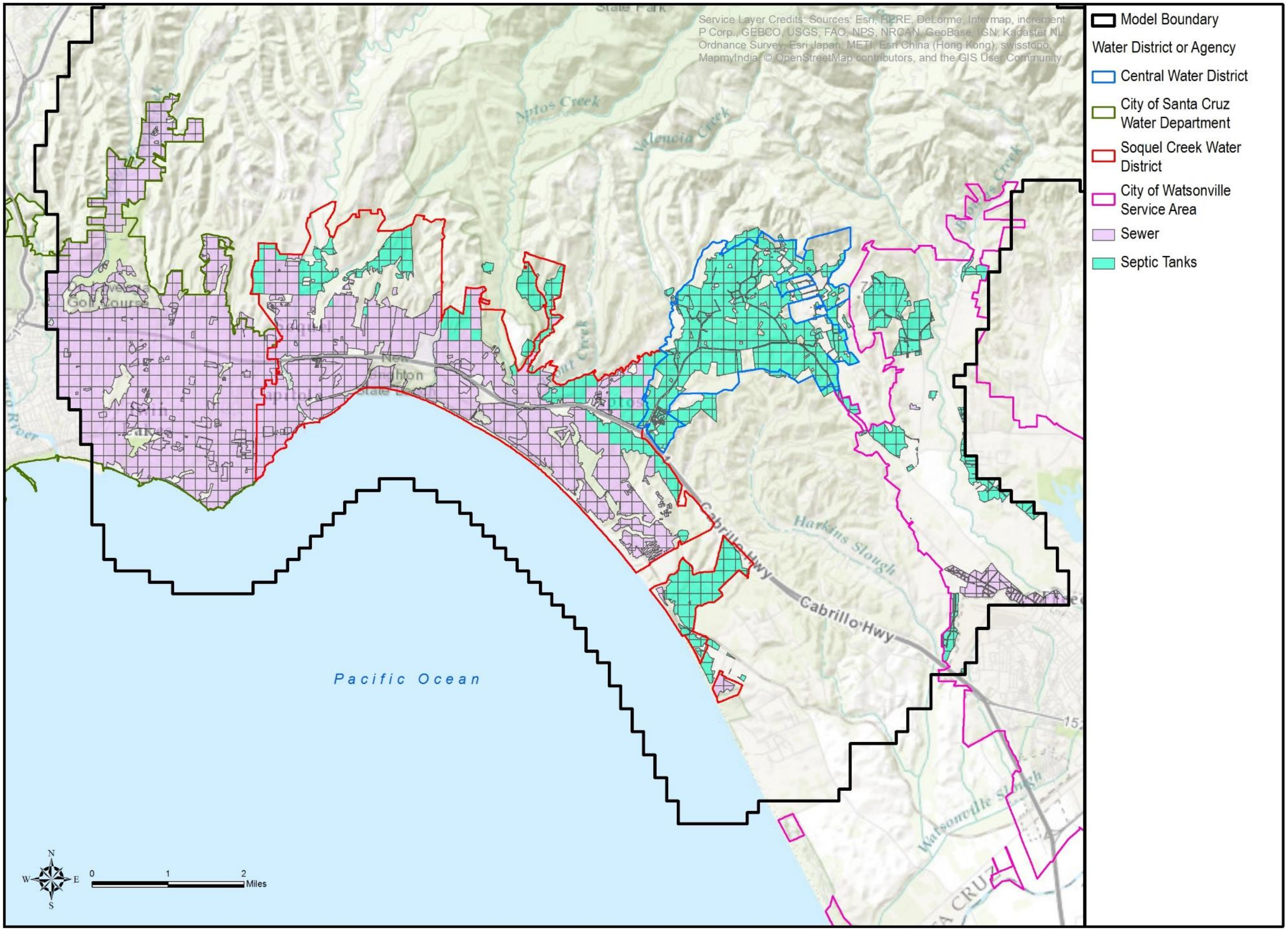


Figure 6: Municipal Sewered and Septic Tank Areas

Table 3: City of Watsonville Return Flow Estimates

Water Year	Water Supply to Service Area in Model, acre-feet	Return Flow in acre-feet						Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Large-Scale Landscape Irrigation	Small-Scale Landscape Irrigation	Sewer Losses	Septic Systems	Total Return Flow	
1985	478.1	28.7	0.3	14.2	6.5	206.8	227.9	47.7%
1986	497.3	29.8	0.3	14.8	6.7	215.2	237.1	47.7%
1987	511.9	30.7	0.3	15.3	6.9	221.6	244.1	47.7%
1988	529.1	31.7	0.3	15.8	7.2	229.1	252.3	47.7%
1989	543.1	32.6	0.3	16.2	7.4	235.2	259.0	47.7%
1990	561.0	33.7	0.3	16.7	7.6	243.0	267.6	47.7%
1991	577.5	34.6	0.3	17.2	7.8	250.2	275.5	47.7%
1992	596.8	35.8	0.3	17.8	8.1	258.6	284.8	47.7%
1993	614.0	36.8	0.3	18.3	8.3	266.1	293.0	47.7%
1994	633.2	38.0	0.3	18.9	8.6	274.4	302.2	47.7%
1995	650.5	39.0	0.3	19.4	8.8	282.0	310.5	47.7%
1996	708.8	42.5	0.3	21.2	9.6	307.4	338.5	47.7%
1997	724.8	43.5	0.3	21.7	9.8	314.3	346.1	47.7%
1998	742.7	44.6	0.3	22.2	10.1	322.1	354.7	47.8%
1999	766.0	46.0	0.3	22.9	10.4	332.2	365.8	47.8%
2000	816.4	49.0	0.3	24.4	11.1	354.2	390.0	47.8%
2001	823.0	49.4	0.3	24.6	11.2	357.1	393.1	47.8%
2002	819.0	49.1	0.3	24.5	11.1	355.3	391.2	47.8%
2003	828.3	49.7	0.3	24.8	11.2	359.4	395.7	47.8%
2004	850.9	51.1	0.3	25.4	11.5	369.2	406.5	47.8%
2005	843.1	50.6	0.3	25.2	11.4	365.8	402.7	47.8%
2006	860.6	51.6	0.3	25.7	11.7	373.5	411.2	47.8%
2007	868.5	52.1	0.3	26.0	11.8	376.9	414.9	47.8%
2008	872.4	52.3	0.3	26.1	11.8	378.6	416.8	47.8%
2009	850.2	51.0	0.3	25.4	11.5	368.9	406.2	47.8%
2010	852.1	51.1	0.3	25.5	11.6	369.7	407.1	47.8%
2011	858.4	51.5	0.3	25.7	11.6	372.5	410.1	47.8%
2012	861.6	51.7	0.3	25.8	11.7	373.9	411.6	47.8%
2013	866.0	52.0	0.3	25.9	11.8	375.8	413.7	47.8%
2014	798.0	47.9	0.3	23.9	10.8	346.2	381.2	47.8%
2015	744.0	44.6	0.3	22.2	10.1	322.7	355.3	47.8%
Average	727.3	43.6	0.3	21.7	9.9	315.4	347.3	47.7%

Table 4: City of Santa Cruz Return Flow Estimates

Water Year	Water Supply to Service Area in Model, acre-feet	Return Flow in acre-feet					Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Large-Scale Landscape Irrigation	Small-Scale Landscape Irrigation	Sewer Losses	Total Return Flow	
1985	6,593.7	461.6	72.1	162.3	238.6	934.6	14.2%
1986	6,663.3	466.4	68.7	165.3	243.0	943.4	14.2%
1987	6,941.7	485.9	84.4	168.3	247.4	986.1	14.2%
1988	6,258.3	438.1	77.5	151.3	222.5	889.4	14.2%
1989	5,749.4	402.5	61.8	141.9	208.6	814.7	14.2%
1990	5,209.9	364.7	55.0	126.8	186.4	732.9	14.1%
1991	4,891.0	342.4	53.1	120.3	176.8	692.6	14.2%
1992	5,419.7	379.4	57.6	133.7	196.5	767.2	14.2%
1993	5,455.4	381.9	47.1	137.9	202.8	769.7	14.1%
1994	5,648.9	395.4	47.4	143.2	210.5	796.4	14.1%
1995	5,777.5	404.4	47.1	147.0	216.1	814.6	14.1%
1996	6,143.6	430.1	51.7	155.8	229.0	866.6	14.1%
1997	6,633.3	464.3	64.7	165.5	243.2	937.7	14.1%
1998	5,887.4	412.1	43.9	151.0	221.9	828.9	14.1%
1999	6,192.2	433.5	52.4	156.9	230.7	873.4	14.1%
2000	6,183.4	432.8	51.5	157.0	230.7	872.0	14.1%
2001	6,255.6	437.9	63.6	155.4	228.4	885.2	14.2%
2002	6,072.7	425.1	62.4	150.5	221.3	859.4	14.2%
2003	6,072.7	425.1	69.6	148.4	218.2	861.4	14.2%
2004	6,191.6	433.4	75.0	150.1	220.6	879.2	14.2%
2005	5,780.4	404.6	58.0	143.7	211.3	817.6	14.1%
2006	5,579.3	390.6	62.6	136.8	201.0	790.9	14.2%
2007	5,477.2	383.4	54.7	136.3	200.4	774.8	14.1%
2008	5,537.2	387.6	60.7	136.1	200.1	784.6	14.2%
2009	4,840.5	338.8	44.0	121.7	178.9	683.5	14.1%
2010	4,764.2	333.5	41.4	120.4	177.0	672.4	14.1%
2011	4,569.3	319.8	36.8	116.4	171.1	644.2	14.1%
2012	4,870.7	341.0	47.2	121.7	178.8	688.7	14.1%
2013	5,078.7	355.5	54.5	125.3	184.1	719.4	14.2%
2014	4,083.1	285.8	35.7	103.1	151.6	576.3	14.1%
2015	3,837.2	268.6	42.4	94.3	138.6	543.9	14.2%
Average	5,634.2	394.4	56.3	140.1	206.0	796.8	14.1%

Table 5: Soquel Creek Water District Return Flow Estimates

Water Year	Water Supply to Service Area in Model, acre-feet	Return Flow in acre-feet						Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Large-Scale Landscape Irrigation	Small-Scale Landscape Irrigation	Sewer Losses	Septic Systems	Total Return Flow	
1985	4,318.5	302.3	13.2	116.5	135.8	559.0	1,126.8	26.1%
1986	4,272.5	299.1	10.3	116.1	137.1	529.0	1,091.6	25.5%
1987	5,234.6	366.4	13.8	141.9	163.7	708.1	1,393.9	26.6%
1988	4,858.7	340.1	14.8	131.1	151.0	658.1	1,295.2	26.7%
1989	4,797.2	335.8	12.7	130.0	149.0	664.8	1,292.3	26.9%
1990	4,818.5	337.3	13.3	130.5	150.6	649.1	1,280.7	26.6%
1991	4,703.0	329.2	10.4	128.1	148.1	634.4	1,250.3	26.6%
1992	4,908.3	343.6	13.9	132.8	152.6	672.0	1,314.9	26.8%
1993	4,863.2	340.4	11.6	132.2	152.2	665.2	1,301.7	26.8%
1994	5,089.3	356.2	10.4	138.9	159.4	706.7	1,371.6	27.0%
1995	4,854.9	339.8	9.9	132.5	153.5	650.6	1,286.3	26.5%
1996	5,183.2	362.8	12.7	140.8	163.4	688.0	1,367.7	26.4%
1997	5,570.8	390.0	14.7	151.0	174.1	755.0	1,484.8	26.7%
1998	4,966.1	347.6	7.8	136.2	157.8	670.0	1,319.4	26.6%
1999	5,211.5	364.8	8.2	142.9	165.0	712.3	1,393.2	26.7%
2000	5,270.8	369.0	9.9	144.1	166.6	712.7	1,402.2	26.6%
2001	5,174.7	362.2	9.7	141.5	164.3	688.2	1,365.9	26.4%
2002	5,375.8	376.3	9.6	147.1	172.6	689.3	1,394.9	25.9%
2003	5,331.8	373.2	11.1	145.4	171.4	667.7	1,368.9	25.7%
2004	5,372.0	376.0	13.0	146.0	172.8	659.2	1,367.0	25.4%
2005	4,543.8	318.1	7.3	124.6	147.2	566.2	1,163.4	25.6%
2006	4,548.6	318.4	10.2	123.9	144.5	591.7	1,188.7	26.1%
2007	4,625.8	323.8	12.0	125.5	144.9	623.6	1,229.7	26.6%
2008	4,557.0	319.0	12.6	123.4	141.7	625.9	1,222.6	26.8%
2009	4,162.1	291.3	12.5	112.4	131.6	529.8	1,077.6	25.9%
2010	3,932.5	275.3	10.3	106.6	127.5	461.6	981.3	25.0%
2011	4,011.2	280.8	8.7	109.3	131.0	467.1	997.0	24.9%
2012	4,159.1	291.1	12.7	112.2	134.0	487.8	1,037.9	25.0%
2013	4,217.5	295.2	19.2	111.9	132.2	509.1	1,067.6	25.3%
2014	3,702.9	259.2	20.0	97.3	115.6	432.6	924.7	25.0%
2015	3,153.9	220.8	22.4	81.3	96.9	355.8	777.2	24.6%
Average	4,702.9	329.2	12.2	127.5	148.6	612.6	1,230.2	26.1%

Table 6: Central Water District Return Flow Estimates

Water Year	Water Supply to Service Area in Model*, acre-feet	Return Flow in acre-feet				Percentage of Water Supply that Becomes Return Flow
		Water System Losses	Small-Scale Landscape Irrigation	Septic Systems	Total Return Flow	
1985	352.9	27.5	9.8	205.0	242.3	68.7%
1986	363.0	28.3	10.0	210.9	249.2	68.7%
1987	399.4	31.1	11.1	232.1	274.2	68.6%
1988	393.2	30.6	10.9	228.4	270.0	68.6%
1989	363.2	28.4	10.0	210.9	249.4	68.7%
1990	387.1	30.1	10.7	224.9	265.7	68.6%
1991	383.9	29.8	10.6	223.1	263.5	68.6%
1992	417.5	32.7	11.5	242.5	286.7	68.7%
1993	429.6	33.7	11.9	249.4	295.0	68.7%
1994	431.2	33.7	11.9	250.4	296.1	68.7%
1995	409.5	32.2	11.3	237.7	281.2	68.7%
1996	469.4	36.8	13.0	272.5	322.3	68.7%
1997	539.5	42.3	14.9	313.2	370.4	68.7%
1998	476.0	37.4	13.2	276.3	326.9	68.7%
1999	479.9	37.7	13.3	278.6	329.6	68.7%
2000	489.2	38.3	13.5	284.1	335.9	68.7%
2001	496.7	39.0	13.7	288.4	341.1	68.7%
2002	529.1	41.5	14.6	307.2	363.3	68.7%
2003	519.3	40.8	14.4	301.5	356.7	68.7%
2004	565.6	44.3	15.6	328.4	388.4	68.7%
2005	456.9	36.0	12.6	265.2	313.8	68.7%
2006	483.1	38.1	13.3	280.3	331.8	68.7%
2007	532.3	41.7	14.7	309.1	365.5	68.7%
2008	520.0	40.9	14.4	301.9	357.1	68.7%
2009	530.4	41.6	14.7	307.9	364.2	68.7%
2010	428.8	33.6	11.9	248.9	294.4	68.7%
2011	434.4	34.1	12.0	252.2	298.3	68.7%
2012	479.3	37.5	13.3	278.4	329.1	68.7%
2013	501.2	39.1	13.9	291.1	344.1	68.7%
2014	452.3	35.0	12.5	262.9	310.4	68.6%
2015	352.7	27.4	9.8	204.9	242.1	68.6%
Average	453.8	35.5	12.5	263.5	311.6	68.7%

* This column is water supply for residential/commercial use only, and does not include water delivered for agricultural use.

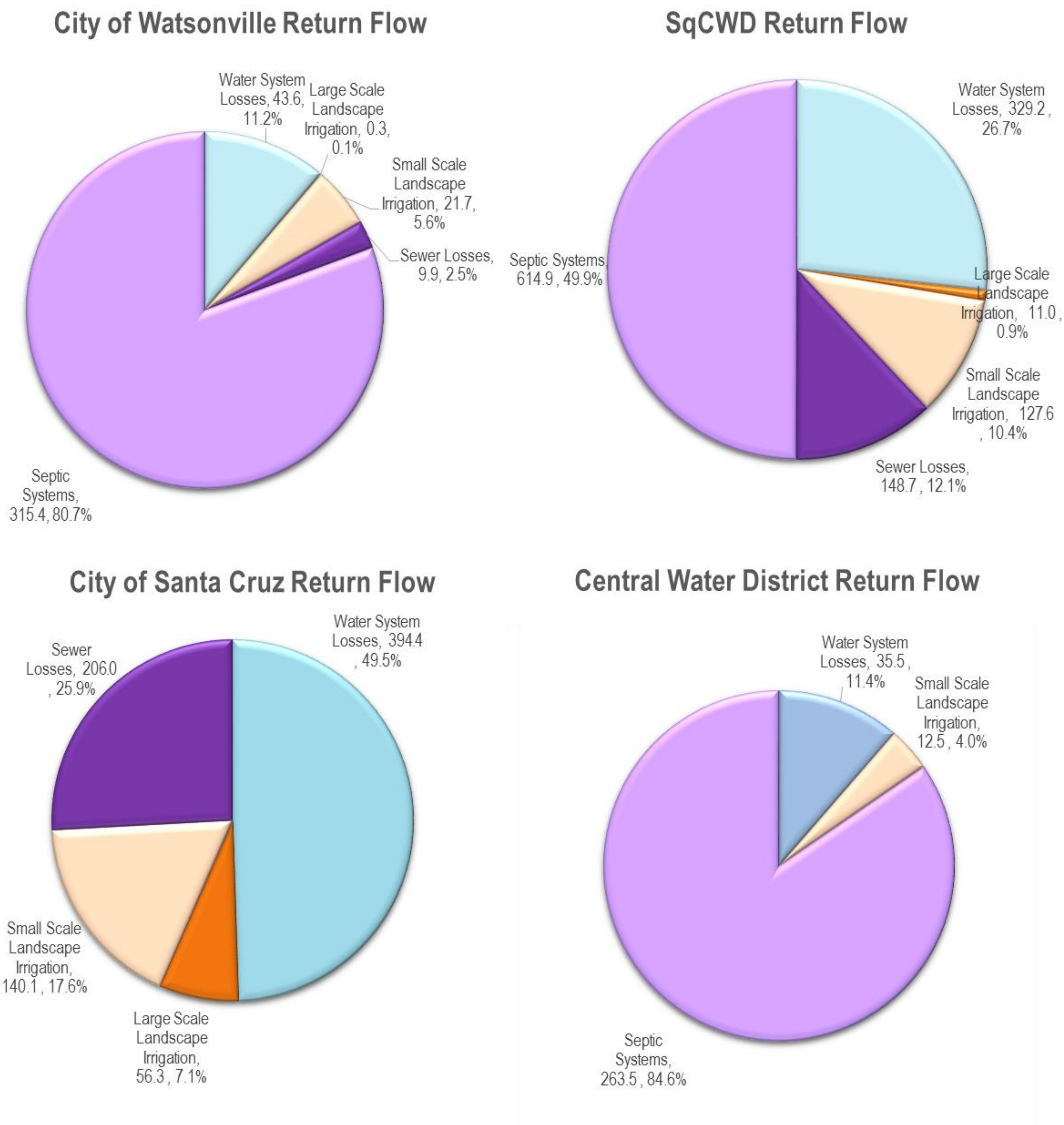
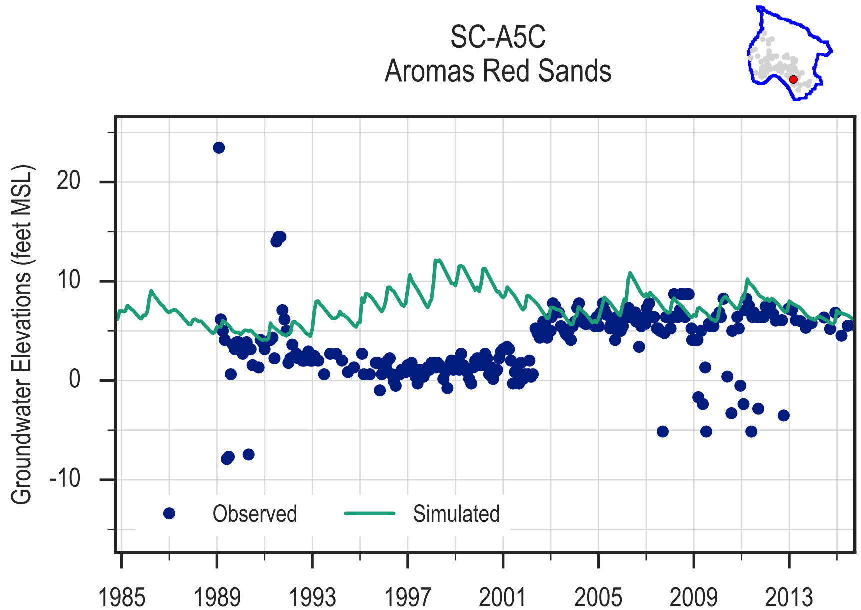


Figure 7: Municipal Return Flow Pie Charts (in acre-feet per year)

Appendix C

Selected Well Hydrographs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Aromas Red Sands
Groundwater Elevations (feet MSL)
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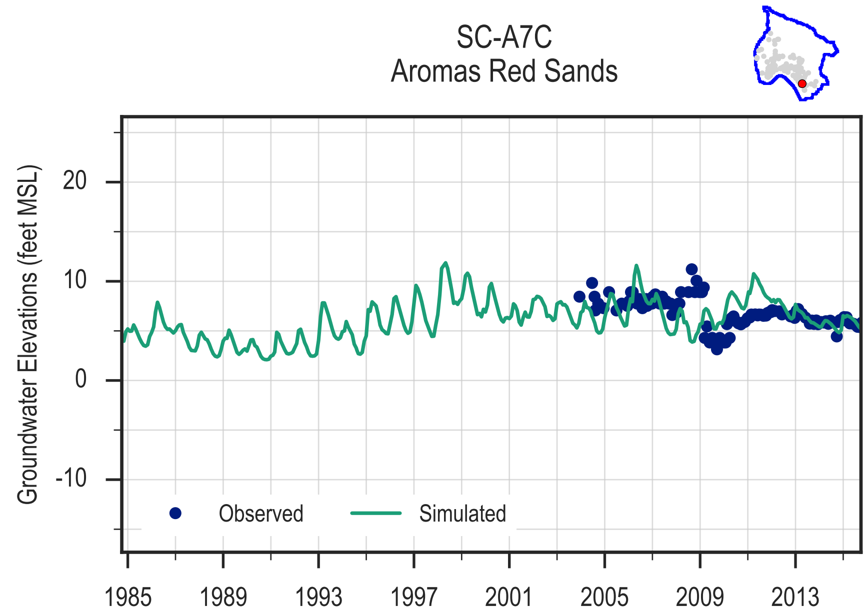
0
-10
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013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2009
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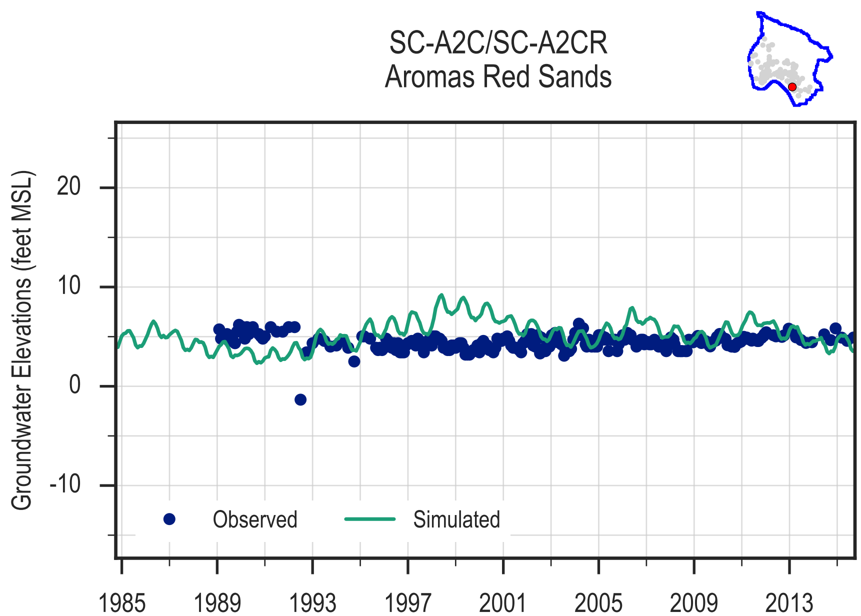
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-10
Observed
Simulated
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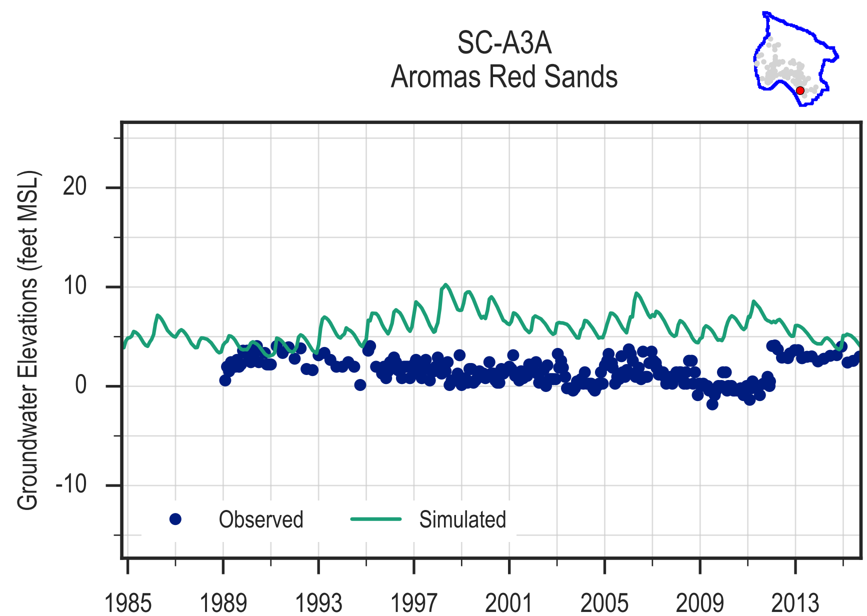
1989
1993
1997
2001
2005
2009
2013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Aromas Red Sands
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Observed
Simulated
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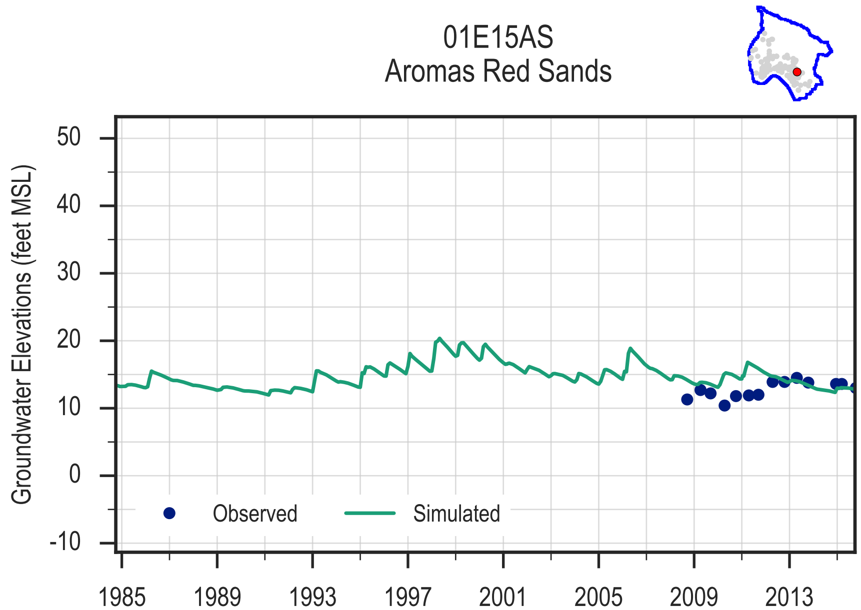
1997
2001
2005
2009
2013


01E15AS
Aromas Red Sands
Groundwater Elevations (feet MSL)
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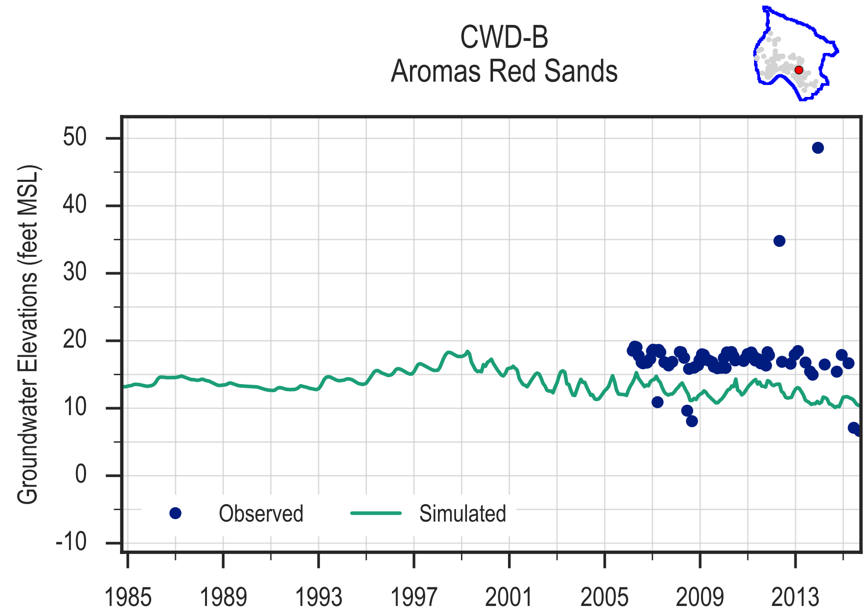
0
-10
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013


CWD-B
Aromas Red Sands
Groundwater Elevations (feet MSL)
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Observed
Simulated
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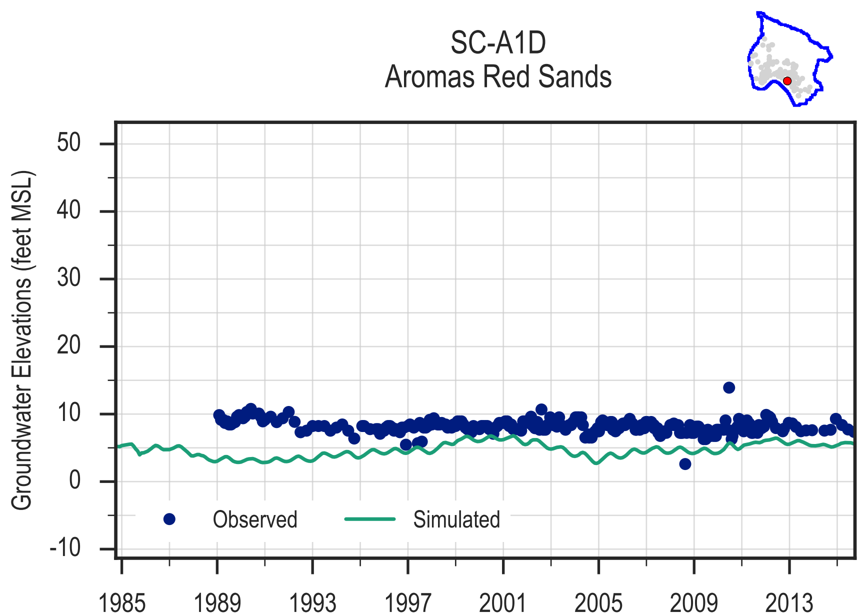
1989
1993
1997
2001
2005
2009
2013


SC-A1D
Aromas Red Sands
Groundwater Elevations (feet MSL)
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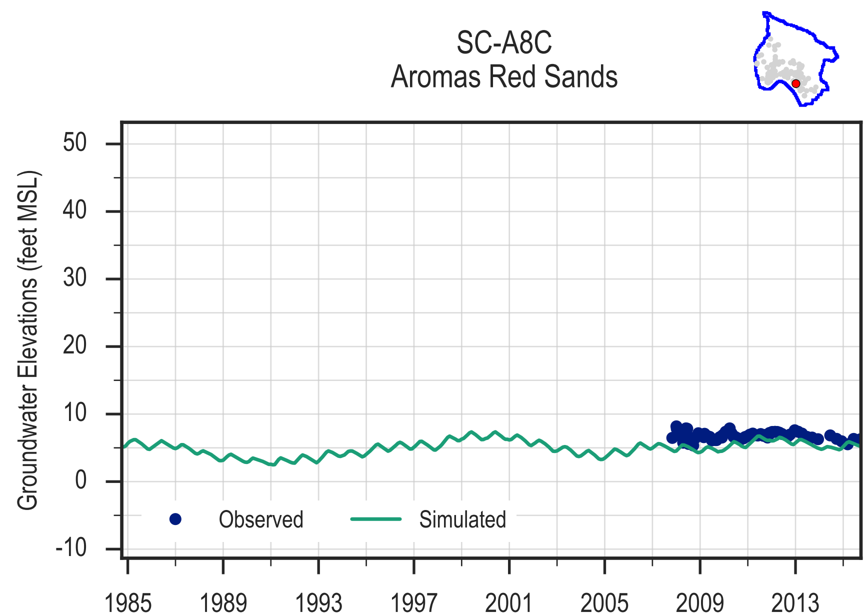
2005
2009
2013


SC-A8C
Aromas Red Sands
Groundwater Elevations (feet MSL)
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Observed
Simulated
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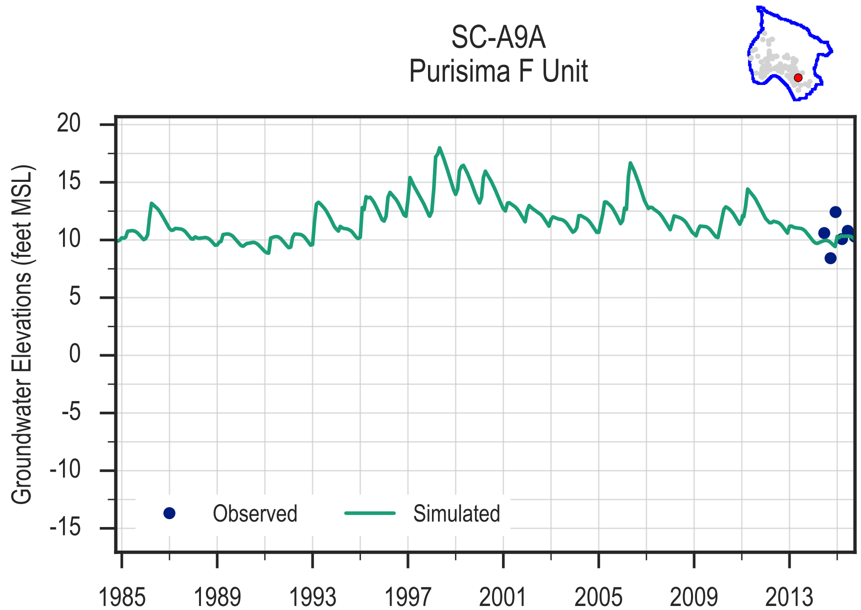
1997
2001
2005
2009
2013


SC-A9A
Purisima F Unit
Groundwater Elevations (feet MSL)
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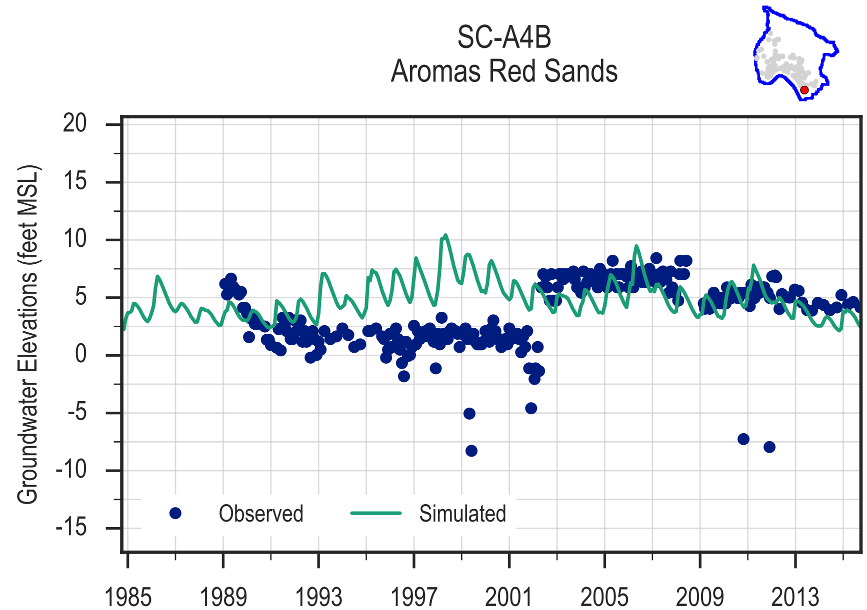
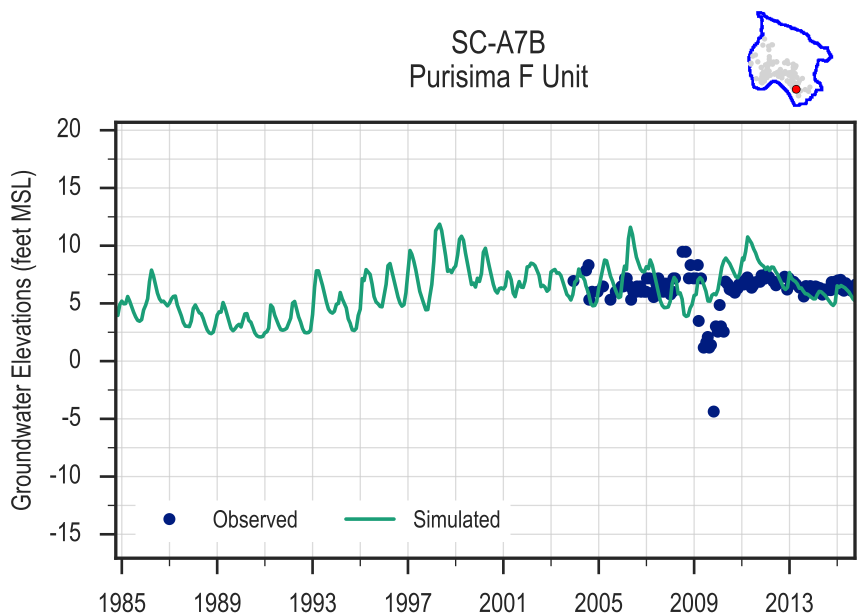
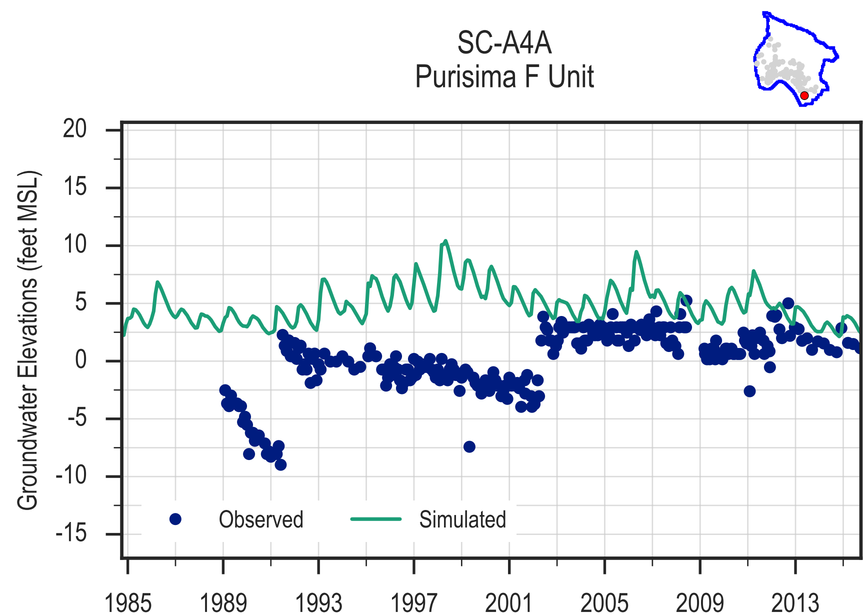
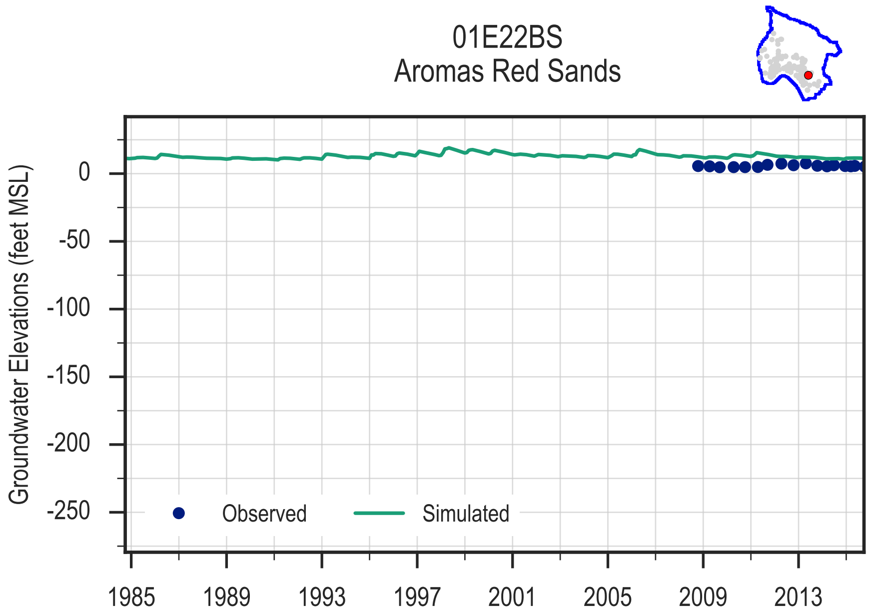
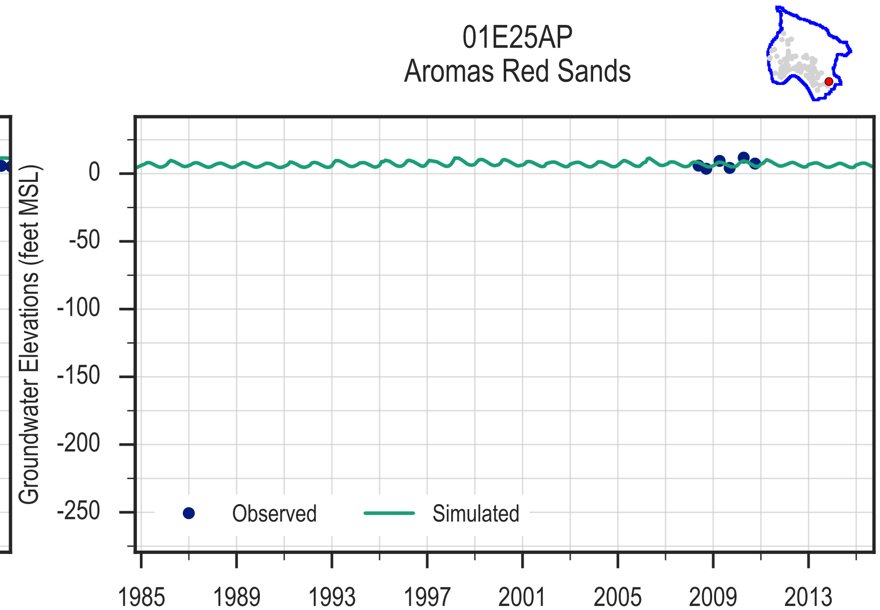
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

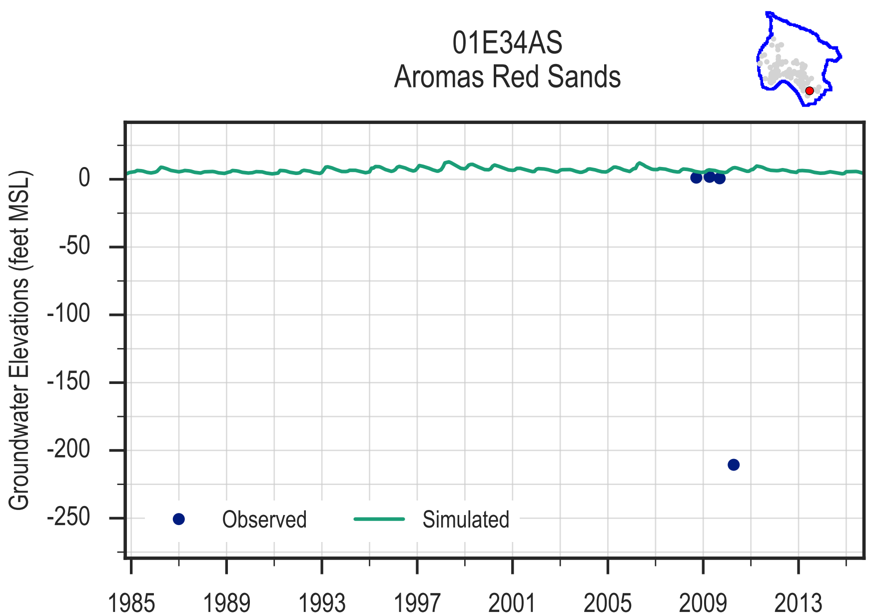

SC-A4B
Aromas Red Sands
Groundwater Elevations (feet MSL)
20
15
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

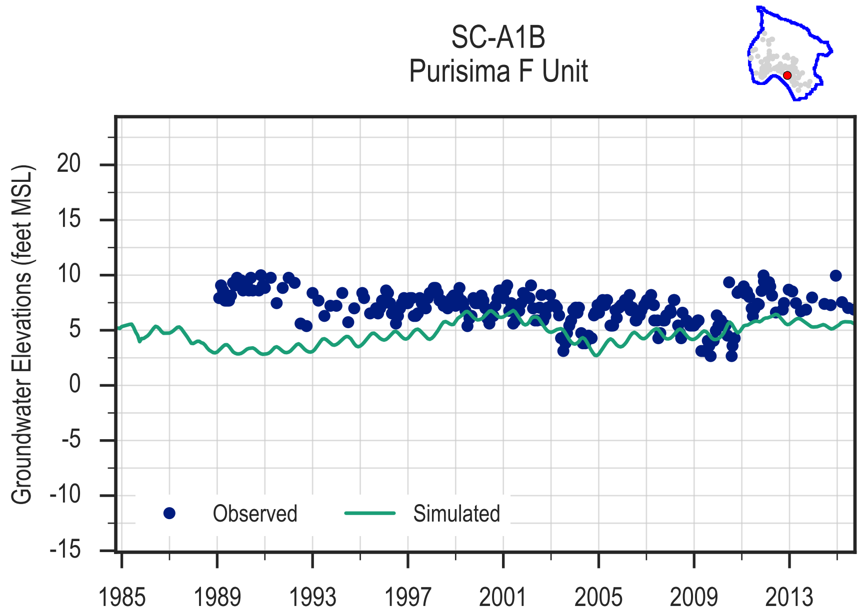

SC-A7B
Purisima F Unit
Groundwater Elevations (feet MSL)
20
15
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

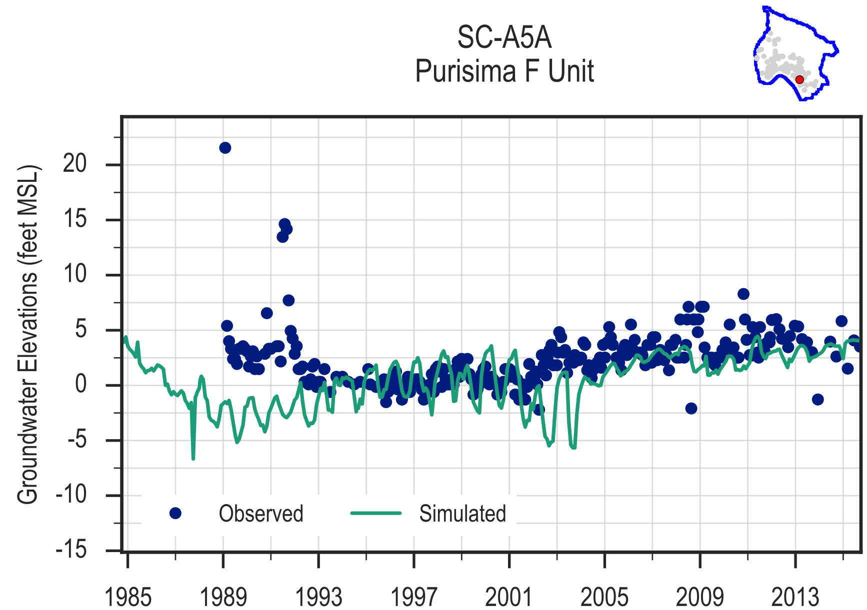

SC-A4A
Purisima F Unit
Groundwater Elevations (feet MSL)
20
15
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

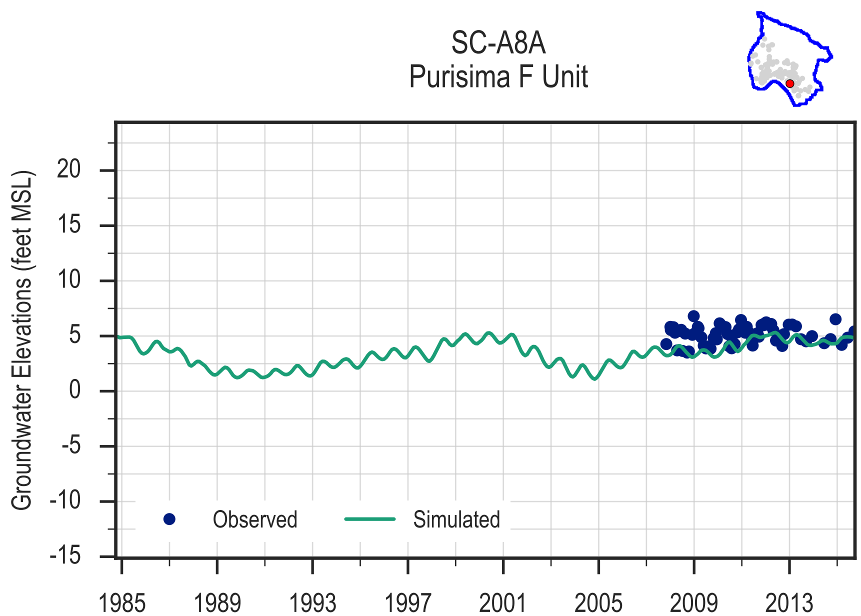

01E22BS
Aromas Red Sands
Groundwater Elevations (feet MSL)
0
-50
-100
-150
-200
-250
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

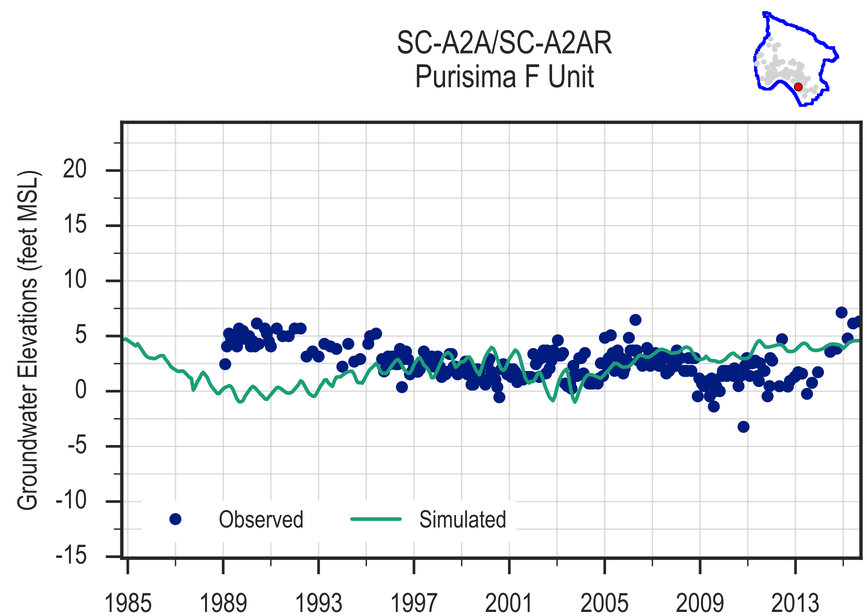

01E25AP
Aromas Red Sands
Groundwater Elevations (feet MSL)
0
-50
-100
-150
-200
-250
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

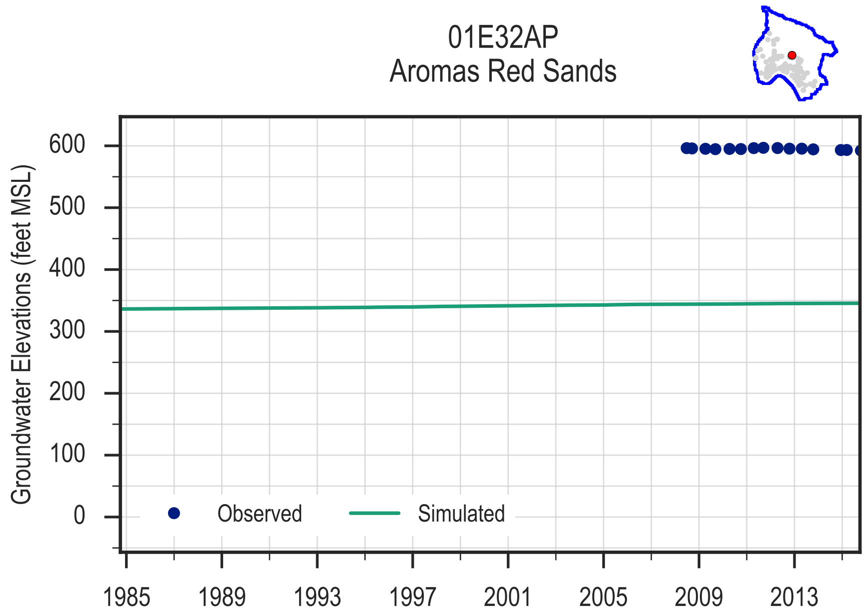

01E34AS
Aromas Red Sands
Groundwater Elevations (feet MSL)
0
-50
-100
-150
-200
-250
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

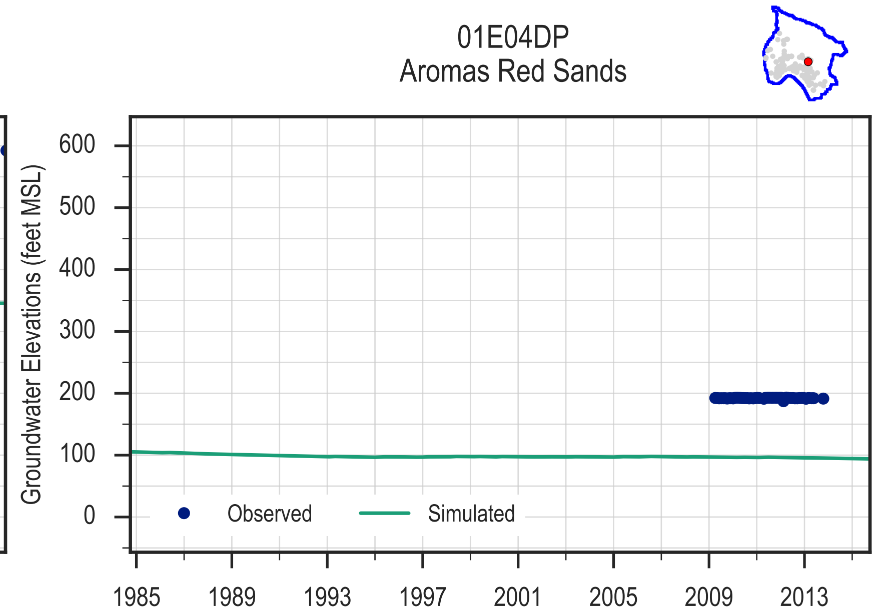

SC-A1B
Purisima F Unit
Groundwater Elevations (feet MSL)
20
15
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

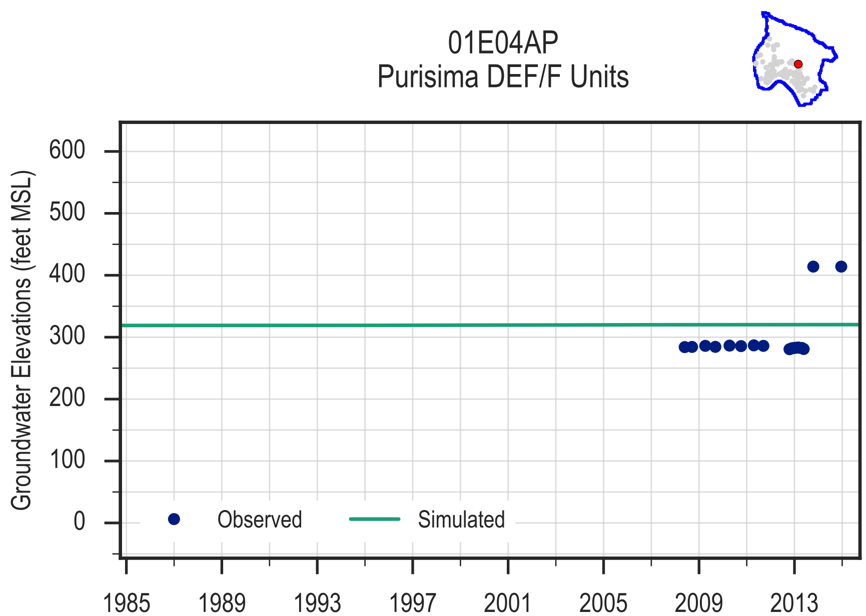

SC-A5A
Purisima F Unit
Groundwater Elevations (feet MSL)
20
15
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

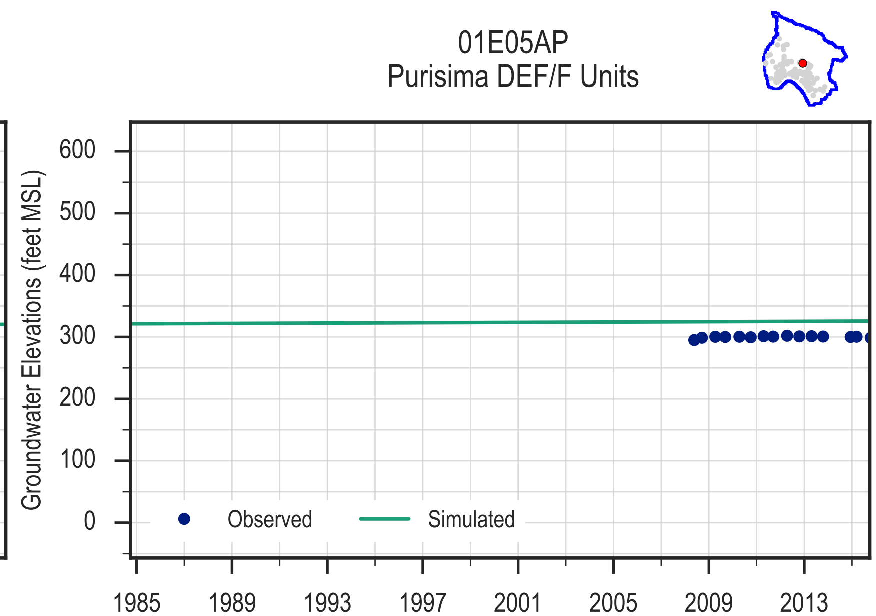

SC-A8A
Purisima F Unit
Groundwater Elevations (feet MSL)
20
15
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

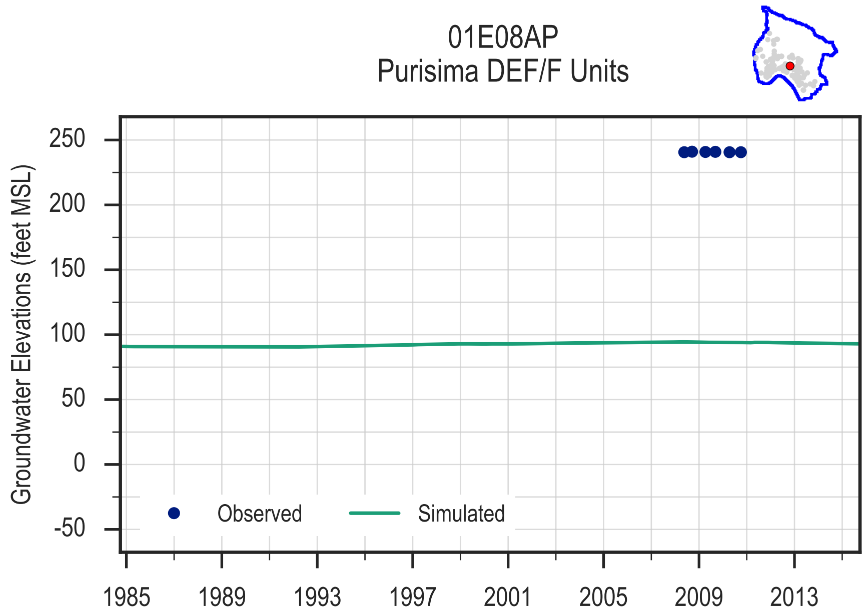

SC-A2A/SC-A2AR
Purisima F Unit
Groundwater Elevations (feet MSL)
20
15
10
5
0
-5
-10
-15
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated


01E32AP
Aromas Red Sands
Groundwater Elevations (feet MSL)
600
500
400
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

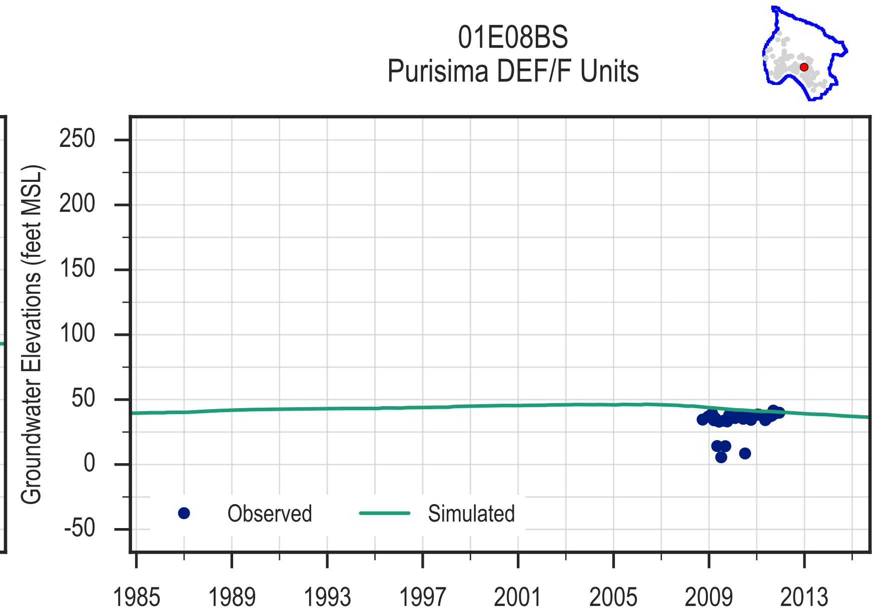

01E04DP
Aromas Red Sands
Groundwater Elevations (feet MSL)
600
500
400
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013


01E04AP
Purisima DEF/F Units
Groundwater Elevations (feet MSL)
600
500
400
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

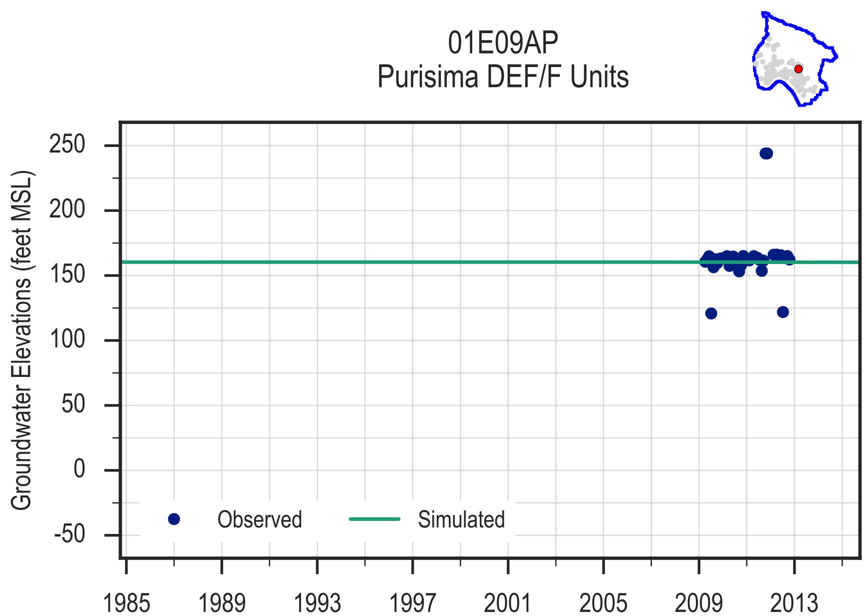

01E05AP
Purisima DEF/F Units
Groundwater Elevations (feet MSL)
600
500
400
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



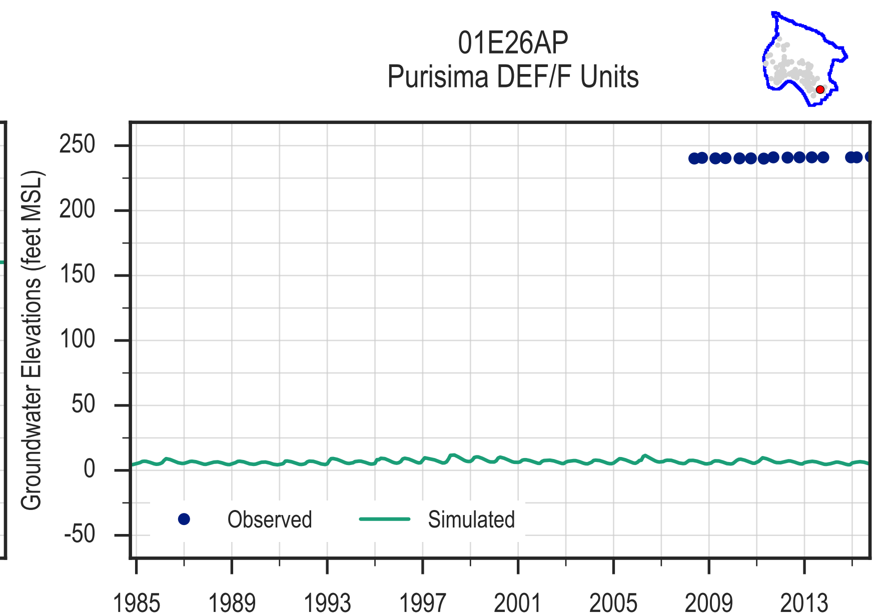
01E08AP
Purisima DEF/F Units
Groundwater Elevations (feet MSL)
250
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



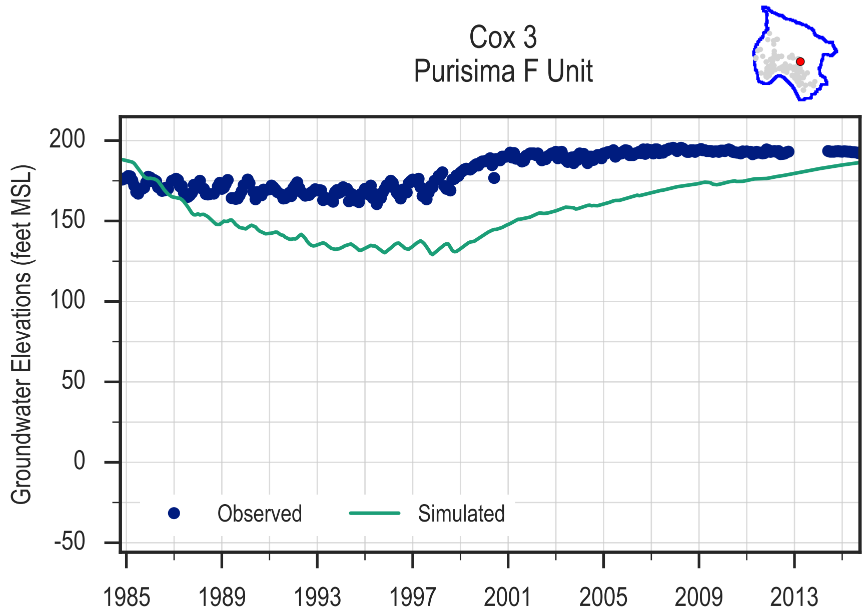
01E08BS
Purisima DEF/F Units
Groundwater Elevations (feet MSL)
250
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

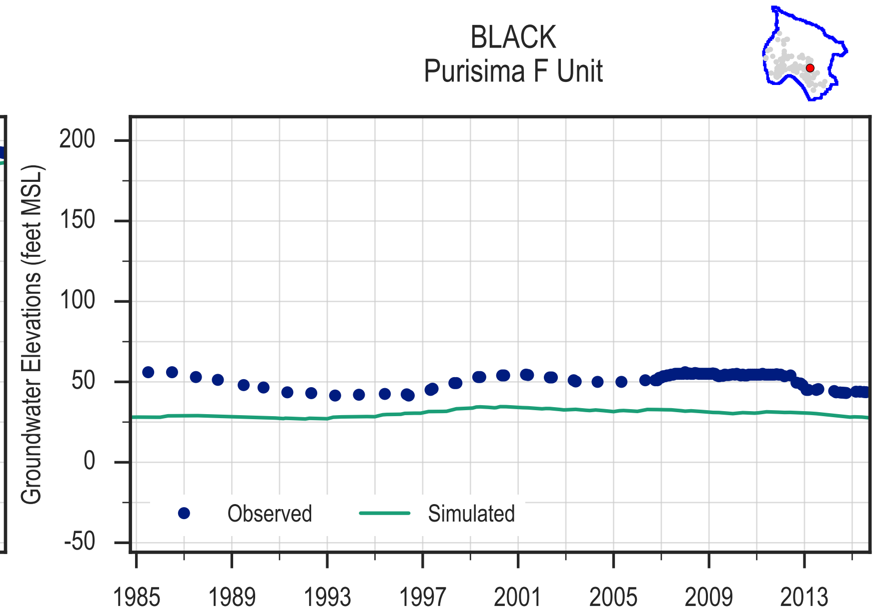


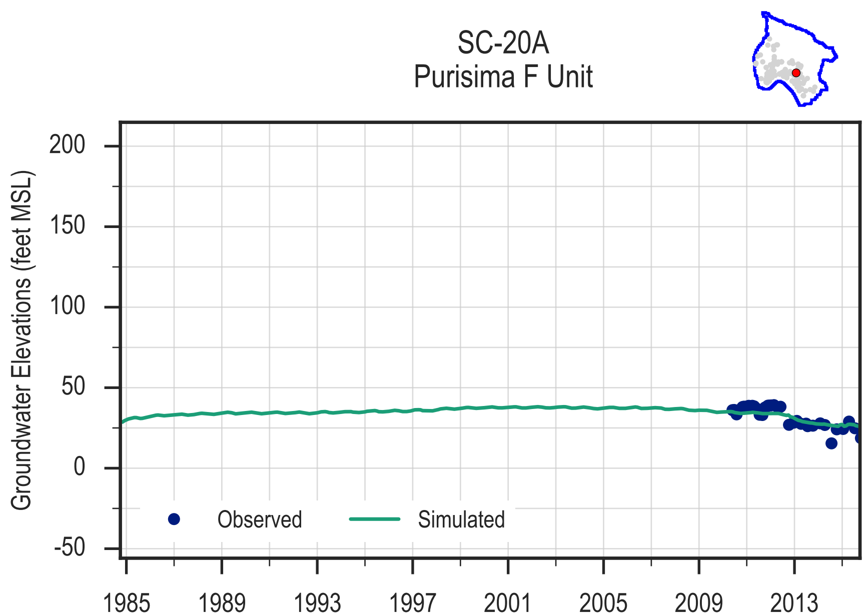
01E09AP
Purisima DEF/F Units
Groundwater Elevations (feet MSL)
250
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

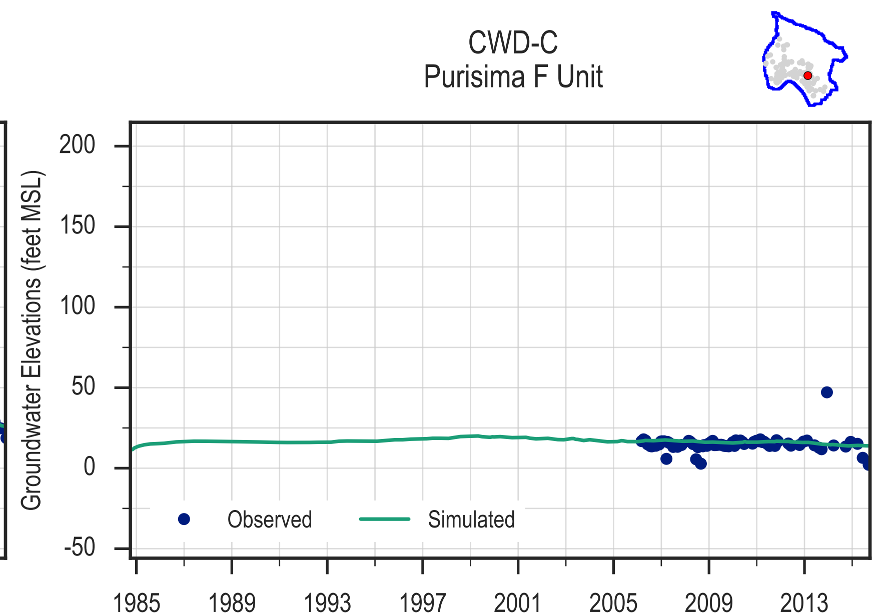


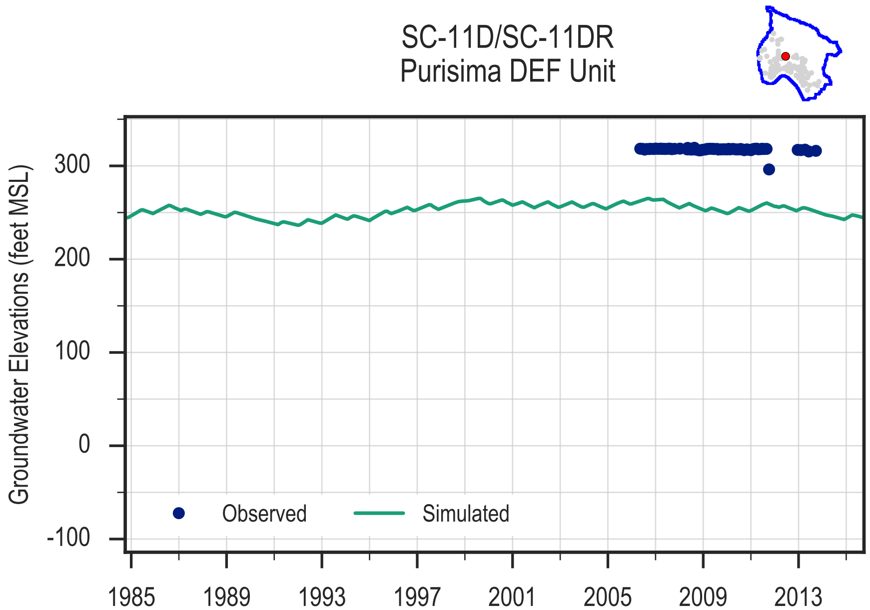
01E26AP
Purisima DEF/F Units
Groundwater Elevations (feet MSL)
250
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

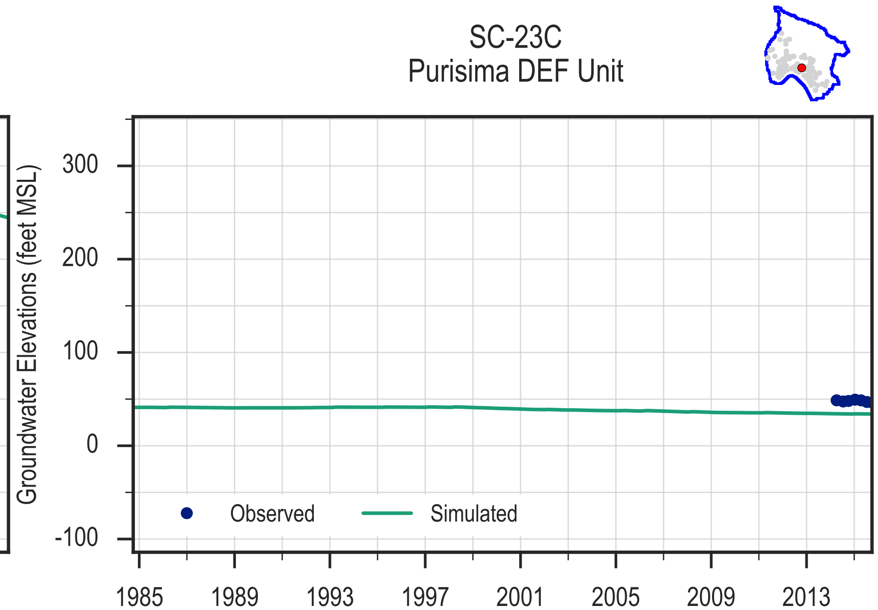

Cox 3
Purisima F Unit
Groundwater Elevations (feet MSL)
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

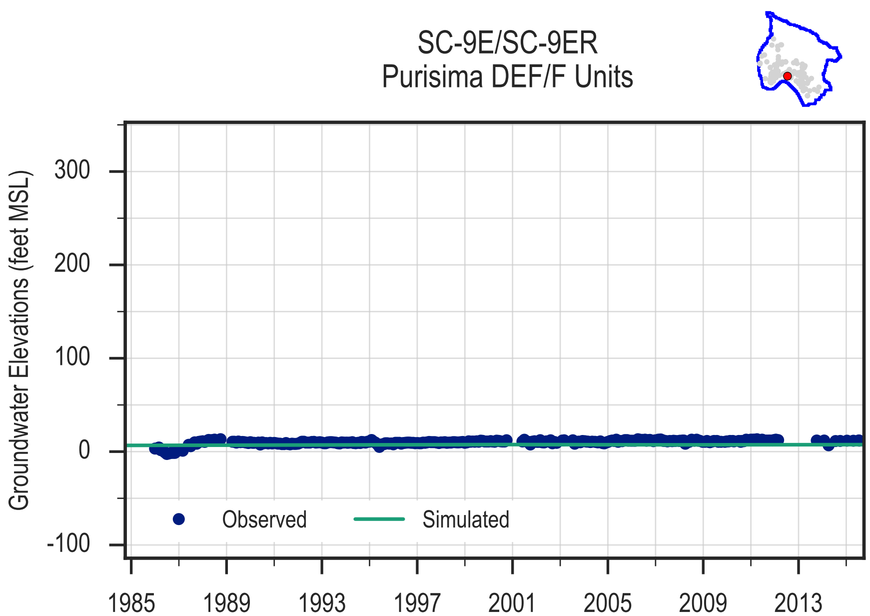

BLACK
Purisima F Unit
Groundwater Elevations (feet MSL)
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

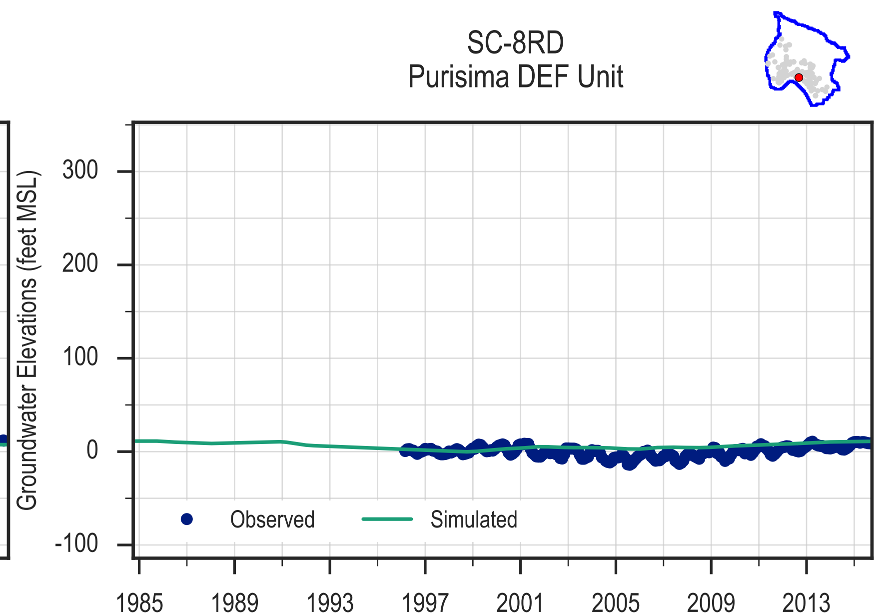

SC-20A
Purisima F Unit
Groundwater Elevations (feet MSL)
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

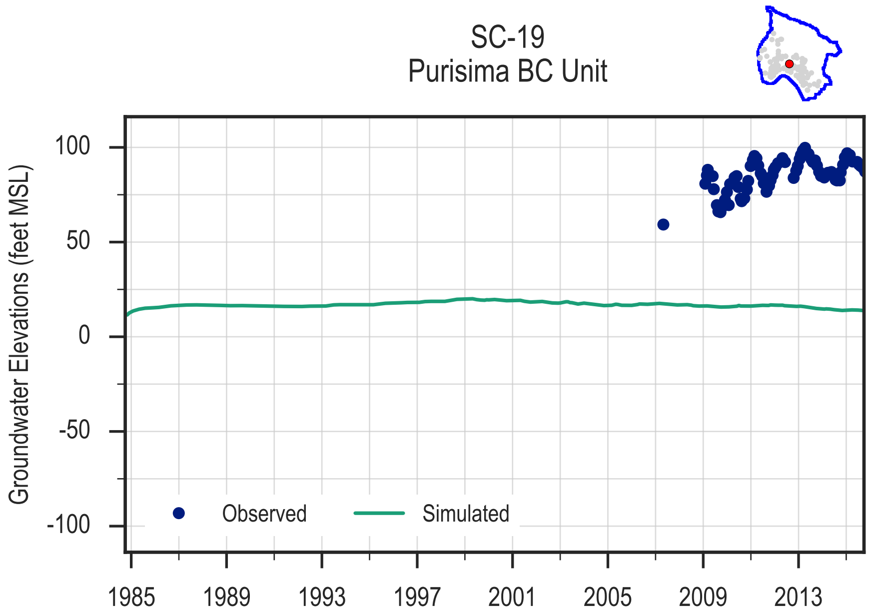

CWD-C
Purisima F Unit
Groundwater Elevations (feet MSL)
200
150
100
50
0
-50
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013


SC-11D/SC-11DR
Purisima DEF Unit
Groundwater Elevations (feet MSL)
300
200
100
0
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

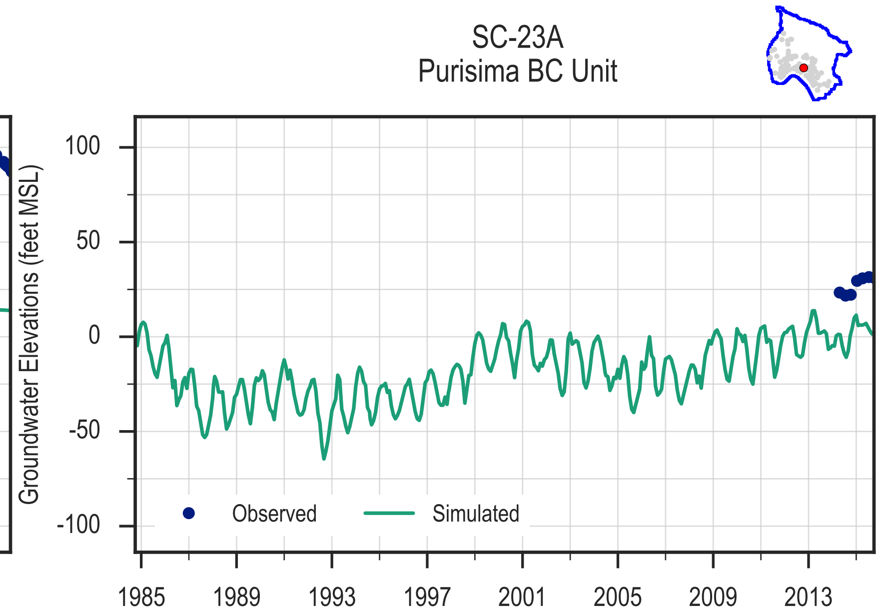

SC-23C
Purisima DEF Unit
Groundwater Elevations (feet MSL)
300
200
100
0
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013


SC-9E/SC-9ER
Purisima DEF/F Units
Groundwater Elevations (feet MSL)
300
200
100
0
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

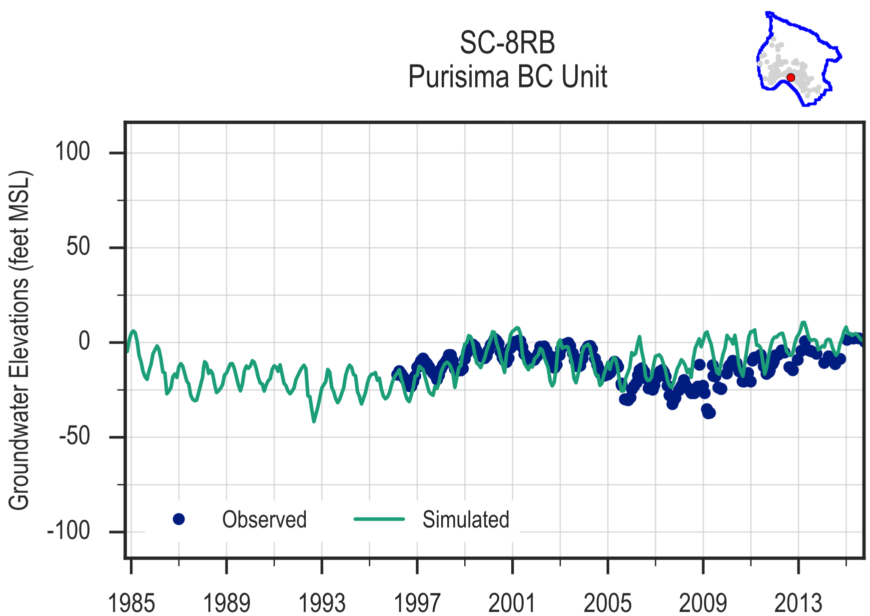

SC-8RD
Purisima DEF Unit
Groundwater Elevations (feet MSL)
300
200
100
0
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



