NORTH COAST RESOURCE PARTNERSHIP

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2018/19 IRWM Project Application

The North Coast Resource Partnership (NCRP) 2018/19 Project Application Instructions and additional information can be found at the NCRP 2018/19 Project Solicitation webpage (https://northcoastresourcepartnership.org/proposition-1-irwm-round-1-implementation-funding-solicitation/). Please fill out grey text boxes and select all the check boxes that apply to the project. Application responses should be clear, brief and succinct.

Project Applications will be accepted until 5:00 pm, ~~March 8, 2019~~ **March 15, 2019.** It is important to save the application file with a distinct file name that references the project name. When the application is complete, please email to kgledhill@westcoastwatershed.com

If you have questions, need additional information or proposal development assistance please contact:

- Katherine Gledhill at kgledhill@westcoastwatershed.com or 707.795.1235
- Tribal Projects: Sherri Norris, NCRP Tribal Coordinator at sherri@cieaweb.org or 510.848.2043

Project Name: Rainwater Catchment Rebate and Streamflow Enhancement Pilot Project

A. ORGANIZATION INFORMATION

1. **Organization Name: Gold Ridge Resource Conservation District**

2. **Contact Name/Title**
   Name: John Green
   Title: Lead Scientist
   Email: John@goldridgercd.org
   Phone Number (include area code): 707.823.5244

3. **Organization Address (City, County, State, Zip Code):**
   2776 Sullivan Rd, Sebastopol, Sonoma County, CA 95472

4. **Organization Type**
   ☒ Public agency

☐ Non-profit organization
☐ Public utility
☐ Federally recognized Indian Tribe
☐ California State Indian Tribe listed on the Native American Heritage Commission's California Tribal Consultation List
☐ Mutual water company
☐ Other:

5. **Authorized Representative** (if different from the contact name)
   Name: Brittany Jensen
   Title: Executive Director
   Email: Brittany@goldridgercd.org
   Phone Number (include area code): 707.823.5244

6. **Has the organization implemented similar projects in the past?** ☒ yes ☐ no
   Briefly describe these previous projects.
   The Gold Ridge Resource Conservation District (GRRCD) and its project partners have led design and implementation of numerous rural residential rainwater catchment systems through various funding programs, including NCIRWMP Prop 50 & 84. Sonoma Water is ideally suited to administer the rebates as an extension of its existing water rebate programs. Both Sonoma Water and Daily Acts also currently conduct workshops of a similar format to that proposed for the rainwater catchment training.

7. **List all projects the organization is submitting to the North Coast Resource Partnership for the 2018/19 Project Solicitation in order of priority.**
   This is the only submittal by the Gold Ridge RCD.

8. **Organization Information Notes:**

Established in 1941, the Gold Ridge Resource Conservation District (GRRCD) has been a leader in western Sonoma County natural resource stewardship for over 75 years. GRRCD has received six grants through the NCIRWMP program since 2010, while partnering with the Sonoma RCD on a seventh, for a combined total of over $2.2 million. The NCIRWMP program has been critical for past GRRCD projects promoting water sustainability in the district, providing funds for the design and construction of both small- and large-scale rainwater catchment and water storage projects. Most notable among these are a 1.3-million gallon system on a dairy offsetting 7,000 gallons/day of summer riparian diversions from Salmon Creek, and a water conservation and storage project at a summer camp on Dutch Bill Creek that offset stream diversions of 4 acre-feet each year. The latter had such a profound effect on summer streamflow, its construction year is apparent on Dutch Bill's hydrograph.

B. ELIGIBILITY

1. **North Coast Resource Partnership and North Coast IRWM Objectives**

   GOAL 1: INTRAREGIONAL COOPERATION & ADAPTIVE MANAGEMENT
   ☒ Objective 1 - Respect local autonomy and local knowledge in Plan and project development and implementation

☒ Objective 2 - Provide an ongoing framework for inclusive, efficient intraregional cooperation and effective, accountable NCIRWMP project implementation
☐ Objective 3 - Integrate Traditional Ecological Knowledge in collaboration with Tribes to incorporate these practices into North Coast Projects and Plans

GOAL 2: ECONOMIC VITALITY
☒ Objective 4 - Ensure that economically disadvantaged communities are supported and that project implementation enhances the economic vitality of disadvantaged communities by improving built and natural infrastructure systems and promoting adequate housing
☐ Objective 5 - Conserve and improve the economic benefits of North Coast Region working landscapes and natural areas

GOAL 3: ECOSYSTEM CONSERVATION AND ENHANCEMENT
☒ Objective 6 – Conserve, enhance, and restore watersheds and aquatic ecosystems, including functions, habitats, and elements that support biological diversity
☒ Objective 7 - Enhance salmonid populations by conserving, enhancing, and restoring required habitats and watershed processes

GOAL 4: BENEFICIAL USES OF WATER
☒ Objective 8 - Ensure water supply reliability and quality for municipal, domestic, agricultural, Tribal, and recreational uses while minimizing impacts to sensitive resources
☐ Objective 9 - Improve drinking water quality and water related infrastructure to protect public health, with a focus on economically disadvantaged communities
☒ Objective 10 - Protect groundwater resources from over-drafting and contamination

GOAL 5: CLIMATE ADAPTATION & ENERGY INDEPENDENCE
☐ Objective 11 - Address climate change effects, impacts, vulnerabilities, and strategies for local and regional sectors to improve air and water quality and promote public health
☒ Objective 12 - Promote local energy independence, water/ energy use efficiency, GHG emission reduction, and jobs creation

GOAL 6: PUBLIC SAFETY
☐ Objective 13 - Improve flood protection and reduce flood risk in support of public safety

2. **Does the project have a minimum 15-year useful life?**
   ☒ yes ☐ no
   If no, explain how it is consistent with Government Code 16727.

3. **Other Eligibility Requirements and Documentation**

   CALIFORNIA GROUNDWATER MANAGEMENT SUSTAINABILITY COMPLIANCE
   a) Does the project that directly affect groundwater levels or quality?
      ☐ yes ☒ no
   b) If Yes, will the organization be able to provide compliance documentation outlined in the instructions, to include in the NCRP Regional Project Application should the project be selected as a Priority Project?
      ☐ yes ☐ no

CASGEM COMPLIANCE

a) Does the project overlie a medium or high groundwater basin as prioritized by DWR?
   ☒ yes ☐ no
b) If Yes, list the groundwater basin and CASGEM priority: Santa Rosa Plain; This basin's boundary was finalized on 2/11/2019. The draft prioritization for this basin is being determined and scheduled to be released in spring of 2019.
c) If Yes, please specify the name of the organization that is the designated monitoring entity: Sonoma Water
d) If there is no monitoring entity, please indicate whether the project is wholly located in an economically disadvantaged community.
   ☐ yes ☐ no

URBAN WATER MANAGEMENT PLAN

a) Is the organization required to file an Urban Water Management Plan (UWMP)?
   ☐ yes ☒ no
b) If Yes, list the date the UWMP was approved by DWR:
c) Is the UWMP in compliance with AB 1420 requirements?
   ☐ yes ☐ no
d) Does the urban water supplier meet the water meter requirements of CWC 525?
   ☐ yes ☐ no
c) If Yes, will the organization be able to provide compliance documentation outlined in the instructions, to include in the NCRP Regional Project Application should the project be selected as a Priority Project?
   ☐ yes ☐ no

AGRICULTURAL WATER MANAGEMENT PLAN

a) Is the organization – or any organization that will receive funding from the project – required to file an Agricultural Water Management Plan (AWMP)?
   ☐ yes ☒ no
b) If Yes, list date the AWMP was approved by DWR:
c) Does the agricultural water supplier(s) meet the requirements in CWC Part 2.55 Division 6?
   ☐ yes ☐ no

SURFACE WATER DIVERSION REPORTS

a) Is the organization required to file surface water diversion reports per the requirements in CWC Part 5.1 Division 2?
   ☐ yes ☒ no
d) If Yes, will the organization be able to provide SWRCB verification documentation outlined in the instructions, to include in the NCRP Regional Project Application should the project be selected as a Priority Project?
   ☐ yes ☐ no

STORM WATER MANAGEMENT PLAN

a) Is the project a stormwater and/or dry weather runoff capture project?
   ☐ yes ☒ no
b) If yes, does the project benefit a Disadvantaged Community with a population of 20,000 or less?
   ☐ yes ☐ no

e) If No, will the organization be able to provide documentation that the project is included in a Stormwater Resource Plan that has been incorporated into the North Coast IRWM Plan, should the project be selected as a Priority Project?

☐ yes ☐ no

C. GENERAL PROJECT INFORMATION

1. Project Name: Rainwater Catchment Rebate and Streamflow Enhancement Pilot Project

2. Eligible Project Type under 2018/19 IRWM Grant Solicitation

- ☐ Water reuse and recycling for non-potable reuse and direct and indirect potable reuse
- ☐ Water-use efficiency and water conservation
- ☐ Local and regional surface and underground water storage, including groundwater aquifer cleanup or recharge projects
- ☐ Regional water conveyance facilities that improve integration of separate water systems
- ☒ Watershed protection, restoration, and management projects, including projects that reduce the risk of wildfire or improve water supply reliability
- ☒ Stormwater resource management projects to reduce, manage, treat, or capture rainwater or stormwater
- ☐ Stormwater resource management projects that provide multiple benefits such as water quality, water supply, flood control, or open space
- ☐ Decision support tools that evaluate the benefits and costs of multi-benefit stormwater projects
- ☐ Stormwater resource management projects to implement a stormwater resource plan
- ☐ Conjunctive use of surface and groundwater storage facilities
- ☐ Decision support tools to model regional water management strategies to account for climate change and other changes in regional demand and supply projections
- ☐ Improvement of water quality, including drinking water treatment and distribution, groundwater and aquifer remediation, matching water quality to water use, wastewater treatment, water pollution prevention, and management of urban and agricultural runoff
- ☐ Regional projects or programs as defined by the IRWM Planning Act (Water Code §10537)
- ☐ Other:

3. Project Abstract

This multi-partner pilot project seeks to promote water conservation, provide alternatives to extractive water sources, enhance streamflow for wildlife, and foster water use awareness throughout Sonoma County's North Coast region by piloting a standardized and cost-effective rebate program for small-scale rainwater catchment systems, while building capacity among both local landscapers and homeowners to design and install them.

4. Project Description

With the North Coast facing extended droughts, less predictable weather patterns, and increasingly catastrophic weather events threatening water supply infrastructure, more localized household-level water security is an increasingly critical aspect of climate change resiliency.

Through a partnership between Sonoma Water, the Gold Ridge and Sonoma RCDs, Sonoma-Marin Saving Water Partnership, and the non-profit Daily Acts, this proposal seeks to build upon the partners' current success in fostering community water conservation, security, and awareness, by developing and implementing a pilot rebate and training program to promote household-level water storage through rainwater catchment.

Partners will assist rebate program applicants with onsite project scoping, system design, implementation oversight, and system verification and monitoring, with rebates provided on a tiered, per-gallon basis designed to incentivize both large and small systems, anticipated to facilitate construction of approximately 75 small (<2,500-gallon) and 20 large (2,500-10,000+ gallon) systems during this pilot phase.

Through the Sonoma-Marin Saving Water Partnership, the partners will also create and promote a training module through the QWEL (Qualified Water-Efficent Landscapers) program, produced in both English and Spanish, and conduct four trainings to certify at least 40 licensed landscapers in rainwater catchment permitting, design, and installation. The module will be widely transferable for similar efforts throughout the region and will continue to be offered as a QWEL training module for all 23 Professional Certifying Organizations currently offering the QWEL training program.

A second workshop series led by Daily Acts will target at least 80 participants, providing instruction and technical assistance education residents and/or small businesses install smaller systems on their own.

Finally, project partners will collaborate to research and develop a more comprehensive rebate program to promote additional water sustainability practices through increased water use efficiency, runoff reduction, and groundwater recharge. The comprehensive rebate program may include, but not be limited to: greywater, rain gardens, downspout redirects, permeable pavement, and turf replacement. This work product will build off the lessons learned from the proposed program and develp a framework for implementing a comprehensive rebate program in the region.

5. **Specific Project Goals/Objectives**

Goal 1: Enhance water security and resource use awareness through a region-wide rainwater catchment rebate

Goal 1 Objective: Provide technical and financial support for the design and construction of at least 20 large-scale (>2,500-gallon) rainwater catchment systems, protecting streamflow and enhancing water security

Goal 1 Objective: Provide technical and financial support for design and construction of at least 75 small-scale (<2,500-gallon) rainwater catchment systems, focused in urban DACs and fire rebuild areas.

Goal 1 Objective: Enhance summer streamflow for wildlife, including endangered and threatened anadromous fish, by offsetting riparian diversions in coordination with the Coho Partnership

Goal 1 Objective:

Goal 2: Increase technical capacity for rainwater catchment installation among landscapers and homeowners

Goal 2 Objective: Create and produce a rainwater catchment training module for certification of licensed landscapers through the QWEL Program

Goal 2 Objective: Conduct 4 trainings to certify at least 40 licensed landscapers in rainwater catchment design and construction

Goal 2 Objective: Conduct 4 trainings targeting at least 80 participants to provide technical instruction and assistance for participants to install their own small rainwater catchment systems.

Goal 2 Objective:

Goal 3: Expand the rebate program to include additional sustainable water management practices

Goal 3 Objective: Evaluate pilot rebate program structure and cost-effectiveness to develop a second phase for the program

Goal 3 Objective: Research and develop a technical assistance and rebate program for other practices such as greywater, rain gardens, etc.
Goal 3 Objective: Coordinate with the Cities and water suppliers to develop incentive programs for water management practices

Additional Goals & Objectives (List)

6. **Describe how the project addresses the North Coast Resource Partnership and North Coast IRWM Plan Goals and Objectives selected**.
Goal 1, Objectives 1 & 2: Partners will work with property owners on a voluntary basis and carry out rainwater catchment design and implementation according to landowner desires while ensuring a natural resource benefit of each system. This pilot phase will allow partners to assess the strengths and weaknesses of the program, initiating a framework to be developed for improvement in efficiencies and effectiveness. Goal 3, Objectives 6 & 7: The project will offset streamflow and groundwater extraction, enhancing streamflow for endangered coho salmon, threatened steelhead trout, and other species. Goal 4, Objectives 8 & 10: The project will provide additional water resources for municipal water users, as well as for domesic, agricultural, Tribal, and recreational uses, depending on who participates, that will offset streamflow and groundwater extraction, which may impair groundwater quality. Goal 5, Objective 12: The project stores rainwater for dry season and drought use.

7. **Describe the need for the project**.
Our region's recent five-year drought has highlighted the need for household-level water security and alternative water sourcing, as many residential wells and riparian diversions began to run dry with declining aquifer and stream levels. Others found themselves subject to regulatory emergency orders, restricting water use where it was deemed to impact salmonid-bearing streams in critical areas. The subsequent devastating wildfires in 2017 also brought renewed concern for water availability, particularly in rural areas. Finally, the initial steps towards groundwater management in several area basins and the growing recognition of groundwater as a public resource has led many residents to think more critically about where their water comes from. Additional intensifying threats to water supplies and delivery infrastructure, such as flooding, earthquakes, and groundwater contamination, also highlight the need for a paradigm shift in how we meet our most basic needs.

8. **List the impaired water bodies (303d listing) that the project benefits:**
Russian River HU: Austin Creek HSA, Guerneville HSA, Green Valley Creek watershed, Big Sulphur Creek HSA, Geyserville HSA, mainstem Laguna de Santa Rosa and its tributaries, Windsor Creek and its tributaries, mainstem Mark West Creek and its tributaries, mainstem Santa Rosa Creek and its tributaries, Warm Springs HSA, Lake Sonoma; Bodega HU: Bodega Harbor HA, Americano Creek, Estero Americano HA estuary, Stemple Creek/Estero de San Antonio, Campbell Cove.

9. **Will this project mitigate an existing or potential Cease and Desist Order or other regulatory compliance enforcement action?** ☐ yes ☒ no
If so, please describe?

10. **Describe the population served by this project.**
The rebate program and training workshops will be made available to all residential homeowners, small businesses, schools, and other appropriate land uses within Sonoma County's North Coast region, with

focus on Disadvantaged Communities (DACs), fire recovery/rebuild areas, and water insecure communities.

11. Does the project provide direct water-related benefits to a project area comprised of Disadvantaged Communities or Economically Distressed Communities?

- ☐ Entirely
- ☒ Partially
- ☐ No

List the Disadvantaged Community(s) (DAC)
Block Group: 060971542012, 060971542023, 060971540002, 060971537044, 060971537051, 060971537043, 06097153703, 060971537052, 060971534041, 060971538081, 060971527015, 060971527014, 060971528011, 060971530021, 060971530054, 060971530061, 060971530031, 060971522013, 060971522014, 060971514012, 060971522021, 060971522024, 060971522022, 060971525022, 060971525023, 060971517001, 060971517004, 060971513082, 060971513063; Tract: 06097153704, 06097153703, 06097153705, 06097152802, 06097153001, 06097152203, 06097152000, 06097151900, 06097153104, 06097153102, 06097151402, 06097151305, 06097151201; Cazadero, Monte Rio CDP, Guerneville CDP, Graton CDP

12. Does the project provide direct water-related benefits to a project area comprised of Severely Disadvantaged Communities (SDAC)?

- ☐ Entirely
- ☒ Partially
- ☐ No

List the Severely Disadvantaged Community(s)
Block Group: 060971542013, 060971536001, 060971521001, 060971529033, 060971531033, 060971515025, 060971513083, 060971528021, 060971519004, 060971514023, 060971514024, 060971513051, 060971513054, 060971512011, 060971512015

13. Does the project provide direct water-related benefits to a Tribe or Tribes?

- ☐ Entirely
- ☒ Partially
- ☐ No

List the Tribal Community(s)
All tribes in the project area are welcome to participate and include: Cloverdale Rancheria of Pomo Indians of California, Dry Creek Rancheria Band of Pomo Indians, Federated Indians of Graton Rancheria, Kashia Band of Pomo Indians of the Stewarts Point Rancheria, Koi Nation of Northern California, Lytton Band of Pomo Indians
If yes, please provide evidence of support from each Tribe listed as receiving these benefits.

14. If the project provides benefits to a DAC, EDA or Tribe, explain the water-related need of the DAC, EDA or Tribe and how the project will address the described need.
Water-related needs of DACs, EDAs, and Tribes in the project area are similar to the rest of the project area, with the exception that DACs, EDAs, and Tribes may not have the same level of resources to meet their water needs as other places in the project area. DACs, EDAs, and Tribes contend with droughts, harsh dry seasons, floods, overwhelming wet seasons, water insecurity, impaired water bodies, groundwater quality issues, biodiversity loss related to water quality and flow impairments, and several threats to water quality and supply, including wildfire and earthquake hazard risk.

15. **Does the project address and/or adapt to the effects of climate change? Does the project address the climate change vulnerabilities in the North Coast region?** ☒ yes ☐ no
If yes, please explain.
Climate change impacts in the North Coast include prolonged durations of drought and dry seasons, temperature impairments in water bodies, and increased wildfire risk. The proposed project offsets direct stream diversions and groundwater extraction during times of flow impairments that hinder the recovery of endangered and threatened anadromous fish and other aquatic species. The project also provides participants with greater water security and a water source in the event of a fire.

16. **Describe how the project contributes to regional water self-reliance.**
The North Coast region of Sonoma County is an area of great variability in water self-reliance, with some areas exporting water to Marin County and Bay Area regions of Sonoma County, while in other areas fractured geology fails to support substantial aquifers. Even areas supporting groundwater basins are not sustainable into perpetuity, as is evidenced by the Department of Water Resources recent designation of the Santa Rosa Plain groundwater basin as medium priority. The area has also been experiencing substantial population growth during the past decades and continues to maintain irrigated agriculture as a central industry for the region's economic vitality and cultural heritage, which necessitates enhanced sustainable water management. The proposed project allows individual property owners to increase their local self-reliance by developing sources of water to use in place of stream diversions and groundwater that are critical for wildlife and the sustainability of the region.

17. **Describe how the project benefits salmonids, other endangered/threatened species and sensitive habitats.**
The project will serve to supplement the ongoing work of the Gold Ridge and Sonoma RCDs in assisting landowners with alternative water sourcing and storage through the NFWF-funded Russian River Coho Water Resources Partnership, which focuses on enhancing summer streamflow in key reaches of five critical coho-bearing subwatersheds. The proposed rebate program can be used to assist those outside of the focus reaches, and more broadly, normalize alternatives to streamflow diversions.

18. **Describe local and/or political support for this project.**
This proposal has stemmed both from collaboration between the project partners and city water system managers, who expressed eagerness to develop incentive programs similar to the City of Santa Rosa's existing rainwater catchment rebate program and have provided cost share; and in response to water-insecure residents' requests for technical and financial assistance for alternative water sourcing.

19. **List all collaborating partners and agencies and nature of collaboration.**
This project pools efforts of multiple local entities currently involved in water management and sustainability, including Sonoma Water, Gold Ridge and Sonoma RCDs, all 11 water utility members of the Sonoma-Marin Saving Water Partnership, and Daily Acts. The collaborative approach allows for synergy with other existing rebate programs, Daily Acts' outreach and trainings, and the RCDs' leading role in the Coho Partnership's rainwater catchment program along critical coho-bearing streams.

20. **Is this project part or a phase of a larger project?** ☒ yes ☐ no
Are there similar efforts being made by other groups? ☒ yes ☐ no
If so, please describe?
This project is designed to be the first pilot phase to expand the City of Santa Rosa's rainwater catchment rebate system to the rest of Sonoma County, incentivize construction of more and larger

systems, and build local technical capacity to facilitate implementation. While initially focused on rainwater catchment, the program is meant ultimately to expand into other water conservation practices promoting widespread sustainable water management.

21. Describe the kind of notification, outreach and collaboration that has been done with the County(ies) and/or Tribes within the proposed project impact area, including the source and receiving watersheds, if applicable.
The program has been developed based on consistent demand from constituents, and will be widely promoted by all project partners through websites, social media posts, e-blasts, newsletters, community event tabling, and targeted outreach to water-insecure communities that have previously expressed demand for the program.

22. Describe how the project provides a benefit that meets at least one of the Statewide Priorities as defined in the 2018 IRWM Grant Program Guidelines and Tribal priorities as defined by the NCRP?
The program meets multiple Statewide Priorities, promoting water self-reliance and expanding water storage at the household level, protecting summer streamflow and riparian ecosystems where participants rely on riparian diversions, and assisting communities in preparing for droughts and dry seasons. Most importantly, the program seeks to foster awareness among participants, instilling a conservation ethic about water use and a greater understanding of its value as a vital but finite resource.

23. Project Information Notes:
Rebates will initially be offered on a per-gallon tiered schedule, designed to incentivize both small-scale urban systems that landowners can install themselves, and larger rural systems designed to offset riparian diversions or provide summer water security. Initial estimates for tiered reimbursement rates are shown below. However, as this is a pilot project, these incentives may need to be adjusted as the program unfolds. The current consensus among multiple consulted water utilities with incentive rebate programs is that the programs are not subject to prevailing wage requirements, and thus far have not been challenged. However, if the Department of Industrial Relations were to issue a determination to the contrary, the rates below would need to be adjusted to not exceed the cost of materials, to clarify that the rebate is not being used to cover any labor costs.

Tier 1:Up to $500 for a up to 250 gallon rain barrel ($2.00/ gallon)
Tier 2:Up to $825 for a 250-550 gallon barrels or small cistern ($1.50/gallon)
Tier 3:Up to $3,125 for a >550-2,500 gallon cistern ($1.25/gal)
Tier 4:Up to $10,000 for a >2,500+ gallon cistern ($1.00/ gallon)

Program participants interested in smaller systems they install themselves will receive technical guidance through the program from RCD and Daily Acts staff, including a pre-installation site visit to discuss any complications, and a post-installation system verification. Participants will also be required to submit documentation of system installation, including receipts and invoices, in order to be reimbursed through the program. The program will coordinate with the City of Santa Rosa on city properties where the existing $0.25/gallon rebate will be supplemented by the program.

Landowners seeking larger systems will receive designs, completed by the RCD licensed engineers, RCD staff certified by the American Rainwater Catchment Systems Association, or other qualified consultants. Landowners will sign agreements confirming their commitment to the process, and will be required to pay approximately 10% cost share towards design costs (with waivers provided for financial hardship where appropriate). Partner staff will also assist in identifying and communicating with licensed contractors where needed, and will oversee installation of the systems. Landowner agreements may include forbearance requirements where appropriate, specifying that any collected water must be used to offset, rather than augment, riparian water use, and may dictate times of use to allow for greatest benefit to the stream.

Sonoma-Marin Saving Water Partnership: The Sonoma-Marin Saving Water Partnership represents 11 water utilities in Sonoma and Marin counties who have joined together to provide a regional approach to water use efficiency, including several within the North Coast region: Sonoma Water and the Cities of Santa Rosa, Rohnert Park, and Windsor. Of these, only the City of Santa Rosa currently offers a rebate program for rainwater catchment systems for city water users, providing $0.25/gallon. As of February 2019, over 100 rate payers have received over $36,000 in rebates through the program. The proposed larger program will collaborate with the City, assisting applicants with design and implementation oversight, while supplementing its current rebate as needed to meet the proposed program's tiered rates.

D. PROJECT LOCATION

1. **Describe the location of the project**
   Geographical Information
   The project area covers the entire North Coast region within Sonoma County

2. **Site Address (if relevant):**
   n/a

3. **Does the applicant have legal access rights, easements, or other access capabilities to the property to implement the project?**
   ☐ Yes If yes, please describe
   ☒ No If No, please provide a clear and concise narrative with a schedule, to obtain necessary access.
   ☐ NA If NA, please describe why physical access to a property is not needed.
   Access for project implementation will be granted by rebate program applicants, who will sign an agreement specifying terms of participation

4. **Project Location Notes:**

Large sections of the program area suffered alternatively from water insecurity during the recent 5-year drought, massive wildfires in October 2017, and most recently severe flooding in February 2019, the latter of which affected primarily DAC communities along the lower Russian River. These areas are still in the process of recovery and rebuild, with many residents more acutely aware of their reliance on complex, extensive infrastructure to meet their basic needs. Targeted outreach efforts will be conducted in areas in recovery from these catastrophic events.

E. PROJECT TASKS, BUDGET AND SCHEDULE

1. **Projected Project Start Date:** 3/1/20
   Anticipated Project End Date: 10/31/25

2. **Will CEQA be completed within 6 months of Final Award?**
   ☐ Yes State Clearinghouse Number:
   ☒ NA, Project is exempt from CEQA
   ☐ NA, Not a Project under CEQA
   ☐ NA, Project benefits entirely to DAC, EDA or Tribe, or is a Tribal local sponsor. [Projects providing a water-related benefit entirely to DACs, EDAs, or Tribes, or projects implemented by Tribes are exempt from this requirement].
   ☐ No

3. **Please complete the CEQA Information Table below**
   Indicate which CEQA steps are currently complete and for those that are not complete, provide the estimated date for completion.

CEQA STEP	COMPLETE? (y/n)	ESTIMATED DATE TO COMPLETE
Initial Study		
Notice & invitation to consult sent to Tribes per AB52		
Notice of Preparation		
Draft EIR/MND/ND		
Public Review		
Final EIR/MND/ND		
Adoption of Final EIR/MND/ND		
Notice of Determination		
N/A - not a CEQA Project	N/A	

If additional explanation or justification of the timeline is needed or why the project does not require CEQA, please describe.
The Gold Ridge RCD as lead applicant will file a Notice of Exemption for the implementation component of the project, citing a categorical exemption 15303 New Construction or Conversion of Small Structures.

4. **Will all permits necessary to begin construction be acquired within 6 months of Final Award?**
   ☒ Yes
   ☒ NA, Project benefits entirely to DAC, EDA, Tribe, or is a Tribal local sponsor
   ☐ No

5. **PERMIT ACQUISITION PLAN**

Type of Permit	Permitting Agency	Date Acquired or Anticipated

For permits not acquired: describe actions taken to date and issues that may delay acquisition of permit.
No permits are required for the project. If a rebate program participant opts for a system that requires a building permit (using tanks >5,000 gallons), the landowner will be responsible for obtaining a building permit. However, the program is designed to promote systems using 5,000-gallon or smaller tanks.

6. **Describe the financial need for the project**.
   The rebate component of the proposed project is required to provide an incentive for property owners to adopt rainwater catchment systems that they would not otherwise adopt without a monetary incentive, even for those who would like to improve their water conservation. For some DACs, EDAs, and Tribes, rebate funding may provide the finances necessary for some property owners to feasibly be able to adopt rainwater catchment systems.

7. **Is the project budget scalable?** ☒ yes ☐ no
   Describe how a scaled budget would impact the overall project.
   The number of systems rebated would be reduced to meet the scaled budget

8. **Describe the basis for the costs used to derive the project budget according to each budget category.**
   Project costs for staff time were derived from estimates from each project partner, based on each's experience implementing similar programs (the RCDs currently work with homeowners to design and build rainwater catchment systems, while Sonoma Water and Daily Acts currently conduct workshops. The tiered rebate structure (described in Project Notes) was developed based on the experiences of other municipalities' programs.

9. **Provide a narrative on cost considerations including alternative project costs.**
   This proposed rebate program is structured to allow participants to contract directly with qualified landscapers, a structure used widely by municipality rebate programs throughout California as it is not subject to prevailing wage. Participants still receive significant financial incentives through technical assistance, design, construction oversight, and a per-gallon rebate not exceeding materials costs. Similar systems constructed under prevailing wage have cost over $4/gallon to complete.

10. **List the sources of non-state matching funds, amounts and indicate their status**.

   Cost share for the project is provided by the Gold Ridge and Sonoma RCDs through federal funding provided through the Russian River Coho Water Resources Partnership ("Coho Partnership") and the Conservation Parters Program, both funded by the National Fish and Wildlife Foundation; by Daily Acts through contracts with the Cities of Cotati, Windsor, Sebastopol, and Santa Rosa; the Sonoma-Marin Water Saving Partnership through rebates administered by the City of Santa Rosa; and in-kind contributions from Sonoma Water. Cost share match funds will be fully expended by March 2020 and all expenses occurred after January 1, 2015.
   Gold Ridge RCD: NFWF (Russian River Coho Water Resources Partnership) $199,215
   NFWF (Conservation Partners Program) $26,001
   in-kind (CEQA compliance) $161
   Sonoma RCD: NFWF (Russian River Coho Water Resources Partnership) $243,447
   Daily Acts: City of Cotati $24,997
   City of Santa Rosa $5,005
   Town of Windsor $25,090.50
   City of Sebastopol $4,525

Sonoma Water: in-kind $32,495
Sonoma-Marin Water Saving Partnership: $23,309

11. List the sources and amount of state matching funds.

n/a

12. Cost Share Waiver Requested (DAC or EDA)? ☐ yes ☒ no

Cost Share Waiver Justification: Describe what percentage of the proposed project area encompasses a DAC/EDA, how the community meets the definition of a DAC/EDA, and the water-related need of the DAC/EDA that the project addresses. In order to receive a cost share waiver, the applicant must demonstrate that the project will provide benefits that address a water-related need of a DAC/EDA.

13. Major Tasks, Schedule and Budget for NCRP 2018 IRWM Project Solicitation

Please complete MS Excel table available at https://northcoastresourcepartnership.org/proposition-1-irwm-round-1-implementation-funding-solicitation/; see instructions for submitting the required excel document with the application materials.

14. Project Tasks, Budget and Schedule Notes:

Rebate totals, which will be administered by Sonoma Water, were calculated with the following estimates of program participation.

gallons	$/gal	# systems	total
250	$ 2.00	25	$ 12,500.00
550	$ 1.50	25	$ 20,625.00
1000	$ 1.25	25	$ 31,250.00
3000	$ 1.00	8	$ 24,000.00
5000	$ 1.00	8	$ 40,000.00
10000	$ 1.00	4	$ 40,000.00
total rebates			$ 168,375.00

F. PROJECT BENEFITS & JUSTIFICATION

1. Does the proposed project provide physical benefits to multiple IRWM regions or funding area(s)?

☒ yes ☐ no

If Yes, provide a description of the impacts to the various regions.

The QWEL rainwater catchment training module for landscapers, and materials developed for the small-scale system workshops, will be easily transferable and available for use throughout the region.

2. Provide a narrative for project justification. Include any other information that supports the justification for this project, including how the project can achieve the claimed level of benefits. List

any studies, plans, designs or engineering reports completed for the project. *Please see the instructions for more information about submitting these documents with the final application.*

The profound impacts that rainwater catchment and household-level water management can have on both community water security and resource conservation can be difficult to quantify, with most public funding requiring immediate and measurable results in streamflow improvements or other objective measurements. However, a streamflow availability analysis recently conducted in west Sonoma County (O'Connor Environmental, 2016) highlighted the complication with this requirement: that many critical coho-bearing streams in this highly-parcelized region suffer from a "death by a thousand straws" effect, with numerous rural residential wells collectively having significant impacts through creation of cones of depression in the alluvium or by drawing down rearing pools (see "Notes").

A focus on urban areas, where residents currently have reliable city water, can have an equally signficant yet equally difficult-to-measure impact. While this initial phase of the project will provide direct assistance to a relatively small percentage of residents within the project area, the greater justification for this pilot is in its emphasis on promoting and normalizing water management and self-reliance at the household level. Small-scale systems that store a relatively small percentage of dry season household water use may appear to do little to immediately offset resource use, but their impacts on awareness of water can be significant.

A research team led by Dr. Cleo Woelfle-Erskine conducted a number of studies in the Bodega area of west county's coastal Salmon Creek watershed, where the Gold Ridge RCD (through NCIRWMP Prop 50 and 84 funding) had worked with multiple local water company customers, the Bodega Volunteer Fire Department, and several farmers and ranchers to construct rainwater catchment systems, offsetting diversions from the coho-bearing Salmon Creek stream network and the springs that feed it. Part of Woelfe-Erskine's work focused on the social/behavioral factors of participation in these projects, and highlights the greater sense of awareness of resource use and that use's effects on one's environment. In a 2014 article, he states:

". . . .Participating in citizen science and living with rainwater cisterns increases residents' sense of interdependence with other human and nonhuman watershed residents. In residents' reflections on their daily water practices and their practices of returning Coho salmon to their watershed, I find the concept of water as a commons co-evolving with small-scale rainwater harvesting infrastructure. . . .These findings suggest that decentralising water governance and infrastructure involves more than a change in water management. . . .Active, daily involvement with water reminds of its life force. When people have built channels and vessels to store water, awaited the first storms, and seen silver bodies flashing upstream after the first big flow, water can no longer be seen as a dead resource for human use alone."

3. **Does the project address a contaminant listed in AB 1249 (nitrate, arsenic, perchlorate, or hexavalent chromium)?** ☐ yes ☒ no

   If yes, provide a description of how the project helps address the contamination.

4. **Does the project provide safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes consistent with AB 685?** ☐ yes ☒ no

   If Yes, please describe.

   Water collected through roof rainwater catchment is currently not considered acceptable for human consumption. However, for households suffering from inadequate summer supply currently forced to truck in water, increasing rainwater storage to use for non-potable uses can extend the availability of potable sources.

5. **Does the project employ new or innovative technologies or practices, including decision support tools that support the integration of multiple jurisdictions, including, but not limited to, water supply, flood control, land use, and sanitation?** ☒ yes ☐ no
   If Yes, please describe.
   While in reality an ancient technology, rainwater catchment has only recently been promoted in California. The rebate component of the project has also been used for about a decade in Santa Rosa but it will be new to the rest of the North Coast region of Sonoma County with this project. The project's QWEL module development and training of landscapers will help to scale the program as well as expand rainwater catchment beyond the program.

6. **For each of the Potential Benefits that the project claims complete the following table to describe an estimate of the benefits expected to result from the proposed project.** [*See the NCRP Project Application Instructions, Potential Project Benefits Worksheet and background information to help complete the table. The NCRP Project Application, Attachment B includes additional guidance, source materials and examples from North Coast projects*.]

PROJECT BENEFITS TABLE

Potential Benefits Description	Physical Amt of Benefit	Physical Units	Est. Economic Value per year	Economic Units
Water Supply				
Increased instream flow for environmental purposes	200,000 gal/yr	gallon/year	$200	$1/1,000 gal
Increased water supply reliability	100,000 gal/yr	gallon/year	$100	$1/1,000 gal
Avoided water supply purchases (ave water system rates incl associated sewer rates)	70,000 gal/yr	gallon/year	$420	$6/1,000 gal
Avoided water shortage costs (trucked water to rural residences)	100,000 gal/yr	gallon/year	$7,000	$10/gal
Water Quality				
Other Ecosystem Service Benefits				
decreased groundwater withdrawals	50,000 gal/yr	gallon/year	$18.50/yr	$120 ac/yr

Potential Benefits Description	Physical Amt of Benefit	Physical Units	Est. Economic Value per year	Economic Units
Other Benefits				
Jobs created or maintained	2 FTE		not monetized	
Education or technology benefits	120 participants		not monetized	
Carbon Emissions Reductions from trucking water	30 tons	tons CO2e/year	$990	$33/ton CO2e

7. **Project Justification & Technical Basis Notes:**

Streamflow impacts of small alternative water source projects:

We expect that many of the rural residential rainwater project sites will be located on parcels where water is sourced from shallow alluvial wells. The impact of each individual well on streamflow is generally relatively small, and is very difficult to measure. Unlike direct diversions, where every gallon of water diverted is a gallon less surface flow in the stream, the impacts of well diversions are attenuated because water is being diverted from the alluvial aquifer providing groundwater for the stream's baseflow. A well diversion creates a cone of depression in this aquifer – essentially an area of aquifer where the groundwater surface elevation is depressed in relation to the surrounding area. This equates to a volume of aquifer into which water will flow from the surrounding area (to refill the depression), including from the stream. This can be thought of as a small losing stream reach, and its volume and spatial and temporal extents are controlled by a number of factors, including groundwater elevation at the time of diversion, the speed at which water can move through the aquifer, the rate of pumping from the well, and its location in relation to the stream. In areas where multiple parcels source their water from alluvial wells (a situation common in Sonoma County), a series of often overlapping cones of depression will form, each centered on a single well, and groundwater is constantly flowing in to fill them. This pulls water from surface flow. Reducing the rate and frequency of diversion from an alluvial well (in this case, by developing alternative, non-extractive water sources to offset a portion of the water extracted from the well) will shrink its cone of depression, reducing the volume of water lost to the aquifer from streamflow. The impact (and the goal in implementing these systems) is to reduce the spatial and temporal extents of streamflow impairment, as well as its frequency. In areas with multiple alluvial wells, each alternative water source project implemented contributes incrementally to the overall impact. As implementation of this pilot project progresses, the project partners, working in conjunction with the Coho Partnership, will evaluate its effectiveness in order to optimize its impacts on enhancing streamflow and reducing groundwater extraction as we continue to scale up the availability of the program to more and more property owners.

Aiding in this evaluation process will be several studies currently being conducted by the Sonoma RCD through grants from the WIldlife Conservation Board's Streamflow Enhancement program to develop detailed integrated hydrologic models of both the Mark West Creek and Mill Creek watersheds, in order to provide the basis for describing spatial and temporal variations in hydrologic conditions throughout the watershed. This modeling work will prioritize reaches for restoration based on flow availability-based habitat indices, and help guage the effectiveness of strategies to maintain or enhance summer stream flows.

The hydrologic models will run scenarios which include rainwater harvesting and well/creek water forbearance as a water conservation strategy. The results from this model will help guide the strategies of the Rainwater Rebate program including targeting specific implementation locations as well as providing supporting technical data to increase participation.

Similar modeling work conducted by Gold Ridge RCD in Green Valley and Dutch Bill Creeks has provided guidance as to where to focus flow restoration efforts, and resulted in the reintroduction of coho juveniles into the the Atascadero subwatershed by the Russian River Coho Captive Broodstock Program. This subwatershed, part of the Green Valley Creek watershed in the lower Russian, provides high quality rearing habitat and sufficient summer stream flows, but is outside of the critical watershed areas prioritized by the Coho Partnership and therefore not eligible for its financial assistance with alternative water sourcing. As most of the landowners along the Broodstock's placement reach rely exclusively on direct riparian diversions, outreach efforts for the proposed rebate program will include this area as a priority focus.

Major Tasks, Schedule and Budget for North Coast Resource Partnership 2018/19 IRWM Project Solicitation

Project Name: Rainwater Catchment Rebate and Streamflow Enhancement Pilot Project
Organization Name: Gold Ridge Resource Conservation District

Task #	Major Tasks	Task Description	Major Deliverables	Current Stage of Completion	IRWM Task Budget	Non-State Match	Total Task Budget	Start Date	Completion Date
A	**Category (a): Direct Project Administration**								
1	Administration	In cooperation with the County of Humboldt, develop and sign a sub-grantee agreement for work to be completed on this project, including detailed scope of work and budget. Provide audited financial statements and other deliverables as required	Detailed scope of work and budget, audited financial statements and other deliverables as required	0%	$1,150.00	$0.00	$1,150.00	03.01.2020	10.31.2025
2	Monitoring Plan	Develop Monitoring Plan to include goals and measurable objectives	Final Monitoring Plan	0%	$555.00	$0.00	$555.00	03.01.2020	04.30.2020
3	Invoicing and Reporting	Develop monthly or quarterly reports describing work completed, challenges, and strategies for reaching remaining project objectives. Develop Final Report	Invoices, Monthly/Quarterly and Final Reports	0%	$40,345.00	$0.00	$40,345.00	04.01.2020	10.31.2025
B	**Category (b): Land Purchase/Easement**								
1				0%	$0.00	$0.00	$0.00		
C	**Category (c): Planning/Design/Engineering/Environmental Documentation**								
1	Project Outreach	Promote the rebate program through social media postings, e-blasts, website updates, tabling at community events, and through targeted outreach to water-scarce and disadvantaged communities	screenshots of social media postings and website pages; copies of flyers or other outreach materials; summaries of tabling events included in reports	0%	$21,020.00	$53,495.00	$74,515.00	03.01.2020	05.31.2025
2	Rainwater catchment system planning/design	Provide technical assistance and develop designs for at least 20 large-scale (>2,500 gallon) rainwater catchment systems for residences, schools, and small businesses, while providing technical assistance for at least 75 small-scale (<2,500 gallon) systems landowners can implement themselves	summaries and map of designs in progress/completed with monthly/quarterly reporting	0%	$160,450.00	$236,675.84	$397,125.84	03.01.2020	05.31.2025
3	QWEL Rainwater training module development	Develop and produce a bi-lingual training module to certify licensed landscapers through the Qualified Water Efficient Landscaping Program on the design and installation of rainwater catchment systems	copy of module	0%	$48,577.00	$0.00	$48,577.00	03.01.2020	08.31.2020
4	Development of comprehensive rebate program	Research and develop a rebate program structure and materials for additional water management practices, including greywater, rain gardens, permeable hardscaping, downspout redirects, and others	copy of draft program materials	0%	$18,490.00	$9,215.00	$27,705.00	03.01.2021	10.31.2025
5	CEQA Compliance	Submit a Notice of Exemption to the State Clearinghouse and County of Sonoma Clerk	copy of stamped NOE	0%	$0.00	$161.00	$161.00	03.01.2020	04.30.2020
D	**Category (d): Construction/Implementation**								
1	Rainwater catchment system construction assistance	Provide technical assistance, construction oversight, post-construction verification, and rebates for at least 20 large-scale (>2,500 gallon) rainwater catchment systems for residences, schools, and small businesses, while and at least 75 small-scale (<2,500 gallon) systems landowners can implement themselves	summaries and map of systems constructed, including gallons of storage and totals rebated	0%	$242,463.10	$275,173.46	$517,636.56	04.01.2020	10.31.2025
2	QWEL Rainwater training workshops	Conduct 4 workshops for at least 40 licensed landscapers to receive QWEL certification in rainwater catchment design and construction	attendance sheets; workshop summaries	0%	$20,332.80	$5,000.00	$25,332.80	09.01.2020	06.30.2025
3	Small-scale residential rainwater systems workshops	Conduct 4 workshops for at least 80 people providing instruction on the design and installation of small-scale (<2,500-gallon) systems that landowners can install themselves	attendance sheets; workshop summaries and copies of materials provided to participants	0%	$30,862.40	$4,525.00	$35,387.40	04.01.2020	06.30.2025
	Total North Coast Resource Partnership 2018/19 IRWM Grant Request				**$584,245.30**	**$584,245.30**	**$1,168,490.60**		
	Is Requested Budget scalable by 25%? If yes, indicate scaled totals; if no delete budget amount provided.				**$438,183.98**	**$438,183.98**	**$876,367.95**		
	Is Requested Budget scalable by 50%? If yes, indicate scaled totals; if no delete budget amount provided.				**$292,122.65**	**$292,122.65**	**$584,245.30**		

Budget Detail for North Coast Resource Partnership 2018/19 IRWM Project Solicitation

Project Name: Rainwater Catchment Rebate and Streamflow Enhancement Pilot Project
Organization Name: Gold Ridge Resource Conservation District

Budget Detail

Row (a) Direct Project Administration Costs						
Personnel by Discipline	**Task Description**	**Number of Hours**	**Rate**	**Total Admin Cost**	**Match**	**Project Total by Task**
GRRCD Executive Director	A. 1 Contract and subcontract adminstration	10	$115	$1,150.00	$0.00	
GRRCD Lead Scientist	A. 2 Development of monitoring plan, A.3 invoicing and reporting	250	$111	$27,750.00	$0.00	
GRRCD Conservation Planner	A.1. Scope of work and budget development, A. 2 Development of monitoring plan, A.3 invoicing and reporting	50	$111	$5,550.00	$0.00	
GRRCD Bookkeeper	A. 3 Invoicing	80	$95	$7,600.00	$0.00	
Total				**$42,050.00**	$0.00	**$42,050.00**
						7%

7%	total	match provided
GRRCD	$115,935.80	$225,376.96
SCWA	$195,875.00	$55,804.00
SRCD	$189,192.00	$243,447.34
DA	$83,242.50	$59,617.00
	$584,245.30	$584,245.30

Row (b) Land Purchase/Easement

Row (c)							
Personnel	**Task Description**	**hours/ units**	**Rate**	**Requested from NCRP**	**Match**	**Project Total by Task**	
C.1. Outreach							
GRRCD Outreach Coordinator	C. 1 All project partners will coordinate to promote the rebate program through social media postings, e-blasts, website updates, tabling at community events, and through targeted outreach to water-scarce and disadvantaged communities	50	$88.00	$4,400			
GRRCD Lead Scientist		10	$111.00	$1,110			
printing costs				$1,500			
IT Specialist				$1,500			
Subcontractors							
Sonoma RCD				$10,310	$52,127.00		SRCD NFWF task 3 match
Sonoma Water				$0	$1,368.00		
Daily Acts				$2,200			
C.2 Rainwater catchment system planning/design							
GRRCD Lead Scientist	C. 2 RCD staff will provide technical assistance and develop designs for at least 20 large-scale (>2,500 gallon) rainwater catchment systems while supporting Daily Acts staff with smaller-scale systems where needed. Sonoma RCD costs include the SRCD Engineer, who will provide design work for both RCDs.	100	$111.00	$11,100	$83,388.50		GRRCD NFWF task 3 match (Coho Partn and ConPar III)
Subcontractors							
Sonoma RCD				$122,200	$128,290.34		

Budget Detail for North Coast Resource Partnership 2018/19 IRWM Project Solicitation

Project Name: Rainwater Catchment Rebate and Streamflow Enhancement Pilot Project

Organization Name: Gold Ridge Resource Conservation District

Daily Acts	C. 2 Daily Acts staff will provide technical assistance for at least 75 small-scale (<2,500 gallon) systems landowners can implement themselves			$27,150	$24,997.00		Daily Acts - city of Cotati
C.3 QWEL module development							
GRRCD Lead Scientist	C.3 GRRCD Lead Scientist and SRCD Engineer will develop the technical content of the QWEL training module	85	$111.00	$9,435			
Subcontractors							
SRCD				$11,642			
Sonoma Water	C.3 Sonoma Water will finalize and produce the module, including formatting, illustrations, additional engineering details and drawings, branding, etc			$27,500			
C.4 Development of comprehensive rebate program							
GRRCD Conservation Planner	C. 4 Project partners will collaborate to research and develop a rebate program structure and materials for additional water management practices, including greywater, rain gardens, permeable hardscaping, downspout redirects, and others	30	$111.00	$3,330			
GRRCD Lead Scientist		30	$111.00	$3,330			
GRRCD Outreach Coordinator		30	$111.00	$3,330			
Subcontractors							
Sonoma RCD				$7,420			
Sonoma Water				$0	$4,210.00		
Daily Acts		12	$90.00	$1,080	$5,005.00		Daily Acts - city of Santa Rosa
C.5 CEQA compliance	C.5 GRRCD staff will prepare and submit a Notice of Exemption as cost share				$161.00		
Total				**$248,537**	$299,547	**$548,083.84**	
Row (d) Construction/Implementation							
Personnel (Discipline)	**Work Task and Sub-Task (from Work Task Table)**	**hours/ units**	**rate**	**Total Cost**			
D. 1 Rainwater Catchment construction support							
GRRCD Lead Scientist	D.1 GRRCD Lead Scientist and SRCD Engineer will provide rainwater catchment construction oversight and post-construction verification for large systems, while assisting Daily Acts with techical assistance to landowners of smaller systems where needed	200	$111.00	$22,200	$141,827.46		GRRCD NFWF Task 4 match
GRRCD mileage		600	$0.58	$348			
Subcontractors							

Budget Detail for North Coast Resource Partnership 2018/19 IRWM Project Solicitation

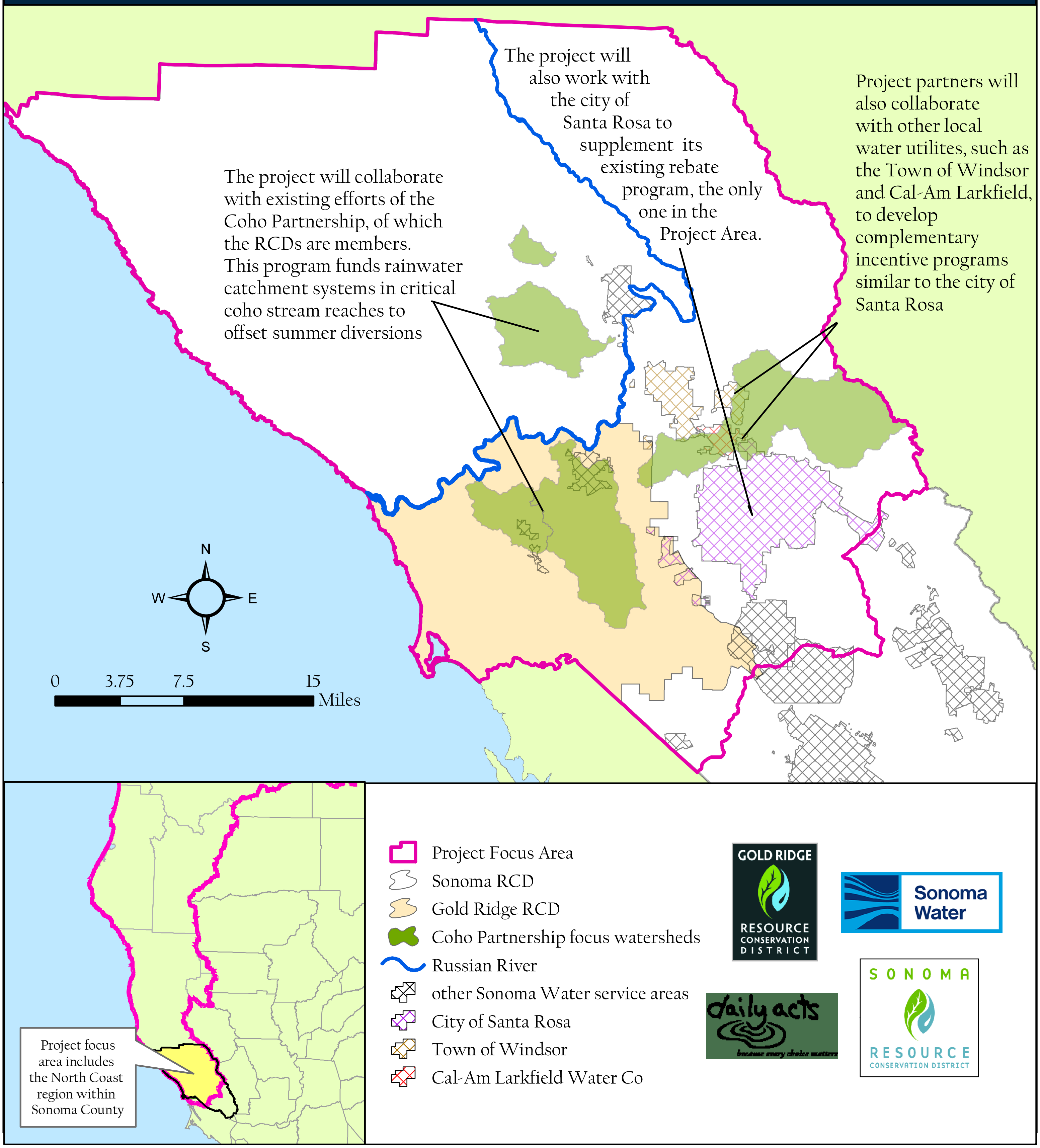
Project Name: Rainwater Catchment Rebate and Streamflow Enhancement Pilot Project

Organization Name: Gold Ridge Resource Conservation District

Sonoma RCD				$23,030	$63,030.00		SRCD NFWF Task 4 match
Daily Acts				$28,510	$25,090.00		Daily Acts - Town of Windsor
Sonoma Water	D.1 Sonoma Water will administer program rebates, while providing in-kind cost share for rebate adminstration. Cost share also includes $23,309 from the matching SMSWP rebate program, administered through the City of Santa Rosa.			$168,375	$45,226.00		
D.2 QWEL workshops (4)							
GRRCD Lead Scientist	D.2. Sonoma Water will host a series of 4 workshops for at least 40 licensed landscapers to receive QWEL certification in rainwater catchment design and construction; GRRCD and Sonoma RCD staff will provide instruction with Daily Acts staff participation.	80	$111.00	$8,880			
GRRCD mileage		80	$0.58	$46			
Subcontractors							
Sonoma RCD				$10,520			
Sonoma Water					$5,000.00		
Daily Acts				$886			
D.3 Small-scale rainwater workshops (4)							
GRRCD Lead Scientist	D. 3 Daily Acts staff, with assistance from SRCD and GRRCD staff, will conduct 4 workshops for at least 80 people providing instruction on the design and installation of small-scale (<2,500-gallon) systems that landowners can install themselves	30	$111.00	$3,330			
GRRCD mileage		80	$0.58	$46			
Subcontractors							
Sonoma RCD				$4,070			
Daily Acts				$23,416	$4,525.00		Daily Acts - city of Sebastopol
Task D Implementation Total				**$293,658**	$284,698	**$578,357**	
GRAND TOTAL				**$584,245.30**	$584,245.30	$1,168,490.60	

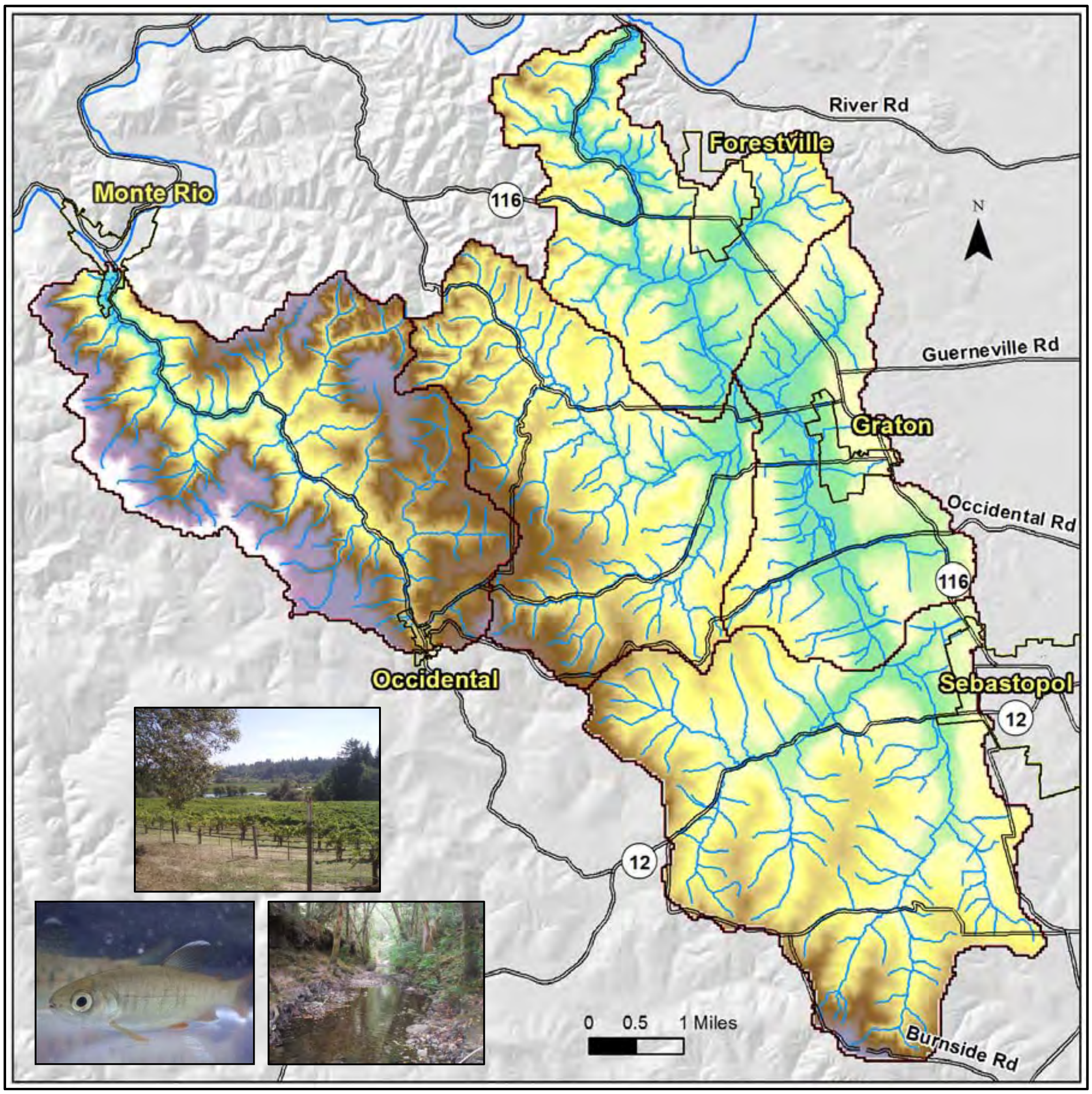
North Coast Integrated Regional Watershed Management Program
Proposition 1 Round 1 Implementation

Rainwater Catchment Rebate and Streamflow Enhancement Pilot Project
Gold Ridge Resource Conservation District



Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning:

Green Valley\Atascadero and Dutch Bill Creek Watersheds, Sonoma County, California



Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning:

Green Valley\Atascadero and Dutch Bill Creek Watersheds

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Matthew O'Connor, PhD, CEG #2449
President

March 15, 2016

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Document Organization

This document is organized in four parts as follows:

1. The Executive Summary provides an overview of the project with a moderate level of technical detail.
2. Chapters 1 through 10 comprise the main body of the report with a high level of technical detail.
3. Appendix A contains the project summary that was distributed at two public meetings held in February and March of 2016 and is intended to provide an overview of the project for less technical readers.
4. Appendix B provides a summary of the key restoration recommendations developed from the project and is intended to serve as a reference guide for restoration practitioners working in the watershed.

Executive Summary

Introduction

The Dutch Bill and Green Valley Creek watersheds (Figure E1) have been identified by state and federal fisheries agencies as providing some of the best remaining habitat for coho salmon in the Russian River watershed. Several factors have been identified as limiting coho survival in these watersheds including lack of quality pool habitat, lack of winter refugia, and insufficient summer stream flow (CDFG, 2004; NMFS, 2012). Numerous restoration projects have been implemented in the watersheds in recent years primarily aimed at improving pool conditions and reducing fine sediment inputs, and increasing effort has recently been devoted by the Russian River Coho Water Resources Partnership to address the problem of insufficient summer stream flow. Owing to drought conditions in 2015, the California State Water Resources Control Board (SWRCB) implemented an emergency order intended to maintain or improve stream flows in these watersheds (SWRCB, 2015). The order required water conservation and water use data from rural residents using surface and/or groundwater in these watersheds, for the most part without regard to specific circumstances such as well depth, well location, diversion location and quantity of use. When this project was initiated in 2012, it was evident that better understanding of the spatial and temporal distribution of stream flow and groundwater and the various natural and man-made controls on the hydrologic systems in these watersheds was needed to better inform management of water resources for recovery of endangered coho salmon. Statewide drought and State-level water resources policy changes have magnified the need for this project.

In light of ongoing drought conditions and climate change coupled with an increasing demand for water, developing strategies to sustain or improve summer stream flow conditions is of paramount importance for coho restoration. The goal of this project was to perform a comprehensive analysis of the spatial and temporal distribution of stream flow throughout the watersheds relative to coho habitat requirements to assist in prioritizing restoration efforts and developing strategies to maintain or improve summer stream flow. Although this project has limited immediate objectives, much additional information regarding hydrologic processes and conditions in these watersheds has been developed and is applicable to a wide range of water resources management objectives.

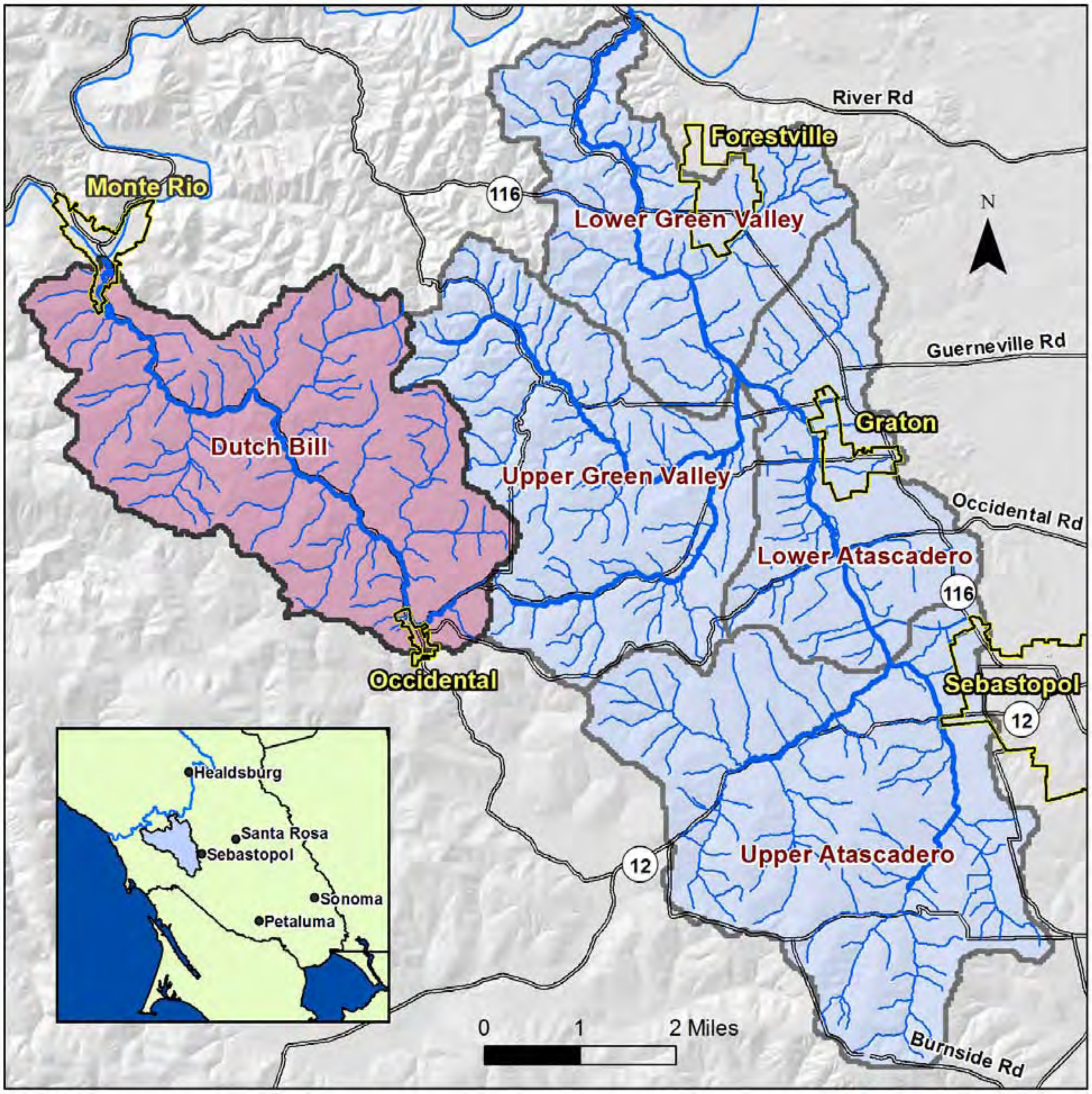


Figure E1 - Map of the study area showing locations of towns, streams, and sub-watersheds.

Hydrologic Modeling

The focus of this project was the development, calibration, and application of a distributed hydrologic model (MIKE SHE, Graham and Butts, 2005; DHI, 2015) capable of simulating surface water/groundwater interactions and quantifying the distribution of summer baseflows. The model utilized available data characterizing the climate, topography, land cover, soils, water use, and hydrogeology of the watershed and provided estimates of the annual and seasonal water balance, stream flow hydrographs, and groundwater levels throughout the watersheds. The model simulated all major land-based processes of the hydrologic cycle on a daily or subdaily time-step for Water Years 2010 through 2014 (corresponding to the period from October 1, 2009 through September 30, 2014) and was successfully calibrated to stream flow data at seven locations throughout the Green Valley and Dutch Bill Creek watersheds and to groundwater elevation data from seven monitoring wells used for by a State-sponsored groundwater management program (CASGEM, 2014). Additionally, the model results were validated against detailed stream flow depth measurements at riffle crests and maps prepared by California Department of Fish & Wildlife and University of California Cooperative Extension (UCCE) documenting the spatial distribution of stream reaches where summer stream flows were observed to be absent or intermittent in the principal fish-bearing reaches in the watersheds.

Hydrologic Characterization

The model results revealed significant spatial and temporal variability of water balance components and stream flow conditions throughout the watersheds (Figure E2). For example, groundwater recharge in the Atascadero/Green Valley Creek watershed ranged from 2.0 inches in the dry Water Year 2014 to 10.5 inches in the above average Water Year 2011 and varied spatially from near zero to more than 22 inches during Water Year 2010. Surface water/groundwater exchange, which is a major factor determining the persistence of stream flow and wetted habitat throughout the summer and fall, also exhibited significant variability with seepage loses from channels to groundwater occurring in certain (losing) stream reaches and significant gains to stream flow from groundwater discharge occurring in other (gaining) stream reaches. Some reaches, such as portions of upper Green Valley Creek, which were gaining reaches in wetter Water Years became losing reaches during drier Water Years. The patterns of summer stream flow exhibited significant variability as well. Stream flow disappeared completely in some reaches while in other reaches minimum flows exceeded one cubic foot per second (cfs). Stream flow also varied considerably in relation to annual variation in climate. Summer stream flow in much of Dutch Bill and Purrington Creeks was comparable during wet and dry years. In contrast, there were substantial differences in summer stream flow during wet and dry years in portions of upper Green Valley, Atascadero and West Fork Atascadero Creeks.

Habitat Characterization

This study focuses on evaluating habitat conditions only with respect to the quantity (depth) of summer stream flow required for rearing of juvenile coho salmon. Existing and/or future studies examining the distribution and quality of rearing habitat, water quality conditions, and other factors should be synthesized with these findings in order to develop a more comprehensive understanding of habitat conditions.

The primary means of relating the hydrologic model results to habitat suitability was to apply the critical riffle depth concept to the model simulated water depths. This approach assumes that the model cross sections represent riffle locations (shallowest portions of the stream between adjacent pools). This assumption is reasonable given the fact that the cross sections are developed using LiDAR (Light Detection and Ranging) technology which does not penetrate water and therefore does not directly identify deeper water rearing habitat (pools) and by the generally high degree of agreement between model simulated depths and riffle depth measurements collected by UCCE. The concept of “critical riffle depth” (CDFG, 2013) is based on defining minimum flow depth criteria for fish passage through riffles. In essence these criteria represent the minimum flow condition where fish are able to move between pools (the primary habitat areas for juvenile coho). A minimum passage depth of 0.3 feet has been estimated for juvenile coho (R2 Resource Consultants, 2008; CDFG, 2013). This depth criteria is somewhat conservative by design and fish passage and over-summer survival has been observed with shallower riffle depths therefore it is useful to define a lower criteria below which passage is presumably not possible. For the purposes of this study, a flow depth of 0.3 feet or more was considered an indicator of “optimal” rearing habitat.

Through field monitoring in Green Valley Creek, UCCE has found that coho can survive in pools that become disconnected for short periods of time, however survival decreases sharply as a function of the duration of pool disconnection (UCCE, 2015) largely due to the low dissolved oxygen conditions that develop in disconnected pools. Thus in addition to delineating reaches where passage between pools is possible, this study also delineated reaches that become dry (zero discharge) for short periods of time and reaches that become dry for extended periods of time. A disconnection length of 14 consecutive days was used for this analysis which corresponds to an 85% survival rate and the point beyond which survival begins to decline sharply (UCCE, 2015).

During average Water Years, pools remain connected providing perennial habitat in the lowest 3.4 river miles of upper Green Valley Creek (Figure E3). During dry Water Years only the lowest 2.1 river miles provided perennial habitat with continuous pool connectivity. The entire creek may be considered flow-impaired given that water depths drop below optimal passage depths (0.3-ft) even during average Water Years (Figure E3). The best habitat conditions in upper Green Valley Creek occur within Reach UGV3 (Figures E3 & E5). Reaches UGV1 and UGV2 (Figure E5) are characterized by marginal flow conditions where depths may fall below minimum passage depths and long-term pool disconnection may occur during dry Water Year conditions. Short-term disconnection of pools may also occur in UGV4.

The lowest 5.7 river miles of lower Green Valley Creek provide perennial habitat for juvenile coho during average Water Year conditions, however this extent was reduced to the lower 3.6 river miles during dry Water Year conditions. Reach LGV2 provides some of the best habitat conditions in the entire study area and is one of only a few reaches where minimum water depths exceeded the 0.3-ft optimal passage threshold (Figures E3 & E5). In contrast to the lower reach, the upper 2.1 miles of lower Green Valley Creek (LGV1) were characterized by long-term disconnection of pools during dry Water Year conditions.

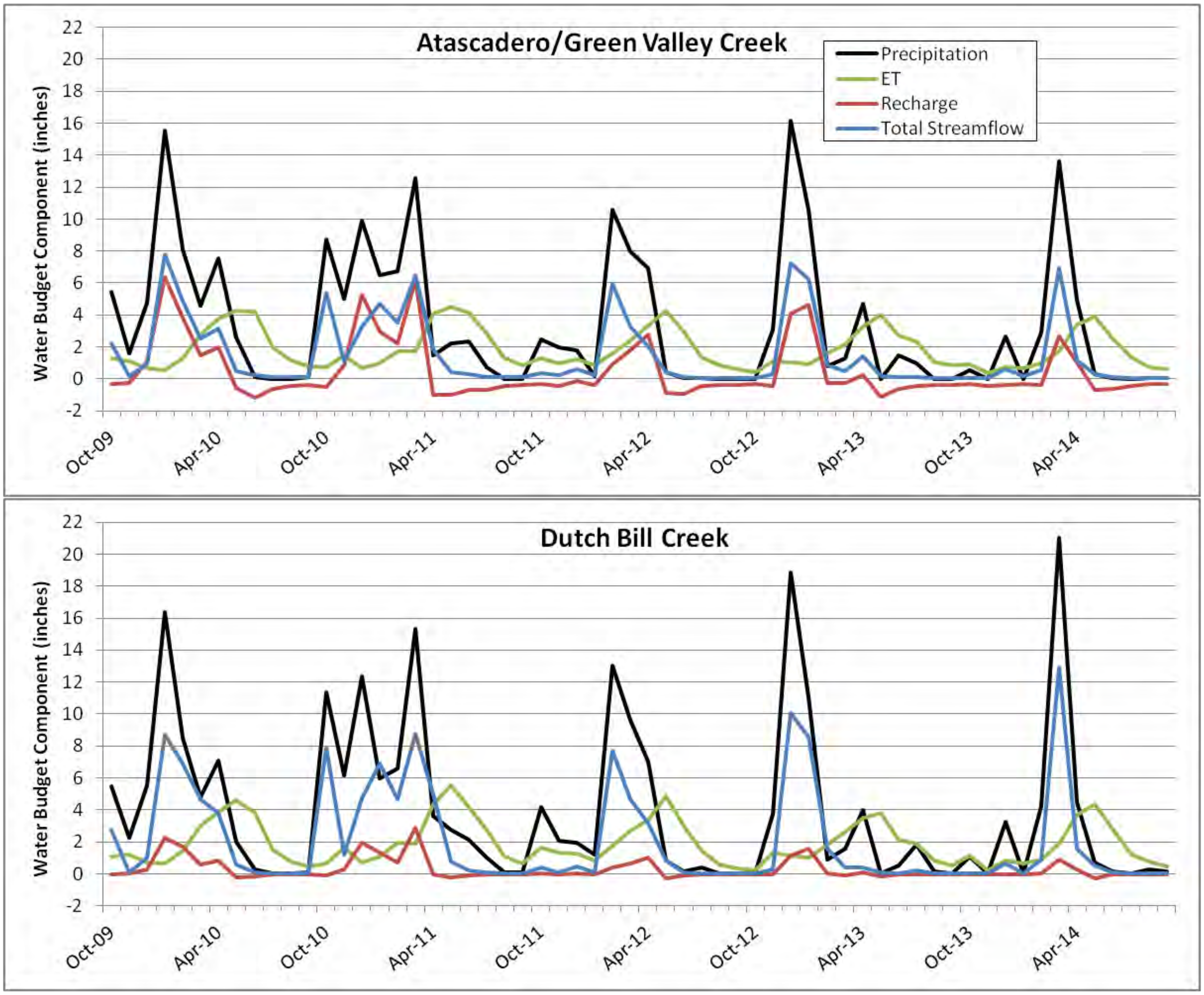


Figure E2 - Simulated monthly water budget for select water budget components for WY 2010 - 2014.

During both dry and average Water Year conditions, the lowest 2.8 river miles of Purrington Creek provide perennial habitat for juvenile coho, however the entire creek may be considered flow-impaired given that water depths drop below optimal passage depths even during average Water Year conditions. Reaches PUR2 and PUR4 provide the best habitat conditions in Purrington Creek. Pools in reach PUR1 appear to remain connected even during dry conditions, however depths likely fall below minimum passage depths (Figures E3 & E5). Reach PUR3 represents a potential passage barrier caused by low depth of flow during dry Water Year conditions when conservative assumptions regarding licensed flow diversion operations are used.

During both dry and average Water Year conditions, the 4.3 river miles of Dutch Bill Creek between the confluence with Lancel Creek and the Tyrone Road crossing provide perennial habitat for juvenile coho, however the entire creek may be considered flow-impaired given that water depths drop below optimal passage depths even during average Water Year conditions.

The lowest 2.1 miles (DB2) provide the best habitat conditions, whereas minimum passage depths were not maintained within the upper 2.2 miles (DB1) (Figures E3 & E5).

The extent to which coho salmon use Atascadero Creek is not known, however more than eight river miles within Atascadero Creek and West Fork Atascadero Creek have flow conditions that are better than or equivalent to conditions in the best reaches of upper Green Valley and Purrington Creeks. The lower 1.7 river miles of Atascadero Creek above the confluence with Green Valley Creek (LA2) are characterized by periods of zero discharge even during average Water Year conditions. In contrast, the upper 2.3 river miles below the confluence with West Fork Atascadero Creek (LA1) provides some of the best flow availability conditions in the entire study area (Figures E3 & E5).

Scenario Analysis

In addition to simulating existing watershed conditions, the model can be used to test scenarios involving various changes in land and/or water management. For this stage of the modeling work, a scenario for augmenting instream flows by releasing water from existing ponds was evaluated. Two ponds were selected for this analysis based on potential feasibility and their locations within key reaches of upper Green Valley Creek which provide some of the highest quality coho habitat in the Russian River watershed but are considered flow impaired (NMFS, 2012). Based on an analysis of the available pond storage remaining at the end of the dry season (carryover storage), it was determined that 0.1 and 0.5 cfs could be released between July 1st and September 30th from the upper and lower ponds respectively.

This flow augmentation scenario was very effective at increasing water depths and reducing the extent of reaches with disconnected pools in upper Green Valley Creek. The additional flow extended the reach where pools remained connected for an additional 1.3 river miles upstream during Water Year 2010 and for an additional 2.2 miles upstream during Water Year 2014 as compared to existing conditions (Figure E4). This represents a doubling of the length of stream with continuously connected pools during dry Water Year conditions. Although the quantity of additional flow diminished with distance downstream from the source, the effects of the flow releases persisted into the upper portions of lower Green Valley Creek. This was more significant during Water Year 2014 where the additional flow reduced the extent of the reaches experiencing short- and long-term disconnection in lower Green Valley Creek.

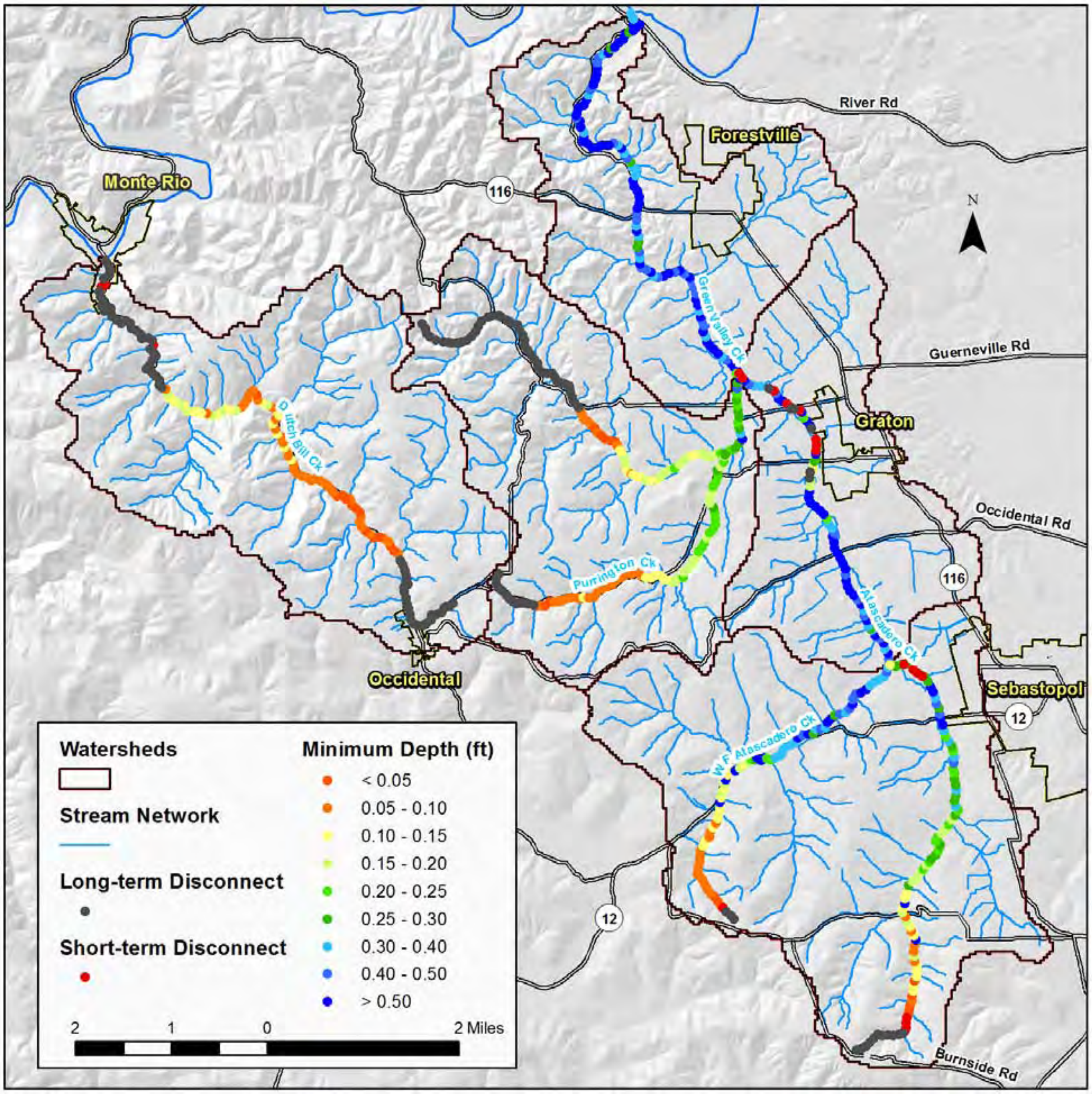


Figure E3 - Simulated water depths and extent of disconnected reaches for WY 2010.

