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Via E-Mail Only

Sonoma County Planning Commission
c/o McCall Miller, Department Analyst,
Cannabis Program, County Administrator's Office
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Re: Sonoma County Cannabis Land Use Ordinance Update and General Plan Amendment and Draft Subsequent Mitigated Negative Declaration

Dear Commissioners:

This firm represents the Friends of Mark West Watershed ("FMWW") in connection with the Sonoma County Cannabis Land Use Ordinance Update and General Plan Amendment ("Project"). This firm concurrently represents Save Our Sonoma Neighborhoods and will submit separate comments on their behalf. FMWW believes that approval and implementation of the Project as presented will result in the reduction of streamflow in Mark West Creek below the critical levels necessary to sustain spawning and rearing of federally- and state-listed endangered salmon, resulting in a "take" of these species. The SMND does not adequately describe and analyze these impacts or provide mitigations that will prevent their occurrence. Therefore, the County must prepare a full EIR for the Project. In addition, FMWW contends that the approval of individual cannabis production projects requires the exercise of judgement and discretion by the permitting agency and cannot qualify as ministerial action.

The purpose of this letter is to inform Sonoma County that the Subsequent Mitigated Negative Declaration ("SMND") for the Project fails to comply with the requirements of the California Environmental Quality Act ("CEQA"), Public Resources Code § 21000 et seq., and the CEQA Guidelines, California Code of Regulations, title 14,

§ 15000 et seq. ("Guidelines"). As detailed below, numerous inadequacies and omissions in the SMND render it insufficient as an environmental review document.

The SMND fails to disclose, analyze, and propose adequate mitigation for significant environmental impacts related to hydrology and water quality, groundwater supply, and loss of habitat for endangered fish species, among others. What analysis the SMND does present is fraught with errors. As a result, the SMND fails to describe measures that could avoid or substantially lessen the Project's numerous significant impacts. In addition, the SMND fails to provide any meaningful analysis of allowing events at cannabis cultivation sites. As set forth in this letter, the California Environmental Quality Act ("CEQA") requires the preparation of an environmental impact report ("EIR") before the County may approve the Project.

In addition, the Project conflicts with Sonoma County's General Plan in violation of State Planning and Zoning Law, Govt. Code § 65000 et seq. As described in more detail below, the Project would conflict with multiple policies designed to protect the County's natural and agricultural resources.

Finally, based on the Project's significant environmental impacts and its inconsistency with the County's General Plan, the County must exclude the Mark West Watershed and any other similarly impaired watersheds from the Cannabis Ordinance. As detailed below, the state of California has determined that the Mark West Watershed is impaired and the cannabis operations authorized by the Project would exacerbate the already fragile nature of this important ecosystem. Therefore, the County must exclude the Mark West Watershed and other similarly impaired watersheds from areas where cannabis operations would be permitted in the County.

This letter is submitted along with the report prepared by our expert consultant, Greg Kamman, Senior Ecohydrologist with CBEC Ecoengineering, whose letter dated March 16, 2021 is attached as Exhibit 1 ("Kamman Report").

I. The County may not approve the Project without preparing an environmental impact report under CEQA.

CEQA is designed to ensure that "the long-term protection of the environment shall be the guiding criterion in public decisions." *Friends of College of San Mateo Gardens v. San Mateo County Community College District* (2017) 11 Cal.App.5th 596, 604 [hereinafter "*San Mateo Gardens II*"] (quoting *No Oil, Inc. v. Los Angeles* (1974) 13 Cal.3d 68, 74). Thus, the statute requires an agency evaluating a project to develop an EIR whenever "substantial evidence supports a fair argument that a proposed project 'may have a significant effect on the environment.'" *Committee for Re-Evaluation of T-*

Line Loop v. San Francisco Municipal Transportation Agency (2016) 6 Cal.App.5th 1237, 1245-46 (quoting *Laurel Heights Improvement Assn. v. Regents of University of California* (1993) 6 Cal.4th 1112, 1123).

When an agency approves changes to a previously approved project studied in a prior negative declaration, additional subsequent environmental review is required when "whenever there is substantial evidence to support a fair argument that proposed changes 'might have a significant environmental impact not previously considered . . . .'" *San Mateo Gardens II*, 11 Cal.App.5th at 606 (quoting *Friends of College of San Mateo Gardens v. San Mateo County Community College District* (2016) 1 Cal.5th 937, 959 ["*San Mateo Gardens I*"]; *see also San Mateo Gardens I*, 1 Cal.5th at 953. In other words, an agency *must* prepare a subsequent EIR if substantial evidence supports a fair argument that the proposed changes to the project may result in a significant environmental impact. *San Mateo Gardens II*, 11 Cal.App.5th at 606-07. Proposed changes might have a significant impact "when there is some competent evidence to suggest such an impact, even if other evidence suggests otherwise."[1] *Id.* at 607.

The fair argument standard establishes a "low threshold" for requiring a lead agency to prepare an EIR. *Pocket Protectors v. City of Sacramento* (2004) 124 Cal.App.4th 903, 928. Courts "owe no deference to the lead agency's determination," and judicial review must show "*a preference for resolving doubts in favor of environmental review.*" *Id.* (italics in original). Further, where the agency fails to study an entire area of environmental impacts, deficiencies in the record "enlarge the scope of fair argument by lending a logical plausibility to a wider range of inferences." *Sundstrom v. County of Mendocino* (1988) 202 Cal.App.3d 296, 311.

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[1] The relevant analysis under CEQA's subsequent review provisions concerns the changes since the original Medical Cannabis Land Use Ordinance was adopted in 2016, and not only the changes since the 2018 amendments to allow adult use cannabis. This is because the 2016 ordinance was studied in a negative declaration, while the Board of Supervisors determined that the 2018 amendments were exempt from CEQA. *See* Resolution No. 18-0442 (Oct. 16, 2018). CEQA's subsequent review provisions apply only when there has been a prior *environmental review*. *See* Pub. Res. Code § 21166 (applies "[w]hen an environmental impact report has been prepared for a project"); Guidelines § 15162 (applies "[w]hen an EIR has been certified or a negative declaration adopted for a project"). In any event, the development potential allowed by the 2018 Amendments has not been fully realized. *See* SMND 18. To the extent the Project would facilitate new development in areas opened to cannabis in 2018, that new development potential must be analyzed as a foreseeable effect of this Project.

Substantial evidence supporting a fair argument may consist of personal observations of local residents on nontechnical subjects, *Oro Fino Gold Mining Corp. v. Cty. of El Dorado* (1990) 225 Cal. App. 3d 872, 882; *Protect Niles v. City of Fremont* (2018) 25 Cal.App.5th 1129, 1152, as well as expert opinion supported by facts—even if that opinion is not based on a specific analysis of the project at issue, *Pocket Protectors*, 124 Cal.App.4th at 928. In marginal cases, where it is not clear whether there is substantial evidence that a project may have a significant impact and there is a disagreement among experts over the significance of the effect on the environment, the agency "must treat the effect as significant" and prepare an EIR. CEQA Guidelines § 15064(g); *City of Carmel-By-The-Sea v. Board of Supervisors*, (1986) 183 Cal.App.3d 229, 245.

As explained further below, ample evidence supports a "fair argument" that the Project may result in significant environmental impacts that were not studied in the 2016 Negative Declaration. These impacts would include, but not be limited to: hydrology and water quality, groundwater supply, and loss of sensitive aquatic habitat, among others. Because the Project has the potential to result in significant impacts, the County is required to prepare an EIR before it may approve the Project.

II. The Project description is inadequate.

A. The Project description is incomplete, inaccurate, and inconsistent.

In order for a CEQA document to adequately evaluate the environmental ramifications of a project, it must first provide a comprehensive description of the project itself. "An accurate, stable and finite project description is the sine qua non of an informative and legally sufficient EIR." *San Joaquin Raptor/Wildlife Rescue Center v. County of Stanislaus*, (1994) 27 Cal.App.4th 713, 730. As a result, courts have found that even if an environmental document is adequate in all other respects, the use of a "truncated project concept" violates CEQA and mandates the conclusion that the lead agency did not proceed in the manner required by law. Id. at 729-30. Furthermore, "[a]n accurate project description is necessary for an intelligent evaluation of the potential environmental effects of a proposed activity." Id. at 730 (citation omitted). Thus, an inaccurate or incomplete project description renders the analysis of significant environmental impacts inherently unreliable.

As an initial matter, the SMND does not provide a meaningful description of the "development potential"—i.e., the scope and extent of cannabis cultivation and other commercial cannabis activities—that may be permitted by the proposed updates to the cannabis ordinance ("Ordinance"). The CEQA Guidelines define "project" as "the whole of an action" that may result in a direct or reasonably foreseeable indirect change in the environment, and require the lead agency to fully analyze each "project" in a single environmental review document. CEQA Guidelines § 15378(a); *see also* Guidelines §§ 15165, 15168. CEQA further requires environmental review to encompass future actions enabled or permitted by an agency's decision. *Christward Ministry v. Superior County* (1986) 184 Cal.App.3d 180, 194; *City of Redlands v. County of San Bernardino* (2002) 96 Cal.App.4th 398, 409 ("An evaluation of a 'first phase-general plan amendment' must necessarily include a consideration of the larger project, i.e., the future development permitted by the amendment.").

Here, the SMND purports to provide an outer limit on possible development. The SMND states that "a maximum of up to 65,753 acres" could be subject to future cannabis cultivation. SMND at16, 19. This acreage is 10% of the 657,534 acres in the County that are both zoned for agricultural uses and located on parcels larger than 10 acres, likely to reflect the Project's limit on outdoor cannabis cultivation area to 10% of a parcel. *Id.* As explained below, the SMND's description of the Project's development potential is misleading and inadequate to allow the public and decisionmakers to accurately assess the potential effects of the ordinance.

Troublingly, the SMND omits any analysis of the possible extent of cannabis cultivation in existing permanent structures. The ordinance itself contains *no limits* on indoor and greenhouse cultivation canopy in existing permanent structures. *See* proposed § 38.12.030(A)(2) ("Indoor cultivation and greenhouse cultivation canopy in an existing permanent structure is not limited."). The SMND should include a description—or at least an estimate—of the number and extent of existing permanent structures in the County that may be converted to cannabis cultivation and their square footage. The SMND should also analyze how much cannabis may be grown in such indoor spaces—especially since indoor cultivation can occur on shelved units, potentially *quadrupling* the canopy area possible in an existing structure. This existing permanent structure loophole could portend significant impacts on the environment that have not been analyzed. Because the Ordinance allows an unknown, but potentially massive, amount of indoor cannabis cultivation, the corresponding impacts (in terms of increased water usage, energy usage, VMTs, greenhouse gas emissions, etc.) are similarly unknown, and potentially massive.

The Ordinance also apparently allows indoor cultivation in existing permanent structures *in addition to* both (1) indoor cultivation in up to 43,560 square feet of new or expanded permanent structures *and* (2) outdoor cultivation of 10% or less of a parcel. *See* proposed § 38.12.030(B) (limitations on indoor cultivation apply to "all *new* building coverage," not to *total* building coverage). For example, a grower on a 10 acre parcel could have 1 acre of outdoor cannabis cultivation, in addition to 43,560 square feet of cultivation in a new or expanded permanent structure, plus additional indoor cultivation in existing permanent structures currently on the parcel. As a result, the County's assumption that cannabis activities would occur on no more than 10% of the 657,534 eligible acres is incorrect. The Project could result in converting significantly greater acreage to cannabis cultivation.

The County's incomplete and inaccurate estimate of the Project's full development potential could conceal significant potential impacts. For example, the SMND's hydrology analysis concludes that groundwater supply impacts would likely be less than significant because of "the relatively low quantities of water use (from .002 to 1.8 acre-feet per year)."[2] SMND at 69. The SMND then explains that the size limitations—10 percent of a parcel for outdoor grows and no more than one acre of *new* building coverage—would limit water use at individual sites. SMND at 69. This analysis, however, does not take into account the fact that each site can apparently include outdoor cultivation, indoor cultivation in new structures, and additional indoor cultivation in existing structures; or that indoor cultivation can be multi-tiered or stacked for greater growing area in the same building footprint. Thus, because of the flawed Project description, the SMND's analysis could be significantly underestimating the amount of water demand that could be created by the Project, which could impact both hydrological and biological resources.

In addition to the flaw identified above, and as described at greater length below, the SMND incorrectly describes a central feature of the Project as the conversion of commercial cannabis permitting in agricultural and resource zones from a discretionary to a ministerial process. SMND at 5, 8. The SMND further asserts that various proposed provisions in Article 12 of Chapter 38 set forth standards that do not require the exercise of discretion. SMND at 8-13.

The County's description of the "ministerial" nature of the permit review process established by the Ordinance is inaccurate and misleading: the Ordinance establishes a process that *requires* County officials and staff to exercise discretion. For example, the SMND implies that the County does not need to exercise discretion in evaluating

[2] By the SMND's own explanation of how to convert inches per year to acre-feet, SMND 69 at fn. 1, these figures appear incorrect. If cannabis requires 25-35 inches per year of water for outdoor grows and 20-25 inches per year for indoor grows, SMND 69, then, assuming a cultivation area of one acre, water use should be approximately 2-3 acre feet per year. Of course, this estimate does not account for possible cultivation on areas considerably larger than one acre. And, as explained at greater length by hydrologist Greg Kamman, these figures appear to be gross underestimates. *See* Exhibit 1, Letter from Greg Kamman (Mar. 16, 2021) (citing estimates of water use from cannabis that are 172%-746% higher than those estimates provided in the SMND).

biological resources because permit applications must include "a biotic resource assessment prepared by a qualified biologist that demonstrates," among other things, that the activity subject to the permit "will not impact sensitive or special status species habitat." SMND 39. The Ordinance also requires discretionary review of a permit application if the qualified biologist recommends mitigation measures. *Id.* The Project, however, does not include any objective standards to guide County officials in determining whether the biologist's assessment is adequate. Thus, County officials will have to exercise their discretion in making these determinations. *People v. Department of Housing & Community Development* (1975) 45 Cal.App.3d 185, 193-94 (holding that a permit process granting officials broad power to determine whether particular elements were sufficient or adequate required the exercise of discretion). The Project contains many similar examples of plans, studies, and reports prepared by experts, each of which suffers from the same defect. *See,* for example, Exhibit 1, Letter from Greg Kamman (Mar. 16, 2021) (discussing hydrogeologic reports required for cannabis supply wells located in a priority groundwater basin: "It is my opinion that report/plan review is a discretionary process integral to the authorization of a cannabis cultivation permit that can't be done under a ministerial process.").

The SMND also contains an incomplete and inconsistent description of the special events that may be permitted as part of the Project. For example, the SMND states that the Project would no longer prohibit cannabis-related tours and events, SMND 5, and that such events would "be *subject to existing regulations* in the Zoning Code," SMND 13 (emphasis added). The SMND also states, however, that the County is developing a "Winery Events Ordinance" that may address cannabis-related special events. SMND 18. This assertion that events would be governed by regulations currently under development directly contradicts the prior statement that events would be subject to *existing* regulations. Additionally, because the SMND contains no additional details about the planned winery events ordinance, it is impossible for the public to determine what events may be permitted, let alone whether those events will cause or contribute to a significant environmental impact (e.g., by increasing noise, traffic, greenhouse gas emissions, or vehicle miles traveled).

The SMND is similarly inconsistent and inaccurate in its description of the relationship between cannabis cultivation and other forms of agriculture. A core feature of the Project is the revision of the General Plan to include cannabis cultivation within the definition of agricultural land use. SMND 6. To support this change, the SMND asserts that cannabis cultivation "functions similarly to other agricultural operations." SMND 14. The SMND, however, repeatedly contradicts this conclusion. For example, the SMND states that, "*due to the unique characteristics of cannabis operations*, under the updated Ordinance *provisions applicable to traditional agriculture are expressly not* *applicable to cannabis cultivation*." SMND 25 (emphasis added). The SMND also describes the unique impacts cannabis may have on the environment compared to traditional forms of agriculture. For example, the SMND states that cannabis cultivation and processing operations "generate distinctive odors" that can be "reminiscent of skunks, rotting lemons, and sulfur." SMND 33; *see also* SMND 34 (acknowledging that cannabis cultivation "can generate particularly strong odors" compared to other agricultural land uses). Cannabis cultivation also involves different aesthetic, energy, and hazardous materials practices compared to traditional agriculture. *See* SMND 19 (explaining that cannabis "often involves the use of visible structures"); SMND 23 (stating that cannabis may include new light sources in otherwise dark areas); SMND 48 (describing cannabis's uniquely significant energy demands); SMND 62 (describing hazardous components of high-powered lights used in cannabis operations). Cannabis cultivation is an intensive land use, involving intensive water and energy use, and energy and other infrastructure demands, that is more similar to industrial uses than to traditional agriculture. The SMND's inconsistent and inaccurate characterization of cannabis as similar to traditional agriculture is misleading to the public and decisionmakers and serves to conceal cannabis's unique features (water demand, energy demand, odors etc.) that could contribute to the Project's significant environmental impacts.

The Project description is also muddled by the County's adoption of an entirely new Chapter 26 of the zoning code on February 9, 2021. While the current Project includes revisions to Chapter 26, the revisions released with the SMND show changes to the *old* Chapter 26, rather than changes to the *new* Chapter 26 adopted on February 9. The competing versions of Chapter 26 make reviewing the Project more complicated and confusing. Furthermore, they hinder the public's ability to conduct a meaningful review of the changes the proposed Project would cause to the County Code text, implementation of the permitting regime, and the physical environment. As a result, it is not possible to determine the full scope or extent of the physical impacts that would result from the Project, which violates CEQA. The County must prepare an EIR that shows the changes that would result as applied to the *new* Code, and include an analysis of the cumulative impact of the Project with the Board's recent action to update Chapter 26.

B. The SMND's description of the environmental setting is inadequate.

The SMND also fails to describe the Project setting as required by CEQA and the CEQA Guidelines. An environmental document "must include a description of the physical environmental conditions in the vicinity of the project, as they exist at the time the notice of preparation is published, or if a notice of preparation is not published, at the time environmental analysis is commenced, from both a local and regional perspective." CEQA Guidelines § 15125(a). This description of the environmental setting constitutes the baseline physical conditions by which a lead agency determines the significance of an impact. *Id.* "Knowledge of the regional setting is critical to the assessment of environmental impacts." CEQA Guidelines § 15125(c). Without such an understanding, any impacts analysis or proposed mitigation becomes meaningless.

The environmental setting section of the SMND consists of four paragraphs and a single map describing (1) the location and extent of lands zoned for agriculture, (2) the number of agricultural acres located on parcels larger than 10 acres, (3) the right-to-farm ordinance, and (4) the number of cannabis permits currently issued and in process. SMND at 16-18.

This bare description of land uses falls far short of the description of physical environmental conditions in the vicinity of the project that is required.

For example, the environmental setting entirely lacks a description of where the County's water resources are located. Although the SMND later acknowledges that "[o]ver 80% of the county is designated in marginal Class 3 or 4 zones where groundwater supplies are limited and uncertain," SMND at 69, there is no map or overlay showing where these zones are located and whether (and how) they overlap with areas in which cannabis cultivation may be permitted. This omission makes it difficult to assess whether the Project will have a substantial impact on groundwater supplies.

The same flaw is duplicated as to sensitive waterways and riparian habitats. The SMND does not describe how the County's sensitive waterways may overlap with areas that could be subject to cannabis cultivation.[3] This omission conceals what is likely to be a significant impact of the Project. For example, a comparison of maps of the Mark West Watershed and County zoning maps shows that most of the watershed is covered by the LIA, LEA, and RRD zoning designations, in which the Project would ministerially permit cannabis cultivation. *See* Exhibit 2, Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning, Upper Mark West Creek Watershed, Sonoma County, CA (Dec. 2020), Figure E1, Page 2. The SMND also fails to consider or describe the likely linkages between surface water features and groundwater. To fully and accurately analyze whether the Project will have an effect on stream flows—and species and habitats dependent on those flows—in sensitive waterways, the County should describe the relationships between the County's groundwater basins, its surface waterways, and the areas where cannabis cultivation may be permitted. *See* Exhibit 3, Letter from Robert Coey, National Marine Fisheries Service

[3] While the Project includes required setbacks from riparian corridors, SMND at 40, to assess the effectiveness of those setbacks, the public and decisionmakers must know the extent of cannabis cultivation that may be permitted near waterways.

(Feb. 26, 2021) (explaining that groundwater use by cannabis cultivators may affect surface streams and their resident threatened and endangered species).

The environmental setting's discussion of the current status of cannabis cultivation operations in the County is also inadequate. The SMND notes that 78 ministerial permits and 32 conditional use permits have been issued, and 78 ministerial and 55 conditional use permits are in process. SMND at 18. But particularly because, as the SMND notes, these permits may include renewals, may involve activities other than cultivation, and may include more than one license for the same location, these figures do not convey any meaningful information about the scope of cannabis activity currently permitted in the County. At the very least, the SMND should state the total acreage permitted for cultivation, broken down by the zoning district in which it is located. This data is needed to inform the County's analysis of cumulative impacts, as well as to reveal the scope of potential new development that may be allowed by the Project.

The SMND's discussion of cannabis operations in the County is also inadequate because it almost entirely ignores illegal cultivation, including its extent and its associated impacts. The SMND notes, without further elaboration or detail, that "[m]any cannabis operations have been operating illegally within the RRD land use areas." SMND at 67. It does not provide even an *estimate* of the number, extent, or actual impacts of these illegal cultivation operations. The extent of illegal operations in the County is an important part of the existing environmental baseline. As the SMND itself acknowledges, unregulated cannabis cultivation can be extremely damaging to the environment. Illegal cannabis cultivation: "has been associated with impacts to biological resources," including to sensitive species and their habitats, SMND at 38; has caused negative impacts to waterways, SMND at 55; and creates "high fire risk" related to "inadequate or improper electrical equipment" and explosions "due to the use of volatile chemicals," all located in "high fire hazard areas due to steep slopes, dense vegetation, and insufficient emergency services due to a lack of safe emergency vehicle access," SMND at 67.

Indeed, the conversion of illegal operations to permitted grows and the associated reduction in environmental impacts was a significant assumption underlying the County's determinations that (1) the 2016 Ordinance would not have a significant impact and (2) the 2018 Amendments were exempt from CEQA. *See* 2016 Negative Declaration, p. 2 ("This Ordinance would provide a regulatory structure, with operational standards, to allow existing operators to become permitted."); Resolution 18-0442, p. 3 ("[T]he Ordinance expands regulation of the County's cannabis industry to encompass adult-use for the full supply chain, encouraging illegal cannabis cultivators to come into compliance with the environmental protection standards provided for in the Ordinance."). The 2016 Negative Declaration estimated that there were as many as *ten thousand* existing (unregulated) cultivators, the majority of which were located in the RRD zone. 2016 Negative Declaration at 2. According to the 2016 Negative Declaration, "[u]nregulated cannabis cultivation is associated with habitat destruction, pollution of waterways, illegal road construction causing erosion and increased sedimentation, unauthorized use of pesticides, illegal water diversion, large amounts of trash, human waste, non-biodegradable waste, and excessive water and energy use," as well as "offensive odor, security and safety concerns," and "use of hazardous materials." *Id.*

To accurately assess the Project's impacts on the current environment, the County must provide data and analysis concerning current status of illegal operations on the County. The County and the public must be able to determine whether the current regulations have succeeded in converting illegal operations to permitted grows or if, in fact, the legal, regulated regime has grown up alongside and in addition to the prior illegal regime. Without this information, it is impossible for the County and the public to assess the Project's impacts, including (1) whether the Project will reduce impacts of illegal grows by bringing cultivators into compliance, or (2) whether the County's environmental baseline is significantly off because it fails to account for the impacts associated with thousands of illegal operations.

In short, the SMND's incomplete description of the Project and its environmental setting frustrates the core goals of CEQA: to provide a vehicle for intelligent public participation and to provide an adequate environmental impact analysis. See *County of Inyo v. City of Los Angeles*, (1977) 71 Cal.App.3d 185, 197.

III. The SMND's analysis impermissibly focuses solely on the impacts of individual permits and fails to adequately analyze the impacts of the Project as a whole.

The CEQA Guidelines define a "project" as "*the whole of an action*" that may result in a direct or reasonably foreseeable indirect change in the environment. Guidelines § 15378(a). "'Project' is given a broad interpretation in order to maximize protection of the environment." *McQueen v. Bd. of Directors* (1988) 202 Cal.App.3d 1136, 1143 (disapproved on other grounds). The analysis of a project's environmental effects must occur at the earliest discretionary approval. *See, e.g.*, *Laurel Heights Improvement Assn. v. Regents of University of California* (1988) 47 Cal.3d 376, 396 (EIR must analyze future action that is a "reasonably foreseeable consequence" of the initial action that would "likely change the scope or nature" of the effects of the initial action).

A lead agency considering an ordinance or a general plan amendment must analyze the impacts of all the potential activity that may be permitted by or could foreseeably result from those actions. *See Terminal Plaza Corp. v. City and County of*

San Francisco (1986) 177 Cal.App.3d 892, 905 (City was required to prepare an EIR to analyze the reasonably foreseeable effects of an ordinance). This analysis is required even though enacting an ordinance or general plan amendment is, in itself, an action that occurs largely on paper. *See* Guidelines § 15378(c) ("The term 'project' refers to the activity which is being approved" and not "each separate governmental approval.").

CEQA documents must analyze an ordinance's full potential level of development. As the court in *City of Redlands v. County of San Bernardino* explained, "an evaluation of a 'first phase-general plan amendment' must necessarily include a consideration of the larger project, i.e., the *future development permitted* by the amendment." (2002) 96 Cal.App.4th 398, 409 (emphasis added). Environmental review of the development allowed by a planning enactment must take place regardless of whether that development will actually materialize. *See Bozung v. Local Agency Formation Comm'n of Ventura County* (1975) 13 Cal.3d 263, 279, 282; *Christward Ministry v. Superior Court* (1986) 184 Cal.App.3d 180, 194–95 ("The fact future development is not certain to occur and the fact the environmental consequences of a general plan amendment changing a land use designation are more amorphous does not lead to the conclusion no EIR is required"); *City of Carmel-by-the-Sea v. Board of Supervisors of Monterey County* (1986) 183 Cal.App.3d 229, 235 (EIR for rezoning must be prepared even though "no expanded use of the property was proposed"). The lead agency's obligation to *fully* review an activity's potential environmental effects applies even when the activity is subject to later discretionary approvals. *Laurel Heights*, 47 Cal.3d at 396. That obligation is especially important, however, when the later approvals would be ministerial and would not present an opportunity for further environmental review or mitigation.

Here, the SMND fails to analyze the impacts of the Project as a whole—i.e., whether the sum of all potential activities that may be allowed by the Ordinance would have a significant environmental impact. Instead, the SMND repeatedly bases its analysis of the Project's impacts on whether *each individual permit* that may be issued under the Ordinance would have a significant effect or violate a threshold of significance. This type of analysis is impermissible. *Cf. Bozung v. Local Agency Formation Commission* (1975) 13 Cal.3d 263, 283-84 ("[E]nvironmental considerations do not become submerged by chopping a large project into many little ones—each with a minimal potential impact on the environment—which cumulatively may have disastrous consequences."). The County's analysis is equivalent to determining that a massive shopping center development would not have a significant impact on the environment because the impacts of each individual store would be less than significant. This type of analysis does not inform the public or decisionmakers about the effects of the Project as a whole.

For example, the SMND's analysis of biological resources is improperly focused on the impacts of individual permits rather than the Project as a whole. The Project requires each applicant to include a biotic resource assessment that "demonstrates that the cannabis cultivation area and related structures and development will not impact sensitive or special status species habitat." SMND at 39. Each assessment, however, will focus on the impacts from "the cannabis cultivation area" associated with an individual permit, and not the combined potential impacts of all of the cannabis permits allowed by the Project. The SMND concludes that these assessments, combined with exclusions from limited biotic habitat combining zones and setbacks from riparian corridors, would result in a less than significant impact to sensitive species and riparian habitat. SMND at 40-41.

This myopic analysis misses significant potential impacts of the Project as a whole. The SMND acknowledges that cannabis activities will rely on a combination of surface or well water sources. SMND at 69. It then concludes that it is unlikely that cultivators using groundwater would result in overdraft. *Id.* This conclusion, however, is not explained and is based on unsupported estimates of groundwater usage from cannabis cultivators. *See* Exhibit 1, Letter from Greg Kamman (Mar. 16, 2021) (criticizing the SMND's conclusion). But even assuming that each individual cultivator's water usage is not enough, on its own, to reduce water supplies in a way that threatens sensitive species and riparian habitat, a group of cultivators all drawing water from the same surface water source, from hydrologically-linked surface water sources, or from hydrologically-linked groundwater basins could significantly decrease the water available for in-stream flows despite required setbacks, potentially harming the plant and animal species that rely on those flows.

The combined impact of multiple cultivators drawing upon limited groundwater supplies could have significant impacts on biological resources. For example, a recent analysis of streamflow in the Mark West Watershed prepared for the Sonoma Resource Conservation District and California Wildlife Conservation Board emphasized the importance of groundwater to providing habitat for sensitive species. According to the streamflow analysis, groundwater discharge "represents the primary process responsible for generating summer streamflow" in the watershed. Exhibit 2, Jeremy Kobor, et al., Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning, Upper Mark West Creek Watershed, Sonoma County, CA (Dec. 2020) at 3. The report also showed that human consumption of groundwater threatens streamflow, concluding that groundwater pumping depleted streamflows over the long term. *Id.* at 11. The study determined that increased demand for groundwater, combined with other factors, make efforts to sustain or improve streamflows "of paramount importance for coho recovery" in the watershed. *Id.* at 25; *see also id.* at 1 ("The Mark West Creek watershed provides critical habitat for threatened and endangered anadromous fish"). Similarly, hydrogeologist Greg Kamman emphasized that one of his "biggest concerns" regarding stewardship of natural resources in Sonoma County is "the increased demand on already stressed groundwater supplies." Exhibit 1, Letter from Greg Kamman (March 16, 2021).

The biotic resources assessments, with their narrow focus on each individual permit applicant's activities, would not address the combined effects of multiple permittees decreasing groundwater available for streamflows. An EIR for the Project that analyzes these combined potential effects of all potential permits allowed by the Project is the proper place for this analysis, as well as an analysis of feasible mitigation to address such impacts.

IV. The Project has the potential to result in significant environmental impacts.

The evaluation of a proposed project's environmental impacts is the core purpose of an EIR. *See* CEQA Guidelines § 15126.2(a) ("An EIR shall identify and focus on the significant environmental effects of the proposed project"). As explained below, the SMND fails to analyze the Project's environmental impacts, including those affecting hydrology and water quality and biological resources. In addition, as discussed above, the SMND never considers the full impacts of the Project—the foreseeable impacts of facilitating cannabis cultivation and production through ministerial permit approvals and the foreseeable impacts of events that the proposed Project would allow. In this way, the SMND fails to disclose the extent and severity of the Project's broad-ranging impacts. This approach violates CEQA's requirement that environmental review encompass all of the activity allowed by the proposed Project. The County must analyze all of the aggregated impacts of all of the foreseeable development and activities. Without this analysis, the environmental review will remain incomplete and the Project cannot lawfully be approved.

Below, we discuss several examples of impact areas with particular deficiencies. To ensure that both decision-makers and the public have adequate information to consider the effects of the proposed Project, and to comply with CEQA's requirements, the County must prepare an EIR that properly describes the Project, analyzes its impacts, and considers meaningful mitigation measures that would help ameliorate those impacts.

The SMND claims that it is a "programmatic" document and therefore detailed analysis is not within its scope. SMND at 36. Even if it were a programmatic analysis, however, the 'programmatic' nature of this SMND is no excuse for its lack of detailed analysis. CEQA requires that a program EIR provide an in-depth analysis of a large project, looking at effects "as specifically and comprehensively as possible." CEQA Guidelines § 15168(a), (c)(5). Because it looks at the big picture, a program level analysis should provide "more exhaustive consideration" of effects and alternatives than an EIR for an individual action, and should consider "cumulative impacts that might be slighted by a case-by-case analysis." CEQA Guidelines § 15168(b)(1)-(2).

Further, it is only at this early stage that the County can design wide-ranging measures to mitigate County-wide environmental impacts. *See* CEQA Guidelines § 15168(b)(4) (programmatic EIR "[a]llows the lead agency to consider broad policy alternatives and program wide mitigation measures at an early time when the agency has greater flexibility. . . ."). A "program" or "first tier" EIR is expressly not a device to be used for deferring the analysis of significant environmental impacts. *Stanislaus Natural Heritage Project v. County of Stanislaus* (1996) 48 Cal.App.4th 182, 199. It is instead an opportunity to analyze impacts common to a series of smaller projects, in order to avoid repetitious analyses. Thus, it is particularly important that the environmental analysis for this Project analyze the overall impacts for the complete level of development it is authorizing now, rather than when individual specific projects are proposed at a later time.

Deferring analysis to a later stage is unlawful, as it leaves the public with no real idea as to the severity and extent of environmental impacts. Where, as here, the environmental review document fails to fully and accurately inform decisionmakers and the public of the environmental consequences of proposed actions, it does not satisfy the basic goals of CEQA and its Guidelines. *See* Pub. Resources Code § 21061 ("The purpose of an environmental impact report is to provide public agencies and the public in general with detailed information about the effect which a proposed project is likely to have on the environment . . . ."). The evaluation of a proposed project's environmental impacts is the core purpose of an EIR. See Guidelines § 15126.2(a) ("An EIR shall identify and focus on the significant effects of the proposed project on the environment."). It is well-established that the City cannot defer its assessment of important environmental impacts until after the project is approved. *Sundstrom v. County of Mendocino* (1988) 202 Cal.App.3d 296, 306-07.

The SMND fails to provide the legally required analysis of the extensive growth in cannabis cultivation and operations that the Project allows and promotes. Thus, the County must revise the environmental analysis to accurately disclose the impacts of the maximum amount of cannabis cultivation allowed by the Project. Detailed below are the specific legal inadequacies of the SMND's various impact sections related to hydrology, water quality, and biological resources.

As discussed above, the SMND's failure to consider the impacts of the whole of the project undermines the document's analysis of Project-related impacts, including those impacts related to groundwater supply, water quality, and impacts to sensitive biotic resources. The letter prepared by Greg Kamman provides detailed comments on the shortcomings of the SMND's hydrology and water quality impacts analysis. We incorporate the Kamman Report into these comments. Some of the SMND's most troubling errors identified in the Kamman Report are described below.

A. The SMND's analysis of water supply impacts is inadequate and there is a fair argument that the project will have a significant impact on groundwater resources.

CEQA requires that an EIR present decision makers "with sufficient facts to evaluate the pros and cons of supplying the amount of water that the [project] will need." *Vineyard Area Citizens for Responsible Growth, Inc. v. City of Rancho Cordova*, 40 Cal.4th 412, 430-31 (2007). This includes identifying and analyzing water supplies that "bear a likelihood of actually proving available; speculative sources and unrealistic allocations ('paper water') are insufficient bases for decision making under CEQA." *Id.* at 432. The fact that an agency has identified a likely source of water for the Project does not end the inquiry.

> The ultimate question under CEQA . . . is not whether an EIR establishes a likely source of water, but whether it adequately addresses the reasonably foreseeable impacts of supplying water to the project. If the uncertainties inherent in long-term land use and water planning make it impossible to confidently identify the future water sources, an EIR may satisfy CEQA if it acknowledges the degree of uncertainty involved, discusses the reasonably foreseeable alternatives—including alternative water sources and the option of curtailing the development if sufficient water is not available for later phases—and discloses the significant foreseeable environmental effects of each alternative, as well as mitigation measures to minimize each adverse impact.

Id. at 434.

This analysis is crucial in light of the drought that has gripped this State for the past several years. This SMND's analysis of impacts to groundwater supply fails to meet CEQA's standards.

The SMND discloses that "over 80 percent of the county is designated in marginal Class 3 or 4 zones where groundwater supplies are limited and uncertain." SMND at 69. It also acknowledges that cannabis facilities in rural areas would rely on surface or well water sources and would thus increase the use of water. *Id*. Despite these statements, the SMND fails to conduct the necessary analysis to evaluate the extent and severity of these impacts. What analysis the SMND does present is cursory and unsupported. For example, the SMND presents unsubstantiated figures on estimated water use by cannabis cultivation and production facilities. The SMND estimates that water use by each cultivator would be less than 2.0 acre-feet of water per year, but it fails to disclose how this estimate is derived. SMND at 69; Kamman Report at 2 and 3. The SMND relies on the estimate of water use to conclude that "substantial groundwater overdraft is unlikely." *Id.* However, as explained above, the SMND fails to consider the impacts of the whole of the Project, or the impacts of all permits facilitated by this Project.

The SMND relies on groundwater supply standards included in the updated Ordinance to conclude that the Project "would not decrease groundwater supplies or interfere substantially with groundwater recharge such that the project may impede sustainable groundwater management of the basin." SMND at 71. The SMND fails to provide evidence to support this conclusion. The standards include requirements for monitoring and reporting conditions of groundwater level (i.e., groundwater level measurements, submission of annual reports, and provision of a recorded easement to provide County personnel access to the well to collect water meter readings) and for hydrogeologic reports demonstrating that cannabis facilities permitted through implementation of the Project will not cause or exacerbate overdraft conditions. Kamman Report at 3 and 4. However, the SMND fails to explain how the annual reports will be evaluated or what the triggers will be for remedial actions. Kamman Report at 4. In addition, as the Kamman Report explains, the well-yield test evaluates if the minimum yield will meet irrigation demands, but it does not evaluate if pumping would adversely impact surface water and groundwater resources. *Id*. Therefore, the SMND fails to provide evidence that required monitoring and well-yield tests for applications in Zone 3 and 4 will prevent impacts to groundwater supplies. *Id*.

The investigation by Kamman Hydrology and Engineering, Inc. also indicates that the Mark West Watershed is vulnerable to both groundwater overdraft and to reduced groundwater recharge. *See*, Kamman Report at 3-6. As explained in the Kamman Report, given the conditions in the watershed, allowing expanded cannabis operations in the Mark West Watershed would exacerbate groundwater overdraft. *Id*. at 2-5.

In sum, the SMND fails to adequately evaluate the Project's impacts of groundwater use on the County's groundwater resources. The Mark West Watershed is vulnerable to both groundwater overdraft and to reduced groundwater recharge. See, Letter from Greg Kamman at 2-4. As the Kamman Report explains, the increased demand on the County's already stressed groundwater supplies is a well-documented concern, yet the SMND fails to adequately analyze the impacts of the Project on this limited resource. Kamman Report at 2 and 3. Given the conditions in the watershed, allowing expanded cannabis operations in the Mark West Watershed would exacerbate groundwater overdraft. *Id*. An EIR for the Project must include the necessary groundwater recharge analysis that demonstrates the Project will not add or contribute to the current state of declining groundwater storage.

B. The SMND's analysis of hydrology and water quality impacts is inadequate and there is a fair argument that the Project may have a significant impact on water quality.

FMWW is particularly concerned that implementation of the Project would result in significant adverse impacts to Mark West Creek and its watershed. The State Water Board has also listed portions of Mark West Creek and its tributaries as 303(d) impaired water bodies for sedimentation and temperature (upstream of the confluence with the Laguna de Santa Rosa). Kamman Report at 9. Because hydrological resources in the MWW and downstream are already impaired, expansion of cannabis operations has the potential to significantly impact those resources.

The SMND discloses that future cannabis operations "have the potential to impact water quality due to grading, pesticide application, fertilizers, and the use of irrigation." SMND at 68. Unfortunately, the SMND foregoes actual analysis of the Project's impacts on water quality. Specifically, the SMND fails to adequately analyze impacts from increased sedimentation resulting from ground disturbance and from vegetation clearing. Nor does the SMND adequately analyze the impacts of groundwater pumping on creeks, streams, and rivers. Kamman Report at 2-4. In addition, given that the Project will increase development and introduce industrial processes in remote rural areas, which in turn exacerbates wildfire risk, the SMND should have evaluated fire-related erosion's impacts on waterways. *See also* Letter submitted from Save Our Sonoma Neighborhoods to the County dated March 18, 2021. The SMND does none of this.

The proposed amendments would result in allowing cannabis production countywide in much of the undeveloped areas of the County, including the Mark West Watershed. Without further environmental review, the County would be making this broad approval with far-reaching effects without having answers to critical questions. These questions, which were raised in comments in 2018, remain relevant today and remain unanswered by the SMND. Specifically, the SMND: fails to accurately estimate the Project's water demand or explain how that water demand compares to other agricultural and industrial uses in the County; fails to explain what sorts of impacts related to contaminated run-off can be anticipated from these operations; and fails to identify areas of the County that may be more appropriate for cultivation than others. Without answers to these and other questions, the County cannot know the extent of potential impacts to groundwater and surface water quality.

In sum, the DEIR lacks sufficient evidentiary support for its conclusion that the Project's impacts on hydrology and water quality would be less than significant. An EIR for the Project must adequately describe the hydrologic setting, and comprehensively evaluate and mitigate the proposed Project's hydrology and water quality impacts .

C. The SMND's analysis of biological impacts Is inadequate and there is a fair argument that the Project will have a significant impact on sensitive habitat and species.

Given that the Mark West Watershed is a sensitive environment comprising critical habitat, essential fish habitat, and biological resources, the environmental analysis should have provided a thorough assessment of the Project's impacts on these resources. *See* Exhibit 1, Kamman Report, and Exhibit 3, Letter from Robert Coey, National Marine Fisheries Service (Feb. 26, 2021). The SMND's treatment of biological impacts does not meet CEQA's well established legal standard for impacts analysis. Given that analysis and mitigation of such impacts are at the heart of CEQA, the SMND will not comply with the Act until these serious deficiencies are remedied.

First, the SMND's failure to describe the existing setting (as discussed above) severely undermines its analysis of Project impacts on sensitive biological resources. Despite the SMND's acknowledgement that "the updated Ordinance could result in direct and indirect effects on sensitive biological resources including special-status species" the SMND fails to adequately analyze adverse impacts to these species. SMND at 37 and 38.

Second, the SMND fails to evaluate the extent and severity of the Project's impacts on biological resources. As explained throughout this letter and in the attached Kamman Report, erosion resulting from activities allowed by the proposed Project—both from the change in use and from associated construction of cannabis production facilities—is likely to lead to increased sedimentation of Mark West Creek and its tributaries, impairing the Mark West Watershed critical habitat area. Kamman Report at 5 and 6. The delivery of fine sediment from erosion and runoff has been documented to have negative effects on water and habitat quality, specifically degrading spawning gravel habitat, juvenile rearing pool habitats, and juvenile salmonid survival and growth. *Id*. Therefore, an increase in high-intensity uses, such as those associated with cannabis cultivation, are likely to result in sediment deposits to Mark West Creek and to increase negative impacts on aquatic habitat.

The precise extent and potential significance of such increases would only become evident with a more detailed investigation of the specific construction features and operational methods associated with the activities that would be allowed under the ordinance amendments. Given this potential for erosion in a critical habitat area, it is crucial that the County perform a thorough analysis of this issue prior to approving the Project. Without further analysis, the County cannot know the extent of potential impacts to sensitive biological resources, such as endangered fish and other species. These are exactly the type of impacts that must be analyzed in an EIR.

V. The mitigation measures identified in the SMND are not sufficiently adequate, measurable, or enforceable.

Because, as discussed above, the SMND fails to thoroughly examine and analyze the Project's impacts, it also fails to adequately mitigate for the related impacts. Moreover, the SMND relies on insufficient mitigation and fails to consider and adopt all feasible mitigation.

The County cannot approve projects with significant environmental impacts if any feasible mitigation measure or alternative is available that will substantially lessen the severity of any impact. Pub. Res. Code § 21002; CEQA Guidelines § 15126(a). The County is legally required to mitigate or avoid the significant impacts of the projects it approves whenever it is feasible to do so. Pub. Res. Code § 21002.1(b). An EIR is inadequate if it fails to suggest feasible mitigation measures, or if its suggested mitigation measures are so undefined that it is impossible to evaluate their effectiveness. *San Franciscans for Reasonable Growth v. City and County of San Francisco* (1984) 151 Cal.App.3d 61, 79. Of course, the County may not use the inadequacy of its impacts review to avoid mitigation: "The agency should not be allowed to hide behind its own failure to collect data." *Sundstrom v. County of Mendocino* (1988) 202 Cal.App.3d 296, 36. Nor may the City use vague mitigation measures to avoid disclosing impacts. *Stanislaus Natural Heritage Project*, 48 Cal.App.4th at 195. Put another way, an EIR must set forth specific mitigation measures or set forth performance standards that such measures would achieve by various, specified approaches. See CEQA Guidelines § 15126.4; see also *Sacramento Old City Assn. v. City Council of Sacramento* (1991) 229 Cal.App.3d 1011, 1034; *Communities for a Better Environment v. City of Richmond* (2010) 184 Cal.App.4th 70, 93-95 (agency may not approve a vague mitigation measure that contains no performance standards and criteria to guide its later implementation). Without performance standards and an explanation of why mitigation cannot be developed now, the SMND cannot insist the impact will be insignificant and defer the development of specific mitigation measures to some future time. Guidelines § 15126.4 (a)(1)(B). The SMND failed to comply with this bedrock CEQA requirement.

"In the case of the adoption of a plan, policy, regulation, or other public project [such as the proposed Code and General Plan amendments], mitigation measures can be incorporated into the plan, policy, regulation, or project design." CEQA Guidelines § 15126.4(a)(2). Mitigation is defined by CEQA to include "[m]inimizing impacts by limiting the degree or magnitude of the action and its implementation." CEQA Guidelines § 15370(b). In addition to proposing new "policies" as mitigation, mitigation should include changes in where development is planned, what kind is planned, and how dense or intense that development is planned to be.

Here, the SMND relies on standards in the Ordinance to reduce the Project's impacts. For example, the SMND points to requirements for permit applicants to document a net zero water plan demonstrating that the proposed facility would not result in a net increase of groundwater. However, this approach does not comply with CEQA, both because evaluating water use for each facility fails to evaluate the use and impacts of the whole of the project and because this provision defers the assessment until after Project approval. It is well-established that the County cannot defer its assessment of important environmental impacts until after the project is approved. *Sundstrom v. County of Mendocino* (1988) 202 Cal.App.3d 296, 306-07.

In addition, there is no indication that the SMND considered additional policies or modifications to the proposed amendments to mitigate the impacts of the Project. For example, as described above, the Project would exacerbate already stressed groundwater supplies in the county. Kamman Report at 3. These increased risks and hazards constitute a significant impact requiring the County to identify feasible mitigation measures and alternatives to minimize them. Instead, the SMND relies on unsupported statements about the limited size and number of cultivation sites and on unsubstantiated estimates of groundwater supply required for cannabis cultivation to conclude that impacts to water supply would be less than significant. Id. and SMND at 69-70.

As discussed throughout this letter, the County must first gather data on the number of existing legal and illegal cultivation sites, estimate the number of existing and eligible sites that may apply for permits, accurately estimate the amount of water supply needed for those sites, and evaluate the potential impacts on groundwater resources. A revised environmental document must identify feasible mitigation measures for such impacts (e.g., prohibiting or limiting the number of cannabis facilities within Groundwater Availability Zones 3 or 4 and excluding commercial cannabis facilities within the MWW).

VI. The permit approval process contemplated by the Ordinance requires the exercise of discretion by County officials.

The Ordinance purports to allow "ministerial" approvals of commercial cannabis operations throughout the County. Yet, proposed Chapter 38 does not describe ministerial approvals. Per the Ordinance's plain language, every approval of a commercial cannabis operation will necessarily be a discretionary action and thus subject to CEQA. By adopting an ordinance that purports to authorize "ministerial" approvals which in actuality trigger CEQA, the County is heading toward certain litigation from those objecting to future siting decisions for commercial cannabis operations, and from applicants for these projects.

"A project is discretionary when an agency is required to exercise judgment or deliberation in deciding whether to approve an activity. It is distinguished from a ministerial project, for which the agency merely determines whether applicable statutes, ordinances, regulations, or other fixed standards have been satisfied. Ministerial projects are those for which the law requires [an] agency to act ... in a set way without allowing the agency to use its own judgment .... They involve little or no personal judgment by the public official as to the wisdom or manner of carrying out the project. The public official merely applies the law to the facts as presented but uses no special discretion or judgment in reaching a decision." *Protecting Our Water & Env't Res. v. Cty. of Stanislaus* (2020) 10 Cal.5th 479, 489 ("*POWER*") (internal quotations and citations omitted).

Under the proposed Ordinance, the Agriculture Commissioner *must* use their judgment to decide whether to issue permits. Thus, this is different from the situation in *Sierra Club v. County of Sonoma* (2017) 11 Cal.App.5th 11, where the court held that the permit in question did not involve the Commissioner's judgment, even though the County's ordinance might allow for discretion in other instances. *Sierra Club* therefore does not apply here. Instead, a court would hold that the County has improperly classified *all* commercial cannabis permit approvals under the ordinance as ministerial, when in fact the ordinance requires the Commissioner to exercise discretion for each permit. *POWER*, 10 Cal.5th at 499 ("County's blanket classification … enable[d] County to approve some discretionary projects while shielding them from CEQA review").

The Ordinance in many instances requires plans or surveys by qualified professionals to assess impacts, but does not provide standards governing *how* these surveys/plans will be evaluated or deemed sufficient. Thus, County officials will have to exercise discretion to determine whether they are good enough.

For example, every permit application must include a "biotic resource assessment" that "demonstrates" to the Commissioner's satisfaction that the project would not impact sensitive or special status species habitat. Proposed § 38.12.070(A)(1). Whether this plan adequately demonstrates the avoidance of impacts—including whether surveys were properly conducted to determine the presence of sensitive or special status species habitat, and what constitutes an "impact"—is necessarily left to the Commissioner's individual discretion.

Similarly, each permit application must include a wastewater management plan that, among other things, "demonstrates" to the Commissioner's satisfaction that the project would have adequate capacity to handle domestic wastewater discharge from employees. Proposed § 38.12.130(A)(5). Each application must also include a storm water management plan and an erosion and sediment control plan that "ensure," again to the Commissioner's satisfaction, that runoff containing sediment or other waste or byproducts does not drain to the storm drain system, waterways or adjacent lands. Proposed § 38.12.130(B). Obviously, whether an applicant's plans sufficiently "demonstrate" the necessary wastewater capacity, or "ensure" that runoff would not drain to waterways, would require the Commissioner's individual judgment. Proposed sections § 38.12.070(A)(1), 38.12.130(A)(5) and 38.12.130(B) would apply to *all* applications regardless of size or proposed location. Thus the Commissioner will have to exercise their discretion for every permit application they process.