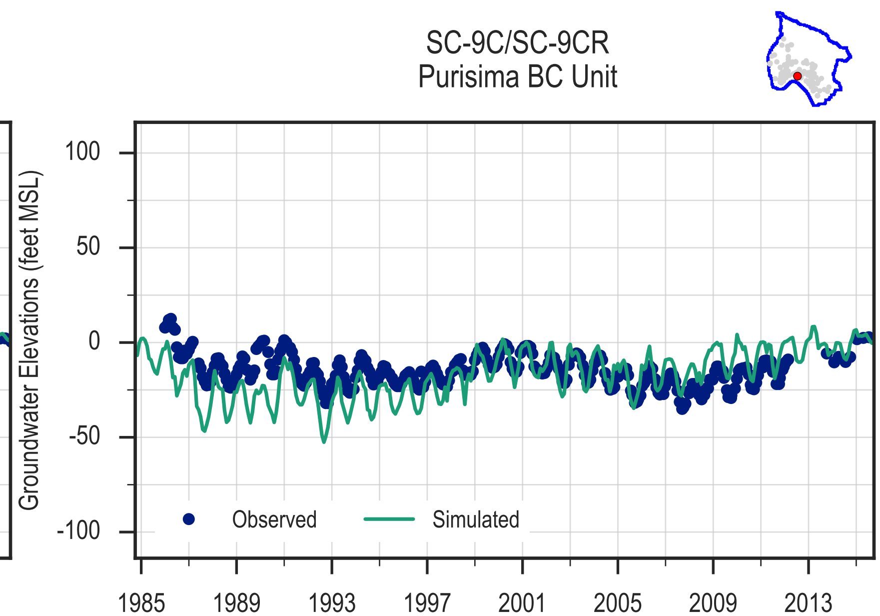
SC-19
Purisima BC Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



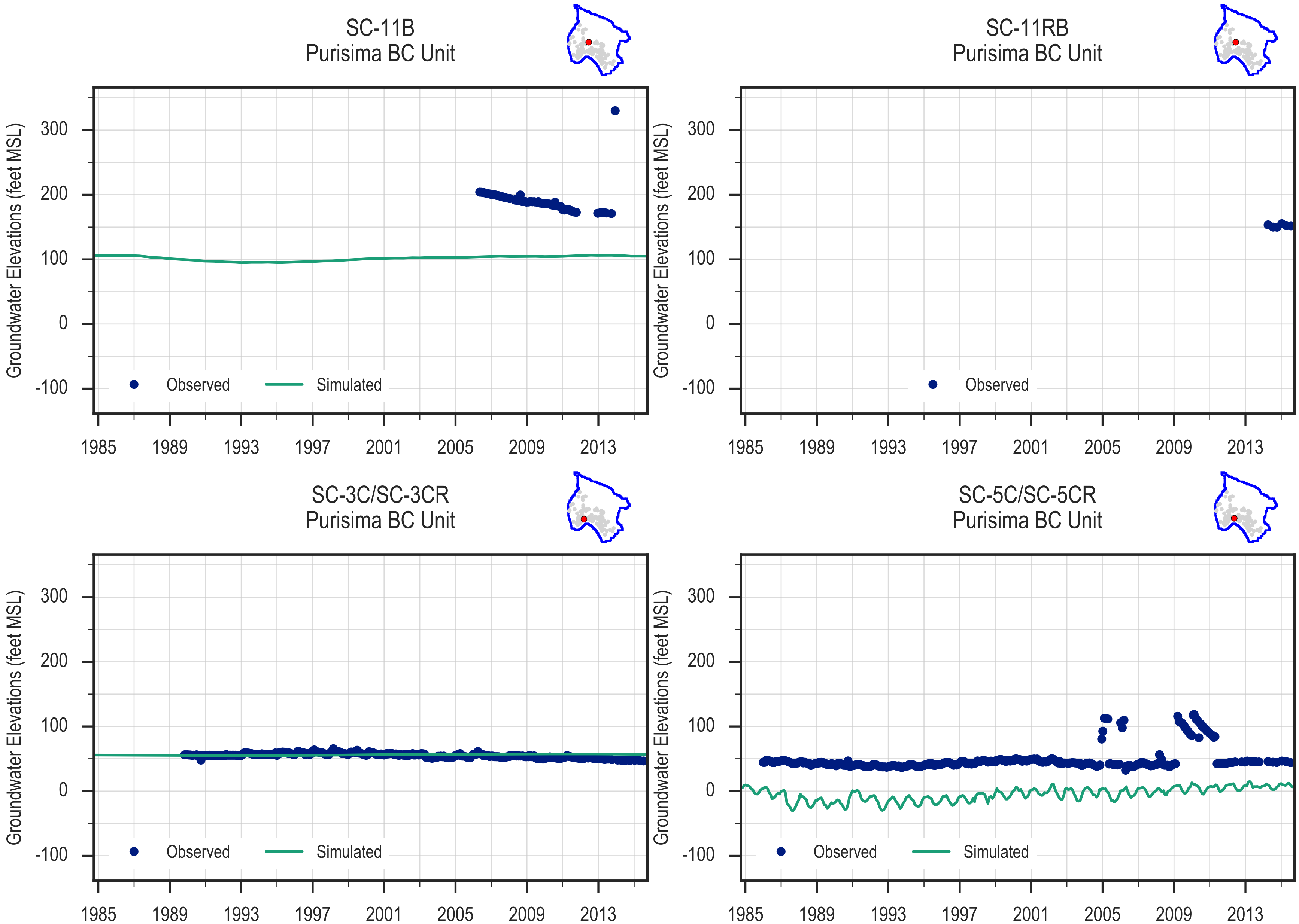
SC-23A
Purisima BC Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

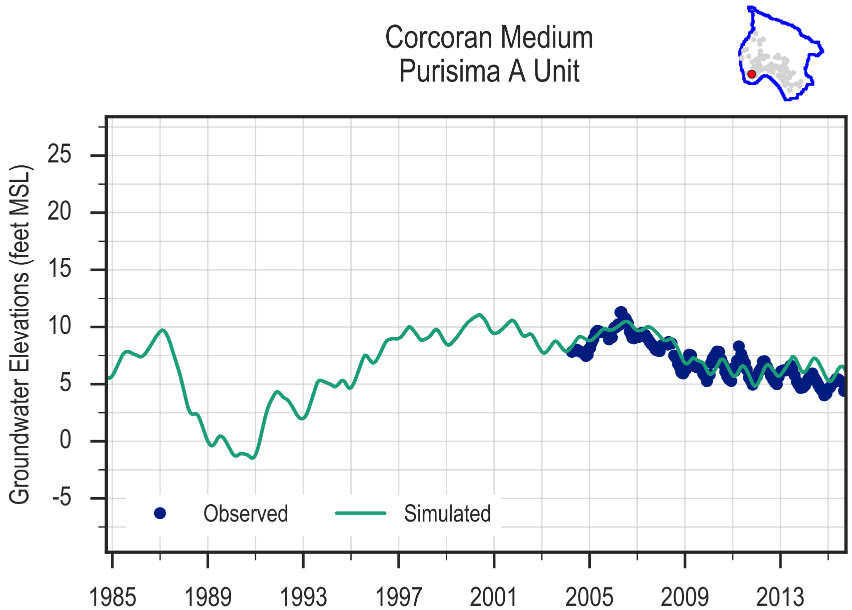


SC-8RB
Purisima BC Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

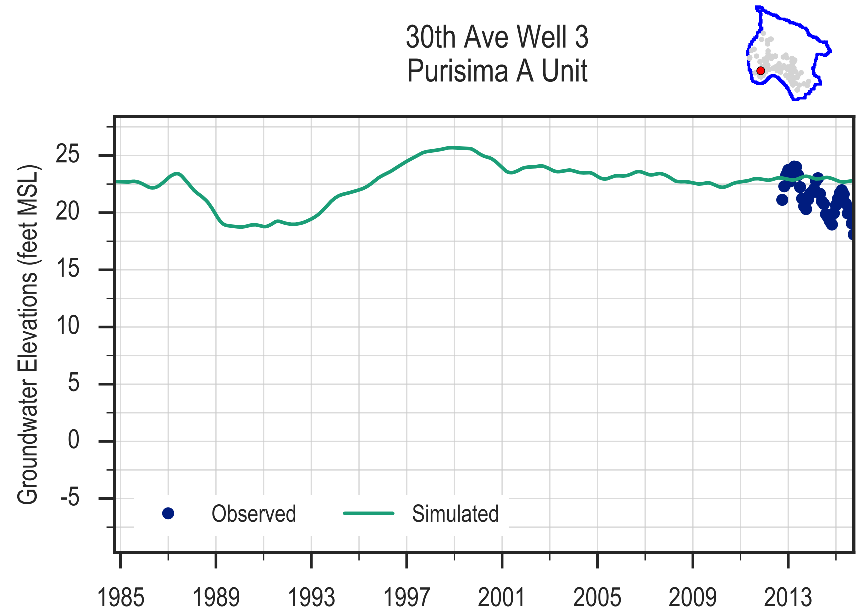


SC-9C/SC-9CR
Purisima BC Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

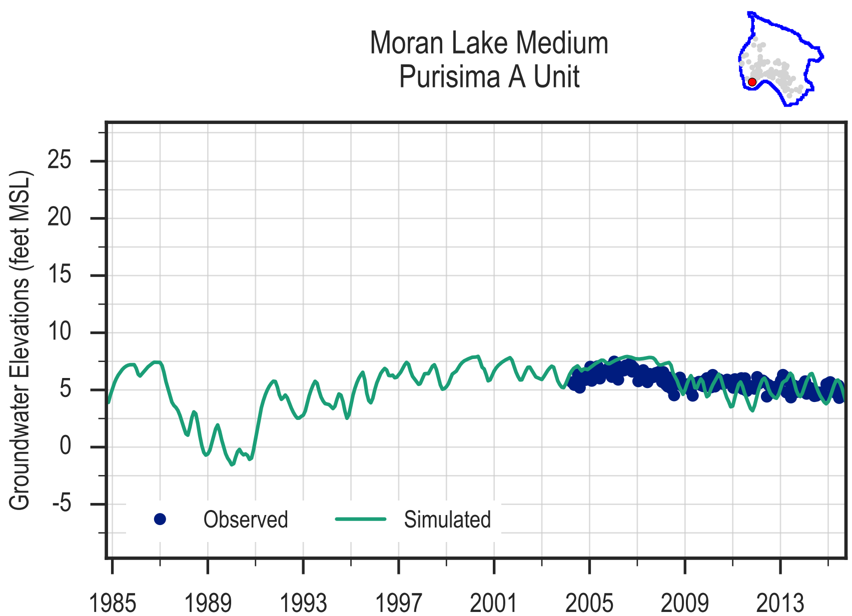

SC-11B
Purisima BC Unit
SC-11RB
Purisima BC Unit
SC-3C/SC-3CR
Purisima BC Unit
SC-5C/SC-5CR
Purisima BC Unit
Groundwater Elevations (feet MSL)
300
200
100
0
-100
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated



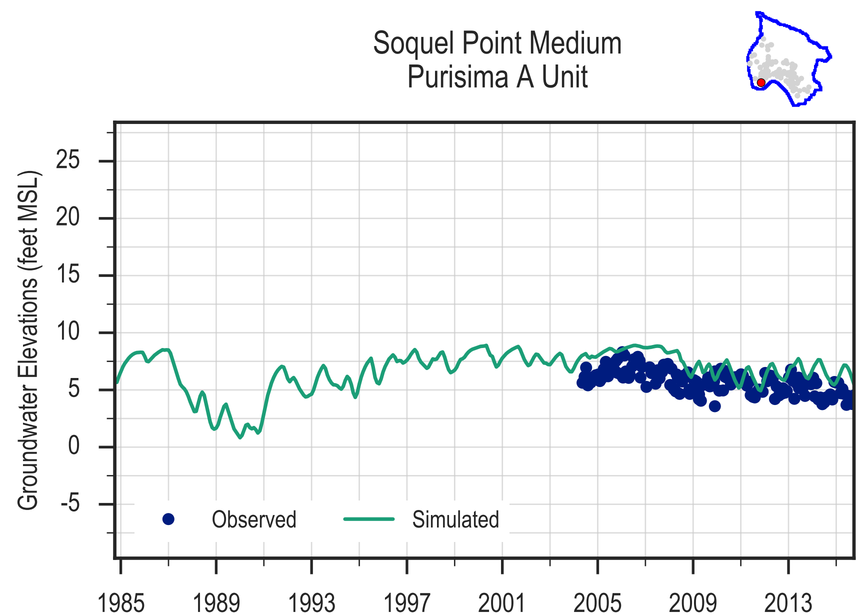
Corcoran Medium
Purisima A Unit
Groundwater Elevations (feet MSL)
25
20
15
10
5
0
-5
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



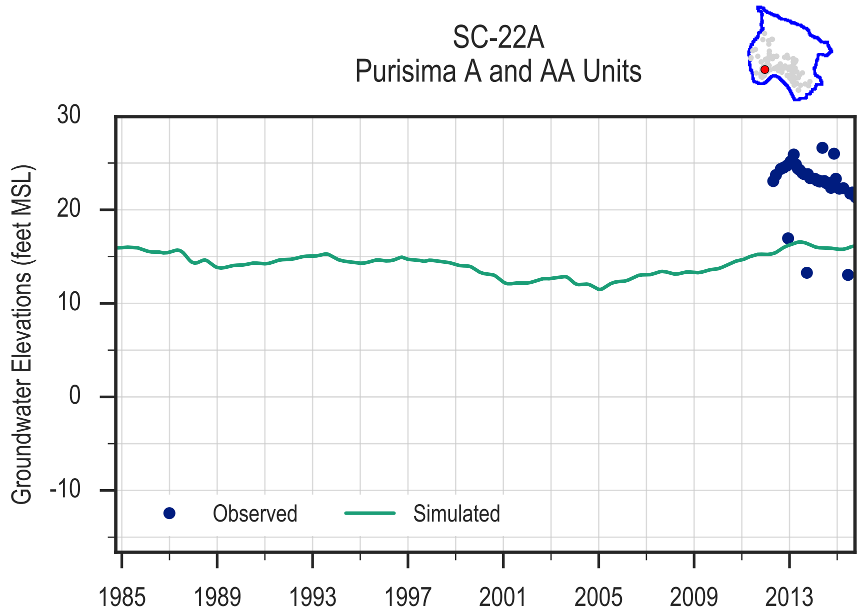
30th Ave Well 3
Purisima A Unit
Groundwater Elevations (feet MSL)
25
20
15
10
5
0
-5
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

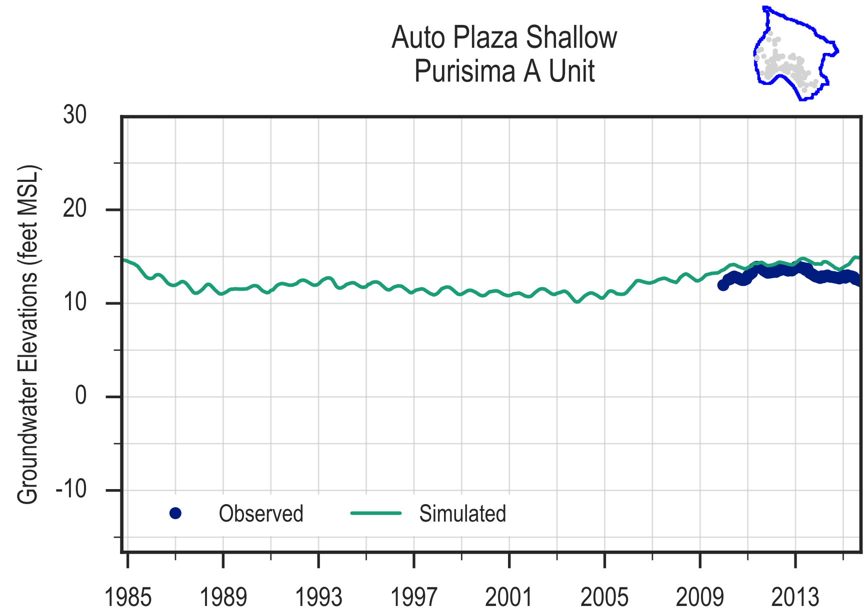


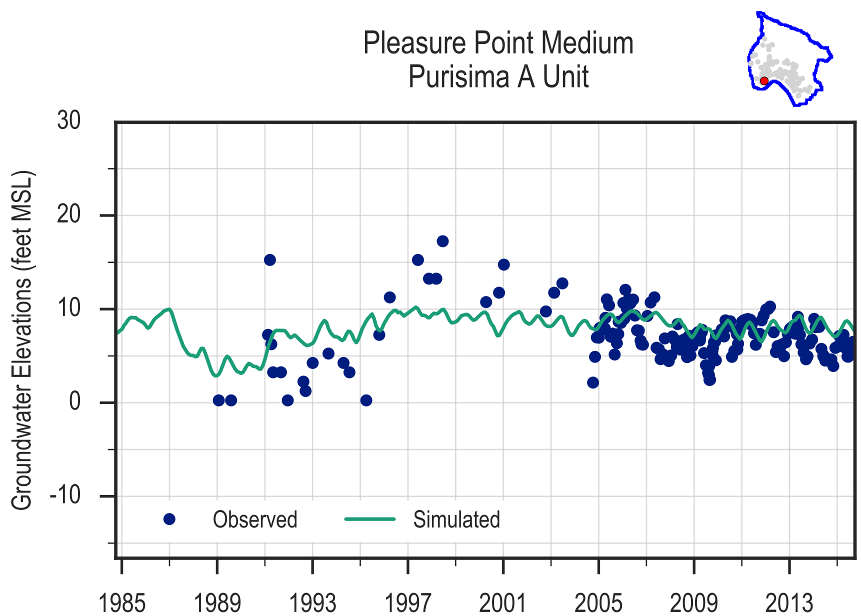
Moran Lake Medium
Purisima A Unit
Groundwater Elevations (feet MSL)
25
20
15
10
5
0
-5
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

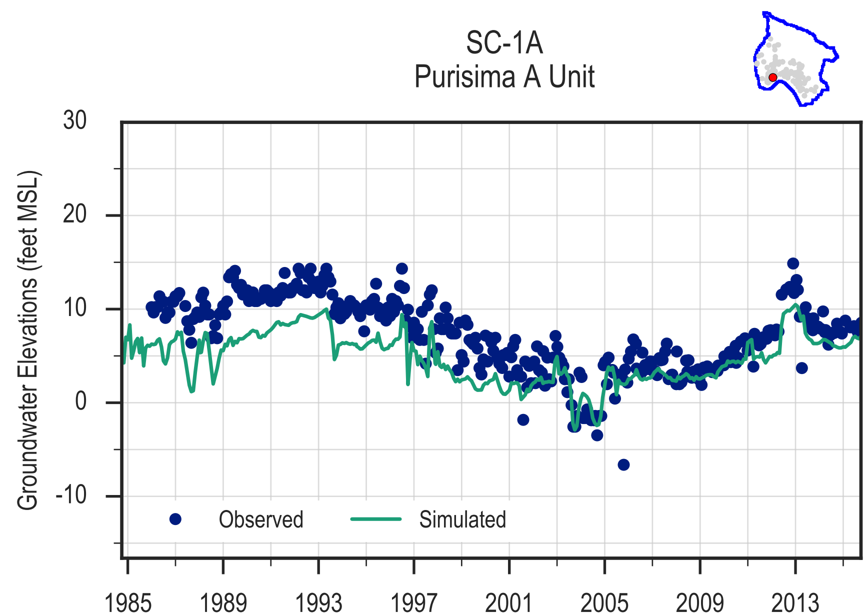


Soquel Point Medium
Purisima A Unit
Groundwater Elevations (feet MSL)
25
20
15
10
5
0
-5
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

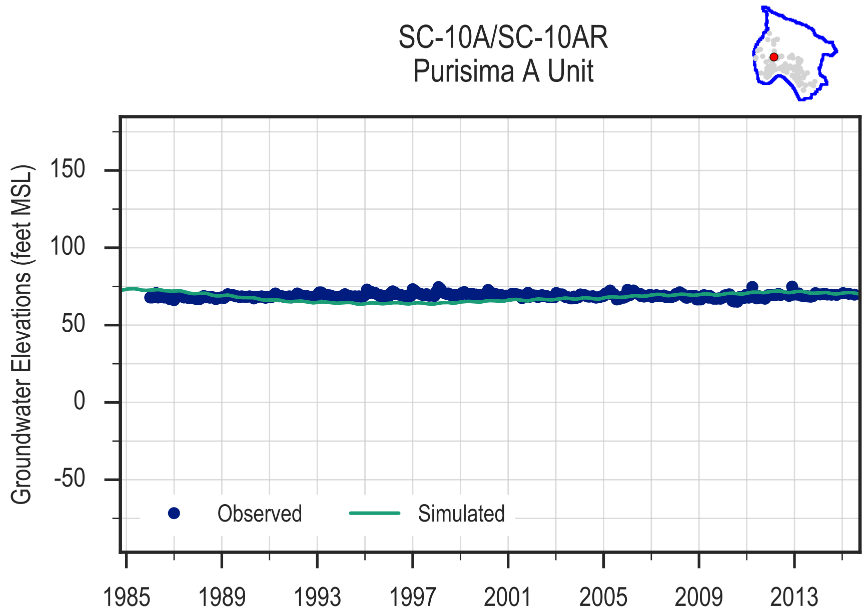

SC-22A
Purisima A and AA Units
Groundwater Elevations (feet MSL)
30
20
10
0
-10
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated


Auto Plaza Shallow
Purisima A Unit
Groundwater Elevations (feet MSL)
30
20
10
0
-10
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

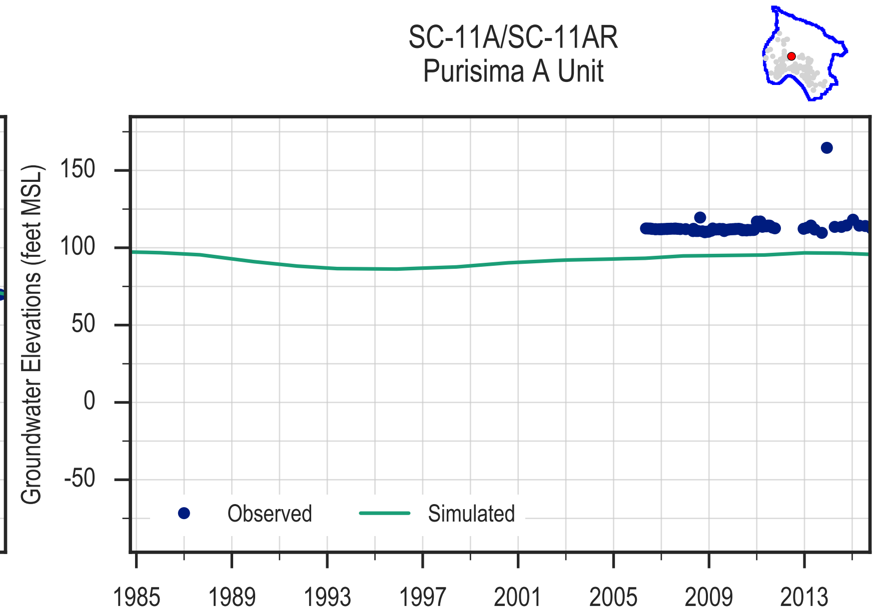

Pleasure Point Medium
Purisima A Unit
Groundwater Elevations (feet MSL)
30
20
10
0
-10
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated


SC-1A
Purisima A Unit
Groundwater Elevations (feet MSL)
30
20
10
0
-10
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

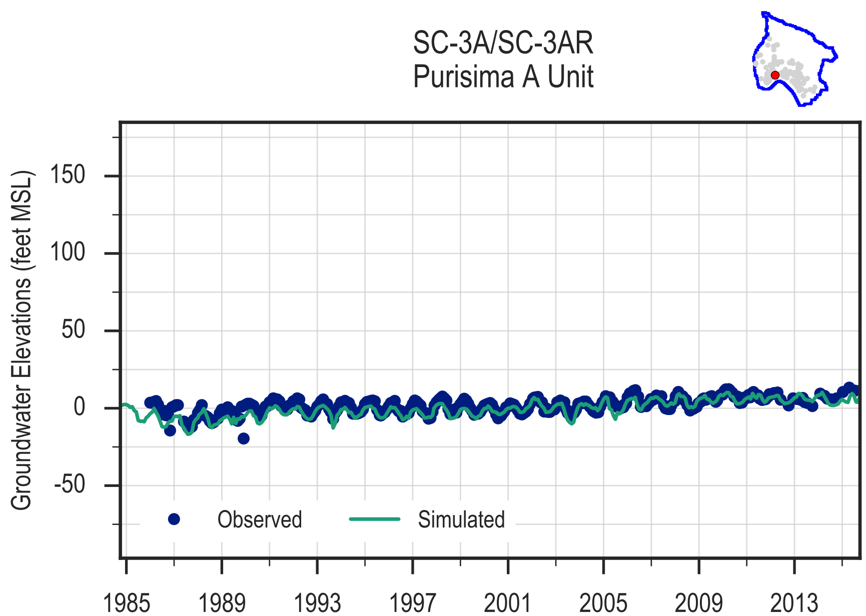
SC-10A/SC-10AR
Purisima A Unit



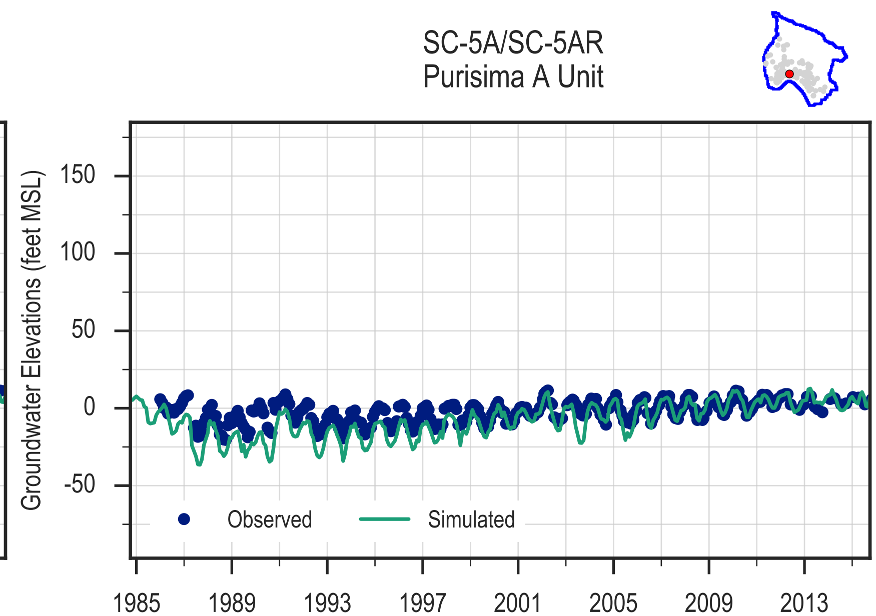
SC-11A/SC-11AR
Purisima A Unit

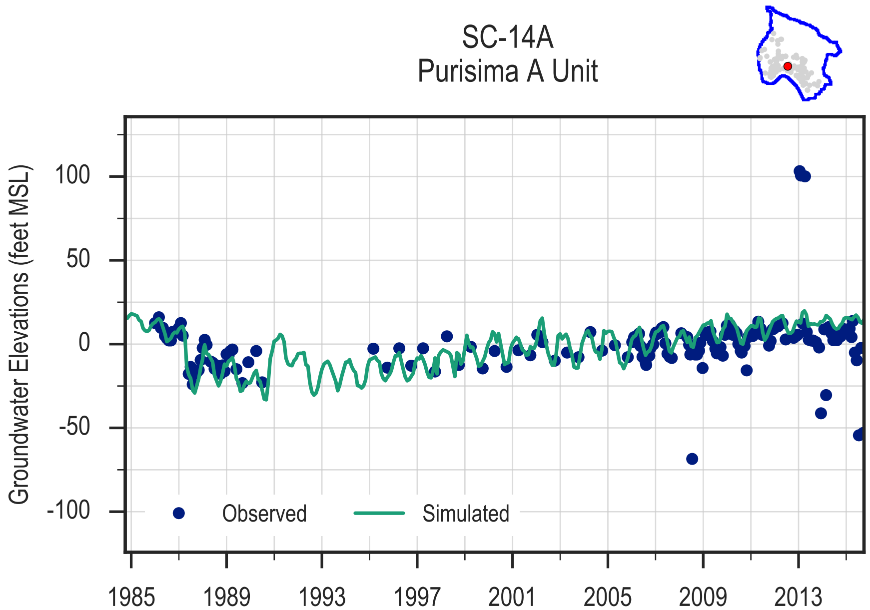


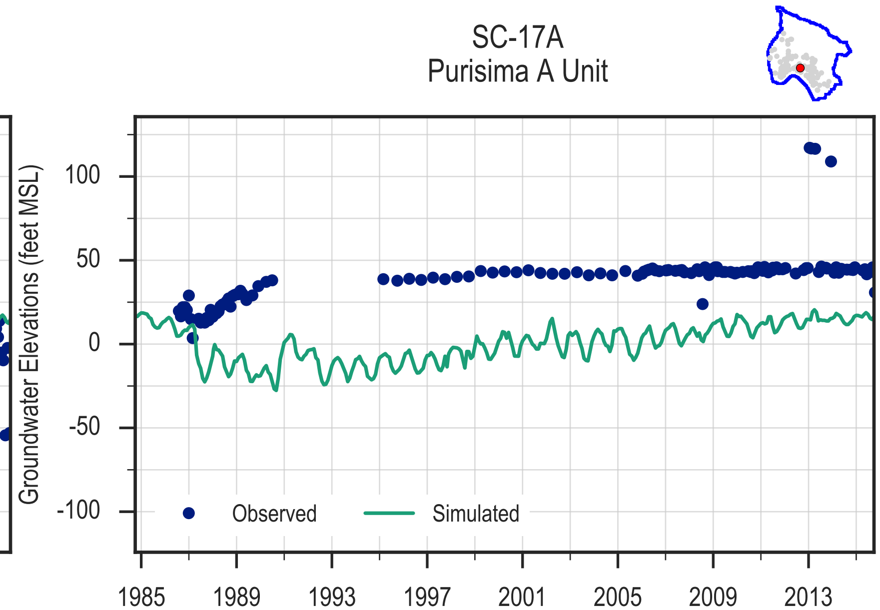
SC-3A/SC-3AR
Purisima A Unit

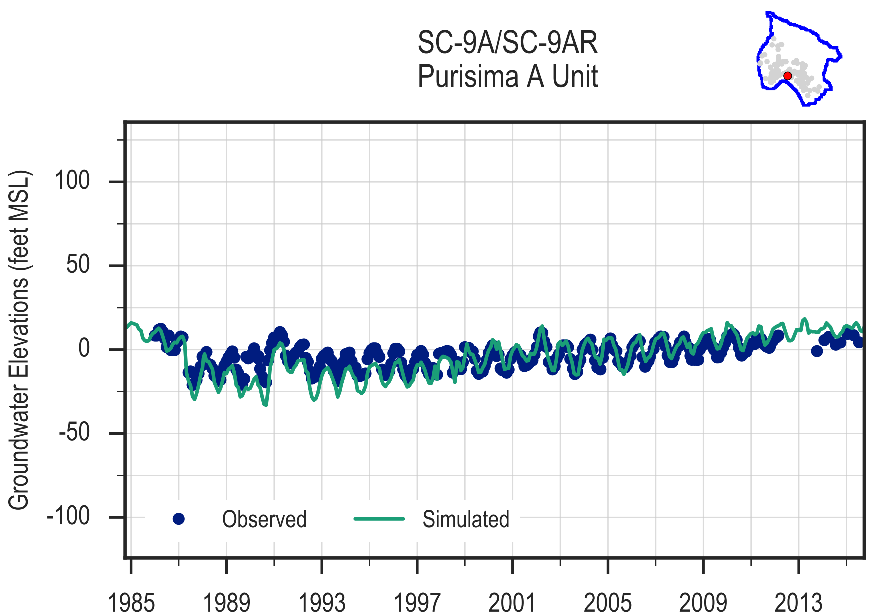


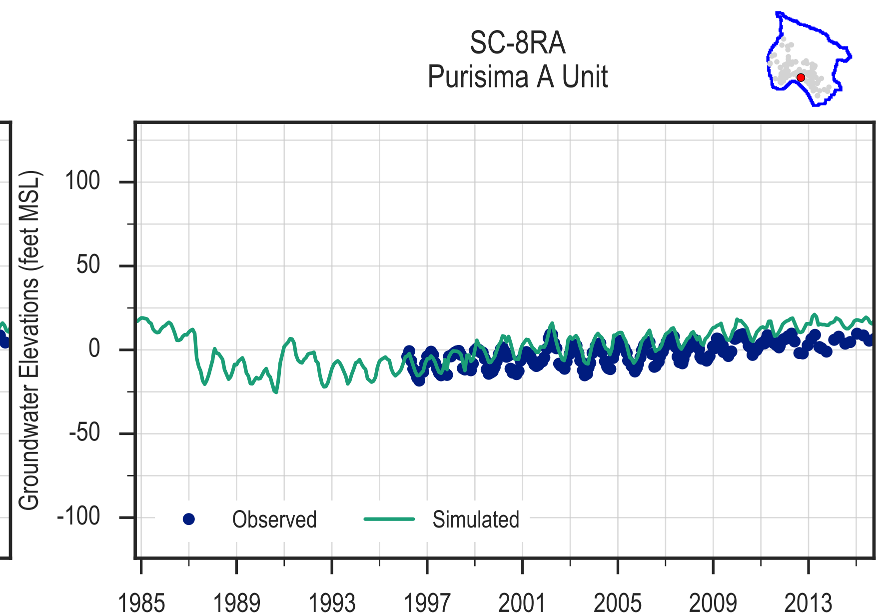
SC-5A/SC-5AR
Purisima A Unit



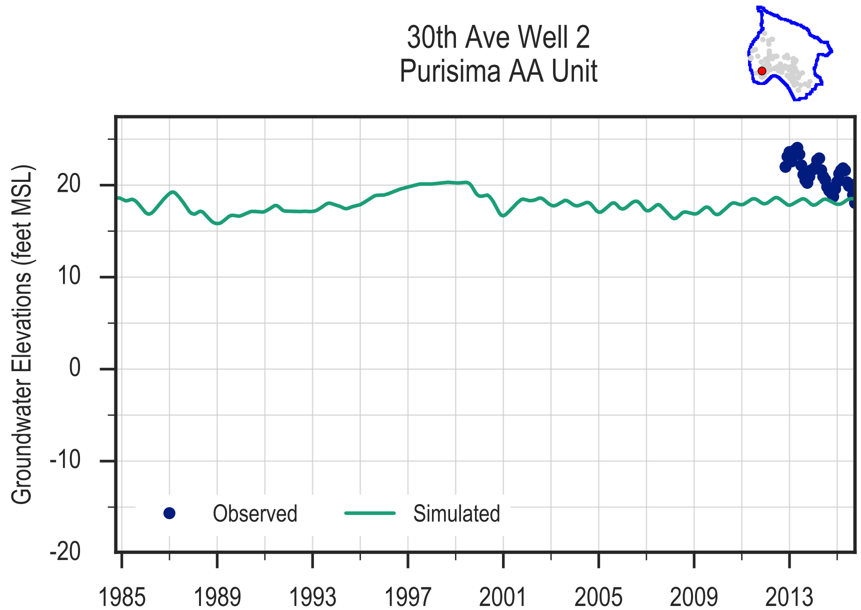

SC-14A
Purisima A Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013


SC-17A
Purisima A Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

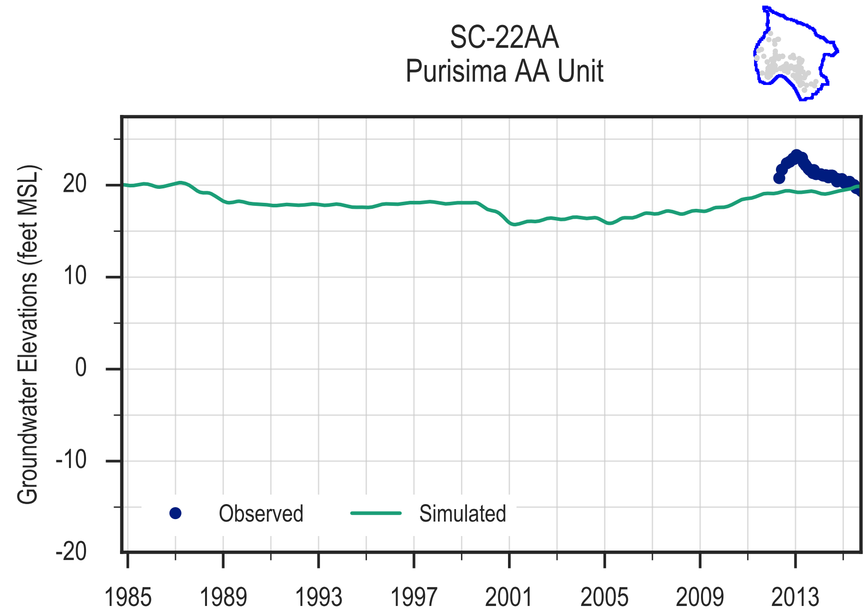

SC-9A/SC-9AR
Purisima A Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013


SC-8RA
Purisima A Unit
Groundwater Elevations (feet MSL)
100
50
0
-50
-100
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

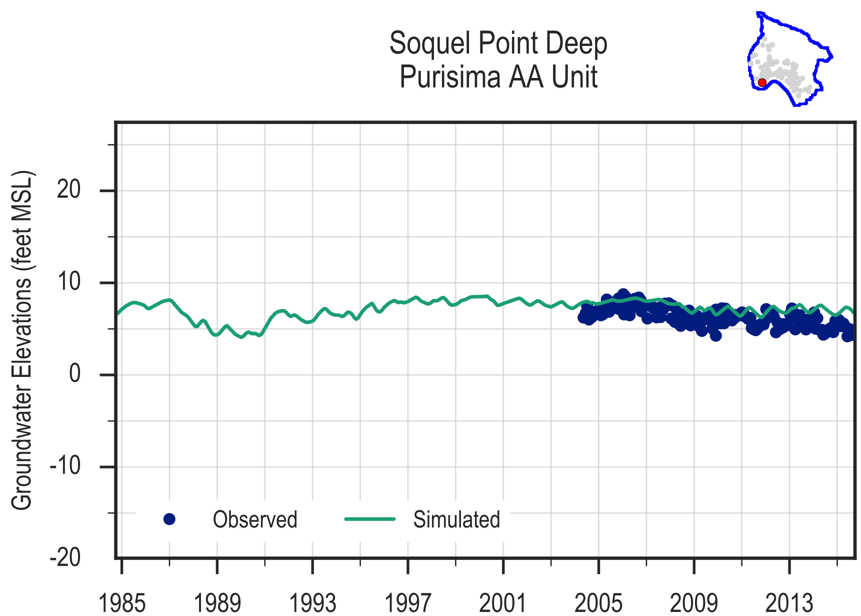
30th Ave Well 2
Purisima AA Unit



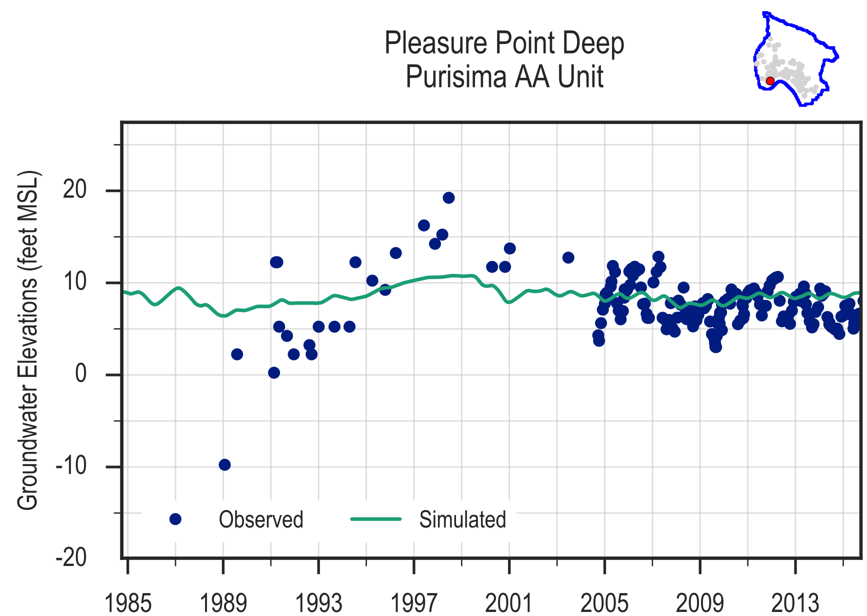
SC-22AA
Purisima AA Unit

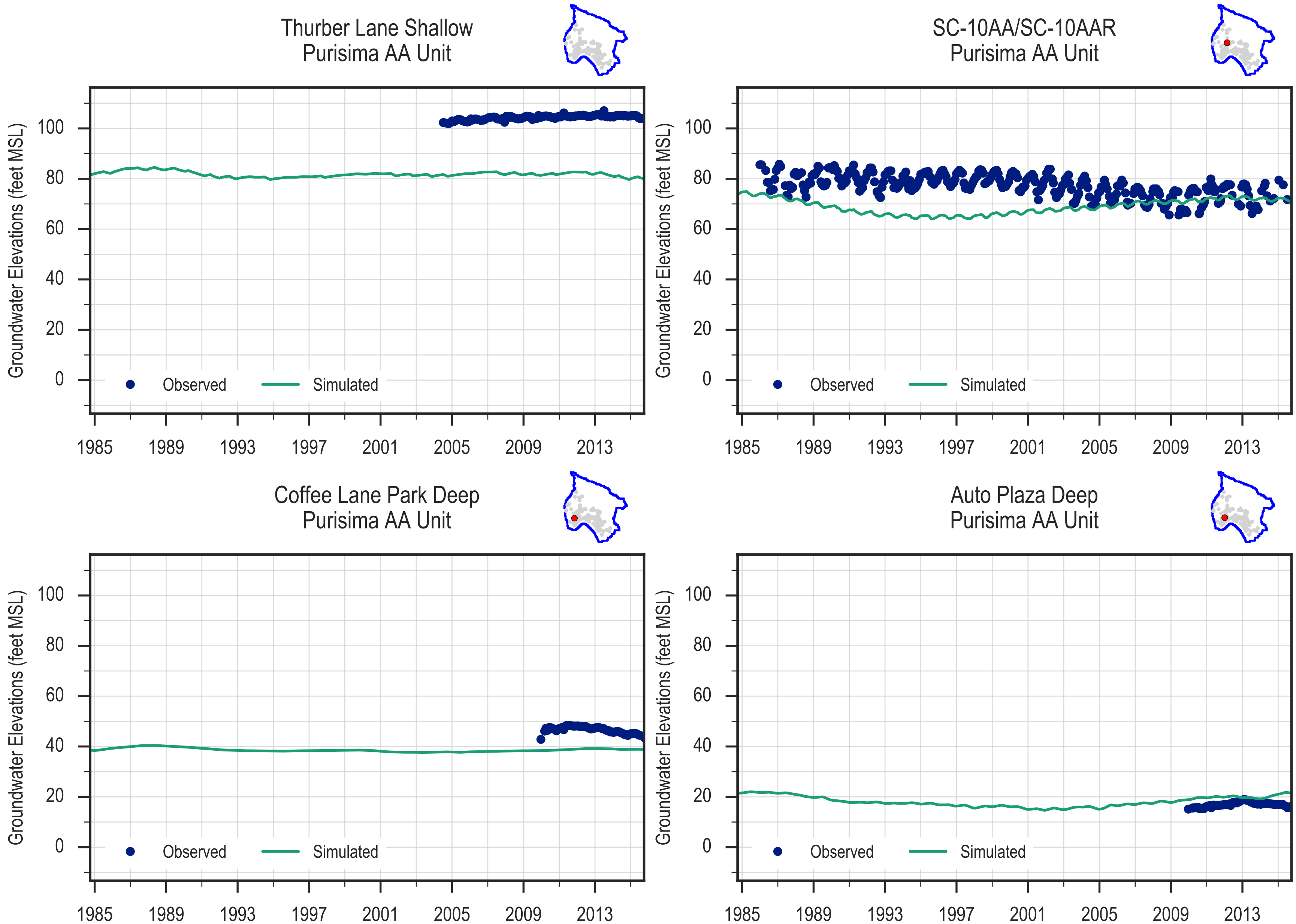


Soquel Point Deep
Purisima AA Unit

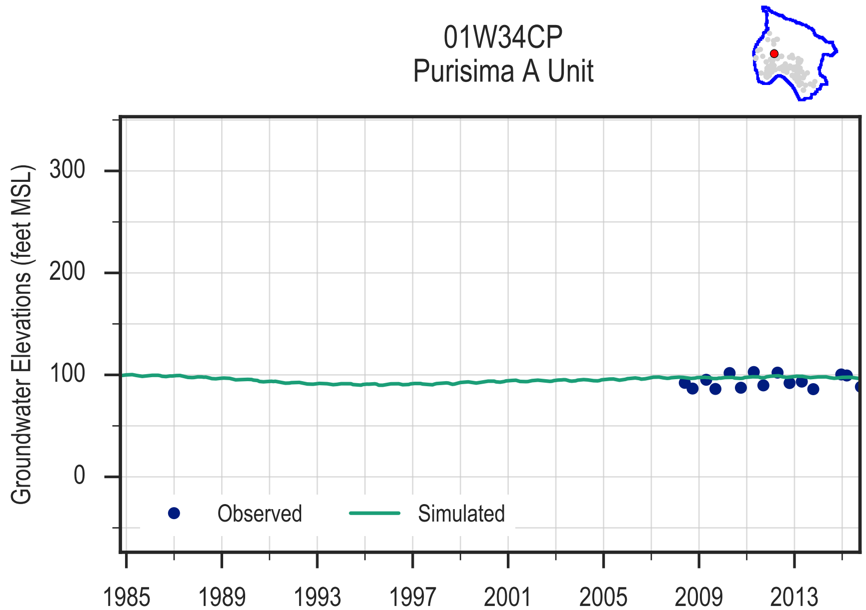


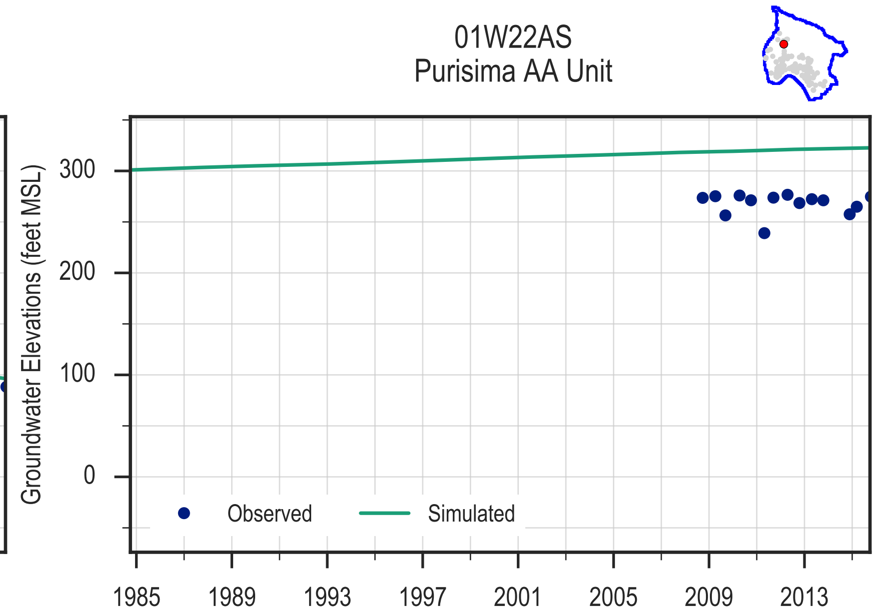
Pleasure Point Deep
Purisima AA Unit

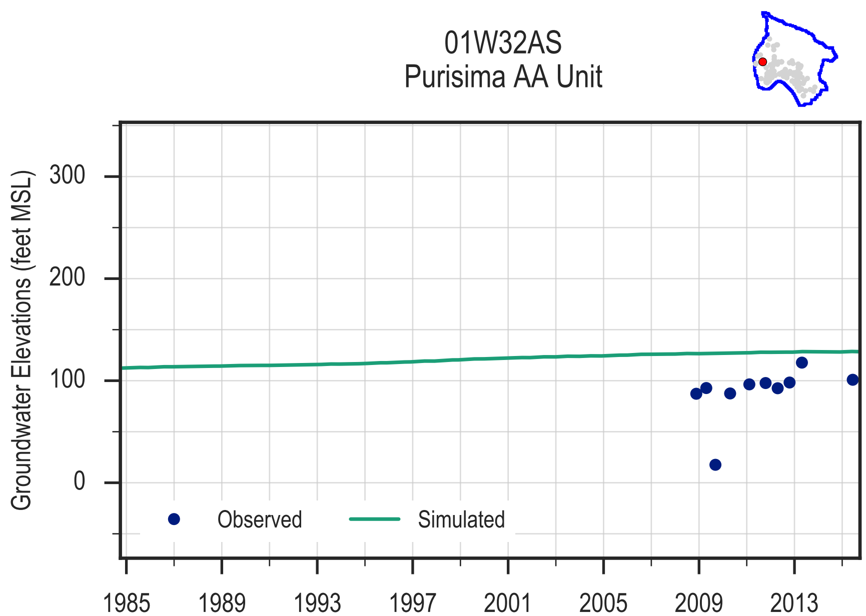


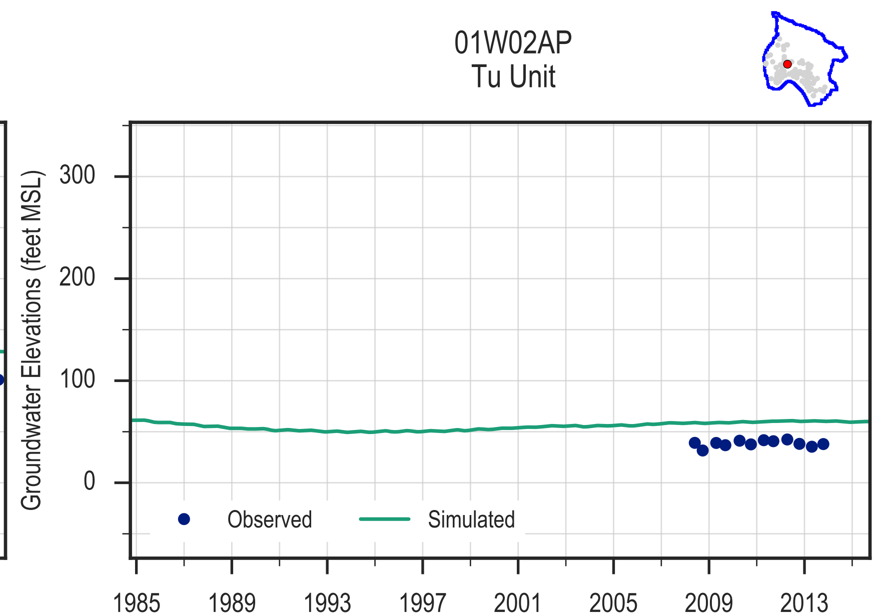


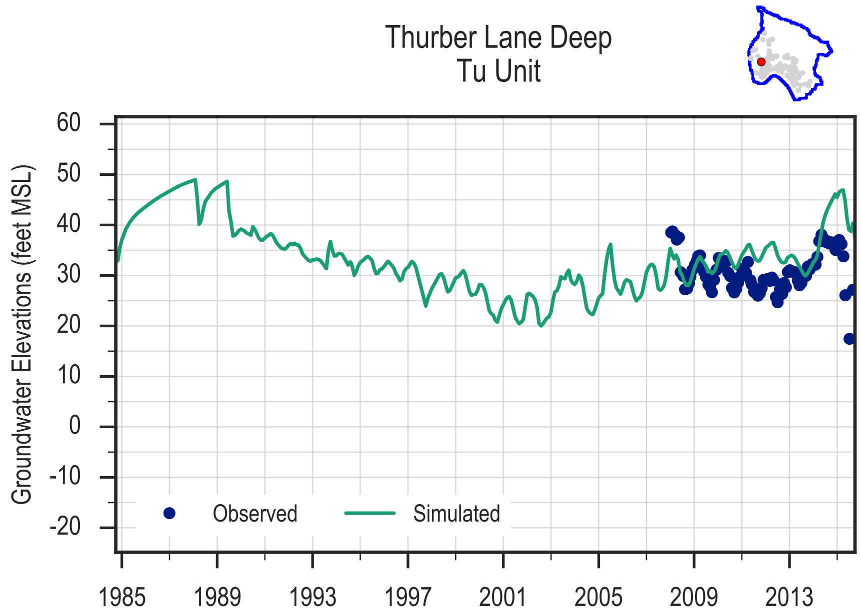
Thurber Lane Shallow
Purisima AA Unit
SC-10AA/SC-10AAR
Purisima AA Unit
Coffee Lane Park Deep
Purisima AA Unit
Auto Plaza Deep
Purisima AA Unit
Groundwater Elevations (feet MSL)
100
80
60
40
20
0
1985
1989
1993
1997
2001
2005
2009
2013
Observed
Simulated

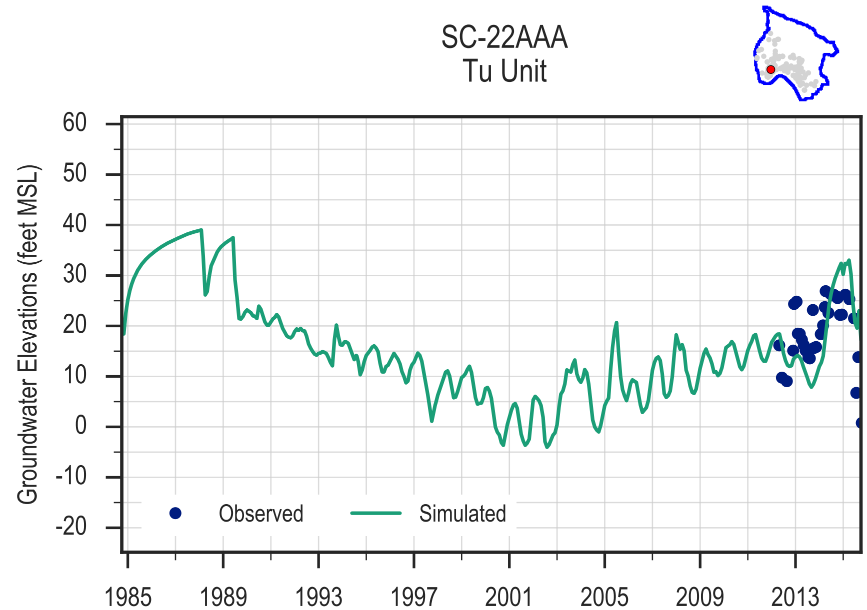

01W34CP
Purisima A Unit
Groundwater Elevations (feet MSL)
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

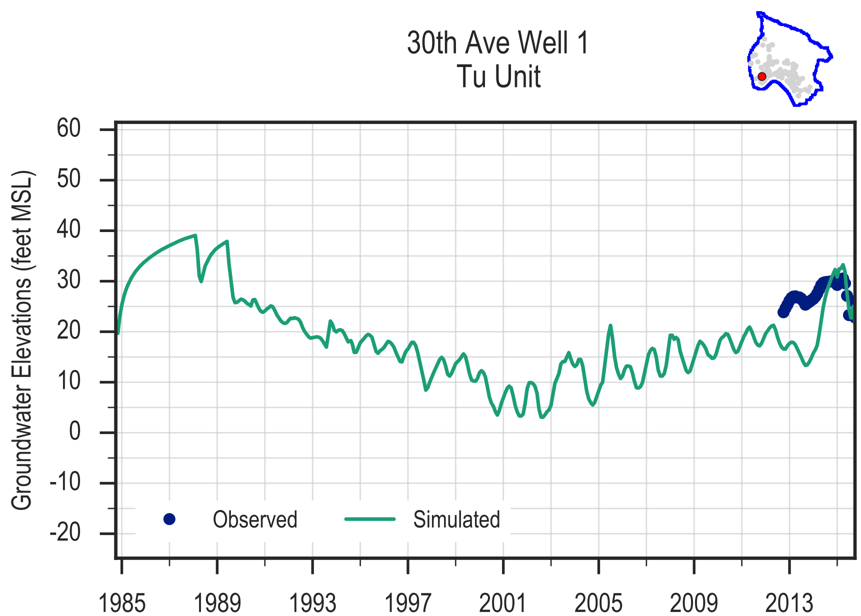

01W22AS
Purisima AA Unit
Groundwater Elevations (feet MSL)
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

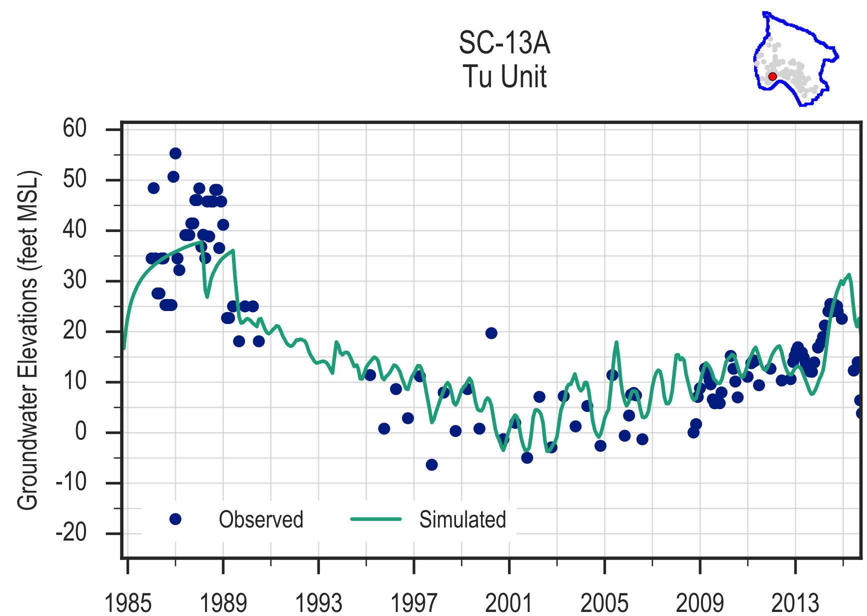

01W32AS
Purisima AA Unit
Groundwater Elevations (feet MSL)
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

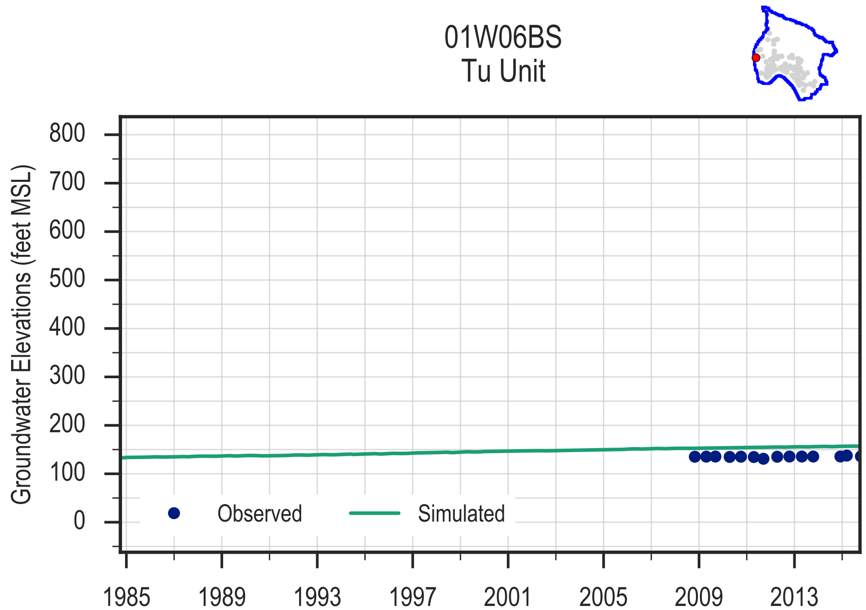

01W02AP
Tu Unit
Groundwater Elevations (feet MSL)
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

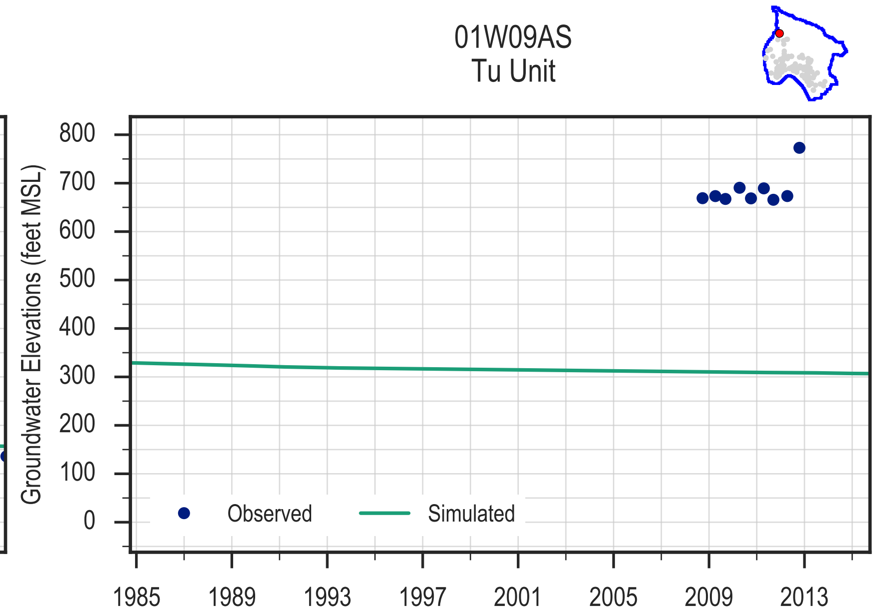

Thurber Lane Deep
Tu Unit
Groundwater Elevations (feet MSL)
Observed
Simulated

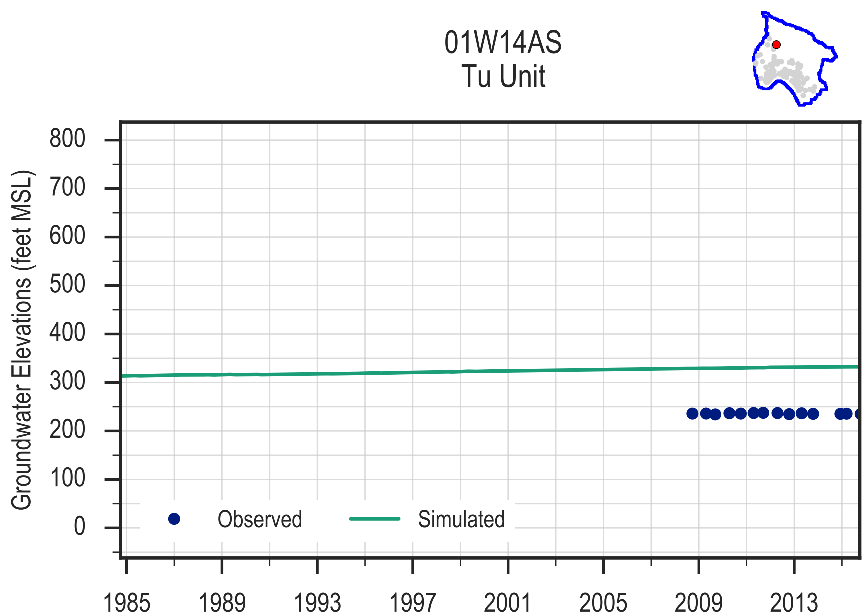

SC-22AAA
Tu Unit
Groundwater Elevations (feet MSL)
Observed
Simulated

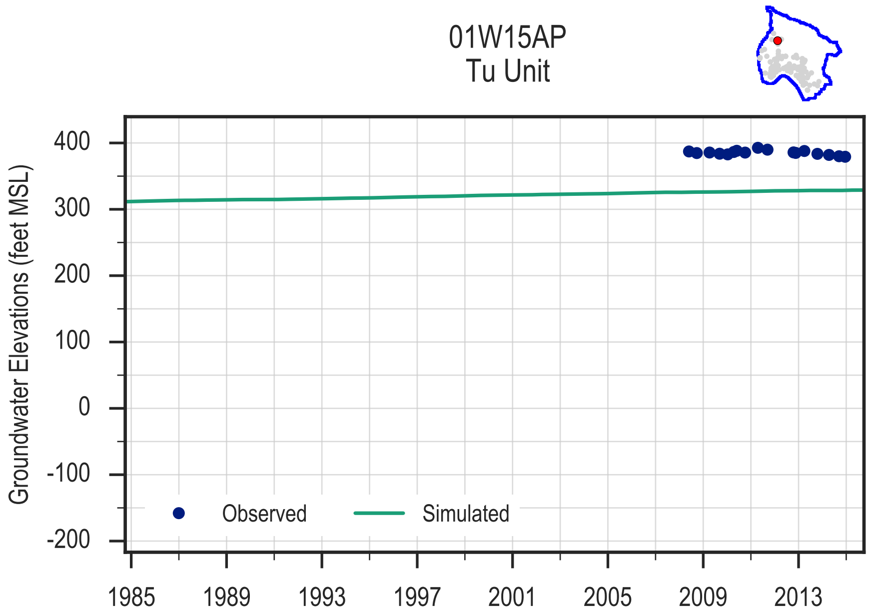

30th Ave Well 1
Tu Unit
Groundwater Elevations (feet MSL)
Observed
Simulated


SC-13A
Tu Unit
Groundwater Elevations (feet MSL)
Observed
Simulated

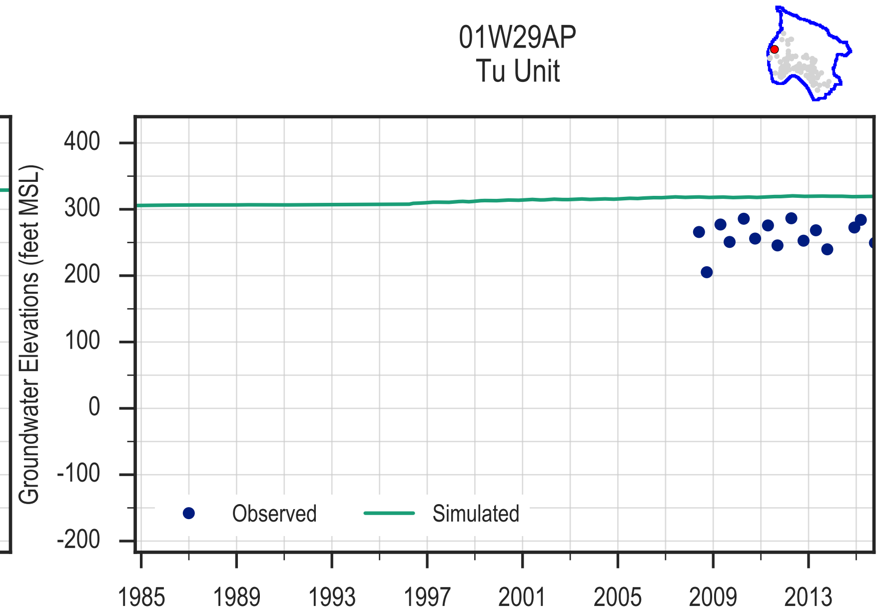

01W06BS
Tu Unit
Groundwater Elevations (feet MSL)
800
700
600
500
400
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013


01W09AS
Tu Unit
Groundwater Elevations (feet MSL)
800
700
600
500
400
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

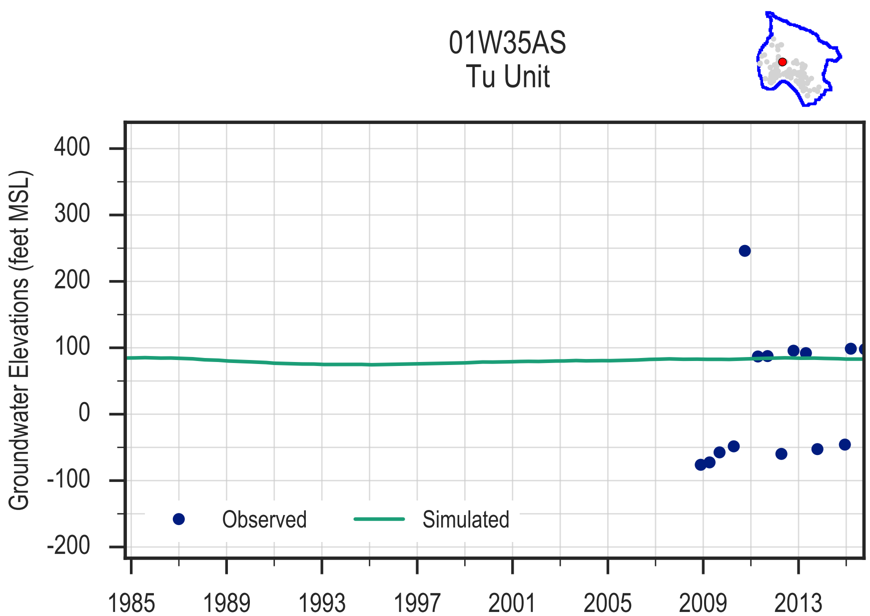

01W14AS
Tu Unit
Groundwater Elevations (feet MSL)
800
700
600
500
400
300
200
100
0
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



01W15AP
Tu Unit
Groundwater Elevations (feet MSL)
400
300
200
100
0
-100
-200
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



01W29AP
Tu Unit
Groundwater Elevations (feet MSL)
400
300
200
100
0
-100
-200
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013



01W35AS
Tu Unit
Groundwater Elevations (feet MSL)
400
300
200
100
0
-100
-200
Observed
Simulated
1985
1989
1993
1997
2001
2005
2009
2013

Appendix B

Comparison of Model Parameters to Parameters Estimated by Pumping Tests

		Thickness [ft]				Horizontal Hydraulic Conductivity [ft/day]						Transmissivity [ft^2/day]						Vertical Hydraulic Conductivity [ft/day]					
Well_Name_Data_Type	**Aquifer(s)**	**b_rcl**	**b_min**	**b_max**	**b_am**	**Kx_rcl**	**Kx_min**	**Kx_max**	**Kx_hm**	**Kx_gm**	**Kx_am**	**T_rcl**	**T_min**	**T_max**	**T_hm**	**T_gm**	**T_am**	**Kz_rcl**	**Kz_min**	**Kz_max**	**Kz_hm**	**Kz_gm**	**Kz_am**
Aptos Jr High 2 [aquif. tests]	F		246	246	246		9.0	9.0	9.0	9.0	9.0		2,203	2,203	2,203	2,203	2,203		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Aptos Jr High 2 [L3]	F	879	599	1169	832	0.90	0.06	6.5	0.40	0.7	1.1	787	38	5,179	293	579	896	2.7E-02	3.6E-05	1.1E+00	7.9E-04	2.6E-02	1.6E-01
Beltz 07 [aquif. tests]	A/AA		100	100	100		2.5	2.5	2.5	2.5	2.5		125	125	125	125	125		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Beltz 07 [L7]	A	110	7	239	134	10.4	1.0	10	4.8	5.2	5.5	1,154	34	2,067	322	561	783	2.3E-03	1.0E-04	1.8E-02	2.4E-03	3.7E-03	4.6E-03
Beltz 07 [L8]	AA	403	332	406	383	1.67	0.36	24	1.0	1.7	3.5	676	137	8,665	401	633	1,301	1.2E-03	8.4E-04	2.6E-02	1.8E-03	2.3E-03	3.6E-03
Beltz 08 [aquif. tests]	A		90	100	93		37	108	66	70	74	729	3,650	9,690	6,133	6,449	6,767		3.0E-03	5.4E+00	1.5E-02	4.1E-01	1.6E+00
Beltz 08 [L7]	A	163	13	216	145	4.5	3.2	29	5.5	5.9	6.7	838	66	5,769	480	745	1,082		1.1E-03	2.4E-02	3.2E-03	3.7E-03	4.7E-03
Beltz 09 [aquif. tests]	A	A	90	110	100	26	26	68	42	44	47	4,418	2,370	6,830	4,158	4,418	4,658	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01
Beltz 09 [L7]	A	161	39	266	178	5.2	3.2	12.7	6.0	6.4	6.9	838	199	3,350	790	1,046	1,327	2.6E-03	1.6E-03	3.0E-01	3.5E-03	4.9E-03	1.4E-02
Beltz 12 [aquif. tests]	AA/Tu		0	0	#DIV/0!		0.00	0.00	#N/A	#NUM!	#DIV/0!		2,470	2,470	2,470	2,470	2,470		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Beltz 12 [L8]	AA	382	189	428	346	1.37	0.43	4.11	1.17	1.38	1.63	522	163	1,516	397	474	569	5.8E-02	3.8E-03	1.2E-01	1.8E-02	3.2E-02	4.7E-02
Beltz 12 [L9]	Tu	213	124	318	196	5.21	2.44	8.85	4.61	4.81	5.00	1,111	510	1,339	896	916	934	1.0E-07	1.0E-07	1.0E-07	1.0E-07	1.0E-07	1.0E-07
Bonita [aquif. tests]	F/Aromas		475	475	475		15	15	15	15	15		7,200	7,200	7,200	7,200	7,200		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Bonita [L2]	Aromas	361	224	616	406	16.2	8.5	114	18	26	40	5,842	2,189	66,971	6,251	10,010	17,370	1.03	0.40	1.07	0.94	0.95	0.96
Bonita [L3]	F	880	737	1041	876	3.93	0.63	11	2.6	3.8	5.1	3,458	563	8,743	2,341	3,273	4,267	1.1E-01	1.0E-02	6.8E-01	3.9E-02	9.5E-02	2.2E-01
Cox #3 [aquif. tests]	DEF/F		143	143	143		3.3000	3.400	3.349	3.350	3.350		470	488	479	479	479						
Cox #3 [L3]	DEF/F	1232	789	1675	1237	0.0525	0.0033	0.071	0.016	0.021	0.027	65	4	85	19	26	35	5.3E-04	7.6E-05	5.7E-03	1.8E-04	2.9E-04	6.5E-04
Estates [aquif. tests]	A/BC		415	615	515		3.90	5.70	4.63	4.71	4.80		2,380	2,400	2,390	2,390	2,390		4.0E-02	4.0E-02	4.0E-02	4.0E-02	4.0E-02
Estates [L5]	BC	190	190	190	190	10.68	0.21	12.54	1.07	1.78	3.26	2,030	40	2,382	203	338	620	3.7E-03	9.6E-04	1.2E-02	2.2E-03	2.5E-03	2.9E-03
Estates [L7]	A	307	266	307	299	4.66	0.55	10.00	1.90	2.76	3.89	1,428	163	3,061	570	825	1,164	7.0E-05	1.4E-05	3.3E-03	7.4E-05	2.6E-04	7.3E-04
Garnet [aquif. tests]	A		200	200	200		17.00	19.00	17.62	17.64	17.67		3,350	4,480	3,673	3,705	3,740		4.0E-01	5.0E-01	4.4E-01	4.5E-01	4.5E-01
Garnet [L7]	A	199	93	255	192	5.07	1.83	47.98	4.90	5.99	8.41	1,007	412	9,975	894	1,123	1,674	1.8E-03	6.0E-05	1.1E-01	5.4E-04	2.7E-03	1.2E-02
Granite Way [aquif. tests]	DEF												238	238	238	238	238						
Granite Way [L3]	DEF	593	335	1067	597	0.301	0.048	0.78	0.15	0.20	0.26	178	24	548	88	112	142	1.6E-04	1.1E-05	4.4E-02	8.7E-05	4.5E-04	4.6E-03
Ledyard [aquif. tests]	BC		215	215	215		1.80	1.80	1.80	1.80	1.80		300	300	300	300	300		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Ledyard [L5]	BC	190	190	190	190	17.10	0.34	17.10	1.34	2.08	3.61	3,248	64	3,248	255	394	685	2.0E-03	1.1E-03	3.7E-03	1.9E-03	2.0E-03	2.0E-03
Madeline [aquif. tests]	BC		160	230	195		1.40	1.50	1.45	1.45	1.45		240	300	267	268	270		2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02
Madeline [L5]	BC	190	190	190	190	5.48	0.11	17.10	0.74	1.69	3.61	1,040	21	3,248	140	321	686	1.7E-03	9.6E-04	1.2E-02	2.1E-03	2.3E-03	2.8E-03
Main St [aquif. tests]	AA/Tu		172	600	399		3.28	14.90	8.70	9.24	9.67		563	4,600	3,040	3,530	3,728		2.0E-03	8.0E-01	1.0E-02	3.2E-02	1.3E-01
Main St [L8]	AA	369	335	404	358	2.33	1.07	4.11	1.79	1.90	2.02	858	378	1,516	636	678	729	2.3E-02	3.1E-03	8.9E-02	1.5E-02	2.2E-02	3.2E-02
Main St [L9]	Tu	110	59	184	116	7.78	0.09	8.85	0.64	1.91	3.71	853	11	1,129	69	215	455	1.0E-07	1.0E-07	1.0E-07	1.0E-07	1.0E-07	1.0E-07
Rosedale [aquif. tests]	A		350	350	350		14.00	14.00	14.00	14.00	14.00		4,800	4,800	4,800	4,800	4,800		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Rosedale [L7]	A	255	72	281	223	6.04	1.91	7.64	4.33	4.59	4.84	1,541	194	1,932	845	989	1,102	2.1E-03	1.6E-05	1.1E-01	2.2E-04	3.0E-03	1.8E-02
Rosedale [L8]	AA	345	324	411	360	2.10	1.22	4.11	1.74	1.83	1.94	724	411	1,516	624	658	702	7.9E-03	6.8E-04	8.9E-02	3.5E-03	7.1E-03	1.5E-02
San Andreas [aquif. tests]	F/Aromas		350	450	400		13.00	14.00	13.48	13.49	13.50		4,700	6,300	5,384	5,442	5,500		2.4E+00	2.4E+00	2.4E+00	2.4E+00	2.4E+00
San Andreas [L2]	Aromas	346	215	651	432	9.34	8.47	100.18	13.43	16.64	23.33	3,234	2,061	56,958	5,143	6,978	11,128	1.0	0.8	1.1	1.0	1.0	1.0
San Andreas [L3]	F	886	738	1050	882	6.07	0.99	11.14	3.67	4.70	5.81	5,383	889	8,743	3,369	4,129	4,887	2.0E-01	8.0E-03	6.2E-01	3.3E-02	7.6E-02	1.8E-01
Seascape [aquif. tests]	F/Aromas		420	420	420		29.00	29.00	29.00	29.00	29.00		12,000	12,000	12,000	12,000	12,000		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Seascape [L2]	Aromas	464	198	599	404	10.00	8.47	18.12	9.90	9.97	10.06	4,644	1,982	10,136	3,778	3,928	4,097	1.0	0.5	1.0	0.9	0.9	0.9
Seascape [L3]	F	808	666	964	808	8.90	1.17	11.14	4.86	5.79	6.55	7,186	869	8,743	3,853	4,656	5,266	4.0E-02	7.4E-03	5.6E-01	1.9E-02	3.5E-02	1.0E-01
Sells [aquif. tests]	F/Aromas		330	330	330		210.00	210.00	210.00	210.00	210.00		66,800	73,500	69,990	70,070	70,150		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Sells [L2]	Aromas	478	342	735	503	9.80	9.07	29.95	10.65	10.93	11.34	4,684	3,422	17,716	5,075	5,405	5,928	0.6	0.3	1.1	0.7	0.7	0.8
Sells [L3]	F	769	634	955	777	1.58	0.88	8.24	1.57	1.89	2.40	1,218	557	7,142	1,153	1,457	1,954	9.4E-03	7.5E-03	1.8E-02	9.6E-03	9.7E-03	9.8E-03
Tannery II [aquif. tests]	A		235	235	235		8.80	10.00	9.36	9.38	9.40		2,020	2,060	2,040	2,040	2,040		7.0E-01	7.0E-01	7.0E-01	7.0E-01	7.0E-01
Tannery II [L7]	A	265	231	305	264	5.05	0.55	7.64	2.82	3.61	4.22	1,337	163	1,932	776	950	1,086	2.5E-04	1.2E-05	1.2E-02	7.5E-05	5.5E-04	2.1E-03

Notes:

"Well-Name [aquif. Tests]" denotes parameter summary stats for pumping well based on pumping test results

"Well-Name [LX]" denotes averaged model paramters around each well based on averaging grid cells in Layer X that are within 3200 feet radial distance (4 grid cells) of the grid cell containing the well.