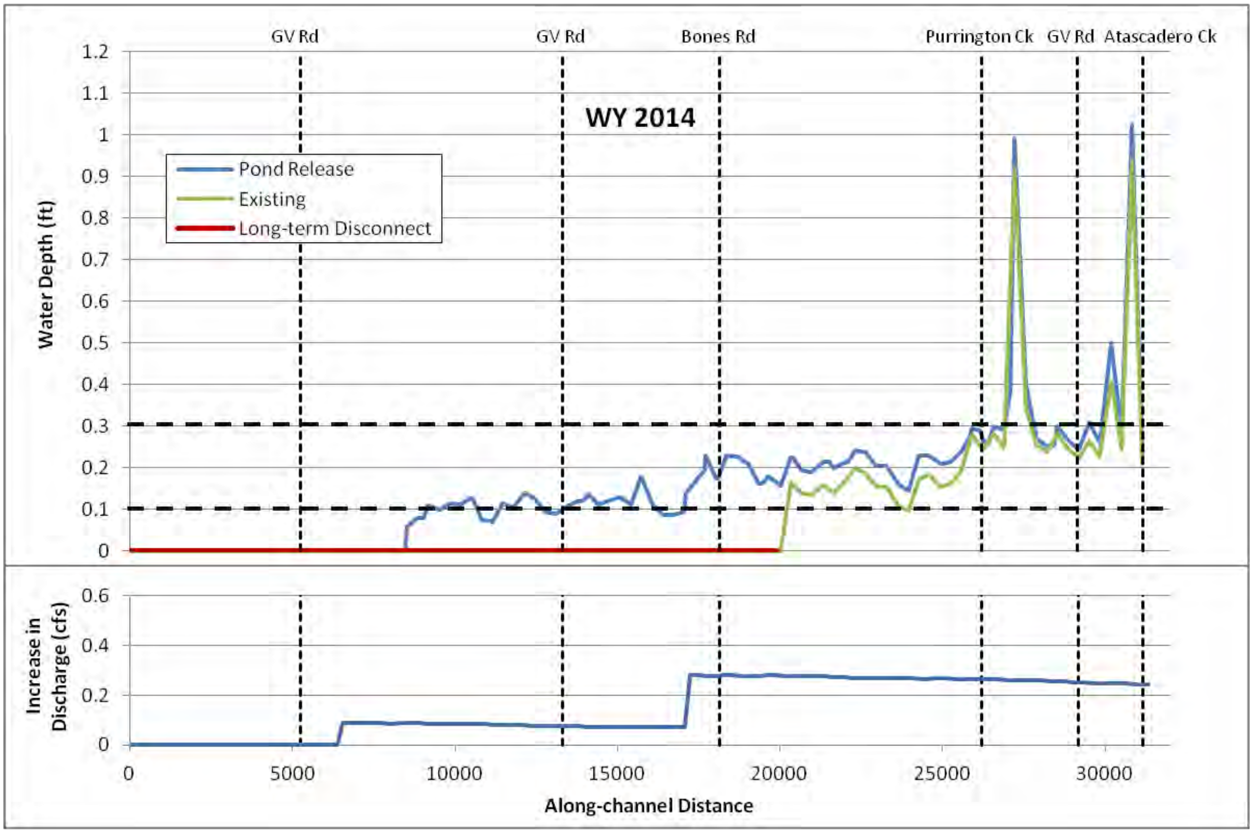


Figure E4 - Comparison of longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek between existing conditions and the pond release scenario for WY 2014. The increase in total discharge under the pond release scenario is shown in the lower plot.

Restoration Recommendations

Under existing flow conditions, the reaches identified as providing the best stream flow conditions in terms of flow depth and duration even during drought conditions are probably the most important reaches on which to focus habitat enhancement work. It is recommended that restoration projects designed to improve pool habitat be focused in reaches UGV3, LGV2, PUR2, PUR4, and DB2 where pools may be expected to function in concert with sufficient flow availability (Figure E5). If flow augmentation projects similar to those simulated in this study can be implemented, the extents of reaches where restoration projects are recommended would increase based on the modified flow regime.

Efforts to improve stream flow either through releases of stored water or water use modifications (conservation through reduced rates of use or through managed timing of use) would be best focused in the reaches that are currently providing significant habitat value at a marginal level in terms of flow depth and/or duration, particularly during dry Water Year conditions. Small changes in flows within these marginal reaches may be expected to yield significant increases in habitat quality. It is recommended that flow augmentation projects be focused in reaches UGV1, UGV2, PUR1, and DB1 (Figure E5). Reaches UGV4 and PUR 4 are also

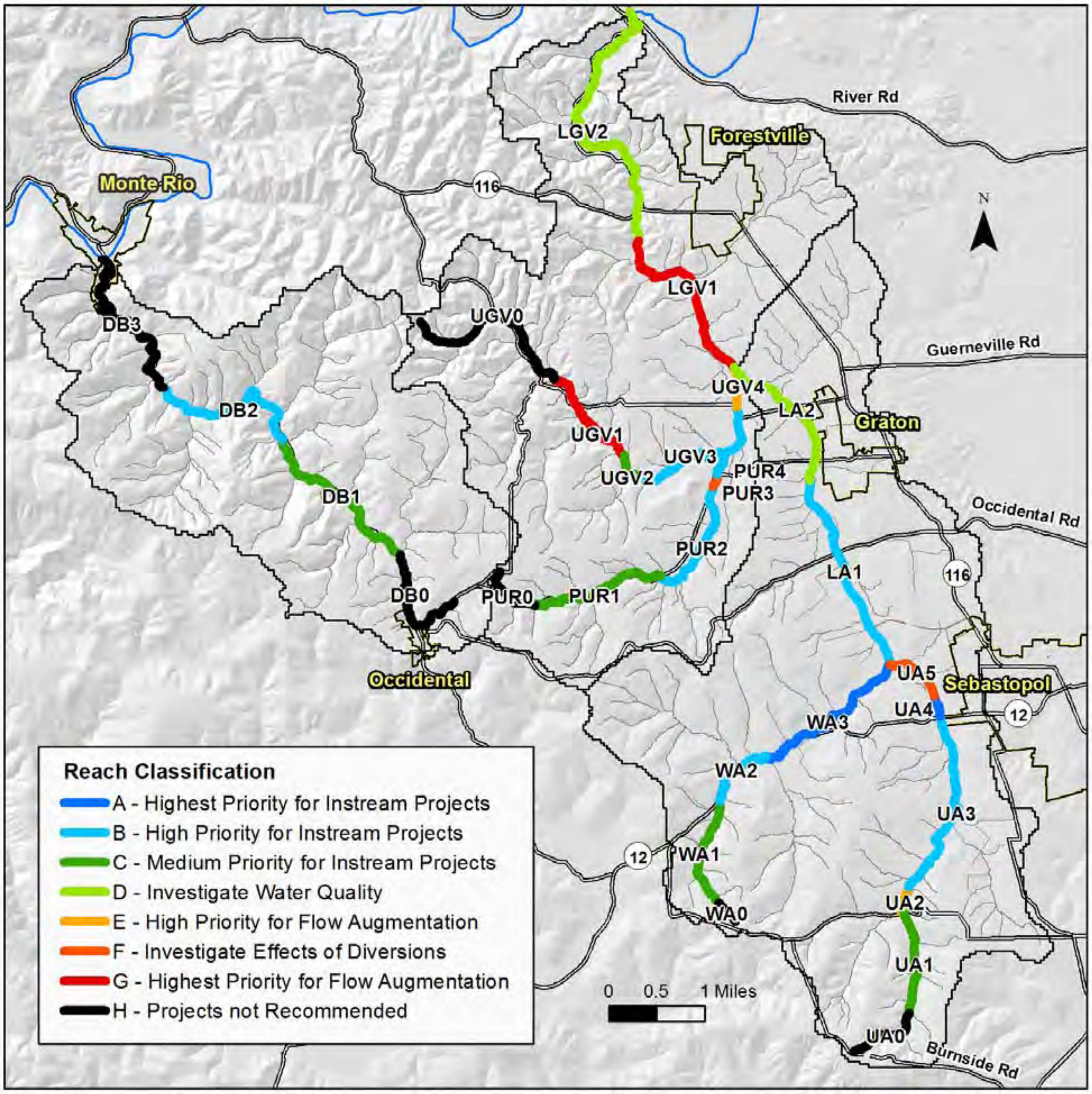


Figure E5 - Flow availability-based reach classification and restoration prioritization map. In general, reaches shown as blue have the best existing habitat conditions and should be the focus of instream restoration projects aimed at improving pool conditions, and reaches shows as red, orange, or green are more flow-limited and flow augmentation projects such as intentional flow releases or water use modifications are recommended.

characterized by marginal flow conditions, and flow augmentation efforts in the other reaches may be expected to benefit these downstream reaches as well. PUR4 is located in close proximity to several licensed surface water diversions and it is recommended that diversion operations be reviewed and modified if necessary to avoid impacts to flow availability.

Coho use of Atascadero Creek remains poorly understood, and given that Atascadero and West Fork Atascadero creeks contain more than eight river miles with stream flow conditions better than or equivalent to conditions in the best reaches of Purrington and upper Green Valley creeks, further study of Atascadero Creek is highly recommended. Such a study should investigate the degree to which coho utilize Atascadero Creek under existing conditions and the factors that are limiting that use. The degree to which the stagnant water and associated unfavorable temperature and/or dissolved oxygen conditions in the lower 1.7 miles of Atascadero Creek (LA2) could be limiting coho use of the upper watershed should be a key component of this study.

More detailed descriptions of the various reaches and associated restoration recommendations are provided in Appendix B.

Data Gaps and Next Steps

The model presented here provides a powerful tool for understanding hydrologic conditions and prioritizing restoration planning efforts throughout the Green Valley, Atascadero, and Dutch Bill Creek watersheds. The model is flexible and can similarly inform land use management planning with respect to effects on water resources. As in any modeling analysis, there is uncertainty in model results and accuracy of model predictions. In order to better understand uncertainty it is instructive to evaluate the completeness and quality of the input data used to develop the model as well as the degree and quality of the model calibration. Recommended improvements to models are often based on providing improved input data and/or additional calibration that result in improved model accuracy or reduced uncertainty with respect to model predictions used to address key management questions. Ideally the modeling work is not a static product but instead becomes a working management tool where the model is incrementally improved with new data and utilized to address new questions or to meet new objectives.

One of the original objectives of the modeling effort was to gain a better understanding of how surface water and groundwater use in the watershed affect stream flow conditions and to develop strategies for improving stream flows by modifying water use patterns. Although a significant amount of information describing the distribution and volume of water use was available, certain data were unavailable. Consequently, simplifying assumptions were required to simulate the timing and volume of water use. In order to utilize the model to evaluate water use impacts on stream flow and have confidence in the results, some refinements to the model are required. Specifically, data describing the locations, rates, and timing of diversions of water from streams are needed as are specific well locations and well completion details for water wells, particularly those located near stream channels. These data correspond to data submittals required of land owners in much of Dutch Bill and upper Green Valley Creek by the State Water Board in its emergency order issued in summer 2015 (SWRCB, 2015).

Additional refinement of the representation of groundwater conditions in the Franciscan Complex bedrock might be warranted, particularly with respect to the influence of groundwater on stream flow in Dutch Bill Creek. The model has been developed based on available data and calibrated at the scale made possible by stream gauges and monitoring wells. It should still be expected that deviations would exist between local conditions in specific wells or specific stream reaches and model predictions. Hydrologic investigations and analyses conducted at finer spatial scales using local data with greater hydrogeologic detail of aquifer characteristics could produce valid conclusions that are inconsistent with model simulations.

Despite these limitations the model can be used in its current form to inform planning and policy-making processes in relation to a variety of water and land use management issues. The flow augmentation scenario discussed in this report is one such example. The model was able to quantitatively predict the effect on stream flow and coho rearing habitat of water released from ponds in upper Green Valley Creek. If new potential flow augmentation projects are identified, the model can be used to assess their potential impact on coho rearing habitat and optimize their effectiveness. The model is also particularly well-suited for simulating the effects of ongoing climate change given the availability of regional down-scaled climate model data (Flint and Flint, 2012). The model is also capable of examining the effects of land use change (e.g. ongoing conversion of orchards or forest to vineyards), future population increases, and water conservation effects on stream flow. Model scenarios could be used to inform practices and policies regarding the sustainability of both surface water and groundwater resources for human use and ecosystems. Although the focus of this study was on low flow conditions for juvenile coho rearing habitat, the model simulates continuous hydrographs and can be used to examine flow conditions important for other coho life stages and/or other species of interest.

Chapter 1 - Introduction

The project described in this report was completed by O'Connor Environmental Inc. (OEI) in cooperation with the Gold Ridge Resource Conservation District (GRRCD) and was funded by a Fisheries Restoration Grant from the California Department of Fish and Wildlife (CDFW Contract #P1130405).

The Dutch Bill and Green Valley Creek watersheds have been identified by state and federal fisheries agencies as providing some of the best remaining habitat for coho salmon in the Russian River Watershed. Several factors have been identified as limiting coho survival in these watersheds including lack of quality pool habitat, lack of winter refugia, and insufficient summer baseflows (CDFG, 2004; NMFS, 2012). Numerous restoration projects have been implemented in the watersheds in recent years primarily aimed at improving pool and off-channel habitat conditions, however relatively little effort has been spent to address the problem of insufficient stream flow. This is in part due to a lack of data and understanding regarding the distribution of flow conditions and the various natural and man-made controls on these flows.

In light of ongoing drought conditions and climate change coupled with an increasing demand for water, developing strategies for sustaining or improving summer stream flow conditions is of paramount importance for coho restoration. The goal of this project was to perform a comprehensive analysis of the spatial and temporal distribution of flow availability conditions throughout the watersheds relative to coho habitat requirements to assist in prioritizing restoration efforts and developing strategies for protecting summer baseflows.

Specifically, this project involved the development, calibration, and application of a distributed hydrologic model which utilized a wide variety of climate, topographic, land cover, soils, water use, and hydrogeologic data for the watershed and provided estimates of the annual and seasonal water balance, stream flow hydrographs, and groundwater levels throughout the watersheds. The modeling results provided the basis for performing a flow availability analysis, characterizing the distribution and quality of available habitat for juvenile coho, and making recommendations about restoration priorities for various sub-reaches within the study area. Additionally, the model has been applied to evaluate the potential improvements to flow availability and habitat conditions resulting from implementing flow augmentation projects, and the model provides the framework for evaluating the effects of land and water management decisions and global climate change on watershed hydrology and flow availability for salmonids during future work.

Chapter 2 - Study Area Description

Physiography

The Green Valley/Atascadero Creek (GVAC) and Dutch Bill Creek (DBC) watersheds are part of the Northern Coast Range geomorphic province. Atascadero Creek is bounded by relatively steep topography separating the watershed from the Salmon Creek and Dutch Bill Creek watersheds to the south and west and by a gentle ridge associated with the Sebastopol Fault which separates the watershed from the Santa Rosa Plain to the east (Figure 1).

The headwaters of Atascadero Creek are located southwest of Sebastopol at elevations of about 800 feet. The upper 3.6 miles of the creek are characterized by relatively steep gradients and limited floodplain development. From this point at an elevation of about 155-ft, the creek flows through a southeast-northwest trending valley on the order of 2,000 to 4,000-ft wide for another 6.0 mi before joining Green Valley Creek west of Graton at an elevation of about 95 ft. The watershed area above the confluence with Green Valley Creek is approximately 21 square miles.

The headwaters of Green Valley Creek are located northeast of Camp Meeker at elevations of about 800 ft. The Creek flows through a northwest-southeast trending valley on the order of 1,000-ft wide for approximately 6.0 miles before joining Atascadero Creek. Below the confluence, the valley narrows to widths of 500- to 1000-ft and flows northwest for another 5.7 miles where it enters the Russian River west of Forestville at an elevation of about 30 ft. The watershed area of Green Valley Creek excluding Atascadero Creek is approximately 18 square miles (Figure 1).

Dutch Bill Creek is bounded to the south and west by a southeast-northwest trending ridge with elevations ranging from 1,000 - 1,450 ft separating the watershed from the Willow Creek and Salmon Creek watersheds. The watershed is bounded by Green Valley Creek to the east and by Smith Creek to the north. The headwaters of the creek are located east of Occidental at elevations of about 800 ft. The creek flows southwest for approximately 0.6 miles where it bends and flows through a narrow southeast-northwest trending valley on the order of 500-ft wide for about 7.7 miles where it enters the Russian River in Monte Rio at an elevation of about 20 ft. The watershed area of Dutch Bill Creek is approximately 12 square miles (Figure 1).

Climate

The GVAC and DBC watersheds experience a Mediterranean climate characterized by cool wet winters and warm dry summers. Precipitation varies substantially across the study area from an average of about 60 inches per year on the western edge of the DBC watershed to about 41 inches per year on the Atascadero Creek valley floor on the eastern side of the GVAC watershed (PRISM, 2010). In general, mean temperatures do not vary significantly across the watershed, however winter temperatures tend to be slightly warmer with less frost on the western side of the study area where the coastal influence is stronger and summer temperatures tend to be warmer on the eastern side of the study area which also experiences less fog.

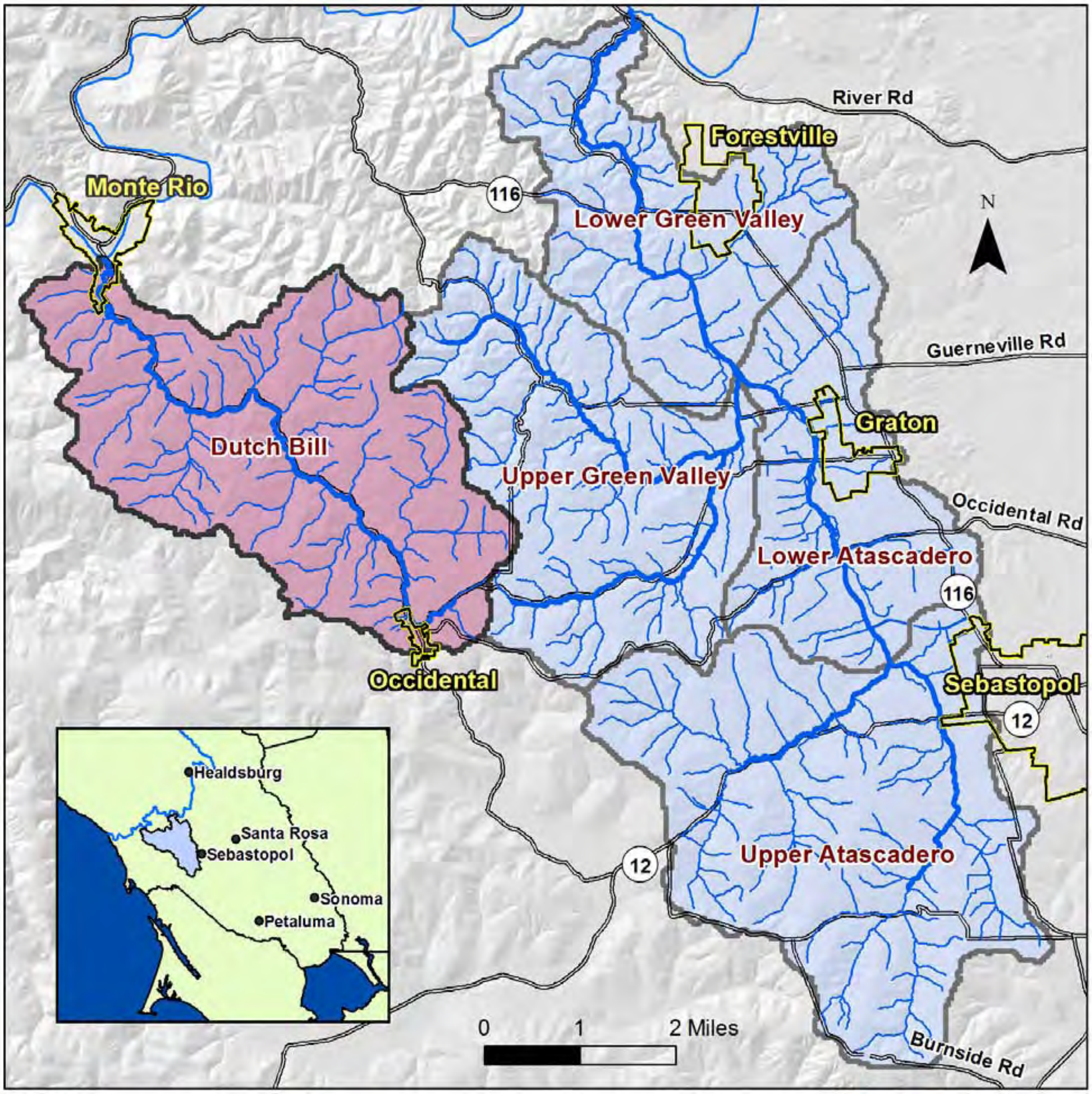


Figure 1 - Map of the study area showing locations of streams, towns, and sub-watersheds.

Land Use

Significant changes in land use have occurred in the study area over the past century. Prior to European and American settlement in the late 18th and early 19th centuries much of the area was forested with meadows and natural grasslands occupying valley bottom areas. Extensive timber harvesting occurred during the 1920s and 1950s followed by heavy grazing (CDFG, 2006). Many of the natural grasslands were converted to orchards in the early 20th century (PWA, 2008). Residential development increased substantially beginning in the early 1970s (SCCES, 1978), and orchards have been increasingly converted to vineyards since the early 1980s. From the 1930s through the 1990s, riparian cover and large woody debris were periodically mechanically cleared from stream channels in order to maintain channel conveyance and reduce flooding of agricultural lands (GRRCD, 2012). These practices have ceased over the past two decades as regulatory constraints and ecological awareness have increased and there has been a marked increase in the extent of riparian cover particularly in main-stem Atascadero Creek.

Existing land cover in the Dutch Bill Creek watershed is primarily forest (73%), with the remainder divided between grassland (12%), shrubland (6%), mixed (4%), vineyards (3%), and riparian vegetation (2%). The Mixed category consists primarily of rural residential areas that are non-forested, not used for agriculture, and are not primarily hardscape. In the Green Valley Creek watershed, the primary land cover is also forest (48%) with 27% mixed, 12% vineyards, and less than 3% each of the following land cover types: orchard, riparian vegetation, grassland, hardscape, and shrubland. Existing land cover is more evenly distributed in the Atascadero Creek watershed with 46% mixed, 22% forest, 10% vineyard, 10% orchard, 7% grassland, 3% riparian vegetation, and 2% hardscape.

Geology

The majority of the Atascadero Creek watershed is underlain by the late Pliocene to late Miocene Wilson Grove Formation (WGF). The WGF is a fine- to medium-grained sandstone and serves as the primary aquifer in the study area. The WGF also outcrops in portions of the Green Valley Creek watershed including much of the Purrington Creek watershed and the lower portions of upper Green Valley Creek above the confluence with Atascadero Creek. The remainder of the Green Valley Creek watershed is underlain by various rocks of the Franciscan Complex and to a lesser degree by various rocks of the Great Valley Sequence. The WGF only outcrops in a small area near the headwaters of Dutch Bill Creek and the majority of the DBC watershed is underlain by various rocks of the Franciscan Complex and the Great Valley Sequence. Relatively shallow Quaternary alluvium occupies the valley floor along most of the length of Atascadero and Green Valley creeks and the lowest reach of DBC.

Chapter 2 - Conceptual Model

Prior to developing a numerical hydrologic model it is useful to develop a conceptual model of the hydrologic system to aid in understanding the movement of water throughout the study area and provide a framework for developing the numerical model. A conceptual model was developed using measured and estimated physical and hydrologic characteristics of the hydrologic system to describe how these characteristics influence the flow and storage of water. Following Markstrom et al., (2008) and Nishikawa et al. (2013) the watershed was divided into four hydrologic zones (Figure 2):

Zone A - the Land Surface Zone which includes the plant canopy and the land surface;
Zone B - the Surface Water Zone which includes the surface water features of the watershed;
Zone C - the Unsaturated Zone which includes the soil zone; and
Zone D - the Saturated Zone which includes the groundwater system

Water is held in storage within each of the three regions and water flows into, out of, and within each region by a variety of flow processes. The primary goal of the conceptual model was to identity and characterize the inflow, outflow, and storage characteristics of each region as described in greater detail below. This conceptual model was then used as a guide for developing the numerical model as described in Chapter 4.

Zone A - Land Surface Zone

Zone A Inflows

Precipitation falling primarily as rainfall is the dominant source of inflow to Zone A. Mean annual precipitation for 1981 - 2010 was about 55.5 inches for the DBC watershed, 47.7 inches for the GVC watershed, and 45.0 inches for the AC watershed. Over the entire study area this precipitation represents about 129,314 acre-feet per year (acre-ft/yr).

Applied water for irrigation and frost protection represents another important source of water for Zone A. The vast majority of the applied water in the watersheds is for the ~2,947 acres of vineyards under cultivation. Additional irrigation water is applied for orchards, pasture, and other crop types. Review of the California State Water Resources Control Board's Electronic Water Rights Information Management System (eWRIMS) suggests that approximately 549 acres of vineyards are irrigated at least partially with surface water with the irrigation for the remaining 2,398 acres presumably sourced from groundwater. Based on a review of the eWRIMS, vineyard irrigation rates in the study area average about 3.6 inches per unit land surface area. This represents a total annual irrigation volume of approximately 884 acre-ft/yr.

Review of the Sonoma County Frost Protection Database reveals that approximately 1,157 acres of vineyards (39% of total vineyard acreage) use water for frost protection in the study area (SCDA, 2014). Of these, approximately 796 acres or 69% utilize groundwater for frost protection with the remainder relying on surface water. Frost protection demand was

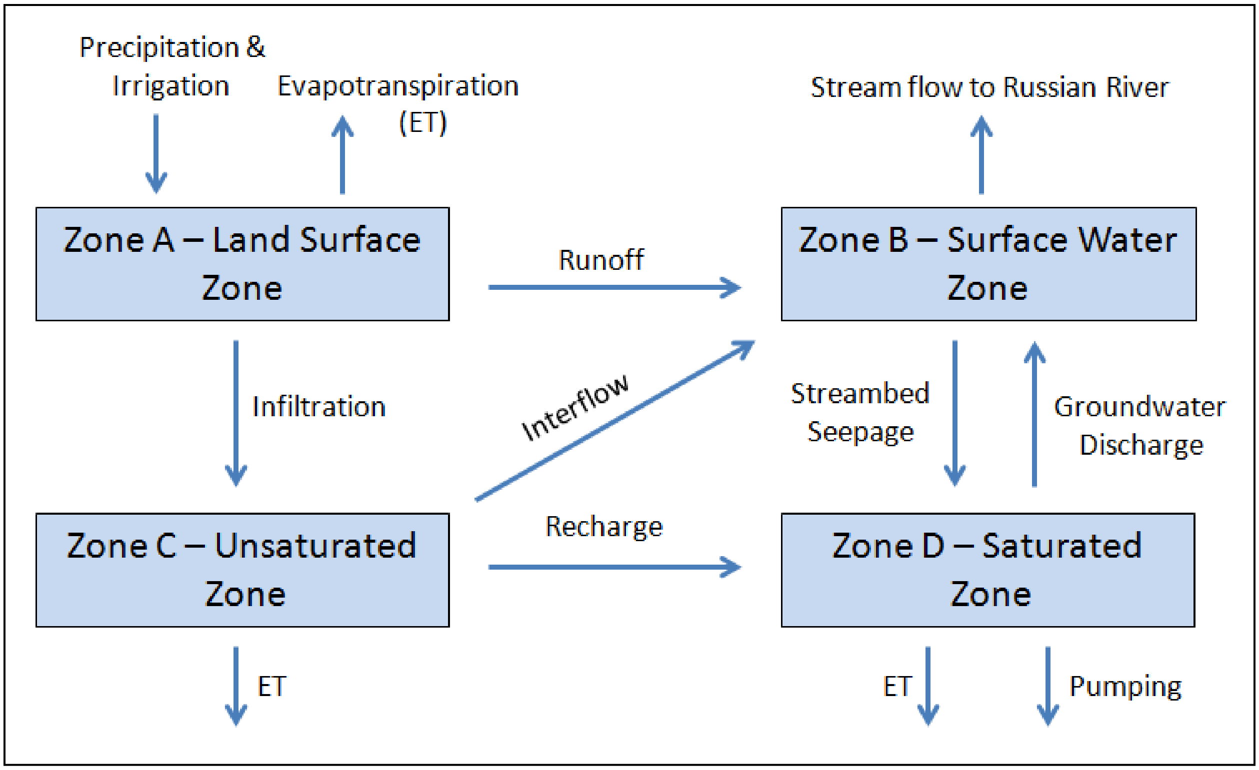


Figure 2 - Schematic diagram of the general features of the conceptual model of the GVAC and DBC watersheds (modified from Markstrom et al., 2008; Nishikawa et al., 2013).

estimated for 2008 through 2014 based on an analysis of hourly temperature records during the frost protection season (CIMIS, 2005), a compilation of acreages with regular versus micro sprinklers from the Frost Protection Database, and stated average sprinkler flow rates. This analysis suggests that total water use for annual frost protection varied from 81 acre-ft/yr in 2014 to 716 acre-ft/yr in 2008; 2008 was the most recent year when significant frost protection demands occurred.

Applied water in the study area displays a high degree of temporal variability with irrigation occurring primarily July through October and frost protection occurring primarily March 15 through May 15. At other times of the year applied water for commercial agricultural operations is minimal to non-existent.

Natural groundwater discharge generally flows directly to a surface water feature (Zone B), however, during especially wet conditions groundwater may discharge to the soil zone or directly to the land surface. Such groundwater discharge may serve to replenish soil moisture and water availability for Evapotranspiration (ET). At certain times groundwater discharge may be a significant inflow component to Zone A, particularly in low-lying areas with a shallow water table such as the marshy low-lying areas along the main-stem of Atascadero Creek.

Zone A Outflows

Actual evapotranspiration and runoff are the primary outflows from Zone A. Actual evapotranspiration (AET) is a function of potential evapotranspiration (PET), water availability, and vegetation characteristics. Hourly PET data are available at the California Irrigation Management Information System (CIMIS) station for Santa Rosa located just east of Sebastopol (CIMIS, 2005). The Turc Method (Turc, 1961) was used in conjunction with solar radiation data, mean monthly temperature data (PRISM, 2010), and DEM-derived landscape attributes (slope and aspect) to compute a spatially-distributed map of mean monthly PET for the study area. The resulting maps were calibrated to match the observed mean monthly PET for the CIMIS station. This analysis revealed that mean annual PET varies from 25 in/yr on north facing slopes in the higher elevations of the DBC watershed to 49 in/yr on south facing slopes in the lower portions of the GVC and AC watersheds. Averaged across each watershed, mean annual PET was 42.0 in/yr in the DBC watershed, 43.3 in/yr in the GVC watershed, and 44.1 in/yr in the AC watershed.

In the adjacent Santa Rosa Plain (SRP), AET was recently estimated to be ~40% of PET (Woolfenden and Hevesi, 2014). Assuming a similar ratio holds for the DBC and GVAC watersheds suggests that AET is on the order of 17.2 inches per year or 45,877 ac-ft/yr over the entire study area. This figure is likely too low because due to the higher rainfall in the study area relative to the SRP, there would presumably be more soil water available to plants. Woolfenden and Hevesi also found that mean annual ET was ~49% of the mean annual precipitation in the SRP. Using this ratio suggests that ET is on the order of 23.9 in/yr or 63,805 ac-ft/yr over the entire study area.

Runoff varies as a function of the precipitation, topography, and land cover and soil characteristics. Runoff potential is classified as high for most of the DBC watershed and the western portions of the GVAC watershed and medium for most of the eastern portions of the GVAC watershed (USDA, 2007). Runoff was estimated to be ~43% of the mean annual precipitation in the SRP (Woolfenden and Hevesi, 2014). Assuming a similar ratio for the study area suggests that runoff is on the order of 21.0 in/yr or 56,012 ac-ft/yr across the entire study area.

Zone A Storage

Water can be stored temporarily in various storage elements in Zone A. These include water stored in the vegetation canopy through interception storage, water stored on the land surface through depression storage, and water stored in the soil zone. Interception storage may be relatively significant in areas of dense vegetation such as the forested areas of the study area which are primarily located in DBC watershed and the western portions of the GVAC watershed, and is important primarily during small rainfall events with limited effect during large, long-duration rain storms. Depression storage may be significant in some areas, particularly the low-lying marshy areas along the main-stem of Atascadero Creek. Soil moisture storage is expected to vary widely across the study area as a function of soil type with thicker soils and soils with higher clay contents retaining more water than thinner soils with lower clay contents. Zone A storage is expected to exhibit a strong seasonality with storages replenished during the rainy season and depleted during the dry season.

Zone B - Surface Water Zone

Zone B Inflows

Runoff and groundwater discharge (the source of baseflow in surface streams) are the primary inflows to Zone B. Wastewater treatment plant discharges are an additional inflow component but are expected to be minimal relative to runoff and baseflow. Runoff is described above in greater detail under Zone A outflows. The Green Valley Creek above Atascadero Creek gauge (GV03 in Figure 27) has a complete and reliable flow record for July through September for Water Years 2011 through 2014 Average stream flow during these months (i.e. baseflow) can be used as a proxy for estimating the groundwater discharge to Zone B. Scaling up the average summer discharges at the Green Valley gauge to the full GVAC watershed area yields baseflow estimates ranging from 301 to 1,806 ac-ft/yr depending on rainfall conditions. Given that the gauge location represents only a small portion of the total drainage area, this estimate contains significant uncertainty. Scaling the average summer discharges at the Dutch Bill Creek above Tyrone Road gauge (DB04 in Figure 27) for Water Years 2012 through 2014 yields baseflow estimates ranging from 92 to 588 ac-ft/yr for the DBC watershed.

Zone B Outflows

The primary outflow from Zone B is stream discharge flowing from the outlets of Dutch Bill Creek and Green Valley Creek to the Russian River. Additional outflows occur from seepage losses into the subsurface (Zone C), ET, and diversions for irrigation. No long-term stream gauging stations are available in the study area, however a number of short-term stations are available. Among these, Purrington Creek at Graton Road, Green Valley Creek at Bones Road, and Dutch Bill Creek above Tyrone Road are the most useful in that they have the longest periods of record and the best-developed rating equations (GV02, GV01, and DB04 in Figure 27).

Complete flow data at both the Green Valley Creek and Purrington Creek gauges is only available for Water Year 2011. The average 2011 flow rates at these gauges were 10.4 and 8.3 cfs respectively. Although these gauges only capture a small portion of the total GVAC watershed area, scaling the flow rates up to the full watershed area provides a crude approximation of the total surface water outflow from Zone B. This exercise yields an outflow estimate of between 62,595 and 64,985 ac-ft/yr for the GVAC watershed. Water Year 2011 was an average to above average rainfall year with 50.3 inches recorded at Graton compared to the long-term annual average of 40.9 inches.

Complete flow data at the Dutch Bill Creek gauge is available for Water Years 2012 and 2013 and the 2-yr average flow rate was 12.2 cfs. The gauge captures about 80.4% of the total watershed area; scaling the average flow rate up to the full Dutch Bill Creek watershed area suggests that the total Dutch Bill Creek surface water outflow from Zone B is on the order of 11,064 ac-ft/yr. This estimate is likely lower than the long-term average given that the 2012-

2013 average annual rainfall was only 42.3 inches at Occidental compared to the long-term annual average of 53.9 inches.

Examination of the California State Water Resources Control Board's Electronic Water Rights Information Management System (eWRIMS) revealed that during Water Years 2009 through 2013 an average of 85 ac-ft/yr was diverted from ten locations in the AC watershed, 130 ac-ft/yr was diverted from twelve locations in the GVC watershed, and 115 ac-ft/yr was diverted from seven locations in the DBC watershed. Most of the diversions are associated with either on-stream or off-stream ponds. An inventory using LiDAR-derived elevation data and aerial photography revealed the presence of more than 130 ponds in the study area. Twenty-three on-stream ponds were identified and the remaining majority of the ponds fill primarily from local surface runoff or groundwater inflow. Direct diversions were a relatively small component of the total surface water use, accounting for 16, 21, and 40 ac-ft-yr in the AC, GVC, and DBC watersheds respectively. Diversions associated with Riparian Water Rights are largely unreported in the eWRIMS and have not been quantified, but may be significant.

Zone C - Unsaturated Zone

Zone C Inflows

The primary inflows to Zone C are infiltration from Zone A, seepage through the streambeds and ponds of Zone B, and septic tank effluent. Infiltration to the soil zone varies across the study area primarily as a function of precipitation and soil hydraulic conductivity. Although precipitation increases substantially from east to west across the study area, the wide variations in soil conductivities across the study area is expected to be the primary driver of variations in infiltration. Soil conductivities are highest in areas underlain by the Wilson Grove Formation and areas underlain by coarse alluvium such as the alluvium along the lower reaches of Dutch Bill Creek and the upper reaches of Atascadero Creek. Soil conductivities are lowest in the north-central portion of the DBC watershed and in the areas of fine-grained alluvium along Green Valley, Purrington, and lower Atascadero Creeks. During the dry summer months, water tables may drop below streambed elevations in some areas resulting in seepage from streambeds and ponds. Domestic water use is significant in the study area and thus septic effluent is a potentially significant inflow to Zone C, however it is expected to be much less than the infiltration as discussed in greater detail under Zone D Inflows.

Zone C Outflows

Transpiration by vegetation and recharge to the saturated zone (Zone D) are the primary outflows from Zone C. Transpiration is discussed in more detail under Zone A Outflows. Recharge varies across the study area as a function of the precipitation, soil conductivity, and vertical hydraulic conductivity in the upper portions of the saturated zone. Recharge is expected to be highest in areas underlain by the Wilson Grove Formation and coarse alluvium and lowest in areas underlain by low-permeability basement rocks (primarily Franciscan Complex) and fine-grained alluvium.

Zone D - Saturated Zone

Zone D Inflows

Inflows to Zone D include recharge from Zone C, recharge from streams, and underflow from adjacent basins. Woolfenden and Hevesi (2014) estimated the long-term average annual recharge from the unsaturated zone for areas within the adjacent Santa Rosa Plain that are underlain by the Wilson Grove Formation. Applying this estimate to the portion of the study area underlain by the Wilson Grove Formation yields an estimate of recharge from the unsaturated zone of 8,373 ac-ft/yr. This is equivalent to ~14% of the mean annual precipitation falling over this area. Boudreau (1978) estimated that recharge of the Wilson Grove Formation was on the order of 25% of annual precipitation as part of a 1978 Groundwater Study of Green Valley. Examination of groundwater elevation data from California Statewide Groundwater Elevation Monitoring (CASGEM) wells (CASGEM, 2014) for the primary aquifer in the study area (the Wilson Grove Highlands) indicates that the gradient direction is away from the study area and towards the adjacent Santa Rosa Plain to the east. Thus underflow is not expected to be a significant component of inflow.

Zone D Outflows

Outflows from Zone D include discharge to surface water features in Zone B, underflow to adjacent basins, ET, groundwater pumping, and discharge to the soil zone (Zone C). As discussed above for Zone B Outflows, groundwater discharge to streams as estimated from available stream gauging data ranges from 301 to 1,806 ac-ft/yr for the GVAC watershed and from 92 to 588 ac-ft/yr for the DBC watershed. CASGEM data from Spring 2012 indicate a groundwater gradient towards the adjacent Santa Rosa Plain of approximately 0.01 ft/ft. Based on borehole log interpretations and the CASGEM data, the average saturated thickness along this 11.3 mile-long boundary is approximately 460-ft. Assuming a hydraulic conductivity of 0.5 ft/day and applying Darcy's Law yields an estimate of the underflow of 1,152 ac-ft/yr. The Santa Rosa Plain groundwater model simulated a boundary inflow of 5,100 ac-ft/yr to the Wilson Grove subarea which loosely corresponds to the boundary with the GVAC watershed (Woolfenden & Hevesi, 2014). The Santa Rosa Plain estimate is significantly larger than the estimate presented here because of differences in the interpretation of the saturated thickness of the Wilson Grove Formation in the vicinity of the boundary.

Based on 2010 census data and a per capita use assumption, domestic pumping in the study area is on the order of 1,535 ac-ft/yr. Based on examination of the Electronic Water Rights Information Management System (eWRIMS) and the Sonoma County Frost Protection Database, irrigation pumping is on the order of 725 ac-ft/yr and frost protection pumping ranged from 110 to 1,041 ac-ft/yr between 2008 and 2014. The mean annual total groundwater pumping for all uses is approximately 2,519 ac-ft/yr which represents the largest outflow component from Zone D.

Chapter 3 - Numerical Modeling Methodology

The hydrologic model of the GVAC and DBC watersheds was constructed using the MIKE SHE model (Graham and Butts, 2005; DHI, 2014). Model development activities have been ongoing since its inception in 1977, and the model has been applied successfully in hundreds of research and consultancy projects covering a wide range of climatic and hydrologic regimes around the world (Graham and Butts, 2005).

The MIKE SHE model is a fully-distributed, physically-based hydrologic model capable of simulating all of the land-based phases of the hydrologic cycle including overland flow, channel flow, evapotranspiration, infiltration and unsaturated flow, groundwater flow, and stream/aquifer interactions. The distributed nature of the model makes it well-suited for examining the hydrologic impacts of changes in climate, land and/or water management. Complex physics-based watershed models, while potentially powerful tools, require large amounts of input data and ideally should be well-calibrated to observed stream flow and/or groundwater data for a number of years. It is important to bear in mind that a model created with MIKE SHE is a simplification of a real hydrologic system and while it can provide useful estimates of various flows and storages within the system, the estimates contain uncertainty and should not be viewed as a replacement for real data or as static since the model will need to be updated on a periodic basis as new data become available.

Overland Flow

The overland flow component of MIKE SHE solves the 2-dimensional St. Venant equations for shallow free surface flows using the diffusive wave approximation. A finite-difference scheme is used to compute the fluxes of water between grid cells on a 2-dimensional topographic surface. Net rainfall, evaporation, and infiltration are introduced as source/sink terms and the model assumes that a sheet flow approximation is valid for non-channelized surface flows and that roughness is uniform over various flow depths. The primary inputs for the overland flow module include topographic information in the form of a Digital Elevation Model (DEM) and a corresponding spatial distribution of overland roughness coefficients (Manning's n) which is generally referenced to the model's land cover categories. Sub-grid scale depressions in the topography and barriers to overland flow are represented conceptually through the use of the detention storage parameter.

Channel Flow

The channel flow component of the model calculates unsteady water levels and discharges using an implicit finite-difference formulation to solve the 1-dimensional St. Venant equations for open channel flow. The model is capable of simulating ephemeral stream flow conditions and backwater effects, and includes formulations for a variety of hydraulic structure types (e.g. bridges, weirs, culverts). Either a no-flow or a discharge boundary can be used as the upstream boundary condition, and the downstream boundary can be represented using a water level or water level/discharge relationship boundary condition. Other than boundary conditions, the primary inputs for the channel flow model include channel geometry information and a spatial distribution of Manning's roughness coefficients.

Channel Flow Interactions

Interaction between the channel flow and overland flow components of the model is driven by the gradient between the overland water depths in a given grid cell and the head in a corresponding computational node in the channels, and is computed using a broad crested weir equation. Depending on the direction of the gradient, the channel flow component of the model can either receive overland flow during runoff events or release water back onto the floodplain as overbank flow when heads in the channel exceed the adjacent floodplain levels. The model is also capable of simulating backwater effects onto the overland flow plane due to restricted channel flow.

The channel flow component of the model is also coupled to the groundwater component of the model. Stream/aquifer exchanges are driven by the head differences between channel nodes and corresponding watershed grid cells, and fluxes are computed through a bed sediment layer with an associated vertical hydraulic conductivity value. The interaction is computed continuously and fluxes are added or subtracted to the corresponding component of the model at the beginning of each time step.

Evapotranspiration and Interception

Evapotranspiration (ET) is handled in the model using a 2-layer water balance approach which divides the unsaturated zone into a root zone from which water can be transpired and a lower zone below the root zone where transpiration does not occur. The model computes the Actual ET (AET) as a function of the Potential ET (PET) by tracking the available moisture content in the vegetation canopy, on the overland flow plain, and in the unsaturated zone. The model first extracts water from interception (based on specified values of the interception storage coefficient and the Leaf Area Index or LAI). Next water is extracted from ponded water (evaporation) on the land surface, and finally water is extracted from the unsaturated zone and/or the saturated zone as transpiration if the rooting depth exceeds the depth to the water table in a given time step. The PET is adjusted for each land cover category in the model through the use of a crop coefficient (Kc). The simulated position of the water table along with the specified rooting depth determines the thickness of the zone of transpiration.

Unsaturated Flow

The unsaturated flow component of MIKE SHE functions with the 2-layer water balance method described above for ET. The method considers average conditions in the unsaturated zone and tracks the available soil moisture to regulate ET and groundwater recharge using a 1-dimensional (vertical) formulation. A soil map is used to distribute the primary soil properties used to drive the model including the soil hydraulic conductivity and the moisture contents at saturation, field capacity, and the wilting point. The unsaturated flow component of the model interacts with the overland component of the model by serving as a sink term (infiltration) and with the groundwater flow component by serving as a source term (recharge).

Groundwater Flow

The groundwater component of the model solves the 3-dimensional Darcy equation for flow through saturated porous media using an implicit finite-difference numerical scheme solved using the preconditioned conjugate gradient (PCG) technique which is nearly identical to the one used in the USGS's groundwater model, MODFLOW. The primary inputs to the model are the horizontal and vertical hydraulic conductivities, specific yield, and storage coefficients, as well as the upper and lower elevations of each layer(s) considered in the model. External boundary conditions can be no-flow, head, or gradient boundaries, and pumping wells can be added as internal sink terms. The lower boundary of the model can either be a zero-flux or a specified-flux boundary, and the upper boundary condition is a flux term calculated by the unsaturated flow component of the model (recharge). If the water table reaches land surface, the unsaturated flow calculations are disabled and the groundwater component of the model interacts directly with the overland flow plane.

Chapter 4 - Model Construction

Model Overview

The Green Valley/Atascadero and Dutch Bill Creek hydrologic model covers the full extent of these watersheds upstream of their confluences with the Russian River. The model is discretized onto a 50-meter by 50-meter grid and includes a total of 53,158 cells covering an area of approximately 51.3 square miles. The grid resolution was selected so as to represent the watershed in as much detail as was possible consistent with the overall resolution of input data while ensuring reasonable computation times for the model runs.

The model simulates a continuous 5-yr simulation period from 10/1/2009 through 10/1/2014. This period was selected because it is relatively recent, it corresponds to the period with the most data available for model calibration, and it includes a wide variety of precipitation conditions ranging from the relatively wet Water Year of 2011 where annual precipitation at Graton and Occidental was 50.3 and 61.5 inches respectively to the very dry Water Year of 2014 where annual precipitation at Graton and Occidental was 22.7 and 34.2 inches respectively.

Climate

The Graton and Occidental precipitation records were used to provide daily precipitation inputs to the model (Figure 4). Based on the PRISM data set (PRISM, 2010) which provides gridded average annual precipitation data for the period 1981-2010 for the continental U.S., a significant east-west gradient in precipitation occurs across the basin with precipitation increasing from approximately 41 in/yr in the eastern portion of the AC watershed to 60 in/yr in the western portion of the DBC watershed (Figure 5).

In order to capture the spatial variability of precipitation conditions, the watershed was divided into twenty precipitation zones based on one-inch annual average precipitation contours derived from the PRISM data. A scaling factor for each zone was determined by calculating the difference between the 1981-2010 average annual precipitation from the station records and the corresponding value from each PRISM zone. The Graton record was applied for the 41 to 52 in/yr zones and scaled by factors ranging from 0.99 to 1.26 and the Occidental record was applied for the 53 to 60 in/yr zones and scaled by factors ranging from 0.98 to 1.11. The transition from 52 to 53 in/yr roughly corresponds to the watershed divide between the GVAC and DBC watersheds such that the Graton record is used for the GVAC watershed and the Occidental record is used for the DBC watershed.

The California Irrigation Management Information System (CIMIS) station at Santa Rosa (located near eastern Sebastopol) was used to provide daily PET inputs to the model (CIMIS, 2005). In order to capture the spatial variation in PET across the study area, we applied the Turc Method (Turc, 1968) to compute PET using gridded solar radiation data from the National Solar Radiation Database (NSRD, 2010), and mean monthly temperature data from PRISM (PRISM, 2010). We compared the mean annual PET predicted from the Turc Method with the mean annual PET computed from the CIMIS stations at Santa Rosa and Windsor and globally scaled the Turc Method results to conform with the CIMIS data. The resulting PET grid shows that mean annual PET in the GVAC and DBC watersheds was 43.7 and 42.0 in/yr respectively but that locally, PET was as low as 25 in/yr on steep north facing slopes and as high as 49 in/yr in exposed areas with higher temperatures (Figure 6). The gridded PET results were used to divide the study area into twenty-five PET zones (25 to 49 in/yr). A scaling factor for each zone was determined by calculating the difference between the 1990-2014 average annual PET from the Santa Rosa CIMIS station and the corresponding value from each PET zone. The CIMIS record was scaled by factors ranging from 0.56 to 1.10 to produce daily PET time series for each PET zone in the model (Figure 7). Crop coefficients were then used to modify this PET time series for each of the land cover categories in the model as described below in the Land Cover section.

Topography

A 3-ft resolution Sonoma County LiDAR dataset from autumn 2013 (SC LiDAR) was used to represent the topography in the watershed by re-sampling the data to conform to the 50-meter resolution model domain. Elevations in the GVAC watershed range from 600 to 900-ft above sea level (asl) along the ridges forming the western and southern watershed boundaries to ~30-ft asl at the confluence of Green Valley Creek and the Russian River. In the DBC watershed, elevations range from 1,000 to 1,450-ft asl along the ridge forming the western watershed boundary to ~20-ft asl at the confluence of Dutch Bill Creek and the Russian River (Figure 8).

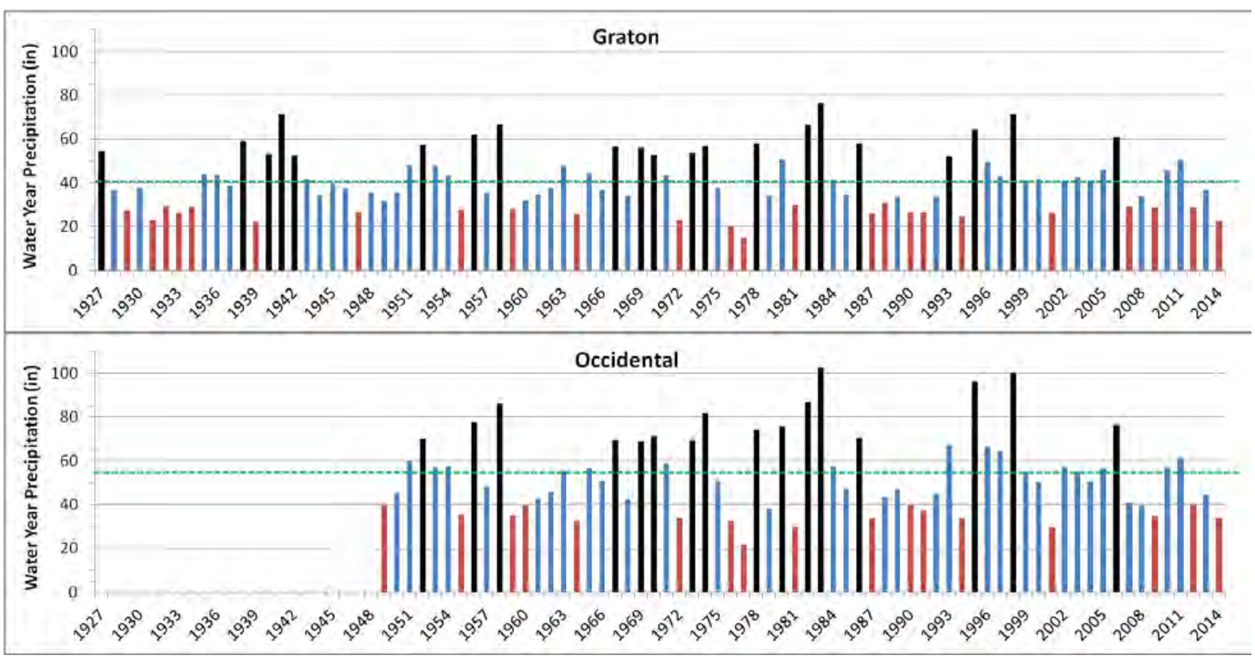


Figure 3 - Mean annual precipitation at Graton and Occidental (black and red values indicate wet and dry years defined as +/- 25% of the long term average as shown with the dashed line).

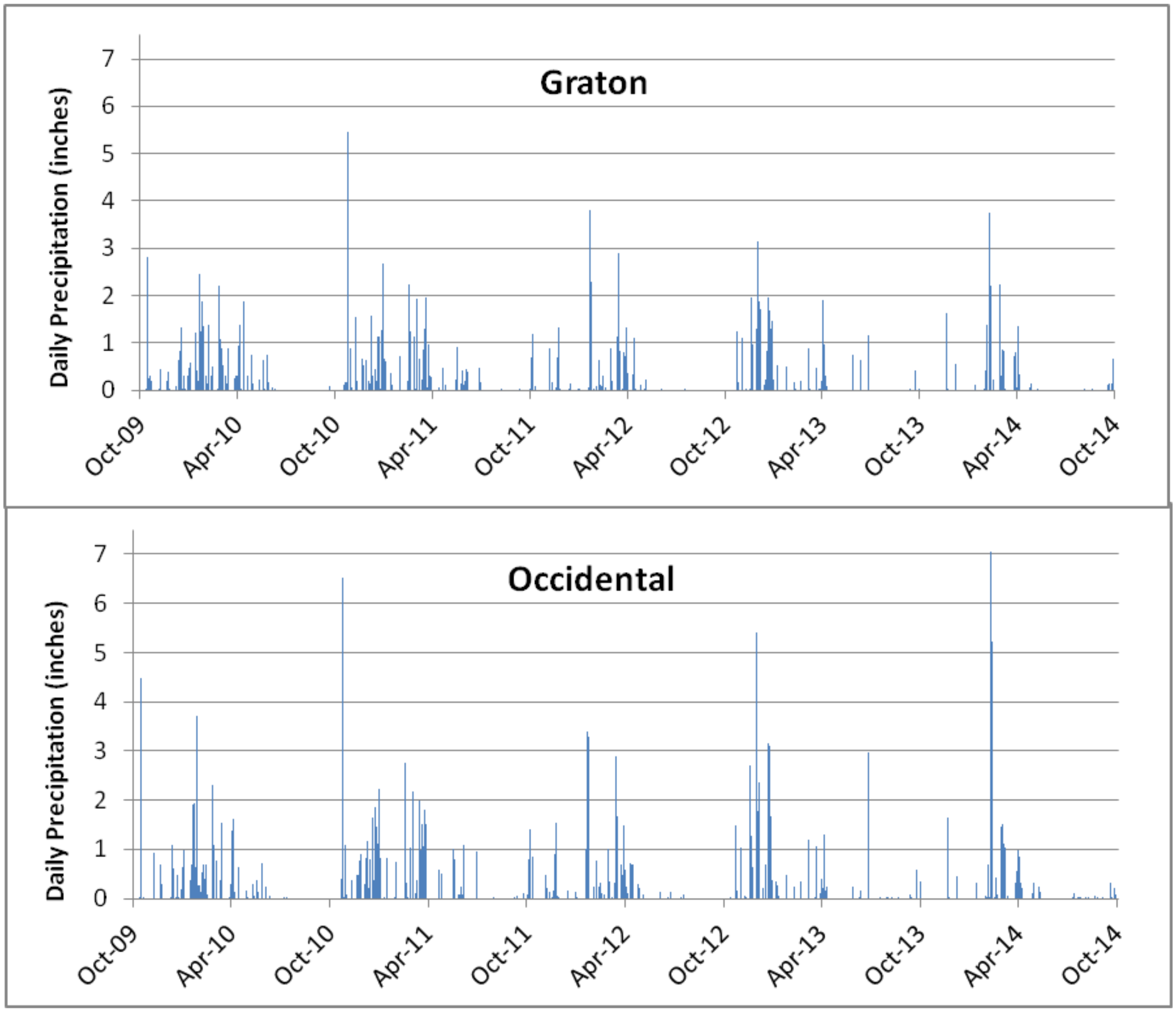


Figure 4 - Daily Precipitation at Graton and Occidental for the WY 2010 - 2014 simulation period.

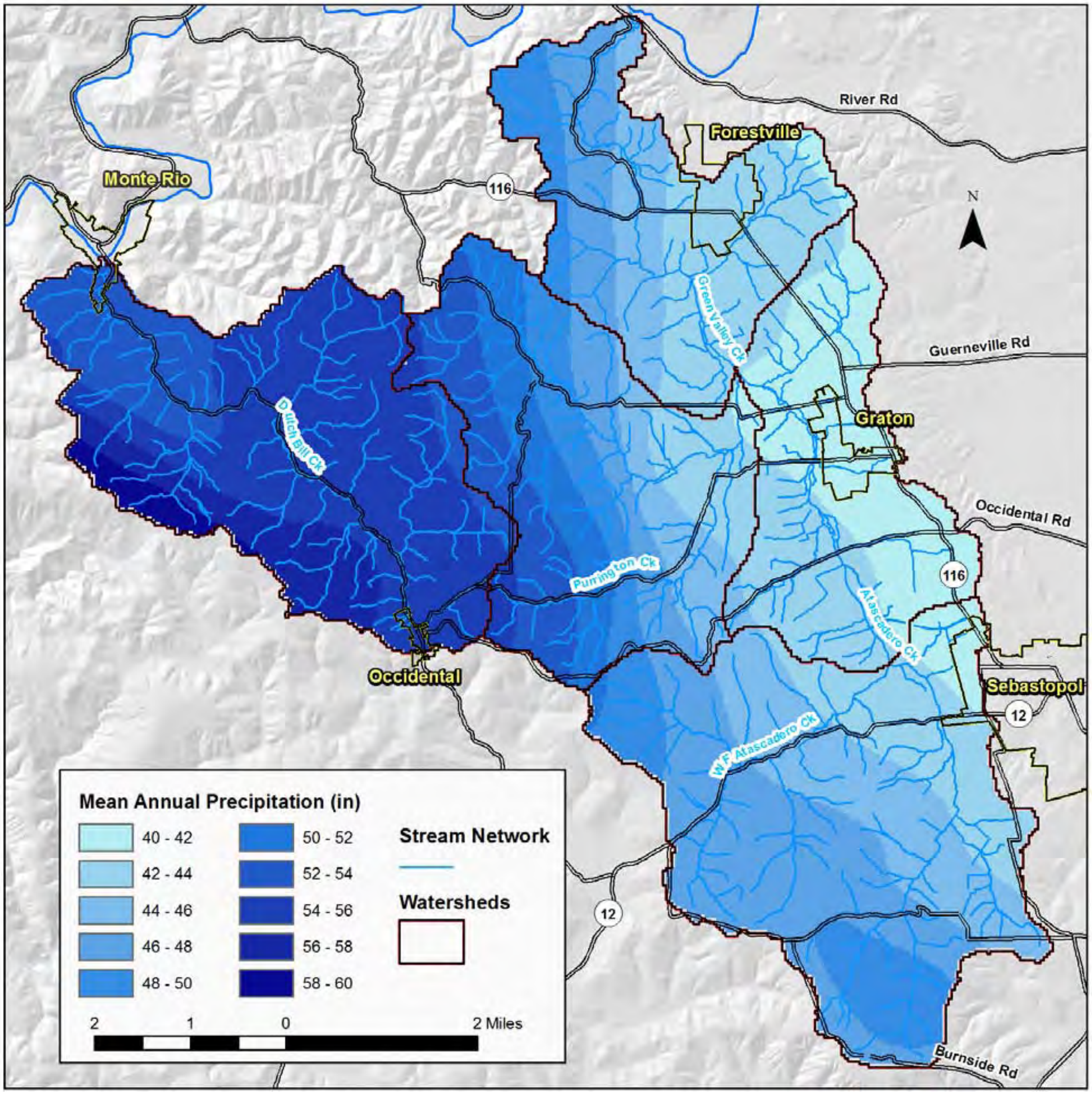


Figure 5 - Spatial variation of mean annual Precipitation used in the hydrologic model.

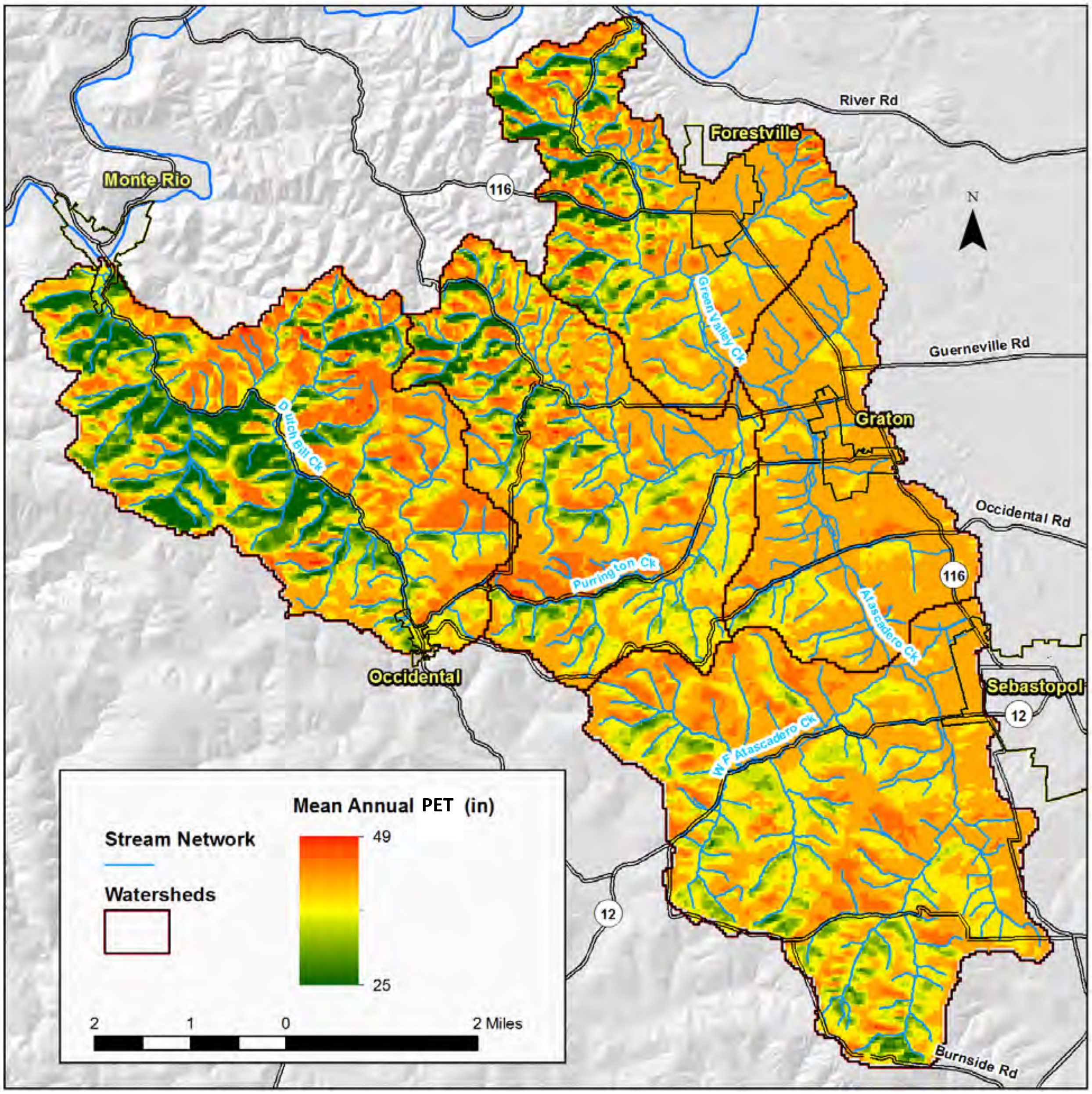


Figure 6 - Spatial variation of mean annual Potential Evapotranspiration (PET) used in the hydrologic model.

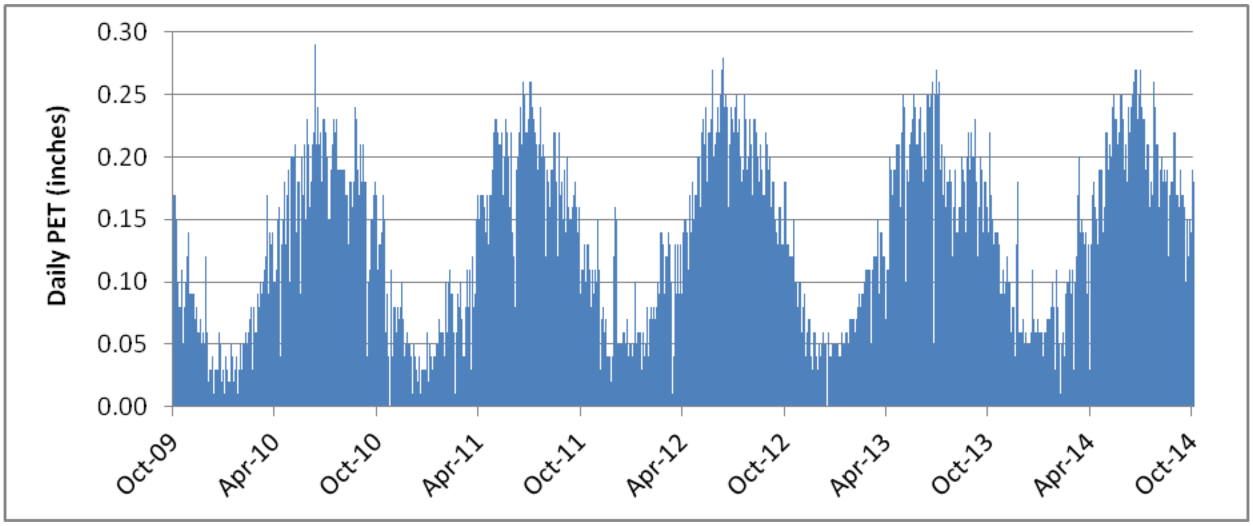


Figure 7 - Daily PET from the CIMIS station at Santa Rosa for the WY 2010 - 2014 simulation period.

Land Cover

The available land cover datasets for the study area included a parcel-based Sonoma County PRMD Land Use Area map, the 30-m resolution National Land Cover Dataset, and a map showing vineyard areas in Upper Green Valley Creek (Deitch, 2010). Given that a highly accurate land cover data set is one of the most important inputs for the hydrologic analysis, a revised land cover data set was developed by digitizing polygons over a 2009 aerial photograph and using the existing land cover and vineyard datasets as a guide. This revised land cover data set includes the following categories: Forest, Vineyard, Orchard, Mixed, Hardscape, Riparian, Shrubland, Grassland, and Water (Figure 9). The Mixed category consists primarily of rural residential areas that are non-forested, not used for agriculture, and are not primarily hardscape. The hardscape category consists of large building footprints, major paved and un-paved roads, and other areas relatively free of vegetation. Field reconnaissance was performed to verify the suitability of the land cover categories and adjust the land cover map where feasible.

In the GVAC watershed, the dominant land cover categories are Mixed (37%) and Forest (34%), with most of the remaining area consisting of Vineyard (11%), Orchard (7%), and Grassland (5%). In the DBC watershed, the dominant land cover is Forest (73%), with most of the remaining area consisting of Grassland (12%), Shrubland (6%), Mixed (4%), and Vineyard (3%). More details on the distribution of land cover types in the various sub-watersheds is provided in Table 1.

A series of model parameters are utilized in the model based on the land cover map. These parameters include the Manning's roughness coefficient, detention storage, interception coefficient, crop coefficient, Leaf Area Index, and rooting depth. For land cover types with a deciduous vegetation component, the crop coefficient, Leaf Area Index, and rooting depth were assigned two values, one corresponding to the growing season (March 15th - October 15th) and one corresponding to the dormant season. Many of these parameters are difficult to measure in the field and site-specific values are generally unavailable. Thus a typical approach for populating the model with these parameter values is to use literature values from similar land cover types initially and adjust them within the range of reasonable limits as part of the calibration process (Table 2).

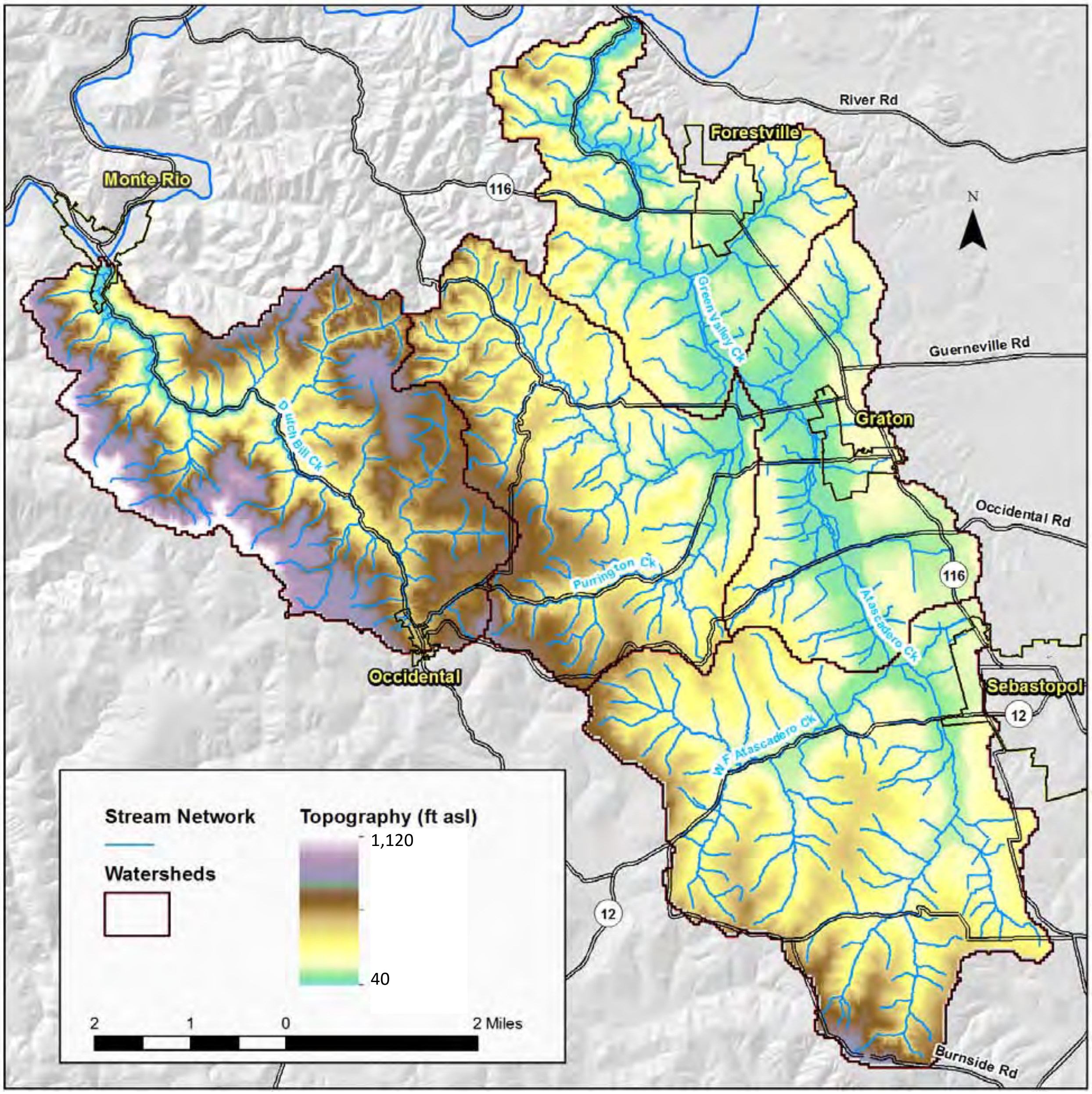


Figure 8 - Hydrologic model topography.

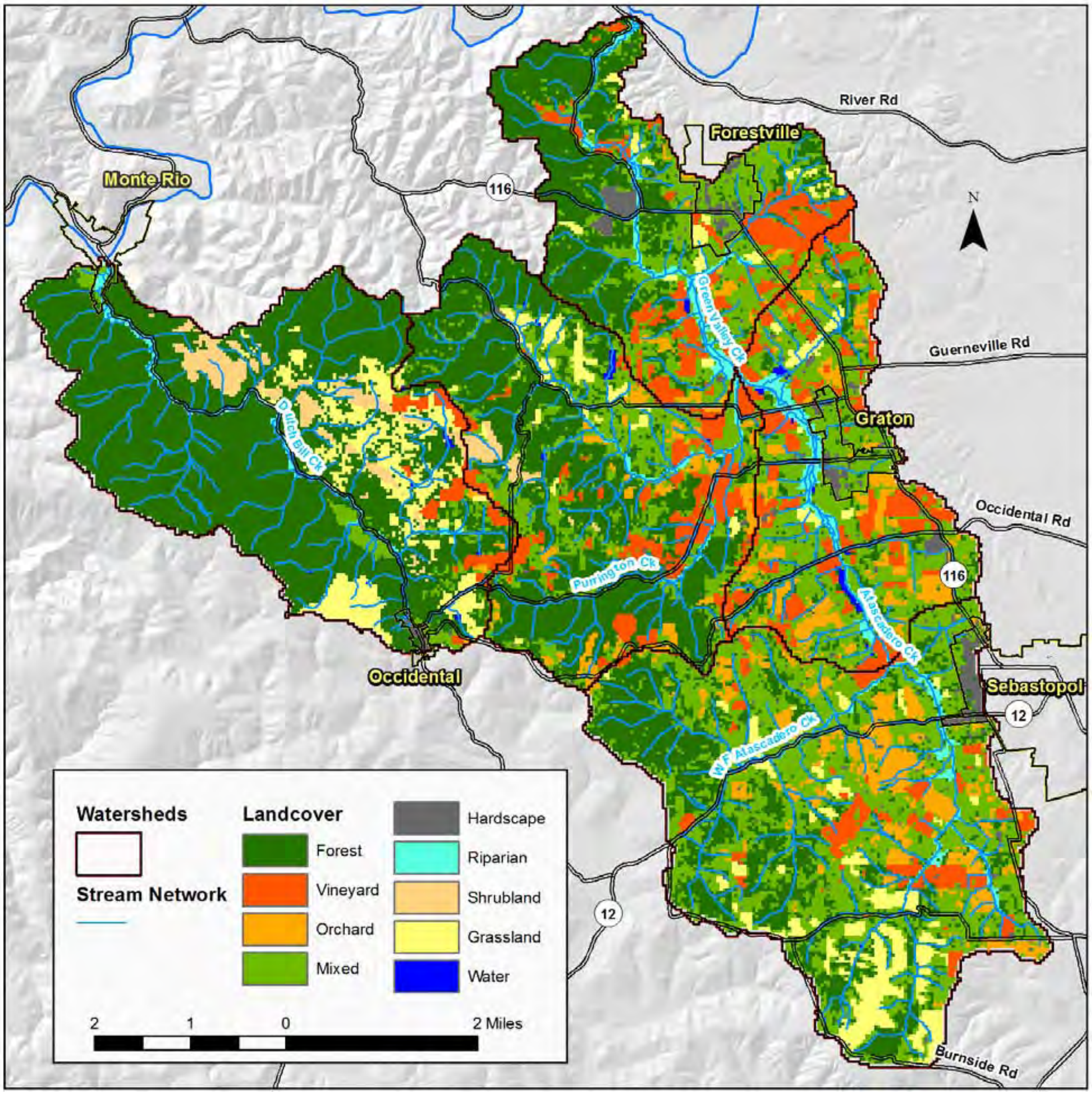


Figure 9 - Hydrologic model land cover.

Table 1 - Distribution of land cover types by subwatershed.

	Dutch Bill		Green Valley		Atascadero		All	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Forest	5,584	73.0%	5,464	48.0%	2,731	21.1%	13,883	43.4%
Vineyard	207	2.7%	1,399	12.3%	1,342	10.4%	2,947	9.2%
Orchard	19	0.2%	391	3.4%	1,366	10.5%	1,777	5.6%
Mixed	277	3.6%	3,067	26.9%	5,913	45.6%	9,257	28.9%
Hardscape	28	0.4%	204	1.8%	318	2.5%	550	1.7%
Riparian	135	1.8%	321	2.8%	395	3.0%	851	2.7%
Shrubland	436	5.7%	113	1.0%	0	0.0%	549	1.7%
Grassland	951	12.4%	381	3.3%	839	6.5%	2,171	6.8%
Water	16	0.2%	30	0.3%	56	0.4%	101	0.3%
Total	**7,654**		**11,387**		**12,961**		**32,002**	

Table 2 - Land cover-based hydrologic and vegetation properties used in the hydrologic model.