Other provisions that require the exercise of discretion to approve or deny a permit include, but are not limited to, proposed sections 38.12.050(B) (historic resource survey), 38.12.050(C) (cultural resource survey), 38.12.130 (wastewater management plan), and 38.12.140 (documentation of water supply).

Furthermore, unlike in *Sierra Club*, here, the Commissioner's necessary exercise of discretion under the Ordinance would be directly tied to the mitigation of impacts from individual projects. For instance, the SMND states that "future cannabis projects facilitated by a ministerial permit . . . could result in direct and indirect impacts on sensitive biological resources including sensitive-status species. . . However, to *reduce impacts* to status species and their habitat," applicants would be required to submit the "biotic resource assessment." SMND at 39. As explained above, the Commissioner would have authority to decide whether this assessment adequately demonstrates that no impact would occur—in other words, whether the impact is effectively mitigated.

CEQA, and not the personal judgment of County staff, governs the discretionary review of projects, including mitigation of impacts. *See Sierra Club*, 11 Cal.App.5th at 22 (ministerial approval process "is one of determining conformity with applicable ordinances and regulations, and the official has no ability to exercise discretion to mitigate environmental impacts"). Here, however, the Commissioner and/or staff would have the authority to deny a proposed project which in their judgment would not avoid biological or other environmental impacts. *Id.* at 23 (if agency can deny, or modify, project proposal in ways that would mitigate environmental problems that CEQA compliance might conceivably have identified, then the process is discretionary). Thus, the proposed Ordinance contemplates a discretionary, and not ministerial, approval process.

If adopted, the Ordinance's permit approval regime would be in clear violation of CEQA, and each permit approval would risk a legal challenge and ultimately being overturned by a court. The County must revise the Ordinance and accompanying environmental document to acknowledge that all subsequent permit approvals will necessarily be discretionary decisions subject to review under CEQA.

VII. Approval of the Project, which is inconsistent with the County's General Plan, would violate the State Planning and Zoning Law.

The state Planning and Zoning Law (Gov't Code § 65000 et seq.) requires that development approvals be consistent with the jurisdiction's general plan. As reiterated by the courts, "[u]nder state law, the propriety of virtually any local decision affecting land use and development depends upon consistency with the applicable general plan and its elements." *Resource Defense Fund v. County of Santa Cruz* (1982) 133 Cal.App.3d 800, 806. Accordingly, "[t]he consistency doctrine [is] the linchpin of California's land use and development laws; it is the principle which infuses the concept of planned growth with the force of law." *Families Unafraid to Uphold Rural El Dorado County v. Board of Supervisors* (1998) 62 Cal.App.4th 1332, 1336.

It is an abuse of discretion to approve a project that "frustrate[s] the General Plan's goals and policies." *Napa Citizens for Honest Gov't v. Napa County* (2001) 91 Cal.App.4th 342, 379. The project need not present an "outright conflict" with a general plan provision to be considered inconsistent; the determining question is instead whether the project "is compatible with and will not frustrate the General Plan's goals and policies." *Napa Citizens*, 91 Cal.App.4th at 379. Here, the proposed Project does more than just frustrate the General Plan's goals. As discussed in more detail below, the Project is directly inconsistent with numerous provisions in the General Plan.

In comments submitted on behalf of FMWW in 2018 regarding the County's amendments to the Medical Cannabis Land Use Ordinance, we commented that the proposed amendments were inconsistent with the County's General Plan, particularly with policies related to the protection of agricultural land and policies directed at preserving natural resources, such as groundwater, surface water, and sensitive habitat areas. The proposed Project would be inconsistent with these same policies. For the County's convenience, we reiterate the inconsistencies below.

The MWW is located within portions of Plan Area 3 (Healdsburg and Environs) and portions of Plan Area 5 (Santa Rosa and Environs) and is also within the Franz Valley Specific Plan Area. The proposed ordinance revisions would conflict with policies applicable to these plan areas. For example, the Sonoma County General Plan Land Use

Element includes objectives and policies directed at locating commercial and industrial development in areas that protect rural and agricultural lands. These policies include:

> Franz Valley Specific Plan
> Hydrology - Within groundwater recharge areas, construction activities, creation of impervious surfaces, and changes in drainage should be avoided through discretionary actions.
>
> Healdsburg and Environs (Plan Area 3)
> Objective LU-14.2: Make Windsor and Healdsburg the commercial and industrial centers for the planning area. *Avoid additional commercial and industrial uses* and tourist related businesses *in the rural areas of this region*. Maintain compact urban boundaries for Windsor and Healdsburg. (Emphasis added.)
>
> Santa Rosa and Environs (Plan Area 5)
> Policy LU-16f: Avoid amendments to include additional commercial or industrial use outside urban service areas.

The Project is inconsistent with these policies because it would allow cannabis cultivation (both indoors and outdoors) in rural areas outside urban service areas. The ordinance revisions would also allow cannabis cultivation without discretionary review, which would be inconsistent with the Franz Valley Specific Plan.

The Sonoma County General Plan Land Use Element includes multiple objectives and policies directed at locating development in areas that protect environmentally sensitive areas. These policies include:

> Goal LU-7: Prevent unnecessary exposure of people and property to environmental risks and hazards. *Limit development on lands that are especially vulnerable or sensitive to environmental damage*. (Emphasis added.)
>
> Objective LU-7.1: Restrict development in areas that are constrained by the natural limitations of the land, including but not limited to, flood, fire, geologic hazards, *groundwater availability* and septic suitability. (Emphasis added.)
>
> GOAL LU-10: The uses and intensities of any land development shall be consistent with preservation of important biotic resource areas and scenic features.

> Objective LU-10.1: Accomplish development on lands with important biotic resources and scenic features in a manner which preserves or enhances these features.

The Project is inconsistent with these policies because it would allow cannabis uses in Agricultural and Resources and Rural Development designations without adequate limitations to ensure that environmentally sensitive resources, and groundwater resources are protected.

The Land Use Element also includes multiple policies directed at the protection of water resources. Specifically:

> Goal LU-8: Protect Sonoma County's water resources on a sustainable yield basis that avoids long term declines in available surface and groundwater resources or water quality.
>
> Objective LU-8.1: Protect, restore, and enhance the quality of surface and groundwater resources to meet the needs of all beneficial uses.
>
> Objective LU-8.5: Improve understanding and sound management of water resources on a watershed basis.
>
> Policy LU-8h: Support use of a watershed management approach for water quality programs and water supply assessments and for other plans and studies where appropriate.
>
> Policy LU-11g: Encourage development and land uses that reduce the use of water. Where appropriate, use recycled water on site, and employ innovative wastewater treatment that minimizes or eliminates the use of harmful chemicals and/or toxics.

The Project is inconsistent with these policies because, as explained in the Kamman Letter, cannabis cultivation within the Mark West Watershed would exacerbate groundwater overdraft and reduced groundwater recharge, which would adversely impact biotic resources. Cannabis cultivation is a water-intensive use that requires approximately twice as much water as wine grapes. See, K. Ashworth and W. Vizuete, *High Time to Assess the Environmental Impacts of Cannabis Cultivation*, Environmental Science & Technology (2017) at 2531-2533, attached as Exhibit 4 and at https://pubs.acs.org/doi/10.1021/acs.est.6b06343. According to the article, a study of illegal outdoor grow operations in northern California found that "rates of water extraction from streams threatened aquatic ecosystems and that water effluent contained high levels of growth nutrients, as well as pesticides, herbicides and fungicides, further damaging aquatic wildlife." *Id*. Another article indicates that "water demand for marijuana cultivation has the potential to divert substantial portions of streamflow in the study watersheds, with an estimated flow reduction of up to 23% of the annual seven-day low flow in the least impacted of the study watersheds. Estimates from the other study watersheds indicate that water demand for marijuana cultivation exceeds streamflow during the low-flow period. In the most impacted study watersheds, diminished streamflow is likely to have lethal or sub-lethal effects on state-and federally-listed salmon and steelhead trout and to cause further decline of sensitive amphibian species." *See*, Bauer et al., *Impacts of Surface Water Diversions for Marijuana Cultivation on Aquatic Habitat in Four Northwestern California Watersheds*, PLos ONE (2015), attached as Exhibit 5 and at http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0120016. This increased intensity in water use has the potential to result in significant impacts to biotic resources and to other users.

Cannabis cultivation also has the potential to lead to increased use of fertilizers and pesticides that could impact groundwater and source waters and pose unique challenges related to treatment and disposal of chemicals in run-off and wastewater. These impacts would be even more pronounced in sensitive watersheds, such the Mark West Creek watershed and other Russian River tributaries.

Similarly, the Project would be inconsistent with the following Land Use Element objectives and policies calling for the protection of agricultural lands[4]:

> GOAL LU-9: Protect lands currently in agricultural production and lands with soils and other characteristics that make them potentially suitable for agricultural use. Retain large parcel sizes and avoid incompatible non-agricultural uses.
>
> Objective LU-9.1: Avoid conversion of lands currently used for agricultural production to non-agricultural use.

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[4] As noted in our comments submitted on behalf of Save Our Sonoma Neighborhoods, the County should maintain its characterization of cannabis cultivation as unique from traditional agricultural practices, as it did in 2016, and as it describes in the SMND. SMND at 23, 33, 34, 48 and 62. *See* also, SOSN Comments dated March 18, 2021.

> Objective LU-9.2: Retain large parcels in agricultural production areas and avoid new parcels less than 20 acres in the "Land Intensive Agriculture" category.
>
> Objective LU-9.3: Agricultural lands not currently used for farming but which have soils or other characteristics that make them suitable for farming shall not be developed in a way that would preclude future agricultural use.

In contrast to these General Plan goals and objectives, the proposed amendments would allow conversion of lands designated for agricultural uses for cannabis production, which includes construction of buildings to house indoor cultivation and would expand the allowed production of cannabis cultivation area from the current one acre to 10 percent of the parcel.

As noted above, and in the letter submitted on behalf of Save Our Sonoma Neighborhoods on March 17, 2021, the Project will have substantial environmental impacts that have not been addressed by the County. These unanalyzed impacts will also result in inconsistencies with the General Plan. Therefore, the County must fully evaluate and mitigate the impacts of the Project before it can find the Project consistent with the County General Plan.

VIII. The County must exclude the Mark West Watershed and other similarly impaired watersheds from the proposed Project.

Under CEQA, a proper analysis of alternatives is essential for the County to comply with CEQA's mandate that significant environmental damage be avoided or substantially lessened where feasible. Pub. Resources Code§ 21002; Guidelines §§ 15002(a)(3), 15021(a)(2), 15126(d); *Citizens for Quality Growth v. City of Mount Shasta* (1988) 198 Cal.App.3d 433, 443-45. Given the Project's potential for significant impacts as outlined above, the County must require an EIR to analyze the extent and severity of the Project's impacts related to hydrology and biological resources. The EIR must also consider feasible alternatives to avoid or minimize these impacts. Moreover, the County cannot make findings if there is an alternative that would reduce impacts to the surrounding community.

In 2018, the Planning Commission considered provisions that would have created an Exclusion Combining District, which would have excluded commercial cannabis activities from areas meeting certain criteria, including:

(d) Areas where, because of topography, access, water availability or vegetation, there is a significant fire hazard; and

(e) Areas with sensitive biotic resources or significant environmental sensitivity exists.

Here, the Mark West Watershed ("MWW") satisfies both criteria. First, the area is characterized by steeply sloped areas and encompasses areas identified as moderate, high, and very high wildland fire hazard zones. Sonoma County General Plan 2020, Public Safety Element, Figure PS-1G. Second, as discussed above and in the attached Kamman Report, the MWW is an "area with sensitive biotic resources or significant environmental sensitivity", which satisfies the criteria considered in 2018 for exclusion. Kamman Report at 5.

As enumerated in the Kamman letter and above, the MWW hosts critical aquatic and riparian habitat and endangered and sensitive aquatic species. *See* Exhibit 2, Jeremy Kobor, et al., Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning, Upper Mark West Creek Watershed, Sonoma County, CA (Dec. 2020) at p. 1. Because of its unique physical and biological characteristics, the watershed has been identified in numerous natural resource planning efforts for protection and enhancement. *See id;* Kamman letter at 5.

There is also a documented trend in decreased groundwater availability in the MWW over the long term. Exhibit 2, Kobor et al., at p. 11 and Kamman Report at 7. This trend, and an acknowledged strong linkage between groundwater and creek summer base flow, Exhibit 2, Kobor, et al., at p. 3, indicate that the MWW is susceptible to groundwater overdraft conditions, Kamman at 5 and 7.

In addition, the Groundwater Management Plan (GMP) for the Santa Rosa Plain Watershed indicates that groundwater levels have decreased in response to groundwater pumping in the Santa Rosa Plain groundwater basin. See http://santarosaplaingroundwater.org/wp-content/uploads/SRP_GMP_12-14.pdf (accessed on March 15, 2021) at ES-2 ("The study shows that increased groundwater pumping has caused an imbalance of groundwater inflow and outflow. This imbalance could affect wells, and eventually will likely reduce flows in creeks and streams, leading to a potential for decline in habitat and ecosystems"), ES-7, and ES-8; Kamman Report at 9. Mark West Creek flows into the Santa Rosa Plain. The GMP indicates that seepage from streams flowing onto the Santa Rosa Plain, including Mark West Creek, are a major source of recharge to the groundwater basin. The Sustainable Groundwater Management Act "requires governments and water agencies of high and medium priority basins [such as the Santa Rosa Plain Watershed] to halt overdraft and bring groundwater basins into balanced levels of pumping and recharge." California Department of Water Resources, SGMA Groundwater Management, available at https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management.

As explained in the Kamman Letter, any incremental increase in groundwater pumping within the upper Mark West Creek watershed would not only exacerbate overdraft of local aquifers, but would reduce streamflow in Mark West Creek and associated downstream recharge, additionally exacerbating overdraft in the Santa Rosa Plain groundwater basin. Kamman Report at 10. Any future increases in groundwater pumping due to cannabis cultivation in the upper Mark West Creek watershed and other similarly impaired watersheds would also exacerbate groundwater overdraft in the Santa Rosa Plain basin. Exhibit 3, Letter from Robert Coey, National Marine Fisheries Service (Aug. 30, 2018) (explaining that restoring area groundwater basins "will likely include greater groundwater recharge, less groundwater pumping, or some combination of the two," and requesting that Sonoma County delay permitting cannabis cultivation activities relying on groundwater to avoid further harm to groundwater supplies).

Significantly, the setbacks from riparian corridors incorporated in the Project do not eliminate impacts to the Mark West Watershed and other similarly impaired watersheds or the linked groundwater basins. A streamflow analysis of the Mark West Watershed determined that, while wells at increased distance from streams depleted streamflows at slower rates, "all wells generated depletion given enough time." Exhibit 2, Kobor et al., at p. 11. "Requiring new wells to be drilled at a specified minimum distance from a stream or spring . . . may extend the length of time before streamflow depletion occurs; however, *it will not prevent streamflow depletion from occurring*." *Id.* at 21 (emphasis added). Thus, the measures currently included in the Project are insufficient to address potential significant impacts. Excluding the Mark West Watershed and other similarly impaired watersheds from the Project entirely, however, would prevent new commercial cannabis activities from drawing groundwater, thus preventing decreases in streamflow and avoiding significant environmental impacts to sensitive watersheds.

State regulations governing cannabis activities in environmentally sensitive watersheds further support exclusion of the Mark West watershed and other similarly impaired watersheds. Specifically, the Department of Food and Agriculture is prohibited from issuing new licenses for commercial cannabis activities in watersheds that the State Water Resources Control Board or the Department of Fish and Wildlife determine are significantly impacted by cannabis cultivation. 3 Cal. Code Regs. § 8216; *see also* Bus. & Prof. Code § 26069(c)(1); Water Code § 13149. If the County were to issue licenses for cannabis cultivation in these areas, it would conflict with the intent of the state regulations to protect sensitive environments from cannabis-related impairments.

Though the State Water Resources Control Board and the Department of Fish and Wildlife have not yet determined that cannabis activities have significantly impacted the Mark West Watershed, it seems foolish to wait for this eventuality—and the associated degradation of a sensitive habitat—to occur. *See also* Exhibit 3, Letter from Robert Coey, National Marine Fisheries Service (Aug. 30, 2018) ("Since continued groundwater development in [the Mark West Watershed] will likely further impair summer baseflows in the future, NMFS recommends Permit Sonoma limit future groundwater development in these basins until the effects of long-term, chronic groundwater depletion and its impact on summer baseflows are properly analyzed."). As this letter has emphasized, the Mark West watershed has already been identified as impaired in various respects. For example, the North Coast Regional Water Quality Control Board has identified Mark West Creek as impaired with respect to aluminum, dissolved oxygen, phosphorus, manganese, sedimentation/siltation, and temperature. Exhibit 6, North Coast Regional Water Quality Control Board, Laguna de Santa Rosa TMDLs. Further, the Mark West Creek is one of five streams the California Water Action Plan selected for an effort to restore important habitat for anadromous salmonids. See *Study Plan*, California Department of Fish and Wildlife, June 2018, at i.v., 9-11, attached as Exhibit 7. The study plan for this effort notes that "Water diversions, modifications to riparian vegetation, and sediment delivery to streams [like Mark West Creek] . . . have contributed to the degradation and loss of habitat" for endangered salmonid species. *Id*. Considering (1) the existing sensitivity of the watershed, and (2) the numerous impacts on water and aquatic resources resulting from cannabis cultivation that are contemplated by the State Water Resources Control Board's Cannabis Cultivation Policy,[5] it makes no sense to allow cannabis cultivation in the Mark West Watershed. Instead, excluding cannabis cultivation from the Mark West Watershed avoids incompatibility with state regulations and avoids degradation of a valuable environmental resource.

Therefore, the FMWW request that commercial cannabis activities be excluded from the Mark West Watershed and other similarly impaired watersheds. Only by excluding cannabis cultivation operations from the Mark West Watershed and similar watersheds can the County ensure that sensitive biotic resources present in these watersheds are protected.

Finally, it is important to note that property owners do not have an absolute right to grow cannabis. State and federal law simply provide that the County must allow an

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[5] *Cannabis Cultivation Policy: Principals and Guidelines for Cannabis Cultivation*, California State Water Resources Control Board, Oct. 17, 2017, https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2017/final_cannabis_policy_with_att_a.pdf.

economically reasonable use of property. *Agins v. Tiburon* (1980) 447 U.S. 255, 260. Property owners are not entitled to any particular use of property, nor are they entitled to compensation for even a "very substantial" diminution in the value of their property. *Long Beach Equities v. County of Ventura* (1991) 231 Cal. App. 3d 1016, 1036. By contrast, the County has an obligation to protect public trust resources and to comply with state law. *National Audubon Society v. Superior Court* (1983) 33 Cal. 3d 419.

Even if ensuring compliance with these state and local laws substantially diminishes the value of the applicant's property, there is no automatic taking or County liability. For example, in *MacLeod v. Santa Clara County*, a property owner sued for a taking after he was denied a timber harvesting permit for his 7,000 acre ranch. (9th Cir. 1984) 749 F.2d 541, 542-44. On appeal, a 9th Circuit court held that the denial of the permit was not a taking because the owner could continue to use or lease the land for cattle grazing as well as hold the property as an investment. *Id*. at 547. "The fact that the denial of the permit prevented [the owner] from pursuing the highest and best use of his property does not mean that it constituted a taking." *Id.* at 548. Similarly, in *Long Beach Equities*, the court found that even where "zoning restrictions preclude recovery of the initial investment made." they do not result in a taking as long as some use of the property remains. 231 Cal. App. 3d at 1038. Further, to the extent that there are existing permitted cannabis grows in the watershed, the County may create exceptions to the exclusion for existing uses, and may require them to phase out operations over time.

Designation of the Mark West Watershed and other similarly impaired watersheds as an exclusion zone will simply prohibit the cultivation of cannabis in an area that is ecologically sensitive; it will not preclude other uses of property in the area. Because other less impactful uses of property remain, the County will have more than met its obligation to ensure some economic use of property in these watersheds.

IX. Conclusion

As set forth above, the SMND does not come close to satisfying CEQA's requirements. It fails to describe the Project and the existing setting and fails to provide a complete analysis of Project impacts and feasible mitigation measures. At the same time, ample evidence demonstrates that a fair argument exists that the Project may result in significant environmental impacts. In light of this evidence, CEQA requires that an EIR be prepared. For this reason, and because the Project conflicts with core policies of the County's General Plan, the Friends of Mark West Watershed request that the Project be denied. The Project should not be reconsidered until a legally adequate EIR is prepared and certified.

Very truly yours,

SHUTE, MIHALY & WEINBERGER LLP

Joseph "Seph" Petta

Aaron M. Stanton

Carmen J. Borg, AICP
Urban Planner

Exhibits:

1. Letter from Greg Kamman, Senior Ecohydrologist with CBEC Ecoengineering, dated March 16, 2021

2. Jeremy Kobor, et al., Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning, Upper Mark West Creek Watershed, Sonoma County, CA (Dec. 2020)

3. Letter from Robert Coey, National Marine Fisheries Service (Feb. 26, 2021)

4. K. Ashworth and W. Vizuete, *High Time to Assess the Environmental Impacts of Cannabis Cultivation*, Environmental Science & Technology (2017)

5. Bauer et al., *Impacts of Surface Water Diversions for Marijuana Cultivation on Aquatic Habitat in Four Northwestern California Watersheds*, PLos ONE (2015)

6. North Coast Regional Water Quality Control Board, Laguna de Santa Rosa TMDLs

7. *Study Plan*, California Department of Fish and Wildlife, June 2018

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EXHIBIT 1

March 16, 2021

Ms. Carmen Borg
Shute, Mihaly & Weinberger LLP
396 Hayes Street
San Francisco, CA 94102-4421

Subject: Review of Draft Subsequent Mitigated Negative Declaration
Permit Sonoma File No: ORD20-0005
Sonoma County Cannabis Land Use Ordinance Update and General Plan Amendment

Dear Ms. Borg:

I am a state licensed Professional Geologist and Certified Hydrogeologist with over thirty years of technical and consulting experience in the fields of geology, hydrology, and hydrogeology. I have been providing professional hydrology and hydrogeology services throughout California since 1989 and routinely manage and lead projects in the areas of surface- and groundwater hydrology, water supply, water quality assessments, water resources management, and geomorphology. A copy of my resume is provided as Attachment A.

I have been retained by Shute, Mihaly & Weinberger LLP (SMW) to review and evaluate the Draft Subsequent Mitigated Negative Declaration (SMND) for the Sonoma County Cannabis Land Use Ordinance Update and General Plan Amendment. Based on my review of this document, it is my professional opinion that the SMND is inadequate in evaluating and mitigating the potential significant impacts of Project actions on hydrology, groundwater supply and biological resources, especially in the upper Mark West Creek watershed (MWW)[1].

[1] For purposes of this letter, the upper Mark West watershed is defined as the Critical Habitat Area of the Porter Creek-Mark West Creek drainage indicated on the County's Groundwater Availability map, dated December 6, 2016 and contained in Policy and Procedure Number 8-1-14, "Procedures for Groundwater Analysis and Hydrogeologic Reports" (PRMD, 2017).

In addition, as written, I don't agree that authorization of permits for cannabis cultivation can be done under a ministerial process, but rather will require some discretion on the part of the County. The rationale for these opinions is based on the findings presented below.

1. Potentially underestimated and undocumented water use estimates

The SMND (pg. 69) state that water use requirements for outdoor cannabis production ranges from 25- to 35-inches per year[2]. The origin and/or derivation of these water use rates are not presented in the SMND. Water use estimates presented in Table 1 (Projected Water Use for Cannabis) of the County's 2015 Discussion Paper (Cannabis Cultivation RRD Zone, ORD15-0005)[3] translate to much higher water use rates, ranging from 43- to 261-inches per year, values that are 172% to 746% higher than those presented in the SMND. The potential impact on water resources due to cannabis cultivation center on the volume of water use required. The unsubstantiated and significant divergence in water use estimates presented in County documents calls into question the validity of analysis and conclusions based on these estimates. The SMND does not disclose any information regarding the source, accuracy or validity of water use estimates. Therefore, they should be considered arbitrary and unsupported in their use in impact analysis.

2. Unsubstantiated impact assessment of water use

The SMND states (pg. 71) that the ordinance would result in less than significant impact to groundwater supplies, recharge and sustainable management. A key premise of this finding is based on the stated low quantities of anticipated groundwater use for cannabis cultivation. The analysis to support this finding is omitted and unsupported for the following reasons.

- Page 69 of the SMND contains the following sentence, "*Based on the relatively low quantities of water use (from 0.002 to 1.8 acre-feet per year), the likelihood that an individual cultivator or group of cultivators using groundwater from an alluvial aquifer would, by themselves, cause substantial groundwater overdraft is unlikely*." There is no discussion or explanation on how the water use estimate of 0.002 to 1.8 acre-feet per year is derived. Without substantiating how these estimates are derived, they are just arbitrary numbers. Nor is there any analysis or justification to support the claim that one or more cultivators using groundwater will not deplete groundwater resources.

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[2] The volumes listed in the last sentence of Footnote 1 in the SMND is incorrect. It should read: For example, 12 inches (1 foot) per year applied over an area of 1 acre would be a volume of 1 acre-foot; 12 inches per year applied over an area of 10,000 square feet would be a volume of **10,000** cubic feet (approximately **74,805** gallons), or **0.23** acre-feet.

[3] Discussion Paper – Key Issues and Policy Options, Cannabis Cultivation within Resources and Rural Development (RRD) Lands, ORD15-0005.

- Page 69 of the SMND states, "*Future cannabis facilities in rural areas would rely on either surface (river, lakes and springs) or well water sources. Accordingly, the introduction of cannabis cultivation in these areas could increase the use of groundwater*." This statement echoes one of my biggest concerns regarding responsible stewardship of Sonoma County natural resources, which is the increased demand on already stressed groundwater supplies. The SNMD does not analyze the potential impact of increased groundwater demand. Statements that, "*The size limitations for cultivation sites under the updated ordinance would limit water use*" (pg. 69) and *"… cannabis cultivation would not use more water than other crops that could grow under existing regulatory setting without permit*" (pg. 69) fail to address the fact that increase the number of sites initiating cannabis cultivation will increase cumulative demands on surface- and ground-water resources; resources the County already knows are stressed in groundwater scarce and over draft basins (Kleinfelder, 2003; Santa Rosa Plain Basin Advisory Panel, 2014; and Woolfenden and Nishikawa, 2014).

3. Net zero water plan for wells located in a Priority Groundwater Basin

The SMND (pg. 70) indicates that for cannabis irrigation supply wells located in a Priority Groundwater Basin, the permittee must provide a hydrogeologic report prepared by a qualified professional demonstrating and concluding that the commercial cannabis use will not result in or exacerbate conditions of a basin or aquifer, consistent with the requirements for sustainable groundwater management plans under the California Sustainable Groundwater Management Act (SGMA). Having reviewed and assisted in the preparation of Groundwater Sustainability Plans (GSP) under SGMA, I know that preparing these reports requires considerable technical analysis, interpretation and professional judgement. It is also my experience, that data gaps are a frequent impediment. The reports will determine whether groundwater pumping will impart potential significant impacts on the environment.

The SMND does not identify who will review the analyses and conclusions presented in these reports/plans. Regardless, report/plan review will require a decision maker to determine if the report/plan conforms to standard practices and federal/state/County codes and policies. It may also require the decision maker to place limitations and conditions on the permittee to avoid environmental impacts. It is my opinion that report/plan review is a discretionary process integral to the authorization of a cannabis cultivation permit that can't be done under a ministerial process.

4. Potential impacts to interconnected surface water in Groundwater Availability Zone 1 or 2

Subdivision b. on page 70 of the SMND appears focused on ensuring groundwater pumping within 500 feet of a blue-line stream does not deplete interconnected surface waters. Under Subdivision b., there are three options to demonstrate this impact will not occur. Option 2) implies that wells within 500 feet of the Russian River and Dry Creek will not deplete interconnected surface water. Option 3) implies that wells within 500 feet of a blue-line stream and located in Groundwater Availability Zone 1 or 2 will not deplete interconnected surface water. However, the SMND does not present any analysis or justification for these determinations. Similar to the concerns raised by NMFS in their comment letter to this section of the Ordinance (see page 2 of Attachment B), it is my opinion and experience that it is possible for wells to deplete interconnected surface waters along any stream or creek depending on the well proximity, pumping rate and hydrogeologic properties of the aquifer and stream substrate. In short, the potential to deplete interconnected surface water is based on localized conditions, not a broad characterization of aquifer type. Therefore, the SMND is incomplete as it does not present any analysis to demonstrate that Options 2) and 3) will not potentially deplete interconnected surface water and adversely impact the beneficial uses of surface waters.

5. Potential impacts to interconnected surface water in Groundwater Availability Zone 3 or 4

The purpose of Subdivision c. on page 70 of the SMND is to demonstrate that there is enough yield (i.e., minimum yield) from the well to meet irrigation demands. A well yield test determines what is the maximum sustainable pumping rate from the well. However, the SMND does not evaluate or demonstrate that pumping at the "minimum yield" rate will not potentially deplete groundwater volumes, lower groundwater levels, or deplete interconnected surface waters[4]. The well yield test requirements listed under Subdivision c. evaluates if the minimum yield will meet irrigation demands but does not evaluate if pumping adversely impacts surface water and groundwater resources. Thus, it is my opinion that complying with Subdivision c. on page 70 of the SMND does not evaluate if well pumping results in potentially adverse impacts to water resources.

6. Groundwater level monitoring and annual reporting

Page 71 of the SMND indicates the updated Ordinance places monitoring and reporting conditions on the permit, including: equipping groundwater wells with a calibrated water meter and sounding tube (to measure water levels); submission of annual report including quarterly data on water meter readings and total quantity of water pumped; static water level readings; and providing a recorded easement to provide County personnel access to the well to collect water meter readings and groundwater level measurements. The SMND does not provide an explanation for how the annual reports will be evaluated or what the triggers will be for remedial actions. However, these reports are a condition placed on the permit, which will be evaluated to likely inform a discretionary decision or action. Thus, like the net zero water plan discussed under

[4] An analogy: if a car can sustain a 100-mph speed, driving it at this speed will exceed the speed limit.

item 3. above, annual reporting is a condition requiring discretionary action to the administration of a cannabis cultivation permit.

7. Upper MWW should be excluded from the Cannabis Ordinance due to the presence of sensitive biotic resources

The Mark West Creek watershed is unique to Sonoma County in that it hosts critical aquatic and riparian habitat and endangered and sensitive aquatic species. Because of its unique physical and biological characteristics, the watershed has been identified in numerous natural resource planning efforts for protection and enhancement, including the following.

- Upper Mark West Creek provides habitat for the following listed species under the U.S. Endangered Species Act (ESA): CCC steelhead listed as threatened in 1997; CC Chinook Salmon listed as threatened in 1999; CCC Coho Salmon listed as endangered in 2005. Coho in the Russian River watershed have also been listed as endangered under the California Endangered Species Act (CESA) in 2005 and were nearly extirpated from the watershed in the late 1990s (CDFW, 2018). Other aquatic species of special concern found in the upper watershed include California Roach (*Lavinia symmetricus*), Northwestern Pond Turtle (*Actinemys marmorata*), and Foothill Yellow-Legged Frog (*Rana boylii*) (Ibid).
- Mark West Creek is ranked as critical habitat for steelhead and coho salmon and assigned as a Phase 1 (highest priority) stream for coho recovery in National Marine Fisheries Service's (NMFS) Central California Coast Evolutionary Significant Unit (CCC ESU) Coho Recovery Plan (NMFS, 2012).
- The Mark West Creek watershed was selected in 2014 as one of only five watersheds under the California Water Action Plan (CWAP) to receive coordinated efforts by the SWRCB and California Department of Fish and Wildlife (CDFW) to enhance stream flows in systems that support critical habitat for anadromous fish (CDFW, 2018; OEI, 2020).
- In response to the CWAP, the CDFW has recently begun a Habitat and Instream Flow Study in the upper Mark West Creek. Goals and objectives of the study are to identify and develop relationships between stream flow and available salmonid habitat and determine the flows and water quality conditions needed to maintain rearing habitat and connectivity for juvenile salmonids and their food sources (CDFW, 2018).
- The upper Mark West Creek watershed was designated a "Natural Landscape"[5] Priority Conservation Area (PCA) by ABAG in 2008 (ABAG, 2021). Priority Conservation Areas (PCAs) are open spaces that provide agricultural, natural resource, scenic, recreational, and/or ecological values and ecosystem functions. These areas are identified through

[5] PCAs are categorized by four designations: Natural Landscapes, Agricultural Lands, Urban Greening and Regional Recreation.

consensus by local jurisdictions and park/open space districts as lands in need of protection due to pressure from urban development or other factors.

- The majority of the upper Mark West Creek watershed that falls within the jurisdiction of the Franz Valley Specific Plan study area (2012) and has been assigned a "resource conservation" designation, recognizing the resource suitability, environmental and public service constraints, and natural sensitivities of the area[6]. Because the majority of the Plan area occurs within areas of marginal (or less) groundwater availability, the Plan recommends that construction activities, creation of impervious surfaces and changes in drainage should be avoided through the Planning Division's discretionary actions. The Plan also recommends, "Maintain a low intensity of residential development in the Mark West Creek area to maintain future County preserve options; especially observe riparian setbacks along this creek".
- In 2008, with funding from the Sonoma County Water Agency through the Cooperative Russian River Watershed Program, Sotoyome Resource Conservation District initiated the Upper Mark West Watershed Management Plan. The goals of the Plan are to meet water quality standards for sediment, support aquatic life and restore aquatic habitat, protect and enhance wetland habitat, promote native biodiversity in upland habitats and improve water conservation.

As demonstrated in the planning and study efforts listed above, the Mark West Creek watershed is an area with sensitive biotic resources or significant environmental sensitivity and should be excluded from the added water demands associated with cannabis cultivation.

8. Upper MWW should be excluded from the Cannabis Ordinance because local groundwater aquifers are in overdraft

The County funded a study by Kleinfelder, Inc. in 2003 to explore the factors affecting the availability of groundwater in three water scarce areas experiencing concentrated building and well construction (Kleinfelder, 2003). One area, the Mark West Study Area, is a 7.5 square mile intermountain valley located just north of Santa Rosa lying within the Mark West Springs Creek watershed[7]. The aquifer underlying the Study Area is primarily fractured bedrock of the Sonoma Volcanics, though thick deposits of the Glen Ellen formation occur in the northwest portion of the area where there is relatively little development. Kleinfelder states that the availability of groundwater in these formations is not predictable, but where groundwater is found, it is generally sufficient to supply current demand.

As part of their study, Kleinfelder quantified changes in residential and urban water demands between 1950 and 1997 along with construction depth and water levels of numerous wells. They found that the

[6] The 1979 Plan contains substantial description and analysis of natural resources in the study area. This original background language was deleted from all subsequent modified versions (1993, 2008 and 2012) of the Plan. The landuse designations cited here are from the 1979 Plan.
[7] The other two study areas included the Joy Road and Bennett Valley Areas.

mean depth to water in new wells trends downward in each study area over time; the trend in Mark West Study Area drops from 90 feet in 1950 to about 175 feet in 1997. They conclude that the downward trend in depth-to-water in new wells corresponds to the trend of overall development. They also found a clear trend of increasing average well depths over time. They attribute the trend of increasing well depths to the need for drillers to reach groundwater levels that are lowering over time.

Kleinfelder's analysis of the annual average depth to water in new wells shows a trend of decreasing water levels over time in the three Study Areas. They conclude the decline in water levels is most likely explained by increased groundwater extraction over time. The trend analysis of depth to water in new wells together with reports of dropping water levels, seasonal well failures, and complete well failures all suggest groundwater overdraft[8] conditions. Additional development beyond the 1997 levels will likely increase overdraft as indicated in the following excerpt from the Kleinfelder report (pg. 40).

> *There is a potential for further residential and agricultural development in the Study Areas because they have not been developed to the maximum density allowed by existing zoning ordinances. New homes and vineyards require water and more wells would be needed to meet demand. Additional groundwater extraction is likely to increase the rate of overdraft and result in further decline of groundwater levels. In fact, if an overdraft condition currently exists, groundwater levels may continue to decline even if no additional extraction occurs. Levels will continue to drop as long as extraction exceeds recharge.*

In response to the expansion of vineyards and rural residences in rural Sonoma County over the recent decades, CEMAR (Center for Ecosystem Management and Restoration) completed a study on how human development has effected hydrologic conditions and salmonid habitat in the upper Mark West Creek watershed[9] (CEMAR, 2015). CEMAR states that in the Mark West Creek watershed irrigated agriculture and rural residences are the two most evident forms of water use, with vineyards being the most prevalent agricultural cover type. As part of their study, CEMAR quantified annual water demands for human uses in the upper watershed for comparison to summer streamflow data collected at several locations along the main stem Mark West Creek. Key findings and conclusions from the CEMAR report include the following.

- The upper watershed is geologically and topographically diverse. The majority of the watershed is underlain by Sonoma Volcanics and a large portion is Franciscan Complex.
- The source of summer base flows in Mark West Creek come from springs and groundwater seepage from the Sonoma Volcanics[10]. Although flow rates are low (ranging from around 0.5 to

[8] Groundwater overdraft occurs when groundwater use exceeds the amount of recharge into an aquifer, which leads to a decline in groundwater level.
[9] The CEMAR report focuses specifically on the area upstream of the confluence with Humbug Creek with Mark West Creek (near the west end of St. Helena Road).
[10] The 1979 Franz Valley Specific Plan corroborates this conclusion in the following statements, "In addition to the valley recharge in the alluvial soils and the stream gravels of the Franz and Knight Valleys, the more permeable and fractured areas of the Sonoma Volcanics are of major importance for groundwater recharge. Two areas along the

0.03 ft^3/s, the creek exhibits consistent stable low flow through summer months, especially in headwaters.

- Study estimates indicate that residential and agricultural summer water demands exceed creek flow rates throughout the dry season May-October.
- Though there may be very few surface water diversions directly from Mark West Creek, water needs satisfied through pumping groundwater or from spring boxes likely remove water that would otherwise become base flow.
- Base flow in late summer could increase substantially if human water needs met through pumping groundwater or diverting from streams during the dry season were reduced.
- The potential for groundwater pumping to deplete streamflow is much greater for Sonoma Volcanic geology than Franciscan bedrock, even if Franciscan bedrock is thicker and closer in proximity to the stream.
- The data describing depth to water in well completion reports indicates an overall trend of greater depth to water among those wells located within the entire study region, as well as those wells within one-quarter mile of Mark West Creek for the period 1965-2014[11].
- Summer base flows are lower or recede into subsurface alluvium in portions of the main stem Mark West Creek and North Fork Mark West Creek due to excessive sediment accumulation and channel aggradation.
- Groundwater pumping likely results in reduced creek base flow, especially if wells are located in bedrock fractures that would otherwise provide base flow in summer.
- Given the range of possible scenarios for describing surface water-groundwater relationships in fractured bedrock, it is not possible to know how pumping groundwater from fractured bedrock may affect streamflow without conducting a test of well operation and streamflow response to see whether and how streamflow patterns deviate from baseline conditions when water is pumped.

In 2016, a notably dry year, the State Water Resources Control Board (SWRCB) submitted an Emergency Regulatory Action regarding enhanced water conservation and additional reporting requirements for the protection of specific fisheries in the Mark West Creek watershed (OAL, 2016). The SWRCB has authority to ensure the protection and preservation of streams and to limit diversions to protect critical flows for species, including for state- and federally-threatened and endangered salmon and steelhead species. An important and relevant statement in this emergency order is the acknowledged role groundwater plays in sustaining

upper reaches of Mark West Creek are responsible for maintaining summer flow and the high quality of the riparian vegetation and the fishery habitat of the creek".

[11] Although not stated in the CEMAR report, similar to the Kleinfelder study, the long-term trend of declining (lowering) groundwater levels suggest groundwater overdraft.

creek flows. The order states, "*Due to the known hydraulic connection between sub-surface water and surface streams in the Russian River watershed, as well as the limited water use information in the area, additional information on diversions, whether surface or subsurface, and use of water is needed to better assess impacts on surface stream flows*". The emergency regulatory action was effective from 3/30/2016 to 12/28/16.

Based on available technical studies, groundwater supplies in the upper Mark West Creek Watershed have steadily declined over the past 70 years and several local aquifers are in overdraft condition. It is acknowledged that groundwater sustains summer creek base flows. Existing creek base flow rate in upper Mark West Creek are very low during summer and is reduced to a level that threatens salmonids and other aquatic species during dry year-types (OEI, 2020). The increased water demands associated with expanded cannabis cultivation will only further exacerbate existing cumulative impacts on water/aquatic resources in upper Mark West Creek. Because of the documented trend in decreased groundwater availability and strong linkage between groundwater and creek summer base flow, I agree with NMFS comments to the Ordinance (see Attachment B), that the potential for adverse impacts from unrestricted groundwater pumping for cannabis irrigation are high. Therefore, I recommended that the upper Mark West Creek be excluded from the Cannabis Ordinance.

9. Upper MWW should be excluded from the Cannabis Ordinance due to existing water quality impacts in the watershed

The RWQCB has listed Mark West Creek and its tributaries upstream and downstream of the confluence with the Laguna de Santa Rosa as 303(d) impaired water bodies for sedimentation/siltation and temperature (RWQCB, 2018). Downstream of the confluence with the Laguna, Mark West Creek is also listed as impaired for aluminum, dissolved oxygen, phosphorous, and manganese. Cannabis cultivation typically requires earth disturbance that generates potential sediment discharge to nearby water bodies, especially in steep or unstable terrain or where in close proximity to drainages. Given the existing upper watershed is impacted by sediment delivery to the creek, even small and unintentional sediment loading will add to existing cumulative adverse impacts to the creek. Therefore, it is recommended that the upper Mark West Creek watershed should be excluded from the Cannabis Ordinance to avoid this impact.

10. Upper MWW should be excluded from the Cannabis Ordinance due to reduced recharge to the Santa Rosa Plain Groundwater Basin

The County is developing a Groundwater Management Plan (GMP) for the Santa Rosa Plain Watershed (Santa Rosa Plain Basin Advisory Panel, 2014) pursuant to the state Sustainable Groundwater Management Act (SGMA). As stated in the GMP, groundwater levels have decreased in response to groundwater pumping in the Santa Rosa Plain groundwater basin.

SGMA requires governments and water agencies of medium priority basins[12] to halt overdraft and bring groundwater basins into balanced levels of pumping and recharge.

The GMP indicates that seepage from streams flowing onto the Santa Rosa Plain, including Mark West Creek, are a major source of recharge to the groundwater basin. Thus, any incremental increase in groundwater pumping within the upper Mark West Creek watershed would not only exacerbate overdraft of local aquifers but would reduce streamflow in Mark West Creek and associated downstream recharge, additionally exacerbating overdraft in the Santa Rosa Plain groundwater basin. Any future increases in groundwater pumping due to cannabis cultivation in the upper Mark West Creek watershed would also exacerbate groundwater overdraft in the Santa Rosa Plain basin. Therefore, it is recommended that the upper Mark West Creek watershed should be excluded from the Cannabis Ordinance to avoid this impact.

11. Further amendments to the Ordinance are needed to provide consistency with state law and regulations

<u>Stream flow monitoring requirement:</u> CEMAR (2014) concludes that the complex geology and surface water-groundwater interaction of the upper Mark West Creek watershed render standard County "hydrogeologic investigations" insufficient to evaluate the impacts of groundwater pumping on creek flow. This scenario likely exists in many other County watersheds. CEMAR recommends that coordinated well operation (pumping) observations and creek flow monitoring is required to identify and quantify groundwater-surface water interaction. The Counties Cannabis Ordinance [Sec. 26-88-254, (g), (10)] includes the requirement for the preparation of a net zero water plan, hydrogeologic report and/or water yield test to certify that operation of an onsite groundwater supply does not exacerbate an overdraft condition in basin or aquifer or result in reduction of critical flow in nearby streams. However, the following section of the ordinance [Sec. 26-88-254, (g), (11)] only discusses groundwater monitoring and reporting protocols. As indicated above, stream flow monitoring is also required to definitively assess potential impacts on instream flows from groundwater withdrawals. Therefore, I recommend that an additional stream flow monitoring requirement be added to the ordinance for sites located within Groundwater Availability Zone 3 or 4, consistent with surface water flow monitoring requirements contained in the RWQCB Cannabis Cultivation Policy.

<u>Instream flow requirements:</u> A stated purpose of the County's ordinance amendment is to "harmonize" and "align" the ordinance with state law. Numerous requirements under the

[12] The Santa Rosa Plain groundwater sub-basin (defined in DWR's Bulletin 118) is currently identified as a medium priority basin/subbasin and is, therefore, subject to the requirements of SGMA.

RWQCB Cannabis Cultivation Policy are triggers and/or mitigations in response to impacts on water and aquatic resources that are clearly anticipated (and articulated) from increased cannabis cultivation (e.g., minimum instream flow requirements). The State regulations clearly identify/anticipate and address potential adverse impacts from the legalization of cannabis cultivation. The County's ordinance should do likewise.

Please feel free to contact me with any questions regarding the material and conclusions contained in this letter.

Sincerely,

Greg Kamman, PG, CHG
Senior Ecohydrologist

REFERENCES

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ATTACHMENT A

Greg Kamman, PG, CHG
Senior Ecohydrologist

Education

MS, 1989, Geology, Sedimentology and Hydrogeology, Miami University, Oxford, OH

BA, 1985, Geology, Miami University, Oxford, OH

Professional Registration

1993, Professional Geologist, California, #5737

1995, Certified Hydrogeologist, California, #360

Professional Experience

cbec, inc., eco-engineering, West Sacramento, CA, Senior Ecohydrologist, 2020-present

Kamman Hydrology & Engineering, Inc., San Rafael, CA, Principal Hydrologist/Vice President, 1997-2020

Balance Hydrologics, Inc., Berkeley, CA , Sr. Hydrologist/ Vice President, 1994-1997

Geomatrix Consultants, Inc., San Francisco, CA, Project Geologist/Hydrogeologist, 1991-1994

Environ International Corporation, Princeton, NJ, Sr. Staff Geologist/Hydrogeologist, 1989-1991

Miami University, Oxford, OH, Field Camp Instructor and Research Assistant, 1986-1989

Greg Kamman is a professional geologist and certified hydrogeologist with over 30 years of technical and consulting experience in the fields of geology, hydrology, and hydrogeology. He specializes in directing and managing projects in the areas of surface and groundwater hydrology, stream and tidal wetland habitat restoration, water supply and water quality assessments, water resources management, and geomorphology. Mr. Kamman has worked extensively throughout California's coastal watersheds and estuaries, and on multiple projects in Oregon and Hawaii.

Mr. Kamman's experience and expertise includes evaluating surface and groundwater resources and their interaction, stream and wetland habitat restoration assessments and design, characterizing and modeling basin-scale hydrologic and geologic processes, assessing watershed hydraulic and geomorphic responses to land-use change , and designing and conducting field investigations characterizing surface and subsurface hydrologic and water quality conditions. Greg commonly works on projects that revolve around sensitive fishery, wetland, wildlife, and/or riparian habitat enhancement within urban and rural environments. Mr. Kamman performs many of these projects in response to local, state (CEQA) and federal statutes (NEPA, ESA), and other regulatory frameworks. Mr. Kamman frequently applies this knowledge to the review and expert testimony on state and federal water operation plan EIR/EIS reports, Groundwater Sustainability Plans, Habitat Conservation Plans, and biological assessments.

Mr. Kamman is accustomed to working multi-objective projects as part of an interdisciplinary team including biologists, engineers, planners, architects, lawyers, and resource and regulatory agency staff. Mr. Kamman is a prime or contributing author to over 360 technical publications and reports in the discipline of hydrology, the majority pertaining to the protection and enhancement of aquatic resources. Mr. Kamman has taught the following courses: stream restoration through U.C. Berkeley Extension (2001-2008); wetland hydrology through San Francisco State University's Romberg Tiburon Center (2007 and 2012-2014); and presented webinars (2020) to California Water Boards staff on hydrologic and hydraulic modeling. He has devoted his career to the protection, enhancement and sustainable management of water resources and associated ecosystems.

SELECTED EXPERIENCE

Floodplain Management Projects

Flood Reduction, Mitigation Planning, and Design on Yreka Creek, Siskiyou County, CA
City of Yreka as subcontractor to WRA, Inc., 2008-2010

Mr. Kamman completed a series of field and hydraulic model investigations for restoration planning and design along Yreka Creek to reduce flood hazards and potential damage to the City's water treatment plant and disposal field infrastructure. This work also addresses and satisfies dike repair mitigation conditions stipulated by state resource agencies. While achieving these goals, Mr. Kamman tailored analyses and study objectives to assist the City in: enhancing the ecological floodplain restoration along Yreka Creek; providing opportunities for expanded public access and trail planning consistent with the goals of the Yreka Creek Greenway Project; and improving the water quality of Yreka Creek.

Key elements of this work included: review and synthesize existing information; identify and analyze the feasibility for three conceptual alternatives; and conceptual design and report preparation. Funding for implementation of restoration work over such a large area was a significant concern to the City. Therefore, designs identify and define phasing in a fashion that gives the City flexibility in implementation.

SELECTED EXPERIENCE *(CONTINUED)*

West Creek Drainage Improvement Assessment, Marin County, CA
Marin County Flood Control, 2006-2008

Mr. Kamman prepared a study focused on characterizing existing flood conditions and developing and evaluating flood reduction measures along West Creek in Tiburon. The work was completed through the implementation of hydrologic and hydraulic feasibility and design assessments. The conceptual design and analysis of potential flood reduction strategies (alternatives) was completed through the development of a HEC-RAS hydraulic model that simulates historic, existing and proposed project flood conditions. It was intended that the conceptual design developed under this scope of work would be of sufficient detail and quality to initiate project permitting and the environmental compliance process and documentation. Opportunities for riparian corridor and aquatic habitat enhancement were also considered and integrated into the conceptual design. Mr. Kamman also developed and assessed six alternative flood hazard reduction measures. The hydraulic model results for each alternative were compared against baseline conditions in order to evaluate their ability to alleviate flood hazards.