rcl = value at the well grid cell (at row=r, col=c, layer=l)

min = minimum value

max = maximum value

hm = harmonic mean

gm - geometric mean

am = arithmetic mean

		Specifc Storage [1/ft]						Storativity [ft/ft]						Hydraulic Diffusivity (K/Ss) [ft^2/day]					
Well_Name_Data_Type	Aquifer(s)	Ss_rcl	Ss_min	Ss_max	Ss_hm	Ss_gm	Ss_am	S_rcl	S_min	S_max	S_hm	S_gm	S_am	D_rcl	D_min	D_max	D_hm	D_gm	D_am
Aptos Jr High 2 [aquif. tests]	F		1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06		4.3E-04	4.3E-04	4.3E-04	4.3E-04	4.3E-04		5.1E+06	5.1E+06	5.1E+06	5.1E+06	5.1E+06
Aptos Jr High 2 [L3]	F	9.5E-05	9.0E-05	9.9E-04	1.3E-04	1.3E-04	1.6E-04	8.31E-02	6.9E-02	6.1E-01	9.8E-02	1.1E-01	1.3E-01	9.5E+03	6.3E+01	6.5E+04	1.1E+03	5.4E+03	1.1E+04
Beltz 07 [aquif. tests]	A/AA		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Beltz 07 [L7]	A	9.2E-04	9.2E-06	9.2E-04	2.4E-04	2.4E-04	3.6E-04	1.01E-01	5.0E-04	1.2E-01	1.1E-02	2.6E-02	4.0E-02	1.1E+04	3.7E+03	5.7E+05	1.4E+04	2.2E+04	4.5E+04
Beltz 07 [L8]	AA	8.6E-05	6.7E-05	1.1E-04	8.8E-05	8.8E-05	8.9E-05	3.48E-02	2.4E-02	4.3E-02	3.3E-02	3.4E-02	3.4E-02	1.9E+04	5.3E+03	2.5E+05	1.2E+04	1.9E+04	3.7E+04
Beltz 08 [aquif. tests]	A		1.8E-06	4.9E-05	3.7E-06	6.2E-06	1.3E-05		1.6E-04	4.4E-03	3.5E-04	5.8E-04	1.2E-03		1.5E+06	5.6E+07	5.6E+06	1.1E+07	1.9E+07
Beltz 08 [L7]	A	2.7E-04	7.8E-07	9.2E-04	8.6E-05	8.6E-05	2.7E-04	4.43E-02	1.5E-04	1.2E-01	1.8E-03	1.1E-02	3.0E-02	1.6E+04	3.7E+03	8.2E+06	1.8E+04	6.9E+04	8.3E+05
Beltz 09 [aquif. tests]	A	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.40E-02	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.4E-02	0.0E+00	3.1E+05	3.1E+05	3.1E+05	3.1E+05	3.1E+05
Beltz 09 [L7]	A	5.4E-04	4.3E-05	9.2E-04	2.8E-04	2.8E-04	3.7E-04	8.76E-02	8.7E-03	2.0E-01	3.6E-02	4.6E-02	5.8E-02	9.6E+03	3.7E+03	2.0E+05	1.6E+04	2.3E+04	3.5E+04
Beltz 12 [aquif. tests]	AA/Tu		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		1.0E-03	1.0E-03	1.0E-03	1.0E-03	1.0E-03		2.5E+06	2.5E+06	2.5E+06	2.5E+06	2.5E+06
Beltz 12 [L8]	AA	1.0E-04	7.4E-05	1.0E-04	9.3E-05	9.3E-05	9.3E-05	3.90E-02	1.9E-02	3.9E-02	3.1E-02	3.2E-02	3.2E-02	1.3E+04	5.8E+03	4.4E+04	1.3E+04	1.5E+04	1.7E+04
Beltz 12 [L9]	Tu	4.2E-06	2.7E-06	8.0E-06	4.4E-06	4.4E-06	4.6E-06	8.92E-04	6.5E-04	1.2E-03	8.4E-04	8.4E-04	8.5E-04	1.2E+06	5.8E+05	1.6E+06	1.1E+06	1.1E+06	1.1E+06
Bonita [aquif. tests]	F/Aromas		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Bonita [L2]	Aromas	1.0E-05	9.6E-06	1.2E-05	1.0E-05	1.0E-05	1.0E-05	3.61E-03	2.2E-03	7.5E-03	3.8E-03	3.9E-03	4.1E-03	1.6E+06	8.5E+05	1.2E+07	1.8E+06	2.6E+06	4.0E+06
Bonita [L3]	F	1.0E-04	9.8E-05	1.0E-04	1.0E-04	1.0E-04	1.0E-04	8.80E-02	7.4E-02	1.0E-01	8.7E-02	8.7E-02	8.8E-02	3.9E+04	6.3E+03	1.1E+05	2.6E+04	3.8E+04	5.1E+04
Cox #3 [aquif. tests]	DEF/F		7.0E-07	1.7E-06	1.0E-06	1.1E-06	1.2E-06		1.0E-04	2.5E-04	1.4E-04	1.6E-04	1.8E-04		2.0E+06	4.7E+06	2.8E+06	3.0E+06	3.3E+06
Cox #3 [L3]	DEF/F	1.6E-04	1.5E-04	1.1E-03	3.9E-04	3.9E-04	5.0E-04	1.93E-01	1.9E-01	1.5E+00	4.0E-01	4.8E-01	5.8E-01	3.3E+02	3.5E+00	4.5E+02	2.3E+01	5.4E+01	1.2E+02
Estates [aquif. tests]	A/BC		4.8E-07	4.8E-07	4.8E-07	4.8E-07	4.8E-07		2.0E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04		1.2E+07	1.2E+07	1.2E+07	1.2E+07	1.2E+07
Estates [L5]	BC	5.7E-07	2.0E-07	5.0E-06	7.9E-07	7.9E-07	1.2E-06	1.08E-04	3.8E-05	9.5E-04	1.1E-04	1.5E-04	2.2E-04	1.9E+07	1.0E+05	4.5E+07	9.0E+05	2.3E+06	5.0E+06
Estates [L7]	A	3.4E-07	6.1E-08	3.4E-05	7.7E-07	7.7E-07	3.1E-06	1.03E-04	1.8E-05	1.0E-02	1.0E-04	2.3E-04	9.3E-04	1.4E+07	2.0E+04	1.5E+08	3.6E+05	3.6E+06	1.4E+07
Garnet [aquif. tests]	A		1.0E-06	8.0E-06	1.8E-06	2.8E-06	4.5E-06		2.0E-04	1.6E-03	3.6E-04	5.7E-04	9.0E-04		2.1E+06	1.7E+07	3.8E+06	6.0E+06	9.4E+06
Garnet [L7]	A	7.8E-07	2.0E-07	2.7E-04	3.3E-06	3.3E-06	2.1E-05	1.55E-04	4.6E-05	4.4E-02	2.0E-04	6.2E-04	3.3E-03	6.5E+06	1.6E+04	6.0E+07	2.3E+05	1.8E+06	7.5E+06
Granite Way [aquif. tests]	DEF																		
Granite Way [L3]	DEF	1.8E-04	1.2E-04	9.9E-04	3.3E-04	3.3E-04	3.9E-04	1.04E-01	8.1E-02	6.1E-01	1.7E-01	1.9E-01	2.2E-01	1.7E+03	6.3E+01	6.4E+03	3.6E+02	6.0E+02	9.4E+02
Ledyard [aquif. tests]	BC		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Ledyard [L5]	BC	2.0E-06	2.0E-07	6.4E-06	8.8E-07	8.8E-07	1.1E-06	3.86E-04	3.8E-05	1.2E-03	1.4E-04	1.7E-04	2.1E-04	8.4E+06	1.4E+05	4.5E+07	1.3E+06	2.4E+06	4.7E+06
Madeline [aquif. tests]	BC		2.8E-05	2.8E-05	2.8E-05	2.8E-05	2.8E-05		4.5E-03	4.5E-03	4.5E-03	4.5E-03	4.5E-03		5.3E+04	5.3E+04	5.3E+04	5.3E+04	5.3E+04
Madeline [L5]	BC	6.5E-07	2.0E-07	5.0E-06	8.8E-07	8.8E-07	1.2E-06	1.23E-04	3.8E-05	9.5E-04	1.2E-04	1.7E-04	2.3E-04	8.4E+06	1.0E+05	4.5E+07	7.0E+05	1.9E+06	5.1E+06
Main St [aquif. tests]	AA/Tu		1.1E-07	1.3E-03	7.6E-07	4.6E-06	8.2E-05		3.9E-05	2.3E-01	2.4E-04	1.4E-03	1.5E-02		2.4E+03	1.1E+08	4.5E+04	2.4E+06	1.7E+07
Main St [L8]	AA	9.5E-05	3.1E-05	1.0E-04	8.1E-05	8.1E-05	8.5E-05	3.51E-02	1.1E-02	4.1E-02	2.7E-02	2.9E-02	3.0E-02	2.4E+04	1.4E+04	4.4E+04	2.2E+04	2.3E+04	2.4E+04
Main St [L9]	Tu	8.0E-06	4.4E-06	2.1E-05	8.9E-06	8.9E-06	9.9E-06	8.75E-04	5.8E-04	1.9E-03	9.7E-04	1.0E-03	1.0E-03	9.7E+05	7.0E+03	1.2E+06	5.4E+04	2.1E+05	5.1E+05
Rosedale [aquif. tests]	A		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!		0.0E+00	0.0E+00	#N/A	#NUM!	#DIV/0!
Rosedale [L7]	A	4.1E-06	4.3E-07	1.0E-04	6.2E-06	6.2E-06	2.0E-05	1.05E-03	1.0E-04	1.5E-02	5.0E-04	1.3E-03	3.3E-03	1.5E+06	2.3E+04	1.0E+07	1.7E+05	7.4E+05	2.7E+06
Rosedale [L8]	AA	9.9E-05	6.6E-05	1.1E-04	9.4E-05	9.4E-05	9.4E-05	3.41E-02	2.3E-02	4.1E-02	3.4E-02	3.4E-02	3.4E-02	2.1E+04	1.1E+04	4.4E+04	1.8E+04	1.9E+04	2.1E+04
San Andreas [aquif. tests]	F/Aromas		2.9E-06	2.9E-06	2.9E-06	2.9E-06	2.9E-06		1.0E-03	1.0E-03	1.0E-03	1.0E-03	1.0E-03		4.7E+06	4.7E+06	4.7E+06	4.7E+06	4.7E+06
San Andreas [L2]	Aromas	1.0E-05	9.6E-06	1.1E-05	1.0E-05	1.0E-05	1.0E-05	3.46E-03	2.2E-03	7.3E-03	4.1E-03	4.2E-03	4.3E-03	9.3E+05	8.5E+05	9.7E+06	1.3E+06	1.7E+06	2.3E+06
San Andreas [L3]	F	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	8.86E-02	7.4E-02	1.0E-01	8.7E-02	8.8E-02	8.8E-02	6.1E+04	9.9E+03	1.1E+05	3.7E+04	4.7E+04	5.8E+04
Seascape [aquif. tests]	F/Aromas		4.8E-07	4.8E-07	4.8E-07	4.8E-07	4.8E-07		2.0E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04		6.0E+07	6.0E+07	6.0E+07	6.0E+07	6.0E+07
Seascape [L2]	Aromas	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	4.64E-03	2.0E-03	6.0E-03	3.8E-03	3.9E-03	4.0E-03	1.0E+06	8.5E+05	1.8E+06	9.9E+05	1.0E+06	1.0E+06
Seascape [L3]	F	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	8.08E-02	6.7E-02	9.6E-02	8.0E-02	8.0E-02	8.1E-02	8.9E+04	1.2E+04	1.1E+05	4.9E+04	5.8E+04	6.5E+04
Sells [aquif. tests]	F/Aromas		2.4E-06	2.4E-06	2.4E-06	2.4E-06	2.4E-06		8.0E-04	8.0E-04	8.0E-04	8.0E-04	8.0E-04		8.4E+07	9.2E+07	8.7E+07	8.8E+07	8.8E+07
Sells [L2]	Aromas	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-05	4.78E-03	3.4E-03	7.4E-03	4.9E-03	4.9E-03	5.0E-03	9.8E+05	9.1E+05	3.0E+06	1.1E+06	1.1E+06	1.1E+06
Sells [L3]	F	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	7.69E-02	6.3E-02	9.5E-02	7.7E-02	7.7E-02	7.8E-02	1.6E+04	8.8E+03	8.2E+04	1.6E+04	1.9E+04	2.4E+04
Tannery II [aquif. tests]	A		2.3E-06	2.3E-06	2.3E-06	2.3E-06	2.3E-06		5.5E-04	5.5E-04	5.5E-04	5.5E-04	5.5E-04		3.7E+06	3.7E+06	3.7E+06	3.7E+06	3.7E+06
Tannery II [L7]	A	1.7E-06	1.6E-07	3.2E-05	1.9E-06	1.9E-06	4.8E-06	4.43E-04	4.8E-05	8.0E-03	2.5E-04	5.1E-04	1.3E-03	3.0E+06	1.2E+05	1.1E+07	7.0E+05	1.9E+06	4.1E+06

Notes:
"Well-Name [aquif. Tests]" denotes parameter summary stats for pumping well based on pumping test results
"Well-Name [LX]" denotes averaged model paramters around each well based on averaging grid cells in Layer X that are within 3200 feet radial distance (4 grid cells) of the grid cell containing the well.
rcl = value at the well grid cell (at row=r, col=c, layer=l)
min = minimum value
max = maximum value
hm = harmonic mean
gm - geometric mean
am = arithmetic mean

Appendix D

Water Budgets by Model Layer

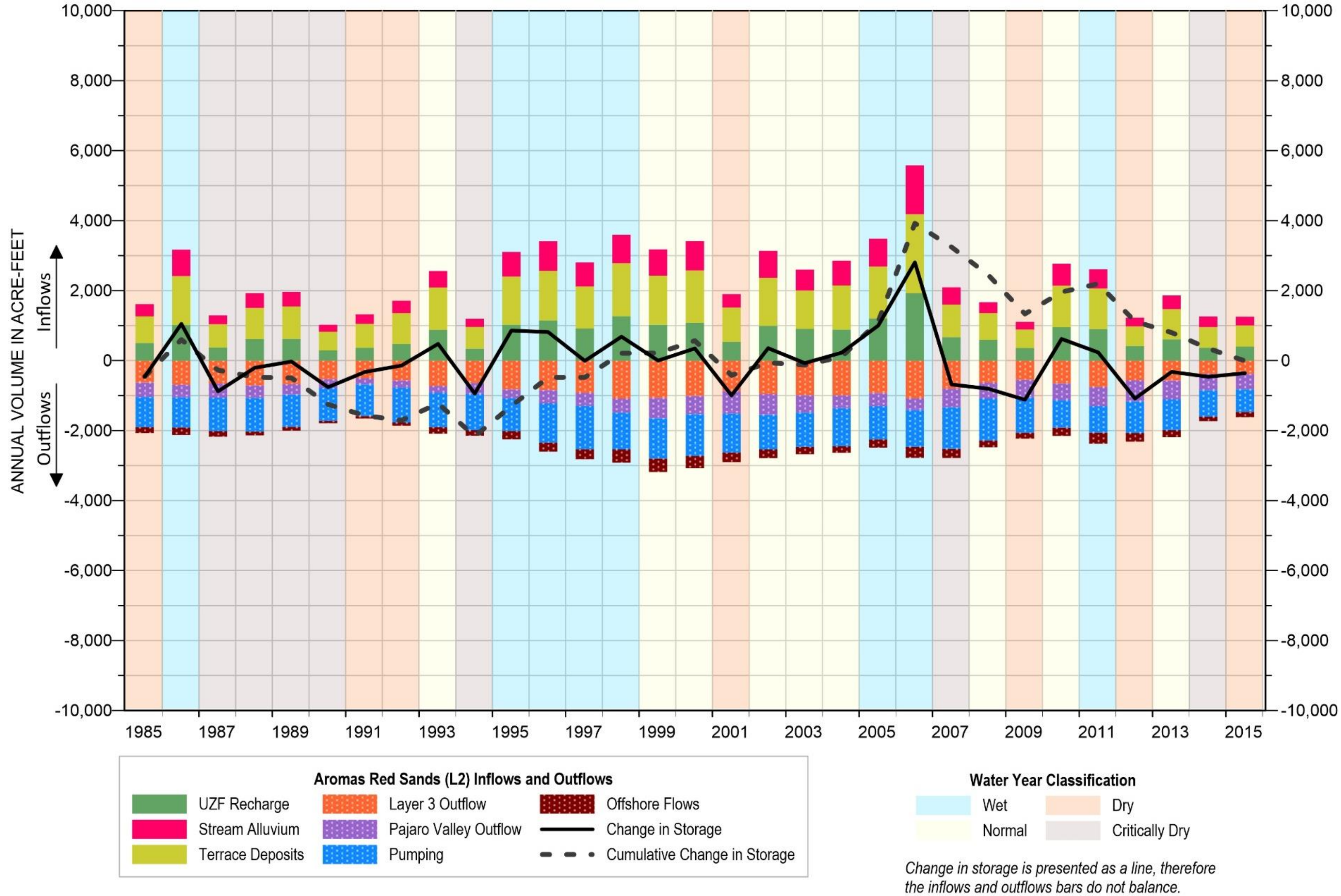


Figure C-1: Detailed Annual Water Budget for Layer 2 (Aromas Red Sands) in Mid-County Basin

MONTGOMERY & ASSOCIATES

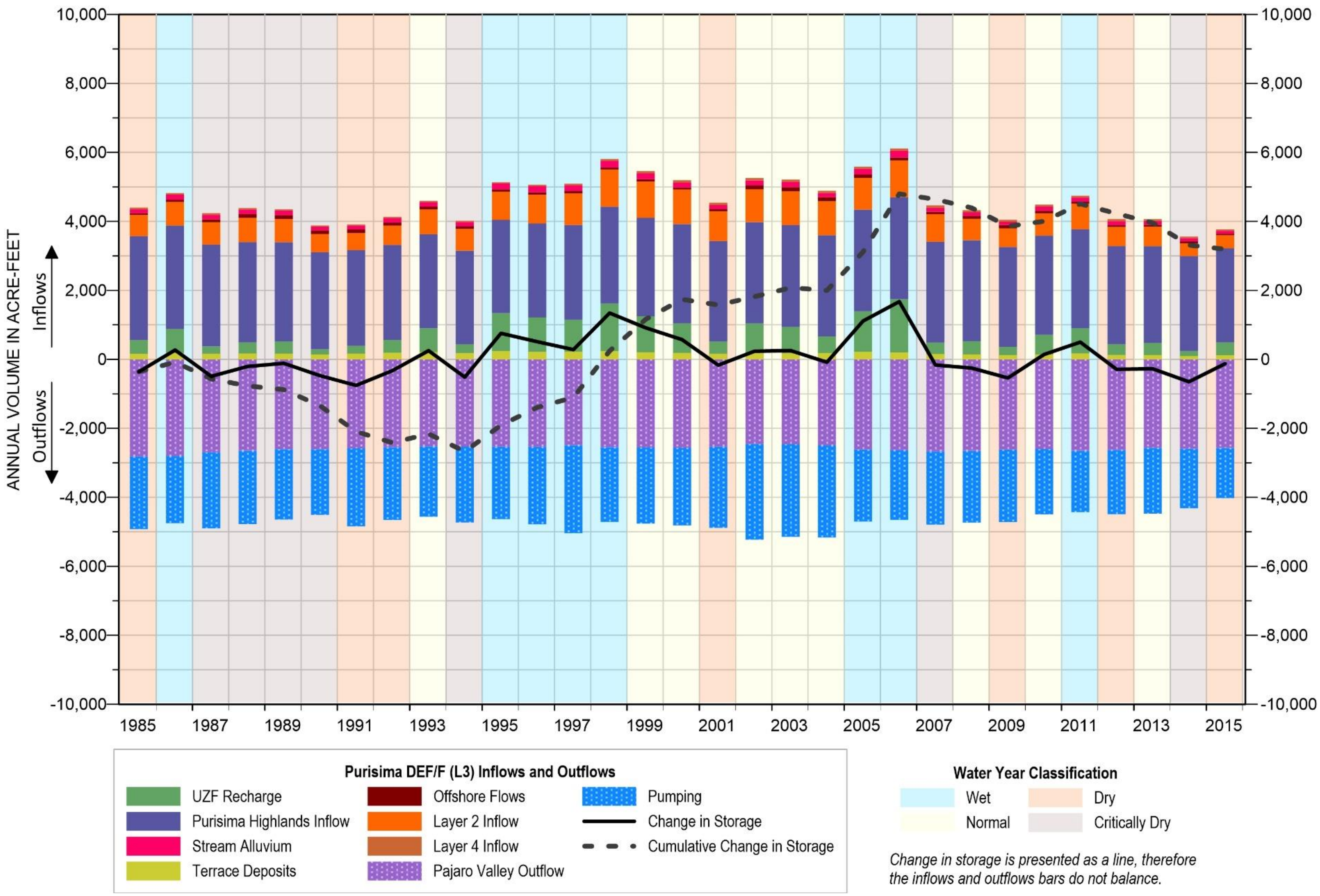


Figure C-2: Detailed Annual Water Budget for Layer 3 (Purisima F/DEF) in Mid-County Basin

MONTGOMERY & ASSOCIATES

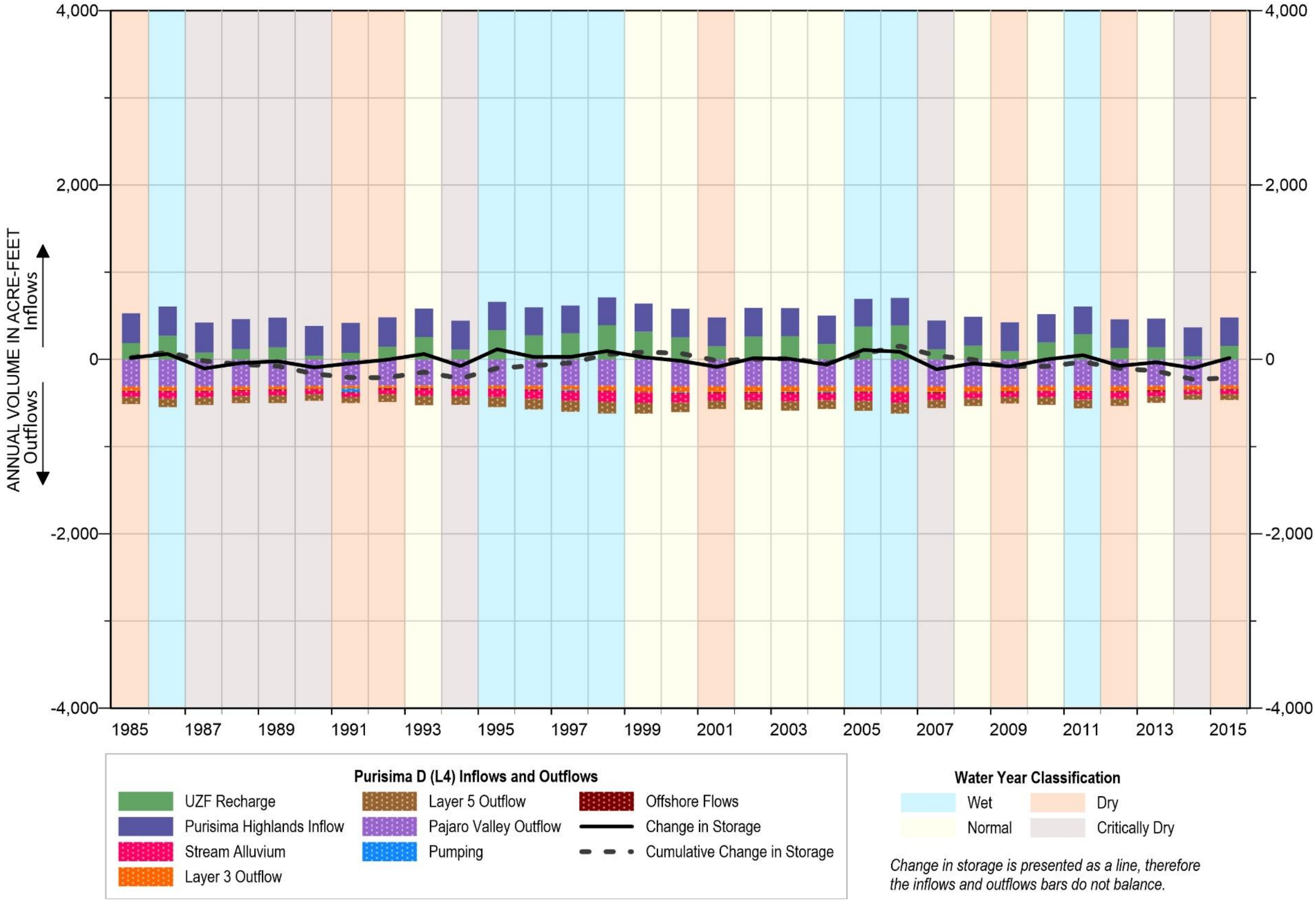


Figure C-3: Detailed Annual Water Budget for Layer 4 (Purisima D) in Mid-County Basin

MONTGOMERY & ASSOCIATES

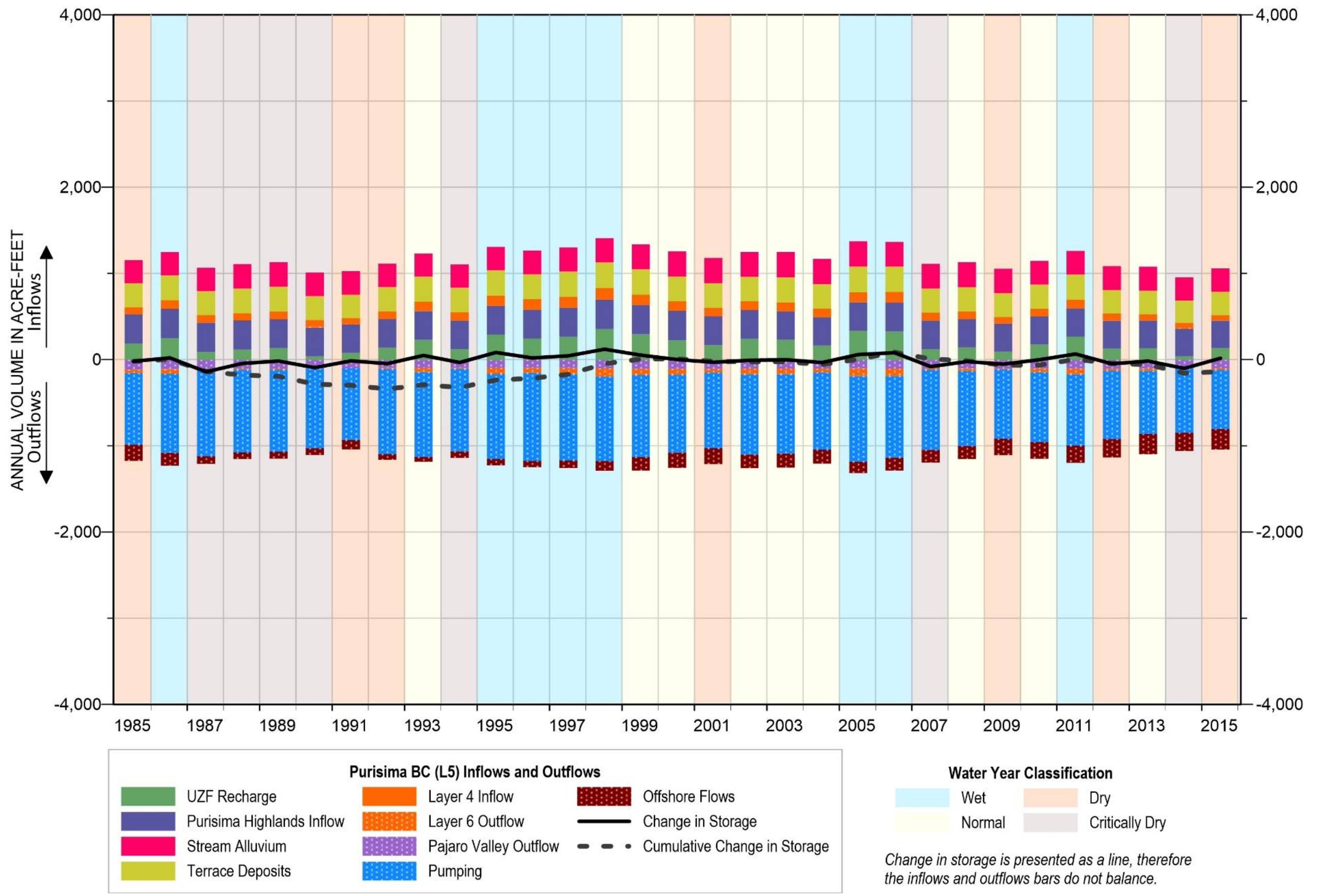


Figure C-4: Detailed Annual Water Budget for Layer 5 (Purisima BC) in Mid-County Basin

MONTGOMERY & ASSOCIATES

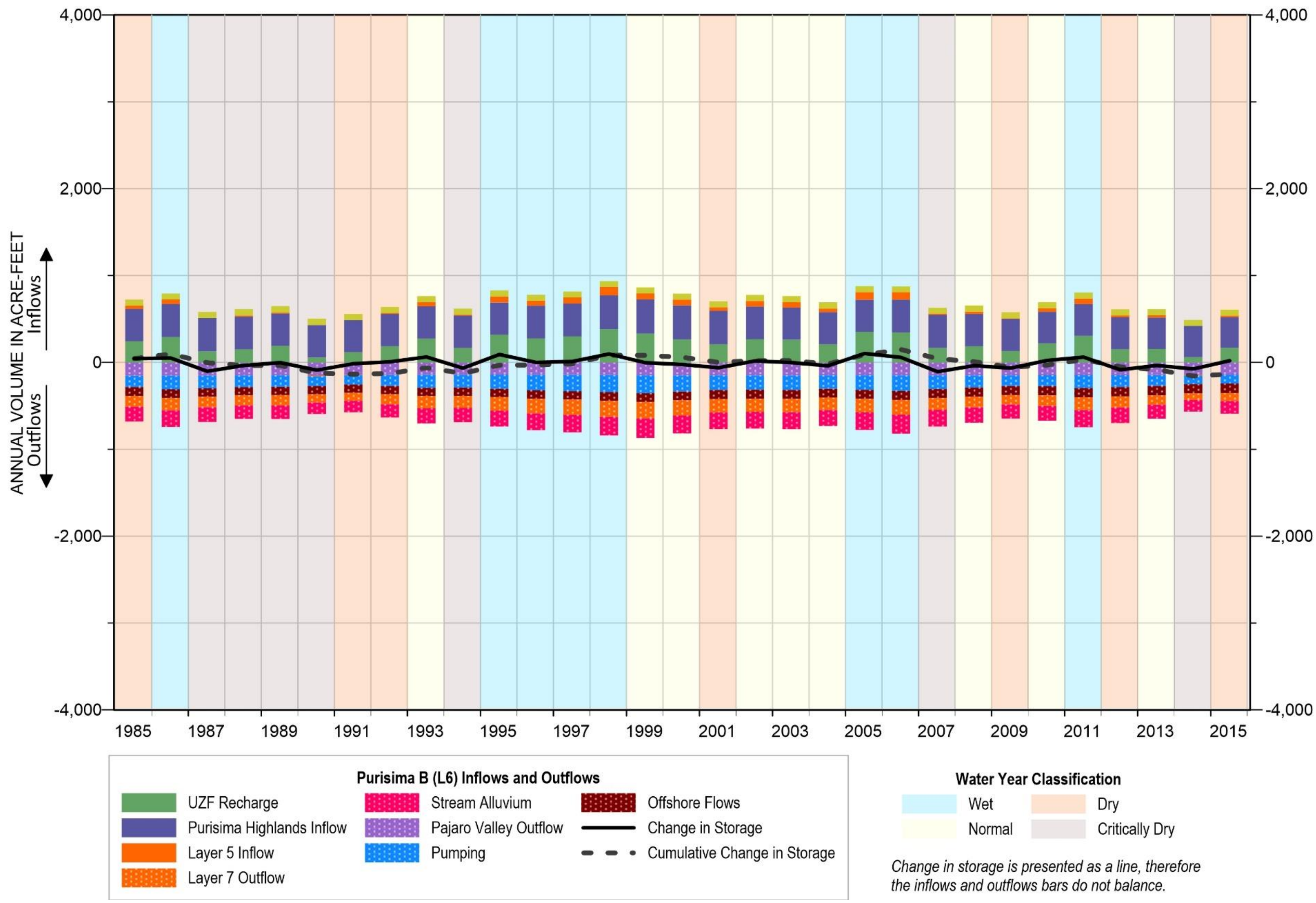


Figure C-5: Detailed Annual Water Budget for Layer 6 (Purisima B) in Mid-County Basin

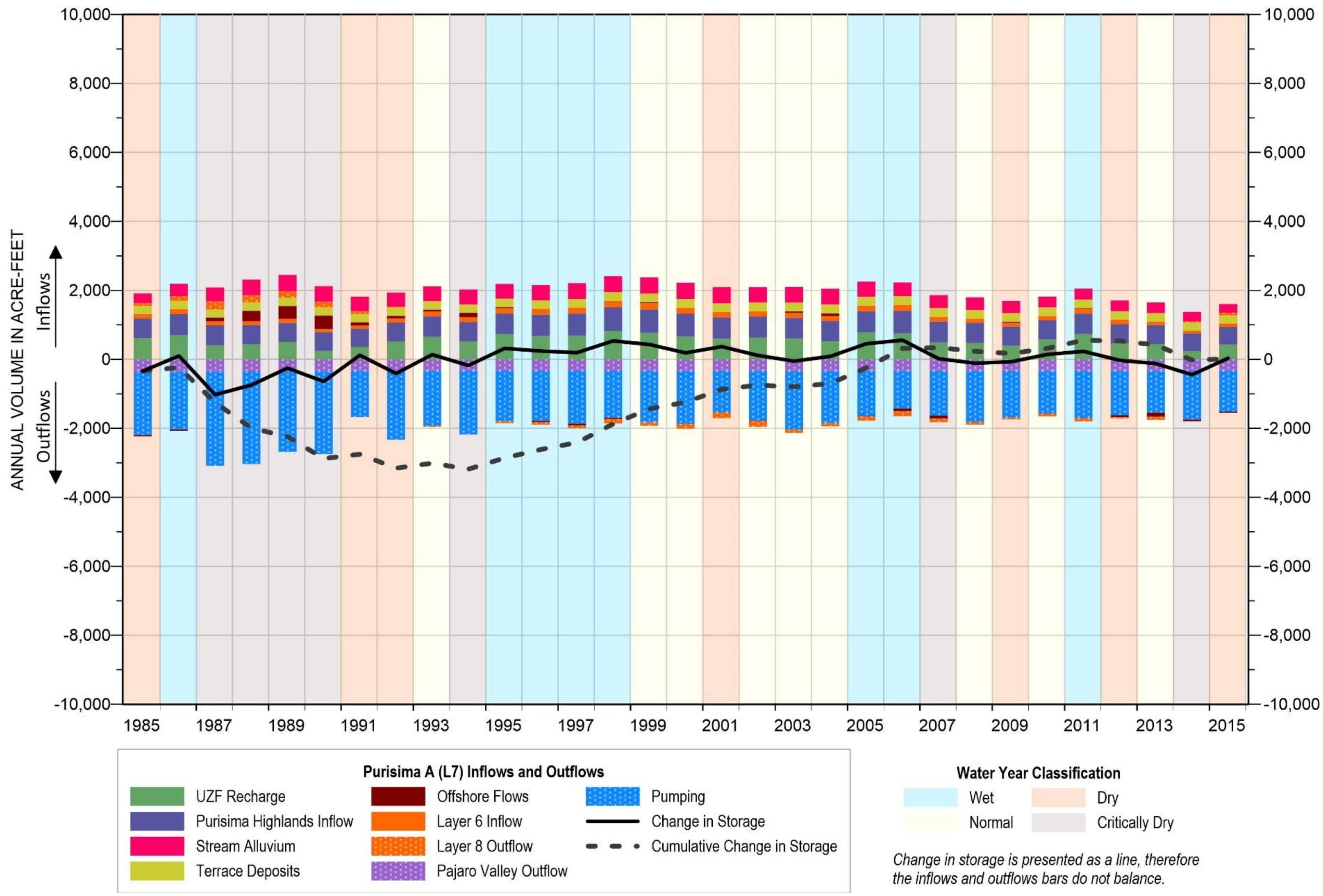


Figure C-6: Detailed Annual Water Budget for Layer 7 (Purisima A) in Mid-County Basin

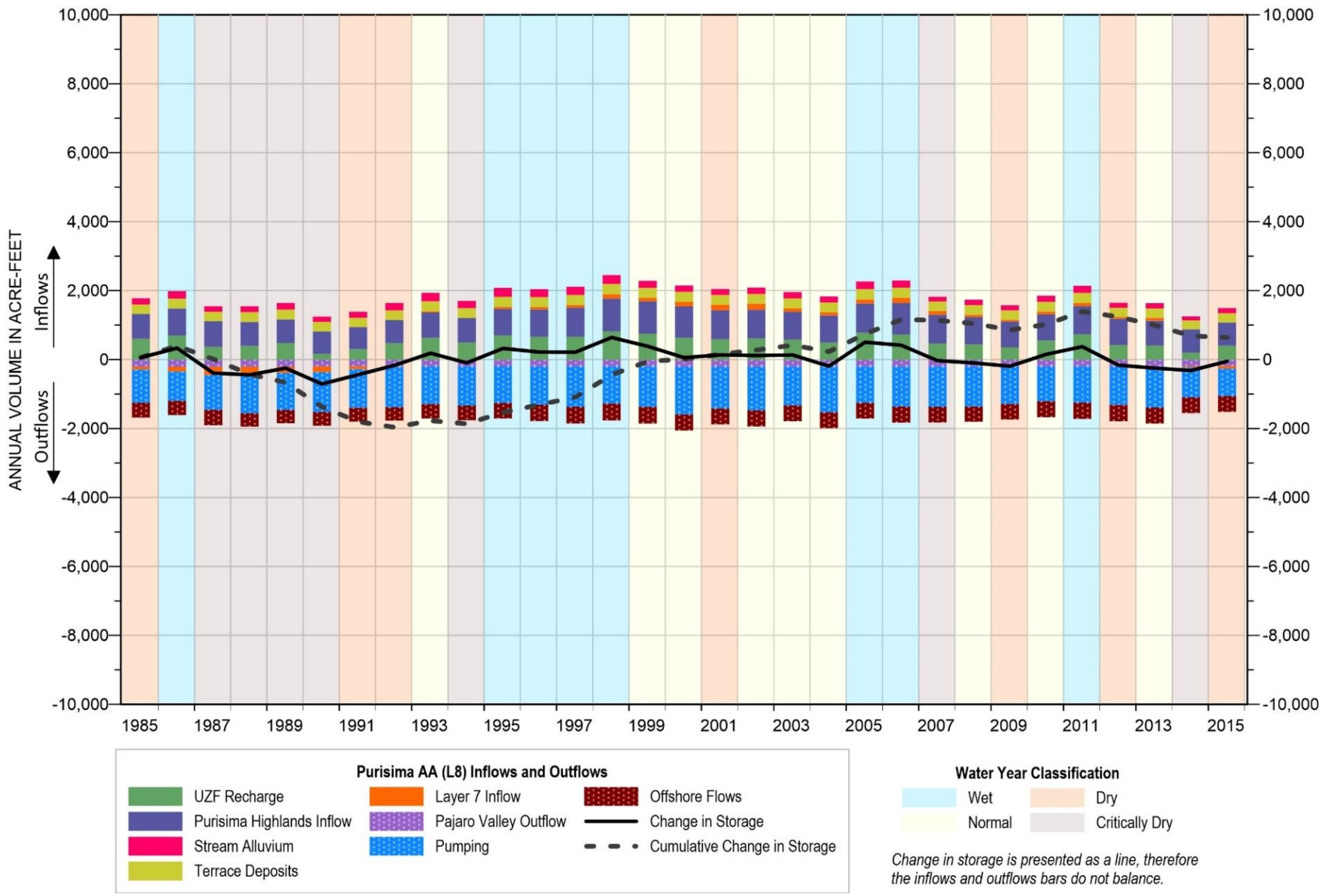


Figure C-7: Detailed Annual Water Budget for Layer 8 (Purisima AA) in Mid-County Basin

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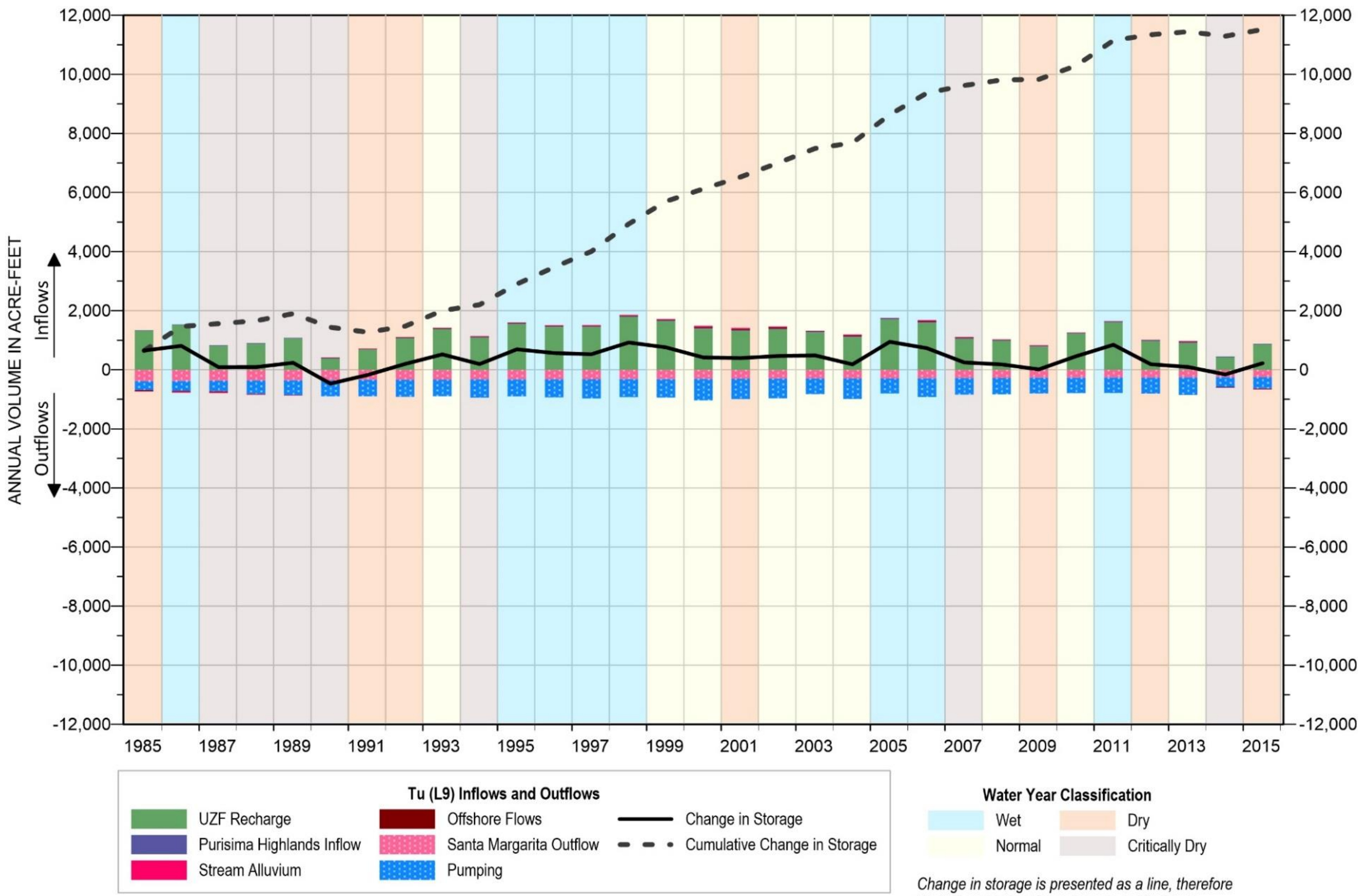

Change in storage is presented as a line, therefore the inflows and outflows bars do not balance.

Figure C-8: Detailed Annual Water Budget for Layer 9 (Tu) in Mid-County Basin

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APPENDIX 2-G

SANTA CRUZ MID-COUNTY GROUNDWATER FLOW MODEL: FUTURE CLIMATE FOR MODEL SIMULATIONS (TASK 5) MEMORANDUM

1814 Franklin St, Suite 501
Oakland, CA 94612

TECHNICAL MEMORANDUM

To: Mid-County Groundwater Agency Executive Staff

From: Georgina King and Cameron Tana

Date: August 17, 2017

Subject: Santa Cruz Mid-County Basin Groundwater Flow Model: Future Climate for Model Simulations (Task 5)

Contents

1.0 INTRODUCTION

This technical memorandum documents our approach for developing an initial future climate scenario to be implemented with simulations using the GSFLOW model of the Santa Cruz Mid-County Groundwater Basin currently under development, and presents two proposed climate scenarios. Climate data used in GSFLOW includes minimum and maximum temperature, and precipitation at the Santa Cruz Co-op and Watsonville Waterworks stations.

The objective of this subtask is to develop a reasonable climate scenario that adequately represents the warmer temperatures that are being predicted due to global climate change. At the August 24, 2016 TAC meeting, Prof. Andrew Fisher suggested using a catalog of historical annual climate instead of one of the multitude of General Circulation Models (GCM) available for future climate scenarios. The premise of this approach is that we use actual historical climate data representing the warmest years on record and not modeled climate data such as GCM. This approach is appropriate because to retain integrity of the climate data, the future climate scenario must have temperature data that corresponds to precipitation data, which is ensured by using historical data. A similar approach using historical data instead of using future climate predictions is used by Metropolitan Water District of Southern California to evaluate its region's future water supply reliability (MWD, 2016).

As discussed in our revised scope of work for fiscal year 2016-2017 approved by the MGA Board, downscaling one or more GCM scenarios to develop additional climate change scenarios has been re-prioritized for implementation in 2017. This is still recommended because the GCMs predict temperatures warmer than even the warmest years on record.

2.0 CLIMATE DATASETS

2.1 SANTA CRUZ CO-OP STATION

The Santa Cruz Co-op station has climate data available from January 1893 through present. Figure 1 shows the average annual temperature ranges and overall average for Water Years 1894 through 2016. It is visually evident that minimum temperatures have been higher since 1977. Maximum temperatures do not show the same trend, perhaps because of the moderating influence of the ocean. Expectedly, average annual temperatures also show an increase but of a lower magnitude than the minimum temperature increase due to more stable maximum temperatures. Water Years 2013 through 2016 have four of the five hottest average annual temperatures in the record. Table 1 illustrates that post-1977, average annual temperatures at the Santa Cruz Co-op station are 1.3° F warmer than before 1977. The 1985-2015 average for the model calibration period is also shown.

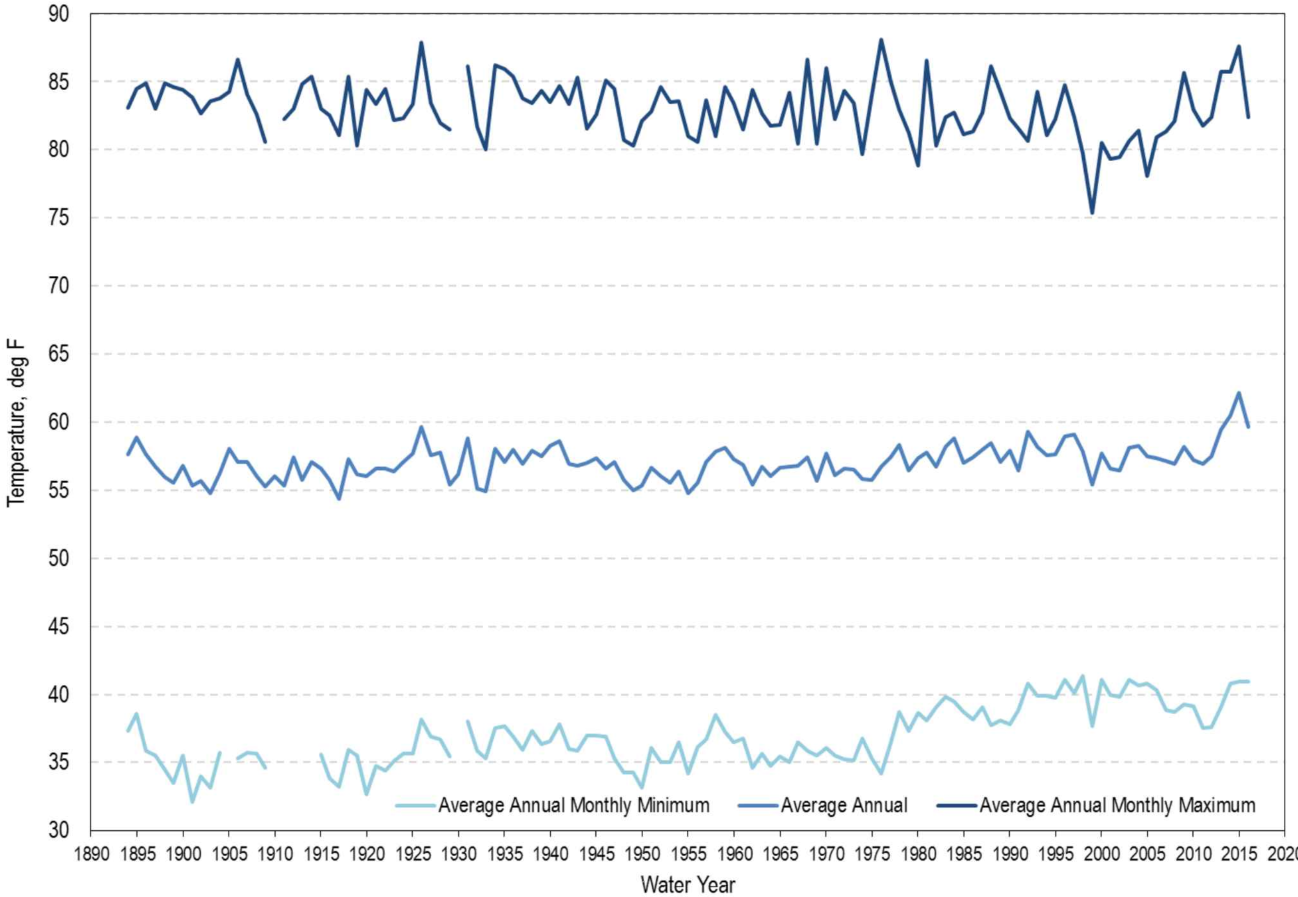


Figure 1: Measured Minimum, Maximum, and Average Annual Temperatures at the Santa Cruz Co-op Station

Table 1: Santa Cruz Co-op Station Average Annual Temperatures for Selected Periods

Annual Temperature, °F	
1985-2015 Average	57.9
1977-2016 Average	57.9
Pre-1977 Average	56.6
1894-2016 Average	57.0

Figure 2 presents the annual precipitation recorded at the Santa Cruz Co-op station. The average annual precipitation for various periods of interest are provided in Table 2. Although the chart on Figure 2 does not show any discernible trends, the averages in Table 2 indicate that pre-1977 precipitation was very slightly lower than that experienced from 1977 onwards. In general however, the data do not show a trend that is visually evident like temperature.

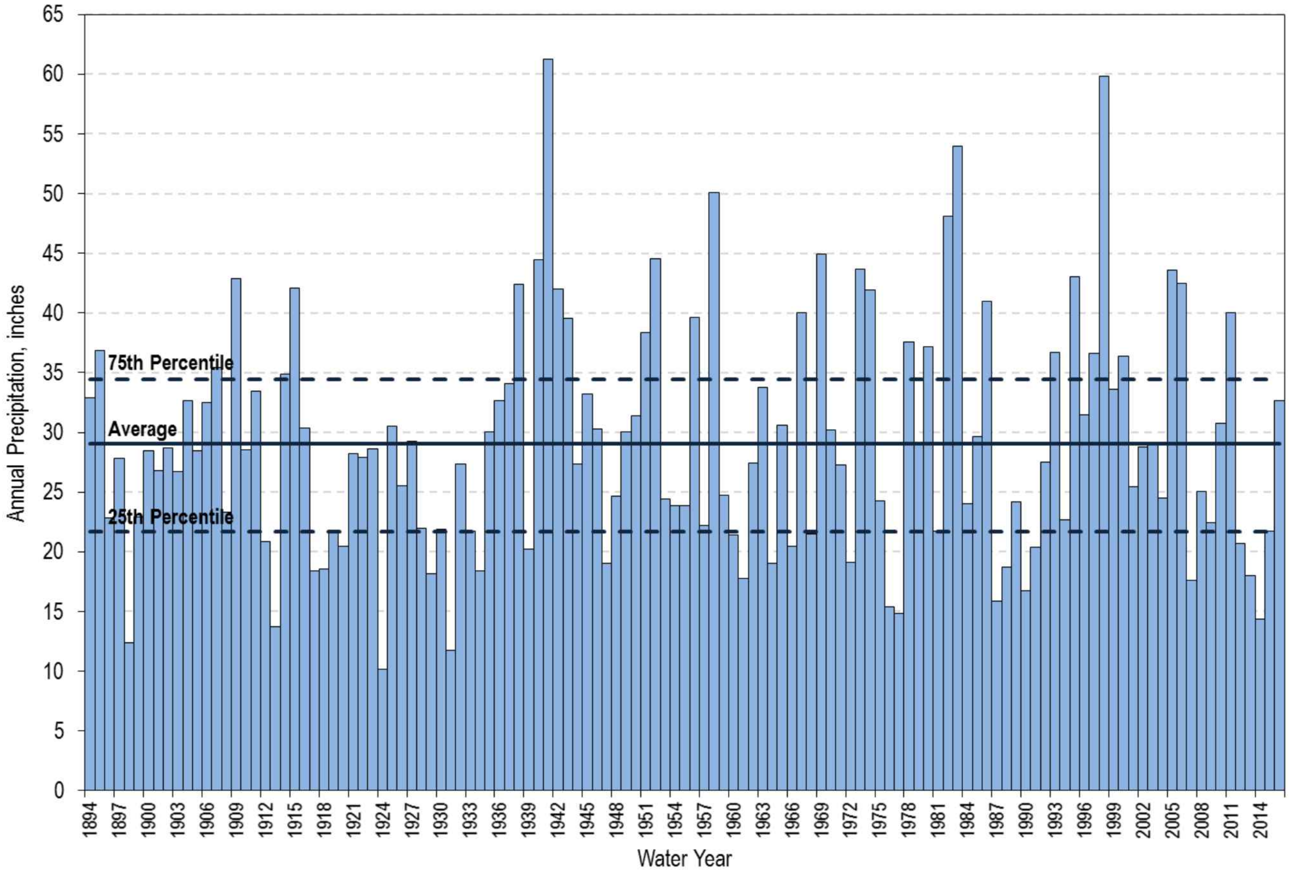


Figure 2: Annual Precipitation at the Santa Cruz Co-op Station

Table 2: Santa Cruz Co-op Station Average Precipitation for Selected Periods

Annual Precipitation, inches	
1985-2015 Average	29.0
1977-2016 Average	30.0
Pre-1977 Average	28.7
1894-2016 Average	29.1

2.2 WATSONVILLE WATERWORKS STATION

The Watsonville Waterworks station has climate data available from January 1908 through present. Figure 3 shows average annual temperature ranges and overall average for Water Years 1909 through 2016; note there were a number of missing records in the monthly data used to generate the annual averages; therefore those years are not included on the chart. The line showing minimum temperatures has a clear increasing trend over the period of record, with a slight jump in temperatures from 1977 onwards where minimum temperatures mostly remain consistently above pre-1977 temperatures. At this station, maximum temperatures also show an increasing trend like minimum temperatures but they are more muted. The Watsonville Waterworks station is 4.5 miles from the ocean compared to the Santa Cruz Co-op station which is two miles from the ocean, and has less effects from the ocean. Average annual temperatures also show a noticeable increase after 1977. Table 4 illustrates that post-1977, average annual temperatures at the Watsonville Waterworks station are 1.7 °F warmer than before 1977.

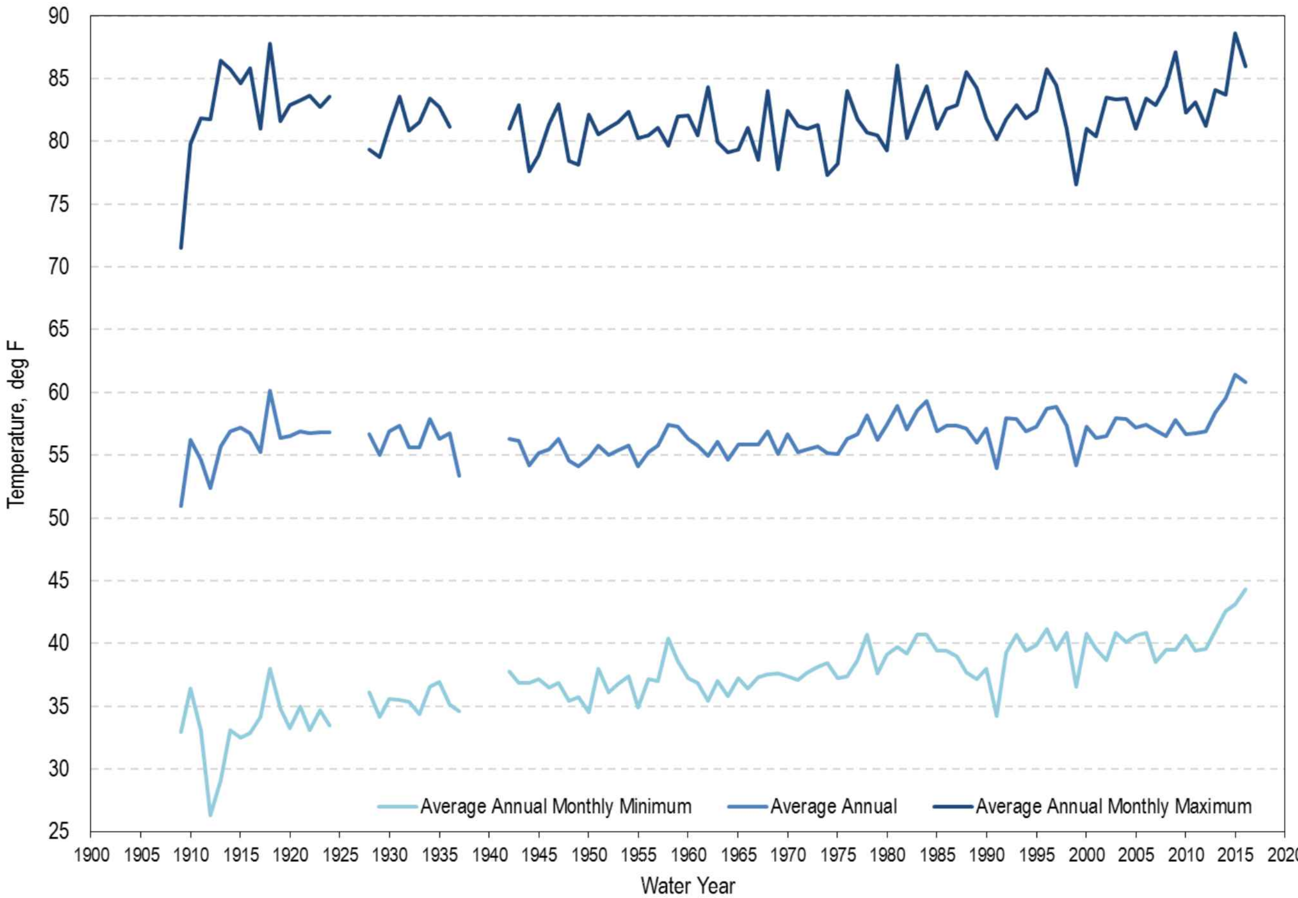


Figure 3: Measured Minimum, Maximum, and Average Annual Temperatures at the Watsonville Waterworks Station

Table 3: Watsonville Waterworks Station Average Annual Temperatures for Selected Periods

Annual Temperature, °F	
1985-2015 Average	57.3
1977-2016 Average	57.5
Pre-1977 Average	55.8
1894-2016 Average	56.5

Figure 4 presents the annual precipitation recorded at the Watsonville Waterworks station. The average annual precipitation for various periods of interest are provided in Table 4. The data suggest that since the 1980s, there has been an increase in the amount of precipitation at this station. This is confirmed in Table 4 where post-1977 precipitation is 2.8 inches more than before 1977.

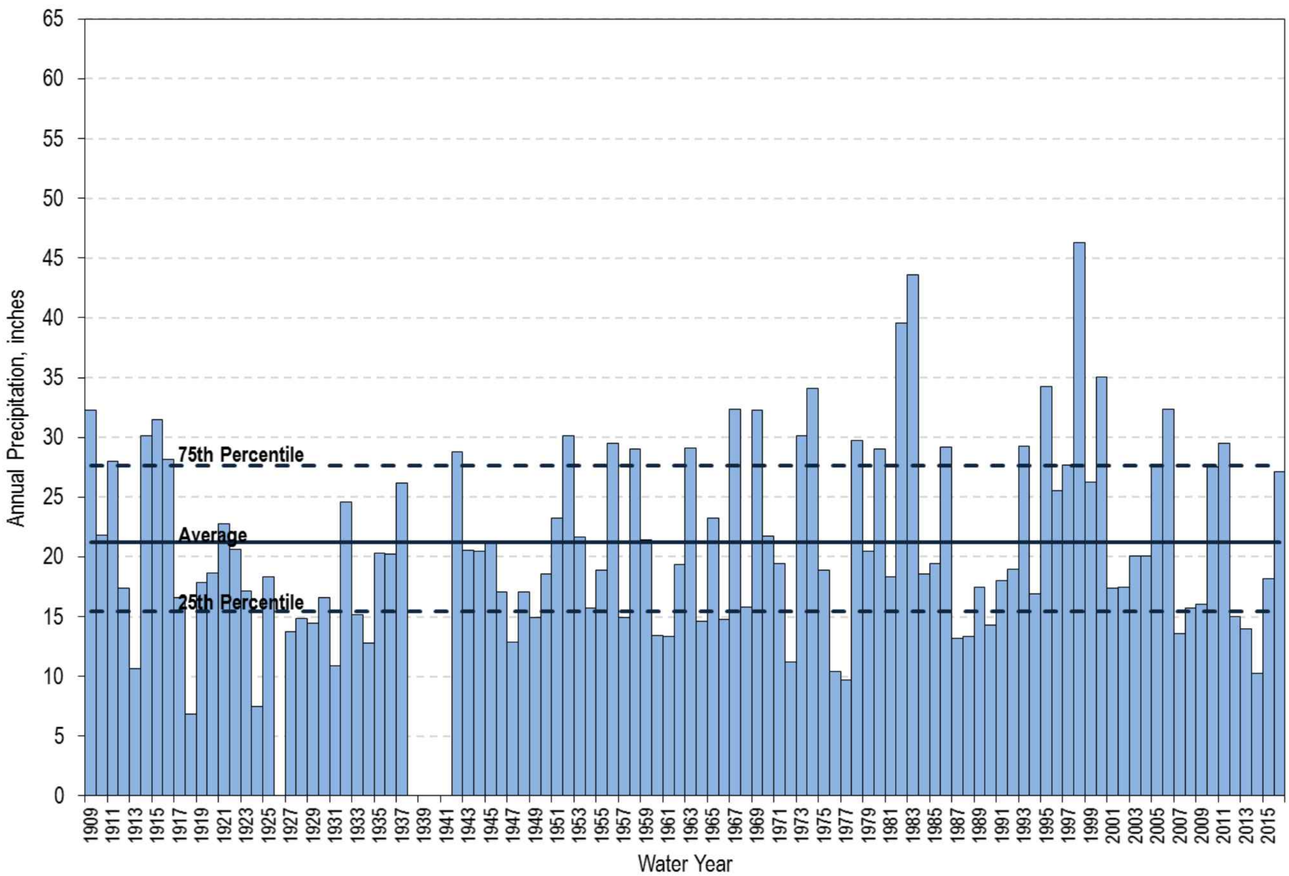


Figure 4: Annual Precipitation at the Watsonville Waterworks Station

Table 4: Watsonville Waterworks Station Average Precipitation for Selected Periods

Annual Precipitation, inches	
1985-2015 Average	21.9
1977-2015 Average	22.9
Pre-1977 Average	20.1
1909-2015 Average	21.2

3.0 APPROACH

3.1 CLIMATE CATALOG

Using the general method for creating a catalog of each historical year suggested by Prof. Andrew Fisher (Young, 2016), exceedance probabilities (p) for both temperature and precipitation are calculated using the following equation for the full dataset on record for the climate station:

$$p = \frac{m}{n+1}$$

where m is the rank based on total precipitation or temperature (from largest to smallest), and n is the total number of years in the dataset. A chart of exceedance probabilities for temperature and precipitation at the Santa Cruz Co-op station is provided on Figure 5. The catalog is based on the Santa Cruz Co-op station because the majority of model cells are assigned to it for rainfall distribution in PRMS, the watershed component of the GSFLOW model.

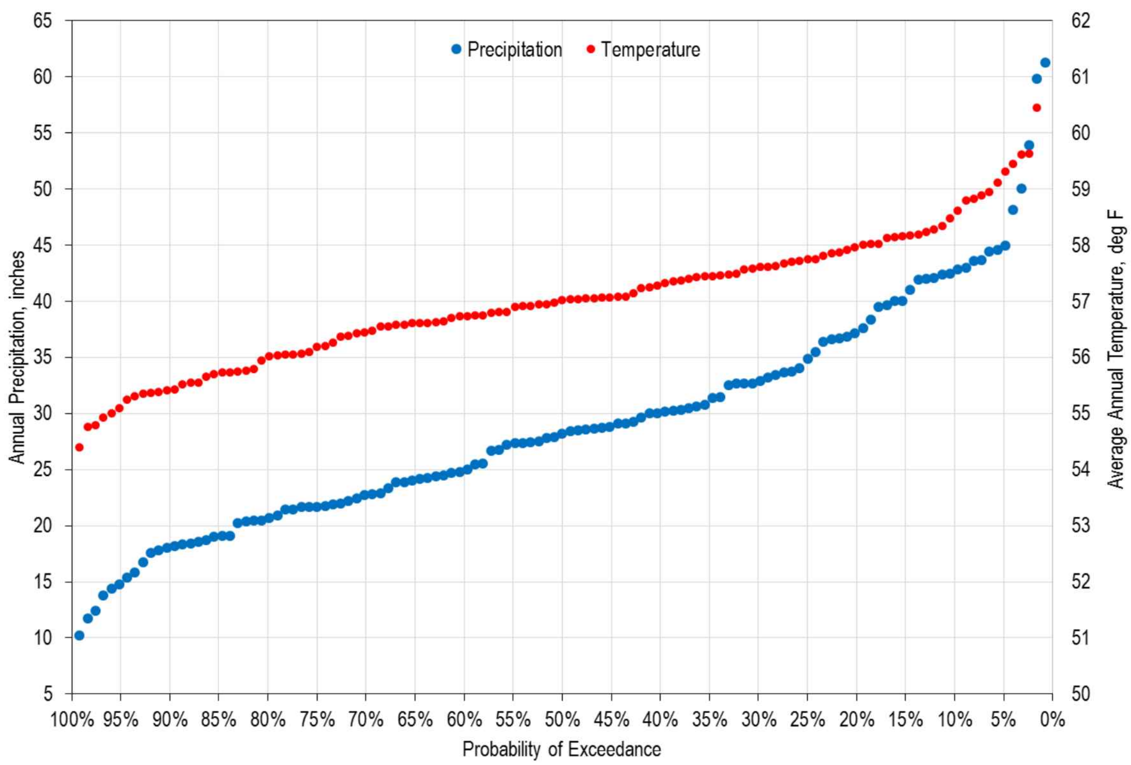


Figure 5: Probability of Exceedance for Annual Precipitation and Average Annual Temperature, Santa Cruz Co-op Station

Figure 6 and Figure 7 graphically show consecutive water years' probabilities of exceedance for temperature and precipitation at the Santa Cruz Co-op Station, respectively. Figure 6, similar to Figure 1, shows that since 1977, there has been an increased number of years that have less than a 50% probability of exceedance, i.e., warmer than the rest of the record. Figure 7 shows no visual trend towards either decreasing or increasing precipitation over time like temperature does.

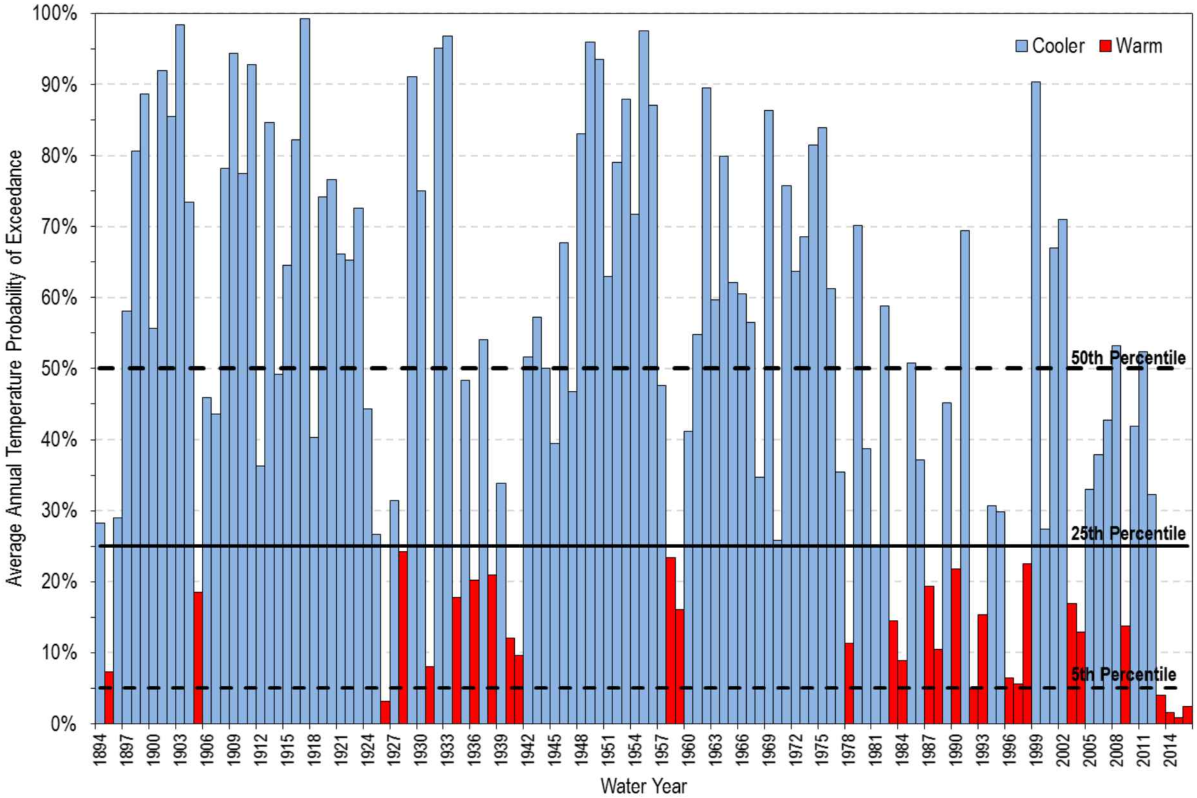


Figure 6: Average Annual Temperature Probability of Exceedance for the Santa Cruz Co-op Station

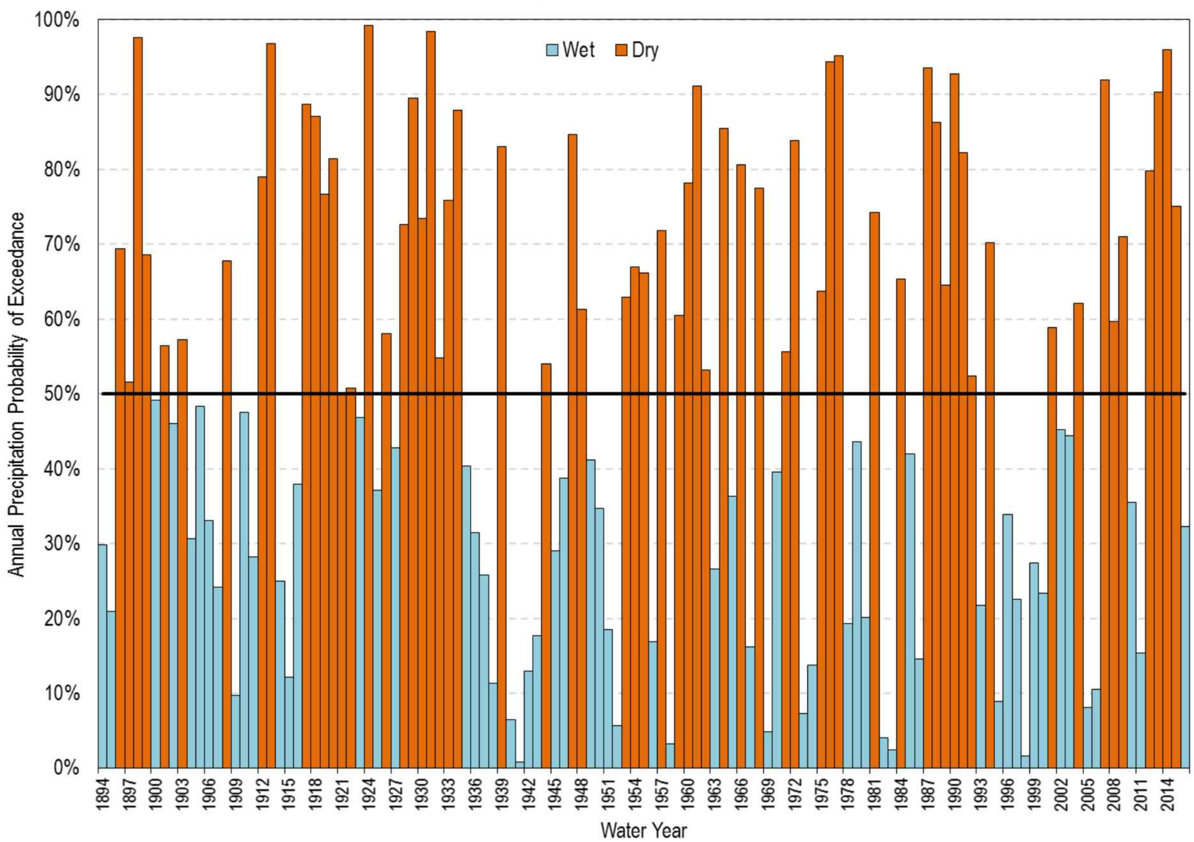


Figure 7: Annual Precipitation Probability of Exceedance for the Santa Cruz Co-op Station

Another way to visualize the climate data based on probabilities of exceedance is to classify each water year according to a combination of temperature and precipitation probabilities shown in Table 5. Appendix A provides the probabilities for all water years on record for the Santa Cruz Co-op Station, and Figure 8 presents the historical data color-coded by classification plotted against precipitation.

Table 5: Classification of Probabilities

Probability of Exceedance		Category
Precipitation	Average Temperature	
>= 50%	< 25%	Warm and Dry
< 50%	< 25%	Warm and Wet
< 50%	>= 25%	Cooler and Wet
>= 50%	>= 25%	Cooler and Dry

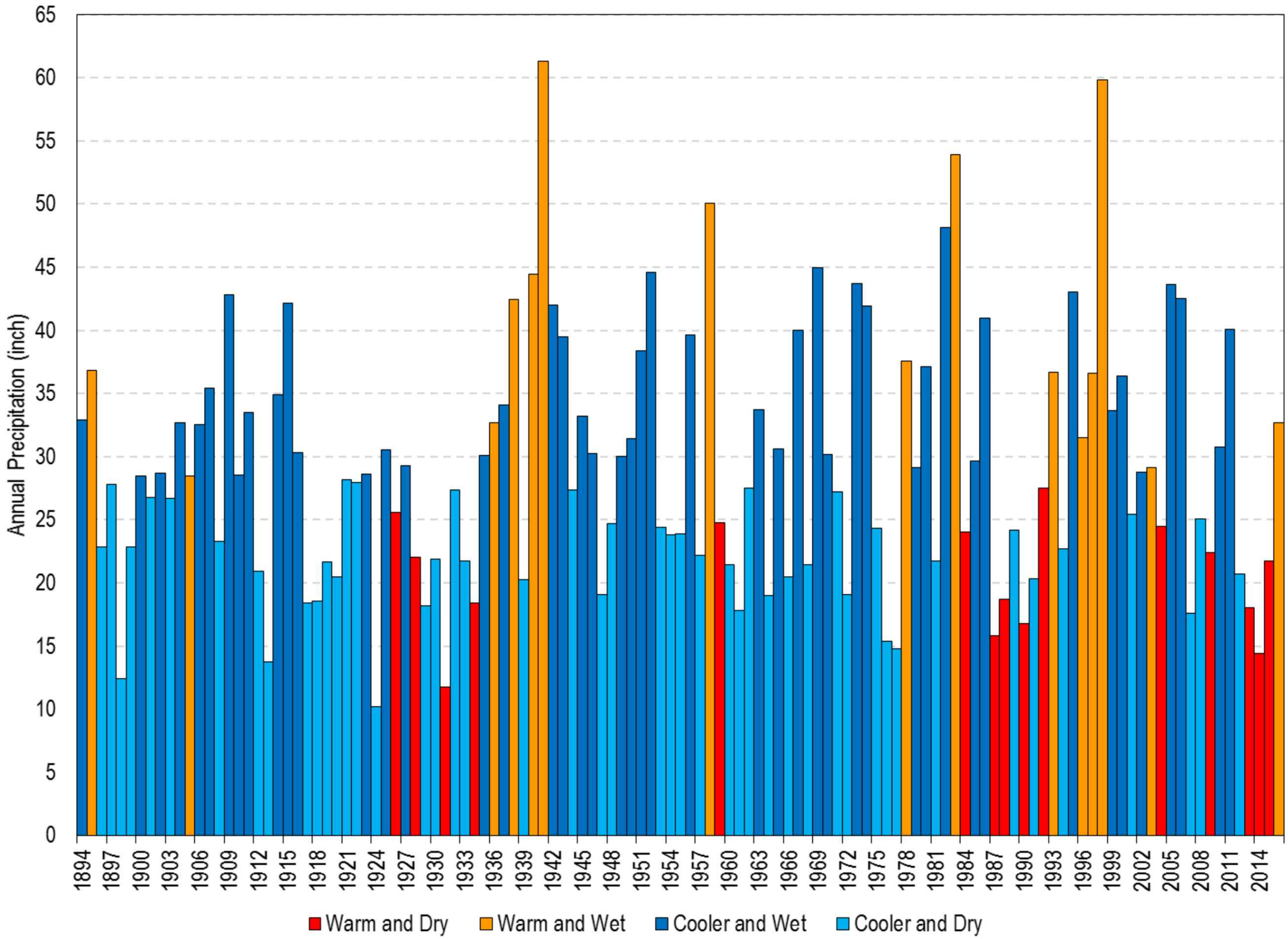


Figure 8: Santa Cruz Co-op Station Classification of Historical Water Years

3.2 FUTURE CLIMATE SCENARIO GENERATION

The future climate scenario will cover Water Years 2016-2069. This time span is selected to meet the requirement in California Department of Water Resources regulations for Groundwater Sustainability Plans (GSP) to evaluate sustainability for future climate over fifty years. Fifty years after the 2020 GSP deadline for the critically overdrafted Santa Cruz Mid-County Groundwater Basin goes through Water Year 2069. Water Year 2016 will be simulated based on recorded climate data using initial conditions from the end of the calibrated model run of Water Years 1985-2015. The 53 water years 2017-2069 will be simulated using the approach described below.

As temperature shows a much more evident trend than precipitation, the catalog of annual average temperature at the Santa Cruz Co-op station is used to generate one future climate scenario. First, a subset of historic climate is selected to form a catalog from which to generate the future climate scenario. The catalog of years selected are all the years from 1977 to 2016 representing the most recent period where warming has been observed, plus six additional years from 1909[1] to 1977 that have a temperature probability of exceedance of 25% or less, i.e., the warmest years and that don't have entire months of missing temperature data in the Watsonville Waterworks station record. See bold records in Appendix A for those years included in the catalog.

The catalog is then randomly ordered using the Random Number Generator in Excel to generate the scenario. The Random Number Generator uses weights applied to each water year to ensure a pre-determined distribution of temperature exceedance probabilities results from the process. Weights are assigned by categories of exceedance probabilities for temperature shown in Table 6. For example, the warmest category (<5% exceedance probability) is given a 50% weight and includes Water Years 1992, and 2013-2016. Warmer years are given greater weights than cooler years to ensure an overall warmer scenario is generated.

[1] Water Year 1909 was selected because this is the first water year for the Watsonville Waterworks station climate records. If we used prior years, there would be no climate data for the Watsonville Waterworks station for the future climate scenario for those years.

Table 6: Weights Assigned to Catalog of Water Years Based on Temperature Exceedance Probabilities

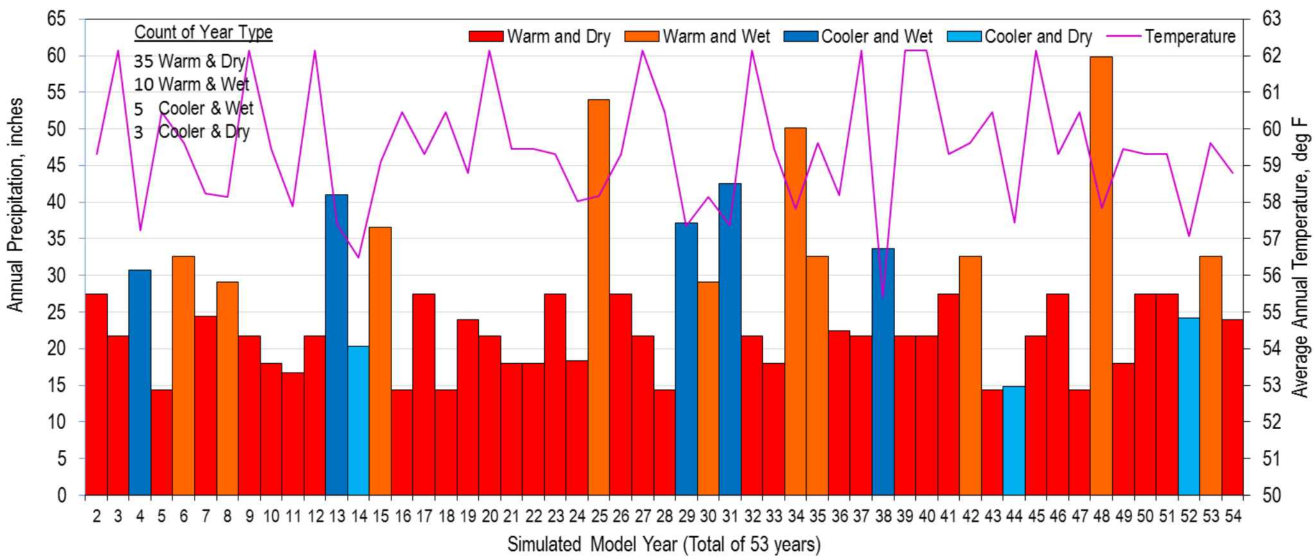
Exceedance Probability Category	Weight
< 5%	0.5
5 – 25%	0.3
>=25 – 50%	0.1
> = 50%	0.1

After the water year sequence is selected based on the Santa Cruz Co-op temperature data, climate data for the future climate scenario for the Watsonville Waterworks station is selected based on the same water year sequence. Climate data for both the Santa Cruz Co-op and Watsonville Waterworks stations are input into the GSFLOW model.

4.0 PROPOSED CLIMATE SCENARIOS

4.1 TEMPERATURE WEIGHTED

The first scenario is generated using the temperature weights shown in Table 6 and the Random Number Generator to arrive at a sequence of 53 water years with an average temperature that is as high as we could get without manually selecting the warmest years. Figure 9 shows the color-coded distribution of water years for the Santa Cruz Co-op station representing a potential future climate scenario that is on average 2.4 °F warmer than the long-term average and 1.6 °F warmer than the average annual temperature from 1977-2016. The scenario also has 3.1 inches less precipitation per year than the long-term historical average as 4 of the 5 hottest years used for 50% of the scenario are dry years. Appendix B provides a list of the randomly selected historic years generated for this scenario.

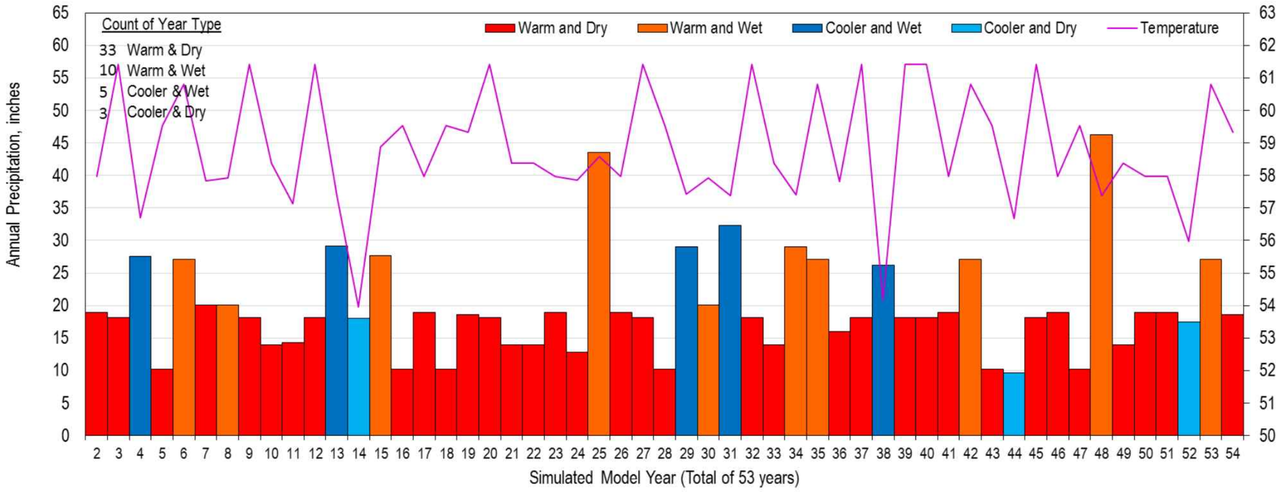


Annual Temperature, deg F	
Scenario Average	59.4
1985-2015 Average	57.9
1977-2016 Average	57.8
Pre-1977 Average	56.6
1894-2016 Average	57.0

Annual Precipitation, inches	
Scenario Average	26.0
1985-2015 Average	29.0
1977-2016 Average	29.9
Pre-1977 Average	28.7
1894-2016 Average	29.1

Figure 9: Temperature Weighted Climate Scenario for Santa Cruz Co-op Station

Using the same sequence of 53 water years used for the Santa Cruz Co-op station temperature weighted climate scenario. Figure 10 shows a potential future climate scenario for the Watsonville Waterworks station that is on average 2.4 °F warmer than the long-term average and 1.4°F warmer than the average annual temperature from 1977-2016. The scenario also has 1.3 inches less precipitation per year than the long-term historical average.



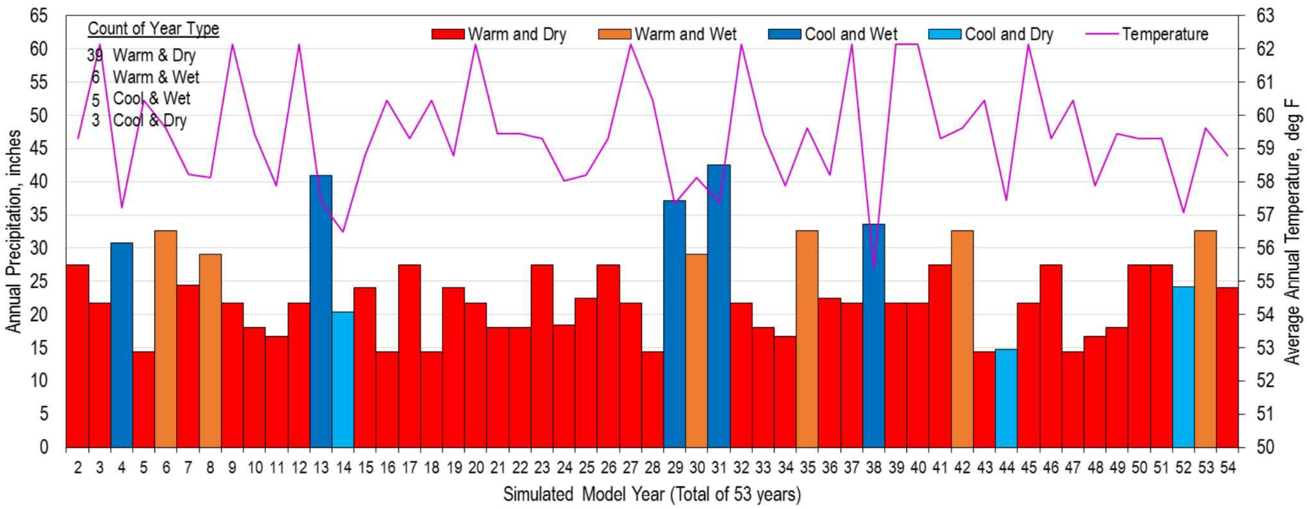
Annual Temperature, deg F	
Scenario Average	58.8
1985-2015 Average	57.3
1977-2016 Average	57.4
Pre-1977 Average	55.8
1894-2016 Average	56.4

Annual Precipitation, inches	
Scenario Average	19.8
1985-2015 Average	21.9
1977-2016 Average	22.8
Pre-1977 Average	20.1
1894-2016 Average	21.1

Figure 10: Temperature Weighted Climate Scenario for Watsonville Waterworks Station

4.2 TEMPERATURE WEIGHTED AND PRECIPITATION ADJUSTED

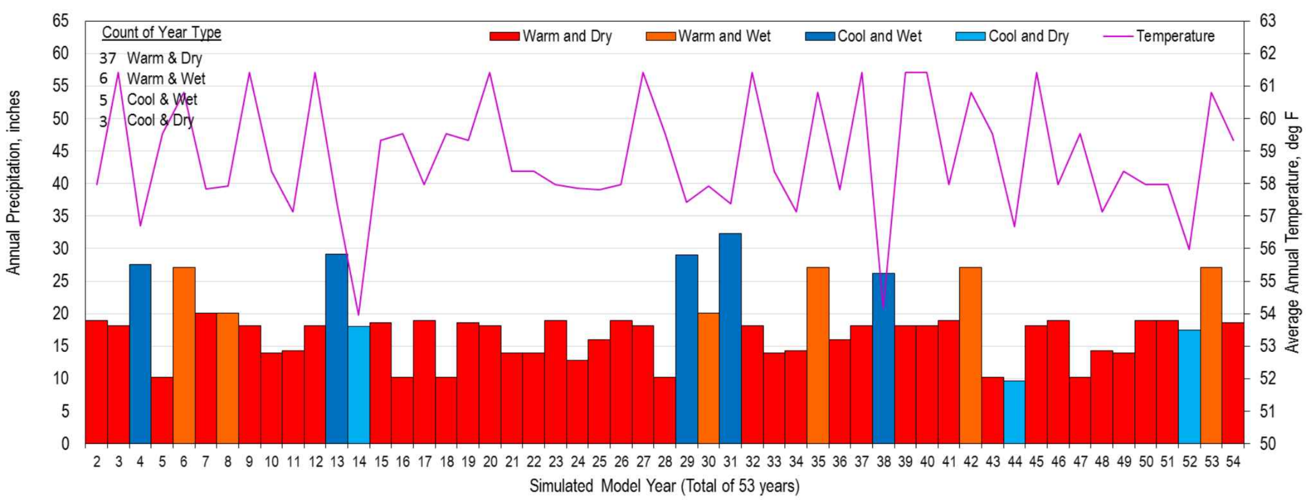
Although there is no trend of decreased precipitation in the Santa Cruz area, a drier scenario than that generated by weighting temperature only is also generated for consideration. We avoided randomly generating a new dataset based on both temperature and precipitation weights as we want a scenario that we can compare with the temperature weighted climate scenario. To arrive at this scenario, we start with the temperature weighted scenario and then adjust the four wettest "Warm and Wet" years to "Warm and Dry" by substituting the "Warm and Wet" years with "Warm and Dry" years with similar temperatures but less precipitation. Figure 11 shows the color-coded distribution of water years for the Santa Cruz Co-op station representing a potential future climate scenario that has the same average temperature as the temperature weighted scenario but has 5.4 inches less precipitation per year than the long-term average. Appendix B provides a list of the randomly selected historic years generated for this scenario. Figure 12 shows this potential future climate scenario applied to the Watsonville Waterworks station that results in the same average temperature as the temperature weighted scenario but has 2.9 inches less precipitation per year than the long-term average.