	Manning's Roughness Coefficient	Detention Storage (in)	Interception Coefficient (in)	Leaf Area Index	Rooting Depth (in)	Crop Coefficient
Forest	0.60	0.30	0.05	7.0	60	1.25
Vineyard	0.15	0.05	0.01	2.0 - 2.5	16 - 32	0.85 - 0.95
Orchard	0.18	0.05	0.02	2.0 - 4.5	16 - 70	0.90 - 1.20
Mixed	0.23	0.05	0.01	3.0 - 4.0	20 - 28	0.90 - 1.10
Hardscape	0.08	0.00	0.00	0.0	0	0.60
Riparian	0.60	0.30	0.05	3.0 - 7.0	16 - 70	0.80 - 1.30
Shrubland	0.38	0.05	0.02	2.0 - 4.5	20 - 40	0.90 - 1.10
Grassland	0.18	0.05	0.01	2.0 - 3.0	16	1.00
Water	0.08	0.00	0.00	0.0	0	1.00

Surface Water

Streams

A tributary stream channel network was extracted from the 3-ft resolution SC LiDAR dataset by computing flow directions and flow accumulations using standard ArcGIS techniques. Various drainage area thresholds were explored for defining channel head locations. Based on field observations a threshold of five acres was selected. A length threshold of 1,000-ft was applied to thin the resulting drainage network; this resulted in a stream network that was quite detailed but not overly complicated such that it would lead to excessive computational requirements. A separate LiDAR dataset (high-res LiDAR) of higher resolution (1.6-ft) was obtained for this project in autumn 2012 for the riparian corridor of the main-stem streams in the GVAC watershed. This dataset was used to delineate the streamlines for the main-stems of Atascadero, West Atascadero, Green Valley, and Purrington Creeks. Field reconnaissance was performed to map the major road-side ditches in the study area and refine the LiDAR-derived stream network where necessary. A length threshold of 500-ft was applied to the mapped ditches.

The main-stem, tributary, and ditch networks were combined to produce a final stream network for the model (Figure 10). In the GVAC watershed, the stream network includes 11.0 miles of Atascadero Creek, 4.7 miles of West Atascadero Creek, 11.8 miles of Green Valley Creek, 4.3 miles of Purrington Creek, 132.1 miles of tributary streams, and 19.2 miles of road-side ditches. In the DBC watershed, the stream network includes 8.3 miles of Dutch Bill Creek, 48.5 miles of tributary streams, and 1.5 miles of road-side ditches (Table 3). Routing of concentrated runoff in smaller stream channels that are not represented in the model stream network is handled by the overland flow component of the model which utilizes the model DEM as described above under Topography.

For the four main-stem streams in the GVAC watershed described above, cross sections were extracted from the high-res LiDAR at 328-ft (100-m) intervals; Dutch Bill Creek cross sections were extracted from the SC LiDAR. Comparisons between surveyed cross sections and LiDAR-derived cross sections in Green Valley, Purrington, and Dutch Bill Creeks were used to evaluate the LiDAR accuracy and suitability for hydrologic modeling in previous work (OEI, 2013). For the tributary streams, relationships between drainage area and average channel dimensions (Figure 11) were developed from field measurements and used in conjunction with thalweg elevations extracted from the SC LiDAR to construct channel cross sections at the same 328-ft interval. Ditches were classified into two size categories with characteristic cross section dimensions based on field measurements (small: 2.5-ft x 1.1-ft and large: 5.0-ft x 1.5-ft). The model includes a total of 3,885 cross sections. For more details on the two LiDAR datasets and their accuracy, please refer to OEI (2013).

For reaches not mapped as containing alluvium, river/aquifer exchange was driven by the vertical hydraulic conductivity of the underlying hydrogeologic material as described below in the Hydrogeology section. For the reaches underlain by alluvium, streambed leakage coefficient values were assigned and used to derive the conductance term for simulating river/aquifer exchange. A value of 0.0001 (1/seconds) was used for most of these reaches with the exception of the lowest reach of upper Green Valley Creek below the lowest Green Valley Road crossing and the lowest alluvial reach of Dutch Bill Creek where a value of 0.0002 (1/seconds) was used.

Ponds

More than 130 ponds were identified from examination of the SC LiDAR and aerial photography. Of these, 23 were identified as on-stream ponds having either a surface water right and/or a surface area of greater than 0.5 acres (Figure 10). These 23 ponds were added to the model by extracting additional cross sections from the SC LiDAR to represent the pond storage and spillway elevations.

Stormwater Drainage
Maps of stormwater inlets and pipes were obtained from the City of Sebastopol and Sonoma County. Any erroneous surface water features were removed for these areas and the areas drained by stormwater drainage systems were simulated conceptually by applying a 'paved area runoff coefficient' such that 80% of the runoff generated from these areas flows directly to the nearest surface water feature (Figure 10).

Diversions
Review of the Electronic Water Rights Information Management System (eWRIMS) revealed that there are 51 active surface water rights in the study area. Monthly diversion rates are available for one or more years within the reporting period of 2008 through 2013. An average monthly diversion rate was calculated from the years with available data and these averages were then applied for the years without reported rates to construct a continuous time-series of diversion rates for the model simulation period. Of the 51 active water rights, 18 of them reported either no use or very small use (<10 gal/day) and were thus not considered in the analysis. Examination of the remaining 33 water rights indicate that on average 330 ac-ft/yr was diverted from 29 locations in the study area over the 2008 through 2013 reporting period (Figure 10). These diversions varied spatially as follows: 85 ac-ft/yr was diverted from ten locations in the AC watershed, 130 ac-ft/yr was diverted from twelve locations in the GVC watershed, and 115 ac-ft/yr was diverted from seven locations in the DBC watershed.

Most of the diversions are associated with either on-stream or off-stream ponds and direct diversions were a relatively small component of the total surface water use accounting for 16, 21, and 40 ac-ft-yr in the AC, GVC, and DBC watersheds respectively. It is important to note that only one riparian water right in the study area is included in the eWRIMS and the model. Additional diversions associated with riparian water rights may be significant, however given that no information is available to describe the majority of these diversions, they have not been included in this analysis.

Boundary Conditions
Upstream boundary conditions are zero discharge inflows due to the fact that all surface water inflows are generated by other components within the MIKE SHE model. Downstream boundary conditions consist of rating curves which were developed by solving Manning's equation for the downstream cross sections on Dutch Bill Creek and Green Valley Creek.

Soils
A soil series map of the watershed was obtained from the USDA's SSURGO database (USDA, 2007). Soil series with similar hydraulic properties were aggregated to produce a simplified soils map for the model which includes 15 soil types named by texture (Figure 12 & Table 4). The dominant soil type in the GVAC watershed is Fine Sandy Loam C (57%), with 17% Very

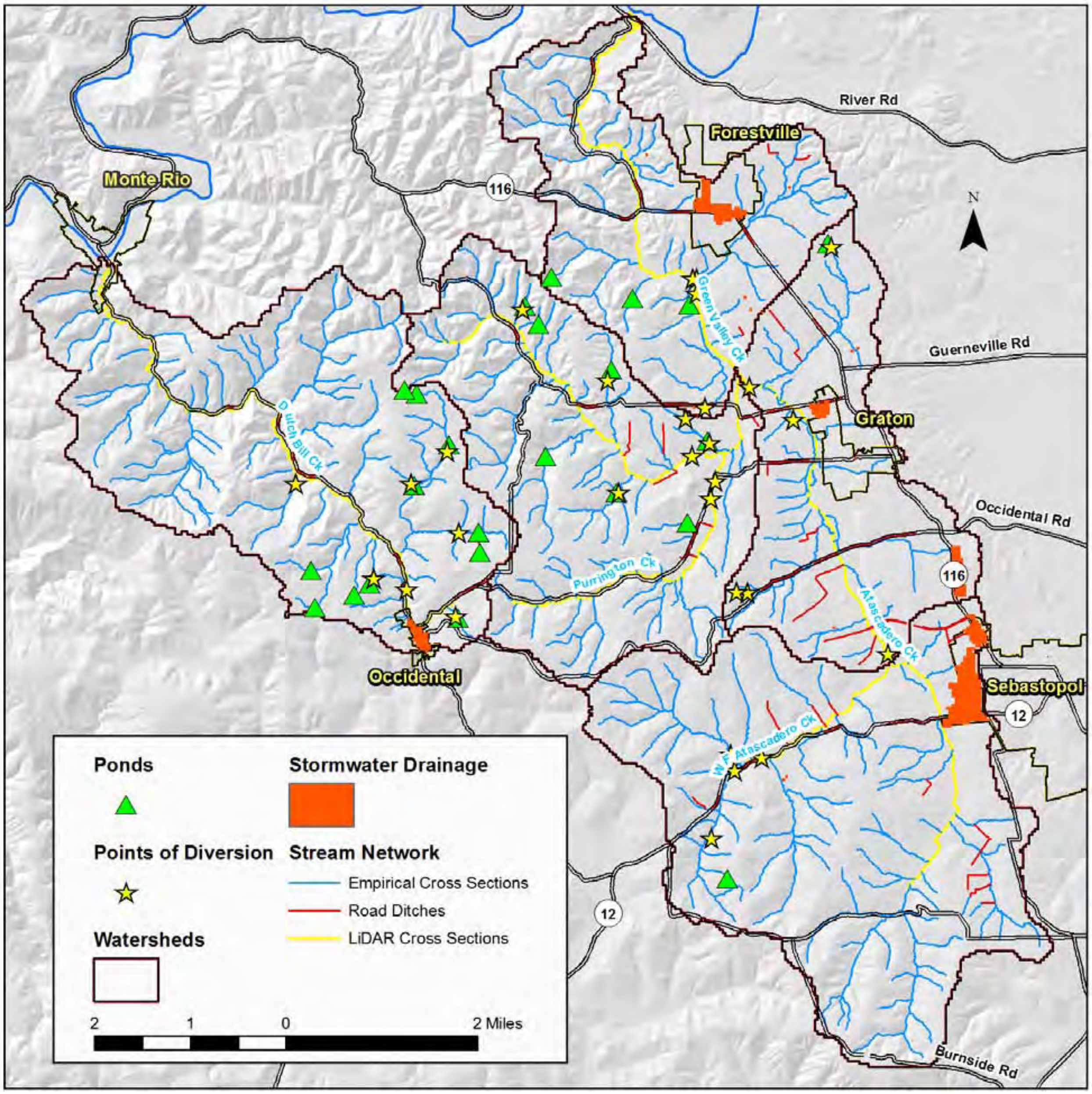


Figure 10 - Stream network and locations of on-stream ponds, points of diversion, and stormwater drainage areas included in the hydrologic model.

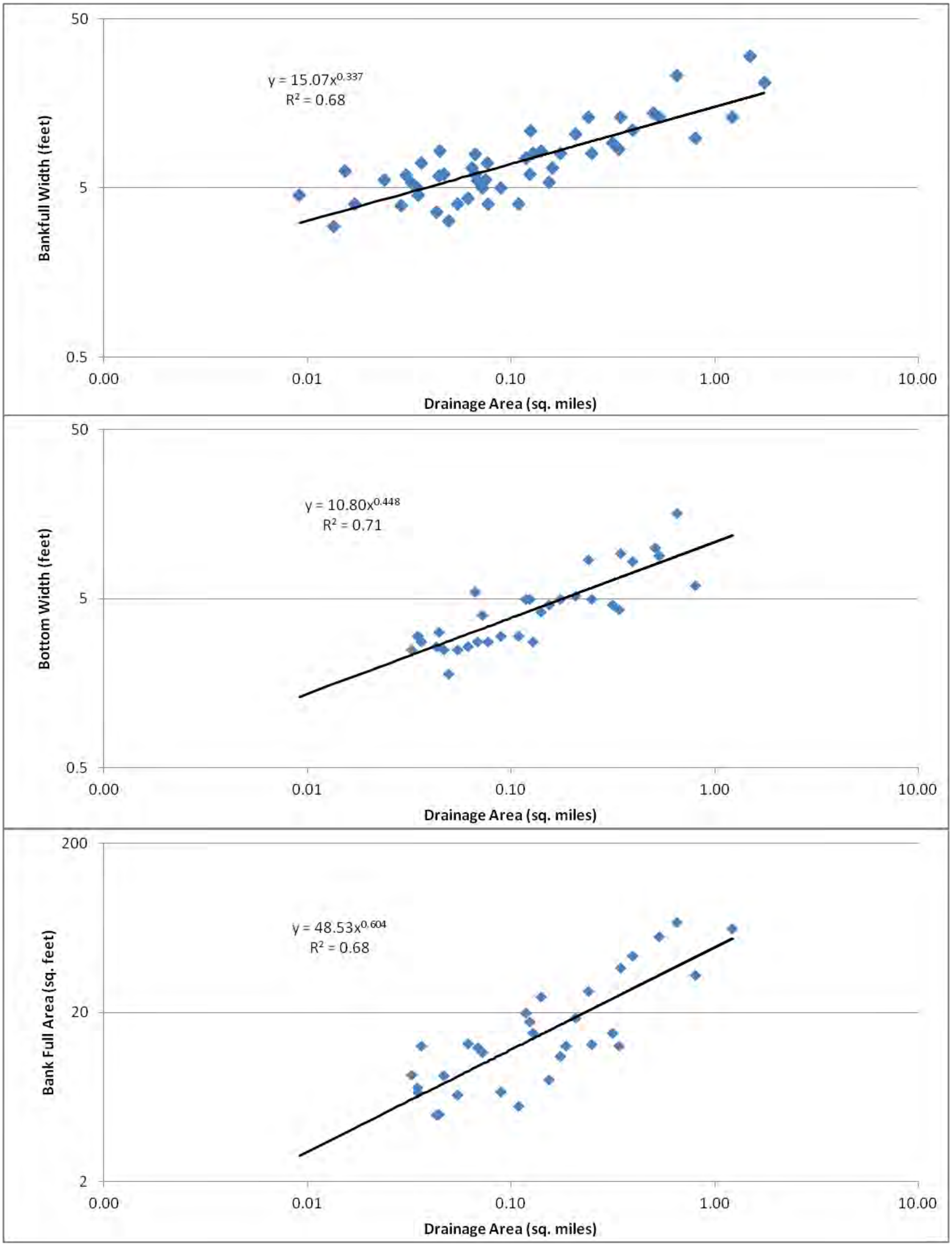


Figure 11 - Relationships between drainage area and bankfull width, bottom width, and bankfull area used to construct tributary channel cross sections for the hydrologic model.

Gravelly Loam A, 8% Fine Sandy Loam B, 6% Loam A, 4% Loam B, and the remaining 8% of the watershed consisting of eight other soil types (Table 5). The dominant soil type in the DBC watershed is Very Gravelly Loam A (54%), with 19% Fine Sandy Loam C, 10% Gravelly Loam, 7% Clay Loam, 5% Cobbly Clay Loam, and the remaining 5% of the watershed consisting of seven other soil types (Table 5).

Initial estimates of the saturated hydraulic conductivity and the moisture contents at saturation, field capacity, and the wilting point for each of these soil types were made from the physical properties report in the SSURGO database and final values were determined through model calibration. Initial values were taken as the weighted average of all soil horizons and values were adjusted during calibration by scaling the initial values up or down by a uniform factor. The calibrated saturated hydraulic conductivity values ranged from 0.006 ft/day for Clay to 0.6 ft/day for the Alluvium (Table 6). Soil moisture contents at saturation, field capacity, and the wilting point ranged from 0.32 to 0.44, 0.12 to 0.37, and 0.06 to 0.25 respectively.

Drainage parameters were assigned to represent interflow processes in the model. Drainage occurs in the model when groundwater elevations exceed a specified depth threshold, and drain flow is routed to surface water features in the model based on the surface topography and a specified time constant. When the drainage parameters are properly calibrated, the drainage term serves to represent the interflow component of the stream flow hydrograph. Drainage was included for all areas with slopes greater than 20%. In the GVAC watershed, a drainage level of 3.5-ft below land surface was used and in the DBC watershed a drainage level of 5-ft below land surface was used. A drainage time constant of $1e^{-7}$ was used throughout the model domain. Both the drainage levels and time constant values were determined through the calibration process.

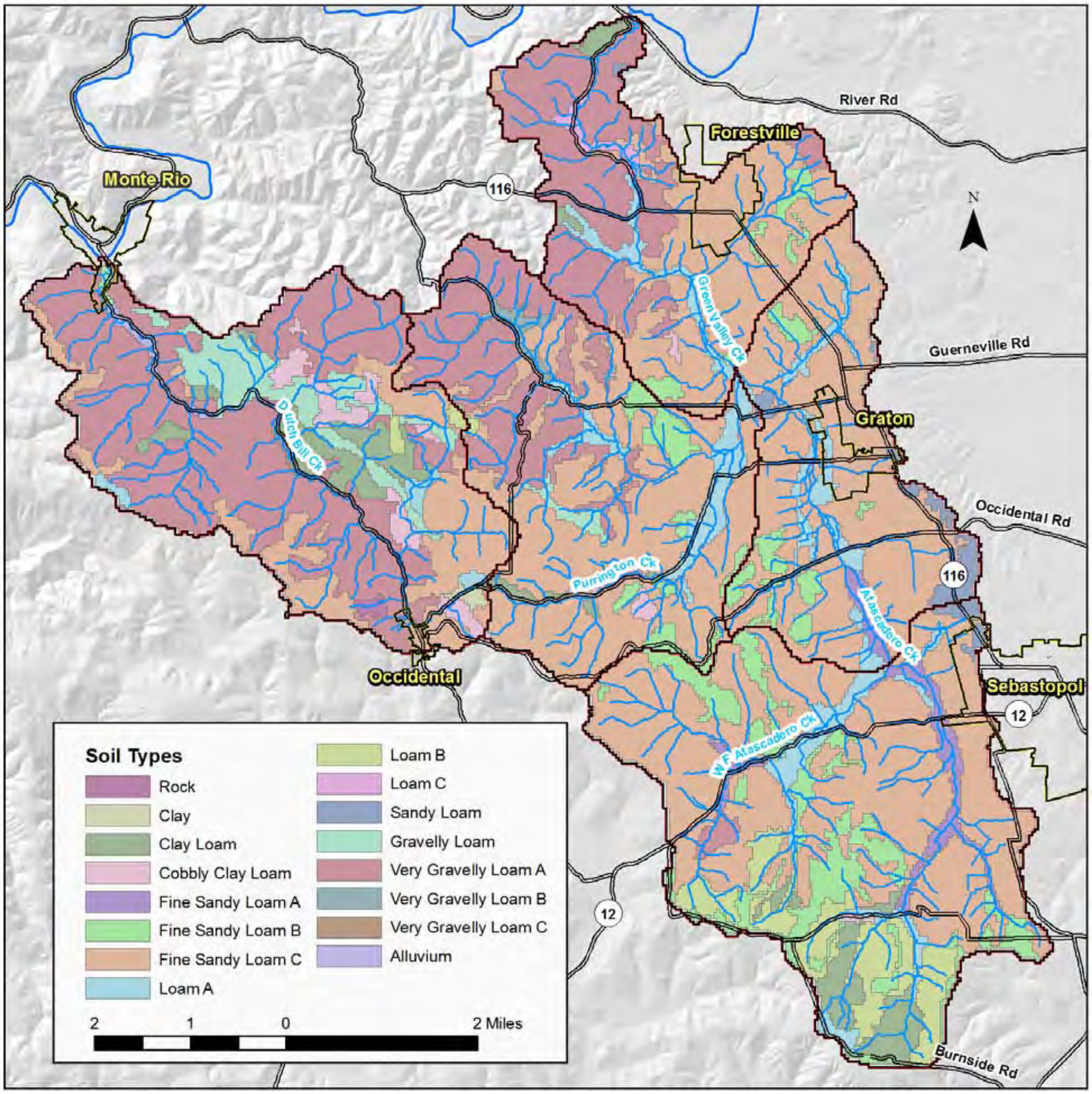


Figure 12 - Hydrologic model soil types.

Table 4 - SSURGO soil series represented by each of the soil types in the hydrologic model.

Model Soil Type	SSURGO Soil Series 1	2	3	4	5
Rock	Rock Land				
Clay	Raynor Clay	Los Osos Clay Loam (thin solum)	Yorkville Clay Loam	Suther Loam	Clear Lake Clay
Clay Loam	Atwell Clay Loam				
Cobbly Clay Loam	Montara Cobbly Clay Loam	Goulding Cobbly Clay Loam			
Fine Sandy Loam A	Pajaro Fine Sandy Loam				
Fine Sandy Loam B	Steinbeck Loam (<15% slopes)	Goldridge Fine Sandy Loam (eroded <15% slopes)			
Fine Sandy Loam C	Goldridge Fine Sandy Loam	Josephine Loam	Blutcher Fine Sandy Loam		
Loam A	Blutcher Loam	Blutcher Clay Loam	Mendocino Sandy Clay Loam	Los Osos Clay Loam	
Loam B	Steinbeck Loam (>15% slopes)				
Loam C	Empire Loam	Yolo Loam Overwash			
Sandy Loam	Sebastopol Sandy Loam	Yolo Sandy Loam	Hely Silt Loam		
Gravelly Loam	Henneke Gravelly Loam				
Very Gravelly Loam A	Laughlin Loam	Hugo Loam	Hugo Very Gravelly Loam	Hugo-Atwell Complex	Hugo-Josephine Complex
Very Gravelly Loam B	Arbuckle Gravelly Loam	Maymen Gravelly Sandy Loam			
Very Gravelly Loam C	Cortina Very Gravelly Loam				
Alluvium	Alluvial Land				

Table 5 - Distribution of soil types used in the hydrologic model.

	Dutch Bill		Green Valley		Atascadero		All	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Rock	46	0.6%	0	0.0%	0	0.0%	46	0.1%
Clay	43	0.6%	0	0.0%	0	0.0%	43	0.1%
Clay Loam	522	6.8%	162	1.4%	471	3.6%	1,155	3.6%
Cobbly Clay Loam	371	4.8%	77	0.7%	30	0.2%	478	1.5%
Fine Sandy Loam A	0	0.0%	0	0.0%	476	3.7%	476	1.5%
Fine Sandy Loam B	33	0.4%	543	4.8%	1,515	11.7%	2,091	6.5%
Fine Sandy Loam C	1,462	19.1%	5,616	49.3%	8,228	63.5%	15,306	47.8%
Loam A	107	1.4%	653	5.7%	841	6.5%	1,601	5.0%
Loam B	56	0.7%	15	0.1%	1,008	7.8%	1,079	3.4%
Loam C	0	0.0%	99	0.9%	0	0.0%	99	0.3%
Sandy Loam	0	0.0%	0	0.0%	309	2.4%	309	1.0%
Gravelly Loam	728	9.5%	95	0.8%	0	0.0%	823	2.6%
Very Gravelly Loam A	4,165	54.4%	4,001	35.1%	83	0.6%	8,248	25.8%
Very Gravelly Loam B	0	0.0%	126	1.1%	0	0.0%	126	0.4%
Very Gravelly Loam C	39	0.5%	0	0.0%	0	0.0%	39	0.1%
Alluvium	82	1.1%	0	0.0%	0	0.0%	82	0.3%
Total	**7,654**		**11,387**		**12,961**		**32,002**	

Table 6 - Soil properties used in the hydrologic model.

	Saturated Hydraulic Conductivity (ft/day)	Moisture Content at Saturation	Moisture Content at Field Capacity	Moisture Content at the Wilting Point
Rock	0.00	0.03	0.02	0.01
Clay	0.01	0.44	0.37	0.25
Clay Loam	0.01	0.39	0.34	0.20
Cobbly Clay Loam	0.01	0.37	0.28	0.19
Fine Sandy Loam A	0.15	0.41	0.25	0.11
Fine Sandy Loam B	0.06	0.41	0.26	0.11
Fine Sandy Loam C	0.08	0.41	0.25	0.11
Loam A	0.03	0.39	0.29	0.12
Loam B	0.08	0.39	0.26	0.12
Loam C	0.06	0.39	0.30	0.12
Sandy Loam	0.02	0.41	0.25	0.10
Gravelly Loam	0.10	0.37	0.16	0.09
Very Gravelly Loam A	0.06	0.37	0.21	0.09
Very Gravelly Loam B	0.07	0.37	0.23	0.09
Very Gravelly Loam C	0.13	0.37	0.18	0.09
Alluvium	0.62	0.32	0.12	0.06

Hydrogeology

Hydrogeologic Units

The Late Pliocene to Late Miocene Wilson Grove Formation (WGF) which consists of fine-grained loosely consolidated sandstone with layers of beach or dune sand is the primary aquifer in the study area. The WGF underlies much of the GVAC watershed (67%) as well as a small (7%) portion of the DBC watershed along its south and eastern boundaries. Underlying the WGF and exposed in most of the remainder of the watershed are a series of rocks of the Franciscan Complex and to a lesser extent the Great Valley Sequence. The rocks of the Franciscan Complex include sandstone and shale, a mélange of clastic rocks, serpentinite, basaltic pillow lava and breccias, and a mélange of metamorphic rocks. The rocks of the Great Valley Sequence are primarily siltstones.

In general the Franciscan Complex and the Great Valley Sequence are considered poor aquifer materials with limited groundwater available in bedrock fractures. Wells drilled in these bedrock units are often unsuccessful, and wells that do produce useful quantities of water typically have low capacities. The hydraulic properties of these rock types are highly variable depending on rock type and the degree of fracturing. The hydraulic characteristics of these primarily fractured bedrock units are not well known, and are expected to be spatially discontinuous. Consequently, for the purposes of this analysis, the fractured bedrock units have all been lumped into a single unit and termed the Franciscan Complex (FC). This simplified representation characterizes the FC with aquifer parameters that contrast distinctly with the WGF where groundwater is generally available without attempting to describe the variability within the FC. Holocene Alluvium is present along most of the length of main-stem Atascadero Creek, West Atascadero Creek, Green Valley Creek, lower Purrington Creek, and the lowest reaches of Dutch Bill Creek.

Model Discretization

Several thousand driller's logs (Well Completion Reports) were obtained from the State of California Department of Water Resources for the study area. The number of logs was reduced substantially by selecting the deepest logs with the greatest amount of stratigraphic detail, while simultaneously seeking to obtain good spatial coverage throughout the study area. Two hydrogeologic contacts were identified from these logs to constrain the structure of the simulated aquifers: the base of the WGF, and the base of the Alluvium. An isopach map of the WGF was interpolated from 111 driller's logs that fully penetrated the formation. This map indicates that the WGF thickens from west to east from less than 100-ft in the western portions of the GVAC watershed to more than 650-ft along the divide with the Santa Rosa Plain (Figure 13).

An isopach map of the Alluvium was interpolated from 31 driller's logs that fully penetrated the alluvium. This map indicates that the Alluvium is relatively thin (20 - 40-ft) along lower Dutch Bill Creek, most of Green Valley Creek, and the upper reaches of Atascadero Creek. Above the confluence of Atascadero and West Fork Atascadero Creeks, the alluvium thickness along both creeks increases in the downstream direction from approximately 40- to 100-ft. Below this confluence the alluvium reaches a maximum thickness of ~150-ft upstream of Occidental Road, then decreases in thickness in the downstream direction to less than 40-ft at the confluence with Green Valley Creek. Along Purrington Creek the alluvium increases in thickness in the downstream direction from approximately 40- to 100-ft in the vicinity of Graton Road, then decreases sharply back to ~40-ft at the confluence with Green Valley Creek (Figure 14).

A two-layer groundwater model was developed based on the isopach maps described above. MIKE SHE requires that all layers be continuous across the entire model domain, thus Layer 1 represents the alluvium where present and either the WGF or FC elsewhere. Where the alluvium is present, Layer 2 represents the underlying WGF or FC and outside of the alluvium areas, the WGF or FC are represented in both Layers 1 and 2. The bottom of Layer 2 was developed first by subtracting the WGF isopach map from the surface topography and assuming

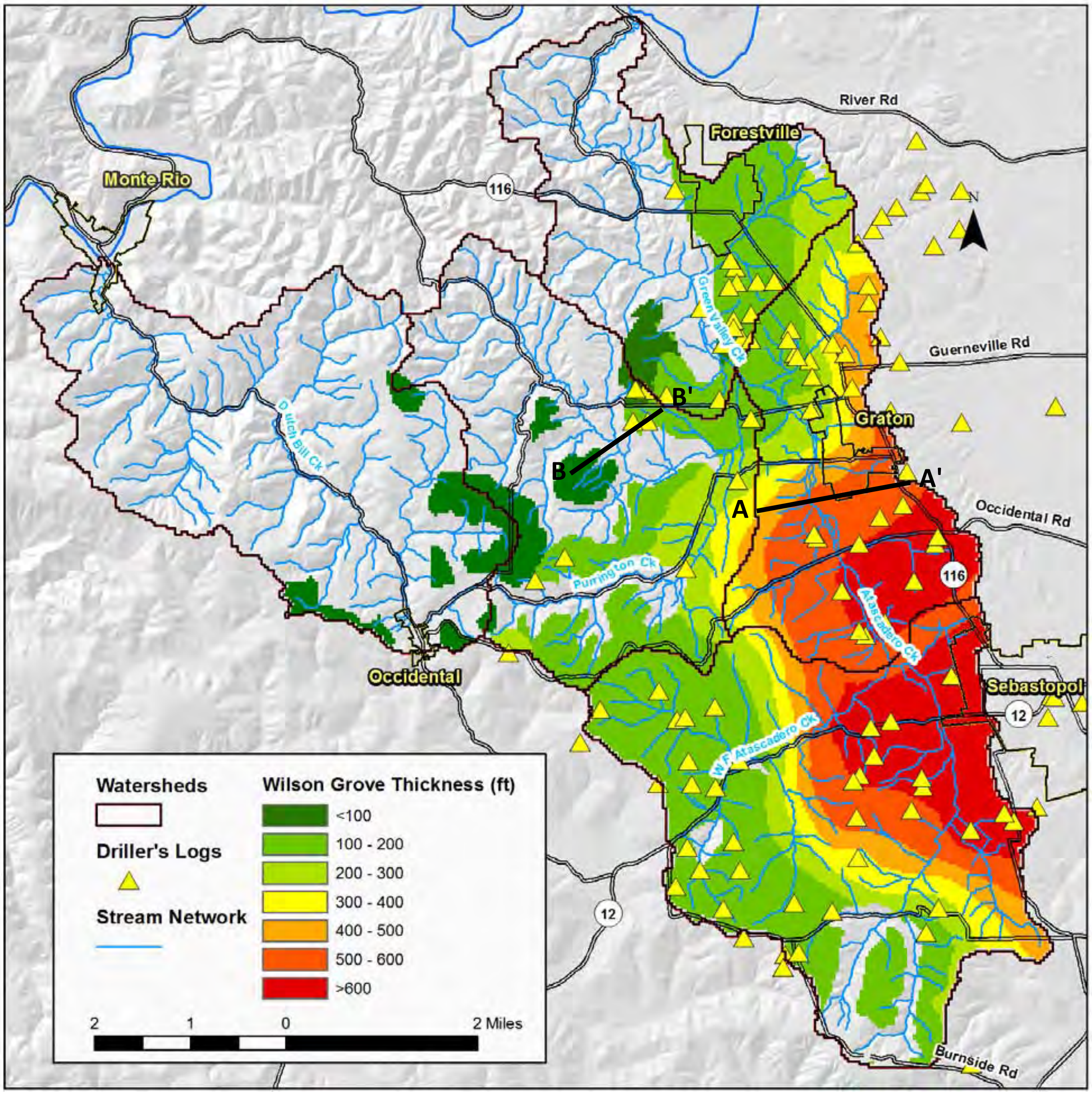


Figure 13 - Isopach map of the Wilson Grove Formation and geologic cross section locations.

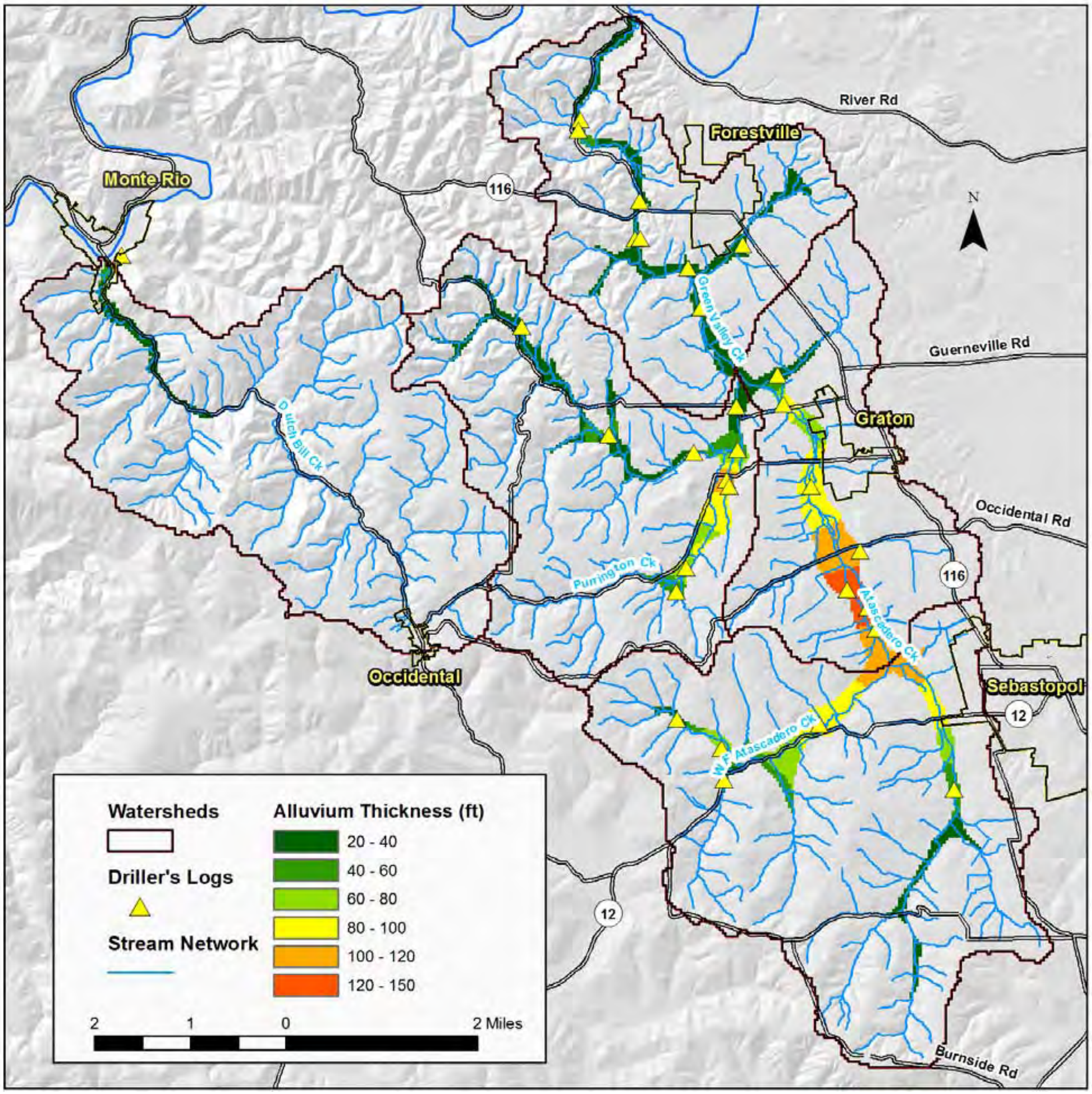


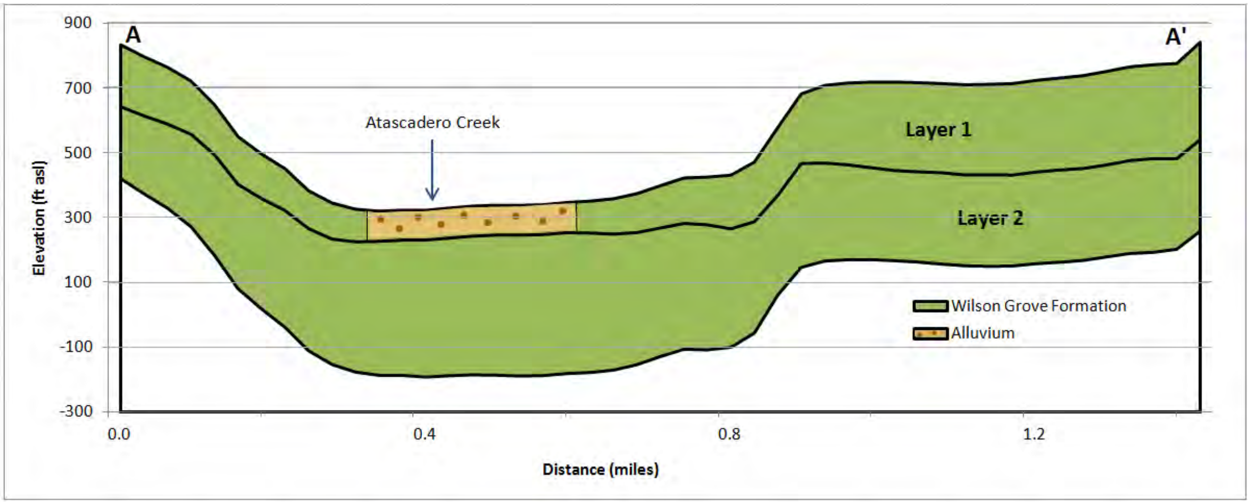
Figure 14 - Isopach map of the Holocene Alluvium.

a minimum thickness of 100-ft for the WGF and for the areas underlain by the FC. To develop the bottom of Layer 1, two surfaces were developed individually and then combined to generate the final surface. The first surface was developed by subtracting the Alluvium isopach map from the surface topography and assuming a minimum thickness of 20-ft for the Alluvium. A second surface was developed for areas not underlain by Alluvium by halving the thickness of Layer 2 such that the thicknesses of the non-alluvial materials are approximately equal in Layers 1 and 2. The two surfaces were then mosaiced and the transition between them was smoothed by interpolation of thicknesses around the margins of the Alluvium to produce a final surface for the bottom of Layer 1. The thicknesses and materials represented by the resulting layers are summarized in Table 7 and two geologic cross sections through the model domain are shown in Figure 15.

Hydraulic Properties

Aquifer test data are available for eleven wells completed in the WGF in the adjacent Santa Rosa Plain. These data indicate a range of hydraulic conductivity (K) values of 3 to 65 ft/day (Kadir and McGuire, 1987; Nishikawa et al., 2013). Additionally, Cardwell (1958) estimated a range of K values for the WGF of 2 to 33 ft/day. Although no long duration aquifer test data was available, short-duration test data is recorded on many of the driller's logs. This data can be used to derive estimates of the specific capacity (Sc) which can be related to transmissivity (T) using the empirical relationship: T = 1500 * (Sc) (Driscoll, 1986), and then to K by dividing by the saturated thickness. This exercise was performed for 24 wells that fully penetrated the WGF in the watershed and the resulting values of K ranged from 0.03 to 2.9 ft/day with a mean value of 0.5 ft/day, significantly lower than previous estimates. A K value of 0.25 ft/day was determined for the WGF as part of the calibration process (Figure 16 & 17; Table 7). Although this value is lower than estimates derived from aquifer test data in the Santa Rosa Plain, this is consistent with descriptions of the formation from Cardwell (1958) where wells tapping the lower portion of the formation west of the Santa Rosa Plain were found to have specific capacity values significantly lower than wells tapping the upper portion of the formation within the Santa Rosa Plain.

No estimates of K were available for the FC or the Alluvium in the study area so initial model values were taken from literature values for similar materials (Freeze and Cherry, 1979). The driller's logs indicate a wide variation in sediment sizes for the Alluvium ranging from sand and gravel to clay. Most logs (28 of 31) indicate the presence of at least some significant clay strata. Static water levels from logs penetrating through the Alluvium and into the underlying WGF indicate that confined or partially confined conditions are present in the WGF aquifer where it is overlain by alluvium. This is consistent with the description of confined conditions within the WGF in this area given by Cardwell (1958). The presence of confined conditions suggests that the Alluvium likely has a fairly low K value, and a value $2.5e^{-4}$ ft/day was determined through calibration for most of the Alluvium in the GVAC watershed. The single driller's log penetrating the alluvium in lower Dutch Bill Creek indicates primarily sand and gravel, and the saturated K value for the soils in this area is the highest in the entire study area, thus a higher initial K



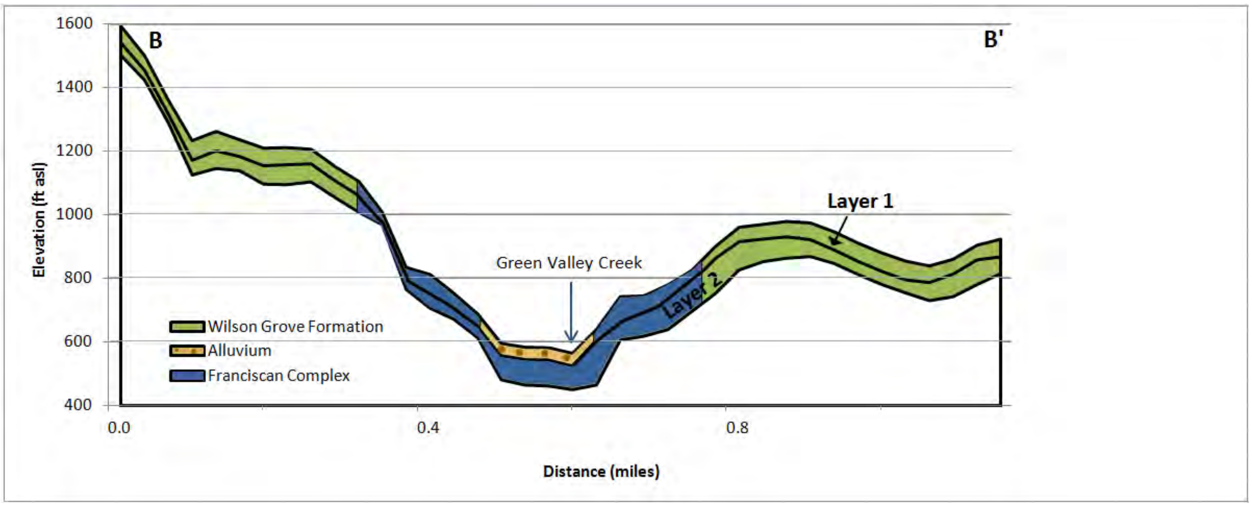


Figure 15 - Geologic cross sections through the lower Atascadero Creek Watershed (top) and the upper Green Valley Creek Watershed (bottom), cross section locations are shown in Figure 13.

estimate of 1 ft/day was assumed for the Alluvium in the DBC watershed. The soils data also indicate an area of high saturated K for the area underlain by alluvium in a portion of central Atascadero Creek, thus a higher K estimate of 0.001 ft/day was assumed for this area (Figure 16 & 17; Table 7). A K value of $2.5e^{-5}$ ft/day was assumed for the FC which is consistent with previous findings that characterized the FC as non-water-bearing (Cardwell, 1958; Kunkel and Upson, 1960; Nishikawa et al., 2013).

Herbst et al. (1982) estimated a range of Specific Yield (Sy) values of 10 to 20% for the WGF. A value of 15% was assumed for the model (Table 7). Sy was estimated to be less than 3% for the FC (Herbst el al., 1982) and a value of 2% was used in the model. No estimates of Sy for the Alluvium in the study area were available, thus initial estimates were based on literature values from similar materials (Freeze and Cherry, 1979). Storativity (S) is only used by the model when confined conditions are present. Given the discretization and hydraulic properties used in the model, confined conditions are only possible for portions of the WGF overlain by Alluvium, thus the WGF is the only hydrogeologic unit requiring an estimate of S. Estimates of S for the WGF formation are available from aquifer tests at 5 wells in the adjacent Santa Rosa Plain (Kadir and McGuire, 1987; Nishikawa et al., 2013). These estimates were converted to an equivalent value for the model of 0.0005 based on the relative thicknesses of the aquifers from the test data and the model aquifer thickness.

Boundary Conditions

A no-flow boundary condition was applied for the bottom of Layer 2 based on the assumption that the interface between the WGF and the underlying low-permeability FC represents the depth of the active aquifer system such that only minor amounts of groundwater are exchanged across this boundary. Similarly, the margins of the model domain that consist of FC were simulated as no flow boundaries based on the assumption that only limited groundwater flow is transmitted into or out of the study area within the low-permeability FC.

Groundwater elevation data for Spring 2012 was available at twelve California Statewide Groundwater Elevation Monitoring (CASGEM) wells completed in the WGF in the GVAC watershed and in the western-most portion of the adjacent Santa Rosa Plain (CASGEM, 2014). Groundwater elevation contours derived from interpolation of the CASGEM data indicate that groundwater flows from west to east across the GVAC watershed and towards the Santa Rosa Plain (Figure 18). The contours indicate a flow direction roughly parallel to the GVAC/Santa Rosa Plain watershed divide and a gradient of ~0.01 ft/ft. Thus a constant gradient boundary of -0.01 ft/ft was applied for the boundary cells underlain by the WGF (Figures 16 and 17). This is consistent with the findings from the recent Santa Rosa Plain Groundwater Model which represented this watershed divide using boundary conditions that permitted inflow from the GVAC watershed to the Santa Rosa Plain (Woolfenden, 2014).

Table 7 - Layer thicknesses and aquifer properties used in the hydrologic model.

		Layer 1			Layer 2		
	Total Thickness (ft)	Thickness (ft)	Hydraulic Conductivity (ft/day)	Specific Yield (%)	Thickness (ft)	Hydraulic Conductivity (ft/day)	Specific Yield (%)
Alluvium	20 - 151	20 - 151	0.00025 - 1	8 - 23	-	-	-
Wilson Grove	50 - 654	20 - 327	0.25	15	50 - 593	0.25	15
Franciscan	50 - 232	20 - 115	0.000025	2	50 - 205	0.000025	2

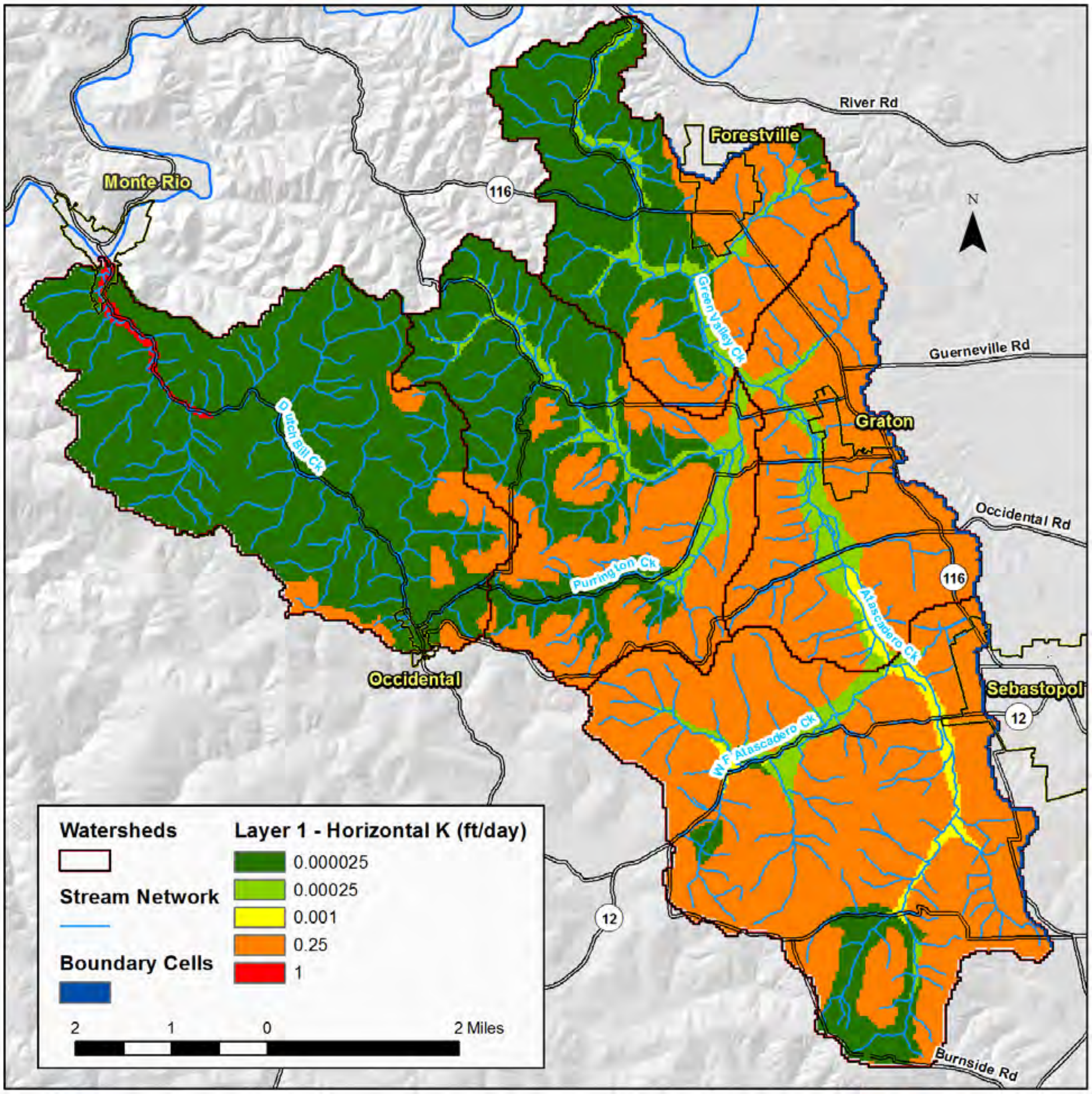


Figure 16 - Distribution of Hydraulic Conductivity (K) and locations of boundary conditions for groundwater Layer 1.

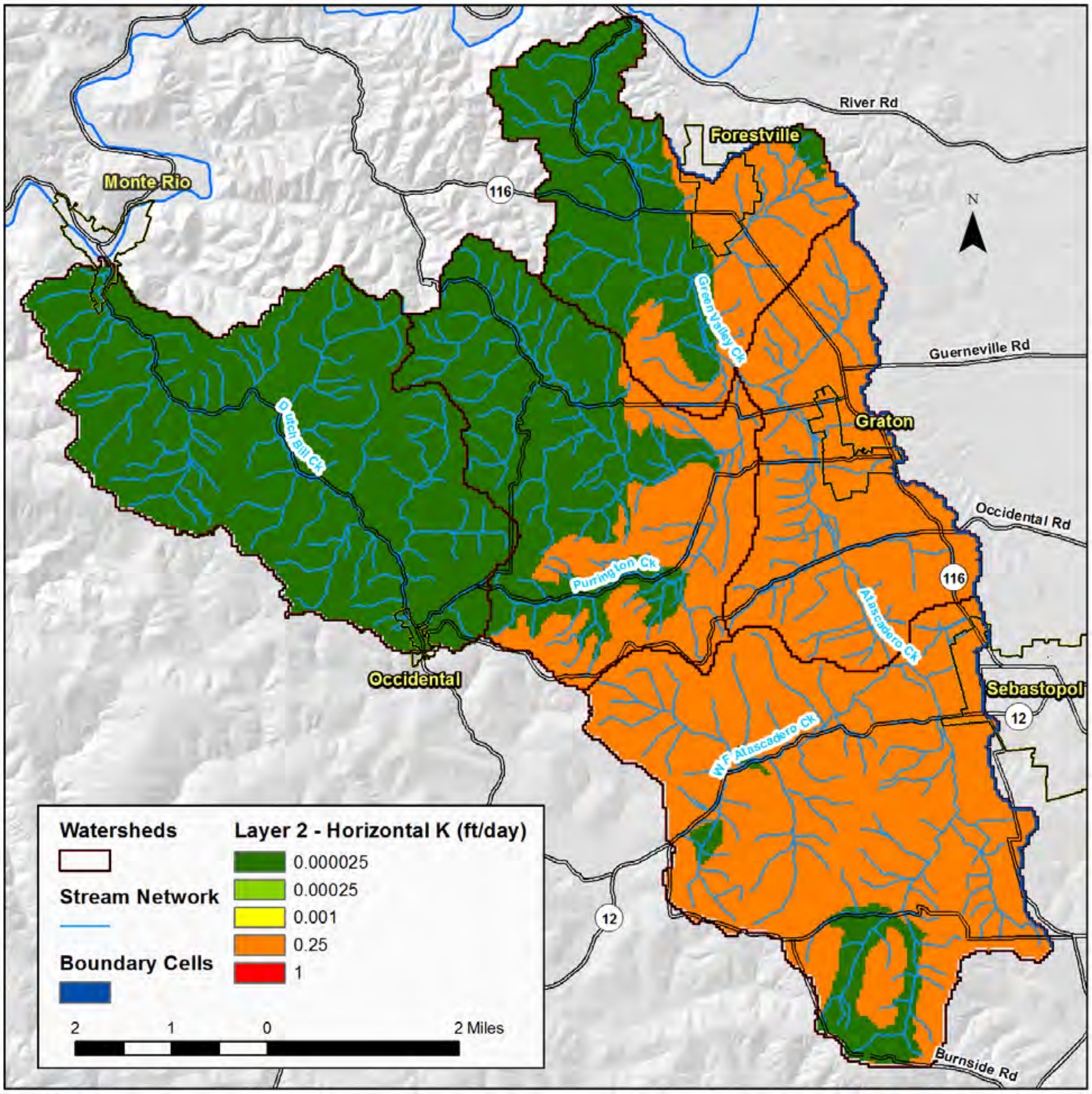


Figure 17 - Distribution of Hydraulic Conductivity (K) and locations of boundary conditions for groundwater Layer 2.

Groundwater Pumping

Domestic Pumping

In order to estimate the distribution and rates of domestic groundwater pumping, we first identified the portions of the study area receiving water from sources outside the study area and excluded them from the analysis. These areas include western Sebastopol which receives water from municipal wells located in the Santa Rosa Plain, Forestville and Monte Rio and surrounding areas, and portions of Camp Meeker and Occidental which all receive water from the Russian River (Figure 19).

The study area includes all or portions of 315 census blocks and the total population in each census block was tabulated from the 2010 census data. The census data indicate that a total of 15,028 people reside in the study area. Of these 4,465 are served by water delivery from external sources. The remaining population of 10,563 was assumed to rely on groundwater for domestic use. An assumption was made that each parcel in the study area (excluding the water delivery areas) contains one domestic well; it was thus estimated that there are 4,352 domestic wells in the study area (Figure 20). The total population within each of the 315 census blocks was divided by the number of wells within each block to determine the number of people served by each well which ranged from 1.0 to 9.8 with an average of 2.4.

Per capita water use data was obtained for the City of Sebastopol for 2010 through 2013 indicating an average per capita use of 129 gallons per day (gal/d). Dry weather water treatment plant flow data was also obtained from the City of Sebastopol which indicated that 54% of the total use for 2010-2013 represented outdoor use with the remaining 46% representing indoor use. This outdoor use was assumed to occur between May and October in proportions that were based on irrigation data described in greater detail below for irrigation pumping. The Sebastopol data was used to develop a per capita time series of domestic groundwater pumping (Figure 21) which was then scaled based on the number of people served by each well and applied to the 4,352 domestic wells added to the model.

Irrigation Pumping

To estimate the distribution and rates of groundwater pumping for irrigation, each parcel corresponding to vineyard in the land cover map was assumed to contain one irrigation well. This resulted in an estimated 217 irrigation wells in the study area (Figure 20). The number of acres of vineyard served by each well (total vineyard acreage within each parcel) ranged from 0.6 to 101.9 with an average of 10.9 acres. Vineyards are the dominant irrigated crop in the study area. Some orchards and other crop types also receive irrigation water, however many orchards are not irrigated and insufficient data was available to delineate irrigated areas for other crop types, thus only vineyard irrigation was included.

All active surface water rights in the study area were compiled from the California State Water Resources Control Board's (SWRCB) Electronic Water Rights Information Management System (eWRIMS). From among these, nine water rights were identified where monthly water use was reported for 2008 through 2013 and vineyard irrigation was the only stated use. The average

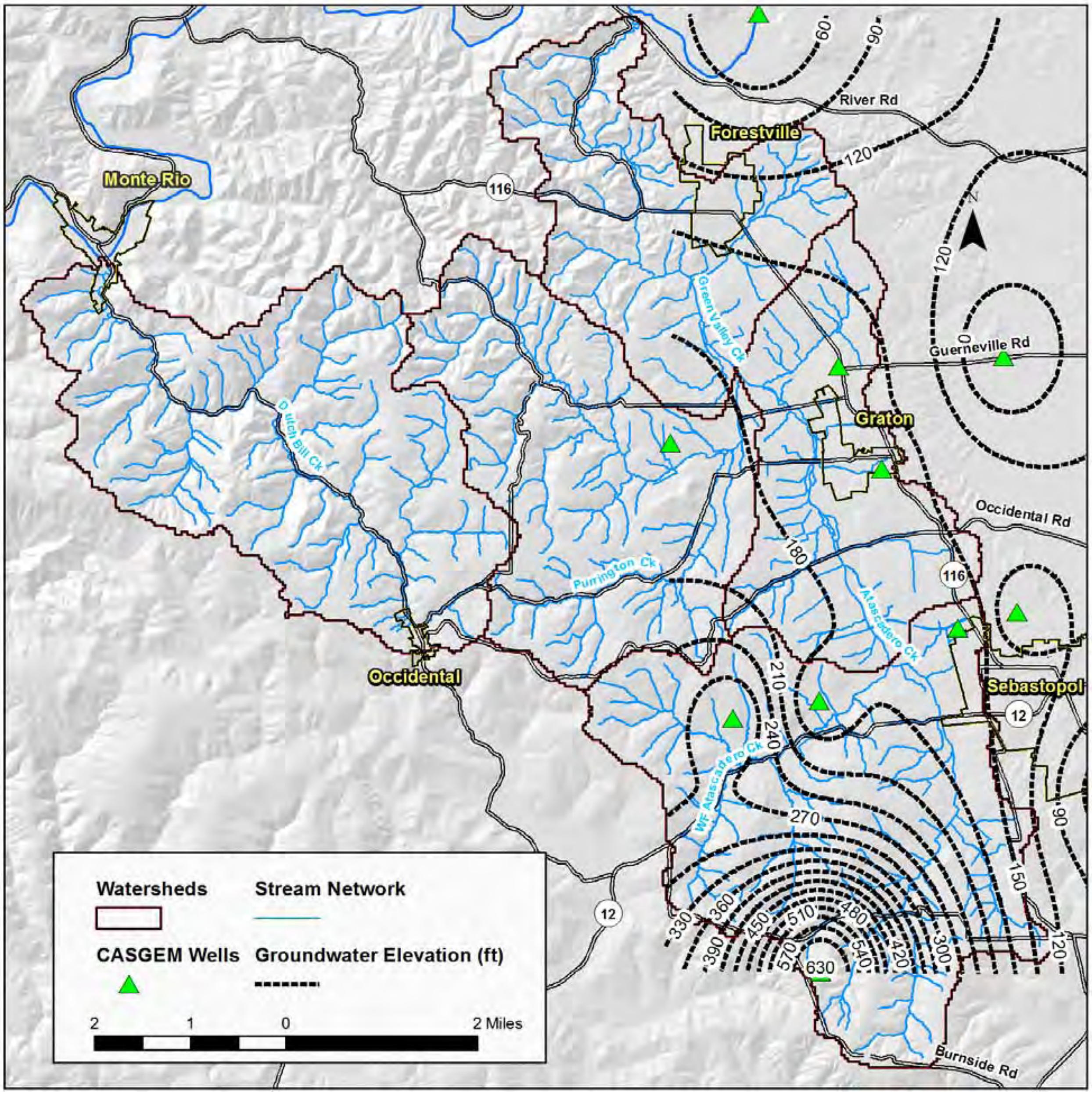


Figure 18 - Groundwater elevation contours based on Spring 2012 measurements from CASGEM wells completed in the Wilson Grove Formation.

irrigation rate calculated from these nine water rights was 3.7 in/yr/ac. The reported water use data also provided a means of estimating the temporal distribution of irrigation which ranged from 0.21 inches in October to 1.15 inches in July (Figure 22). These average rates were scaled based on the number of acres served by each irrigation well and applied to the 217 irrigation wells added to the model. The temporal distribution of irrigation was also used to distribute the outdoor domestic use as described above for domestic pumping.

Frost Protection Pumping

All vineyards with frost protection systems that use water are required to register with the Sonoma County Agricultural Commissioner. A review of these registrations as compiled in the Sonoma County Frost Protection Registration Database revealed that 1,052 acres of vineyards in the study area were registered as using water for frost protection (SCDA, 2014). The registration compliance was estimated to be 90% (SCDA Staff, 2014), thus approximately 1,157 acres (39% of the total vineyard acreage) of vineyards in the study area use water for frost protection. The frost protected vineyards were located based on the parcel numbers provided in the frost protection database; the model land cover distribution of vineyards required some adjustments so that total frost protected acreage in the model agreed with the database. All of these vineyards are located in lower elevation areas within the GVAC watershed which are more prone to heavy frost (Figure 23).

The frost protection database also provides the number of acres using regular sprinklers versus micro-sprinklers and average application rates for each sprinkler type, however this data is not given for all of the registrations. Based on the reported proportions using each sprinkler type, an average application rate of 36.9 gal/min/ac was applied for all of the frost protected areas. Hourly temperature data was compiled for the Santa Rosa California Irrigation Management Information System (CIMIS) station located east of Sebastopol (CIMIS, 2005) which experiences temperatures similar to temperatures in the low-lying areas of the GVAC watershed (PRISM, 2010). The number of hours where temperatures were below 35 degrees between March 15th and May 15th of each year were tabulated to estimate the number of hours of frost protection application which ranged from 14 hours in 2014 to 110 hours in 2008. A time series of frost protection pumping was then developed from the temperature data and the average application rate (Figure 25).

Summary of Groundwater Pumping

Total estimated domestic groundwater pumping demand in the study area was 1,546 ac-ft/yr. Total estimated irrigation groundwater pumping demand was 726 ac-ft/yr. The frost protection groundwater pumping demand ranged from 81 ac-ft/yr in 2014 to 595 ac-ft/yr in 2008. Averaged over Water Years 2010 – 2014, domestic pumping represented 61% of the total demand, irrigation represented 28% of the total demand, and frost protection represented 11% of the demand (Figure 26). It is important to bear in mind that these breakdowns of demand by use category represent total annual demands and that the demands and distribution of demands by use category exhibit significant seasonal variability.

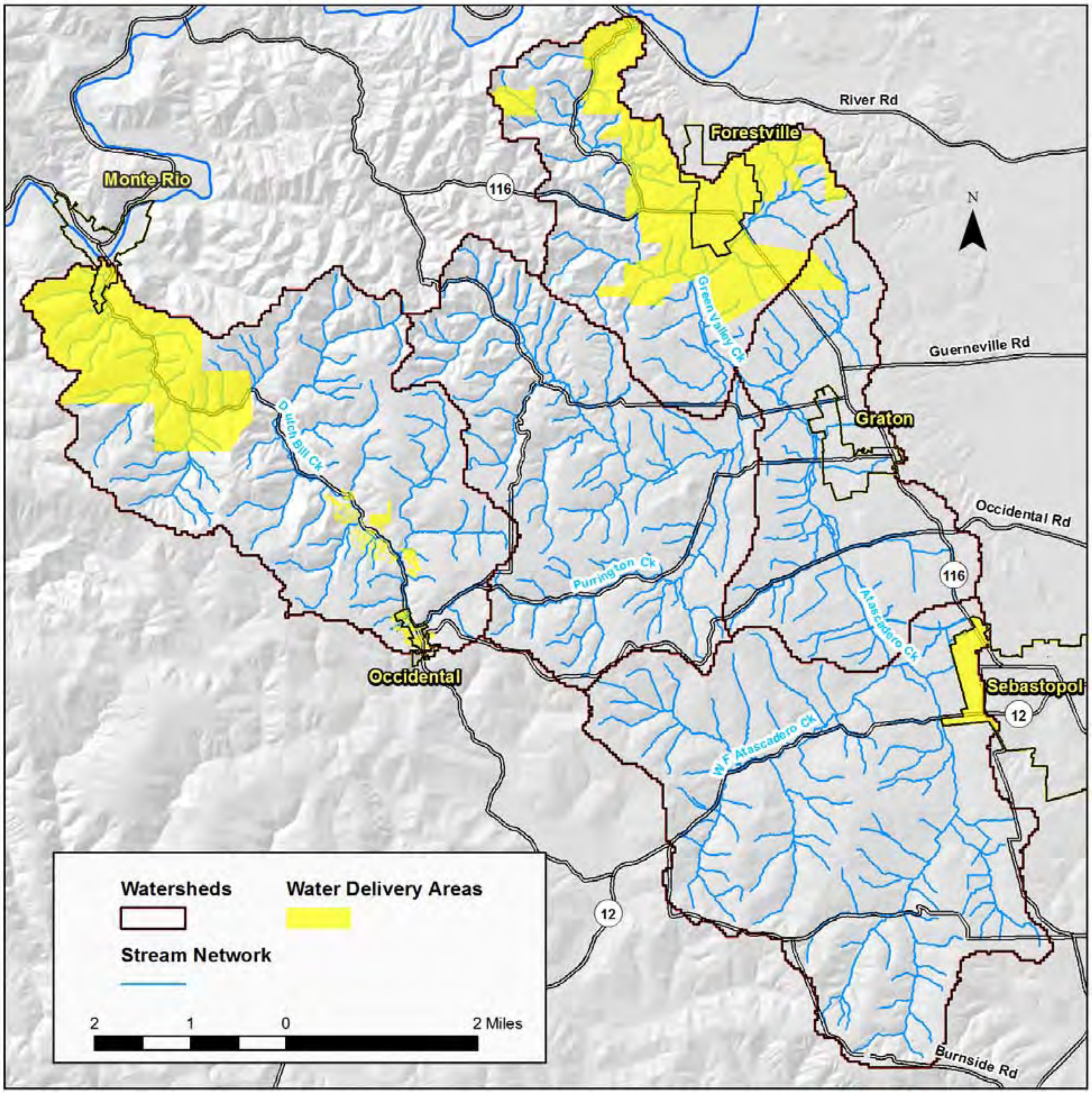


Figure 19 - Locations of water delivery areas and included in the hydrologic model.

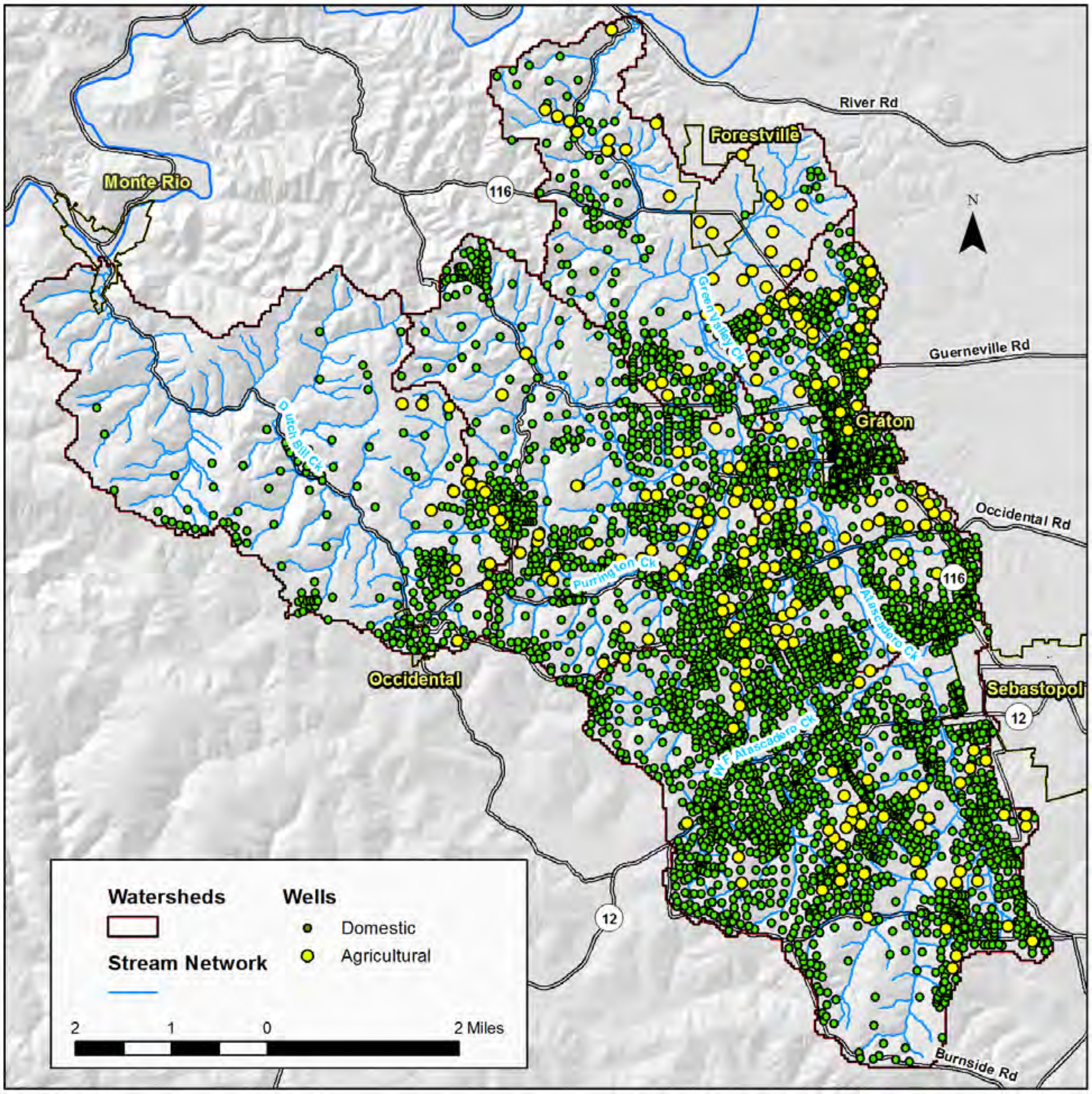


Figure 20 - Locations of groundwater pumping wells included in the hydrologic model.

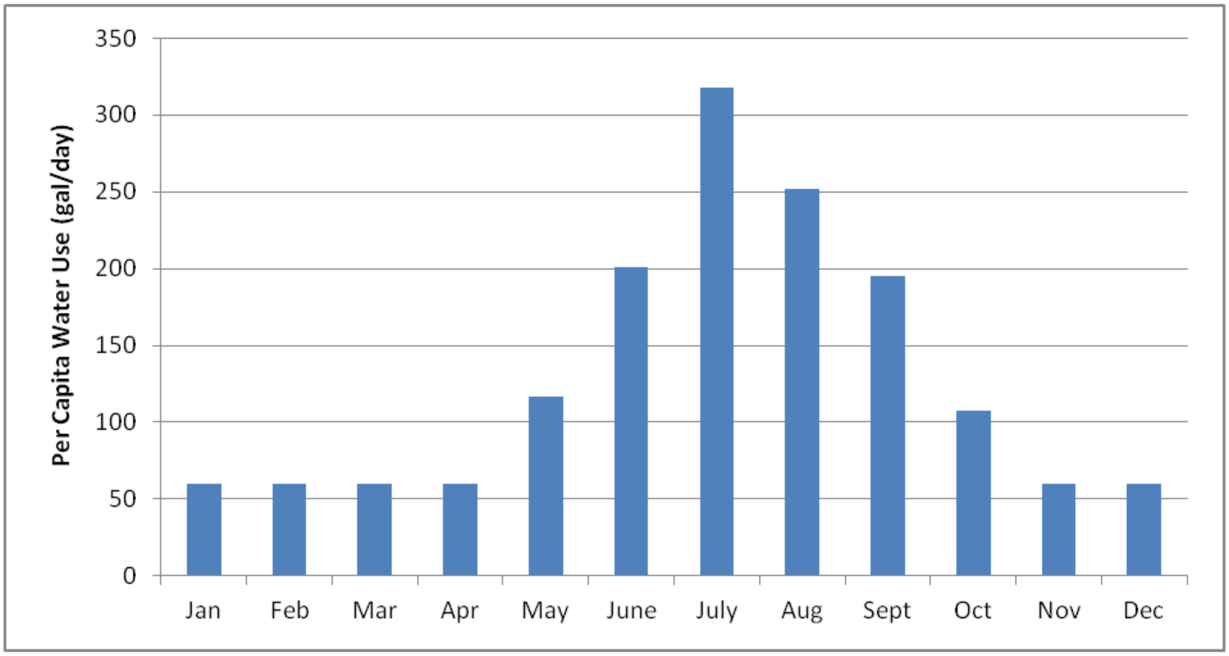


Figure 21 - Timeseries of per capita domestic groundwater pumping used in the hydrologic model.

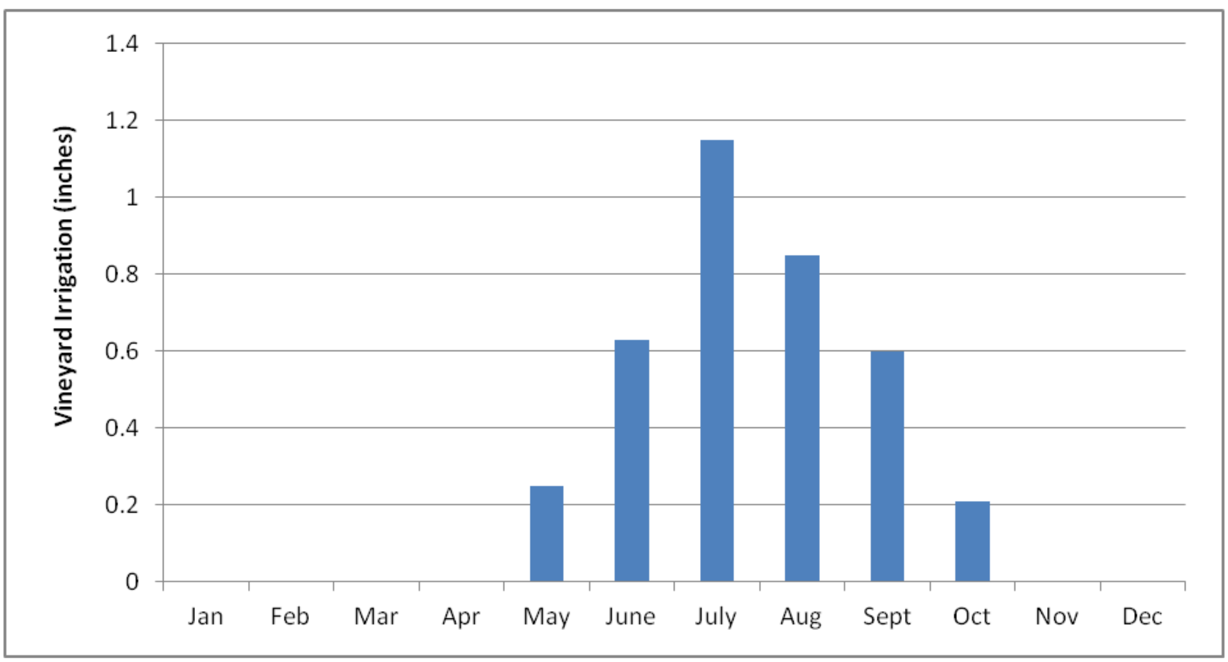


Figure 22 - Timeseries of groundwater pumping for irrigation used in the hydrologic model.

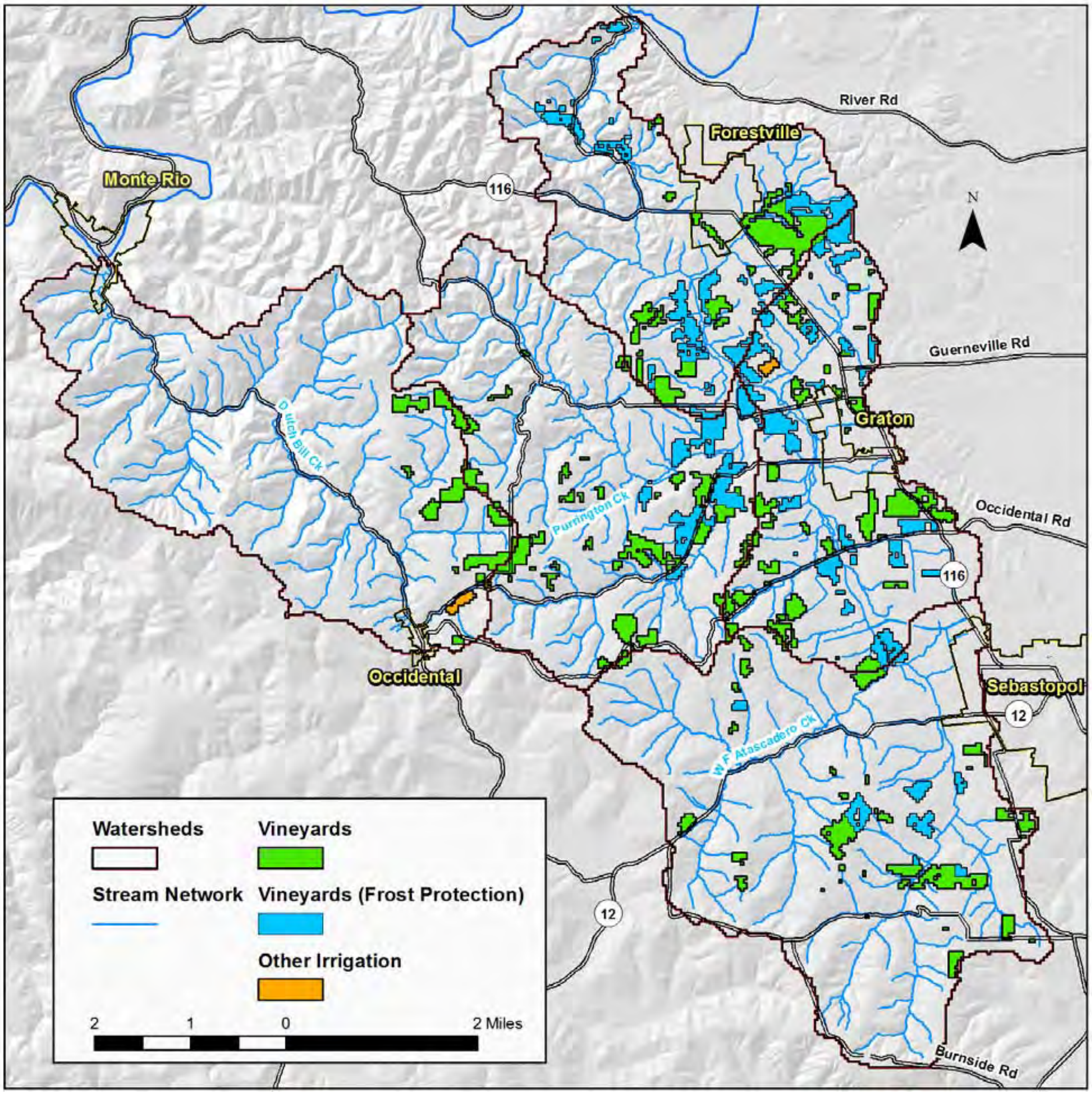


Figure 23 - Distribution of irrigation and frost protection used in the hydrologic model.