Gallinas Creek Restoration Feasibility Assessment, Marin County, CA
San Francisco Bay Institute, 2003-2005

Mr. Kamman completed a feasibility assessment for restoration of Gallinas Creek in northern San Rafael. Restoration will require removal of a concrete trapezoidal flood control channel and replacement with an earthen channel and floodplain in a "green belt" type corridor. Work included the collection of field data and development of a HEC-RAS hydraulic model to evaluate and compare existing and proposed project conditions. Designs must continue to provide adequate flood protection to the surrounding community. The study also includes and evaluation of existing habitat values, potential habitat values, and restoration opportunities and constraints.

Hydrologic and Hydraulic Evaluation for Trinity County Bridge Replacement, Trinity County, CA
Trinity County Planning Department, 2002

Mr. Kamman completed technical peer review of peak flow estimates and hydraulic design parameters associated with the replacement of 4 bridges across the upper Trinity River in Trinity County, California. A primary study component was accurately predicting the magnitude and frequency of flood releases from Trinity Dam. Numerous flood frequency analytical approaches were evaluated and used throughout this study.

Restoration of Lower Redwood Creek Floodway and Estuary, Humboldt County, CA
California State Coastal Conservancy and Humboldt County DPW, 2002-2003

Mr. Kamman provided technical review for the development of a hydraulic model to evaluate river and estuary restoration alternatives along the lower portions of Redwood Creek between Orrick (Highway 1) and the Pacific Ocean. This work was completed to evaluate the feasibility for creek/estuary restoration alternatives developed by the County, and effects on flood hazards along this flood-prone reach.

In order to better address and evaluate the current flood hazards along the entire floodway and identify potential flood hazard reduction measures, Mr. Kamman was retained to update HEC-2 models previously prepared by the Army Corps, and to evaluate the impacts of vegetation encroachment (increased roughness) and sediment deposition on floodway conveyance. Mr. Kamman expanded the Corps hydraulic model with newly completed channel surveys and channel roughness observations. The impetus for this work was to assist the County in identifying mutually beneficial strategies for ecosystem restoration and flood hazard reduction. Technical work was completed under close coordination and communication with county engineers. Study results and findings were presented at public meetings of local area landowners and stakeholders.

Tembladero Slough Small Community Flood Assessment, Monterey County, CA
Phillip Williams & Associates, Ltd., 1997

Mr. Kamman completed a flood information study of Tembladero Slough near Castroville on behalf of the San Francisco District Corps of Engineers. The purpose of this work was to identify and document local flood risks existing in the community and propose potential floodplain management solutions as part of the Corps 1995/1997-flood recovery process. Work centered on conducting a field reconnaissance, reviewing available historical data, and conducting discussions/interviews with local landowners and agency personnel.

Fluvial Projects

Muir Woods National Monument Bank Stabilization Plan for Conlon Creek, Marin County, CA
Golden Gate National Parks Conservancy (GGNPC), 2018-present

Mr. Kamman developed a grading and drainage plan for the Conlon Avenue Parking Lot, located adjacent to Redwood Creek and sensitive Coho salmon habitat. More recently, he has assisted GGNPC and the NPS in assessing the planning and design for creek bank stabilization and ecological enhancement at a failed culvert on a tributary channel at the project site. This work includes constructing a HEC-RAS model to evaluate: culvert removal and channel design; fish passage; and water quality impacts. Work is currently in development of 50% engineering design.

Hydrology and Hydraulic Assessments for Design of Butte Sink Mitigation Bank Project, Colusa County, CA
WRA, Inc., 2017-2018

Mr. Kamman was retained to provide hydrology and hydraulic modeling support in the development of design and Draft Prospectus for the Butte Sink Mitigation Bank (Bank). This work entailed developing the necessary hydrology information, hydraulic model and documentation to support further design, environmental compliance and agency approvals/permitting of the Bank. The main objective of work was to develop a design that provides the necessary ecological conditions and functions for successful establishment and operation of the Bank.

Lagunitas Creek Salmonid Winter Habitat Enhancement Project, Marin County, CA
Marin Municipal Water District, 2013-2018

Mr. Kamman designed and led a study to evaluate opportunities to enhance winter habitat for coho and other salmonids in Lagunitas Creek and its largest tributary - Olema Creek. This work was done as a two-phase assessment and design effort. The first phase (completed in 2013) included a winter habitat assessment to evaluate existing juvenile salmonid winter habitat in Lagunitas Creek and lower Olema Creek. The results of this assessment were used to prioritize winter habitat needs, and identify opportunities for winter habitat enhancement to increase

SELECTED EXPERIENCE *(CONTINUED)*

the winter carrying capacity of coho salmon and steelhead. The second phase (completed in 2017) consisted of a designing winter habitat enhancements. These enhancements focused on restoring floodplain and in-channel habitat structures. Winter habitat enhancement work also needed to consider potential impacts to or benefits for California freshwater shrimp (Syncaris pacifica), a federally endangered species.

This work included field reconnaissance, topographic surveys and the preparation of final design drawings at nine different project sites. An overall self-maintaining design approach was developed to guide individual project plan, with minimal earthwork and disturbance to existing riparian and wetland habitat. Self-sustained, natural evolution of a multi-thread channel within a more active floodplain is a desired outcome of project actions. Design elements and structures are intended to enhance or restore natural hydrologic processes to promote geomorphic evolution of more active high flow (side) channels and floodplain. Design elements include construction of 24 individual log structures.

Lower Miller Creek Management and Channel Maintenance, Marin County, CA
Las Gallinas Valley Sanitary District, 2013-2015

Mr. Kamman was commissioned to formulate and implement a plan for sediment removal and improved flood flow conveyance in the Lower Miller Creek channel. The need for improved flood and sediment conveyance is driven by the following factors. Progressive accumulation of course sediment in the project reach had reduced area wide discharge efficiencies along Miller Creek and at District outfalls. The District had an immediate need to dredge Lower Miller Creek to protect existing operations and facilities. Miller Creek supports a population of federally listed Steelhead, and adjacent wetland areas potentially support other state and federally listed special status species. Therefore, permitting requirements and cost efficiency required minimizing the extent and frequency of channel excavation/maintenance that may adversely impact habitats in the wetland and riparian corridor.

The design objective of the project was to define and optimize an integrated channel maintenance, flood, and sediment management plan, that protects existing facilities from stream and coastal flood hazards. The plan's objective was to minimize costs and ecological impacts of future anticipated and designed maintenance activities required under District operations. Working with District Staff, Mr. Kamman developed a suite of potential project alternatives and identified a preferred approach. Mr. Kamman completed all CEQA compliance (IS/MND) and permitting. Mr. Kamman also managed and directed development of engineered drawings and assisted in bid document preparation.

Mr. Kamman provided site assessment, long term management planning and channel maintenance support to the Sanitary District to maintain flood conveyance, manage sediment aggrading at District outfalls, and improve ecological values in the intertidal Bayland reaches of Miller Creek. The creek supports multiple federal and state listed endangered species. Initial work included completing hydraulic and geomorphic assessments to characterize causes of channel aggradation, and quantify sediment yields. Assessments included evaluation of climate change impacts on habitat and flood hazards, and water quality modeling of District outfalls to quantify tidal exchange and dilution. Based on this analysis and supporting biological resource assessments, Mr. Kamman identified alternatives for channel maintenance, performed a cost benefit assessment of dredging alternatives, and is assisted the District in developing short and long term management objectives. Mr.Kamman also led a multidisciplinary design team in the preparation of engineering plans and specifications as well as permits and environmental compliance documents.

Vineyard Creek Channel Enhancement Project, Marin County, CA
Marin County Department of Public Works, 2007-2013

Mr. Kamman managed the preparation of designs and specifications for a flood conveyance and fish habitat and passage improvement project on Vineyard Creek. Creek corridor modifications included replacing the box culvert at the Center Road crossing with a free span bridge or bottomless arch culvert (civil and structural design by others), providing modifications to the bed and bank to eliminate erosion risks to adjacent properties and improve water quality, promoting active channel conveyance of both water and sediment, and providing improved low and highflow fish passage, improved low flow channel form and enhanced in-stream habitat, repairing eroding banks, and expanding/enhancing adjacent channel floodplains. The riparian corridor was replanted to provide a low-density native understory, "soft" bank erosion protection, and increased tree canopy along the tops of banks. Mr. Kamman prepared the JARPA for the project and conducted permit compliance and negotiations with all participating resource agencies. Designs and permitting also address the known presence of Native American artifacts. This work was contracted under an expedited design schedule and phased construction was initiated the summer of 2008 and continued the summer of 2009.

Bear Valley Creek Watershed and Fish Passage Enhancement Project, Marin County, CA
The National Park Service and Point Reyes National Seashore Association, 2005-2013

Working on behalf of the NPS and PRNSA, Mr. Kamman completed a watershed assessment and fish passage inventory and assessment for Bear Valley Creek. Work included a geomorphic watershed assessment and completing field surveys and hydraulic modeling (including flood simulations) of ten road/trail crossings to identify and prioritize creek and watershed restoration efforts while considering and addressing current flooding problems at Park Headquarters – a major constraint to channel restoration efforts that would likely exacerbate flooding. Mr. Kamman also completed a suite of conceptual restoration designs (Phase 1) including: the replacement of two county road culvert crossings with bridges; channel creation through a ponded freshwater marsh (former tidal marsh); and replacement of 4 trail culverts with prefabricated bridges; and associated in-channel grade control and fishway structures. Engineered drawings and specifications were also developed for some of these sites to assist PORE with emergency culvert replacements after damages sustained during the New Year's Eve flood of 2005. Mr. Kamman also directed geotechnical, structural and civil design of project components.

Two projects were completed in 2006 on emergency repair basis resulting from flood damages suffered during the New Year's Eve storm of 2005. The two most recent projects were constructed in 2013, consisting of a large bank repair and adjacent to main access road/trail and culvert replacement further upstream on same road. The bank repair utilized bioengineering approaches including engineered log revetments and log diversion vanes.

SELECTED EXPERIENCE *(CONTINUED)*

Kellogg Creek Restoration Project, Contra Costa County, CA
Olberding Environmental on behalf of the Contra Costa County Water District, 2012-2013

Mr. Kamman led the development of PS&E to restore 3,000 linear feet of riparian and associated creek corridor habitat. Project was designed as compensatory mitigation for direct and indirect impacts to jurisdictional waters from the Los Vaqueros Reservoir Expansion Project that Contra Costa Water District. Work included field investigations and data analysis to characterize hydrologic/ geomorphic conditions and numerical modeling to optimize desired inundation and hydroperiods. Work was completed under subcontract to.

Miller Creek Sanitary Sewer Easement Restoration, Marin County, CA
Las Gallinas Valley Sanitary District, 2010

Working on behalf of the District, Mr. Kamman completed field surveys and technical feasibility studies to develop engineering plans and specifications for a stream bank restoration project to protect an exposed sanitary sewer pipeline, stabilize incised banks, and promote an ecologically healthy stream corridor along an approximately 50 linear foot damaged reach of Miller Creek. The design includes backfill and materials to accommodate construction of a vegetated stabilized slope. The eroded bank repair included design of a 1:1 Envirolok vegetated slope with geogrid reinforced soil lifts extending eight to ten feet back from the slope face. One-quarter-ton rock will be placed in front of the Envirolok wall at the toe of the reconstructed bank to provide added scour protection. In order to perform the work, the project site will be dewatered. An existing felled tree perpendicular to the creek flow will be relocated and secured into the right creek bank with root wad remaining in active channel. All work on the bank and within the creek bed must be completed pursuant to project permits due to presence of steelhead trout.

California Coastal Trail Planning and Design at Fitzgerald Marine Reserve, San Mateo County, CA
WRA, Inc., 2008-2009

Mr. Kamman provided hydrology and hydraulics expertise in the planning and design for the 0.25-mile segment of the California Coastal Trail at the Fitzgerald Marine Reserve. The project was overseen by the San Mateo County Parks Department. This segment of Coastal Trail provides improved access from the trailhead to the beach as well as a free span bride over Vicente Creek. Greg completed the field surveys and hydraulic modeling to assist an interdisciplinary team to design the project. Understanding the hydrology of Vicente Creek and quantifying flood conditions was critical to successfully designing and constructing the free span bridge. He also evaluated how creek hydrology and coastal wave processes interact at the beach outfall in order to identify opportunities and constraints to beach access improvements (which will include crossing the creek on the beach) during both wet and dry season conditions in order to evaluate both permanent and seasonal crossing design alternatives.

Hydrologic Assessment and Conceptual Design for Conservation and Wetland Mitigation Bank Project, Stanislaus County, CA
WRA, Inc., 2009

Working as a subcontractor to WRA, Inc., Mr. Kamman provided hydrology, geomorphology and engineering support for the planning and design for a Conservation and Wetland Mitigation Bank on the San Joaquin River, in the Central Valley near Newman, California. The property is currently owned by the Borba Dairy Farms. The primary objective of the study was to characterize the hydrologic and geomorphic controls on the spatial distribution of habitat types. To meet this objective, Mr. Kamman's assessment included: (1) collecting and synthesizing hydrologic data to characterize existing and historic streamflow, geomorphic and shallow groundwater conditions; (2) filling a data gap by collecting topographic data of hydrologic features; (3) developing a hydraulic model capable of predicting water surface profiles for a range of design flows; and (4) quantifying the linkage between surface water/groundwater conditions and specific vegetation communities and habitat types through implementation of reference site assessments. Mr. Kamman also provided conceptual design and permitting support in evaluating habitat enhancement and creation opportunities on the site.

Redwood Creek Floodplain and Salmonid Habitat Restoration, Marin County, CA
Golden Gate National Recreation Area and Golden Gate Parks Conservancy, 2005-2008

Mr. Kamman lead development of a preferred project alternative and final project design drawings and specifications for a floodplain and creek restoration and riparian corridor enhancement effort on lower Redwood Creek above Muir Beach at the Banducci Site. A primary objectives of the project was to: improve salmonid passage/rearing/refugia habitat; riparian corridor development to host breeding by migratory song birds; and wetland/pond construction to host endangered red-legged frog. The preferred design includes: excavation along the creek banks to create an incised flood terrace; engineered log deflector vanes; removing and setting back (constructing) approximately 400-feet of levee; creating in- and off-channel salmonid rearing and refugia habitat; reconnecting tributary channels to the floodplain; and creating California red-legged frog breeding ponds. Designs were completed in 2007 and the project constructed in the summer of 2007.

Considerable hydraulic modeling was completed to evaluate and develop means to help reduce chronic flood hazards to surrounding roadways and properties. Alternatives that included set-back levees and road raising were developed and evaluated. Detailed and careful hydraulic (force-balance) analyses and computations were completed as part of engineered log deflector designs. These were unique and custom designed structures, building on past project efforts and in consultation with other design professionals.

This project demonstrates Mr. Kamman's ability to work closely with the project stakeholders to develop a preferred restoration alternative in a focused, cost-effective and expedited fashion. This was achieved through close coordination with the NPS and the effective and timely use of design charrette-type meetings to reach consensus with participating stakeholders. Conceptual through full PS&E were completed on-time and on-budget in 2007 and was project constructed in the fall of 2007. Mr. Kamman worked closely with NPS staff to "field fit" the project, by modifying grading plans to protect existing riparian habitat. Mr. Kamman also provided construction management and oversight to floodplain grading and installation of engineered log structures. Based on field observations, the project is performing and functioning as desired.

Pilarcitos Creek Bank Stabilization Project, San Mateo County, CA
TRC Essex, 2006-2007

Mr. Kamman directed field surveys and technical modeling analyses to develop restoration design alternatives for a Bank Stabilization Project on Pilarcitos Creek

SELECTED EXPERIENCE *(CONTINUED)*

in unincorporated San Mateo County, California. This work included hydrology and hydraulic design and preparation of plan sheets and technical specifications as well as a revegetation plan. Due to the importance of protecting an existing gas mainline, the design package will be completed in close coordination with TRC Essex geotechnical staff and revegetation subcontractor and PG&E civil staff. Design feasibility analyses focused on developing hydraulic design criteria for the project, including: estimates of design flood flow magnitudes (2-, 5-, 10-, 25-, 50- and 100-year floods); water surface elevation estimates for a suite of design floods; associated average channel velocities and shear stresses; and estimates for riprap sizing for channel bank toe protection. Plan sheets, technical specifications and cost estimates were provided for review and approval.

Watershed Assessments

Evaluation of Project Impacts on Oregon Spotted Frog, Klamath County, OR
Oregon Water Watch and Earthjustice, 2016-2019

Mr. Kamman designed a suite of hydrologic, hydraulic and geomorphic studies to evaluate proposed change operations of the Crane Prairie, Wickiup and Crescent Lake dams and reservoirs as related to harm to Oregon spotted frogs. Work began with analyzing impacts associated with proposed water delivery operations and developing a proposed alternative prioritizing protection and enhancement of frog habitat. This work followed with a technical review and critique of the USFWS's Biological Assessment. Work included preparation of four declarations for the clients.

Tennessee Hollow Creek Riparian Corridor Restoration, San Francisco County, CA
Presidio Trust, 2001-present

Mr. Kamman has been leading and assisting the Trust and Golden Gate National Recreation Area (GGNRA) in the planning and design on over a dozen multi-objective riparian corridor restoration and watershed management projects in the Tennessee Hollow/Crissy Marsh watershed since 2001. Specific project objectives include: daylighting creeks; riparian corridor restoration; expanding Crissy Marsh; enhancing recreation, education, archeological, and cultural resource opportunities; improving water quality discharges to San Francisco Bay; and remediation of numerous landfills within the watershed. Typical initial phases of work focus on characterizing surface and groundwater conditions within each project area and identifying opportunities and constraints to restoration of natural wetlands and creek/riparian corridors. Notable challenges of this work include restoring heavily disturbed natural resources in an urban setting while integrating designs with recreation, archeology/cultural resources, education and remediation programs. Mr. Kamman has acted as lead hydrologist and designer on eight separate reaches in the 271-acre Tennessee Hollow Creek watershed and several other projects within and in the vicinity of Mountain Lake.

All task authorizations under these on-call and individual design contracts and included hydrology and water quality assessments and conceptual restoration planning and design. The project areas overlapped both the Presidio Trust and NPS-GGNRA management areas. Preliminary construction cost estimates for project alternatives within the Tennessee Hollow watershed range from $10- to $20- million. Several restoration projects are also tied to providing mitigation for the current San Francisco Airport expansion and Doyle Drive Seismic Improvement projects. Several projects have been constructed since 2012 (Thompson's Reach, El Polin Loop), two projects (East Arm Mtn. Lake and YMCA Reach) were constructed in 2014, and MacArthur Meadow restoration in 2016.

This work illustrates the Mr. Kamman's ability to complete a broad variety of hydrologic analyses, including: multiple years of rigorous and thorough surface water and groundwater hydrologic and water quality monitoring throughout the entire watershed to characterize and quantify existing hydrologic conditions; development of a detailed watershed-scale water budget for existing and proposed land-used conditions (capturing existing and proposed vegetation cover types and land use activities) to calculate groundwater recharge estimates input into the numerical watershed model; preparation of EA sections on water resources and water quality (NEPA compliance) regarding Environmental Conditions, proposed Impacts, and Proposed Mitigations associated with the project; preparing detailed alternative plans; and coordination and preparation of engineered plans/specifications for construction. All work was completed on budget and in a timely fashion.

Mountain Lake Water Budget, San Francisco County, CA
Presidio Trust, 2012-2017

Mr. Kamman was retained to develop a water balance model for Mountain Lake in the Presidio of San Francisco. Through development of a water balance model, the Trust seeks to understand: the major source(s) of inflow to both Mountain Lake; anticipated seasonal (monthly) changes in water level relative to various outflow assumptions; and the relationship of surface and groundwater interaction. This information gained from this study will be used to: 1) better understand and manage lake levels for ecological habitats; 2) identify flood storage capacity of Mountain Lake and fluctuations in lake level under various storm conditions; 3) better understand and maintain wetland habitat in the east arm; and 4) complete mass balance calculations to assess water quality in and feeding into the lake.

To implement this study, Mr. Kamman developed a water budget model to identify and quantify the primary water inputs and outputs to the lake and determine major controls over water storage. Primary water budget variables analyzed includes: precipitation; evaporation/evapotranspiration; groundwater exchange; and surface runoff. This study also included a long-term field investigation completed between 2012 and 2016 to: identify all point source inputs such as culverts and drainage outlets; identify diffused surface runoff inputs from surrounding lands, including a golf course; better characterizing the function and performance of the primary lake outfall structure; monitor groundwater levels surrounding the lake; and continuously monitor lake water level and storage over a mult9i-year period. These data were used to quantify water budget variables used to build the water budget model. Precipitation and barometric pressure data used in the model was provided by the Trust maintained weather station. Model daily evaporation estimates came from a variety of local area gauges maintained by state agencies.

The water budget model developed for this study is successful in accurately simulating historic water level conditions. The model using a daily time-step appears more accurate than model using a weekly time-step, but both provide reasonable agreement with observed conditions. The model is highly sensitive to groundwater exchange with the lake. The water budget is also a proven useful tool for the design and analysis of improvements to the lake outfall structure and establishing flood storage needs to protect the adjacent highway.

SELECTED EXPERIENCE *(CONTINUED)*

Cordilleras Creek Hydrologic Assessment, San Mateo County, CA
City of Redwood City, 2002-2003

Mr. Kamman assisted the Cordilleras Creek Watershed Coordinator in planning, seeking funding, and implementing a hydrologic and biologic assessment of the Cordilleras Creek watershed. Work completed included completing a full creek reconnaissance and channel stability assessment, preparation of a watershed assessment work plan, presentations at public meetings, and study/review of flooding issues in the watershed. Challenges faced in this predominantly privately owned watershed include removal of numerous fish passage barriers and educating/coordinating property owners.

Capay Valley Hydrologic and Geomorphic Watershed Assessment, Yolo County, CA
Yolo County RCD, 2008-2010

Mr. Kamman designed and supervised a hydrologic, geomorphic watershed assessment, and conceptual restoration design for the Capay Valley segment of Lower Cache Creek . Funding for the project was from a CALFED Watershed Program grant. The Capay Valley reach of Cache Creek experiences considerable stream bank erosion, which contributes to downstream sedimentation. The channel instability also threatens adjacent homes and can negatively impact the riparian habitat along the creek that functions as an important wildlife corridor from the Western Coastal Range to the Yolo Bypass. Additionally, a significant proportion of methylmercury transported into the Bay-Delta originates from the Cache Creek watershed. The main goal of this proposed study is to address both the causes and the aforementioned consequences of bank erosion.

The assessment was designed to evaluate and quantify changes in hydrologic and geomorphic conditions in response to historical changes in land-use and water development (e.g., diversions, reservoir construction, groundwater pumping, etc.). This assessment also evaluated how historic human induced changes in hydrologic and geomorphic conditions affect riparian ecology in terms of the lost or altered floodplain area, character, and inundation frequency. A key product of this assessment was to distinguish between “natural” and “accelerated” bank erosion, and to identify the underlying causes (both natural and anthropogenic) so that appropriate solutions can be developed. Desired outcomes of the study included: reduce bank erosion by developing restoration designs for typical trouble sites; produce a ranking system to prioritize sites for stabilization and restoration; contribute to community education through watershed science education and the Yolo STREAM Project outreach program; improve water quality through reduction in accelerated erosion; and contribute to riparian corridor restoration and support the RCD’s Wildlife Conservation Board funded efforts to remove non-native tamarisk and around from the creek corridor. Work was completed through a broad spectrum of field and analytical investigations that received close review by the RCD, stakeholders, and a Technical Advisory Committee.

Ventura River Unimpaired Flow and Habitat Assessment, Ventura County, CA
City of Buenaventura and Nautilus Environmental, 2006-2007

Mr. Kamman completed a hydrology feasibility assessments as part of evaluating the reuse of Ojai Valley Sanitary District (OVSD) effluent for other beneficial uses. Currently, OVSD discharges treatment plant effluent to the lower Ventura River. The City and OVSD recognize that the reduction in the discharge of treated effluent to the Ventura River could have an environmental effect on sensitive and endangered species. In light of these concerns, this study was conducted to determine if a reuse project is feasible without significant environmental harm.

The assessment included hydrologic and geomorphic field and analytical assessments of past (unimpaired), current and proposed surface and groundwater flow conditions over a wide range of dry- through wet water year-types. The main objective if these analyses was to determine the linkage to water quality and aquatic habitat conditions including: flow durations; extent of gaining vs. losing reaches; low flow inundation/wetted area; and influence on barrier beach dynamics. Mr. Kamman collaborated with a team of other professionals to prepare a facility plan documenting the analyses and conclusions of respective water recycling investigations.

Hydrologic Analysis of FERC Minimum Flows on Conway Ranch Water Rights, Mono County, CA
Law Office of Donald Mooney, 2001-2002

Mr. Kamman completed a hydrologic analysis to evaluate if FERC’s proposed Minimum Flow Plan for Mill Creek would interfere with the exercise of the Conway Ranch’s water rights from Mill Creek. The approach to this analysis was to quantify the duration of time the Conway Water right was met under historic gaged and simulated proposed Minimum Flow Plan conditions. The primary objective of the analysis was to evaluate impacts during the winter period when flows are typically limited due to water storage as snow pack. Minimum Flow Plan conditions were simulated by developing a spreadsheet model that redistributes actual (historic) Lundy Lake releases in a fashion that maintains a minimum flow of 4 cfs to Mill Creek to accommodate the downstream Southern California Edison’s (SCE) power plant. The analysis period for both historic and simulated Minimum Flow Plan conditions consisted of water years (WY) 1990 through 1998 to capture an exceptionally diverse range of wet and dry year-types.

The primary method used to quantify changes in flow between historical and simulated Minimum Flow Plan conditions was to prepare and compare flow duration curves for each condition during both the winter and summer periods during a variety of water year types. Model results were tabulated for each conditions to determine the differences in the percentage of time target flows were equaled or exceeded. Based on these findings, Greg was contracted to complete more in-depth monthly modeling.

Groundwater Management Projects

Assessments of Groundwater-Surface Water Interaction, Stanislaus County, CA
The Law Offices of Thomas N. Lippe, APC and California Sportfishing Protection Alliance, 2015-present

Since 2015, Mr. Kamman has been assessing groundwater conditions within Stanislaus County and evaluating potential impacts of groundwater pumping on surface water flow and aquatic habitat of the Stanislaus, Tuolumne and San Joaquin Rivers. Mr. Kamman completed a comprehensive review and synthesis report of available groundwater and interconnected surface water (ISW) reports and data. Using available soils, geology and hydrology information, Mr. Kamman also delineated and mapped subterranean streams and Potential Stream Depletion Areas (PSDAs) to identify stream corridors susceptible to adverse impacts from groundwater pumping. This information is intended to help Groundwater Sustainability Agencies identify potential impacts to ISW.

SELECTED EXPERIENCE *(CONTINUED)*

Most recently, Mr. Kamman has been retained to review and comment on 7 Groundwater Sustainability Plans (GSPs) for critically overdraft groundwater subbasins within or adjacent to Stanislaus County. This review focused on how GSPs address Groundwater Dependent Ecosystems (GDE) and ISW. Comments included recommendations on monitoring and study plans to identify and quantify impacts of groundwater pumping on stream flow rates and associated ecological habitats.

Assessment of Surface Water-Groundwater Interaction, Humboldt County, CA
Friends of the Eel River (FOER), 2020-present

Mr. Kamman is currently providing technical assistance in understanding surface water-groundwater interactions in the Lower Eel River Valley. Work includes reviewing and synthesizing available reports and hydrologic data and providing a science-based opinion on the role groundwater plays in supporting stream flow and aquatic habitats. This analysis addresses conditions and changes associated with seasonal and long-term wet-dry cycles. Data gaps will be identified and documented during the analysis.

This work is being completed to support FOER efforts at protecting aquatic resources within the framework of current water management practices and the public trust doctrine under California law. Additionally, this work includes providing hydrologic and hydrogeologic review, comment and recommendations during development of the basin's Groundwater Sustainability Plan (GSP) under the California Sustainable Groundwater Management Act (SGMA).

Scott Valley Subbasin Technical Hydrogeologist Assistance, Siskiyou County, CA
Klamath Tribal Water Quality Consortium and Quartz Valley Indian Reservation, 2019-present

Mr. Kamman is providing technical review and comment on the groundwater models and associated studies in the Scott Valley groundwater subbasin under the Sustainable Groundwater Management Act (SGMA) process. Work includes: review of groundwater models; synthesis and review of available groundwater quality data; assisting to identify constituents of concern; and review of the planning and technical studies being used to develop a basin Groundwater Sustainability Plan (GSP).

Middle Russian River Valley Shallow Groundwater Storage Enhancement Study, Sonoma County, CA
Friends of the Eel River, 2016

Working on behalf of Friends of the Eel River, Mr. Kamman completed a study to identify and quantify the volume of recoverable aquifer storage along two independent 6-mile reaches within the alluvial fill valley of the Russian River. The approach to this study was to quantify how channel incision has reduced shallow groundwater levels and quantify how much aquifer storage can be increased if channel bed elevations are restored to historic levels. The goal of this investigation was to identify feasible approaches to increase groundwater storage that would off-set losses associated with the termination of out-of-basin diversions from the Eel River. This work was completed through: intensive review and mapping of available groundwater level data; quantification of aquifer hydraulic properties; and calculating the shallow aquifer storage volume. In total, reclaiming the shallow aquifers within these two areas yield a total added storage volume of over 20,000 AF.

Green Gulch Farm (GGF)/Zen Center Water Resources Investigation, Marin County, CA
Green Gulch Farm, 1998-2019

Mr. Kamman completed a multi-phase study to evaluate the short- and long-term water uses and resources at GGF. Work was initiated by developing comprehensive water usage/consumption estimates and assessing available water resources, including spring, surface water, and ground water sources. Water demand estimates included quantifying potable and agricultural water usage/demands. Once reliable water supplies were identified and water usage/demand figures calculated, Mr. Kamman provided recommendation for improvements to water storage and distribution systems, land-use practices, conservation measures, treatment methods, waste disposal, and stream and habitat restoration. The initial phase of work included: in-depth review of available reports and data; review of geology maps and aerial photography; review of water rights and historic land use records; field reconnaissance including year-round spring flow monitoring; mapping and quantifying existing runoff storage ponds; and surface water peak- and base-flow estimates.

The second phase of work included identification of possible groundwater sources and siting and installation of production wells. This included sighting three drilling locations, obtaining County and State well drilling permits for a domestic water supply; coordination and oversight of driller; and directing final well construction. Upon completion of a well, Mr. Kamman directed a well pumping yield test and the collection and analysis of water quality samples (including Title 22) for small water supply system use. The final phase of work included assisting GGF with water treatment system options at the well head and integration of the groundwater supply into an existing ultra-violet light treatment system servicing spring water sources. Work was completed in 2000 with a budget of approximately $25,000, including all driller and laboratory subcontracting fees.

Stanford Groundwater Assessments, Santa Clara County, CA
Stanford University Real Estate Division, 2012-2016

Mr. Kamman provided technical hydrogeologic services to evaluate groundwater conditions and drainage requirements associated with the construction of several new facilities on or near Page Mill Road. The main objective of this study is to determine the seasonal depth to groundwater beneath the project site under existing and potential future conditions and provide an opinion on if the project is required to comply with the City of Palo Alto, Public Works Engineering Basement Exterior Drainage Policy (effective October 1, 2006). This work included obtaining and reviewing available technical reports, maps and literature pertaining to groundwater conditions in the project vicinity. Based on this review, we have prepared a letter report of findings and recommendations.

Bodega Bay Wetland Water Supply, Sonoma County, CA
Friends of Bodega Bay, 2007

Mr. Kamman Conducted an evaluation of the groundwater underflow feeding a large coastal wetland in Bodega Bay and recommended mitigation measures for potential losses in supply associated with proposed residential development in recharge areas. Work included: long-term monitoring of ground water quality and supply; monitoring surface water and spring flow and water quality; assessing and characterizing the interaction between surface and subsurface water sources during different seasons and water year-types; developing a detailed water budget for the site to assess impacts to recharge areas; and developing a number of physical solutions to mitigate for recharge losses.

SELECTED EXPERIENCE *(CONTINUED)*

L.A. Department of Water and Power, Groundwater Recharge Facility Operation Study, Los Angeles County, CA
ICF Consulting, 2006

Working as a subcontractor to ICF Consulting of Laguna Niguel, California, Mr. Kamman provided technical assistance in the hydraulic modeling of sediment accumulation in selected spreading ground facilities owned and operated by the Los Angeles Department of Public Works. The object of this work is to evaluate changes in infiltration and groundwater recharge rates over time within the spreading grounds in association with sediment accumulation from turbid waters.

Corde Valle Golf Club Surface-Groundwater Interaction Study, Santa Clara County, CA
LSA Associates, 2004

On behalf of LSA Associates of Pt. Richmond, CA, Mr. Kamman completed a 3rd party independent review of available reports and data sets (boring logs, well water levels, groundwater quality, aquifer pump-test, and surface water monitoring) to evaluate if pumping of the Corde Valle irrigation well is adversely impacting flow in West Llagas Creek. This investigation was implemented in response to a concern expressed by California Department of Fish and Game staff regarding the potential for differential drying of the West Branch of Llagas Creek along Highland Avenue. The analysis was also complicated by the likely effects of pumping from surrounding off-site wells.

Aquifer Testing for Tennessee Hollow Watershed Project, San Francisco County, CA
Presidio Trust, 2002

The Mr. Kamman assisted in the design and implementation of an aquifer test at the Presidio of San Francisco. We prepared an aquifer test work plan and conducted step-drawdown and constant-rate aquifer tests at the site using both manual and electronic data collection methods. This work included interpretation of the aquifer test results using software-based solution methods and prepared a written summary of methods and findings. In addition, Mr. Kamman located, coordinated and managed a drilling effort for the logging and installation of several groundwater monitoring wells in the project area to address identified data gaps.

San Joaquin River Riparian Corridor Restoration Project, San Joaquin Valley, CA
McBain-Trush, 2002

Mr. Kamman completed an assessment of historic and existing shallow groundwater conditions beneath and adjacent to the San Joaquin River between Friant Dam and the Merced River. This work focused on reviewing available reports and flow/groundwater- level data to characterize surface water and groundwater interaction and implications for riparian vegetation, water quality and fishery habitat restoration. Hydrologic analyses were performed to identify the location and seasonal evolution of losing and gaining reaches an implication on future restoration planning and design efforts. The main deliverable for this analysis was a report section focused on describing the historical changes in regional and local groundwater conditions in the San Joaquin Valley and evolution of anthropogenic activities (e.g., groundwater withdrawals, irrigation drainage systems and return flows, development of diversion structures, changes in land-use; and introduction of CVP/State Water Project deliveries) and associated impacts on deep/shallow groundwater levels, surface water flows, and surface and groundwater quality.

Tidal, Estuarine & Coastal Projects

Quartermaster Reach Wetland Restoration Project, San Francisco County, CA
Presidio Trust, 2006-present

Mr. Kamman was retained in 2006 as part of a multi-disciplinary team to develop restoration alternative designs for a 10-acre filled and paved site marking the historic confluence of Tennessee Hollow Creek and Crissy Marsh adjacent to San Francisco Bay. The Trust's planning documents define the main objectives for Tennessee Hollow restoration as: a) "Restoration [of Tennessee Hollow] will expand riparian habitat and allow for an integrated system of freshwater streams and freshwater, brackish, and tidal marsh, re-establishing a connection to Crissy Marsh" and b) "Restore and protect Tennessee Hollow as a vibrant ecological corridor". The project is located within the setting of a National Park and a National Historic Landmark District. Thus, another goal for the project is to protect the area's historic buildings and sensitive cultural and archeological resources to the extent possible, to enhance visitor experience to the area, and to integrate creek restoration with other urban land uses.

Mr. Kamman provided H&H technical input and consultation to the design team to develop a restoration project consisting of a creek-brackish marsh-salt marsh interface and associated upland habitats. His work included evaluating surface water, groundwater and tidal sources. In addition, the development of a hydrodynamic model has informed and guided a preferred project design, including evaluation of storm surge, road crossing and Tsunami impacts to the project. A technical challenge addressed with the use of the model included predicting and quantifying salt/brackish marsh habitat zones within the restored wetland in response to periodically but prolonged closed-inlet conditions to Crissy Marsh - a water body that serves as the downstream connection to the proposed project.

Another unique challenge to this project includes integrating restoration planning and design efforts with the replacement and retrofit of Doyle Drive, the main on/off-ramp for the Golden Gate Bridge, being replaced along the entire northern boundary of the Presidio. Mr. Kamman is providing long-term technical review of this project to the Trust with respect to impacts to water resources and associated existing ecological habitats. The Quartermaster project also falls within the managerial jurisdiction of both the Presidio Trust and NPS-GGNRA, requiring work in close cooperation with both Presidio Trust and National Park Service (NPS) staff.

Salt River Ecosystem Restoration Project, Humboldt County, CA
Humboldt County RCD, 2005-2019

Mr. Kamman provided hydrology, engineering and environmental compliance services towards the planning and design of river and tidal wetland restoration on the Salt River (Eel River Delta plain) near Ferndale, California, in Humboldt County. The purpose of the Salt River Ecosystem Restoration Project (SRERP) is to restore historic processes and functions to the Salt River watershed. These processes and functions are necessary for re-establishing a functioning riverine, riparian, wetland and estuarine ecosystem as part of a land use, flood alleviation, and watershed management program. The Salt River Project has three components: 1) dredging the lower Salt River and lower Francis Creek from near the Wastewater Treatment Plant downstream for 2.5 miles; 2) restoring 247 acres of wetland estuary habitat in the lower Salt River within the 440-acre former

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dairy; and 3) reducing sediment inputs from tributary watersheds. The Salt River Project was designed using an "ecosystem approach" to address hydrology, sedimentation, and fish and wildlife habitat.

As part of project feasibility assessment, Mr. Kamman completed a hydrologic and water quality monitoring program, and developed a MIKE11 hydrodynamic model of the lower Salt River and Eel River estuary in Humboldt County, for the Humboldt County RCD. The purpose of this work was to complete a hydrologic, geomorphic, and hydraulic modeling assessments of the character and dominant physical processes controlling flow of water and sediment through the lower Salt River. Land use changes in the area have caused significant aggradation and infilling of the Salt River, significantly reducing tidal exchange, fish passage, and exacerbating flooding in upland areas. A primary goal of this study is to evaluate the feasibility of proposed restoration elements intended to increase tidal prism and exchange and in-channel sediment scour and transport. The desired outcome is a sustained increase in river conveyance capacity to improve drainage of surrounding flood-prone lands and improve aquatic, wetland, and riparian habitat.

As part of project development and feasibility assessment, Mr. Kamman completed a hydrologic and water quality monitoring program and MIKE11 hydrodynamic model development of the lower Salt River and Eel River estuary in Humboldt County for the Humboldt County RCD. The purpose of this work is to complete a hydrologic, geomorphic, and hydraulic modeling assessments of the character and dominant physical processes controlling flow of water and sediment through the lower Salt River. Land use changes in the area have caused significant aggradation and infilling of the Salt River, significantly reducing tidal exchange, fish passage, and exacerbating flooding in upland areas. A primary goal of this study is to evaluate the feasibility of proposed restoration elements intended to increase tidal prism and exchange and in-channel sediment scour and transport. The desired outcome is a sustained increase in river conveyance capacity to improve drainage of surrounding flood-prone lands and improve aquatic, wetland and riparian habitat.

Western Stege Marsh Restoration Project, Contra Costa County, CA
Tetra Tech, 2008-2010

Mr. Kamman provided technical hydrology and wetland hydraulics support to post-project monitoring of the Western Stege Marsh Restoration Project. His involvement began by providing an independent technical review of previous year's hydrologic monitoring results to evaluate the proposed monitoring success criteria and the rationale used to develop these criteria. This work entailed reviewing historic monitoring data and available natural slough channel geometry data-sets for San Francisco Bay area marshes. Mr. Kamman's study approach was to independently develop desired and sustainable channel geometry relationships for natural, healthy San Francisco Bay salt-marshes and compare them to the published success criteria. Greg was also retained to implement the Year 4 post-project hydrologic monitoring, with modifications to aid in better linking hydrologic processes to ecological conditions and function within the restored marsh. This work consisted of completing more targeted water level monitoring and channel geometry surveys in reference marsh areas containing desired physical and ecological attributes. These data were used to develop geomorphic success criteria (target channel geometry) more tailored to the project marsh and augment the criteria provided in available literature. Working closely with the project team of scientists, Mr. Kamman compared these hydrologic monitoring results to available vegetation surveys to better assess the overall success and evolutionary trend of the marsh.

Giacomini Wetland Restoration Project, Marin County, CA
The National Park Service and Point Reyes National Seashore Association, 2003-2012

Mr. Kamman managed a multi-year project for the NPS in the design and feasibility analysis of a tidal wetland, riparian, and freshwater marsh complex, on the 500-acre Giacomini Dairy Ranch, at the south end of Tomales Bay. The project began in 2003 and included hydraulic, hydrologic, and geomorphic assessments to characterize existing physical conditions, developing restoration alternatives, and completing hydrologic feasibility analyses. Restoration alternatives evaluated creation of a mosaic of subtidal through upland wetland and riparian habitat zones, as well as improvements to salmonid passage, red-legged frog habitat, tidewater goby habitat, and clapper-rail habitat. Emphasis was placed on completing detailed studies to quantify project-induced changes in flood frequency, magnitude and duration, impacts on water quality to local groundwater supply wells, and changes in sediment and water quality conditions in Tomales Bay.

Beginning in 2006, Mr. Kamman managed and assisted design engineers, preparing plans, specification, and cost estimates for a three phased construction schedule, that was completed in the summer of 2008. This project illustrates Mr. Kamman's ability to complete a broad variety of hydrologic feasibility analyses, including flood frequency analyses for contributing watersheds, reproducing historic flood events through numerical modeling, flow duration analysis and evaluation of environmental flow regimes, development of a water budget for created freshwater marsh and frog breeding ponds, sediment yield estimates, completing field monitoring (flow, water level, groundwater level, sediment, and water quality monitoring) to characterize existing site hydrologic and geomorphic conditions (fluvial and tidal), wind-wave setup and run-up for levee stability determination and construction design, coordinating and performing topographic and hydrographic surveys, performing hydrodynamic and water quality modeling of existing and alternative conditions, developing detailed construction cost estimates preparation of technical reports and design drawings and specifications in support of NEPA/CEQA environmental compliance, and public meeting presentation and participation. In addition, Mr. Kamman managed staff in the generation of DEM and TIN models of the existing site and all action alternatives. All work was completed on budget and in a timely fashion, despite repeated expansions to the project boundary and last minute changes driven by endangered species issues.

Critical Dune Habitat Restoration to Protect Threatened and Endangered Species, Marin County, CA
The National Park Service, 2009-2010

Mr. Kamman provided and managed engineering, design, and implementation planning support for the restoration of 300 acres of critical dune habitat at Abbots Lagoon within the NPS Point Reyes National Seashore. He developed engineered drawings, technical specifications and engineer's cost estimates, and assisted NPS in defining a range of methodologies suitable to local conditions and sensitive flora and fauna. This area of the park supports the best remaining intact dune habitat, including some of the largest remaining expanses of two rare native plant communities: American dune grass (Leymus mollis) foredunes, and beach pea (Lathyrus littoralis). European beach grass and iceplant were removed from

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the project site using mechanical removal and hand removal techniques. The project goal was to remove these invasive species from approximately 135 acres of prime dune habitat in the 300-acre project site, while not impacting sensitive species and habitats. The intended result was to remobilize this historic dune field and restore their natural form and migratory processes.

This project illustrates Mr. Kamman's ability to work closely with NPS staff to balance habitat protection and restoration across the landscape. As part of project design, he developed grading plans, and specified work flow, equipment movement and access routes which minimize impacts to special status species. Extensive fencing and exclusions zone planning was required to protect existing native habitats, and minimize tracking of plant stock to or through restored sties. In addition work elements had to be structured and prioritized to maximize ground work subject to budgetary constraints and work flow uncertainties. All work has been completed on budget and in a timely fashion, even with repeated expansions to the project boundary and affected area and last minute changes driven by endangered species issues.

Lower Gualala River and Estuary Assessment and Management Plan, Mendocino County, CA
California State Coastal Conservancy and Gualala River Watershed Council, and Sotoyome RCD, 2002-2005

Mr. Kamman worked with fisheries biologists to evaluate the hydrologic and water quality conditions in the lower Gualala River and estuary and identify and evaluate potential impacts to summer rearing habitat for salmonids and other aquatic organisms. This work included: assessing how the impacts of upstream land use (logging and water diversions) have altered water delivery and water quality to the Lower River and estuary over time; characterizing the physical coastal and riverine processes controlling opening and closure of the estuary inlet and lagoon morphology; monitoring and characterizing real-time and seasonal changes in lagoon water level and water quality; and evaluating the sediment transport capacity and geomorphic condition of the lower river and estuary. Mr. Kamman took the lead in developing and editing a management plan for the lagoon, prescribing actions to preserve, protect and enhance ecological habitats (with emphasis on salmonids) within the lagoon and lower Gualala River.

This project was completed on-time and on-budget and demonstrates Mr. Kamman's ability to integrate physical, water quality and biological data and information into a coherent and understandable description of the interrelated processes controlling the aquatic ecology of a lagoon system. A big challenge on this project was completing a high-quality and defensible field monitoring program on a "shoe-string" budget. The outcome of this study provides important understanding on how and why steelhead are surviving in a heavily logged (95% private ownership) watershed. The management plan prescribes recommendations to preserve and protect the lagoon as primary rearing habitat for steelhead.

Suisun Bay Tidal Wetland Restoration Design, Contra Costa County, CA
East Bay Regional Park District and LSA Associates, 1999-2005

Mr. Kamman provided hydrologic design services to the restoration of a 55-acre tidal wetland on Suisun Bay. The design will maximize habitat for special status fish species, and (to the extent possible) habitat for other special status animal and plant species. Working with a multi-disciplinary design team, Mr. Kamman assisted in developing a design based on analysis of habitat needs, tidal hydrodynamic and geomorphic processes, sedimentation rates and soil characteristics. Project tasks included: a site analysis defining existing ecological and hydrologic conditions; a hydrologic and biological restoration opportunities and constraints analysis to define restoration and management objectives; and hydrodynamic and sedimentation modeling to evaluate design alternatives. The final restoration and management plan included a grading plan, landscape revegetation plan and monitoring and maintenance plans. This work again illustrates his capabilities in the characterization of physical site conditions, development and feasibility analysis of project alternatives, and preparation of preliminary designs of sufficient detail to allow for environmental compliance through the CEQA/NEPA process.

Santa Clara River Estuary and Lower River Assessment, Ventura County, CA
Nautilus Environmental on behalf of the City of Ventura, Public Works Department, 2003-2004

Mr. Kamman directed a hydrologic and geomorphic assessment of the lower Santa Clara River and estuary. This work was completed for prime contractor in an effort to assist with re-permitting of treated effluent discharges to the estuary. The proposed study entailed characterizing existing and historic hydrologic and physiographic conditions and an assessment of historic changes in inflow to the estuary. This task included a comprehensive review and evaluation of available hydrologic reports and flow data within the watershed to characterize changes in flow associated with development of numerous water projects within the Santa Clara River basin. The main deliverable from this analysis was the development of a historic unimpaired flow record to the estuary based on regional regression analyses and water operations modeling. Within the estuary, Mr. Kamman designed and conducted a multi-year monitoring program of water levels, water quality (temperature, dissolved oxygen, salinity, and pH), and sand-spit morphology in order to evaluate inlet opening/closure frequency and associated changes in aquatic habitat (esp. tidewater goby) and other ecologic communities. A considerable portion of this subtask included detailed coastal process analysis (including wave power analyses and littoral sand transport), which, considered with the inflow analysis, provides a basis to evaluate the seasonal cycle of barrier beach buildup and destruction.

This project illustrates Mr. Kamman's ability to complete a broad variety of hydrologic and coastal process analyses under strict regulatory oversight. A premier study completed on this project was the development of a detailed water and salinity budget model for the estuary to evaluate the impacts of a wide variety of proposed and modified estuary inflow regimes to determine potential future water level and salinity conditions in the lagoon and impact on frequency of inlet breaching. In addition to coordinating and implementing a variety field monitoring and surveys, Mr. Kamman also provided real-time information and input to informational and negotiation meetings with state resource and regulatory agencies.

Eden Landing Ecological Reserve Restoration, Alameda County, CA
East Bay Regional Park District, 2000-2003

Mr. Kamman developed and completed hydraulic and hydrodynamic modeling assessments for the design of an approximately 1000-acre tidal marsh restoration in former Cargil salt manufacturing ponds, located a mile inland of San Francisco Bay. The restoration goals required balancing the desires to restore tidal marsh conditions to the site, while maintaining and enhancing the open water and salt

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panne habitats preferred by resident and migratory shorebirds. The restoration plan also needed to incorporate restoration objectives with remediation of high soil salinities resulting from past salt production, subsided ground elevations, dredging of new channels to the bay, existing infrastructure constraints, public access for the San Francisco Bay Trail, and preservation of several important cultural and historical sites. Hydraulic design objectives include maximizing both interior circulation and tidal exchange between the restoration parcel and the bay. A series of one-dimensional unsteady hydrodynamic models (MIKE11) were used to design the channel network, identify high velocity areas requiring erosion protection, and characterize expected habitat conditions. An important component of this design and feasibility assessment was to translate desired ecological habitat conditions identified in the EIR into specific hydrologic design criteria, considering channel velocities, scour, sediment transport, tidal water inundation frequencies and seasonality of ponding. Mr. Kamman worked closely with EBRPD civil engineers, assisting with the translation of hydraulic design criteria into final engineered drawings and specifications.

Wetland & Pond Projects

Design of California Red-Legged Frog Breeding Ponds, San Francisco Bay Area (various), CA
The National Park Service and Golden Gate National Parks Conservancy, 1997-present

Mr. Kamman has lead or provided hydrologic and engineering design assistance to the sighting and design of nearly two dozen breeding ponds for California red-legged frog throughout the San Francisco Bay Area. Work has been completed in Marin, Sonoma, Solano, Contra Costa, Alameda, and Santa Clara Counties under the auspices of numerous federal, state, and local county/city agencies. A common study approach consists of an initial site reconnaissance of watershed conditions and identification of potential sites. The reconnaissance is followed by a surface water hydrologic sufficiency analysis using available meteorologic and stream flow information. An important variable sought during pond sighting is the presence of migration corridors between known breeding areas and/or perennial water sources. Based on in-depth research and post-project monitoring, Mr. Kamman has refined or developed site-specific evapotranspiration estimates, which commonly do not match standard applied values. Accurate evapotranspiration rates are necessary if ponds are intended to periodically dry-down as a means to preclude undesired species such as bullfrog or mosquito fish. In many instances, a seasonal groundwater-monitoring program is implemented in order to better investigate and quantify potential and seasonal groundwater contributions. Other design challenges we commonly experience include: design of impermeable liners for ponds located in upland areas or highly permeable soils; hydraulic analyses and design of outfalls/spillways; sedimentation management/maintenance approaches; and requirements of inoculum and water used to line and fill the pond, respectively.