Annual Temperature, deg F	
Scenario Average	59.4
1985-2015 Average	57.9
1977-2016 Average	57.8
Pre-1977 Average	56.6
1894-2016 Average	57.0

Annual Precipitation, inches	
Scenario Average	23.7
1985-2015 Average	29.0
1977-2016 Average	29.9
Pre-1977 Average	28.7
1894-2016 Average	29.1

Figure 11: Temperature Weighted Climate Scenario for Santa Cruz Co-op Station with Decreased Precipitation Adjustment



Annual Temperature, deg F	
Scenario Average	58.8
1985-2015 Average	57.3
1977-2016 Average	57.4
Pre-1977 Average	55.8
1894-2016 Average	56.4

Annual Precipitation, inches	
Scenario Average	18.2
1985-2015 Average	21.9
1977-2016 Average	22.8
Pre-1977 Average	20.1
1894-2016 Average	21.1

Figure 12: Temperature Weighted Climate Scenario for Watsonville Waterworks with Decreased Precipitation Adjustment

5.0 Discussion and Limitations

One of the two scenarios presented in this memo will be selected to run simulations using the GSFLOW model. The selection will be made based on input from MGA member agency staff, the model Technical Advisory Committee, and possibly the MGA Board.

This approach of using historical climate allows us to generate climate scenarios that are warmer than the past 40 years but it does not increase temperatures to the degree that some of the GCMs predict global warming. For example, GCMs (Flint and Flint, 2014) have been downscaled to the San Lorenzo-Soquel Basin, which includes the Santa Cruz Mid-County Groundwater Basin. The downscaled predictions include warming of up to 4.1 °F (GFDL A2, a moderately warmer, drier future) and 6.2°F (MIROC-esm RCP 8.5, the warmest, driest future) over our simulated model period (54 years from Water Year 2016 – 2069). It is important to note that these GCM predicted temperatures are for minimum temperatures which, as shown above, tend to have a greater increase than average temperatures. We used average temperature in our analysis. Additionally, the GCM downscaled predictions are for the entire San Lorenzo-Soquel Basin which extends much farther inland than the Santa Cruz Co-op and Watsonville Waterworks stations.

Assigning lower weights to the "Cooler and dry" and "Cooler and wet" classifications will raise the scenario's average temperature slightly but still not as high as those in the GCMs described above because the hottest years in the historical record are not as hot as what is projected by the GCMs.

Simulating GCM projections will require downscaling GCM results to the Santa Cruz Co-op and Watsonville Waterworks stations for distribution to the model grid by the PRMS watershed component of GSFLOW. The USGS has recommended that the Jensen-Haise formulation for potential evapotranspiration used in the model be changed to Priestly-Taylor or Penman-Monteith when using hotter GCM projections. The Priestly-Taylor and Penman-Monteith evapotranspiration formulations have only recently been added to PRMS so will take additional work to implement with the likelihood of issues implementing new capabilities. Therefore, we will use one of the scenarios described in this memo to represent future climate to perform the initial evaluation of groundwater management alternatives. Implementation of downscaled GCM projections has been re-prioritized to 2017.

This approach also does not project trends for temporal precipitation patterns as previously evaluated by Daniels (2014)[2]. Daniels identified long-term trends in storm intensity, duration, and pauses between storms and assessed effects on groundwater recharge and streamflow of those trends projected into the future. Since those projections are not part of the historical record, they are not part of the climate scenario described in this memo. However, 83% of historical years randomly selected for the future climate scenario in this memo are from 1990-2016, so the historical trends for these patterns are reflected in the scenario.

[2] Dr. Bruce Daniels is Board President of Soquel Creek Water District, a member of the Santa Cruz Mid-County Agency that is funding development of this GSFLOW model. Dr. Daniels also serves on the Technical Advisory Committee for this model.

6.0 REFERENCES

Daniels, B.K. 2014. *Hydrologic response to climate change in California: observational and modeling studies.* Ph.D. dissertation, University of California, Santa Cruz. December.

Flint L.E. and A.L. Flint. 2014. *California basin characterization model: a dataset of historical and future hydrologic response to climate change*, U.S. Geological Survey Data Release, doi:10.5066/F76T0JPB

Metropolitan Water District of Southern California (MWD). 2016. *Integrated Water Resources Plan, 2015 Update*. Report No. 1518. January.

Young, K. 2016. *A high-resolution, regional-scale analysis of stormwater runoff in the San Lorenzo river basin for managed aquifer recharge decision making*. Masters of Science Thesis, University of California, Santa Cruz. June.

Appendix A

Santa Cruz Co-op Station Exceedance Probabilities with Year Type Classification

Water Year	Temperature			Precipitation			Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
	Average (°F)	Rank	Probability of Exceedance	Total (inches)	Rank	Probability of Exceedance	
1894	57.6	35	28.2%	32.9	37	29.8%	3
1895	58.9	9	7.3%	36.8	26	21.0%	2
1896	57.6	36	29.0%	22.9	86	69.4%	4
1897	56.8	72	58.1%	27.8	64	51.6%	4
1898	55.9	100	80.6%	12.4	121	97.6%	4
1899	55.5	110	88.7%	22.9	85	68.5%	4
1900	56.8	69	55.6%	28.4	61	49.2%	3
1901	55.4	114	91.9%	26.8	70	56.5%	4
1902	55.7	106	85.5%	28.7	57	46.0%	3
1903	54.8	122	98.4%	26.7	71	57.3%	4
1904	56.3	91	73.4%	32.7	38	30.6%	3
1905	58.0	23	18.5%	28.5	60	48.4%	2
1906	57.1	57	46.0%	32.5	41	33.1%	3
1907	57.1	54	43.5%	35.5	30	24.2%	3
1908	56.0	97	78.2%	23.3	84	67.7%	4
1909	55.2	117	94.4%	42.9	12	9.7%	3
1910	56.1	96	77.4%	28.6	59	47.6%	3
1911	55.3	115	92.7%	33.5	35	28.2%	3
1912	57.4	45	36.3%	20.9	98	79.0%	4
1913	55.7	105	84.7%	13.8	120	96.8%	4
1914	57.0	61	49.2%	34.9	31	25.0%	3
1915	56.6	80	64.5%	42.1	15	12.1%	3
1916	55.8	102	82.3%	30.4	47	37.9%	3
1917	54.4	123	99.2%	18.4	110	88.7%	4
1918	57.3	50	40.3%	18.6	108	87.1%	4
1919	56.2	92	74.2%	21.7	95	76.6%	4
1920	56.1	95	76.6%	20.5	101	81.5%	4
1921	56.6	82	66.1%	28.2	62	50.0%	4
1922	56.6	81	65.3%	27.9	63	50.8%	4
1923	56.4	90	72.6%	28.6	58	46.8%	3
1924	57.1	55	44.4%	10.2	123	99.2%	4
1925	57.7	33	26.6%	30.5	46	37.1%	3
1926	59.6	4	3.2%	25.6	72	58.1%	1
1927	57.6	39	31.5%	29.3	53	42.7%	3

	Temperature			Precipitation			Classification
Water Year	**Average (°F)**	**Rank**	**Probability of Exceedance**	**Total (inches)**	**Rank**	**Probability of Exceedance**	1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
1928	**57.8**	**30**	**24.2%**	**22.0**	**90**	**72.6%**	1
1929	55.4	113	91.1%	18.2	111	89.5%	4
1930	56.2	93	75.0%	21.9	91	73.4%	4
1931	**58.8**	**10**	**8.1%**	**11.7**	**122**	**98.4%**	1
1932	55.1	118	95.2%	27.4	68	54.8%	4
1933	54.9	120	96.8%	21.7	94	75.8%	4
1934	**58.0**	**22**	**17.7%**	**18.4**	**109**	**87.9%**	1
1935	57.0	60	48.4%	30.1	50	40.3%	3
1936	**58.0**	**25**	**20.2%**	**32.7**	**39**	**31.5%**	2
1937	56.9	67	54.0%	34.1	32	25.8%	3
1938	57.9	26	21.0%	42.4	14	11.3%	2
1939	57.5	42	33.9%	20.2	103	83.1%	4
1940	58.3	15	12.1%	44.5	8	6.5%	2
1941	58.6	12	9.7%	61.3	1	0.8%	2
1942	57.0	64	51.6%	42.0	16	12.9%	3
1943	56.8	71	57.3%	39.5	22	17.7%	3
1944	57.0	62	50.0%	27.4	67	54.0%	4
1945	57.3	49	39.5%	33.2	36	29.0%	3
1946	56.6	84	67.7%	30.3	48	38.7%	3
1947	57.1	58	46.8%	19.1	105	84.7%	4
1948	55.7	103	83.1%	24.7	76	61.3%	4
1949	55.0	119	96.0%	30.0	51	41.1%	3
1950	55.3	116	93.5%	31.4	43	34.7%	3
1951	56.6	78	62.9%	38.4	23	18.5%	3
1952	56.0	98	79.0%	44.6	7	5.6%	3
1953	55.6	109	87.9%	24.4	78	62.9%	4
1954	56.4	89	71.8%	23.8	83	66.9%	4
1955	54.8	121	97.6%	23.9	82	66.1%	4
1956	55.6	108	87.1%	39.7	21	16.9%	3
1957	57.0	59	47.6%	22.2	89	71.8%	4
1958	**57.8**	**29**	**23.4%**	**50.1**	**4**	**3.2%**	2
1959	**58.1**	**20**	**16.1%**	**24.8**	**75**	**60.5%**	1
1960	57.3	51	41.1%	21.4	97	78.2%	4
1961	56.9	68	54.8%	17.8	113	91.1%	4
1962	55.4	111	89.5%	27.5	66	53.2%	4
1963	56.7	74	59.7%	33.7	33	26.6%	3
1964	56.0	99	79.8%	19.0	106	85.5%	4
1965	56.6	77	62.1%	30.6	45	36.3%	3
1966	56.7	75	60.5%	20.5	100	80.6%	4
1967	56.8	70	56.5%	40.0	20	16.1%	3

	Temperature			Precipitation			Classification
Water Year	Average (°F)	Rank	Probability of Exceedance	Total (inches)	Rank	Probability of Exceedance	1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
1968	57.4	43	34.7%	21.5	96	77.4%	4
1969	55.7	107	86.3%	44.9	6	4.8%	3
1970	57.7	32	25.8%	30.2	49	39.5%	3
1971	56.1	94	75.8%	27.2	69	55.6%	4
1972	56.6	79	63.7%	19.1	104	83.9%	4
1973	56.5	85	68.5%	43.7	9	7.3%	3
1974	55.8	101	81.5%	42.0	17	13.7%	3
1975	55.7	104	83.9%	24.3	79	63.7%	4
1976	56.7	76	61.3%	15.4	117	94.4%	4
1977	**57.4**	**44**	**35.5%**	**14.8**	**118**	**95.2%**	**4**
1978	**58.3**	**14**	**11.3%**	**37.6**	**24**	**19.4%**	**2**
1979	**56.5**	**87**	**70.2%**	**29.2**	**54**	**43.5%**	**3**
1980	**57.4**	**48**	**38.7%**	**37.1**	**25**	**20.2%**	**3**
1981	**57.7**	**31**	**25.0%**	**21.7**	**92**	**74.2%**	**4**
1982	**56.7**	**73**	**58.9%**	**48.1**	**5**	**4.0%**	**3**
1983	**58.2**	**18**	**14.5%**	**53.9**	**3**	**2.4%**	**2**
1984	**58.8**	**11**	**8.9%**	**24.0**	**81**	**65.3%**	**1**
1985	**57.0**	**63**	**50.8%**	**29.7**	**52**	**41.9%**	**3**
1986	**57.4**	**46**	**37.1%**	**41.0**	**18**	**14.5%**	**3**
1987	**58.0**	**24**	**19.4%**	**15.9**	**116**	**93.5%**	**1**
1988	**58.5**	**13**	**10.5%**	**18.7**	**107**	**86.3%**	**1**
1989	**57.1**	**56**	**45.2%**	**24.2**	**80**	**64.5%**	**4**
1990	**57.9**	**27**	**21.8%**	**16.8**	**115**	**92.7%**	**1**
1991	**56.5**	**86**	**69.4%**	**20.4**	**102**	**82.3%**	**4**
1992	**59.3**	**6**	**4.8%**	**27.5**	**65**	**52.4%**	**1**
1993	**58.2**	**19**	**15.3%**	**36.7**	**27**	**21.8%**	**2**
1994	**57.6**	**38**	**30.6%**	**22.7**	**87**	**70.2%**	**4**
1995	**57.6**	**37**	**29.8%**	**43.0**	**11**	**8.9%**	**3**
1996	**59.0**	**8**	**6.5%**	**31.5**	**42**	**33.9%**	**2**
1997	**59.1**	**7**	**5.6%**	**36.6**	**28**	**22.6%**	**2**
1998	**57.9**	**28**	**22.6%**	**59.8**	**2**	**1.6%**	**2**
1999	**55.4**	**112**	**90.3%**	**33.7**	**34**	**27.4%**	**3**
2000	**57.7**	**34**	**27.4%**	**36.4**	**29**	**23.4%**	**3**
2001	**56.6**	**83**	**66.9%**	**25.5**	**73**	**58.9%**	**4**
2002	**56.4**	**88**	**71.0%**	**28.8**	**56**	**45.2%**	**3**
2003	**58.1**	**21**	**16.9%**	**29.1**	**55**	**44.4%**	**2**
2004	**58.2**	**16**	**12.9%**	**24.5**	**77**	**62.1%**	**1**
2005	**57.5**	**41**	**33.1%**	**43.6**	**10**	**8.1%**	**3**
2006	**57.4**	**47**	**37.9%**	**42.5**	**13**	**10.5%**	**3**
2007	**57.1**	**53**	**42.7%**	**17.6**	**114**	**91.9%**	**4**

Water Year	Temperature			Precipitation			Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet
	Average (°F)	Rank	Probability of Exceedance	Total (inches)	Rank	Probability of Exceedance	
2008	**56.9**	**66**	**53.2%**	**25.0**	**74**	**59.7%**	**4**
2009	**58.2**	**17**	**13.7%**	**22.4**	**88**	**71.0%**	**1**
2010	**57.2**	**52**	**41.9%**	**30.8**	**44**	**35.5%**	**3**
2011	**57.0**	**65**	**52.4%**	**40.1**	**19**	**15.3%**	**3**
2012	**57.5**	**40**	**32.3%**	**20.7**	**99**	**79.8%**	**4**
2013	**59.4**	**5**	**4.0%**	**18.0**	**112**	**90.3%**	**1**
2014	**60.5**	**2**	**1.6%**	**14.4**	**119**	**96.0%**	**1**
2015	**62.2**	**1**	**0.8%**	**21.7**	**93**	**75.0%**	**1**
2016	**59.6**	**3**	**2.4%**	**32.6**	**40**	**32.3%**	**2**

Bold records denote water years included in the catalog for future climate scenario generation

Appendix B

Proposed Climate Scenarios

The Weighted Temperature Scenario with Precipitation Adjustment columns only show those water years where records are manually adjusted to be drier. For the remaining years, data from the Weighted Temperature Scenario apply.

Model Water Year	Weighted Temperature Scenario					Weighted Temperature Scenario with Precipitation Adjustment (Drier)				
		Temperature		Precipitation			Temperature		Precipitation	
	Historic Water Year	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance	Historic Year if changed	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance
1	2016	59.6	2.4%	32.6	32.3%					
2	1992	59.3	4.8%	27.5	52.4%					
3	2015	62.2	0.8%	21.7	75.0%					
4	2010	57.2	41.9%	30.8	35.5%					
5	2014	60.5	1.6%	14.4	96.0%					
6	2016	59.6	2.4%	32.6	32.3%					
7	2004	58.2	12.9%	24.5	62.1%					
8	2003	58.1	16.9%	29.1	44.4%					
9	2015	62.2	0.8%	21.7	75.0%					
10	2013	59.4	4.0%	18.0	90.3%					
11	1990	57.9	21.8%	16.8	92.7%					
12	2015	62.2	0.8%	21.7	75.0%					
13	1986	57.4	37.1%	41.0	14.5%					
14	1991	56.5	69.4%	20.4	82.3%					
15	1997	59.1	5.6%	36.6	22.6%	1984	58.8	8.9%	24.0	65.3%
16	2014	60.5	1.6%	14.4	96.0%					
17	1992	59.3	4.8%	27.5	52.4%					
18	2014	60.5	1.6%	14.4	96.0%					
19	1984	58.8	8.9%	24.0	65.3%					
20	2015	62.2	0.8%	21.7	75.0%					
21	2013	59.4	4.0%	18.0	90.3%					
22	2013	59.4	4.0%	18.0	90.3%					
23	1992	59.3	4.8%	27.5	52.4%					
24	1934	58.0	17.7%	18.4	87.9%					
25	1983	58.2	14.5%	53.9	2.4%	2009	58.2	13.7%	22.4	71.0%
26	1992	59.3	4.8%	27.5	52.4%					
27	2015	62.2	0.8%	21.7	75.0%					
28	2014	60.5	1.6%	14.4	96.0%					

Model Water Year	Weighted Temperature Scenario					Weighted Temperature Scenario with Precipitation Adjustment (Drier)				
		Temperature		Precipitation			Temperature		Precipitation	
	Historic Water Year	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance	Historic Year if changed	Average (°F)	Probability of Exceedance	Average (inches)	Probability of Exceedance
29	1980	57.4	38.7%	37.1	20.2%					
30	2003	58.1	16.9%	29.1	44.4%					
31	2006	57.4	37.9%	42.5	10.5%					
32	2015	62.2	0.8%	21.7	75.0%					
33	2013	59.4	4.0%	18.0	90.3%					
34	1958	57.8	23.4%	50.1	3.2%	1990	57.9	21.8%	16.8	92.7%
35	2016	59.6	2.4%	32.6	32.3%					
36	2009	58.2	13.7%	22.4	71.0%					
37	2015	62.2	0.8%	21.7	75.0%					
38	1999	55.4	90.3%	33.7	27.4%					
39	2015	62.2	0.8%	21.7	75.0%					
40	2015	62.2	0.8%	21.7	75.0%					
41	1992	59.3	4.8%	27.5	52.4%					
42	2016	59.6	2.4%	32.6	32.3%					
43	2014	60.5	1.6%	14.4	96.0%					
44	1977	57.4	35.5%	14.8	95.2%					
45	2015	62.2	0.8%	21.7	75.0%					
46	1992	59.3	4.8%	27.5	52.4%					
47	2014	60.5	1.6%	14.4	96.0%					
48	1998	57.9	22.6%	59.8	1.6%	1990	57.9	21.8%	16.8	92.7%
49	2013	59.4	4.0%	18.0	90.3%					
50	1992	59.3	4.8%	27.5	52.4%					
51	1992	59.3	4.8%	27.5	52.4%					
52	1989	57.1	45.2%	24.2	64.5%					
53	2016	59.6	2.4%	32.6	32.3%					
54	1984	58.8	8.9%	24.0	65.3%					

APPENDIX 2-H
COMPARISON OF CLIMATE CHANGE SCENARIOS MEMORANDUM

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TECHNICAL MEMORANDUM

DATE: July 17, 2018

TO: Ron Duncan, Santa Cruz Mid-County Groundwater Agency

FROM: Georgina King, John Mejia, and Cameron Tana

PROJECT: Santa Cruz Mid-County Basin Groundwater Model

SUBJECT: Comparison of Climate Change Scenarios

1. BACKGROUND

For the Santa Cruz Mid-County Basin (Basin) Groundwater Flow Model using GSFLOW, we plan to run predictive simulations of groundwater management alternatives for the Santa Cruz Mid-County Groundwater Agency (MGA) using future climate change scenarios. One future climate change scenario based on a catalog of historical climate years has already been developed for the MGA (HydroMetrics WRI, 2016) but we are scoped to also run simulations using projections of climate change downscaled to the Basin. Simulations based on climate change projections are considered important for planning because projections generally have warmer temperatures than the historical record which could have a significant effect on the water resources of the Basin. There are a number of options available for climate change projections. This technical memorandum compares the suite of projections available.

Climate change projections are made primarily on the basis of coupled atmosphere-ocean Global Circulation Model (GCM) simulations under a range of future emission scenarios. Currently, climate projections used in climate change analysis are based on climate model simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The predecessor to CMIP5 was CMIP3.

Climate models in the CMIP5 use a set of emission scenarios called representative concentration pathways (RCPs) to reflect possible trajectories of greenhouse gas (GHG) emissions throughout this century. Each RCP defines a specific emissions trajectory and subsequent radiative forcing (a radiative forcing measures the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system).

For purposes of quantifying benefits or adverse impacts that could result from water storage projects proposed for the Water Storage Investment Program (WSIP) in California (California Water Commission, 2016), technical assistance included recommendations for the use of climate change projections. Twenty climate scenario-model combinations were selected based on recommendations by the California Department of Water Resources' (DWR) Climate Change Technical Advisory Group that they are the most appropriate for California water resources. The climate scenario-model combinations compose 10 global circulation models run with two emission scenarios: one optimistic (RCP 4.5) that stabilizes shortly after 2100 and one pessimistic (RCP 8.5) that is characterized by continuing increased GHG emissions over time.

Included in our comparison is the City of Santa Cruz's (City) climate change projection. The City, since 2008, uses CMIP3 GCM data adopted and made available by the CalAdapt program as the basis for their hydrologic and climate change modeling (Stratus, 2015). Specifically, they have selected the GFDL2.1 GCM for the A2 emissions scenario, which is the worst-case climate change dataset in the CalAdapt dataset. Under a subcontract to Pueblo Water Resources Inc., we have performed bias corrected spatial downscaling (Mejia et al., 2012) of the GFDL2.1-A2 projections to the climate stations in the Basin for use as input to represent climate for Water Years 2020-2069. We are currently using this climate input to simulate City of Santa Cruz Aquifer Storage and Recovery (ASR) preliminary alternatives.

A comparison of climate change projections will lead to a decision on what GCM projections should be used by the MGA for its simulations, including those simulations to guide the Basin's Groundwater Sustainability Plan (GSP). One option is the GFDL2.1-A2, which has already been downscaled to the Basin. If different GCM(s) are deemed appropriate, downscaling of those GCM(s) to climate stations in the Basin will be required to use with the Basin GSFLOW model.

2. COMPARISON OF DATASETS

Downscaling is commonly used to refine the coarse scale of GCM data to local regions. The CMIP5 ensemble of CGMs area available as downscaled projections using local constructed analogs (LOCA) for California on a 6 kilometer grid (Pierce, Cayan, and Dehann, 2016). WSIP used these downscaled projections for its set of 20 climate scenario-model combinations. Although further downscaling from LOCA, similar to what has been done for the GFDL2.1-A2 projection used by the City of Santa Cruz, will be required for the Basin GSFLOW model, we evaluated data from the LOCA cell in which the Santa Cruz Co-Op climate station is located, to compare climate change projections for the Basin region (Figure 1).

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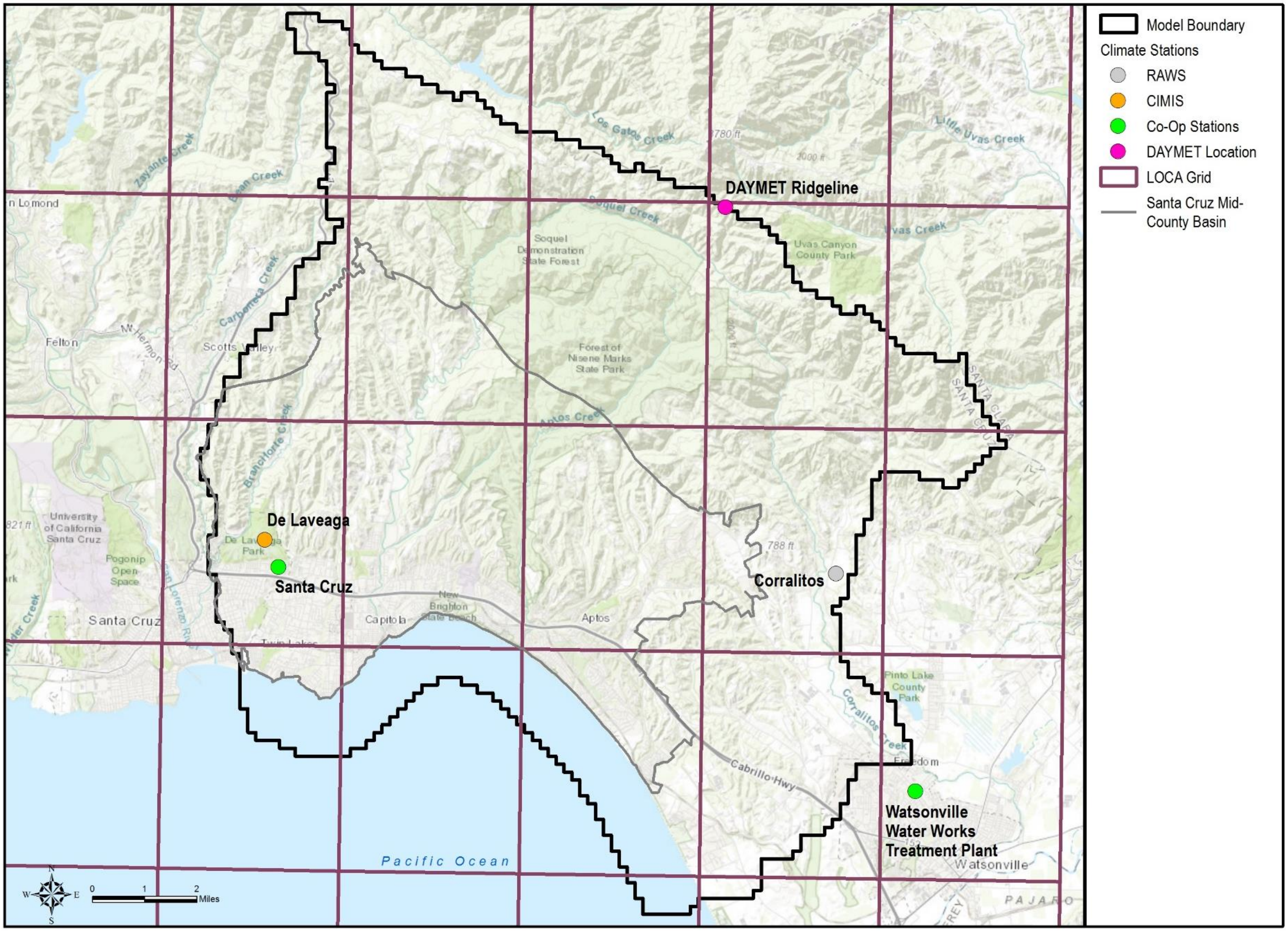

Figure 1. LOCA Grids in the Santa Cruz Area

Our comparison includes all available CMIP5 scenarios. The two different RCPs are compared separately, as are the 20 WSIP emission scenarios. Change in average precipitation, and minimum and maximum temperatures comparisons are summarized in Table 1. The values in the table represent changes between average projected 2020-2069 GCM climate and average reference historical 1984-2015 GCM climate for the grid cell. Comparing modeled results for these time periods are meant to represent the expected change in downscaled climate for a future period versus the Basin GSFLOW model calibration period of 1985-2015. Figure 2 plots the individual scenarios with a line connecting the average minimum and maximum temperature changes against a percentage change in average precipitation for each emission scenario.

Table 1: Climate Change 2020-2069 Compared to Reference Historical 1984-2015 Period

Scenario	Average Precipitation (%)	Average Minimum Temperature (°F)	Average Maximum Temperature (°F)
CMIP5 all	3.16	2.68	2.59
CMIP5 all RCP4.5	1.68	2.35	2.26
CMIP5 all RCP8.5	4.66	3.02	2.91
CMIP5 WSIP	1.79	2.82	2.74
CMIP5 WSIP RCP4.5	0.47	2.48	2.45
CMIP5 WSIP RCP8.5	3.11	3.16	3.04
CMIP3-GFDL-CM-A2 downscaled at Santa Cruz Co-op Station	-1.46	1.2	2.2
Catalog at Santa Cruz Co-op Station	-10.2	0.78	2.29

Notes: Historical Reference for CMIP5 is GCM results for 1984-2015
Historical reference for GFDL and Catalog is 1984-2015 dataset at Santa Cruz Co-op station.

The California Department of Water Resources (DWR) has stated they will use the ensemble of WSIP scenarios as the basis for climate change projections provided to local Groundwater Sustainability Agencies for sustainable groundwater management planning (Hatch, 2017). Personal communication with Tyler Hatch of DWR’s Sustainable Groundwater Management Branch, indicated that for sustainable groundwater planning, DWR will accept a climate change scenario that was more conservative than the WSIP ensemble, i.e., hotter and drier.

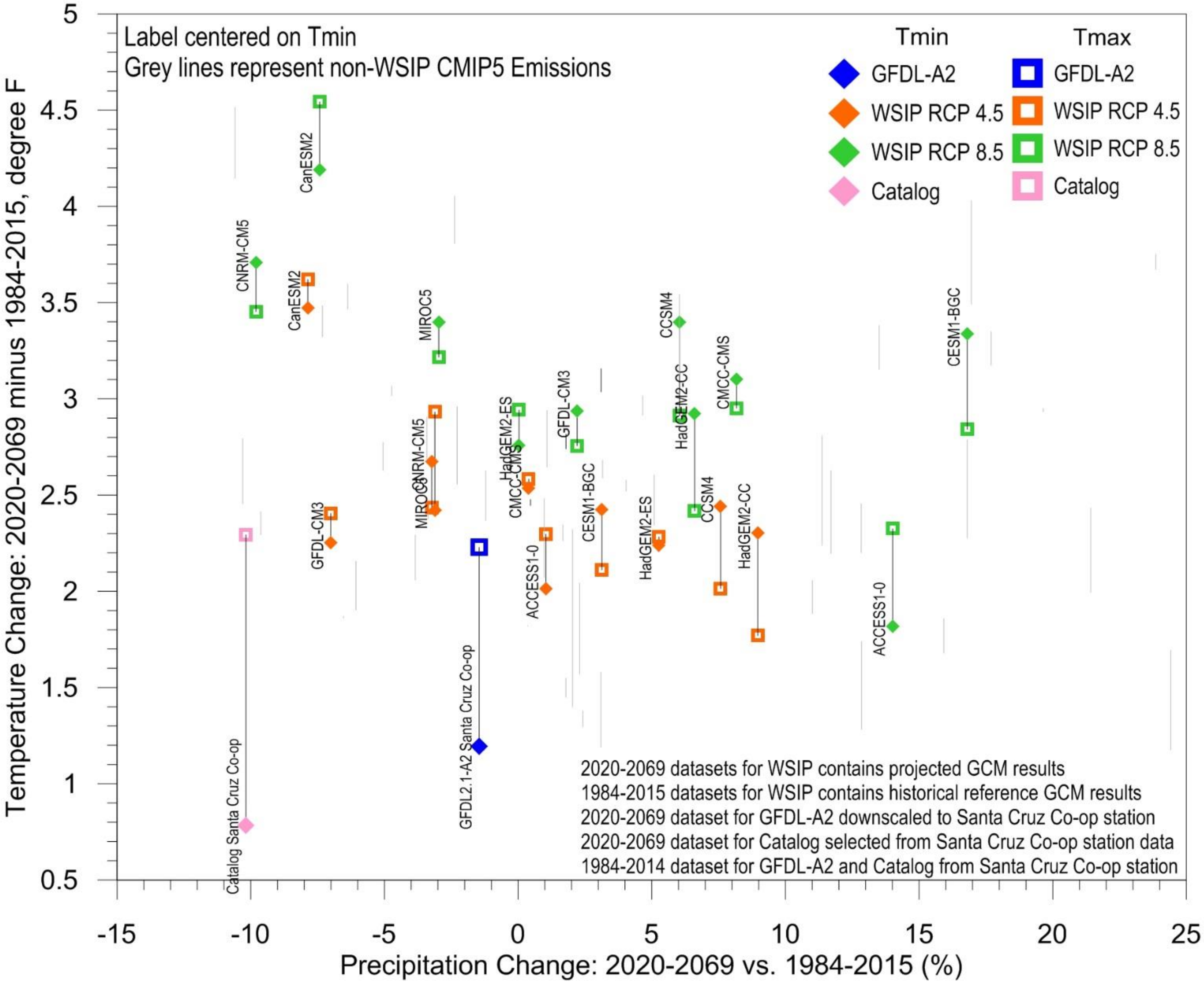

Figure 2. Climate Change 2020-2069 with Respect to Reference Period 1984-2015 for All CMIP5 Emissions

2.1. Precipitation Comparison

Average precipitation increases over 1984 – 2015 precipitation in all groups of CMIP5 scenarios (Table 1). The RCP 4.5 scenarios have lower precipitation increases than the RCP 8.5 scenarios. The WSIP scenarios have lower precipitation increases than the combined CMIP5 scenarios. Median daily precipitation plotted for each year (Figure 3) shows an increasing trend in the precipitation to 2069. Monthly averages of precipitation changes between 2020-2069 and 1984-2015 show only little change or increases every month for medians of all groups of CMIP5 scenarios. December through March precipitation increases in the WSIP scenarios is generally higher than the combined CMIP5 scenarios (Figure 4). The other months have similar daily precipitation changes.

Daily precipitation from the City's GFDL-A2 scenario compared to the full combination of WSIP scenarios is slightly wetter, with 2.04% more precipitation than 1984-2015 reference precipitation (Table 1). There is a notable reduction in precipitation after 2069, which is after our planned GSFLOW model period (Figure 3). GFDL-A2 precipitation from March through May has less precipitation than the reference historical period and less than the CMIP5 scenarios, however September, October, and February precipitation has greater increases than the CMIP5 scenarios (Figure 4).

2.2. Minimum Temperature Comparison

As expected, all RCP 8.5 scenarios are warmer than RCP 4.5 scenarios because of the projected increasing emissions that characterize those scenarios. The combined 20 WSIP scenarios' minimum temperature increases are overall greater than the full complement of CMIP5 scenarios, and more noticeably so in the RCP 8.5 group (Table 1). Figure 5 shows that the median RCP 8.5 minimum temperatures depart from temperatures in the other groups of scenarios around 2056 with an increasing trend.

GFDL-A2 average annual projections of minimum temperature are lower than median CMIP5 temperatures around 2038 and 2060 (Figure 5). Overall, this results in average minimum temperature increases than are lower than all other CMIP5 groups of scenarios (Table 1). Monthly averages for minimum temperatures are higher in all months for median RCP 8.5 emission scenarios than median RCP 4.5 emission scenarios. The average monthly minimum temperatures show less temperature increase in the GFDL-A2 scenario than the CMIP5 scenarios, except from May to August where they are more comparable to the RCP 4.5 scenarios (Figure 6).

2.3. Maximum Temperature Comparison

Similar to minimum temperatures, the combined 20 WSIP scenarios' maximum temperatures are overall slightly warmer than the full complement of CMIP5 maximum temperatures (Table 1). The months of June through October are when the WSIP scenario maximum temperature increases are noticeably greater than the combined CMIP5 scenarios (Figure 8).

Figure 7 shows that the GFDL-A2 scenario maximum temperatures follows the general trend of the WSIP RCP 8.5 emission scenarios better than other scenarios. However, similar to minimum temperature, around 2038 and 2060, the projection of maximum temperature falls below most CMIP5 scenarios (Figure 7). Overall, the average maximum temperature increases for the GFDL-A2 scenario are lower than the WSIP maximum temperatures increases. Monthly averages for maximum temperatures are higher in all months for median RCP 8.5 emission scenarios than median RCP 4.5 emission scenarios. The monthly distribution of average maximum monthly temperatures also show higher temperature increases in the GFDL-A2 scenario than the CMIP5 scenarios from May through August, and generally lower temperature increases in the other months (Figure 8).

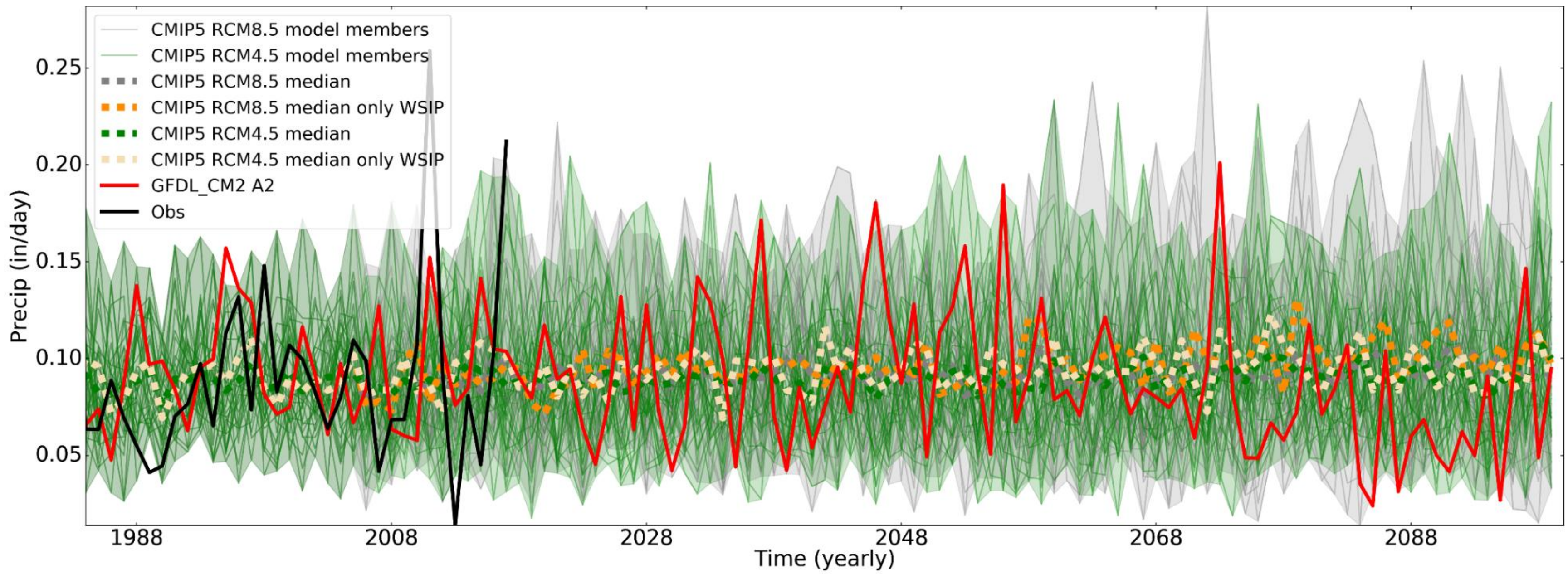

Figure 3. Average Annual Daily Projections for Precipitation

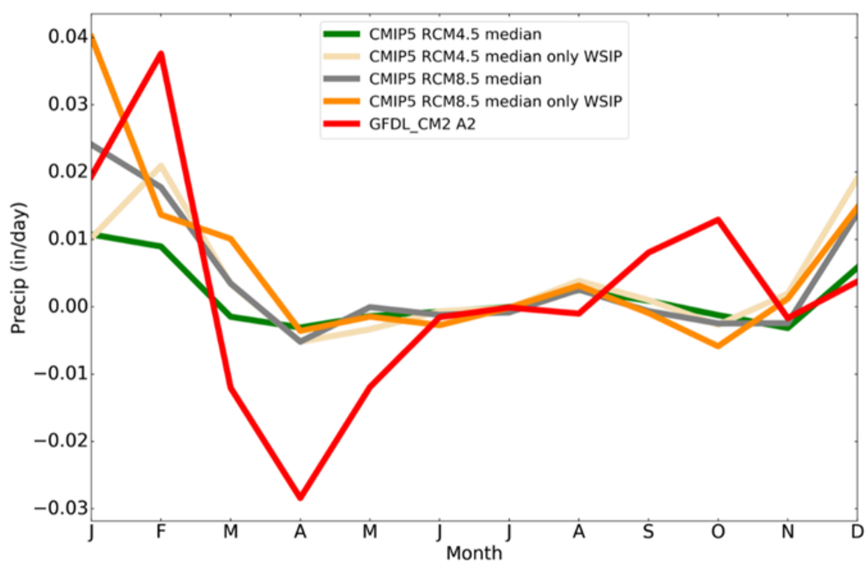

Figure 4. Average Monthly Projections for Precipitation Changes between 2020-2069 and 1985-2015

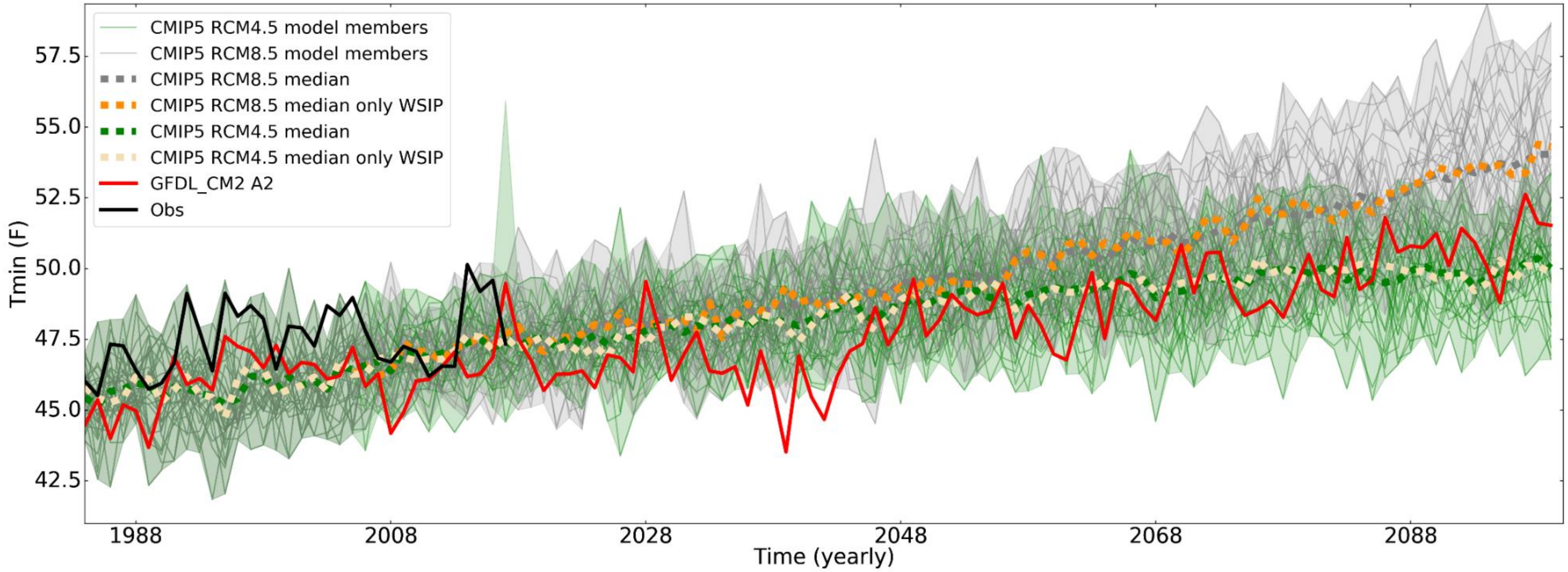

Figure 5. Average Annual Daily Projections for Minimum Temperature (Tmin)

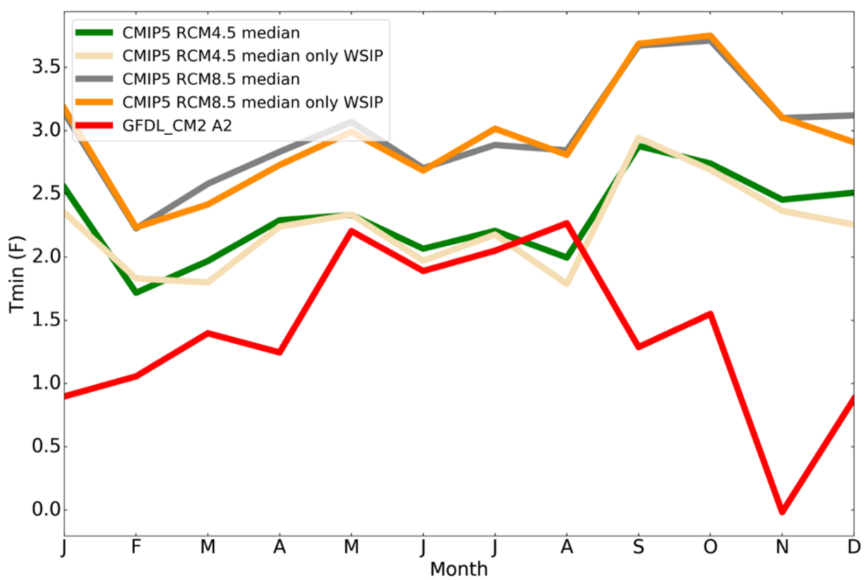

Figure 6. Average Monthly Projections for Minimum Temperature (Tmin) Changes between 2020-2069 and 1985-2015

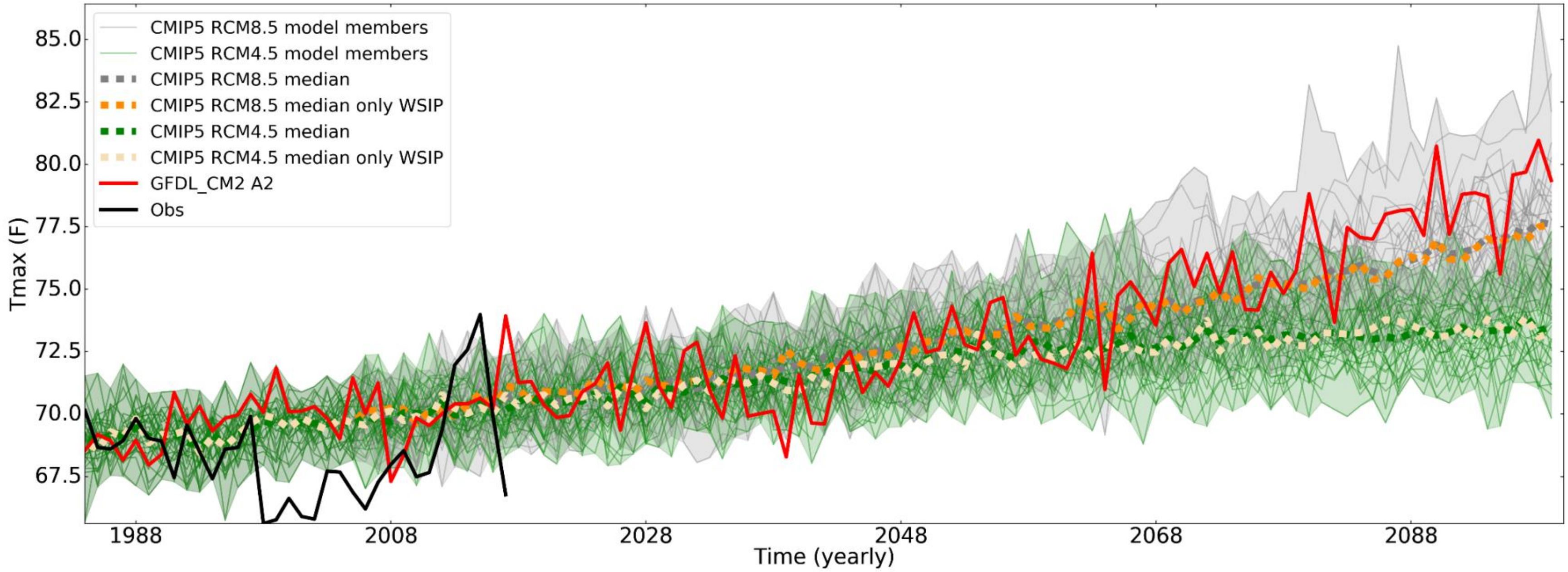

Figure 7. Average Annual Daily Projections for Maximum Temperature (Tmax)

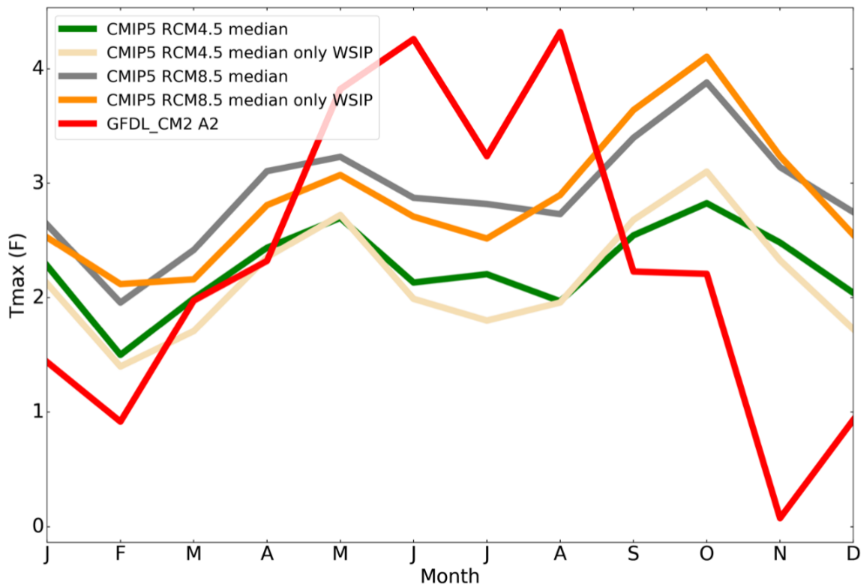

Figure 8. Average Monthly Projections for Maximum Temperature (Tmax) Changes between 2020-2069 and 1985-2015

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. Conclusions

1. All projected average scenario ensembles (CMIP5 and WSIP) are wetter than the reference historical period.
2. The WSIP emission scenarios are drier and warmer than the combined CMIP5 scenarios.
3. The City's GFDL-A2 scenario is both wetter and cooler than many WSIP scenarios, although its maximum temperatures are warmer than WSIP RCP 4.5 scenarios.

3.2. Recommendations

It is expected that for groundwater sustainability planning, DWR will accept a climate change scenario that is more conservative than the WSIP ensemble, i.e., hotter and drier. Since the City's GFDL-A2 scenario does not fulfill this condition, a potential alternative needs to be selected. Although most projections show an increase in precipitation, we recommend selecting a projection that shows a decrease in precipitation. This will contribute to the robustness of groundwater sustainability planning by taking into account the possibility that water supply is reduced. Any projection that shows higher than average increases in temperature than the WSIP ensemble should also meet the requirements for groundwater sustainability planning.

We recommend selecting a scenario from the one of the 20 WSIP scenarios. WISP scenarios that are potential candidates are: MIROC5 RCP 8.5, CanESM2 RCP 4.5, CanESM2 RCP 8.5, and CNRM-CM5 RCP 8.5. These are shown on to have lower projected average precipitation than the reference historical period and higher temperatures than most other CMIP5 scenarios.

- CanESM2 RCP 8.5, CanESM2 RCP 4.5, and CNRM-CM5 RCP 8.5 are extreme scenarios that have over 7% less precipitation and some of the highest temperatures of all projections (Figure 2); such an extreme selection may not be justified.
- A fourth less extreme option is MIROC5 RCP 8.5 has 3% less precipitation than the reference historical period, and average temperatures that are higher than the majority of other scenarios.

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APPENDIX 2-I

IMPLEMENTATION AND ANALYSIS OF PROJECTS AND MANAGEMENT ACTIONS IN MODEL SENARIOS AS PART OF GROUNDWATER SUSTAINABILITY PLAN DEVELOPMENT

November 15, 2019

Implementation and Analysis of Projects and Management Actions in Model Scenarios as Part of Groundwater Sustainability Plan Development

Prepared for:

Santa Cruz Mid-County Groundwater Agency

Prepared by:

Montgomery & Associates

1970 Broadway, Oakland, California

Contents

Tables

Figures

1 INTRODUCTION

A groundwater model (model) of the Santa Cruz Mid-County Groundwater Basin (Basin) has been developed and calibrated as described in the calibration report entitled*: Santa Cruz Mid-County Basin Model Integration and Calibration* (M&A, 2019b). The Santa Cruz Mid-County Groundwater Sustainability Plan (GSP) uses model simulations of future conditions to estimate future water budgets, evaluate the expected benefits of projects and management actions, and estimate sustainable yields. This report documents model simulations of future conditions.

Future water budgets are estimated from model simulation results for both assumed baseline conditions and projects included in the GSP to achieve sustainability. The modeled projects are the two planned projects included in the GSP: Pure Water Soquel (PWS) led by Soquel Creek Water District, and Aquifer Storage and Recovery (ASR) led by the City of Santa Cruz.

The expected benefits of these projects are based on a comparison of groundwater elevations simulated by the model with the projects versus the simulation of baseline conditions. Simulated groundwater elevations are also compared with groundwater elevation proxies for the GSP's sustainable management criteria (SMC) to evaluate whether the projects help prevent or eliminate undesirable results for seawater intrusion and depletion of interconnected surface water.

Sustainable yields by aquifer group are estimated based on testing combinations of pumping and injection rates with the projects that achieve minimum thresholds and therefore sustainability by not causing undesirable results.

2 BASELINE ASSUMPTIONS FOR FUTURE CONDITIONS

Baseline assumptions are implemented into the model simulations of future conditions. The baseline assumptions also represent management actions that Santa Cruz Mid-County Groundwater Agency (MGA) member agencies are already implementing. Except where otherwise noted, these assumptions are consistent for both the simulation of baseline conditions without projects and the simulations of projects.

2.1 Initial Conditions

Initial groundwater elevations for the model are based on simulated groundwater elevations at the end of September 2015 from the calibrated simulation of historical conditions documented in the calibration report. Simulation of Water Year 2016 is based on available data for October 2015 to September 2016. Available data used for Water Year 2016 includes climate data and municipal pumping. Non-municipal pumping and both non-municipal and municipal return flows are estimated following the approaches referenced in the calibration report (HydroMetrics WRI, 2017a and M&A, 2019a).

2.2 Catalog Climate Scenario

Climate for simulated water years representing Water Years 2017-2069 are generated from a catalog of historical climate data from warm years in the Basin's past to simulate warmer temperatures predicted by global climate change (HydroMetrics WRI, 2017b). Specifically, the Catalog Climate uses historical data from the Santa Cruz Co-op and Watsonville Waterworks climate stations as well as corresponding daily temperature values from the DAYMET database of gridded weather parameters (Thornton et al., 2014) for a location near the ridgeline (Figure 1). The model Technical Advisory Committee recommended this approach because it preserves the integrity of the climate data and ensures temperature and precipitation values are associated with real data. The Catalog Climate has an increase of 2.4 °F in temperature at the Santa Cruz Co-op station and decrease of 2.1 - 3.1 inches per year (approximately 10%) in precipitation over the 1985-2015 record at climate stations in Santa Cruz and Watsonville. There is a corresponding increase in potential evapotranspiration of about 6%. Figure 2 shows precipitation and average temperature used for the future simulations at the Santa Cruz Co-op and Figure 3 shows precipitation used at the Watsonville Waterworks climate station. Simulated water years 2-54 shown in these figures represent Water Years 2017-2069.

In comparison to the CMIP5 ensemble of 10 Global Circulation Models (CGM) often applied in California, the simulated Catalog Climate is slightly cooler and drier than most CMIP5 scenarios (M&A, 2018). California Department of Water Resources (DWR) released datasets for climate change projections to use in GSPs, but the use of the data and methods provided by DWR are optional and local data and methods may be more appropriate (DWR, 2018). The datasets provided by DWR result in a 5-8% increase in potential evapotranspiration and a 3-4% increase of precipitation at the closest grid cell to the Santa Cruz-Coop station (Figure 1). Therefore, the Catalog Climate has similar potential evapotranspiration, and has less precipitation than datasets provided by DWR for the Basin area.

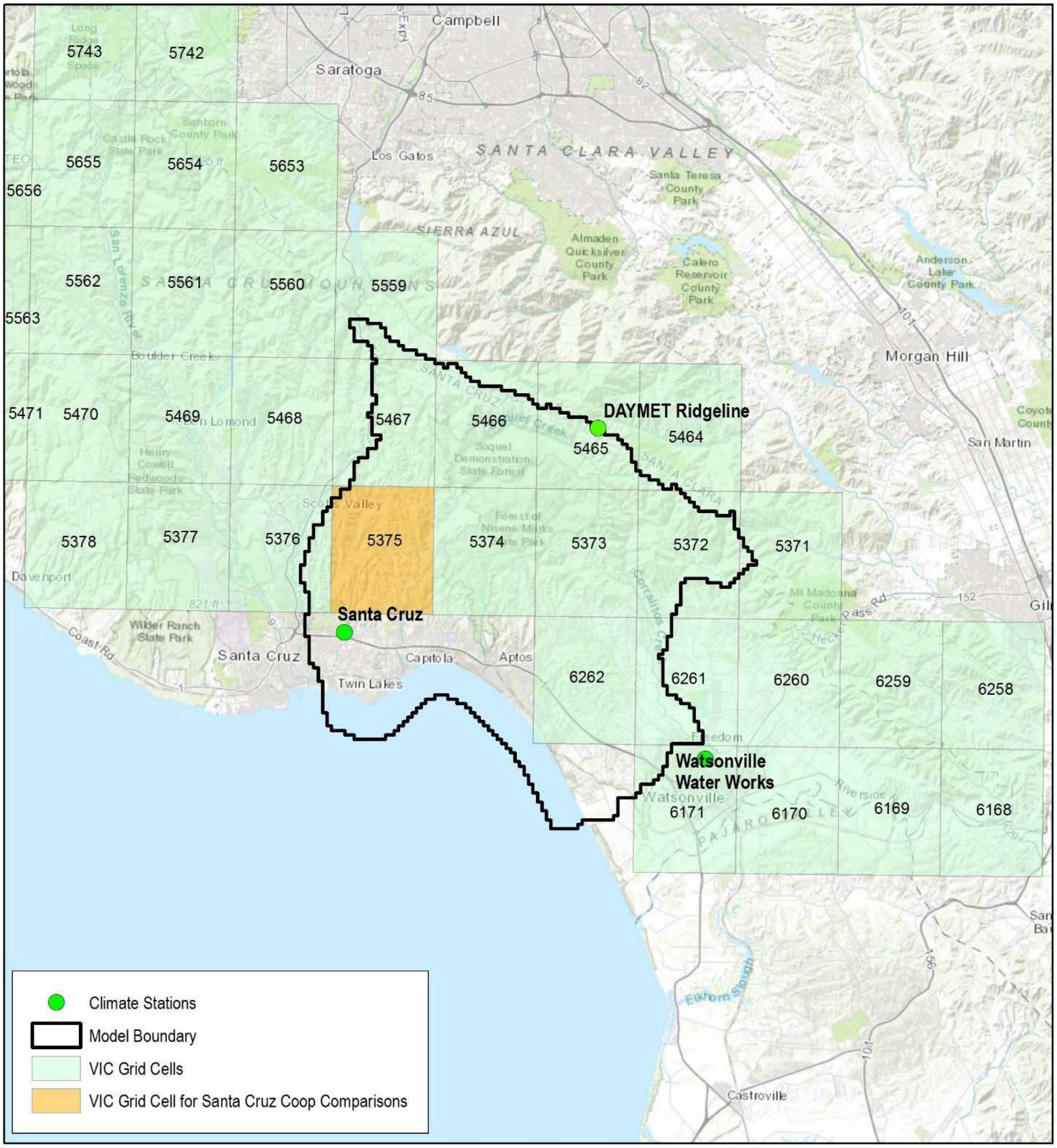

Figure 1. Climate Stations used in Model and Grid Cells for DWR Climate Datasets near Basin

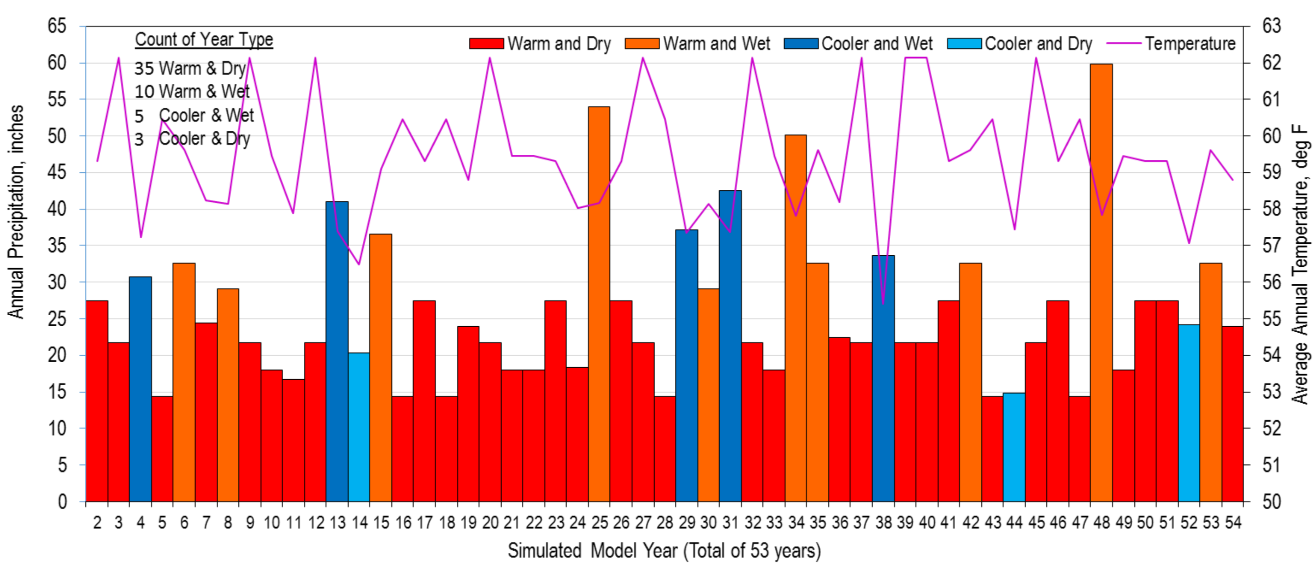

Figure 2. Simulated Future Precipitation and Temperature at Santa Cruz Co-op Station based on Catalog Climate

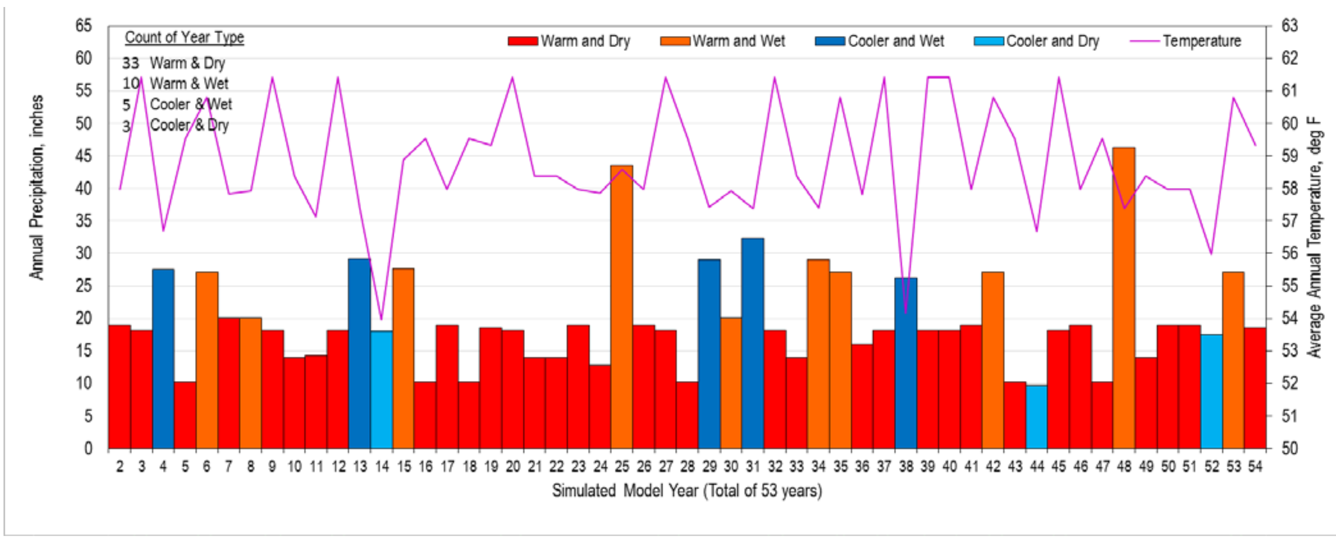

Figure 3. Simulated Future Precipitation at Watsonville Waterworks Station based on Catalog Clima

2.3 Sea Level Rise

Sea level rise is implemented in the model based on projections for Monterey provided by the 2018 update of the *State of California Sea-Level Rise Guidance* (California Natural Resources Agency and California Ocean Protection Council, 2018). The projections used are based on 5% exceedance probability under the high emissions scenario and rise to 2.3 feet by 2070 (Table 1). The increased sea level rise is applied to model general head boundaries with freshwater equivalent heads calculated from sea level.

Table 1. Sea Level Rise Projections Incorporated in Future Simulations

Year	Sea Level Rise (feet)
2030	0.6
2040	0.9
2050	1.3
2060	1.8
2070	2.3

2.4 Land Use

Land use assumed for future simulations are equivalent to land use simulated for historical conditions from Water Years 1985-2015, as documented in the calibration report. Therefore, the distribution of non-municipal pumping and return flows are consistent with the historical simulation. Also consistent are the areal distribution of vegetation type and density and impervious area percentages.

2.5 Baseline Demand

Baseline water demand is assumed to be the same for all future simulations and reflects management actions such as conservation already being implemented, but groundwater pumping to meet that demand changes with implementation of projects.

2.5.1 Municipal Demand

Municipal demand assumed for the future simulations is based on planning projections provided by the three municipal supply water agencies: Central Water District (CWD), City of Santa Cruz Water Department (SCWD), and Soquel Creek Water District (SqCWD).

Assumed future demand for CWD is based on demand from Water Years 2008-2011 prior to the most recent drought. These years are selected as there is anticipated bounce-back in demand from the conservation that occurred during the drought. Annual CWD water demand is assumed to be 550 acre-feet per year in all future simulations with monthly variation based on historical average pumping for Water Years 2005-2014.

Assumed future demand for SCWD is based on demand from 2016-2018 water demand. SCWD has not experienced a rebound in demand from 2014-2015 when SCWD rationed water during the drought (City of Santa Cruz, 2019). SCWD uses the 2016-2018 demand for planning purposes and to evaluate potential future water supply shortages. Therefore, model assumptions for SCWD include the 2016-2018 water demand for all future model simulations.

Assumed future water demand for SqCWD is based on projected demand in its Urban Water Management Plan (WSC, 2016). The SqCWD Urban Water Management Plan (UWMP) projects a demand bounce-back of approximately 65% from the low of Water Year 2016 (3,095 acre-feet per year relative to 2013 (4,279 acre-feet per year) when the drought started. The bounce back is projected in the UWMP to peak around 2020 at 3,900 acre-feet per year. The peak projected bounce-back is based on observed water demand of approximately 3,100 acre-feet per year in Water Year 2016 compared to approximately 3,350 acre-feet per year in Water Year 2018. The UWMP projects SqCWD demand to decline from 3,900 to 3,300 acre-feet per year by 2050 but future simulations do not include a decline in demand and maintain demand at 3,900 acre-feet per year. SqCWD has concluded that its UWMP's demand projections may be underestimated when considering effects such as statewide efforts to address the housing crisis including laws facilitating accessory dwelling uses and is therefore not assuming a long-term decline in demand for planning purposes. Monthly variation in future water demand is based on historical monthly variations in demand data.

2.5.2 Non-Municipal Demand

Non-municipal domestic demand is based on the water use factor used in the historical model simulation for Water Year 2013. Thus, the water use factor is assumed to be 0.35 acre-feet per year per residence in the Basin, the Santa Margarita Basin, and the Purisima Highlands and 0.59 acre-feet per year for the Pajaro Valley Subbasin (HydroMetrics WRI, 2017a). This assumed demand represents slight bounce-back in water demand experienced by small water systems during Water Years 2014 and 2015 during the drought.

Non-municipal domestic demand is assumed to increase over time by projections for population growth rates of 4.2% per year before 2035 and 2.1% per year after 2035. More recent projected growth rates of only 0.2% per year through 2040 as estimated by land use agencies, however, sensitivity runs provided in the calibration report showed a relatively small effect on sustainability by non-municipal pumpers.

Institutional demand and agricultural demand isare estimated based on the approach used for the historical simulation, assuming the same land use and crop type distribution (HydroMetrics WRI, 2017a). Irrigation demand varies with climatic conditions. Since the Catalog Climate is warmer and drier than the historical simulation, institutional and agricultural demand is simulated to be higher in the future simulations than during the historical period.

2.6 Baseline Pumping

Future baseline simulations include assumptions of how much groundwater pumping is needed to meet demand and where pumping occurs. Figure 4 shows the locations of existing and planned municipal pumping wells.

Baseline pumping is simulated in the model via the model's Multi-Node Well 2 (MNW2) MODFLOW package. The package defines the model cell location of the wells and either the screen elevations or model layers of the screens. Monthly time series of well flows for both pumping and injection are assigned to each well in the model.

2.6.1 Central Water District Baseline Pumping

Groundwater pumping at CWD's Rob Roy well field is assumed to meet all of CWD's demand of 550 acre-feet per year. Distribution of pumping between the three Rob Roy wells is based on the 2005-2014 distribution with CWD-12 as the primary pumper and CWD-4 and CWD-10 as secondary pumpers. Any historical pumping occurring at the now inactive Cox well field is assumed to occur at CWD-12 (Table 2). The first chart on Figure 5 shows the groundwater pumping distribution at CWD for future simulations. As CWD pumping is not assumed to change with implementation of projects, the third chart on Figure 5 for the projects simulation is identical to the first chart representing the baseline simulation.

Table 2. Central Water District Pumping Distribution by Wells for Future Simulations

Period	CWD-4	CWD-10	CWD-12	Total
	acre-feet per year			
2017-2069	48	92	410	550

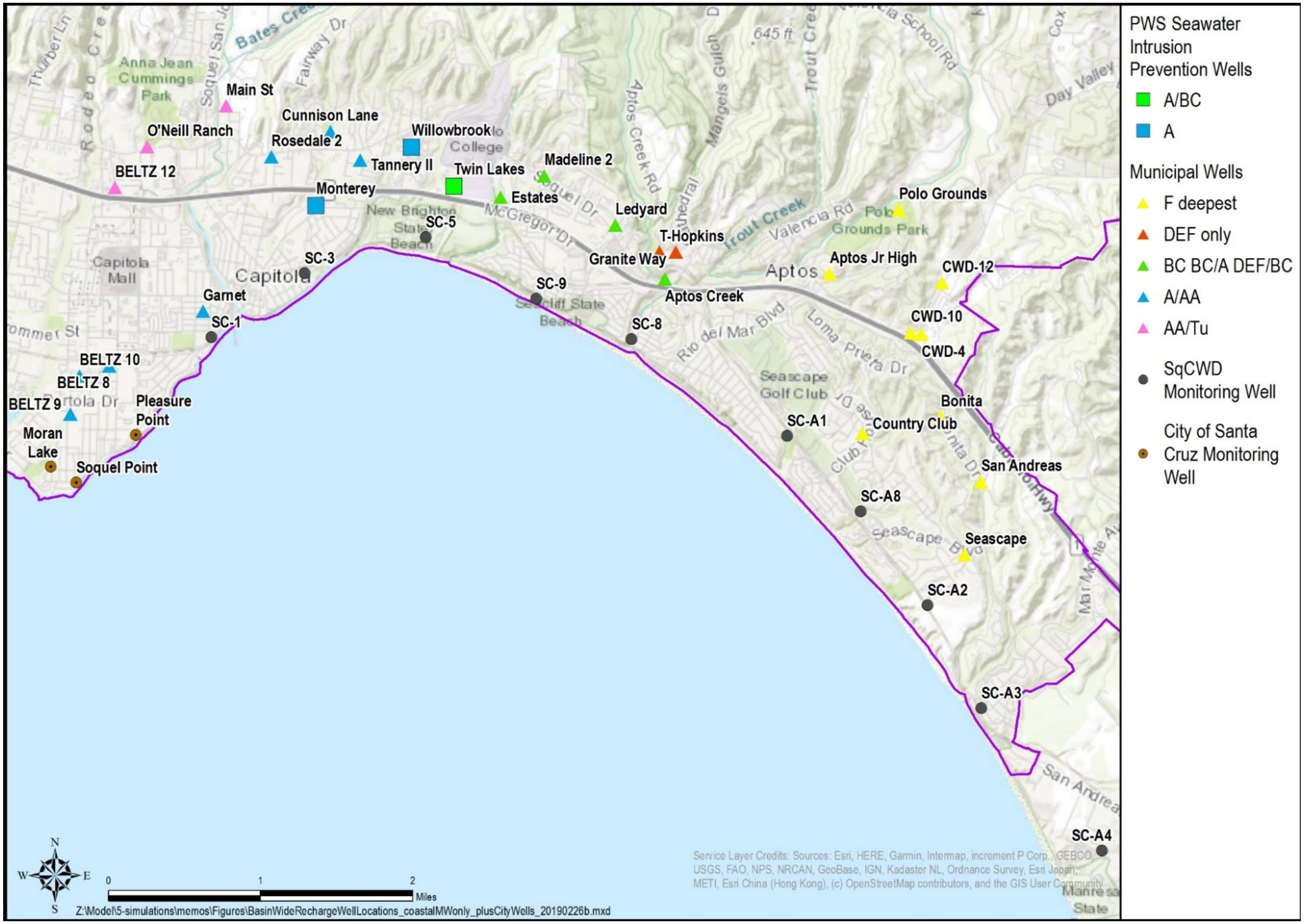

Figure 4. Locations of Existing and Planned Wells for Baseline and Projects Simulation

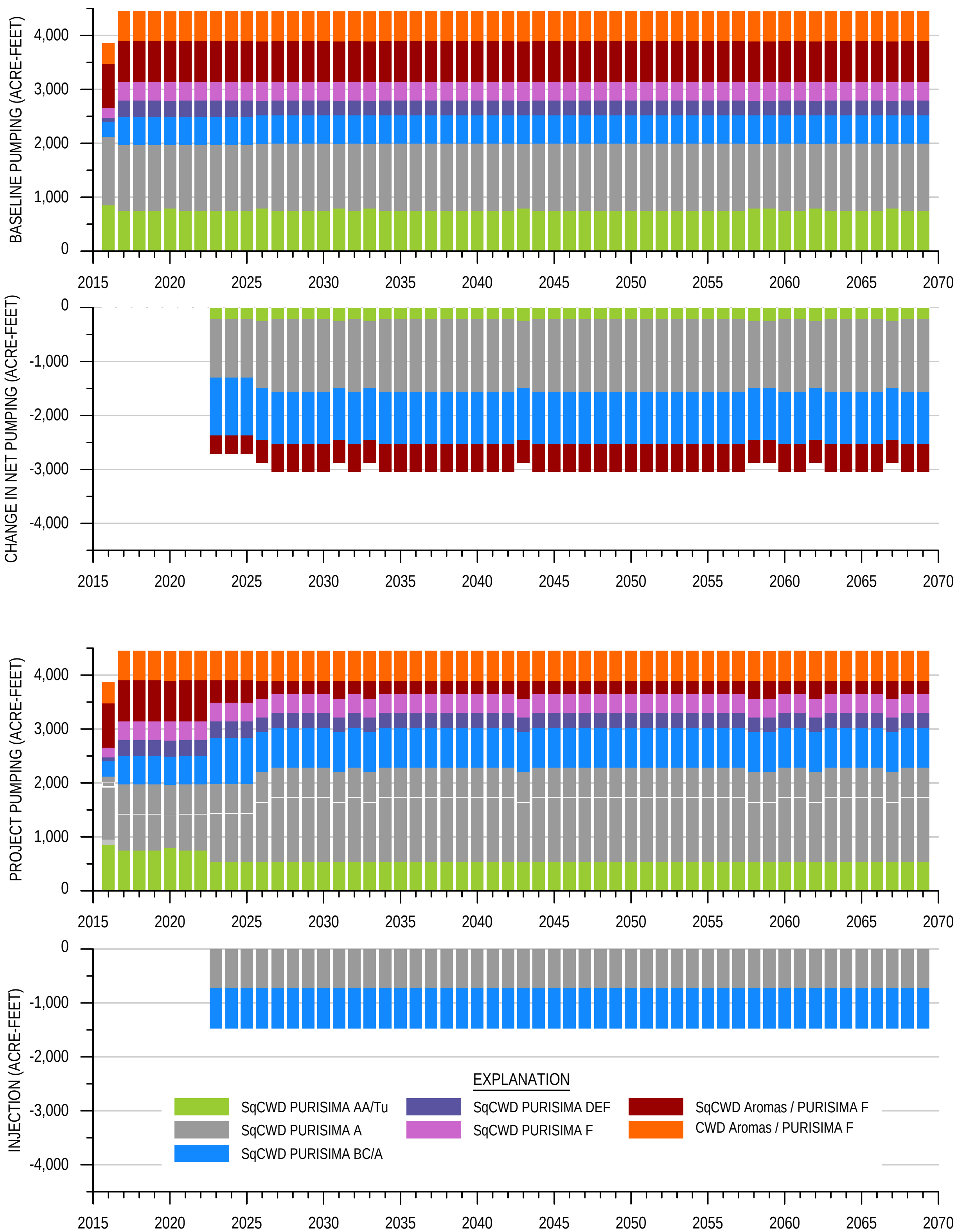

Figure 5. Central Water District and Soquel Creek Water District Pumping Distribution by Aquifer Unit for Baseline and Projects Simulation

2.6.2 City of Santa Cruz Baseline Pumping

Groundwater provides approximately 5% of the City of Santa Cruz's water supply. The City's groundwater pumping varies over time based on the availability of SCWD's surface water supplies. Total SCWD groundwater pumping by month was provided for the baseline simulation by Pueblo Water Resources Inc. based on availability of surface water under the Catalog Climate to meet WY 2016-2018 demands modeled by Gary Fiske & Associates. This work was supported by Balance Hydrologics as part of the SCWD's ASR feasibility evaluation. Groundwater pumping to the four existing Beltz wells was distributed based on historical pumping distributions in those wells during critically and non-critically dry years. Table 3 shows average pumping at the SCWD's Beltz wells for the baseline simulation over different time periods. The first plot of Figure 6 shows the pumping distribution used for the future baseline simulation. Total SCWD pumping averages approximately 350 acre-feet per year for the future baseline simulation.

Table 3. Average Pumping at Beltz Wells for the Baseline Simulation

Period	Beltz 8	Beltz 9	Beltz 10	Beltz 12	Total
	acre-feet per year				
2017-2019	49	127	100	74	350
2020-2025	99	129	96	40	364
2026-2039	100	131	96	42	369
2040-2069	90	119	88	39	337

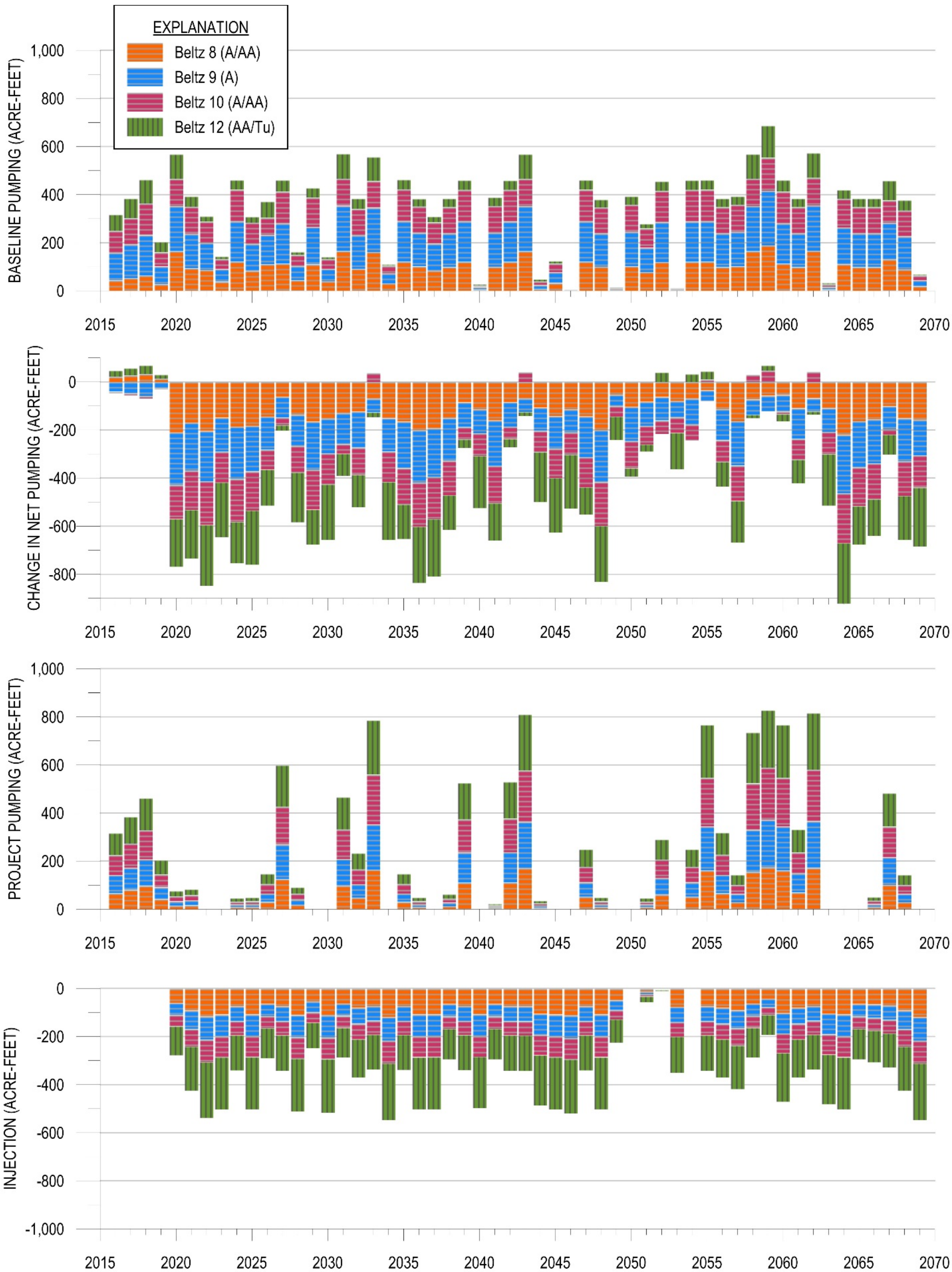

Figure 6. City of Santa Cruz Pumping and Injection for Baseline and Projects Simulations

2.6.3 Soquel Creek Water District Baseline Pumping

Groundwater pumping is assumed to supply 100% of Soquel Creek Water District's demand and thus, as described in Section 2.5.1, 3,900 acre-feet per year is pumped by Soquel Creek Water District in the future simulations. No surface water transfer is assumed and drought curtailment during critically dry years is also not assumed.

The baseline pumping distribution for SqCWD is based on implementing the management action of redistributing pumping to improve Basin sustainability without a project. Production wells used are the same as those included in the simulation of historical conditions, with the addition of the Granite Way well, which will come online in late 2019, and the Cunnison Way well, scheduled to come online in 2026. The pumping distribution is different in critically dry years versus non-critically dry years with the differences applied between April and September. Pumping is shifted inland from the Garnet well in critically dry years when City of Santa Cruz plans increased pumping near the Purisima A unit outcrop area as described in the cooperative monitoring and adaptive management agreement between SqCWD and SCWD. The distribution also changes when the Cunnison Way well comes online. Table 4 shows the pumping distribution. The first chart of Figure 5 shows the pumping distribution by aquifer unit used for the future baseline simulation.

Table 4. Pumping at SqCWD Wells for the Baseline Simulation

Well	Aquifer	2017-2025		2026-2069	
		Non-Critically Dry	Critically Dry	Non-Critically Dry	Critically Dry
		acre-feet per year			
O'Neill Ranch Well	Purisima AA/Tu	222	261	222	261
Main St Well	Purisima AA/Tu	528	532	528	532
Rosedale 2 Well	Purisima A/AA	544	553	544	553
Garnet Well	Purisima A	278	210	278	139
Cunnison Lane	Purisima A	0	0	230	230
Tannery Well II	Purisima A	399	408	196	277
Estates Well	Purisima BC/A	316	316	316	316
Madeline 2 Well	Purisima BC	98	98	98	98
Ledyard Well	Purisima BC	108	108	108	108
Aptos Creek Well	Purisima DEF/BC	0	0	0	0
T-Hopkins Well	Purisima DEF	156	156	137	137
Granite Way	Purisima DEF	145	145	135	135
Polo Grounds Well	Purisima F	100	100	100	100
Aptos Jr High Well	Purisima F	250	250	250	250
Country Club Well	Aromas / Purisima F	70	70	70	70
Bonita Well	Aromas / Purisima F	269	269	269	269
San Andreas Well	Aromas / Purisima F	371	371	371	371
Seascape Well	Aromas / Purisima F	46	46	46	46

Note: Totals do not equal 3,900 acre-feet per year due to rounding error

2.6.4 Non-Municipal Baseline Pumping

Groundwater pumping meets all of the non-municipal demand described in Section 2.5.2. The non-municipal demand averages approximately 1,600 acre-feet per year within the Basin. Figure 7 shows simulated non-municipal demand within the Basin and outside the Basin for categories of private/domestic, institutional, and agricultural. Since land use is not assumed to change, the locations of non-municipal pumping are the same as for simulation of historical conditions documented in the calibration report.