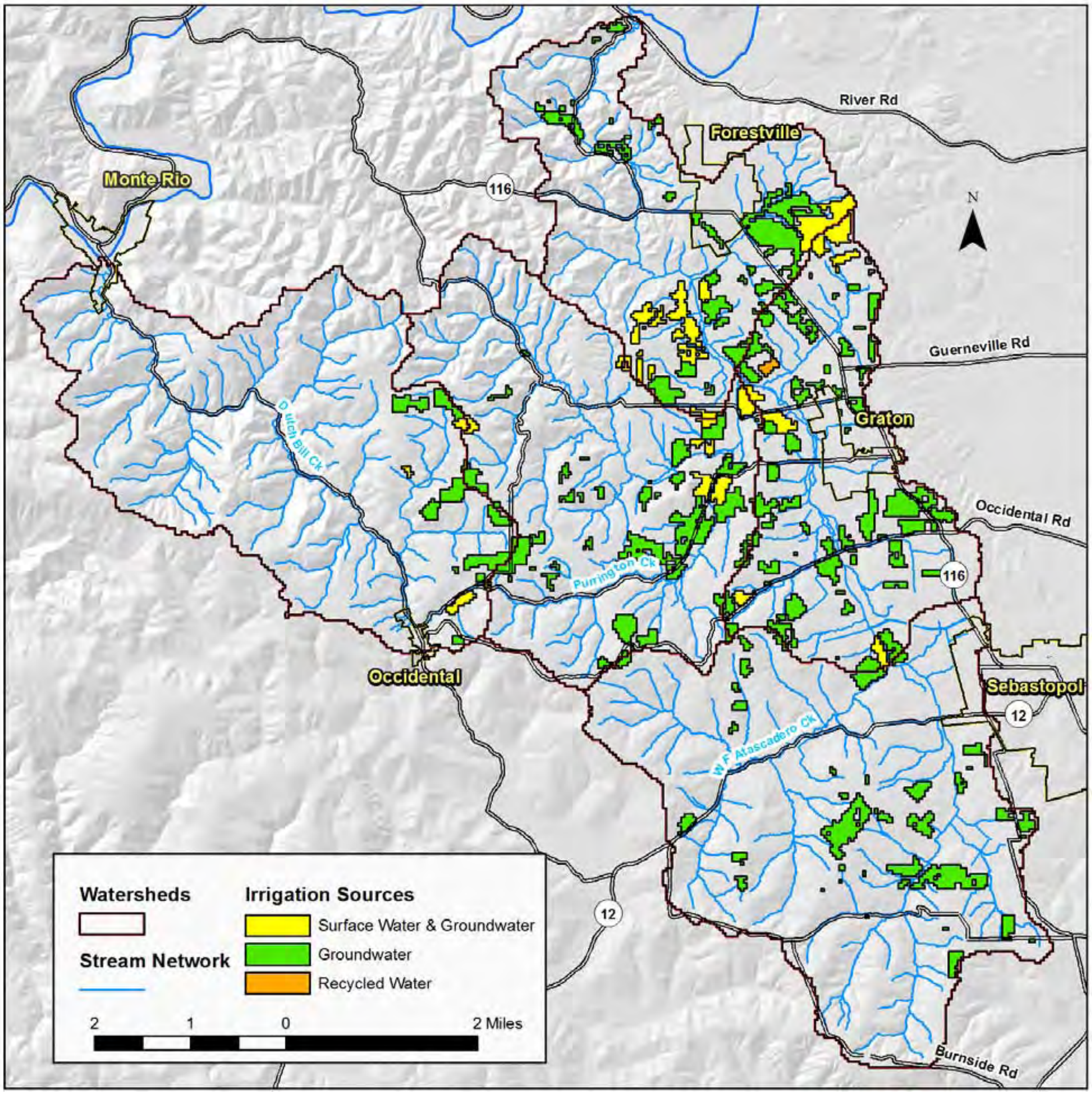


Figure 24 - Distribution of Irrigation sources used in the hydrologic model.

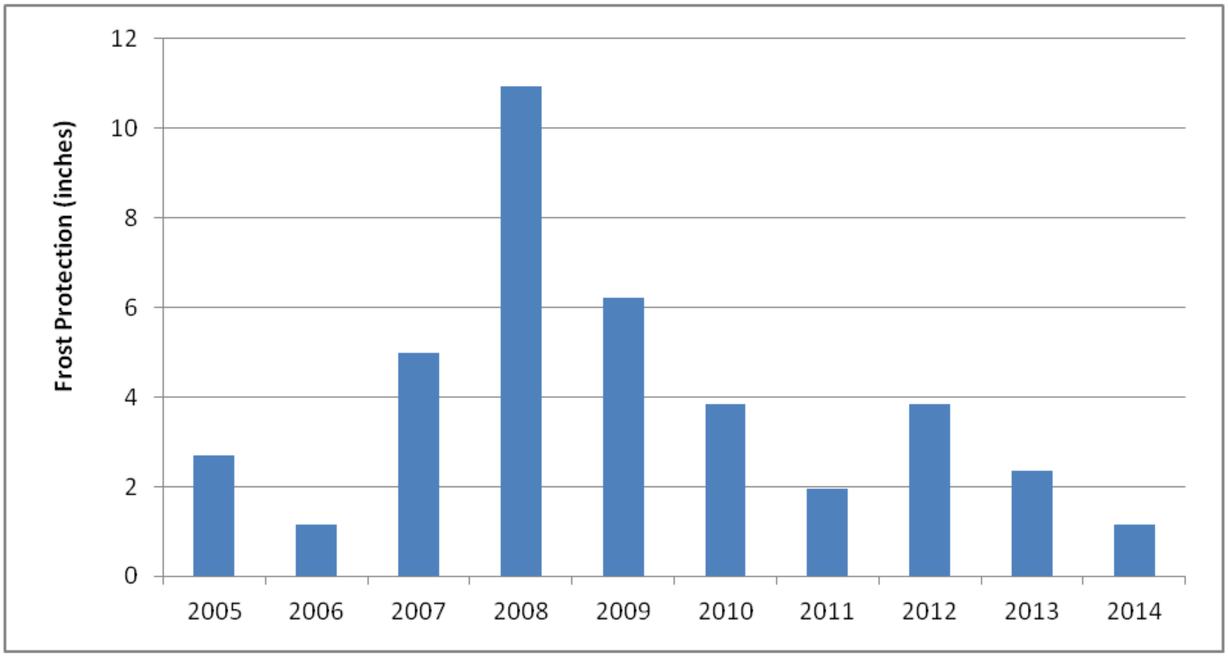


Figure 25 - Timeseries of groundwater pumping for frost protection used in the hydrologic model.

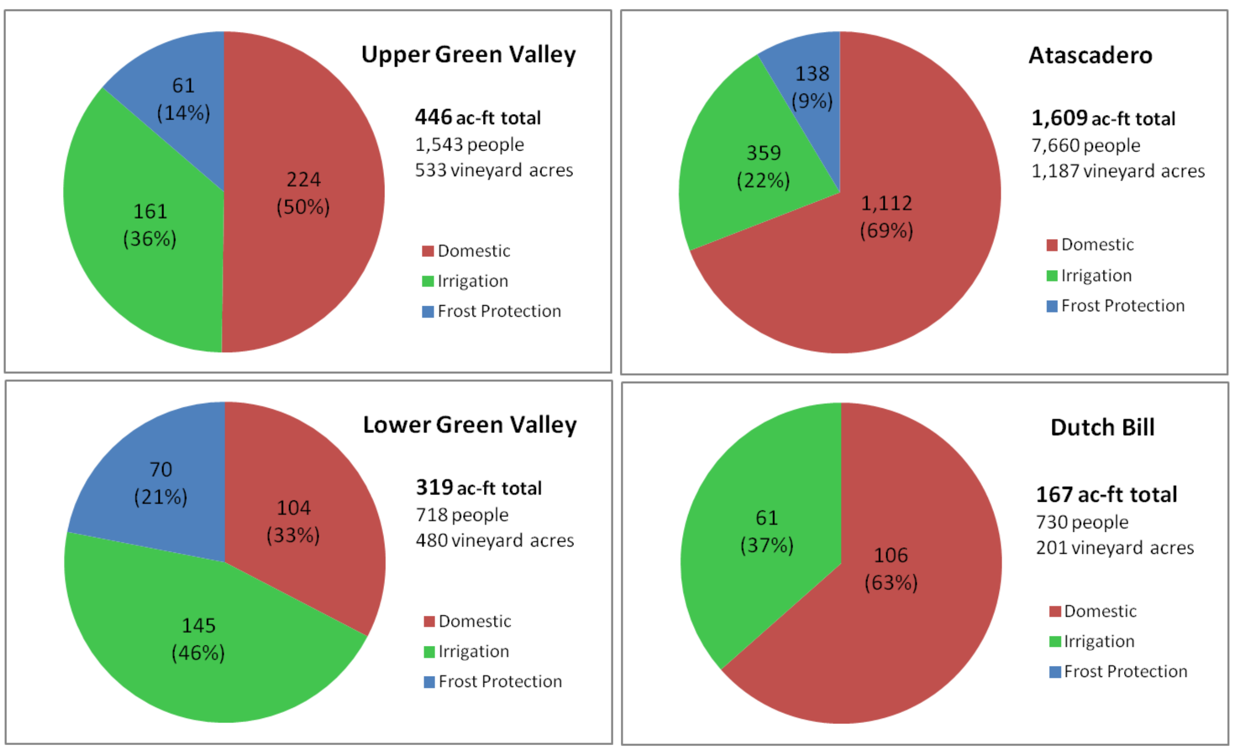


Figure 26 - Summary of groundwater pumping by use category and subwatershed.

Chapter 5 - Model Calibration

Overview

The available stream flow gauging data consists of data from three stations operated by the Center for Environmental Management and Restoration (CEMAR) in the DBC watershed, five stations operated by CEMAR in the GVC watershed, and three stations operated by the National Marine Fisheries Service (NMFS) in the AC watershed. The periods of record are short (Water Year 2010 or 2011 to present) at all of these gauges and complete rating curves extending throughout the range of recorded flow were not available for any of them. We obtained all of the available gauging measurements and selected seven of the eleven gauges for rating curve development (Table 8 & Figure 27). The rating curves generally consist of a single power-law relationship for higher flows and between two and four separate power-law relationships for lower flows with temporal shifts corresponding to larger flow events and associated changes in channel bed configurations. Confidence in the high flow rating curves was sufficient to develop continuous flow records for Dutch Bill Creek above Tyrone Road (DB04), Green Valley Creek at Bones Road (GV01), and Purrington Creek above Graton Road (GV02). At the remaining stations flow records were only calculated for flows less than or equal to the highest measured flow.

In addition to the gauging data, wet/dry mapping of portions of Dutch Bill, Green Valley, and Purrington Creeks was available from the University of California Cooperative Extension (UCCE). This data consists of maps showing flow conditions (flowing, dry, intermittent flow) during September of 2013 and 2014. UCCE has also performed periodic measurements of summer riffle depths in two short reaches each in Dutch Bill Creek and Green Valley Creek. Both the wet/dry mapping and the riffle depth measurements provided a means of validating the surface water component of the model once calibration to the gauging data was complete.

Bi-annual groundwater elevation measurements are available for six wells in the AC watershed and one well in the GVC watershed (Figure 27). All seven wells are part of the California Statewide Groundwater Elevation Monitoring (CASGEM) program (CASGEM, 2014) and all are completed in the Wilson Grove Formation. At most locations measurements were taken in the Fall and Spring with data available between Fall 2011 and Fall 2014 (Table 8). A groundwater elevation contour map was interpolated for Spring 2012 using data from these wells and several others located in the adjacent Santa Rosa Plain (Figure 18) to assist in validating the groundwater component of the model.

Calibrating a complex integrated hydrologic model such as MIKE SHE can be difficult owing to the large number of model parameters and long model run-times. The calibration process involved running an initial sensitivity analysis to identify a subset of parameters that the model results are most sensitive to. An upper and lower bound for each parameter was then defined based on a review of literature values and available watershed data. The model was then calibrated by adjusting one or more parameters in order to achieve a reasonable water balance and optimum fit between measured and simulated stream flows and groundwater elevations. Given the focus of this study on quantifying stream flow conditions to assist in fisheries habitat restoration planning, the bulk of the calibration emphasis was on simulating summer base flow conditions as accurately as possible. The parameters that were adjusted during calibration included the following: horizontal and vertical hydraulic conductivities, streambed leakage coefficients, unsaturated hydraulic conductivities, overland Manning's roughness coefficients, drainage levels, and drainage time constants.

Table 8 - Summary of available stream flow gauges for the study area.

Gauge Name	Symbol	Type	Period of Record	% Complete	# Rating Curve Observations	Highest Gauged Flow (cfs)
Purrington Creek at Graton Road	GV02	Continuous	2/2010 - 3/2014	89	32	134
Green Valley Creek at Bones Road	GV01	Continuous	1/2010 - 7/2014	89	25	156
Dutch Bill Creek above Tyrone Road	DB04	Continuous	6/2011 - 10/2013	97	19	365
Green Valley Creek above Atascadero	GV03	Low Flow Only	6/2010 - 7/2014	93	29	399
Green Valley Creek at Martinelli Road	GV06	Low Flow Only	4/2011 - 6/2011	100	6	27
Atascadero Creek at Watertrough Road	AT01	Low Flow Only	11/2010 - 6/2013	65	16	51
Atascadero Creek at Mill Station Road	AT02	Low Flow Only	11/2010 - 6/2013	65	14	36

Table 9 - Summary of available groundwater observation data for the study area.

Well ID	Symbol	Period of Record	# Measurements
383588N1228706W001	UA1	10/2011 - 10/2014	7
383971N1228879W001	MA1	11/2011 - 10/2014	7
383998N1228713W001	MA2	10/2011 - 10/2014	7
384111N1228448W001	MA3	4/2012 - 10/2014	6
384351N1228597W001	LA1	10/2011 - 10/2014	7
384505N1228683W001	LA2	4/2012 - 10/2014	6
384387N1229005W001	GV1	10/2011 - 10/2014	3

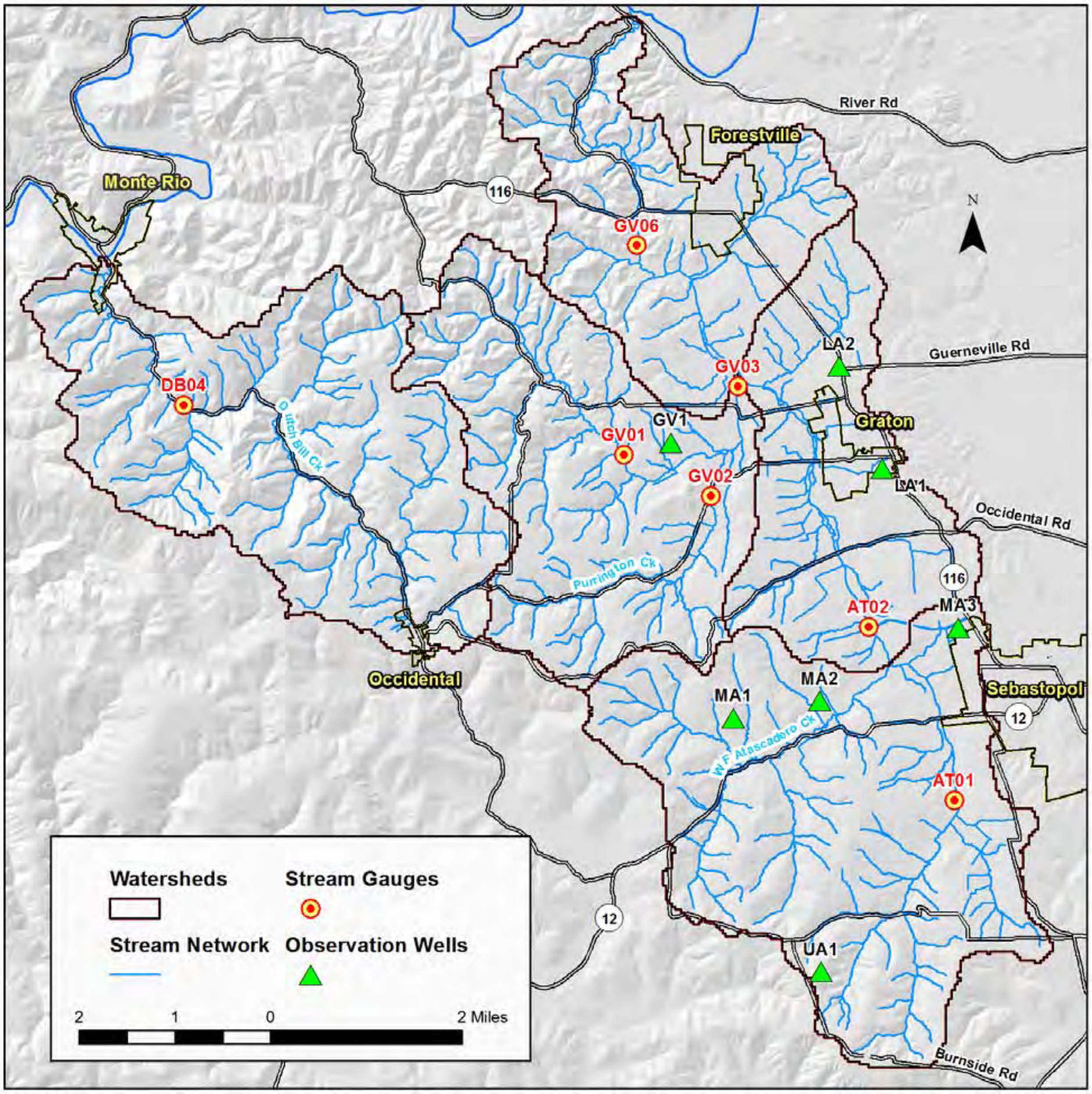


Figure 27 - Locations of stream flow gauging stations and groundwater observation wells located in the study area.

Surface Water Calibration

Three goodness-of-fit statistics were used to evaluate the agreement between model simulated stream discharges and measured stream discharges. These statistics included the Mean Error (ME), Root Mean Square Error (RMSE), and the Nash-Sutcliffe model efficiency coefficient (NSME) (Nash and Sutcliffe, 1970). ME and RMSE provide an overall measure of the model bias and have been calculated for the full period of record at the three gauges with sufficient high flow rating curves and for all seven gauges for the May through September low flow period.

The NSME provides an overall measure of the predictive capability of the model. A NSME value of zero indicates that model predictions are as accurate as the mean of the measured data and a value of one indicates a perfect calibration. NSME has only been calculated for the three gauges with high flow rating curves deemed sufficient for developing continuous flow records. Given the uncertainties in the high flow rating curves, the NSME calculations excluded days when observed discharges exceeded the highest gauged flow (see Table 8).

Due to the limited periods of record at the available gauging locations it was deemed more appropriate to calibrate the model to all of the available data rather than divide the simulation into calibration and validation periods as is more typically done when long-term gauging data is available. Figures 28 through 31 show the comparison between model simulated and measured discharges for the three gauges with continuous flow records. Figures 32 through 35 show the comparison between model simulated and measured discharges for all of the selected gauges focusing on the low flow period that is most critical from a coho habitat perspective. Calibration statistics are presented in Table 10.

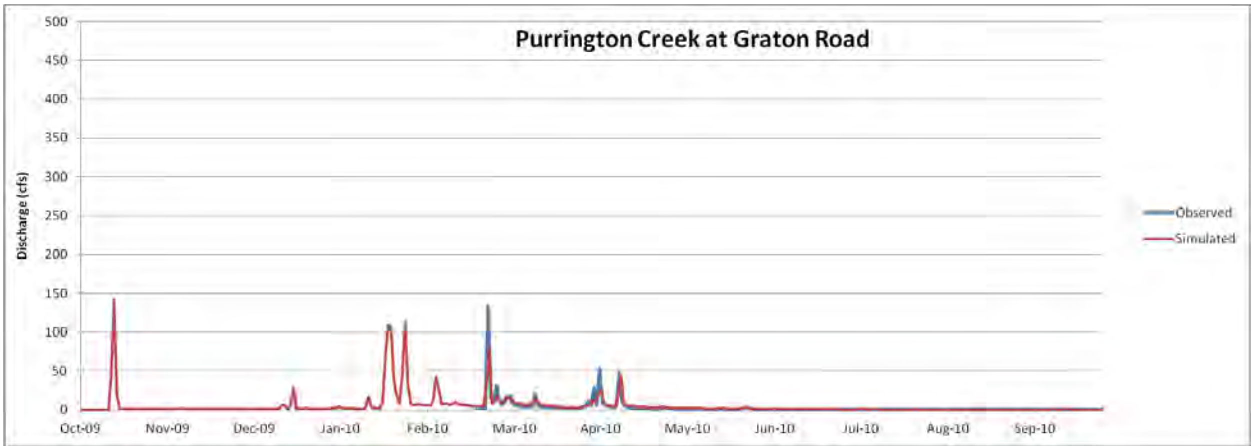
The match between simulated and measured stream flows was generally good at all three of the continuous gauging locations. The model reproduces the quick responses in stream flow during runoff events that is characteristic of the watersheds as well as the overall shape of rising and receding flows. RMSE values ranged from 6.7 to 7.8 cfs and NSME values ranged from 0.67 to 0.73. The largest errors occur during the largest runoff events where the model sometimes significantly over-predicts peak flows and significantly under-predicts at other times. Given the uncertainties in the high flow rating curves at these gauges and the fact that the bulk of the calibration effort was focused on low flow periods most critical for understanding coho habitat, these differences are not surprising.

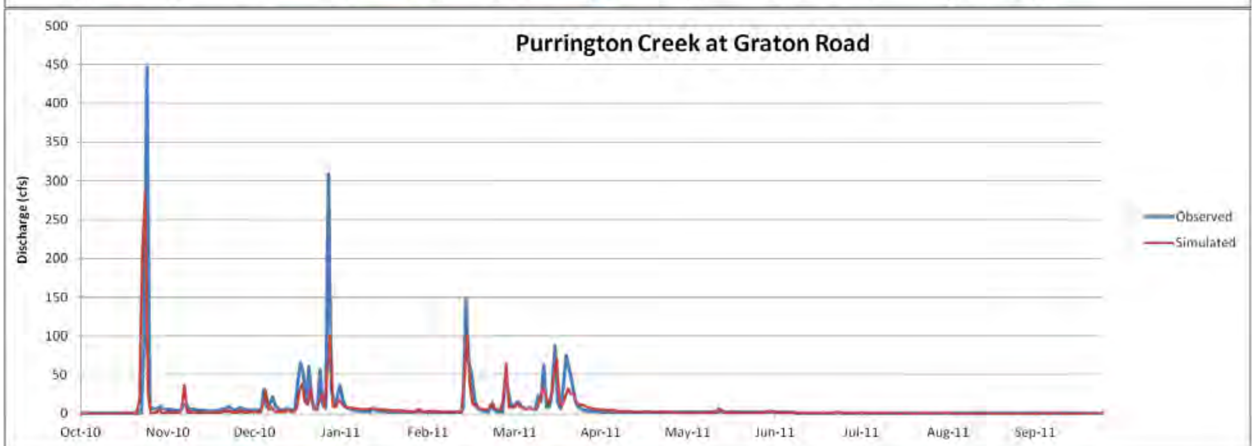
During low flow periods most critical for understanding coho habitat, the model performance is generally very good. Both the shape and timing of the spring flow recessions as well as the magnitudes of summer baseflow are generally well-represented by the model. RMSE values for the May through September low flow period ranged from 0.1 cfs at the Purrington Creek at Graton Road and Green Valley Creek at Bones Road gauges to 1.6 cfs at the Atascadero Creek at Mill Station Road gauge. The overall tendency of the model is to over-predict low flows somewhat particularly during the spring flow recession and in the late summer and early fall when stream flows drop close to zero.

The model appears to significantly over-predict flows during certain runoff events including three events in October of 2010, 2011, and 2012, however closer examination of the precipitation data suggests that these differences may be an artifact of inaccuracies in the rainfall records. For example, the model predicts a large peak on October 24, 2010 and the Graton rainfall gauge recorded 5.5 inches of precipitation on this date whereas the Occidental gauge recorded zero rainfall. Similar discrepancies were found for events on October 5, 2011 and October 22, 2012 where the model predicts significant peak discharge, the Graton gauge recorded 1.2 inches of precipitation, and the Occidental gauge recorded zero or 0.1 inches. Additionally, significant runoff is recorded at several of the stream gauges between October 26, 2011 and October 29, 2011 which the model does not capture because both rainfall gauges recorded zero rainfall on these dates. General consistency between the two rainfall records and generally good agreement between the timing of model simulated and measured stream flow events suggests that these problems with the rainfall records are relatively isolated.

Table 10 - Stream flow calibration results.

Gauge Name	Time Period	ME (cfs)	RMSE (cfs)	NSME
Purrington Creek at Graton Road	Continuous	-0.1	6.7	0.73
Green Valley Creek at Bones Road	Continuous	1.2	7.8	0.67
Dutch Bill Creek above Tyrone Road	Continuous	2.4	7.8	0.76
Purrington Creek at Graton Road	May - Sept	0.3	0.1	-
Green Valley Creek at Bones Road	May - Sept	0.0	0.1	-
Dutch Bill Creek above Tyrone Road	May - Sept	-0.2	0.8	-
Green Valley Creek above Atascadero	May - Sept	0.5	0.4	-
Green Valley Creek at Martinelli Road	May - Sept	0.6	1.1	-
Atascadero Creek at Watertrough Road	May - Sept	0.6	0.5	-
Atascadero Creek at Mill Station Road	May - Sept	1.6	1.6	-





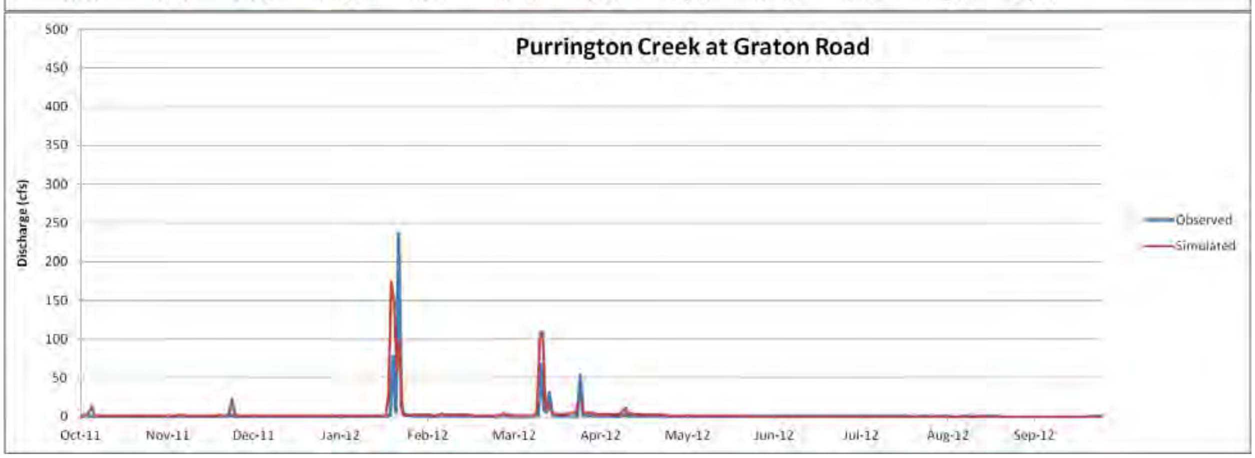
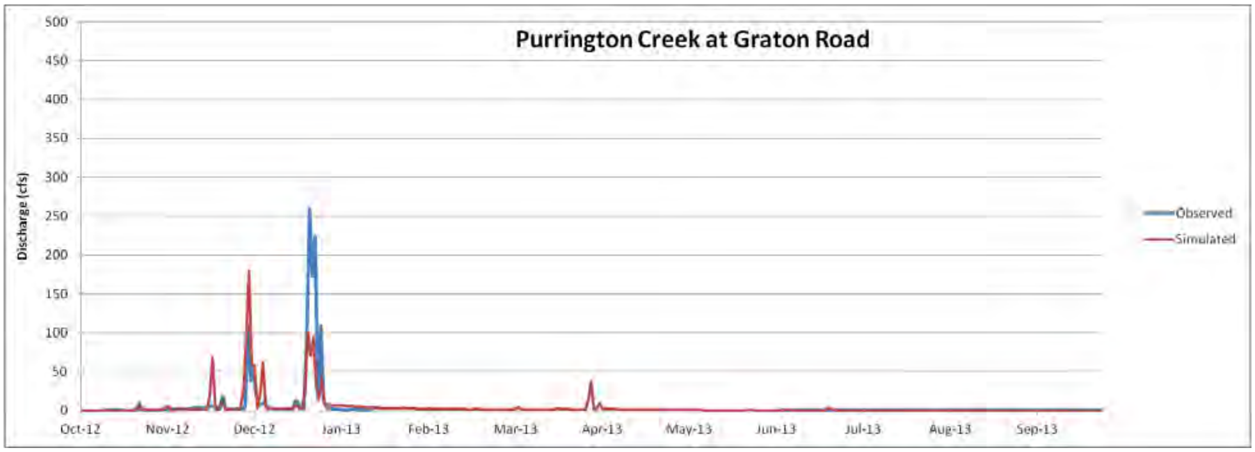


Figure 28 - Comparison of measured and simulated stream flows for WY 2010 - 2013 for Purrington Creek at Graton Road.



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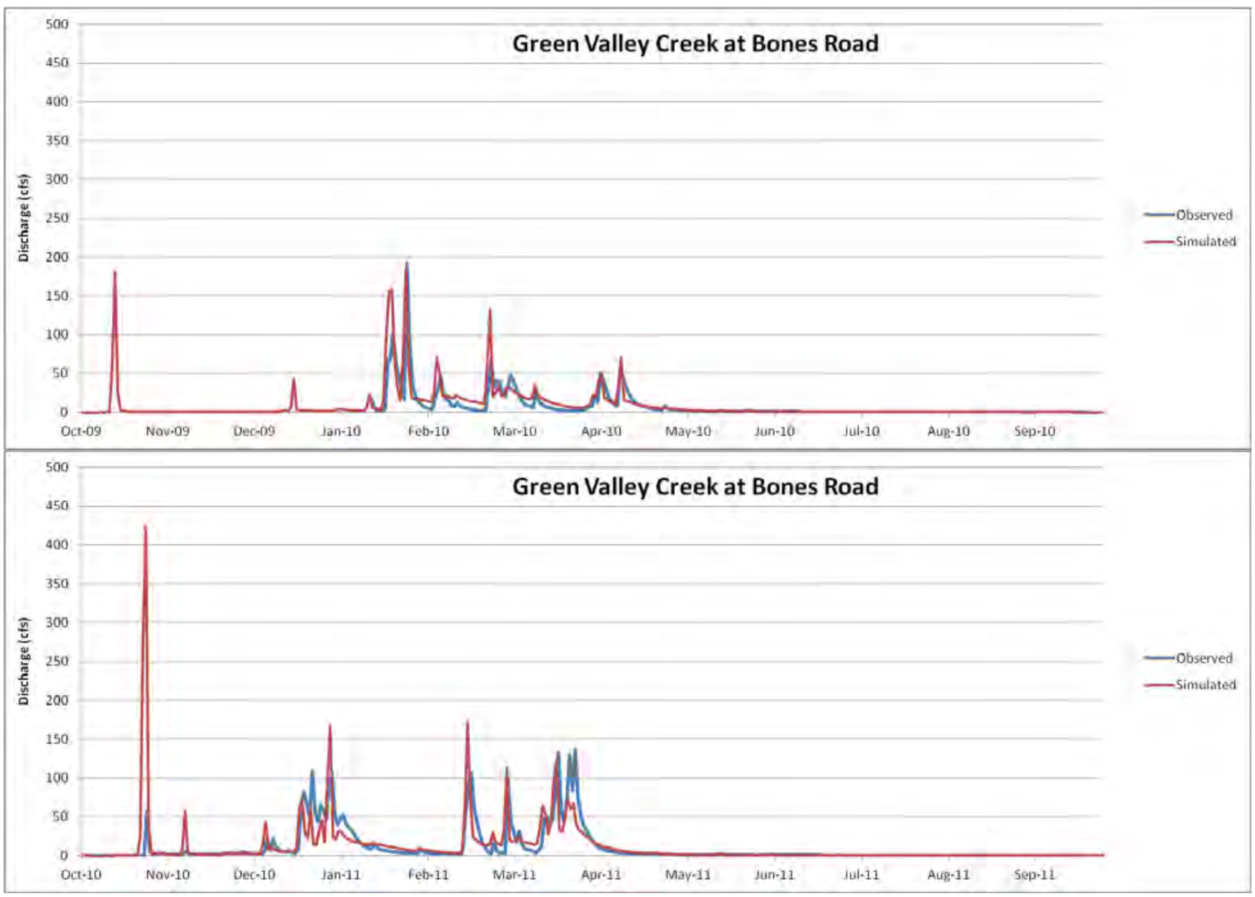
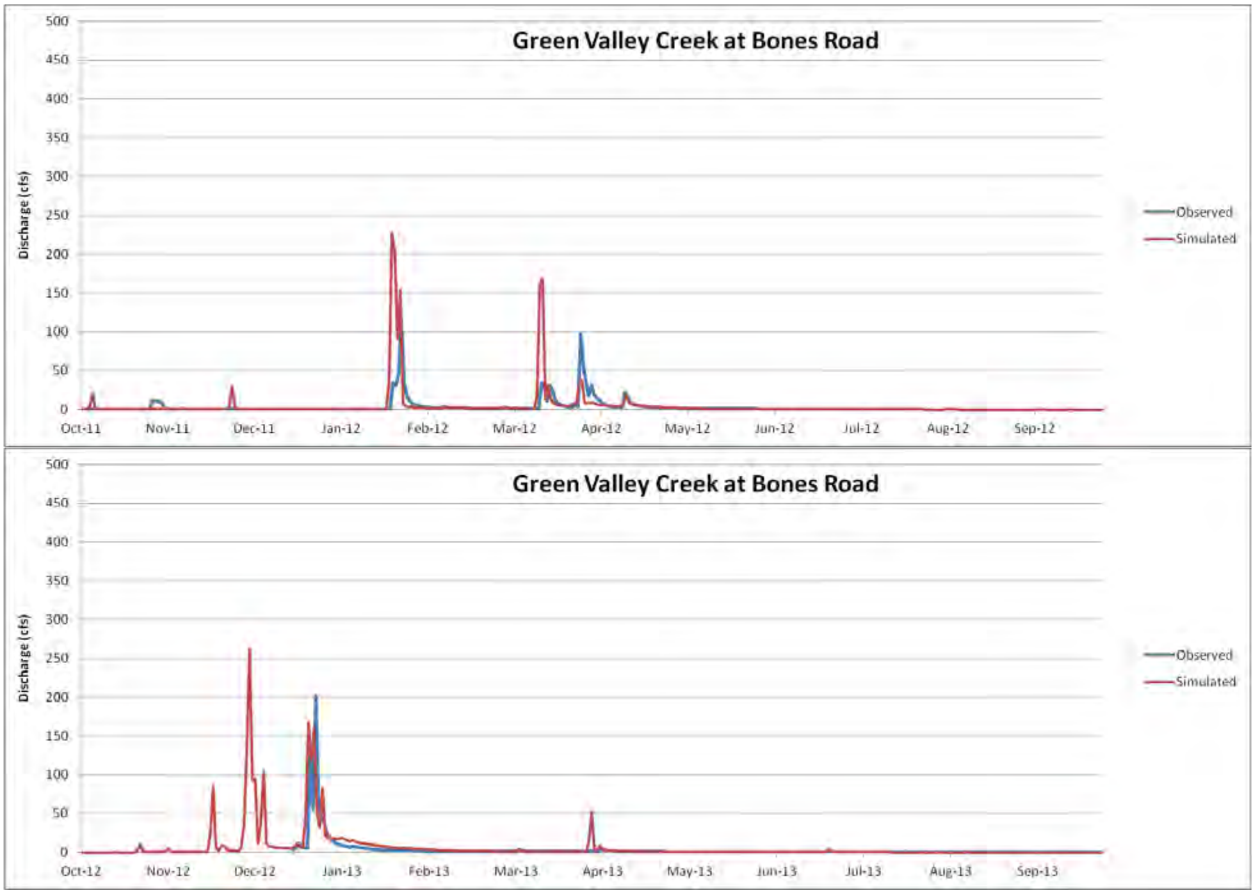


Figure 29 - Comparison of measured and simulated stream flows for WY 2010 - 2013 for Green Valley Creek at Bones Road.



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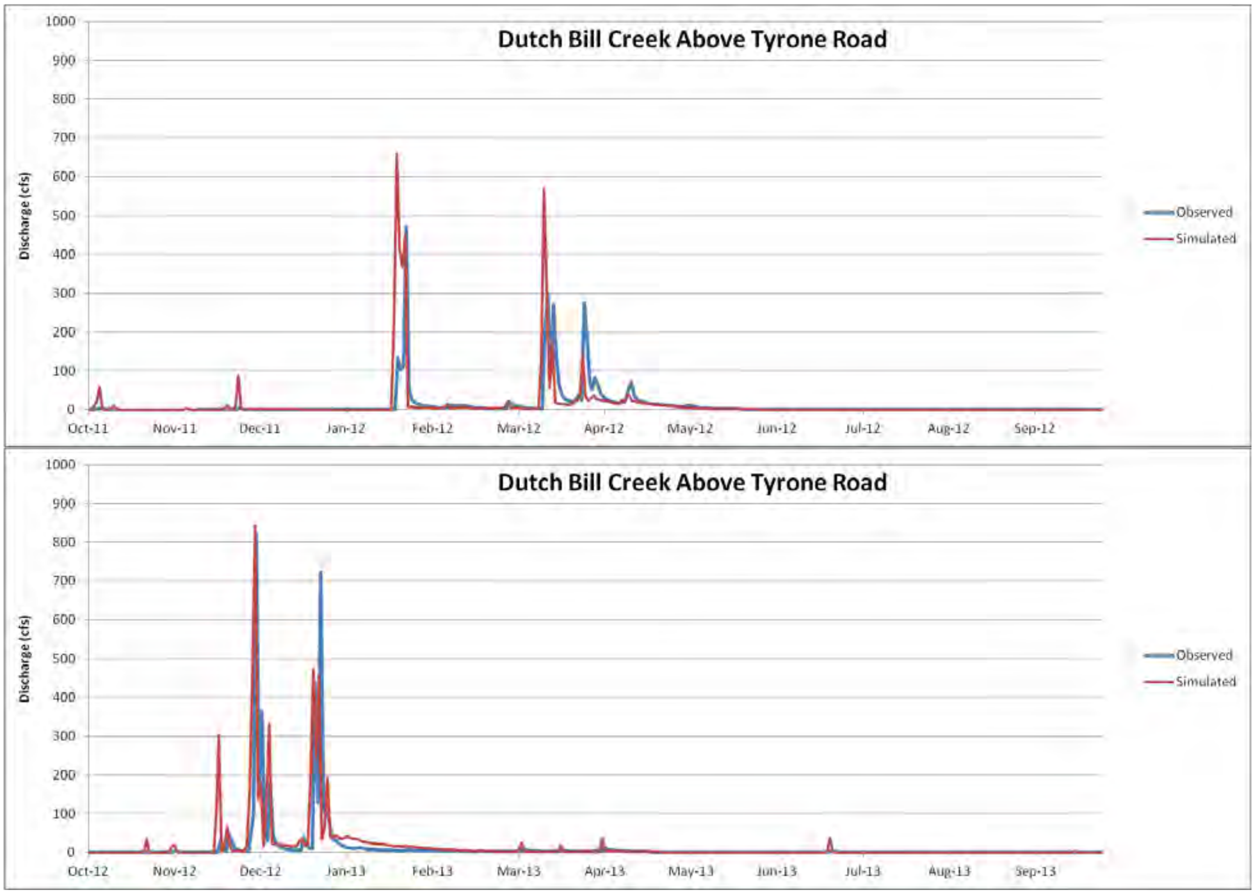


Figure 30 - Comparison of measured and simulated stream flows for WY 2012 - 2013 for Dutch Bill Creek above Tyrone Road.

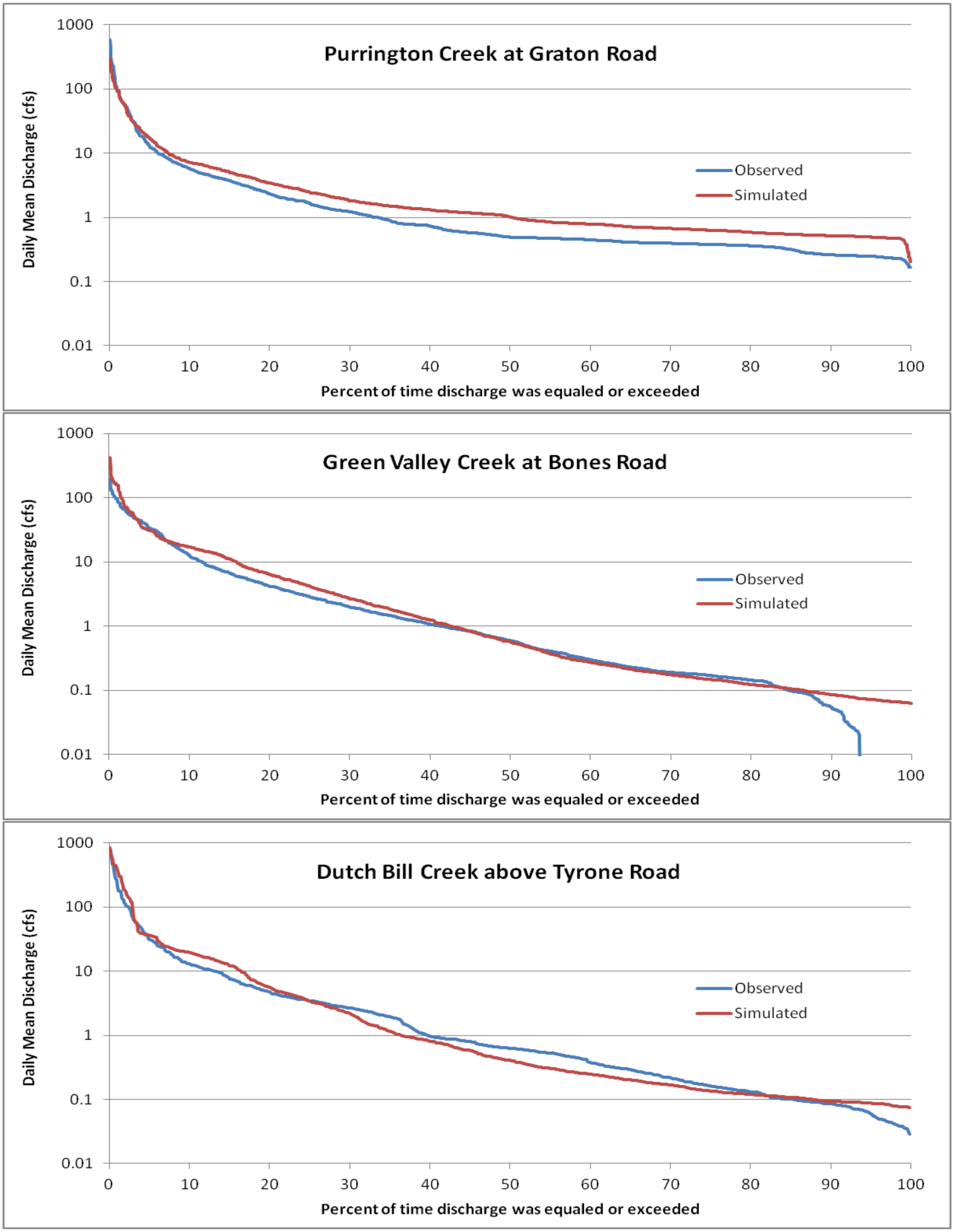


Figure 31 - Comparison of measured and simulated flow durations curves for Purrington Creek at Graton Road, Green Valley Creek at Bones Road, and Dutch Bill Creek above Tyrone Road.

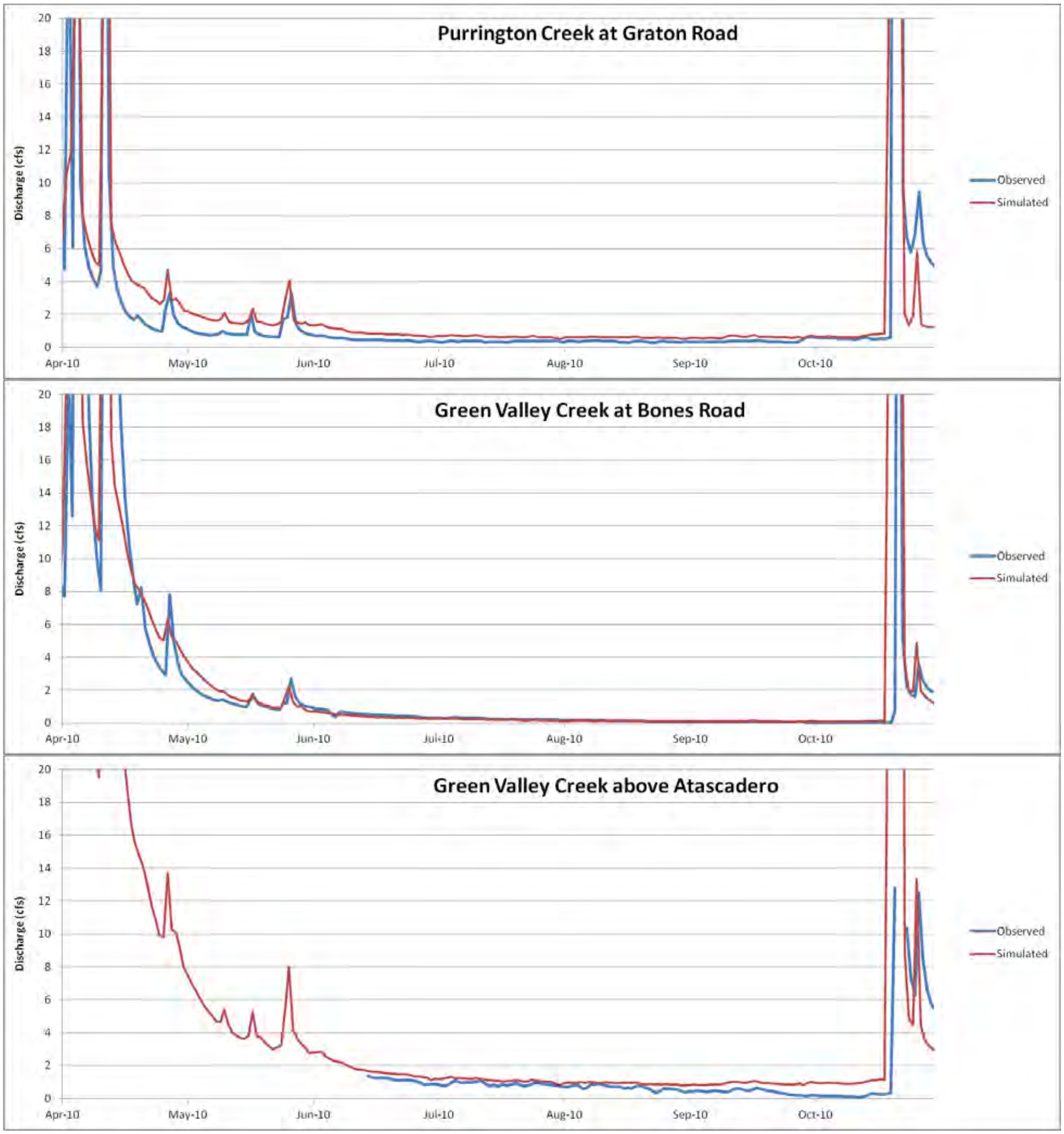


Figure 32 - Comparison of measured and simulated stream flows for the WY 2010 summer baseflow period at all gauging locations with available data.

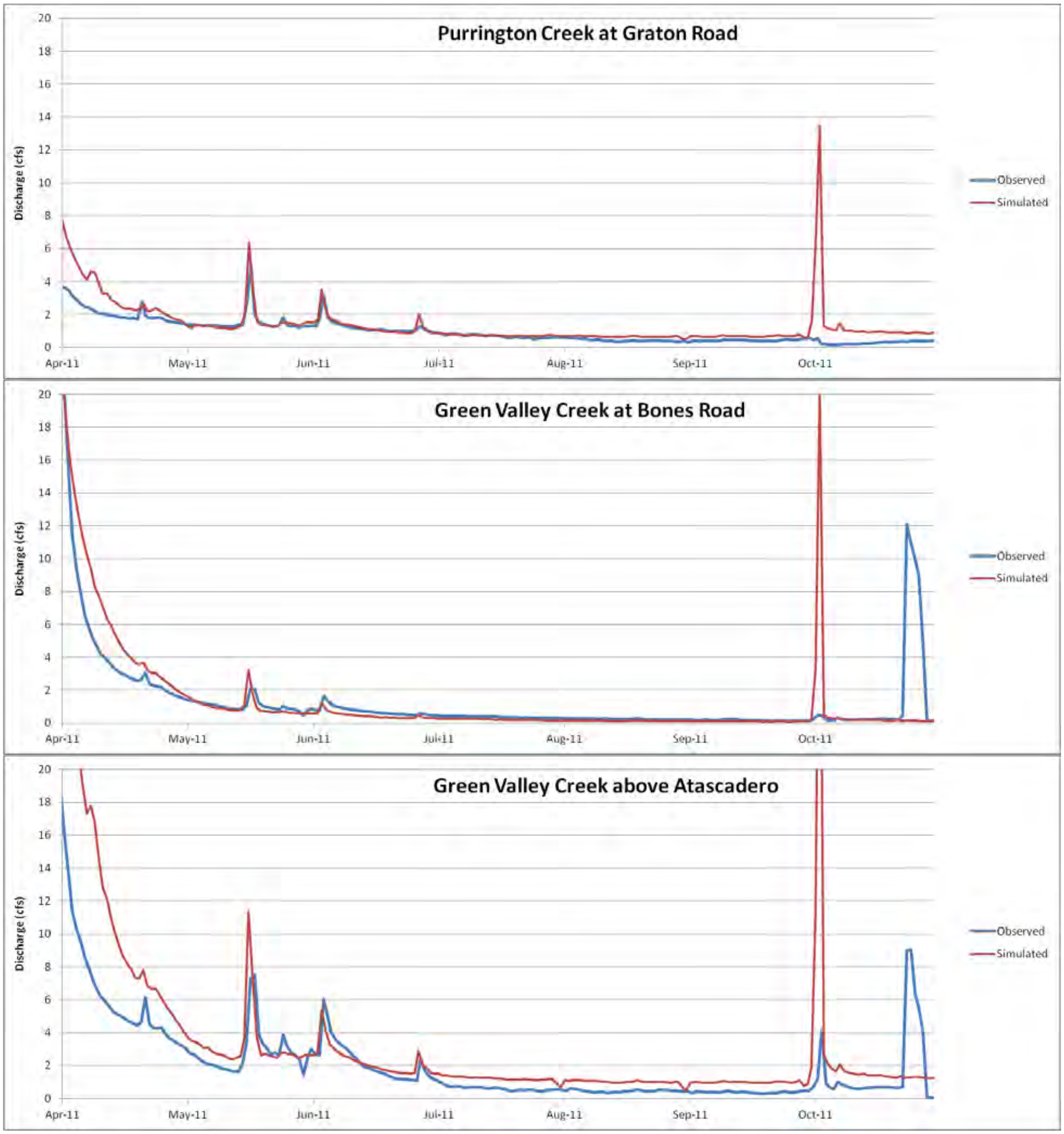


Figure 33 - Comparison of measured and simulated stream flows for the WY 2011 summer baseflow period at all gauging locations with available data.

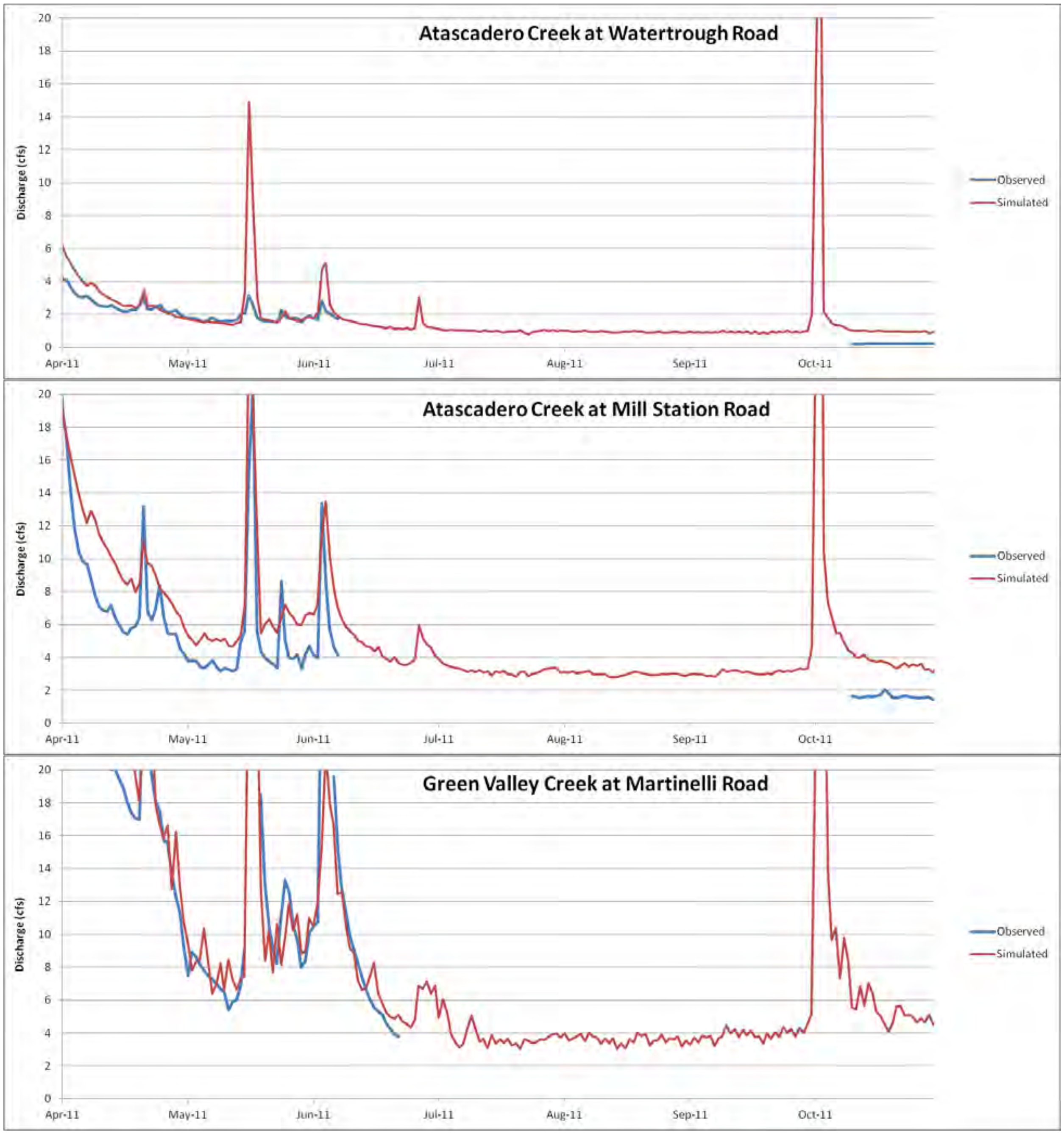
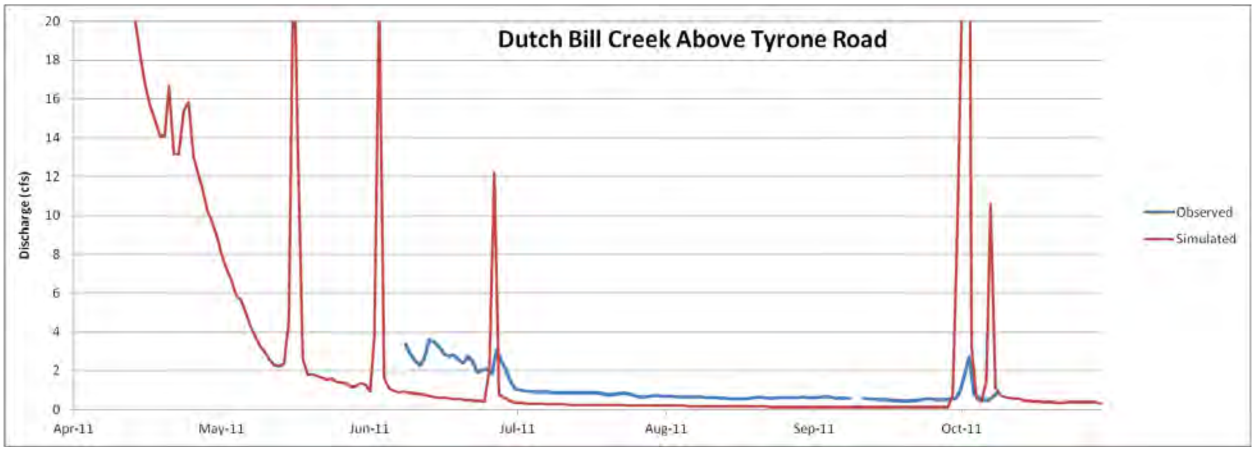


Figure 33 (continued)



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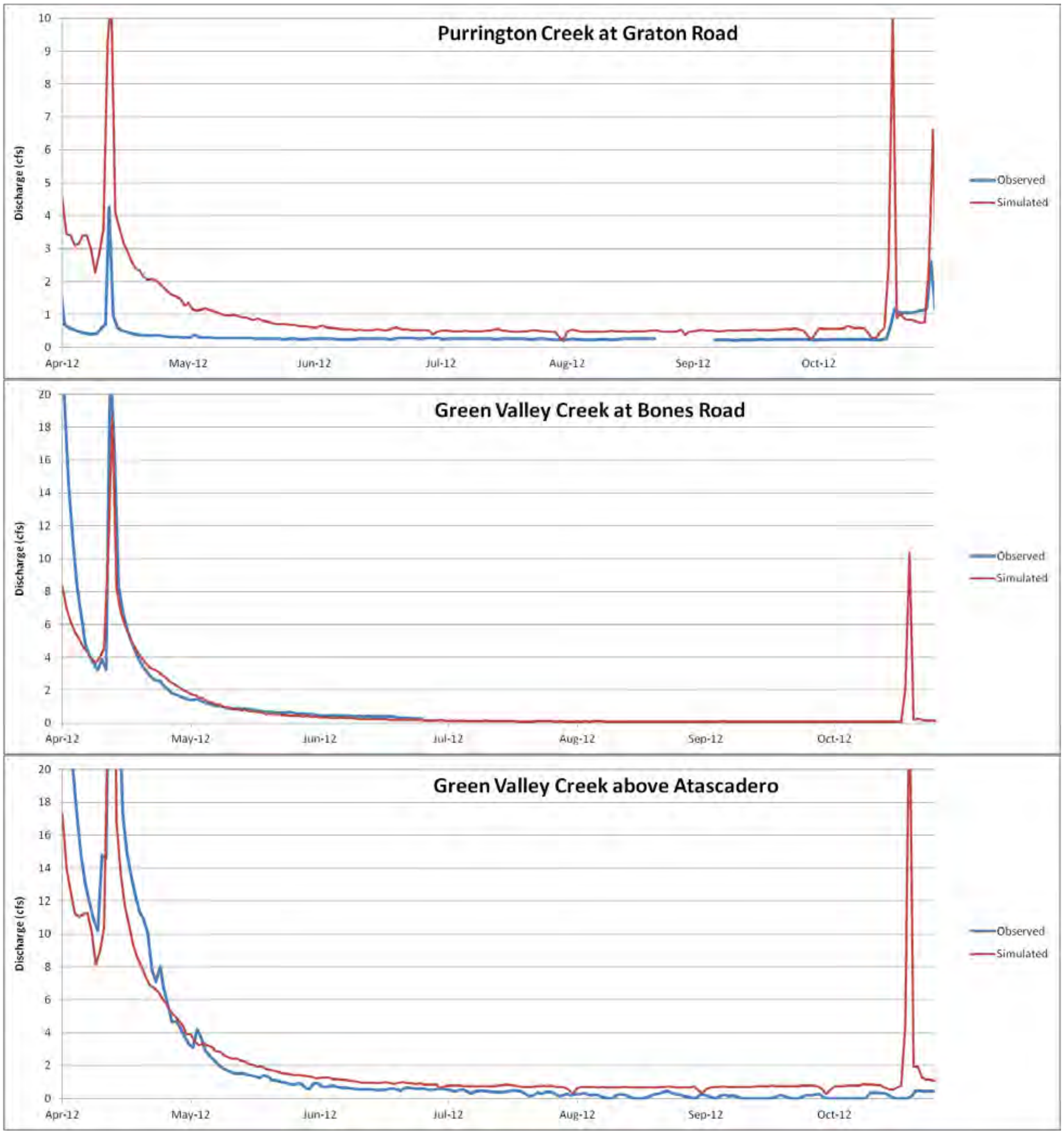
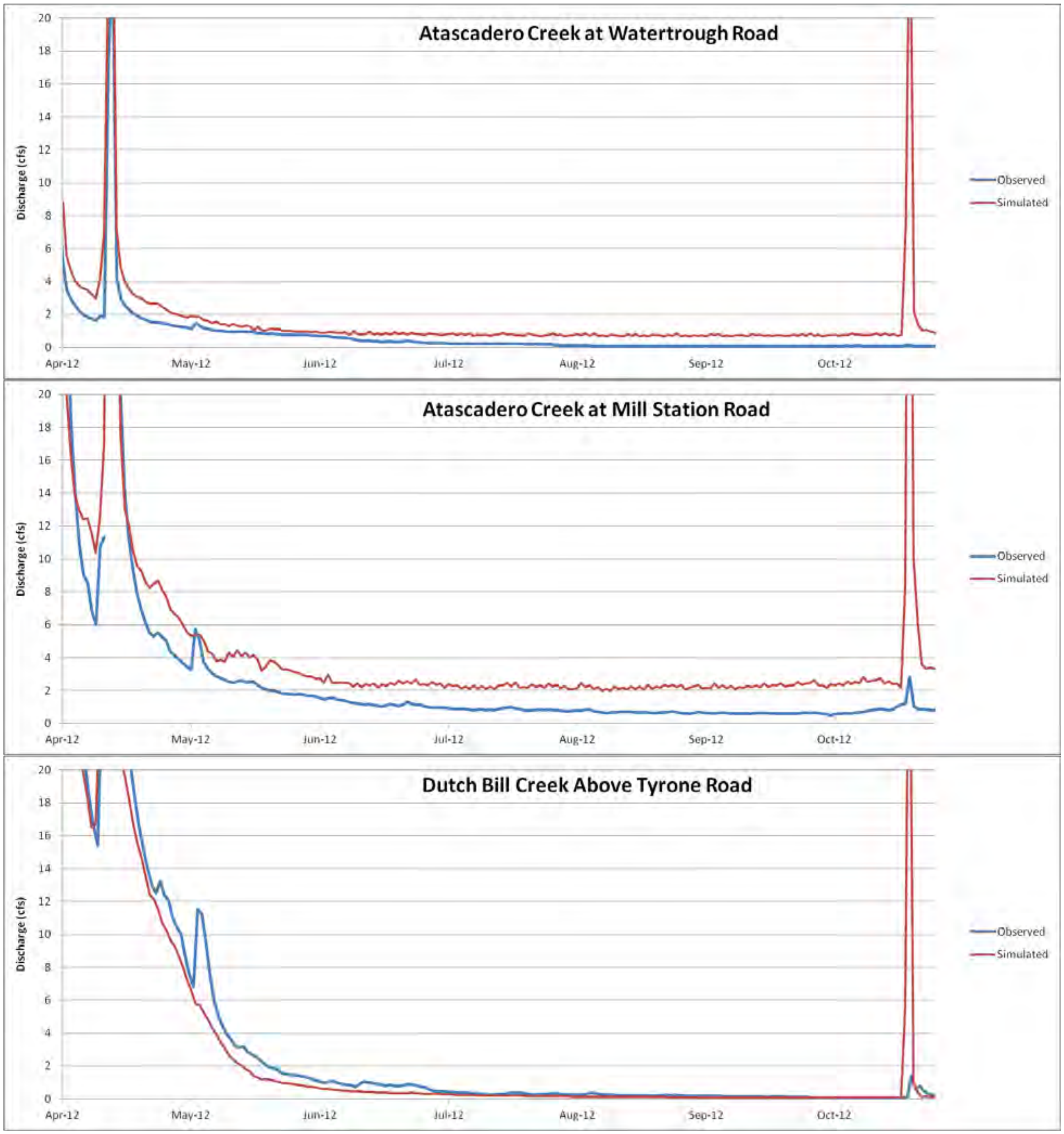


Figure 34 - Comparison of measured and simulated stream flows for the WY 2012 summer baseflow period at all gauging locations with available data.



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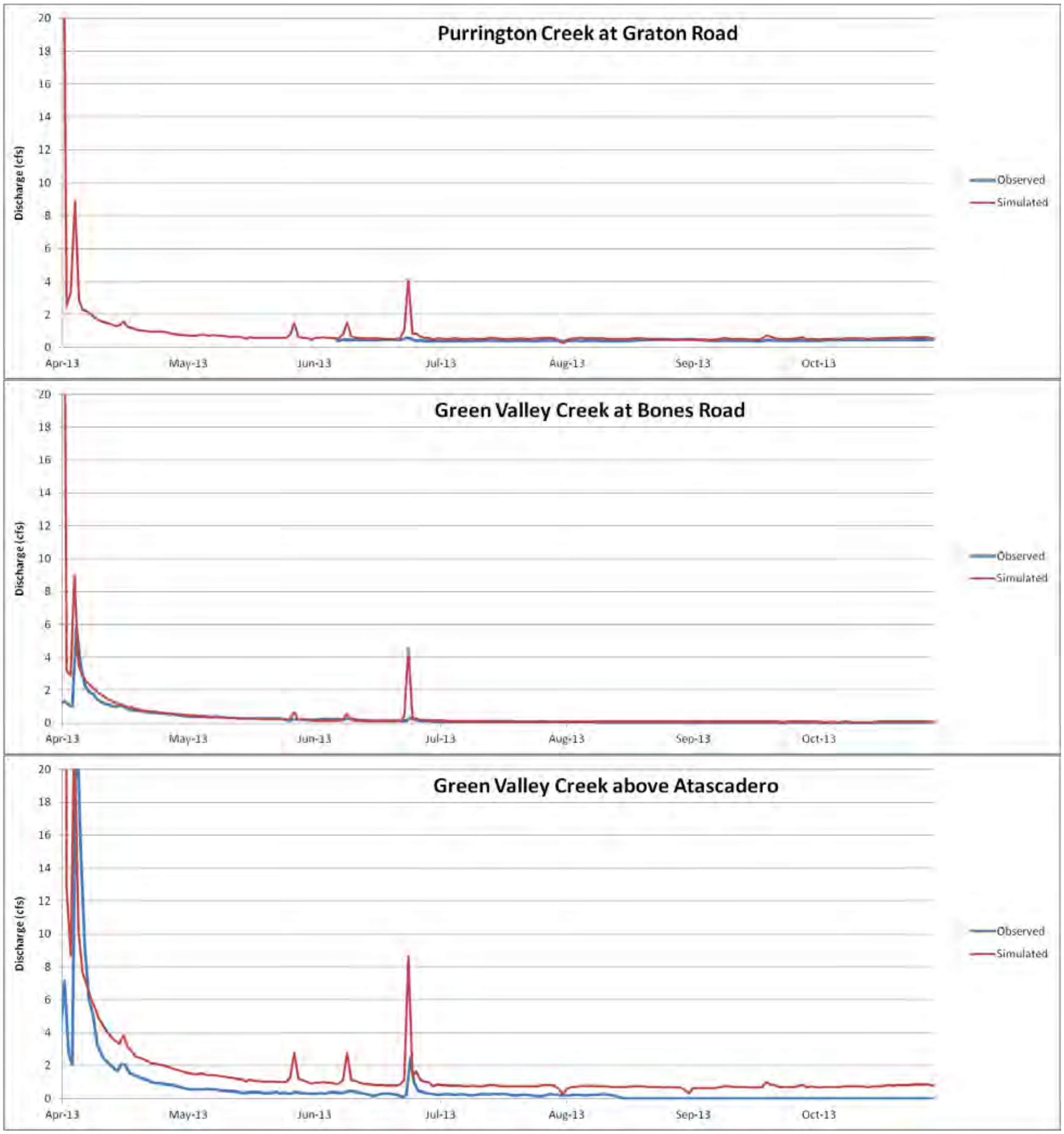


Figure 35 - Comparison of measured and simulated stream flows for the WY 2013 summer baseflow period at all gauging locations with available data.

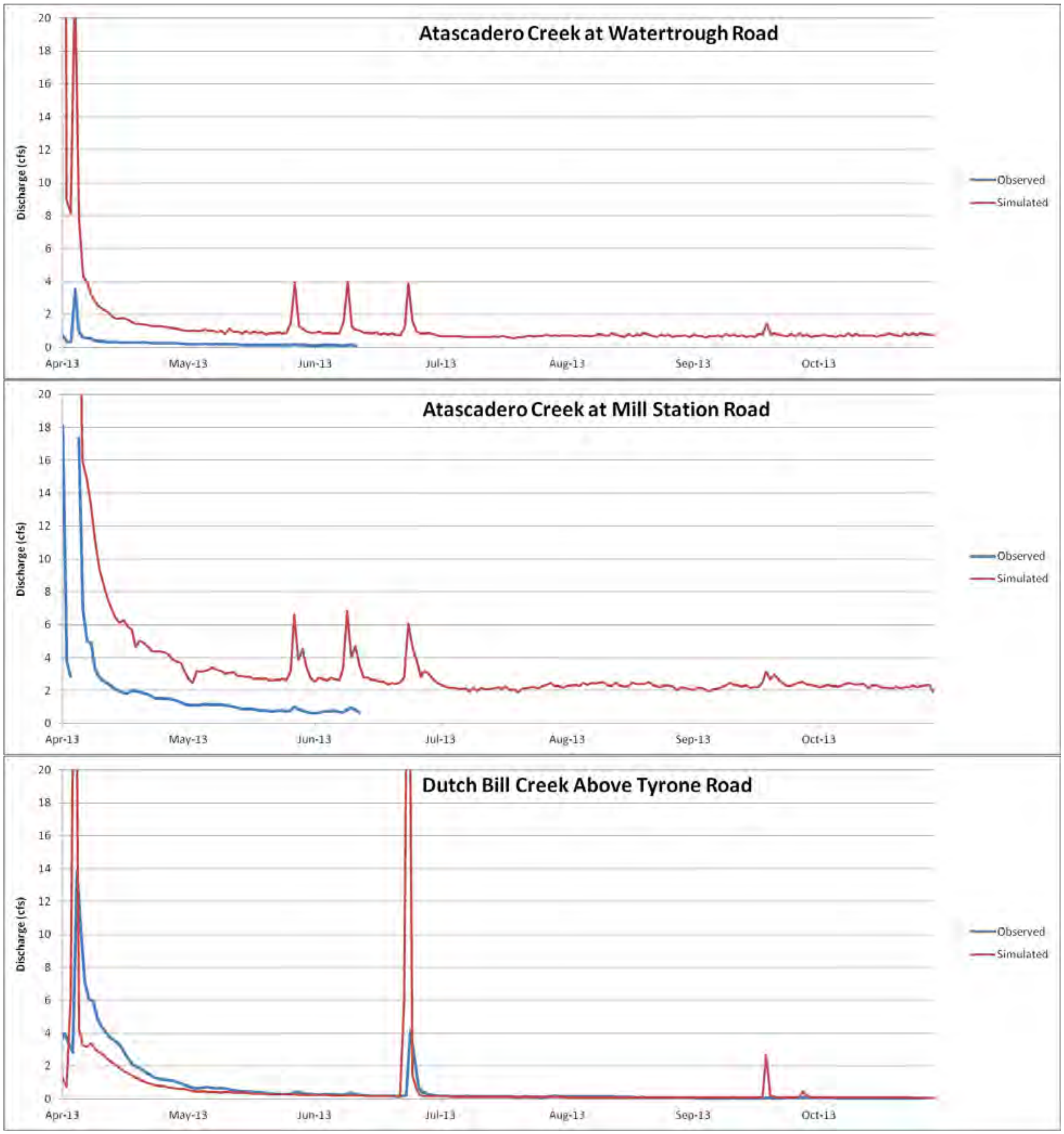


Figure 35 - (continued)

Comparisons between riffle depth measurements collected by UCCE between June and October and simulated water depths at model cross sections within the ~1,000-ft long measurement reaches are shown in Table 11 and Figures 36 & 37. The simulated model depths show overall agreement with the measured riffle depths in terms of the timing and degree of depth declines as the dry season progresses. MEs ranged from -0.15 to 0.14 ft and RMSEs ranged from 0.08 to 0.16 ft. Depths were predicted best at the Green Valley - Upper and Dutch Bill - Lower sites where MEs ranged from -0.01 to -0.06 ft. The model over-predicts (ME of 0.14 ft) depths at the Green Valley - Lower site particularly during the driest conditions and under-predicts (ME of -0.15 ft) depths at the Dutch Bill - Upper site.

Comparisons between reaches mapped as wet, dry, and intermittent and corresponding simulated flow conditions during September of 2013 and September of 2014 are shown in Figures 38 & 39. For the purposes of this comparison, the simulated discharges were used to define dry reaches as those with zero discharge and intermittent reaches as those with discharges of less than 0.05 cfs. There is overall agreement between the patterns of wet and dry reaches. In the upper reaches of Upper Green Valley Creek the model predicts drier conditions than the observations, however the transition to mostly flowing conditions occurs at a similar position in the watershed. In Dutch Bill Creek both the simulated and observed maps show transitions to dry conditions occurring at similar positions in the watershed in both the upper and lower reaches of the creek.

Table 11 - Riffle depth calibration results.

Reach Name	ME (ft)	RMSE (ft)
Green Valley Creek - Lower	0.14	0.16
Green Valley Creek - Upper	-0.06	0.10
Dutch Bill Creek - Lower	-0.01	0.08
Dutch Bill Creek - Upper	-0.15	0.16

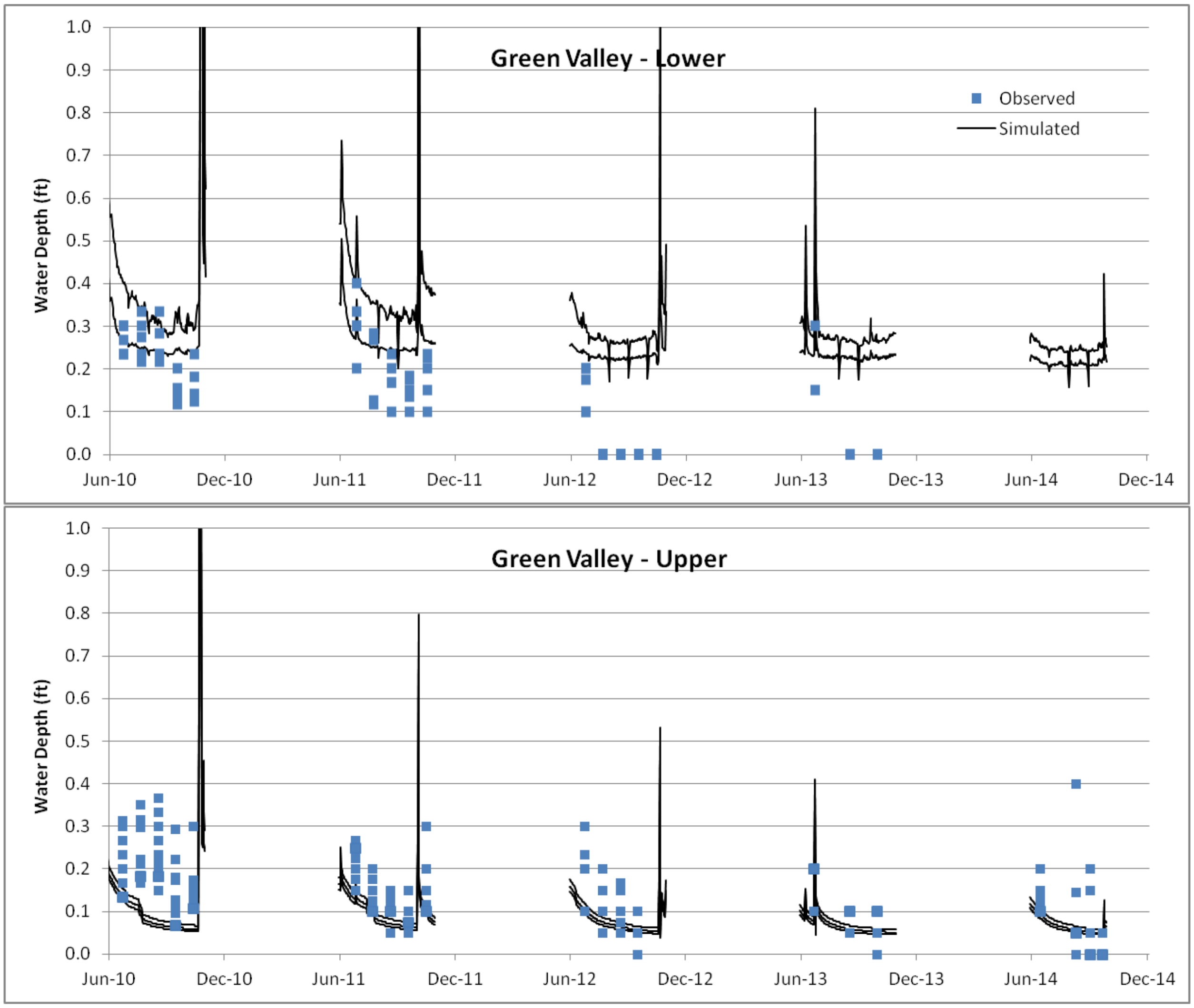


Figure 36 - Comparison of measured riffle depths and simulated water depths for two reaches in upper Green Valley Creek.

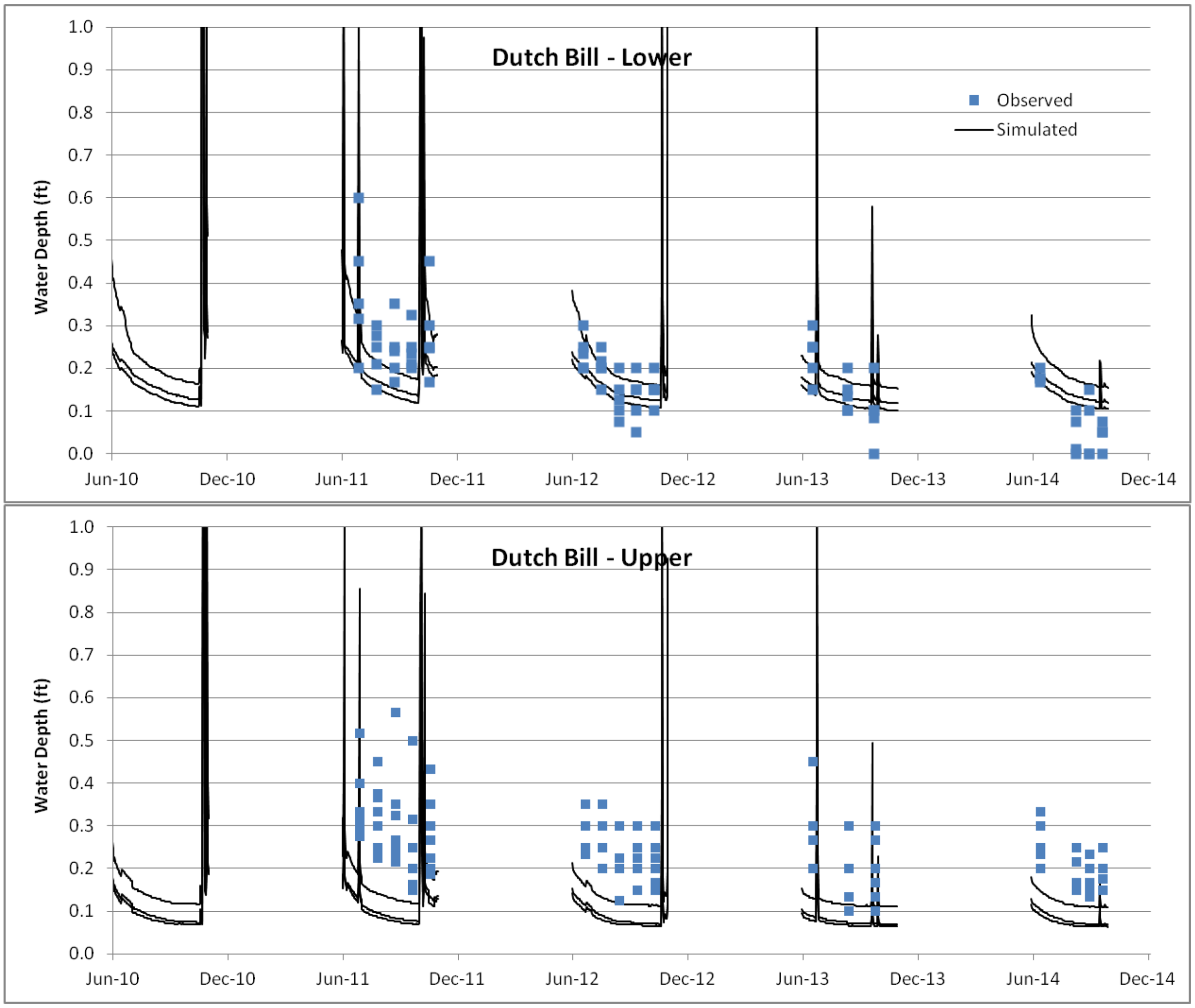


Figure 37 - Comparison of measured riffle depths and simulated water depths for two reaches in Dutch Bill Creek.