Hydrologic Feasibility Assessment for Mana Plain Wetland Restoration Project, Kauai, HI
State of Hawaii Department of Land and Natural Resources, 2010-2019

Working on behalf of the Mana Plain Wetland Restoration Partnership, Mr. Kamman completed a hydrologic feasibility assessment for the Mana Plain Wetland Restoration Project proposed by the State of Hawaii Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW) on the island of Kauai. The Mana Plain Wetland Restoration Project site is approximately 105 acres of low-lying abandoned sugarcane fields immediately north of the Kawaiele Waterbird Sanctuary and east of the Pacific Missile Range Facility. The purpose of the Mana Plain Wetland Restoration Project is to maximize the area of constructed wetlands within the restoration site. Palustrine emergent wetlands within the project will create habitat for four species of endangered Hawaiian waterbirds and other sensitive species, including: Hawaiian stilts; Hawaiian ducks; Hawaiian coots; Hawaiian moorhen; migratory waterfowl; and migratory shorebirds. The Mana Plain is of vital importance for the recovery of endangered waterbirds species. This restoration project will be designed to provide important breeding and feeding wetland habitats on an island where; 1) wetlands have been severely degraded, and 2) mongoose, an introduced predator, have not been established.

Mr. Kamman's work on this project included technical assessments and development of proposed restoration alternatives. Analyses completed included: a synthesis of the physical site setting (topography, geology, hydrogeology and soil); reviewing available data to characterize site meteorology, surface water drainage, water quality, and groundwater conditions; preparing a detailed water budget to describe the characteristics and processes of surface water and groundwater movement into and through the project area; evaluating project feasibility, water supply alternatives and costs; and completing a flood hazard impact assessment to evaluate potential project benefits and impacts to local area flooding. Working with the project partners, Mr. Kamman developed a preferred project alternative and supported in preparation of the project Environmental Assessment document. Mr. Kamman's firm was also retained by the State of Hawaii to develop engineering designs of the project.

MacArthur Meadow Wetland Restoration, San Francisco County, CA
Presidio Trust, 2013-2016

Mr. Kamman has been working on over a dozen independent wetland and creek restoration planning and design efforts within the Presidio of San Francisco since 2001. Most recently (2016), he developed a wetland restoration grading plan for the MacArthur Meadow Wetland Restoration Project in the central portion of the Tennessee Hollow watershed. As part of the site assessment, Greg characterized and modeled surface and groundwater interactions and identified a unique opportunity to restore 4 acres of mixed meadow, natural wetlands and creek/riparian corridor. This was possible due to the discovery of shallow groundwater conditions beneath this historically disturbed landscape. Various design components were integrated into the grading plan in order to enhance groundwater recharge and storage in the Meadow, while retarding runoff and drainage out of the wetland, including: daylighting storm drain runoff into the Meadow; reconfiguring internal channel alignments to enhance channel habitat and groundwater recharge; creation of wetland depressions to retain and recharge surface water; and removal of fill material to decrease the depth to the water table. Notable challenges of this work include restoring heavily disturbed natural resources in an urban setting while integrating designs with archeology/cultural resources, education and remediation programs.

Dragonfly Creek Restoration Project, San Francisco County, CA
Presidio Trust, 2007-2011

Mr. Kamman designed and managed hydrologic monitoring and analysis studies in support of planning and design for riparian and wetland habitat restoration along approximately 500-linear feet of the Dragonfly Creek corridor near Fort Scott of the Presidio of San Francisco. Work has included completing subsurface

SELECTED EXPERIENCE *(CONTINUED)*

investigations including the installation of shallow wells and a sharp-crested weir with recorder to gauge creek flows. Mr. Kamman assisted in the development and selection of a preferred project alternative, considering on-site cultural resource protection, education and resource management issues (including flood control). Mr. Kamman prepared permit applications. Major components of the project included removal of significant fill and building foundations and installation of a new creek road crossing that will maintain the historical alignment, function and architectural character of a culturally significant roadway. Mr. Kamman oversaw development of PS&E for this project, which will create mitigation wetlands for a highway earthquake retrofit project that passes through the Park.

This project illustrates Mr. Kamman's ability to complete a broad variety of hydrologic analyses, including: surface water and groundwater hydrologic monitoring to characterize and quantify existing hydrologic conditions; rainfall-runoff modeling; hydraulic modeling of flood and scour conditions (including road crossing); preservation of existing wetland habitat and vegetation communities; integration with other Presidio Trust programs; and contracting flexibility to assist in conceptual planning and environmental compliance without increasing project design costs.

Mori Point Sensitive Species Habitat Enhancement Project, San Mateo County, CA
Golden Gate National Recreation Area and Golden Gate National Parks Conservancy, 2005-2011

Mr. Kamman provided hydrologic analyses, sighting and engineering design (PS&E) for three California red-legged frog breading ponds within the 105-acre Mori Point area. These efforts were completed in association and collaboration with a larger Coastal Trail improvement and ecosystem restoration effort. Quarrying and off-road vehicle use have left this site heavily scarred. The focus of restoration work was to protect the endangered San Francisco garter snake and the threatened red-legged frog. Most of this work will be focused on invasive species removal and enhancing endangered species habitat. As part of species habitat improvement, Mr. Kamman worked with project ecologists to design the ponds to optimize breeding habitat for California red-legged frog.

Work started with an initial site reconnaissance and study of watershed conditions and identification of potential sites. The reconnaissance was followed by a surface water hydrologic sufficiency analysis using available meteorological and stream flow information and installation and monitoring of shallow piezometers to quantify the proximity and seasonal variability in depth to water table. An important variable sought during pond sighting was the presence of migration corridors between known breeding areas and/or perennial water sources. Based on in-depth research and post-project monitoring for other ponds they created in the San Francisco Bay area, Mr. Kamman refined site-specific evapotranspiration estimates. Accurate evapotranspiration rates are necessary if ponds are intended to periodically dry-down as a means to preclude undesired species such as bullfrog or mosquito fish.

Other design challenges experienced included: design of impermeable liners for ponds located in upland areas or highly permeable soils; hydraulic analysis and design of outfalls/spillways; sedimentation management/maintenance approaches; and requirements of inoculum and water used to line and fill the pond, respectively. Mr. Kamman has designed numerous ponds for the NPS and affiliates within the Bay Area, including Mori Point (constructed 2007), Banducci (constructed 2007) and Giacomini (Phase I and Phase II constructed in 2007 and 2008) project sites.

Hydrologic Assessment and Restoration Feasibility Study for Shadow Cliffs Regional Recreation Area, Alameda County, CA
East Bay Regional Park District, 2009-2010

Mr. Kamman developed and implemented an assessment to identify groundwater levels and supplemental water supplies that will sustain seasonal wetland restoration areas and riparian habitats under an altered future hydrologic regime. This work will inform a forthcoming Land Use Plan Amendment for park occupying a series of former gravel quarry pits. Work included: obtaining and synthesizing available surface water and groundwater data to characterize existing hydrologic and water supply conditions and seasonal variability; quantifying the likely changes in groundwater conditions and quarry pit lake levels in association with changes in regional water transmission and groundwater recharge operations; and identifying, developing and evaluating a suite of ecosystem restoration alternatives. Other important project objectives include: improving habitat for waterfowl and wildlife; broadening recreational use; enhancing visitor education and wildlife interpretation; improve park aesthetics. Mr. Kamman evaluated a preferred park and ecosystem enhancement alternative that involves diverting high winter flows from an adjacent arroyo. This project demonstrates Greg's ability to characterize hydrologic conditions and quantify the relationship between groundwater, surface water and wetland habitat conditions, both under existing conditions and in predicting future hydrologic and ecologic conditions under an altered hydrologic regime (i.e., lower groundwater table).

Laguna Salada Marsh and Horse Stable Pond Restoration Project, San Mateo County, CA
Tetra Tech, 2007-2009

Mr. Kamman provided technical hydrology and hydraulics support to the planning and conceptual restoration design of Laguna Salada marsh and Horse Stable Pond, located adjacent to Sharp Park Golf Course in the town of Pacifica, California. The primary objectives of the project are: to reduce flood impacts within the project vicinity; improve sustainable ecological habitat for the endangered San Francisco garter snake and the threatened California red-legged frog; better understand and characterize the hydrologic and water quality conditions/processes affecting flood and ecological habitat conditions within the project vicinity; provide an effective pumping operation plan to meet ecological objectives; and develop appropriate hydrologic analytical approaches and models to assist Tetra Tech and the San Francisco Recreation and Park Department in the planning and design for marsh, pond, and creek restoration. The project is also a unique opportunity to connect this resource with the California Coastal Trail, the Bay Area Ridge Trail, and the surrounding GGNRA lands.

Mr. Kamman's work included completing a comprehensive review of available hydrologic and site information and implementing selected field investigations to develop and calibrate an integrated hydrology-flood routing-pond water operations model that will quantify the volume and depth of water moving through the project system. The investigation will also further characterize shallow groundwater conditions and water quality with respect to effects on Laguna Salada and Horse Stable Pond. Analytical and numerical modeling tools are being used to better characterize existing hydrologic and water quality conditions and to assist in identifying project opportunities and constraints as well as evaluate potential restoration design components - all necessary to inform a sustainable

SELECTED EXPERIENCE *(CONTINUED)*

and successful restoration design.

Tolay Lake Restoration Feasibility Assessment, Sonoma County, CA
Sonoma County Agricultural Preservation and Open Space District, 2003

Mr. Kamman completed a detailed hydrologic feasibility analysis to evaluate a suite of potential freshwater lake and wetland restoration alternatives. Sites were evaluated under existing watershed land-use practices and under existing and forecasted water demands (in the form of existing water rights/applications). Analysis consisted of developing a detailed water budget model to simulate alternative restored lake inundation areas and depths under median and dry year conditions, as well as a 50-year historic period (1947-1997) displaying highly variable rainfall and runoff supplies. Three lake restoration alternatives were evaluated based on existing topography and likely historic lake configurations. The restoration alternatives include lakes with storage volumes equivalent to 136-, 1100-, and 2550-acre feet.

Haypress Pond Decommissioning and Riparian and Channel Restoration, Marin County, CA
Golden Gate National Recreation Area (GGNRA), 2001-2002

This project restored 170 meters of historic creek and riparian habitat through removal of Haypress Pond dam in Tennessee Valley within GGNRA. The goals of the project were to alleviate long-term maintenance needs and eliminate non-native bullfrog habitat threatening native California red-legged frog habitat in adjacent watersheds.

Working with the Park biologist, Mr. Kamman developed designs to decommission the dam and restore natural riparian and meadow habitat. This work included: characterization of existing topographic conditions; design of a channel profile through the proposed restoration project reach; preparation of a grading plan for the restoration project; and hydrologic and hydraulic analyses to evaluate the performance of the creek channel and flood plain below the former dam during a variety of flows. Challenges of this work included integrating sediment reuse into plans and construction phasing.

Damon Slough Site Seasonal Wetland Design, Alameda County, CA
Port of Oakland, 1999-2001

Working on behalf of the Port of Oakland, Mr. Kamman completed extensive surface and groundwater monitoring and data analyses to develop a detailed water budget to assist in the evaluation and design of a 7.5 acre seasonal freshwater wetland. Primary project objectives included a design that would provide shorebird/waterfowl roosting habitat, minimize impacts to existing seasonal wetland areas, and lengthen the duration of ponding through the end of April to promote use by migratory birds. In addition to developing hydrologic design criteria, responsibilities included development of grading plans to accommodate a local extension of the Bay Trail and wetland outlet works.

Water Quality Projects

Chicken Ranch Beach Soil and Groundwater Quality Investigation and Restoration Planning, Marin County, CA
Tomales Bay Watershed Council, 2007-present

Mr. Kamman is leading scientific and engineering efforts for a wetland and riparian corridor restoration project on Third Valley Creek and Chicken Ranch Beach in Inverness, California. The main project goals are to create a self-sustaining riparian and wetland system (requiring minimal operation and maintenance) and eliminate public exposure to high levels of bacteria that exist in a site drainage ditch discharging to the beach. The design will likely include establishing a blend of habitats, including: riparian stream corridor, seasonal/perennial freshwater marsh, and tidal/saltwater marsh.

Current efforts have included the development and implementation of a soil and groundwater quality investigation to delineate the source of elevated bacteria levels. This work includes: the collection and testing of depth-discrete soil samples; groundwater well installation, sampling and testing; and surface water sampling and testing; analysis of laboratory results; and reporting, including recommendations for further/expanded investigations. Mr. Kamman coordinated this time-sensitive sampling and analysis (six hour hold times) with Brulje and Race Laboratories in Santa Rosa.

Lower Miller Creek Channel Maintenance and Material Reuse Sampling Analysis Plan, Marin County, CA
Las Gallinas Valley Sanitary District, 2015

Mr. Kamman was commissioned to formulate and implement a plan for sediment removal and improved flood flow conveyance in the Lower Miller Creek channel. Accumulation of course sediment in the project reach had reduced discharge efficiencies at District outfalls. Miller Creek supports a population of federally listed Steelhead and adjacent wetland/marsh areas potentially support other state and federally listed special status species. Working with District Staff, Greg developed a suite of potential project alternatives and identified a preferred approach. Mr. Kamman completed all CEQA compliance (IS/MND), permitting and oversaw development of engineered plans and specifications.

In order to evaluate if reuse of excavated material from 2,655 feet of creek corridor in upland areas was feasible, Mr. Kamman developed and implemented a Sampling Analysis Plan (SAP) pursuant to U.S. Army Corps Guidance for Dredging Projects within the San Francisco District. Sample collection, sample handling, and analysis were performed in accordance with the SAP. Results for analytes were compared to a variety of screening criteria to determine the material's suitability for reuse in aquatic environments. A full suite of chemical and physical analyses were performed on soil samples collected from 16 locations, including: metals, PAHs, PCBs, pesticides, TOC, specific conductance, pH, sulfides, percent moisture and grain-size. Mr. Kamman managed all aspects of this effort including reporting and presentations/negotiations at multi-agency meetings through the Corps Dredge Materials Management Office (DMMO).

Lower Pitkin Marsh Hydrologic and Water Quality Monitoring, Sonoma County, CA
Sonoma Land Trust, 2008-2010

Mr. Kamman was retained to develop and implement a hydrologic and water quality monitoring program at Lower Pitkin Marsh outside of Forestville, California. The Pitkin Marsh area is one of the most valuable complexes of mixed riparian woodland and thicket, freshwater marsh, wet meadow, oak woodland and grassland in Sonoma County. The complex interaction of surface water, ground water, and scattered seeps and springs on the site creates unusual hydrologic conditions that promote a rare assemblage of plant species which includes several endemics. The primary objective of the hydrologic monitoring program was to understand the annual and season sources of both surface and ground water supplying wetlands. Hydrologic and water quality monitoring was

SELECTED EXPERIENCE *(CONTINUED)*

initiated during the winter wet season of 2008/09 and will be conducted for a 12-month period through the ensuing summer dry-down and into the following wet season. Understanding how groundwater levels, spring flow and creek flow rates recede from winter wet to summer dry conditions will provide an important understanding and quantification of the seasonal variability in water supplies feeding selected wetland types. General water quality parameters (temperature, pH, specific conductance, and ORP) are measured at all monitoring locations during each visit. Nutrients (N and P) are measured in selected surface water and groundwater samples collected during at least three monitoring events, including a winter high flow, spring high base flow and summer low baseflow.

Pescadero Lagoon Restoration and Enhancement, San Mateo County, CA
California State Coastal Conservancy, 2005-2006

Mr. Kamman was retained to support restoration and water quality enhancement planning efforts in Pescadero Lagoon. In 2005-2006, he completed a synthesis of available hydrologic and water quality information in responding to requests for development of a hydrodynamic and water quality model of the lagoon. This model was considered as a means to identify causes for repeated fish-kills in the lagoon that occurred during initial breaching of the inlet. Mr. Kamman assisted in preparing a synthesis and model development feasibility report from this effort.

Water Temperature Simulations for Trinity River Fish and Wildlife Restoration Project, Trinity County, CA
Trinity County Planning Department, 1994-2004

For over a decade, Mr. Kamman completed a number of hydrology and water quality investigations in support of alternative feasibility studies on the Trinity River Fish and Wildlife Restoration Project in direct support of the Trinity River Restoration EIR/EIS. Studies involve assessing the effects of proposed flow alternatives on water temperature within and downstream of Lewiston Reservoir. Mr. Kamman was responsible for data collection, processing, and flow/temperature modeling of Lewiston Reservoir as part of a coordinated evaluation including other Trinity River system models. Another study included evaluating how project operations could be implemented or modified to optimize Lewiston Lake release temperatures to meet downstream temperature criteria and compensate for increased warming of the river associated with side channel and feather edge restoration activities. Mr. Kamman continues to evaluate how more recent water projects (raising Shasta Dam, Sites Reservoir, and the Waterfix tunnels) consider and integrate with the Trinity Restoration Project.

Upper Eel River Unimpaired Flow and Water Temperature Assessments, Humboldt County, CA
CalTrout, 1997-1999

Mr. Kamman evaluated changes in the natural flow regime of the upper Eel River, and developed an Upper Eel River proposed release schedule to enhance downstream Chinook and Steelhead spawning and rearing habitat. This work was triggered by proposals set forth by PG&E as part of their Potter Valley Project FERC relicensing process. Work consisted of two main investigations. The first included reviewing results of a ten year PG&E study and development of multivariate regression and stream reach (SSTEMP) temperature models to assess the effects proposed flow alternatives would have on downstream temperatures. The second investigation consisted of characterizing unimpaired flow conditions and developing a daily unimpaired flow record for use in project operation models.

Selected Litigation Support Projects

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Kamman, G.R., 2019, Review of Draft Environmental Impact Report/Statement, Sites Reservoir Project. Prepared for: Pacific Coast Federation of Fisherman's Association (PCFFA) and Save California Salmon, January 21, 45p.

Kamman, G.R., 2018, Review of Amendments to the Sonoma County Cannabis Ordinance, California. Prepared for: Shute, Mihaly & Weinberger LLP, August 3, 10p.

Kamman, G.R., 2018, Written Testimony of Greg Kamman for Part 2 of the California Waterfix Change of Diversion Hearing before the State Water Resources Control Board, November 28, 10p.

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Kamman, G.R., 2017, Review Comments: PAD and SD1, FERC Relicensing of Potter Valley Project (PVP). Professional declaration prepared for: Friends of Eel River, July 31, 8p.

Kamman, G.R., 2017, Review Comments, Draft Environmental Impact Report, Fish Habitat Flow and Water Rights Project. Professional declaration prepared for: Friends of Eel River, March 8, 18p.

Kamman, G.R., 2016, Review of Draft General Waste Discharge Requirements for Vineyard Dischargers in the Napa River and Sonoma Creek Watersheds. Prepared for: Law Offices of Thomas N. Lippe APC, December 12, 4p.

Kamman, G.R., 2016, Review of Middle Green Valley Specific Plan Project, Second Revised Recirculated Draft Environmental Impact Report, Solano County, CA, Sch# 2009062048. Professional Declaration Prepared for: Law Offices of Amber Kemble, October 25, 3p.

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Kamman, G.R., 2016, Review of Draft EIR for General Waste Discharge Requirements for Vineyard Dischargers in the Napa River and Sonoma Creek Watersheds. Prepared for: Law Offices of Thomas N. Lippe APC, September 14, 81p.

Kamman, G.R., 2016, Second Declaration of Greg Kamman Plaintiff's Joint Motion for Preliminary Injunction, Prepared for Center for Biological Diversity (Plaintiff) v. U.S. Bureau of Reclamation, Case No. 6:16-cv-00035-TC (Recovery for Oregon Spotted Frog, Upper Deschutes Basin, Oregon) , March 11, 11p.

Kamman, G.R., 2016, Declaration of Greg Kamman Plaintiff's Joint Motion for Preliminary Injunction, Prepared for Center for Biological Diversity (Plaintiff) v. U.S. Bureau of Reclamation, Case No. 6:16-cv-00035-TC (Recovery for Oregon Spotted Frog, Upper Deschutes Basin, Oregon) , February 4, 8p.

Kamman, G.R., 2015, Sharp Park Project Impacts to Laguna Salada. Prepared for National Parks Conservation Association and Wild Equity Institute, April 14, 1p.

Kamman, G.R., 2014, Review of Middle Green Valley Specific Plan Project, Revised Recirculated Draft Environmental Impact Report, Solano County, CA, Sch# 2009062048. Professional Declaration Prepared for: Law Offices of Amber Kemble, August 11, 11p.

Kamman, G.R., 2012, Deposition of Gregory Richard Kamman, R.G., C.H.G., Schaefer vs. City of Larkspur, CA, Superior Court of the State on California, County of Marin. August 23, 2012.

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Kamman, G.R., 2012, Review of groundwater conditions and modeling report by S.S. Papadopulos & Associates, Inc., Scott Valley, California. Prepared for: Yurok Tribe, 4p.

Kamman, G.R., 2011, Supplemental Declaration of Greg Kamman regarding Laguna Salada, Wild Equity Institute v. City and County of San Francisco, et al., Case No.: 3:11-CV-00958 SI, United States District Court, Northern District of California, San Francisco Division. Prepared for Wild Equity Institute, November 4, 50p.

Kamman, G.R., 2011, Declaration of Greg Kamman regarding Laguna Salada, Wild Equity Institute v. City and County of San Francisco, et al., Case No.: 3:11-CV-00958 SI, United States District Court, Northern District of California, San Francisco Division. Prepared for Wild Equity Institute, September 23, 7p.

Kamman, G.R., 2010, Review of Sonoma County Water Agency NOP (issued 9/29/10) Fish Habitat Flow and Water Rights Project. Professional declaration prepared for: Friends of Eel River, November 8, 7p.

Kamman, G.R., 2007, Independent Model Review for Klamath Settlement Negotiations, Klamath Independent Review Project (KIRP). Prepared for Northcoast Environmental Center, November 9, 19p.

Kamman, G.R., 2007, Review of Negative Declaration for File No. UPE04-0040, Gualala Instream Flow. Professional declaration prepared for Friends of the Gualala River, October 21, 2p.

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Kamman, G.R., 1999, Review of Final Supplemental Environmental Assessment, Cirby-Linda-Dry Creek Flood Control Project. Professional declaration prepared for: Monty Hornbeck, Sunrise Office Park Owners Association; Bill Kopper/John Gabrielli, Attorneys at Law; and Sharon Cavello/Cathie Tritel, Placer Group Sierra Club, May 24, 10p.

Kamman, G.R., 1995, Variable Water Resources Available in the Area of Salinas, California. Declaration prepared for Price, Postal, and Parma, Santa Barbara, California, May, 6p.

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Kamman, G.R., 2018, Water is Life! A hydrologist's eye on the Gualala River. Presented to: Friends of the Gualala River and public, Gualala Arts Center, Gualala, CA, May 3.

Kamman, G.R. and Kamman, R.Z., 2015, Landscape Scale Urban Creek Restoration in Marin County, CA - Urban Creek Restoration: Interfacing with the Community. 33rd Annual Salmonid Restoration Conference, March 11-14, Santa Rosa, CA.

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Kamman, G.R., 2012, The role of physical sciences in restoring ecosystems. November 7, Marin Science Seminar, San Rafael, CA.

King, N. and Kamman, G.R., 2012, Preferred Alternative for the Chicken Ranch Beach/Third Valley Creek Restoration Project. State of the Bay Conference 2012, Building Local Collaboration & Stewardship of the Tomales Bay Watershed. October 26, Presented by: Tomales Bay Watershed Council, Inverness Yacht Club, Inverness, CA.

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ATTACHMENT B

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
777 Sonoma Avenue, Room 325
Santa Rosa, California 95404-4731

February 26, 2021

Tennis Wick, Director
County of Sonoma
Permit and Resource Management Department
2550 Ventura Avenue
Santa Rosa, California 95403

Dear Mr. Wick:

This letter communicates NOAA's National Marine Fisheries Service's (NMFS) concerns regarding the proposed Mitigated Negative Declaration (MND) addressing the Sonoma County Cannabis Land Use Ordinance Update and General Plan Amendment (Update) for cannabis cultivation in Sonoma County, California. NMFS is responsible for conserving threatened and endangered marine species under the federal Endangered Species Act (ESA), and ESA-listed Central California Coast (CCC) coho salmon (*Oncorhynchus kisutch*), CCC steelhead (*O. mykiss*), and California Coastal Chinook salmon (*O. tshawytscha*) reside within many rivers and streams throughout the County. Our concerns stem from the proposed requirements for cultivators using groundwater as their water source, and how these requirements will likely be inadequate in preventing impacts to ESA-listed salmonids and their habitat.

Surface water and underlying groundwater are likely hydraulically linked throughout much of Sonoma County, and this linkage is critically important in creating seasonal habitat for juvenile salmonids. Where the groundwater aquifer supplements streamflow, the influx of cold, clean water is critically important for maintaining temperature and flow volume during summer months. Pumping from these aquifer-stream complexes can adversely affect instream habitat by lowering groundwater levels and interrupting the hyporheic flow between the aquifer and stream.

Groundwater is the predominant source of water for cannabis cultivation operations within Sonoma County. State Water Board regulations concerning surface water diversions for cannabis cultivation contain required best management practices (BMP's) highly protective of instream flow volume and fish habitat, such as requiring summer forbearance, winter diversions, and fish friendly bypass flows. However, similar BMP's are not required by the State Water Board for cultivation sites utilizing groundwater wells as a source for cannabis cultivation. Because of this discrepancy under state law, the vast majority of cannabis cultivation applications throughout the County are opting for groundwater wells as their water source. We are concerned in particular, that wells are being drilled and pumped without appropriate analysis regarding their potential impact to surface water, especially near-stream wells that may also impact groundwater/surface water dynamics and result in streamflow depletion. With those concerns in mind, we offer the following comments.

Re Page 70, Section 10(b): The MND states the following: *Future cannabis facilities in rural areas would rely on either surface (rivers, lakes, and springs) or well water sources. Accordingly, the introduction of cannabis cultivation in these areas could increase the use of groundwater.* As explained above, very few rural cultivation sites are currently using surface water diversions as a water source, likely to work around the required BMP's mandated by the State Water Board for surface water diversions. NMFS is concerned about both surface water and groundwater diversions, as they are linked, and we believe the potential for impacts from unrestricted groundwater use is high.

Re Page 71, Section 10(b)(4)(b): This section addresses near-stream wells (e.g., "well is within 500 feet of blue line stream"), and is intended to minimize streamflow depletion impacts. According to the MND, if a well is within 500 feet of a blue line stream, the applicant must document one of three things: 1) prepare a "net zero water plan", 2) document the well is near the Russian River or Dry Creek, or 3) document the well is within the Groundwater Availability Zone 1 or 2. By including the third option, the authors of the MND seem to assume that streamflow depletion impacts are unlikely in Groundwater Availability Zones 1 and 2. However, streamflow depletion can occur within any of the groundwater zones in Sonoma County, and is largely influenced by well distance from the waterway, the pumping intensity, and the transmissivity of the underlying geology, not groundwater availability zones. Thus, the current standards and requirements appear unlikely to adequately mitigate the potential impact of streamflow depletion, making a MND inappropriate. NMFS recommends the Update require either a net zero water plan, or a hydrogeologic analysis confirming streamflow depletion impacts are unlikely, before any cannabis operation utilizing a near-stream well is approved, regardless of which Groundwater Availability zone it may occur in.

Furthermore, while we understand that the current Update applies only to cannabis cultivation, NMFS recommends the County also update their well ordinance and permitting procedures to apply this requirement (i.e., require a net zero water plan, or a hydrogeologic analysis confirming streamflow depletion impacts are unlikely) to all permit applications for near-stream wells.

NMFS appreciates the opportunity to comment regarding the proposed Mitigated Negative Declaration addressing the Sonoma County Cannabis Land Use Ordinance Update and General Plan Amendment for cannabis cultivation If you have any comments or questions regarding this letter, please contact Mr. Rick Rogers at rick.rogers@noaa.gov, or 707-578-8552.

Sincerely,

Robert Coey
North Coast Branch Supervisor
North-Central Coast Office

cc: (via email)
Bryan McFadin, North Coast Regional Water Quality Control Board (Bryan.McFadin@waterboards.ca.gov)
Wes Stokes, California Department of Fish and Wildlife (Wes.Stokes@wildlife.ca.gov)
David Hines, California Department of Fish and Wildlife (David.Hines@wildlife.ca.gov)
Daniel Schultz, State Water Board (Daniel.Schultz@waterboards.ca.gov)
Jessica Maxfield, California Department of Fish and Wildlife (Jessica.Maxfield@wildlife.ca.gov)

EXHIBIT 2

Integrated Surface and Groundwater Modeling and Flow Availability Analysis for Restoration Prioritization Planning, Upper Mark West Creek Watershed, Sonoma County, CA

Wildlife Conservation Board Grant Agreement No. WC-1996AP
Project ID: 2020018

December 2020

Prepared for:

Sonoma Resource Conservation District
1221 Farmers Lane, Suite F, Santa Rosa, CA 95405

and

State of California, Wildlife Conservation Board
1700 9th Street, 4th Floor, Sacramento, CA 95811

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Dedication

In recognition of those many residents of the Mark West Creek watershed that have suffered losses in the past few years to the Tubbs Fire and the Glass Fire, we dedicate this report in their honor. Many of the citizen contributors to this effort have been working for many years to advance the consciousness of the community with respect to wildfire hazards, fuel management and fire safe communities, and it is an unfortunate truth that there remains much to be done. We dedicate this report in the spirit of community service and the example that has been set by these citizens, families, friends, and communities.

Acknowledgements

Many individuals and organizations contributed to the successful completion of this project including the various members of the project team from the Sonoma Resource Conservation District, Coast Range Watershed Institute, O'Connor Environmental Inc., Friends of Mark West Watershed, the Pepperwood Foundation, and Sonoma County Regional Parks. Many individual landowners graciously provided access for field reconnaissance and streamflow and groundwater monitoring work. Other agencies and organizations including California Sea Grant, California Department of Fish and Wildlife, National Marine Fisheries Service, Sonoma Water, Trout Unlimited, Permit Sonoma, and Sonoma Water also contributed significantly to the project by sharing data and providing input through three Technical Working Group meetings.

Limitations

The descriptions of watershed and streamflow conditions described in this report are based on numerical model simulations which were developed using best available data and hydrologic practices. Available model input data varied widely in its resolution and accuracy, and while the model was calibrated successfully to available streamflow and groundwater monitoring data, the extent of available calibration data is relatively limited. All model scenarios represent hypothetical actions on the landscape and do not imply any interest or commitment on the part of landowners to implement them. Both the existing condition and scenario results represent approximations of real-world conditions that contain uncertainty and should be interpreted as a guide for understanding watershed hydrology and the effects of potential management actions rather than as precise quantitative predictions of actual or future conditions.

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Executive Summary

Introduction

The Mark West Creek watershed provides critical habitat for threatened and endangered anadromous fish and was recently identified in the California Water Action Plan as one of five streams statewide for targeted flow enhancement efforts. Effective implementation of a flow enhancement program requires a detailed understanding of the natural and man-made controls on spring and summer streamflows. The primary goal of this project is to provide a comprehensive hydrologic analysis of streamflow conditions and the relative effectiveness of various potential flow enhancement actions in upper Mark West Creek watershed relative to salmonid habitat requirements. The project provides a framework for prioritizing restoration efforts and developing effective strategies and projects to protect and enhance streamflows.

This study evaluates the upper 40 mi^2 of Mark West Creek watershed upstream of the Santa Rosa Plain (Figure E1) identified as critical salmonid summer rearing habitat in the State Water Resources Control Board Emergency Order WR 2015-0026-DWR (SWRCB, 2015). The study was conducted over a three year period and was completed by the Coast Range Watershed Institute (CRWI) in cooperation with the Sonoma Resource Conservation District (SRCD), Friends of Mark West Watershed, Sonoma County Regional Parks, and the Pepperwood Foundation. Assistance was also provided by local staff of California Department of Fish & Wildlife (CDFW). Funding for the project was provided by a Streamflow Enhancement Program grant from the California Wildlife Conservation Board (WCB).

O'Connor Environmental, Inc., completed the modeling analysis under contract with CRWI. The completed model is intended to serve as a tool to help evaluate the hydrologic consequences of future project proposals. The principal mission of CRWI as a tax-exempt scientific not-for-profit organization in this regard is to provide a virtual "home" for the model and to make it available for future use and updates as new management questions arise and new data become available. In this way, CRWI seeks to extend the benefits to the public of this grant-funded project beyond the immediate utility of its findings.

Approach and Methods

The principal element of the project was development and calibration of a distributed hydrologic model using the computer model code MIKE SHE. Inputs included a wide variety of climate, topographic, land cover, soils, water use, and hydrogeologic data. Outputs included estimates of the annual and seasonal water balance, streamflow hydrographs, and groundwater levels throughout the watershed. The model was constructed using 0.5-acre square grid cells to represent the landscape and stream channel cross sections spaced at 100-ft intervals to represent major stream channels. The model simulates continuous daily hydrologic conditions over a 10-yr period from water year 2009 to 2019. The model was calibrated to streamflow data at three locations and groundwater elevation data at nine locations supplemented by observations of flow conditions (wet vs. dry) on the main stem of Mark West Creek and mapped locations of seeps and springs.

A wide variety of existing and new data sources were used to construct the model. Topographic inputs were derived primarily from the Sonoma County LiDAR Digital Elevation Model (DEM). Climate inputs were derived from monitoring data collected by various entities as well as distributed climate estimates from the U.S. Geological Survey. Land cover data and vegetation properties were based on detailed mapping of vegetation communities provided by Sonoma County Agricultural Preservation and Open Space District in combination with LiDAR-derived Leaf Area Index data and literature-based rooting depth estimates. Soil properties were based on the U.S. Department of Agriculture's Soil Survey Geographic Database (SSURGO) and adjusted during model calibration.

Hydrogeologic inputs were based primarily on new analyses performed for this study which included interpretation of the distribution and thickness of geologic materials from more than

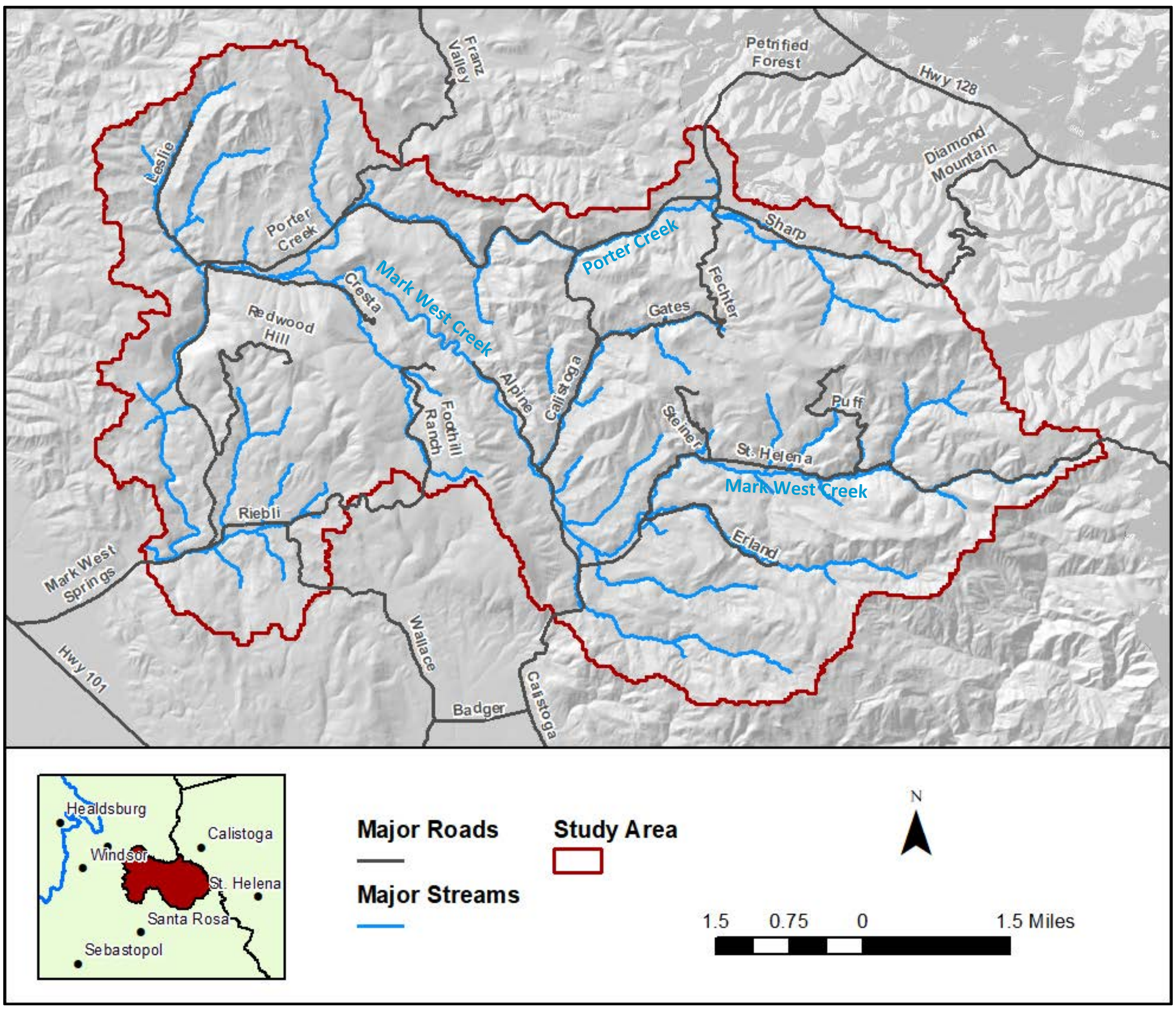


Figure E1: Map of the study area showing major roads and streams.

150 subsurface geologic logs obtained from Well Completion Reports and estimation of aquifer properties from analysis of pump tests completed for Sonoma County Well Yield Certifications at 23 wells. Estimates of the volumes, rates, and sources of water use were based on data from a variety of sources including the State Water Resources Control Board Emergency Order (Order WR 2015-0026-DWR) and Water Rights Database, available Well Completion Reports, spatial mapping of water uses (including vineyards, cannabis farms, wineries, and residences), literature values and other official estimates of water use for various purposes including data from the Town of Windsor and the City of Healdsburg.

Existing Hydrology and Streamflow

Annual precipitation varied widely over the 10-yr study period from 19.5 inches in 2014 to 61.2 inches in 2017, a pattern typical of streams in the California Coast Range (Table E1). Annual streamflow also varied widely from 8.3 to 32.8 inches, largely in response to precipitation patterns. Simulated Actual Evapotranspiration (AET), representing water use by vegetation plus evaporation, accounted for the largest outflow from the watershed over the long-term, ranging from 14.1 to 24.1 inches per year largely in proportion to annual precipitation (Table E1). Simulated annual infiltration recharge to groundwater varied substantially as a function of precipitation from 0.8 inches in the drought year 2014 to 10.1 inches in 2017, an unusually wet year (Table E1).

The simulated groundwater recharge rates indicate large spatial variability, with much of the watershed generating less than 2 in/yr and some portions of the upper watershed generating more than 20 in/yr (Figure E2). Numerous factors affect recharge rates; however, the spatial variations in recharge appear to be primarily controlled by soil properties, topographic position, and the west to east precipitation gradient. Recharge is concentrated in the upper Mark West Creek watershed upstream of and including the Van Buren Creek watershed, as well as in the upper Humbug Creek watershed (Figure E2).

The Climatic Water Deficit (CWD) provides a measure of the seasonal moisture stress and may be indicative of vegetation health and associated fire risk. This metric varied widely across the watershed from 15 to 40 in/yr except locally where lower rates occur due to availability of shallow groundwater (Figure E2). Topographic aspect appears to be a primary control on the spatial variability of CWD with north-facing slopes characterized by lower PET having significantly lower CWD values relative to south-facing slopes.

Groundwater discharge by seeps and springs represents the primary process responsible for generating summer streamflow in the watershed. This discharge is highly concentrated in the upper watershed with the watershed area upstream of Van Buren Creek generating 55% of the total springflow in the watershed despite representing only 17% of the total watershed area. Much of this discharge occurs along steep incised stream banks comprised of bedrock of the Sonoma Volcanics exposed in the upper watershed. Surface water-groundwater interaction through the streambed is relatively limited in most reaches owing to the limited depth and distribution of alluvium overlying bedrock in narrow valley bottoms. The exception to this occurs

Table E1: Annual watershed (top) and groundwater (bottom) water budgets simulated with the hydrologic model, units are inches of water per year.

	Inflows		Outflows			
Water Year	**Precipitation**	**Irrigation**	**AET**	**Streamflow**	**Groundwater Pumping**	**Change in Storage**
2010	42.51	0.07	24.06	17.14	0.15	1.23
2011	43.97	0.07	23.13	17.92	0.15	2.84
2012	28.07	0.07	20.07	10.67	0.15	-2.76
2013	28.87	0.07	17.58	12.83	0.15	-1.62
2014	19.46	0.07	14.06	8.30	0.15	-2.97
2015	26.57	0.07	14.94	12.74	0.15	-1.19
2016	33.30	0.07	17.30	13.83	0.15	2.09
2017	61.18	0.07	21.47	32.75	0.15	6.88
2018	26.59	0.07	18.93	9.07	0.15	-1.49
2019	49.77	0.07	21.63	23.44	0.15	4.62
Average	**36.03**	**0.07**	**19.32**	**15.87**	**0.15**	**0.76**

	Inflows		Outflows					
Water Year	**Infiltration Recharge**	**Streambed Recharge**	**Interflow**	**Baseflow**	**Springflow**	**ET from Groundwater**	**Groundwater Pumping**	**Change in Storage**
2010	6.05	0.71	4.29	0.76	0.58	0.82	0.15	0.16
2011	7.49	0.70	4.00	0.80	0.62	0.89	0.15	1.73
2012	2.22	0.57	1.72	0.63	0.84	1.08	0.15	-1.63
2013	2.39	0.58	2.19	0.60	0.68	0.98	0.15	-1.62
2014	0.84	0.52	1.09	0.50	0.76	1.06	0.15	-2.19
2015	2.10	0.66	1.53	0.59	0.67	1.02	0.15	-1.20
2016	4.44	0.60	2.55	0.67	0.48	0.75	0.15	0.44
2017	10.12	1.03	3.39	0.86	0.97	1.07	0.15	4.72
2018	2.87	0.53	1.91	0.62	0.72	1.06	0.15	-1.05
2019	8.17	1.03	3.48	0.83	0.99	0.99	0.15	2.76
Average	**4.67**	**0.69**	**2.61**	**0.69**	**0.73**	**0.97**	**0.15**	**0.21**

in a short reach of Mark West Creek immediately upstream of the Porter Creek confluence where relatively thick and broad alluvial deposits create losing conditions and local disconnection of surface flow in drier water years. Across the entire study area, the volume of water that recharges from streams to groundwater is approximately balanced by the volume that discharges to streams through the streambed (Table E1).

In wet years the average summer streamflow in Mark West Creek was about 0.7 cubic feet per second (cfs) below Van Buren Creek and 1.5 cfs below Porter Creek, whereas in dry years these flows declined to about 0.3 and 0.7 cfs, respectively (Figure E3 shows 10-yr average conditions). Except for the reach upstream of Porter Creek that experiences local surface flow disconnection during drier years, most reaches retain small but consistent streamflows even under drought conditions. Year to year variations in springtime streamflows were substantially larger than the variations in summer flows with average springtime flows below Van Buren Creek ranging from 2 to 8 cfs and below Porter Creek from 6 to 30 cfs.

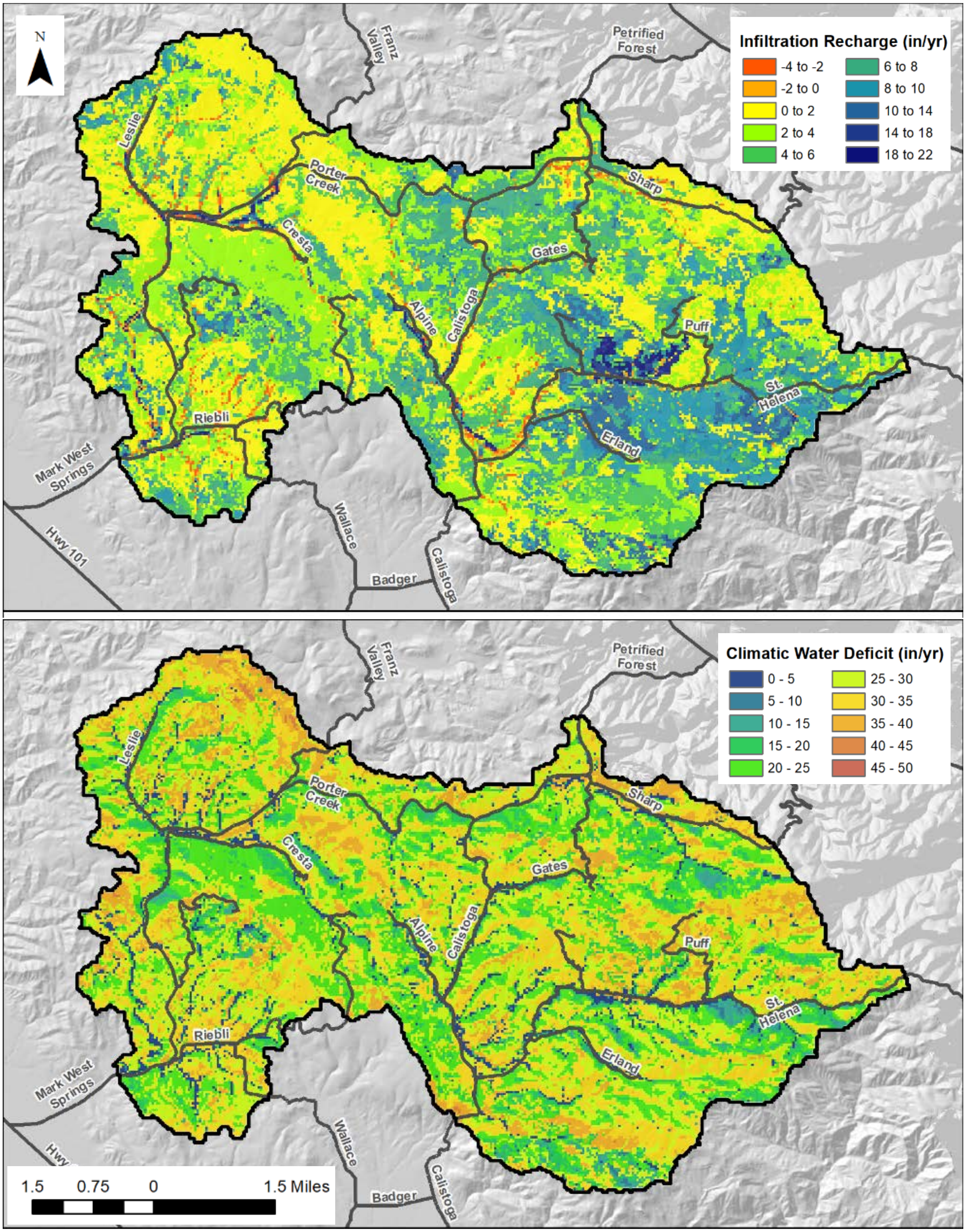


Figure E2: Mean annual infiltration recharge (top) and climatic water deficit (bottom) simulated with the hydrologic model of the upper Mark West Creek watershed.

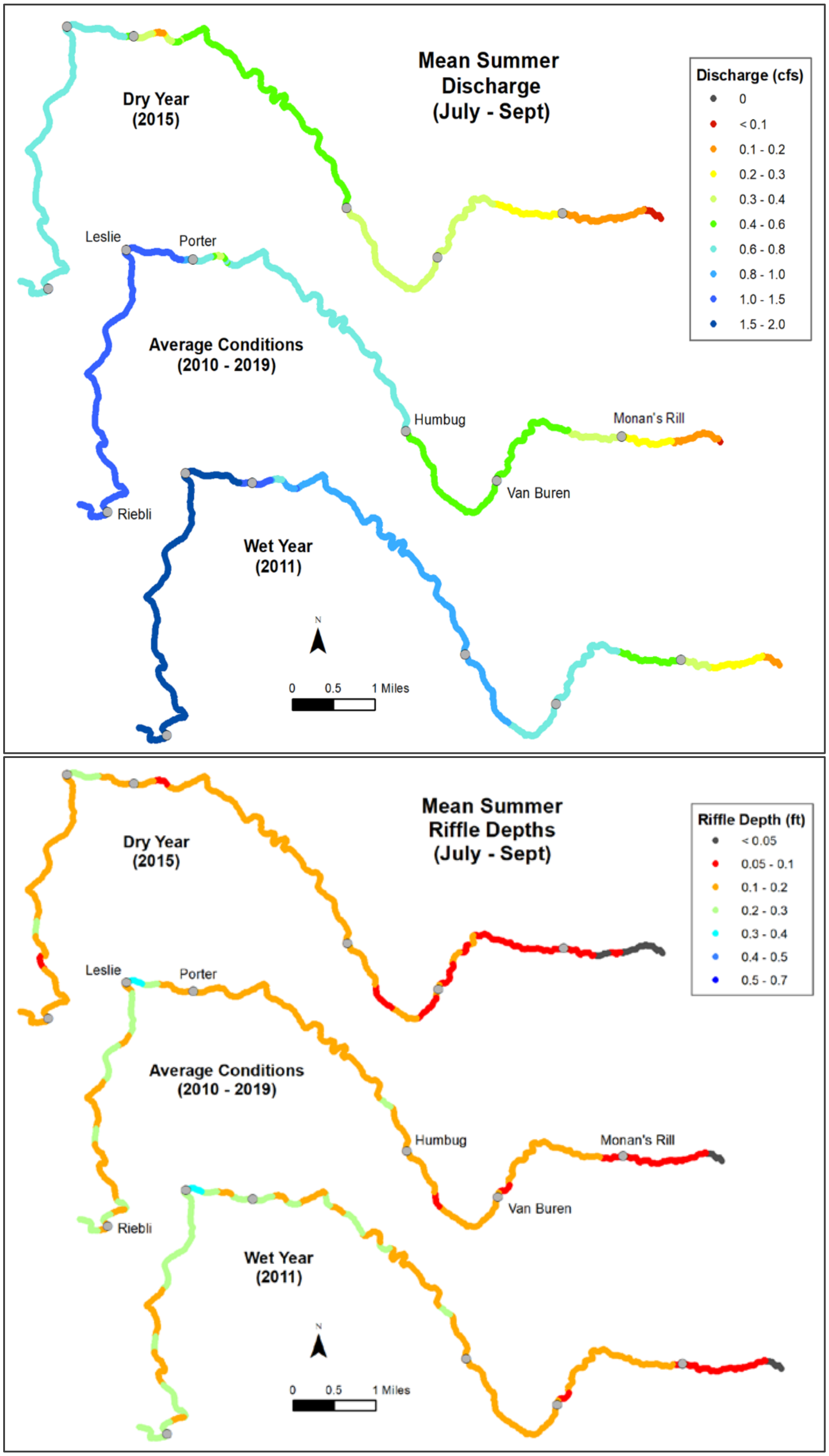


Figure E3: Mean summer streamflows (top) and riffle depths (bottom) in mainstem Mark West Creek simulated by the hydrologic model.