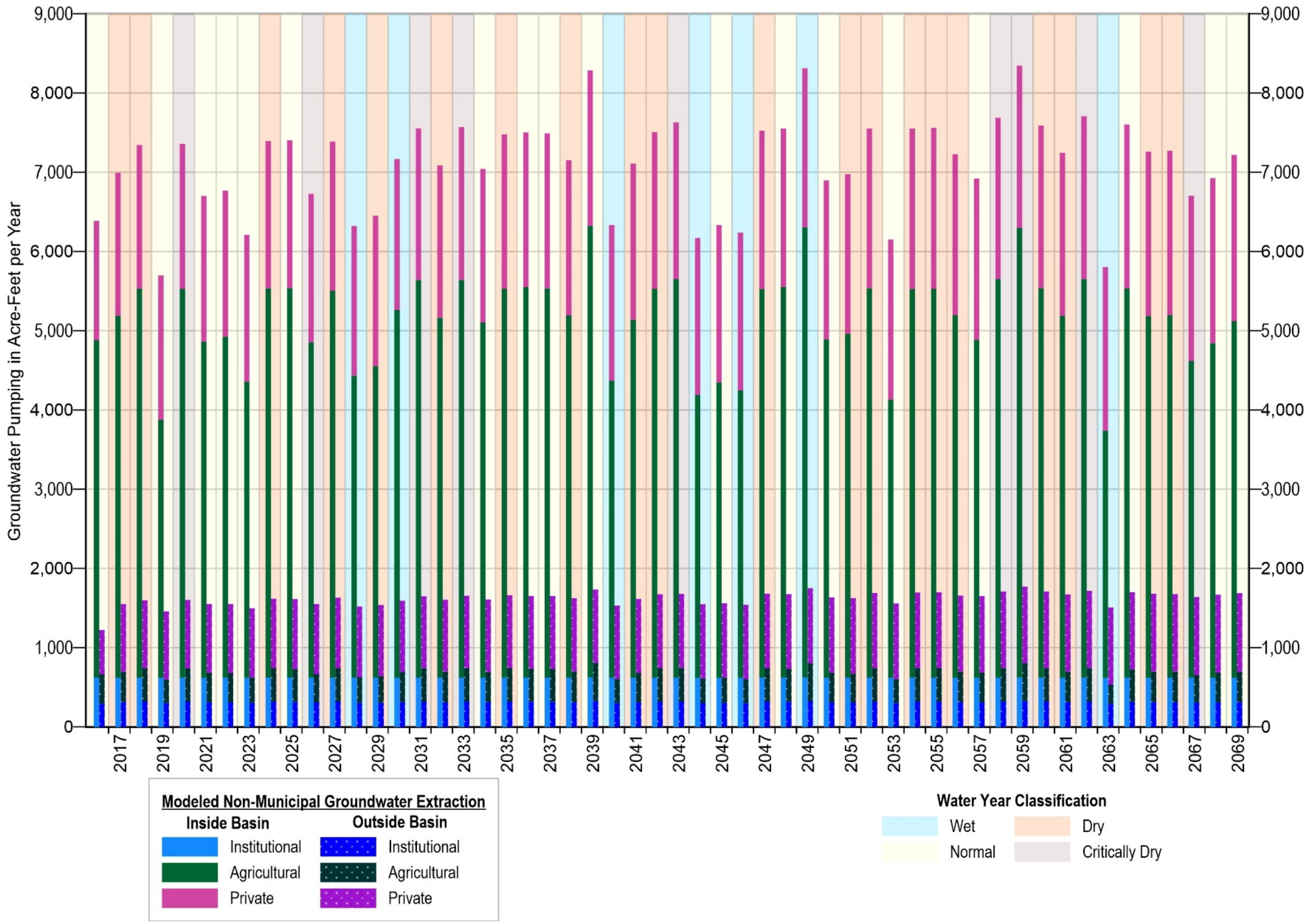

Figure 7. Non-Municipal Pumping for Baseline and Projects Simulation

3 PROJECT ASSUMPTIONS FOR FUTURE SIMULATIONS

The projects simulated by the model are SqCWD Pure Water Soquel (PWS) and the City of Santa Cruz Aquifer Storage and Recovery (ASR). These projects are included in the GSP as projects and management actions evaluated against the sustainable criteria. These are the projects included because they have been developed and thoroughly vetted by their respective proponent MGA member agency and are planned for near-term implementation by that agency.

The simulation of future conditions for the GSP includes both the PWS and ASR projects. This simulation provides information on whether the projects help achieve the sustainability goal and interim milestones. It is also used to estimate the future water budget with projects and management actions implemented as part of the GSP. In order to evaluate expected benefits of each project separately, a simulation of only PWS is performed. The expected benefits of PWS are evaluated by comparing the results of this simulation with the baseline simulation. The expected benefits of ASR are evaluated by comparing the results of the simulation of future conditions with both projects (PWS + ASR) to simulation of PWS only.

3.1 Description of Projects

3.1.1 Pure Water Soquel

SqCWD's Pure Water Soquel (PWS) would provide advanced water purification to existing secondary-treated wastewater that is currently disposed of in the Monterey Bay National Marine Sanctuary. The project would replenish 1,500 acre-feet per year of advanced purified water that meets or exceeds drinking water standards into aquifers within the Basin. Replenishment is currently planned at three locations in the central portion of SqCWD's service area. Purified water would mix with native groundwater and contribute to the restoration of the Basin, provide a barrier against seawater intrusion, and provide a drought proof and sustainable source of water supply. The conveyance infrastructure of PWS is being sized to accommodate the potential for future expansion of the Project's treatment system (if desired at a later time) and to convey up to approximately 3,000 acre-feet per year of purified water.

The PWS Environmental Impact Report (EIR) and project were approved by the lead agency in December 2018. The project is currently in the design and permitting phase and construction is anticipated to be completed in late 2022 with the project to come online in early 2023.

PWS injection is planned into the Basin's Purisima A and BC units. PWS also supports in-lieu recharge in aquifer units and areas where water is not directly injected. In-lieu recharge is facilitated in this simulation of PWS for the GSP by increasing SqCWD pumping from Purisima A and BC aquifer units where PWS injection takes place, which allows for reductions of

SqCWD pumping from the Tu aquifer unit in the western portion of the Basin and from the Purisima F and Aromas Red Sands in the eastern portion of the Basin. Figure 8 shows a map schematic of this strategy for the areas of injection (recharge, down arrows), increased pumping (plus signs), and decreased pumping (minus signs). Therefore, PWS is designed to provide benefits for sustainability throughout the portion of the Basin pumped by SqCWD.

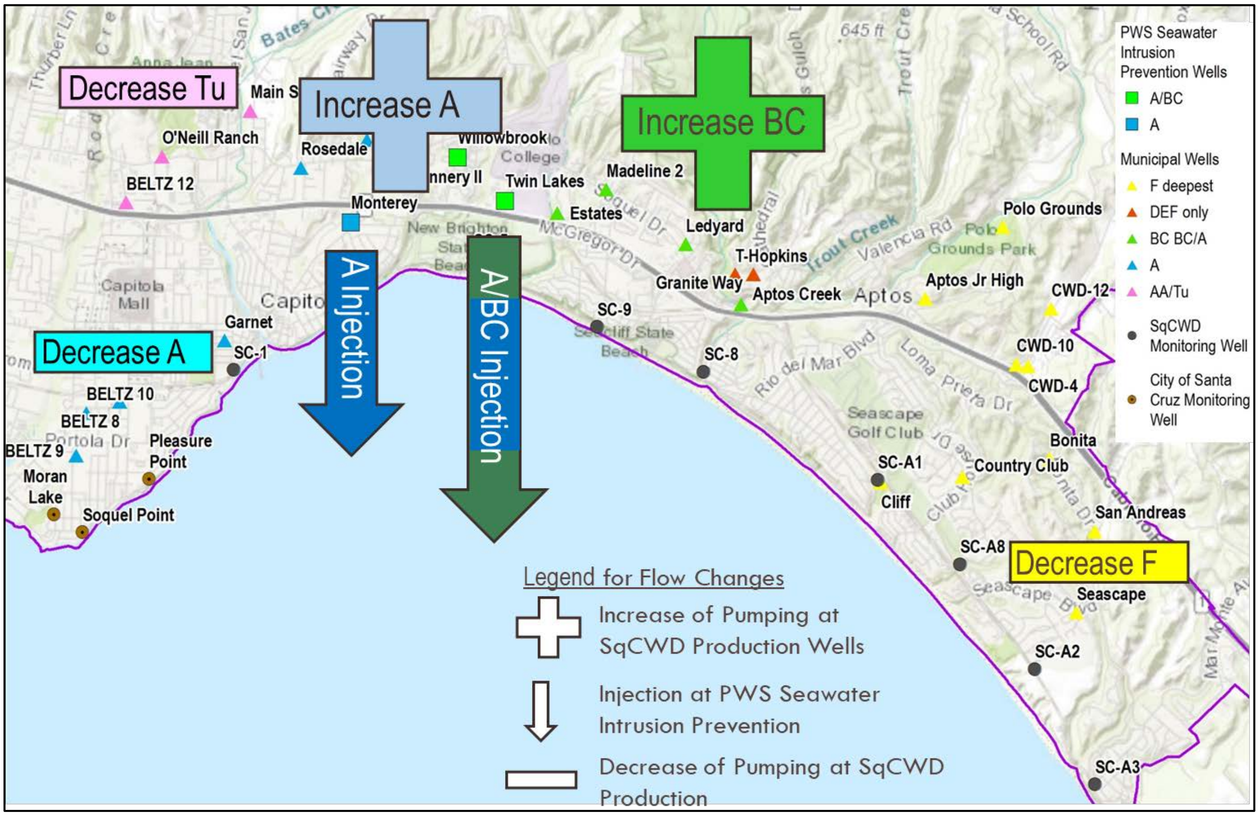

Figure 8 Map Schematic of Changes in Pumping Distribution from Pure Water Soquel Injection

3.1.2 City of Santa Cruz ASR

The ASR project would inject surface water from excess winter flows, treated to drinking water standards, into the natural structure of Basin aquifers which act as an underground storage reservoir. SCWD can treat excess surface water by improving the treatment process at its Graham Hill Water Treatment Plant. Surface water can only be considered excess if it is produced within SCWD's water rights, is above the volume of water required for SCWD operations, and after allowing for fish flows. The primary purpose of the ASR project is to store drinking water in the Basin to provide a drought supply for SCWD's service area. The ASR project is expected to also contribute to Basin sustainability but this may require additional capacity and changes to water rights.

As part of its efforts to update and align its water rights on the San Lorenzo River to incorporate fish flow requirements and provide additional operational flexibility including for ASR, the SCWD has initiated a water rights change process with the State Water Resources Control Board. Compliance with the California Environmental Quality Act (CEQA) for the water rights changes and the ASR project as well additional permitting will need to be completed before full scale ASR is implemented.

ASR pilot tests began at SCWD's Beltz 12 well in 2019. During the winter of 2019/2020, additional pilot testing at Beltz 12 may occur and an additional Beltz well is slated to be retrofitted for pilot testing. Assuming results from the initial pilot testing during 2019 continues to be positive and regulatory requirements are met, full scale phased implementation of ASR would occur beginning in 2021.

The ASR project modeled for the GSP optimizes existing SCWD infrastructure as a more efficient use of available resources to inject excess drinking water into Basin aquifers. However, since SCWD is in the process of developing its plans for the ASR project, eventual implementation of the ASR project may include different strategies and possibly new infrastructure. For evaluation in the GSP, simulations of the ASR project assume that injection and pumping recovery for ASR occurs at the existing Beltz wells: Beltz 8, Beltz 9, Beltz 10, and Beltz 12. These wells are screened in the Purisima A, Purisima AA, and Tu units. The simulation of ASR for the GSP also includes the possibility of in-lieu recharge that reduces groundwater pumping over some periods due to improved treatment and therefore delivers drinking water quality surface water to directly meet demand. Figure 9 shows a map schematic of the strategy for this simulation of ASR for the areas of injection (recharge, down arrows), increased average pumping (plus signs), and decreased average pumping (minus signs). The schematic shows average simulated changes from the assumed baseline, but injection and pumping compared to baseline varies over time based on surface water availability and demand.

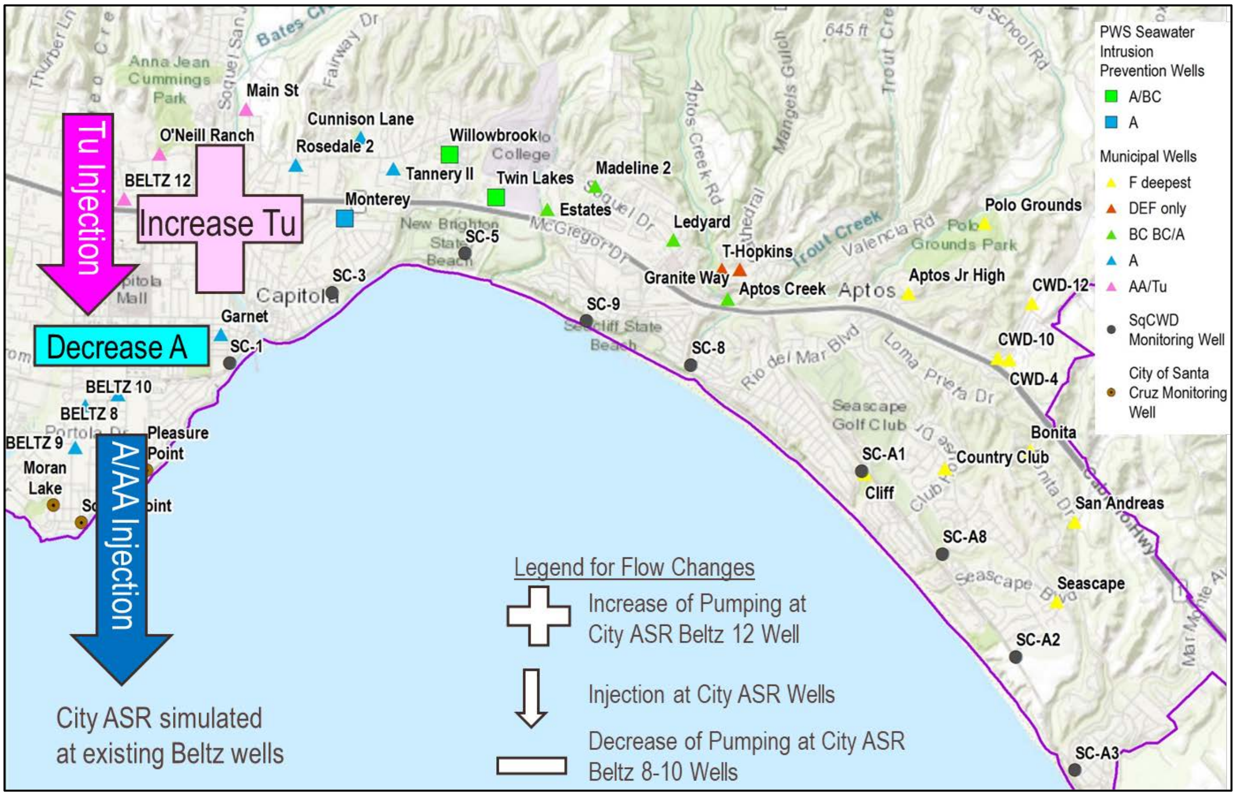

Figure 9 Map Schematic of Changes to ASR Injection and Pumping Distribution

3.2 Implementation of Projects in Model

Projects are simulated in the model by the Multi-Node Well 2 (MNW2) MODFLOW package. The package defines the model cell location of the wells and either the screen elevations or model layers of the screens. Monthly time series of well flows for both pumping and injection are assigned to each well in the model.

3.2.1 Pure Water Soquel

The PWS seawater intrusion prevention (SWIP) wells are added to the wells included in the baseline simulation. The SWIP wells are assigned to model cells based on their planned location and assigned specific model layers for injection. Injection rates are assigned based on estimated injection capacities for the wells and adjusted if model results show simulated groundwater elevations at the SWIP well rising above ground surface elevations. PWS injection at the SWIP wells is simulated to start October 2022 for Water Year 2023 and to continue for the remainder of the future conditions simulation (through Water Year 2069).

Table 5. Simulated SWIP Well Location and Injection Rates

Well	Aquifer	Injection (acre-feet per year)	Capacity Estimate Source	Notes
		2023-2069		
Monterey SWIP	Purisima A	500	Carollo, 2016	-
Willowbrook SWIP	Purisima A	233	Section 4.1	Screening Purisima BC also to be evaluated
Twin Lakes SWIP	Purisima BC/A	742	Preliminary Estimate from Pilot Testing	-

SqCWD pumping for PWS is redistributed from the baseline simulation to represent the strategy shown in Figure 8. Redistribution commences in Water Year 2023 with the commencement of PWS injection. Redistribution changes starting in Water Year 2026 when the Cunnison Lane well is simulated to come online. As with the baseline, redistributed pumping is different between critically and non-critically dry years. Monthly pumping is redistributed such that total monthly pumping is the same as the baseline simulations while pumping at any well does not exceed the well's monthly pumping capacity based on 50% runtime. The following summarizes the wells with pumping changes for PWS.

- Pumping increases at Tannery, Cunnison Lane (after it comes online in 2026), and Estates wells screened in the Purisima A unit where injection occurs from PWS SWIP wells.
- Pumping increases at the Estates, Madeline, Ledyard, and Aptos Creek wells screened in the Purisima BC unit where injection occurs from PWS SWIP wells.. The Estates well is screened in both the Purisima A and BC units.
- Pumping decreases at the Main Street and O'Neill Ranch wells in the Purisima AA and Tu units in the western portion of the Basin.
- Pumping decreases at the Garnet well in the Purisima A unit in the western portion of the Basin.
- Pumping decreases at the Bonita and San Andreas wells simulated to extract from the Purisima F unit in the eastern portion of the Basin.

Table 6 shows the pumping changes from baseline assumptions and redistributed pumping for simulations of PWS for critically and non-critically dry years. Figure 5 shows the change in pumping from baseline assumptions by aquifer unit over time and the redistributed pumping for the simulations of PWS under future conditions.

Table 6. Soquel Creek Water District Pumping Distribution by Well for Project Simulations in Critically and Non-Critically Dry Years

Well	Aquifer	Non-Critically Dry	Non-Critically Dry	Critically Dry	Average Change From Baseline
		acre-feet per year			
		2023-2025	2026-2069		
O'Neill Ranch Well	Purisima AA/Tu	182	182	181	-47
Main St Well	Purisima AA/Tu	348	348	352	-180
Rosedale 2 Well	Purisima A/AA	544	544	553	0
Garnet Well	Purisima A	222	222	123	-49
Cunnison Lane	Purisima A	0	426	426	184
Tannery Well II	Purisima A	689	563	563	348
Estates Well	Purisima BC/A	466	398	398	86
Madeline 2 Well	Purisima BC	122	122	122	24
Ledyard Well	Purisima BC	120	120	120	12
Aptos Creek Well	Purisima DEF/BC	144	102	102	105
T-Hopkins Well	Purisima DEF	156	137	137	0
Granite Way	Purisima DEF	145	135	135	0
Polo Grounds Well	Purisima F	100	100	100	0
Aptos Jr High Well	Purisima F	250	250	250	0
Country Club Well	Aromas / Purisima F	70	70	70	0
Bonita Well	Aromas / Purisima F	137	68	107	-190
San Andreas Well	Aromas / Purisima F	159	64	106	-293
Seascape Well	Aromas / Purisima F	46	46	46	0

Note: Totals do not equal 3,900 acre-feet per year due to rounding error

3.2.2 City of Santa Cruz ASR

The ASR project simulated for the GSP involves pumping and injection at existing SCWD wells also simulated in the baseline simulation: Beltz wells 8, 9, 10, and 12. Based on this configuration assumed for evaluation in the GSP, SCWD groundwater pumping and injection by month at each well was provided for the projects simulation by Pueblo Water Resources Inc. assuming a combined capacity for the four wells of 1.0 million gallons per day of injection and 1.5 million gallons per day of extraction. This time series input was based on availability of surface water under the Catalog Climate and WY 2016-2018 demands to meet ASR storage objectives as modeled by Gary Fiske & Associates as part of the SCWD's ASR feasibility evaluation. ASR is simulated to commence injection in Water Year 2020 and injection and pumping recovery continues through Water Year 2069 for the remainder of the simulation of future conditions.

The ASR pumping and injection distribution is based on estimated pumping and injection capacities for the wells and prioritization of Beltz 12 use due to less susceptibility to seawater intrusion. Beltz 12 is considered less susceptible to seawater intrusion based on its distance from coast and being screened in the Purisima AA and Tu units that do not outcrop offshore like the Purisima A unit where the other Beltz wells are screened. Therefore, the ASR pumping distribution is different than the pumping distribution assumed under the baseline simulation. As shown in Figure 9, ASR results in an increase in gross pumping from the Tu unit at the Beltz 12 well and a decrease in gross pumping from the Purisima A unit at the Beltz 8, 9, and 10 wells compared to the baseline simulation. Table 7 shows average assumed injection and pumping at the Beltz wells for ASR for different time periods.

Table 7. Average Pumping and Injection at Beltz Wells for Simulation of ASR

Period	Pumping (acre-feet per year)					Injection (acre-feet per year)				
	Beltz 8	Beltz 9	Beltz 10	Beltz 12	Total	Beltz 8	Beltz 9	Beltz 10	Beltz 12	Total
2017-2019	74	84	92	100	350	0	0	0	0	0
2020-2025	9	10	11	12	42	93	77	74	186	430
2026-2039	47	53	58	64	222	84	70	67	167	388
2040-2069	54	61	67	73	255	73	61	58	146	338

Based on the availability of the SCWD's surface water supply, injection and pumping with ASR varies over time as shown on Figure 6. The second chart of Figure 6 shows the annual change in net pumping with ASR compared to the baseline simulation. The third and fourth charts of Figure 6 shows annual pumping and injection respectively. The most significant shortage of surface water supply availability occurs in the two year period of Water Years 2058 and 2059 when pumping recovery is the greatest.

4 MODEL RESULTS

4.1 Evaluation of Well Capacities

The model is used to evaluate well capacities during injection by evaluating simulated heads at the well during injection in comparison to ground surface. Simulated heads substantially above ground surface indicate that the well capacity has been exceeded. Simulated heads at the wells are based on output from the model's MNW2 package that distinguish simulated heads in the well from groundwater elevations for the model grid cell representing aquifer conditions.

4.1.1 Pure Water Soquel

Simulated heads at the Monterey, Willowbrook, and Twin Lakes Church PWS SWIP wells are compared to ground surface elevations. The estimated injection rates of 500 acre-feet per year at the Monterey SWIP well and 742 acre-feet per year at the Twin Lakes Church SWIP well are not simulated to raise heads at the wells to ground surface. The injection rate of 233 acre-feet per year at the Willowbrook SWIP well is the estimated injection capacity based on simulated well heads rising near ground surface. Figure 10 shows the simulated heads at the three SWIP wells for the simulations of PWS with green line labeled PWS+ASR, and without (blue dashes labeled PWS) ASR compared to ground surface (black dashes). The difference between the simulations is negligible.

4.1.2 City of Santa Cruz ASR

Simulated heads at Beltz 8, 9, 10, and 12 wells planned for ASR are compared to ground surface elevations for the project simulation including ASR operations. The estimated total injection rate of 1.0 million gallons per day and distribution are based on groundwater levels at the wells rising to ground surface elevations but not substantially above ground surface. Figure 11 shows the simulated heads at the four Beltz ASR wells for the project's simulation, including ASR shown as a green line and labeled PWS+ASR compared to ground surface (black dashes). Also shown on Figure 11 are simulated heads for the baseline simulation (yellow line) and the simulation of PWS (blue dashes) without ASR. There is negligible effect of PWS at Beltz 8, 9, and 10. Reduction of Tu aquifer pumping planned with implementation of PWS does potentially limit injection capacity at Beltz 12.

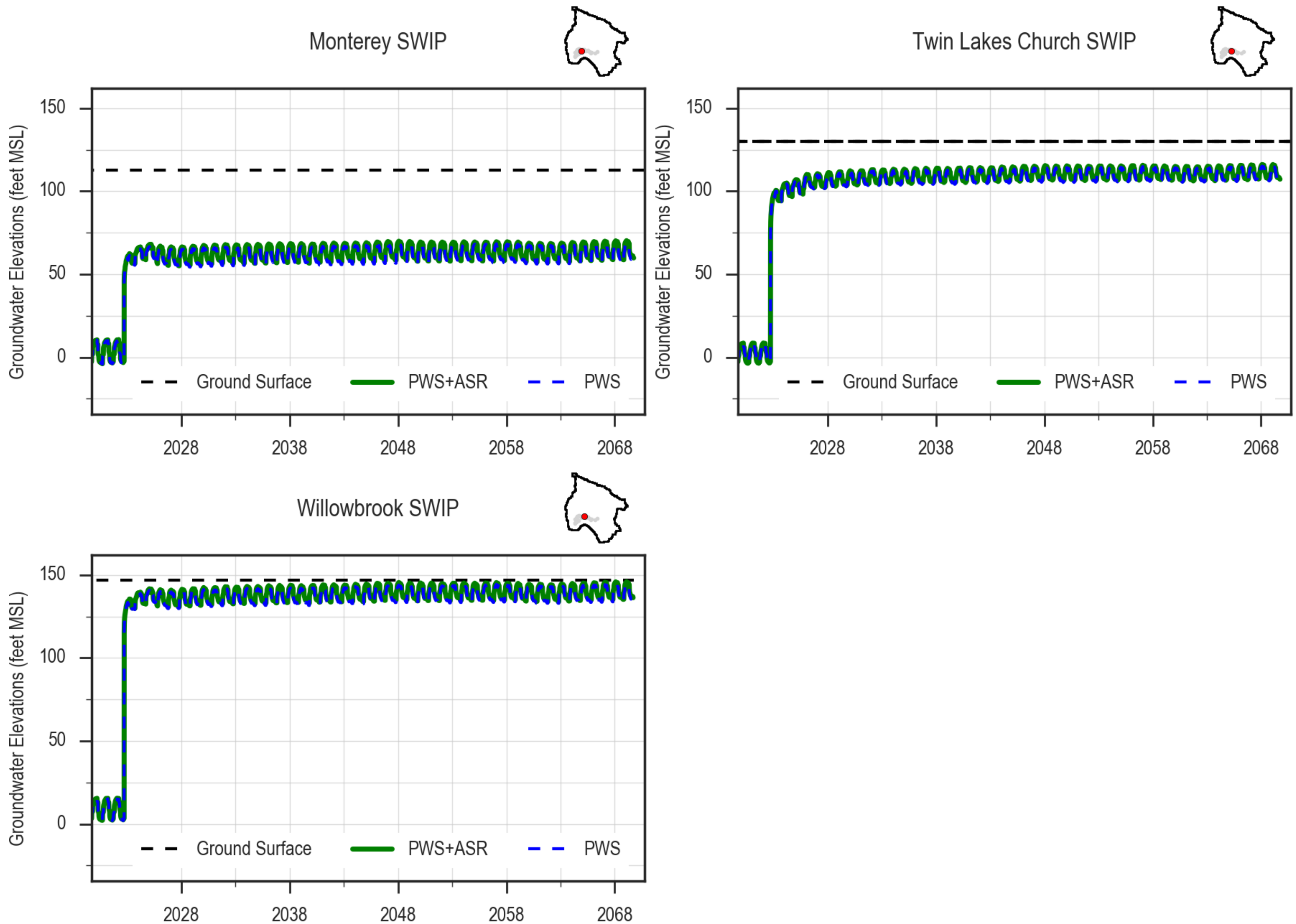

Figure 10. Simulated Well Heads at PWS Seawater Intrusion Prevention Wells versus Ground Surface

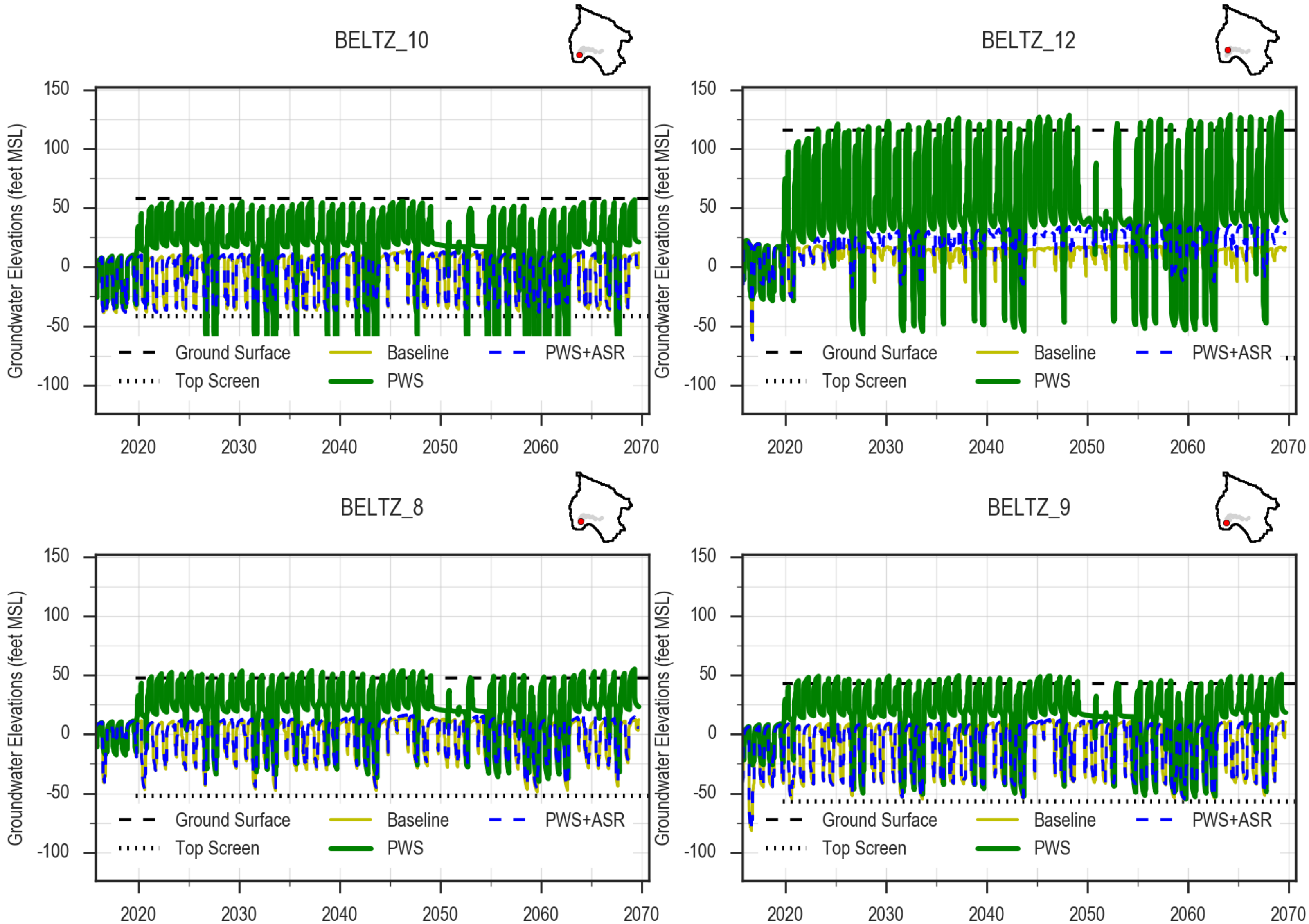

Figure 11. Simulated Well Heads at Beltz ASR Wells vs. Ground Surface

4.2 Expected Seawater Intrusion Benefits of Projects

Expected seawater intrusion benefits of projects are evaluated based on simulated groundwater elevations at the GSP's representative monitoring points with groundwater elevation proxies for protecting the Basin from seawater intrusion (Figure 12). The GSP defines the groundwater elevation proxies based on five-year averages so running five-year averages are calculated from the model's monthly output for comparison with minimum thresholds and measurable objectives. To avoid undesirable results, the running five-year average must achieve the groundwater elevation proxy for the minimum threshold at all of the representative monitoring points by 2040 and be maintained above the minimum threshold thereafter. The goal of the GSP is to achieve measurable objectives to provide operational flexibility, but five-year averages of groundwater elevations below measurable objectives are not considered undesirable results.

The effect of sea level rise is incorporated into the model evaluation of whether projects can raise and maintain groundwater elevations to meet and exceed the groundwater elevation proxies for minimum thresholds. As described in Section 2.3, the model incorporates projected sea level rise up to 2.3 feet in the offshore boundary condition for simulations of future conditions. Since the datum in the model is set at current sea level, simulated future groundwater levels were compared to the groundwater elevation proxies plus the total sea level rise of 2.3 feet. This allows evaluation of whether projects and management actions will raise and maintain groundwater elevations to meet groundwater elevation proxies relative to projections of higher sea levels.

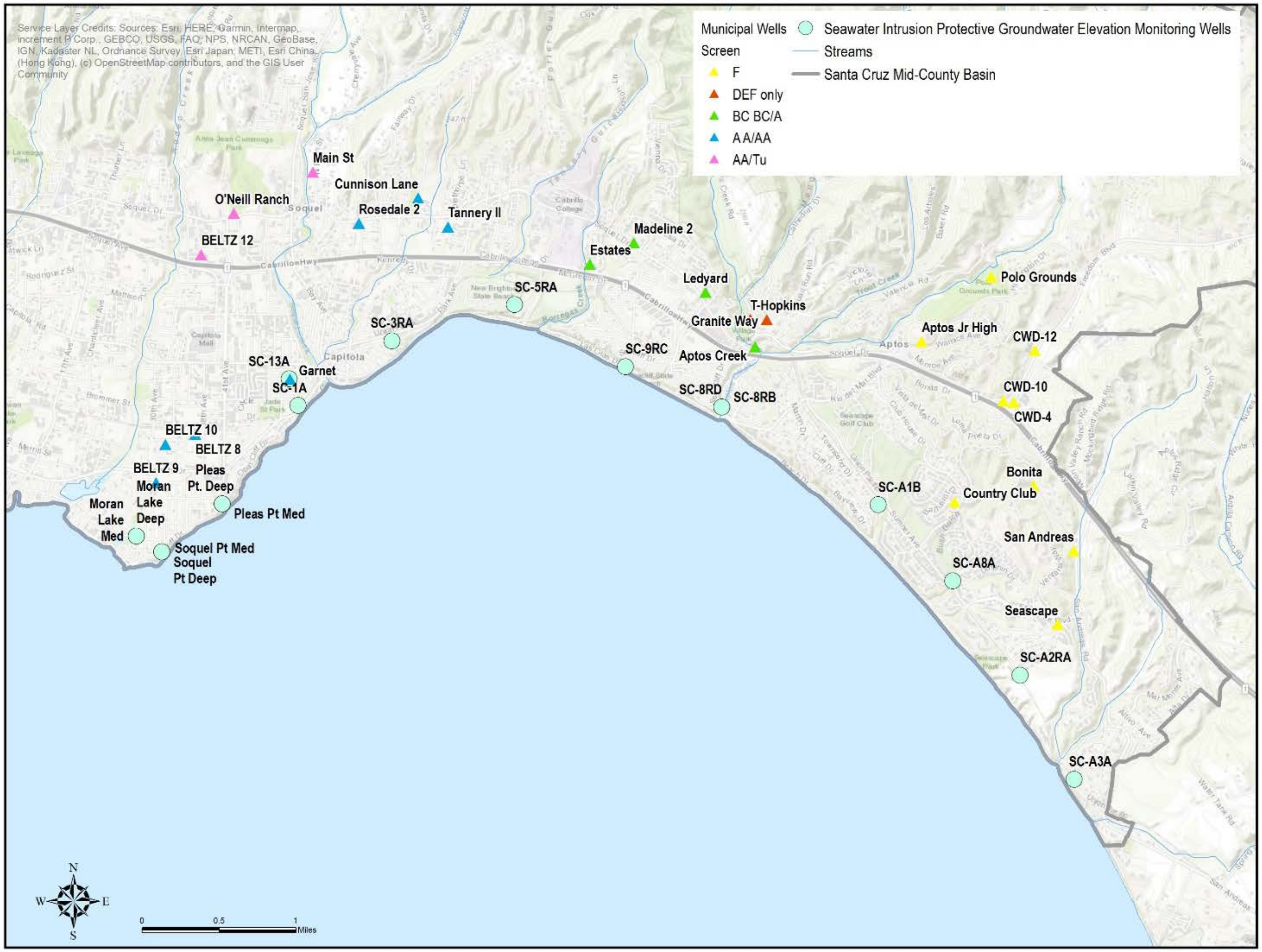

Figure 12. Locations of Representative Monitoring Points with Groundwater Elevation Proxies for Seawater Intrusion in Relation to Municipal Production Wells

4.2.1 Pure Water Soquel

A simulation of the PWS project under projected future climate conditions using the model demonstrates expected Basin sustainability benefits include raising running five-year average groundwater levels at coastal monitoring throughout SqCWD's service area to reduce the risk of seawater intrusion. The figures below show running five-year averages of simulated groundwater levels at representative monitoring points for seawater intrusion in the SqCWD's service area. The simulated groundwater levels are compared to groundwater elevation proxies for minimum thresholds (black dots) and measurable objectives (black dashes) adjusted for sea level rise.

Without the project (yellow line labeled Baseline), undesirable results for seawater intrusion are projected to occur in the Purisima A (Figure 13), Purisima BC (Figure 13), Purisima F (Figure 14) and Tu aquifer units (Figure 15). Running five-year average simulated groundwater levels are projected to be below the minimum threshold at representative monitoring points in these aquifer units pumped by SqCWD.

In the Purisima A and BC aquifer units where PWS injection occurs, groundwater levels are projected to rise to or above measurable objectives (blue dashes labeled PWS) even as pumping is increased from these aquifer units (Figure 13).

In the Purisima F and Aromas Red Sands aquifer units where pumping is reduced under PWS, groundwater levels (blue dashes labeled PWS overlying green line labeled PWS+ASR) are projected to rise above or near measurable objectives by 2040 and to be maintained above minimum thresholds thereafter so that undesirable results for seawater intrusion do not occur (Figure 14).

Figure 15 shows how pumping reduction from the Purisima AA and Tu units under PWS (blue dashes) also is projected to raise groundwater levels above minimum thresholds to prevent undesirable results for seawater intrusion.

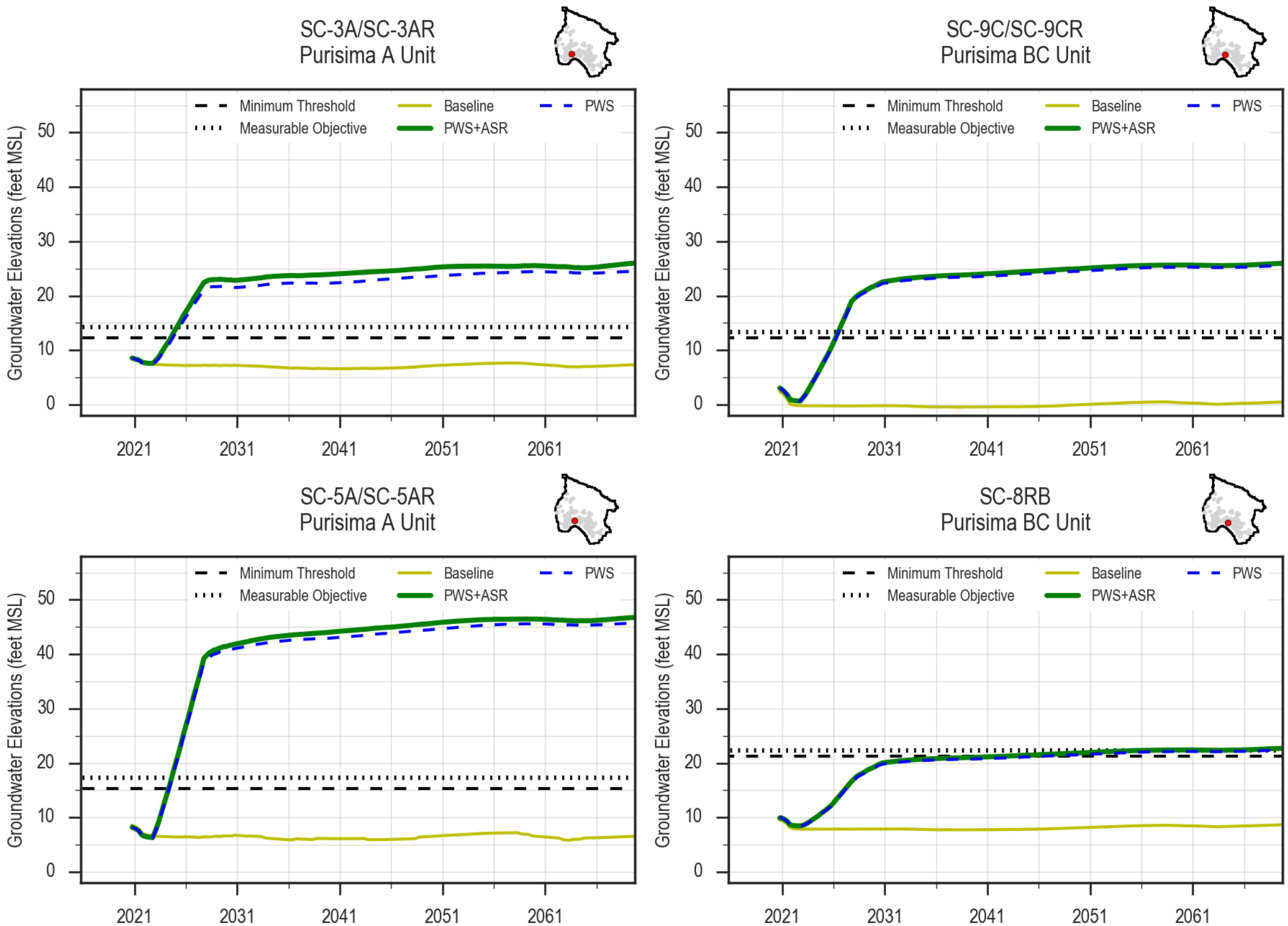

Figure 13. Running Five-Year Average Model Simulated Groundwater Elevations at Coastal Monitoring Wells in Purisima A and BC Units

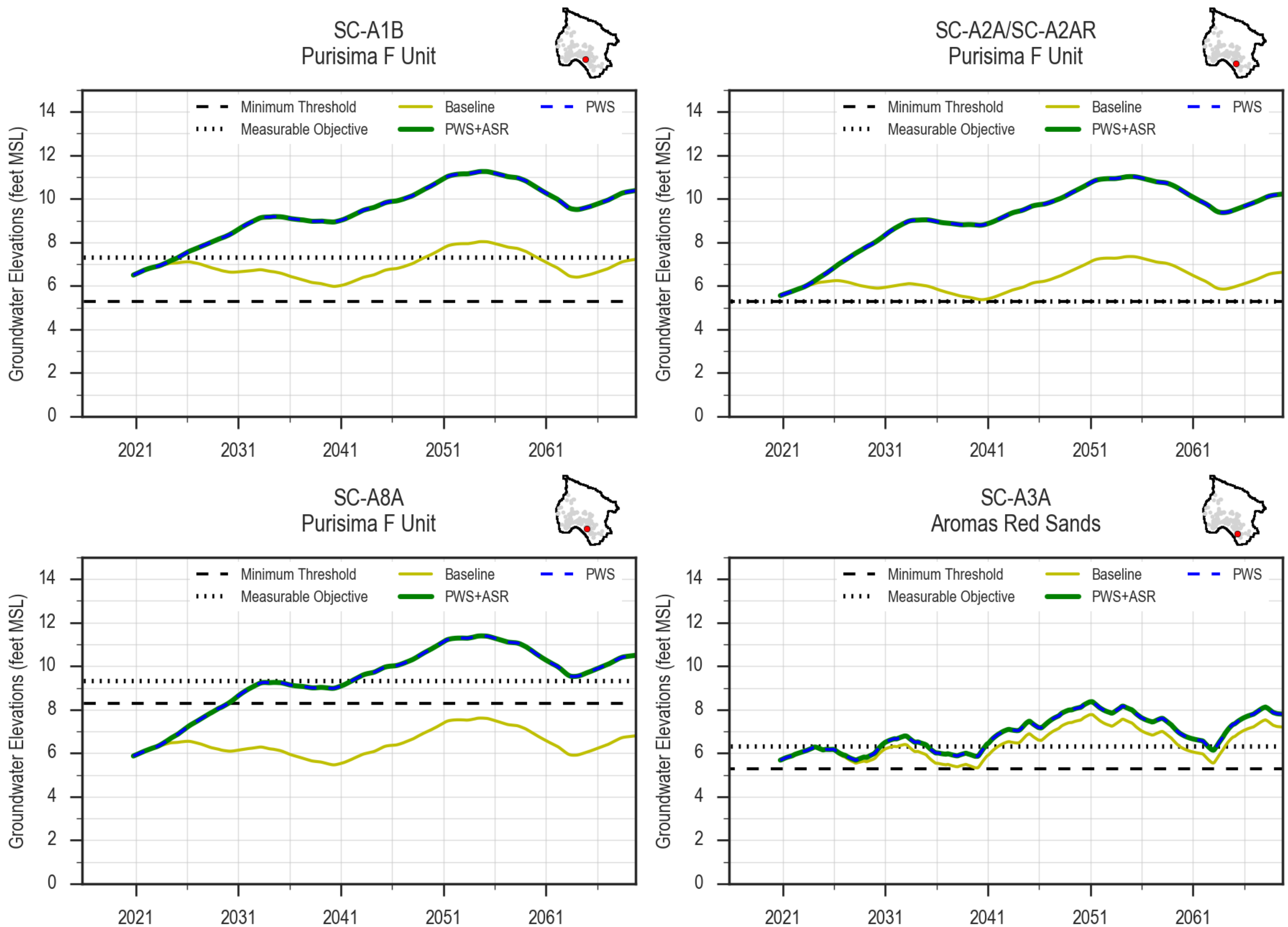

Figure 14. Running Five-Year Average Model Simulated Groundwater Elevations at Coastal Monitoring Wells in Purisima F and Aromas Red Sands Units

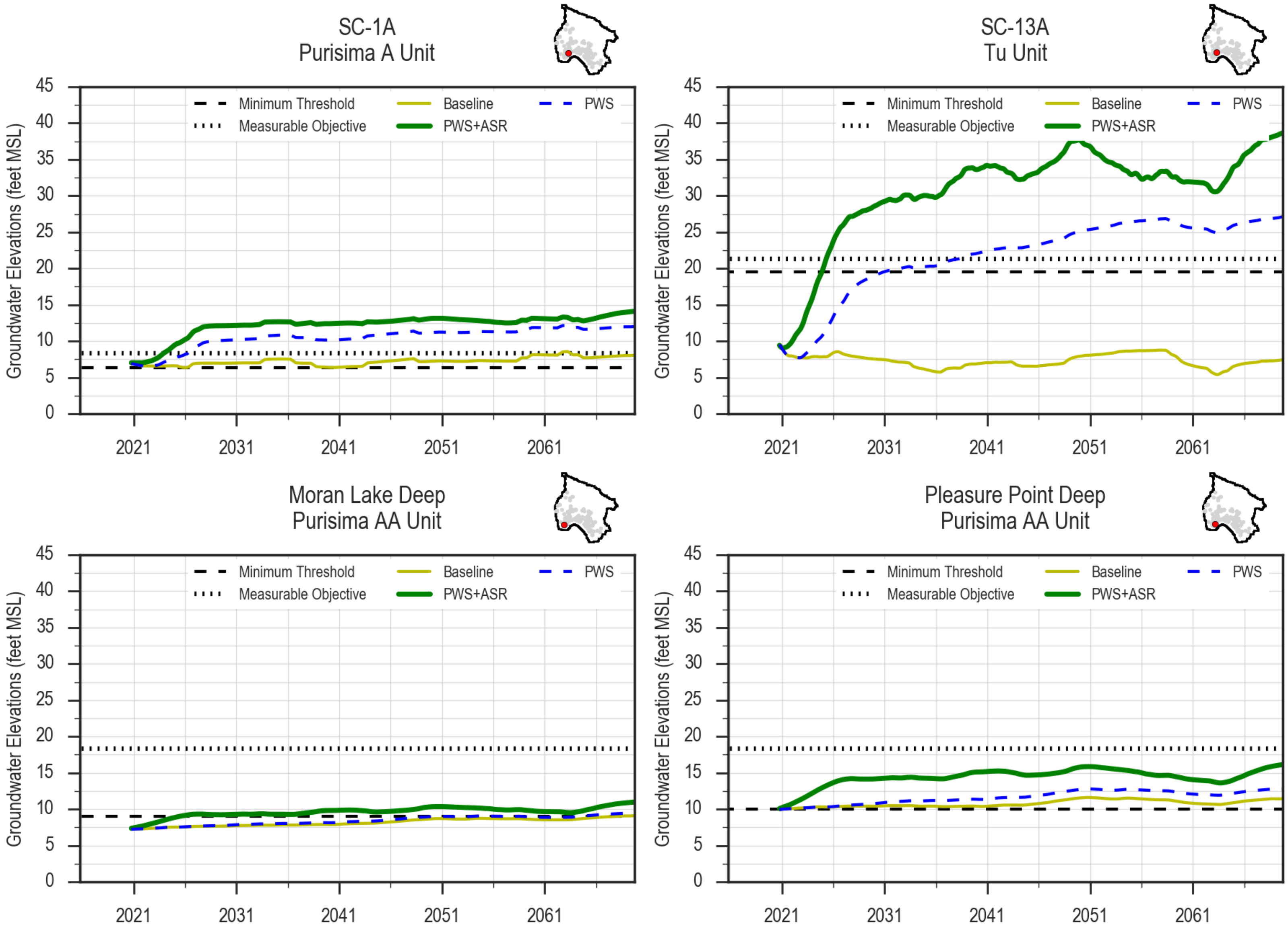

Figure 15. Running Five-Year Average Groundwater Elevations at Coastal Monitoring Wells in Tu and Purisima AA and A Units

4.2.2 City of Santa Cruz ASR

Expected benefits for seawater intrusion sustainability are to raise average groundwater levels at coastal monitoring in SCWD's service area and reduce the risk of seawater intrusion. A simulation of ASR, in combination with the PWS, under projected future climate conditions using the model demonstrates these expected benefits. Figure 15 shows running five-year average simulated groundwater levels at Moran Lake, Soquel Point and Pleasure Point representative monitoring points for seawater intrusion (Figure 12) in SCWD's service area. The simulated groundwater levels are compared to groundwater elevation proxies for minimum thresholds (black dots) and measurable objectives (black dashes) adjusted for sea level rise.

Without ASR, undesirable results are projected to occur as running five-year average simulated groundwater levels are projected to be below the minimum threshold in the Purisima AA unit under the baseline projection. The baseline projection also projects that measurable objectives at the representative monitoring points in the Purisima A unit will not be achieved or maintained. These conditions occur whether or not PWS is implemented (yellow line labeled Baseline vs. blue dashes labeled PWS) as PWS does not substantially raise groundwater levels in much of the SCWD service area.

With ASR that injects water at the existing SCWD Beltz wells and reduces pumping at the Beltz wells (green line labeled PWS+ASR), it is projected that measurable objectives will be achieved and maintained in the Purisima A unit that is the primary source of groundwater supply for SCWD, and minimum thresholds will be achieved and maintained in the Purisima AA unit such that undesirable results for seawater intrusion do not occur. ASR is projected to raise groundwater levels sufficiently such that sustainability is maintained even as SCWD increases recovery pumping to meet drought demand from the 2050s into the early 2060s.

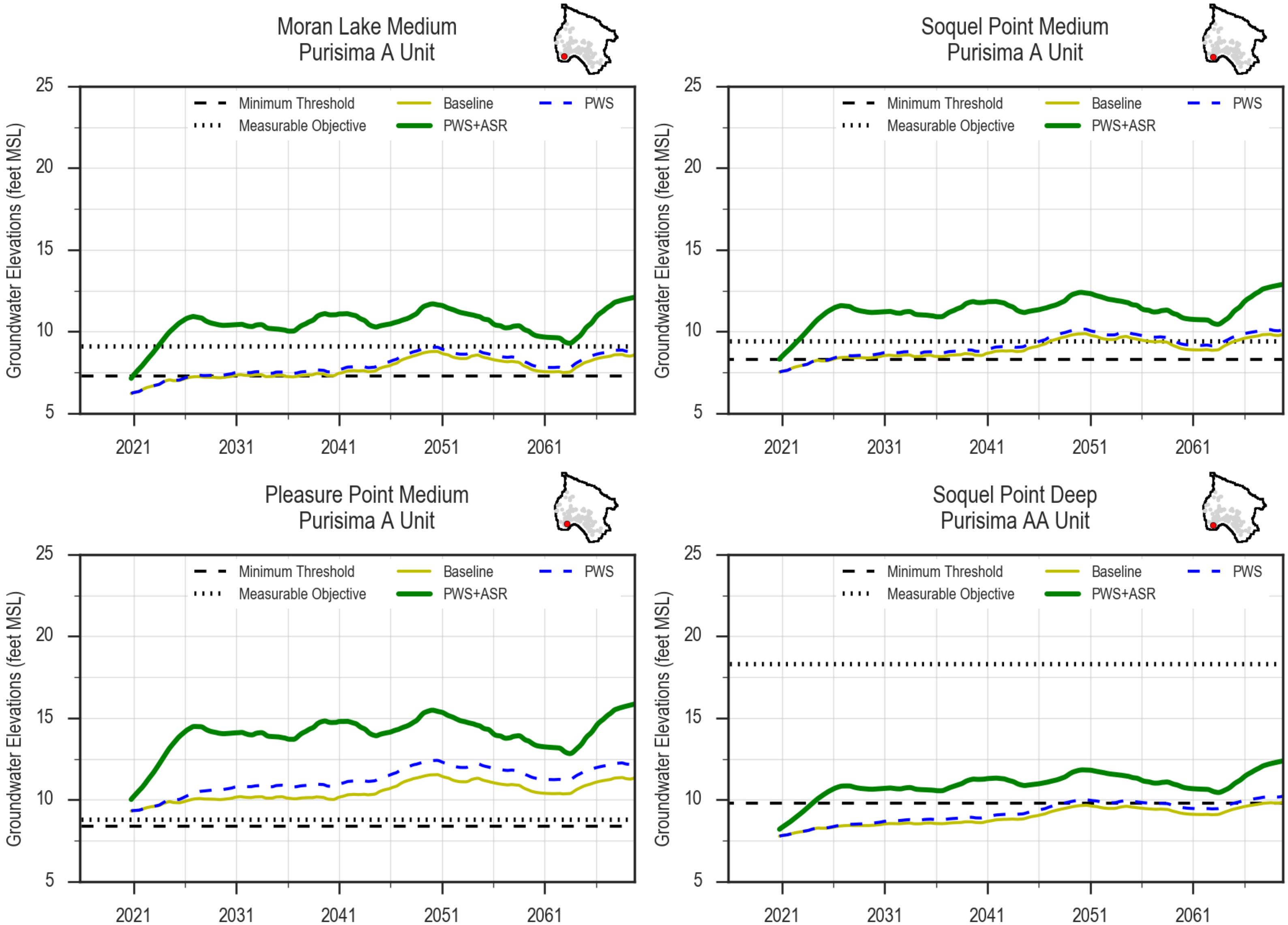

Figure 16. Running Five-Year Average Groundwater Elevations at Coastal Monitoring Wells in Purisima AA and A Units

4.3 Expected Streamflow Depletion Benefits of Projects

Expected streamflow depletion benefits of projects are evaluated based on simulated groundwater elevations at the GSP's representative monitoring points at shallow wells along Soquel Creek with groundwater elevation proxies for preventing increased surface water depletion (Figure 17). The GSP defines the groundwater elevation proxies based on minimum annual groundwater elevations so monthly results from the model are compared to groundwater elevation proxies. To avoid undesirable results, seasonal low groundwater elevations must be above the groundwater elevation proxy for the minimum threshold at all of the representative monitoring points starting in 2040. The goal of the projects is to achieve measurable objectives to provide operational flexibility, but groundwater elevations below measurable objectives are not considered undesirable results.

Figure 17. Locations of Monitoring Wells used as Representative Monitoring Points with Groundwater Elevation Proxies for Streamflow Depletion

4.3.1 Pure Water Soquel

Pure Water Soquel replenishment into the Purisima A unit is also expected to benefit the streamflow depletion sustainability indicator by raising shallow groundwater levels along Soquel Creek. Without PWS (yellow line labeled Baseline), simulated monthly groundwater levels are projected to be below the minimum threshold at most of the shallow wells. With the PWS project, shallow groundwater levels (blue dashes labeled PWS) are projected to rise to measurable objectives and be maintained above minimum thresholds to prevent undesirable results for surface water depletions (Figure 18 and Figure 19).

Figure 18. Simulated Groundwater Elevations at Purisima A Unit along Soquel Creek

4.3.2 City of Santa Cruz ASR

The hydrographs on Figure 19 show that expected benefits are maintained when combining SCWD’s ASR project to PWS (green line labeled PWS+ASR). In addition, shallow groundwater levels rise to measurable objectives at the representative monitoring points for surface water depletion.

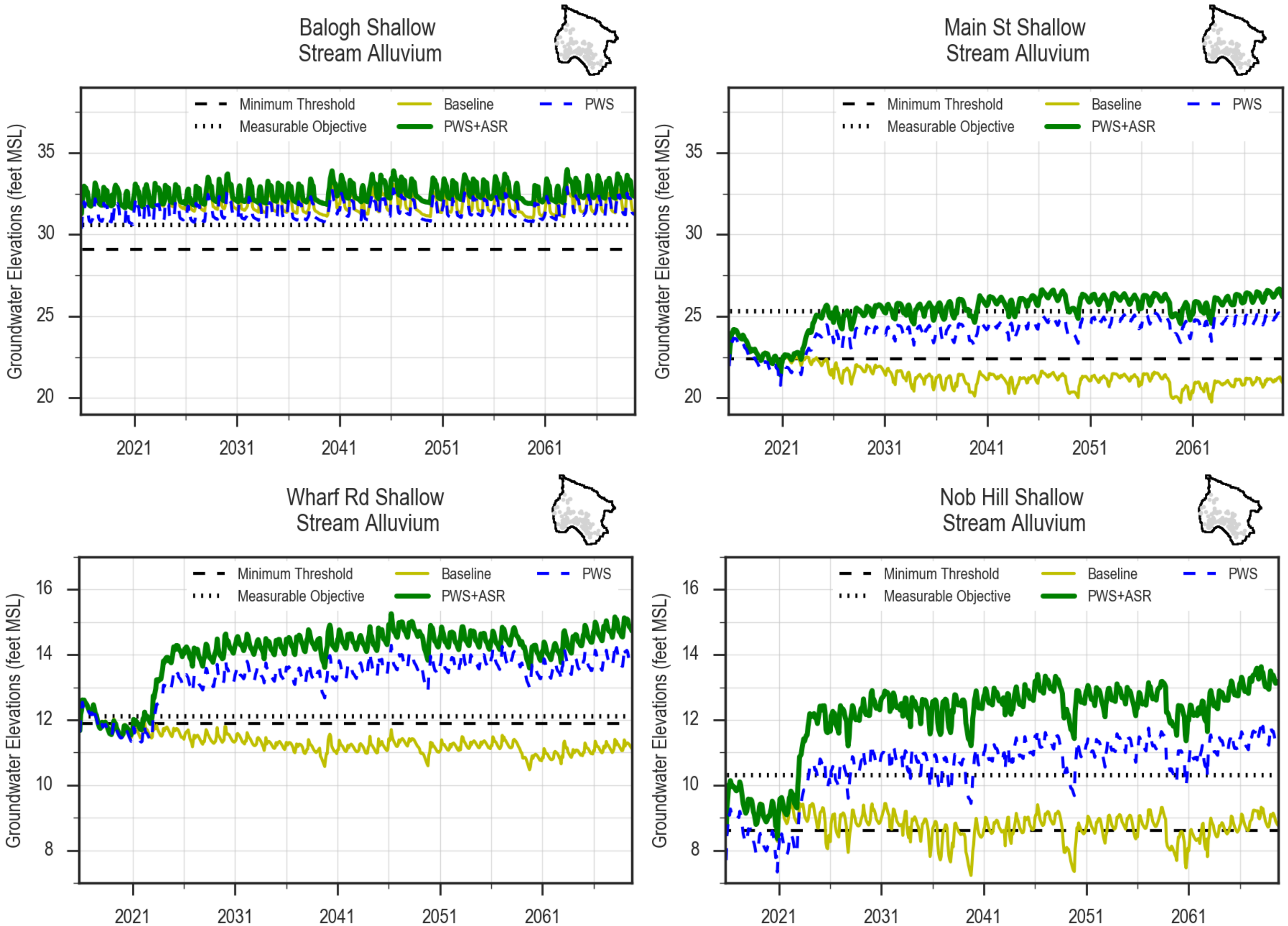

Figure 19. Simulated Groundwater Elevations at Shallow Monitoring Wells along Soquel Creek

4.4 Estimates of Interim Milestones

Interim milestones are interim measurable objectives set at five-year intervals and will be used to measure progress toward the minimum thresholds and measurable objective by 2040. The model is used to estimate groundwater elevation proxies for interim milestones based on the simulation of projects (PWS+ASR) under future conditions at representative monitoring points for seawater intrusion and surface water depletion. The interim milestones are based on modeled groundwater elevation results at representative monitoring points for 2025, 2030, and 2035.

If simulated groundwater elevations in 2025 are above minimum thresholds, the minimum thresholds are used as the interim milestone because there is some uncertainty about when projects would begin. This GSP sets as an interim milestone the elimination of undesirable results by 2025 at locations where model results show it is achievable with project implementation. If modeled groundwater levels in 2030 and 2035 are above measurable objectives, the measurable objectives are used as the interim milestones for those years.

4.4.1 Seawater Intrusion Interim Milestones

Groundwater elevation proxies for seawater intrusion are based on the five-year average of simulated groundwater elevations in Water Years 2025, 2030, and 2035. The simulated groundwater elevations are plotted as the green line labeled PWS+ASR in Figure 13 through Figure 16. Table 8 summarizes the interim milestones for seawater intrusion groundwater elevation proxies.

Table 8. . Interim MIlestones for Seawater Intrusion Groundwater Elevation Proxies

Representative Monitoring Well with Aquifer Unit in Parenthesis	Minimum Threshold	Measurable Objective	Interim Milestone 2025	Interim Milestone 2030	Interim Milestone 2035
	feet above mean sea level				
SC-A3A (Aromas)	3	7	3	3.7	3.7
SC-A1B (F)	3	5	3	5	5
SC-A8RA (F)	6	7	4.5	6.0	6.9
SC-A2RA (F)	3	4	3	4	4
SC-8RD (DEF)	10	11	10	10	10
SC-9RC (BC)	10	11	4.6	11	11
SC-8RB (BC)	19	20	8.4	16.6	18.1
SC-5RA (A)	13	15	13	15	15
SC-3RA (A)	10	12	10	12	12
SC-1A (A)	4	6	4	6	6
Moran Lake Medium (A)	5	6.8	5	6.8	6.8
Soquel Point Medium (A)	6	7.1	6	7.1	7.1
Pleasure Point Medium (A)	6.1	6.5	6.1	6.5	6.5
Moran Lake Deep (AA)	6.7	16	6.7	8.1	7.8
Soquel Point Deep (AA)	7.5	16	7.5	8.3	8.3
Pleasure Point Deep (AA)	7.7	16	7.7	11.8	11.9
SC-13A (Tu)	17.2	19	8.3	16.7	18.1

4.4.2 Surface Water Depletion Interim Milestones

Groundwater elevation proxies for seawater intrusion are based on the annual minimum of simulated groundwater elevations in Water Years 2025, 2030, and 2035. The simulated groundwater elevations are plotted as the green line labeled PWS+ASR in Figure 19. Table 9 summarizes the interim milestones for depletion of interconnected surface water groundwater elevation proxies.

Table 9. Interim Milestones for Deletion of Interconnected Surface Water Groundwater Elevation Proxies

Representative Monitoring Well with Aquifer Unit in Parenthesis	Minimum Threshold	Measurable Objective	Interim Milestone 2025	Interim Milestone 2030	Interim Milestone 2035
	feet above mean sea level				
Balogh	29.1	30.6	29.1	30.6	30.6
Main St. SW 1	22.4	25.3	20.7	22.9	23.2
Wharf Road SW	11.9	12.1	11.3	12.1	12.1
Nob Hill SW 2	8.6	10.3	7.3	9.5	9.9
SC-10RA	68	70	68	70	70

4.5 Basinwide Groundwater Elevation Effects of Projects

Projects are also evaluated based on the area where the projects affect groundwater elevations. Three maps are created for each aquifer unit to evaluate effects of PWS and ASR individually, and the projects in combination.

1. Pure Water Soquel: The effect of PWS is evaluated by mapping the groundwater elevation (head) difference between the PWS simulation and the baseline simulation in September 2039, the approximate seasonal low period before the January 2040 deadline to achieve sustainability.

2. City of Santa Cruz Aquifer Storage and Recovery: The effect of ASR is evaluated by mapping the groundwater elevation (head) difference between the PWS+ASR simulation and the PWS simulation in September 2039, the approximate seasonal low period before the January 2040 deadline to achieve sustainability.

3. Projects in Combination: The effect of the projects in combination is evaluated by mapping the groundwater elevation difference between the PWS+ASR simulation and the baseline simulation in October 2059 at the end of the two year drought over which ASR has its maximum pumping recovery. This will evaluate effects of combined projects when ASR pumping recovery to meet SCWD drought needs is causing groundwater elevations to drop.

The following subsections describe groundwater elevation effects by aquifer unit.

4.5.1 Purisima DEF/F Unit Groundwater Elevation Effects

The simulations of PWS redistribute pumping so that pumping is reduced at the San Andreas and Bonita wells in the Purisima F unit. The PWS and PWS+ASR simulations also increase pumping at the Aptos Creek well that is screened in both the Purisima DEF and BC units. The ASR project does not make any pumping or injection changes to the Purisima DEF or F units.

The upper map of Figure 20 shows the benefits of pumping redistribution with PWS that reduces pumping in the Purisima F unit. Pumping reductions facilitate in-lieu recharge to raise groundwater elevations (green areas) in the Aromas area (southeast portion of the Basin). Increases in groundwater elevations extend to the coastal boundary of the Basin and also across the Basin boundary into the Pajaro Valley Subbasin.

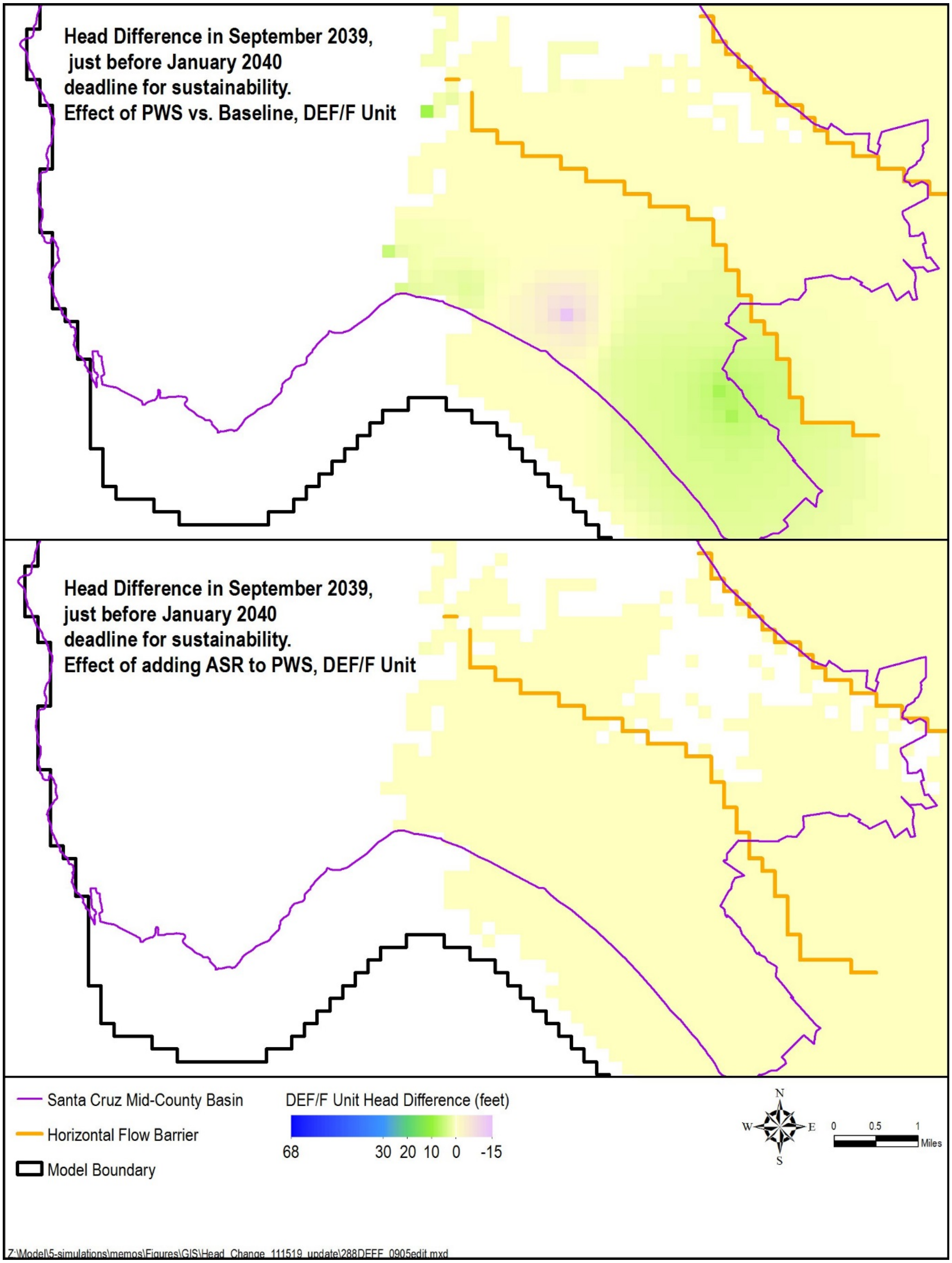

Figure 20. Simulated Effect of ASR and PWS on September 2039 Groundwater Elevations, DEF/F Unit

The upper map of Figure 20 shows decreases in groundwater elevations in the Purisima DEF unit (violet area) related to increased pumping at the Aptos Creek well. These simulation results show that the groundwater level decrease in the Purisima DEF unit does not extend to the coast, but the calibration report notes that the model is not calibrated to simulate the confined portion of the Purisima DEF unit. Adjustments to pumping from the Aptos Creek well and other Purisima DEF wells will likely be necessary during implementation to ensure groundwater elevations do not decline at the coast.

The ASR project does not have any effect in these aquifer units as shown on the lower map of Figure 20. Figure 21 that shows the effects of projects in combination is very similar to the upper map of Figure 20 because only PWS affects this area.

4.5.2 Purisima BC Unit Groundwater Elevation Effects

The simulations of PWS include injection into the Purisima BC unit at the Twin Lakes Church SWIP well. The PWS and PWS+ASR simulations also increase pumping at the Aptos Creek, Madeline, Ledyard, and Estates wells screened in the Purisima BC unit. The ASR project does not make any pumping or injection changes to the Purisima BC unit.

The upper map of Figure 22 shows the benefits of PWS injection into the Purisima BC unit. The largest increase (darkest blue area) is at the Twin Lakes Church SWIP well and increases extend to the coastal boundary of the Basin. Groundwater elevation increases are also simulated in the area of the Purisima BC unit where pumping from the unit is increased at SqCWD production wells.

The ASR project does not have any effect in this aquifer unit as shown on the lower map of Figure 22. Figure 23 that shows the effects of projects in combination is similar to the upper map of Figure 22 because only PWS affects this area. Figure 23 shows groundwater elevations are simulated to rise between 2040 and 2059 with nearly 20 years of additional injection into the Purisima BC unit.

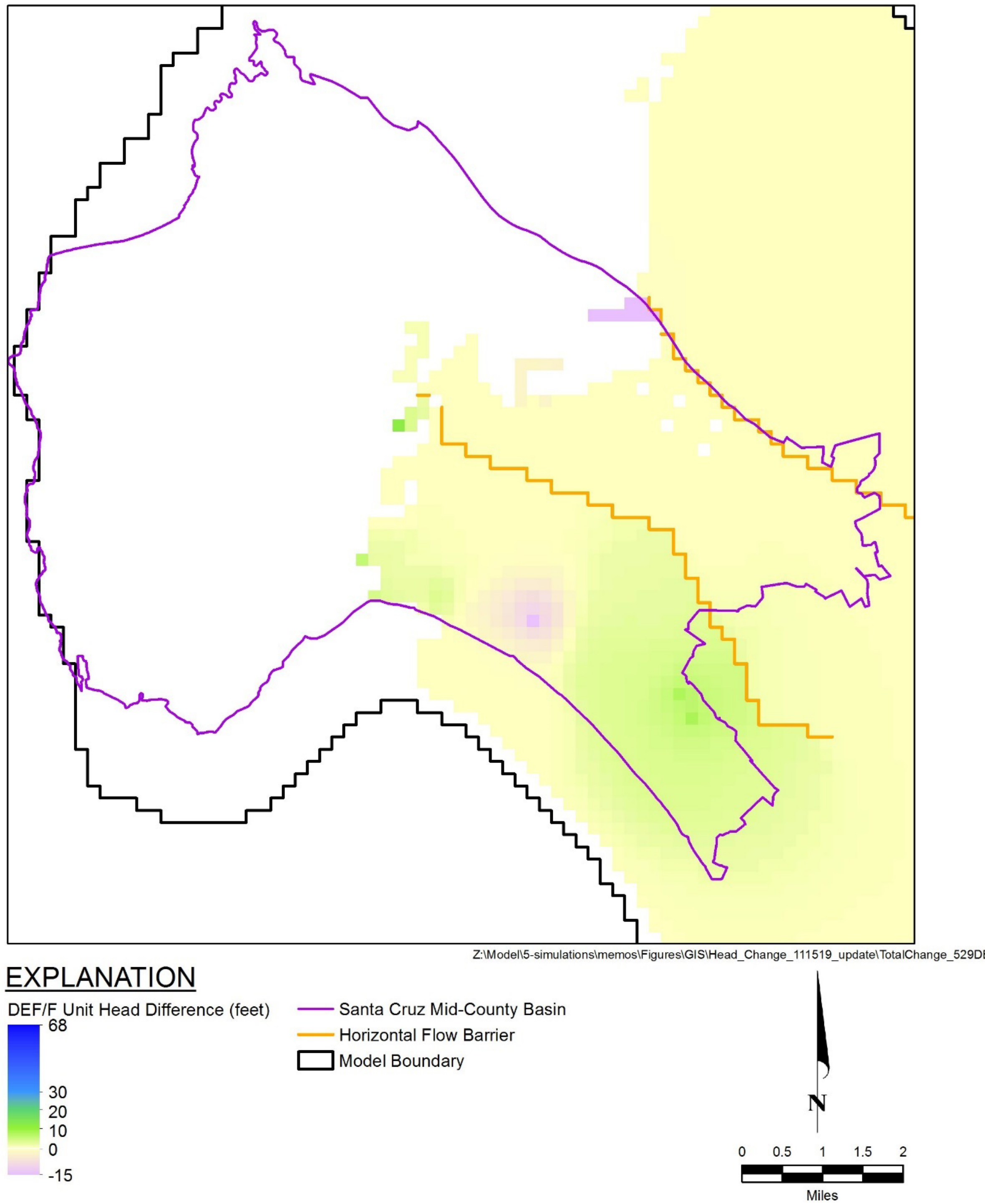

Figure 21. Simulated Effect of ASR and PWS on Groundwater Elevations on October 2059, DEF/F Unit

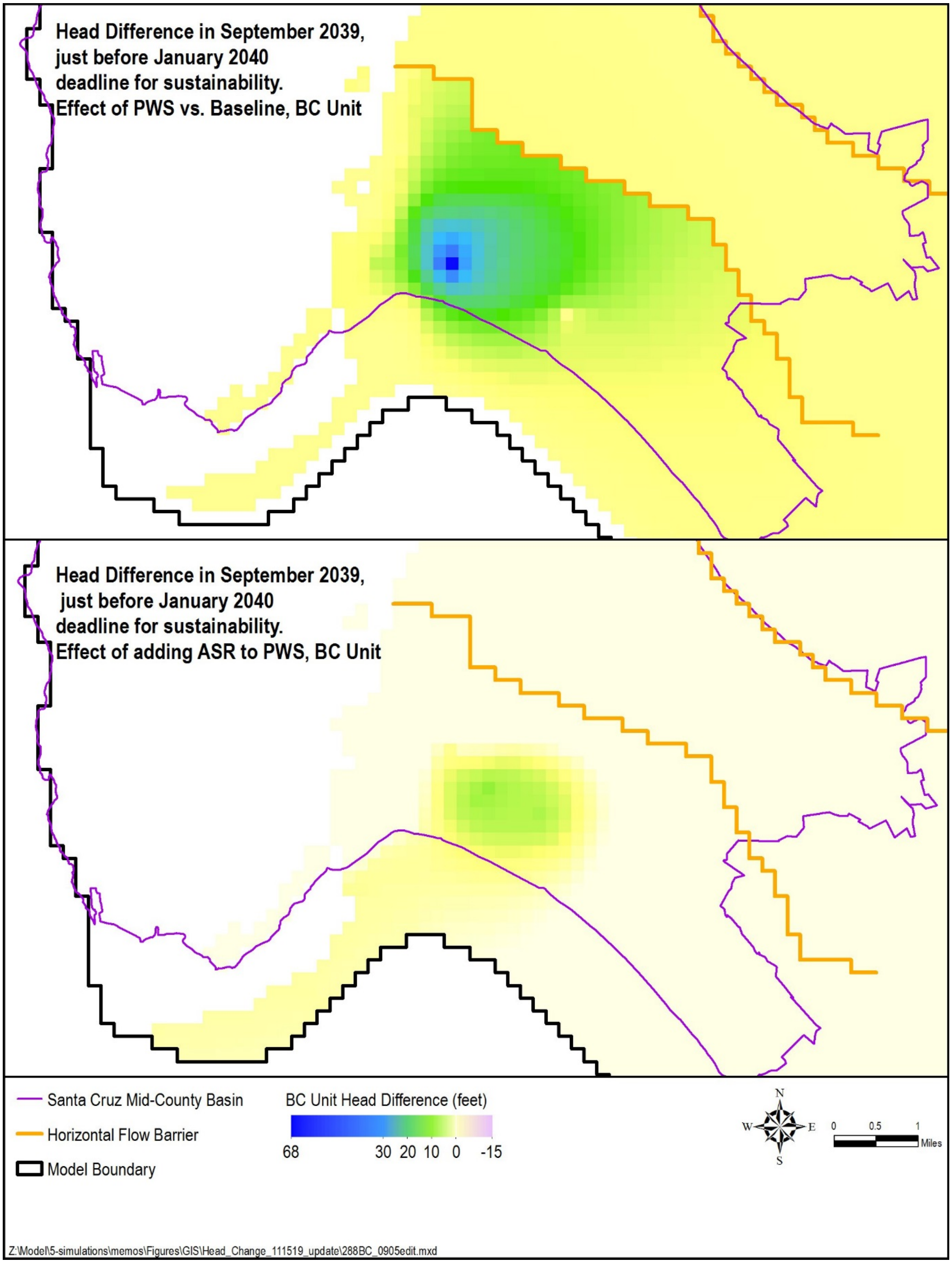

Figure 22. Simulated Effect of ASR and PWS on September 2039 Groundwater Elevations , BC Unit

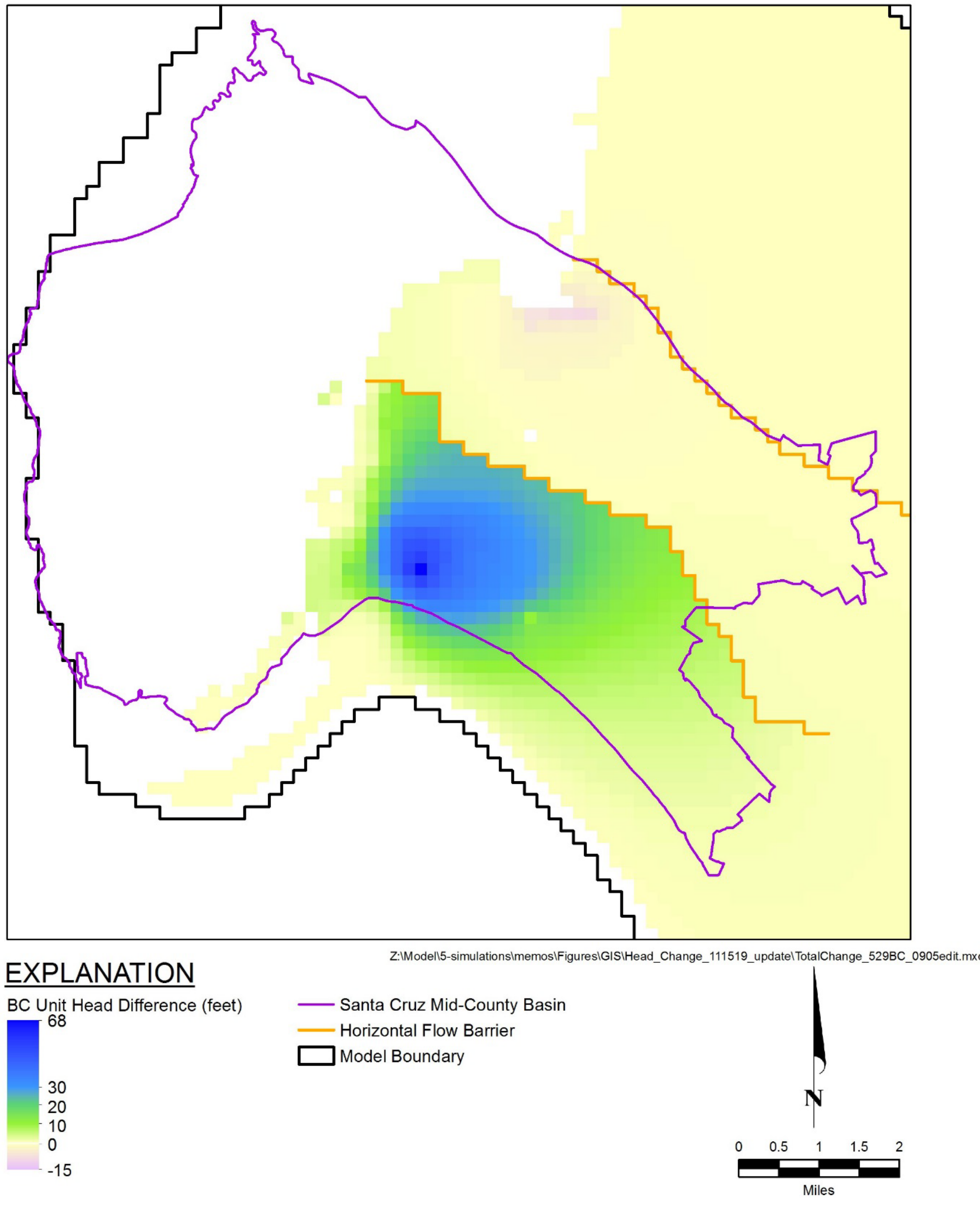

Figure 23. Simulated Effect of ASR and PWS on October 2059 Groundwater Elevations, BC Unit

4.5.3 Purisima A Unit Groundwater Elevation Effects

The simulations of PWS include injection into the Purisima A unit at the Twin Lakes Church, Willowbrook, and Monterey SWIP wells. The PWS and PWS+ASR simulations also increase pumping at the Estates, Tannery II, and Cunnison Lane wells screened in the Purisima A unit. Pumping is decreased at the Garnet well in the Purisima A unit and at the Main Street and O'Neill Ranch wells partially screened in the Purisima AA unit to the west. The simulation (PWS+ASR) incorporating the ASR project includes injection into the Purisima A and AA units at the Beltz 8, 9, and 10 wells. The ASR project also changes pumping at these Purisima A and AA unit wells compared to the baseline simulation. On average, pumping is reduced at the Beltz wells in the Purisima A and AA units, but there are a number of years with lower surface water availability when pumping is increased to meet projected SCWD demand.

The upper map of Figure 24 shows the benefits of PWS injection into the Purisima A unit. The largest increase (darkest blue area) is at the SWIP wells and increases extend to the coastal boundary of the Basin. Groundwater elevation increases are also simulated in the area of the Purisima A unit where pumping from the unit is increased at SqCWD production wells. Groundwater elevation increases are simulated to extend to the west where pumping is decreased in the Purisima A and AA units.

The lower map of Figure 24 shows the benefits of ASR injection and overall pumping reduction in the Purisima A and AA units where groundwater elevations increase (green areas) with the increases extend to the coastal Basin boundary. ASR increases groundwater elevations to the west of most of the groundwater elevation increases caused by PWS. The projects therefore have complementary benefits.

In areas where the PWS SWIP wells are located, groundwater elevation differences in Figure 25 are similar to the upper plot of Figure 24 as ASR has little effect in this area. Figure 21 shows effects of the maximum two-year pumping recovery period under ASR to the west. The model simulates small areas where groundwater elevations fall below baseline groundwater elevations at the Beltz wells (light violet areas) to the west but these declines do not extend to the coastal boundary of the Basin.