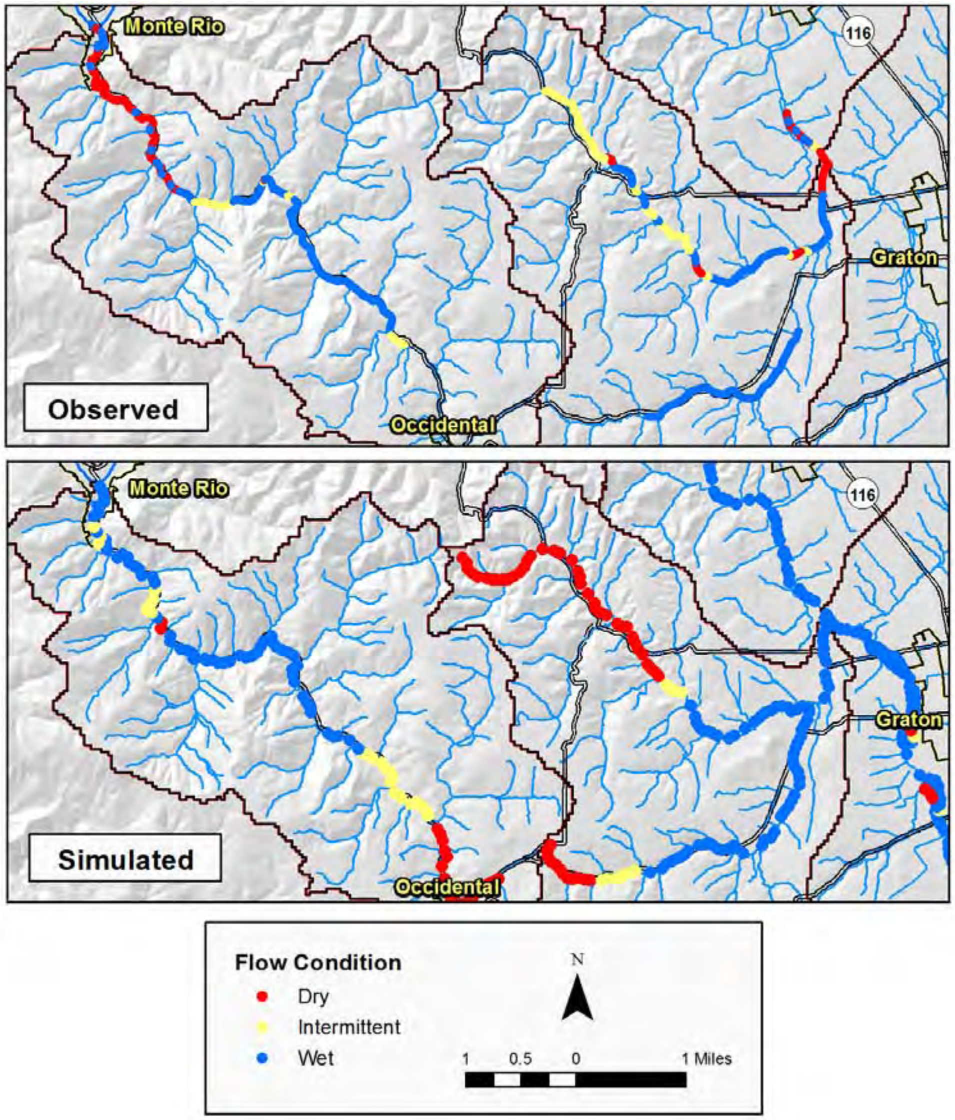


Figure 38 - Comparison between September 2013 wet/dry mapping and the extent of wet/dry reaches simulated with the hydrologic model.

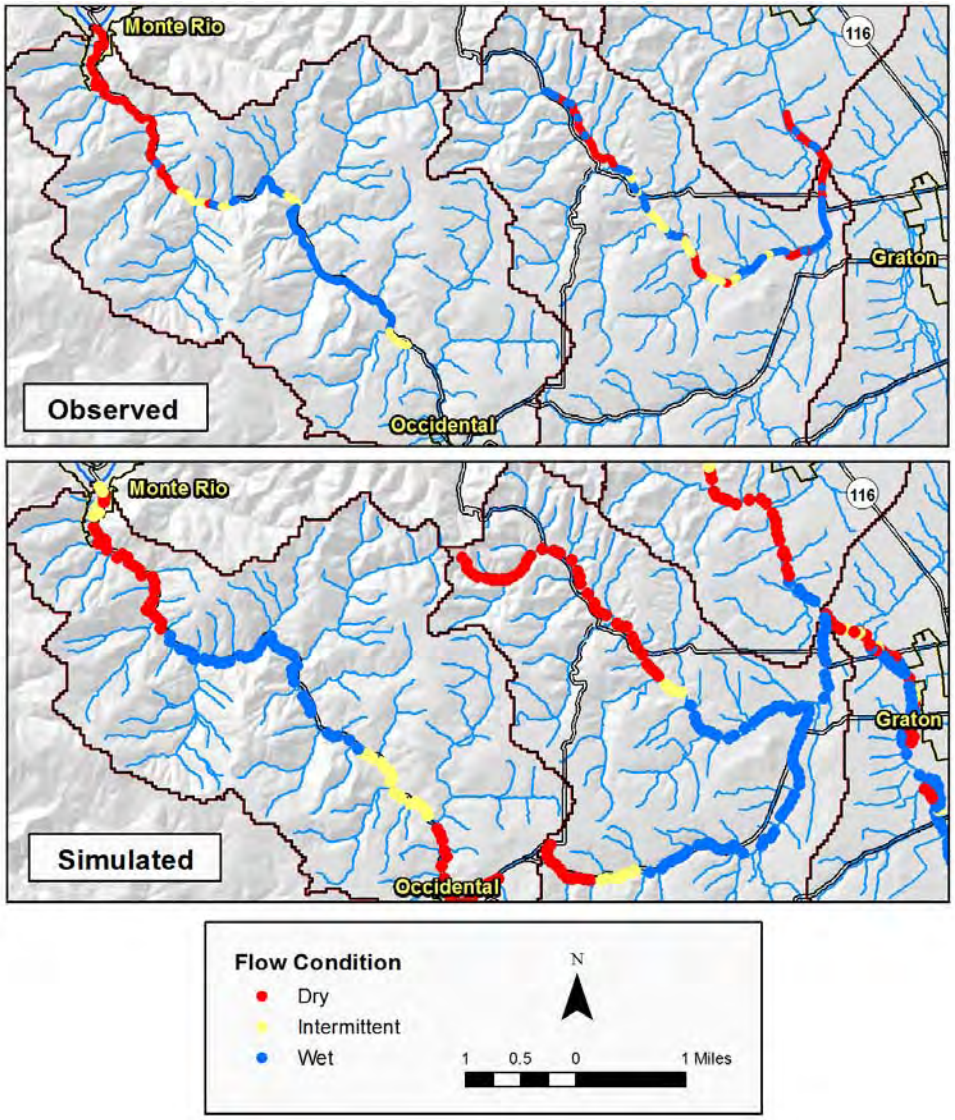


Figure 39 - Comparison between September 2014 wet/dry mapping and the extent of wet/dry reaches simulated with the hydrologic model.

Groundwater Calibration

In order to evaluate the agreement between model simulated groundwater elevations and measured groundwater elevations, Mean Error (ME) and Root Mean Square Error (RMSE) were calculated for the residuals (difference between simulated and observed groundwater elevations) at each of the seven monitoring wells. Due to the limited periods of record at the available monitoring locations it was deemed more appropriate to calibrate the model to all of the available data rather than divide the simulation into calibration and validation periods as is more typically done when long-term gauging data is available. The composite comparison of simulated and measured groundwater elevations is shown in Figure 40. Figure 41 shows the comparison between model simulated and measured groundwater elevations for each of the seven monitoring wells with available data and calibration statistics are presented in Table 12.

It should be noted that six of the seven monitoring wells used for model calibration are drilled in the WGF aquifer. The WGF aquifer has relatively consistent hydraulic properties and the groundwater calibration using these data provides a regionally-representative estimate of WGF hydraulic characteristics. Well GV1 is located in the FC at the edge of a thin, isolated outcrop of the WGF and should not be considered to provide adequate representation of groundwater conditions in the FC.

Overall, groundwater elevations are reasonably well-predicted by the model. MEs range from -3.7 to 7.7-ft at the UA1, GV1, MA1, and MA2 stations. At the remaining stations (MA3, LA1, LA2), groundwater elevations are over-predicted and MEs range from 12.1 to 35.1-ft. These three wells are all located relatively close to the boundary separating the study area from the Santa Rosa Plain where simulated groundwater elevations would be expected to be influenced by the assumptions made to represent the boundary. Additional monitoring data in this vicinity could be used to refine the model representation of the boundary, possibly leading to improved calibration at wells MA3, LA1, and LA2 and refined estimates of groundwater outflows to the Santa Rosa Plain. Both the simulated and measured data show minor seasonal fluctuations in groundwater elevations on the order of 2 to 5-ft and either a stable or slight negative trend in elevations between 2011 and 2014.

Table 12 - Groundwater calibration results.

Well	ME	RMSE
UA1	-3.7	4.1
MA1	2.7	4.7
MA2	7.7	9.7
MA3	12.1	12.2
LA1	35.1	35.2
LA2	30.3	30.4
GV1	1.8	2.1

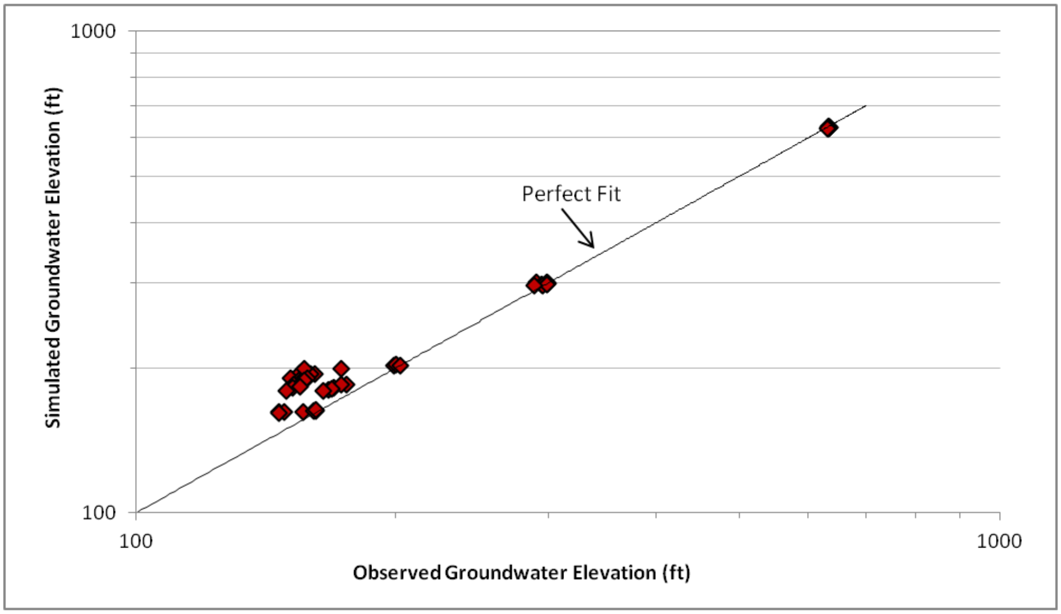


Figure 40 - Composite of simulated and measured groundwater elevations at seven monitoring wells for WY 2011 - 2014.

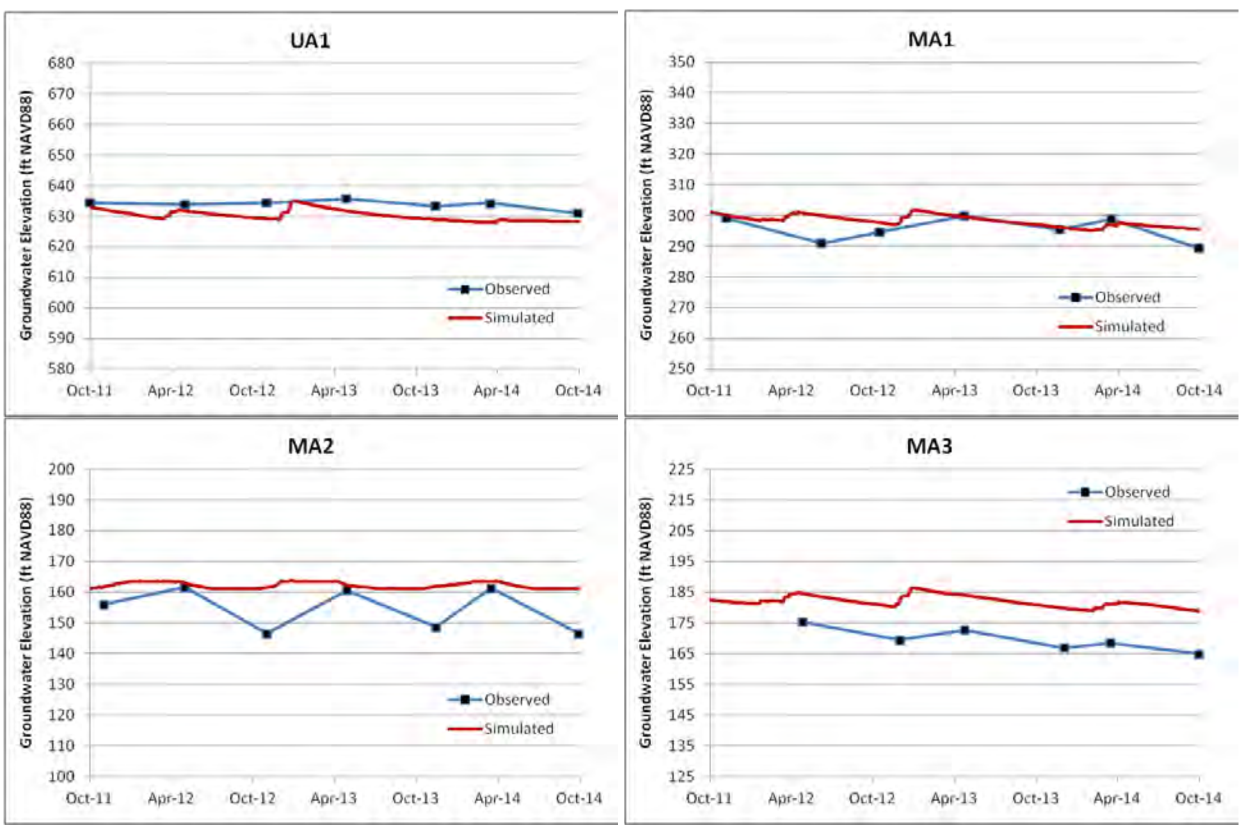


Figure 41 - Comparison of measured and simulated groundwater elevations for WY 2011 - 2014.

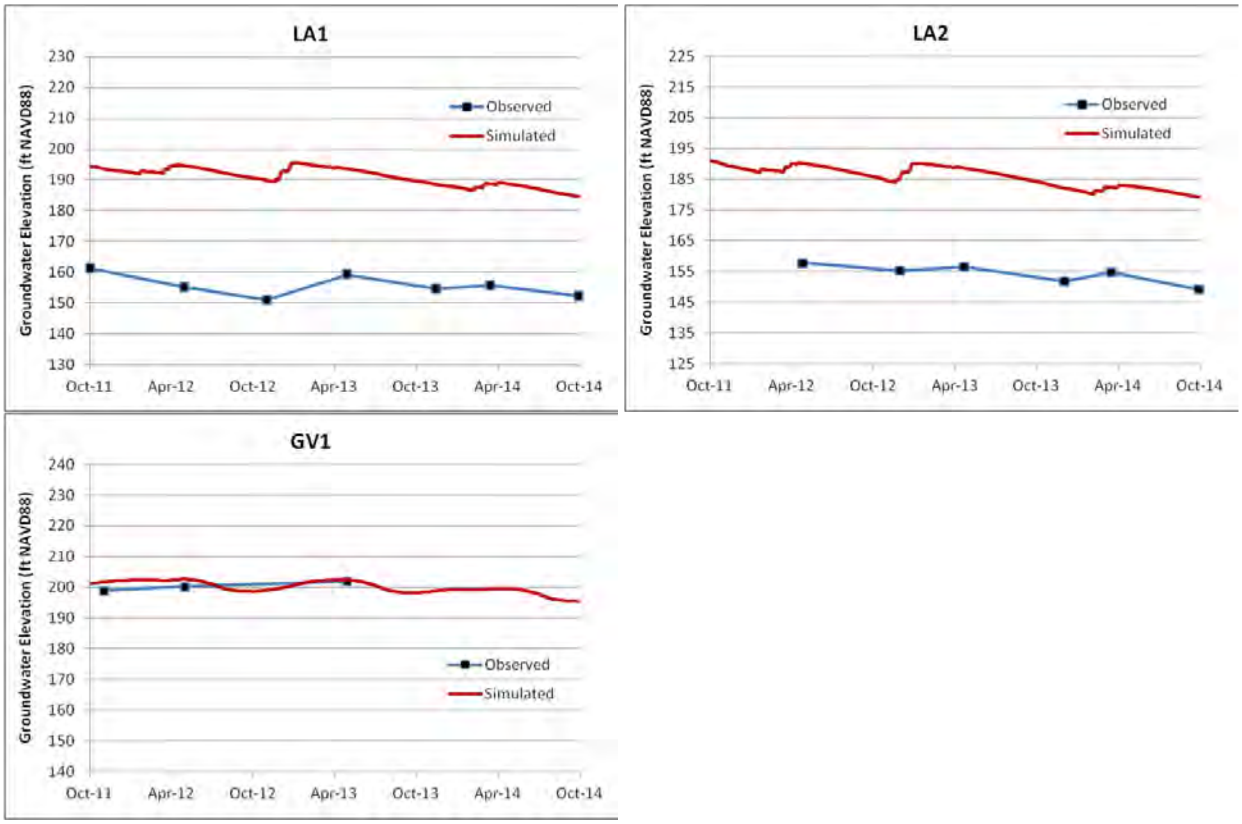


Figure 41 (continued)

Chapter 6 - Results

Water Budgets

A description of the water balance is one of the most fundamental outputs from the model. Water balance information can be extracted for the full study area or for any subarea. Water balances can be highly detailed (e.g. decompose ET into interception, evaporation, transpiration from the unsaturated zone, and transpiration from groundwater) or more general. For the purposes of this preliminary modeling effort, a basic overall annual water budget and a groundwater budget are presented for the GVAC and DBC watersheds for each of the simulated Water Years of 2010 - 2014. A monthly water budget is also presented for selected water budget terms as are maps depicting the spatial variations of key water budget components.

Hydrologic Water Budgets

The primary inflow in the GVAC watershed was precipitation, which ranged from 25.7 inches in the dry Water Year of 2014 to 56.3 inches in the moderately wet Water Year of 2011 (Table 13). Irrigation is a much less significant additional source of inflow (0.5 to 0.6 in/yr) and it was relatively uniform between Water Years owing to the way the irrigation demands were calculated. Except for the moderately wet year of 2011, ET was the largest outflow from the watershed. Variations in ET were significantly less than the variations in precipitation and ranged from 18.1 inches in 2014 to 25.1 inches in 2011. Stream flow was the next largest outflow from the watershed and it varied substantially and in a similar fashion to precipitation ranging from 10.0 inches in 2014 to 27.3 inches in 2011. Groundwater pumping was more than an order of magnitude less than ET or stream flow (1.1 to 1.2 in/yr) and was relatively uniform owing to the way input water demands were calculated. Groundwater boundary outflows were a constant 0.3 in/yr. Increases in storage of 3.0 to 3.1 inches occurred during Water Years 2010 and 2011 and decreases in storage of 0.3 to 3.4 inches occurred during Water Years 2012 -2014.

Nearly all of the inflow in the DBC watershed was precipitation, which ranged from 35.0 inches in the dry Water Year of 2014 to 67.5 in the moderately wet Water Year of 2011 (Table 13). Irrigation is a much less significant additional source of inflow (0.1 in/yr). ET was the largest outflow from the watershed during the driest two Water Years and stream flow was the largest outflow during the three other Water Years. Variations in ET were significantly less than the variations in precipitation and ranged from 18.9 inches in 2014 to 26.7 inches in 2011. Stream flow varied substantially and in a similar fashion to precipitation ranging from 16.8 inches in 2014 to 40.3 inches in 2011. Groundwater pumping was a very small component of the water budget (0.2 in/yr). Decreases in storage of 0.7 to 0.8 inches occurred during the two driest Water Years 2012 and 2014 and increases in storage of 0.2 to 0.4 inches occurred during the remaining three Water Years.

Groundwater Budgets

Infiltration recharge represented the largest source of groundwater recharge to the GVAC watershed in 2010, 2011, and 2013, however during the driest two years 2012 and 2014,

Table 13 - Annual water budget simulated with the hydrologic model.

Watershed	Water Year	Inflows		Outflows				Change in Storage
		Precipitation	Irrigation	ET	Streamflow	Groundwater Pumping	Groundwater Outflow	
Green Valley/ Atascadero Creek	2010	50.4	0.6	24.0	22.6	1.2	0.3	3.0
	2011	56.3	0.5	25.1	27.3	1.1	0.3	3.1
	2012	32.4	0.6	21.7	13.3	1.2	0.3	-3.4
	2013	39.6	0.5	21.9	17.2	1.1	0.3	-0.3
	2014	25.7	0.5	18.1	10.0	1.1	0.3	-3.3
	Average	**40.9**	**0.5**	**22.1**	**18.1**	**1.1**	**0.3**	**-0.2**
Dutch Bill Creek	2010	52.5	0.1	23.1	28.7	0.2	0.0	0.4
	2011	67.5	0.1	26.7	40.3	0.2	0.0	0.2
	2012	40.1	0.1	22.9	17.7	0.2	0.0	-0.7
	2013	43.7	0.1	21.4	21.7	0.2	0.0	0.4
	2014	35.0	0.1	18.9	16.8	0.2	0.0	-0.8
	Average	**47.8**	**0.1**	**22.6**	**25.0**	**0.2**	**0.0**	**-0.1**

Table 14 - Annual groundwater budget simulated with the hydrologic model.

Watershed	Water Year	Inflows		Outflows					Change in Storage
		Infiltration Recharge	Streambed Recharge	Baseflow	Surface Discharge	ET from Groundwater	Groundwater Pumping	Boundary Outflow	
Green Valley/ Atascadero Creek	2010	9.8	6.2	6.7	3.1	2.3	1.2	0.3	2.5
	2011	10.5	6.4	6.7	3.5	2.4	1.1	0.3	2.9
	2012	3.2	4.9	5.5	2.0	2.3	1.2	0.3	-3.2
	2013	5.7	5.6	5.9	2.3	2.4	1.1	0.3	-0.6
	2014	2.0	4.8	5.5	1.4	2.1	1.1	0.3	-3.5
	Average	**6.2**	**5.6**	**6.1**	**2.4**	**2.3**	**1.1**	**0.3**	**-0.4**
Dutch Bill Creek	2010	4.3	0.6	2.8	1.1	0.8	0.2	0.0	0.1
	2011	5.3	0.8	3.4	1.7	0.8	0.2	0.0	0.1
	2012	2.6	0.9	2.2	0.6	0.8	0.2	0.0	-0.3
	2013	3.2	1.0	2.7	0.8	0.7	0.2	0.0	-0.1
	2014	2.0	1.3	1.9	0.8	0.7	0.2	0.0	-0.2
	Average	**3.5**	**0.9**	**2.6**	**1.0**	**0.7**	**0.2**	**0.0**	**-0.1**

streambed recharge was the dominant component of total recharge (Table 14). Annual infiltration recharge varied from 2.0 inches during the dry Water Year of 2014 to 10.5 inches during the moderately wet Water Year of 2011. Streambed infiltration varied much less than infiltration ranging from 4.8 to 6.4 inches. Baseflow discharge to streams was the largest source of groundwater outflow and it was relatively uniform between Water Years, ranging from 5.5 to 6.7 inches. Groundwater discharge directly to the land surface varied from 1.4 inches in WY 2014 to 3.5 inches in WY 2011. ET from groundwater was relatively uniform and ranged from 2.1 to 2.4 inches. Groundwater pumping and groundwater boundary outflows were both relatively uniform and were 1.1 and 0.3 inches per year respectively.

Infiltration recharge represented the largest source of groundwater recharge to the DBC watershed and varied from 2.0 inches during the dry Water Year of 2014 to 5.4 inches during the moderately wet Water Year of 2011 (Table 14). In contrast to the GVAC watershed, streambed infiltration was highest during the dry Water Year of 2014 (1.3 inches) and lowest during the average Water Year of 2010 (0.6 inches). Baseflow discharge to streams was the largest source of groundwater outflow and it ranged from 1.9 to 3.4. Groundwater discharge directly to the land surface varied from 0.6 to 1.7 inches. ET from groundwater was relatively uniform and ranged from 0.7 to 0.8 inches. Groundwater pumping was a small component of the groundwater budget and was a uniform 0.2 inches per year.

Spatial and Temporal Variations of Water Budget Components

ET was generally lowest during the winter months, highest during May when potential ET was relatively high and available soil moisture was plentiful, and progressively decreasing throughout the summer months as available soil moisture diminished (Figure 42). Groundwater recharge only occurred during months with significant precipitation. During Water Year 2010 recharge occurred every month between November and April whereas during the dry Water Year of 2014 recharge only occurred during March and April. Small negative recharge values (indicating groundwater discharge to the land surface in excess of infiltration recharge) occurred between May and October of most years, however exceptionally dry conditions resulted in negative recharge persisting for 12 of 13 months between February of 2013 and February of 2014. These effects are more pronounced in the GVAC watershed where a larger proportion of the watershed is characterized by high water table conditions and consequently transpiration from groundwater and rejected recharge are higher.

Figure 43 shows the monthly variations in the different components responsible for stream flow generation. On an overall annual basis, runoff was the largest component of stream flow (62%), with interflow (drainage) being the next most significant component (36%), and baseflow accounting for only 2%. Despite being dwarfed by runoff and interflow on an annual basis, between May and October of most years, baseflow is the dominant source of stream flow. During months of high precipitation, a net loss of stream flow to groundwater occurs (streambed losses exceed gains). Some losses continue throughout the year, however a net gain of stream flow from groundwater occurs throughout the summer months. These effects are more pronounced in the GVAC watershed where the degree of surface water/groundwater interaction tends to be greater than in the DBC watershed. The pattern of interflow tends to follow that of runoff but with some temporal lag resulting in a situation where interflow becomes the dominant component of stream flow during March and/or April of some years. This effect is most pronounced in the DBC watershed.

Significant variations in groundwater recharge across the watersheds occurs as the result of numerous landscape factors, most notably soil hydraulic conductivity, geology, topographic position, land cover and ET, and the east to west precipitation gradient. Recharge ranged from as low as -1 inches to more than 23 inches during Water Year 2010 and from -2 to 13 inches during the dry Water Year of 2014 (Figures 44 & 45). Recharge was lowest in the valley-bottom areas with extensive clay soils along Atascadero Creek, lower Green Valley Creek, and lower Purrington Creek and in other areas with clayey soils scattered throughout the watershed.

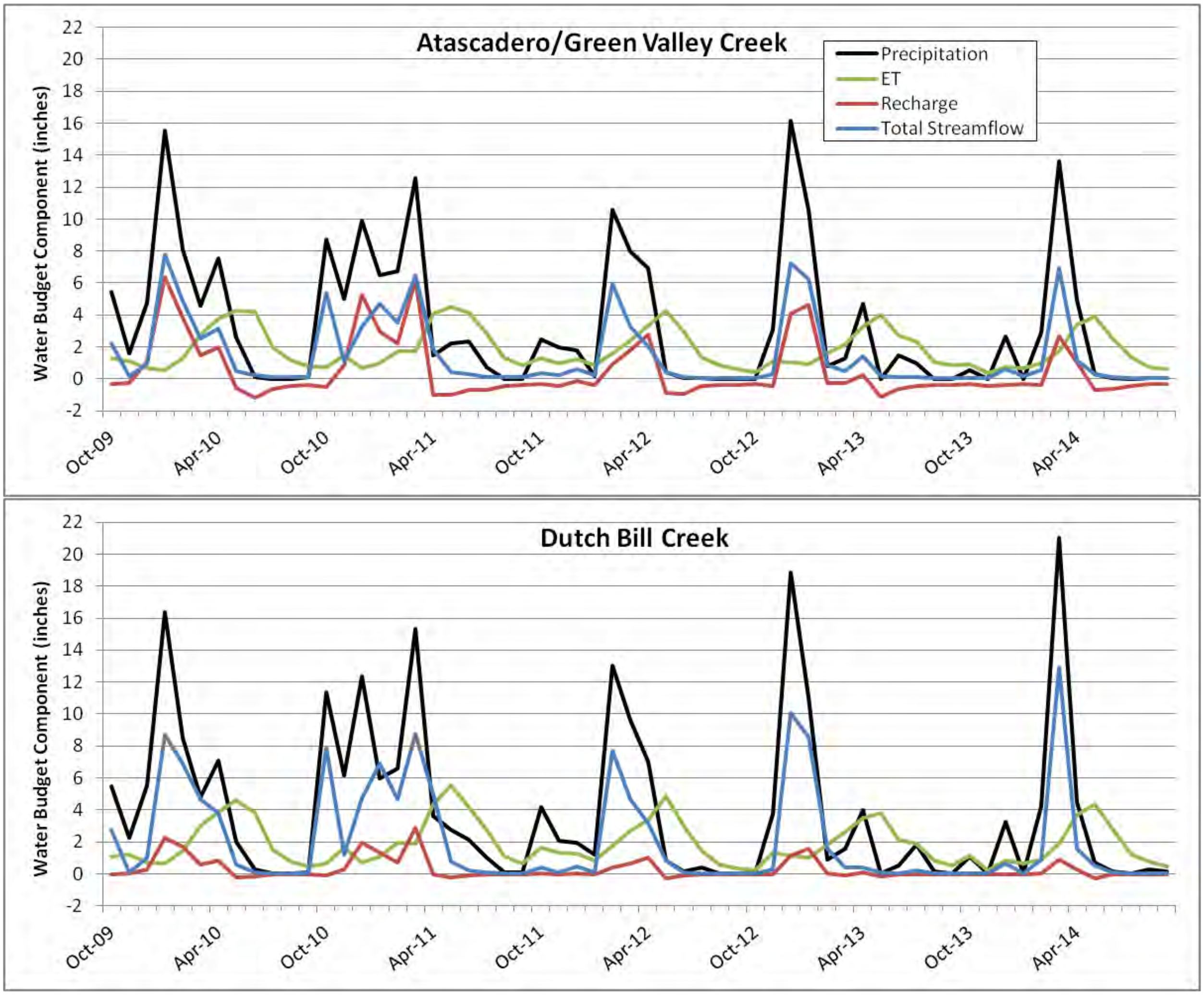


Figure 42 - Simulated monthly water budget for select water budget components for WY 2010 - 2014.

Highest recharge values occurred throughout the higher elevation areas of the watersheds that are underlain by coarser soils.

Surface water/groundwater interactions defined as losses from streams to groundwater (losing stream reaches) and gains to streams from groundwater (gaining stream reaches) vary substantially across the study area and through time. On an average annual basis lower Atascadero and lower Green Valley Creeks were losing reaches with seepage losses of up to 30 cubic feet per day per foot of channel length (Figures 46 & 47). Surface water/groundwater interaction was minimal throughout most of the DBC watershed and in upper Purrington Creek owing to the low-permeability bedrock in those areas. In Water Year 2010 when conditions were relatively wet, the lower main-stem of Dutch Bill Creek and most of upper Green Valley, lower Purrington, Atascadero, and West Fork Atascadero Creeks were gaining reaches with gains of between 0.3 and 15 cubic feet per day per foot of channel length. During the dry Water Year of 2014, the extent of gaining reaches decreased dramatically compared to 2010 and many reaches that were gaining in 2010 were losing reaches in 2014 (Figure 48).

Transpiration varies across the watershed from less than 2 inches per year to more than 30 inches per year (Figures 49 & 50). The variations appear to be driven primarily by the distribution of land cover types, soil moisture capacity, and potential ET. Comparing the simulated Water Year 2014 transpiration with 2010 transpiration reveals than transpiration values are lower in 2014 than in 2010 in many areas, however values remain relatively unchanged in other areas. In particular the areas along the reaches of lower Atascadero and Green Valley Creeks that were shown to be net losing reaches have very high transpiration that persists even in dry 2014 conditions. This can be attributed to the presence of willows and other phreatophytes that are able to maintain access to the shallow water table in this area even under drought conditions.

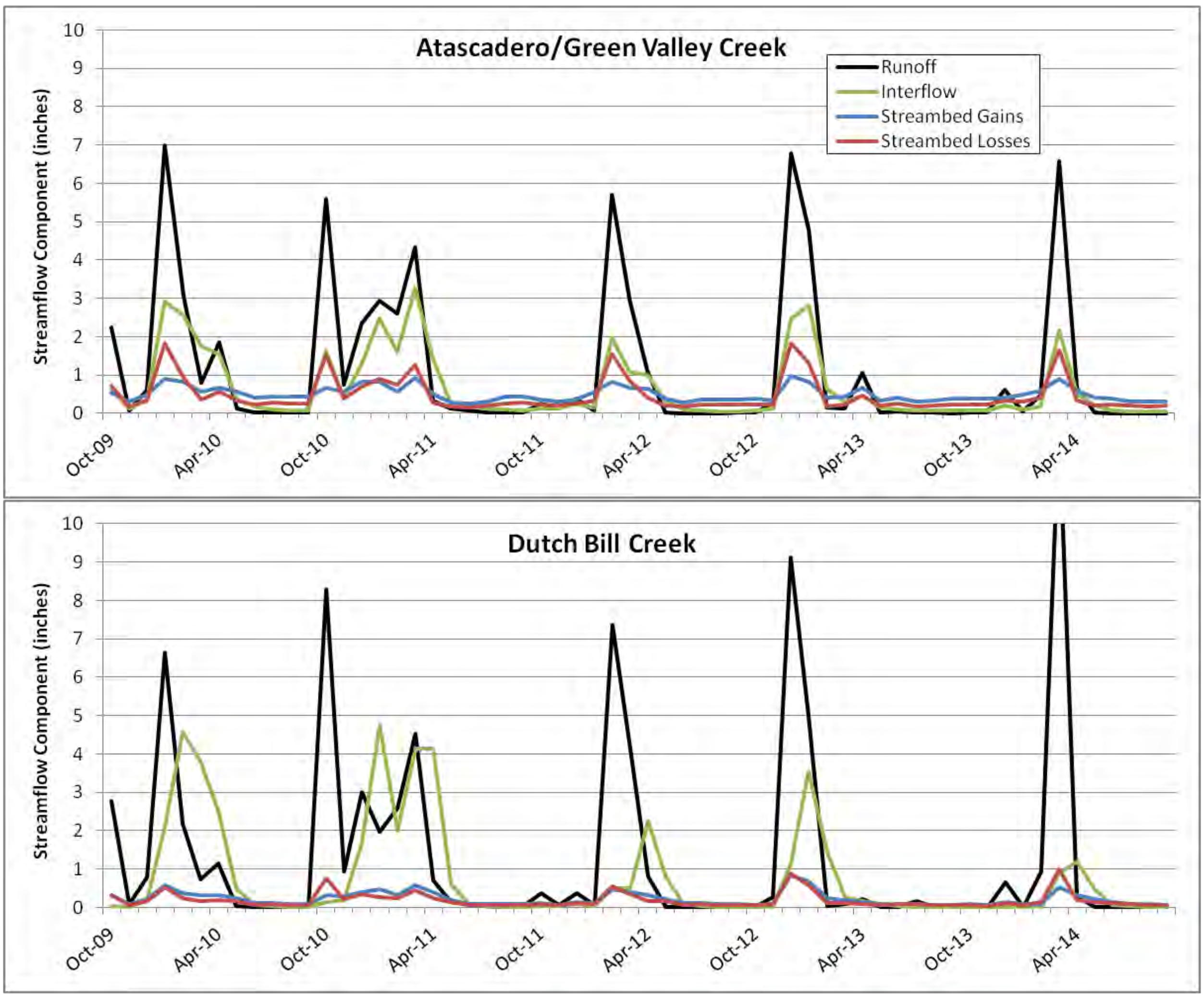


Figure 43 - Simulated monthly water budget for the various components of total stream flow for WY 2010 - 2014.

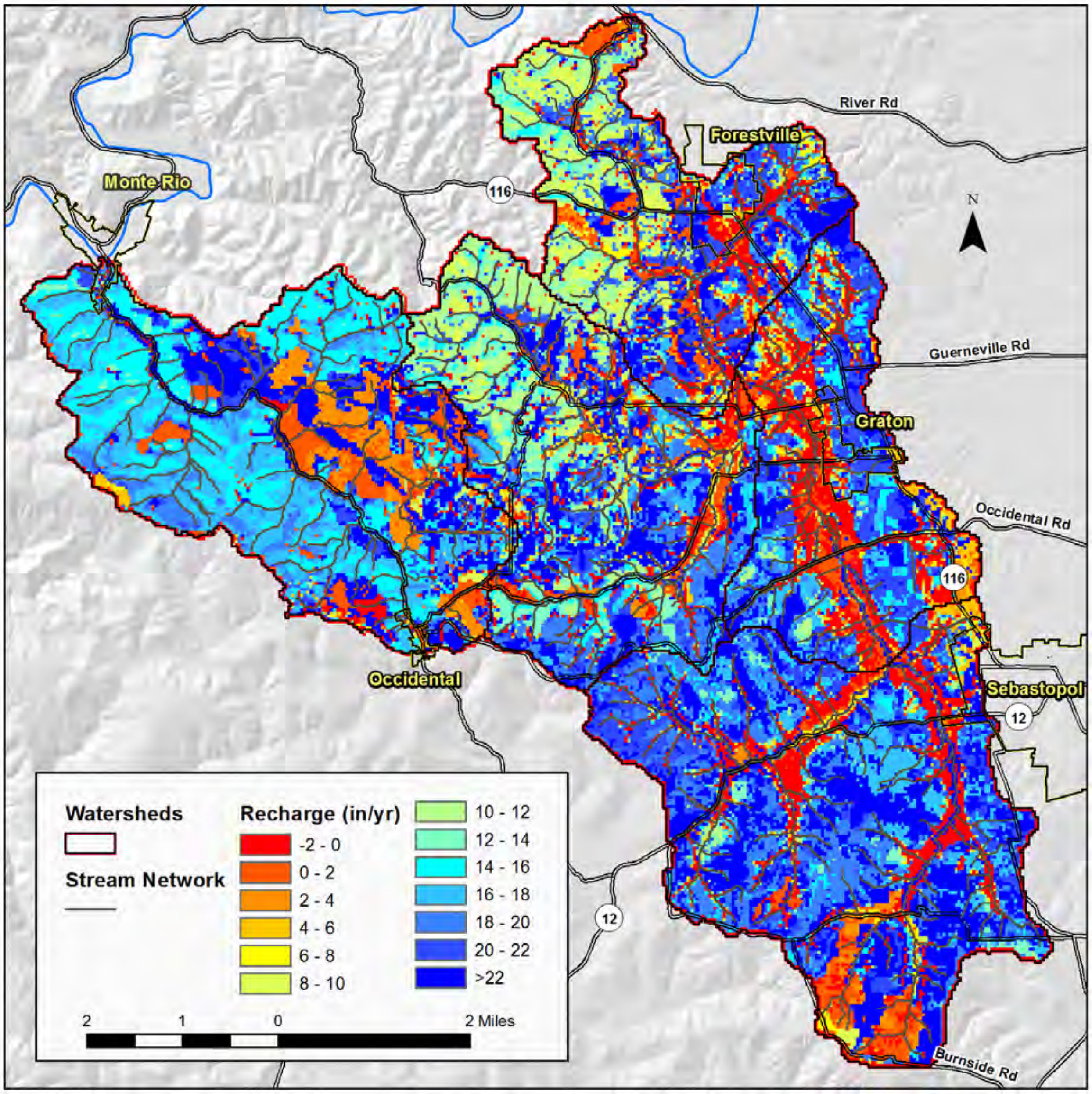


Figure 44 - Simulated annual groundwater recharge for WY 2010.

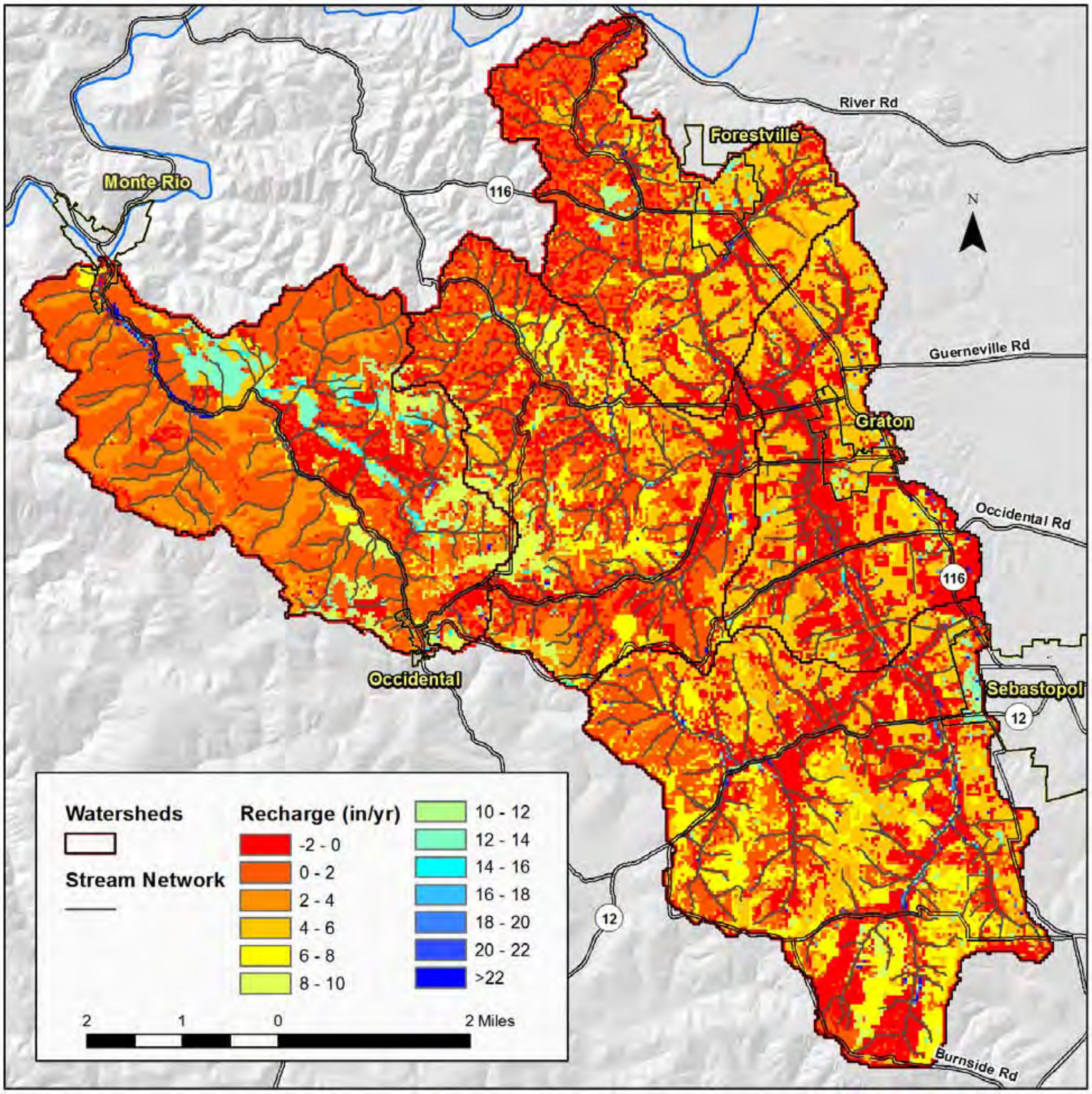


Figure 45 - Simulated annual groundwater recharge for WY 2014.

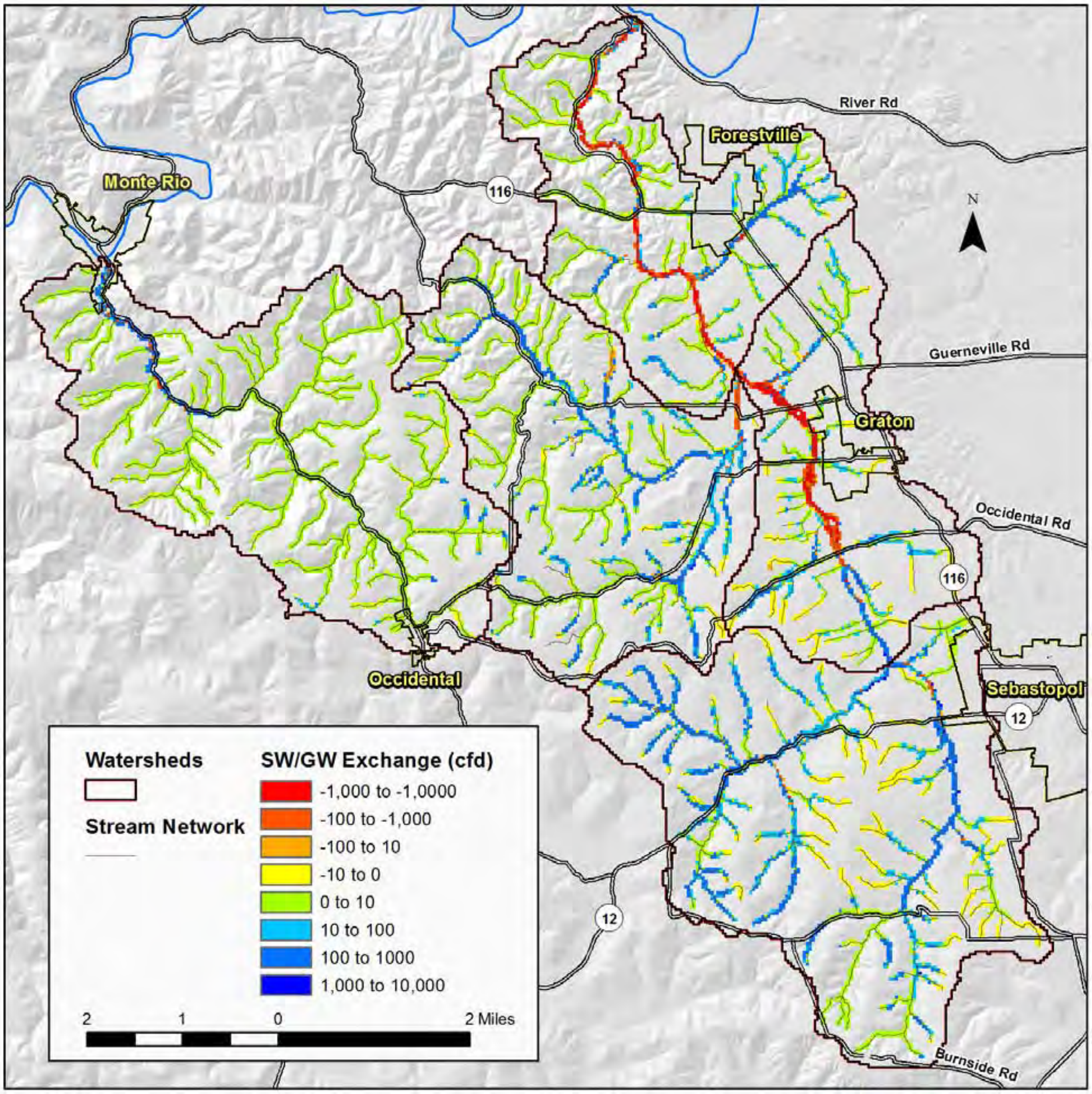


Figure 46 - Simulated mean annual surface water/groundwater exchange for WY 2010.

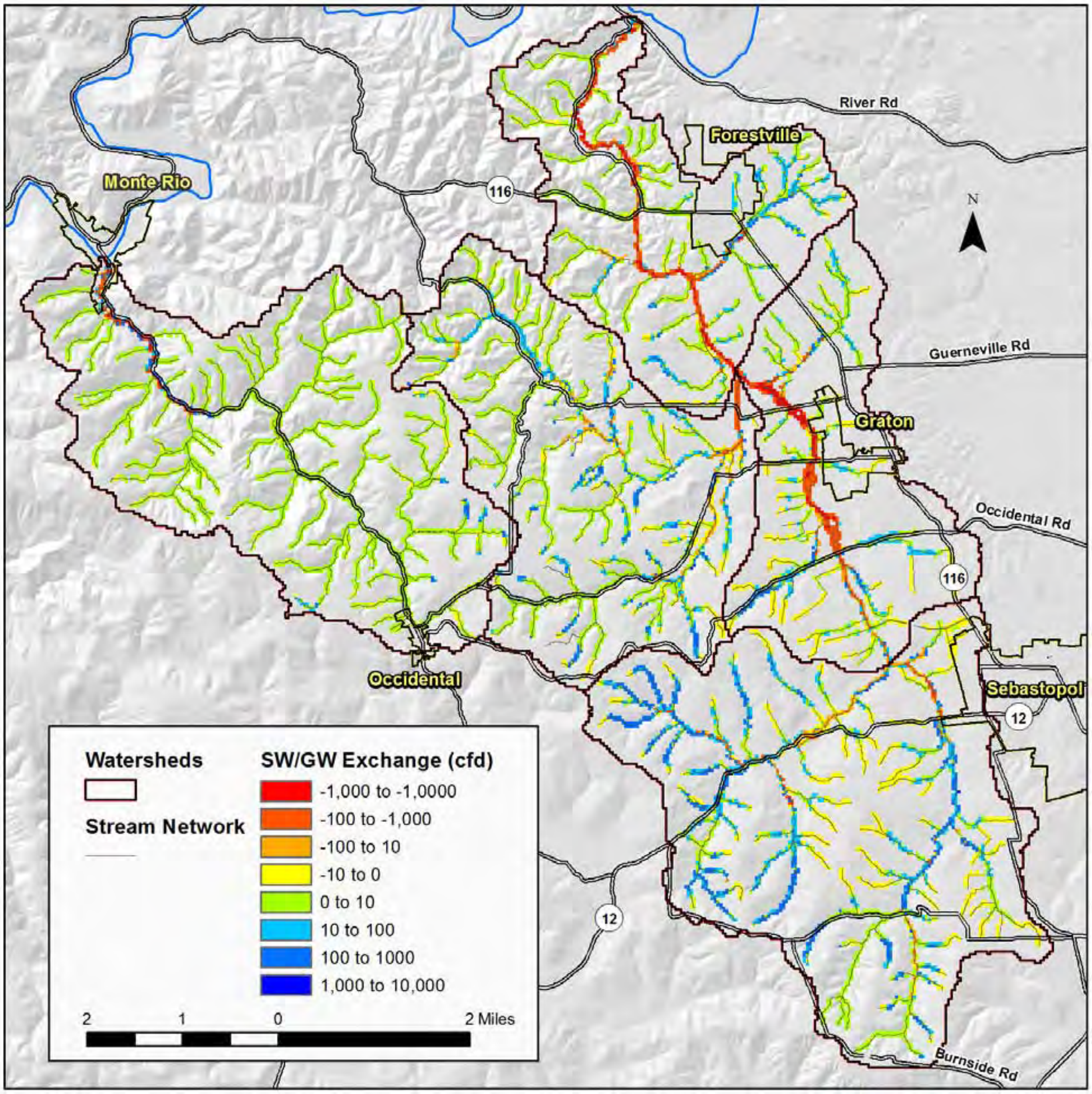


Figure 47 - Simulated mean annual surface water/groundwater exchange for WY 2014.

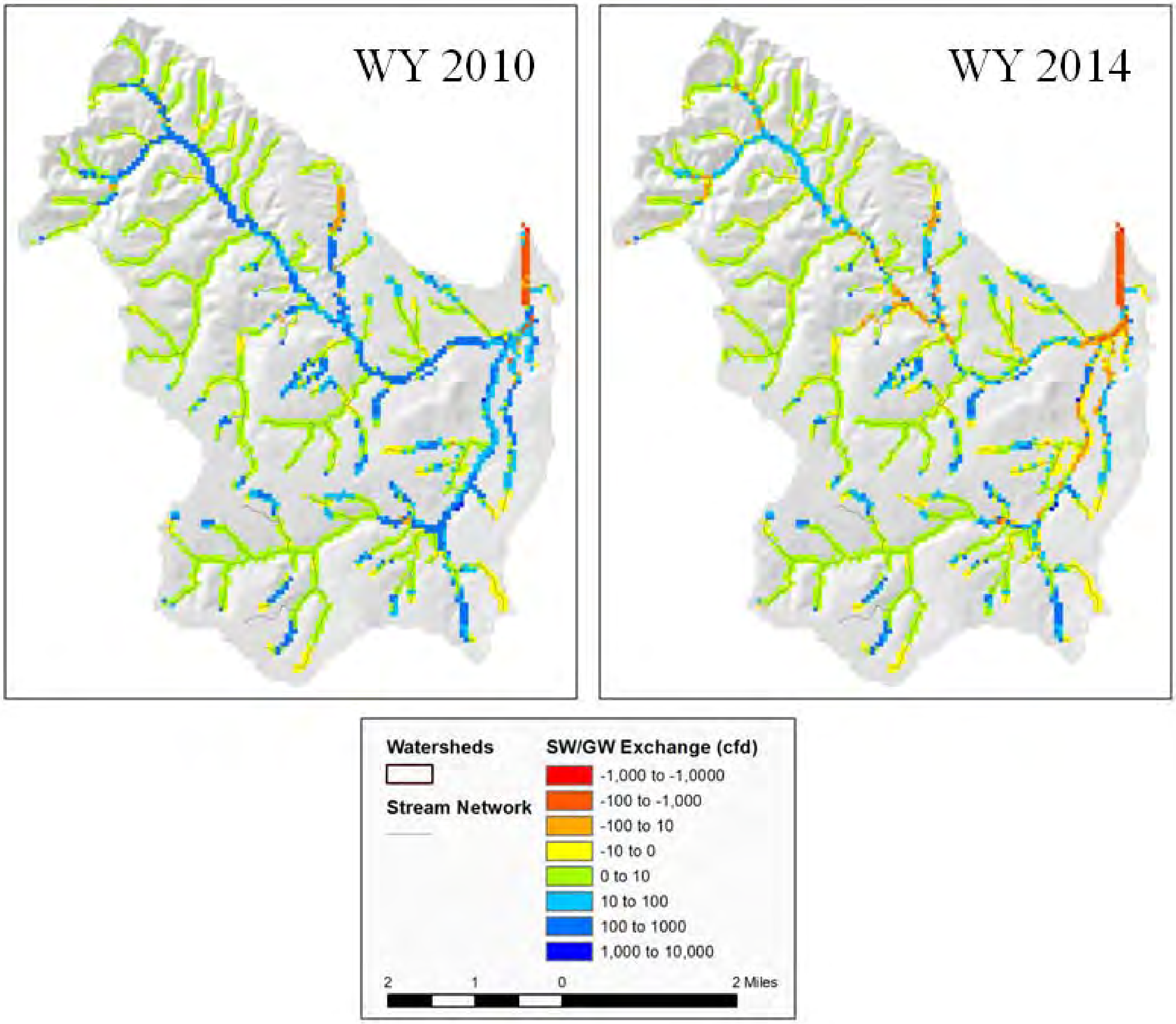


Figure 48 - Comparison of mean annual surface water/groundwater exchange for WY 2010 and WY 2014 in Purrington Creek and upper Green Valley Creek.

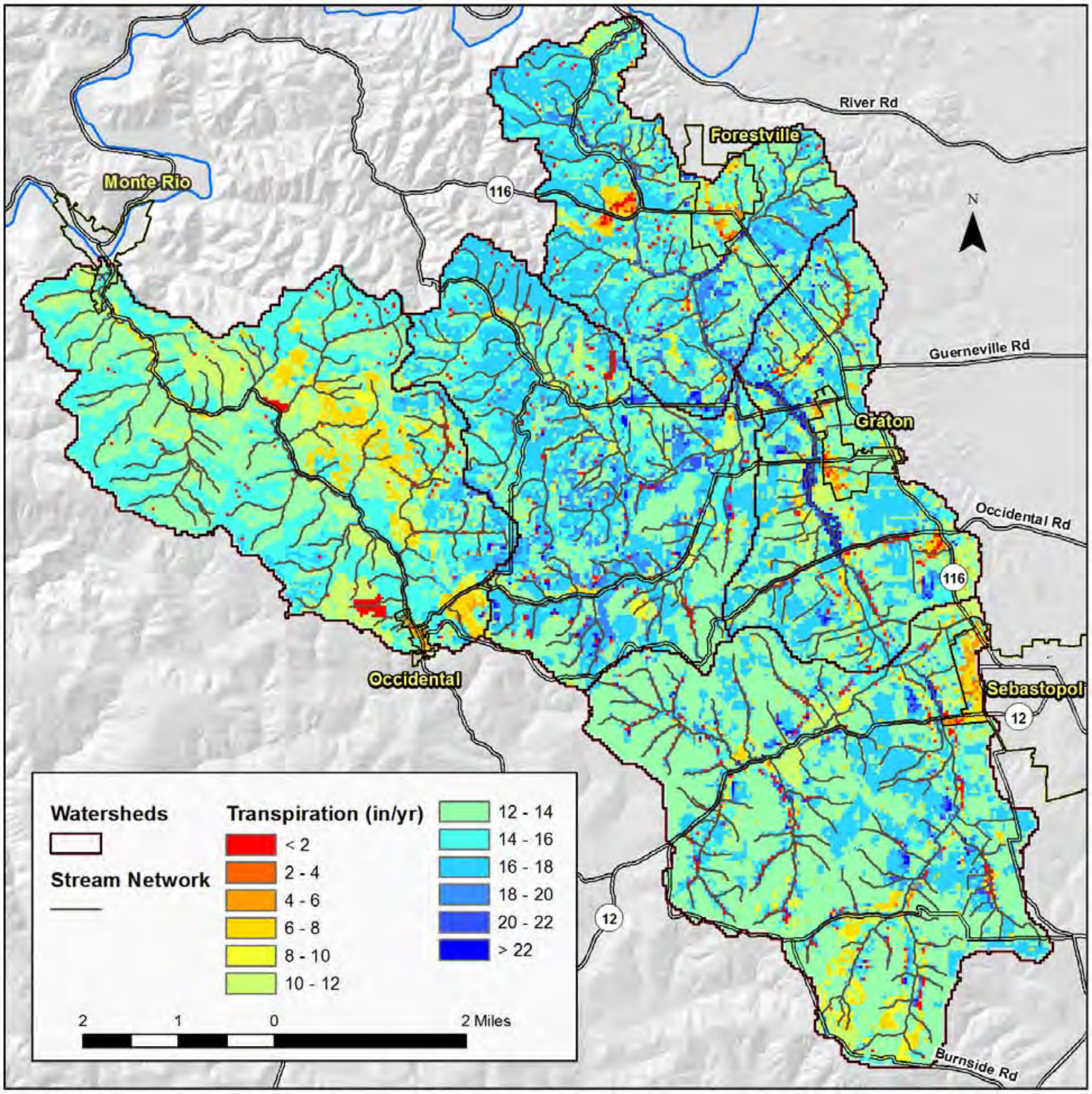


Figure 49 - Simulated annual transpiration for WY 2010.

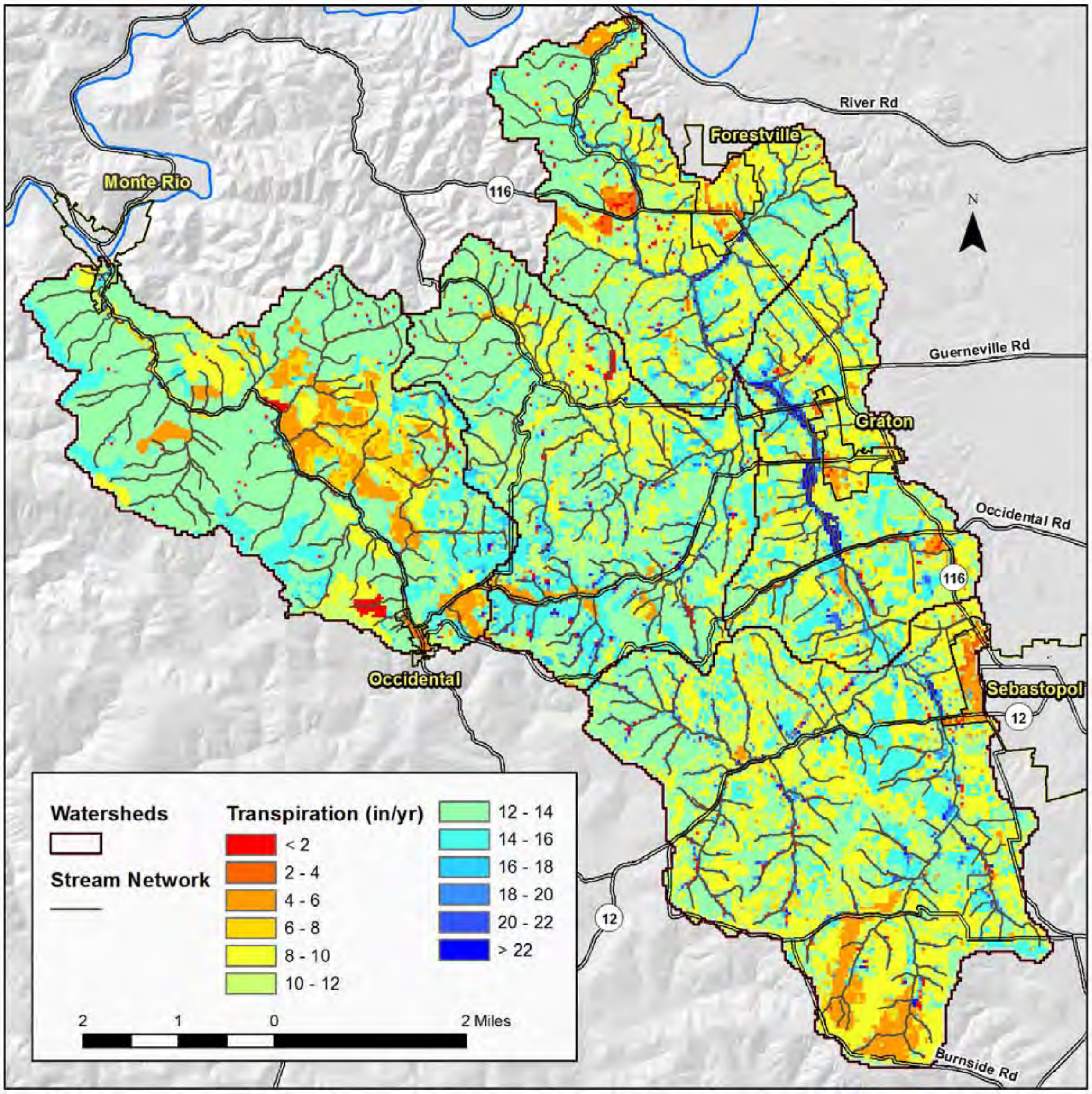


Figure 50 - Simulated annual transpiration for WY 2014.

Streamflow

Mean Annual Discharge
Mean annual discharges varied from <1 cfs in headwater reaches to 25 to 50 cfs in lower Green Valley Creek depending on the Water Year (Figures 51 & 52). Mean annual discharge in Atascadero Creek and West Fork Atascadero Creek increased in the downstream direction from <1 to 15 cfs during WY 2010 and from <1 to 10 cfs during WY 2014. Below the confluence of those two creeks and upstream of Occidental Road, mean annual discharges in Atascadero Creek ranged from 20 to 30 cfs in WY 2010 and from 10 to 15 cfs in WY 2014. Between Occidental Road and the confluence with Green Valley Creek, flows decreased to 10 to 20 cfs in WY 2010 and to 5 to 15 cfs in 2014.

In Purrington Creek, mean annual discharge increased in the downstream direction from <1 cfs to 10 cfs in WY 2010 and from <1 to 5 cfs in WY 2014. During WY 2010, mean annual discharge in upper Green Valley Creek increased in the downstream direction from <1 to 15 cfs at the confluence with Purrington Creek and to 20 cfs at the confluence with Atascadero Creek. During WY 2014 flows ranged from <1 to 10 cfs throughout the reach upstream of the Atascadero confluence. Lower Green Valley Creek had the highest mean annual discharges which ranged from 40 to 60 cfs in WY 2010 and from 15 to 30 in WY 2014. Discharges in Dutch Bill Creek increased progressively in the downstream direction from <1 to 30 cfs in WY 2010 and from <1 to 20 cfs in WY 2014.

Mean Summer Discharge
Mean June 15th to September 15th baseflow discharges (hereafter referred to as summer discharge) varied from zero in headwater reaches to 1.3 cfs in portions of Atascadero, West Fork Atascadero and Green Valley Creeks (Figures 53 and 54). Mean summer discharge in West Fork Atascadero Creek increased in the downstream direction from zero to 1.0 cfs during WY 2010 and from zero to 0.5 cfs during WY 2014. Above the confluence with West Fork Atascadero Creek, Atascadero Creek summer discharges ranged from zero to 0.3 cfs in WY 2010 and from zero to 0.2 cfs in WY 2014. Below the confluence of those two creeks and upstream of Occidental Road, discharges in Atascadero Creek ranged from 0.7 to 1.3 cfs in WY 2010 and from 0.3 to 0.5 cfs in WY 2014. The reach of Atascadero Creek between Graton Road and the confluence with Green Valley Creek was particularly dry with mean summer flows ranging from zero to 0.2 cfs.

In Purrington Creek, mean summer discharges increased from zero to 1.0 cfs in WY 2010 and from zero to 0.5 cfs in WY 2014. During WY 2010, mean summer discharges in upper Green Valley Creek increased in the downstream direction from zero to 0.5 cfs at the confluence with Purrington Creek and to 1.3 cfs at the confluence with Atascadero Creek. During WY 2014 flows ranged from zero to 0.2 cfs above the Purrington Creek confluence and to 0.7 cfs at the confluence with Atascadero Creek. Lower Green Valley Creek was characterized by declining flows in the downstream direction ranging from 0.3 cfs to 1.3 cfs in WY 2010 and from <0.05 to 1.3 cfs in WY 2014. With the exception of the lowest alluvial reach where conditions were very dry (<0.05 cfs), discharges in Dutch Bill Creek increased progressively in the downstream direction from zero to 0.3 cfs in WY 2010 and from zero to 0.2 cfs in WY 2014.

Minimum Summer Discharge

The patterns of minimum summer discharge are generally similar to those of mean summer discharge. The following discussion focuses on describing the extent of reaches with very dry minimum discharge conditions and any significant differences between mean and minimum summer discharges. A short reach of Atascadero Creek just upstream of the confluence with West Fork Atascadero Creek was dry during both WY 2010 and WY 2014 as was most of the reach extending from ~1,000-ft upstream of Graton Road to the confluence with Green Valley Creek (Figures 55 & 56).

In Purrington Creek, flows remained perennial for the most part with the exception of a short reach upstream of the lowest Graton Road crossing that was dry in WY 2014. Upper Green Valley Creek was dry upstream of the upper Green Valley Road crossing in WY 2010 and for an additional 1,500-ft below the crossing in WY 2014 (Figures 55 & 56). Small flows persisted throughout lower Green Valley Creek in WY 2010, however the creek was dry between the confluence of Atascadero Creek downstream to a point 1,200-ft upstream of the Highway 116 crossing in WY 2014. The extent of perennial flow in Dutch Bill Creek is very similar in both WY 2010 and 2014. The creek was dry upstream of the confluence with Lancel Creek and for the lowest 9,500-ft above the confluence with the Russian River.

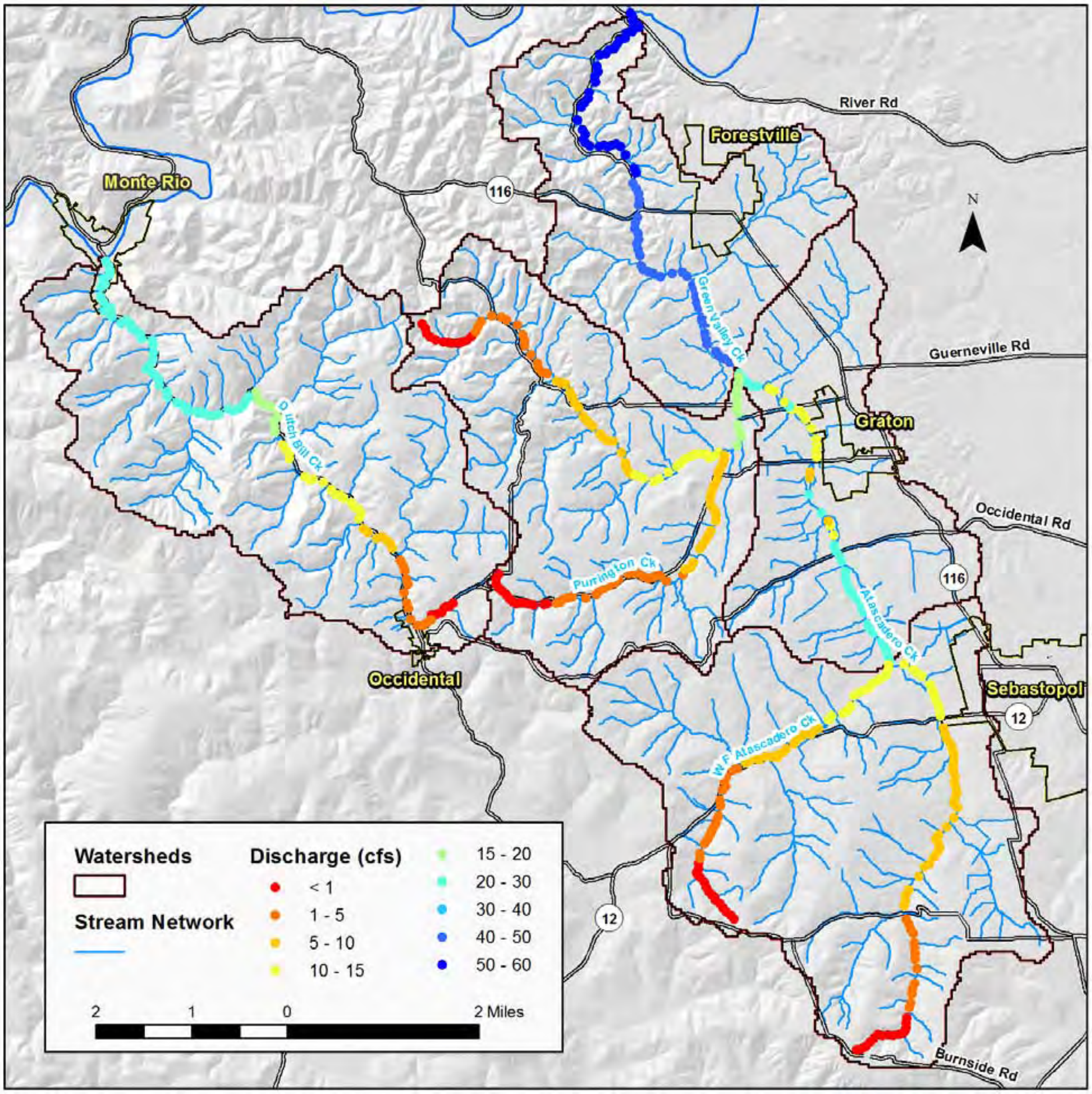


Figure 51 - Simulated mean annual discharge for WY 2010.

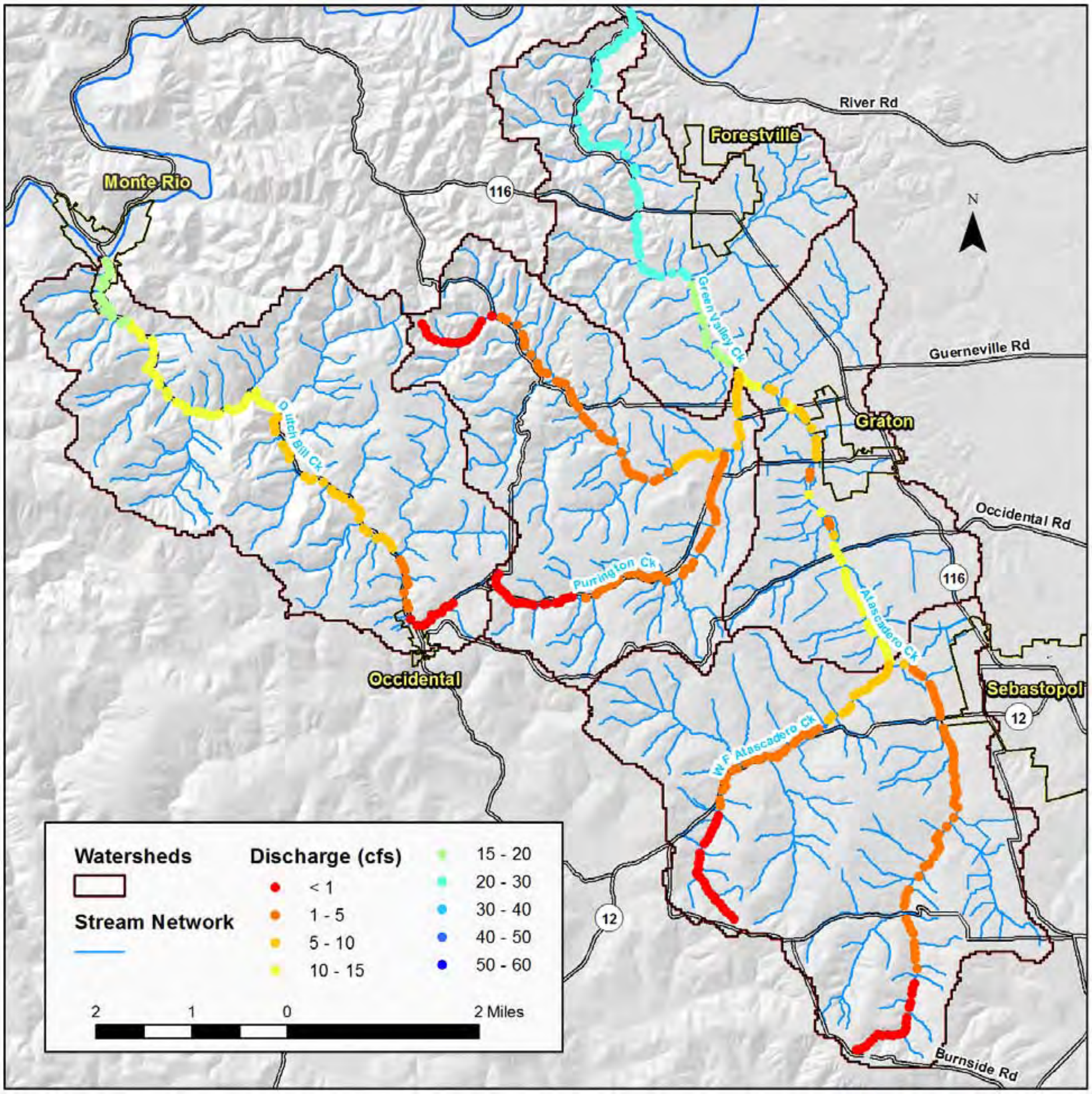


Figure 52 - Simulated mean annual discharge for WY 2014.

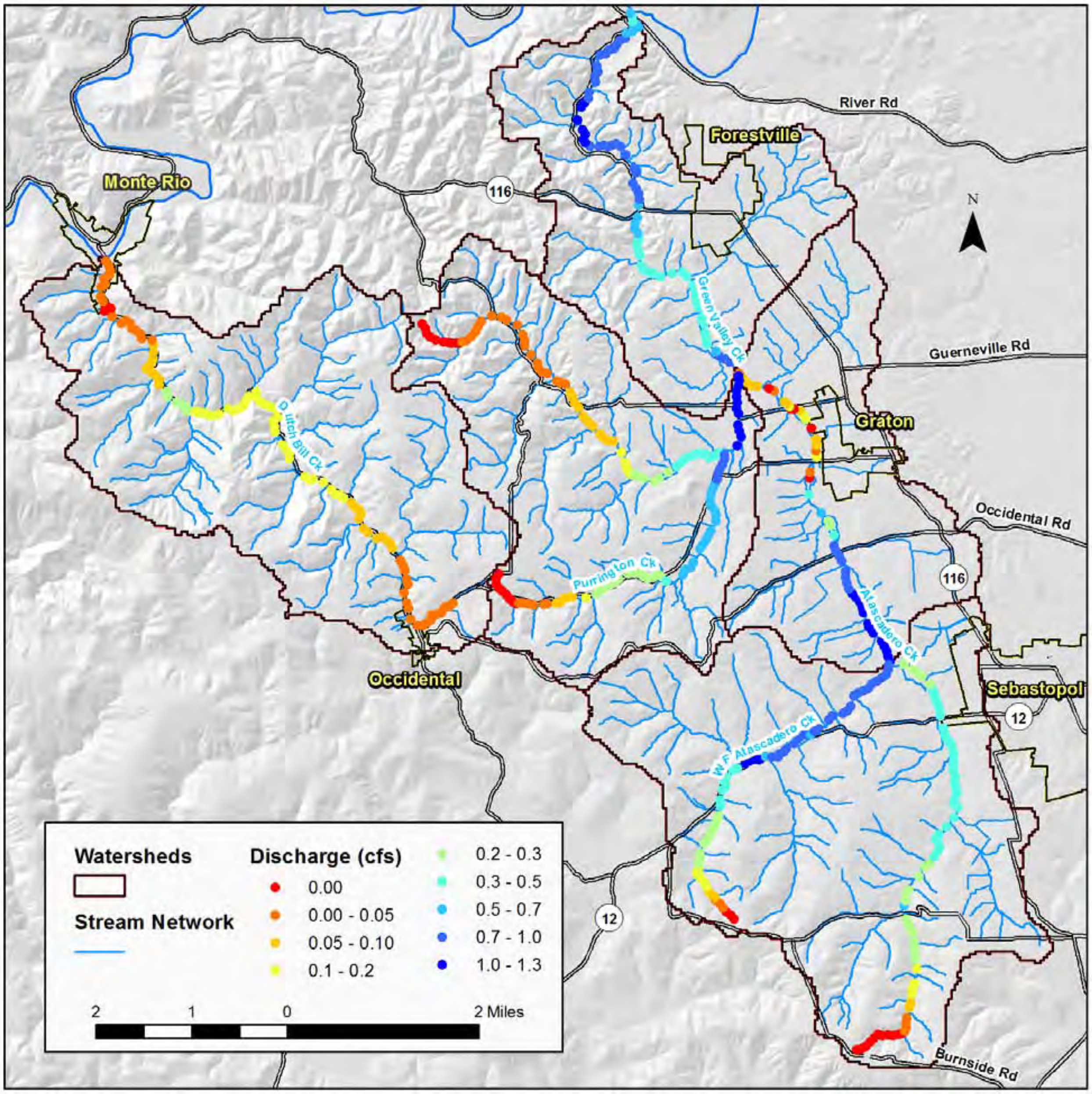


Figure 53 - Simulated mean June 15th - Sept 15th discharge for WY 2010.