In most water years, average summer riffle depths remain above 0.1-ft in most locations downstream of Monan's Rill, and below Porter Creek depths reach 0.2 - 0.3 ft in many locations (Figure E3). Minimum flow depth in riffles are of interest as an indicator of fish habitat conditions. Average springtime riffle depths vary substantially between years. During the drought conditions of 2014, depths were less than 0.2-ft upstream of Van Buren Creek and between 0.2-0.4 ft below Porter Creek. In the wet water year 2017, riffle depths remained above 0.2-ft as far upstream as one river mile above Monan's Rill and were above 0.5-ft in portions of the lower watershed. The simulated spatial distributions of riffle depths reflect both reaches where riffle depths are limited by reduced streamflows (most notably the reach upstream of Porter Creek which loses flow to the alluvium) as well as where depths are limited by geomorphic controls such as the reaches about 1-mile upstream of Riebli Creek (Figure E3).

Existing Water Use

Total water use in the watershed was estimated to be approximately 430 ac-ft/yr, equivalent to about 0.5% of the mean annual precipitation. The largest uses are residential and vineyard irrigation which account for about 48% and 33% of the total water use respectively (Figure E4). Industrial uses account for the next largest fraction at about 9%. The remaining 10% consists of irrigation for pasture and other crops (6%), irrigation of cannabis (3%), winery use (<1%), and vineyard frost protection (<1%) (Figure E4). About 85% (367.1 ac-ft/yr) of the total use in the watershed is from groundwater with the remaining 15% (63.6 ac-ft/yr) coming from surface water sources. About 81% (51.5 ac-ft/yr) of the total surface water use is direct diversion to pond storage, 10% (6.7 ac-ft/yr) is direct stream diversions, and 9% (5.4 ac-ft/yr) is diversion at springs.

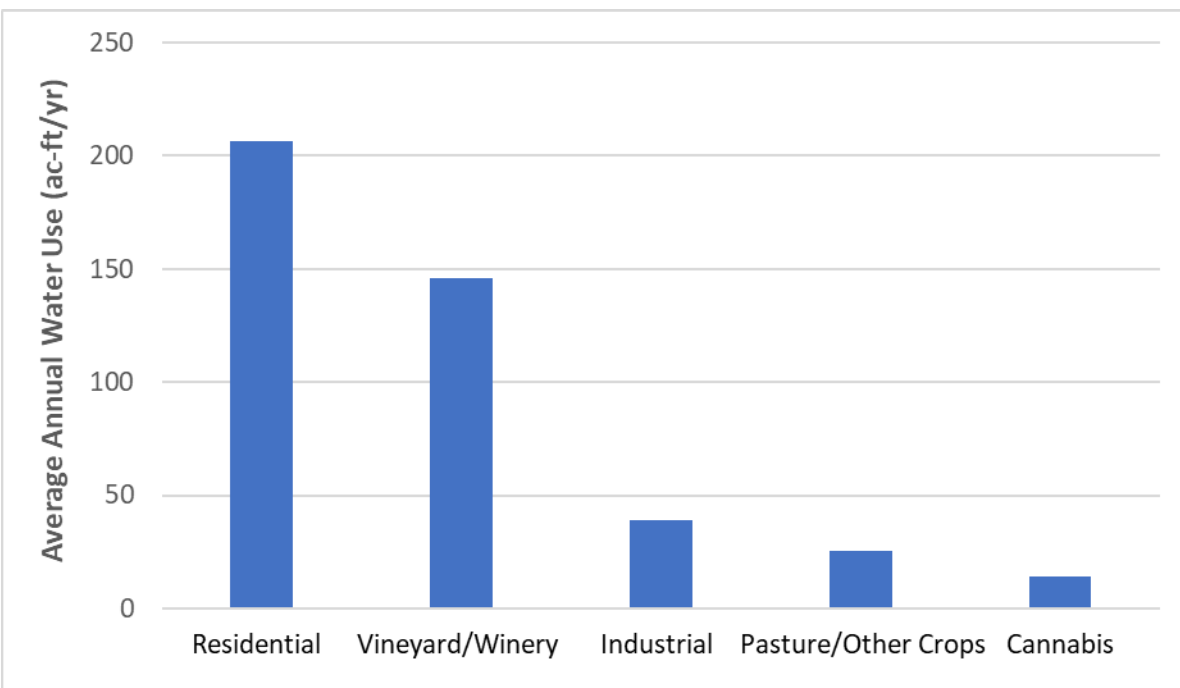


Figure E4: Water use in the Mark West Creek watershed study area by major water use category.

Fish Habitat Characterization

We developed two streamflow classifications based on the simulation results to represent habitat conditions, one for smolt outmigration and one for juvenile summer rearing. Both classifications focus on a 0.2-ft Riffle Crest Thalweg Depth (RCTD) threshold which is intended to represent the minimum flow conditions required to provide suitable habitat for salmonids (optimal habitat conditions require higher RCTDs than these minimum thresholds). We also compiled available continuous temperature data collected by CDFW, Trout Unlimited, CA Sea Grant, and Sonoma Water from 15 locations to develop a simple water temperature classification based on Maximum Weekly Maximum Temperature (MWMT) relative to thresholds of impairment for salmonids. Finally, we compiled available physical habitat data from CDFW habitat surveys and our own field observations to describe other important factors for salmonid habitat including pool characteristics along with spawning and winter refugia conditions.

A simple scoring system was used for each flow classification. Scores range from zero for reaches where RCTDs never reach the target of 0.2-ft during the summer rearing and spring outmigration timeframes in the 10-yr average condition to four for reaches that continuously maintain 0.2-ft RCTDs even during drought conditions. We developed a final habitat suitability classification based primarily on the flow and temperature classifications but also informed by the other available physical habitat data and recent fisheries monitoring information.

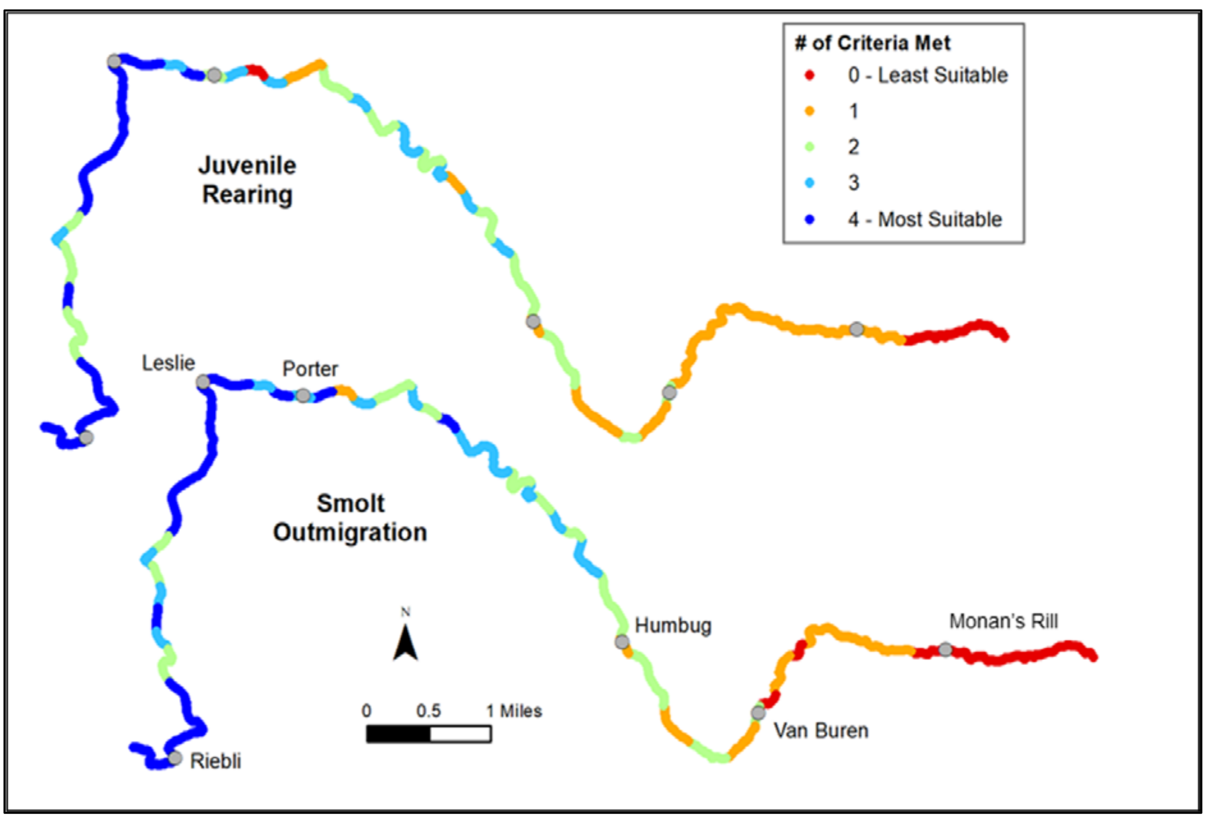


Figure E5: Flow-based habitat suitability classifications for juvenile rearing and smolt outmigration in mainstem Mark West Creek.

The flow-based habitat classification results indicate that most reaches are impaired for smolt outmigration and juvenile rearing (Figure E5). Upstream of Van Buren Creek either zero or one of four flow classification criteria are met, most reaches between Humbug Creek and Porter Creek meet two or three of the criteria, and most reaches below Porter Creek meet three or four criteria (Figure E5). Notable exceptions to this include short reaches upstream of Porter Creek and between Leslie and Riebli Creeks which are more flow-limited than adjacent upstream and downstream reaches. Most reaches are also impaired with respect to stream temperature, with two of three temperature criteria met upstream of Van Buren Creek and only one criterion met between Van Buren Creek and a point about 2-miles upstream of Porter Creek (Figure E5). Documented temperature impairment is most severe in the 2-mile reach upstream of Porter Creek with none of the criteria met (MWMT > 23.1 °C) at available monitoring stations; no data was available farther downstream (Figure E6).

We examined temporal variations in temperatures relative to streamflows observed at the stream gauges in the watershed and found no obvious correlations between streamflow and temperature at the most temperature-impaired locations. This suggests that streamflow is not the primary control on temperature and that even significant streamflow enhancement is unlikely to mitigate elevated temperatures. We also examined the relationship between pool depth and temperature in six pools monitored in 2017 by CDFW upstream and downstream of Humbug Creek. Pools with depths greater than 3.5-ft maintained temperatures below severely impaired levels whereas shallower pools less than 2.5-ft deep did not. Although based on a limited sample size and a single water year, these observations suggest that deep pools likely

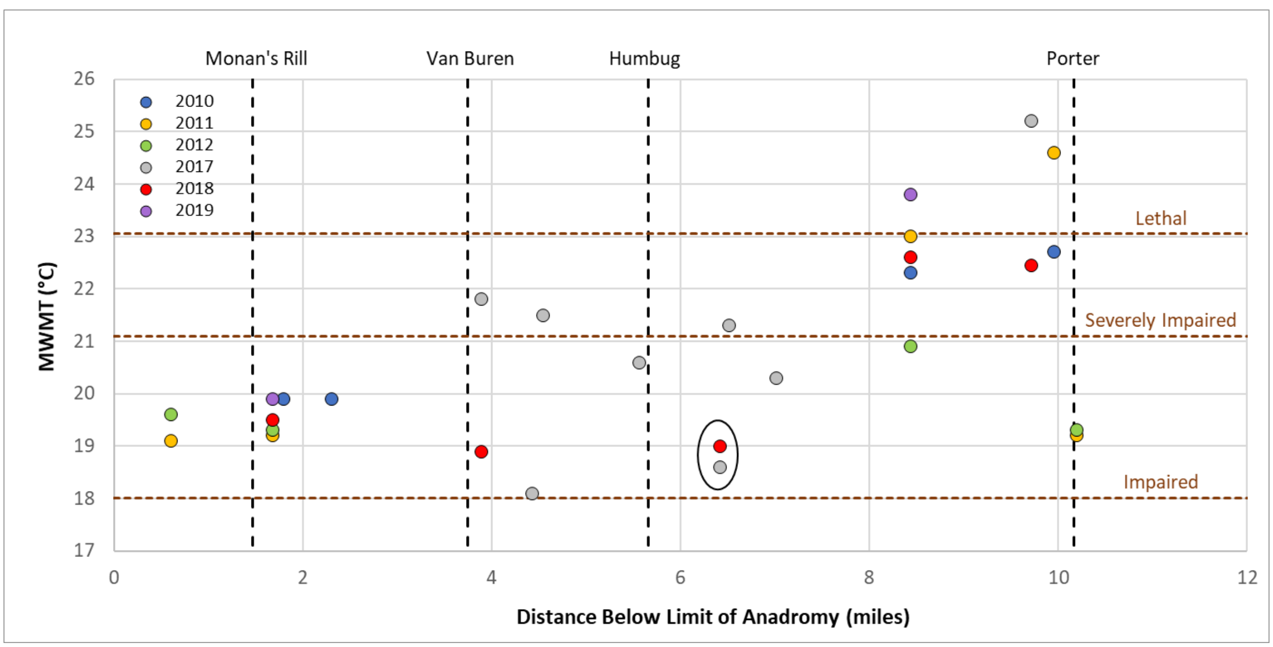


Figure E6: Longitudinal and temporal variations in Mean Weekly Maximum Water Temperature (MWMT) derived from continuous temperature data at 15 stations between 2010 and 2019, black oval indicates location of deep pool cold water refugia; temperature data from CDFW, Sonoma RCD, CA Sea Grant, and Trout Unlimited.

provide critical refugia for salmonids in Mark West Creek when extreme high temperatures occur in shallower pool habitats.

The overall salmonid habitat classification identifies an ~4 mile reach of Mark West Creek between about 0.5 river miles downstream of Van Buren Creek and about 2 river miles upstream of Porter Creek as providing the best overall habitat for salmonids in the watershed (Figure E7). This reach is considered most suitable because it represents the best combination of flow and water temperature conditions and is also consistent with available data and observations about other indicators of habitat quality such as pool and spawning conditions.

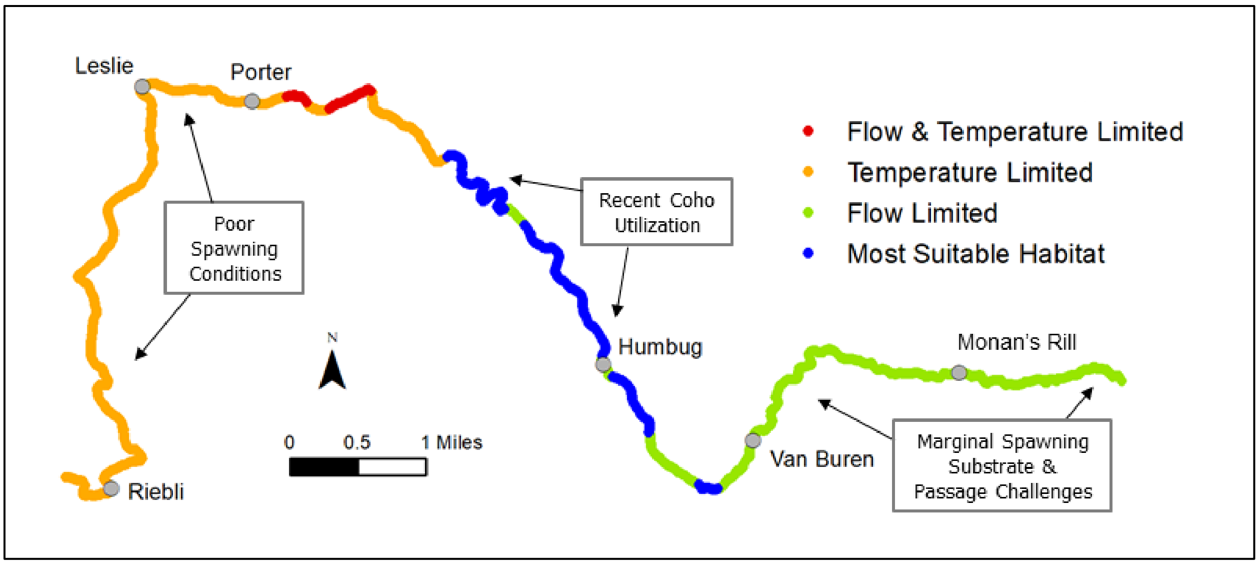


Figure E7: Final overall habitat suitability classification for Mark West Creek identifying the high priority reaches with the most suitable overall habitat conditions in blue.

Scenario Analysis

The model was used to evaluate alternative streamflow enhancement strategies along with predictions of climate change effects on streamflow. Individual enhancement strategies, combinations of these strategies, and alternative future climate conditions were evaluated in different model runs (scenarios) to identify advantages and disadvantages of different strategies under a variety of conditions. The scenario analysis is intended to provide guidance regarding streamflow management to stakeholders in the watershed, natural resource managers, and government regulatory authorities. Scenarios analyzed are summarized in Table E2.

Water Use

Analysis of changes in streamflow revealed that the sustained cumulative effects of surface water diversions and groundwater pumping are modest and that cessation of all water use would result in increases in mean summer streamflow of about 6% (0.04 cfs) in the ~4-mile high priority reach and ~8% (0.09 cfs) at the watershed outlet (Figure E13). The analysis suggests that the groundwater response timescales are long and the reported flow increases represent conditions in the 10-yr period following 40-yrs without water use. Cumulatively, surface water diversion and groundwater pumping each have an approximately equal sustained effect on streamflows, however cumulative groundwater use is more than five times that of surface water use in the watershed. Surface water diversions were also found to result in more substantial short-term (daily) streamflow depletion up to about 14% with the largest impacts occurring in the reach downstream of Humbug Creek (Figure E8).

Streamflow depletion from groundwater pumping was found to occur over long (decadal) timescales. While we did find some sensitivity in the rate of depletion as a function of distance of wells from streams and springs and depths of screened intervals, all wells generated depletion given enough time. The rate of depletion from near-stream wells (within 500-ft) screened in the upper 200-ft was about 1.7 times the rate for wells at greater horizontal distance from streams screened at depths greater than 200-ft. No direct relationship between the seasonality of pumping and the timing of streamflow depletion was apparent, with maximum depletion occurring during winter despite maximum pumping occurring during the summer months. This results from pumping effects on groundwater recharge and discharge processes being most pronounced during the active recharge season and from buffering of summer streamflow depletion by reductions in transpiration of riparian vegetation.

Pond Releases

The summer pond release scenario generated the largest increases in average summer streamflow of the stand-alone scenarios, with increases of about 13-14% (0.08 cfs in the high priority reach and 0.16 cfs at the watershed outlet) (Figure E13). The predominance of gaining streamflow conditions (groundwater discharge to streams) in most reaches of the creek causes only limited flow losses to groundwater (losing streamflow condition) downstream of the releases, which makes this strategy particularly well-suited for this watershed which is characterized by a lack of thick alluvial deposits adjacent to streams. The springtime pond release scenario was designed to increase flows over a short (3-week) period coinciding with the timing of the end of typical peak smolt outmigration in May. Examination of discharge and riffle depth hydrographs during drought conditions of 2014 shows that the spring releases substantially increase flows in the identified high priority reach during this critical period, extending the duration of passable conditions by approximately two weeks.

Forest, Grassland, & Runoff Management

Large-scale implementation of forest, grassland, and runoff management projects resulted in modest but significant changes in the water balance. All three strategies increase groundwater recharge but through different mechanisms. Forest management decreased actual evapotranspiration by about 5% on treated lands resulting in more water available for recharge, grassland management increased the water holding capacity of soils increasing soil water availability for recharge, and runoff management increased infiltration resulting in increased recharge as well as AET (Figure E9). Watershed-wide increases in infiltration recharge ranged from about 2-4% (230-420 ac-ft/yr).

Table E2: Overview of the scenarios evaluated with the hydrologic model.

Scenario Category	Scenario #	Scenario Name	Brief Description
Water Use	1	No Diversions	All surface water diversions turned off
	2	No Groundwater Pumping	All groundwater pumping turned off
	2B	No Pumping Near Streams	Wells within 500-ft of streams and screened in upper 200-ft turned off
	2C	No Pumping Near Springs	Wells within 500-ft of springs turned off
	2D	No Pumping From Tuff	Wells screened in surficial tuffaceous materials turned off
	2E	No Distal Pumping	Wells distal to streams/springs/tuff and not screened in upper 200-ft turned off
	3	No Water Use	All surface diversions and groundwater pumping turned off
Land/Water Management	4	Forest Management	Forest treatment on 7,054 acres of oak and Douglas Fir forests
	5	Grassland Management	Application of organic matter on 2,874 acres of grasslands
	6	Runoff Management	Manage runoff from 310 acres of developed lands to maximize infiltration
	7	Summer Pond Releases	Release water from three ponds with a total release of 0.19 cfs from June 15th to Sept 15th
	7B	Spring Pond Releases	Release water from three ponds with a total release of 0.82 cfs from May 7th to May 28th
	8	Combined Management	Combination of Scenarios 4 through 7
Climate Change	9	CNRM Climate Change	2070-2099 timeframe future climate as predicted by the CNRM model under the rcp8.5 emmisions pathway
	10	CCSM4 Climate Change	2070-2099 timeframe future climate as predicted by the CCSM4 model under the rcp8.5 emmisions pathway
	11	GFDL Climate Change	2070-2099 timeframe future climate as predicted by the GFDL model under the SRES B1 emmisions pathway
	12	MIROC esm Climate Change	2070-2099 timeframe future climate as predicted by the MIROC esm model under the rcp8.5 emmisions pathway
Mitigated	13	GFDL & Pond Releases	Combination of Scenarios 11 & 7 or 7B
	14	GFDL & Combined Management	Combination of Scenarios 11 & 7 or 7B

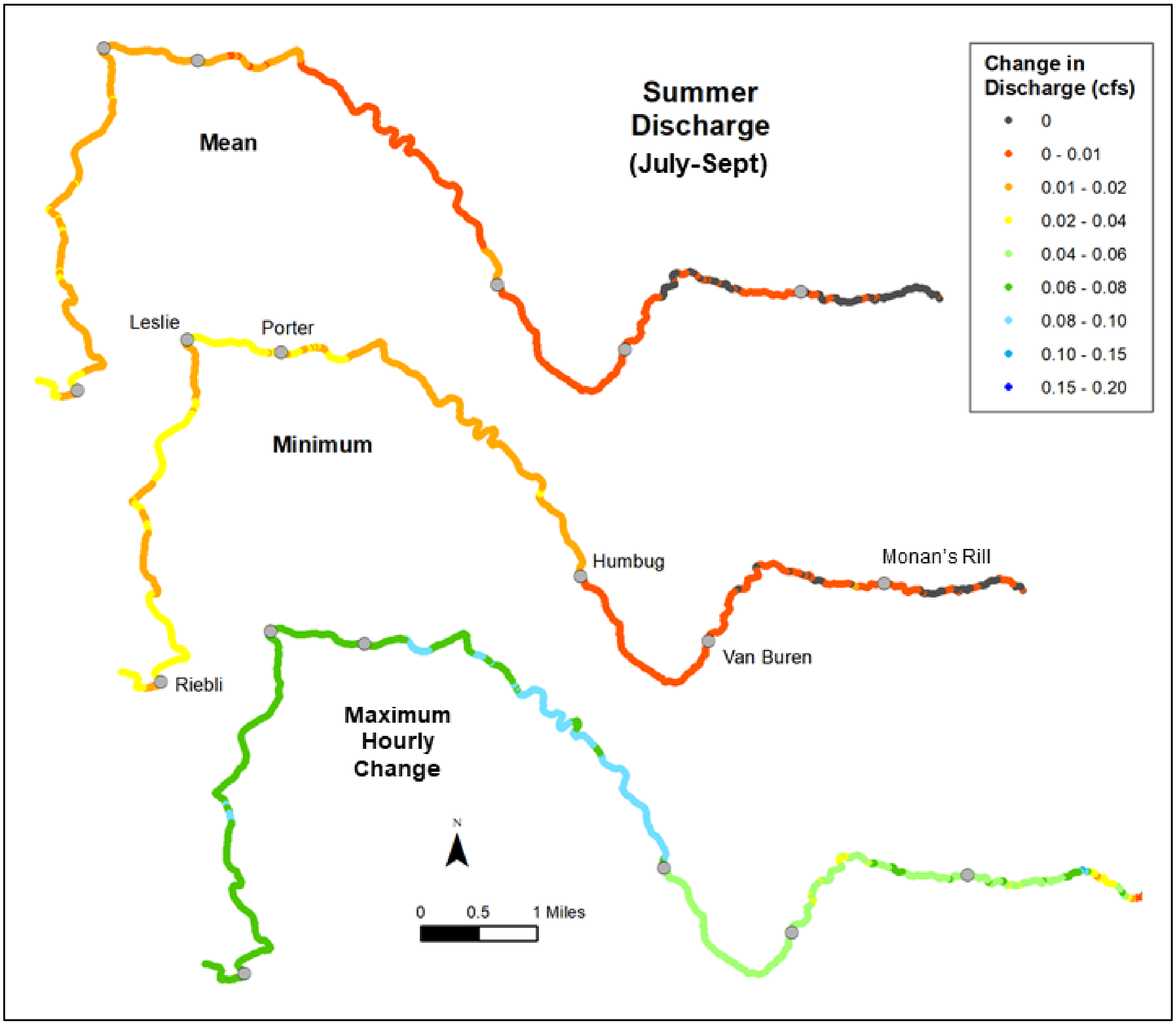


Figure E8: Changes to mean and minimum summer streamflow, and maximum hourly changes from cessation of all surface water diversions (Scenario 1).

Of the three management scenarios, forest management generated the largest increases in average summer streamflow (6%) in the high-priority reach followed by runoff management (3%), and grassland management (2%) (Figure E13). Runoff management generated a larger response at the watershed outlet (10%) reflecting the concentration of developed areas in the lower watershed. Increases in springtime discharges for the runoff and grassland management scenarios were minimal, however the forest management scenario generated increases of 0.5-0.7 in the high priority reach. These changes represent 4-6% of the total flow and primarily reflect small increases in runoff during spring storms.

Combined Management

Combining all the land/water management scenarios (pond releases with forest, grassland and runoff management), mean summer discharges in the high priority reach increased by about 21% (0.13 cfs) and by about 28% (0.31 cfs) at the watershed outlet (Figures E10 & E13). These changes represent about 86% of the sum of the changes of the four individual scenarios indicating a small negative feedback in effectiveness when the effects on the water balance dynamics from the various actions are combined.

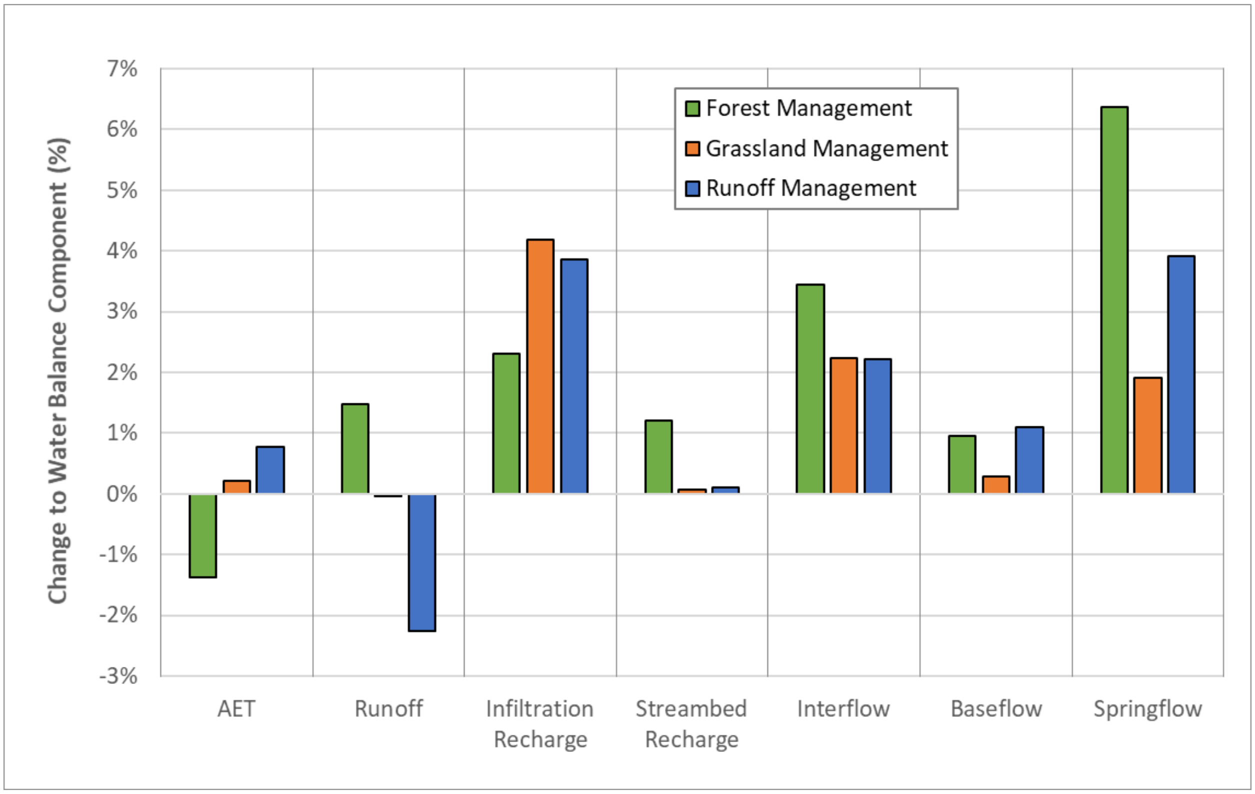


Figure E9: Watershed-wide percent change in select water balance components for the forest, grassland, and runoff management scenarios (Scenarios 4-6).

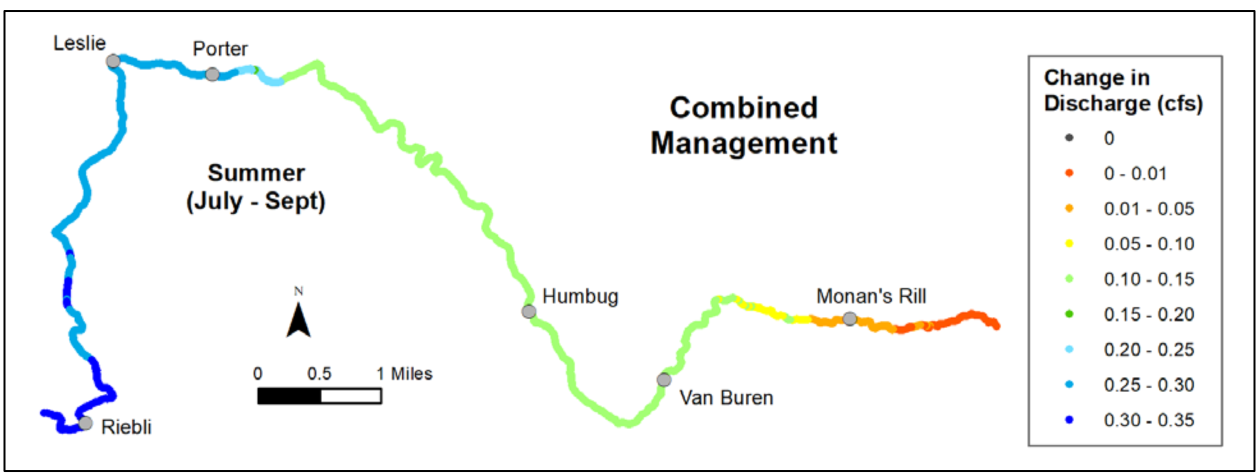


Figure E10: Simulated changes to the 10-yr average mean summer streamflow for the combined management scenario (Scenario 8, note the scale in the legend is different from previous figures for other scenarios).

Climate Change

Four climate change scenarios were selected to represent the range of plausible changes to precipitation and temperatures as predicted by available climate model data, and to include a scenario representative of the mean projections. These scenarios predict a range of maximum temperature increases of between 3.7 and 11.0°F and changes in mean annual precipitation ranging from a decrease of 21% to an increase of 37%.

The 10-yr mean annual water balance results indicate substantial variability in predictions of future hydrologic changes. The CNRM scenario predicts large increases in both infiltration recharge (44%) and streambed recharge (33%), the CCSM4 model predicts minimal changes in recharge, and the GFDL and MIROC esm scenarios predict significant decreases in infiltration recharge (29-40%) and streambed recharge (17-25%) (Figure E11). Increased recharge in the CNRM scenario results in increases in groundwater discharge expressed as interflow (32%), baseflow (11%), and springflow (36%). Similarly, groundwater discharge decreases for the scenarios that predict decreases in recharge. The largest decreases are predicted by the MIROC esm scenario where interflow, baseflow, and springflow are predicted to decrease by 30%, 21%, and 46% respectively (Figure E11). Comparison of the water balance for the driest of the 10 years in each simulation reveals that the trajectories of the changes in the water balance between the four scenarios are more similar during drought conditions than for long term average conditions, with all four scenarios predicting decreases in runoff, infiltration recharge, and streambed recharge under drought conditions (Figure E11).

All four scenarios indicate increases in Climatic Water Deficit (CWD). The mean CWD for the watershed over the 10-yr simulation period is predicted to increase from 26.0 in/yr under existing conditions to between 30.3 and 33.9 in/yr under future climate conditions. Increases in CWD of this magnitude (17-30%) may be expected to lead to significant changes in vegetation communities and increases in fire risk. It is important to note that these simulations represent the hydrologic effects of changes in climate but do not include secondary effects that may be expected under a significantly altered future climate regime such as changes in vegetation cover and irrigation water demands.

The climate change scenarios generated a wide range of predictions of future streamflows with three of the four scenarios indicating decreases in average summer streamflow of between 6% and 47% and one scenario indicating increases of about 15-19% (Figure E13). In contrast to the variable predictions in mean summer discharges, all four models predict large decreases in mean spring discharges that would be expected to hinder outmigration of juvenile salmonids. The CNRM scenario produces the smallest decreases with mean spring discharge in the high-priority reach of Mark West Creek decreasing from 7.8 cfs to 5.1 cfs (Figure E13). The MIROC esm scenario predicts the largest decreases with flows in the high priority reach decreasing from 7.8 cfs to 3.0 cfs.

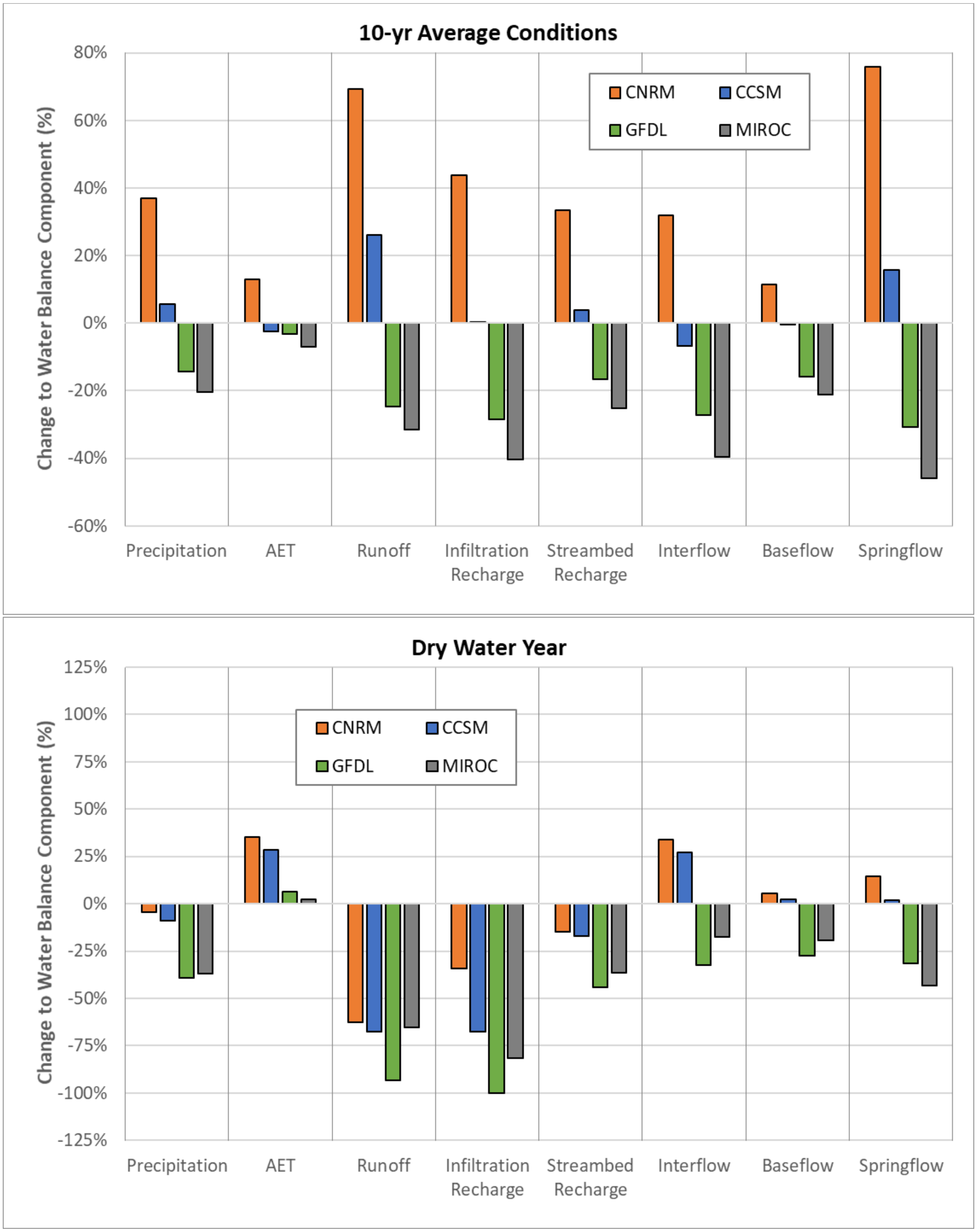


***Figure E11:** Percent change in various components of the water balance for the four climate change scenarios relative to existing conditions; 10-yr average conditions (top) and the driest water year in each 10-yr simulation period (bottom).*

Mitigated Scenarios

The mitigated scenarios combine the pond release and combined management scenarios with the GFDL future climate scenario. These scenarios indicate that pond releases can likely offset a significant portion of the projected decreases in summer streamflow predicted by some of the climate models and if combined with forest, grassland, and runoff management, are likely large enough to completely offset these projected decreases (Figures E12 & E13). If future climate more closely resembles the predictions of the CNRM or CCSM4 models, pond releases and combined management would be expected to result in summer flow enhancement above existing conditions. None of the potential actions generate changes large enough to significantly offset the substantial decreases in springtime discharges predicted by the four climate scenarios. Shorter-duration flow releases over periods of days to weeks strategically timed during the critical smolt outmigration period in spring could increase flow depths above fish passage thresholds and likely provide a key climate change mitigation strategy to address predicted reductions in streamflow during the spring season (Figure E12).

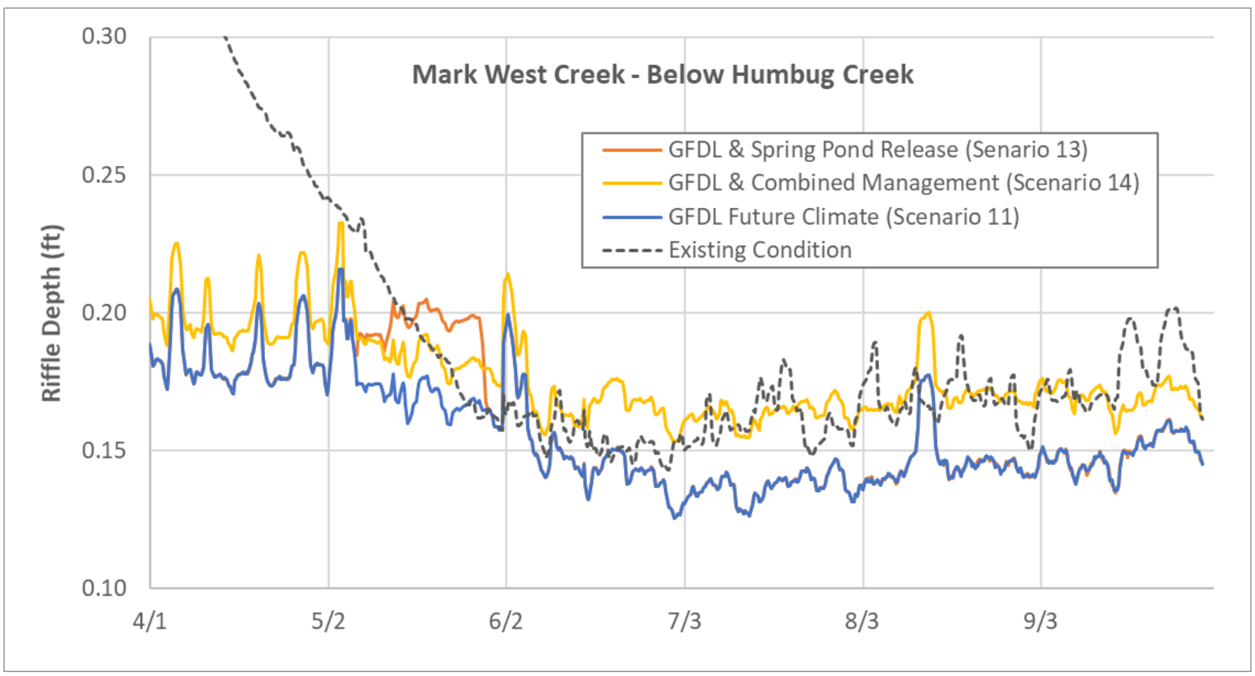
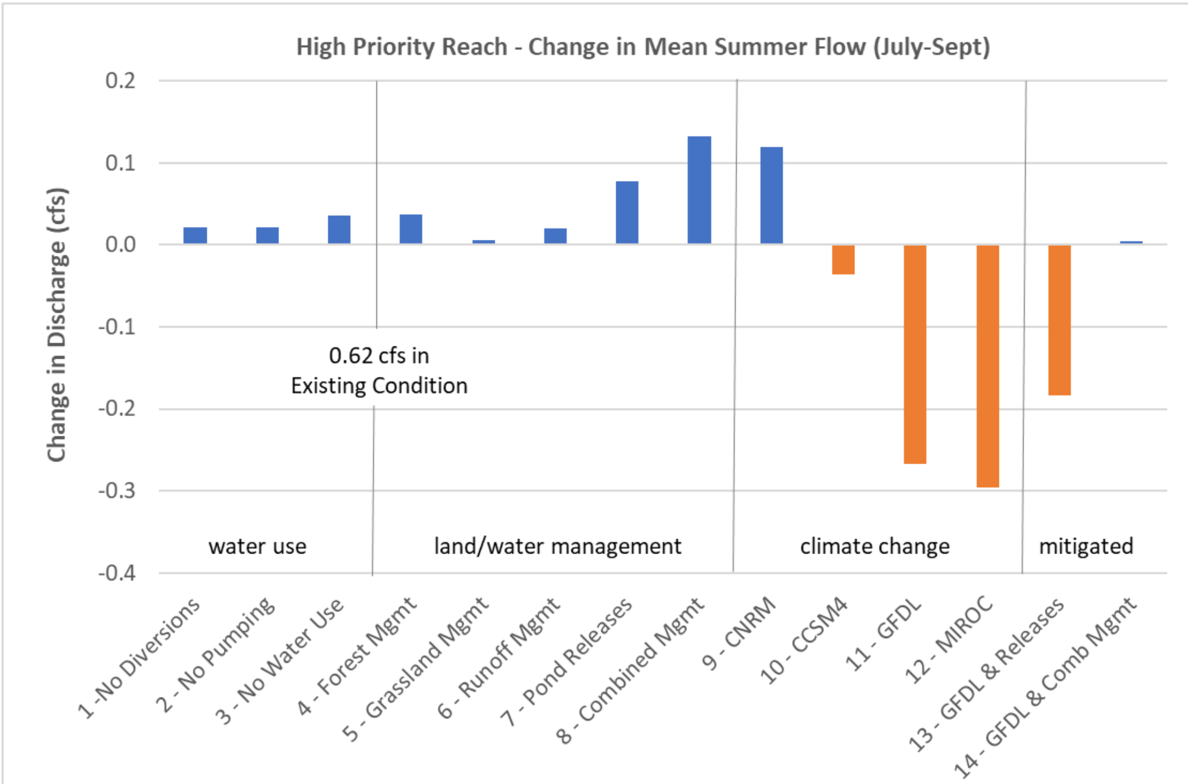


Figure E12: Spring and summer riffle depths for the driest year in the 10-yr simulation in Mark West Creek below Humbug Creek for existing conditions, the GFDL future climate scenario (Scenario 11), the GFDL & spring pond release scenario (Scenario 13), and the GFDL & combined management scenario (Scenario 14).



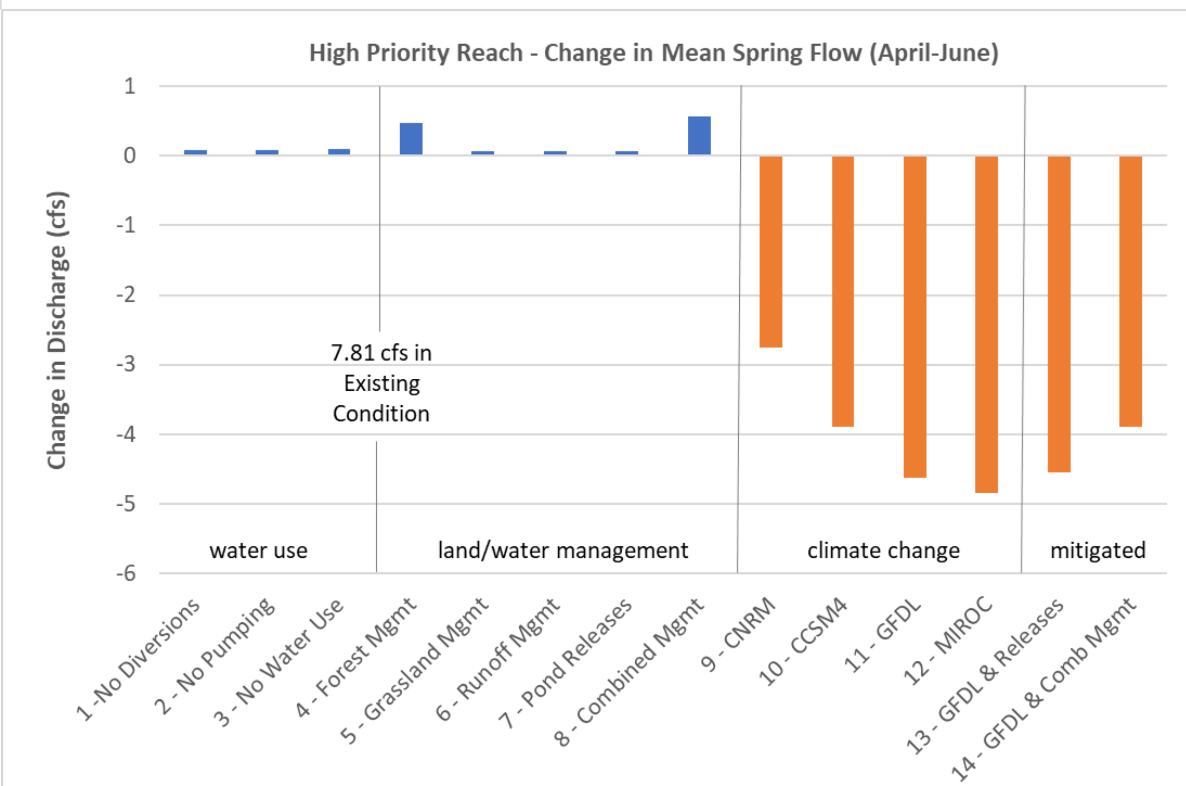


Figure E13: Summary of the simulated changes in mean summer (top) and mean spring (bottom) streamflow for Scenarios 1-14 averaged over the high-priority habitat reach.

Restoration & Management Recommendations

Habitat Enhancement

Based on simulated riffle depth and observed water temperature data informed by CDFW habitat inventory and CA Sea Grant fisheries monitoring data, the four mile reach extending from 0.2 miles upstream of Alpine Creek to 2.0 miles upstream of the Porter Creek confluence has the best overall conditions for supporting salmonids (Figure E14). We recommend that habitat enhancement projects be focused in this high priority reach where there exists the greatest likelihood of supporting overall reach conditions suitable for salmonids.

Based on a limited number of sample sites, water temperatures in the high priority reach appear to remain below severely impaired levels in pools with depths above about 3.5-ft whereas severely impaired temperatures occur in shallower pools (see Figure E6). More temperature monitoring and pool inventory analysis is recommended to identify pools providing critical temperature refugia. A temperature study is also warranted to better understand the controls on water temperatures and identify possible mitigation actions. Our preliminary findings suggest that streamflow is not the primary control on temperature and that encouraging formation of stable deep pools and maximizing shade on the stream surface are likely the most important immediate mitigation actions.

In-stream large wood (logs and trees) loads are low in Mark West Creek and projects to install large wood to encourage formation and enhancement of existing deep pools is recommended. Where needed, riparian planting projects to maximize shading of the summer water surface are recommended. Opportunities for development of off-channel habitat projects to enhance winter rearing habitat are also available in the identified reach, and these types of projects are also recommended to support improved conditions in the reach for other limiting life cycle stages.