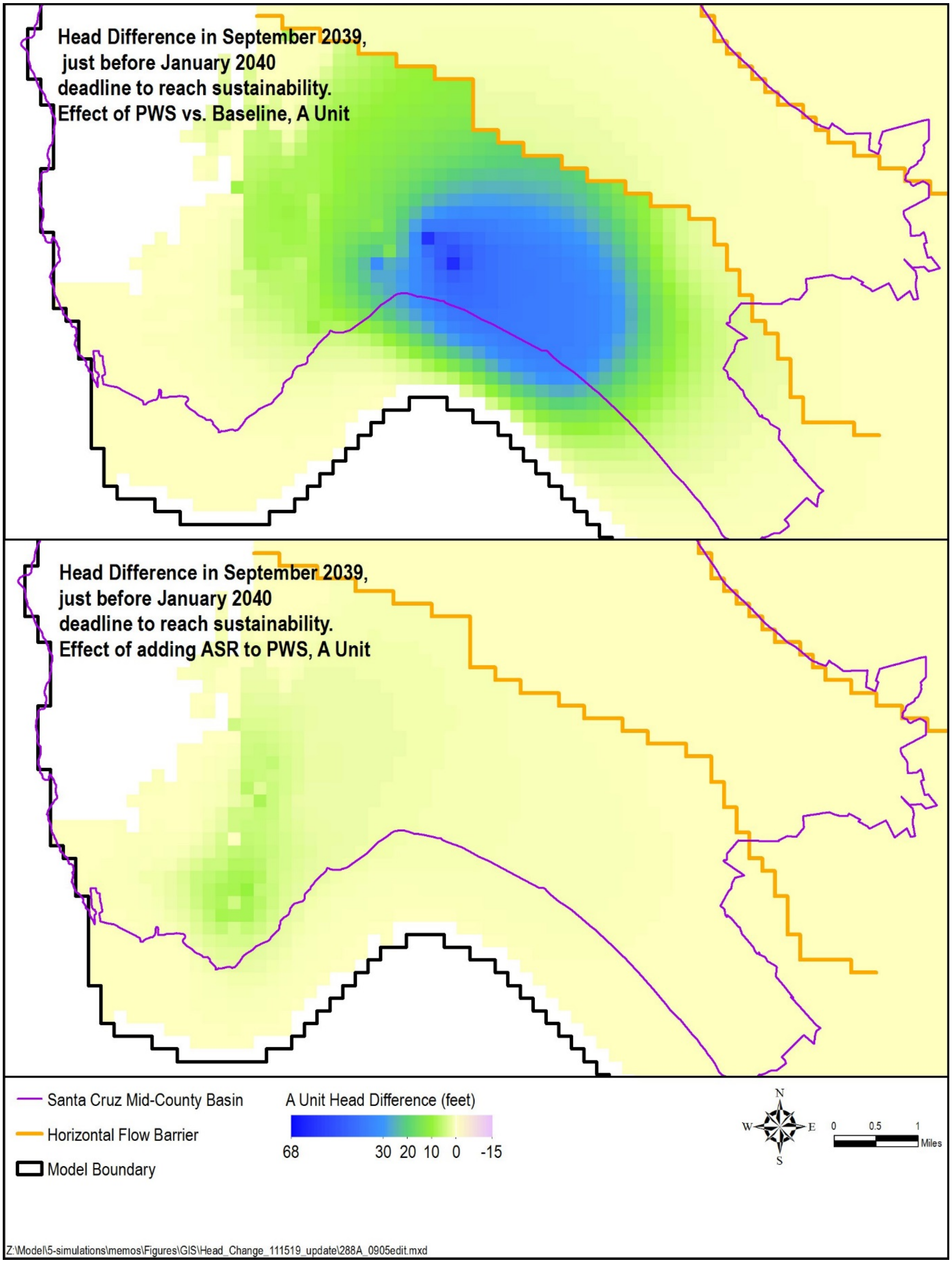

Figure 24. Simulated Effect of ASR and PWS on September 2039 Groundwater Elevations, A Unit

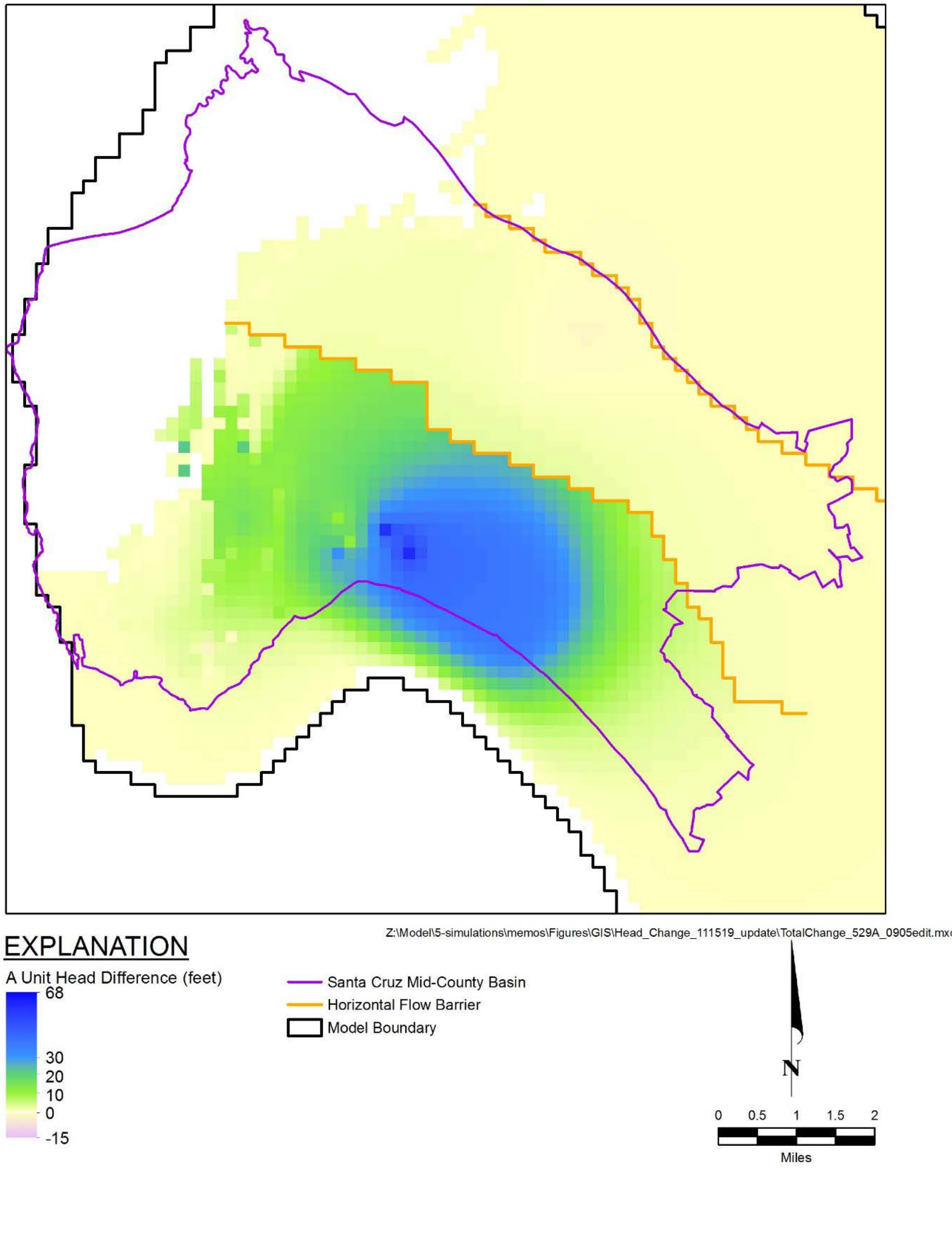

Figure 25. Simulated Effect of ASR and PWS on October 2059 Groundwater Elevations A Unit

4.5.4 Tu Unit Groundwater Elevation Effects

The simulations of PWS include reduction of pumping from the Tu unit at the Main Street and O'Neill Ranch wells. The simulation (PWS+ASR) with the ASR project includes injection into the Tu unit at the Beltz 12 well. The ASR project also changes pumping from the Beltz 12 well from the baseline simulation. On average, pumping is increased at the Beltz 12 well. Both injection and pumping with the ASR project varies over time based on surface water availability.

The upper map of Figure 26 shows the benefits of pumping reduction in the Tu unit that is part of the PWS project. The pumping reduction facilitates in-lieu recharge to raise groundwater elevations with the largest increase (blue area) at the O'Neill Ranch and Main Street wells. The increases extend to the coastal boundary of the Basin.

The lower map of Figure 26 shows a decline in groundwater elevations in the Tu unit at the Beltz 12 well after Water Year 2039 resulting from ASR. ASR has relatively high pumping and low injection in Water Year 2039 due to simulated reduced surface water supply. However, the lower map of Figure 26 shows increases in groundwater elevations resulting from ASR in the Tu unit at the coastal Basin boundary resulting from overall net injection by ASR over the previous twenty years.

Figure 27 shows the effects of projects in combination that raise groundwater elevations throughout the Tu unit compared to the baseline simulation even after ASR's maximum two-year pumping recovery period.

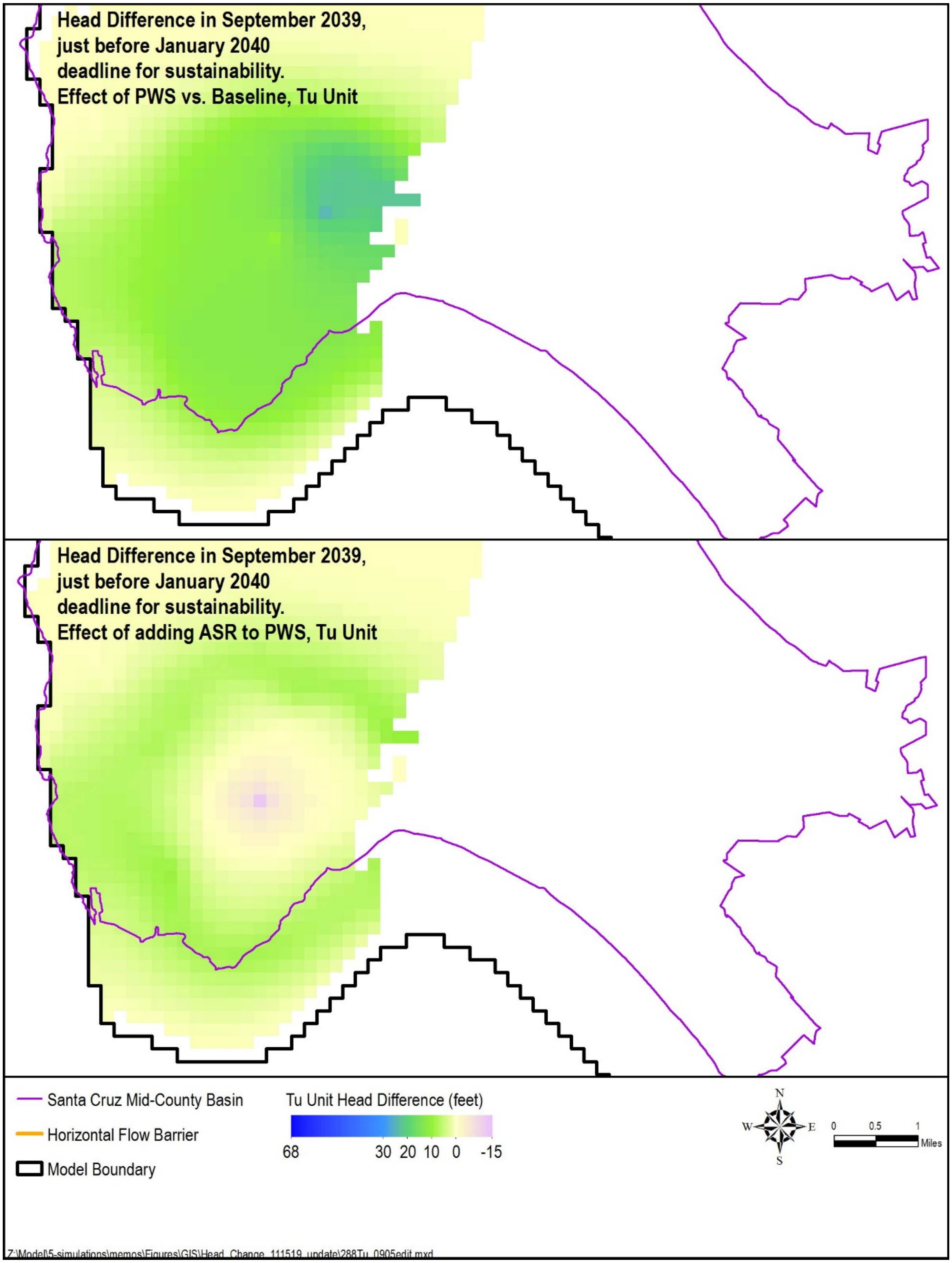

Figure 26. Simulated Effect of ASR and PWS on September 2039 Groundwater Elevations, Tu Unit

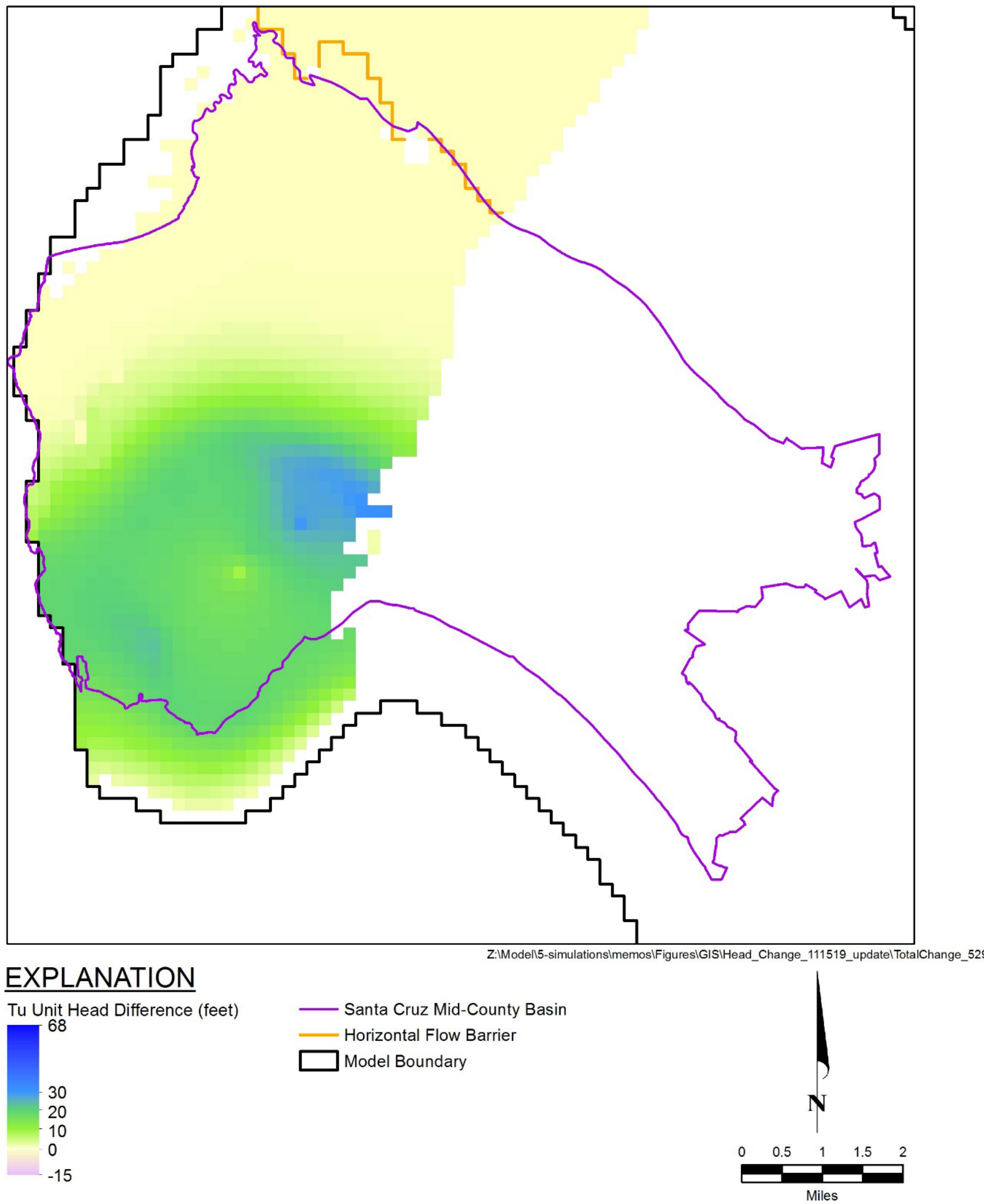

Figure 27. Simulated Effect of ASR and PWS on October 2059 Groundwater Elevations, Tu Unit

4.6 Effect of Projects on Groundwater Budget Components

The combination of PWS and ASR have significant effects on multiple water budget components when simulated over the future time period as shown by a comparison of the PWS+ASR simulation compared to the baseline simulation. The effects of the individual projects can also be evaluated by comparing the PWS simulation to the baseline simulation for the effects of PWS and the PWS+ASR simulation to the PWS simulation for the effects of ASR. These effects are tabulated and presented visually in Table 10 and Figure 28, respectively. The effect of ASR can be seen on Figure 28 starting in 2020, when the City of Santa Cruz begins injection at its Beltz wells. The effects of PWS begins in 2023, the planned start date for injection at the PWS SWIP wells.

Table 10. Groundwater Budget Components, Comparison Between Baseline and Project Scenarios

Groundwater Budget Components	Average (PWS)	Average (ASR)	Average (PWS + ASR)	Difference From Baseline (PWS + ASR)
Inflows	acre-feet per year			percent
UZF Recharge	0	0	0	0%
Net Recharge from Stream Alluvium	-260	-80	-330	- 33%
Recharge from Terrace Deposits	-30	-10	-50	- 3%
Subsurface Inflow from Purisima Highlands	0	0	0	0%
Outflows				
Pumping	-1,280	-460	-1,740	- 28%
Subsurface Outflow to Santa Margarita Basin	0	0	0	0%
Net Subsurface Outflow to Pajaro Valley Subbasin	250	0	250	+ 7%
Offshore	520	320	840	+ 73%
Change in Storage	220	50	280	400%

Note: Differences are normalized so that all decreases indicate a smaller volume of flow, and all increases indicate a greater volume of flow. All values rounded to nearest 10 acre-feet per year

The effects of both projects are most immediately visible in the groundwater pumping budget component, where PWS decreases annual average net pumping by 21%, and ASR causes a further decrease of 7%. Figure 28 shows the decrease in net pumping for PWS is constant while the decrease for ASR varies annually depending on surface water availability. The decreases in net pumping, which includes addition of injection, result in increases of groundwater in storage as plotted by the solid and dashed lines on Figure 28. Groundwater in storage increases an average of approximately 230% with PWS and 60% with ASR. The annual increases of groundwater in storage from PWS decline over the time corresponding with groundwater elevations stabilizing over time, and there are both increase and decreases of groundwater in storage from ASR.

Offshore flows are a key indication of project performance for achieving sustainability, as seawater intrusion is the critical sustainability indicator in the Basin. When compared to baseline, the PWS+ASR simulation displays a 76% higher volume of offshore flow, reflecting higher overall groundwater elevations within the Basin, and a general promotion of conditions that can prevent and possibly reverse seawater intrusion. In an average year, PWS is responsible for about 47% of this increase, while ASR contributes the remaining 29%. These effects are seen over the entire projected period, and are present during both wet and dry climatic conditions (Figure 29).

The PWS+ASR simulation displays a reduction in stream alluvium recharge when compared to baseline, indicating a greater flow of water from groundwater to streams and creeks within the Basin (groundwater flows). In an average year, the majority of the increase in groundwater flows to alluvium is due to PWS injection, while ASR contributes the remaining amount.

Figure 30 specifically examines this relationship in the Soquel Creek watershed, where results highlight the positive effect of both projects on groundwater flows to Soquel Creek during minimum flow months.. As discussed in the calibration report, the magnitude of groundwater flows to streams are not well calibrated so simulation results are only meant to demonstrate that there are expected benefits to streamflow from the projects as opposed to quantifying the benefit.

Higher groundwater elevations resulting from decreases in pumping from the Purisima F unit with PWS in the Aromas area result in a net increase of outflow (or net decrease of inflow) to Pajaro Valley Subbasin so the PWS project should have benefit for sustainability in that neighboring subbasin.

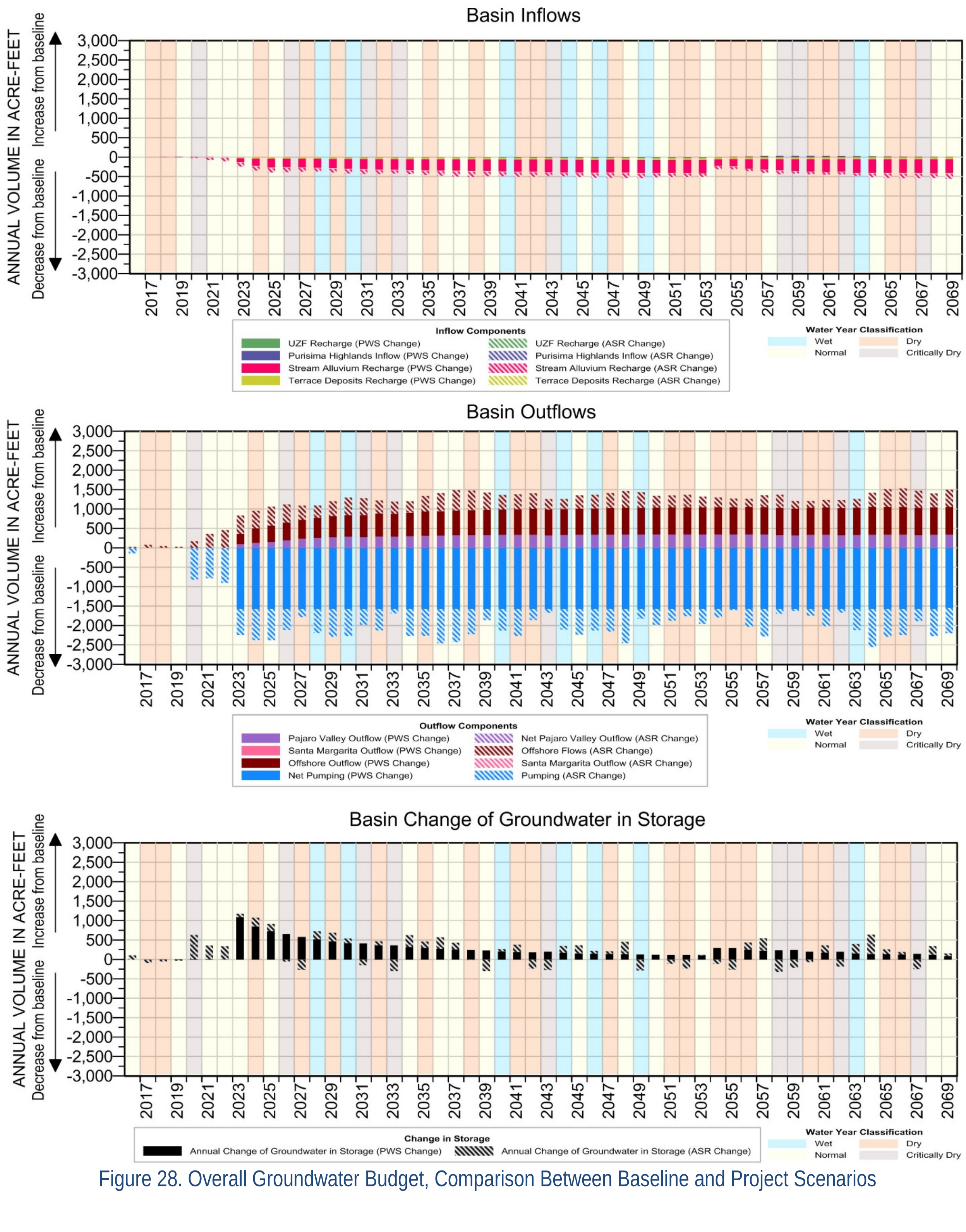

Figure 28. Overall Groundwater Budget, Comparison Between Baseline and Project Scenarios

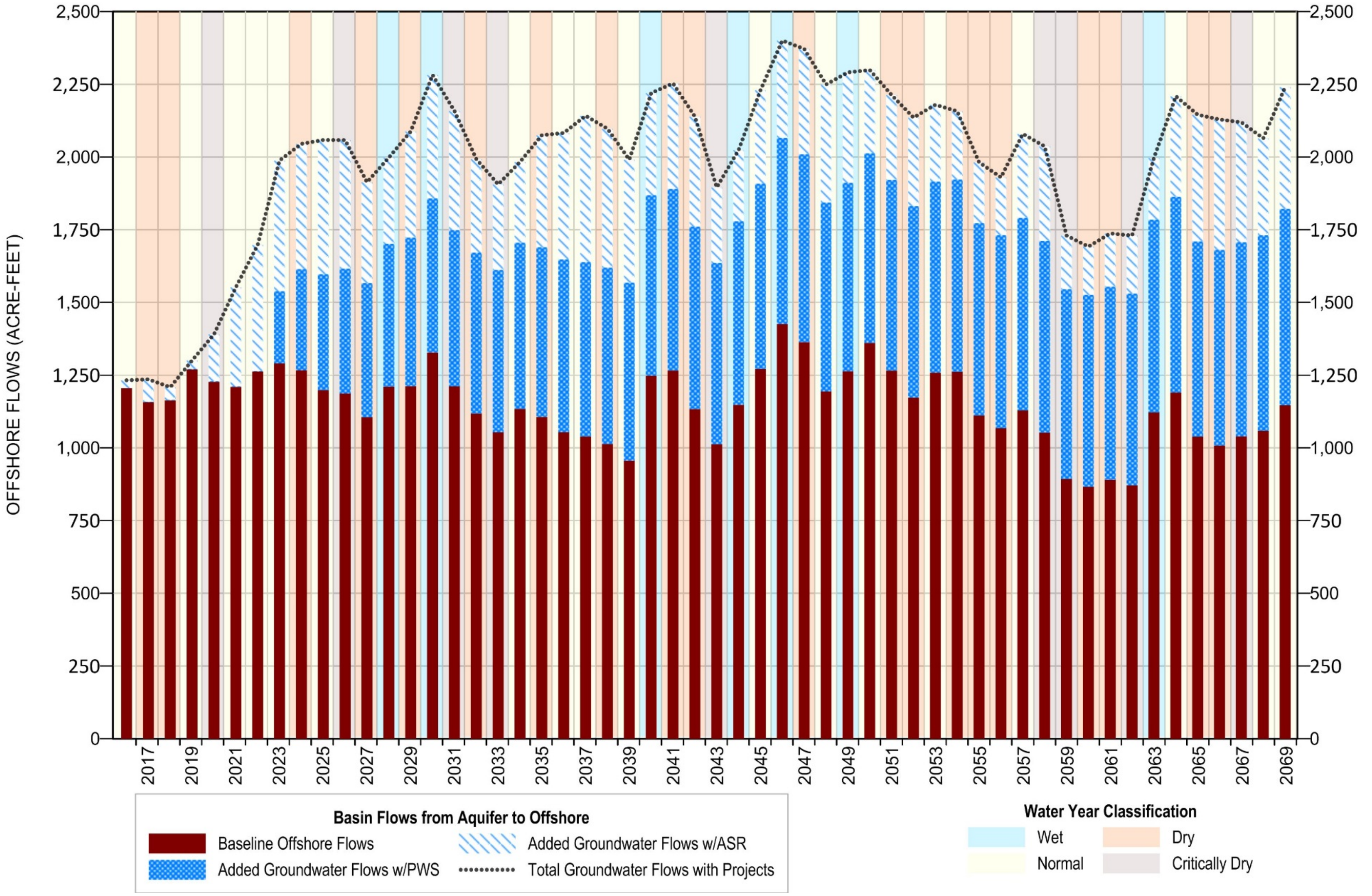

Figure 29. Offshore Flows, Comparison Between Baseline and Project Scenario

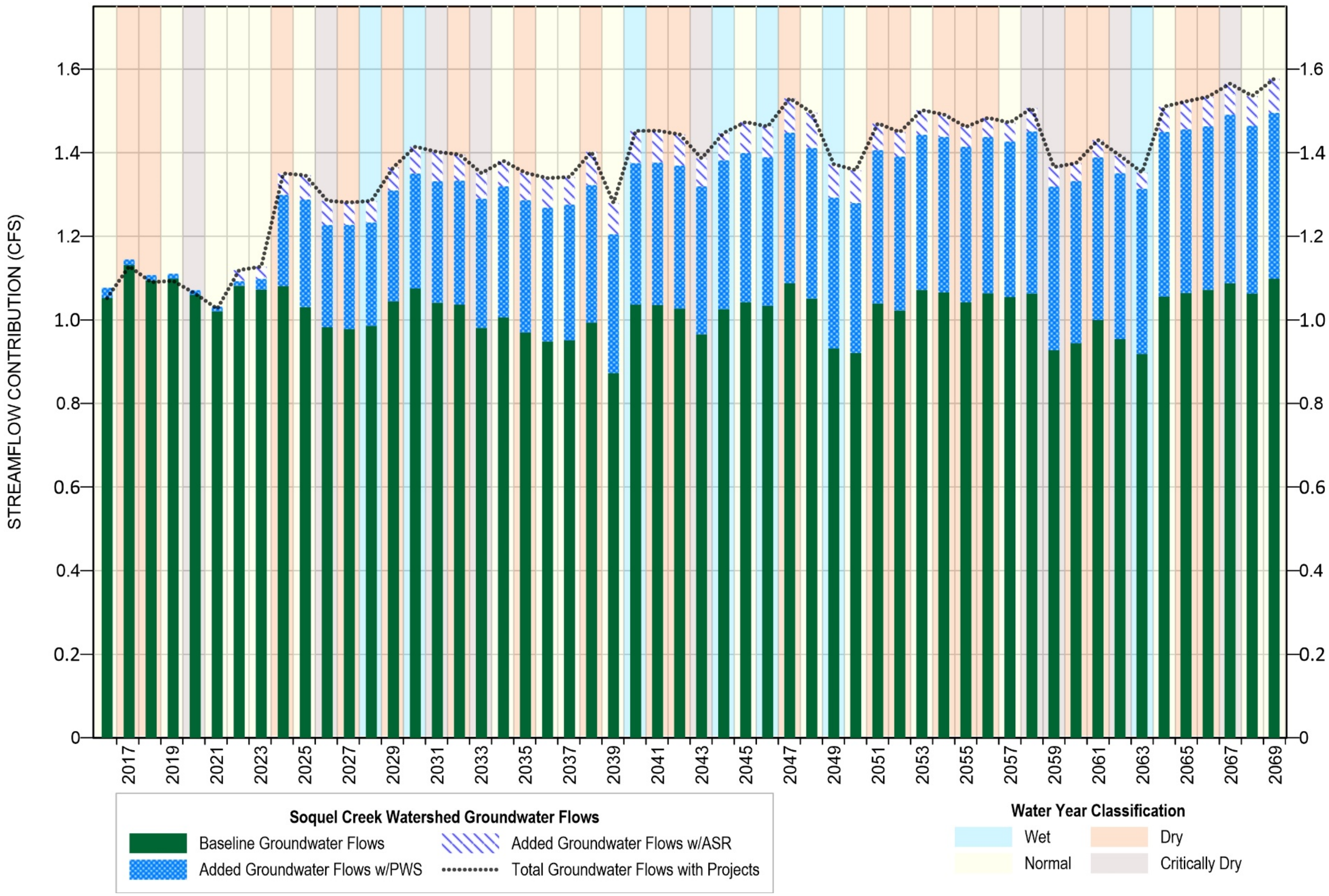

Figure 30. Soquel Creek Watershed Groundwater Flows during Minimum Flow Month Each Year, Comparison between Baseline and Project Scenarios

5 MODELING FOR SUSTAINABLE YIELD ESTIMATES

The GSP requires an estimate of Basin sustainable yield. For the Santa Cruz Mid-County Basin, sustainable yield is defined as the net pumping that avoids undesirable results in the Basin. Net pumping is pumping extraction minus managed recharge such as injection. Sustainable yield is also used as the minimum threshold for the reduction of groundwater in storage sustainability indicator. The Basin GSP sets separate sustainable yields for three aquifer unit groups: Aromas Red Sands/Purisima F, Purisima DEF/BC/A/AA, and Tu. The sustainable yields are based on simulations of future conditions because the Basin has experienced historical and current undesirable results.

5.1 Sustainable Yield Approach

The baseline simulation of future conditions shows undesirable results, but the simulation with projects shows that projects achieve sustainability by meeting minimum thresholds and therefore avoiding undesirable results. In general, projects show groundwater elevations rising higher than minimum thresholds and meeting measurable objectives. As sustainability is defined as avoiding undesirable results by meeting minimum thresholds, the sustainable yield is greater than the net pumping achieved by the projects. The approach for estimating sustainable yield is to use the configuration of the projects but increase net pumping while still meeting minimum thresholds. The estimates of sustainable yield are therefore specific to the configuration of PWS and ASR simulated under future conditions.

5.2 Groundwater Pumping Simulated

Different rates for pumping and injection were tested at SqCWD and SCWD wells included in the configuration of PWS and ASR to test whether minimum thresholds were met. Rates were revised beginning in Water Year 2026 when the final configuration of the projects were set with the Cunnison Lane well coming online. Project rates were used prior to Water Year 2026. CWD and non-municipal rates were not revised from baseline assumptions. Table 11 shows the distribution of pumping rates that achieve minimum thresholds to estimate sustainable yields for each aquifer unit group. There are likely other distributions of pumping rates within each aquifer unit group that also achieve sustainability.

Table 11. Groundwater Pumping and Injection 2026-2069 for Sustainability Estimate

Aquifer Group	Well Name	Average Net Pumping (for Sustainable Yield)	Average Net Pumping (Baseline)	Average Net Pumping (PWS+ASR)
		acre-feet per year		
Aromas Red Sands and Purisima F	Polo Grounds	100	100	100
	Aptos Jr High	250	250	250
	Country Club	0	70	70
	Bonita	75	269	79
	San Andreas	232	371	78
	Seascape	46	46	46
	CWD 4	48	48	48
	CWD 10	92	92	92
	CWD 12	410	410	410
	Domestic	84	84	84
	Institutional	199	199	199
	Agricultural	203	203	203
	Total	1,739	2,142	1,659
Purisima DEF, D, BC, A, and AA	Beltz 8	0	93	-29
	Beltz 9	58	123	-10
	Beltz 10	0	91	-1
	Monterey	-450	0	-500
	Willowbrook	-233	0	-233
	Twin Lakes Church	-742	0	-742
	Rosedale 2	546	545	545
	Garnet	253	254	205
	Cunnison	426	215	399
	Tannery 2	563	223	571
	Estates	398	316	402
	Madeline 2	122	98	122
	Ledyard	120	108	120
	Aptos Creek	102	0	105
	T-Hopkins	137	139	139
	Granite	135	135	135
	Domestic	579	579	579
	Institutional	109	109	109
	Agricultural	162	162	162
	Total	2,285	3,190	2,083

Aquifer Group	Well Name	Average Net Pumping (for Sustainable Yield)	Average Net Pumping (Baseline)	Average Net Pumping (PWS+ASR)
		acre-feet per year		
Tu	Beltz 12	40	39	66
	Main St	349	529	349
	O'Neill	229	229	182
	Domestic	278	278	278
	Institutional	7	7	7
	Agricultural	23	23	23
	Total	927	1,105	905
All Aquifers	Total	4,950	6,437	4,502

5.3 Comparison to Minimum Thresholds

Groundwater elevations for future conditions simulated with the pumping rates used to estimate sustainable yield are compared to groundwater elevation proxies at representative monitoring points for seawater intrusion and surface water depletion. Simulated groundwater elevations meeting minimum thresholds demonstrate that the aquifer unit group yields are sustainable.

The following summarizes where pumping rates at specific wells were revised substantially from the projects simulation and which representative monitoring points for seawater intrusion controlled the change.

For the Aromas Red Sands/Purisima F sustainability yield estimate:

- Country Club well pumping is removed to achieve minimum thresholds at SC-A1B and SC-A8A while pumping is increased by greater amounts farther to the east.
- San Andreas well pumping is increased and minimum thresholds are still met at SC-A2A and SC-A3A.

For the Purisima DEF/BC/A/AA sustainability yield estimate:

- The full project net pumping including injection at SWIP wells are needed to achieve minimum thresholds in the Purisima BC unit at representative monitoring points SC-8B and SC-9C.
- Net pumping from Purisima A unit can be increased in SqCWD wells, including increased pumping from the Tannery II, Cunnison Lane, and Garnet wells together with a

decrease in injection at the Monterey SWIP well can still achieve minimum thresholds at representative monitoring points SC-5A, SC-3A, and SC-1A.

- ASR includes net injection on average, but net pumping at the Beltz wells without injection can still achieve minimum thresholds at the Medium (A) and Deep (AA) completions of the Pleasure Point, Soquel Point, and Moran Lake well representative monitoring point.

For the Tu sustainability yield estimate:

- Net pumping from the Tu unit can still achieve minimum thresholds at representative monitoring point SC-13 without ASR injection. The distribution simulated includes no injection, baseline pumping at Beltz 12 and O'Neill Ranch wells, and assumed pumping at the Main Street well under PWS. The simulated distribution achieves sustainability, but other sustainable distributions amongst the three municipal wells in the Tu unit likely also exist.

Figure 34 and

Figure 35 also show that the simulation of net pumping shown in Table 11 also meets minimum thresholds for groundwater elevation proxies for surface water depletion preventing undesirable results for that indicator.

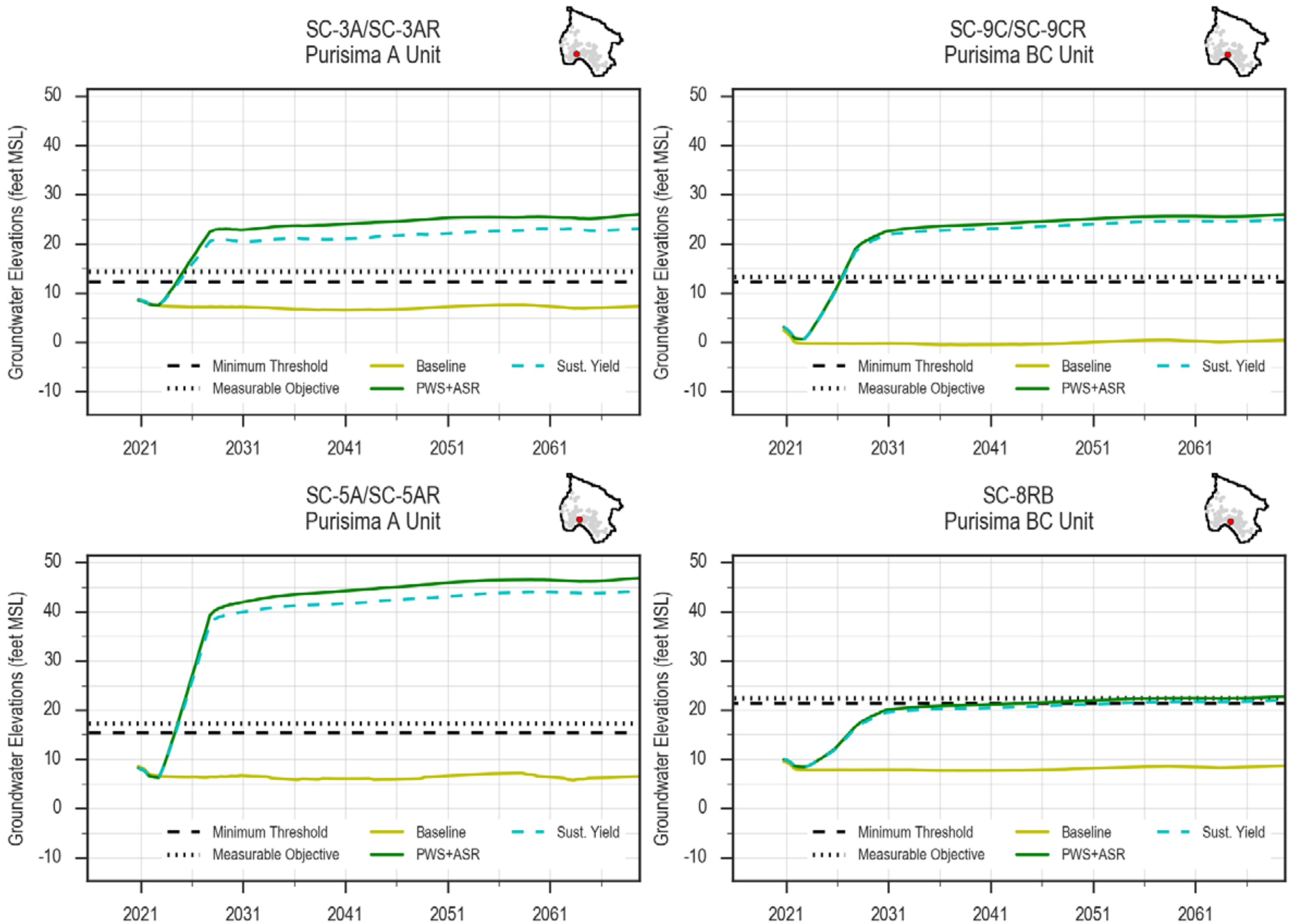

Figure 31. Running Five-Year Average Model Simulated Groundwater Elevations at Coastal Monitoring Wells in Purisima A and BC Units for Sustainable Yield Estimate

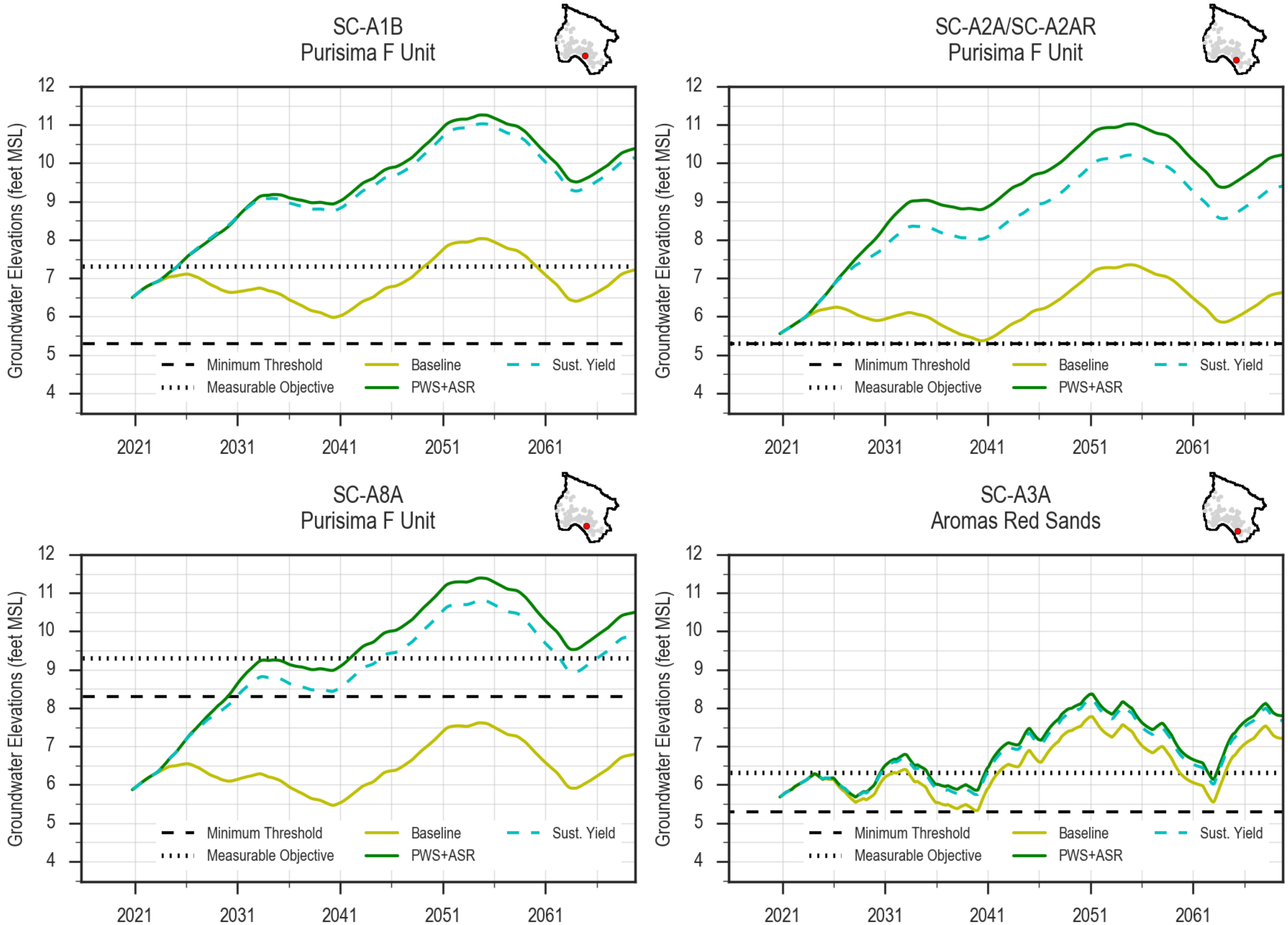

Figure 32. Running Five-Year Average Model Simulated Groundwater Elevations at Coastal Monitoring Wells in Purisima F and Aromas Red Sands Units for Sustainable Yield Estimate

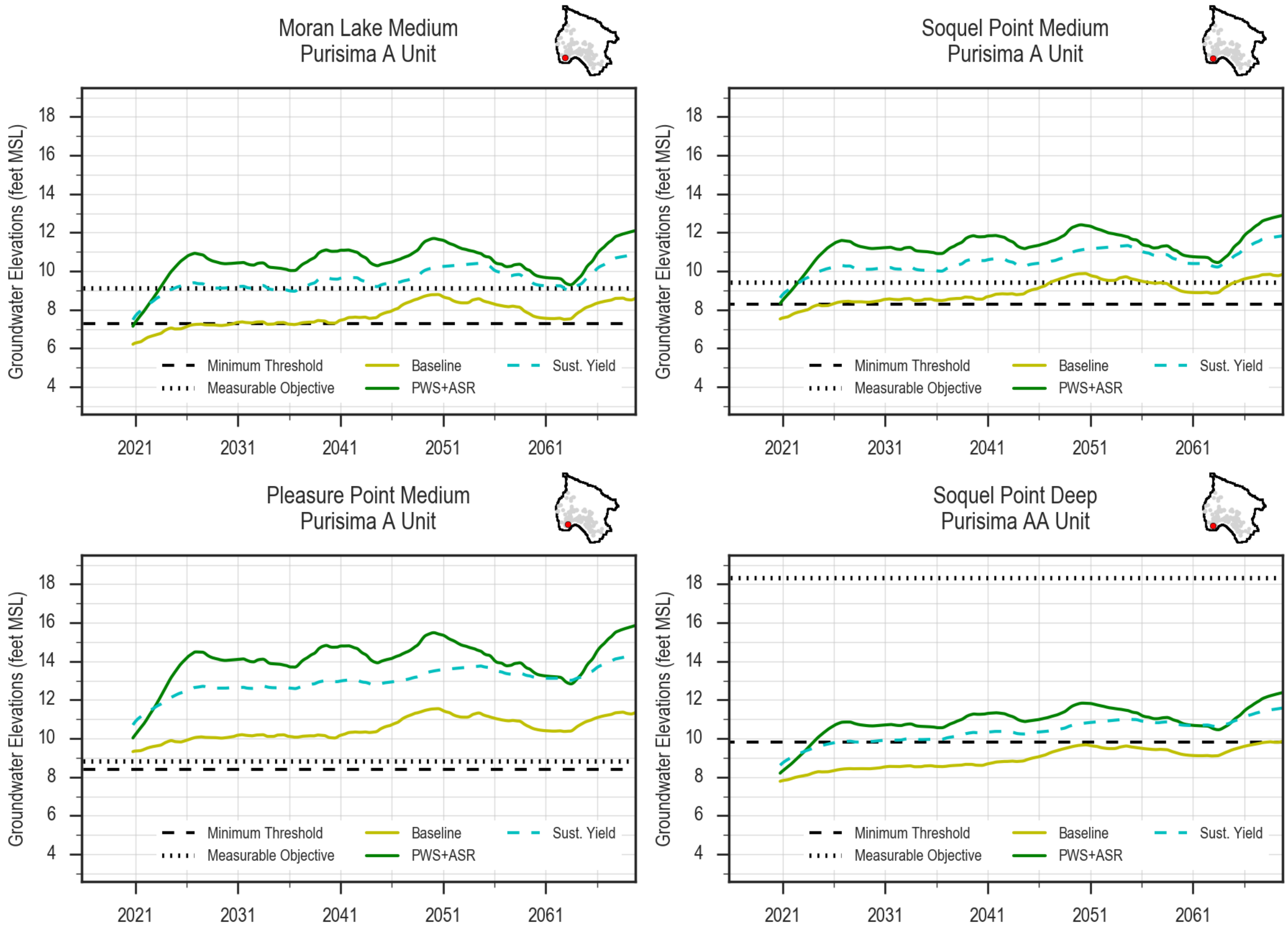

Figure 33. Running Five-Year Average Model Simulated Groundwater Elevations at Coastal Monitoring Wells in Tu and Purisima AA and A Units for Sustainable Yield Estimate

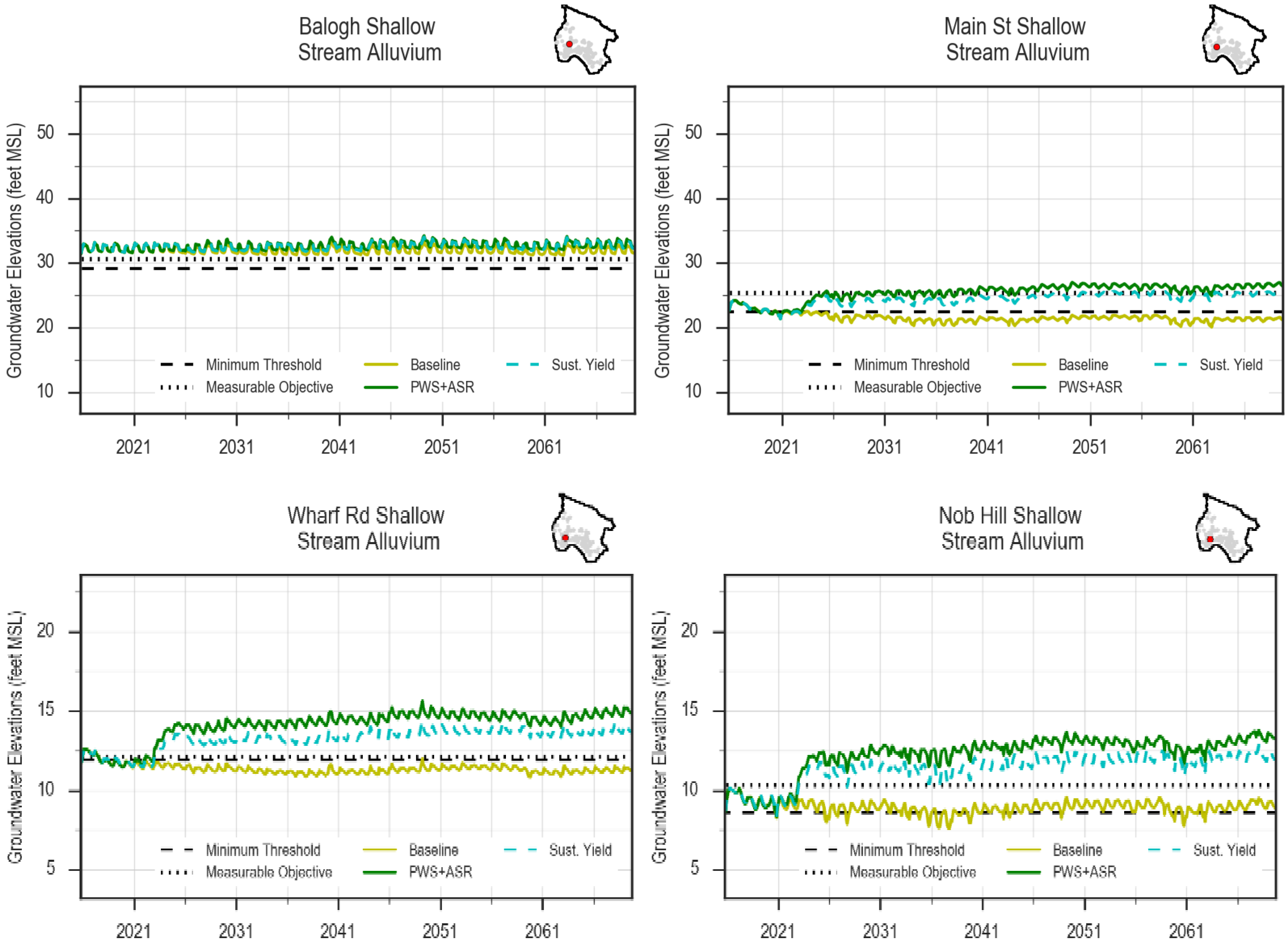

Figure 34. Simulated Groundwater Elevations at Shallow Wells along Soquel Creek for Sustainable Yield Estimate

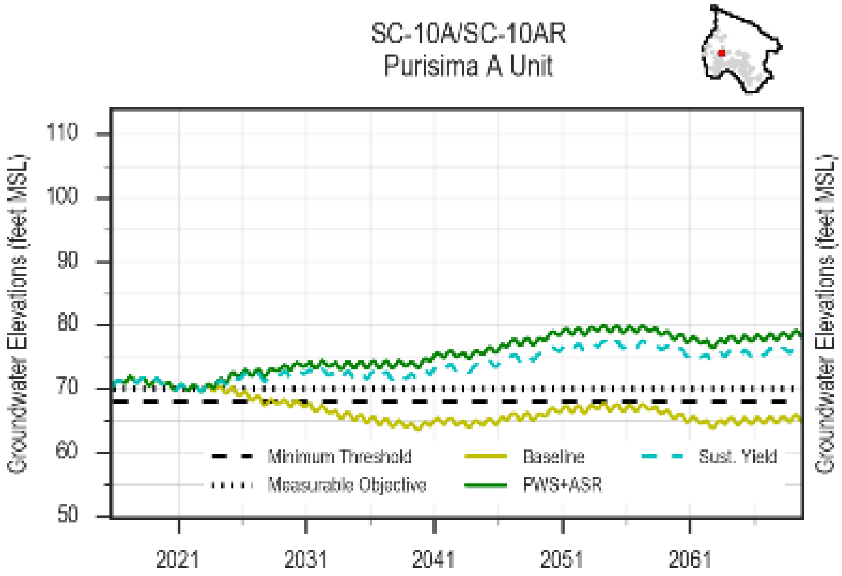

Figure 35. Simulated Groundwater Elevations at Purisima A Unit Well along Soquel Creek for Sustainable Yield Estimate

5.4 Sustainable Yield Estimates

As the simulation of net pumping to estimate sustainable yield shows that minimum thresholds are achieved and undesirable results are eliminated and avoided, Table 12 provides estimates of sustainable yield based on ASR and PWS configuration.

Table 12. Estimates of Sustainable Yield Based on Configuration of Pure Water Soquel and City of Santa Cruz ASR

Aquifer Group	Sustainable Yield (acre-feet per year)
Aromas Red Sands and Purisima F	1,740
Purisima DEF, BC, A, and AA	2,280
Tu	930
Total	4,950

6 CONCLUSIONS

The simulations of future conditions show that implementation of the PWS and ASR projects help the Basin achieve sustainability while the simulation of baseline conditions show continued undesirable results. The simulations show that both PWS and ASR contribute to achieving basin sustainability and are largely complementary in benefiting different areas of the Basin. The model is also used to provide an estimate of sustainable yield based on the configuration of the PWS and ASR projects.

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8 ACRONYMS & ABBREVIATIONS

ASR................Aquifer Storage and Recovery
CWD..............Central Water District
DWR..............California Department of Water Resources
EIR.................Environmental Impact Report
GCM..............Global Circulation Model
GSP ....Groundwater Sustainability Plan
MGA..............Santa Cruz Mid-County Groundwater Agency
MNW2...........Multi-Node Well 2
PWS...............Pure Water Soquel
SCWD............City of Santa Cruz Water Department
SMC...............sustainable management criteria
SqCWD..........Soquel Creek Water District
SWIP..............seawater intrusion prevention
UWMP...........Urban Water Management Plan

APPENDIX 3-A

TECHNICAL APPROACH FOR DETERMINING GROUNDWATER ELEVATION MINIMUM THRESHOLD FOR CHRONIC LOWERING OF GROUNDWATER LEVELS IN REPRESENTATIVE MONITORING WELLS

Technical Approach for Determining Groundwater Elevation Minimum Threshold for Chronic Lowering of Groundwater Levels in Representative Monitoring Wells

The general premise for determining Minimum Thresholds for chronic lowering of groundwater levels is that groundwater levels cannot go below a level which prevents overlying groundwater users from meeting their typical water demand. Overlying water demand is determined from land use and by the well use indicated on well driller logs in the vicinity of the RMP.

The saturated thickness of an aquifer is an important factor that can limit well yields. When groundwater levels decline, the saturated thickness of the aquifer decreases. The saturated thickness may decrease to a point at which the aquifer can no longer produce water to the well at the minimum rate of pumping needed to meet typical demands.

The pump rate and aquifer properties control how much saturated aquifer thickness (distance between the bottom of the well and the groundwater level) is needed to meet water demands. Water demands by municipal wells are known as municipal agencies have detailed records of each well's pump capacity and volumes pumped. Private domestic and agricultural well users generally do not have this information, and therefore assumptions are made to estimate their water usage. For domestic use, average rates of 10 gpm were provided by a local pump contractor. For purposes of estimating the minimum saturated thickness (MST) needed, a more conservative rate of 15 gpm was used as this needs more saturated thickness than a well pumping at 10 gpm (i.e. the groundwater level needs to be higher for 15 gpm). For agricultural wells, the estimated capacity provided on the well driller's logs available indicated 250 gpm is typical.

A theoretical MST for each RMP is estimated using a spreadsheet tool developed by the Kansas Geological Survey based on the overlying water demand (Brookfield, 2016). The tool considers well efficiency, nearby pumping wells, and drawdown in the well due to pumping at a given rate. To consider uncertainties in the MST estimation, a 20% safety factor is added to the MST obtained from the spreadsheet tool. It is also assumed that a well pump can be placed no deeper than 20 feet from the bottom of the well to prevent the pump from being damaged by settled sediment in the bottom of the well. This is the typical depth well pumps are set in domestic wells according to a local pump installer. To account for this, a further 20 feet is added to the estimated MST. Figure 1 provides a generalized schematic that illustrates the method described above. The resultant adjusted MST is the minimum thickness of saturated aquifer that is needed for overlying groundwater users to meet their typical demand. In some areas, there may be two overlying uses, such as agricultural and domestic, or municipal and domestic. For these cases, the adjusted MST of the use type that results in the shallowest groundwater level is used.

As a conservative measure, the approach assumes the RMP has a depth equal to the shallowest nearby well screened in the same aquifer as the RMP. This results in a shallower groundwater elevation than if the actual depth of the RMP is used (if it is deeper than nearby wells).

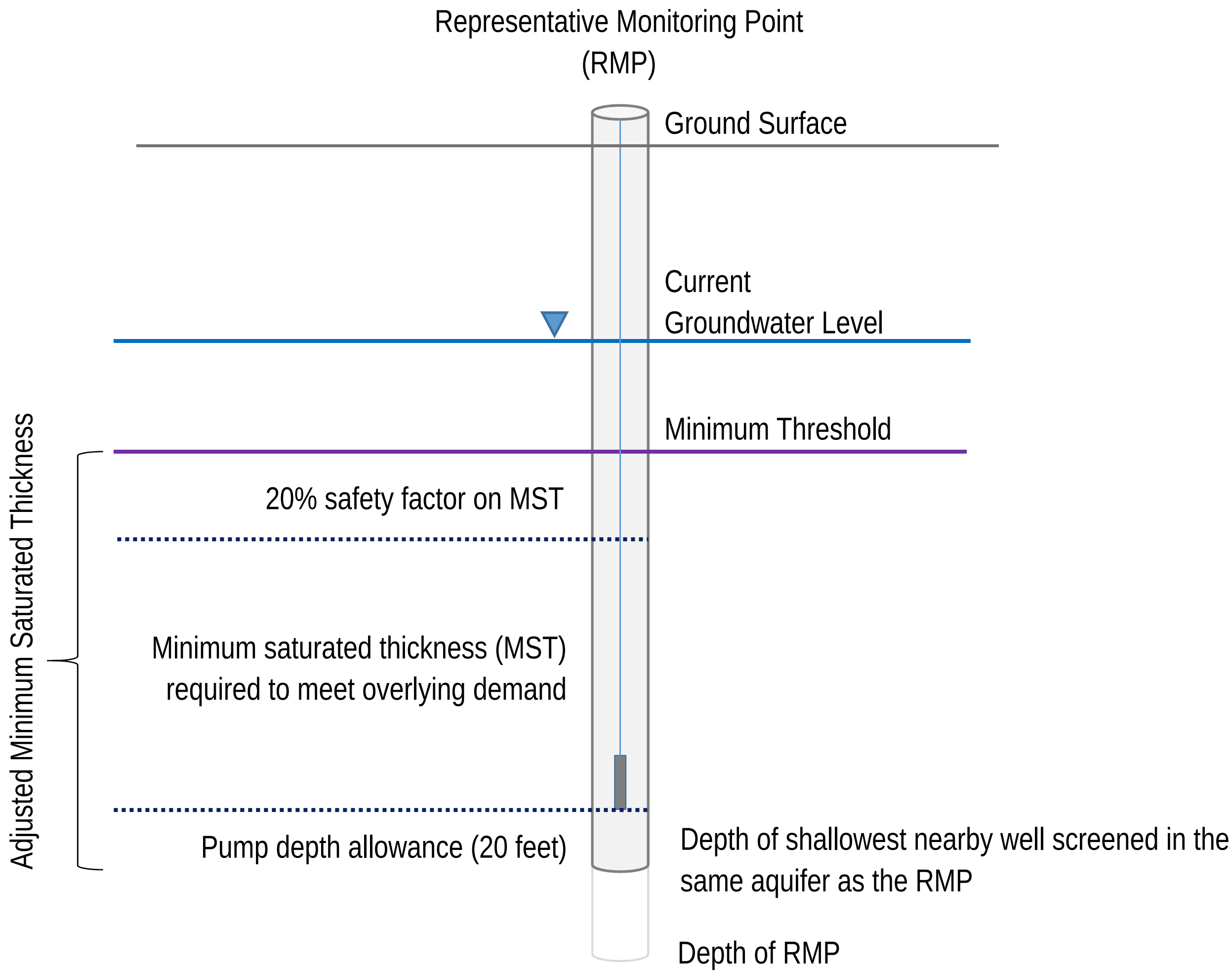

Figure 1. Schematic of Minimum Saturated Thickness Approach

Table 1 summarizes the minimum thresholds for 17 RMPs selected as representative across the Basin. There are five RMPs that had adjusted MSTs that are greater than 30 feet below historic low groundwater levels. For these RMPs, the minimum threshold was raised to 30 feet below historic low groundwater levels. This was done because, although the wells could meet their demand with a much lower groundwater level, having groundwater levels drop to these depths may influence other sustainability indicators. The rationale for selecting a maximum of 30 feet below historic low is that the majority of the RMPs have adjusted MSTs less than 30 feet below historic low levels as shown on Figure 2.

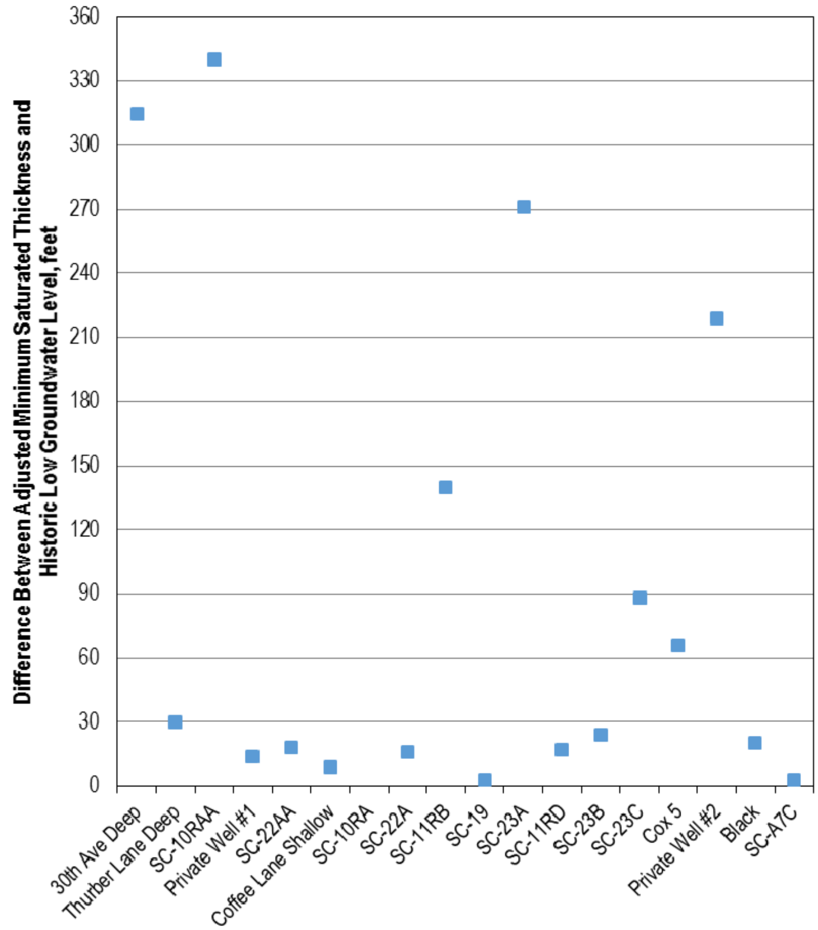

Figure 2. Representative Monitoring Points Difference between Adjusted Minimum Saturated Thickness and Historic Low Groundwater Level

There are four wells where the minimum thresholds were raised to sea level as these are close to protective elevation coastal monitoring wells and having groundwater levels below sea level will make it difficult to achieve protective elevations at the coast. Other reasons for raising elevations from the MST levels are provided in Table 1.

References

Brookfield, A. 2016. Minimum Saturated Thickness Calculator, Method Overview and Spreadseet Description. Kansas Geological Survey Open---File Report 2016---3, pp 6.

Table 1. Summary of Representative Monitoring Points with Minimum Threshold Groundwater Elevations

RMP Name	Overlying Demand Type	Aquifer	Minimum Threshold Elevation (feet amsl)	Minimum Saturated Thickness (MST) Assumptions and Adjustments made to Minimum Thresholds (MT)
30th Ave Deep	Municipal	Tu	0	No private wells screened in this very deep aquifer. There are some municipal wells screened in this aquifer > 0.8 mile to the north. Shallowest municipal well depth results in a minimum elevation of -324 ft amsl based on the MST. However, well screens are typically at 200 ft below ground so the MT is adjusted upwards to sea level which is typically above well screens.
Thurber Lane Deep	Private Domestic	Purisima AA/Tu	-10 Upward	Shallowest domestic well depth results in a minimum elevation of -33 ft amsl that still meets demands. Increase the elevation to -10 ft amsl so that there is not such a steep gradient between this RMP and the coast where there are higher protective groundwater elevations.
SC-10RAA	Private Domestic	Purisima AA/Tu	35 30 ft below low	There are no deep domestic wells in the area of this RMP that are screened in the Pur AA/Tu similar to the RMP. They are screened shallower in Pur A/AA and in the alluvium. Even using the shallowest domestic well depth (not screened in the same aquifer), adjusted MST is at -275 ft amsl, MT is therefore set to 30 ft below historic low levels.
Private Well #1	Private Domestic	Purisima AA/Tu	362	Shallowest domestic well depth in same aquifer as RMP.
SC-22AA	Municipal	Purisima AA	0	Shallowest municipal well depth and municipal well MST. The adjusted MST is --3 ft amsl, MT is therefore increased to sea level.
Coffee Lane Shallow	Municipal	Purisima A/AA	27	Shallowest domestic well depth in same aquifer as RMP.
SC-22A	Municipal/Private Domestic	Purisima A	2	Shallowest domestic well depth, adjusted MST at muni well MST is -3 ft amsl. MT set at 2 ft above SC-22AA MT because groundwater levels in SC-22A are typically 2 ft higher than SC-22AA levels, which has a minimum threshold of 0 ft amsl.
SC-11RB	Private Domestic	Purisima BC	120	Not many domestic wells are deep enough in this location to go down through the Purisima DEF and D units into the underlying Purisima BC unit. Shallowest domestic well depth in same aquifer as RMP (555 ft). MT set to 30 ft below historic low because adjusted MST results in > 30 ft below historic low level.
SC-19	Municipal/Private Domestic	Purisima BC	56	Not many private wells nearby. Municipal wells are shallower than private wells with County records. Used shallowest municipal well depth

RMP Name	Overlying Demand Type	Aquifer	Minimum Threshold Elevation (feet amsl)	Minimum Saturated Thickness (MST) Assumptions and Adjustments made to Minimum Thresholds (MT)
				in same aquifer as RMP.
SC-23A	Municipal	Purisima BC	0	No domestic wells at this depth in the area. Shallowest municipal well depth, adjusted MST >30 ft below historic low. Raise MT to sea level 0 ft amsl which is 21 ft below historic low.
SC-11RD	Private Domestic	Purisima DEF	295	Shallowest domestic well depth in same aquifer as RMP.
SC-23B	Small Water System/ Private	Purisima DEF	50	Shallowest domestic well depth results in a minimum elevation of -137 ft amsl that still meets demands. Increase the elevation to 50 ft amsl. Difference in groundwater levels between SC-23B and SC-23A is 50 ft during historic low levels on hydrograph.
SC-23C	Municipal	Purisima F	15	Shallowest domestic well depth results in a minimum elevation of -14 ft amsl that still meets demands. Increase the elevation to 15 ft amsl. This is both 30 ft lower than historic low and equal to the average depth below SC-23B elevation.
CWD-5	Private Domestic	Purisima F	133	Shallowest domestic well depth results in a minimum elevation of 97 ft amsl that still meets demands. Increase the MT elevation to 30 ft below average historic lows.
Private Well #2	Private Domestic	Purisima F	562	Shallowest domestic well depth results in a minimum elevation of 433 ft amsl that still meets demands. Increase the elevation to 562 ft amsl, which is 30 ft below historic lows.
Black	Private Domestic	Purisima F	21	Other domestic wells in the area are screened in both the Aromas and Purisima F, while this RMP is screened in only the Purisima F. The MT is set at a level less than 30 ft below the historic low.
SC-A7C	Ag/Municipal	Aromas	0	Shallowest Ag well depth results in a minimum elevation of --20 ft amsl that still meets demands. MT is therefore set at sea level.

APPENDIX 3-B

HYDROGRAPHS OF REPRESENTATIVE MONITORING POINTS FOR CHRONIC LOWERING OF GROUNDWATER LEVELS

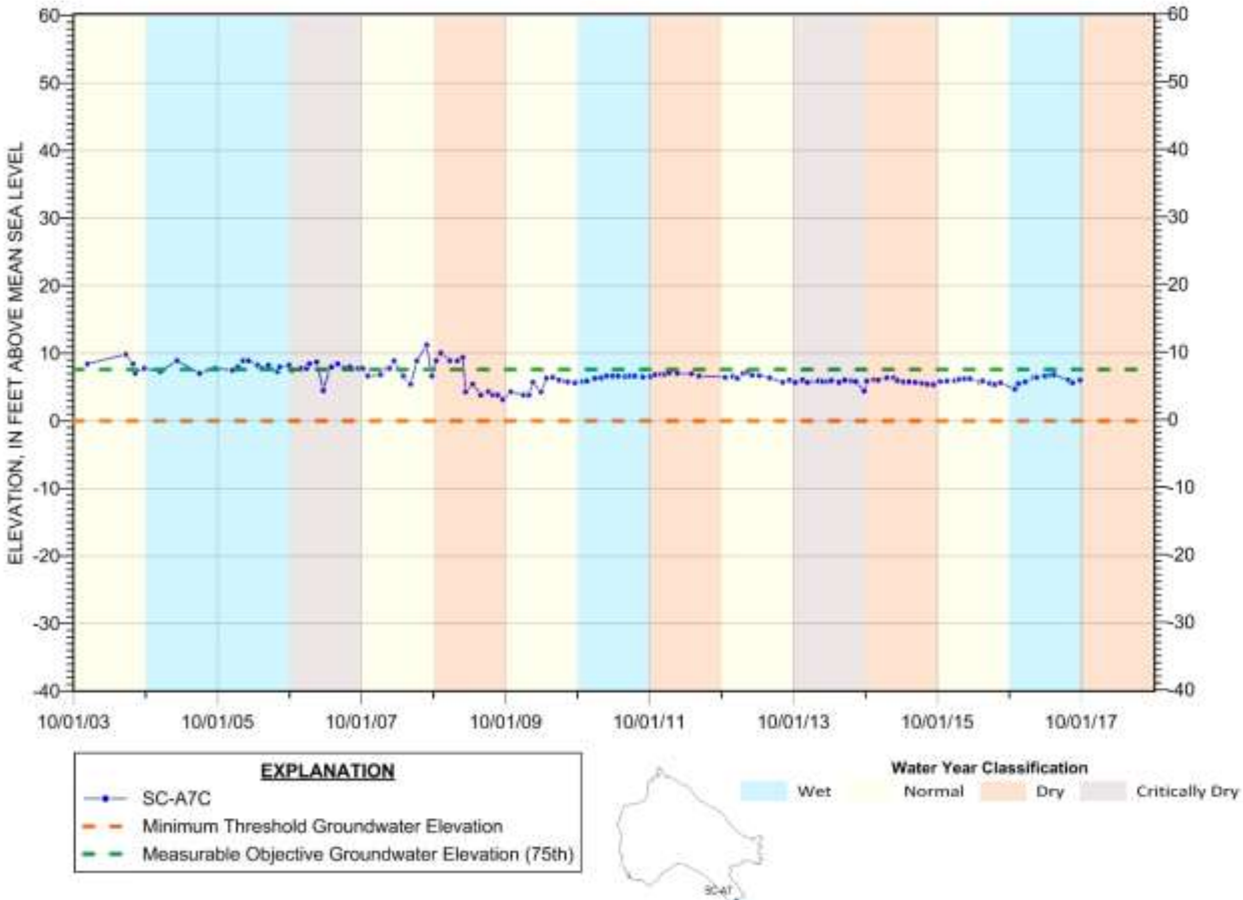

Figure 3-B.1. SC-A7C Hydrograph with Minimum Threshold and Measureable Objective

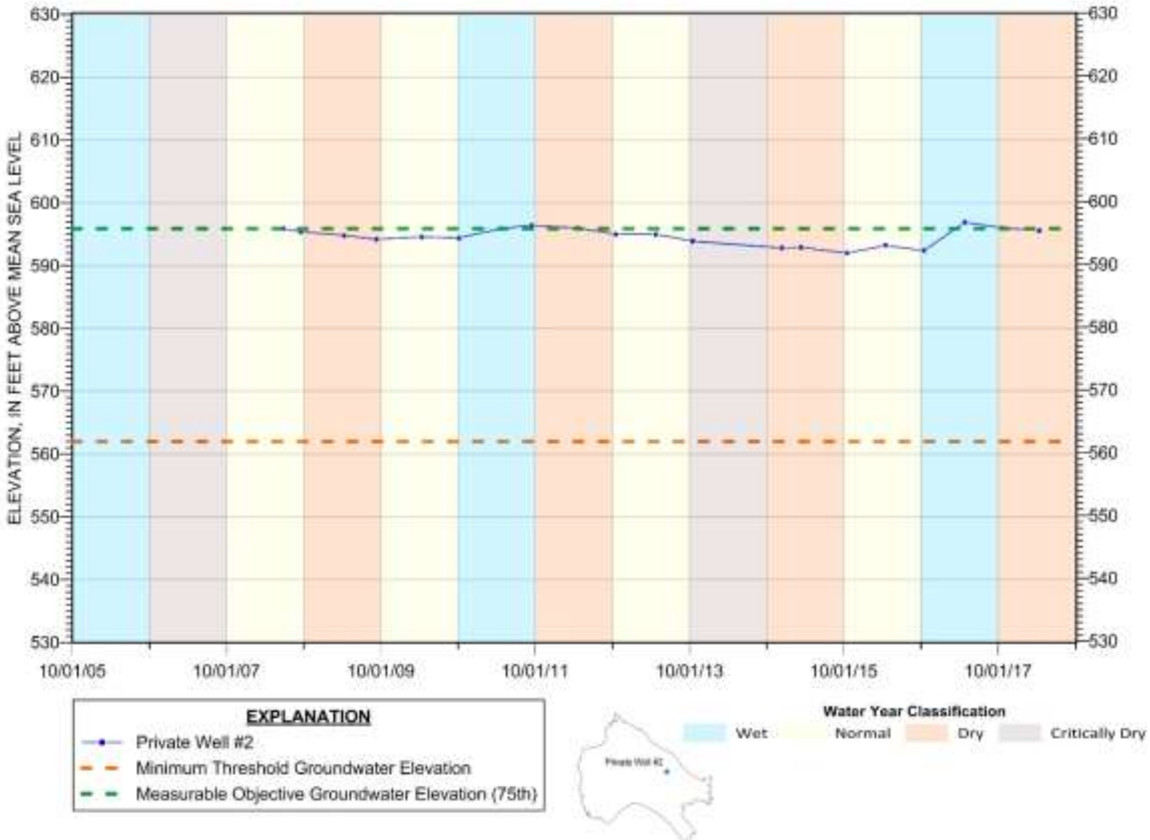

Figure 3-B.2. Private Well #2 Hydrograph with Minimum Threshold and Measureable Objective

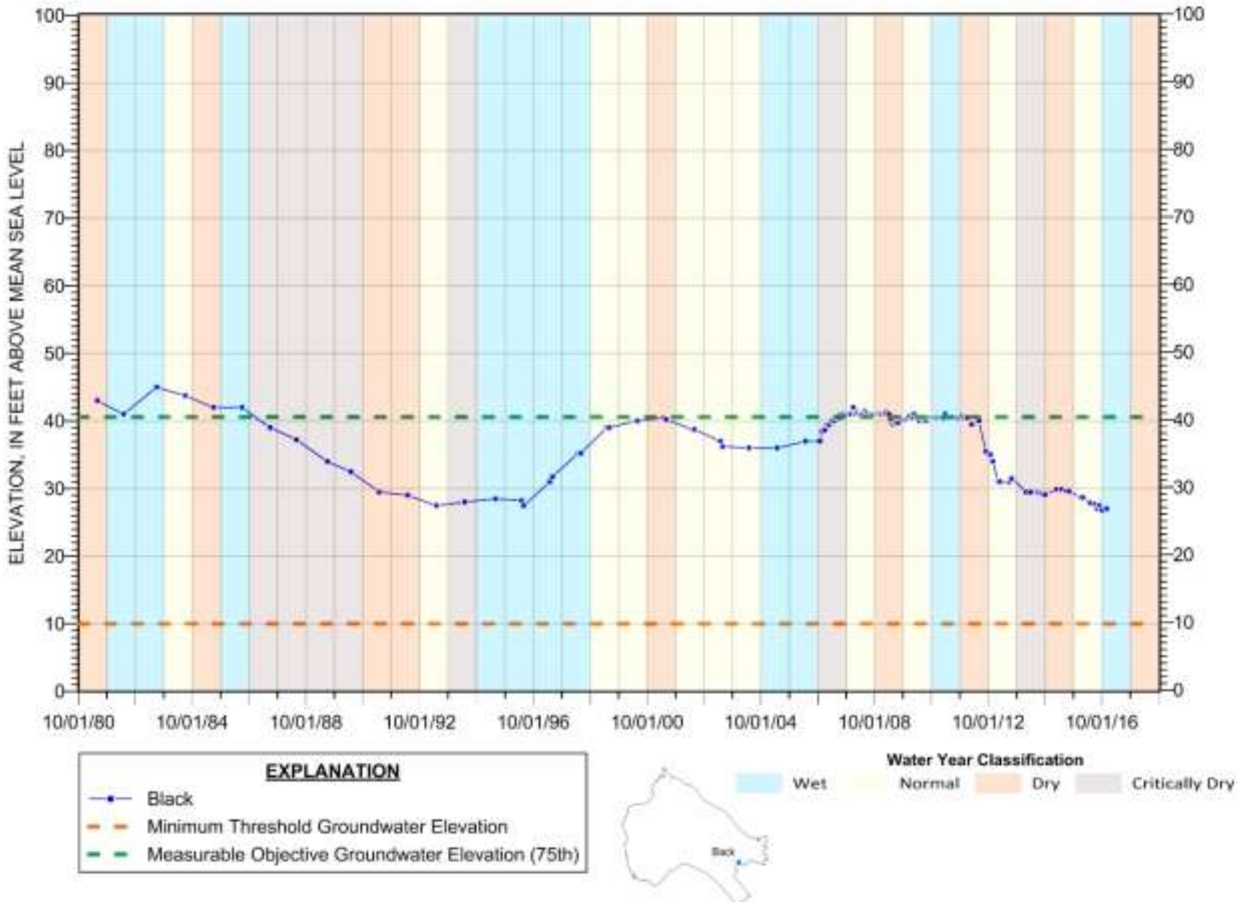

Figure 3-B.3. Black Hydrograph with Minimum Threshold and Measureable Objective

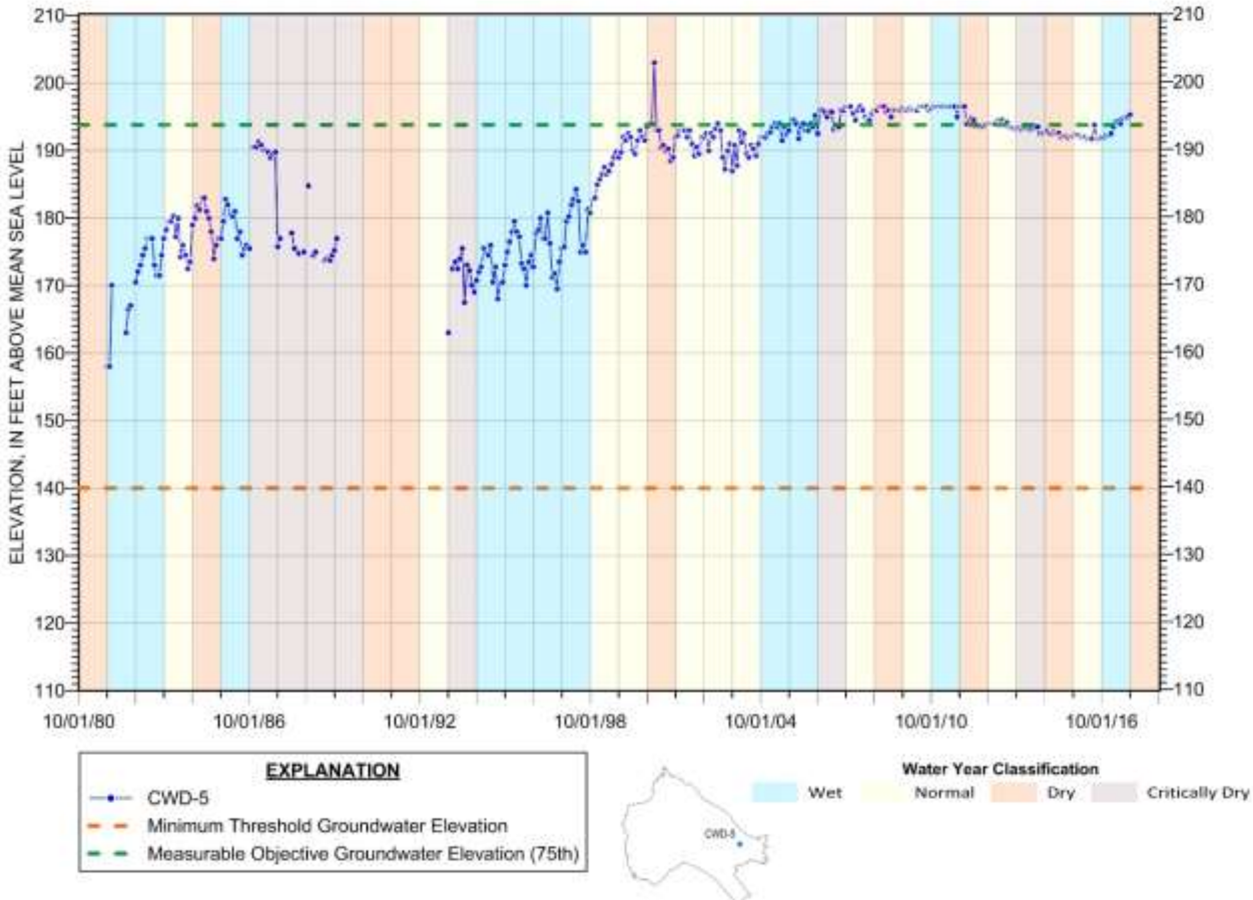

Figure 3-B.4. CWD-5 Hydrograph with Minimum Threshold and Measureable Objective

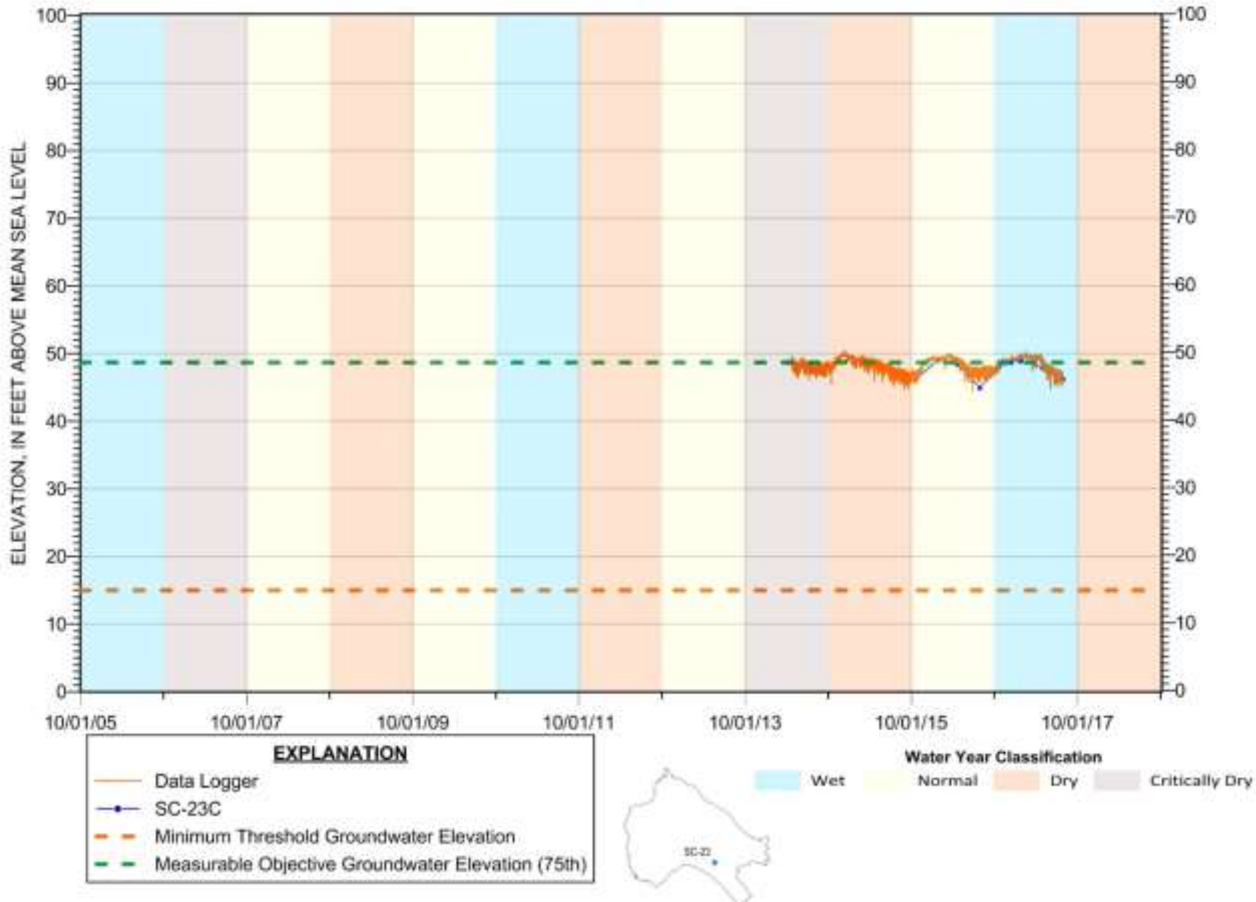

Figure 3-B.5. SC-23C Hydrograph with Minimum Threshold and Measureable Objective

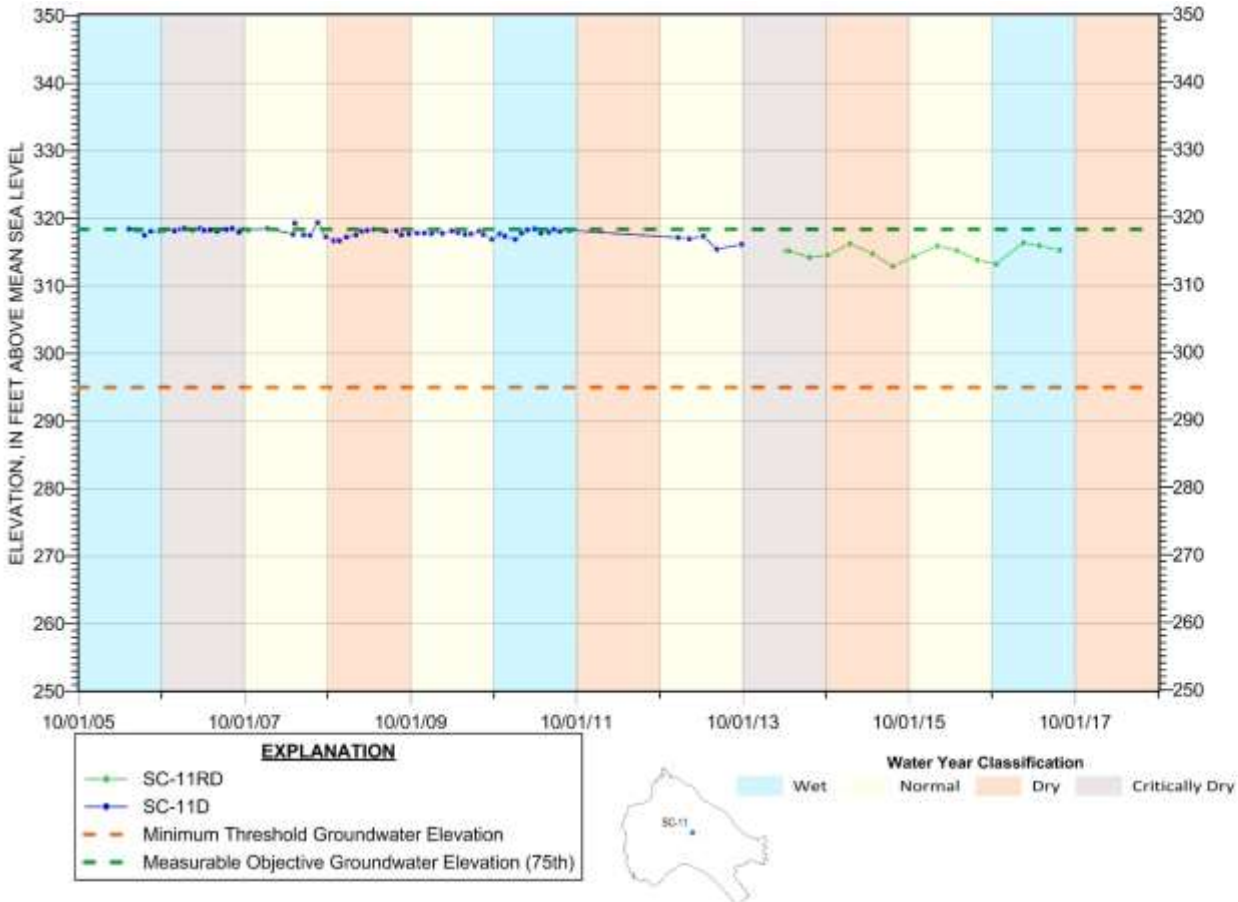

Figure 3-B.6. SC-11RD Hydrograph with Minimum Threshold and Measureable Objective