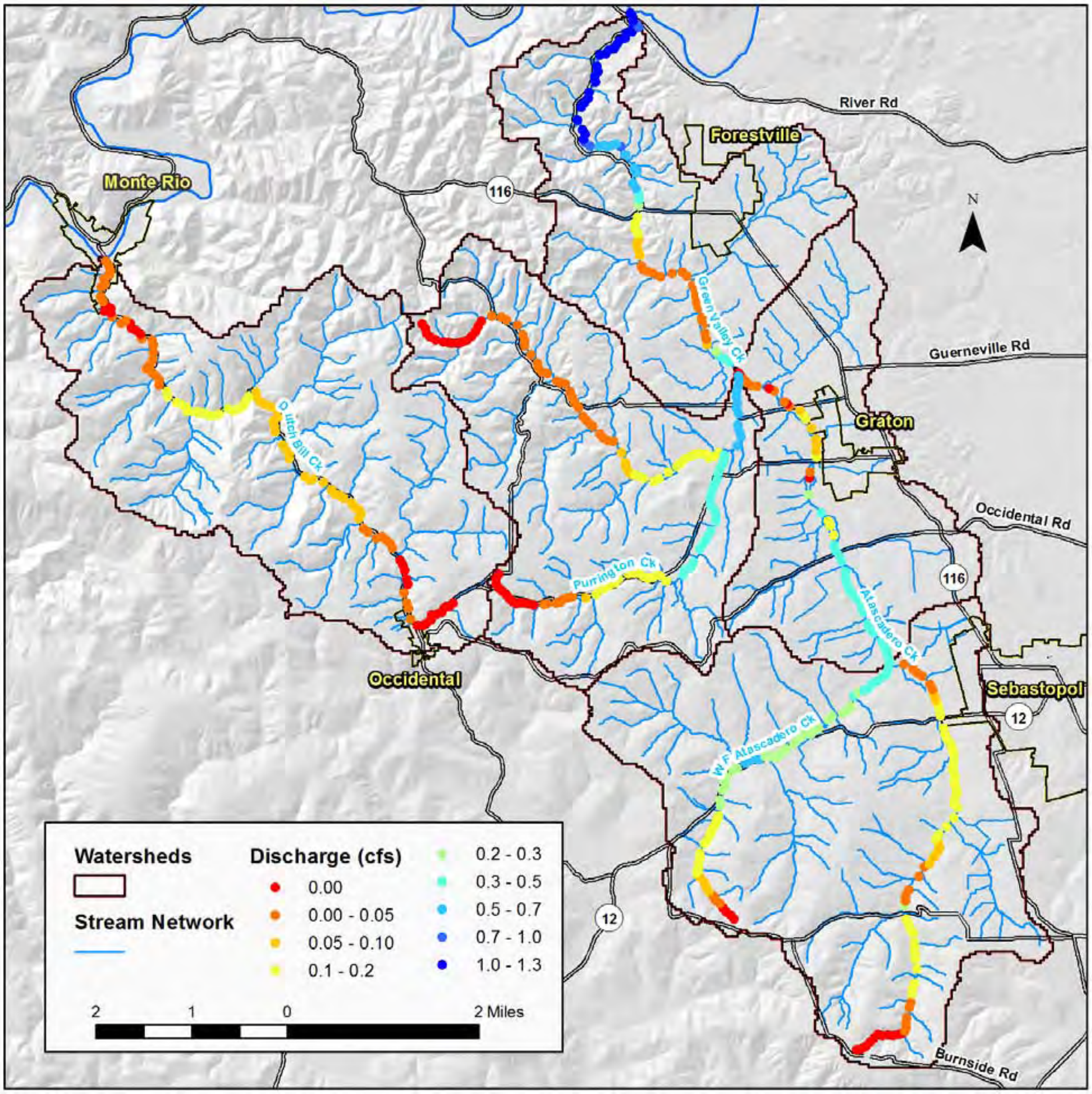


Figure 54 - Simulated mean June 15th - Sept 15th discharge for WY 2014.

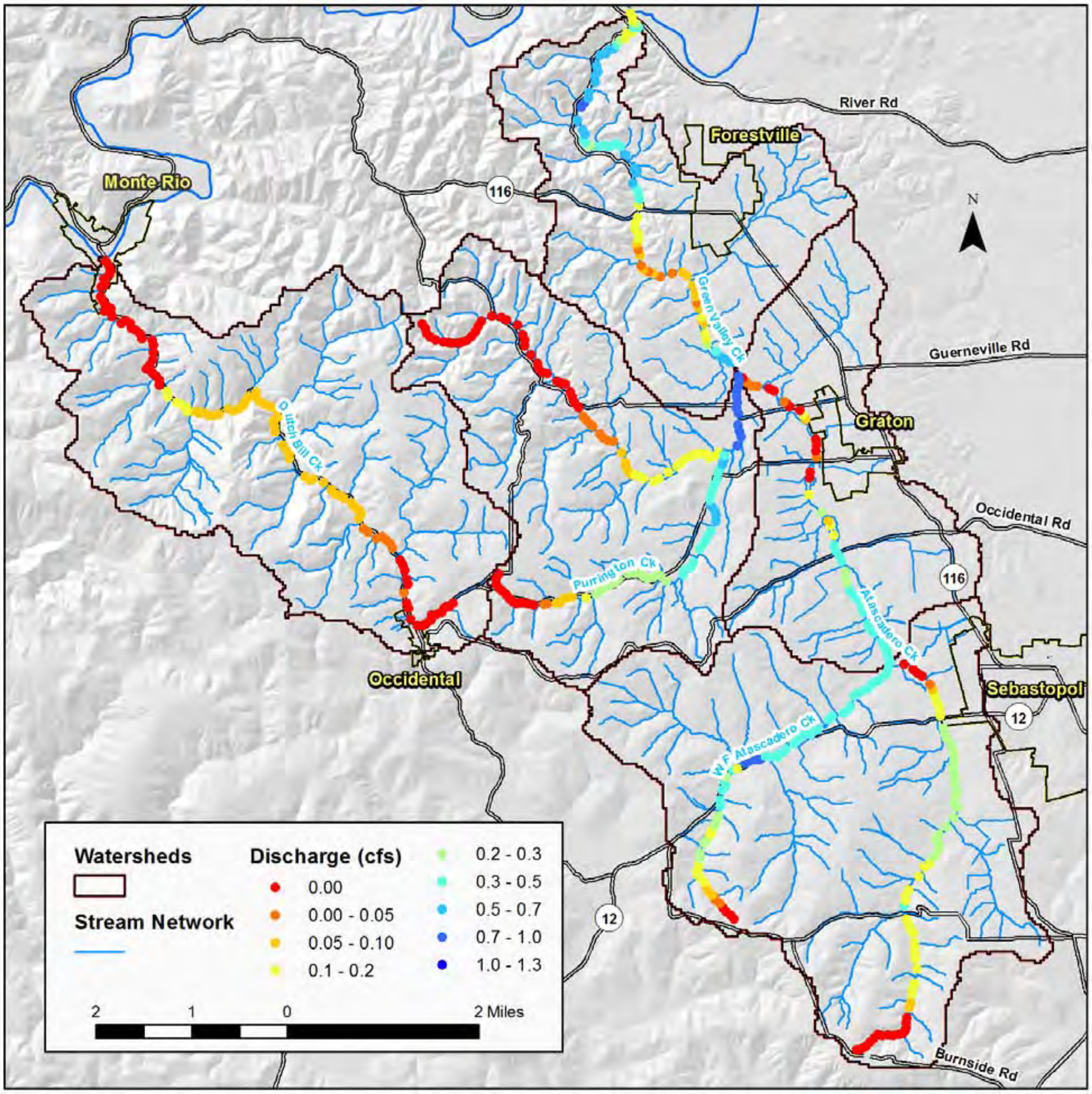


Figure 55 - Simulated minimum discharge for WY 2010.

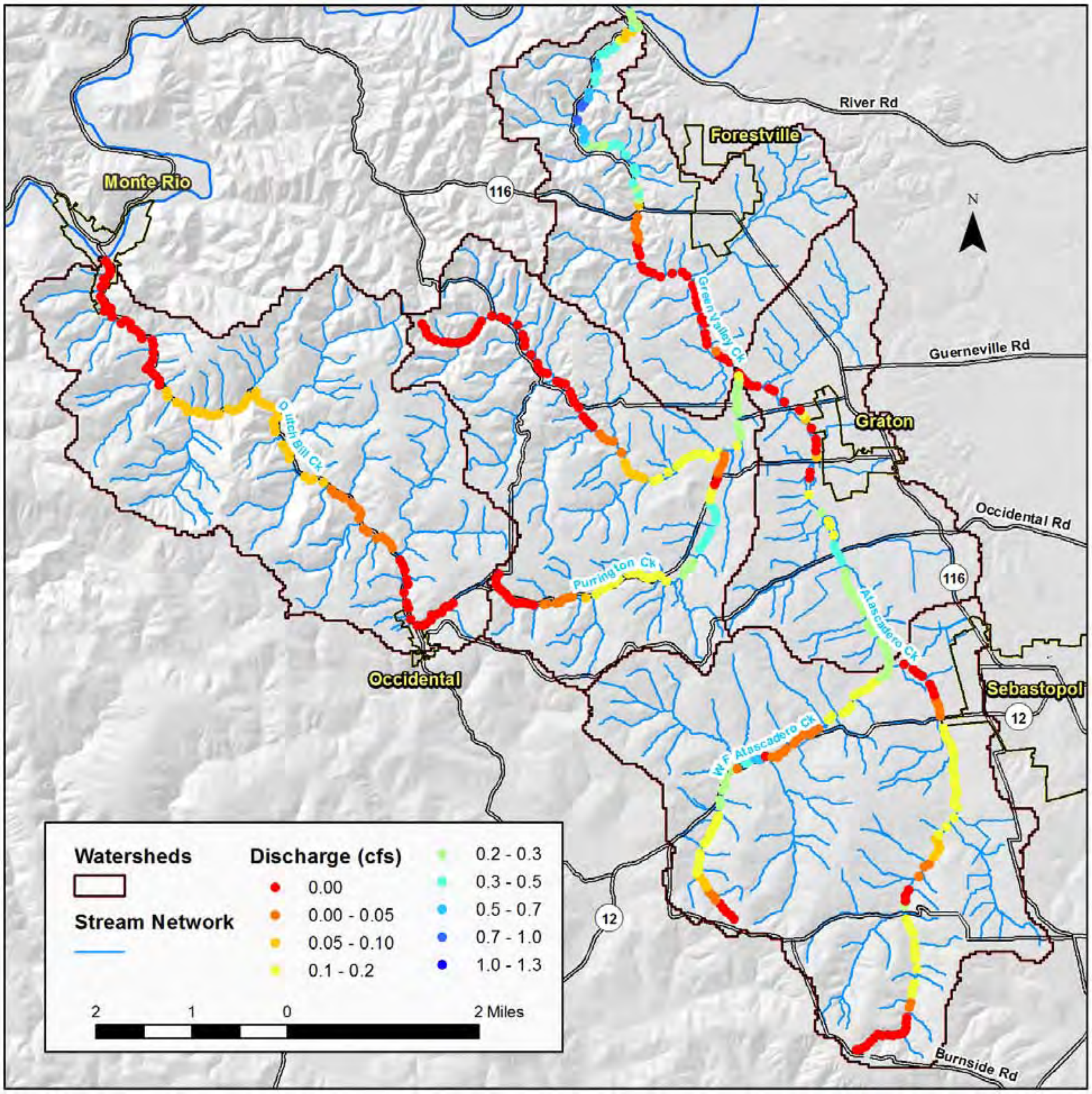


Figure 56 - Simulated minimum discharge for WY 2014.

Groundwater

Simulated Layer 1 groundwater elevations for April 1st, 2010 and October 1st, 2010 are shown in Figures 57 and 58. These elevations represent a composite of all of the geologic materials represented by Layer 1 (Alluvium, Wilson Grove Formation, Franciscan Complex). Groundwater flow directions generally follow topographic patterns with elevations in the GVAC watershed ranging from 700 to 1,000-ft asl in the headwaters of Atascadero, upper Green Valley and Purrington Creeks to less than 100-ft asl in lower Green Valley Creek. Groundwater gradients are much steeper in the DBC watershed with elevations ranging from 1,400-ft asl along the eastern watershed divide to less than 100-ft asl near the confluence with the Russian River. Throughout the study area groundwater gradients generally converge towards the major stream channels, and in lower Atascadero Creek, groundwater also flows southwest to northeast towards the adjacent Santa Rosa Plain. Groundwater elevations are slightly lower in October than in May, however the overall directions of groundwater flow are very similar seasonally and throughout the five year simulation period.

Figure 59 shows the change in groundwater elevations between October 1st, 2010 and October 1st, 2014. Areas underlain by rocks of the Franciscan Complex exhibited relatively small changes in groundwater elevations whereas areas underlain by the Wilson Grove Formation exhibited larger changes. Within the Franciscan Complex, changes were generally less than 2-ft and within the Wilson Grove Formation changes ranged from slight increases to decreases of up to 14-ft. The largest changes occurred along the western edges of the upper Atascadero and West Fork Atascadero creek watersheds, and in smaller areas in the lower Purrington Creek watershed and near the watershed divide between the lower portion of upper Green Valley Creek and lower Green Valley Creek. Decreases in elevations of up to 10-ft also occurred along the eastern-side of lower Atascadero and lower Green Valley Creeks.

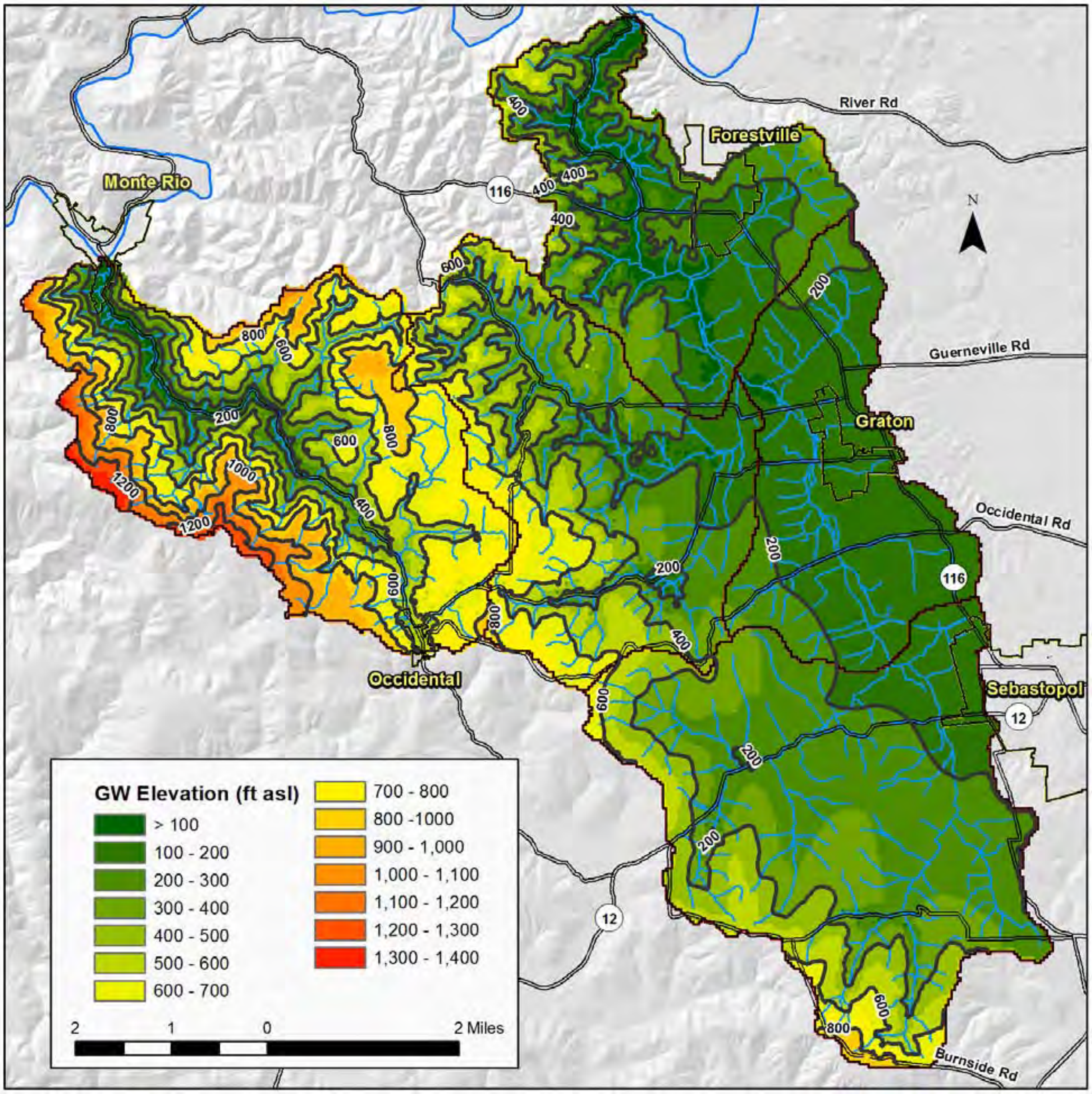


Figure 57 - April 2010 simulated groundwater elevations. Note that areas underlain by the Franciscan Complex have been simulated using a simplified representation of aquifer characteristics and that simulated groundwater elevations in these areas may not be representative of local conditions.

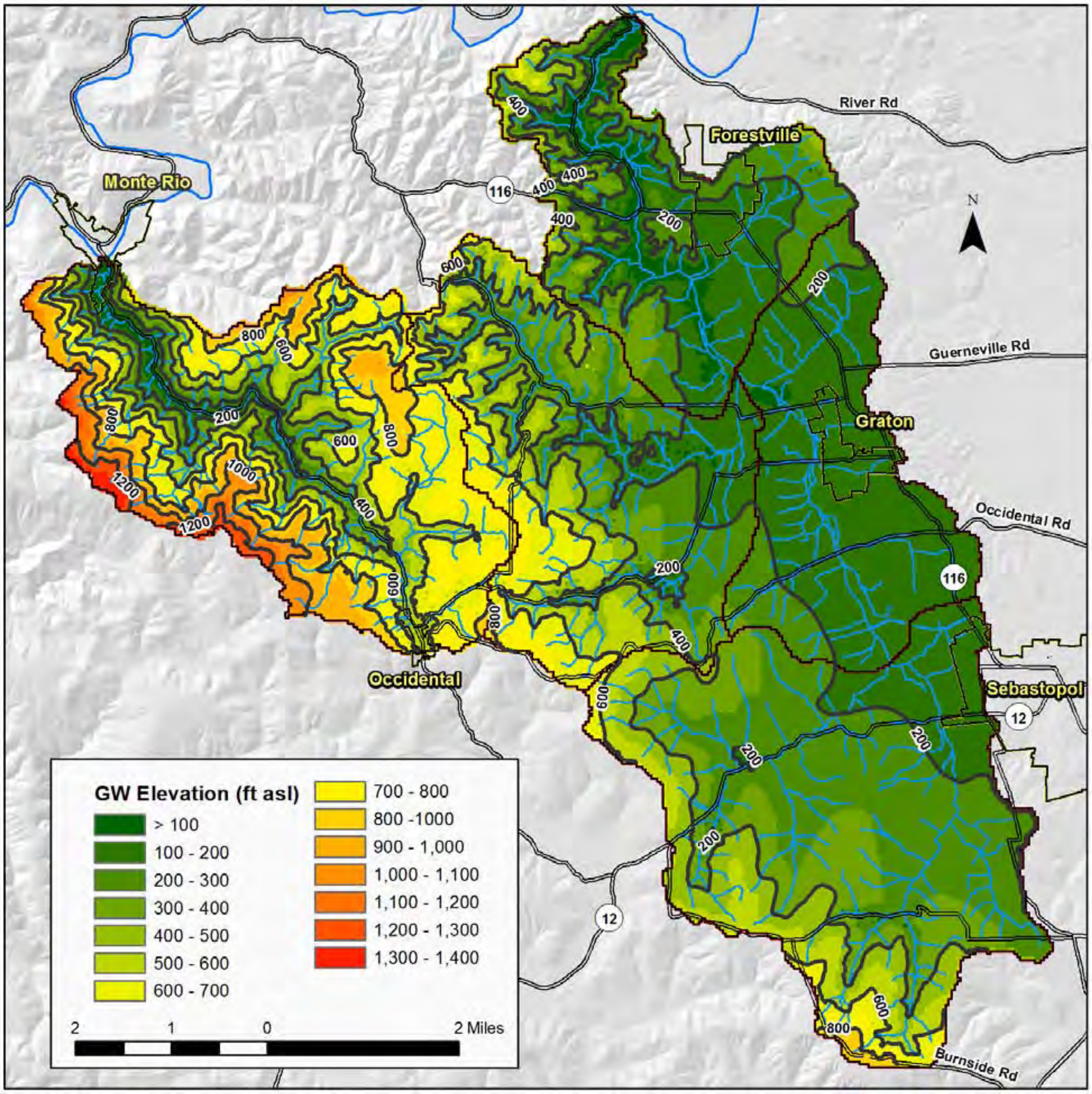


Figure 58 - October 2010 simulated groundwater elevations. Note that areas underlain by the Franciscan Complex have been simulated using a simplified representation of aquifer characteristics and that simulated groundwater elevations in these areas may not be representative of local conditions.

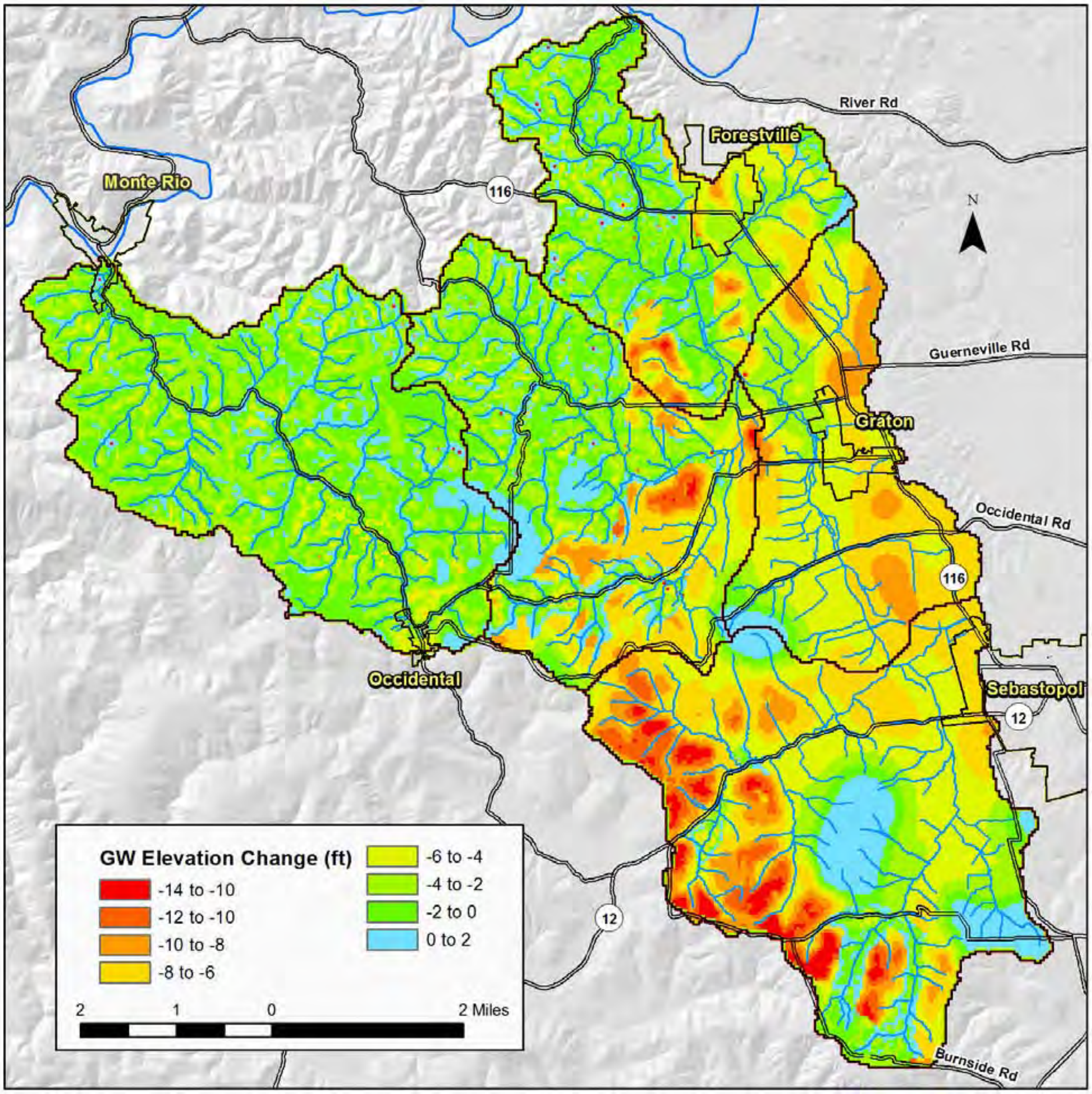


Figure 59 - Simulated change in groundwater elevations from October 1, 2009 to October 1, 2014. Note that areas underlain by the Franciscan Complex have been simulated using a simplified representation of aquifer characteristics and that simulated groundwater elevations in these areas may not be representative of local conditions.

Chapter 7 - Habitat Characterization

Approach

A lack of adequate stream flow to support juvenile rearing habitat during the summer months has been identified as a primary limiting factor for coho survival in Russian River tributaries in general (CDFG, 2004; NFMS, 2012) and in Green Valley Creek specifically (GRRCD, 2010; GRRCD, 2013). Numerous methods have been developed to relate stream flow conditions to habitat quality and define minimum flow requirements for a specific species and life stage of interest. These methods include applying regional regression equations that have been developed from multiple habitat suitability curve studies (e.g. Hatfield and Bruce, 2000), wetted perimeter and critical riffle depth methods (e.g. Swift, 1979, R2 Resource Consultants, 2008), and direct habitat mapping approaches (e.g. McBain and Trush, 2010).

Regional regression equations produce discharge estimates for Green Valley and Dutch Bill Creeks that are an order of magnitude higher than those observed during the summer months at the stream flow gauges in the watersheds. Given that these streams provide some of the best remaining coho habitat in the Russian River watershed despite these very low flow conditions, application of these regional equations may be of limited value for delineating the extent and quality of existing habitat availability with respect to base flow. Direct habitat mapping approaches require detailed fieldwork which is beyond the scope of this study, however these approaches could be utilized in future work. Perhaps the most straightforward way to utilize the hydrologic model results to delineate habitat availability is by applying the critical riffle depth concept to the model simulated water depths. The application of this approach assumes that the modeled cross sections represent riffle locations. This assumption is reasonable given the fact that the cross sections are developed from LiDAR which does not penetrate water and therefore would not be expected to capture pool geometry and by the good agreement between model simulated depths and riffle depth measurements collected by UCCE.

The critical riffle depth concept is based on defining minimum flow depth criteria for fish passage through critical riffles. In essence these criteria represent the minimum flow condition where fish are able to move between pools. A minimum passage depth of 0.3 feet has been estimated for juvenile coho (R2 Resource Consultants, 2008; CDFG, 2013). This depth criteria is somewhat conservative by design and fish passage has been observed at shallower depths therefore it is useful to define a lower criteria below which passage is presumably not possible. For the purposes of this study, that depth was defined as 0.1 feet.

Through field monitoring in Green Valley Creek, UCCE has found that coho can survive in pools that become disconnected for short periods of time, however survival decreases sharply as a function of the length of pool disconnection (UCCE, 2015) largely due to the low dissolved oxygen conditions that develop in disconnected pools (Figure 60). Thus in addition to delineating reaches where passage between pools is possible it is useful to delineate reaches that become dry for short periods of time and reaches that become dry for extended periods of time. A disconnection length of 14 consecutive days was used for this analysis which corresponds to an 85% survival rating and the point beyond which survival begins to decline sharply (UCCE, 2015).

Extensive characterization of pool availability has been conducted in these watersheds and numerous instream restoration projects designed to enhance pool habitat have been implemented in recent years. This analysis assumes that pool habitat availability is adequate and instead focuses on characterizing the degree of connectivity between pools. Future work to combine the flow connectivity results produced here with pool inventory data could be used to develop a more comprehensive analysis that considers both pool availability and connectivity, however such work is beyond the scope of this analysis.

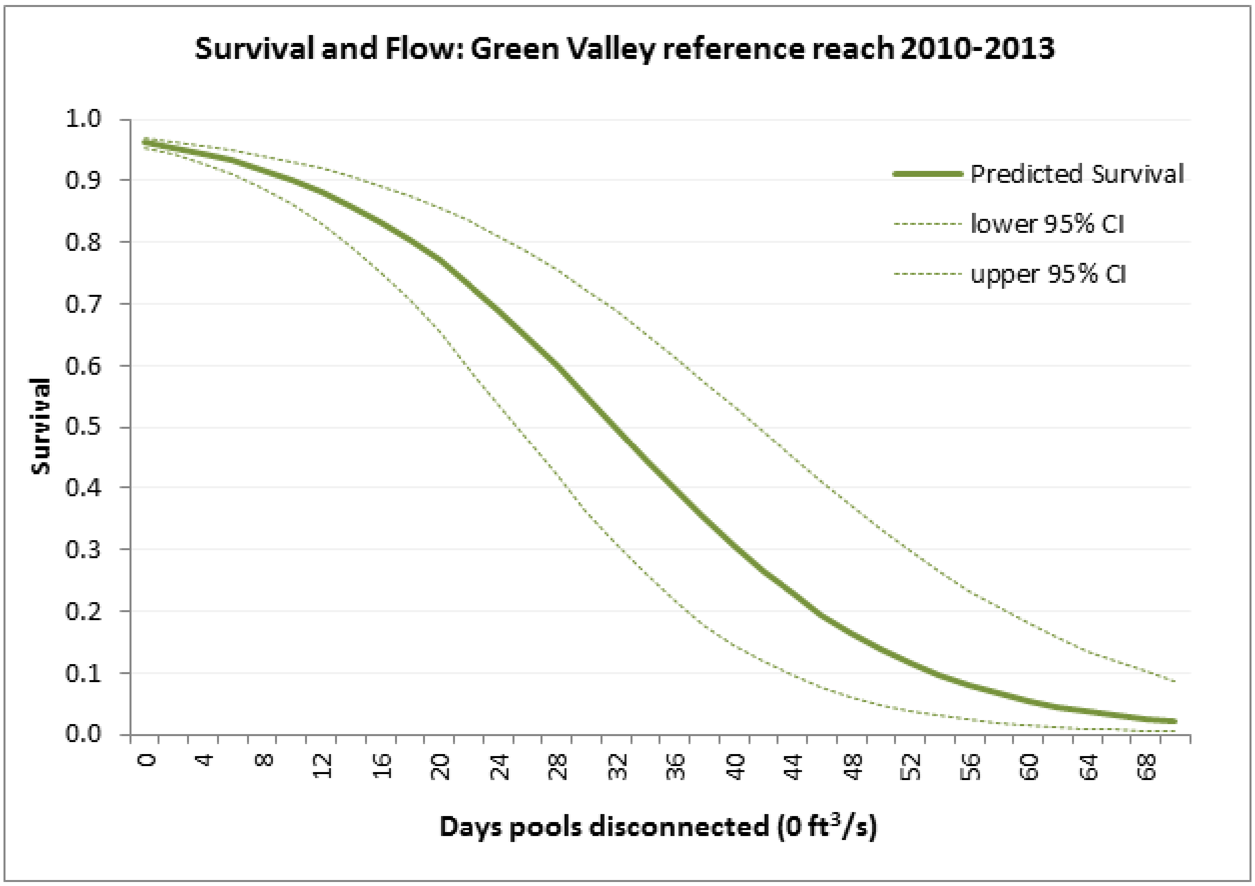


Figure 60 - Relationship between coho survival and the length of pool disconnection established by UCCE in Green Valley Creek.

Results

Flow availability-based habitat maps depicting the minimum water depths and extent of short- and long-term disconnected reaches for WY 2010 and WY 2014 are presented in Figures 61 and 62. Longitudinal profiles of flow-availability based habitat showing both minimum and average June 15 - September 15th conditions for Upper Green Valley, Purrington, and Dutch Bill creeks are presented in Figures 63 through 65. The flow-availability conditions discussed in detail below are summarized on a reach-by-reach basis in Table 15.

Upper Green Valley Creek

Long-term disconnection of pools is predicted to occur during both dry and average flow conditions throughout the reach extending from the headwaters of upper Green Valley Creek through the middle Green Valley Road crossing. Pools within the reach between the middle Green Valley Road crossing and the Bones Road crossing remained connected during WY 2010 but long-term disconnection occurred throughout the reach during WY 2014. During WY 2010, minimum water depths were below the minimum passage threshold (0.1-ft) and summer average water depths were approximately equal to the threshold indicating that passage between pools within this reach was marginal and likely only possible during the early summer months.

Pools within the reach between the Bones Road crossing and the confluence with Purrington Creek remained connected during both dry and average flow conditions with the exception of the ~1,900-ft reach below Bones Road where pools became disconnected during WY 2014. Water depths remained above the 0.1-ft minimum passage threshold but below the 0.3-ft optimal passage threshold during both dry and average flow conditions. This suggests that aside from the ~1,900-ft reach below Bones Road, passage between pools was adequate throughout the reach even during dry Water Year conditions.

The reach between the confluence with Purrington Creek and the confluence with Atascadero Creek remained connected with flow depths near the 0.3-ft optimal passage threshold during WY 2010 and between the minimum and optimal passage threshold during WY 2014. It should be noted that the model calibration shows that the model over-predicts depths in the lowest portion of this reach above the Atascadero Creek confluence and that some disconnected pools have been observed in this reach during dry Water Year conditions.

Lower Green Valley Creek

Pools remained connected throughout lower Green Valley Creek during WY 2010 with flow depths above the 0.3-ft optimal passage threshold except in a few short reaches where depths remained well above the minimum passage threshold. During WY 2014, the reach between the confluence with Atascadero Creek and a point ~1,600-ft upstream of the Hwy 116 crossing was characterized by alternating reaches of short- and long-term disconnection of pools indicating that passage in this reach was marginal and likely only possible during the early summer months. Downstream of this reach through the confluence with the Russian River, pools in lower Green Valley Creek remained connected even in dry Water Year flow conditions with water depths well above the minimum passage threshold and exceeding the optimal passage threshold in much of the reach.

Purrington Creek

Long-term disconnection of pools is predicted to occur between the headwaters of Purrington Creek through a point ~2,700-ft downstream of the upper-most Graton Road crossing. Between this point and the third Graton Road crossing (just downstream of Green Hill Road) pools remained connected, however water depths were generally below the 0.1-ft minimum passage threshold even during average Water Year conditions. This suggests that passage between pools was likely possible only during early summer conditions in this reach.

Between the third Graton Road crossing and the confluence with Green Valley Creek, pools remained connected during both WY 2010 and WY 2014 with the exception of a ~400-ft reach immediately upstream of the downstream-most Graton Road crossing where short-term disconnection occurred in WY 2014. Excluding this short reach, water depths were between the minimum and optimal passage threshold during both dry and average Water Year conditions indicating that passage between pools was adequate throughout this reach even during dry Water Year conditions.

West Fork Atascadero Creek

With the exception of the upper-most ~1,300 feet, pools in West Fork Atascadero Creek remained connected during both dry and average Water Year conditions. Upstream of the Wagnon Road crossing (1,800-ft upstream of the upper-most Hwy. 12 crossing) water depths were below the 0.1-ft minimum passage threshold for the most part indicating that passage between pools was generally not adequate. Between the Wagnon Road crossing and the second Hwy. 12 crossing, water depths were generally between the minimum and optimal passage depths during both dry and average Water Year conditions. Between the second Hwy. 12 crossing and the confluence with Atascadero Creek, passage depths were above the 0.3-ft optimal passage threshold during WY 2010 and either close to or above the threshold in WY 2014 as well.

Upper Atascadero Creek

Long-term disconnection of pools occurred throughout the upper-most ~4,300-ft of upper Atascadero Creek. Between this point and the Barnett Valley Road crossing pools remained connected, however water depths were below the 0.1-ft minimum passage threshold in some reaches indicating that passage between pools was likely only possible during the early portion of summer. Between the Barnett Valley Road crossing and the Hwy. 12 crossing, pools remained connected with water depths between the minimum and optimal passage thresholds with the exception of the 1,600-ft reach below Barnett Valley Road which experienced short-term disconnection during WY 2014. Short-term disconnection of pools occurred in the lower-most ~2,400-ft reach between the Hwy. 12 crossing and the confluence with West Fork Atascadero during WY 2010, and long-term disconnection of pools occurred within this reach during WY 2014.

Lower Atascadero Creek

Pools remained connected with passage depth generally above the 0.3-ft optimal passage depth threshold between the confluence of Atascadero and West Fork Atascadero creeks and a point ~1,200-ft upstream of the Graton Road crossing during both dry and average Water Year conditions. The reach between this point and the confluence with Green Valley Creek was characterized by alternating reaches of short- and long-term periods of zero discharge indicating the potential for temperature and/or dissolved oxygen problems to develop.

Dutch Bill Creek

Between the headwaters of Dutch Bill Creek and the confluence with Lancel Creek, long-term disconnection of pools occurred during both dry and average Water Year conditions. Between the Lancel Creek and Grub Creek confluences, pools remained connected, however water depths were generally below the 0.1-ft minimum passage threshold indicating that passage between pools was likely only possible during the early summer months. Between the confluence with Grub Creek and a point ~600-ft upstream of the Tyrone Road crossing, pools remained connected with water depths close to but generally above the 0.1-ft minimum passage threshold indicating that passage conditions were adequate even during dry Water Year conditions in this reach. Long-term disconnection of pools occurred throughout the lowest reach of Dutch Bill Creek from ~600-ft upstream of the Tyrone Road crossing to the confluence with the Russian River.

Table 15 - Summary of flow-availability based habitat conditions for various sub-reaches within Green Valley, Atascadero, Purrington, and Dutch Bill creeks. Reach codes refer to the reaches delineated on Figure 70.

			Average Water Year Conditions (2010)				Dry Water Year Conditions (2014)				
Creek	Reach Extent	Reach Length (ft)	Continuous Pool Connection	No Long-term Pool Diconnection	Water Depths Above Minimum Passage Threshold	Water Depths Above Optimal Passage Threshold	Continuous Pool Connection	No Long-term Pool Diconnection	Water Depths Above Minimum Passage Threshold	Water Depths Above Optimal Passage Threshold	# of Criteria Met
Upper Green Valley	Headwaters to middle Green Valley Rd	13,300									0
	UGV1 - Harrison Creek to Bones Rd*	6,900	X	X							2
	UGV2 - Bones Rd to 1,900-ft below Bones Rd	1,900	X	X	X						3
	UGV3 - 1,900-ft below Bones Rd to Green Valley Rd	8,850	X	X	X		X	X	X		6
	UGV4 - Green Valley Rd to Atascadero Ck**	2,650	X	X	X	X		X	X		6
Lower Green Valley	A1 - Atascadero Ck to 1,600-ft above Hwy 116	10,900	X	X	X	X					4
	A2 - 1600-ft above Hwy 116 to Russian River	19,000	X	X	X	X	X	X	X	X	8
Purrington	Headwaters to 2,700-ft below 1st Graton Rd	3,200									0
	PUR 1 - 2,700-ft below Graton Rd to 3rd Graton Rd	4,900	X	X			X	X			4
	PUR 2 - Graton Rd to ~400-ft above 4th Graton Rd	8,200	X	X	X		X	X	X		6
	PUR3 - above 4th Graton Rd to 4th Graton Rd	400	X	X	X			X			4
	PUR4 - 4th Graton Rd to Green Valley Ck	1,350	X	X	X		X	X	X		6
West Fork Atascadero	Headwaters to 1,300-ft below headwaters	1,300									0
	WFA1 - 1,300-ft below headwaters to Wagnon Rd	7,050	X	X			X	X			4
	WFA2 - Wagnon Rd to 2nd Hwy 12	5,500	X	X	X		X	X	X		6
	WFA3 - 2nd Hwy 12 to Atascadero Ck	10,650	X	X	X	X	X	X	X	X	8
Upper Atascadero	Headwaters to 4,300-ft below headwaters	4,300									0
	UA1 - 4,300-ft below headwaters to Barnett Vly Rd	6,800	X	X			X	X			4
	UA2 - Barnett Vly Rd to 1,600-ft below Barnett Vly Rd	1,600	X	X	X			X			4
	UA3 - 1,600-ft below Barnett Valley Rd to Hwy 12	11,750	X	X	X		X	X	X		6
	UA4 - Hwy 12 to 2,400 above WF Atascadero Ck	2,450	X	X	X	X	X	X	X		7
	UA5 - 2,400 above WF Atascadero Ck to WFAC	2,400		X							1
Lower Atasca-dero	LA1 - WF Atascadero Ck to 1,200-ft above Graton Rd	12,250	X	X	X	X	X	X	X	X	8
	LA2 - 1,200-ft above Graton Rd to Green Valley Ck	8,900		X							1
Dutch Bill	Headwaters to Lancel Ck	8,150									0
	DB1 - Lancel Ck to Grub Ck	11,400	X	X			X	X			4
	DB2 - Grub Ck to 600-ft above Tyrone Rd	11,200	X	X	X		X	X	X		6
	600-ft above Tyrone Rd to Russian River	12,750									0

* long-term pool disconnection does occur in average water years within the upper portion of this reach (Harrison Creek confluence to middle Green Valley Road crossing), however UGV1 was extended to include this area owing to the significant coho use documented in the reach

** although the model did not predict disconnection in this reach, field observations indicate some disconnection does occur during dry Water Year conditions

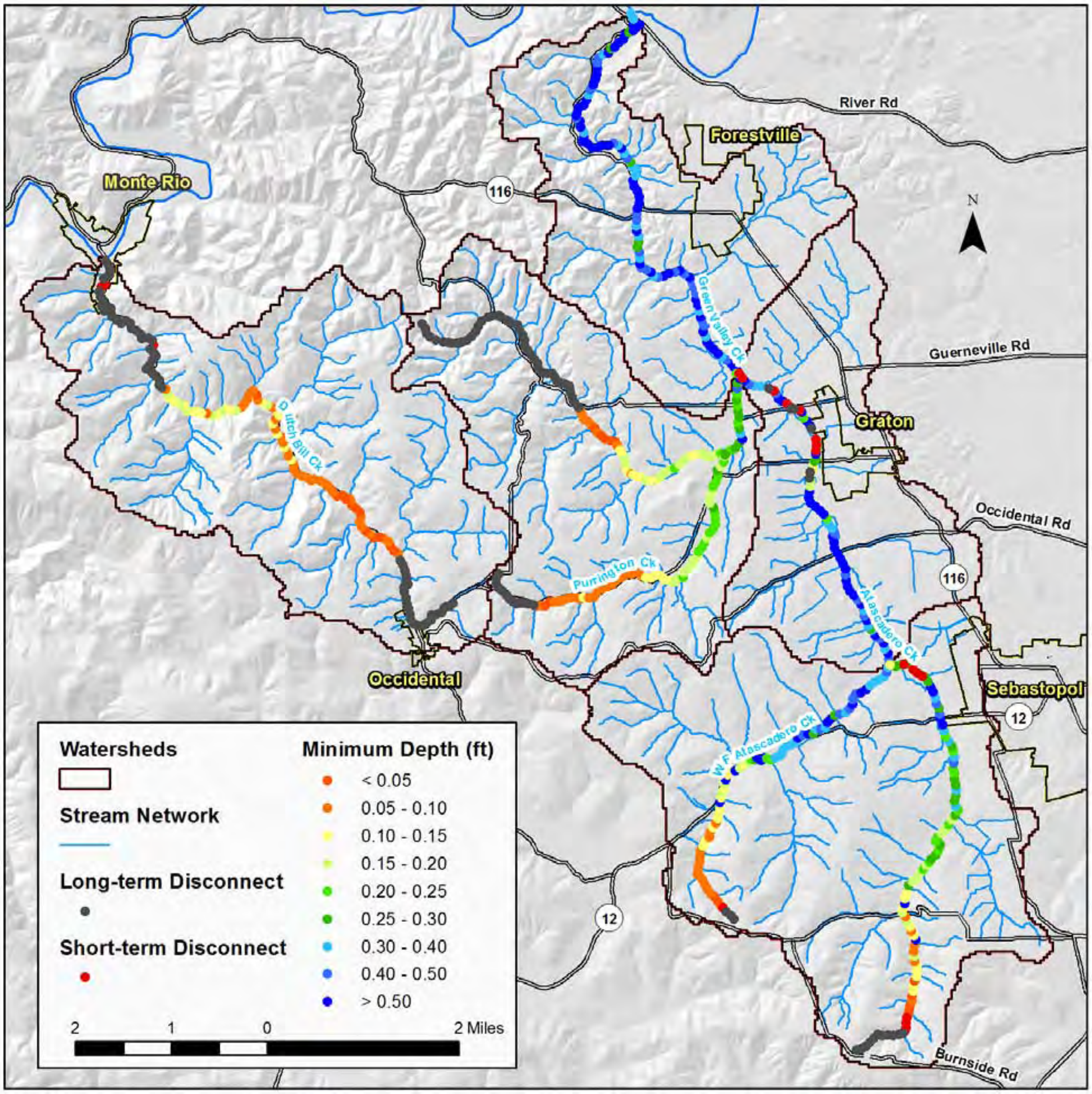


Figure 61 - Simulated water depths and extent of disconnected reaches for WY 2010.

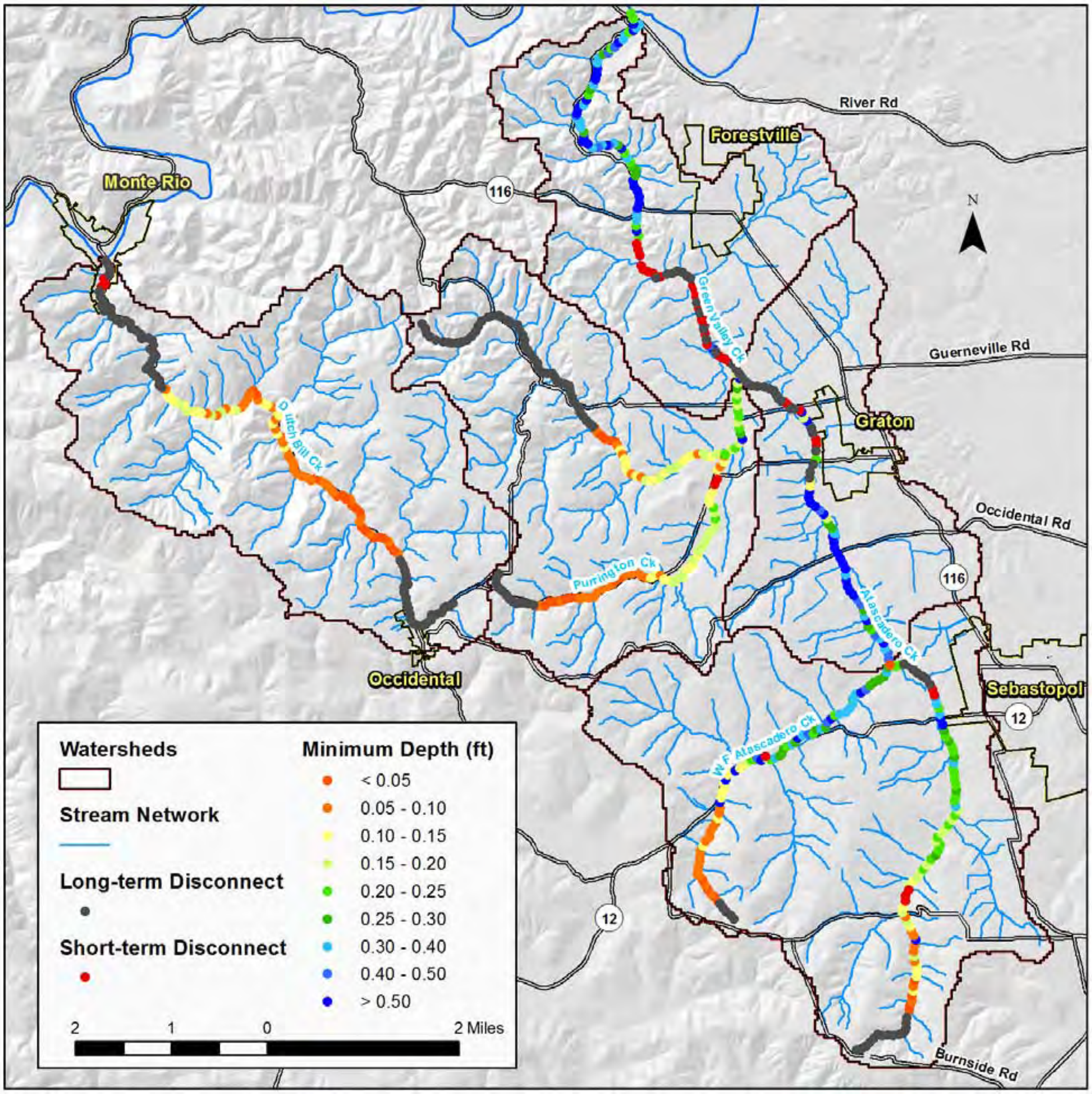


Figure 62 - Simulated water depths and extent of disconnected reaches for WY 2014.

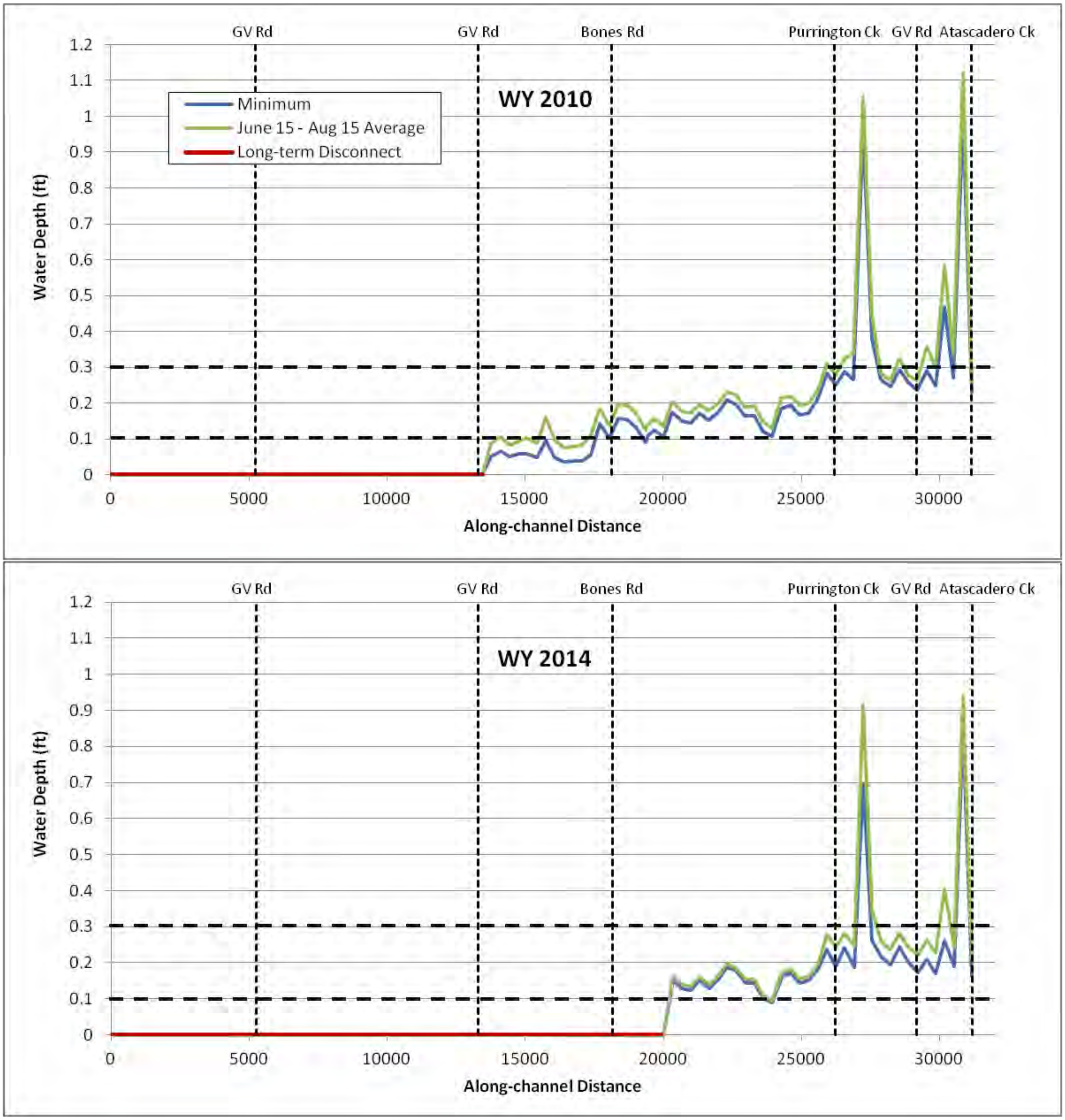
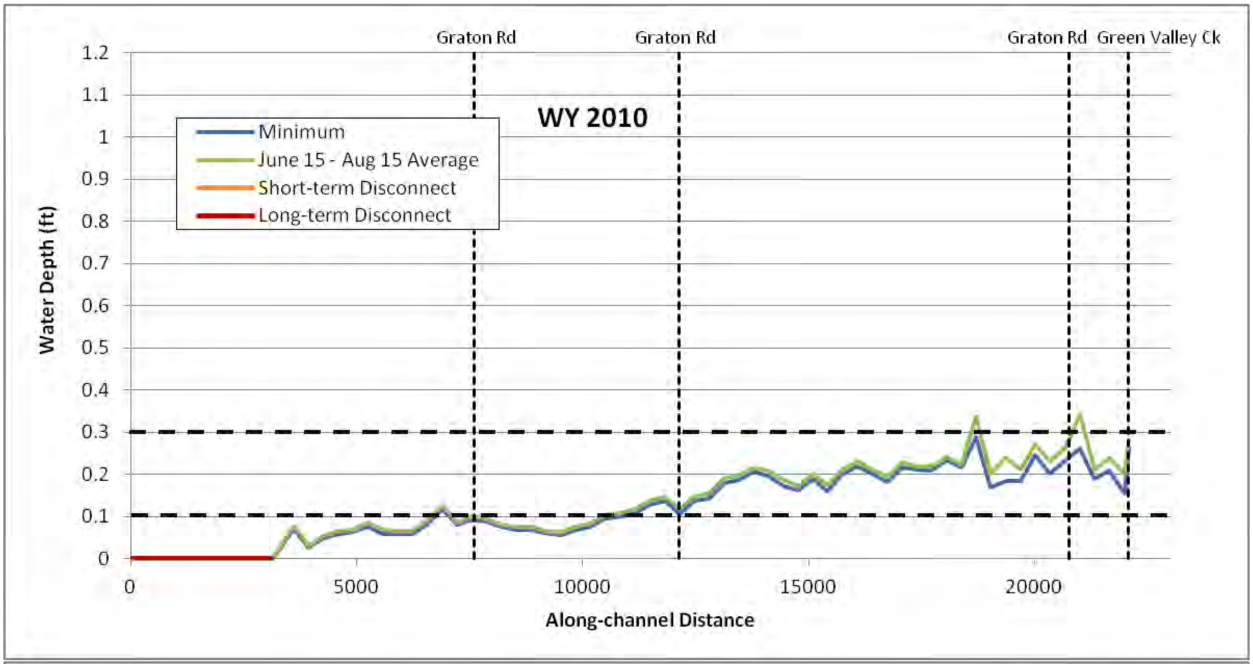


Figure 63 - Longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek., horizontal dashed lines show depth thresholds and vertical dashed lines show locations labeled on the top of the plots.



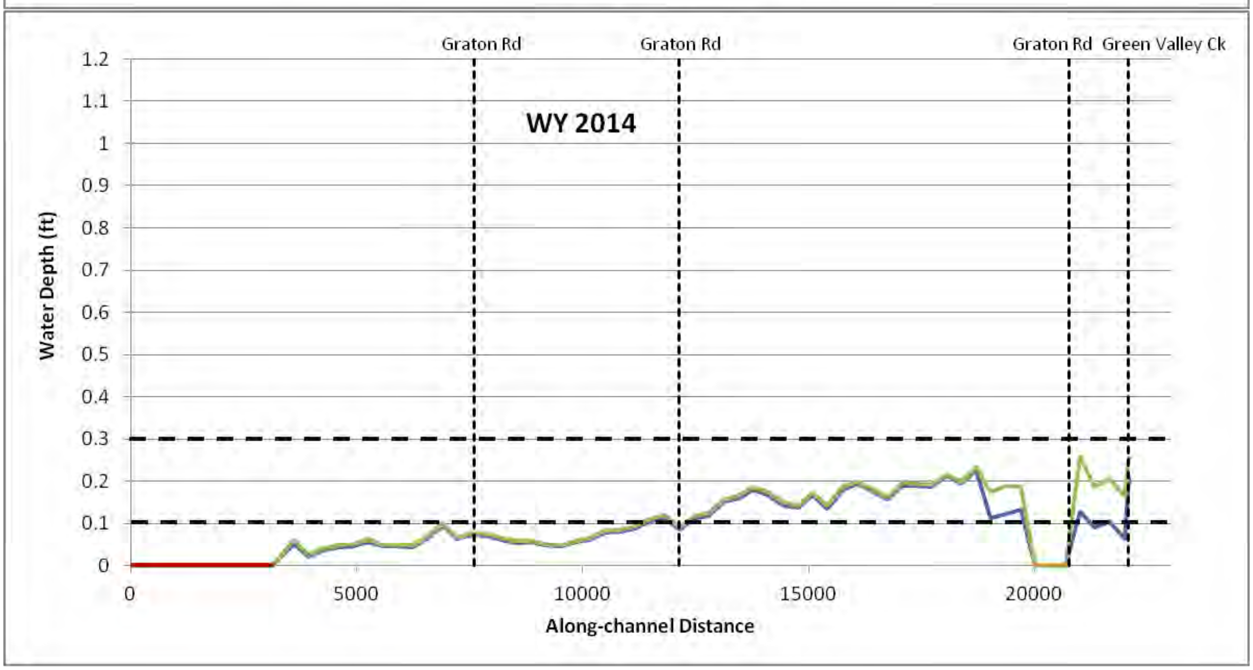


Figure 64 - Longitudinal profiles of simulated water depths and extent of disconnected reaches for Purrington Creek., horizontal dashed lines show depth thresholds and vertical dashed lines show locations labeled on the top of the plots.

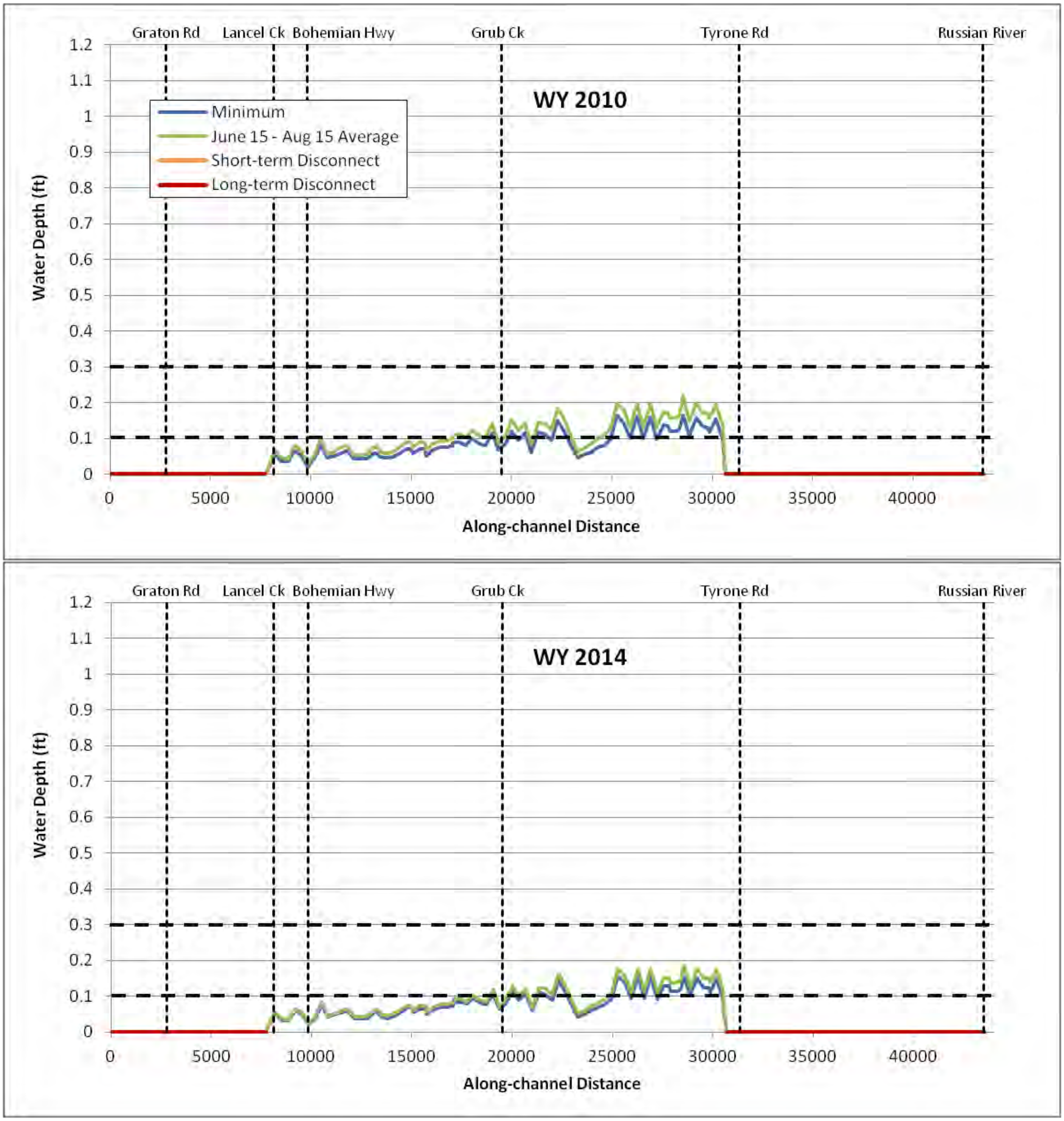


Figure 65 - Longitudinal profiles of simulated water depths and extent of disconnected reaches for Dutch Bill Creek, horizontal dashed lines show depth thresholds and vertical dashed lines show locations labeled on the top of the plots.

Chapter 8 - Scenario Analysis

Overview

Several types of scenarios focused on enhancing flow availability conditions for juvenile coho were envisioned. These included reducing or eliminating direct diversions that may be reducing summer base flow, reducing or eliminating groundwater pumping that may be reducing summer base flow, and augmenting stream flows via intentional releases from existing on-stream ponds. Although the model represents all direct diversions listed in the eWRIMS and reporting of diversions is now required for all riparian diversions, only one riparian diversion is listed in the database for the entire study area. There are almost certainly additional riparian diversions in the watersheds, however no information is available about diversion locations or rates. Also there are no direct diversions listed in the eWRIMS in upper Green Valley Creek which is of particular interest as a key stream for providing coho habitat. Given the incomplete knowledge of existing diversion operations, the decision was made to delay evaluating the effects of stream flow diversions on flow availability conditions in order to avoid coming to possibly incorrect conclusions about diversion impacts due to incomplete data.

Similarly, although the model represents rates and locations of groundwater pumping based on reasonably good information, wells were located based on parcel centroids and generalized well completion information was used in the model. Given that the effects of pumping on stream flows is likely to be very sensitive to the distance of the wells from streams, local hydrogeologic conditions, and the specific well completion details, the decision was made to delay evaluation of the effects of groundwater pumping on flow availability conditions in order to avoid coming to possibly incorrect conclusions about pumping impacts due to incomplete data. The specific types of data needed to refine the model such that it is ready for evaluation of diversion and groundwater pumping impacts are discussed in the Data Gaps and Recommendations for Future Work section of this report.

A single model scenario involving augmenting flows through intentionally releasing water from existing ponds was evaluated. Two ponds were selected for this analysis based on potential or demonstrated landowner cooperation and their locations within key reaches of upper Green Valley Creek which are considered to be flow impaired yet still provide some of the best remaining coho habitat in the Russian River watershed. The existing conditions model was used to estimate the carryover storage in these two ponds (the available storage on October 1st after accounting for evaporation and existing water use). These storages represent an estimate of the volume of water that could be released downstream during the summer months while still allowing the ponds to serve their existing water use functions. The storages were estimated following the end of WY 2010 which represents near average Water Year conditions. The storage volumes were converted to a constant flow rate that could be maintained for the 92-day period from July 1st through September 30th. These flow rates were 0.1 cfs for the upper pond and 0.5 cfs for the lower pond. Water was released from both ponds during this time window during each of the five Water Years simulated with the model, and the results were tabulated and compared to the existing conditions results in order to quantify the potential for improving stream flow and habitat conditions via intentional pond releases.

Results

The pond release scenario was very effective at increasing water depths and reducing the extent of reaches with disconnected pools in upper Green Valley Creek. Approximately 0.08 of the 0.10 cfs released from the upper pond reached Green Valley Creek. This additional flow extended the reach where pools remained connected for an additional 1.3 river miles upstream during Water Year 2010 and for an additional 2.2 miles upstream during Water Year 2014 as compared to existing conditions (Figures 66 & 67; Table 16). This represents a doubling of the length of continuously connected pool habitat during dry Water Year conditions. Average summer water depths remained close to the minimum passage threshold (0.1-ft) within these reaches.

A significant portion of the flow released from the lower pond infiltrated into the streambed and only 0.21 to 0.24 of the 0.50 cfs release reached Green Valley Creek. This additional flow was enough to increase depths by ~0.05-ft from where the lower pond discharges to Green Valley Creek (~0.4 miles downstream of Bones Road) downstream to the confluence with Purrington Creek. Below the Purrington Creek confluence, the additional flow resulted in smaller increases in average summer water depths. Although the quantity of additional flow diminished with distance downstream, the effects of the flow releases persisted into the upper portions of lower Green Valley Creek (Figures 68 & 69). This was more significant during Water Year 2014 where the additional flow reduced the extent of the reaches experiencing short- and long-term disconnection in lower Green Valley Creek.

Table 16 - Comparison of flow-availability based habitat conditions in upper Green Valley Creek between existing and pond release scenario conditions.

	River miles with continuously connected pools		depths above minimum passage threshold	
	WY 2010	WY 2014	WY 2010	WY 2014
Existing Conditions	3.4	2.2	2.5	2.2
Pond Release Conditions	4.7	4.4	3.8	3.6

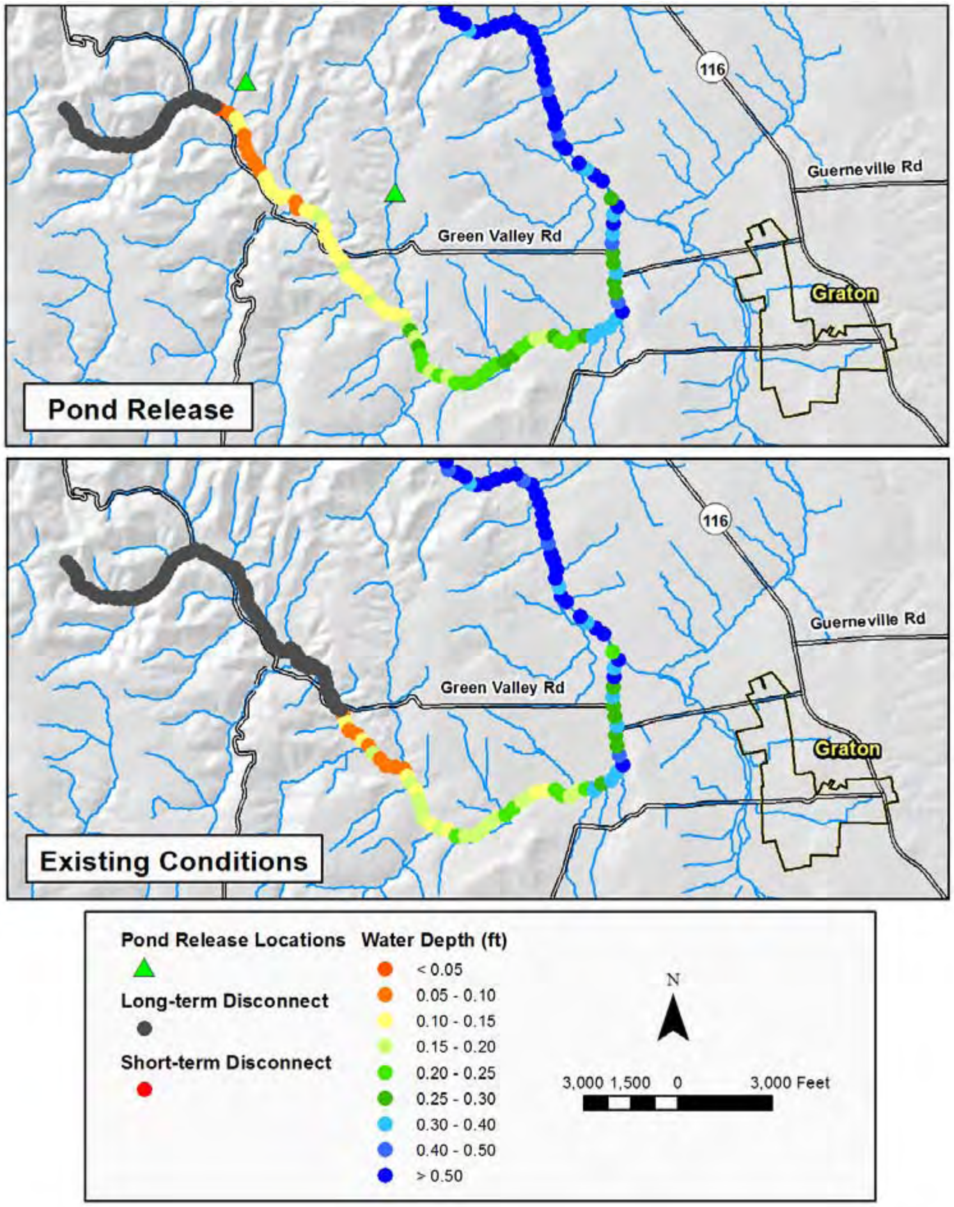


Figure 66 - Comparison of simulated water depths and extent of disconnected reaches in Green Valley Creek for WY 2010 between existing conditions and the pond release scenario.

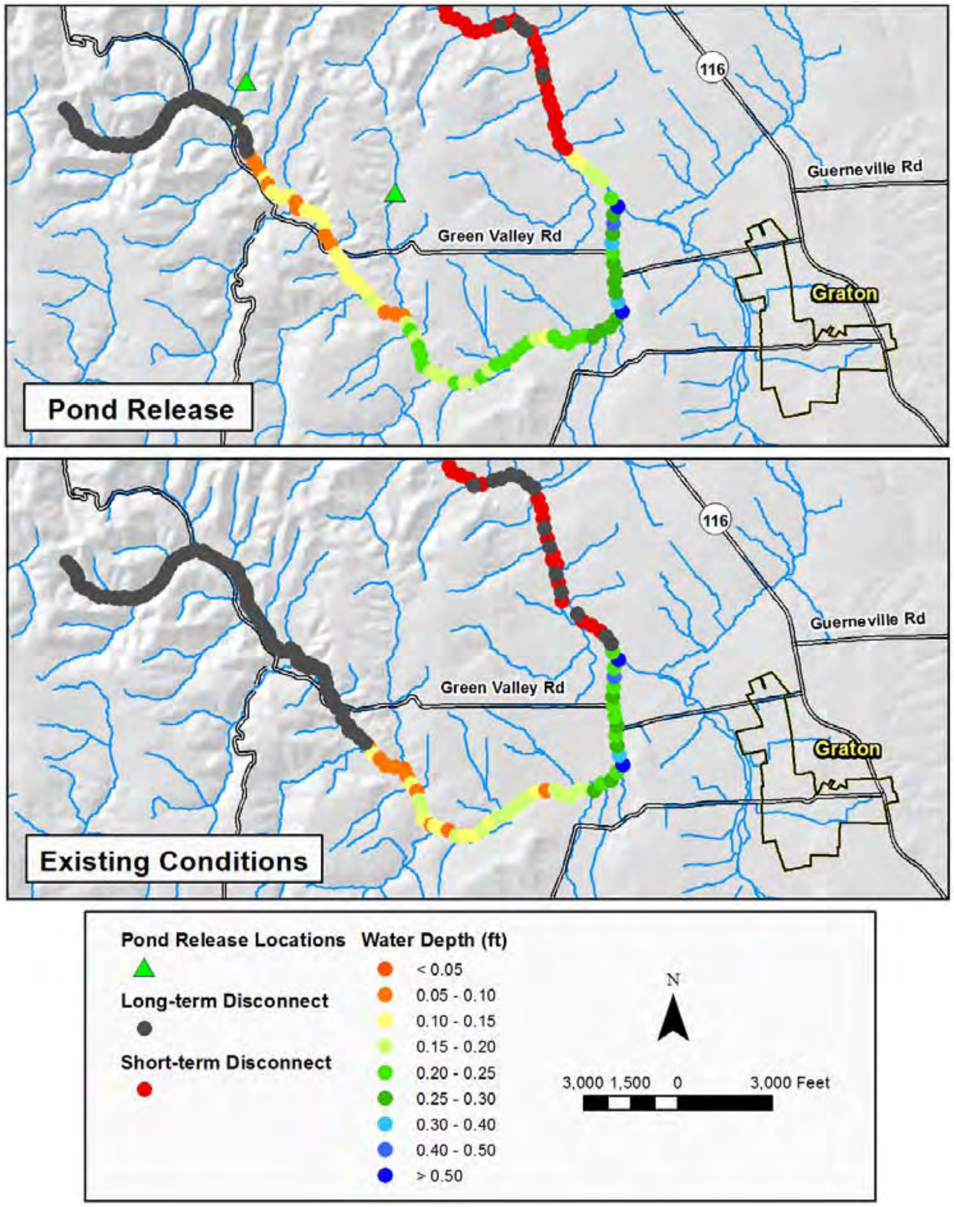


Figure 67- Comparison of simulated water depths and extent of disconnected reaches in Green Valley Creek for WY 2014 between existing conditions and the pond release scenario.

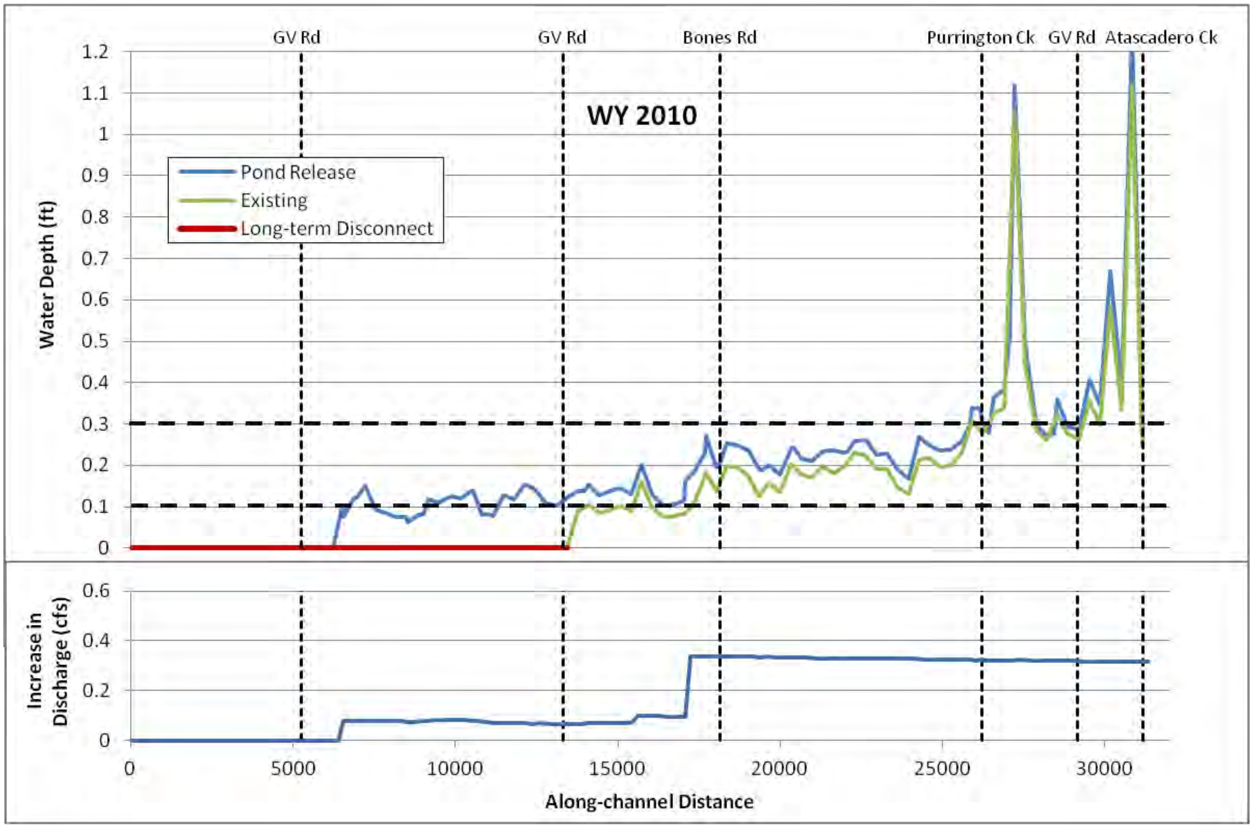


Figure 68 - Comparison of longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek between existing conditions and the pond release scenario for WY 2010. The increase in total discharge under the pond release scenario is shown in the lower plot.