Flow Protection/Enhancement

Summer baseflow throughout Mark West Creek is controlled primarily by spring discharge concentrated in the upper watershed. We recommend that the various flow protection and enhancement actions described below be focused in the watershed area contributing to the identified high priority reach where they are more likely to provide the most meaningful flow benefits. The portion of the watershed upstream of Van Buren Creek is of even greater importance for streamflow protection and enhancement given the disproportionate role this area plays in generating summer streamflow supplied to downstream reaches (Figure E14).

To assist in understanding the relative effectiveness of the various flow enhancement strategies we normalized simulated increases in streamflow based on a ‘typical’ parcel/project for six project types in consultation with Sonoma RCD. We also developed a rough cost estimate for each typical project and normalized the results again based on a $25,000 project cost. The six projects and estimated costs include:

- Groundwater Pumping Offset – installation of a 10,000 gallon rainwater catchment tank and associated reduction in groundwater pumping - $38,000

- Surface Diversion Replacement – replacement of a direct stream or spring diversion with a new groundwater well - $33,000
- Runoff Management – construction of an infiltration basin sized to capture the 10-yr 48-hr storm volume from a 3,000 ft^2 rooftop or other impervious area - $22,500
- Grassland Management – compost application on 4.6 acres of grassland (average per parcel acreage in the model scenario) - $7,000
- Forest Management – thinning and/or controlled burning on 5.6 acres of forested lands requiring treatment (average per parcel acreage in the model scenario) - $15,000
- Pond Release – summer flow release of 11.3 ac-ft from an existing on-stream pond (average release volume of the three ponds in the model scenario) - $20,000

Releasing water from existing ponds was found to be by far the most effective individual strategy for enhancing streamflows. On a cost basis, the streamflow benefits of one flow release project were found to be more than 50 times greater than an average surface water diversion replacement project and more than 500 times greater than an average grassland management project (the second and third most effective strategies, Figure E15). Examination of existing ponds revealed that there are only three ponds upstream of the high-priority reach with sufficient storage to provide meaningful releases, and we recommend that flow release projects be developed for these ponds if possible.

There are many existing ponds that could likely be enhanced, and new ponds could be created specifically for flow releases. Given the disproportionate effectiveness of pond releases for streamflow enhancement this approach should be seriously considered. Water temperature and other water quality and invasive species considerations should be an important aspect of planning flow release projects since water temperatures are already impaired and it is critical that flow releases do not further increase temperatures or introduce invasive species. There are various strategies that may be employed to mitigate elevated pond temperatures during planning and design (e.g. bottom releases, surface covering, cooling towers).

Replacing direct stream or spring diversions from surface water with groundwater pumping was the second most effective of the six project types, whereas offsetting groundwater pumping with storage was the least effective (Figure E15). While the modeling did suggest some relationship between the degree of streamflow depletion and the screen depth and distance of wells from streams/springs, these differences were modest and we did not find any direct relationship between the timing of pumping and the timing of streamflow depletion. These findings suggest that replacing direct stream and spring diversions with storage and/or groundwater pumping is a viable approach for enhancing streamflow conditions but that offsetting groundwater pumping with storage or shifting the timing of pumping from summer to winter is unlikely to lead to appreciable improvements in flow conditions. This is not to suggest that specific wells in specific locations are incapable of streamflow depletion; however, our review of well data and modeling results indicate that this would be uncommon in the study area.

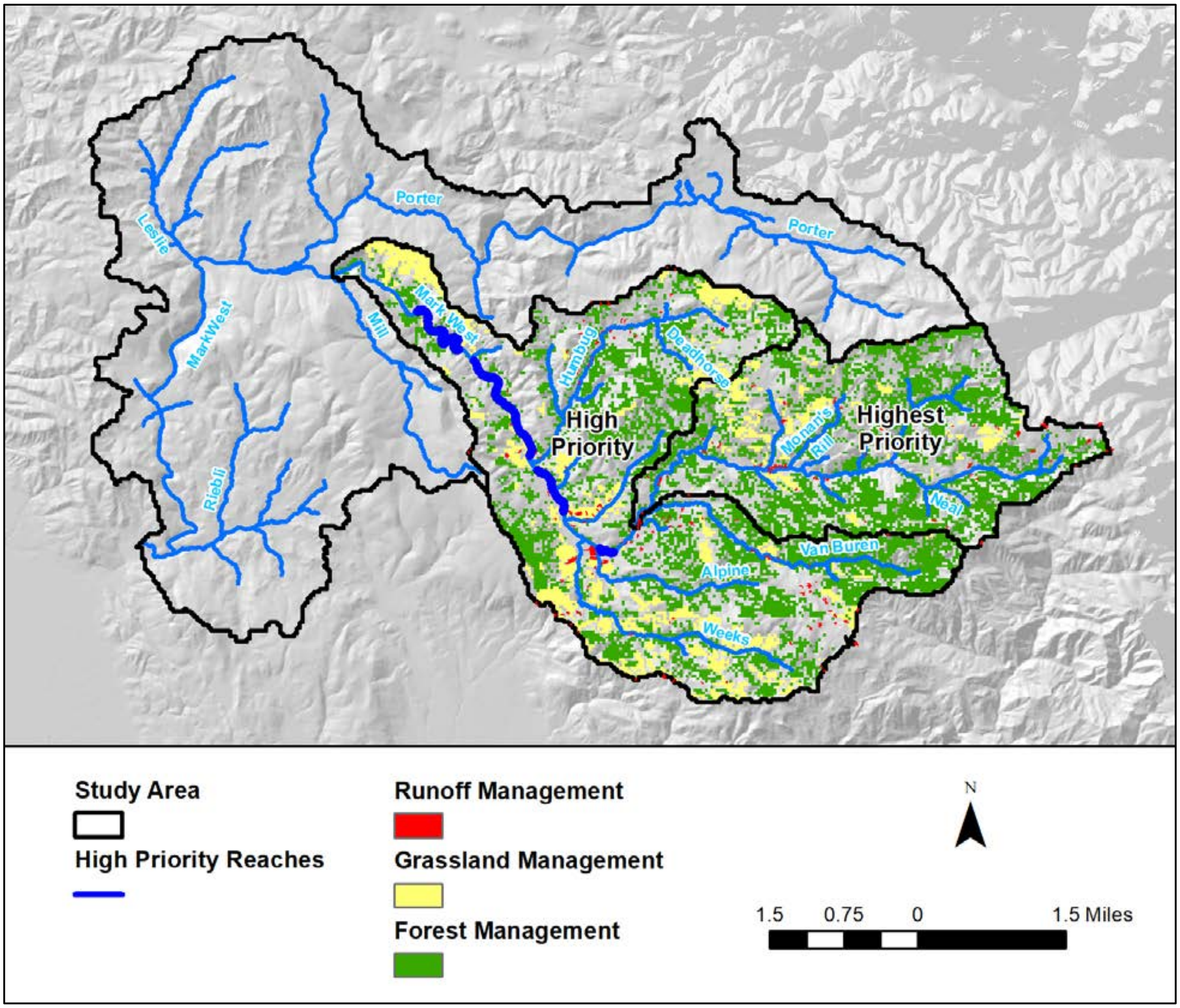


Figure E14: Locations of the identified high priority reaches for habitat enhancement projects and high priority watershed areas for flow enhancement projects.

Requiring new wells to be drilled at a specified minimum distance from a stream or spring or screened at a minimum depth may extend the length of time before streamflow depletion occurs; however, it will not prevent streamflow depletion from occurring. The long response timescale (decades) of streamflow to groundwater pumping revealed by our modeling suggests that a volumetric approach to managing groundwater is more likely to mitigate streamflow depletion compared to approaches focused on well location or time of use. It is important to note that the total pumping stress in the watershed is relatively small (~3% of mean annual infiltration recharge) and that the limited degree of streamflow depletion under existing conditions is not meant to suggest that groundwater pumping could not lead to significant streamflow depletion were the total volume of pumping to increase substantially in the future. That said, our analysis indicates that streamflow is not very sensitive to groundwater pumping at current rates.

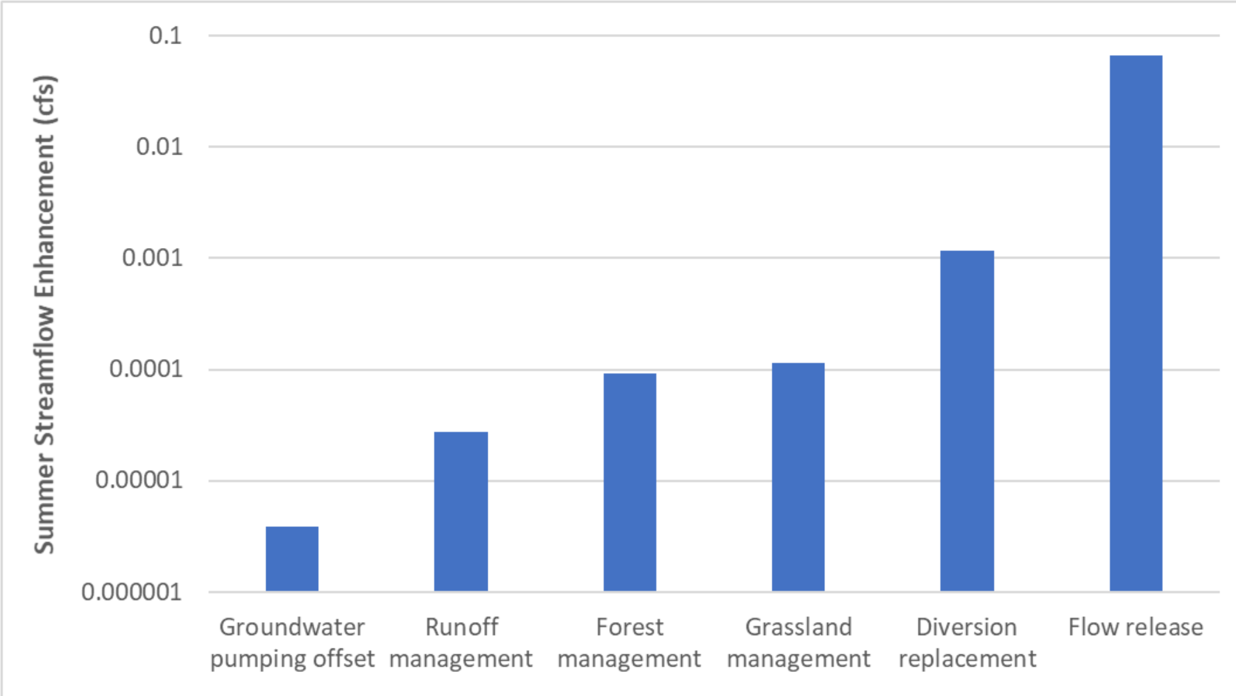


Figure E15: Summary of the simulated increase in mean summer streamflow for the six primary individual flow enhancement actions represented by the model scenarios and normalized to a $25,000 average project cost.

Grassland, forest, and runoff management were also found to result in summer streamflow improvement; however, the benefits per unit cost are one to two orders of magnitude lower than those of pond releases or diversion replacement (Figure E15). Grassland and forest management resulted in about equal benefits on a unit cost basis with about three to four times the effectiveness of runoff management. These three strategies also have important secondary hydrologic benefits in addition to enhancing streamflows in that they reduce seasonal vegetation moisture stress which may be expected to reduce fire risk. These benefits are in addition to the primary non-hydrologic benefits of these types of projects for reducing fuel loads (forest management) and sequestering carbon (grassland management). There are also potential negative consequences of extensive forest management in terms of potential habitat loss for avian and terrestrial species which must be carefully considered. In summary, while runoff, forest, and grassland management may not directly result in substantial streamflow improvement, these efforts have multiple benefits and are likely important strategies for managing fire risk and mitigating climate change impacts as discussed in more detail below.

<u>Climate Change Adaptation</u>

Climate change is expected to result in a dramatic decrease in springtime streamflow, particularly during drought conditions. These declines are expected to have significant effects on salmonid outmigration with some scenarios predicting impassable conditions developing as early as late winter and persisting through spring and summer. The only feasible strategy to mitigate these changes is to implement spring pond releases. While it may not be possible to significantly improve conditions throughout the smolt outmigration period, relatively high release rates could be achieved for a period of several days to weeks to provide a window of passable flow conditions timed to coincide with expected peak smolt outmigration. Although the summer streamflow predictions vary widely, some scenarios show significant declines in summer streamflow. We recommend that flow release projects be developed and adaptively managed to provide a combination of larger pulses of streamflow during outmigration and lower-magnitude releases to sustain streamflow during summer baseflow depending on conditions in a given year.

The runoff, forest, and grassland management strategies influence the quantity of flow from springs which in general is relatively cold, therefore these approaches may be expected to assist in mitigating elevated water temperatures whereas the more effective strategies (pond releases and diversion replacement) would not be expected to provide significant temperature benefits. These strategies also help reduce vegetation moisture stress by increasing the quantity of water available to plants in the case of runoff and grassland management and decreasing water demand from the landscape for the case of forest management. Reduced moisture stress may be considered an important benefit in terms of reducing current wildfire risk and the increase in wildfire risk expected resulting from climate change. In summary, implementation of runoff, forest, and grassland management projects are expected to help build resiliency to climate change by providing multiple benefits beyond potential streamflow improvement and spring and summer pond releases provide a means of adaptively managing flow conditions for salmonids in the face of a changing climate.

Conceptual Designs

The final phase of the project involved development of conceptual designs for two site specific streamflow enhancement projects. The projects focus on the approach of runoff management and were selected to take advantage of local site conditions and project opportunities on properties managed by our project partners the Pepperwood Foundation and Sonoma County Regional Parks. The projects illustrate two possible approaches to managing runoff for enhanced groundwater recharge and we anticipate similar approaches as well as other alternative methods could be applied on parcels throughout the watershed.

Goodman Meadow

Site 1 is located within the Pepperwood Preserve at the Goodman Meadow near the headwaters of Leslie Creek in the northwest corner of the Mark West Creek watershed. The Goodman Meadow site consists of a relatively flat, approximately 12-acre natural basin perched on a topographic bench. The design converts portions of the meadow into an infiltration basin by constructing a berm and outlet structure along the downstream edge of the meadow (see Appendix A). The design creates approximately 5.3 ac-ft of storage within 1.4-acres comprising the lower portion of the meadow. Based on hydrologic modeling of the conceptual design, the basin would be capable of generating about 1.9 ac-ft/yr of additional infiltration recharge. This enhanced recharge would increase the mean springtime flow in upper Leslie Creek by about 0.01 cfs and extend the duration of connected surface flow by about 12 to 21 days.

Mark West Regional Park

Site 2 is located on a terrace on the east bank of Porter Creek about 1,800-ft upstream of its confluence with Mark West Creek. The site is slated to be developed as the main entrance and parking area for Mark West Regional Park managed by Sonoma County Regional Parks. Park facilities have not yet been designed in detail but are expected to be contained within approximately 3.1 acres currently occupied by a barn structure and an adjacent parking area and gravel road (see Appendix B). The stormwater management design described here is intended to become a part of the overall design for the park facilities and consists of collecting runoff from the developed portions of the park entrance in a network of diversion ditches and directing these flows into a series of two linear, gravel filled infiltration basins designed to maximize groundwater recharge. The total storage capacity of the basins is 0.65 ac-ft.

The scale of the site design features is too fine to be accurately represented in the regional hydrologic model; however, based on regional runoff management scenario results, we estimate that the project will generate between 0.3 and 1.2 ac-ft/yr of additional infiltration recharge. It is unlikely that the project by itself will generate significant increases in streamflow in Porter Creek, however the regional modeling suggests that large-scale adoption of stormwater best management practices has the potential to increase the mean springtime streamflow in lower Porter Creek by about 0.05 cfs and extend the duration of surface flow connection by up to 13 days.

Chapter 1 – Introduction

The project described in this report was completed by O'Connor Environmental, Inc. (OEI) under the direction of the Coast Range Watershed Institute (CRWI) in cooperation with the Sonoma Resource Conservation District (SRCD), Friends of Mark West Creek, Sonoma County Regional Parks, and the Pepperwood Foundation. The project was funded by a Proposition 1 Streamflow Enhancement Program grant (Grant Agreement No. WC-1996AP) from the California Wildlife Conservation Board (WCB).

The Mark West Creek watershed has been identified by California Department of Fish & Wildlife (CDFW) and National Oceanic & Atmospheric Administration National Marine Fisheries Service (NMFS) as providing some of the best remaining habitat for coho salmon (*Oncorhynchus kisutch*) in the Russian River watershed. Several factors have been identified as limiting for coho survival in the watershed 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 watershed in recent years aimed primarily at improving pool and off-channel habitat conditions. Additional efforts have begun to address the problem of insufficient stream flow primarily through water storage and flow release projects. Successful efforts to improve streamflow conditions will require greater understanding regarding the distribution of flow conditions and the various natural and man-made controls on these flows.

The combination of frequent drought conditions, ongoing and future climate change, and increasing human demand for water make development of strategies for sustaining or improving summer streamflow conditions of paramount importance for coho recovery in the Mark West Creek watershed. The goal of this project was to conduct a comprehensive analysis of the spatial and temporal distribution of streamflow conditions throughout the watershed relative to coho habitat requirements to assist in prioritizing restoration efforts and developing strategies for protecting/enhancing summer baseflows.

Specifically, this project involved the development, calibration, and application of a distributed hydrologic model (MIKE SHE) with inputs comprised of climate, topographic, land cover, soils, water use, and hydrogeologic data for the watershed. Model outputs include estimates of the annual and seasonal water balance, simulated stream flow hydrographs, and predicted groundwater elevations and flow gradients among many other hydrologic parameters. The modeling results provided the basis for performing an analysis of streamflow, 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 potential improvements to streamflow and aquatic habitat conditions resulting from various streamflow restoration strategies including forest management, stormwater management and recharge enhancement, adjustments to surface diversions and groundwater pumping regimes, and flow releases from existing ponds. Conceptual designs were developed for two specific projects which were identified and evaluated as part of the project. The model was also used to investigate the effects of ongoing climate change on streamflow and habitat conditions. In addition to the findings and recommendations discussed in this report, the model also provides a working Decision Support System for ongoing restoration efforts and land and water management decision making and should be considered a "living" model that can be updated as new data and information become available and utilized to help answer new management questions as they arise.

Chapter 2 – Study Area Description

Overview

The Mark West Creek (MWC) watershed is part of the Coast Range Geomorphic Province draining approximately 57 mi^2 of the lower Russian River watershed discharging to the Laguna de Santa Rosa about five miles upstream of its confluence with the Russian River. MWC watershed is commonly divided into an upper watershed in the Mayacamas Mountains and a lower watershed located within the Santa Rosa Plain. Neighboring watersheds include Franz and Maacama Creeks to the north, Santa Rosa Creek to the south, and the Napa River to the east.

The study area is defined as the MWC watershed above Quietwater Road which encompasses all of the 40 mi^2 upper MWC watershed (Figure 1). The upper MWC watershed is characterized by relatively steep topography, confined channels, and bedrock aquifers. Elevations range from 180 feet at Quietwater Road to over 2,300 feet near the headwaters. The study area includes 18 river miles of MWC, several major tributaries such as Porter, Leslie, Humbug, Mill, Weeks, Alpine, and Van Buren Creeks as well as numerous smaller tributary streams. Quietwater Road was selected as the downstream boundary of the study area because it coincides with the extent of the reach identified as critical salmonid summer rearing habitat in the State Water Resources Control Board Emergency Order (WR 2015-0026-DWR). This boundary also approximately coincides with the boundary of the Santa Rosa Plain aquifer as defined by the State Groundwater Management Act (SGMA). Below Quietwater Road, MWC enters the alluvial system of the Santa Rosa Plain which has significantly different characteristics and water management issues.

Upper MWC was severely affected by the October 2017 Tubbs Fire which burned through approximately 48% of the study watershed (19.4 mi^2). Following the fire, forest management and fuel reduction have become a greater concern to many residents in the watershed. The watershed has a substantial number of existing and proposed cannabis cultivation operations which has also generated significant concern among residents, and county, state, and federal regulatory authorities regarding potential adverse impacts of cannabis cultivation on streamflow and salmonid habitat. In addition to being identified in state and federal recovery plans as a high priority watershed for restoration of endangered coho, MWC watershed was identified in the 2014 California Water Action Plan as one of five priority streams, and is the site of several ongoing studies including a CDFW Instream Flow Study and a hydrologic modeling effort by the U.S. Geological Survey (USGS) and Sonoma Water coupled to implementation of the SGMA in the Santa Rosa Plain Groundwater Basin.

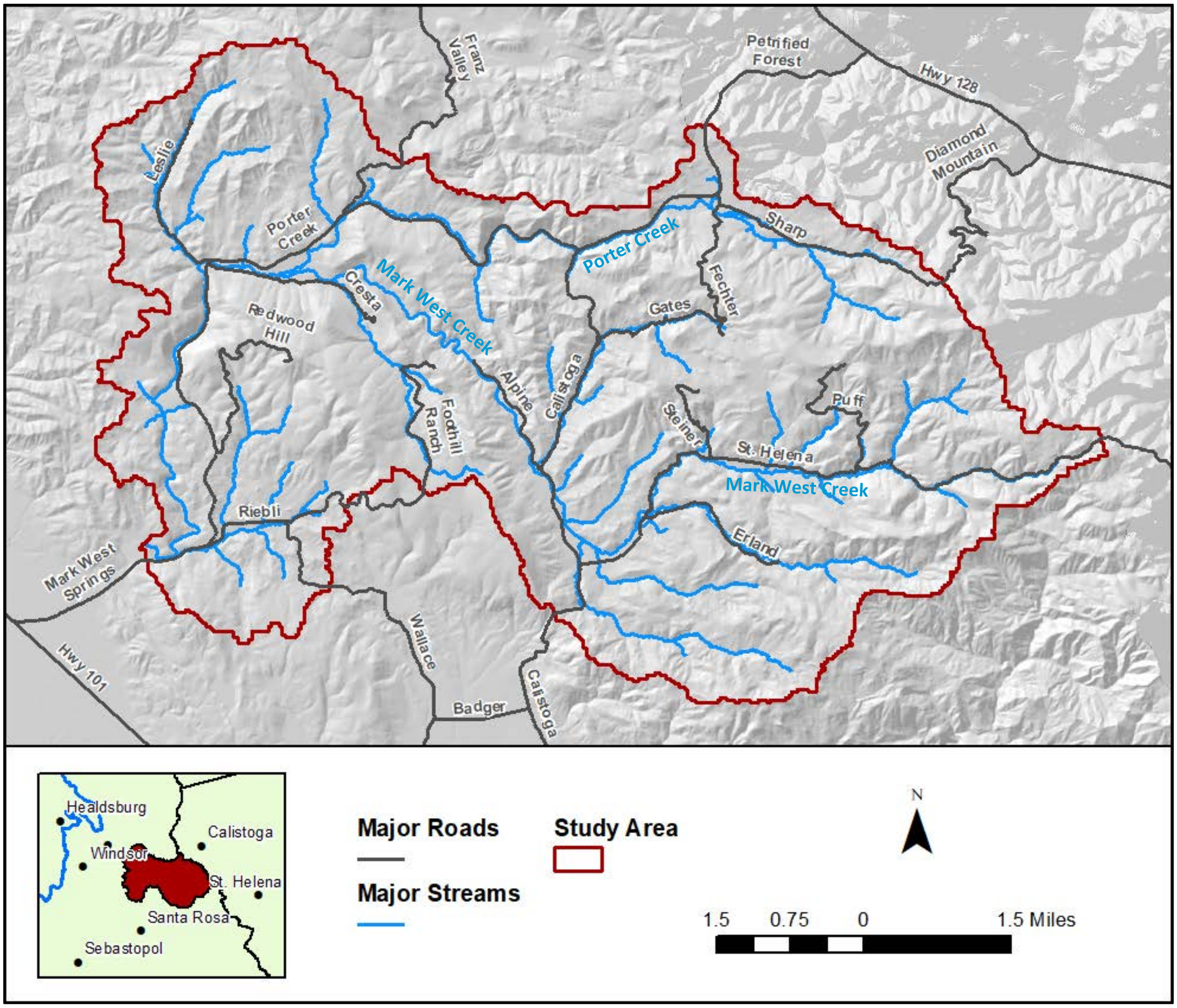


Figure 1: Map of the study area showing major roads and streams.

Climate

The upper MWC watershed has a Mediterranean climate characterized by cool wet winters and warm dry summers. Precipitation varies substantially across the study area from an average of approximately 38 inches per year near the Santa Rosa Plain to approximately 51 inches per year near the crest of the Mayacamas Mountains (Flint & Flint, 2014). For much of the year there is a strong east/west temperature gradient with warmer conditions in the higher elevations to the east relative to lower elevations to the west. This gradient is most pronounced during the daytime where mean maximum monthly temperatures are up to 6.9 °F (3.8 °C) higher at the St. Helena 4WSW climate station in the Mayacamas compared to the Santa Rosa climate station in the Santa Rosa Plain. During the winter (November – February) this gradient flattens or reverses with temperatures in the Mayacamas being the same or slightly (~1 °F) cooler than in the Santa Rosa Plain.

Land Use

Early settlement of the watershed began in earnest during the 1850s and 1860s due to reports of gold in the Russian River area and passage of the Homestead Act. During this time, land use activity in the upper portions of the watershed was focused on mining for silver and mercury, and livestock grazing. Agricultural activities were primarily focused in the lower portions of the watershed and included orchards, vineyards, and hop fields. Logging operations and associated road building also began around this time to clear fields for crops and support the demand for timber from the growing population in the Bay Area. Since World War II, agricultural development has increasingly been replaced by residential development (SRCD, 2015).

Existing land cover is primarily forest (72%), with the remainder divided between grassland (16%), shrubland (7%), developed and sparsely vegetated areas (3%), and agriculture (2%). Most of the forest areas are comprised of various species of oak (48%) and Douglas Fir (36%) with significant stands of Bay Laurel (5%), Coast Redwood (4%), and Madrone (2%) comprising most of the remainder. Ongoing forest succession has been occurring in the watershed in recent decades with expansion of Douglas Fir into Oak Woodlands. Vegetation recovery and potential changes to vegetation patterns following the October 2017 Tubbs Fire which burned about 48% of the study watershed area (20% with moderate or high burn severity) have not been well-quantified.

Land ownership in the watershed is primarily privately-owned rural residential properties with a few agricultural parcels. The Sonoma County Agricultural Preservation and Open Space District and Sonoma County Regional Parks own multiple properties including the Saddle Mountain Preserve, and the Cresta and McCullough Ranch which is slated to become the Mark West Regional Park. The Pepperwood Preserve in the northern portion of the watershed is the site of many ongoing scientific investigations and educational programs. The watershed also includes the Safari West wildlife preserve and portions of the Mayacamas Golf Club.

Geology

The geology of the Upper Mark West Creek watershed is complex and includes several distinct rock types which are offset by a series of faults and fracture zones. The northwest by southeast-trending Maacama Fault Zone bisects the study area and separates distinct geologies to the east and west. West of the Maacama Fault Zone, the study area is dominated by the early-Pleistocene and Pliocene-aged Glen Ellen Formation and bedrock units of the Pliocene and late-Miocene-aged Sonoma Volcanics (basalt and volcanic tuff). East of the fault zone, the study area is dominated by volcanic tuff and andesite of the Sonoma Volcanics and by the Cretaceous and Jurassic-aged Franciscan Complex. Other significant faults include the Larkfield, Rincon Creek, and Mark West Fault Zones to the west of the Maacama Fault Zone which form contacts between the Sonoma Volcanics and the Glen Ellen Formation. The Gates Canyon and Petrified Forest Thrust to the east of the Maacama Fault Zone place rocks of the Sonoma Volcanics in contact with older rocks of the Franciscan Formation.

Other geologic formations, including the Pliocene-aged Fluvial and Lacustrine Deposits of Humbug Creek and the Cretaceous and Jurassic-aged Great Valley Sequence occupy smaller portions of the study area. Quaternary-aged landslide and fluvial deposits are also present but are typically shallow and occupy a relatively small portion of the study area. Interpretation of subsurface geologic conditions from Well Completion Reports reveals that the landslide and fluvial deposits are generally less than 25-ft thick and that most wells are completed in underlying bedrock units. The thickest and most widespread alluvium is found along Mark West Creek near its confluence with Porter Creek where it reaches thicknesses of up to 65-ft. Examination of Well Completion Reports also revealed that the Glen Ellen Formation is generally unsaturated and relatively thin (50-100 ft). Most wells drilled in the Glen Ellen Formation extend into the underlying Sonoma Volcanics where groundwater is more frequently found.

Aquatic Habitat

Coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) are present in upper MWC and its tributaries. CDFW habitat surveys were conducted in Porter Creek in 1974 and 1996, in Humbug Creek in 1996, and in Horse Hill, Mill, Weeks, and Van Buren creeks in 1997. These surveys documented steelhead presence in Porter, Mill, Humbug, and Van Buren creeks but not in Horse Hill or Weeks Creek. Coho were not documented in any of these tributary surveys. Notable limiting factors in the tributaries included insufficient summer flows, inadequate pool habitat and riparian canopy, and a lack of quality spawning gravels.

Wild coho were observed in upper MWC in 2001 by CDFW during a snorkel survey as well as in more recent CA Sea Grant snorkel surveys. Available data from Sonoma Water and CA Sea Grant indicates that adult coho returned to spawn in MWC in water year 2011, 2012, and 2013 but not during the drought conditions of 2014. The Russian River Coho Salmon Captive Broodstock Program first released hatchery salmon into the MWC watershed in autumn of 2011; between 13,000 and 23,000 juvenile coho were released in Mark West Creek and Porter Creek each year between 2011 and 2014, and in 2016. In 2017, 6,000 fish were released only in Porter Creek. In addition to salmonids, California red-legged frog (*Rana draytonii*) and yellow-legged frog (*Rana boylii*), which are both listed as threatened, have been documented in the watershed.

Chapter 3 – Numerical Modeling Methodology

The hydrologic model of the upper Mark West Creek watershed was constructed using the MIKE SHE model (Graham and Butts, 2005; DHI 2017). Model code development activities have been ongoing since its inception in 1977 and the model has been applied successfully to 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 model capable of simulating all the land-based phases of the hydrologic cycle including overland flow, channel flow, evapotranspiration, unsaturated flow, saturated flow, and stream/aquifer interactions. The distributed nature of the model makes it well-suited for examining the hydrologic impacts of changes in climate and water management. Complex physics-based watershed models, while powerful tools, require extensive input data and should ideally be well-calibrated to observed stream flow and groundwater data spanning a number of years. It is important to bear in mind that a model is a simplification of a complex and in some ways unknowable hydrologic system and although 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 a static condition. Such models are best updated on a periodic basis as new data become available.

Overland Flow

The overland flow component of MIKE SHE solves the two-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 two-dimensional topographic surface. Net precipitation, evaporation, and infiltration are introduced as sources or sinks 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 of 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 use of a 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 one-dimensional St. Venant equations for open channel flow. The model is capable of simulating ephemeral stream conditions and backwater effects and includes formulations for a variety of hydraulic structure types including bridges, weirs, and 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 stage or stage discharge relation. Other than boundary conditions, the primary inputs for the channel flow model include channel geometry information and roughness coefficients for channelized flow (Manning's n).

Channel Flow Interactions

Interaction between the channel flow and overland flow components for 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 into the floodplain as overland flow. The model is also capable of simulating backwater effects onto the overland flow plane due to restricted channel flow.

Evapotranspiration and Interception

Evapotranspiration (ET) is handled in the model using a two-layer water balance approach which divides the unsaturated zone into a root zone from which water can be transpired and a lower zone where it cannot. The model computes actual evapotranspiration (AET) as a function of potential evapotranspiration (PET) and the available water content in the vegetation canopy, overland flow plane, and the unsaturated zone. The model first extracts water from interception storage which is based on vegetation properties including leaf area index (LAI) and an interception storage coefficient. Next, water is extracted from ponded water on the land surface and, finally, from within the unsaturated zone or, if the rooting depth exceeds the depth to water for a given timestep, the saturated zone. PET can be adjusted for each land cover category in the model through 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 two-layer water balance method described above. The method considers average conditions in the unsaturated zone and tracks available soil moisture to regulate ET and groundwater recharge using a one-dimensional (vertical) formulation. A soil map Is used to distribute the primary soil properties used to drive the model, including saturated hydraulic conductivity (K_{sat}) and moisture contents (Θ) at saturation, field capacity, and wilting point. The unsaturated flow component of the model interacts with the overland flow component by serving as a sink term (infiltration) and with the groundwater flow component by serving as a source term (recharge).

The unsaturated zone component of the model does not explicitly represent lateral movement through and discharge from the unsaturated zone commonly referred to as interflow. In the MWC watershed, interflow occurring at or near the contact between soils and underlying bedrock is expected to be an important process. Because interflow is often associated with a temporary increase in groundwater elevations during and following precipitation events, interflow processes can be approximated in MIKE SHE with a saturated zone drainage function.

Saturated Flow

The groundwater component of the model solves the three-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 that used in MODFLOW, a widely used U.S. Geological Survey groundwater model. The primary inputs to the model are horizontal and vertical hydraulic conductivity, specific yield, storage coefficients, and the upper and lower elevation 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 sinks. The lower boundary of the model is 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 Upper Mark West Creek hydrologic model is defined as the Mark West Creek watershed upstream of Quietwater Road. The model is discretized into over 50,000 45-meter by 45-meter (0.5-acre) grid cells covering a 40.2 mi^2 area. The grid resolution was selected to represent the watershed in as much detail as possible consistent with the overall resolution of input data while enabling reasonable computation times (about 100 hours).

The model simulates a continuous 10-yr period from 10/1/2009 through 9/30/2019 (Water Years 2010 - 2019). This period was selected because it corresponds to the period with the most data available for model calibration, is representative of long-term average precipitation conditions, and includes a wide variety of precipitation conditions ranging from the very dry Water Year (WY) 2014 when annual precipitation at the Santa Rosa and St. Helena 4SW climate stations was 14.9 and 28.9 inches respectively to the very wet WY 2017 when annual precipitation at the two stations was 50.2 and 74.0 inches respectively (Figures 2 & 3). Based on the long-term precipitation record for Santa Rosa from 1906 – 2019, WY 2014 was the 4th driest year on record and WY 2017 was the 5th wettest (Figure 2). The 2-yr rainfall total for WY 2013-2014 was the second driest on record (14.9 inches versus 12.8 inches for 1976-1977). Mean annual precipitation at the Santa Rosa climate station for the simulation period was 31.1 inches, which is similar to both the 1906-2019 and 1981-2010 averages of 30.2 and 32.1 inches respectively (Figure 2).

A longer streamflow record is available for the upper watershed, but streamflow data from the lower watershed (developed for this project to facilitate model calibration) is only available for WY 2018 and 2019. Although simulation of post-fire hydrologic impacts and subsequent recovery from the Tubbs Fire was not part of the scope of this project, given the timing and scale of the October 2017 fire event just prior to collection of streamflow data, it was necessary to incorporate a simplistic representation of the post-fire landscape into the model to facilitate calibration. Post-fire hydrologic effects are complex and adjust rapidly in the years following disturbance. An ongoing USGS is underway to better understand the effects of the fire on soil hydrologic conditions, and preliminary findings suggest highly localized effects and that recovery to pre-fire characteristics occurs rapidly (Perkins, personal communication).

We did not attempt to represent the long-term effects of fire or recovery; rather, we developed a version of the model representing the short-term effects (first and second year after disturbance) of the fire exclusively for calibration purposes, and maintained the pre-fire landscape for the primary simulation of existing conditions and future scenarios. This decision acknowledges that the available data describing vegetation in the watershed was collected prior to the fire and that the long-term recovered landscape is likely to more closely resemble the pre-fire landscape than the short-term post-fire landscape, and thus represents a more appropriate basis for evaluating management decisions.

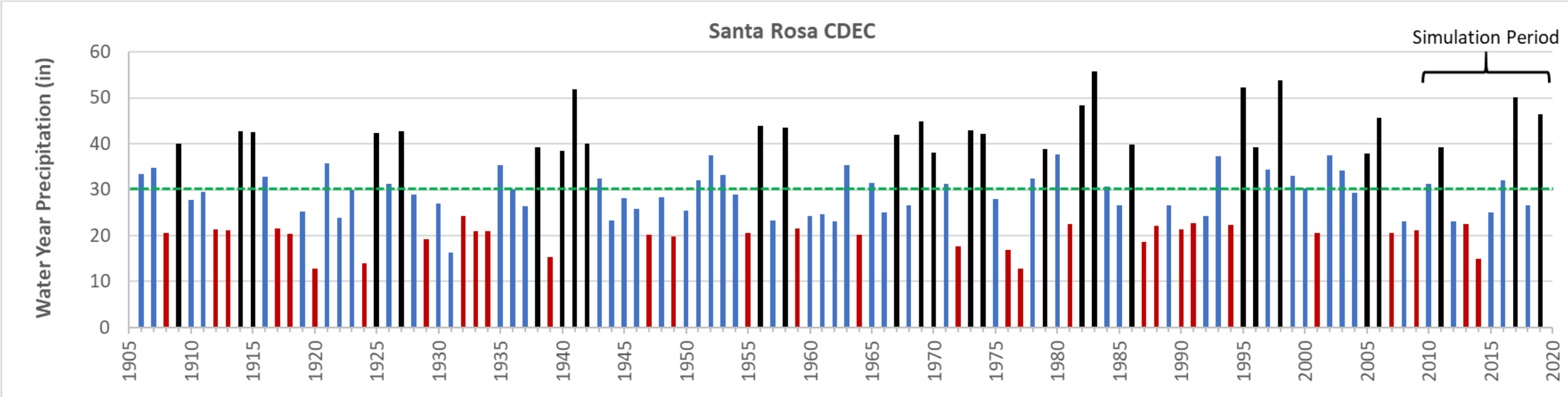


Figure 2: Long-term annual precipitation record for the Santa Rosa CDEC climate station (black and red values indicate wet and dry years defined as +/- 25% of the long-term average as shown with the dashed line).

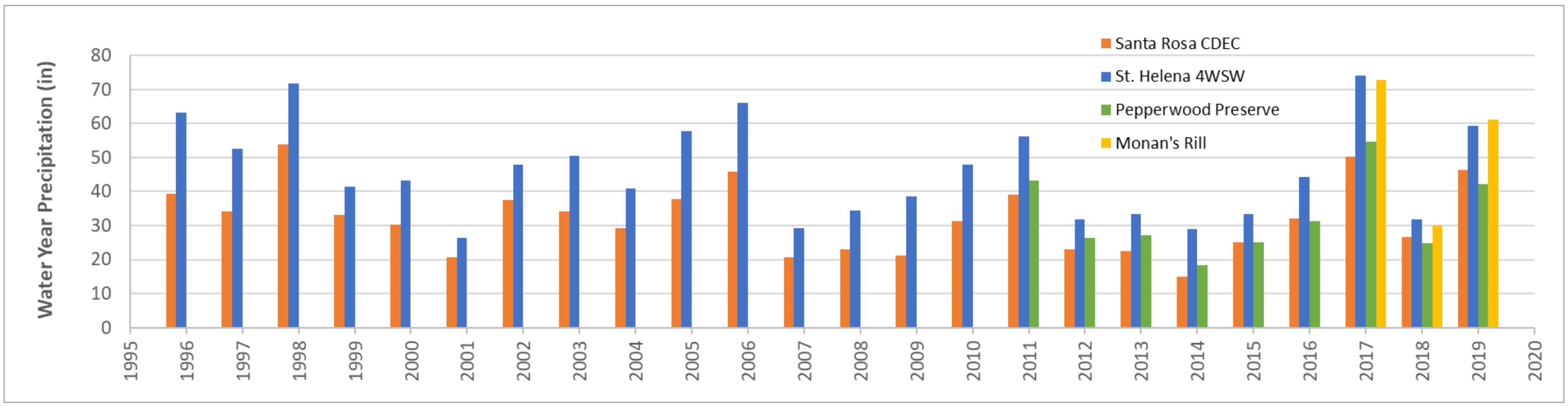


Figure 3: Annual precipitation records for various climate stations in and around the MWC watershed.

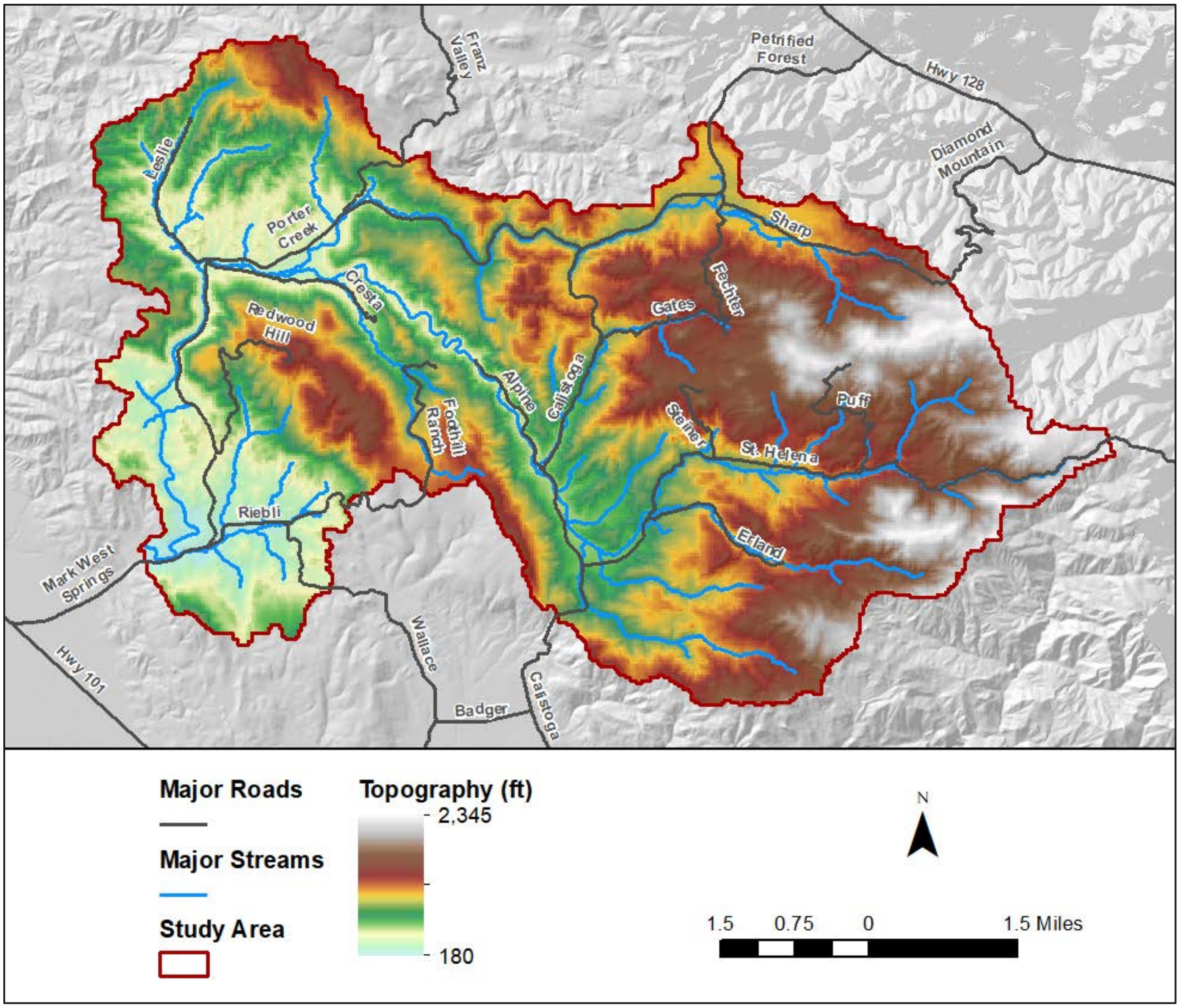


Figure 4: Topography used in the MWC hydrologic model.

Topography

Model topography is based on the 3-foot resolution Sonoma County LiDAR dataset (WSI, 2016) which was resampled to conform to the 45-meter grid cells used in the model. Elevations in the model domain range from 180 feet near Quietwater Road to 2,345 feet on Diamond Mountain near the border between Sonoma and Napa Counties (Figure 4).

Climate

Precipitation and Potential Evapotranspiration (PET) are the primary climatic inputs to the model; both are represented on a daily timestep. Based on the Basin Characterization Model (BCM) (Flint et al., 2013; Flint & Flint, 2014) which provides gridded estimates of average annual precipitation for the 1980-2010 period throughout California, a significant east-west gradient in precipitation exists across the watershed. Mean annual precipitation is estimated to increase from 38 in/yr near the Santa Rosa Plain to 51 in/yr near the crest of the Mayacamas Mountains. Based on analysis performed for this study (as described below) PET varies primarily with aspect and is estimated to range from 30 to 52 in/yr. To account for the spatial variability in climate, the model domain was divided into 1-inch interval precipitation and PET zones (Figures 5 & 6).

Precipitation

There are several weather stations within the Upper Mark West watershed and surrounding areas (Figure 5). A long-term daily precipitation record dating back to Water Year (WY) 1906 is available from the Santa Rosa station operated by Sonoma County and located southwest of the watershed in the Santa Rosa Plain (Figure 2). A shorter but significant precipitation record dating to WY 1996 is available from the St. Helena 4WSW station operated by the California Department of Water Resources (DWR) and located southeast of the watershed along the ridge separating Sonoma and Napa County. Another significant record dating to WY 1991 is available from the Windsor station operated by the California Irrigation Management Information System (CIMIS) and located near the Town of Windsor. The Pepperwood Preserve has the longest operating precipitation station in the watershed dating to WY 2011. CRWI operated two stations at the Monan's Rill community in the upper watershed beginning in WY 2017. Three additional stations were installed by Sonoma Water in the watershed in February 2018 including Mark West Creek at Michelle Way, Mark West Creek at Porter Creek Road, and Mark West Regional Park (Figures 3 & 5).

The model domain is divided into 14 precipitation zones to account for the west to east gradient in precipitation (Figure 5). These zones are based on 1-inch annual isohyets derived from the BCM 1981-2010 mean annual precipitation data which is available at a 270-meter spatial resolution (Flint and Flint, 2014). Each zone was assigned to a rainfall station and precipitation was scaled up or down based on the ratio of the mean annual precipitation in the zone to the mean annual precipitation at the corresponding weather station. The station assignments vary throughout the simulation period as more stations became available during more recent time periods. For 10/1/2009 through 10/4/2010, all zones utilized the St. Helena 4WSW station. For the period 10/5/2010 to 11/15/2016, all zones utilized the Pepperwood station, and for the period 11/16/2016 to 2/1/2018, the 38 to 44-inch zones utilized the Pepperwood station and the 45 to 51-inch zones utilized the Monan's Rill station. For the most recent time period from 2/2/2018 to 9/30/2019, the 38 and 39-inch zones utilized the Michelle Way station, the 40 to 42-inch zones utilized the Pepperwood station, the 43 to 45-inch zones utilized the Mark West Regional Park station, and the 46 to 51-inch zones utilized the Monan's Rill station (Table 1 & Figure 7).

Comparisons between the BCM long-term average precipitation and the long-term average precipitation at the Santa Rosa and St. Helena 4WSW gages suggest that the BCM may over-predict rainfall by ~15-20%. Nevertheless, the magnitude of the gradient across the MWC watershed as predicted by the BCM agrees well with the station data, and the BCM provides the

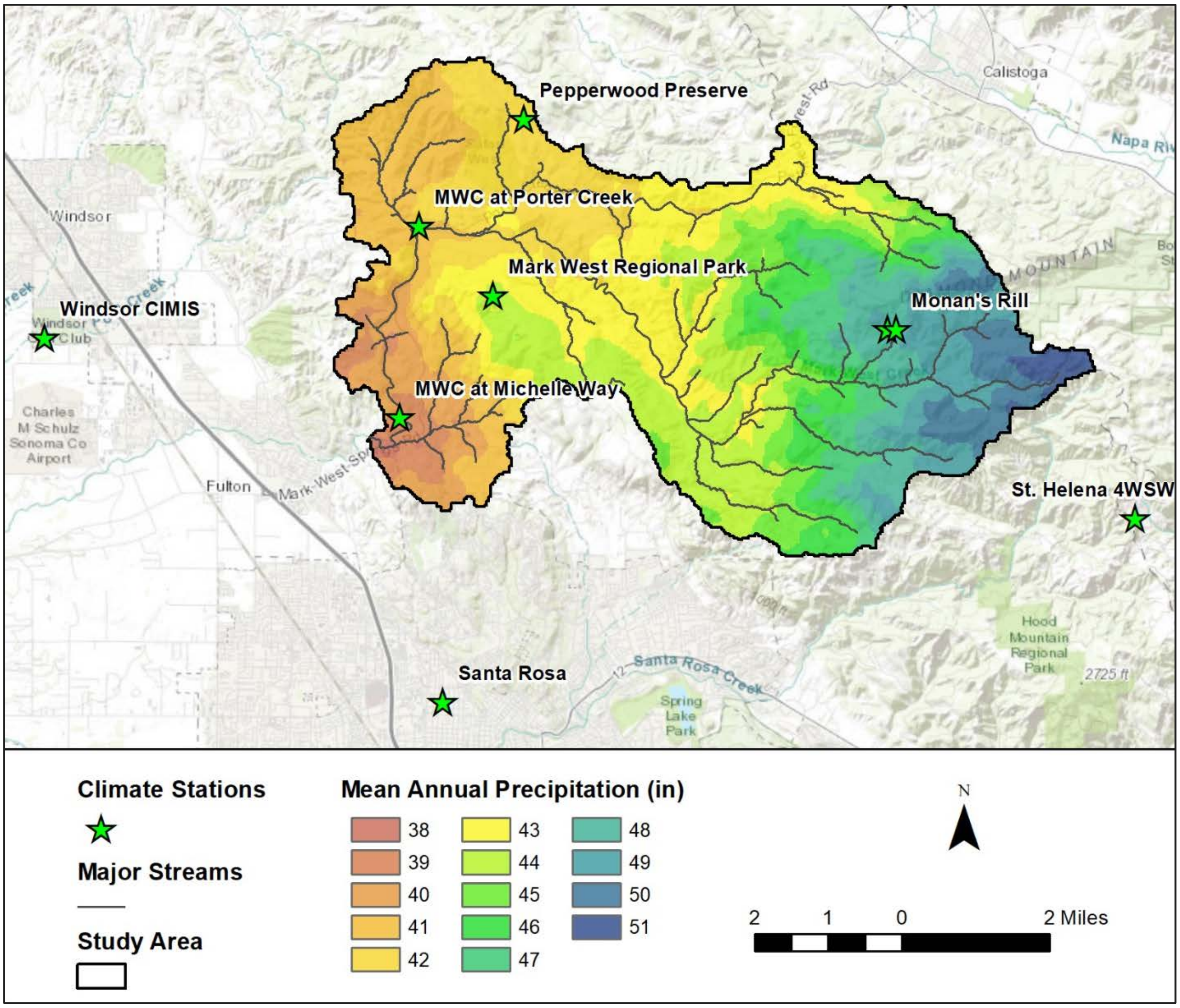


Figure 5: Precipitation zones and climate stations used in the MWC hydrologic model.