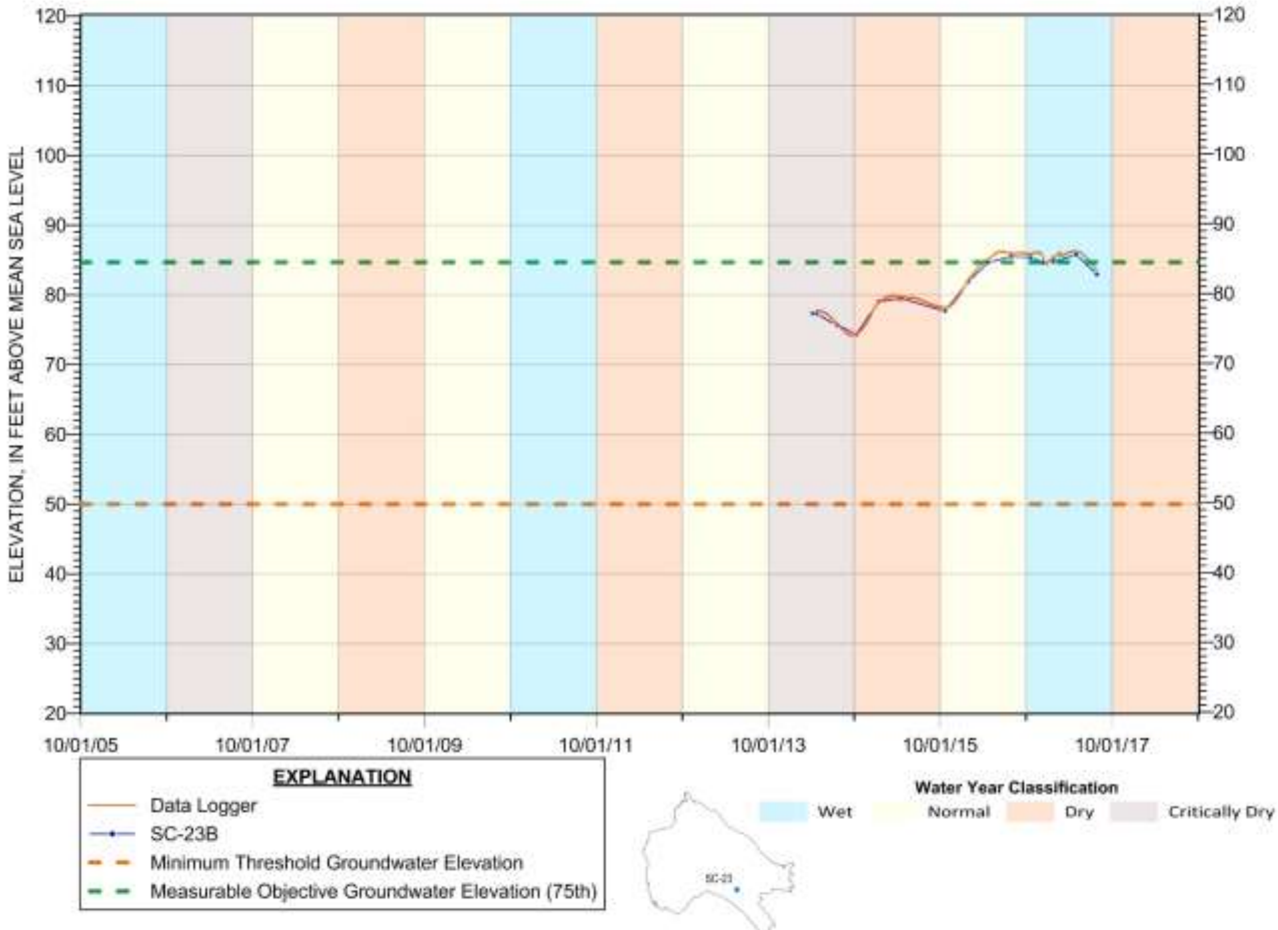

Figure 3-B.7. SC-23B Hydrograph with Minimum Threshold and Measurable Objective

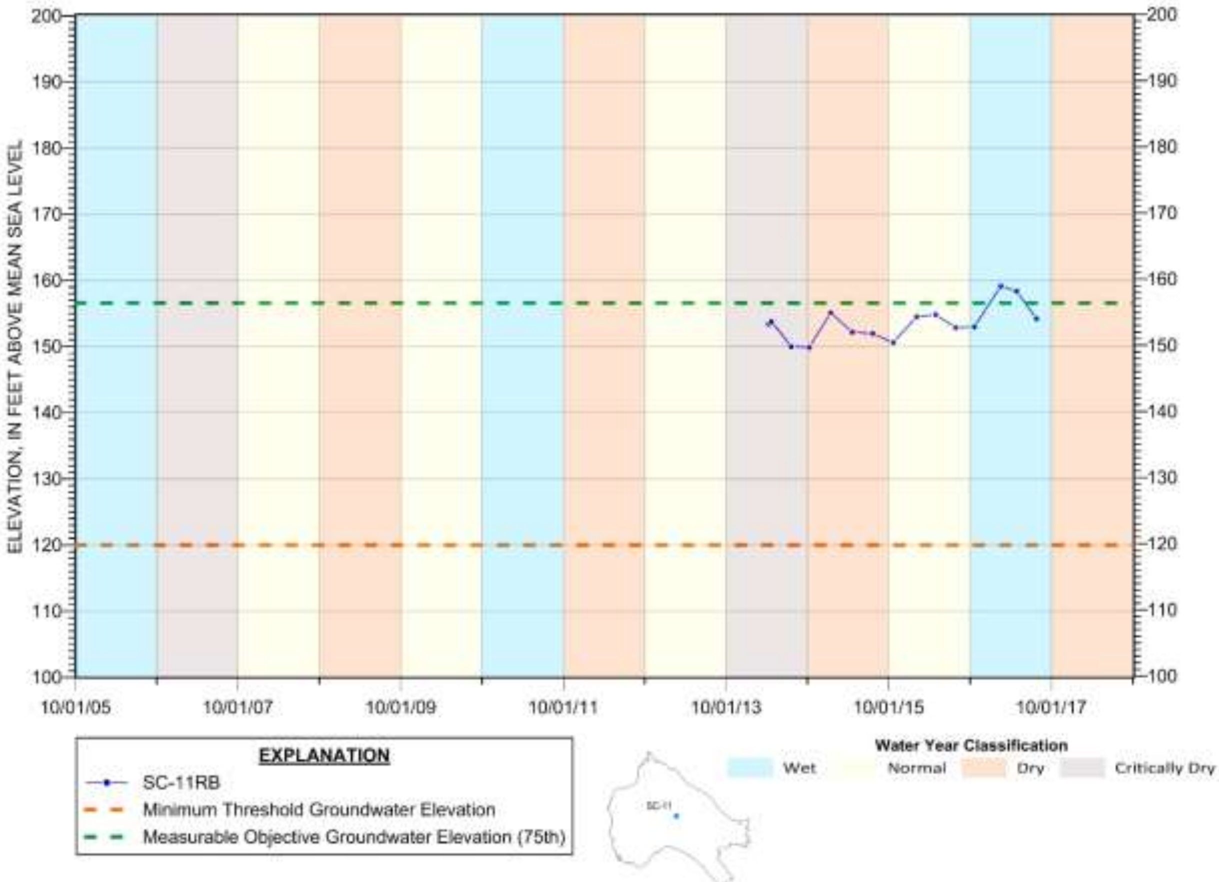

Figure 3-B.8. SC-11RB Hydrograph with Minimum Threshold and Measureable Objective

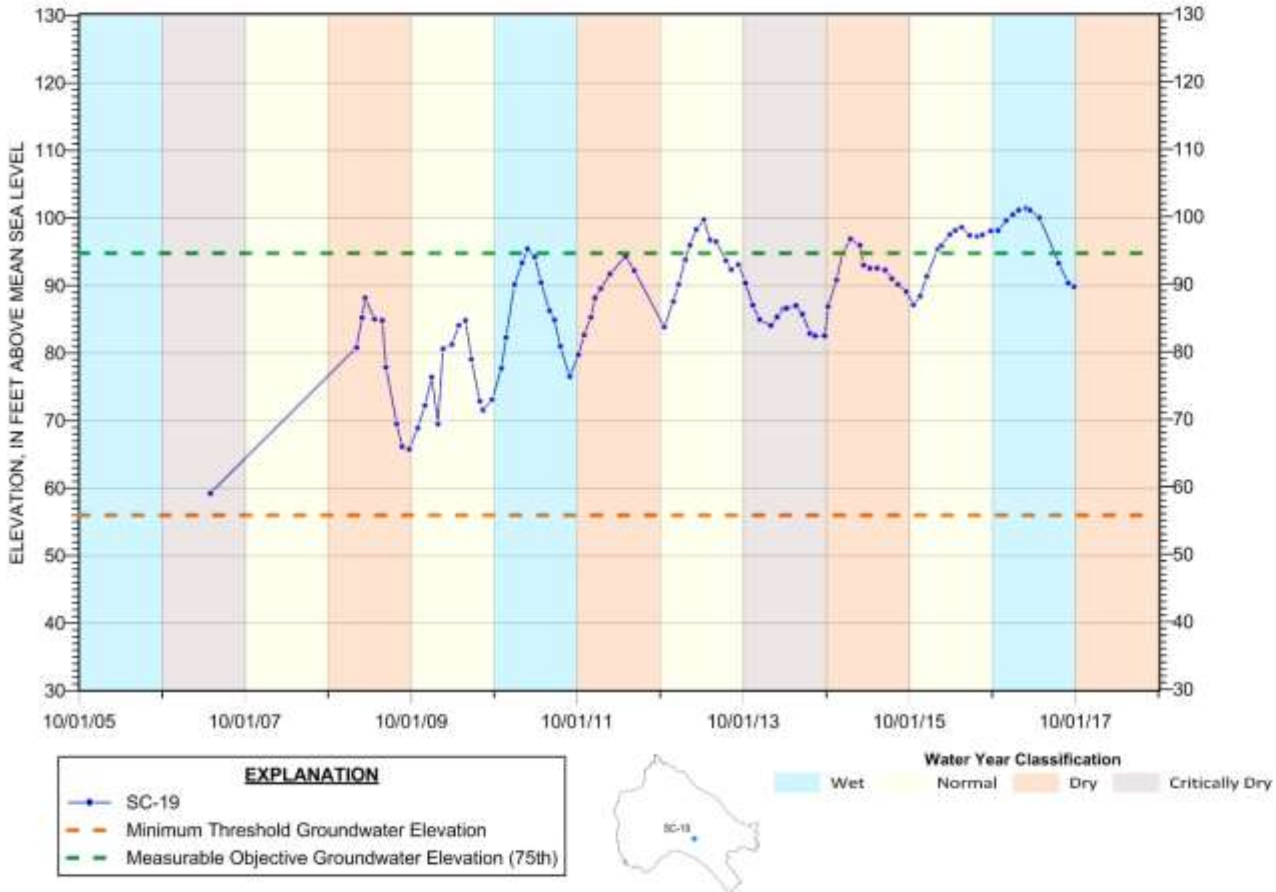

Figure 3-B.9. SC-19 Hydrograph with Minimum Threshold and Measureable Objective

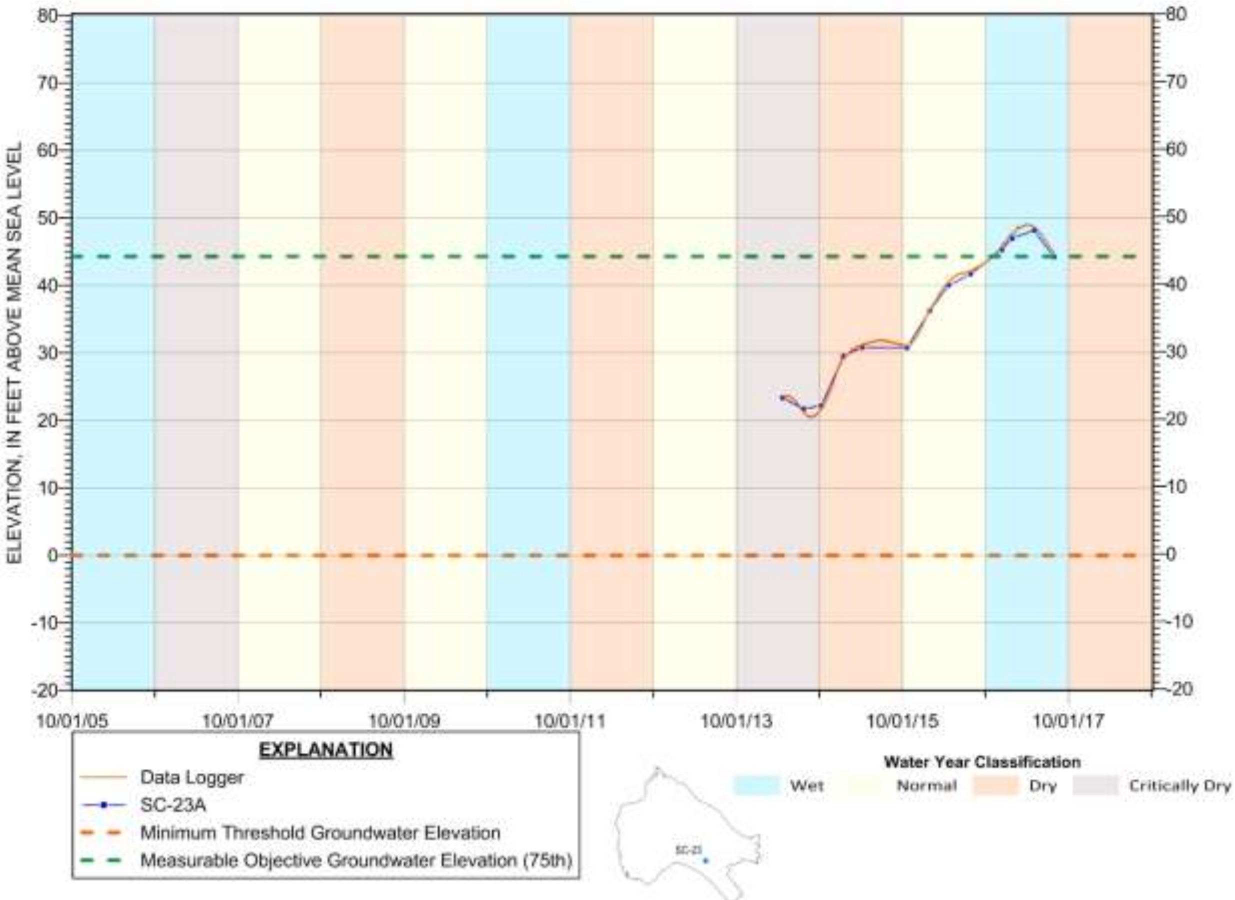

Figure 3-B.10. SC-23A Hydrograph with Minimum Threshold and Measureable Objective

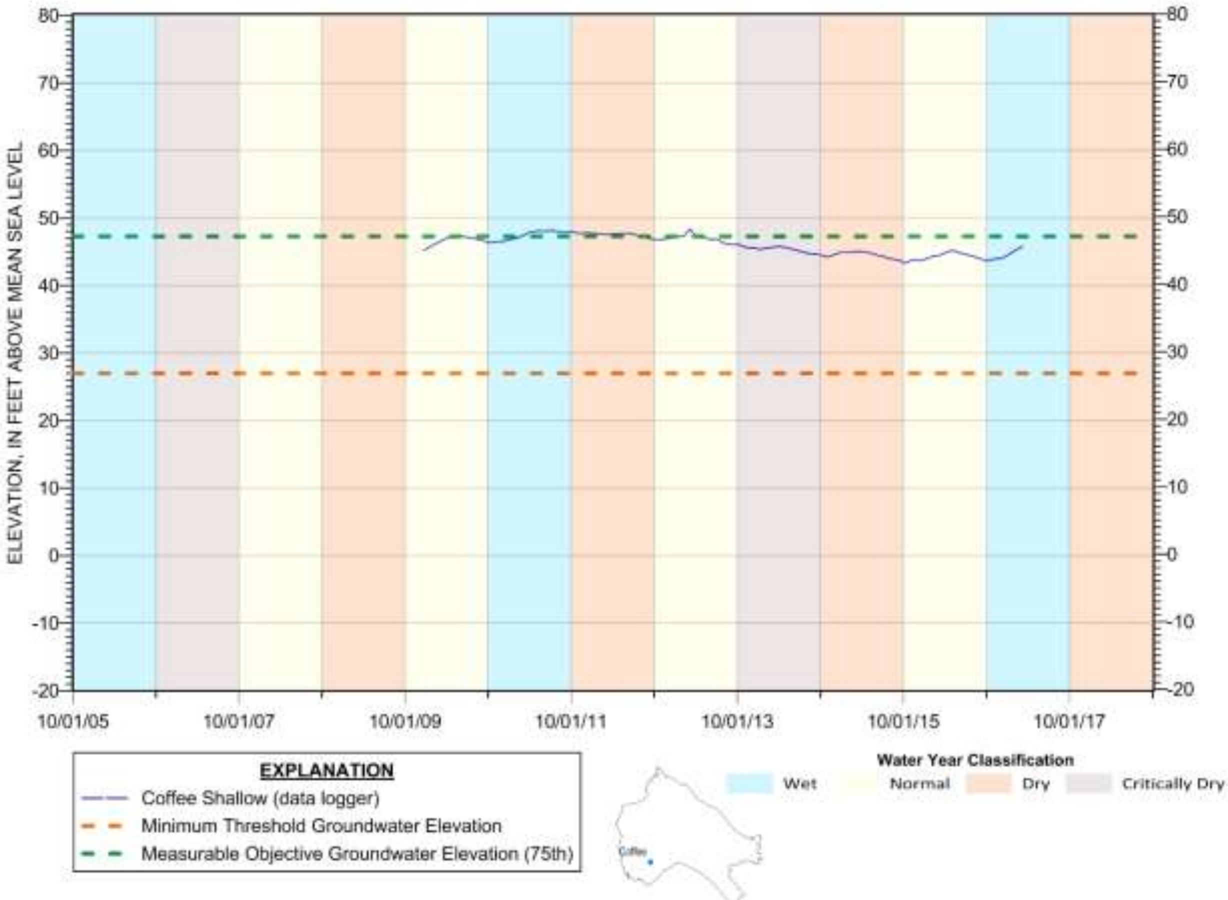

Figure 3-B.11. Coffee Lane Shallow Hydrograph with Minimum Threshold and Measureable Objective

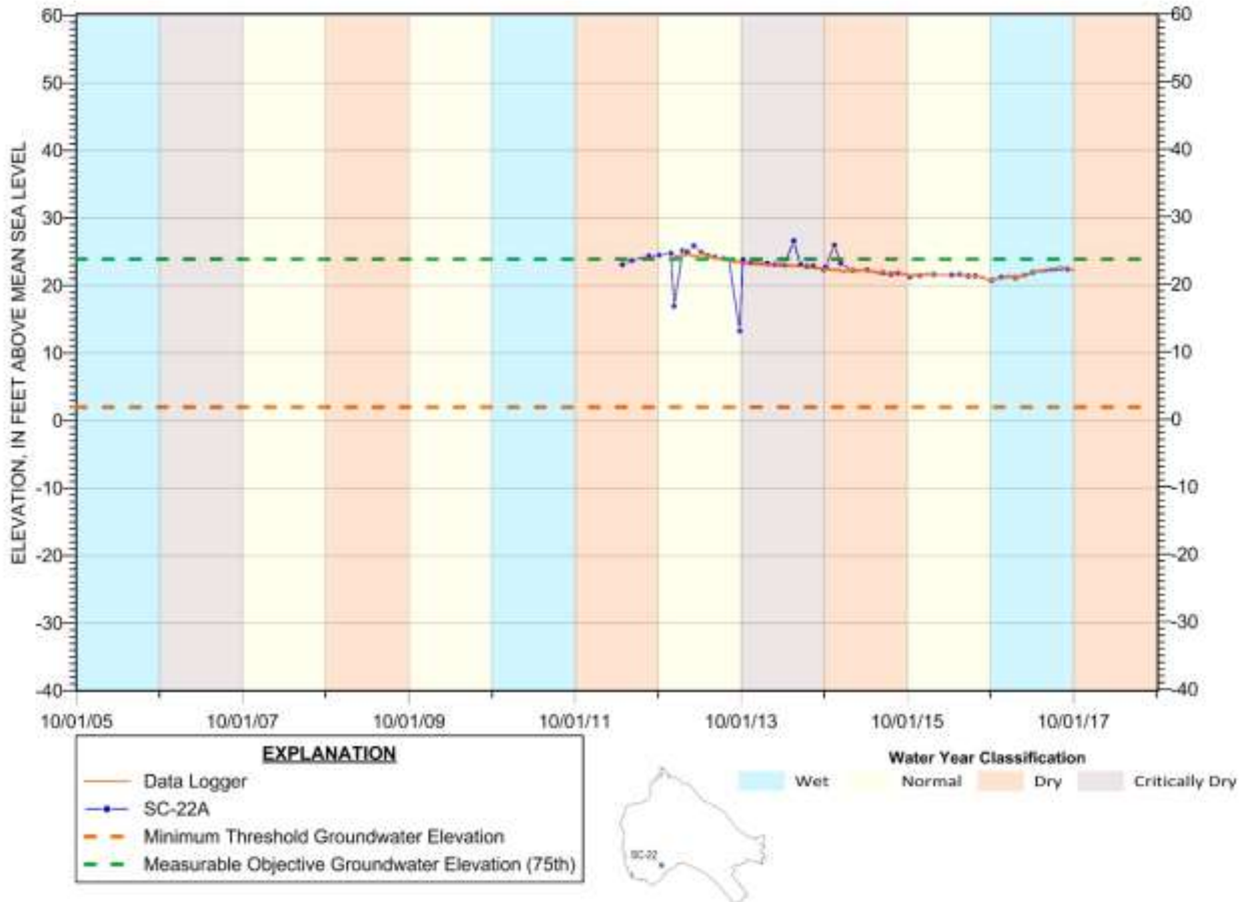

Figure 3-B.12. SC-22A Hydrograph with Minimum Threshold and Measureable Objective

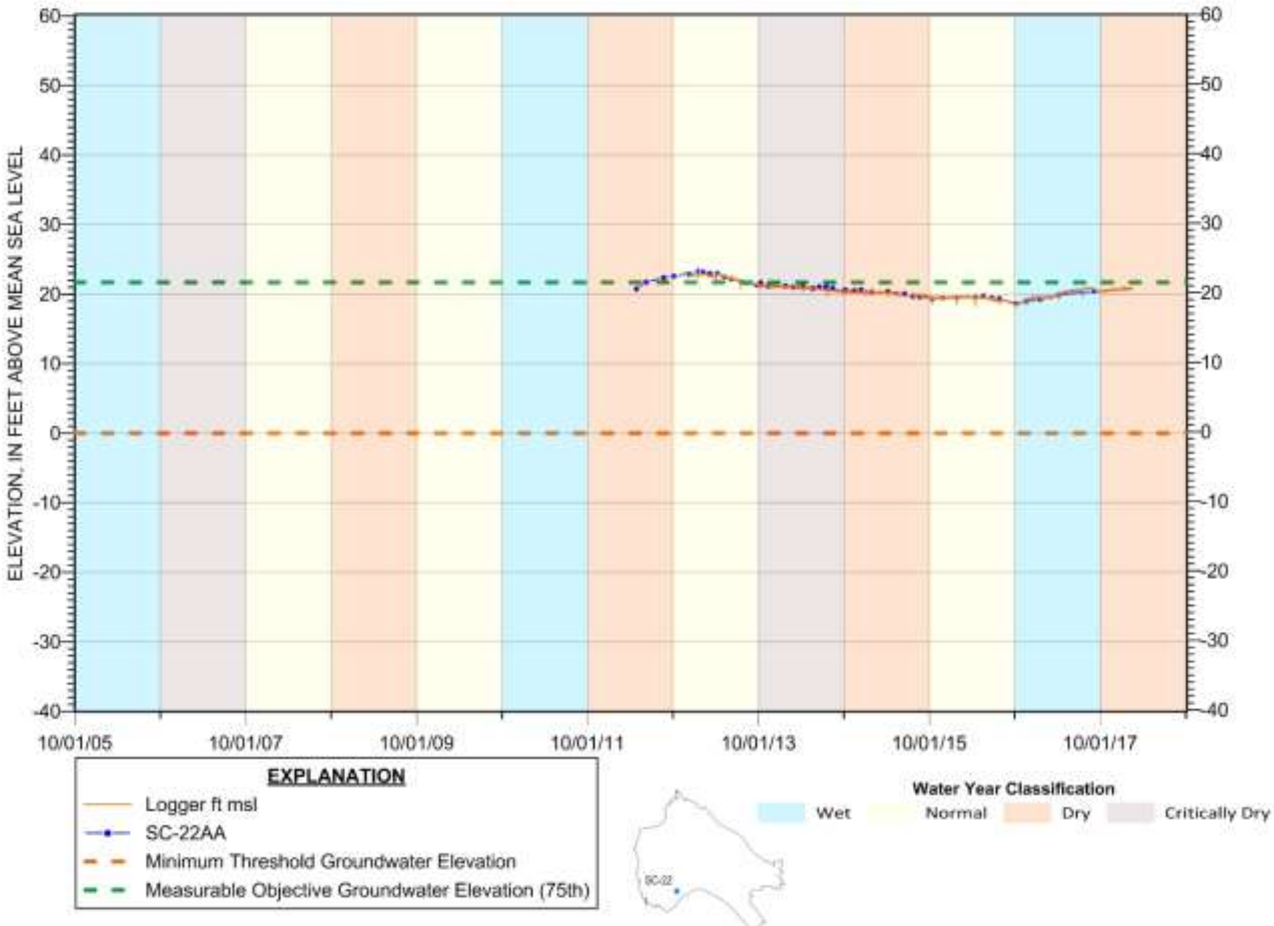

Figure 3-B.13. SC-22AA Hydrograph with Minimum Threshold and Measureable Objective

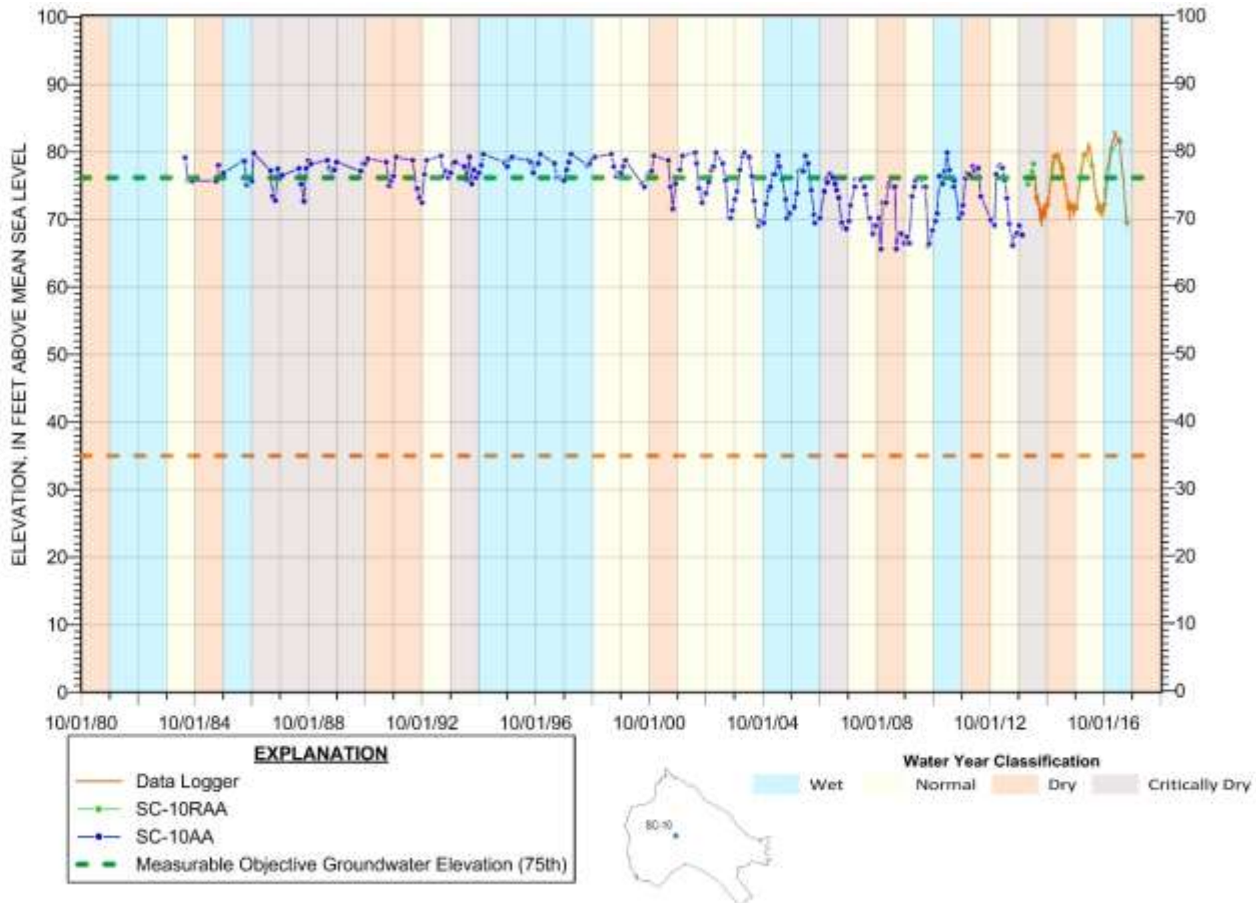

Figure 3-B.14. SC-10RAA Hydrograph with Minimum Threshold and Measureable Objective

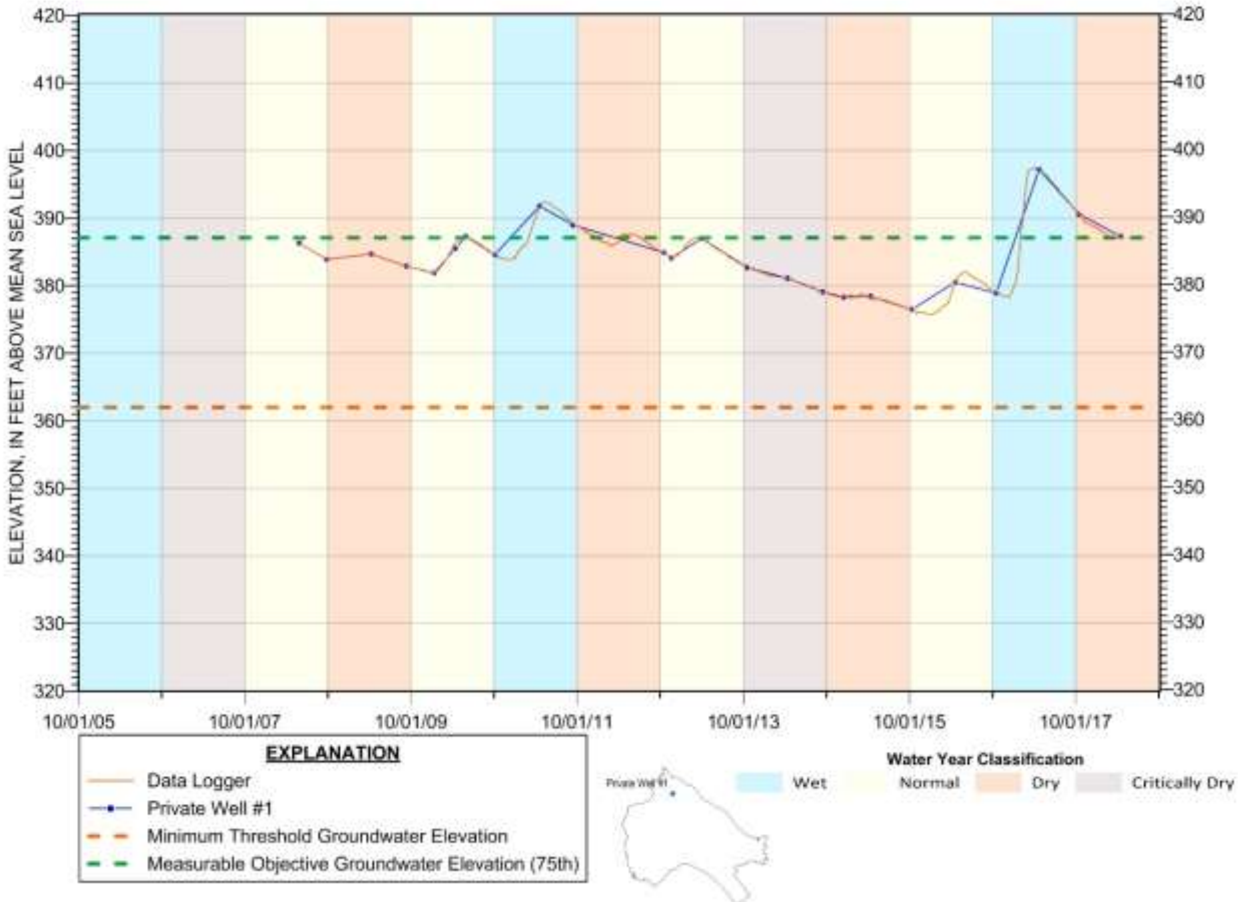

Figure 3-B.15. Private Well #1 Hydrograph with Minimum Threshold and Measureable Objective

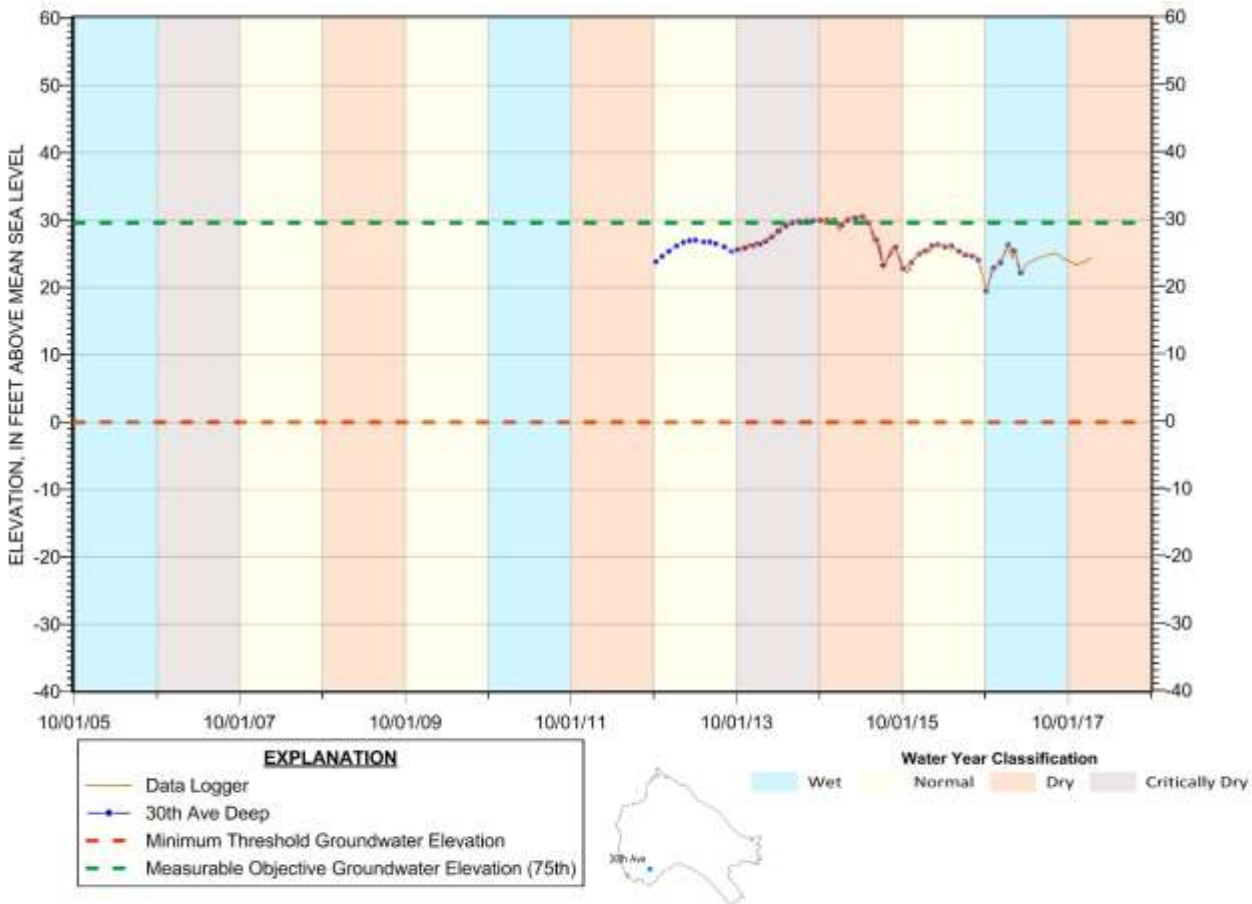

Figure 3-B.16. 30th Ave Deep Hydrograph with Minimum Threshold and Measureable Objective

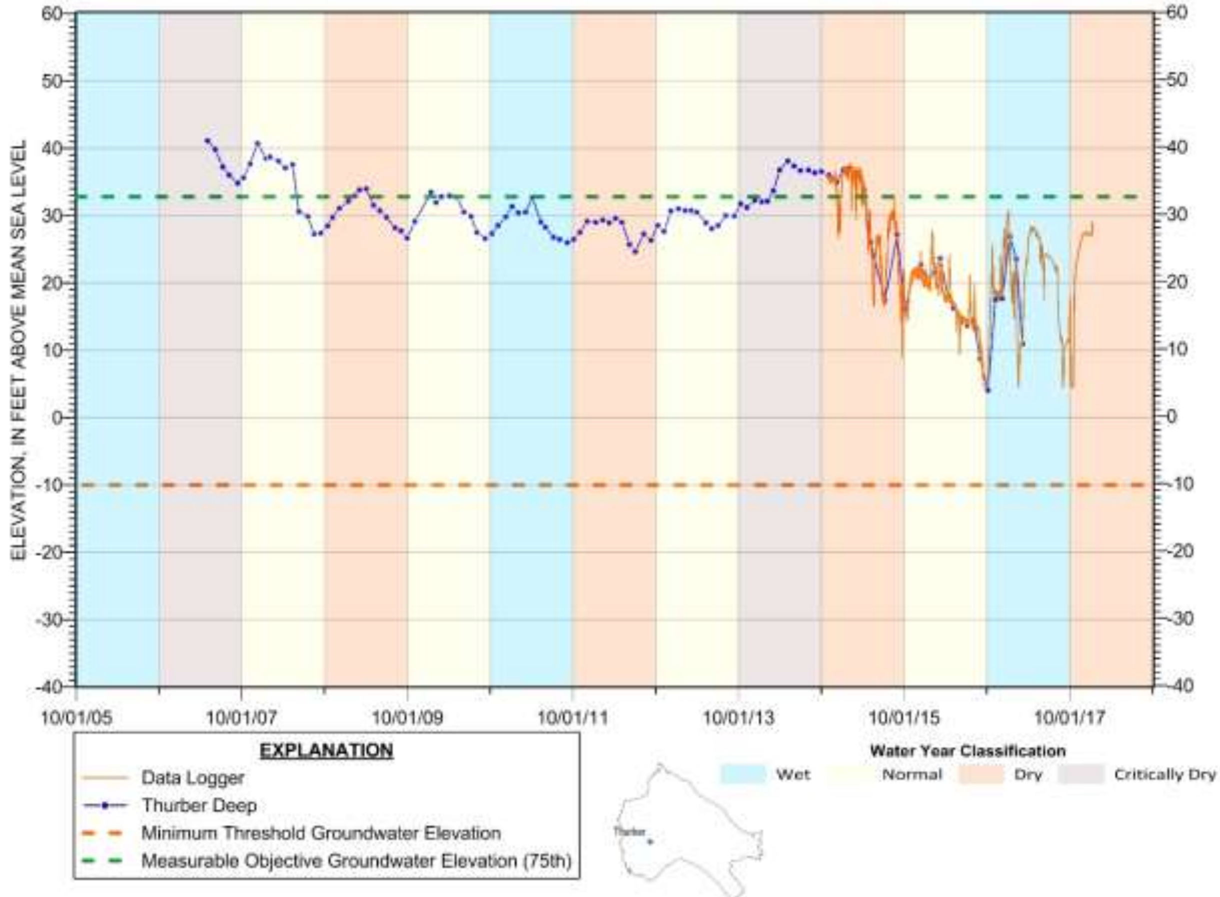

Figure 3-B.17. Thurber Lane Deep Hydrograph with Minimum Threshold and Measureable Objective

APPENDIX 3-C

SUMMARY OF FEDERAL, STATE, AND LOCAL WATER QUALITY REGULATIONS

Existing Regulatory Policies Related to Groundwater

This appendix provides an overview of federal, state, and local environmental laws, policies, plans, regulations, and guidelines (referred to generally as "regulatory requirements") relevant to groundwater resources and applicable to the MGA member agencies. The text is almost entirely from Pure Water Soquel's Draft Environmental Impact Report (EIR). The full Draft EIR document can be found at: https://www.soquelcreekwater.org/PWS-CEQA.

Federal and State Regulations

CLEAN WATER ACT (1972)

The federal Clean Water Act (CWA) of 1972's primary objective is to restore and maintain the integrity of the nation's waters. The objective translates into two fundamental national goals:

- to eliminate the discharge of pollutants into the nation's waters, and
- to achieve water quality levels that are fishable and swimmable.

To achieve the second objective, Designated Uses have been established for individual water bodies (e.g., lake, stream, creek, river) with typical designated uses including:

- Protection and propagation of fish, shellfish and wildlife;
- Recreation;
- Public drinking water supply; and
- Agricultural, industrial, navigational and other purposes.

The Clean Water Act includes an Antidegradation Policy (40 CFR 131.12).

Federal Antidegradation Policy

Section 303 of the Clean Water Act (CWA) (33 U.S.C. § 1313) requires that states adopt water quality standards for waters of the United States within their applicable jurisdiction. Such water quality standards must include, at a minimum, (1) designated uses for all waterbodies within their jurisdiction, (2) water quality criteria necessary to protect the most sensitive of the uses, and (3) antidegradation provisions. Antidegradation policies and implementing procedures must be consistent with the regulations in 40 C.F.R. § 131.12. Antidegradation is an important tool that states use in meeting the CWA requirement that water quality standards protect public health and welfare, enhance water quality, and meet the objective of the Act to "restore and maintain the chemical, physical and biological integrity" of the nation's waters. The CWA requires that states adopt antidegradation policies and identify implementation methods to provide three levels of water quality protection to maintain and protect (1) existing water uses and the level of water quality, (2) high quality waters, and (3) outstanding national resource waters.

SAFE DRINKING WATER ACT (1972)

The Safe Drinking Water Act (SDWA) is the federal law that is intended to protect public drinking water supplies throughout the nation (see: https://www.epa.gov/sdwa). Under the SDWA, EPA sets standards for drinking water quality and, with its partners (e.g., states), implements various technical and financial programs to ensure drinking water safety.

State agencies accepting primacy[1] authority from EPA implement drinking water regulations that are no less stringent than federal standards. Federal regulations and standards also apply to underground injections including Aquifer Storage and Recovery wells (see: https://www.epa.gov/uic/class-v-wells-injection-non-hazardous-fluids-or-above-underground-sources-drinking-water).

STATE WATER RESOURCES CONTROL BOARD RESOLUTION 68-16 ANTI-DEGRADATION POLICY

In 1968, the State Water Resources Control Board (SWRCB) adopted an anti-degradation policy (policy) aimed at maintaining the high quality of waters in California through the issuance of Resolution No. 68-16 ("Statement of Policy with Respect to Maintaining High Quality Waters in California"). They apply to both surface waters and groundwaters (and thus groundwater replenishment projects), protect both existing and potential beneficial uses of surface water and groundwater, and are incorporated into Regional Water Quality Control Board (RWQCB) Water Quality Control Plans (e.g., Basin Plans).

The policy requires that existing high water quality be maintained to the maximum extent possible, but allows lowering of water quality if the change is "consistent with maximum benefit to the people of the state, will not unreasonably affect present and anticipated use of such water (including drinking), and will not result in water quality less than prescribed in policies." The policy also stipulates that any discharge to existing high quality waters will be required to "meet waste discharge requirements which will result

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[1] States accepting primacy are delegated authority by EPA to implement the regulation for which they have accepted primacy. The SDWA and CWA programs are typically delegated to states via primacy agreements.

in the best practicable treatment or control of the discharge to ensure that (a) pollution or nuisance will not occur and (b) the highest water quality consistent with maximum benefit to the people of the State will be maintained."

The policy prohibits actions that tend to degrade the quality of surface and groundwater. The RWQCBs oversee this policy (SWRCB, 1968). The anti-degradation policy states that:

- Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality will be maintained until it has been demonstrated to the State that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed in the policies.

- Any activity which produces or may produce a waste or increased volume or concentration of waste and which discharges or proposes to discharge to existing high quality waters must meet waste discharge requirements which will result in the best practicable treatment or control of the discharge necessary to assure that (a) a pollution or nuisance will not occur and (b) the highest water quality consistent with maximum benefit to the people of the State will be maintained.

SWRCB has interpreted Resolution No. 68-16 to incorporate the federal anti-degradation policy, which applies if a discharge that began after November 28, 1975 would lower existing surface and groundwater quality. This policy would apply to any project that brings in supplemental sources of water into the Basin because the projects would be required to comply with the state resolution maintaining the existing water quality.

Furthermore, one of the requirements for any recycled water project is that it must be compatible with State Board Resolution 68-16 and the Recycled Water Policy (see below). This can be evaluated on a project-specific localized impacts basis or can be evaluated in terms of the utilization of basin-wide groundwater assimilative capacity. Utilization of more than 10% of basin-wide assimilative capacity for compliance with anti-degradation policy has typically required a Salt and Nutrient Management Plan for the basin or a similar level of evaluation (Brown and Caldwell, 2018).

PORTER-COLOGNE WATER QUALITY CONTROL ACT

The Porter-Cologne Water Quality Control Act (Division 7 of the California Water Code) provides the basis for water quality regulation within California and defines water quality objectives as the limits or levels of water constituents established for the reasonable protection of beneficial uses. The SWRCB administers water rights, water pollution control, and water quality functions throughout California, while the Central Coast RWQCB (CCRWQCB) conducts planning, permitting, and enforcement activities. The Porter-Cologne Act requires the RWQCB to establish a regional Basin Plan with water quality objectives, while acknowledging that water quality may be changed to some degree without unreasonably affecting beneficial uses. Beneficial uses, together with the corresponding water quality objectives, are defined as standards, per federal regulations. Therefore, the regional basin plans form the regulatory references for meeting state and federal requirements for water quality control. Changes in water quality are allowed if the change is consistent with the maximum beneficial use of the State waters, it does not unreasonably affect the present or anticipated beneficial uses, and it does not result in water quality less than that prescribed in the water quality control plans. The basin plan regulations also apply to groundwater. The Basin Plan for this location is discussed below in the local regulations subsection.

This Act would apply to any project where any supplemental sources of water are brought into the Basin because they would have potential to affect water quality and beneficial uses in the Basin. Thus, it is likely that most supplemental water supply projects would be required to comply with the Basin Plan water quality objectives established by the CCRWQCB to protect the beneficial uses of groundwater. This is discussed in the Local Regulations subsection below.

STATE WATER RESOURCES CONTROL BOARD POLICIES RELATED TO GROUNDWATER

Sources of Drinking Water Policy

The Sources of Drinking Water Policy (adopted as Resolution 88-63) designates the municipal and domestic supply (MUN) beneficial use for all surface waters and groundwater except for those waters: (1) with total dissolved solids exceeding 3,000 mg/L, (2) with contamination that cannot reasonably be treated for domestic use, (3) where there is insufficient water supply, (4) in systems designed for wastewater collection or conveying or holding agricultural drainage, or (5) regulated as a geothermal energy producing source. Resolution 88-63 addresses only designation of water as drinking water source; it does not establish objectives for constituents that threaten source waters designated as MUN.

Recycled Water Policy

The Recycled Water Policy, adopted by the SWRCB in February 2009, and amended in 2013 to include monitoring for CECs (discussed below) for groundwater replenishment projects. The Recycled Water Policy was a critical step in creating uniformity in how RWQCBs were individually interpreting and implementing the Anti-degradation Policy in Resolution 68-16 for water recycling projects, including groundwater replenishment projects. The critical provisions in the Policy related to groundwater replenishment projects are discussed in the following subsections.

Constituents of Emerging Concern

As defined in the SWRCB Recycled Water Policy, CECs are chemicals in personal care products, pharmaceuticals including antibiotics, antimicrobials, agricultural and household chemicals, hormones, food additives, transformation products and inorganic constituents. These chemicals have been detected in trace amounts in surface water, wastewater, recycled water, and groundwater. The Recycled Water Policy includes monitoring requirements for six CECs for subsurface application groundwater replenishment projects using recycled water, four of which are used as health-based indicators and others serving as performance-based indicators. In addition to the Recycled Water Policy CECs, as part of the SWRCB regulations for groundwater replenishment projects with recycled water, a project sponsor must recommend CECs for monitoring in recycled water and potentially in groundwater in the project's Engineering Report. For recharge projects that use recycled water that has been treated using reverse osmosis (RO) and an advanced oxidation process (AOP), the monitoring requirements in the Recycled Water Policy only apply to recycled water prior to and after RO/AOP treatment (i.e., no groundwater sampling). None of the CECs currently have regulatory limits. The Recycled Water Policy includes monitoring trigger levels (MTLs) for the four health-based CEC indicators and response actions to be taken by groundwater replenishment project sponsors based on monitoring results compared to the MTLs. The MTLs were based on Drinking Water Equivalent Levels. A Drinking Water Equivalent Level represents the amount of a CEC in drinking water that can be ingested daily over a lifetime without appreciable risk (MRWPCA and MPWMD, 2016). The following CECs from the Recycled Water Policy are those with health-based indicators, treatment/performance- based indicators, or both as indicated below in parentheses.

- 17-β-estradiol - steroid hormone (health-based indicator)
- Caffeine – stimulant (health-based and performance-based indicator)
- N-nitrosodimethylamine (NDMA) – disinfection byproduct (health-based and performance- based indicator) [Note: NDMA's current California NL is 0.01μg/L]
- Triclosan – antimicrobial (health-based indicator)
- N,N-diethyl-metatoluamide (DEET) – ingredient in personal care products (performance- based indicator)
- Sucralose – food additive (performance-based indicator)

Salt and Nutrient Management Plans

In recognition that some groundwater basins in the state contain salts and nutrients that exceed or threaten to exceed Basin Plan groundwater objectives, and that some Basin Plans do not have adequate implementation measures to achieve compliance, the Recycled Water Policy includes provisions for managing salts and nutrients on a regional or watershed basis through development of Salt and Nutrient Management Plans (SNMP) rather than imposing requirements on individual recycled water projects (which had been the practice prior to adoption of the Recycled Water Policy). Unfavorable groundwater salt and nutrient conditions can be caused by natural soils, discharges of waste, irrigation using surface water, groundwater, or recycled water, and water supply augmentation using surface or recycled water (although treating the recycled water through RO prior to application would typically prevent this from occurring). The Recycled Water Policy recognizes that regulation of recycled water alone will not address these conditions. SNMPs are to be developed for every groundwater basin/sub-basin by May 2014 (May 2016 with a RWQCB-approved extension). SNMPs were not prepared for the Santa Cruz Mid-County Basin because it does not contain salts and nutrients in excess of Basin Plan objectives. If a SNMP is not prepared for a basin underlying a project or a project is using a limited amount of be available assimilative capacity (described below), the recycled water policy requires the preparation of a dedicated anti-degradation evaluation.

Antidegradation and Assimilative Capacity

Assimilative capacity is the ability for groundwater to receive contaminants without detrimental effects to human health or other beneficial uses. It is typically derived by comparing background ambient chemical concentrations in groundwater to the concentrations of the applicable Basin Plan groundwater quality objectives. The difference between the ambient concentration and groundwater quality objective is the available assimilative capacity.

The Recycled Water Policy establishes two assimilative capacity thresholds in the absence of an adopted SNMP. A groundwater replenishment project that utilizes less than 10% of the available assimilative capacity in a groundwater basin/sub-basin (or multiple projects utilizing less than 20% of the available assimilative capacity in a groundwater basin/subbasin) are only required to conduct an anti-degradation analysis verifying the use of the assimilative capacity. In the event a project or multiple projects utilize more than the designated fraction of the assimilative capacity (e.g., 10% for a single project or 20% for multiple projects), the project proponent must conduct a RWQCB-deemed acceptable (and more elaborate) anti-degradation analysis.

A RWQCB has the discretionary authority to allocate assimilative capacity to groundwater replenishment projects. There is a presumed assumption that allocations greater than the Recycled Water Policy thresholds would not be granted without concomitant mitigation or an amendment to the Basin Plan groundwater quality objective to create more assimilative capacity for allocation. Groundwater replenishment projects that utilize advanced treated recycled water will use very little to essentially none of the available assimilative capacity because of the high quality of the water.

Regional Water Quality Control Board Groundwater Requirements

The Recycled Water Policy does not limit the authority of a RWQCB to impose more stringent requirements for groundwater replenishment projects to protect designated beneficial uses of groundwater, provided that any proposed limitations for the protection of public health may only be imposed following regular consultation with the California SWRCB Division of Drinking Water (DDW). The Recycled Water Policy also does not limit the authority of a RWQCB to impose additional requirements for a proposed groundwater replenishment project that has a substantial adverse effect on the fate and transport of a contaminant plume (for example those caused by industrial contamination or gas stations), or changes the geochemistry of an aquifer thereby causing the dissolution of naturally occurring constituents, such as arsenic, from the geologic formation into groundwater. These provisions require additional assessment of the impacts of groundwater replenishment projects on areas of contamination in a basin and/or if the quality of the water used for replenishment causes constituents, such as naturally occurring arsenic, to become mobile and impact groundwater.

SWRCB DIVISION OF DRINKING WATER (DDW)

California's drinking water program was originally created in 1915, when the California State Board of Health established the Bureau of Sanitary Engineering. In 1976, two years after the Safe Drinking Water Act was passed, California adopted its own safe drinking water act (contained in the Health and Safety Code) and adopted implementing regulations (contained in Title 22 California Code of Regulation). The state's act had two main goals: (1) to continue the state's drinking water program, and (2) to be the delegated authority (referred to as the "primacy") by the EPA for enforcement of the federal Safe Drinking Water Act. As required by the federal act, California's program must set drinking water standards that are at least as stringent as the EPA's standards. Each public water system also must monitor for a specified list of contaminants, and the findings must be reported to the state.

The DDW regulates public water systems, oversees water recycling projects, permits water treatment devices, supports and promotes water system security, and performs a number of other functions. DDW has adopted enforceable primary and secondary maximum contaminant levels (MCLs). The MCLs are either based on the federal MCLs or as part of DDW's own regulatory process. For example, California has an MCL for perchlorate while there is no federal MCL. The MCLs account for not only chemicals' health risks, but also factors such as their detectability and treatability, as well as costs of treatment. Health and Safety Code Section116365(a) requires a contaminant's MCL to be established at a level as close to its Public Health Goal (PHG) as is technologically and economically feasible, placing primary emphasis on the protection of public health. The Office of Environmental Health Hazard Assessment (OEHHA) established PHGs. They are concentrations of drinking water contaminants that pose no significant health risk if consumed for a lifetime, based on current risk assessment principles, practices, and methods. OEHHA establishes PHGs pursuant to Health and Safety Code Section116365(c) for contaminants with MCLs, and for those for which MCLs will be adopted. Public water systems use PHGs to provide information about drinking water contaminants in their annual Consumer Confidence Reports. Certain public water systems must provide a report to their customers about health risks from a contaminant that exceeds its PHG and about the cost of treatment to meet the PHG, and hold a public hearing on the report. Action levels (AL) are included in CCRs for certain constituents where no MCLs have been established, i.e., under the lead and copper rule. If a constituent exceeds its AL, this triggers treatment or other requirements.

There are also a variety of chemicals of health concern whose occurrence is too infrequent in conventional drinking water sources to justify the establishment of national standards, but are addressed using advisory levels. The DDW, with the assistance of OEHHA, has established notification levels (NL) and Response Levels (RL) for that purpose. If a chemical is present in drinking water that is provided to consumers at concentrations greater than the RL (10 to 100 times greater than the NL depending on the toxicological endpoint of the constituent), DDW recommends that the source be taken out of service. If the source is not taken offline and a chemical concentration is greater than its NL in drinking water that is provided to consumers, DDW recommends that the utility inform its customers and consumers about the presence of the chemical, and about health concerns associated with exposure to it.

Final Groundwater Replenishment with Recycled Water Regulations hereafter, referred to as "Groundwater Replenishment Regulations," went into effect June 18, 2014 (SWRCB, 2014). The overarching principles taken into consideration by DDW in developing the Groundwater Replenishment Regulations were:

- Groundwater replenishment projects are replenishing groundwater basins that are used as sources of drinking water.
- Control of pathogenic microorganisms should be based on a low tolerable risk that was defined as an annual risk of infection from pathogen microorganisms in drinking water of one in 10,000 (10-4). This risk level is the same as that used for the federal Surface Water Treatment Rule for drinking water.
- Compliance with drinking water standards for regulated chemicals.
- Controls for unregulated chemicals.
- No degradation of an existing groundwater basin used as a drinking water source.
- Use of multiple barriers to protect water quality and human health.
- Projects should be designed to identify and respond to a treatment failure. A component of this design acknowledges that groundwater replenishment projects inherently will include storage in a groundwater aquifer and include some natural treatment.

CENTRAL COAST REGIONAL WATER QUALITY CONTROL PLAN (BASIN PLAN)

The CCRWQCB, under the authority of the California Water Code, is responsible for authorizing and regulating activities that may discharge wastes to surface water or groundwater resources.

This authority includes adoption of Basin Plans (Section 13240) with beneficial uses and water quality objectives (both narrative and numeric) to reasonably protect those uses (Section 13050). The Basin Plan also establishes guidelines for water used for irrigation. The Basin Plan for the Central Coast was originally adopted in 1971 and was last amended in 2011.

Groundwater beneficial uses for the Basin are listed as agricultural water supply (AGR), municipal and domestic water (MUN). The Basin Plan has:

- For MUN beneficial uses – groundwater criteria for bacteria and DDW primary and secondary MCLs.
- For AGR beneficial uses – objectives to protect soil productivity, irrigation, and livestock watering and guidelines to interpret a general narrative objective to prevent adverse effects on the beneficial use.

Permit limits for groundwater replenishment projects are set to ensure that groundwater does not contain concentrations of chemicals in amounts that adversely affect beneficial uses or degrade water quality. For some specific groundwater sub-basins, the Basin Plan establishes specific mineral water quality objectives for total dissolved solids, chloride, sulfate, boron, sodium, and nitrogen.

WATER WELL STANDARDS

Under California Water Code Section 231, enacted in 1949, California Department of Water Resources (DWR) is responsible for developing standards for the protection of well water quality. Authority for enforcing the standards as they apply to the construction, destruction, and modification of water wells rests with the Santa Cruz County Environmental Health Services, which also implements additional local requirements. The California Water Code requires contractors that construct or destruct water wells to have a C-57 Water Well Contractor's License, follow DWR well standards, and file a completion report with DWR (Water Code Sections 13750.5 et seq.).

WELL COMPLETION REPORTS

DWR is responsible for maintaining a file of well completion reports (DWR Form 188), which must be submitted whenever a driller works on a water well. Well completion reports must be filed with DWR within 60 days from the date of the work and must also be filed with the County. Well completion reports may be used by public agencies conducting groundwater studies, and may also be made available to the public as long as the owner's name is not made public (Water Code Sections 13751 and 13752).

GROUNDWATER RIGHTS

In California, water rights involve the right to use water, not the right to own water. While the Water Code implies the existence of groundwater rights, their doctrinal bases and characteristics are essentially the product of the decisions of the courts. There are three types of groundwater rights:

Overlying Rights. All property owners above a common aquifer possess a mutual right to the reasonable and beneficial use of a groundwater resource on land overlying the aquifer from which the water is taken. Overlying rights are correlative (related to each other) and overlying users of a common water source must share the resource on a pro rata basis in times of shortage. A property overlying use takes precedence over all non-overlying uses.

Appropriative Rights. Non-overlying uses and public uses, such as municipal uses, are called appropriative uses. Among groundwater appropriators, the "first in time, first in right" priority system applies. Appropriative users are entitled to use the surplus water available after the overlying user's rights are satisfied.

Prescriptive Rights. Prescriptive rights are gained by trespass or unauthorized taking that can yield a title because it was allowed to continue longer than the five year statute of limitations. Claim of a prescriptive water right to non-surplus water by an appropriator must be supported by many specific conditions, including a showing that the pumpage occurred in an open manner, was continuous and uninterrupted for five years, and was under a claim of right.

From a water law standpoint, rights of public agencies to store water via in-lieu recharge and to recapture water in the Santa Cruz Mid-County Basin can be summarized by the following general rules:

- The agencies have the right to recapture water that has been added to the groundwater supply as a result of in-lieu recharge;

- The agencies have the right to prevent other groundwater producers from extracting the replenished supply, although this could require litigation, and in some cases, adjudication of all rights to the groundwater basin may be necessary to determine rights to the total supply; and

- The underground storage and recovery of the groundwater basin cannot substantially interfere with the basin's native or natural groundwater supply.

Material Injury. Groundwater case law has generally adopted the threshold that "…material injury… turns on the existence of an appreciable diminution in the quantity or quality of water…" (District, 2010) A reasonable definition of "appreciable" would render a nearby well incapable of meeting its:

1. Historically measured maximum daily production level;
2. Historically measured dry-season production levels; or
3. Historically measured annual production levels under drought conditions.

Local Regulations

California Government Code Section 53091 (d) and (e) provides that facilities for the production, generation, storage, treatment, or transmission of water supplies are exempt from local (i.e. city and county) building and zoning ordinances. However, they would not be exempt from the requirements of Local Coastal Programs.

COASTAL ZONE MANAGEMENT ACT FEDERAL CONSISTENCY REVIEW

The federal consistency requirement set forth in Section 307 of the Coastal Zone Management Act (CZMA) requires that activities approved or funded by the federal government (e.g., the federally-funded California Clean Water State Revolving Fund Program) that affect any land or water use or natural resource of a state's coastal zone, must be consistent with the enforceable policies of the state's federally approved coastal management program.

California's federally approved coastal management program consists of the California Coastal Act, the McAteer-Petris Act, and the Suisun Marsh Protection Act. The California Coastal Commission implements the California Coastal Act and the federal consistency provisions of the CZMA for activities affecting coastal resources outside of San Francisco Bay. Subparts D and F of the federal consistency regulations govern consistency review for activities involving a federal permit and federal funding, respectively. These sections generally require the applicant to provide the subject state agency (e.g., the Coastal Commission) with a brief assessment of potential coastal resources impact and project conformity with the enforceable policies of the management program.

The Coastal Commission considers an application for a coastal development permit to satisfy the Subpart D and F conformity assessment requirements. Typically, the Coastal Commission will provide its response (concurrence, conditional concurrence, or objection) in its staff report for the coastal development permit. In cases where the coastal development permit is issued by a local government with a certified local coastal program (LCP), the Coastal Commission will typically provide its response in a letter, following the permit issuance and the completion of any appeals process.

California Coastal Act

The California Coastal Act (Public Resources Code Section 30000 et seq.) provides for the long-term management of lands within California's coastal zone boundary. The Coastal Act includes specific policies for management of natural resources and public access within the coastal zone. Of primary relevance to groundwater and water quality are Coastal Act policies concerning protection of the biological productivity and quality of coastal waters. For example, Article 4 of the Act details policies related to the marine environment, such as biological productivity and water quality. Specifically, and relevant to groundwater hydrology and water quality, the Act requires the quality of coastal waters, streams, wetlands, estuaries appropriate to maintain optimum populations of marine organisms and for the protection of human health, to be maintained and, where feasible, restored through, among other means, preventing depletion of groundwater supplies (Cal. Pub. Res. Code §§ 30231).

Santa Cruz County Environmental Health Services

At the local level, the Santa Cruz County Environmental Health Services enforces the well drilling and reporting requirements of the California Water Code (Sections 13750.5 et seq.) through enforcement of Title 7, Chapter 7.70, Water Wells, of the Santa Cruz County Code. The Santa Cruz County Environmental Health Services well program provides permitting for the construction, destruction, and repair/modification of all wells, including geothermal heat exchange wells, cathodic protection wells, test wells, and monitoring wells.

Summary of Key Points

1. There are strong federal and state statutes and regulations governing water quality that will apply to implementation of management actions and/or projects that become part of the GSP;
2. Federal and state anti-degradation policies are particularly important in considering how projects and/or management actions might be used to support basin sustainability; and
3. Federal and state policy and regulations are not static but are continuously evolving based on new information and experience.

APPENDIX 3-D

HYDROGRAPHS OF REPRESENTATIVE MONITORING POINTS FOR DEPLETION OF INTERCONNECTED SURFACE WATER

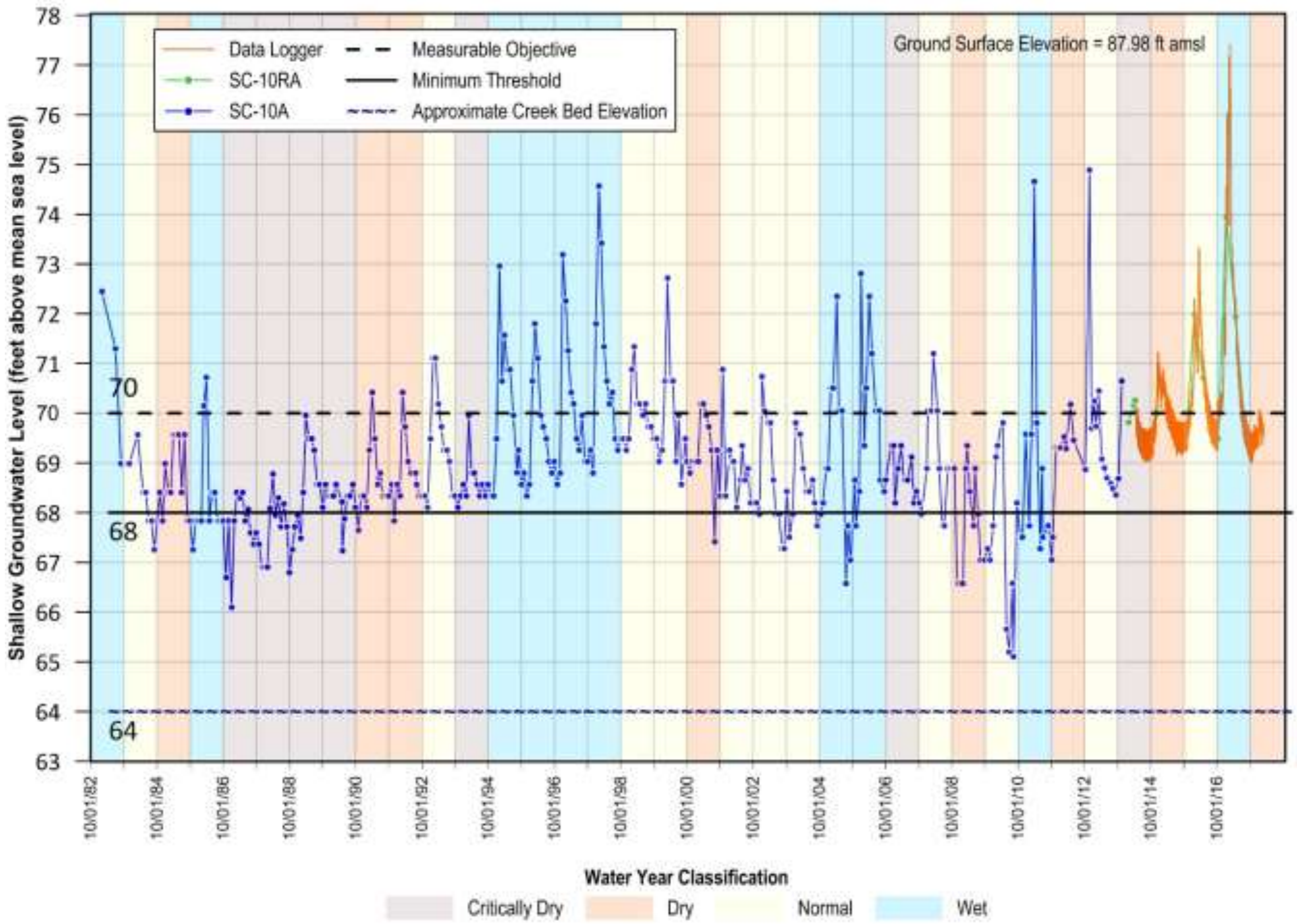

Figure 3-C.1. SC-10RA Hydrograph with Minimum Threshold and Measureable Objective

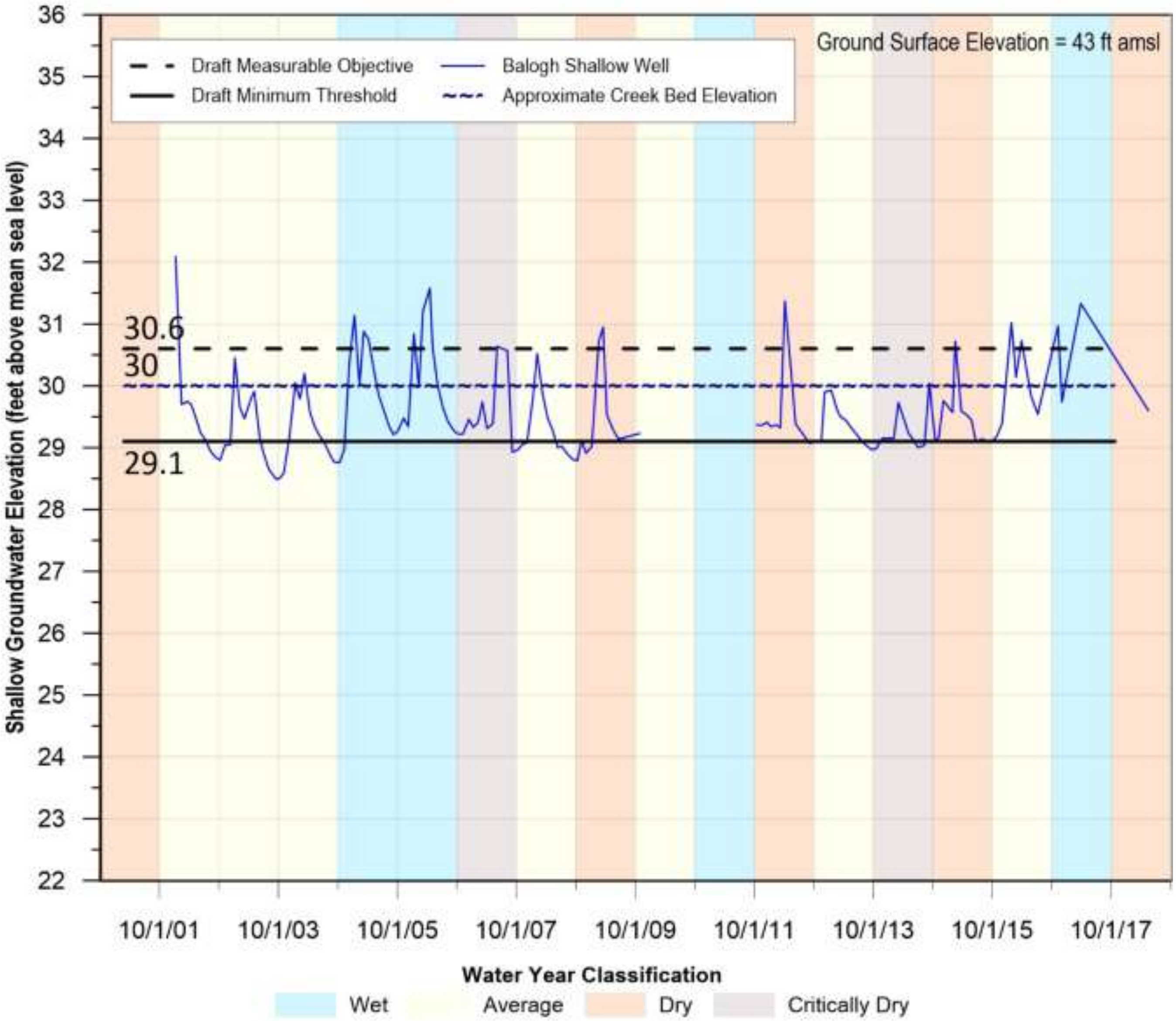

Figure 3-C.2. Balogh Shallow Monitoring Well Hydrograph with Minimum Threshold and Measureable Objective

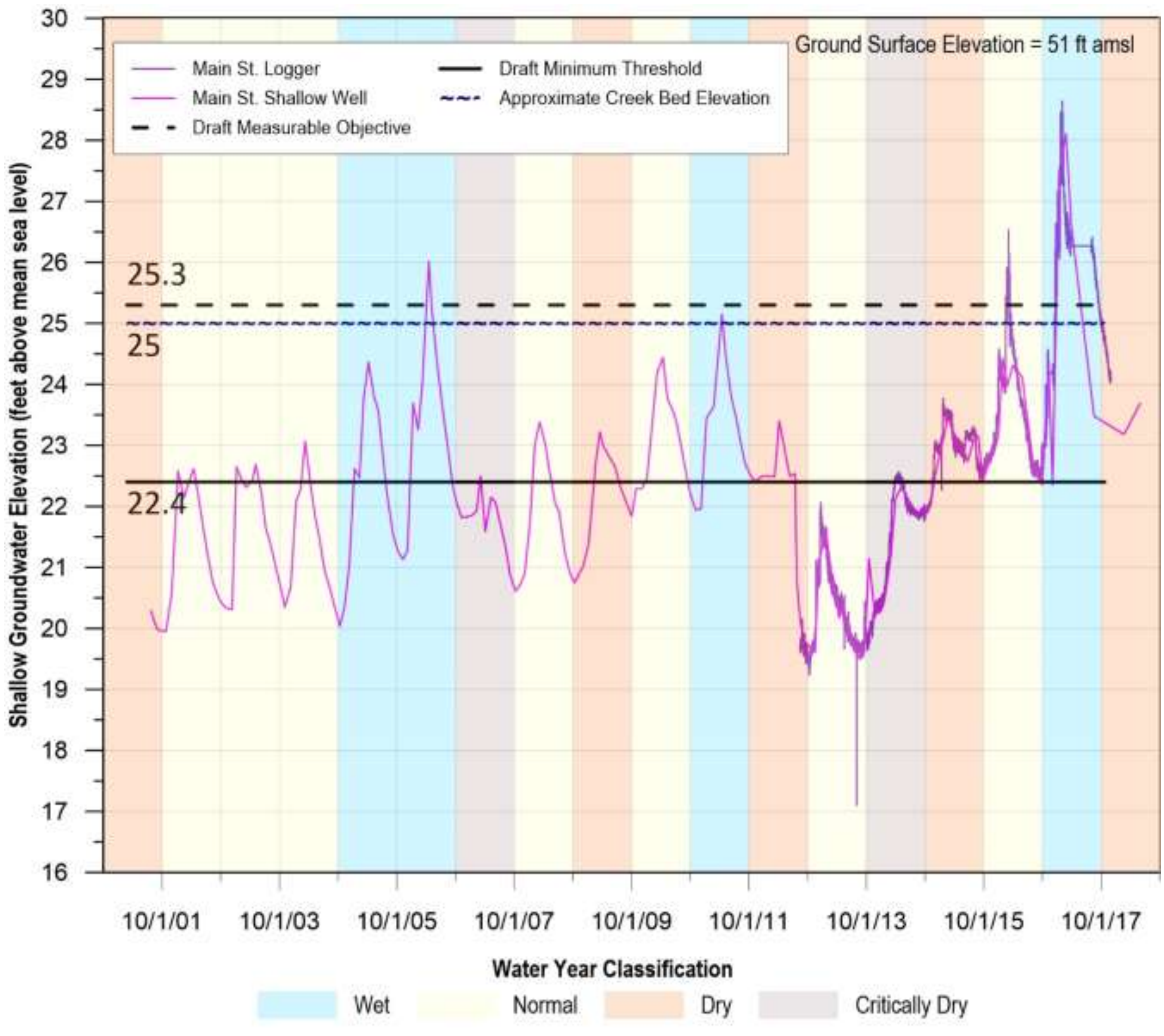

Figure 3-C.3. Main Street Shallow Monitoring Well Hydrograph with Minimum Threshold and Measureable Objective

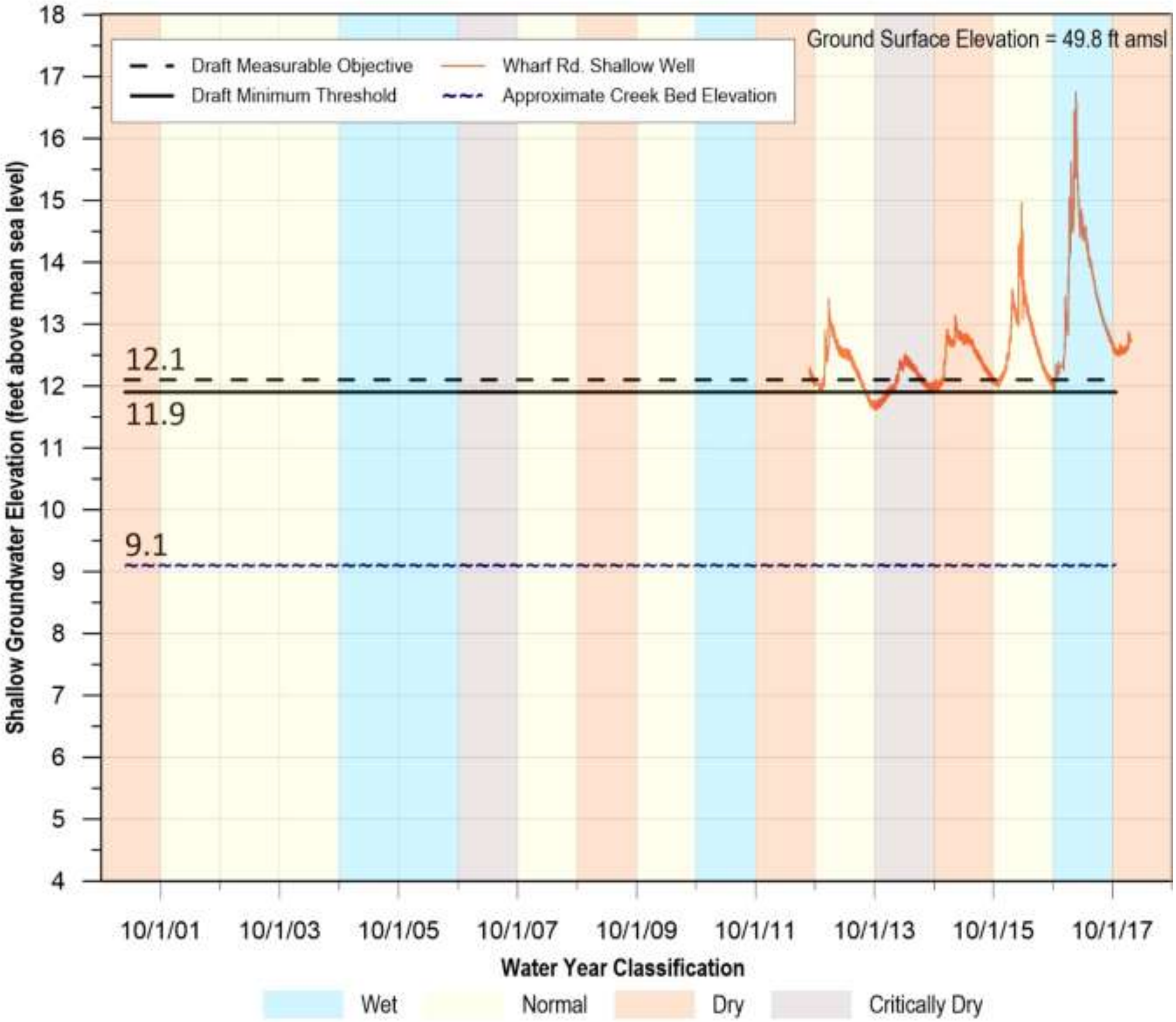

Figure 3-C.4. Wharf Road Shallow Monitoring Well Hydrograph with Minimum Threshold and Measureable Objective

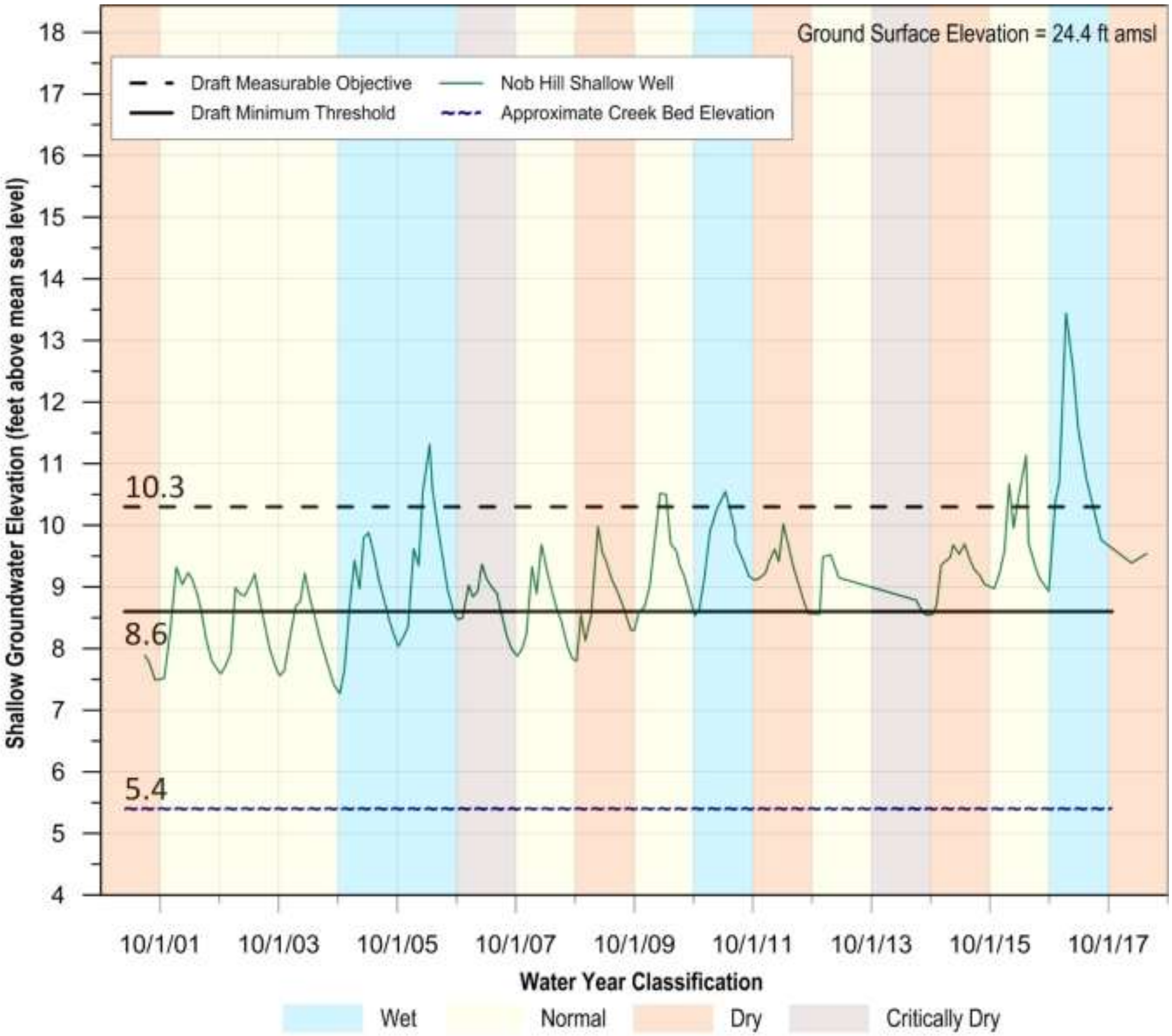

Figure 3-C.5. Nob Hill Shallow Monitoring Well Hydrograph with Minimum Threshold and Measureable Objective

APPENDIX 5-A

SANTA CRUZ MID-COUNTY GROUNDWATER AGENCY EVALUATION OF PRIVATE PUMPER FUNDING MECHANISMS AND FEE CRITERIA, RAFTELIS, MAY 2019

SANTA CRUZ

MID-COUNTY GROUNDWATER AGENCY

Evaluation of Private Pumper Funding Mechanisms and Fee Criteria

May 2019

RAFTELIS

May 3, 2019

John Ricker
Water Resources Division Director
County of Santa Cruz
701 Ocean Street, Room 312
Santa Cruz, CA 95060

Subject: Private Non-de minimis Funding Options and Fee Criteria

Dear Mr. Ricker:

This memorandum identifies opportunities for the Santa Cruz Mid-County Groundwater Agency (MGA) to recover costs of Groundwater Sustainability Plan (GSP) administration and management. The criteria, necessary policies, and data required for charging non-de minimis pumpers are explained in detail as well as estimated charges based on preliminary cost estimates and groundwater user data. Development of a funding mechanism is critical to facilitate successful implementation of the GSP consistent with the requirements of the Sustainable Groundwater Management Act (SGMA). A key success factor is preparing a cost allocation that is equitable to GSA members and basin users.