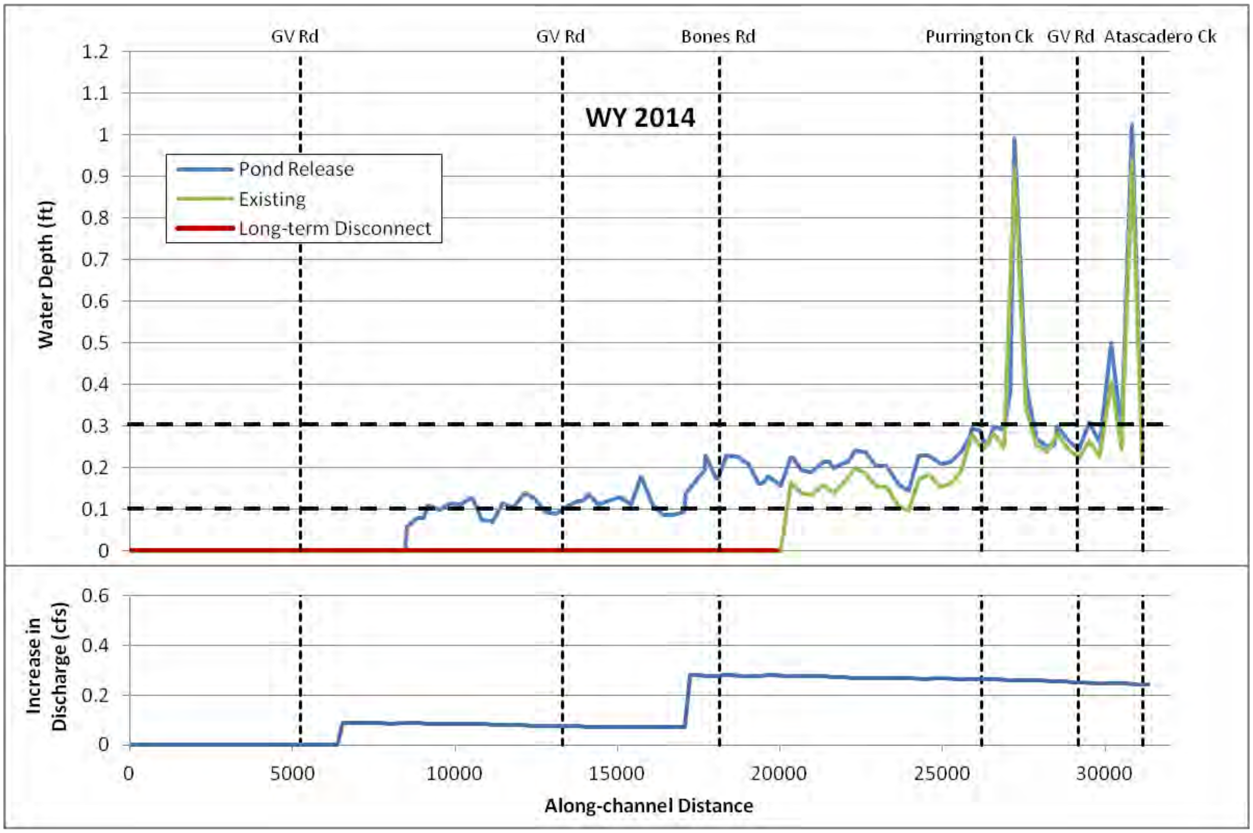


Figure 69 - Comparison of longitudinal profiles of simulated water depths and extent of disconnected reaches for upper Green Valley Creek between existing conditions and the pond release scenario for WY 2014. The increase in total discharge under the pond release scenario is shown in the lower plot.

Chapter 9 - Restoration Recommendations

The delineation of flow availability conditions relative to coho habitat requirements presented here provides a means of prioritizing restoration actions on a reach by reach basis. Specifically, the reaches identified as providing the best flow availability conditions and those that maintain habitat value even during drought conditions are probably the most important reaches to focus habitat enhancement work aimed at addressing limiting factors other than flow (e.g. ensuring quality pool habitat). Efforts to improve flow availability conditions either through intentional flow releases or water use modifications would be best focused in the reaches that are currently providing significant habitat value but at a more marginal level, particularly during dry Water Year conditions. Small changes in flows within these marginal reaches may be expected to yield significant increases in habitat value.

Finally reaches where existing flow availability conditions generally are not suitable can be identified as reaches that do not provide significant juvenile rearing habitat and where restoration efforts should probably be given low priority. It is important to note that if flow augmentation projects similar to those simulated in this study can be implemented, the extents of reaches where restoration projects are recommended would increase based on the new modified flow regime. The reaches described below are shown and color coded based on existing flow availability and recommended restoration actions in Figure 70. More detailed reach maps and recommendation summaries are provided in Appendix B.

Upper Green Valley Creek

The lower-most 3.8 river miles of upper Green Valley Creek from the Harrison Creek confluence downstream to the confluence with Atascadero Creek appears to be the extent of the reach with suitable flow conditions for providing juvenile coho rearing habitat. Upstream of the Harrison Creek confluence, pools become disconnected for extended periods of time even under average Water Year flow conditions indicating limited rearing habitat potential. Pools also become disconnected in the 0.4 mile reach between the Harrison Creek confluence and the middle Green Valley Road crossing, however significant coho use has been documented in this reach so it has been included in the mapping of suitable habitat extent.

The reach with suitable flow conditions can be divided into four reaches as follows: UGV1 - upper 1.3 river miles from the Harrison Creek confluence to the Bones Road crossing, UGV2 - 0.4 river miles below the Bones Road crossing, UGV3 - 1.6 river miles from 0.4 miles below the Bones Road crossing to the lower Green Valley Road crossing, UGV4 - lower 0.5 river miles above the confluence with Atascadero Creek (Figure 70).

All four reaches can be considered flow-impaired given that, with a few exceptions, water depths dropped below optimal passage threshold depths even under average Water Year conditions. UGV3 provides the best flow conditions, maintaining minimum passage depths even under dry Water Year conditions. Under the present flow regime, restoration projects aimed at improving juvenile habitat conditions would be most beneficial within this 1.6 river

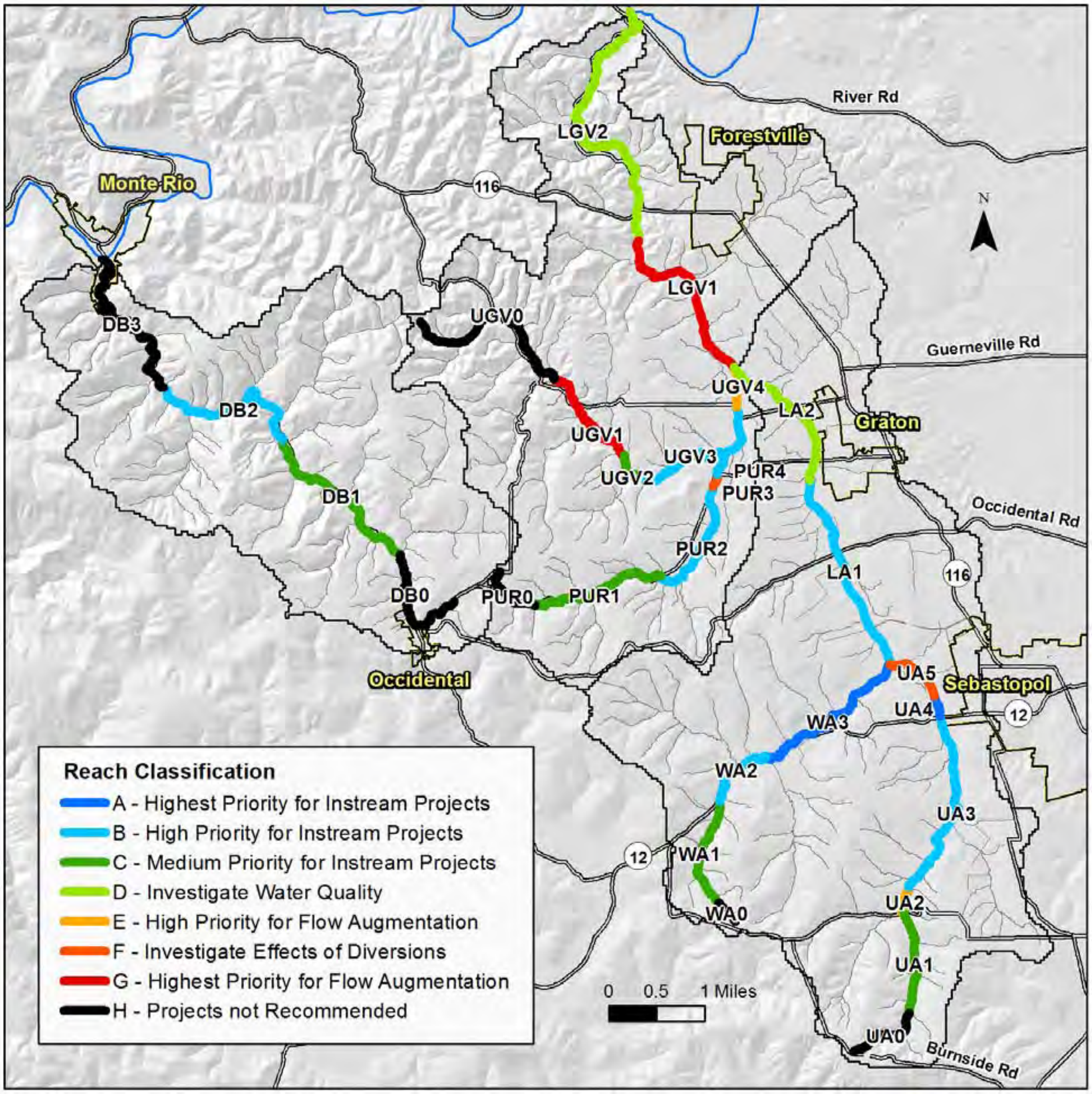


Figure 70 - Flow availability-based reach classification and restoration prioritization map. In general, reaches shown as blue have the best existing habitat conditions and should be the focus of in-stream restoration projects aimed at improving pool conditions, and reaches shows as red, orange, or green are more flow-limited and flow augmentation projects such as intentional flow releases or water use modifications are recommended.

mile reach. UGV1 did not maintain minimum passage depths under average Water Year conditions and long-term disconnection of pools occurred during dry water conditions in both UGV1 and UGV2. UGV4 is also flow-impaired, but not to the degree of UGV1 and UGV2 and disconnection in this reach may be related to the ongoing sand and gravel deposition and associated aggradation of the channel in this reach. Restoration focused on flow augmentation would be most beneficial within UGV1 and UGV2 (1.3 river miles total); such efforts may be expected to benefit UGV4 as well.

Augmenting flows by intentionally releasing water from existing ponds was shown to be a very effective strategy for improving flow availability conditions. If such flow release projects can be implemented, the extent of the creek with suitable flow conditions for providing juvenile coho rearing habitat could be extended significantly farther upstream. Under the flow regime simulated with the pond release scenario (described in the Scenario Analysis section of this report), restoration projects aimed at improving juvenile habitat conditions would also be recommended in reaches UGV1 and UGV2 and possibly even farther upstream.

Lower Green Valley Creek

Lower Green Valley Creek can be divided into two reaches: LGV1 - upper 2.1 river miles from the Atascadero Creek confluence to ~1,600-ft upstream of the Highway 116 crossing, and LGV2 - lower 3.6 river miles above the Russian River confluence (Figure 70).

LGV2 provides some of the best flow conditions for juvenile coho in the study area maintaining depths above the optimal passage threshold during average water year conditions and depths above the minimum passage threshold during dry water year conditions. LGV1 is characterized by favorable flow conditions during average water year flows but periods of long-term pool disconnection during dry water year conditions. Given the lack of adequate flow availability in LGV1 during dry water years under the present flow regime, restoration projects aimed at improving juvenile rearing habitat would be most beneficial within LGV2. Flow augmentation efforts in lower Green Valley Creek should be focused on LGV1 and could potentially provide an additional 2.1 river miles of dry year rearing habitat. Pond releases in upper Green Valley Creek may improve conditions in LGV1 somewhat, however additional flow augmentation is likely needed in this reach in order to eliminate disconnection of pools during dry Water Year conditions.

There is some evidence that water quality conditions may be limiting habitat quality within both LGV1 and LGV2. It is recommended that water quality conditions in these reaches be evaluated and that efforts to improve water quality be pursed as appropriate.

Purrington Creek

The lower-most 2.8 river miles of Purrington Creek from ~0.5 miles downstream of the upper-most Graton Road crossing to the confluence with Green Valley Creek appears to be the extent of the reach with suitable flow conditions for providing juvenile coho rearing habitat. Upstream of this reach, pools become disconnected for extended periods of time even under average Water Year flow conditions indicating limited rearing habitat potential.

The reach with suitable flow conditions can be divided into four reaches as follows: PUR1 - upper 0.9 river miles upstream of the 3rd Graton Road crossing, PUR2 - 1.5 river miles between the 3rd and 4th Graton Road crossings, PUR3 - 0.1 river miles upstream of the 4th Graton Road crossing, and PUR4 - lower 0.2 river miles above the confluence with Green Valley Creek (Figure 70).

All four reaches can be considered flow-impaired given that water depths dropped below optimal passage threshold depths even under average water year conditions. Reaches PUR2 and PUR4 provide the best flow conditions, maintaining minimum passage depths even under dry water year conditions. Under the present flow regime, restoration projects aimed at improving juvenile habitat conditions would be most beneficial within these two reaches (1.7 river miles total).

In contrast to upper Green Valley Creek, none of the reaches experienced long-term disconnection of pools under dry water year conditions, however PUR3 did experience short-term disconnection and water depths fell below minimum passage depth thresholds in PUR1 even under average Water Year conditions. Flow augmentation efforts should be focused on PUR1 and PUR3. Small increases in flow within PUR1 could potentially provide an additional 0.9 miles of available rearing habitat and PUR3 essentially represents a depth passage barrier during dry years which should be verified and removed if possible. PUR3 appears to be influenced by the diversions located in this vicinity. These diversions were modeled using the maximum diversion rates reported in the eWRIMS which may overstate the effects of the diversions depending on the details of the actual diversion operations which are not completely known.

Upper Atascadero Creek and West Fork Atascadero Creek

Coho use has not been documented in upper Atascadero Creek, however reaches with flow conditions suitable for providing juvenile coho rearing habitat are present throughout much of the upper watershed, and juvenile steelhead do currently utilize these areas. In particular the lowest 2.0 river miles of West Fork Atascadero Creek and a 0.5 river mile reach of upper Atascadero Creek have flow conditions that are better than any of the reaches in Upper Green Valley or Purrington Creek. A total of 3.1 river miles of West Fork Atascadero Creek and 2.7 river miles of upper Atascadero Creek have flow conditions that maintain minimum passage threshold depths even under dry water year conditions.

The 0.5 river mile reach upstream of the confluence of Atascadero and West Fork Atascadero Creeks (UA5) becomes disconnected even under average water year conditions. This essentially represents a depth passage barrier which should be verified and removed if possible. UA5 appears to be influenced by the diversions located in this vicinity. These diversions were modeled using the maximum diversion rates reported in the eWRIMS which may overstate the effects of the diversions depending on the details of the actual diversion operations which are not completely known. Given the availability of extensive reaches with suitable flow conditions for juvenile coho in Upper Atascadero Creek, additional effort to understand the extent of coho presence in Atascadero Creek and the factors limiting access to and survival in the upper watershed is highly recommended.

Lower Atascadero Creek

Lower Atascadero Creek can be divided into two reaches: LA1 - upper 2.3 river miles from the West Fork Atascadero Creek confluence to ~1,200-ft upstream of Graton Road, and LA2 - lower 1.7 river miles above the Green Valley Creek confluence (Figure 70). LA1 provides some of the best flow conditions for juvenile coho in the study area, maintaining depths above the optimal passage threshold during average water year conditions and depths above the minimum passage threshold during dry water year conditions. Small water depths persist in LA2, however, a stagnant water (zero discharge and velocity) condition develops during the late summer even during average water year conditions.

As discussed above for upper Atascadero Creek, the degree to which coho use Atascadero Creek and the factors limiting that use have not been studied in detail. This analysis suggests that the stagnant water conditions in LA2 may result in temperature and/or dissolved oxygen conditions that limit access to the upper portions of the watershed. Given that more than eight river miles of habitat better than or equivalent to the best reaches of upper Green Valley and Purrington Creeks lie upstream of this reach, further investigation of the role of LA2 in limiting coho use of Atascadero Creek is highly recommended. Flow augmentation efforts focused on LA2 may improve access to the upper watershed and would be expected to also improve flow conditions in LA1 of lower Green Valley Creek located immediately downstream.

Dutch Bill Creek

The 4.3 river miles of Dutch Bill Creek between the confluence with Lancel Creek and a point ~600-ft upstream of the Tyrone Road crossing appears to be the extent of the reach with suitable flow conditions for providing juvenile coho rearing habitat. Upstream and downstream of this reach, pools become disconnected for extended periods of time even under average water year flow conditions indicating limited rearing habitat potential. The reach with suitable flow conditions can be divided into two reaches as follows: DB1 - upper 2.2 river miles between the Lancel Creek confluence and the Grub Creek confluence, and DB2 - 2.1 river miles downstream of the Grub Creek confluence (Figure 70).

Both reaches can be considered flow-impaired given that water depths dropped below optimal passage threshold depths even under average water year conditions. DB2 provides the best flow conditions, maintaining minimum passage depths even under dry water year conditions. Under the present flow regime, restoration projects aimed at improving juvenile habitat conditions would be most beneficial within this 2.1 river mile reach. Pools in DB1 remain connected, however water depths drop below minimum passage depths even in average water year conditions. Flow augmentation efforts should be focused on DB1 as small increases in flow within this reach could potentially provide adequate passage depths throughout this 2.2 river mile reach. In the summer of 2015, the Camp Meeker Recreation and Park District released about 0.1 cfs into Dutch Bill Creek which appears to have been very effective at increasing stream flow and preventing downstream pool disconnection. This effort demonstrates the efficacy of flow augmentation efforts for improving habitat conditions during critically dry periods.

Chapter 10 - Data Gaps and Recommendations for Future Work

The model presented here provides a powerful tool for understanding hydrologic conditions and informing water resource and land use management policies and restoration planning efforts throughout the Green Valley, Atascadero, and Dutch Bill Creek watersheds. Like any modeling analysis, there is uncertainty in the model results and the accuracy of model predictions. In order to better understand this uncertainty it is useful to examine the completeness and quality of the input data that went into developing the model and the degree and quality of the model calibration. Recommended improvements to the model are based on areas where better input data and/or additional calibration would be expected to lead to improved model performance and/or increased suitability for addressing key management questions. Ideally the modeling work would not be a static product but instead represent a working management tool where the model is periodically improved as new data becomes available and new questions arise.

Although a significant amount of information describing the distribution and volumes of water use was available, certain data was missing requiring simplifying assumptions be made regarding the details of water use patterns. In particular, the model includes all known surface water diversions as reported in the California State Water Resources Control Board's eWRIMS, however it is believe that the vast majority of diversions associated with Riparian Water Rights (formalized by a Statement of Use) are not reported. Data describing the locations, rates, and timing of these riparian diversions is required in order for the model to be used to more accurately quantify the effects of surface water diversions in the watershed and the potential habitat benefits of changing diversions patterns. The considerable degree to which model predictions are correlated with observed flows suggests that the un-quantified surface diversions may not be of enormous significance.

Groundwater wells were represented in the model by locating them at the center or each parcel, and well completion details were generalized from Well Completion Reports. This representation of wells provides a reasonable approximation of pumping distributions, however it is not suitable for examining the potential effects of pumping on stream flow conditions in detail. Thousands of driller's reports are available providing valuable information regarding well completion details, however the usefulness of these reports is limited by several factors. Perhaps most significantly, the reports generally only locate wells based on the parcel number or address, and in many cases there are multiple logs for a given parcel or no parcel identification making it difficult or impossible to assign a single log to each parcel. Many parcels within the study area are very large and the parcel centroid could be hundreds or thousands of feet away from the actual well location.

From an overall water balance and recharge perspective, these approximations of well characteristics are probably not significant, however it is critical for understanding potential stream flow impacts of pumping in cases where wells are located in close proximity to streams. Pumping rates for short-duration pump tests performed at the time of well completion are often reported in Well Completion Reports, however these rates are often not reflective of actual pumping operations and virtually no information regarding pumping volumes or durations for individual wells is readily available short of a lengthy effort to obtain pump test data from County files. The recent California State Water Resources Control Board Emergency Drought Regulation for four lower Russian River tributaries (SWRCB, 2015) may provide some of the missing information. Near the completion of this study, two relatively detailed groundwater assessment reports completed by a Sonoma County hydrogeologist (Eugene Boudreau) were obtained from a resident of upper Green Valley Creek. These reports locate wells (subject to similar uncertainty with respect to actual location) and provide associated driller's log (Well Completion Report) information for many of the wells in upper Green Valley Creek. These reports along with a landowner outreach effort related to the SWRCB Emergency Order could provide the basis for refining the model representation of groundwater pumping and increase the model's utility as a tool for understanding the effects of groundwater pumping on stream flow and habitat conditions.

Although the model was calibrated to a significant amount of stream flow and groundwater observation data, the periods of record for all of the stream gauges and observation wells was relatively short (2-5 years). Ideally the model would be calibrated over a longer time period and a separate multiple year validation period would be used to validate the model's predictive capabilities. Most of the calibration gauges and observation wells remain active and it is recommended that an updated model calibration and validation be performed following the collection of several more years of data. Additional groundwater elevation monitoring data in the vicinity of the watershed divide separating the GVAC watershed from the Santa Rosa Plain may enable refinement of the model representation of groundwater outflows along this boundary. Groundwater calibration errors were largest at observation wells located close to this boundary suggesting that better characterization of the boundary may lead to improved model performance in this area.

Despite these limitations, the model can be used in its current form to address a wide variety of water and land use management issues. The flow augmentation scenario discussed in this report is one such example, and the model was able to quantify the amount of water released from ponds that reaches Green Valley Creek and the significance of this additional water in terms of improvements to habitat conditions. As new potential flow augmentation projects are identified in the watersheds, the model can be used to test and optimize their effectiveness.

The model is also particularly well-suited for simulating the effects of ongoing climate change given the availability of regional downscaled climate model data (Flint and Flint, 2012). The model is also well-suited for examining the effects of land use change (e.g. ongoing conversion or orchards to vineyards) and future population increases and could be a valuable asset to Sonoma County staff tasked with reviewing permit applications for vineyard, winery, and residential development projects. These types of scenarios can be used to guide policies designed to ensure the sustainability of both surface water and groundwater resources for people and ecosystems. Lastly, although the focus of this study was on low flow conditions for juvenile rearing habitat, the model simulates continuous hydrographs and as such is well-suited for examining flow conditions important for other coho life stages, other species of interest, or other types of management questions.

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Appendix A - Project Summary from 2016 Public Meetings

Green Valley & Dutch Bill
Watershed Update

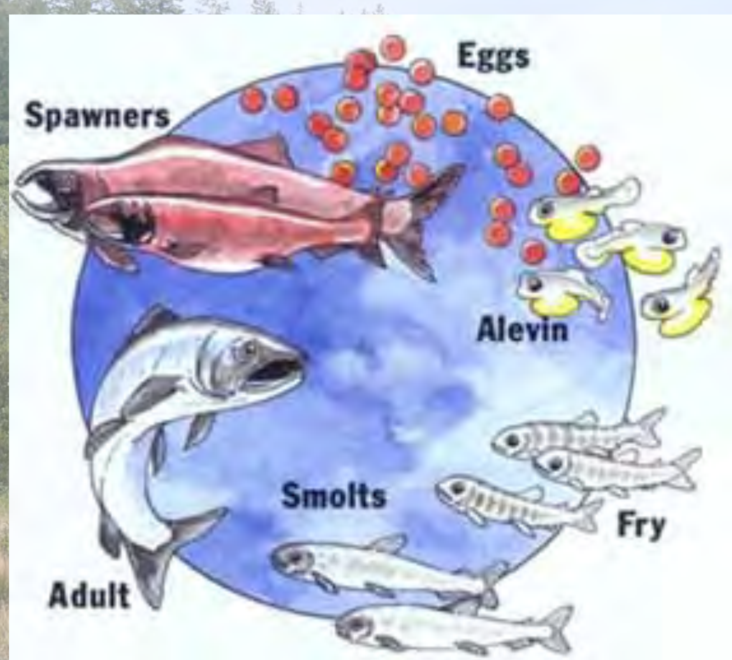
Integrated Groundwater and Surface Water Study for Watershed Restoration Planning

Background

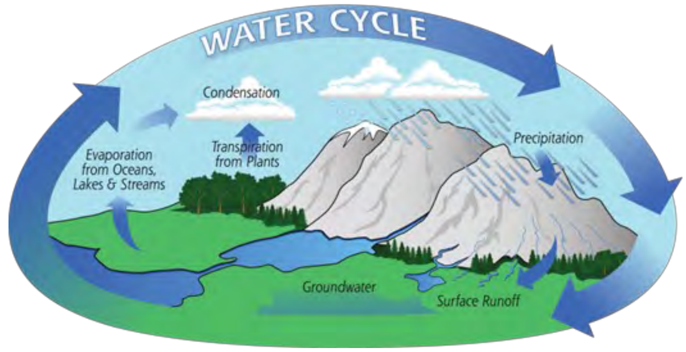
The Dutch Bill and Green Valley/Atascadero Creek watersheds provide some of the best remaining habitat for endangered coho salmon in the greater Russian River watershed. Low stream flows during the summer months are an important factor affecting the survival and recovery of the species. Salmon require sufficient water in the creeks for migrating in from the ocean to their breeding habitat, spawning, developing eggs, rearing young, and migrating back out of the streams to the ocean. Juvenile coho salmon live in creeks for over a year before migrating to the ocean, so they must survive through the summer during periods of low stream flow (Figure 1). In light of recent drought conditions, ongoing climate change, and an increasing demand for water, developing strategies to protect and increase stream flows while having enough water to meet human needs is critically important for sustaining coho in these watersheds.

A four-year scientific study has been completed by the Gold Ridge Resource Conservation District and O'Connor Environmental to gain a better understanding of how stream flows vary across the watersheds and over time, how various natural and man-made factors influence these flows, and what actions can be taken to improve flows and habitat conditions for coho. The study provides a wealth of information and tools for understanding watershed conditions and assisting local stakeholders in sustainably managing water resources and restoring coho populations.

Figure 1:
The Coho Life Cycle
Adults enter the streams during high winter flows and travel throughout the watershed. In our streams, adults mate, spawn, and die. Eggs develop into young who spend a little over one year in freshwater streams. Juvenile smolts migrate down in spring to spend two years in the ocean. In the winter of their third year, they return.

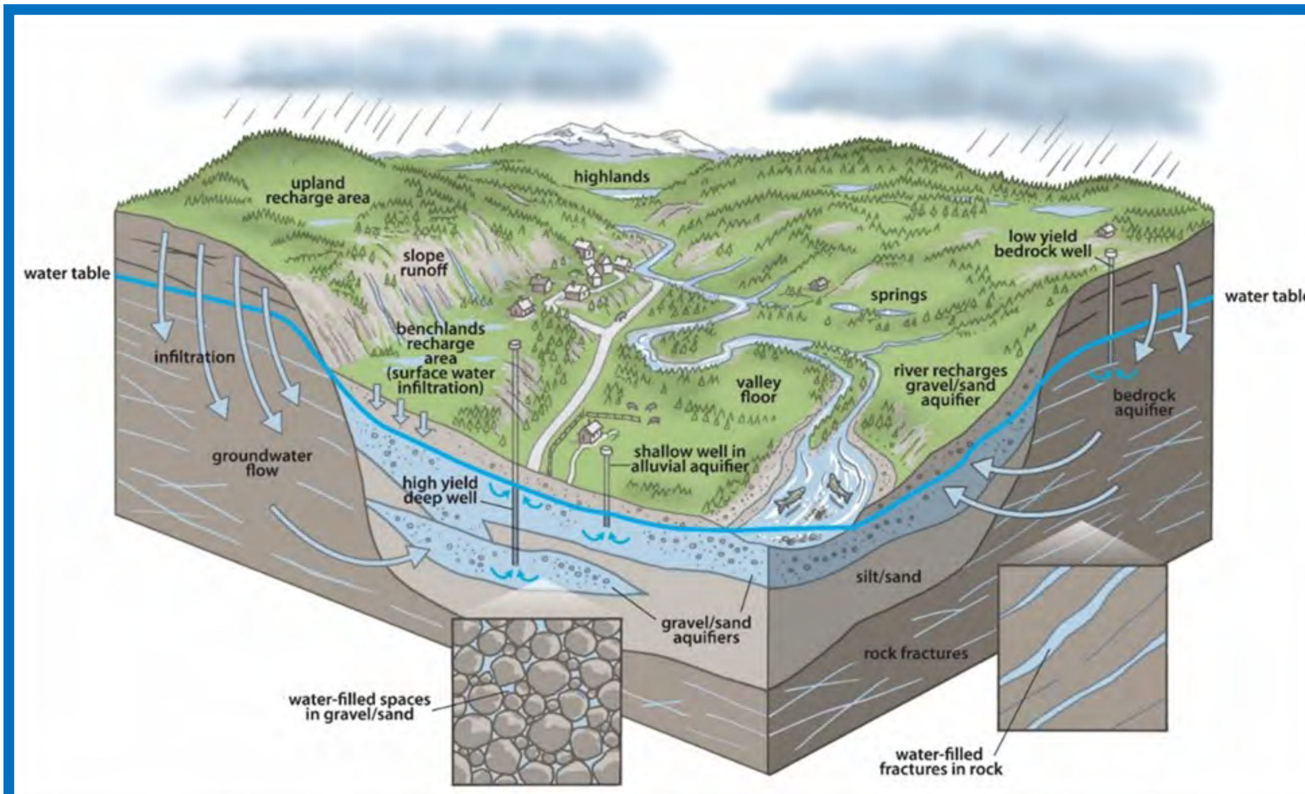


Approach



A major component of the project was the development of a detailed watershed hydrologic model. The model takes into account many of the physical attributes of the watershed, including information about the topography, climate, vegetation, soils, and geology, as well as man-made influences such as urban drainage systems, ponds, water diversions and groundwater wells. The model uses mathematical equations to simulate the movement of water through the various phases of the water cycle including rainfall, water use by plants, soil water, groundwater, and stream flow (Figures 2 and 3). The model has been calibrated to real-world measurements of stream flow and groundwater elevations at various locations throughout the watersheds and it provides estimates of how the various components of the water cycle vary in time and space. We used the model to simulate how drought and streamflow augmentation from existing reservoirs would impact the quantity and timing of stream flow in the study watersheds. The model is well suited for further investigation of the effects of wells, stream diversions, flow augmentation, management of groundwater recharge, land use change, and climate change on stream flow.

Figure 2 (above): Diagram showing the major components of the water cycle.
Figure 3 (below): Diagram shows many of the hydrologic processes and elements evaluated in the study.



Overview of the Watersheds

The Dutch Bill Creek and Green Valley/ Atascadero Creek Watersheds cover a 50-square-mile (32,000 acre) area of western Sonoma County, including portions of the communities of Sebastopol, Graton, Forestville, Occidental, Camp Meeker, and Monte Rio. The watershed map shows town and city limits, the main streams and tributaries, and five sub-watershed areas. Dutch Bill Creek is a distinct and separate watershed from Green Valley Creek, which includes four major sub-watersheds: Lower and Upper Green Valley Creek and Lower and Upper Atascadero Creek.

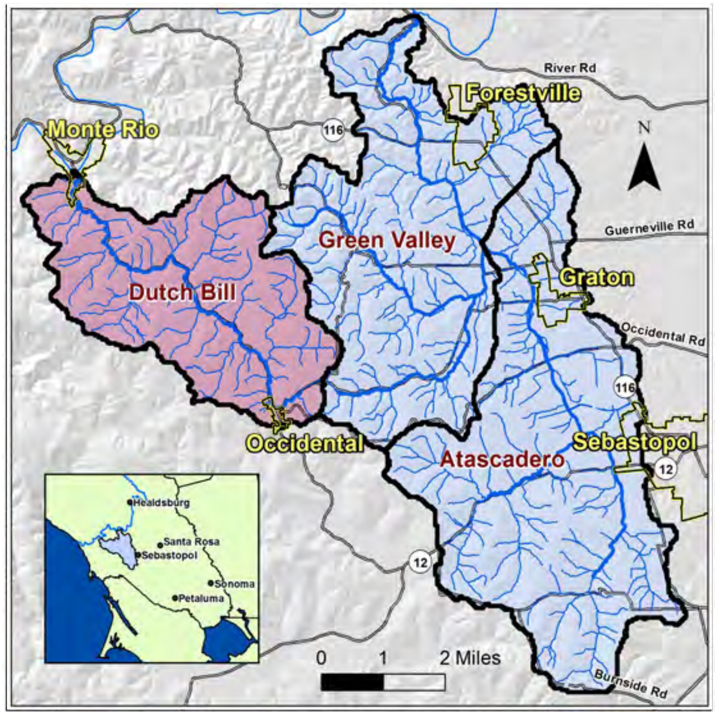
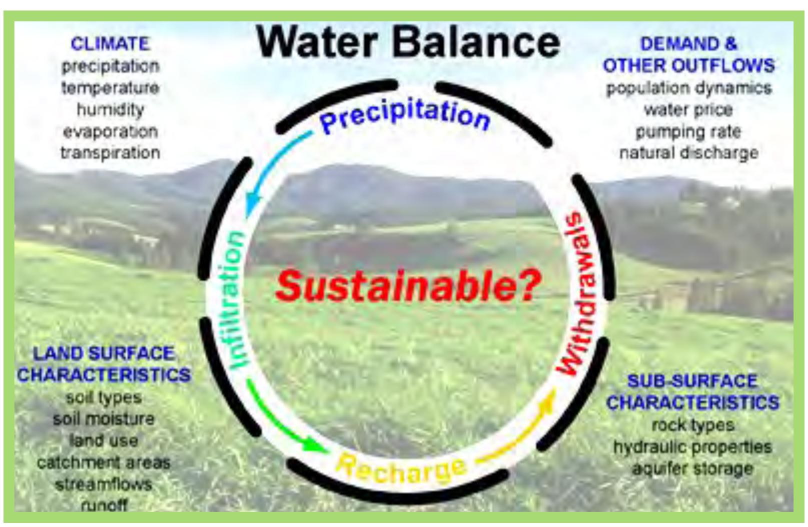


Figure 4: The study area includes both Dutch Bill Creek Watershed (pink) and Green Valley Atascadero Creek Watershed (blue).

Mean annual rainfall varies from about 40 inches per year on the east side of the Green Valley Atascadero Creek Watershed to 60 inches per year on the west side of the Dutch Bill Creek Watershed. Land cover in the two watersheds consists primarily of forests, vineyards, grasslands, orchards and rural residential parcels. Soils range in texture from sandy and gravely loams to clays and clay loams. There are two major geologic units in the study area (Figure 8). The Wilson Grove Formation is sandstone which underlies most of Atascadero Creek watershed and southeastern portions of Green Valley Creek watershed. The second major geologic unit is the Franciscan Complex underlying the Dutch Bill Creek Watershed (DBC) and the northwestern portions of the Green Valley Creek Watershed (GVAC).



Water Balance

A water balance (or water budget) is a method used by hydrologists to analyze how water entering a watershed as rainfall is distributed between watershed outputs (e.g. stream flow and use by plants), human use, and storage in groundwater. With the hydrologic model we developed annual water balances for the GVAC and DBC watersheds which **show that most of the water entering these areas as rainfall either runs off as stream flow or is returned to the atmosphere by evaporation from the soil and transpiration by plants (evapotranspiration).** The relative amounts of stream flow and evapotranspiration vary from year to year, depending on annual rainfall. For example, under drought conditions such as occurred in 2014 with rainfall of about 30 to 35 inches, stream flow made up a smaller proportion of the water leaving the study area than did evapotranspiration, while in average years with rainfall of 50 to 53 inches such as 2010, the reverse is true.

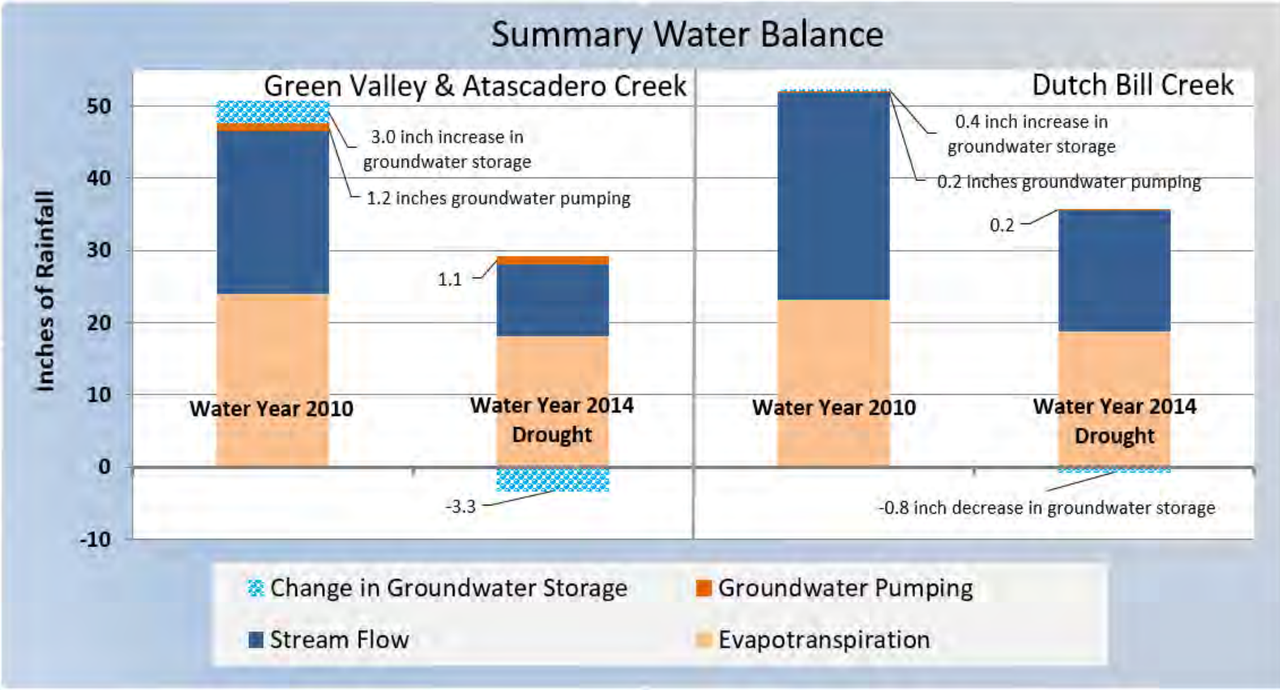


Figure 5: Annual water balances for the GVAC and DBC watersheds.

Annual groundwater pumping from wells represents a small fraction of the annual water balance (Figure 5). Groundwater use in GVAC is equivalent to 1.2 inches of rainfall across the watershed; in DBC, groundwater use is equivalent to 0.2 inches of rainfall. The low rate of use of groundwater in DBD reflects the limited availability of groundwater in the Franciscan bedrock. During years of average rainfall such as 2010 there is a net increase in the amount of stored groundwater (3.0 inches in GVAC and 0.4 inches in DBC) while in drought years such as 2014, there is a net decrease in groundwater storage (-3.3 inches in GVAC and -0.8 inches in DBC). A decline in water table elevation is associated with the decline in groundwater storage, and this creates potential negative impacts on summer stream flow and coho habitat. Although groundwater use is a small component of the annual water budget, it is possible that pumping groundwater from wells could affect water table elevation that in turn affects stream flow, particularly during the summer and in drought years.

Increases and decreases in groundwater storage tend to balance out over many years unless the amount of groundwater use consistently exceeds groundwater recharge, creating overdraft conditions. Model simulations of groundwater cover the five-year period beginning in October 2009 and ending in September 2014. The first two years were aver-

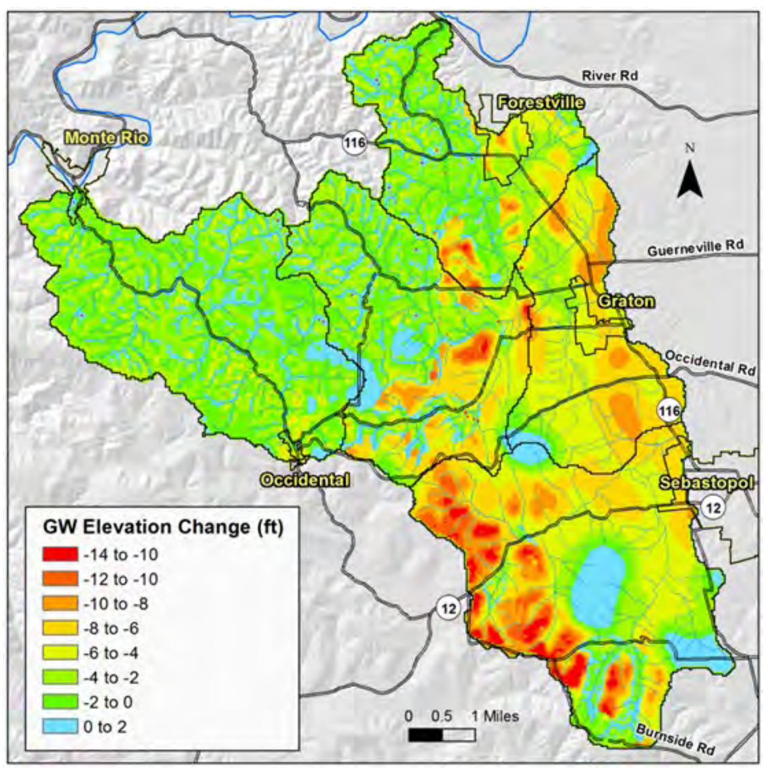


Figure 6: Simulated change in depth to groundwater between 2009 and 2014.

age or wet years and were followed by three consecutive dry years, part of the historic statewide drought that continued through 2015.

The model simulations indicate accumulated reductions in groundwater storage during the drought, but they also indicate that normal rainfall conditions would be expected to replenish groundwater storage. The reductions in groundwater storage manifested as small decreases in groundwater elevations in most areas and modest decreases of up to 14 -ft in other areas such as upper Atascadero Creek (Figure 6). **In other words, the drought created short-term groundwater overdraft, but the model simulations suggest that long-term groundwater overdraft under current climate and water use conditions is NOT occurring.**

Water Use

Water use rates used in the model were estimated from available data. Water use in this study is divided into three categories: vineyard irrigation, vineyard frost protection, and domestic (Table 1 & Figure 7). Domestic use includes both indoor household use and outdoor irrigation of gardens and landscaping. Water use for other agricultural purposes simulated in the model are very small; it is assumed that orchards are not irrigated. Legal or illegal cannabis grown in the region was unknown so not taken into account. Use of surface water diverted from streams for agriculture and water imported by public water suppliers was accounted for first, and the remaining demand for water was assumed to be satisfied by pumping groundwater from wells.

The majority of the water use in both watersheds comes from groundwater sources. Surface water diverted from streams under terms of existing water rights represents a relatively small amount of annual water use compared to groundwater pumped from wells in the GVAC watershed (Table 1). In Atascadero Creek about 85 acre-feet per year is diverted from streams, representing 5% of the total water use in the watershed. In Green Valley Creek watershed about 130 acre-feet per year is diverted from streams, representing about 15% of the total water use in the watershed. In Dutch Bill Creek, 115 acre-feet per year is diverted from streams, representing about 41% of the total water use. Stream diversions locations and rates were obtained in 2013 from the State water rights public database. The model development preceded the State emergency conservation and information order issued in 2015.

Agricultural Use

The annual vineyard irrigation rate was estimated to be 0.3 acre-feet per acre per year of vineyard (equivalent to 3.6 inches of applied water) based on the average use reported for stream diversions for vineyard irrigation allowed by water rights permits. All vineyards are assumed to be irrigated using this average rate which is consistent with the extent of dry-farmed vineyards and low irrigation rates in coastal Sonoma County (the average irrigation rate in Sonoma County is about 0.5 acre-feet per acre of vineyard, equivalent to 6 inches of applied water). Water for irrigation of vineyards with no surface water rights was assumed to be supplied by private wells. **Mean annual water**

use for frost protection was estimated based on available climate data and frost protection system information obtained from County permit data specific to each vineyard.

Domestic Use

A significant portion of the domestic water used in the study area is obtained from outside the watershed and provided to residents by public water supply agencies serving Sebastopol, Forestville, Monte Rio, and portions of Camp Meeker and Occidental. Based on 2010 census data, 4,465 residents of the study area obtain water from such public supplies. The remaining 10,651 residents obtain domestic water from groundwater wells. Domestic water use from private wells was estimated based on census data and City of Sebastopol water use data for 2010 through 2013. **Mean annual per capita use was estimated at 129 gallons per person per day, of which 46% (59 gallons per person per day) is indoor use.**

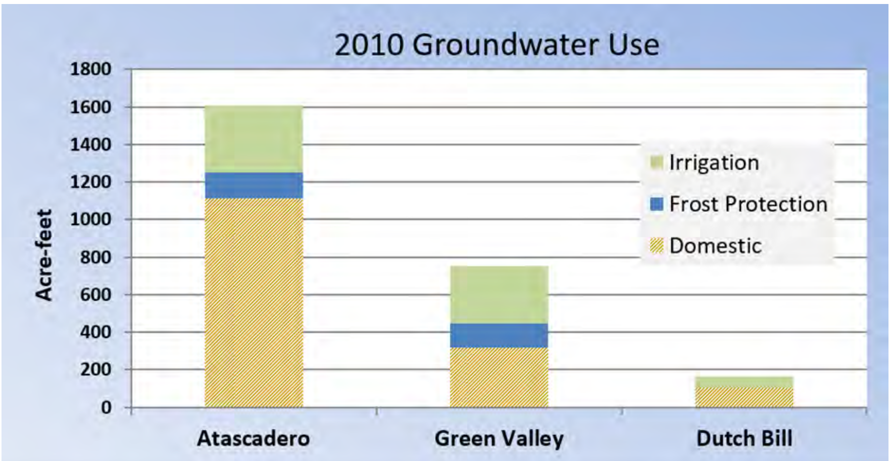


Figure 7: Breakdown of total annual groundwater use by type of use, units are acre-feet per year.

				2010 Groundwater Use (acre-feet)			Surface Water Diversions Reported to SWRCB (acre-feet)
Watershed	Drainage Area (acres)	Population Served by Wells	Vineyard Acres Served by Wells	Irrigation	Frost	Domestic	
Atascadero	12,961	7,660	1,187	359	138	1,112	85
Green Valley	11,361	2,261	1,013	306	131	328	130
Dutch Bill	7,654	730	201	61	0	106	115
Total	31,976	10,651	2,401	726	289	1,546	330

Table 1: Breakdown of annual surface water and groundwater use by sub-watershed.

Groundwater

Most groundwater is pumped from the Wilson Grove Formation, which underlies Atascadero Creek and the southeastern portion of the Green Valley Creek watershed (Figure 8). The thickness of the Wilson Grove Formation increases from west to east from less than 50-ft thick east of Occidental to more than 600-ft thick in the Sebastopol area. Groundwater is also pumped from fractures within rocks of the Franciscan Complex, which underlies all of DBC and the northwestern portion of Green Valley Creek. This source of groundwater is relatively limited compared to groundwater in the Wilson Grove Formation sandstone. The Wilson Grove Formation is a significant source of groundwater; municipal wells operated by the City of Sebastopol drilled in the Laguna de Santa Rosa watershed pump groundwater from the Wilson Grove Formation. Alluvium (sediments deposited by streams) is also present along the major streams in the study area, and many groundwater wells are located to pump water from it. In general the alluvium contains large amounts of

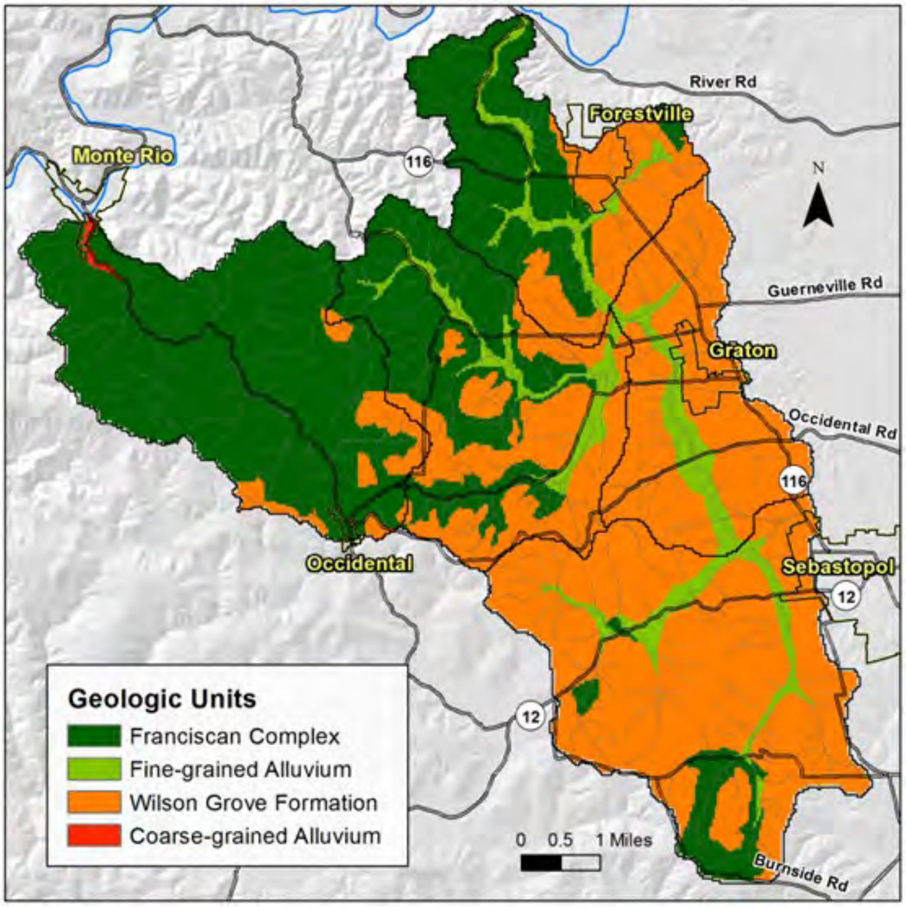


Figure 8: Major geologic units.

silt and clay, is relatively thin, and is not a major source of groundwater. In some areas, however, such as lower Purrington and Atascadero Creeks, the alluvium reaches thickness of more than 100-ft. The alluvium in lower Dutch Bill Creek is much coarser containing large amounts of sand and gravel.

Groundwater stored in our watersheds is replenished by percolation of rainfall through soils and by infiltration through creek beds. The study identified areas where soils with abundant sand and gravel (typically in uplands) are capable of high rates of infiltration of rainfall, as well as clay-rich soils (typically in low-lying floodplains) where infiltration rates are low. During average rainfall years, the mean groundwater recharge rate is about 10 inches per year in the GVAC watershed and about half that in the DBC watershed (Figure 9). Under drought conditions, average recharge is about 2 inches per year. Infiltration of stream flow through stream beds in normal rainfall years is about 6.4 inches per year in GVAC and only about 1 inch in DBC. In drought years, stream bed infiltration declines to 4.8 inches in GVAC, but

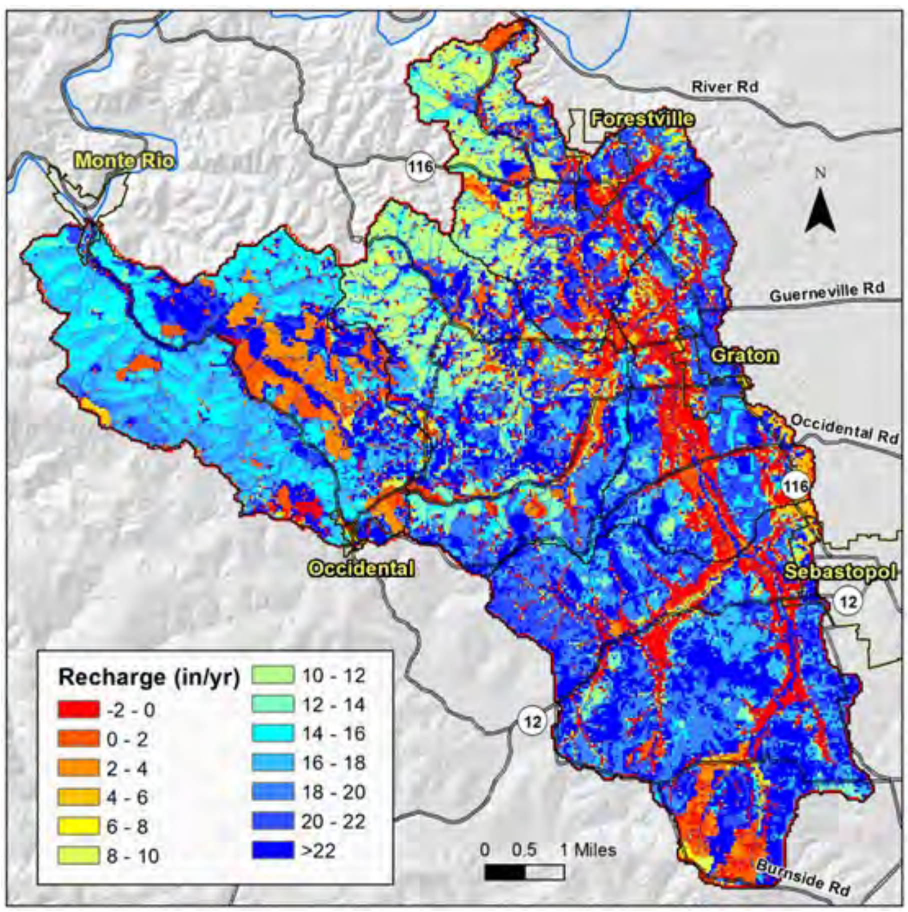


Figure 9: Simulated annual groundwater recharge rate in units of inches per year. Blue areas have high potential recharge rates because of sandy-gravelly soils. Red and orange areas have low potential recharge rates because of clay-rich soils. Recharge rates are also influenced by variations in rainfall, land cover, and geology.

increases somewhat in DBC. It is desirable to maintain recharge processes by constructing percolation ponds or otherwise managing rainfall, runoff, soils and vegetation in areas where soils and bedrock are favorable for percolation. **The model provides an objective starting point for identifying locations where management of groundwater recharge is most important. The model can also be used to develop land management strategies that would maintain and enhance recharge processes.**

Surface Water/Groundwater Exchange

Water flows from groundwater to streams in much of the watershed, maintaining year-round flow in some areas (gaining streams). However in other areas water flows from streams to groundwater (losing streams), sometimes to the point that surface flows disappear, along with fish habitat.

Gaining Stream **Losing Stream**

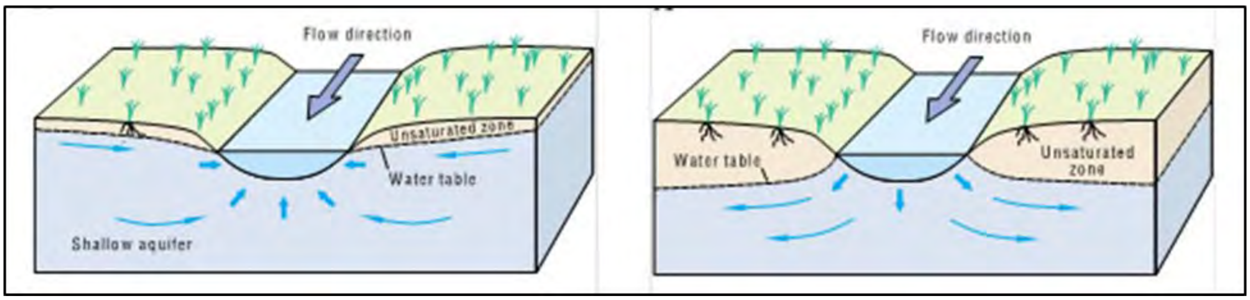


Figure 10: Diagram showing how surface water and groundwater interact in gaining and losing streams.

The location of gaining and losing reaches varies through the watershed as shown in the map of annual net exchange between surface water and groundwater (Figure 11). The exchange can also change seasonally such that the same stream location may be gaining during one season and losing in another. Stream flow conditions during summer at any given location are determined by inflows from upstream and the height of the water table adjacent to the stream.

In many portions of the GVAC watershed, groundwater that can be exchanged with stream

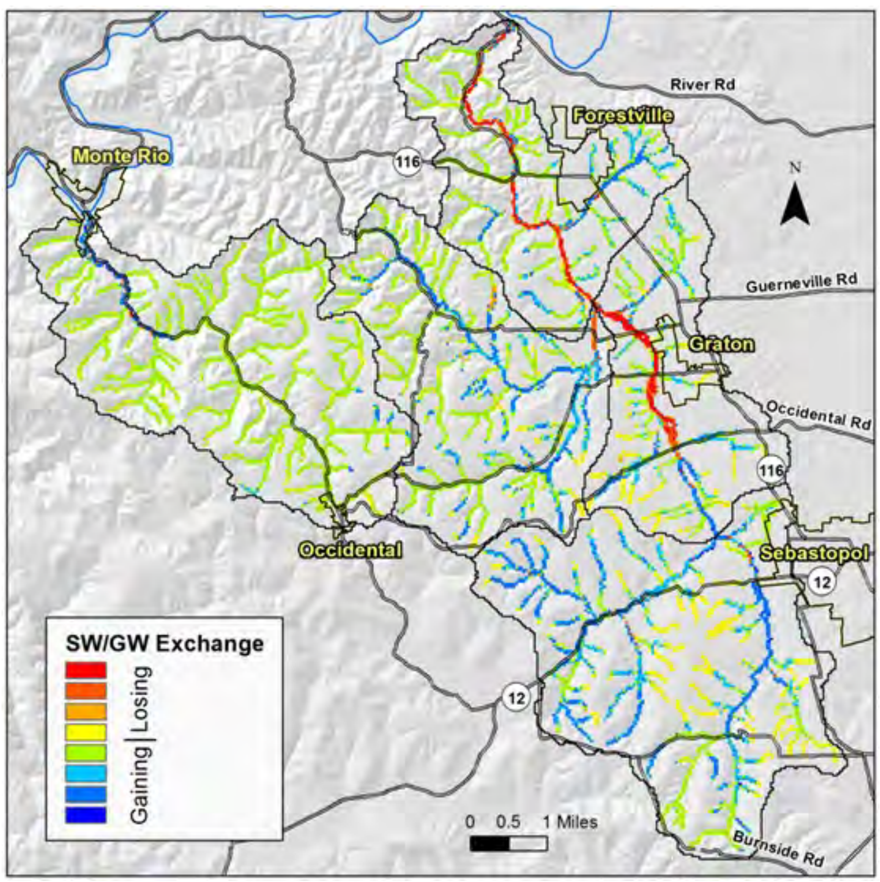


Figure 11: Annual exchange between surface water (SW) and groundwater (GW).

flow may be in alluvial deposits that are separated from the underlying Wilson Grove Formation by thick layers of clay. In these and other hydrogeologic circumstances, groundwater pumping from wells near streams might have little or no effect on stream flow conditions. On the other hand, pumping groundwater from shallow wells near streams could potentially have significant effects on stream flow.

Seasonal Stream Flow Conditions

To learn more about where and when water is available, particularly in creeks where coho salmon could live, the study utilized the hydrologic model to examine groundwater and surface water conditions across the watersheds and through time. The water balance for GVAC watershed described previously on an annual basis can be viewed monthly for the period October 2009 through September 2014 (Figure 13); this graph emphasizes the Mediterranean climate cycle of wet winters and dry summers with low stream flow. The amount of water flowing in streams varies widely from winter to summer with the highest flows occurring during rain storms and declining at various rates through the spring and summer depending largely on the exchange between groundwater and surface water. Portions of the graph showing negative recharge are indicative of groundwater discharge to wetland areas primarily located along portions of Atascadero Creek.

As shown in Figure 12, small but significant flows are maintained year-round where upstream inflows from groundwater are substantial and the stream bed sediment and underlying rock do not permit high rates of loses to groundwater, such as lower Purrington Creek, lower Green Valley Creek, portions of West Fork Atascadero Creek and the middle reaches of Dutch Bill Creek. In streams where upstream groundwater transfers to surface water are relatively low and where the stream bed sediment is comprised of thicker layers of sand and gravel, surface flows tend to disappear in the summer (for example, lower Dutch Bill Creek near Monte Rio and portions of Atascadero and Green Valley Creeks between Graton and Forestville).

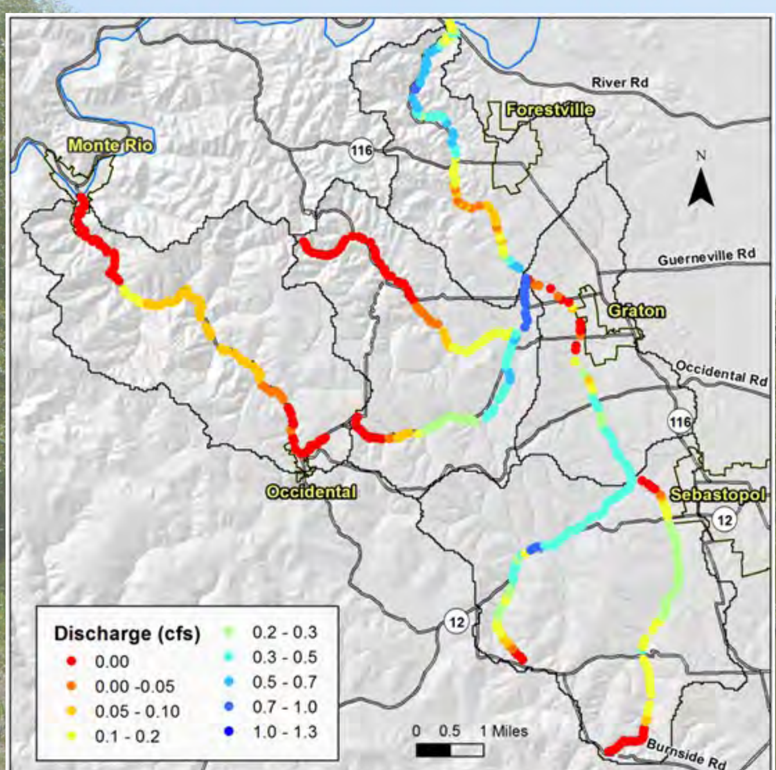
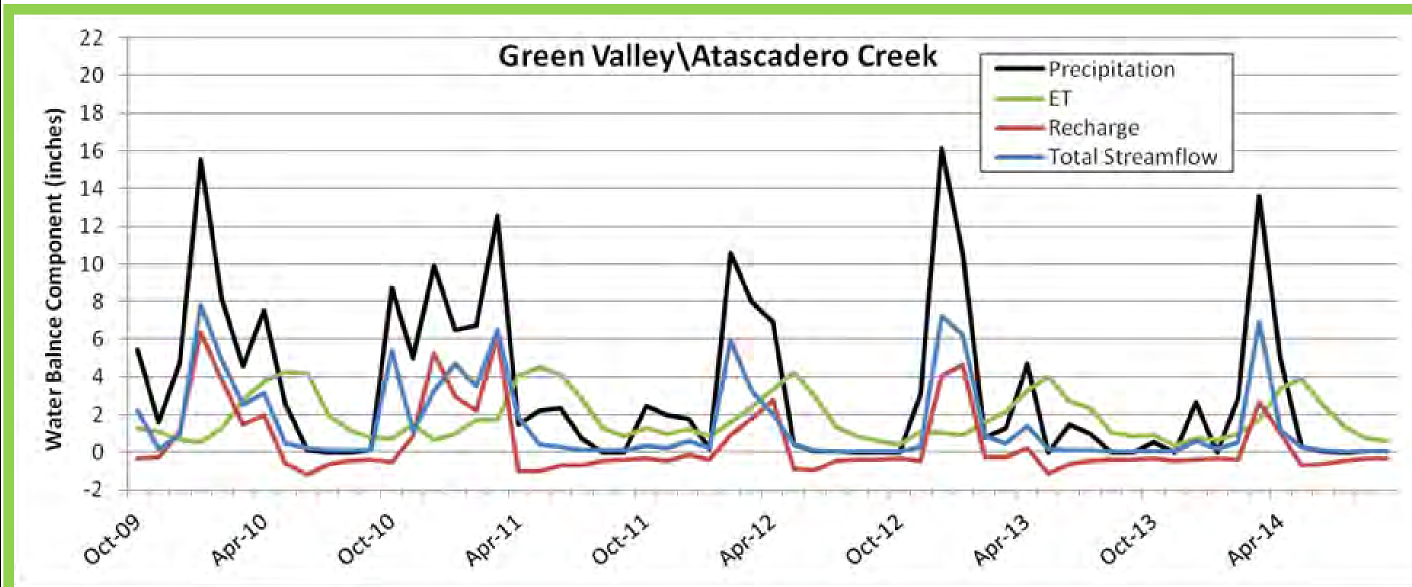


Figure 12: Minimum stream flow or discharge in units of cubic feet per second (cfs) during an average water year (2010).



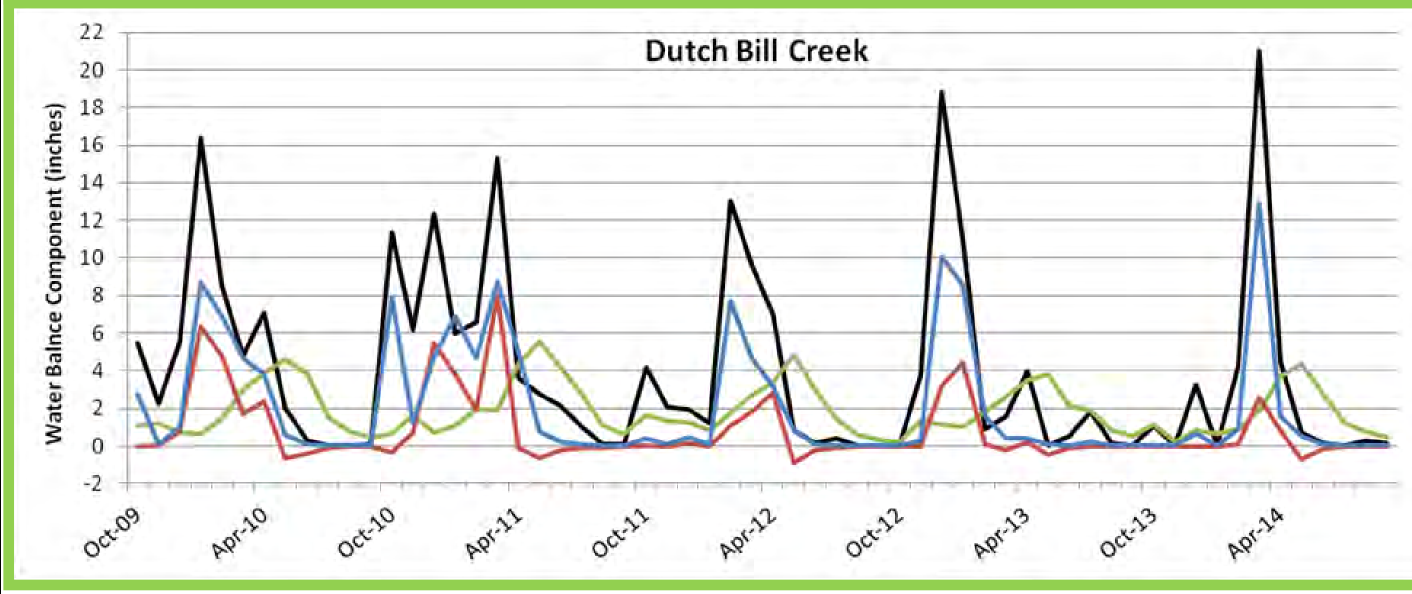


Figure 13: Monthly water balances showing the seasonal and annual variations in rainfall, recharge, evapotranspiration (ET), and stream flow in the GVAC and DBC watersheds.

Habitat Improvement Opportunities

During late summer, the survival of coho salmon is threatened because the extent of habitat defined in terms of quantity of stream flow and surface connectivity of stream flow dramatically declines throughout the watersheds. This occurs in average years and is much worse in drought years. Where stream flows diminish to the point of having no surface flow, coho cannot survive. Where surface flows diminish significantly but deeper areas of the stream (i.e. pools) remain filled with water, coho may survive but habitat is marginal at best. Field studies of coho by University of California Cooperative Extension fish biologists have found that habitat suitability declines when surface flows connecting pools disappear due to low stream flows. When pools are disconnected for more than a few days, coho are at a high risk of mortality.

In an average year, flows are sufficient to maintain connectivity between pools and provide suitable (though not optimal) habitat in about 16.2 stream miles in the study area (Figure 14). During drought, the total habitat area decreases to about 12.8 stream miles. Stream flow simulations corroborated by field observations and flow data indicate that certain stream reaches tend to have persistent flows that maintain higher quality habitat (for example, the middle reaches of Dutch Bill and Purrington Creeks), while other stream reaches tend to have more frequent and extensive interruptions of surface flows and pool habitat or complete loss of surface flow (for example, upper Green Valley Creek).

Coho habitat in the study area was systematically evaluated and classified based on the persistence and depth of stream flow during late summer determined by flow simulations. These classifications of flow conditions provide the basis for prioritization of recommended locations and objectives of coho habitat restoration activities (Figure 14).

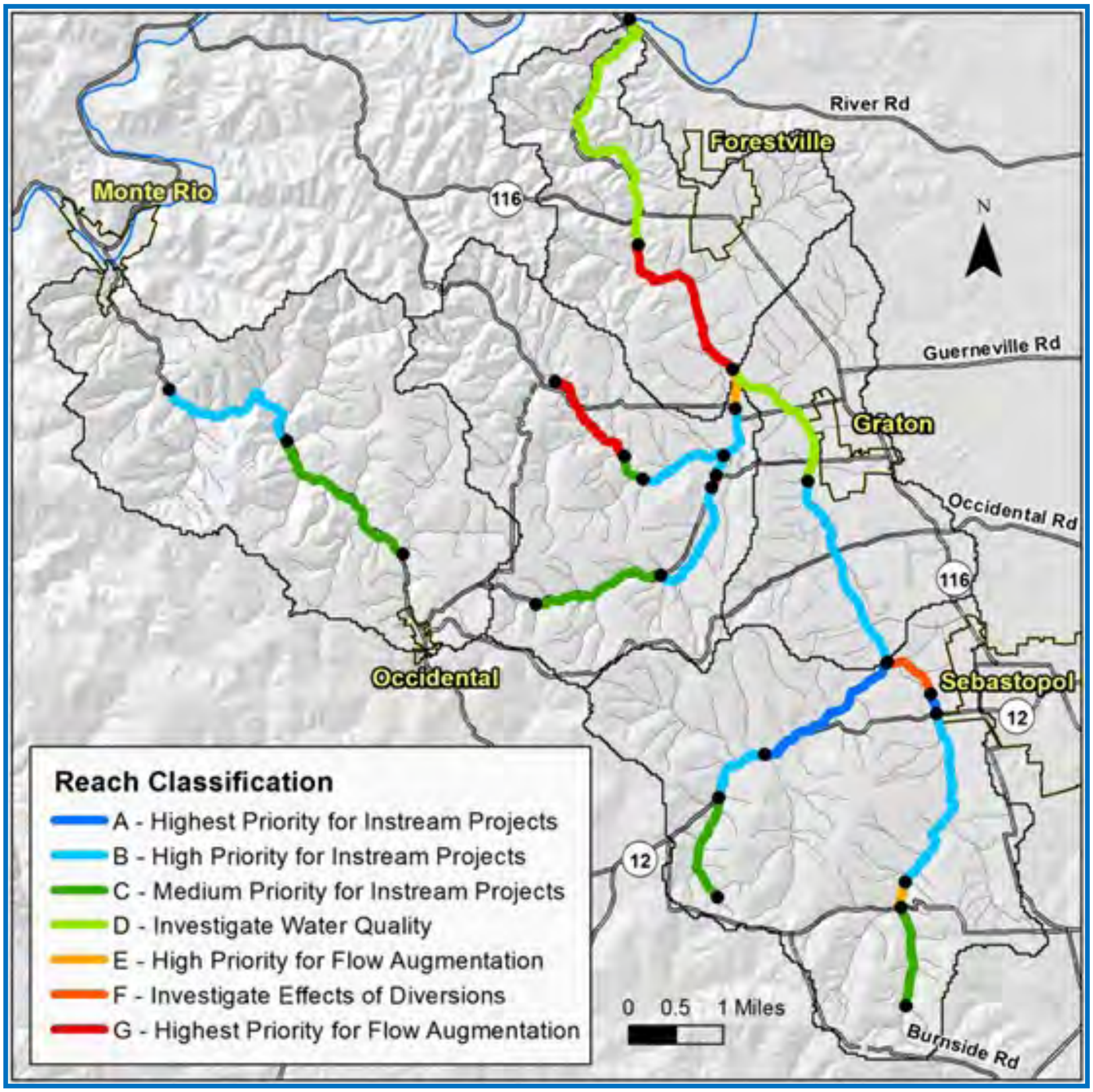


Figure 14: Coho habitat classification based on simulated flow conditions and associated restoration recommendations.

Highest quality habitat (Reaches A & B): Stream flow persists even during drought conditions providing suitable flows for coho summer rearing habitat.

Marginal quality habitat (Reaches C, D, E, & G): Late summer stream flow is very low and pools may become disconnected from surface flow. These reaches are critically sensitive to the effects of drought, and inconsistent flow may severely curtail coho summer rearing habitat.

Habitat potentially impacted by diversions (Reach F): These reaches have the potential to be high quality habitat, but utilization of water rights under existing licenses has the potential to significantly diminish stream flow and coho habitat.

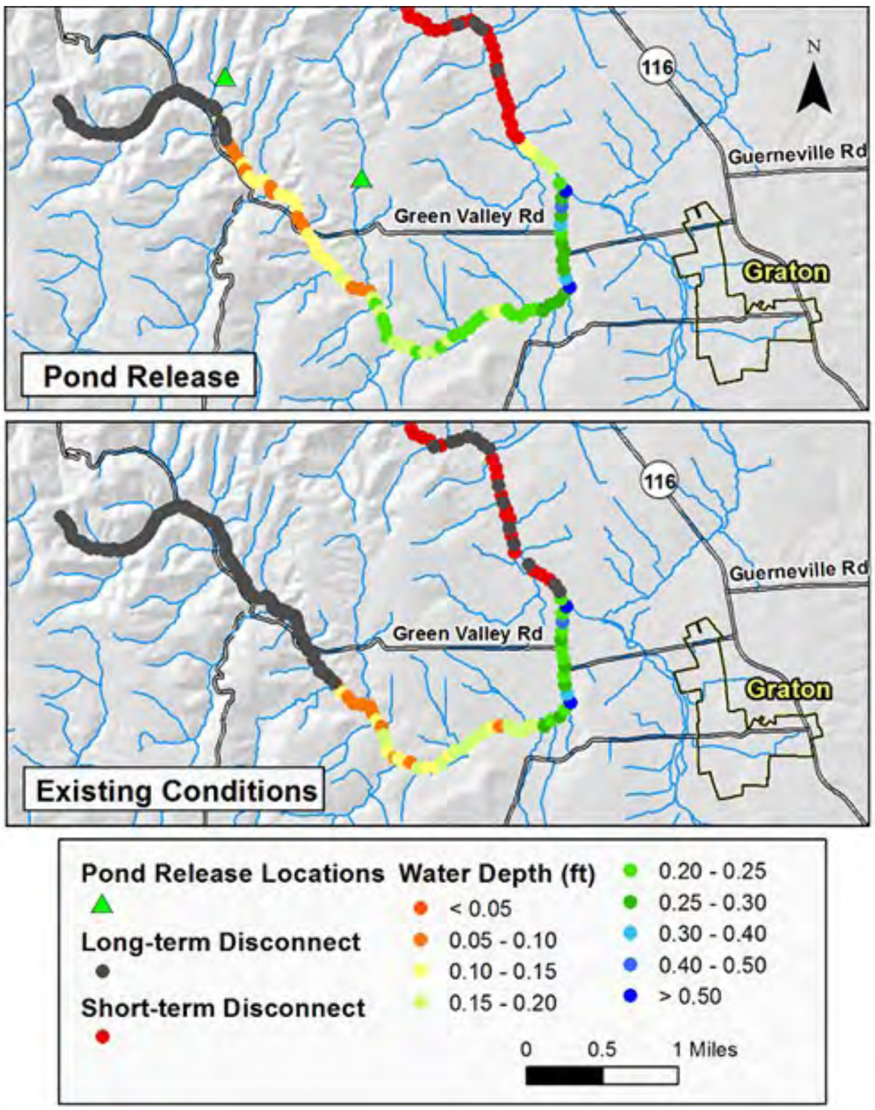
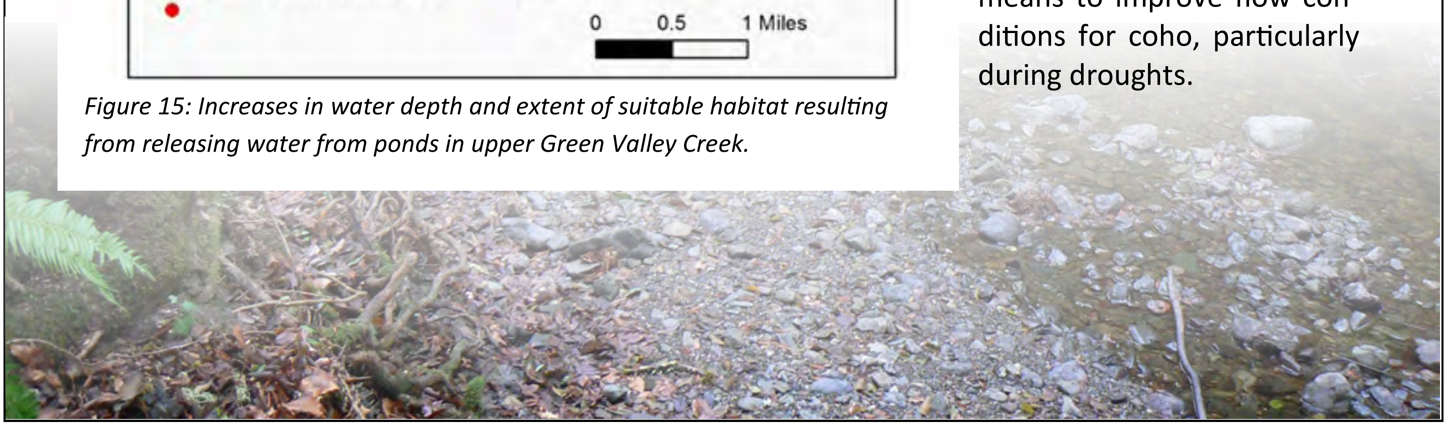


Figure 15: Increases in water depth and extent of suitable habitat resulting from releasing water from ponds in upper Green Valley Creek.

Stream Flow Augmentation

The effectiveness of releasing water back to the creeks from reservoirs was tested using the model. We simulated the release of 0.6 cubic feet per second (cfs) of water (equivalent to about one acre-foot in one day) from two ponds in upper Green Valley Creek. The model indicated that these reservoir releases were very effective at improving streamflow and surface connectivity during drought conditions. These modest flow releases resulted in a two-fold increase in the extent of suitable habitat in upper Green Valley Creek (Figure 15). Based on these findings, efforts to provide water from ponds should be pursued as an effective means to improve flow conditions for coho, particularly during droughts.



Management Recommendations

Highest quality habitat (A and B reaches): Since stream flow in these reaches is not critically limiting coho summer rearing habitat, projects that enhance in-stream habitat are appropriate under existing conditions. Coho habitat can be improved with projects such as restoration of native riparian vegetation, installing large woody debris for fish shelter and improved depth and cover, and constructing off-channel pools or wetlands for juvenile fish habitat.

Marginal quality habitat (C, D, E and G reaches): Increase the amount of water entering these reaches by releasing water from existing or new storage facilities during the summer. Conduct further study of potential effects of wells on stream flow using the model with new well data. Summer release of water that was collected during the winter can significantly improve flow and habitat in these reaches. Projects that could enhance stream flow in these reaches are a high priority. Habitat enhancement projects to improve rearing habitat may have lower priority, but could be appropriate particularly if successful flow enhancement projects are implemented.