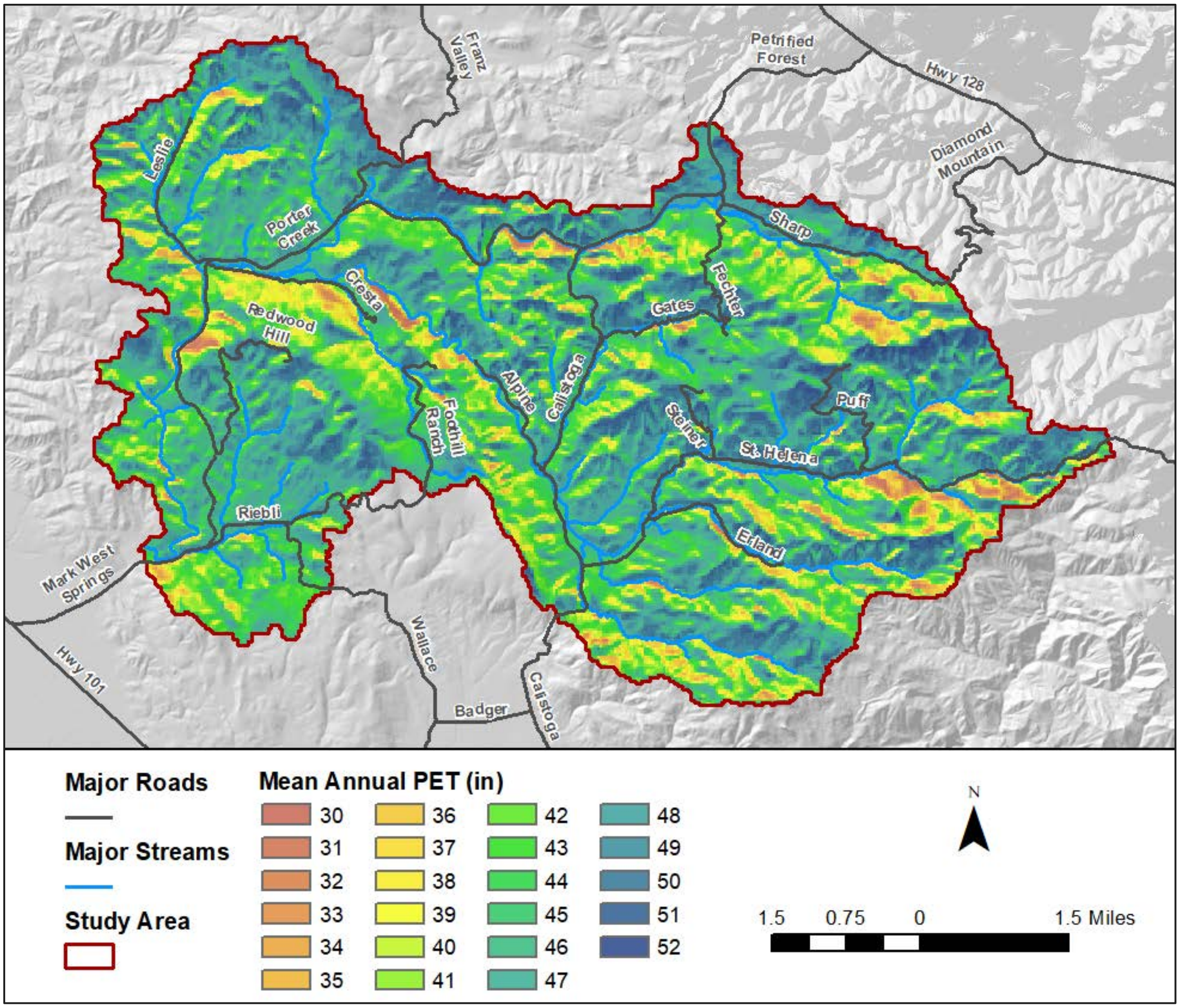


Figure 6: PET zones used in the MWC hydrologic model.

Table 1: Precipitation station assignments used for various time periods. Station codes and associated BCM mean annual precipitation values are as follows: MW – Michelle Way 38.5-in, PEP – Pepperwood 41.5-in, MWRP – Mark West Regional Park 43.8-in, MR – Monan's Rill 48.5-in, SH – St. Helena 4WSW 49.7-in.

	Precipitation Zone													
Time Period	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**
10/1/2009 - 10/4/2010	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH
10/5/2010 - 11/15/2016	PEP	PEP	PEP	PEP	PEP	PEP	PEP	PEP	PEP	PEP	PEP	PEP	PEP	PEP
11/16/2016 - 2/1/2018	PEP	PEP	PEP	PEP	PEP	PEP	PEP	MR	MR	MR	MR	MR	MR	MR
2/2/2018 - 9/30/2019	MW	MW	PEP	PEP	PEP	MWRP	MWRP	MWRP	MR	MR	MR	MR	MR	MR

best means to spatially distribute the available rainfall station data across the watershed. The actual 10-yr simulation period mean rainfall in the model varies from 30.8 inches/yr to 43.3 inches/yr consistent with the long-term mean from the available gauging data, whereas the BCM shows this variation as 38 to 51 inches.

Potential Evapotranspiration (PET)

Daily PET data from the Windsor CIMIS station was used to derive the PET timeseries used in the model (Figures 6 & 8). A gridded distribution of mean annual PET was created using the Hargreaves-Samani equation (Hargreaves and Samani, 1982). The calculations were performed using gridded solar radiation data from the National Solar Radiation Database (NSRDB, 2010) and average monthly minimum and maximum temperatures for the 1980 -2010 period from the BCM dataset (Flint & Flint, 2014). The empirically derived KT coefficient was calibrated based on reported PET from the Santa Rosa and Windsor CIMIS Stations. A KT value of 0.152 was selected, consistent with KT values of 0.15 to 0.16 previously proposed for the Bay Area.

From this annual distribution, the model domain was divided into zones, each corresponding to a one-inch range in average annual PET. Scaling factors were calculated for each zone as the ratio of PET at the Windsor CIMIS gage and the PET for a given zone. These scaling factors were then applied to the daily CIMIS data and applied to each zone in the model. From February 2013 to March 2017 PET was not reported at the Windsor CIMIS gage. This gap was filled using scaled data from the Santa Rosa CIMIS gage located west of Sebastopol. Smaller gaps and missing days of data were also filled using Santa Rosa data.

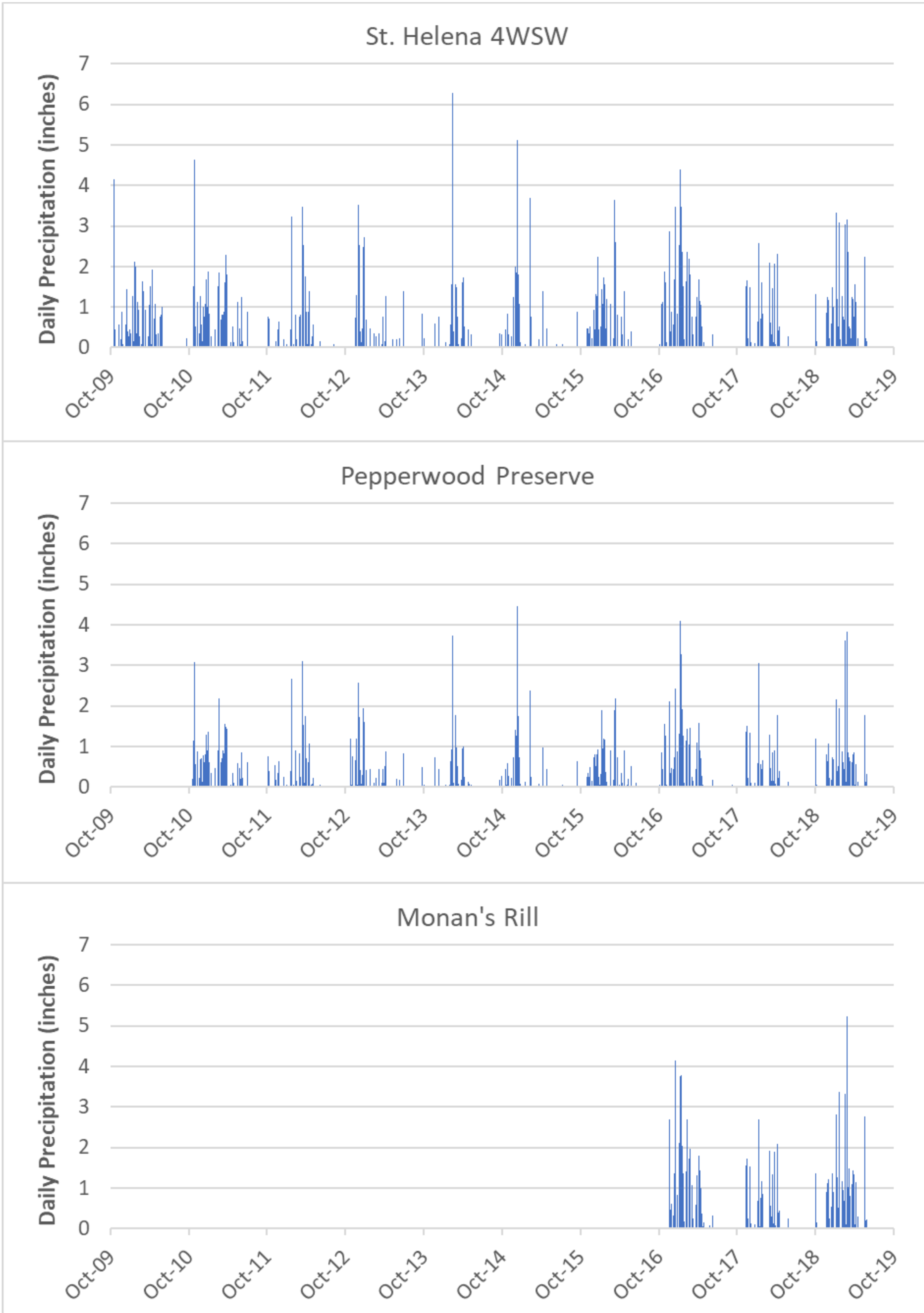


Figure 7: Daily precipitation at the five climate stations used in the MWC hydrologic model for the WY 2010 – 2019 simulation period.

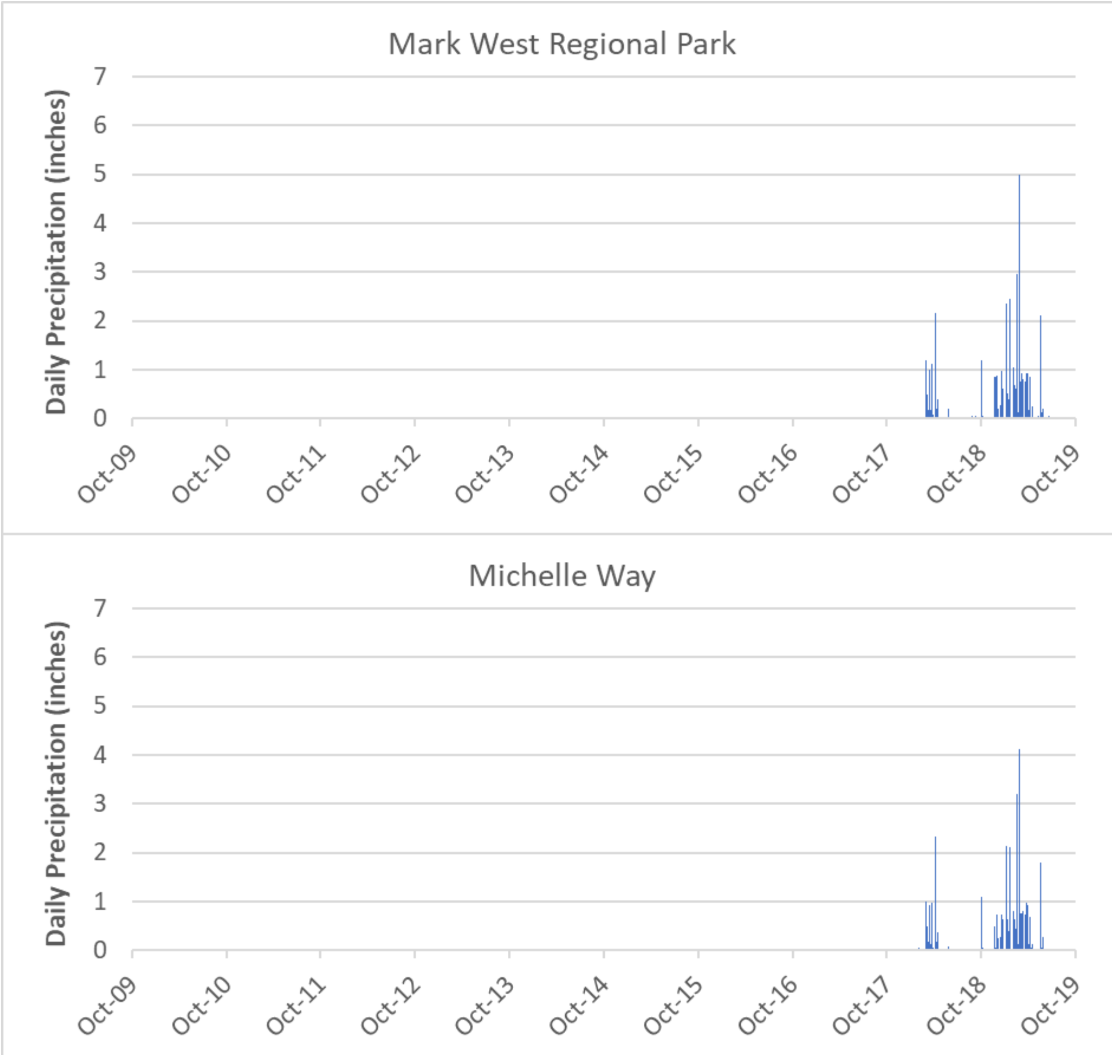


Figure 7 (continued)

Land Cover

Within the upper Mark West watershed, coniferous and deciduous forest are the dominant landcover types with grasslands making up much of the remaining area (Table 2). Land cover varies significantly with elevation in the watershed. Downstream of St. Helena Road, Mark West Creek and several other tributaries including Leslie, Porter, Riebli, and Weeks Creeks contain predominately oak woodland interspersed with other deciduous woodlands and grasslands. Upstream of St. Helena Road, Mark West Creek has several tributaries including Alpine, Humbug, and Van Buren Creeks; these tributary watersheds are dominated by coniferous forest including Coastal Redwoods and Douglas Fir. Several vineyards are located along the mainstem of Mark West Creek as well as along Porter and Riebli Creeks. Much of the Riebli Creek watershed, as

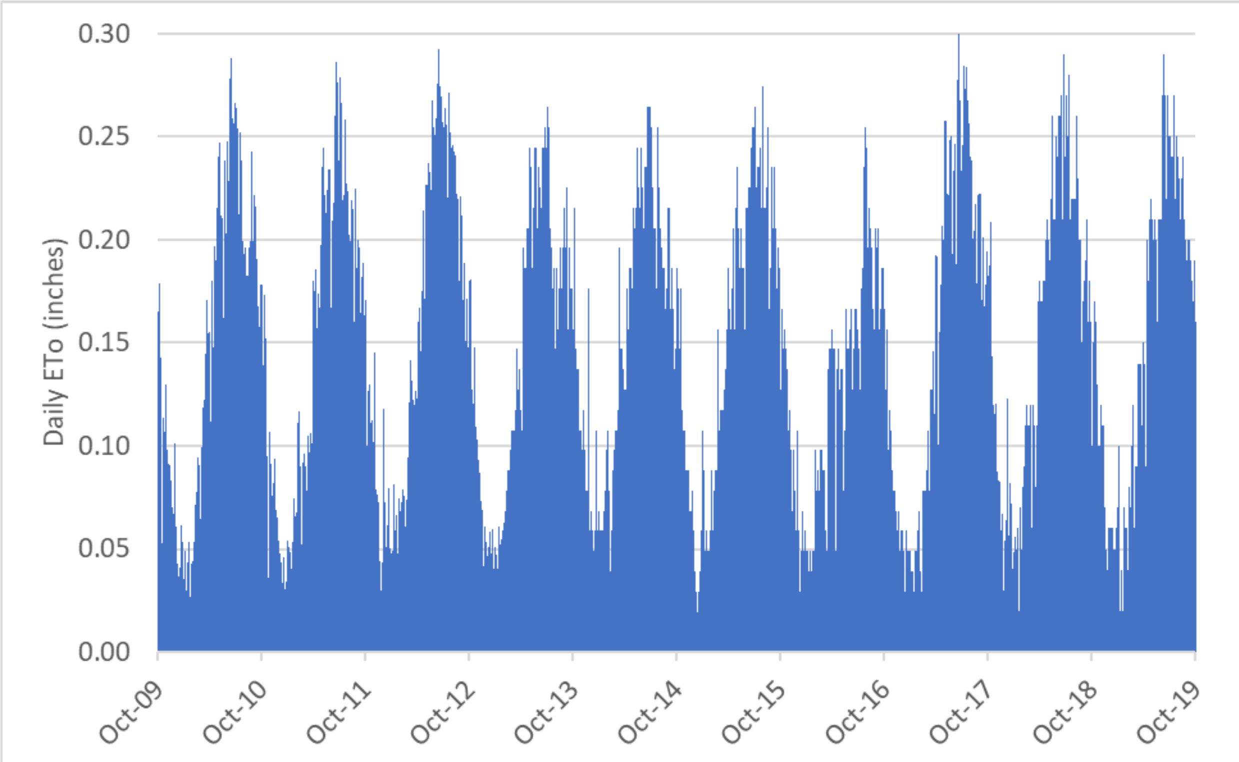


Figure 8: Daily PET at the Winsor CIMIS station used in the MWC hydrologic model for the WY 2010 – 2019 simulation period.

well as small portions of the uppermost Mark West Creek and Humbug Creek watersheds, contain relatively dense rural residential development.

The model domain was discretized into 28 land cover zones based on vegetation classes from the Sonoma County Vegetation Mapping & LiDAR Program's Fine Scale Vegetation and Habitat Map (Figure 9) (SCVMLP, 2015). This map was generated for the Vegetation Mapping & LiDAR Program using automated processing of returns from the 2013 countywide LiDAR flight and interpretation of aerial imagery by the modelers (SCVMLP, 2015). It includes a detailed accounting of dominant species including several species of oak and conifer and is intended for use at a scale of 1:5000 or smaller. Land cover zones that represent less than 0.3% of the model domain (approximately 0.1 mi^2) are grouped with similar or adjacent cover types. Because these land cover zones are based on 2013 data, they do not reflect changes caused by the 2017 Tubbs Fire which were accounted for separately as described below.

A unique combination of model parameters was assigned to each of the 28 land cover zones. These parameters include Leaf Area Index (LAI), Rooting Depth, Manning's Roughness Coefficient for overland flow, and Detention Storage. For land cover types with a deciduous vegetation component, the Leaf Area Index and Rooting Depth vary seasonally based on an assumed growing season of April 15th to October 15th with gradual parameter transitions occurring from March 15th to April 15th and from October 15th to November 15th. Dormant season values for deciduous land

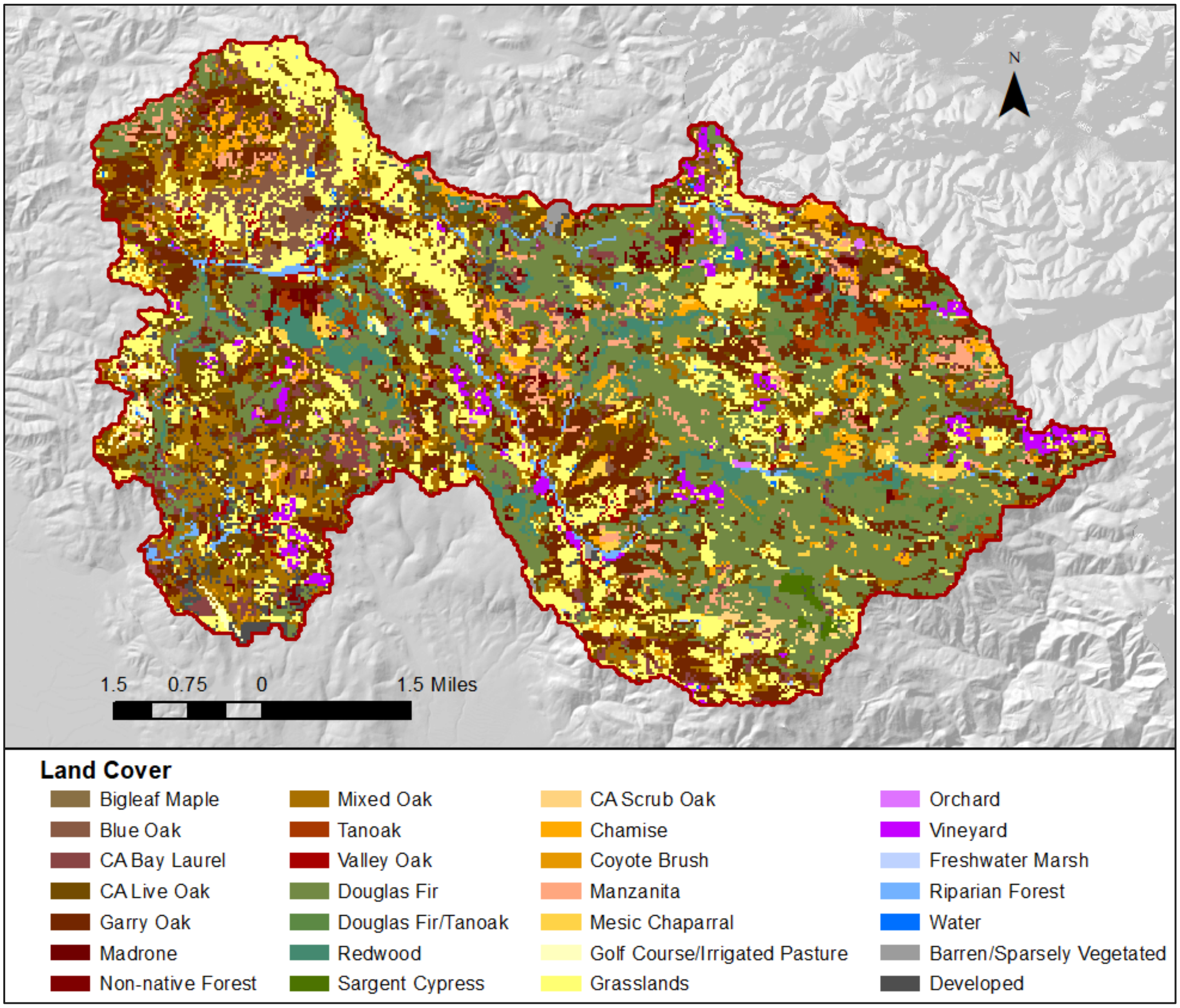


Figure 9: Land cover categories used in the MWC hydrologic model.

cover types were assumed to be equivalent to grassland values. For grasslands, the growing season was assumed to occur from December 15th to May 15th and the dormant season was assumed to occur from July 1st to October 15th with gradual parameter transitions in between. Many of these parameters are difficult to measure in the field and site-specific values are generally unavailable. With the exception of LAI, land cover parameters were initially estimated from literature values (e.g. Allen et al., 1988; TNC, 2018) and then adjusted within the range of reasonable limits as part of the calibration process (Table 2).

LAI was estimated for each vegetation zone using a spatially distributed LAI dataset created by the University of Maryland (Tang, personal communication, Tang, 2015) (Figure 10). This dataset was created using vegetation returns from the countywide LiDAR dataset and has a 3-foot spatial resolution. The remotely sensed LAI values in this dataset represent a combination of the canopy properties of individual plants and the density and spacing of those plants. This differs from LAI

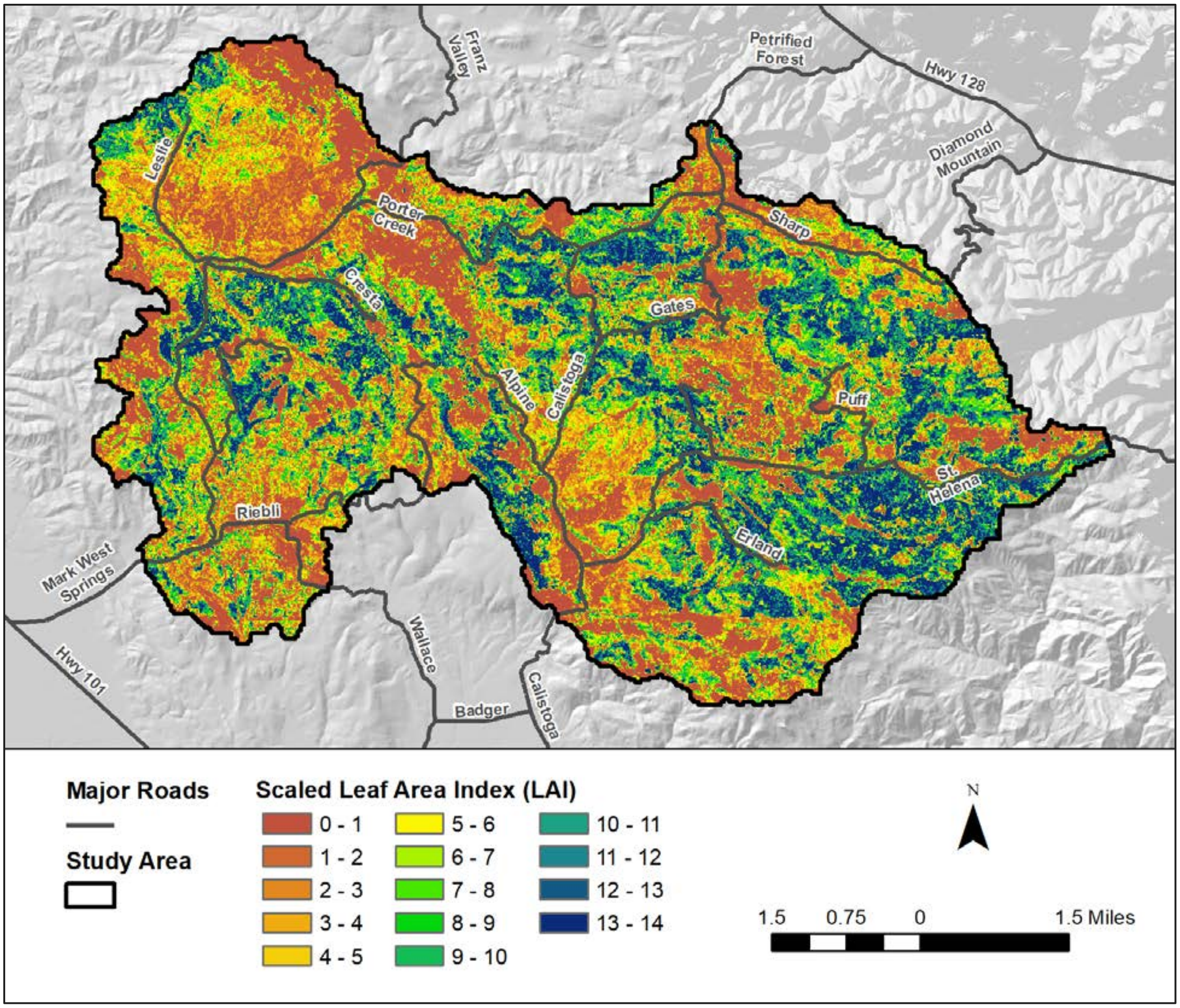


Figure 10: Distribution of LiDAR-derived Leaf Area Index (LAI).

Table 2: Land cover types and associated hydraulic and vegetation properties used in the MWC hydrologic model.

Land Cover Category	Proportion of Model Domain	Overland Flow Mannings n	LAI	Rooting Depth (ft)	Detention Storage (in)
Bigleaf Maple	0.2%	0.60	7.4	11.5	0.9
Chamise	2.2%	0.40	2.7	6.4	0.3
Madrone	1.3%	0.60	9.8	8.6	0.9
Manzanita	3.0%	0.40	4.3	6.6	0.3
Coyote Brush	0.8%	0.40	1.5	6.5	0.3
Barren/Sparsely Vegetated	0.2%	0.04	0.3	0.5	0.0
Grasslands	15.4%	0.24	0.4	2.1	0.3
Mesic Chaparral	1.5%	0.40	4.1	5.0	0.3
Sargent Cypress	0.3%	0.60	4.5	5.6	0.9
Irrigated Pasture	0.4%	0.24	0.4	3.1	0.3
Non-native Forest	0.2%	0.60	3.7	7.6	0.9
Tanoak	0.9%	0.60	1.5	15.0	0.9
Orchard	0.2%	0.24	11.3	6.7	0.9
Douglas Fir/Tanoak	0.9%	0.60	(8.0 - 14.7)	9.4	0.9
Douglas Fir	25.6%	0.60	(7.2 - 15.1)	3.7	0.9
Mixed Oak	8.4%	0.60	(4.0 - 10.1)	19.5	0.9
CA Live Oak	11.3%	0.60	(5.0 - 10.2)	24.0	0.9
Blue Oak	2.1%	0.60	(2.7 - 9.0)	15.0	0.9
CA Scrub Oak	0.3%	0.60	2.8	15.0	0.9
Garry Oak	11.3%	0.60	(4.0 - 10.8)	15.0	0.9
Valley Oak	0.9%	0.60	(3.9 - 9.8)	24.0	0.9
Redwood	3.2%	0.60	11.2	11.1	0.9
CA Bay Laurel	3.9%	0.60	8.1	3.0	0.9
Riparian Forest	1.1%	0.60	6.0	7.3	0.9
Vineyard	1.7%	0.24	1.0	4.9	0.3
Water	0.1%	0.04	1.0	0.5	0.0
Marsh	0.1%	0.04	0.5	1.3	0.0
Developed	2.3%	0.04	2.9	5.9	0.0

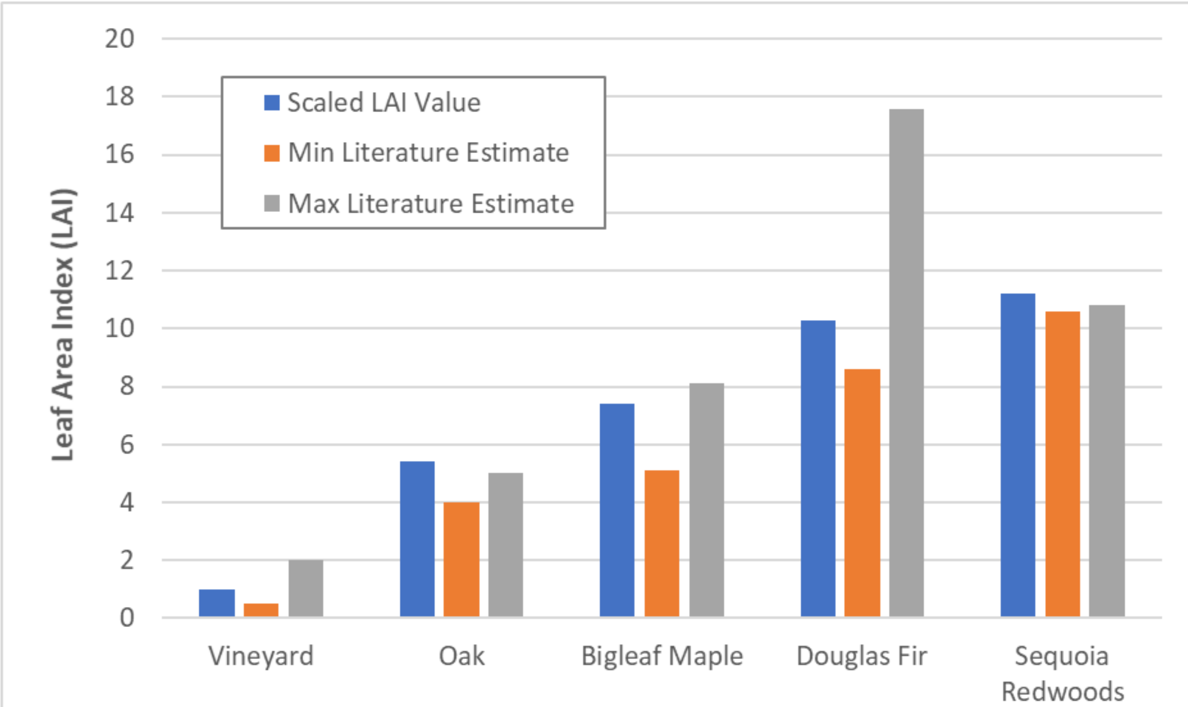


Figure 11: Comparison between scaled LAI values used in the MWC hydrologic model and estimates from the literature for various vegetation types.

values representing individual plant specimens which is the standard convention for empirical evapotranspiration equations used in our model. We compared the remotely sensed LAI values for various vegetation classes with individual specimen values from the literature (Iio & Ito, 2014; Johnson, 2003; Karlik & McKay, 2002; Scurlock et al., 2001) and translated the LiDAR-derived values to specimen values consistent with the literature by applying a uniform scaling factor to the LiDAR-derived LAI (Figure 11). LAI values were calculated for each of the vegetation zones in the model by calculating the mean LAI for each zone from the scaled LAI dataset (Table 2). For Douglas Fir, Douglas Fir/Tanoak, and the various types of Oaks, we further subdivided the LAI estimates into areas requiring no forest treatment, minor treatment, and major treatment based on LAI thresholds we defined from plot-scale forest mapping performed in the upper watershed as described in greater detail in the Chapter 8.

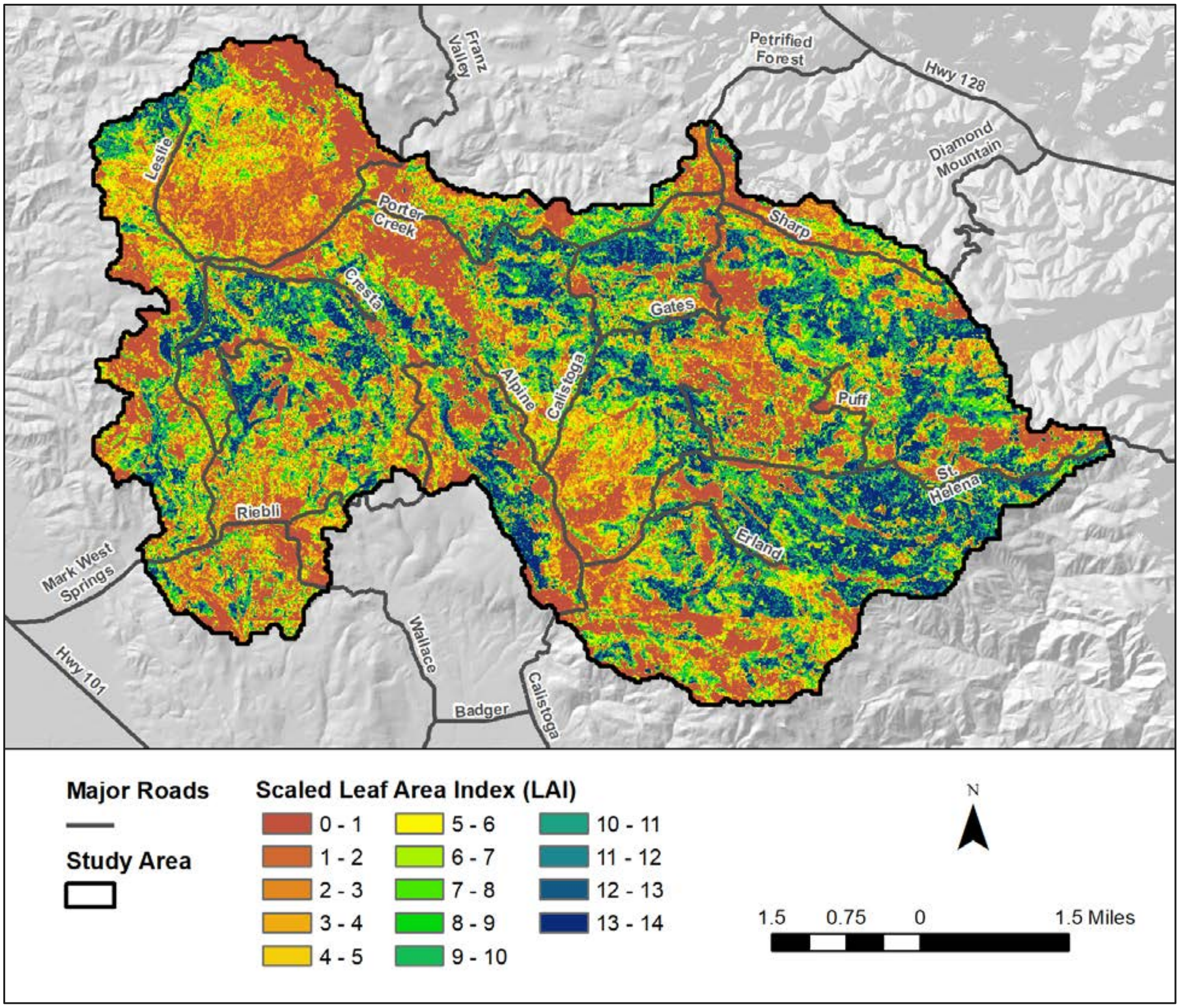


Figure 10: Distribution of scaled LiDAR-derived Leaf Area Index (LAI).

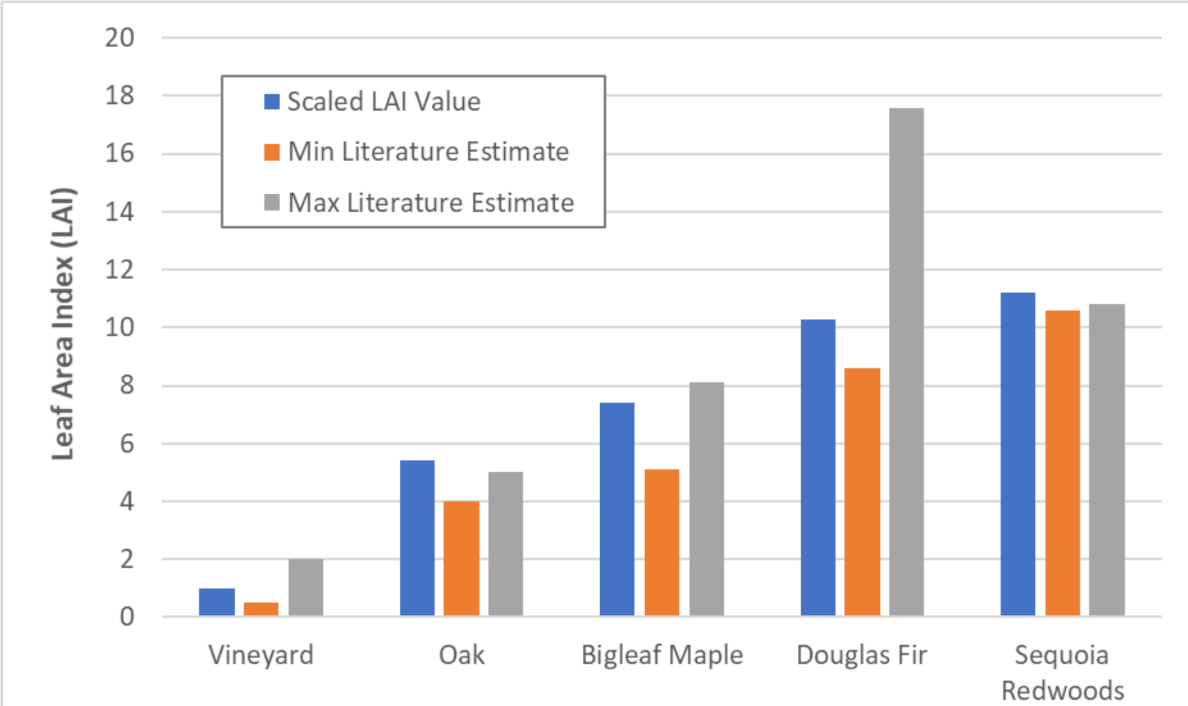


Figure 11: Comparison between scaled LAI values used in the MWC hydrologic model and estimates from the literature for various vegetation types.

Land Cover Adjustments for the Tubbs Fire

As discussed at the beginning of this chapter, we developed a second version of the model incorporating the short-term effects of the Tubbs Fire to facilitate calibrating the model to post-fire streamflow data collected within the burn area at Michelle Way. The canopy-damage raster dataset generated by SCAPOSD (Green & Tuckman, 2018) and Soil Burn Severity dataset generated by the U.S. Forest Service (USFS, 2018) were used to identify the portions of the watershed where we judged that the fire was severe enough to result in significant short-term changes in evapotranspiration. These areas included forested lands where canopy damage was >80% and non-forested lands where soil burn severity was classified as moderate or severe (Figure 12). The delineated area of hydrologically-significant vegetation damage is about 18% of the upper MWC watershed evaluated in this study and approximately 42% of the total identified burn area.

Post-fire vegetation data or Leaf Area Index (LAI) mapping is not available, therefore a simple means of adjusting vegetation parameters was employed for the subset of the burn area judged to have hydrologically significant fire damage. The vegetation in the burn area was assumed to have LAI and rooting depth properties mid-way between the original cover type (undisturbed) and grasslands (full conversion). This simple representation is intended to approximate the short-term effects (1-2 yrs) of the fire on evapotranspiration but is not intended to reflect long-term landscape recovery. A CalFire parcel-based shapefile identifying burned structures was used to identify wells and surface water diversions within the burn area to turn off in the model.

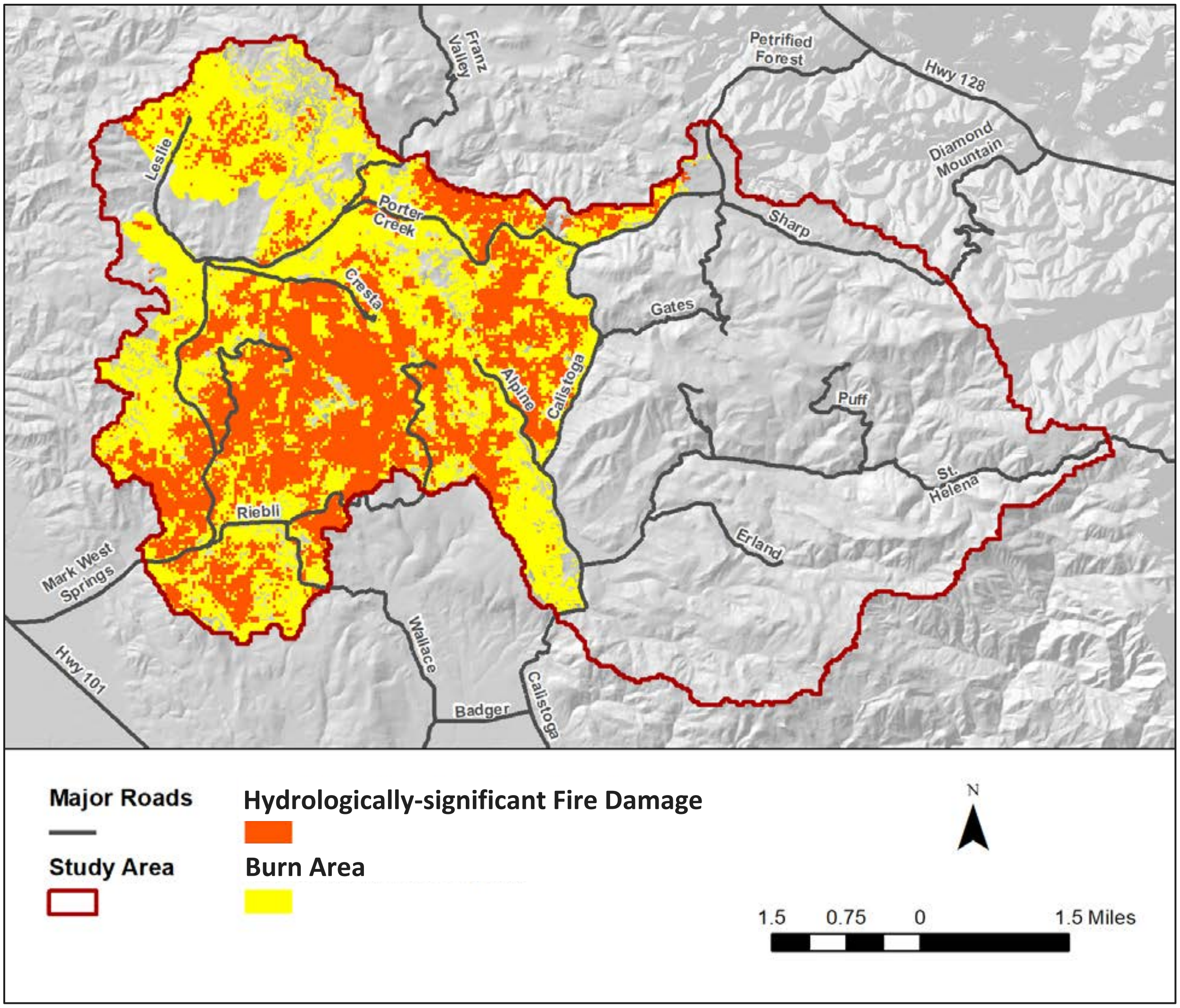


Figure 12: Footprint of the 2017 Tubbs Fire and the severely burned portion of the burn area where vegetation properties were adjusted in the MWC hydrologic model to reflect the fire for the purposes of model calibration.

Short-term fire effects on overland roughness and detention storage or soil hydraulic conductivities were not considered.

The version of the model with these adjustments to land cover values was used for model calibration only. The pre-fire representation of cover was retained for model simulations of existing conditions and scenario evaluations since the long-term effects of the fire on vegetation patterns are unknown and future vegetation is expected to resemble pre-fire conditions more so than immediate post-fire conditions.

Surface Water

Channelized flows are represented using a detailed stream network derived from the 3-foot resolution Sonoma County LiDAR dataset (WSI, 2016). This network includes all major perennial streams and many smaller tributaries as well as all major on-stream ponds. Off-channel ponds, some intermittent streams, and ephemeral tributaries are not explicitly represented in the stream network. In total, 79 river miles of stream and 18 on-stream ponds are included and represented by approximately 3,300 cross-sections in the surface water hydraulics component of the model.

Streams

The stream network includes all channels with a drainage area of more than 0.2 mi^2 and a stream length of at least 500 feet. These limits were designed to maximize the extent of the channel network within the limits of the ability of the LiDAR data to accurately represent channel geometry and to avoid excess computational burden. These thresholds allow for inclusion of all perennial streams and all reaches with slope characteristics (<7%) indicative of potential salmonid habitat suitability. In a limited number of cases, channels were extended to include on-stream ponds. Additionally, three channels with drainage areas of less than 0.2 mi^2 were included based on the presence of perennial summer baseflow as observed during stream surveys performed August 27th through August 29th, 2018 by OEI and CDFW staff.

The stream network was derived from the 3-foot Sonoma County LiDAR dataset by computing flow directions and flow accumulations using standard ArcGIS techniques. Channel-cross sections were extracted from the LiDAR DEM at 100-ft intervals for major channels and those known to contain salmonids, including Mark West, Alpine, Humbug, Leslie, Mill, Porter, Riebli, Van Buren, and Weeks Creeks. For the remaining channels, cross-sections were extracted at 200-ft intervals.

Prior to defining the stream network and extracting cross sections, a series of cross sections were surveyed in the field and compared to LiDAR-derived cross sections at various drainage areas and locations throughout the watershed. These comparisons revealed that the LiDAR dataset represents the channel geometry with acceptable accuracy at drainage areas above about 0.2 mi^2. In some cases, accuracy was reasonably high in smaller drainage areas; however, when smaller streams were incised relatively deeply the LiDAR did not capture the details of the channel geometry in sufficient detail for hydraulic modeling. Examples comparing survey- and LiDAR-derived cross sections with accuracy judged to be acceptable for purposes of hydraulic simulation in the model are shown in Figure 14.

A uniform Manning's Roughness coefficient (n) of 0.055, representative of rocky channels with brush along the banks (Chow, 1959), was applied to all cross-sections. A downstream boundary condition was defined as a rating curve established using normal depth calculations for the downstream-most cross section in the model. Because all inflows are generated by other spatially distributed components of the MIKE SHE model, upstream boundary conditions are zero-discharge inflows.