This White Paper includes discussion on the following items:

- Preliminary GSA Budget
- Fee basis options
- Criteria for including/excluding users from cost recovery
- Calculation of hypothetical non-de minimis private pumper charges
- Costs and benefits of various types of charges
- Proposition 218 and 26 requirements in the context of SGMA

The tasks identified to prepare the White Paper include:

1. Determine the suite of options to recovery GSA costs from non-de minimis pumpers based on geographic location, proximity to surface water and the coast, volume of water pumped, and other criteria
2. Calculate fees using preliminary data based on parcels, acreage, and volumetric production of water
3. Assess the costs and benefits of each fee structure and mechanism for implementing each fee
4. Relate the implications of each fee type to the requirements of Proposition 218 and Proposition 26
5. Describe the conditions, if any, whereby de minimis users can be charged for a fair share of MGA costs

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1. Introduction and Study Background

1.1 Santa Cruz Mid-County Groundwater Agency

The Santa Cruz Mid-County Groundwater Agency (MGA) is a Joint Powers Authority (JPA)[1] formed by the Central Water District, the City of Santa Cruz, the Soquel Creek Water District, and the County of Santa Cruz to oversee groundwater management activities in the Mid-County Basin of Santa Cruz County. The MGA is governed by an eleven-member board consisting of two officials each from the agencies named in the JPA as well as three private well owner representatives. The MGA is charged with implementing the requirements of the Sustainable Groundwater Management Act (SGMA) of 2014 which consists of developing a Groundwater Sustainability Plan (GSP) and implementation of the adopted GSP over a long horizon.

Due to chronic over-pumping and impending seawater intrusion into the aquifer, the Mid-County Basin has been designated a critically overdrafted basin by the Department of Water Resources (DWR) in Bulletin 118. Basins designated as "critical" must submit sustainability plans to DWR by January 2020 and achieve "sustainability" over a 20-year period. Sustainability is defined as mitigation of the following six undesirable results[2]:

- Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
- Significant and unreasonable reduction of groundwater storage.
- Significant and unreasonable seawater intrusion.
- Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.
- Significant and unreasonable land subsidence that substantially interferes with surface land uses.
- Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

1.2 Study Purpose

The MGA has acquired grant funds to develop and submit the GSP. This paper concerns the long-term costs of managing, administering, and regulating the basin after GSP adoption, otherwise referred to as GSP implementation. More specifically, this paper addresses options in regulating and recovering plan implementation costs from private groundwater users not affiliated with the three municipal water agencies who are party to the JPA. Plan implementation costs include regulatory activities associated with groundwater monitoring, administration of the GSP, periodic reporting, outreach, and fee collection, among other activities. The following sections detail the estimated plan implementation costs (budget), identify several fee setting mechanisms for

[1] Joint Exercise Powers Agreement signed March 17, 2016
[2] Water Code §10721(x)

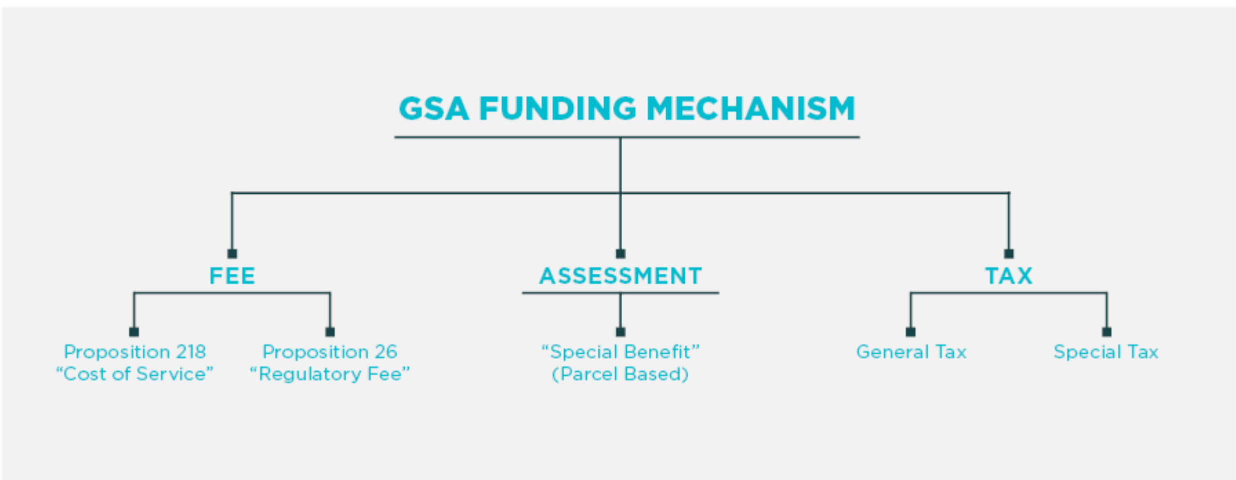
evaluation, discuss different measurement options for determining a regulatory fee, and considers the MGA's authority to charge non-de minimis[3] private groundwater users for groundwater management activities.

[3] SGMA defines de minimis users as those that are residential *and* extract less than two acre-feet of water per year. All other extractors are considered non-de minimis.

2. Funding Mechanisms

Due to Constitutional limitations imposed through California's Propositions 13, 218, and 26, there are strict distinctions between, and regulations associated with, fees and taxes. Taxes and assessments require voter approval. Water rates passed under Proposition 218 are subject to mandatory noticing and a potential majority protest. Regulatory fees are identified as an exemption from taxes under Proposition 26 and can be passed by majority vote of the governing body of the Agency imposing the fee[4]. An example is a dollar per acre foot ($/AF) pumping charge levied by a groundwater management agency. Other fees require protest proceedings for individuals who are paying the fees, for example water rates of a public utility. Figure 1 is a graphical illustration of the broad options available to MGA. What follows in this section is a primer on the various funding mechanisms available for exploration and considerations for the use of each as they relate to future MGA charges.

Figure 1- Funding Options



Raftelis is not a law firm and does not purport to give legal advice or make any recommendation on the legality of individual options in the context of SGMA. The aim is to illustrate the universe of funding mechanisms that may be available to the MGA. The legality of various funding options in the context of GSA fees and charges is fluid. The most recent meaningful case for MGA to consider is the *City of San Buenaventura versus United Water Conservation District* decision (Cal. Supreme Court Case No. S226036). Ultimately the GSA Counsel must opine on the legality of the funding mechanisms and MGA must choose what it believes to be most appropriate for the basin and its groundwater users. The following section introduces four potential funding mechanisms, including the statutory authorization and adoption procedures of each.

2.1 Regulatory Fee (Proposition 26)

The Agency can assess regulatory fees governed by Proposition 26 (Prop 26). This Proposition, passed in 2010, states that everything is a tax under the California Constitution Article XIII C, section 1(e), except:

[4] Proposition 26 and 218 Implementation Guide, League of California Cities, Sacramento, California, 2017

- **A charge imposed for a specific benefit** conferred or privilege granted directly to the payor that is not provided to those not charged, and which does not exceed the reasonable costs to the local government of conferring the benefit or granting the privilege.
- **A charge imposed for a specific government service** or product provided directly to the payor that is not provided to those not charged, and which does not exceed the reasonable costs to the local government of providing the service or product.
- **A charge imposed for the reasonable regulatory costs** to a local government for issuing licenses and permits, performing investigations, inspections, and audits, enforcing agricultural marketing orders, and the administrative enforcement and adjudication thereof.
- **A charge imposed for entrance to or use of local government property**, or the purchase, rental, or lease of local government property.
- **A fine, penalty, or other monetary charge** imposed by the judicial branch of government or a local government, as a result of a violation of law.
- **A charge imposed as a condition of property development**.
- **Assessments and property-related fees** imposed in accordance with the provisions of Article XIII D.

Property-related fees and special benefit assessments levied under Article XIII D are an exemption (number 7) from the requirements of Proposition 26. Additionally, every exaction must bear a fair or reasonable relationship to the payer's burden on, or benefits received from, the governmental activity.

Example: City of San Buenaventura (Ventura) Decision, 2017[5]
United Water Conservation District (District) imposes groundwater pumping fees. The District charges non-agricultural users three times that of agricultural uses. The City of Ventura challenged that the difference in pumping charges represented an illegal subsidy to agricultural users and violated Article XIII D, section 6(b) (Proposition 218) because the fees exceeded the cost of service. The appellate court held that the charges are not property related fees because they are based on the pumping activity and not property ownership (Ventura Water customers do not have their own wells). The court determined that the pumping charges are regulatory fees meeting the first two exceptions of Article XIII C, section 1(e): fee imposed for a specific benefit and does not exceed the reasonable cost of the service. Further the court stated that the reasonableness of costs is not to be measured on an individual basis, but on a collective basis. Since the total cost recovery across all users is reasonable, so is the fee.

MGA may argue that the fee imposed on users is for the reasonable regulatory costs related to managing the groundwater basin. This would presumably comply with Section 1(e)(3) *"A charge imposed for the reasonable regulatory costs…"* The calculated fees charged by MGA should not exceed the reasonable costs of administering and managing the GSP and the basin, and the fees should be proportional to the benefits.

[5] City of San Buenaventura v. United Water Conservation Dist. (2017) 3 Cal.5th 1191, 1198 (City of San Buenaventura)

Key Considerations
Cost to develop: Low
Cost to implement: Low
Collected by: Direct billing or County Assessor
Limitations on use of funds: Reasonable costs of managing the basin
Ease of protest: Not applicable

2.2 Rate/Fee for Service (Proposition 218)

Proposition 218 (Prop 218), passed by the voters in 1996, governs property related fees including water, wastewater, and solid waste. The measure created an amendment to the California Constitution: Article XIII D, Section 6. Proposition 218 was enacted to ensure in part that fees and charges imposed for ongoing delivery of a service to a property are proportional to, and do not exceed, the cost of providing service. Proposition 218 defines property related fees for service and the criteria for achieving the amendment's requirements. The principal requirements, as they relate to public water service fees and charges are as follows:

- Revenues derived from the fee or charge shall not exceed the costs required to provide the property-related service.
- Revenues derived by the fee or charge shall not be used for any purpose other than that for which the fee or charge was imposed.
- The amount of the fee or charge imposed upon any parcel shall not exceed the proportional cost of service attributable to the parcel.
- No fee or charge may be imposed for a service unless that service is actually used or immediately available to the owner of property.
- A written notice of the proposed fee or charge shall be mailed to the record owner of each parcel not less than 45 days prior to a public hearing, when the Agency considers all written protests against the charge.

Procedurally, Prop 218 requires noticing of all affected properties with each property allowed to protest the proposed rates. Absent a majority protest, rates can be adopted by majority vote of the governing body at a public hearing. SGMA makes explicit that fees imposed on the extraction of groundwater "shall be adopted in accordance with subdivisions (a) and (b) of Section 6 of Article XIII D of the California Constitution" (Water Code 10730.2(c)). This section is commonly referred to as Proposition 218.

As it exists, the section of the Water Code created by SGMA requires that fees charged by a GSA comply with Proposition 218 as a water service fee. It is Raftelis' understanding that there may be attempts to amend Water Code Section 10730.2(c) and adopt a lower standard. It is also our understanding that water law practitioners have varying opinions of the requirements of Section 10730.2 as it relates to fee adoption and "extraction of groundwater from the basin." The language in the Water Code is clear, however, and the issue will surely be litigated in the courts in the years to come.

The noticing and majority protest requirements of Proposition 218 presents challenges and questions in the context of GSA fees. If only private non-de minimis pumpers are noticed, it would be easy to foresee a majority protest as the groups are generally few and organized. Including de minimis users in the noticing may reduce the likelihood of a protest, however, it is unclear to Raftelis if such noticing would be considered legal since users classified as de minimis would receive a notice but no charge for service. More, if only private users are noticed it is unclear if the substantive requirements of Proposition 218 would be met. Consider for example that all residential, commercial, and irrigation users within a municipal agency boundary are also users of groundwater, albeit with service from municipal wells. Is it legally defensible to exclude these users from noticing even if their water service provider is paying their proportional share of MGA management costs? Inclusion of municipal users to notice the entirety of the management area would almost certainly guarantee no majority protest of the fee, but again if these users were not assessed a fee in the notice it is unknown if this action would be legal. More, if municipal users are de-minimis in their water use (residential with annual consumption below two-acre feet per year (AFY)) is it lawful to charge these parcels if MGA is not "regulating" them at the time of fee adoption? These questions require further exploration by MGA's legal team.

Key Considerations
Cost to develop: Low-Moderate – Cost of Service Study Report
Cost to implement: Low
Collected by: Direct billing or County Assessor
Limitations on use of funds: Only for those costs identified in the Cost of Service Study
Ease of protest: Moderate to high

2.3 Assessment (Special Benefit Nexus)

Special assessments have been redefined over the years. Assessments for special benefit are also governed by Proposition 218 and are exempted from Prop 26; nor are they subject to a 2/3 vote like a special tax. Property owners can be assessed to pay for a public improvement or service if it provides a special benefit to the property. To assess, local government bodies must:

- Develop a Special Benefit methodology to determine each parcel's assessment
- Ensure that each owner's assessment does not exceed its proportional share of total costs when compared to total project costs
- Ensure only special benefits are assessable
- Ensure all parcels which benefit are assessable (with no government property exemptions)
- Prepare an engineer's report that determines the amount of special benefit to each property
- Notify all affected property owners by mail with mail-in protest ballot form

The Agency must then hold a Public Hearing to determine if a majority protest exists. Protest ballots are tabulated and weighted based on the *amount* of each assessment. Assessments have a similar implementation timeline to utility rates and the Agency has complete control over the timeline (unlike taxes). Once the Engineer's Report is approved, notices must be mailed at least 45 days prior to the public hearing. The notice must include the affected parcel's protest ballot. An average project timeline from start to finish is six months.

Like a possible majority protest under Proposition 218, the Agency runs the risk of protest by assessment if a few large users exercise their disproportionate power to protest the special assessment, and if only private non-de minimis pumpers are included. MGA could consider a special assessment for all users basin-wide to reduce the chance of protest, however, the lawfulness of assessing fees to de minimis users who are not "regulated" at the time of adoption is unclear. Further, an assessment may be challenged post-formation by any property owner under the premise that the special benefit is invalid.

Key Considerations
Cost to develop: Moderate – Outreach and special benefit nexus report
Cost to implement: Low
Collected by: County Assessor
Limitations on use of funds: Only for those costs identified in the Engineer's Report
Ease of protest: Moderate to high

2.4 General and Special Taxes (approval from electorate)

Everything that does not meet the exceptions defined in Proposition 26, and is not a special assessment, is considered a tax and must be approved by the voters. The Agency is still required to develop a reasonable relationship between the tax and affected parcels. The tax could potentially be spread based on acreage, parcel, or by estimated pumping. These are not the only options but are the most likely given data availability. General taxes require a simple majority vote; however, the charges required to manage the basin and administer the GSP would most likely be considered a special tax. Article XIII D, Section 2(a) states that "Special purpose districts or agencies, including school districts, shall have no power to levy general taxes." Special taxes require a two-thirds (2/3) approval from the electorate (i.e. registered voters); and with a special tax, government properties are exempt from the tax.

A special tax would need to be placed on a ballot for either a general election or special election. There are specific tasks and a firm timeline that must be followed to include a tax measure on an election ballot. The minimum time required prior to election day to fulfill the requirements is approximately 90 days. A special tax is the option with the highest risk of failure as unlike Proposition 218 fees and assessments that require majority protest, a special tax would fail with any less than a 2/3 majority.

Key Considerations
Cost to develop: Low-Moderate
Cost to implement: High compared to other options
Collected by: County Assessor
Limitations on use of funds: None
Ease of protest: Moderate for General Tax; High (super-majority threshold failure) for Special Tax

2.5 Contract

A novel approach in recovering costs and charging non-de minimis extractors is to sign contracts with each based on individual pumping. Depending on the number of extractors and their agreeability, or lack thereof, negotiation costs may be high. Individual contracts may help to avoid political landmines related to the protest of fees and assessments or the high threshold of a special tax, however, it is Raftelis' recommendation that all non-de minimis users (any residential extractor greater than two AFY or any non-residential extractor) have a contract with MGA.

The Agency could face legal challenge if it was determined that low volume extractors were excluded from a contract because it was cost effective and politically expedient to do so.

Key Considerations
Cost to develop: Unknown
Cost to implement: depends on number of extractors and timeliness of negotiations
Collected by: Direct billing by MGA
Limitations on use of funds: Unknown
Ease of protest: Not applicable

Table 1 - Funding Mechanism Matrix

Basis	Development Cost	Implementation Cost	Collection	Funds Limitation	Ease of Protest
Prop 26 Regulatory Fee	Low	Low	Direct or Assessor Billing	Reasonable Costs	N/A
Prop 218 Fee for Service	Low-Moderate	Low	Direct or Assessor Billing	Cost of Service	Moderate to High
Special Assessment	Moderate	Low	Assessor Billing	Special Benefit Parcels	Moderate to High
Special Tax	Low-Moderate	High	Assessor Billing	None	High
Contract	Unknown	Unknown	Direct	Unknown	N/A

3. GSA Charges

3.1 GSA Budget

The GSA will incur costs in implementing the GSP. These include administrative costs, monitoring costs, and other interim costs. MGA has estimated a preliminary annual and five-year budget (annualized) for these activities including administration and personnel, data management, monitoring and management, and reporting. These costs are summarized in Table 2. The estimated annualized budget in 2019 dollars is $350,000.

3.1.1 ADMINISTRATIVE COSTS

These costs include dedicated MGA staff support, internal reporting, managing Agency information, public outreach, legal retainer, and program coordination.

3.1.2 MONITORING COSTS

There are several costs associated with monitoring groundwater in the basin. These are discussed in further detail below.

1. **Water Quality**

   Includes collection, testing, and analysis of groundwater samples from designated monitoring wells on a semi-annual basis. A trained professional will visit designated wells, perform field testing of select water quality parameters, collect samples, and send samples to a laboratory for water quality testing. Test results will be tabulated and reported per the GSP guidelines. Management of data, as well as annual preparation of a water quality monitoring summary.

   The water budget and numeric groundwater model will be updated and calibrated to incorporate the previous 5 years of applicable data.

2. **Stream Flow Monitoring**

   Inspection and monitoring of streams within the basin on a semi-annual basis. Tasks may include measuring flow rates, visual inspection of streams, noting changes in geomorphology, and preparation of a stream monitoring summary.

3. **Groundwater Monitoring and Shallow Groundwater Elevation**

   Monitoring of groundwater levels conducted semi-annually throughout the well network within the Basin. This may consist of multiple days of field monitoring annually in which a trained professional will manually measure depth to water, or, collect data from transducer data loggers. Management of data, as well as annual preparation of groundwater level monitoring summary.

4. **SkyTEM Offshore Surveys**

Monitoring of the change in the saltwater interface offshore is vital to the assessment of ongoing risk to the basin of saltwater intrusion. The SkyTEM geotechnical survey will be conducted approximately every 5 years.

5. Model Updates

As needed, the numeric groundwater model will be updated and calibrated with the data collected through the monitoring, and will in-turn inform additional data collection gaps.

6. Data Management System

Collected monitoring data will be included in a data management system.

3.1.3 FIVE YEAR ADDITIONAL SCOPE OF WORK

Every 5th year of GSP implementation and whenever the GSP is amended, the GSA is required to prepare and submit an Agency Evaluation and Assessment Report to the Department of Water Resources together with the annual report for that year. The assessment and report will be prepared as described in CWC § 356.10. Five-year costs are annualized to determine the amount of revenue required to fund Five Year activities on an annual basis.

1. Updated Water Budget and Sustainable Yield Value

The water budget will be updated and calibrated to incorporate the previous 5 years of applicable data. Using the updated model, MGA will generate a refined estimate of the sustainable yield of the basin.

2. Five Year Plan Evaluation and Assessment Report

Every 5th year of GSP implementation and whenever the GSP is amended, the GSA is required to prepare and submit an Agency Evaluation and Assessment Report to the Department together with the annual report for that year. The assessment and report will be prepared as described in California Water Commission (CWC) § 356.10.

3.1.4 COST CONTINGENCY

MGA is a new entity and is budgeting from the ground up. The cost estimate should account for a contingency between estimated and actual expenses. Cost contingencies provide a buffer for the variance in costs, particularly in the early years. Most frequently contingencies are estimated as a percentage of the total budget, or with better information, an expected dollar value. Comparable agencies budget for a contingency of 10 to 20 percent of expenditures. As the budgets in Sections 3.1.1, 3.1.2, and 3.1.3 are rough estimates using staff and consultant judgment and best available data, the cost estimate accounts for a $25,000 contingency.

3.1.5 RESERVES

In addition to covering the operations budget, the GSA should consider adoption of a reserves policy which is expressly authorized by SGMA (Section 10730(a) and 10730.2(a)(1)). Reasonable and achievable reserves are a prudent financial tool to aid in cash flow timing and unforeseen expenditures. Generally, a reserve for operations targets a specific percentage of annual operating costs or days of cash on hand. The reserve target is influenced by several factors including the frequency of billing and the recurrence of expenses. Comparable reserve percentage is 50% of operating budget if billing semi-annually and less if billing more frequently (monthly, bi-monthly, or quarterly). For this evaluation no reserve funding is assumed in the first year.

3.1.6 TOTAL REVENUE REQUIRED

The estimated Administrative, Monitoring, Five-year Update, and Contingency is combined to determine the annual revenue required to fund MGA. The total annual budget in 2019 dollars is $350,000 per year. This total includes the annualized amount of Five-year Update costs and does not account for any reserve funds.

Table 2 – MGA Budget Estimate

Task	Expense Items	Cost ($)
Administration	Personnel, Outreach, Program Coordination, Legal, Finance	$200,000
Monitoring and modeling	Water Quality, Stream Flow, Groundwater Elevation, SkyTEM. Model updates, Data Management System	$85,000
Reporting (annual and 5-year)	Updated Water Budget, , Reports	$40,000
Contingency		$25,000
Reserves		$0
Total		**$350,000**

3.2 Unit of Service/Measure Options

The GSA budget discussed in the previous section represents the numerator in developing GSA charges and recovering costs. The denominator must be determined from a suite of options. Each option to define the "unit" has certain advantages and disadvantages, data requirements, and policy and legal considerations. Additionally, specific options relate to possible funding mechanisms in different ways. Raftelis has identified eight preliminary unit options, with certain options having multiple variations. This list is not necessarily exhaustive and is provided to present potential units of measurement for the basin. From a data availability and data quality standpoint, the six main options rank as follows, with those listed earlier having fewer data requirements: well count, parcel count (total parcels and total non-de minimis parcels[6]), acreage, well capacity, irrigated acreage, and pumping (gross extraction). The data requirements of the contract option are unknown.

[6] SGMA defines de minimis use in Section 10721(e) as extraction for domestic use of less than 2 AFY. Non-de minimis use is for any water use greater than 2 AFY. The GSA has evaluated groundwater extractions by de minimis users and determined that they represent approximately 10 percent of total basin withdrawals.

3.2.1 WELL COUNT (TOTAL NON-DE MINIMIS WELLS)

Advantages: Simple to understand and to administer. Data available to MGA.

Disadvantages: Complete dataset may not be available at the start of the GSP. Uncertainty regarding timing of data availability. Not related to actual extraction amount and burden on the basin.

Data requirements: Basin-wide count of non-de minimis wells subject to the GSP.

Other/Policy Requirements: None identified.

Internally Raftelis discussed active versus total (active and non-active) wells and determined that total is appropriate given the non-de minimis threshold of 2 AFY. Additionally, GSA action would be required to clearly define active, non-active, and abandoned wells.

3.2.2 WELL CAPACITY (NON-DE MINIMIS WELLS)

Advantages: All wells are not equal, they have different capacities and ability to extract water.

Disadvantages: More data is required than simple well count.

Data requirements: Need well head/well meter size for all active wells or wells subject to the GSP.

Other/Policy Requirements: Requires adoption of a metering plan, or similar way to validate well head size.

3.2.3 PARCEL COUNT (TOTAL PARCELS)

Advantages: Parcel based approaches are generally simple to understand and to administer. Few data requirements with the data from the County Assessor readily available.

Disadvantages: Approach assumes a broad benefit of groundwater, or a “general benefit logic.” Requires a voter approval process to put on an election ballot.

Data requirements: County Assessor’s parcel database.

Other/Policy Requirements: None identified.

3.2.4 PARCELS COUNT (NON-DE MINIMIS)

Advantages: Generally simple to understand and to administer. Few data requirements. Requires a good data set of parcel owners and non-de diminish classification.

Disadvantages: Inequitable among non-de minimis users. No relation to groundwater extraction.

Data requirements: Basin-wide count of non-de minimis parcels.

Other/Policy Requirements: None identified.

3.2.5 ACREAGE (TOTAL)

Advantages: Simple to understand and to administer. Minimal data requirements. Data is readily available. Acts as a proxy for potential extraction.

Disadvantages: Assumes a general benefit but with a stronger nexus than parcel count. Not related to actual water extraction.

Data requirements: County Assessor’s parcel database.

Other/Policy Requirements: None identified.

3.2.6 ACREAGE (IRRIGATED)

Advantages: Absent another source of supply, irrigated usage is directly tied to groundwater extraction. More equitable than parcel or acreage. Proxy for actual water extraction by land area and land cover data.

Disadvantages: Data intensive. Will require regular updates. May be prone to challenges and manual surveys for confirmation. Will require plant/crop type being irrigated.
Data requirements: Accurate geospatial land cover data and independent estimation.
Other/Policy Requirements: None identified.

3.2.7 PUMPING (GROSS EXTRACTION)

Advantages: Greatest equity since fee based on actual extraction. Easy to understand. Easy to administer provided metering plan adoption.
Disadvantages: Requires flow meter installation to implement. If not, more time, effort, and cost than other options (i.e., wells, parcels, or acreage options).
Data requirements: Validated metered data.
Other/Policy Requirements: Requires adoption of metering plan.

3.2.8 CONTRACT

Advantages: Simple, potentially cost effective, avoids adoption and implementation hurdles and limits legal risk associated with Prop 218/26, taxes, and assessments. Based on negotiation of parties.
Disadvantages: Not necessarily related to past, present, or future extraction. Potential inequity.
Data requirements: None identified.
Other/Policy Requirements: Requires formal agreement/signed contract between basin non-de minimis extractors and MGA.

3.2.9 MEASUREMENT OPTION SELECTION

Raftelis makes no recommendation with regards to the unit of service. Rather, it should be the decision of the MGA Board to select the unit of service approach that is most appropriate for the Agency given the policy objectives, basin characteristics, data availability, and types of costs incurred. There are varying degrees of equity, user flexibility, and ease of administration with each option. These decisions will require input from MGA staff, the Advisory Committee, and the MGA Board.

While Raftelis makes no single recommendation, given the characteristics of the basin's non-de minimis private users and data available at this time, we recommend narrowing down the options to the following three: parcels (non-de minimis), acreage, and estimated gross pumping. Narrowing the options allows a deeper dive into each and an easier comparison across options. In the following sub-section, we have calculated preliminary charges based on these three options and the estimated annual costs of MGA identified in Section 3.1.

3.3 GSA Charge Calculations

Raftelis calculated preliminary charges using the cost estimates in the prior sub-sections and the following units of service: irrigated acreage, estimated pumping volume, and parcel count. Charges are shown in both dollars per year and dollars per month. All rates are rounded up to the nearest whole penny.

The first step is to allocate the total costs (revenue requirement) of MGA between the municipal users and the non-de minimis users based on pumping estimates. The table below shows the class, specific user, estimated pumping, and share of total pumping. Charges developed in this section for non-de minimis users include Small Water

Systems, Institutional, and Agriculture. In total this class accounts for roughly 18 percent of total basin pumping and approximately 20 percent of regulated basin pumping (exclusive of de-minimis pumping which is not included in the cost allocation).

Table 3 – MGA Cost Allocation

Class	Water pumper	2016 Estimate (AF)	Percent of Total GW	2016 Estimate - Regulated (AF)	Percent of Regulated GW	Share of MGA Costs
Municipal	Santa Cruz	480	8.74%	480	9.71%	$34,001
Municipal	Soquel Creek	3,090	56.25%	3090	62.54%	$218,883
Municipal	Central	381	6.94%	381	7.71%	$26,988
Non-de Minimis	Small Water Systems	85	1.55%	85	1.72%	$6,021
Non-de Minimis	Institutional	190	3.46%	190	3.85%	$13,459
de Minimis	Private wells	552	10.05%	0	0.00%	$0
Non-de Minimis	Agriculture	715	13.02%	715	14.47%	$50,648
Total		**5,493**	**100%**	**4,941**	**100%**	**$350,000**

The summation of costs allocated to the three Non-de minimis user classifications - Small Water Systems, Institutional, and Agriculture – yields the total costs required to be recovered from non-de minimis users. The total revenue recovery required from non-de minimis users is $70,128.

Table 4 – Non-de Minimis Cost Allocation to User Classes

Class	Share of MGA Costs
Municipal	$279,872
Non-de Minimis	$70,128
De Minimis	$0
Total Costs Recovered	**$350,000**

3.3.1 PARCEL FEE

Table 5 shows the total count of parcels subject to a fee and Table 6 shows the calculated fee based on the count of non-de minimis parcels. Total costs are divided by the number of parcels to derive the fee. The estimated fee is shown both on an annual and monthly basis. The estimated fee for small water systems does not include the number of parcels served by each system. Therefore, each system is treated as one parcel. Depending upon the actual number of parcels served by small water systems it is possible that there could be a large variance in the calculated parcel fee. Any addition of parcels will reduce the fee as the costs allocable to the class (non-de minimis users) remains fixed.

Table 5 – Non-de Minimis Parcel Count

User Type	Parcel Count
Private Non-de Minimis Users	135
Small Water Systems	22
Total Parcels	**157**

Table 6 – Parcel Fee

Costs	Parcel Count	$ Per Parcel Per Year	$ Per Parcel Per Month
$70,128	157	$446.67	$37.23

3.3.2 IRRIGATED ACREAGE FEE

Table 7 shows the sum of acres subject to the fee and Table 8 shows the calculated fee based on non-de minimis irrigated acreage. Total costs are divided by each class's irrigated acreage to derive the fee per acre. The estimated fee is shown both on an annual and monthly basis. The estimated acreage fee is high as the data for small water systems considers all acreage, not just the total number of irrigated acres served by each system. To be more conservative, Raftelis accounted for the small water systems' total pumping in the acreage estimate, effectively assuming water use at a rate of one acre foot per acre per year. Depending upon the actual acreage of small water systems it is possible there will be a significant variance in the calculated acreage fee. Any additional acreage above what is assumed in the calculation will reduce the fee as the costs allocable to the class remain fixed.

Table 7 – Non-de Minimis Irrigated Acreage

User Type	Acreage
Private Non-de Minimis Users	838.5
Small Water Systems	275.1
Total Parcels	**1,114**

Table 8 – Irrigated Acreage Fee

Costs	Acreage	$ Acre Per Year	$ Per Acre Per Month
$70,128	1,114	$62.97	$5.25

3.3.3 VOLUMETRIC FEE

As previously discussed, MGA may choose to assess charges on all non-de minimis pumpers or at a minimum threshold, yet to be determined. Raftelis calculated fees at the following minimum extraction thresholds: 0 AFY, 2 AFY, 5 AFY, and 10 AFY. For reference 0 AFY represents all 135 identified private non-de minimis users and 100 percent of private non-de minimis pumping (exclusive of small water systems); 2 AFY represents 58 private non-de minimis users and 93 percent of private pumping; 5 AFY represents 31 users and 80 percent of private pumping; 10 AFY represents 15 users and 62 percent of private pumping. The top nine private users pump half of the water in the class. Table 9 summarizes the volume of pumping among private non-de minimis users at these various thresholds. In all scenarios small water systems are charged for all their pumping.

Table 9 – Volumetric Fee Thresholds

User Type	AFY
Private Non-de Minimis User (0 AFY Minimum)	659.74
Private Non-de Minimis User (2 AFY Minimum)	611.05
Private Non-de Minimis User (5 AFY Minimum)	523.64
Private Non-de Minimis User (10 AFY Minimum)	408.86
Small Water System	275.1
Total Acre Feet	**1,113.6**

The following four tables show the calculated volumetric pump charge at each threshold of 0 AFY, 2 AFY, 5 AFY, and 10 AFY. Fees are presented in dollars per acre foot and range from a low of $75.02 per acre foot to a high of $102.53 per acre foot.

Table 10 – 0 AFY Threshold

Costs	Acre Feet per Year	$ acre foot
$70,128	935	$75.02

Table 11 – 2 AFY Threshold

Costs	Acre Feet per Year	$ Per Acre Foot
$70,128	886	$79.14

Table 12 – 5 AFY Threshold

Costs	Acre Feet per Year	$ acre foot
$70,128	799	$87.80

Table 13 – 10 AFY Threshold

Costs	Acre Feet per Year	$ acre foot
$70,128	684	$102.53

3.4 Other GSA Charges

In addition to fees and charges imposed to recover the costs of implementing the GSP and operating MGA, the Agency will assess other charges in cases of pumping over allocations (should allocations be adopted), non-compliance charges, and/or penalties. Non-extraction and over-pumping charges are outlined in the following subsections.

3.4.1 PUMPING OVERAGE CHARGES

Groundwater extractions exceeding the amount that a groundwater user is authorized to pump under regulations adopted by the Agency may be subject to fines or penalties under Water Code section 10732(a). The fine may not exceed $500 per acre-foot extracted in excess of their authorized amount (Water Code §10732 (a)(1)). Implementation of fines or penalties assumes that MGA will adopt a metering plan and develop individual pumping allocations for each non-de minimis user in the basin. Given the nature of the Sub-basin, the Water Code maximum fine of $500/AF appears warranted. Justification for this value is as follows:

- Supplemental water costs (Indirect Potable Reuse (IPR)) – Soquel Creek Water District is designing and constructing a supplemental supply project using tertiary treated wastewater, advanced purification, and groundwater injection. While the project will be wholly owned and funded by an MGA member agency, it will assist in achieving Mid-County Basin sustainability goals. The estimated cost of finished water (operating and capital costs included) will far exceed $500 per AF so it is appropriate for the Agency to charge the maximum fine defined in the Water Code.

- Supplemental water costs (Water Transfers) – High flow events may be captured on the San Lorenzo River and transferred for consumption by municipal users or groundwater recharge within the Mid-County Basin. The costs of water transfers have been estimated to exceed $500 per AF so it is appropriate for the Agency to charge the maximum fine defined in the Water Code.

An argument may be made that the requirements of Article XIII D, section 6(b) (Proposition 218) supersede the maximums presented in the Water Code. Simply, the cost of service based on supplemental supplies through IPR and water transfers trumps the Water Code maximum of $500/AF. Additional legal review by MGA counsel would be required to explore this argument.

Overage Charges (Surcharge Rates) Example – Fox Canyon Groundwater Management Agency

Tier I: One to 25.000 AF = $1,461.00 per AF
Tier II: 25.001 AF to 99.999 AF = $1,711.00 per AF
Tier III: 100 AF or more = $1,961.00 per AF

From the Fox Canyon Ordinance: *Extraction surcharges are necessary to achieve safe yield from the groundwater basins within the Agency and shall be assessed annually when annual extractions exceed the historical and/or baseline allocation for a given extraction facility or the combined sum of historical allocation and baseline allocation for combined facilities. The extraction surcharge shall be fixed by the Board and shall be based upon (1) the cost to import potable water from the Metropolitan Water District of Southern California, or other equivalent water sources that can or do provide non-native water within the Agency jurisdiction; and (2) the current groundwater conditions within the Agency jurisdiction. The Board shall fix the surcharge by Resolution at a cost sufficiently high to discourage extraction of groundwater in excess of the approved allocation when that extraction will adversely affect achieving safe yield of any basin within the Agency. In circumstances where an individual or entity extracts groundwater from* *a facility(s) having no valid extraction allocation, the extraction surcharge shall be applied to the entire quantity of water extracted. Surcharges are assessed annually.*

Deficit Accounting - GSAs can allow unused groundwater extraction allocations to be carried over and transferred only "if the total quantity of groundwater extracted in any five-year period is consistent with the provisions of the [GSP]." § 10726.4(a)(4). If the GSA adopts a carryover policy then deficit pumping may be allowable with sufficient carryover water. However, the policy should be specific and should not allow borrowing from future allocations.

3.4.2 NON-COMPLIANCE CHARGES

If the fine or penalty is for non-compliance with regulations adopted by the GSA (e.g., failing to install a meter), then it is subject to the limitations in Water Code section 10732(b) and the fine or penalty may not exceed $1,000 plus $100 per day additional charges if the violation continues for longer than 30 days after the notice of the violation has been provided. A list of anticipated non-compliance charges is below, including examples identified by Raftelis:

Non-metered use (non-de minimis): The fee is equal to double the current groundwater extraction charge for all estimated water used (Fox Canyon GMA 2013).

Failure to provide access: No known guidance on reasonable costs but may be tied to reasonable staff labor costs.

Failure to report: No known guidance on reasonable costs but may be tied to reasonable staff labor costs.

State Non-Compliance Charges: In the event that a GSA is unwilling or unable to manage the groundwater basin the State will intervene with a schedule of fees set by the State Water Resources Control Board. Fees would be imposed on all users of the "probationary" basin and extractors would be required to file a groundwater extraction report. In probationary basins non-de minimis users may be required to file an extraction report, due by December 15 of each year for the prior water year. For reference, the table below shows the 2017 fee schedule for unmanaged and probationary basins.

Table 14 – SWRCB Non-Compliance Charges

Fee Category	Fee Amount	Applicable Parties
Base Filing Fee	$300 per well	All extractors required to report
Unmanaged Area Rate (metered)	$10/AF	Extractors in unmanaged areas
Unmanaged Area Rate (unmetered)	$25/AF	Extractors in unmanaged areas
Probationary Plan Rate	$40/AF	Extractors in probationary basins
Interim Plan Rate	$55/AF	Extractors in probationary basins where the Board determines an interim plan is required
De minimis Fee	$100 per well	Parties that extract, for domestic purposes, two acre-feet or less per year from a probationary basin, If the Board decides the extractions will likely be significant.
Late Fee	25% of total fee per month late	Extractors that do not file reports by the due date

3.4.3 PENALTIES

If the GSA has adopted an ordinance, it may levy an administrative civil fine or penalty (Government Code §53069.4). The fine or penalty may not exceed $100 for the first violation, $200 for the second violation, and $500 for each additional violation within 12 months of the first (§25132(b) and §36900(b)).

Section 10730.6(a) outlines the authority of a GSA to collect management fees and the remedies available to the Agency for failure to pay. These remedies include collection of interest on late payments at a maximum of one percent per month[7]; assessing penalties "in the same manner as it would be applicable to the collection of delinquent assessments, water charges, or tolls[8]"; or even the cessation of pumping[9] until the outstanding fees are paid and the user is no longer delinquent on payments.

Alternatively, and only if MGA was to adopt individual pumping allocations, in place of monetary penalties the GSA could impose a penalty that results in a percent of volume loss of a following year pumping allocation, or similar allocation reduction penalty.

A series of examples follows from Fox Canyon Groundwater Management Agency (MGA):

Late Statements
Statements submitted after the due date incur a Civil Penalty of $50 per day.

Late fee on extraction
An Extraction Interest Charge of 1.5% is charged for every month the statement and/or payment is overdue. (Extraction charge x 1.5% x month(s) overdue).

Late fee on overage/surcharge[10]
A Surcharge Late Penalty of 1.5% is charged for every month the statement and/or payment is overdue. (Surcharge x 1.5% x month(s) overdue).

Late fee on non-metered water use
Any delinquent Non-Metered Water Use Fee obligations shall also be charged interest at the rate of 1.5% per month on any unpaid balances.

3.5 Other Considerations

3.5.1 METERING PLAN

[7] Water Code Section 10730.6(b)
[8] Water Code Section 10730.6(d)
[9] Water Code Section 10730.6(e) requires a public hearing with at least 15 days' notice to the owner of operator of the well
[10] Greater than an extractors pumping allocation

Aerial survey for landcover data is an accurate method of estimating the irrigation demands of a parcel. However, challenges arise due to timing and frequency of updated crop cover, validating parcel boundaries, and identifying the parcel(s) served by an individual well, among other challenges. A remedy is to require installation of meters on individual non-de minimis wells for precise pumping volumes rather than estimations. However, there are tradeoffs for precision. It is costly to install meters on wells and the cost is greater for small volume users, particularly if the fee amount is low. Consequently, MGA may impose a significant financial burden on the pumper and increase the effort on MGA staff for a relatively small benefit. Conversely, large users have a greater impact on the basin and the cost of meter compliance is low relative to their fee. Additionally, if the fee is based on actual pumping, and a metering plan is not adopted by the MGA Board, a larger user will have an incentive to report lower pumping to reduce the fee. If actual gross pumping is selected as the method of fee-setting, metering should be required along with regular reporting and verification.

3.5.2 PUMPING ALLOCATIONS

MGA may choose to adopt individual pumping allocations for all non-de minimis users. These allocations would be based, at least initially, on estimated pumping from aerial survey and land cover/crop type data. Each extractor will know their allocation which would could become the basis for their pumping fee. MGA should determine if individual allocations are prudent if no pumping reductions are required by individual non-de minimis pumpers. Further, if estimated pumping (and therefore allocation) is greater than actual extraction the private pumper would have an incentive to pump *more* so that their pumping is in line with their allocation.

3.5.3 PUMPING REDUCTIONS AND NON-DE MINIMIS USER FEE THRESHOLD:

The sustainable yield of the Mid-County Basin will be achieved predominantly by using supplemental supply projects from the MGA's Municipal entities. Still, approximately 18 percent of total basin pumping (20% of non-de minimis pumping) comes from non-de minimis private pumpers. Approximately 15 of these users extract greater than 10 AFY. Given the significant pumping of the largest private users, MGA should consider developing pumping reductions for these individuals by identifying the costs and benefits of curtailment. They would effectively be treated as a separate sub-class of private pumper, unique from the de-minimis users and small non-de minimis users.

3.5.4 EXTRACTION THRESHOLD FOR FEE ASSESSMENT

Given that the majority of non-residential, non-de minimis users are estimated to use less than 2 AFY, the question of extraction threshold should be considered. What should the threshold for assessing charges on these users be and why? SGMA and the Water Code give MGA the authority to assess these users however minimal their extraction; however, the burden on staff and administrative costs may not cover the literal dollars, in some cases, of assessing an annual volumetric fee on a user extracting one-tenth of an acre foot per year. Still, MGA would require a sound argument as to why a specific threshold was selected. While a statistical analysis, or some other analytical assessment, could be used to determine an appropriate threshold we would recommend MGA use 2 AFY as the threshold. This volume corresponds to the definition of a de minimis user, were they a residential user. Further a review of MGA's data on non-de minimis users shows that 77 of 135 identified extract less than 2 AFY. In total these 77 extractors amount to 49 AF of pumping relative to 660 AF for the class in total. In other words, the remaining 58 users account for 93 percent of pumping among the user group. Removing the 77 users from the charge calculation has an immaterial effect on the resulting fees to other users (in fee recovery by acreage or pumping volume). Additionally, it reduces the demands on MGA staff and potential for contentious public meetings. Raftelis reviewed our work in the Sonoma GSAs and Borrego GSA, as well as the draft report in the neighboring

SVBGSA, and found no mention of minimum thresholds for non-de minimis users at which they will or will not be assessed management charges. The Borrego Valley GSA is considering a de-minimis threshold of 5 AFY because after long term reductions these users would approach 2 AFY in 2040.

2 AFY identified as de minimis in SGMA seems appropriate even when the user is not Residential in nature. The cost-benefit of charging a private irrigator who uses less than 2 AFY versus a private residential pumper who uses less than 2 AFY may not pan out.

3.5.5 ACTIONS IN OTHER BASINS

Borrego Valley GSA plans to adopt a metering a plan and are currently identifying individual allocations which will then need to be reduced over time (interim and final reductions) to achieve the long-term sustainable yield. The Borrego basin requires a greater than 70 percent reduction in pumping and no supplemental/alternative water supply projects are feasible. Achieving sustainable yield will be achieved with reduced pumping, fallowing of agricultural lands, and conservation. In Sonoma County GSAs there is no plan for metering or reductions for large private pumpers. Groundwater users will be assessed a volumetric charge per acre foot of water based on estimated extractions from the basin (using spatial data analysis). The Salinas Valley Basin GSA (SVBGSA) has released a draft report with non-de minimis users (which are almost exclusively commercial agricultural users) assessed charges based on estimated irrigated acreage (estimates from spatial data analysis). It should be noted that Borrego GSA actions are for GSA fees (GSP implementation) while the Sonoma GSAs and SVBGSA actions are to fund GSP development activities prior to implementation.

4. Fee Recovery Methods

Below are two bill collection options for MGA groundwater users.

4.1 Direct Billing

Direct billing requires more staff, has higher administrative costs (printing, postage, customer service, collections), and has a higher rate of late payments and delinquencies. It requires the Agency maintain its own customer information system and internal accounting. If the existing County system or member agency system is not readily available for use there may be significant one-time costs to purchase, configure, integrate, and train staff on the software. Direct billing results in greater cash flow assuming regular monthly or bi-monthly billing. This results in lower cash reserve requirements.

4.2 Property Tax Roll

Billing users through the County Assessor results in less overhead, lower billing and customer service costs, and a lower rate of late payments and delinquencies. Setup costs should be lower as the Agency relies on the County Assessor. The Agency is still required to maintain accurate parcel data and associated data for charges that may be based on volumetric pumping, well count, or well capacity. Revenue is only received twice per year, so cash flow may be a concern depending on timing. Property Tax Roll billing requires greater cash reserves than direct billing. Additional fees will be incurred by the County to place a charge on the property tax roll.

As it relates to the available funding mechanisms presented in Section 2, assessments and special taxes are always recovered on a parcel's property tax bill. Fees for service are more likely to be directly billed but many agencies find it advantageous to collect fees on the property tax roll. As previously mentioned, the collection rate is frequently higher, and the collected revenue is then transferred to the charging agency twice per year.

5. Management Area Designation

If MGA determines it to be beneficial to differentiate the basin into Management Areas, Raftelis recommends the Agency identify and document the rationale for doing so. In traditional rate and fee setting, costs should be matched to benefits to ensure equity among and between different users, as well as to ensure each user group pays its fair share. In utility rate setting costs are allocated to classes of customers commensurate with their service requirements. In fee setting costs are allocated proportional to the benefits gained through the fee.

Considering that any capital project costs will be borne by the three municipal water service partner agencies, the costs recovered by MGA are for management only. In a certain sense, management zones have unintentionally been derived between coastal municipal users and all other non-de minimis users. Coastal zone users will pay fees, additional to the MGA management fees, through their water rates and charges as customers of Soquel Creek Water District, the City of Santa Cruz, or Central Water District; all other non-de minimis users within the Basin in County areas will only pay the management fee.

If MGA wishes to further designate management zones it may be appropriate to different impact zones using long term monitoring costs. If monitoring costs in coastal zones versus inland zones, or stream adjacent zones versus non-adjacent zones, or high elevation zones versus low elevation zones, can be demarcated with a sound rationale it may be justifiable. However, consider the following analogy: Property A is inland and adjacent to a creek. Property B is near the coast but not creek adjacent. The two properties pay different management fees due to long term monitoring costs with Property A paying a higher fee. However, Property B, the coastal parcel, benefits from the monitoring taking place inland. The exercise leads back to the fact that the fees derived to fund MGA are for basin-wide management, which is an implicit objective of SGMA: all current, future, or potential users benefit from basin management and the benefit of management is general to all.

If MGA decides to differentiate management areas it will need to ensure that specific benefits are identified for users in different areas. Initial questions that arise when hypothesizing include:

- Can we identify all non-de minimis users inside and outside a proposed impact zone?
- Is the “impact” just seawater intrusion, or is it also basin elevation, basin storage reduction, etc?
- What about connectivity with surface water?
- Can we identify and differentiate management, monitoring, and other costs between two or more impact zones?
- What other information would be required to develop separate fees for coastal and creek impact zones that would be *additional to* general basin management fee?
- Would MGA adopt a metering plan for non-de minimis users? This would be beneficial so that charges could be related to impact based on water extraction, and recovered proportionally
- Can creek monitoring costs be used to differentiate? For example, an instream flow fee and a coastal impact fee, etc. Again, a specific benefit would need to be identified for those having the fee imposed.

6. De Minimis Users

SGMA defines a "de minimis extractor" as "a person who extracts, for domestic purposes, two acre-feet or less per year[11]." De minimis "extractors" or de minimis groundwater users cannot be charged fees "unless the agency has regulated the users pursuant to this part[12]." The key operating phrase is "has regulated" and unfortunately the term *regulated* is undefined leaving the meaning up to legal interpretation. Does *has regulated* imply past regulation and management? Or can the new sustainability agency "regulate" de minimis users prior to fee adoption to be able to charge them for basin management over the long-term? At least one GSA that Raftelis consults for is considering the act of noticing de minimis groundwater extractors as "regulating" them. By corresponding with a de minimis user and requesting basic information, the agency *has regulated* the de minimis user and can legally impose a fee.

Beyond the legal gray area and semantics of the Water Code language, a GSA should consider the cost-benefit analysis of recovering management costs from de minimis users. For example, consider a hypothetical groundwater basin experiencing critical overdraft where greater than 95 percent of extraction is from large non-de minimis agricultural interests and a single municipal entity. Are the real costs of management, and the potential costs of litigation, worth the benefit of revenues deriving from users responsible for five percent of water extraction? Or, should the Agency instead focus resources on the 95 percent of extraction which is almost certainly responsible for the required mitigation of the six undesirable results? Conversely, consider a basin experiencing critical overdraft where 75 percent of extraction is from de minimis extractors and the remainder from three municipal agencies. It may be considered unreasonable to expect 100 percent of funding required to mitigate impacts to come from three agencies (and their customers) when they are responsible for only 25 of extraction. In this situation the risk may be in *not* regulating and imposing a fee on de minimis users.

MGA should consider their own cost-benefit analysis with the Advisory Committee and GSA Board. Considerations should include the gross and net extraction by de minimis extractors, their geographical and hydrological location within the basin, and the likely amount of total cost recovery from the group, relative to the whole. Raftelis has developed a Pricing and Policy Objectives exercise for the Board to use to evaluate the decision to regulate and charge de minimis extractors, or not. The Raftelis exercise is attached as an appendix to this paper.

[11] Water Code Section 10721(e)
[12] Water Code Section 10730(a)

7. Appendices

7.1 Comparative Agency Administrative and Management Budgets

Raftelis has researched management and administrative costs of five similar agencies, which represent three GSAs, a groundwater management agency, and a Watermaster in an adjudicated basin. Details of each comparative agency are presented in the subsequent sub-sections. The table below presents a comparison of the five agencies with measurements that may be useful to MGA in identifying long-term management and administrative costs. Where available, the first fiscal year of GSP implementation costs are used; otherwise the most recently available values are used.

	Borrego Valley GSA	Mojave Watermaster	Fox Canyon GMA	North Fork Kings GSA[2]	Kings River East GSA[4]	Southwest Kings GSA
Personnel Costs		$634,955	$735,831	$75,400	$45,000	$50,000
Legal Costs				$27,400	$10,000	$11,139-20,000
Total Admin Budget	$574,566	$759,855	$1,431,744	$156,750	$68,400	$85,884-99,000
Staff Level (FTEs)	2	4	6.5[1]			Time and Materials
Staff Hours			11,700[1]	458[3]		
Management	Borrego Water District	Mojave Water Agency	Ventura County Public Works	Kings River Conservation District	Alta Irrigation District	Provost & Pritchard Consulting
Basin	Borrego	Mojave	Oxnard Plain, etc.	Kings	Kings	Tulare
Water Production (AFY)	20,000	120,000	134,000	TBD	TBD	TBD
Predominant User Groups	Single Municipal & Agriculture	Private Pumpers & Single Municipal	Municipal & Agriculture	Municipal	Municipal	Municipal

[1]Staff levels and hours assume contracted labor from the County of Ventura using 1,800 annual hours per FTE
[2]Estimates based on fiscal year 2020-2021, the first full year of GSP implementation
[3]Extrapolated using January through June 2018 costs
[4]Administrative budget for GSP Development and not GSP implementation

7.1.1 MOJAVE BASIN AREA WATERMASTER

The Mojave Basin Area Watermaster (Mojave Watermaster) is administered as a unit of the Mojave Water Agency (MWA). As Watermaster, the agency's main responsibilities include monitoring, reporting, and verification of water extraction for all parties of the adjudication, collection of assessments, production of annual reports, and facilitating water transfers between parties. In many respects the watermaster of an adjudicated basin and the GSA for a basin subject to SGMA are similar in duties and commitments.

The Budget Summary for the Mojave Watermaster from FY 2015-16 through budget year FY 2019-2020 is presented below. The overwhelming majority of expenses relate to wages and benefits, expected to cost $653,884 in FY 2019-2020. Secondary costs relate to engineering services of $93,500 in FY 2019-2020. The remaining costs of approximately $34,000 relate to travel, training, supplies, and other miscellaneous expenses.

The Mojave Watermaster consists of four staff including two technicians, a database administrator, and a services manager. Assuming four full-time employees (FTEs) and the wages and benefits in the FY 2019-2020 budget, the cost per FTE is approximately $163,500 per year.

Watermaster (WM) – Dept #90

Department Budget Summary

	ADMINISTRATIVE EXPENSES:	FY 15/16 Actual	FY 16/17 Actual	FY 17/18 Budget	Actual YTD as of 03/31/2018	FY 17/18 Projected	FY 18/19 Budget	FY 19/20 Budget
5600	Dept Wages	374,484	409,735	408,253	300,111	409,764	427,645	440,474
5612	Dept Overtime	5,646	3,936	4,000	2,257	859	4,000	4,000
5613	Health Insurance - Medical	54,609	48,960	48,960	36,249	48,960	55,455	57,119
5614	Payroll Taxes	12,048	12,659	13,259	9,667	13,439	14,010	14,430
5615	Misc Benefit	-	-	-	-	-	-	-
5616	Workers Compensation Expense	2,149	2,005	2,602	2,116	2,804	2,554	2,631
5618	Health Insurance - Dental/Vision	9,576	9,524	9,675	5,684	7,979	8,525	8,781
5620	Health Ins Reimb - FSA	6,879	5,949	10,400	4,386	6,000	10,600	10,918
5621	Deferred Comp Contributions	-	-	-	-	-	21,382	22,023
5623	PERS Retirement	67,897	72,908	98,679	81,214	105,656	90,784	93,508
	TOTAL WAGES & BENEFITS	**533,288**	**565,676**	**595,828**	**441,684**	**595,461**	**634,955**	**653,884**
5702	Safety Supplies	-	-	500	-	-	500	500
5710	Small Tools	-	-	100	-	-	250	250
5711	Books & Subscriptions	-	37	50	-	-	50	50
5713	Printing	-	-	500	-	-	500	500
5725	Auto Expenses	2,842	368	500	228	400	500	500
5726	Travel Expenses	-	-	500	-	1,850	8,800	9,000
5728	Education & Training	-	-	1,500	-	1,000	5,800	8,000
5736	Engineering, General	144,370	72,981	73,500	43,930	73,500	93,500	93,500
5741	Aerial Photos	19,750	10,875	12,500	10,875	12,500	15,000	15,000
	NON-LABOR EXP	**166,962**	**84,261**	**89,650**	**55,033**	**89,250**	**124,900**	**127,300**
	TOTAL DEPT EXPENSES	**700,250**	**649,937**	**685,478**	**496,717**	**684,711**	**759,855**	**781,184**
5610	Labor & Benefits from Watermaster	(350,125)	(276,286)	(297,914)	(152,750)	(297,731)	(317,478)	(326,942)
	Total Capital Labor & OH Out	**(350,125)**	**(276,286)**	**(297,914)**	**(152,750)**	**(297,731)**	**(317,478)**	**(326,942)**
	TOTAL NET DEPT EXPENSES:	**350,125**	**373,651**	**387,564**	**343,967**	**386,980**	**442,377**	**454,242**

7.1.2 FOX CANYON GROUNDWATER MANAGEMENT AGENCY (FCGMA)

FCGMA is a special district which governs the extraction of water in southern Ventura County and serves five municipalities and agricultural users in unincorporated areas of the county. While a special district since 1982 FCGMA will also be the GSA for the local groundwater basins including Arroyo Santa Rosa, Oxnard Plain, Pleasant Valley, and Las Posas Valley. The agency is staffed by contract with Ventura County Public Works overseeing technical, legal, financial, and administrative services. Total expenses in FY 2014-2015 were $1,088,951 with 60 percent of expenses ($645,975) towards County staff charges. Another 14 percent was spent on Groundwater Supply Enhancement Assistance Program (GSEAP) funding to assist local agencies with local groundwater projects that increases groundwater supply. 21 percent of costs were associated with professional services.

Per communications with Fox Canyon management, the County of Ventura utilizes 6.5 FTEs at assumed annual hours of 1,800 hours per FTE for a total of 11,700 hours. The fully burdened labor rate is approximately $115 per hour for an average annual cost of $1,345,500.

FOX CANYON GROUNDWATER MANAGEMENT AGENCY
Statements of Revenues, Expenses, and Changes in Net Position
For the Years Ending
June 30, 2016 and 2015

	2016	2015
OPERATING REVENUES		
Extraction charges and surcharges	$ 2,129,739	$1,373,904
Groundwater sustainability fee	274,544	-
Interest and penalties on delinquent accounts	75,969	33,946
Total Operating Revenues	2,480,252	1,407,850
OPERATING EXPENSES		
Ventura County Public Works Agency charges	735,831	645,975
Professional specialty services	603,816	227,410
Management and administrative services	19,580	7,197
Supplies and minor equipment	300	600
Liability insurance	4,707	4,498
Depreciation expense	51,908	51,908
GSEAP spending	-	148,269
Miscellaneous	15,602	3,094
Total Operating Expenses	1,431,744	1,088,951

7.1.3 NORTH FORK KINGS GSA

Located in the Central San Joaquin Valley, North Fork Kings GSA consists of 15 member agencies in the Kings Subbasin. Kings River Conservation District (KRCD) will administer the GSA including data collection and reporting, financial and accounting services, engineering services, and public outreach and education. The cost for administrative services by KRCD in FY 2020-2021 (the first full year of GSP implementation) is estimated at $75,400.

Table 3-2. Projected 5-Year Annual Budget

Category	Prior to 6/30/17	FY[a] 2017-2018	FY[a] 2018-2019	FY[a] 2019-2020	FY[a] 2020-2021	FY[a] 2021-2022	FY[a] 2022-2023	TOTAL
GSA Administration								
KRCD Staffing / Public Outreach		$ 69,000	$ 71,100	$ 73,200	$ 75,400	$ 77,700	$ 80,000	$ 377,400
Office Supplies / Postage / Outreach Materials		$ 6,000	$ 6,200	$ 6,400	$ 6,600	$ 2,000	$ 2,100	$ 23,300
Insurance		$ 2,000	$ 2,100	$ 2,200	$ 2,300	$ 2,400	$ 2,500	$ 11,500
Annual Audit		$ -	$ 4,000	$ 4,100	$ 4,200	$ 4,300	$ 4,400	$ 21,000
Miscellaneous Overhead		$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 7,500
Start-up Costs	$ 188,628		$ -	$ -	$ -	$ -	$ -	$ -
SUBTOTAL	$ 188,628	$ 78,500	$ 84,900	$ 87,400	$ 90,000	$ 87,900	$ 90,500	$ 440,700
Professional Services								
Project Management		$ 20,000	$ 20,600	$ 21,200	$ 21,800	$ 22,500	$ 23,200	$ 109,300
Funding Mechanism Assessment		$ 8,000	$ -	$ -	$ -	$ -	$ -	$ -
Prop 218 Engineer's Report/Elections		$ 30,000	$ 2,000	$ -	$ -	$ -	$ -	$ 2,000
Groundwater Sustainability Plan Preparation[b]		$ 150,000	$ 285,770	$ 80,000	$ -	$ -	$ -	$ 365,770
Legal, Litigation Reserve		$ 25,000	$ 25,800	$ 26,600	$ 27,400	$ 28,200	$ 29,000	$ 137,000
Lobbyist		$ 3,000	$ 3,100	$ 3,200	$ 3,300	$ 3,400	$ 3,500	$ 16,500
Grant Writing		$ 7,000	$ -	$ -	$ -	$ -	$ -	$ -
SUBTOTAL	$ -	$ 243,000	$ 337,270	$ 131,000	$ 52,500	$ 54,100	$ 55,700	$ 630,570
~10% Contingency/Reserve		$ 19,296	$ 42,220	$ 21,840	$ 14,250	$ 14,200	$ 14,620	$ 107,130
Reimbursement to Member Agencies			$ 264,712	$ 264,712	$ -	$ -	$ -	$ 529,424
Total Estimated GSA Administration & Professional Services Cost	$ 188,628	$ 340,796	$ 729,102	$ 504,952	$ 156,750	$ 156,200	$ 160,820	$ 1,707,824
Enterprise Fund for GSP Implementation - Project Development / Groundwater Monitoring			$ 907,435	$ 1,131,585	$ 1,479,787	$ 1,480,337	$ 1,475,717	$ 6,474,861
Total Estimated Cost			**$ 1,636,537**	**$ 1,636,537**	**$ 1,636,537**	**$ 1,636,537**	**$ 1,636,537**	**$ 8,182,685**

Raftelis contacted KRCD which provided a detail of staff hours by function. It is estimated that KRCD will spend approximately 458 staff hours across all functions on GSA administration in calendar year 2018 in support of GSP development. KRCD disclosed that May 2018 hours were higher than normal due to a special assessment hearing.

Employee Description	January-June 2018	Calendar Year 2018 (extrapolated)
Coordinator	72.5	145
Public Relations	50.5	101
Assistant	2	4
Finance	35	70
GIS	22.75	45.5
Accounting	0	0
Minutes	20.25	40.5
Admin	16	32
General Labor	10	20
Total	**229**	**458**

7.1.4 KINGS RIVER EAST GSA

Kings River East GSA is southeast of Fresno and west of the Sierra foothills. The GSA is a MOU between 14 municipalities and special districts in the basin. The total three-year budget is presented below. The administrative budget in each year is $68,400. The budget presented is only for GSP development and not GSP implementation and ongoing administration and management of the GSA. Administrative services are provided by contract with Alta Irrigation District, a party to the MOU. Staff time is billed hourly for costs incurred in servicing the GSA with an estimate of $45,000 per year.

Table 3: Projected Budget
Kings River East Groundwater Sustainability Agency
Groundwater Fee Study

Budget Item	Year 1	Year 2	Year 3	Total
Administration	**$68,400**	**$68,400**	**$68,400**	**$205,200**
Board Members (Per Diem)	$8,400	$8,400	$8,400	$25,200
Insurance	$5,000	$5,000	$5,000	$15,000
Legal	$10,000	$10,000	$10,000	$30,000
Administration Services	$45,000	$45,000	$45,000	$135,000
Grants/Outreach	**$3,500**	**$28,500**	**$3,500**	**$35,500**
Grant Application	$0	$25,000	$0	$25,000
Grower/Landowner Outreach	$3,500	$3,500	$3,500	$10,500
Groundwater Sustainability Plan	**$206,800**	**$235,350**	**$214,350**	**$656,500**
Sub-basin Coordination	$64,600	$64,600	$64,600	$193,800
Coordination Agreement	$0	$7,550	$7,550	$15,100
Data Management System	$0	$21,000	$0	$21,000
Hydrogeology	$75,000	$75,000	$75,000	$225,000
Legal Assistance	$7,800	$7,800	$7,800	$23,400
Monitoring Network	$14,600	$14,600	$14,600	$43,800
Projects & Management Actions	$17,800	$17,800	$17,800	$53,400
Sustainable Management Criteria	$18,700	$18,700	$18,700	$56,100
Report Compilation	$8,300	$8,300	$8,300	$24,900
Other	**$5,000**	**$5,000**	**$5,000**	**$15,000**
Miscellaneous Costs	$5,000	$5,000	$5,000	$15,000
Subtotal	**$283,700**	**$337,250**	**$291,250**	**$912,200**
Contingency (15%)	$42,600	$50,600	$43,700	$136,900
Total	**$326,300**	**$387,850**	**$334,950**	**$1,049,100**

7.1.5 SOUTHWEST KINGS GSA

Located in the Tulare Lake Subbasin, GSA day-to-day management will be provided by a consultant including financial management, reporting to the Board of Directors, and legal functions among others. The proposed five-year budget for on-going management is $85,884 in FY 2018-2019 and is presented below. The budget is drawn from the GSA’s Engineer’s Report dated June, 2017.

Description	2017	2018	2019	2020	2021
ON-GOING MANAGEMENT					
On-Going Management					
Communications, general administration	$ 12,000	$ 12,360	$ 12,731	$ 13,113	$ 13,506
Insurance	3,000	3,090	3,183	3,278	3,377
Website maintenance	5,000	5,150	5,305	5,464	5,628
Financial management	6,000	6,180	6,365	6,556	6,753
Administrative support	6,000	6,180	6,365	6,556	6,753
Assessments, collections	4,000	4,120	4,244	4,371	4,502
Printing, supplies, travel	12,000	12,360	12,731	13,113	13,506
Audit	0	5,000	5,150	5,305	5,464
	$ 48,000	$ 54,440	$ 56,073	$ 57,755	$ 59,488
SWKGSA board meetings (4)					
Board packages, attend, minutes	$ 8,000	$ 8,240	$ 8,487	$ 8,742	$ 9,004
Legal: attend, resolutions, agreements	8,000	8,240	8,487	8,742	9,004
	$ 16,000	$ 16,480	$ 16,974	$ 17,484	$ 18,008
Subbasin meetings (Monthly)					
Management: attend (12)	$ 9,600	$ 9,888	$ 10,185	$ 10,490	$ 10,805
Legal: attend (2)	2,500	2,575	2,652	2,732	2,814
	$ 12,100	$ 12,463	$ 12,837	$ 13,222	$ 13,619
Total On-Going Management	**$ 76,100**	**$ 83,383**	**$ 85,884**	**$ 88,461**	**$ 91,115**

A more recent FY 2018 Budget presented at the Southwest Kings GSA Board Meeting on May 9, 2018 shows a slightly different amount for management and legal costs. The FY 2018 Budget total for on-going management is $79,000 with $50,000 in management and $20,000 in legal representing the overwhelming majority of costs.

SWKGSA
2018 Budget

Description	Proposed 2018 Budget
Management	50,000
Legal	20,000
Clerical	6,000
Insurance	-
Website	2,000
Audit	1,000
GSP	115,000
Contingency	20,000
Total Expenses	214,000
Projected Income	
Assessments	455,906
Reimbursements	(97,939)
Delinquent Assessments	-
Interest	-
Total Income	357,967

7.2 Pricing Objectives Exercise

1. OVERVIEW

Fee structures are best designed when formulated to collect the appropriate amount of revenue while addressing unique characteristics of the Agency and the needs of its locale, basin users, and other stakeholders. Policy objectives for pricing are specifics that support broad policies, such as equity and conservation, and serve as discussion points when designing a fee structure.

Raftelis developed a list of policy objectives, and sub-objectives, according to the specific characteristics of the Santa Cruz Mid-County Groundwater Agency (MGA) and the suite of possible fee structures identified to implement the Groundwater Sustainability Plan (GSP) as part of the Sustainable Groundwater Management Act (SGMA) of 2014. Each pricing objective is defined herein.

2. BACKGROUND

The policy objectives in Table 1 – Administration, Equity, Rate and Revenue Stability, Affordability, and Conservation – were developed by Raftelis and will help guide the selection of an appropriate fee structure and fee recovery mechanism. Each policy objective includes several sub-objectives.

To inform the Board, each policy objective includes a policy statement, discussion notes and advantages and disadvantages of the policies. The seventeen pricing objectives were determined as most relevant to the possible fee structures identified and the characteristics of the groundwater basin.
The ranking of these policy objectives by the GSA Board will be used to develop a framework for the most appropriate fee structure(s) and fee recovery mechanism for the MGA. Recommended fee structure(s) may include a hybrid approach based on management and extraction and/or may include fixed and variable components.

Table 15: Policy Objectives and Associated Sub-Objectives for Fee Structure Evaluation

Administration	Equity	Rate and Revenue Stability	Affordability	Conservation
•Ease of Understanding •Easy of Implementation and Administration (Simplicity) •Defensibility	•Equitable among property owners •Equitable among pumpers •Equity across all basin users (beneficiaries) •Equity across management areas •Inter-generational equity	•Revenue Stability •Rate Stability •Minimize financial impacts	•Shared burden •Affordability for Essential Use	•Rewards past conservation •Tool for GSP implementation •Promotes future conservation •Scientific

Policy Objective 1 –Administration

Policy Statement: Recognizes the advantages of designating a structure and fee recovery mechanism that is easily understood by fee-payers, is simple to implement and administer by staff, and which is most defensible under applicable laws including the water code and the State Constitution.

Discussion: This objective highlights the importance of keeping structures and the process of administering them simple. Basin user education and clarity of bills should be considered as part of this principle.

Advantages of the Policy Objective: Creating structures that are easy for fee payers to understand will minimize fee-related user related administrative issues. If basin users understand the basis of their bills, they will have a greater ability to comprehend their calculated charges and conclude that it is fair.

Disadvantage of the Policy Objective: Simplifying the rate structure does not generally provide a maximum degree of fairness and equity across user groups and may limit conservation and affordable outcomes.

Sub-Objectives:

- **Ease of Understanding** – The ability for the fee structure to be explained in a manner that can be understood by basin users and other stakeholders that will have a positive impact on the ability to build acceptance of fees.
- **Ease of Implementation and Administration (Simplicity)** – Implementing a new fee structure merits careful consideration as fee structure implementation requires upfront (one-time) costs such as data gathering or billing system changes. An easy-to-administer structure does not negatively impact the ongoing costs of administration, which are predominately staffing costs.
- **Defensibility** – Producing a fee structure perceived to be fair, well documented, and well explained reduces the likelihood of legal challenge. This leads to more efficient and less costly administration.

Policy Objective 2 –Equity

Policy Statement: In compliance with the State Constitution (Article XIII D) and governing statutes of State Law (including Water Code §10720-10737.8 (SGMA)), fees should be cost-based, fairly apportioned among basin users, and account for the substantive provisions of law through a sound, technically defensible methodology.

Discussion: This principle highlights the importance of basin users' perception of fairness and equity, while also recognizing that an absolute equity among all basin users and user classes may not be achieved. Rates should generally be perceived as fair, reasonable, and equitable for all basin users.

Advantages of the Policy Objective: This principle reinforces the priority of treating all basin users fairly. Also, it acknowledges the practical obstacles that may prevent perfect equity, such as, excessive administrative costs or technical costs incurred solely to achieve additional equity.

Disadvantages of the Policy Objective: "fairness" and "equity" can be subjective and requires the Board to apply its discretion and judgment. More, equity can be interpreted at the basin-wide level or among and between different user groups or stakeholders.

Sub-Objectives:

- **Equity Among Property Owners** – States that a fee structure achieves equity by allocating costs fairly and proportionally across property owners whose parcels overlay the basin.
    - Example argument for: An impaired groundwater basin may diminish property values while an improved basin may increase land values

- **Equity Among Pumpers -** States that a fee structure achieves equity by allocating costs fairly and proportionally across well owners who extract from the basin.
    - Example argument for: Pumpers, or those owning wells, should pay because they are the actual extractors of groundwater from the basin
- **Equity Across All Basin Users (Beneficiaries) -** States that a fee structure achieves equity by allocating costs fairly and proportionally across all water users in the basin. Considers basin groundwater a general benefit across all users of groundwater.
    - Example argument for: Access to local groundwater benefits all and therefore all should pay
- **Equity Across Management Areas** - Considers specific regions within the basin boundaries that contribute to groundwater replenishment and specific regions which contribute to intrusion, depletion, and/or impairment.
    - Example argument for: It is fair and appropriate for MGA to incorporate natural sub-basin characteristics across the groundwater basin into a fee structure
- **Inter-Generation Equity –**States that a fee structure achieves equity by matching the costs of existing basin impacts to those who have caused the impacts. The objective aims to protect current and future users from disproportionately bearing costs related to groundwater management due to past activities.
    - Example argument for: It is fair and appropriate to recoup mitigation and restoration costs based on past users and their uses

Policy Objective 3 –Rate and Revenue Stability

Policy Statement: There are advantages to an agency in increasing revenue certainty and stabile rates to users. These policies are achieved by selecting specific funding mechanisms or incorporating specific cost components into a fee structure.

Discussion: This principle highlights the importance of ensuring adequate revenue generation for maintaining a self-sustaining agency. Revenues must be adequate to fund technical, personnel, and other operational costs. Revenue generation, and the rates charges to users, should be predictable.

Advantages of the Policy Objective: The practice of ensuring revenue sufficiency and stability generates additional gains in financial health.

Disadvantages of the Policy Objective: While pursuing a rate structure that promotes revenue stability is advantageous, setting user charges in a fashion that fixes a user's bill may be perceived as unfair and inequitable. In addition, the public may perceive the need as unnecessary and that the agency has little incentive to be judicious with operating and management costs.

Sub-Objectives:

- **Revenue Stability** – The ability of the fee structure to generate stable and predictable revenues from month to month or year to year. Specific types of fee structures are more effective at maintaining revenue stability than others. Adequate revenues ensure, for example, that technical studies can be conducted, qualified personnel can be retained, and that operational costs of the agency are covered.
- **Rate Stability** – To reasonably ensure that user fees are predictable from over billing cycles and without sharp fluctuations in magnitude or structure year over year. Similar to the revenue stability objective, certain fee structures are more effective at guarding against fee spikes and highly fluctuating user bills.
- **Minimize Financial Impacts** – Fees imposed by MGA on basin users will be the first of its kind. This objective aims to minimize the financial burden on users to the greatest extent possible. The objective overlaps with the shared burden objective in Policy Objective 4.

Policy Objective 4 –Affordability

Policy Statement: It is important to establish rates that generate adequate revenues from year to year, regardless of climate cycles or variation in basin extractions. Large and unexpected rate changes may impose financial hardships on users large and small. This may negatively affect public opinion of the MGA in terms of revenue management, fiscal responsibility, and rate equity.

Discussion: Affordable fees require a balance between generating stable and sufficient revenue for operations and providing flexibility in user charges. Any new fee structure may result in different impacts to different basin users.

Advantages of the Policy Objective: Flexibility in bills allows users a degree of choice and control over their charges. More, lower income and/or those facing financial hardship are more likely to stay current on their charges with fees deemed affordable by the community.

Disadvantages of the Policy Objective: Affordability is relative to each individual fee payer and can be difficult to define. What may be affordable for one user is unaffordable to another. Additionally, affordability efforts generally present a tradeoff with revenue stability to the agency.

Sub-Objectives:

- **Shared Burden** – Recognizes that the Mid-County Basin benefits all current, future, and potential users of groundwater. In essence, each overlying property benefits from a sustainable groundwater basin and the burden of ensuring basin health should be distributed as broadly as possible.
- **Affordability for Essential Use** – This objective addresses the importance of maintaining the price - i.e. that which is used for health and safety – at the lowest cost possible while considering the needs of the Agency and regulatory conditions.

Policy Objective 5 – Conservation

Policy Statement: The critical condition of the groundwater basin, and the mandate of sustainability as defined by SGMA, should be reflected in the fees and charges. The fee structure should encourage a reduction in basin-wide use and empower necessary water management efforts by the GSA.

Discussion: This principle recognizes the limited water availability of the basin, as well as the environmental and financial impact of mitigation activities. The fees should encourage reduced use of a limited resource to the greatest extent under the law.

Advantages of the Policy Objective: This policy attempts to align the costs of reducing basin extraction with the users causing basin overdraft and seawater intrusion. The fee structure assigns a tangible value on the costs of critical overdraft.

Disadvantages of the Policy Objective: Typically, fee structures emphasizing efficiency, conservation, and reduced water use pose increased costs in implementation, administration, technical services, and outreach.

Sub-Objectives:

- **Reward Past Conservation Efforts** –Recognizes the value either of rewarding individuals for reduced and efficient use according to their needs, or at minimum, not penalizing those users for their conservation efforts prior to SGMA.
- **Tool for Implementing the Groundwater Sustainability Plan (GSP)** –Aims to develop a fee structure that is most likely to achieve the goals of the GSP over the long term. Advocates for a mechanism to allocate costs and incentivize activities to avoid or mitigate undesirable results as defined by SGMA.

- **Promotes Future Conservation** –Aims to reduce total water use through a focus on reduced pumping. The objective may include increased efficiency of basin water use to include development of benchmark standards associated with the appropriate amount of water use based on local characteristics.
- **Scientific Method** – Use of best available science, models, and empirical data-based standards and guidelines should be employed to develop the fee structure. The scientific method is applied to pumping for indoor and outdoor water use, such as the specific amount of water estimated for outdoor requirements given parcel land cover as well as the estimated return of water to the basin based on geology and other hyper-local characteristics.

3. Pricing objectives Exercise

Santa Cruz Mid-County Groundwater Agency
Pricing Objectives Exercise

Please rank each of the objectives from 1 to 17 with
1 being most important and 17 being least important
See Appendix A for the definitions of each Objective

	Objectives	Ranking
Administration	Ease of Understanding	
	Easy of Implementation and Administration	
	Defensibility	
Equity	Equity Among Property Owners	
	Equity Among Pumpers	
	Equity Across All Basin Users (Beneficiaries)	
	Equity Across Geographic Areas	
	Inter-Generational Equity	
Rate and Revenue Stability	Revenue Stability	
	Rate Stability	
	Minimize Financial Impacts	
Affordability	Shared Burden	
	Affordability for Essential Use	
Conservation	Rewards Past Conservation Effort	
	Tool for Implementing the GSP	
	Promotes Future Conservation	
	Scientific Method	

Participant's name ____

4. Sub-Objective Definitions

Affordability for Essential Use: This objective addresses the importance of maintaining the price - i.e. that which is used for health and safety – at the lowest cost possible while considering the needs of the Agency and regulatory conditions.

Defensibility: Producing a fee structure perceived to be fair, well documented, and well explained reduces the likelihood of legal challenge. This leads to more efficient and less costly administration.

Ease of Implementation and Administration (Simplicity): Implementing a new fee structure merits careful consideration, as rate structure implementation requires upfront (one-time) costs such as data gathering or billing system changes. An easy-to-administer structure does not negatively impact the ongoing costs of administration, which are predominately additional staffing costs.

Ease of Understanding: The ability for the fee structure to be explained in a manner that can be understood by basin users and other stakeholders will have a positive impact on the ability to build acceptance of fees.

Equity Across All Basin Users (beneficiaries): This objective states that a fee structure achieves equity by allocating costs fairly and proportionally across all water users in the basin. Considers basin groundwater a general benefit across all users of groundwater.

Equity Across Management Areas: Considers specific regions within the basin boundaries that contribute to groundwater replenishment and specific regions which contribute to intrusion, depletion, and/or impairment.

Equity Among Property Owners: This objective states that a fee structure achieves equity by allocating costs fairly and proportionally across property owners whose parcels overlay the basin.

Equity Among Pumpers: This objective states that a fee structure achieves equity by allocating costs fairly and proportionally across well owners whose parcels overlay the basin.

Inter-Generational Equity: This objective states that a fee structure achieves equity by matching the costs of existing impacts to the basin to those who have caused the impacts. The objective aims to protect current and future users from bearing all costs related to groundwater management due to past activities.

Minimize Financial Impacts: Fees imposed on basin users will be the first of its kind. This objective aims to minimize the financial burden on users to the greatest extent possible. The objective overlaps with the shared burden objective.

Promotes Future Conservation: The objective aims to reduce total water use through a focus on reduced pumping. The objective may include increased efficiency of basin water use to include development of benchmark standards associated with the appropriate amount of water use based on local characteristics.

Rate Stability: The objective is to reasonably ensure that user fees are predictable from billing cycle to billing cycle and without sharp fluctuations in magnitude or structure year over year. Similar to the revenue stability objective, certain fee structures are more effective at guarding against fee spikes and highly fluctuating user bills.

Revenue Stability: The ability of the fee structure to generate stable and predictable revenues from month to month or year to year. Specific types of fee structures are more effective at maintaining revenue stability than others. Adequate revenues ensure, for example, that technical studies can be conducted, qualified personnel can be retained, and that operational costs of the agency are covered.

Reward Past Conservation Efforts: This objective recognizes the value either of rewarding individuals for efficient use according to their needs, or at minimum, not penalizing those users for their conservation efforts prior to SGMA.

Scientific Method: Use of best available science, models, and empirical data-based standards and guidelines should be employed to develop the fee structure. The scientific method is applied to pumping for indoor and outdoor water use, such as the specific amount of water estimated for outdoor requirements given parcel land cover, as well as the estimated return of water to the basin based on geology and other hyper-local characteristics.

Shared Burden: This objective recognizes that the Mid-County Basin benefits all current, future, and potential users of groundwater. In essence each overlying property benefits from a sustainable groundwater basin and the burden of ensuring basin health should be distributed as broadly as possible.

Tool for Implementing the Groundwater Sustainability Plan (GSP): This objective aims to develop a fee structure that is most likely to achieve the goals of the GSP over the long term. Advocates for a mechanism to allocate costs and incentivize activities to avoid or mitigate undesirable results as defined by SGMA.

Appendix B

Part 2.74 of Division 6 of the Water Code contains 12 chapters on Sustainable Groundwater Management. Below are five important sub-sections of Chapter 8: Financial Authority that are pertinent to MGA's ability to develop a fee structure that is most appropriate for the basin and the authority and technical requirements to charge fees. The language that follows is direct from the sub-sections in Chapter 8 of Part 2.74 of the Water Code. Bolded font is emphasis added by Raftelis.

10730.2(d): Fees imposed pursuant to this section may include **fixed fees** and **fees charged on a volumetric basis**, including, but not limited to, fees that increase based on the quantity of groundwater produced annually, the year in which the production of groundwater commenced from a groundwater extraction facility, and impacts to the basin.
10730.8(a): Nothing in this chapter shall affect or interfere with the authority of a groundwater sustainability agency to levy and collect **taxes, assessments, charges**, and tolls as otherwise provided by law.
10730.2(c): Fees imposed pursuant to this section shall be adopted in accordance with subdivisions (a) and (b) of **Section 6 of Article XIII D** of the California Constitution. (*Proposition 218*)
10730(a): A groundwater sustainability agency may impose fees, including, but not limited to, **permit fees** and **fees on groundwater extraction** or other regulated activity, to fund the costs of a groundwater sustainability program, including, but not limited to, preparation, adoption, and amendment of a groundwater sustainability plan, and investigations, inspections, compliance assistance, enforcement, and program administration, including a prudent reserve.
10730.2(a): …may impose fees on the extraction of groundwater from the basin to fund costs of groundwater management, including:

- Administration, operation, and maintenance, including a prudent reserve.
- Acquisition of lands or other property, facilities, and services.
- Supply, production, treatment, or distribution of water.
- Other activities necessary or convenient to implement the plan.