Potentially impacted by diversions (F reaches): Operations of diversions should be evaluated with respect to potential impacts on stream flow and habitat. Management strategies for operation of diversions to avoid impacts to habitat should be identified and their adoption should be encouraged. If appropriate, the feasibility of developing alternatives to direct stream diversion (for example, building new water storage facilities) should be investigated.

Investigate coho habitat potential in Atascadero Creek: The study revealed that more than eight miles of upper Atascadero Creek have flow conditions that are suitable for providing coho habitat. Flow in the lowest two miles of Atascadero Creek stagnates, which likely degrades water quality. Additionally, dense wetland vegetation in this reach has encroached on the principal channels and could inhibit fish migration. Whether or not coho presently utilize Atascadero Creek is not known, but favorable flow conditions in the upper watershed suggest that if conditions in lower Atascadero Creek could be improved, it would be possible to significantly increase the extent of coho habitat in the study area.

An A-grade reach enhanced with large woody debris. Large wood installations add complexity to stream habitat over time, providing scour pools and cover for fish.

C-G grade reaches can be enhanced by increasing the amount of water flowing in the stream in the summer. Here, a landowner works with wildlife agencies to fill a pond with winter water that will be released at a slow rate into the stream in the summer.

Conclusions

This study characterized the spatial and temporal variations in stream flow and groundwater conditions throughout the Dutch Bill and Green Valley/Atascadero Creek watersheds. Stream flow conditions were related to habitat requirements for juvenile coho in order to understand the variations in habitat suitability throughout the watersheds. The study identified reaches with suitable flow conditions where projects to enhance in-stream habitat would be most beneficial, reaches where flow conditions are marginal and where efforts to augment stream flows should be focused, and reaches potentially impacted by diversions. The study found that augmenting stream flows by releasing water from ponds has the potential to significantly enhance habitat conditions. Another key finding is that upper Atasacadero Creek has the potential to provide significant habitat for coho but water quality and/or fish passage issues in the lower portions of the creek may be limiting use of the upper watershed.

In addition to characterizing coho habitat and making restoration recommendations, the study provides detailed hydrologic information for informing a wide variety of land and water use management efforts. For example, maps of groundwater recharge potential provide a valuable means of planning locations of projects designed to protect or enhance recharge processes. The study found that the recent drought resulted in modest declines in groundwater elevations and groundwater storage in some areas and significantly reduced groundwater recharge, summer stream flow, and extent of suitable coho habitat. These findings provide an important basis for understanding the resiliency of the watersheds in terms of maintaining stream flow, fish habitat, and water supply reliability.

Ideally this hydrologic study and its model will become a management tool. The "watershed atlas" produced by the simulation model can be used to inform water resources management now and into the future. A wealth of detailed information is available from the existing study that can be organized or evaluated to identify opportunities to promote groundwater recharge and to augment stream flow from existing or new reservoirs. In addition, the model can be used to evaluate impacts of climate change, increased water use, and changes in land use. As more detailed information about wells and diversions becomes available, the model can be improved and applied to evaluate the effects of water use and water conservation on stream flow and habitat conditions.

For more information including a full technical report please visit the Gold Ridge RCD website www.goldridgercd.org or contact Sierra Cantor at sierra@goldridgercd.org

Appendix B - Summary of Key Restoration Recommendations

SUMMARY OF KEY RESTORATION RECOMMENDATIONS

Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning

Green Valley\Atascadero and Dutch Bill Creek Watersheds

Overview

A watershed hydrologic model has been developed to characterize flow availability conditions throughout the Green Valley\Atascadero and Dutch Bill Creek Watersheds. In-stream flow availability conditions were related to rearing habitat requirements for juvenile coho based on 1) the critical riffle depth concept and 2) relationships between coho survival and the duration of disconnected in-stream flow between pools developed by the UCCE.

The delineation of in-stream flow conditions in these watersheds relative to coho habitat requirements provided a means of prioritizing restoration actions for various stream reaches. The following restoration recommendations were developed:

A. **Highest priority reaches for habitat enhancement projects aimed at addressing limiting factors other than flow (e.g. ensuring quality pool habitat).**

   Pools remain connected during both dry and average water years. Riffle depths remain above the optimal passage threshold. These reaches provide the **best** habitat conditions and maintain habitat value even during drought conditions.

B. **High priority reaches for habitat enhancement projects aimed at addressing limiting factors other than flow (e.g. ensuring quality pool habitat).**

   Pools remain connected during both dry and average water years. Riffle depths remain above the minimum passage threshold. These reaches provide **good** habitat conditions and maintain habitat value even during drought conditions.

C. **Medium priority reaches for habitat enhancement projects. Medium priority reaches for flow augmentation projects.**

   Pools remain connected during both dry and average water years. Riffle depths drop below the minimum passage threshold. These reaches provide **adequate** habitat value but at a more marginal level that A and B reaches.

D. **Water quality conditions should be evaluated and actions to improve water quality should be identified.**

   Pools remain connected during both dry and average water years but velocities drop to zero and/or there are known water quality problems.

E. **High priority reaches for flow augmentation projects. Small changes in flows within these reaches may be expected to yield significant increases in habitat value.**

Pools become disconnected for less than 14 days during dry water years. These reaches provide adequate habitat value during average water years but coho **may** experience late summer mortality during drought conditions.

F. Effects of diversions should be evaluated and mitigated if deemed problematic.

Same as E but flow disconnection appears to be related to surface water diversions.

G. Highest priority reaches for flow augmentation projects. Small changes in flows within these reaches may be expected to yield significant increases in habitat value.

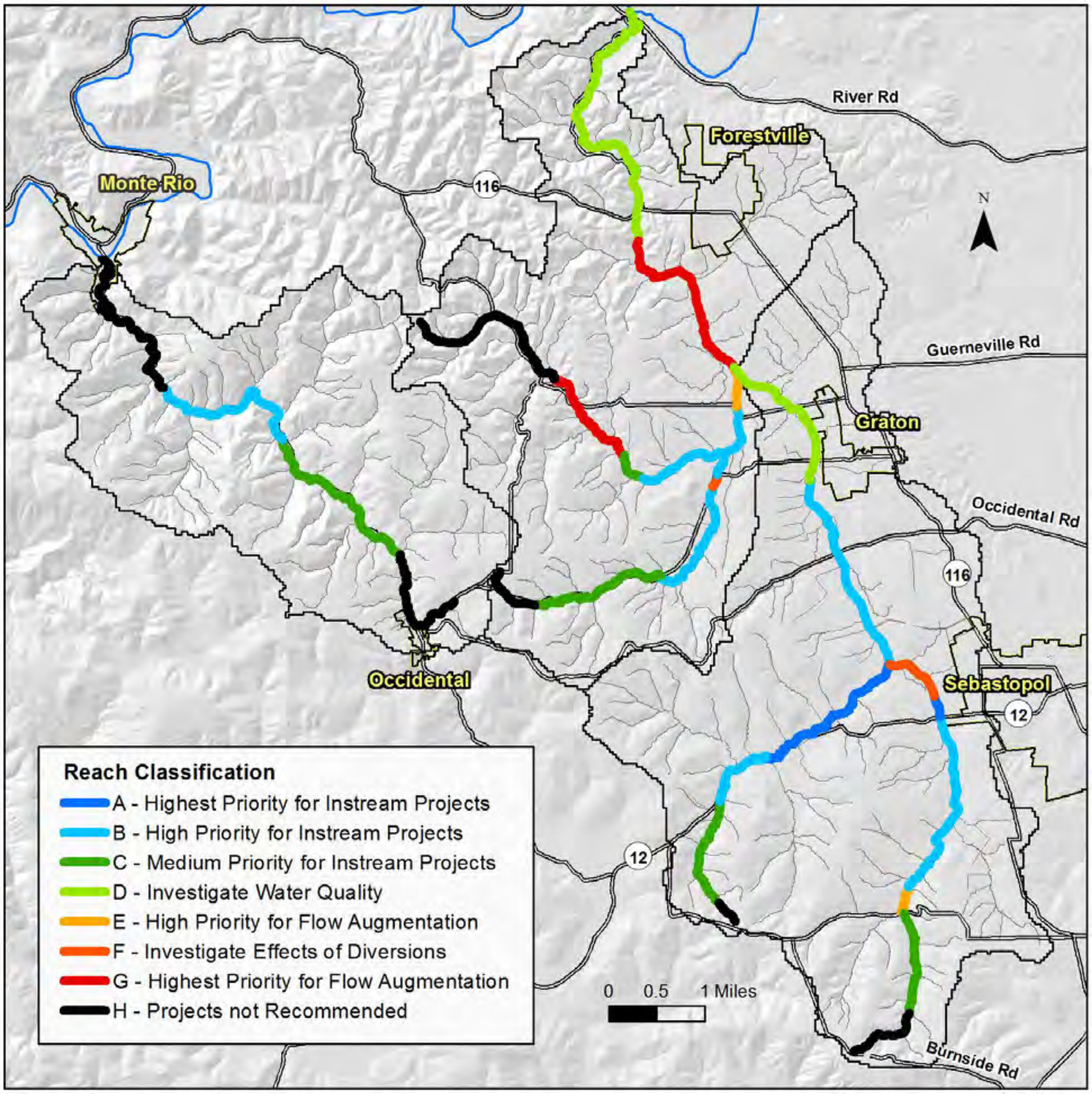
Pools become disconnected for 14 or more consecutive days during dry water years. These reaches provide significant habitat value during average water years but coho are **likely** to experience significant late summer mortality during drought conditions.

H. Habitat enhancement or flow augmentation projects are not recommended.

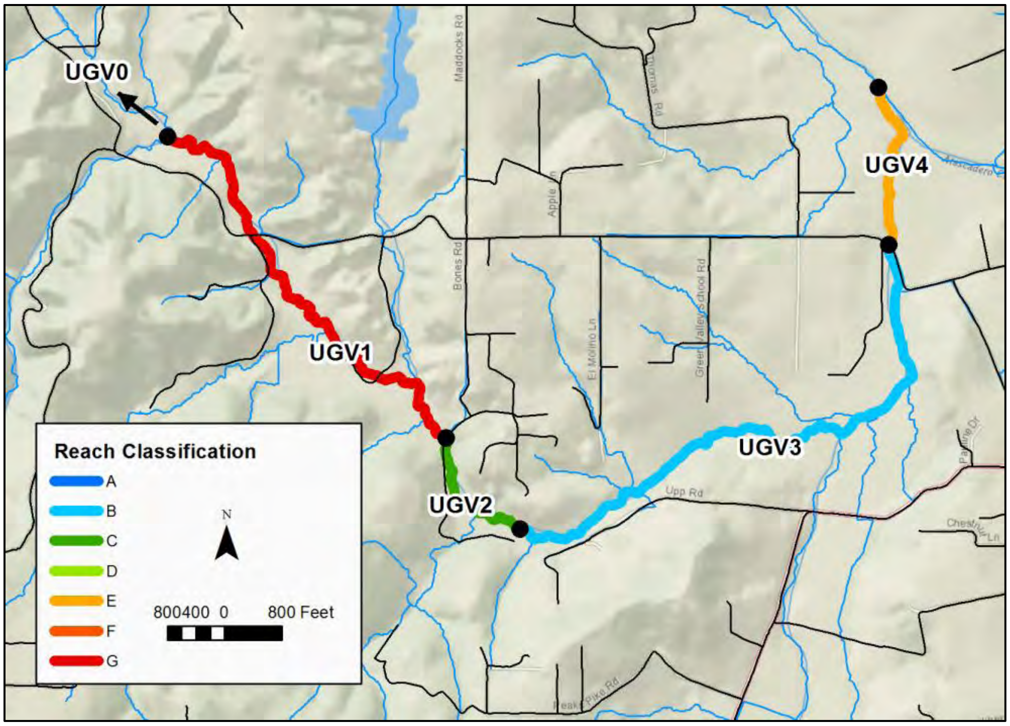
Pools become disconnected for 14 or more consecutive days during both dry and average water years. Flow conditions are **not adequate** to support perennial habitat and coho in these reaches are **likely** to experience significant late summer mortality even during average water years.

The above recommendations are based primarily on observed and model simulated in-stream flow conditions relative to juvenile coho rearing habitat requirements. Existing and/or future studies examining the distribution and quality of available pool habitat, water quality conditions, and other factors should be synthesized with these findings in order to develop a more comprehensive understanding of habitat conditions. It is also important to note that if flow augmentation projects can be implemented, the extents of reaches where habitat enhancement projects are recommended would be expected to increase based on the new modified flow regime.

Flow Availability and Restoration Recommendation Reach Classifications for the Green Valley/Atascadero and Dutch Bill Creek Watersheds



Upper Green Valley Creek



Reach UGV0 - upstream of the Harrison Creek confluence

- Reach Category H - inadequate flow conditions
- habitat enhancement and flow augmentation projects are not recommended

Reach UGV1 - Harrison Creek confluence to Bones Road crossing (1.3 river miles)

- Reach Category G - inadequate flows during drought conditions
- highest priority reach for flow augmentation projects
- significant coho use has been documented in this reach however dry conditions during late summer of 2014 and 2015 resulted in mortality of most or all of these fish

Reach UGV2 - Bones Road crossing to 0.4 miles below Bones Road crossing (0.4 river miles)

- Reach Category C - marginal flow conditions
- medium priority reach for flow augmentation projects
- medium priority reach for habitat enhancement projects

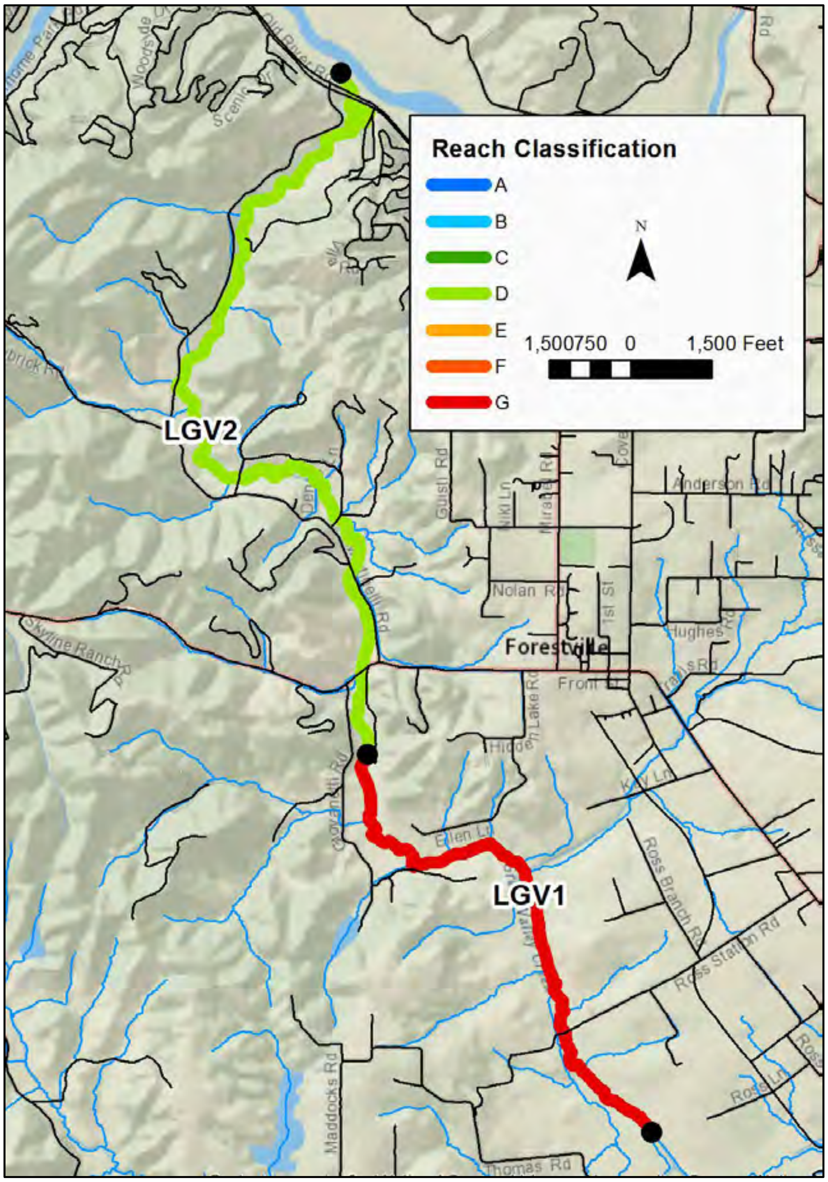
Reach UGV3 - 0.4 miles below Bones Road crossing to 0.5 miles above Atascadero Creek confluence (1.6 river miles)

- Reach Category B - good flow conditions
- high priority reach for habitat enhancement projects

Reach UGV4 - lowest 0.5 miles above Atascadero Creek confluence (0.5 river miles)

- Reach Category E - inadequate flows during drought conditions
- high priority reach for flow augmentation projects

Lower Green Valley Creek



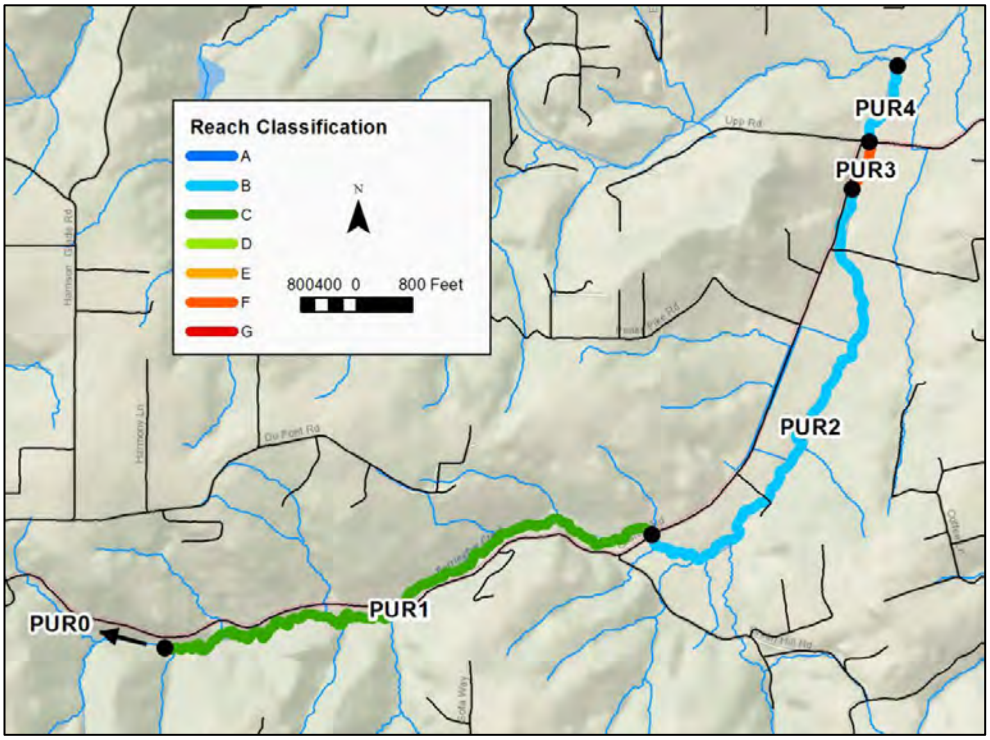
Reach LGV1 - Atascadero Creek to 0.3 miles above Highway 116 crossing (2.1 river miles)

- Reach Category G - inadequate flows during drought conditions
- highest priority reach for flow augmentation projects
- water quality conditions should be evaluated and improved if possible

Reach LGV2 - 0.3 miles above Highway 116 crossing to Russian River (3.6 river miles)

- Reach Category D - good flow conditions
- water quality conditions should be evaluated and improved if possible

Purrington Creek



Reach PUR0 - upstream of 0.9 miles above 3rd Graton Road crossing

- Reach Category H - inadequate flow conditions
- habitat enhancement and flow augmentation projects are not recommended

Reach PUR1 - 0.9 miles above 3rd Graton Road crossing to 4th Graton Road crossing (0.9 river miles)

- Reach Category C - marginal flow conditions
- medium priority reach for flow augmentation projects
- medium priority reach for habitat enhancement projects

Reach PUR2 - 3rd Graton Road crossing to 0.1 miles above 4th Graton Road crossing (1.5 river miles)

- Reach Category B - good flow conditions
- high priority reach for habitat enhancement projects

Reach PUR3 - 0.1 miles above 4th Graton Road crossing to 4th Graton Road crossing (0.1 river miles)

- Reach Category F - inadequate flows during drought conditions
- effects of diversions should be evaluated and mitigated if necessary

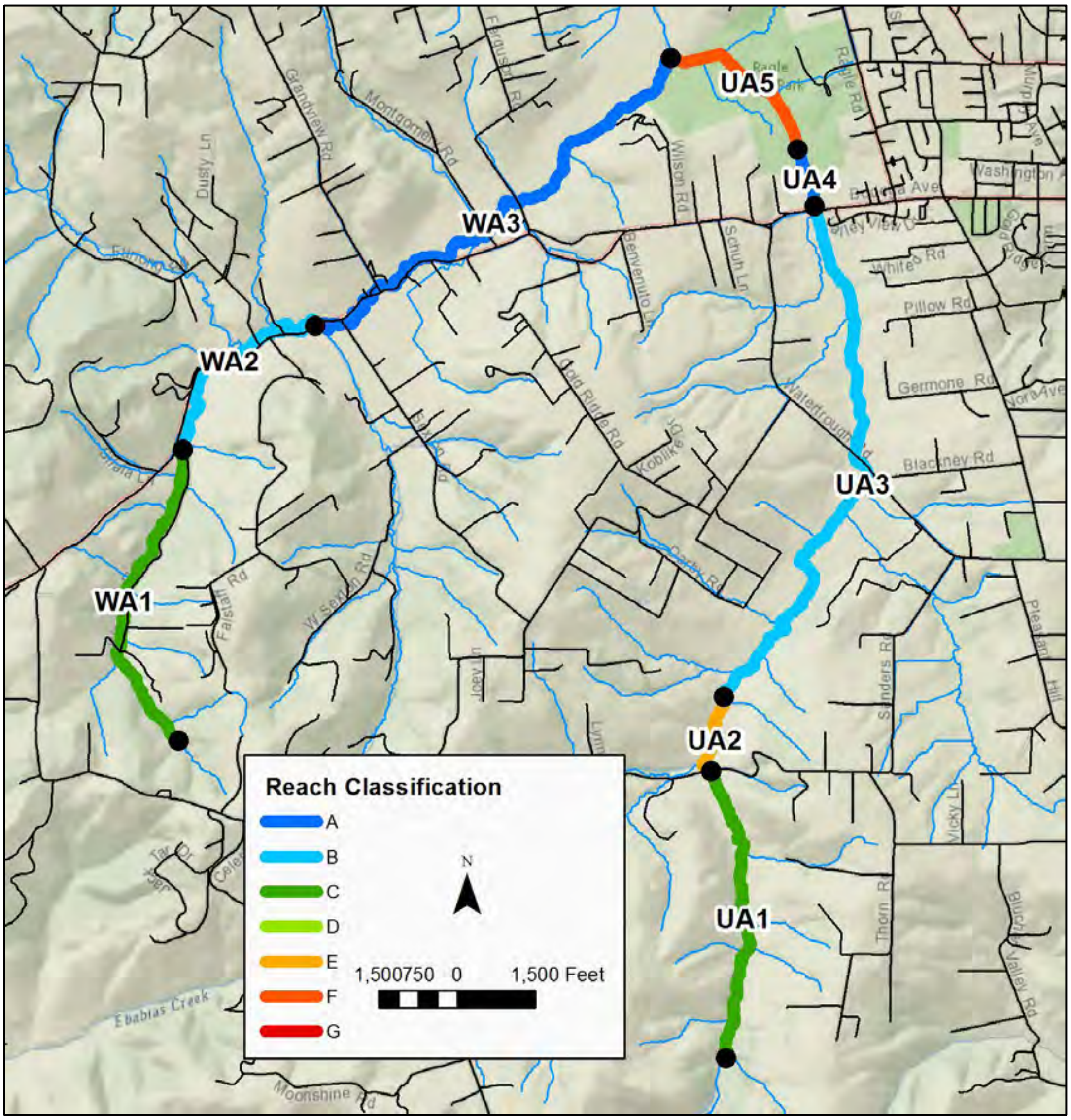
Reach PUR4 - 4th Graton Road crossing to Green Valley Creek (0.2 river miles)

- Reach Category B - good flow conditions

- high priority reach for habitat enhancement projects

Upper Atascadero Creek

The degree to which coho are able to access and utilize upper Atascadero Creek is not well known. Further study is highly recommended given that more than eight miles of stream with suitable flow conditions exist in this watershed.



Reach WA1 - 1.3 miles above Wagnon Road crossing to Wagnon Road crossing (1.3 river miles)

- Reach Category C - marginal flow conditions
- medium priority reach for flow augmentation projects pending study of coho use
- medium priority reach for habitat enhancement projects pending study of coho use

Reach WA2 - Wagnon Road crossing to 2nd Highway 12 crossing (1.0 river miles)

- Reach Category B - good flow conditions
- high priority reach for habitat enhancement projects pending study of coho use

Reach WA3 - 2nd Highway 12 crossing to Atascadero Creek confluence (2.0 river miles)

- Reach Category A - best flow conditions
- highest priority reach for habitat enhancement projects pending study of coho use

Reach UA1 - 1.3 miles above Barnett Valley Road crossing to Barnett Valley Road crossing (1.3 river miles)

- Reach Category C - marginal flow conditions
- medium priority reach for flow augmentation projects pending study of coho use
- medium priority reach for habitat enhancement projects pending study of coho use

Reach UA2 - Barnett Valley Road crossing to 0.3 miles below Barnett Valley Road crossing (0.3 river miles)

- Reach Category E - inadequate flows during drought conditions
- high priority reach for flow augmentation projects pending study of coho use

Reach UA3 - 0.3 miles below Barnett Valley Road crossing to Highway 12 crossing (2.2 river miles)

- Reach Category B - good flow conditions
- high priority reach for habitat enhancement projects pending study of coho use

Reach UA4 - Highway 12 crossing to 0.5 miles above West Fork Atascadero Creek confluence (0.5 river miles)

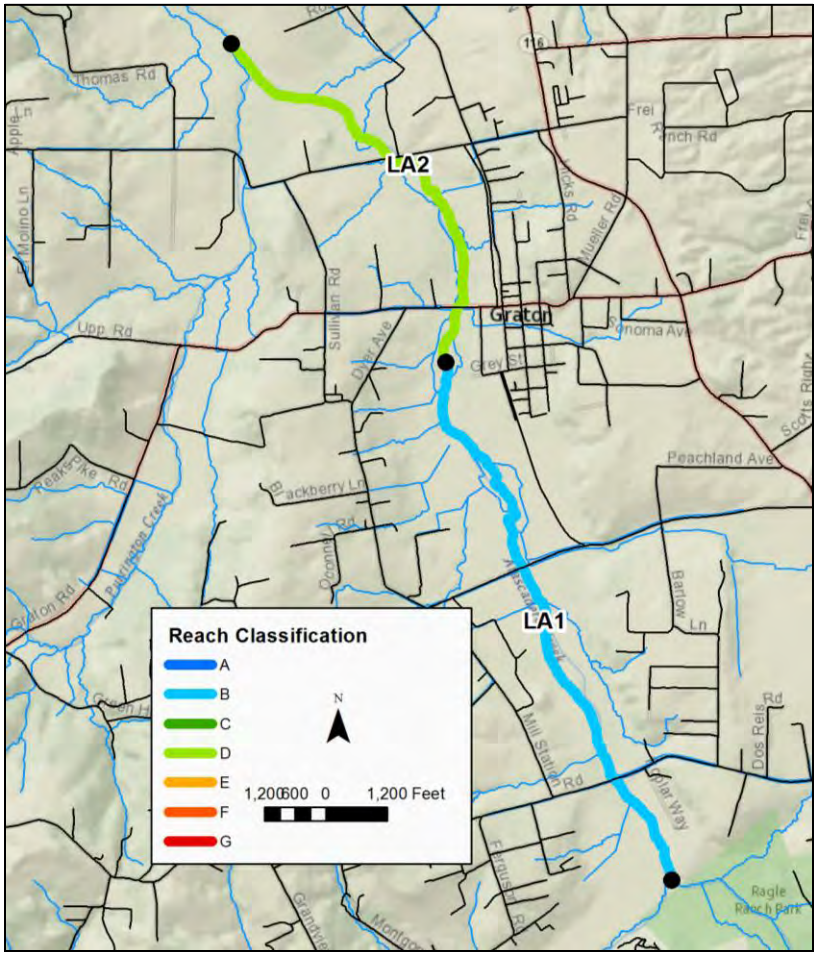
- Reach Category A - best flow conditions
- highest priority reach for habitat enhancement projects pending study of coho use

Reach UA5 - 0.5 miles above West Fork Atascadero Creek confluence to West Fork Atascadero Creek confluence (0.5 river miles)

- Reach Category F - inadequate flows during drought conditions
- effects of diversions should be evaluated and mitigated if necessary

Lower Atascadero Creek

Although adequate water depths are maintained, summer water velocities drop to zero in reach LA2 which may contribute to water quality and/or fish passage problems. Further study is highly recommended given that more than eight miles of stream with suitable flow conditions exist upstream of these reaches.



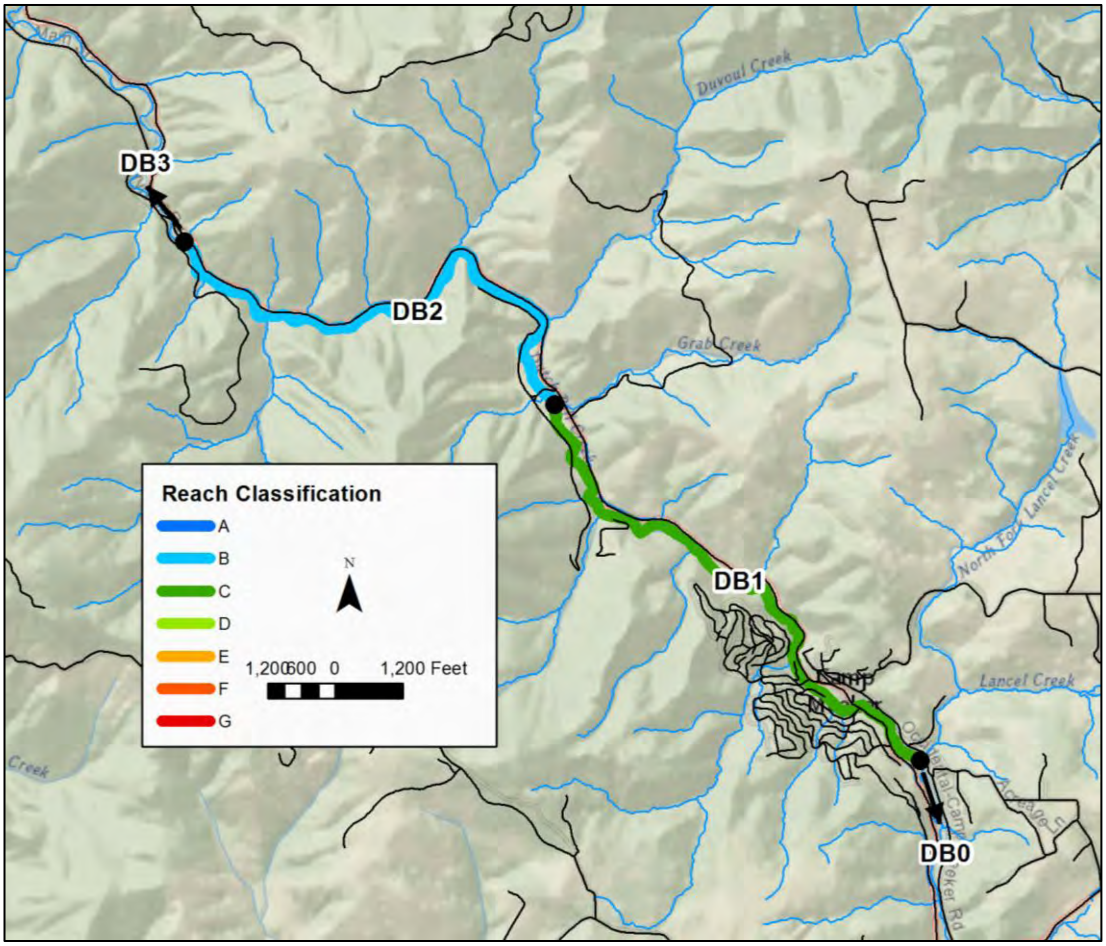
Reach LA1 - West Fork Atascadero Creek confluence to 0.2 miles above Graton Road crossing (2.3 river miles)

- Reach Category B - good flow conditions
- high priority reach for habitat enhancement projects pending study of water quality and coho use
- water quality conditions should be evaluated and improved if possible

Reach LA2 - 0.2 miles above Graton Road crossing to Green Valley Creek confluence (1.7 river miles)

- Reach Category D - good flow conditions
- water quality conditions should be evaluated and improved if possible

Dutch Bill Creek



Reach DB0 - above Lancel Creek confluence

- Reach Category H - inadequate flow conditions
- habitat enhancement and flow augmentation projects are not recommended

Reach DB1 - Lancel Creek confluence to Grub Creek confluence (2.2 river miles)

- Reach Category C - marginal flow conditions
- medium priority reach for flow augmentation projects
- medium priority reach for habitat enhancement projects

Reach DB2 - Grub Creek confluence to 0.1 miles above Tyrone Road crossing (2.1 river miles)

- Reach Category B - good flow conditions
- high priority reach for habitat enhancement projects

Reach DB3 - 0.1 miles above Tyrone Road crossing to Russian River confluence

- Reach Category H - inadequate flow conditions
- habitat enhancement and flow augmentation projects are not recommended

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Thinking with salmon about rain tanks: commons as intra-actions

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Thinking with salmon about rain tanks: commons as intra-actions

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The construction of California's large waterworks was inextricably entangled with a discourse of progress through technoscientific control over unruly rivers. In recent years, a turn towards decentralised governance and diversified infrastructure has produced alternate discourses of human–ecological collaboration and water as a commons. I investigate how water is understood by residents along Salmon Creek (Sonoma Co., CA) engaged in efforts to increase streamflow and restore salmon runs. Drawing on Barad's theory of agential realism, I find that living with springs and rainwater harvesting cisterns enacts intra-actions that increase residents' sense of interdependence with other human and nonhuman watershed residents. I argue that commons frameworks represent a coherent alternative to state and market frameworks of water governance.

Keywords: rainwater harvesting; agential realism; commons; salmon recovery; local knowledge

Introduction

In California, large waterworks spread as a key project of Manifest Destiny, fostered by industrial agriculture and real-estate boosterism (Worster 1982, 1985, Woelfle-Erskine *et al.* 2007). Their construction over the first half of the twentieth century was inextricably entangled with a discourse of progress through technoscientific control over unruly rivers (Worster 1985, Woelfle-Erskine *et al.* 2007). These dams and aqueducts produced a sustained agricultural, industrial, and real-estate boom, while decimating aquatic ecosystems and indigenous and traditional lifestyles connected to rivers and wetlands (King 2004, Katz *et al.* 2012). By freeing farmers and municipal water companies from dependence on local streams and aquifers, this unprecedented engineering project created an artificial divide – in policy and in legal discourse – between ground and surface waters. Large waterworks also severed urban water users from direct access the source of their water as urban streams were turned into concrete flood channels or put underground.

In recent years, a shift towards decentralised governance and diversified infrastructure has produced alternate discourses of human–ecological collaboration and water as a commons (Pahl-Wostl *et al.* 2008, Bakker 2010). Whereas the twentieth-century water planners prioritised economic uses of water and considered in-stream flows wasted water, the 2005 California Water Plan Update "strives to meet all future water demands – urban, agricultural,

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and environmental" and encourages decentralisation of some water governance processes through Integrated Regional Watershed Management Plans (California Department of Water Resources 2005). Integrated water resources management frameworks acknowledge that questions of livelihood, land use, and decision-making frameworks are central to decisions about where and how water should be used (Allan 2003). However, critical research into this integrated framework has questioned its implicit notions of community, the practicality of discursive democracy as a decision-making process, and the potential for participatory processes to entrench existing power dynamics (Ferreyra *et al.* 2008, Smith 2008, Saravanan *et al.* 2009). More recently, water governance scholars have drawn on institutional analysis approaches developed by Ostrom (1990) to design governance frameworks that explicitly account for equity and sustainability (e.g. Larson and Soto 2008, Wiek and Larson 2012, Caves *et al.* 2013, Plummer *et al.* 2013). This approach, and indeed the commons governance literature more broadly, emphasises procedural and managerial aspects of collaborative governance: deciding on decision-making procedures, reconciling local and expert knowledge, and detailing the decisions that emerge (e.g. Kerr 2007, Sarker *et al.* 2008, Innes and Booher 2010, Larson and Lach 2010).

Simultaneous with the decentralising turn in governance, a parallel turn in water infrastructure is coming into view. Sometimes called a "soft path" approach because it turns away from "hard" infrastructures such as dams and sewage treatment plants, this turn emphasises eliminating water use (i.e. through composting toilets), adopting water-efficient technologies, and abandoning wasteful water practices (Brooks *et al.* 2009, Christian-Smith and Gleick 2012). A key premise is that different qualities of water can satisfy different kinds of water demands – for example, untreated rainwater can supply toilets and laundry, and reused laundry "greywater" can irrigate gardens. Rainwater harvesting and shallow groundwater recharge are decentralising infrastructures that have gained ground with water managers in recent years. California climate change adaptation plans encourage utilities to reduce water use by 20% by the year 2020; these targets and deepening drought have spurred several utilities to decentralise water supply infrastructure and promote household rainwater harvesting and greywater use (State Water Resources Control Board 2010). Research that explores how people interact with household water infrastructure is critical to this effort because it identifies opportunities for sustained conservation and reveals how practices and infrastructural factors combine to drive water use.

Whether people adopt a practice such as rainwater harvesting – and whether that practice actually reduces water use – is complex, because savings depend on both infrastructural and social factors. For example, a household that installs water-intensive gardens and a rainwater cistern may use the same amount of municipal water as they did with a low-water landscape and no rain tank; if they water with the hose from time to time, their overall municipal water use may increase despite the rain tank. Several recent studies investigate perceptions and use of greywater systems (Pinto and Maheshwari 2010, Naylor *et al.* 2012), while others analyse how rainwater harvesting or greywater reuse affects household water consumption (Jones and Hunt 2010, Pinto *et al.* 2010, Muthukumaran *et al.* 2011). Most studies have focused on either social/behavioral or infrastructural factors in isolation, without considering feedbacks between infrastructures, values, and social water practices.[1]

However, as practice scholar Shove argues, water practices co-evolve with particular infrastructures, social norms, and values, so studying water systems as complex social–ecological systems is more revealing (2003). Researchers increasingly pursue this approach using a variety of frames. Resilience scholars (e.g. Groenfeldt and Schmidt 2013) characterise water systems as complex social–ecological systems that co-evolve in response to natural, regulatory, and social pressures. In the mainstream of science and technology studies (STS), actor–network theorists conceive of water systems as networks of human and nonhuman actants that mutually influence each other. For example, Teh uses actor–network theory to understand London's toilets and sewer system as a set of material and social relations, while Wagner applies some aspects of actor–network theory to map networks of water governance in the Okanogan Valley (Latour 1993, Wagner 2012, Teh 2013). These perspectives draw attention to dynamic interactions between human societies and local ecosystems, in the first case, and between water users and nonliving nonhumans (such as toilets and pipes) in the second. While my own sense of water systems is also invested in dynamic human–ecological systems, I find that complex systems theory and actor–network theory miss the ways that people's water practices change in response to their relationships with particular streams and the plants and animals that also use those waters.

I take a different tack. I mobilise Barad's theory of agential realism to demonstrate how household water systems emerge through intra-actions[2] between people, their wells and rain tanks, the climate, and local streams (2003, 2007). Like actor–network theory, agential realism considers a home water system as co-constituted by various infrastructural, climatic, human, and ecosystem agents. Both optics trouble the nature/culture binary by making an ontological claim: no discrete, "natural" objects exist that can be discovered by human inquiry, rather, the phenomena that make up the world are always co-constituted with human perception and engagement. Where Barad and other feminist STS thinkers depart from mainstream science studies approaches is radically questioning other binaries – male/female, human/animal, and animate/inanimate – and by focusing on the way that boundaries of race, gender, class, and humanity are constructed discursively (2007, p. 57). De-centering and de-privileging the human re-figure phenomena as lively and entangled relationships between human and nonhuman agents. In extending agential realism into water policy, I see an opportunity for a radical shift in perspective that may open up new approaches to reconciling human and ecosystem needs for water.

Whereas "soft path" approaches emphasise infrastructural and behavioural drivers of water use, and water governance approaches emphasise managerial and institutional factors, my agential realist analysis considers water practices as phenomena that emerge through "intra-actions" between people, salmon, local climate, particular water sources and infrastructures, and institutional arrangements. In exploring how rain tanks are changing water practices in a rural California community, I demonstrate that changes in one of these factors can cascade through a water system, disrupting old water use patterns, reconfiguring values, and opening a space to replace private property approaches to water governance with commons arrangements. Whereas institutionalists focus on property regimes that are already in place, I explore incipient commons. Beginning from Ostrom's insight that "[t]he key fact of life for coappropriators is that they are tied together in a lattice of interdependence so long as they continue to share a single [common-pool resource]," I draw on Wagner's concept of a "commons imaginary" to explain why polycentric governance approaches emerge through citizen science and community water planning (Ostrom 1990, p. 32, Wagner 2012).

Site, methods, and methodological commitments

On Salmon Creek (Sonoma Co., CA), a decade of collaborative research by citizen science groups and resource conservation agencies suggests that rainwater harvesting can restore more natural flow regimes in local streams, which dry up almost completely during the rainless summer (Poff *et al.* 1997). By storing winter rain for late-summer use, agricultural and municipal water users can reduce pumping from the stream and shallow groundwater during the dry season, thereby maintaining flow to isolated pools that become critical refugia for fishes and aquatic invertebrates. Rainwater harvesting may also improve water security for rural residents who source household water from wells, springs, or the Bodega Water Company. (The Bodega Water Company is a small water system with just 39 service connections that lacks a storage reservoir, and thus supplies water from a shallow aquifer connected to Salmon Creek (Hammack *et al.* 2010, WATER Institute *et al.* 2011).) The company lacks the resources to maintain ageing infrastructure and upgrade treatment facilities to remove manganese and iron; as a result, Bodega's water rates are some of the highest in the state of California (WATER Institute and others 2011). In 2009, a grant from the National Oceanic and Atmospheric Administration (NOAA) made large rain catchment storage available to members of the Bodega Water Company and local farmers at 10% of cost (J. Green, Gold Ridge Resource Conservation District, personal communication, 8/7/2012). The 10 systems installed through the pilot programme – eight at residential homes, one at the town fire station, and one on a dairy farm – have a combined storage capacity of approximately 2.2 million litres. This is the highest concentration of such systems in California, yet has an impact on streamflow that is too small to measure (Brian Cluer, NOAA, personal communication, 7/12/2013), suggesting that more widespread rain catchment and recharge projects are needed to achieve salmon recovery and drought resilience goals.[3]

In this study, I investigate how water is valued and understood by rural residents engaged in this watershed-scale effort to increase streamflow and restore salmon runs. This research is part of an on-going study that employs hydro-ecological methods, participant observation in local water monitoring activities, structured interviews with residents and scientists, and collaborative research forums that bring together residents and scientists to formulate goals for restoration and monitoring projects. I developed my research questions in conversation with local residents who are watershed council members and also scientific consultants; they suggested that I focus on measuring unmapped local springs and qualitatively evaluating the Bodega rainwater harvesting pilot project.

From May 2012 to April 2013, I conducted open-ended interviews with 22 Salmon Creek residents from 17 different households who rely on different sources of water: private wells, the Bodega Water Company, springs, rain cisterns, or some combination. I contacted pilot project participants through the Gold Ridge Resource Conservation district, and interviewed six of the eight residential rainwater recipients and the dairy farmer. I recruited the remaining participants through the Salmon Creek Watershed Council list serve and a snowball sampling method, in which participants introduced me to neighbours who were willing to show me their wells and springs. Participants included watershed council members who were concerned about salmon decline and actively involved in salmon recovery efforts, long-term residents who knew about salmon recovery efforts but were primarily motivated to conserve water by their own experiences of water scarcity, and newcomers and part-time residents who possessed little knowledge of the salmon recovery process. In all but three of the interviews, I visited the respondent's water source and asked them to demonstrate how they measured available water and maintained water infrastructure. Several participants shared their written records of rainfall, spring flow, and well depth.

My interview questions explored (1) how different sources and modes of water supply affect people's water use behaviours and overall water use and (2) how current water governance processes monitor and allocate water resources locally and regionally. For residents with rainwater harvesting systems, I asked what motivated them to install a rainwater catchment system and whether living with the system changed their water practices, awareness of local hydrology, or attitudes about waste and conservation. I asked residents with springs and wells about their experience of water scarcity and plans to develop new water supplies (including rain tanks). I asked all participants what factors they thought contributed to the local salmonid decline, who they thought should regulate groundwater development and diversions from Salmon Creek, and what types of policies (e.g. increased state groundwater regulation, county limits on new water development, and watershed restoration efforts) would promote salmon recovery and increase drought resilience for residents and farmers. Interviews were transcribed, augmented with field notes, and coded by hand; prominent themes that emerged (see next section) were explored using the optics of agential realism and commons.

View from above and from the ground

I grew interested in the Salmon Creek watershed because I was interested in what new human–water relationships could emerge in the social and political contexts of twenty-first-century California, yet in a place where no outside water sources would be tapped. I also wanted to understand how much people would change their water use out of concern for another species. Coho salmon (*Oncorhynchus kitsuch*) went locally extinct in the mid-1990s, while steelhead (*Oncorynchus mykiss*) are threatened with extinction; both species of salmonids spawn in Salmon Creek tributaries and spend their first summer in spring-fed sanctuary pools. Understanding how this small region is trying to adapt human livelihoods to local water supplies and balance human–water withdrawals with the needs of local riverine ecosystems can inform water planning in other parts of California and beyond.

On a map, Salmon Creek looks like a fish leaping up a waterfall, or twisting through the air to get free of a hook (Figure 1). Its mouth is at the edge of the Pacific Ocean, and its tail twists up towards the redwoods. Consultants and agency scientists adopt this view from above via satellite images and geographic information systems maps of geology and land use, which become inputs for distributed hydrologic models that produce estimates of streamflow under different climate and pumping scenarios. This exercise is an instance of what Haraway calls the "god trick", because such disembodied views purport to reveal "what is simply there" (1991, p. 582). From above, the view of the stream and built waterworks is fuzzy, obscured, and partial. Maps of springs, landslides, and geological features are incomplete, perhaps because landowners have denied mappers access. Only nine permits to divert water from the creek are registered, yet many more people admit diverting water from the stream. Acting on Haraway's call for mobile positioning and attention to local knowledge is not simple here.

From the road, the Salmon Creek watershed looks rural, with cows, old barns, and an upscale country store that sells oysters. The watershed boundary is marked with signs at road crossings. Descendants of Italian settlers run dairy cows on the grassy slopes above the main stem of Salmon Creek. In part because of water scarcity, these agricultural parcels have not been subdivided into suburban tracts. The ranchers tap wells or small springs; some have permits to divert Salmon Creek water. Up on the redwood-cloaked ridges, newer developments on small parcels rely on individual wells that tap sandstone lenses on the ridge tops, or water secreted in fractured metamorphic rock. Here live recent, often well-off migrants from cities where, as several told me, "we didn't have to

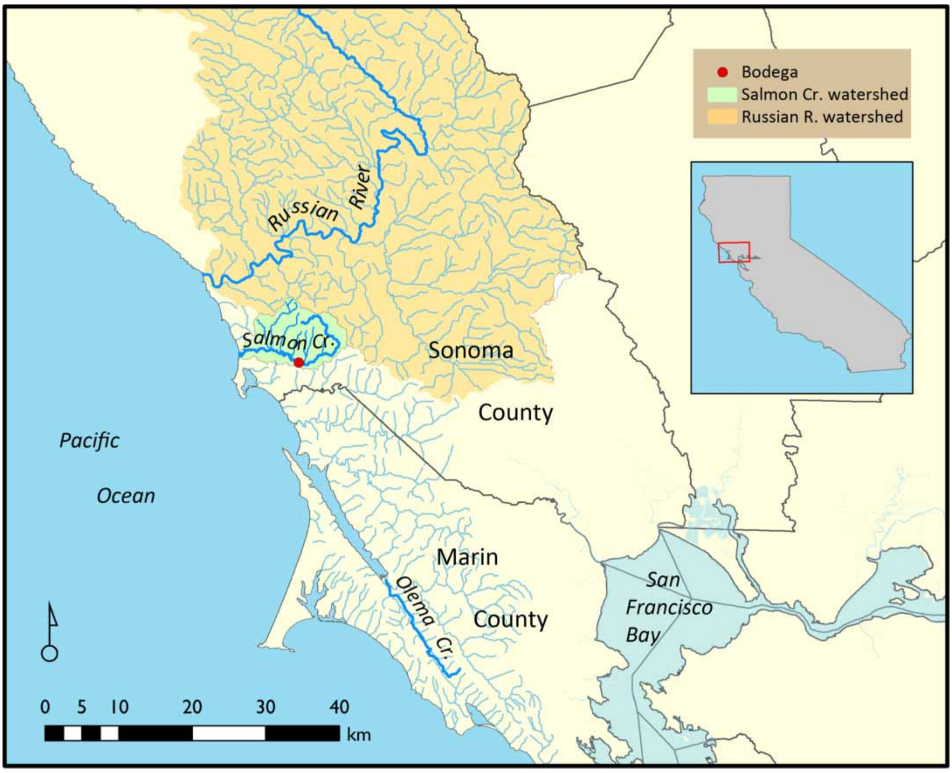

Figure 1. Map of the Salmon Creek region showing the Russian River and Olema Creek. These streams maintain small wild salmon populations that are now bred in hatcheries through the Russian River Captive Broodstock Program, then released in Salmon Creek. This map is also an example of what Donna Haraway calls the "god trick" – a view from everywhere and nowhere.

think about water". On a few ridges in the headwaters live back to the landers who arrived in the late 1960s and tap springs for water. Small towns – Bodega and Freestone – host a motley assortment of retirees (many on fixed incomes), artists, scientists, and service workers. Most residents know each other by face, and many know that their water use affects streamflow. "The Salmon Creek watershed wraps itself around this community and goes out into the ocean. We know it's us," one resident told me. Many residents contrast the local thrifty water culture to profligate habits in nearby cities and towns, which have (comparatively) abundant water because they tap the regulated Russian River. Larger socio-political factors including regional water scarcity and regulatory obstacles in permitting new reservoirs have left this watershed without access to these pipelines. Thus, residents are wholly dependent on local rainfall and what water can be stored in aquifers, ponds, and tanks, or pumped from the stream.

Economic constraints (e.g. the cost of improving the small Bodega Water Company or trucking in water), a lived experience of scarcity, and a desire for salmon and other creatures to return from the brink of extinction are shaping cultural relationships to water along Salmon Creek. These emerging water cultures foster household water use practices and social norms different from those that coevolve with large urban water systems, including:

(1) a different awareness of water supply apparatus, which arises from an acute awareness of scarcity and extends to concern for nonhuman creatures that depend on Salmon Creek;
(2) a detailed local knowledge of one's own water source, of neighbours' wells and water use practices, and of local hydro-ecological cycles; and
(3) the conviction that local self-regulation is preferable to outside regulation.

Below, I elaborate on these three themes, then argue that they evidence an emerging "commons imaginary" that influences discussions of how to manage Salmon Creek's ground and surface water.

Apparatus

In *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, Barad argues that humans, their scientific and everyday apparatus, and all the living and nonliving matter of the universe co-constitute phenomena, which are made real by their engagements with each other (2007). Barad argues that, at the quantum level, observation and influence are inseparable and complementary. She posits intra-action (a neologism that calls attention to the inseparability of the observer and what she observes) as an alternative to a mediated, representational view of the world. Since quantum phenomena operate at all scales of space and time, insights from quantum mechanics are not simply metaphorically applicable to everyday, macroscopic phenomena, but suggest the inseparability of epistemology, ontology, and ethics in all realms of research and action. All matter has agency, which does not inhere in beings, human or nonhuman; rather "[a]gency is the enactment of iterative changes to particular practices through the dynamics of intra-activity." (Barad 2003, p. 827).

Phenomena in Barad's view are intra-actions between differently empowered agents that are co-constituted with particular apparatus. What happens if the phenomena of interest are water systems? I think of waterworks (dams, levees, wells, pipes, pumps, and treatment plants) as a kind of apparatus that variously determines, constrains, and enables people's tangles with water. Water infrastructure beckons people to particular places, making certain economies and lifeways possible, and precluding others. Water development often imposes a human/nature binary when water is extracted from "natural" water systems for human use; this binary reappears during droughts as conflicts between human and ecosystem uses of water.[4]

Larger municipal water systems in the region imported water from dammed rivers following a pattern Sofoulis describes:

> In exchange for being inextricably entangled with Big Water via the meter, the meter-reader, water bills, pipes and drains, users receive the security and abundance of an ever-flowing supply, the comfort of an all-accepting drain, and convenience of doing nothing to maintain water supply except pay the water bills (2005, p. 455).

Such was the pattern that began on Salmon Creek when municipal and agricultural water systems were developed to divert most of its flow. Yet the stream is so small and permitting on-stream reservoirs is near-impossible, the phenomenon of water use evolved differently in Bodega. Service interruptions are common, users receive poor-quality water during the summer, and people often coerce their neighbours into serving a stint on the water board, where they experience the difficulties of maintaining a small water system first hand. Those without a connection from the Bodega Water Company must maintain their own spring or well. In short, all water users interact regularly with their water infrastructure. Perhaps as a result of this frequent interaction, most participants spoke of their household water system as an apparatus made up of human, manufactured, plant, animal, mineral, and atmospheric elements. Many saw the water they drink, wash, and water with as interdependent with a multiplicity of living and nonliving things.

The water source is always local and known. Several residents showed me the sandstone layers that held the water and springs that emerged at the contact between sandstone and metamorphic rock formations. One retired resident who lives on a ridge described the aquifer his well taps as a shallow bowl of sandstone perched atop an impervious metamorphic layer:

> It's a mess – there's fingers and little separate depressions. The only water we get, basically, is what we get in winter. It's saved there in this bowl until we run out. There are places in the woods here that are seeps, where it's overflowing from these bowls year round.

A long-time resident who lives near the stream described his shallow well as being recharged by seasonal pond:

> It's variable, but in the beginning of June or the end of June and the well dries up. During the time when the water table is high and the earth is full of water it works just fine.

Another long-time resident, a fisheries biologist who conducts annual surveys of Salmon Creek, sees the stream dry up downstream from wells, including the Bodega Water Company well on his property. Yet, even where the characteristics of the aquifer and rainfall patterns were mapped and charted, water remained a mysterious force. This force is often elusive when one goes drilling for it, and several people reported resorting to dowsers when engineers failed to find water (with mixed results). One long-time resident said,

> We tried to drill into [the sandstone hill above the spring] from the side in back of the house, nothing. The source of the water is mysterious. We got a dowser to find places where three springs converged – nothing.

Infrastructure is something people build and maintain themselves, though some may call experts in emergencies. When no water comes out of the tap, it could be because of a break in the pipe, because someone left the water on, or because the source went dry. Things break or leak frequently, and people have devised elaborate systems of valves and maintenance checks to make sure a leak does not drain the whole water supply. A recent immigrant from San Francisco who runs a bed and breakfast explained,

> I have all the tanks closed. I open one tank at a time, in case of an accident, or somebody that leaves a faucet on, so I don't lose two or three tanks of water. I only lose one.

In relating how he fixed a leak, one long-time resident describes water as an animate force:

> Once there's a leak, that's the most important thing that's going on, anywhere . . . I was out poking around . . . and I heard something. When I hear water running I stop and go investigate. I walked towards the sound and I saw that there was water gushing out of the pipes and the joint had separated. But I got it about the first fifteen minutes so I only lost 800 gallons.

Human error is seen as a mechanism of leakage. The human–pipe interface is a frequent point of failure, with high economic and sometimes interpersonal costs. Perhaps leaks, and the urgent human action they inspire, make articulation most apparent. A retired couple, recent immigrants from a water-rich region, said:

> Husband: In fact somebody left the hose on last week, and the tank went down to zero, and it couldn't pump enough to fill up the tank. We had to haul in 3000 gallons of water to get it started up again.
>
> Wife: It was me. I was on my way to one of those darned Salmon Creek Watershed Council meetings.
>
> Husband: I'm not trying to point out what a klutz you are, it's just an example. 'Cause I didn't know what was wrong with it, it was just dry all of a sudden.

Climate is articulated with the natural source in that, at least in shallow aquifer areas, it governs how much water will be available in a given year, and how long into the dry season that water will last. Every person I interviewed maintains a rain gauge, and five participants track the flow of their spring, or the level of their well or rain tank. The knowledge of climate is partly held in handwritten records people keep of their rain gauge measurements, but also partly discursive, generated when neighbours meet up and talk about rain. Climate and hydrologic knowledge circulates through informal networks and informs how people manage their own water supplies, and factors into the near-universal opposition to more water-intensive development. Two long-time neighbours said,

> Neighbour 1: This year, I measured 62.9 inches of rain, cumulative. We haven't had 60 inches of rain for the past 20 years. [He consults his rain gauge records.] There's a big variation from year to year.
>
> Neighbour 2: Last year we had rain into June. That's good for fish.
>
> Neighbour 1: We had 1.5 inch on June 3 and 1 inch on June 28. Now the average is around 40 inches. If there is an average. Next year we could have floods. But we probably wouldn't ever go below 30 inches. That's our water supply, that's what we rely on.

Many users practice water monitoring (Figure 2); however, the way they regulate use differs depending on the source of their water. Only users with metered municipal connections can report their daily usage in gallons. Those with cisterns know how much rainwater they have left, how much they use for irrigation, and how much they should have left at a given time of the year. Two residents who installed rain tanks through the pilot programme described how they respond to diminishing stores:

> Watching the tank level go down, I'm thinking well, let's see, I've got this much left, and I've got to make it to the end of October when it starts to rain. So is my consumption too much for what I have available? Perhaps I am thinking a little bit more about level of consumption [now that I have a rain tank].
>
> It's like draining your bank account. When you see it going down, down to almost zero, you're saying well, wait, I can't use too much more.

Users with rain tanks and wells understand water supply in relation to climate and demand. Residents with springs think in terms of flow rates. One resident told me that if flows drop below three gallons per minute in August, he will run short in September. Although he has adapted to water-scarce summers, the prospect of even less spring flow scares him:

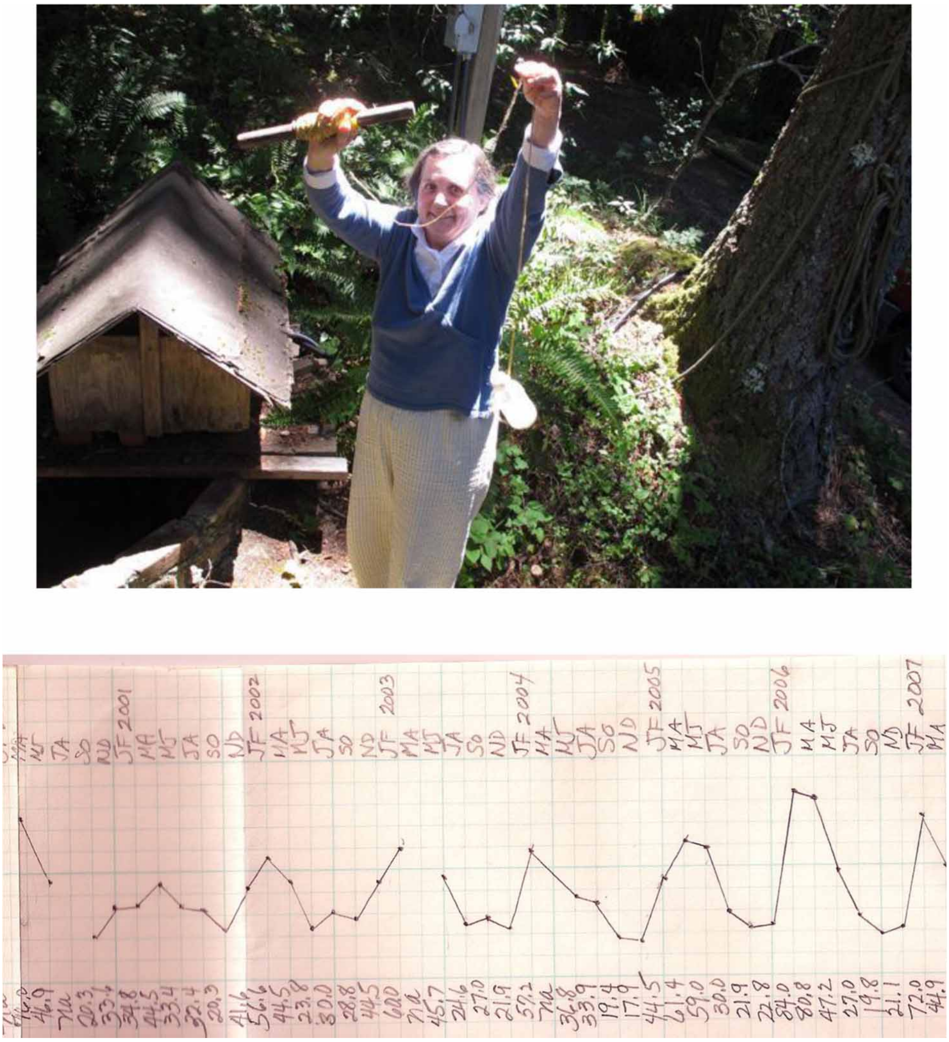

Figure 2. Salmon Creek watershed resident Diane Masura displays a home-made device that she uses to measure the depth of water in her well (top). She maintains detailed records of rainfall and well level that date back 25 years and show a consistent 60-day lag time between rainfall and maximum water level in the well. Many watershed residents maintain such records.

> I've lived here since 1974. Even in droughts, the spring never dried up, never went below 3 gallons per minute in September, except in 2009. That scared me – to see it get down almost to a drip. I had to put a tin chute inside the spring to direct more flow to the pipe that leads to the tank.

Conservation, then, requires action at different articulation points of the apparatus. To cope with scarcity, all participants have installed water-saving devices, commonly low flow toilets, aerators and shutoff valves on fixtures, and water-efficient dish and clothes' washers. Many have also abandoned devices designed for water-rich areas – sprinklers lose water to evaporation, and pressure hoses are prone to leakage:

> Once the garden's started, I just let it be on drip irrigation. I have to check it all the time to make sure the batteries are working.

The particular form of the apparatus – what source people rely on, what appliances and devices it flows through, and people's lived experience of scarcity or running out of water – partly determines water practices and consumption. Two Bodega Water Company members expressed the idea that people with adequate water were disconnected from the impacts their water use had on the creek:

> There's not enough water in Salmon Creek. And they're definitely endangering the salmon by using it. I'm appalled when people misuse the Bodega water. I can't believe people are so asleep. People are so privileged. They think that if they own that property they have a right to use any resource on it. Have you seen [local farmer's place] yet? Oh my god. He was watering all these cattle, and he was using hundreds and thousands of gallons coming right out of the creek. Excuse me! He's a nice man. And he would blithely use as much water as he wanted out of the creek until he was offered this grant.

> [Pumping from the creek] is really bad. And the vineyards do it. [Landowner name] is taking right out of Salmon Creek ... I think that's not right for profit making people to take from the commons.

This same resident also adopted water-saving habits that she teaches to children and visitors:

> We have a special low flow toilet, we have a graywater system. ... We turn off the faucets, we don't leave them running, unless you have a [visiting] ten year old who doesn't have any sense. You say they have to learn sometime, well, he's going to start learning when he wakes up tomorrow morning.

Newcomers learn to adapt their gardens to dry summers, abandoning lawns in favour of xeriscape and fruit trees that need water only for the first three years. One gardener adjusts water use, even selecting plants to sacrifice or take off irrigation if he runs out:

> I only have so much water available, 46,000 gallons, so I plan accordingly ... I tend to plant things like potatoes, garlic, onions early on so that when it stops raining I have already harvested ... In case of an emergency, if I have some plants, I wouldn't let them die. I will use the Bodega water company water. But this will be the last resort.

Several residents said that they only grow plants that have a purpose, and hate to see water thrown away. However, whether a resident considers a particular use of water to be wasteful depends on their conceptual model of local hydrology. For example, most people thought that using well water in the home was not wasteful, since all the water recharged the aquifer via the septic system. As these three residents described, certain watering practices (unattended hoses and daytime use of sprinklers) and crops (lawns) were considered wasteful, but merely having a garden was not:

> Nothing [in my garden] gets water that isn't useful or chosen.

> Being conscious about water conservation is perhaps the biggest thing. You know, what happens when you turn on the tap? Do you have to turn it on? ... Coming out of the faucet and running down the driveway, I don't think that's a good use of water.

> Most of my trees are not irrigated. They just drain their own water from the depths that they need. I don't believe that anybody should have sprinklers. The grass and all of that stuff shouldn't even be permitted, if they have to drain water from close to a creek.

All participants reported adopting some water conservation measures, but most also reported indulging in what they considered wasteful, luxury uses of water. Two participants said that they take long hot baths, one builds tile fountains, one has a fish pond, several maintain lush vegetable and flower gardens, and one couple installed an extra rain tank to top off their swimming pool. Some people admitted to refilling their rain tanks from the municipal supply in order to expand their gardens.

In summary, all participants reported adopting water-saving practices and/or developing new infrastructures to increase their own water security. Some residents were motivated to do so by their desire to see salmon return to Salmon Creek, while others were motivated by desire to expand their gardens and improve reliability during dry periods.

Regulation, local knowledge, and commons

One rainy day early in 2009, a small group of humans carried 300 salmon from a truck to the edge of the water, and released them.[5] The fish slithered and splashed upstream, then spawned. That year, local rain gauges measured the lowest rainfall in decades, and one resident watched his spring dry up for the first time in the 35 years he had lived there. Water trucks rumbled back and forth, bringing Russian River water to residents whose wells had gone dry at $150 per 3000-gallon truck. By summer the streams had gone nearly dry, and dissolved oxygen in the small pools that remained dropped towards zero. Biologists working for the Department of Fish and Game collected the finger-length fry in nets, and took them back to the hatchery. Once the rains began in November, biologists returned the fish to the stream, where they lived for a few more months before swimming out into the ocean (M. Fawcett, personal communication, 8/8/12).

Each winter since then, a few humans re-enact the release of spawners in the estuary, hoping to re-establish each year-class[6] of extinct fish with hybrids of hatchery-raised fish from the Russian River and Olema Creek watersheds (Figure 1). In one sense, this slight change in materiality – a mere 600 pounds of fish that swam upstream, spawned, and died – has transformed the social and material interactions of the watershed's human residents. Now, everyday practices such as flushing the toilet or bringing water to the horses resonate with significance for tiny fry growing up, unseen, in the tributaries. One long-time resident who installed a rain tank said,

> That tree line is Salmon Creek. It's three miles out there, and you probably can't kayak it because of the trees to go across. There are people that seem to remember that there were a lot of fish in this stream at one time, and you could go spear them after school. And we see now, there's Coho in there, and otters, and turtles. There was a deficit of wildlife there from 2002 to 2008 or 2009, but it's coming back now. It's really good to see.

Instead of asking about a commons outright, I ask it aslant:

> Who do you think should be responsible for making sure that residents of the watershed have enough water? Who do you think should decide how much water can be pumped out of Salmon Creek, and whether any needs to remain for the ecosystem?

The answers range from "the state", "the county", "individual water users", "the Bodega Water Company" to "only the federal government can protect the salmon."

All participants believe that the watershed already has been degraded, and will be degraded further if humans withdraw more water for agricultural or household use. Groups of neighbours have organised meetings to discuss strategies for increasing adaptive capacity in the face of a deepening 3-year drought, and are interested in building infiltration basins to recharge winter rain into ridge-top aquifers (Darlene LaMont, personal communication, 12/24/13). To date, these incipient collaborations have not yielded institutional structures for managing groundwater as a common-pool resource. Indeed, my interviews suggest that residents are divided on how best to regulate groundwater use.

More than half of my participants echoed the view that outsiders (county, state, and federal governments) do not know enough about local water needs, sources, and practices to regulate this intricate system. Residents have detailed knowledge of how long their neighbours' water lasts, and who violates community conservation norms, yet few believe that the state should step in and punish people for over extracting. Most preferred incentives for existing development, such as grants for rainwater systems and education. The others thought that some amount of regulatory pressure from state or federal agencies is necessary to motivate conservation and habitat recovery projects.

Several residents who have lived in the watershed for between 10 and 30 years expressed the view that long-term residents have evolved conservation practices to cope with water scarcity, and are capable of self-regulating water use in times of drought. These residents saw newcomers from cities as a threat to aquifers and the local water culture because they lack local knowledge of water scarcity, and may not bow to social pressures to conserve. Half of the participants thought that the county should mandate rainwater catchment for new development, and several participants supported a total ban on new wells in the watershed.

Arguing for government regulation, several participants cited relentless development pressure as the cause for declining water tables. Groundwater is unregulated in California, and only recently have developers had to prove to the county that property has a one gallon per minute (four litre per minute) well. They argue that developers have no incentive to leave land un-developed, particularly since vineyards command high profits. One person said that the county is tightening groundwater regulations, but has been ineffective in monitoring how much water is extracted via wells, determining how new wells affect old wells, or slowing development. Because the county's tax revenues increase with land values and subdivision, they believe that state agencies must regulate water use by regulating development:

> I think there have to be state level rules, regulations, and the townships have to live within those regulations. It has to be monitored, for one thing. That's gonna be the tough part. People don't want a meter on their water supply … They're the only authority that can take care of this. Because the county and these little towns can't do it, or won't do it.

Others think that the watershed is already over-regulated, and resist the idea that state or county agencies would meter and enforce withdrawals from streams or aquifers. In California, data on the level of the water table is not publicly available, and some residents want to keep it that way:

> People are going to ask you, what are you going to do with [your spring and well] data. People are going to be less frank if they think there's any way the county or anyone else is going to monitor them … It's the principle in part – how much should be in the public domain?

For another resident, the rejection of state authority opens the way for some form of collective management:

> I think it would be bizarre to think that there would be a state water agency that could regulate the amount of water that we take out of here. They are remote and they have other issues to pay

> attention to. But I think that . . . thinking as a watershed unit . . . we should be able to regulate our own.

In my interviews and participant observation of local water planning meetings, I found evidence that status quo rules govern de facto governance of groundwater and groundwater-fed streams. These rules operate informally, suggesting that collective governance in Salmon Creek is at an incipient stage, in which people begin to consider scarce groundwater a commons that should be managed collectively to sustain another common-pool resource, salmonid fishes. However, the specific forms of that management – the rules, monitoring, and enforcement that would cohere in an institution to manage the watershed commons – have not yet emerged, despite a decade's effort to foster collaborative watershed management here:

> I think that collaborative efforts work better, but until people get educated – people are angry when they're made to do things. I understand why they have to regulate fisheries because . . . greed takes over and then people don't have any good sense about taking care of Mother Earth and all of her different creatures, and sensibly harvesting, sensibly growing. I hate the vineyard industry because they have big monocultures and they overuse water and they're only doing it for their own gratification.

Only tentatively do people say – or talk around the idea – that water, the watershed, or the riverine ecosystem are commons in need of protection.

> Wife: I do consider it a commons, but I don't think I'm in the majority in this community. People in this community respond more to a specific argument, like "The fish need it, we want the fish, we're going to go get them and eat them." I consider it a commons, don't you?
>
> Woelfle-Erskine: I do
>
> Husband: I think there are two resources that need to be managed like that, and one of them is air quality, and the other one is water. Everything else – the mineral contents, the gold they find on your property – that seems to be built into our political system that it's yours. But . . . we're all using the same water and the same air. There has to be consensus and agreement on how to use them most effectively. People can't get greedy.

In contrast to other studies of water commons, the common-pool resource discussed here is not only (inanimate) water that provides economic goods or social benefit. The commons is the watershed – an animate agent in the Baradian sense – that collects water in ponds and streams for the benefit of humans and nonhumans alike:

> What is the benefit of those creeks to those people who live here, and do the other animals that live here have any rights at all? Who's going to provide a habitat for the fish and the animals– the bobcats and the deer and the coyotes and the raccoons and all of those other animals that go down to the creek to drink? You can hear them down there. Do they have a right to clean water? . . . I happen to think that we all live here together as a living network . . . The creek should be preserved for the benefit of all living people [he corrects himself] all living beings, as well as for humans . . . If that means a regulation of consumption, then maybe we need to self regulate in some regards.

Thus, the idea that the Salmon Creek watershed is commons is, in a Foucauldian sense, sayable and plausible in the Salmon Creek watershed five years after Coho salmon reintroduction, though collective management institutions have not yet emerged (Foucault 1991). Also sayable now is that fish should have water and habitat. During the twentieth century, dams were built on nearby streams with full knowledge that they would decimate salmon runs. At early salmon recovery meetings here in the 1990s, some people opposed reintroduction because they thought that it would threaten agricultural livelihoods and tenuous water rights. Now, "you'd be crucified" if you stood up in a meeting and said that agriculture should trump salmon.

> Wife: At those early community meetings there would always be someone who said the fish were not really important, that agriculture was really important. No one says that anymore.
>
> Husband: [interjecting] You'd be crucified.
>
> Wife: Yeah, right. The whole community has changed . . . Maybe the naysayers aren't coming because they think people would boo them down. But still, they didn't used to be booed down, so I think things have changed.
>
> Husband: I think it's a realization that there's a shortage, or there will be a shortage, of these generally accessible things like water, fresh air, clean air, all that stuff. We're all stuck in this together. Some of the farmers that have stood up recently at some of the water meetings have been very articulate and quite understanding about this.

In community meetings and conversations at the post office and the bar, ranchers, environmentalists, and newcomers alike now say that watershed can sustain agriculture, salmon, and residential use, and believe that restoration strategies should increase the resilience of all three.

My interviews with watershed residents – early adopters, potential adopters, and non-adopters of rainwater harvesting – suggest that interest in rainwater tanks has increased markedly now that people have had a chance to observe the first installations, for several seasons. According to one Bodega Volunteer Fire Department member, fire-fighters were initially sceptical of the project. But when a fire threatened the town and there was not enough water in the creek to fight it, they saw the large storage tank in a new light. With a grant from the NOAA available to help fund a fire station upgrade, the department decided to install a 132,000-L tank, and in the process became supporters of the rain tank effort. During this same time, Bodega residents have witnessed runs of Coho salmon increase from zero, to several dozen, to hundreds. It is as if the materiality of the tanks and the salmon is now entering the discursive practices of public meetings and outreach, and has precipitated a shift in discourses around the stream, fish, water use, and how to reconcile different needs and desires for water.

Conclusion

Through the lenses of Baradian apparatus and intra-action, I see signs that participating in citizen science and living with rainwater cisterns increases residents' sense of interdependence with other human and nonhuman watershed residents. In residents' reflections on their daily water practices and their practices of returning Coho salmon to their watershed, I find the concept of water as a commons co-evolving with small-scale rainwater harvesting infrastructure. This commons differs from many water commons discussed in the literature in that bodies of water are not merely resources for human use, but are lively agents that sustain salmon, humans, cows, trees, frogs, and humans alike.

By incorporating rainwater harvesting into the (partly) centralised[7] Bodega Water System, the system is taking on the qualities of proximal materiality, diversity, and scarcity that, according to Strengers and Maller (2012), characterise decentralised water systems. Like the people Strengers and Maller interviewed, most Salmon Creek watershed residents live with household water infrastructure that is indistinguishable from their urban and suburban neighbours. They have flush toilets, washing machines, and pressure hoses to mist down flowerpots – devices that Sofoulis (2005) describes as "baked in" to large centralised water schemes. In response to scarcity and a large government cost share, some residents are evolving practices and modifying infrastructures in ways that makes their intra-actions with water much richer in social and ecological meaning. In particular, rainwater cisterns foster a sense of connection to local rainfall cycles and increase residents' awareness of seasonal fluctuations in water supply.

These findings suggest that decentralising water governance and infrastructure involves more than a change in water management. Managing one's own water system seems to increase entanglement with local water sources and shift dynamics between oneself and one's neighbours (both humans and other species). In my account of emerging interspecies commons, these entanglements may precipitate changes in culture – specifically, in the social meaning of water – because the apparatus of water use expands to include riverine species that embody a lively materiality that is bound up in human–water relationships. To date, the literature on decentralised water systems has underplayed the cascading social and interspecies effects that can accompany a shift in water infrastructure. But unless these cultural relationships change, a mere shift in infrastructure – be it rain tanks, greywater systems, or groundwater recharge schemes – is unlikely to lead to the far-reaching changes in water provision that will be necessary to avert extinction of most salmonid taxa in California (Katz *et al.* 2012). More research into how particular decentralisation strategies shift social water relations should become a central focus of decentralised infrastructure planning.

Collective choice frameworks represent a coherent alternative to state and market frameworks of water governance. Although changes in human–water relationships along Salmon Creek may not map onto other watersheds directly, they do point to social changes that can be anticipated where people, water, and other living beings jump barriers erected by infrastructures and see that they swim through common currents. Water mains and dams separate city and suburban residents from their water sources and from the other creatures that inhabit them just as surely as redlining and prison walls separate urban residents of different socioeconomic backgrounds. In both cases, out of sight is out of mind, and at a conceptual distance, we rob those people, animals, plants, and waters of agency and animacy.[8] Active, daily involvement with water reminds of its life force. When people have built channels and vessels to store water, awaited the first storms, and seen silver bodies flashing upstream after the first big flow, water can no longer be seen as a dead resource for human use alone.

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Notes

1. In an exception to this trend, Domènech *et al.* (2013) evaluate changes in water use and water practices following installation of decentralised household water infrastructure.

2. Barad explains the term intra-actions as follows: "[T]he notion of 'intra-action' queers the familiar sense of causality (where one or more causal agents precede and produce an effect), and more generally unsettles the metaphysics of individualism (the belief that there are individually constituted agents or entities, as well as times and places). According to my agential realist ontology, or rather ethico-onto-epistemology (an entanglement of what is usually taken to be the separate considerations of ethics, ontology, and epistemology), 'individuals do not preexist as such but rather materialize in intra-action." (Barad 2012)
3. Phase two of the project began in 2013, and will install eight more rainwater harvesting systems in the Bodega area.
4. For example, see news coverage from California's 2013 to 2014 drought (Clarke 2014, The News editorial board 2014).
5. This release is part of the Russian River Captive Broodstock Program, an experimental collaboration between various state and federal agencies in which individual salmon are raised to adulthood in a hatchery, then bred to maximise genetic diversity. The surplus adults are released into the Salmon Creek estuary, where they swim upstream and spawn without further human interference. Their young are then "wild" in the sense that they are subject to all the natural selection pressures at work in a stream habitat.
6. A year-class is a distinct sub-population of an anadromous fish that hatches in a given year. Coho spawn three years after they hatch. In Coho salmon and other anadromous fishes that have high temporal fidelity in their life history, a year-class becomes locally extinct can only recover if spawning fish stray into the depopulated stream or are re-introduced by humans.
7. Only 'partly centralised' because many Bodega Water Company users also have a well or used to pump out of the creek.
8. This insight into acknowledging agency and animacy in humans and nonhumans comes from Kimberly Tallbear's comment on a draft of this paper.

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