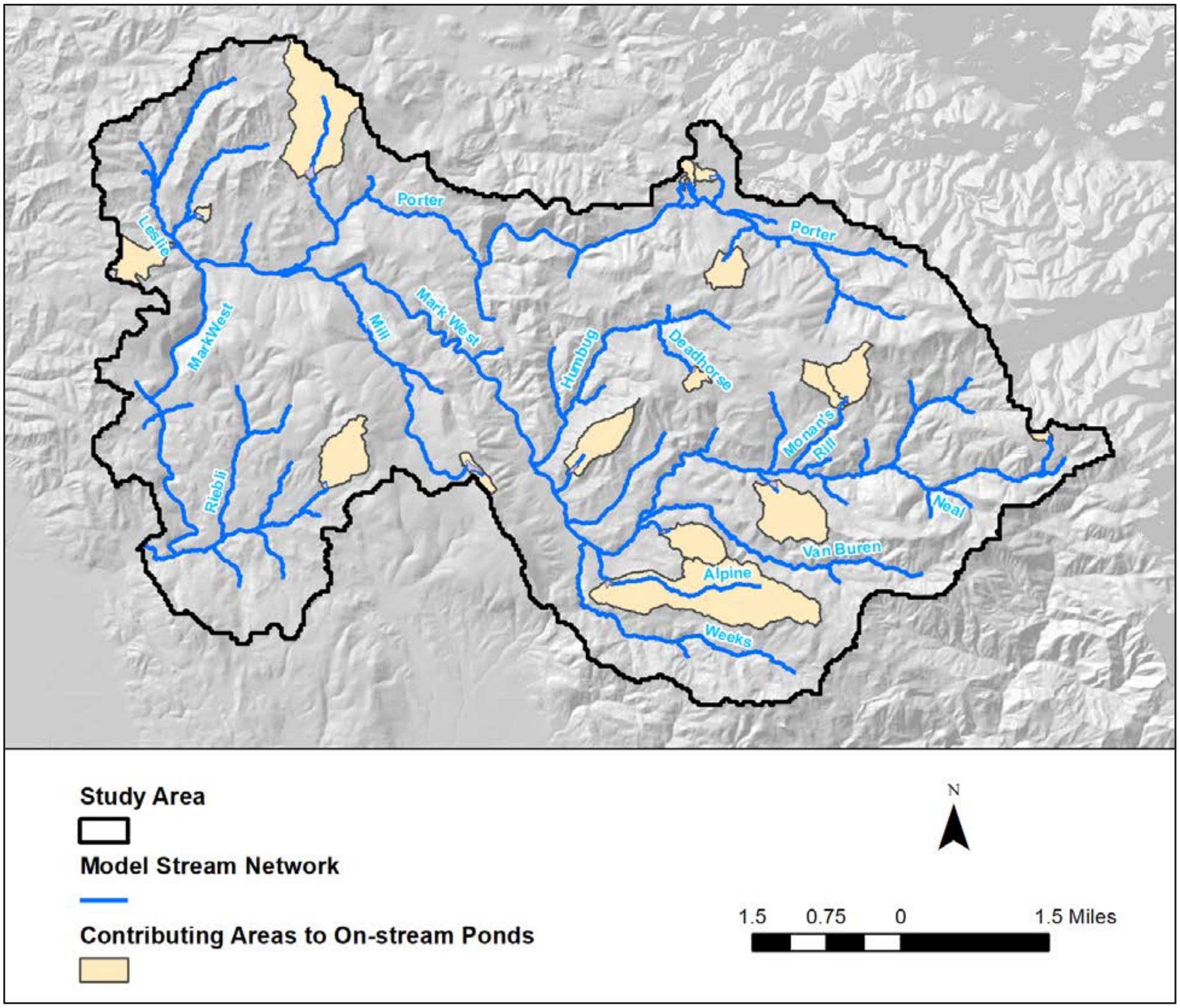


Figure 13: Stream network and on-stream ponds included in the MWC hydrologic model.

Ponds

Within the model domain, approximately 80 ponds have been identified using the 3-foot Sonoma County LiDAR DEM and aerial photography. The majority of these are small off-stream ponds which were not explicitly included in the surface water component of the model. Thirteen on-stream ponds with significant (>0.2 mi^2) contributing areas were included in the model along with five ponds with smaller contributing areas but significant reported water uses.

A stage-storage relationship for each of the 18 ponds included in the model was derived from the 3-foot Sonoma County LiDAR DEM. These data were collected in autumn 2013 and observed water surface elevations are assumed to reflect typical end-of-season storage levels in each pond. The stage-storage relationship for a given pond was associated with cross sections at the upstream and downstream edges of the pond, and cross sections were added at the pond's spillway. Water in the ponds is not explicitly represented in the model grid therefore evaporation

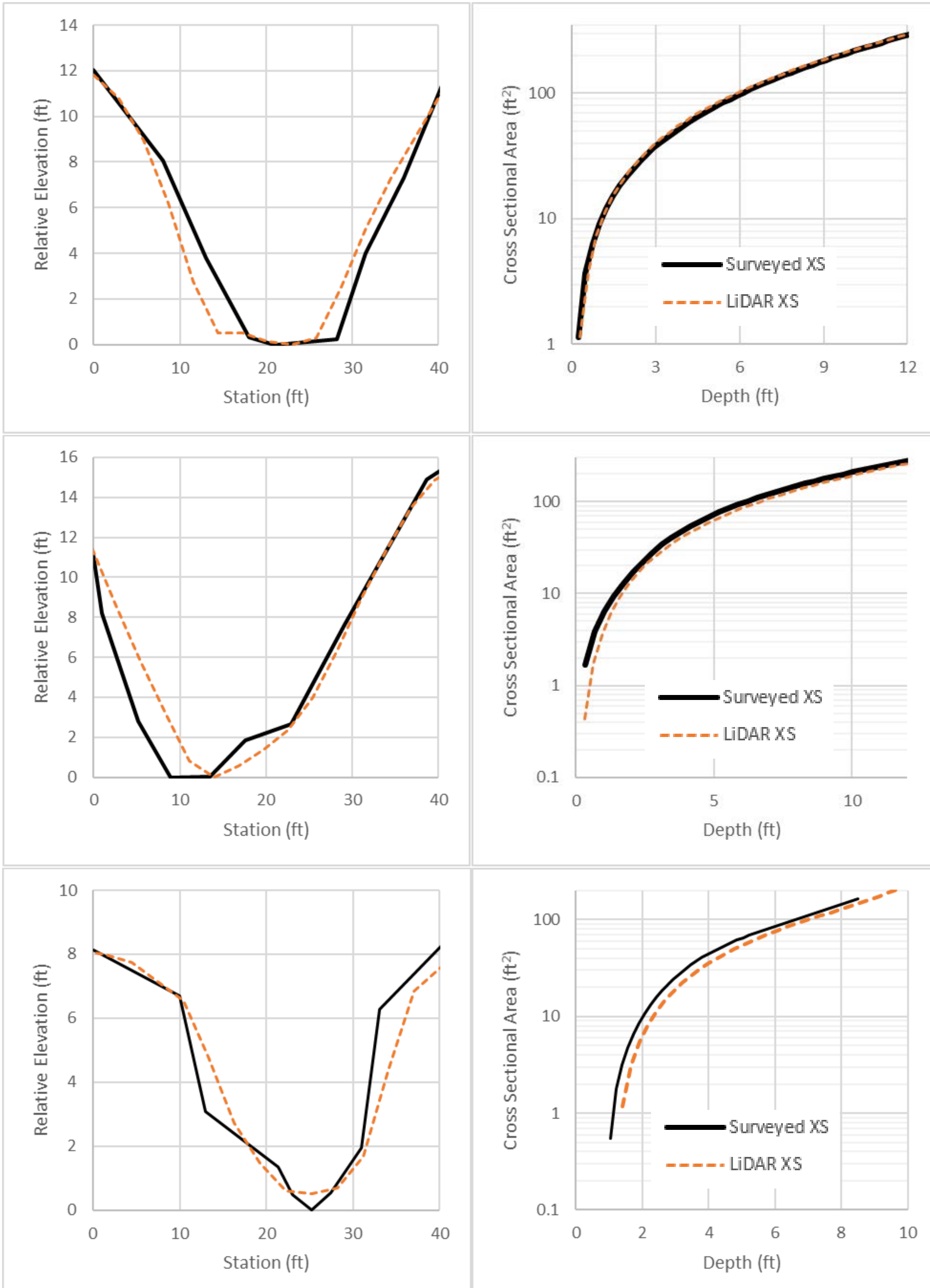


Figure 14: Comparisons between survey- and LiDAR-derived channel cross sections and corresponding depth/area relationships for an unnamed tributary to Mark West Creek with a 0.3 mi^2 drainage area (top), upper Mark West Creek with a 0.5 mi^2 drainage area (middle), and upper Porter Creek with a 2.0 mi^2 drainage area (bottom).

from each pond was included as a surface water boundary condition based on the surface area of the pond and the daily PET data described above.

Soils

The model domain is discretized into 23 different soil zones based on the National Resource Conservation Service's (NRCS) Soil survey Geographic Database (SSURGO) accessed through the Web Soil Survey (WSS). Where reported soil types are similar or where they represent a small portion of the model domain, they are grouped with other similar soil types.

Most soils in the model domain are loams and clay loams. The distribution of soil textures appears to be correlated with underlying geology. Loam soils generally occur in areas underlain by the Sonoma Volcanics and clay loam soils occur in areas underlain by the Franciscan Complex. A major divide in soil types is formed by the Maacama Fault Zone which runs through the central

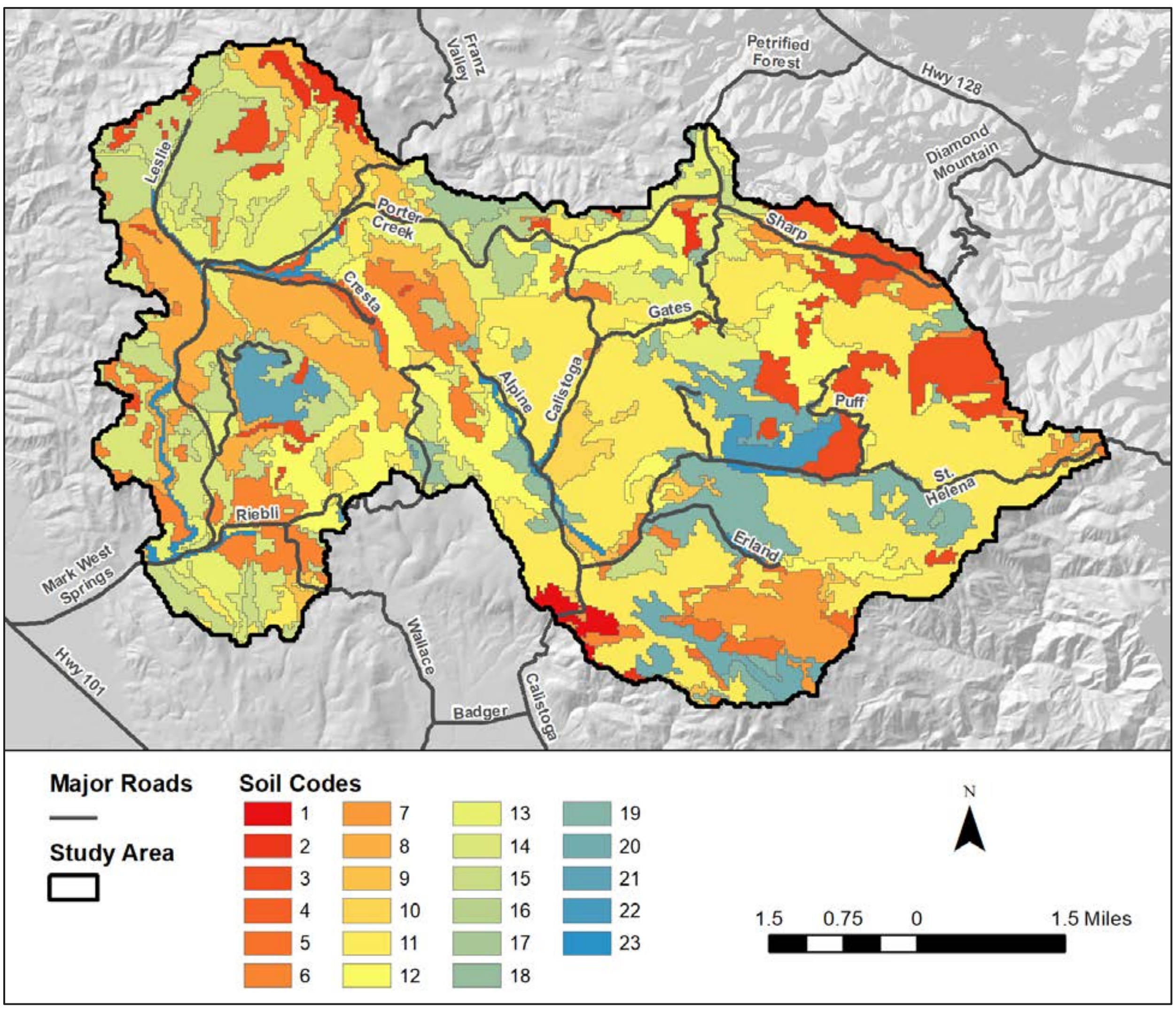


Figure 15: Soil codes used in the MWC hydrologic model (see Table 3 for associated property values).

portion of the study area intersecting Mark West Creek near the confluence with Porter Creek. Downstream of the confluence, the model domain is dominated by NRCS Hydrologic Soil Group B and C soils including the Felta Very Gravelly Loam, Laniger Loam, and Red Hill Clay Loam. Upstream of the confluence, the model domain is dominated by Group D and some Group C soils including the Boomer Loam, Goulding Clay Loam, Henneke Gravelly Loam, and Laniger Loam. Group B soils are relatively well-drained and can absorb and transmit water at relatively high rates whereas Group D soils absorb and transmit water very slowly and thus generate high runoff rates. Group C soils have hydrologic properties intermediate between B and D soils. Group A soils do not occur in the study area.

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 derived from the physical properties report in the SSURGO database and final values have been determined through model calibration. For each zone, saturated hydraulic conductivity was initially estimated using the rate

Table 3: Final calibrated values of soil moisture contents at saturation, field capacity, and wilting point, and saturated hydraulic conductivities used in the MWC hydrologic model.

Soil Code	θsat	θfc	θwp	Ksat (ft/day)
1	0.485	0.366	0.191	0.001
2	0.483	0.220	0.175	0.001
3	0.472	0.216	0.114	0.002
4	0.464	0.271	0.150	0.002
5	0.453	0.161	0.058	0.002
6	0.458	0.301	0.157	0.003
7	0.468	0.195	0.105	0.004
8	0.457	0.304	0.135	0.006
9	0.502	0.342	0.173	0.006
10	0.453	0.270	0.125	0.007
11	0.461	0.195	0.097	0.011
12	0.460	0.224	0.109	0.011
13	0.463	0.235	0.073	0.011
14	0.468	0.103	0.056	0.011
15	0.468	0.139	0.076	0.011
16	0.483	0.232	0.071	0.013
17	0.463	0.186	0.075	0.013
18	0.423	0.246	0.145	0.014
19	0.479	0.254	0.120	0.026
20	0.457	0.280	0.132	0.026
21	0.498	0.350	0.177	0.050
22	0.463	0.168	0.049	0.079
23	0.377	0.019	0.002	0.116

reported for the most limiting layer of each soil. Initial values for water content at field capacity and wilting point were estimated using the weighted average for all horizons within each zone. Saturated water content is not reported by SSURGO and initial values were estimated using the reported average bulk density for each zone and an assumed soil particle density of 2.65 g/cm^3.

The initial values for soil moisture contents were not adjusted significantly. Excluding the alluvial soils which have significantly different properties, soil moisture content at saturation, field capacity, and the wilting point ranged from 0.42 to 0.50, 0.10 to 0.37, and 0.05 to 0.19 respectively. Successful calibration required significantly lower Ksat values relative to the SSURGO estimates. This can be attributed to the model's simplified 2-layer water balance approach which does not account for variations in Ksat as a function of soil moisture, and thus typically requires lower Ksat values to represent overall infiltration dynamics. Additionally, the unsaturated zone in much of the watershed is relatively thick and comprised of soil strata plus underlying weathered and unweathered bedrock, therefore this parameter reflects an average Ksat value for the full unsaturated zone derived from calibration rather than a true soil property. The calibrated saturated hydraulic conductivity values ranged from 0.01 ft/day for clay soils to 0.12 ft/day for alluvial soils (Table 3).

Interflow

As described in Chapter 3, interflow is represented in the model with a saturated zone drainage function. Drain levels and time constants were derived through calibration and primarily influence the springtime flow recession. A time-varying drain level tied to precipitation patterns was required to adequately reproduce the springtime flow recession. A spatially uniform drain level of 20-ft below land surface was used to activate the drainage process during and following

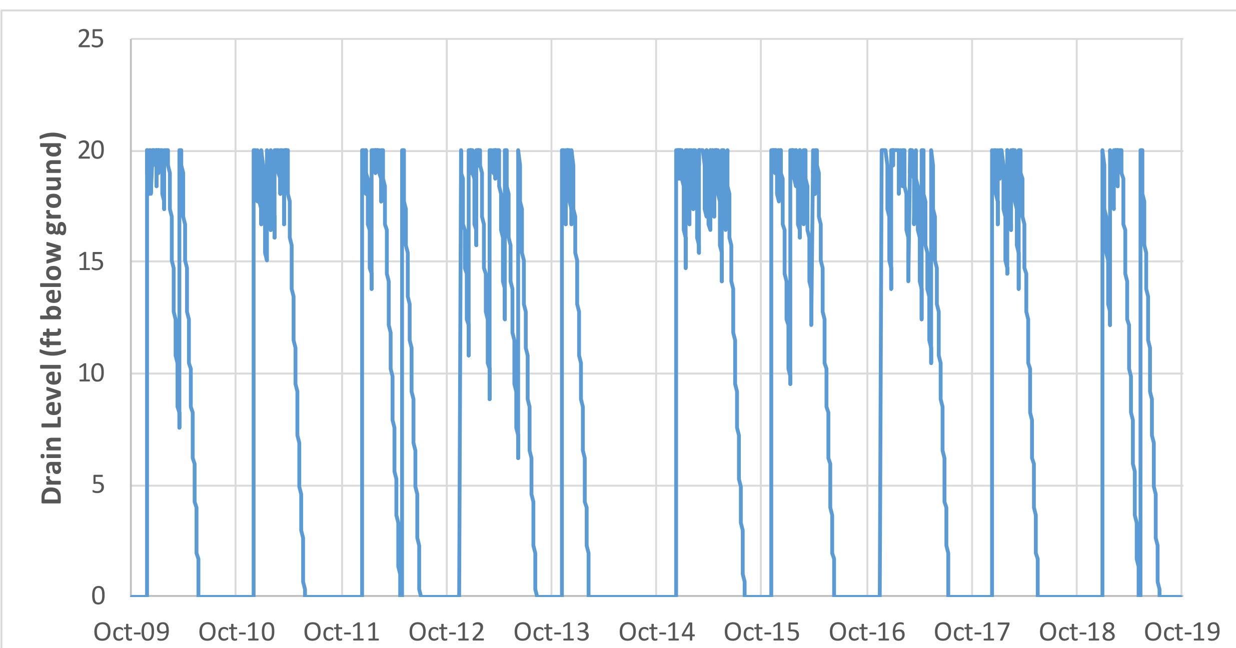


Figure 16: Timeseries of drain levels used to represent interflow in the MWC hydrologic model.

significant precipitation events (defined here as >0.2 in/day). On the third consecutive day with no significant precipitation, drain levels were decreased towards zero at a uniform rate of 0.33 ft/day until a subsequent precipitation event triggered levels to be reset to 20-ft. To account for the delay in the onset of interflow due to low antecedent soil moisture at the beginning of each wet season, drainage was only activated when 2.5 inches of precipitation had fallen over the preceding 21 days (Figure 16).

Hydrogeology

Model Discretization and Boundary Conditions

The geology in the MWC watershed is complex and much of the watershed is characterized by alternating layers of more permeable tuffaceous materials and less permeable basalt and andesite of the Sonoma Volcanics. These layers have varying extents and thicknesses and in some areas are mantled by younger rocks of the Glen Ellen Formation and/or Quaternary Alluvium. As described in detail below, substantial subsurface information could be gleaned from available geologic logs included in Well Completion Reports (WCRs) and aquifer test data obtained from pump test data collected as part of Sonoma County's regulatory requirements for development in water-scarce areas that culminate in Well Yield Certification (WYC).

Despite the available data, it was not possible to accurately delineate individual layers or lenses of geologic materials to use in developing the vertical discretization of the model layers. Given this complexity, we discretized the model into six layers, with layer elevations defined relative to the surface topography. Layers 1-5 generally having a uniform 100-ft thickness and Layer 6 has a uniform 300-ft thickness for a total thickness of 800-ft. The only variation in layer thickness is associated with the alluvium where Layer 1 ranges in thickness from 25- to 50-ft and gradually increases to 100-ft outside of the alluvial body. Where Layer 1 thickness is less than 100-ft, Layer 2 thickness is correspondingly greater than 100-ft such that the base of Layer 2 is 200-ft below land surface (Figure 17 & Table 4).

The base of Layer 6 is defined as a no flow boundary as are the lateral boundaries around the model domain. Available groundwater elevation data is very limited and insufficient for characterizing any groundwater inflows/outflows that may occur across the watershed boundaries. In most areas the no flow boundary assumption (equivalent to assuming a groundwater divide occurs coincident with surface topography) is likely reasonably accurate, however some groundwater outflow likely occurs along portions of the south and southwest watershed divides where more permeable units of the Sonoma Volcanics may contribute flow to alluvial materials in the Santa Rosa Plain down-gradient from our study area. We did not attempt to quantify this component of the groundwater budget as part of our analysis owing to a lack of available data and our focus on processes within the upper watershed.

With the exception of pumping wells which are described in the Water Use section below, all other saturated zone boundary conditions such as infiltration recharge, ET from groundwater, and stream/aquifer interactions are calculated internally by the model through the coupling to other components of the model rather than specified as model inputs.

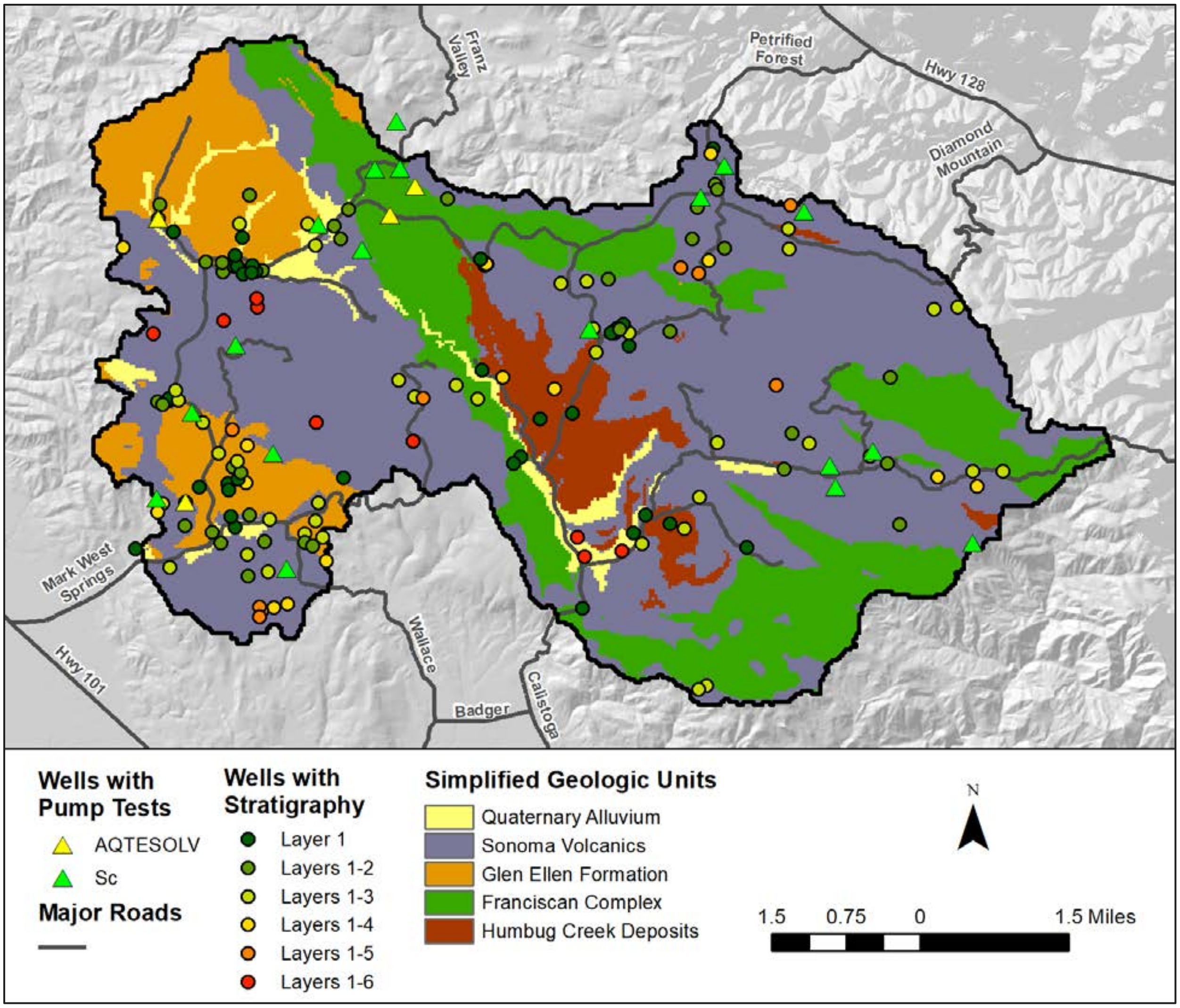


Figure 17: Simplified geologic map and locations of wells where pump test data was available and locations of wells where stratigraphic data was available.

Table 4: Layer thicknesses used in the groundwater component of the MWC hydrologic model.

Layer	Thickness (ft)
1	25 - 100
2	100 - 175
3	100
4	100
5	100
6	300

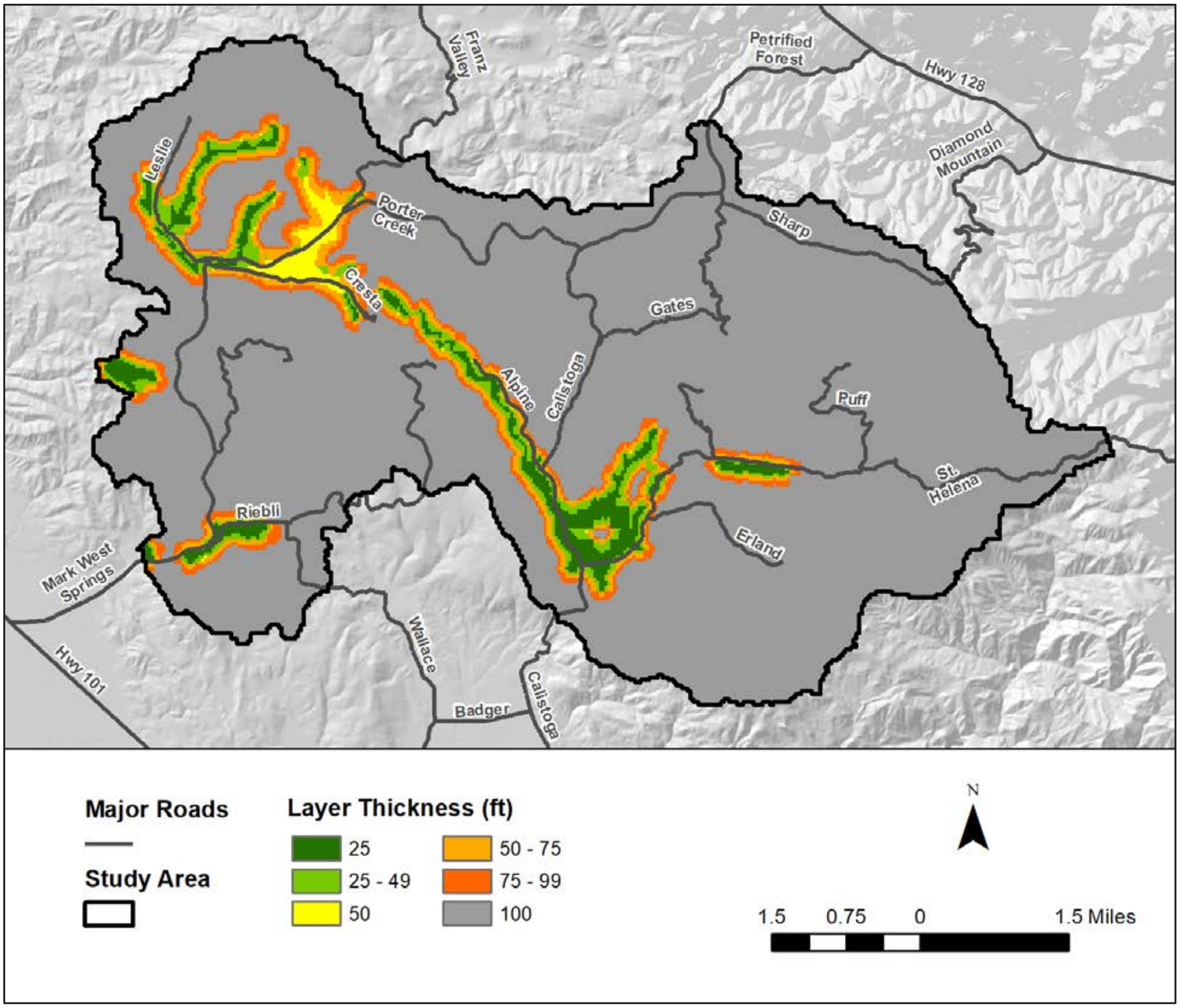


Figure 18: Thickness of groundwater model Layer 1.

Despite the available data, it was not possible to accurately delineate individual layers or lenses of geologic materials to use in developing the vertical discretization of the model layers. Given this complexity, we discretized the model into six layers, with layer elevations defined relative to the surface topography. Layers 1-5 generally having a uniform 100-ft thickness and Layer 6 has a uniform 300-ft thickness for a total thickness of 800-ft. The only variation in layer thickness is associated with the alluvium where Layer 1 ranges in thickness from 25- to 50-ft and gradually increases to 100-ft outside of the alluvial body. Where Layer 1 thickness is less than 100-ft, Layer 2 thickness is correspondingly greater than 100-ft such that the base of Layer 2 is 200-ft below land surface (Figure 18; Table 4).

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With the exception of pumping wells which are described in the Water Use section below, all other saturated zone boundary conditions such as infiltration recharge, ET from groundwater, and stream/aquifer interactions are calculated internally by the model through the coupling to other components of the model rather than specified as model inputs.

Distribution and Description of Geologic Materials

WCRs were obtained for more than 350 wells in the watershed and a subset of these had both detailed descriptions of geologic materials as a function of depth (geologic logs contained in WCRs) to provide useful stratigraphic information and reliable location information to associate the well with a parcel or a specific location. Geologic contacts (vertical boundaries between significantly different rock types) were identified in the logs depending on the geologic materials intersected.

<u>Sonoma Volcanics</u>

Most geologic logs from wells in the Sonoma Volcanics (SV) identify alternating layers of tuffaceous material and other volcanic rocks with andesite being the dominant material in the eastern portion of the watershed and basalt in the western portion. Contacts between tuffaceous materials and other volcanic rocks were delineated where a relatively clear interpretation could be made from the geologic log. Approximately 148 wells provided stratigraphic information within the SV (Figure 17). Within each 100-ft to 300-ft thick model layer interval penetrated by a given well, the geologic materials were classified as predominately (>80% of a given interval) tuffaceous material, predominately basalt or andesite, a combination of materials (<80% of either material), or underlying Franciscan Formation. In most portions of the watershed rocks of the SV extend through the full 800-ft sequence represented in the model. The interpretation becomes less certain with increasing depth from Layer 1 through Layer 6 as the number of wells penetrating a given interval decreases from 148 in Layer 1 to 74 in Layer 3 to just 9 wells in Layer 6 (Figure 17).

<u>Glen Ellen Formation</u>

In and near the Leslie and Riebli Creek subwatersheds, the contact between the Glen Ellen Formation and the underlying Sonoma Volcanics was delineated at 15 wells (Figure 17). These wells revealed that the Glen Ellen Formation ranges in thickness from approximately 130-ft in the upper Leslie Creek watershed to less than 50-ft in the lower watershed and in the Riebli Creek watershed exposure. Static water levels reported in these WCRs revealed that the formation is generally unsaturated and that all the wells are screened predominately in the underlying

Sonoma Volcanics where groundwater is available. The Leslie Creek watershed exposure is much coarser than the materials in Riebli Creek with the former typically described as sand and gravel or sandstone, and the latter typically described as clay or sandy clay. The spatial extent of the available data is insufficient for interpolating an isopach map, therefore a highly simplified representation of the Glen Ellen thickness was developed based on the available information. The Glen Ellen is only present in Layer 1 where we assumed 50-ft thickness in the Riebli Creek and lower portions of the Leslie Creek exposures and 100-ft thickness in the portions of the Leslie Creek exposure above 700-ft in elevation.

Franciscan Complex and Great Valley Sequence

A contact between the Sonoma Volcanics and the underlying rocks of the Franciscan Complex was delineated in a few wells located in the vicinity of the surficial contact between the units. The orientation of these contacts is unknown and the model generally assumes a vertical contact between these materials that extends across the full 800-ft thickness of the model consistent with the deepest available geologic logs which show both of these materials extending to considerable depth. Although hydrogeologic properties may vary substantially within the Franciscan, these variations are expected to depend upon the degree and interconnectivity of fracturing which cannot be characterized from the available data. Owing to the lack of data and the typically low permeability of the Franciscan relative to other geologic materials in the watershed, this unit was assigned uniform hydrogeologic properties. No available wells were located within the exposures of Great Valley Sequence materials in the watershed, consistent with the general experience in the region indicating that that this geologic unit provides poor aquifer material. These materials account for only a small portion of the study area and were treated as equivalent to the Franciscan Complex.

Quaternary Alluvium

A total of 35 WCRs were located within alluvial materials in the watershed (Figure 17). Water level data from the WCRs indicate that the alluvium is unsaturated at about half of these well locations and generally thin (< 25-ft at 22 of the 35 wells), only exceeding 50-ft in the vicinity of the Porter Creek/Mark West Creek confluence where the maximum reported thickness was 60-ft. The alluvium does not appear to be a significant source of water to wells and all of the wells are screened predominately within the underlying geologic materials where groundwater is available. The available geologic logs indicate the alluvium consists of primarily sand, gravel, and boulders with lesser quantities of clay and sandy clay.

The spatial extent of the data is insufficient for interpolating an isopach map, therefore a simplified representation of alluvium thickness was developed based on the available information. Using available surficial geologic mapping, topographic expressions interpreted from LiDAR data, and the subsurface thicknesses as described in WCRs, we reduced the extent of alluvium so as to exclude areas where thicknesses are too small to represent in the model. The alluvium falls entirely within Layer 1, and for most of the revised alluvium extent we assumed a 25-ft thickness, except for the area upstream of the confluence of Mark West and Porter Creeks where we assumed a 50-ft thickness (see Figure 17 for extent & Figure 18 for thickness).

Humbug Creek Lacustrine Deposits

Only a few of the available wells penetrated the Humbug Creek Lacustrine Deposits. They indicate that this material is generally around 25-ft thick and very fine-grained. It is typically described as clay and is generally unsaturated with wells screened in underlying geologic materials. We represented this material in model Layer 1 and assumed a uniform 25-ft thickness based on the extent of the mapped surface exposure.

Aquifer Properties

Hydraulic Conductivity Values

We compiled available pump test data from Well Yield Certifications obtained from the County of Sonoma. A subset of four tests was selected for aquifer analysis based on those tests where 1) the well completion details were known, 2) the test was performed for at least eight hours with a relatively constant pumping rate, 3) drawdowns and pumping rates were reported frequently enough to generate a detailed time-drawdown curve, and 4) the drawdown had stabilized by the end of the test (Figure 17). For the four tests meeting all criteria, the time drawdown data was analyzed using AQTESOLV software and a type-curve matching approach was used to derive estimates of the aquifer Transmissivity (T). The Storage Coefficient (S) cannot be estimated from single-well test data, therefore we solved for T using a range of reasonable estimates of S from the literature and from our previous experience evaluating aquifer test data in similar geologic materials in the region. Depending on the aquifer conditions and drawdown responses, a variety of solutions were used including radial solutions such as the Theis and Cooper-Jacob solutions (Theis, 1935; Cooper & Jacob, 1946), as well dual-porosity solutions such as the Moench slab blocks solution (Moench, 1984). Where more than one solution provided an equally valid description of the data, final T values used in the model were derived by averaging the estimates from the individual solutions.

An additional 19 tests also met the afore-mentioned criteria with the exception of the time-drawdown data which was not detailed enough for type-curve matching to drawdown data (Figure 17). For these tests, the Specific Capacity (Sc) was calculated and used to estimate T using an empirical relationship (Driscoll, 1986). We found good agreement between the T values estimated in AQTESOLV and the T values derived empirically using Sc suggesting that the simplified Sc-based approach is capable of providing reasonable estimates of T (Table 5). The dual-porosity solutions yield an estimate of the Hydraulic Conductivity (K) directly, and T values from the radial solutions were converted to K estimates using the aquifer thickness as derived from the test data and well completion details (Table 6).

We grouped the test data into five categories based on the dominant lithology as interpreted from available WCRs. Test data were classified as representative of Franciscan Complex or one of four categories within in the Sonoma Volcanics: predominately tuff, predominately basalt, predominately andesite, or a mixture of tuffaceous and other volcanics. There are obvious contrasts in well completion details and responses to pumping between the various lithologies with shallower wells (mean of 158-ft) and limited drawdowns (mean of 1.7-ft) within the tuff and deeper wells (mean of 387-ft) and larger drawdowns (mean of 9.9-ft for basalt and 48-ft for andesite) in the hard rock volcanics. Wells in the Franciscan Complex were also generally deeper (mean of 331-ft) and experienced much larger drawdowns (mean of 214-ft) (Table 6).

We calculated the geometric mean of the K estimates for the Sonoma Volcanics for each lithologic category and found that K values varied by nearly two orders of magnitude between the various volcanic materials. The highest value, 23 ft/day, was found for the tuff, followed by the mixed volcanics (3.7 ft/day), and the basalt (0.94 ft/day) and andesite (0.37 ft/day). In the Franciscan Complex, K values were an order of magnitude lower than the andesite (geometric mean of 0.029 ft/day) (Table 6).

No pump test data was available for wells screened entirely within the Glen Ellen Formation, the Humbug Creek Lacustrine Deposits, or the Quaternary Alluvium. This is not surprising given that our analysis showed that few if any wells are completed in these materials which are generally thin and often unsaturated. We relied on descriptions of the geologic materials as described in geologic logs on available WCRs to estimate K values for these materials from literature values (Domenico & Schwartz, 1990). Our initial estimates of K for the coarse-grained northern exposure of the Glen Ellen Formation was 30 ft/day and 0.038 ft/day for the fine-grained southern exposure and for the Humbug Creek deposits. Initial estimates for the alluvium were 30 ft/day in most of the study area and 120 ft/day for the thicker alluvial body delineated upstream of the confluence of Mark West and Porter Creek.

As described in Chapter 5, the initial K estimates were adjusted within reasonable limits to obtain a good fit between measured and simulated potentiometric surface elevations measured at monitored wells and baseflows as described from stream gauge data. Within the Sonoma Volcanics, values were adjusted using a uniform scaling factor in order to maintain the degree of contrast between materials as described from the pump test analyses. The final calibrated values are ~3.8% of the original estimates within the Sonoma Volcanics, the Glen Ellen Formation, and the Humbug Creek deposits. Final values for the Franciscan are ~3.2% of the original estimates, and final values for the alluvium were left unchanged (Table 7). The differences between the original and final values are generally within an order of magnitude of the range of estimates from individual pump tests. These differences are significant but also relatively modest considering that K varies by at least six orders of magnitude in the various materials in Sonoma County and that K estimates for individual pump tests evaluated in this project vary by more than four orders of magnitude. It is plausible that values derived from pump tests over-estimate bulk K values for the large sequences of geologic materials represented by the model layers since most drillers of production wells seek to preferentially screen wells within tuffaceous or highly fractured bedrock intervals to maximize well production and efficiency. Anisotropy in the form of the ratio between horizontal and vertical K was derived through calibration, and the final value was 94 in all units except the alluvium which was parameterized as isotropic.

<u>Specific Yield and Storage Coefficient Values</u>

Previous estimates of the Specific Yield (Sy) for the Sonoma Volcanics range from less than 0.01 to 0.05 and estimates for the Glen Ellen Formation range from 0.03 to 0.20 (Cardwell, 1958; Herbst et al. 1982). Our final calibrated value for Sy in the Sonoma Volcanics was 0.05, and we

Table 5: Comparison of estimates of Transmissivity (T) derived from pump test data analyzed in AQTESOLV and calculated based on the Specific Capacity (Sc).

Material	AQTESOLV T (ft^2/day)	Sc Derived T (ft^2/day)
Sonoma Volcanics	350	710
Sonoma Volcanics	930	1200
Franciscan Complex	1.2	4.9
Franciscan Complex	16	11

Table 6: Pump test and well completion details and estimates of aquifer Hydraulic Conductivity (ft/day).

	Well Depth (ft)	Drawdown (ft)	Test Length (min)	Average Pumping Rate (gpm)	Aquifer Thickness (ft)	Sc (gpm/ft)	K (ft/day)	Source
Sonoma Volcanics Tuff	100	1.7	480	11.4	118	6.7	15	Sc
	150	2.0	480	17.0	138	8.5	16	Sc
	260	2.0	510	25.3	177	13	19	Sc
	70	1.8	480	10.7	61	5.9	26	Sc
	210	1.1	480	14.2	70	13	49	Sc
	158	**1.7**	**486**	**15.7**	**113**	**9.3**	**23**	
Sonoma Volcanics Basalt	807	6.0	510	4.0	177	0.67	1.0	Sc
	420	13.0	480	11.6	215	0.89	1.1	Sc
	200	10.8	500	13.7	140	1.3	2.4	Sc
	476	**9.9**	**497**	**9.8**	**177**	**0.94**	**1.4**	
Sonoma Volcanics Andesite	320	86.0	510	5.0	144	0.06	0.11	Sc
	460	49.0	600	5.0	209	0.10	0.13	Sc
	420	47.0	480	45.3	386	1.0	0.67	Sc
	80	10.0	1440	3.5	91	0.35	1.0	Sc
	320	**48.0**	**758**	**14.7**	**208**	**0.37**	**0.31**	
Sonoma Volcanics Undifferentiated	260	20.0	1530	7.5	91	0.38	1.1	Sc
	220	8.0	1230	21.2	229	2.6	1.5	AQTESOLV
	320	25.0	720	30.0	143	1.2	2.2	Sc
	200	4.8	540	8.9	181	1.9	2.7	Sc
	305	2.0	540	4.4	79	2.2	7.4	Sc
	380	2.0	520	6.5	95	3.3	9.2	Sc
	76	3.3	730	14.7	65	4.4	14	AQTESOLV
	252	**9.3**	**830**	**13.3**	**126**	**2.3**	**3.7**	
Franciscan Complex	540	428.0	720	7.8	614	0.018	0.0019	AQTESOLV
	280	175.0	480	6.0	270	0.034	0.034	Sc
	245	209.9	875	8.3	296	0.040	0.054	AQTESOLV
	260	40.9	510	4.4	152	0.11	0.189	Sc
	331	**213.5**	**646**	**6.6**	**333**	**0.050**	**0.029**	

Table 7: Final hydrogeologic properties used in the calibrated MWC hydrologic model.

Material	Present in Layers	Kh (ft/day)	Kh/Kv	Sy	S (ft^{-1})
Sonoma Volcanics	1 to 6	0.0082 - 0.60	94	0.05	2.0E-04
Franciscan	1 to 6	0.00090	94	0.10	1.1E-05
Glen Ellen	1 to 2	0.0010 - 0.79	94	0.04 - 0.20	1.0E-04 - 5.4E-04
Humbug Creek	1	0.001	94	0.04	5.4E-04
Alluvium	1	30 - 120	1	0.30	1.5E-04

Table 8: Range and average Hydraulic Conductivity (K) values for the Sonoma Volcanics in model Layers 1 through 6.

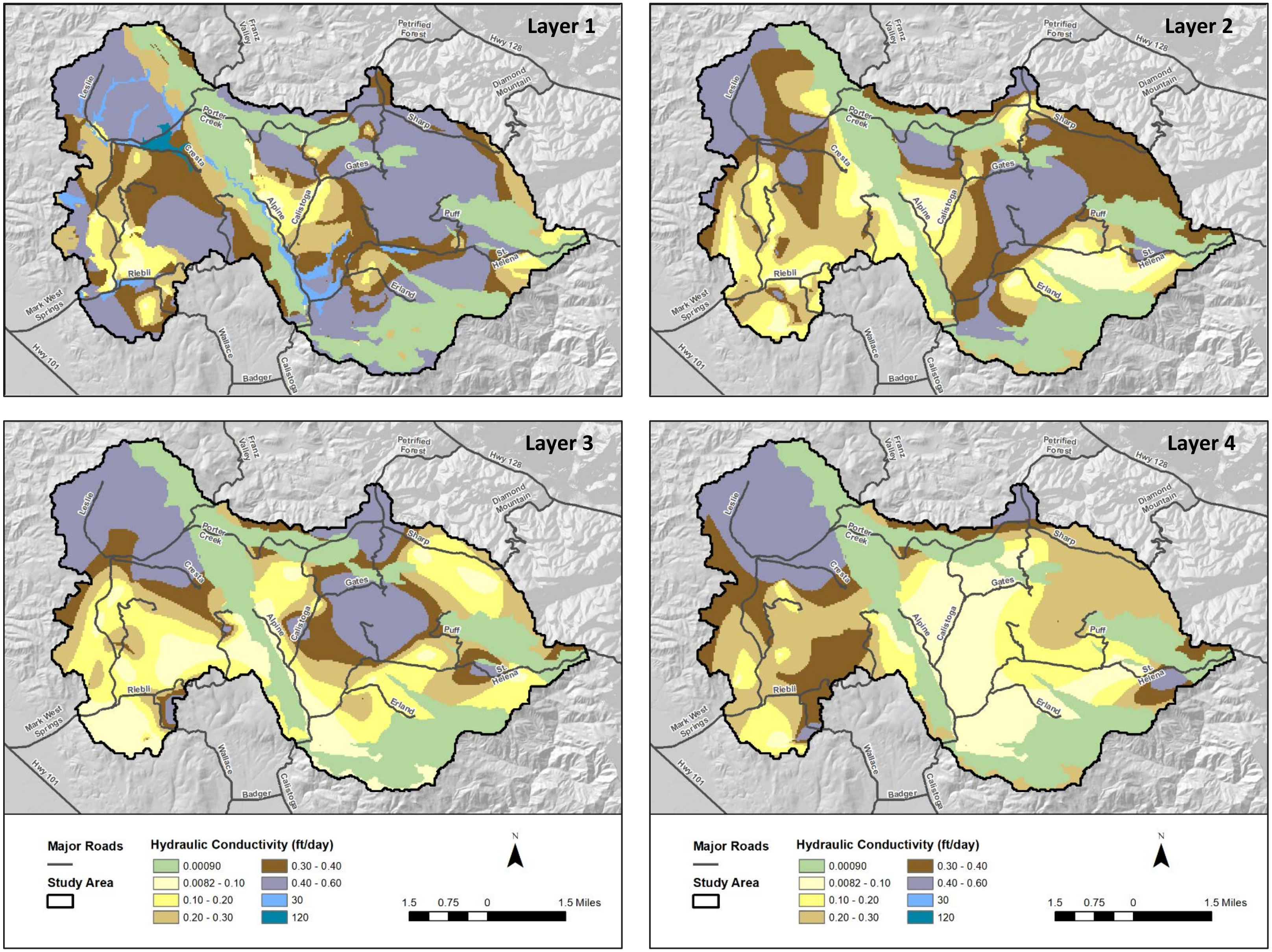
Layer	Sonoma Volcanics Kh (ft/day)	
	Range	Mean
1	0.0082 - 0.60	0.40
2	0.0082 - 0.60	0.29
3	0.0082 - 0.60	0.28
4	0.0082 - 0.60	0.24
5	0.0082 - 0.60	0.21
6	0.0082 - 0.32	0.10

used a value of 0.04 in the fine-grained Reibli Creek exposure of the Glen Ellen and 0.20 in the coarser Leslie Creek exposure (Table 7). No estimates of Sy were available for the Franciscan Complex, the Humbug Creek Deposits, or the Alluvium in the study area, thus estimates were based on literature values from similar materials (Freeze & Cherry, 1979; Domenico & Schwartz, 1990). We used values of 0.04, 0.10, and 0.30 for the Humbug Creek, Franciscan, and alluvium respectively (Table 7). Johnson (1977) estimated a value for the Storage Coefficient (S) for the Sonoma Volcanics of 1.6E-04 (ft^{-1}). No estimates of S are available for the other geologic materials in the watershed; therefore, estimates were based on literature values from similar materials (Domenico & Mifflin, 1965). Values ranged from 1.1E-05 (ft^{-1}) for the Franciscan Complex to 5.4E-04 (ft^{-1}) for the Humbug Creek Deposits (Table 7).

<u>Hydrogeologic Property Distributions</u>

As described above under the heading Distribution and Description of Geologic Materials, we classified geologic materials within the Sonoma Volcanics in each vertical interval corresponding to one of the six model layers using the same four categories examined with the pump test analyses. We assigned each of the well locations with available stratigraphic information the corresponding geometric mean K value from the pump test analyses and interpolated K distributions for each layer in a GIS using kriging (Figure 19). K values for the other materials were assumed to be homogeneous and these materials were assigned corresponding K values from literature estimates as described above. The model layering was constructed such that the base of Layer 1 corresponded to the base of the Quaternary Alluvium; therefore, K estimates were used directly in the model for areas of Layer 1 with alluvium. For the Humbug Creek deposits and lower portions of the Glen Ellen Formation which do not penetrate the full thickness of Layer 1, we calculated a depth-averaged K value based on the relative thicknesses of these materials and underlying formations (Figure 19).

The interpolated K maps for the Sonoma Volcanics reveal that tuffaceous material is widespread in the watershed and that the proportion of tuffaceous versus other volcanic rocks (principally andesite and basalt) generally decreases with depth as is apparent from the mean K value for the volcanics which decreases from 0.40 in Layer 1 to 0.10 in Layer 6 (Figure 19). A significant block of primarily tuffaceous material is present in the upper Mark West and Humbug Creek watersheds, and the interpreted WCRs indicate that the volcanics become dominated by andesite below about 300-ft (Figure 19). Another significant block of primarily tuffaceous material underlies the Glen Ellen Formation in the Leslie Creek watershed where it extends from the base of the Glen Ellen to about 400-ft below land surface and becomes more basaltic-dominated material at greater depths. A third relatively thin block of tuff occurs at greater depth (400 to 500-ft below land surface) in portions of the lower watershed, and less widespread and generally thin blocks of tuff are also present in other portions of the upper Mark West and Porter Creek watersheds (Figure 19).


Layer 1
Layer 2
Layer 3
Layer 4
Franz Valley
Petrified Forest
Hwy 128
Diamond Mountain
Leslie
Porter Creek
Sharp
Cresta
Gates
Alpine
Calistoga
Puff
St. Helena
Riebli
Erland
Mark West Springs
Hwy 101
Wallace
Badger
Major Roads
Study Area
Hydraulic Conductivity (ft/day)
0.00090
0.0082 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.60
30
120
N
1.5 0.75 0 1.5 Miles

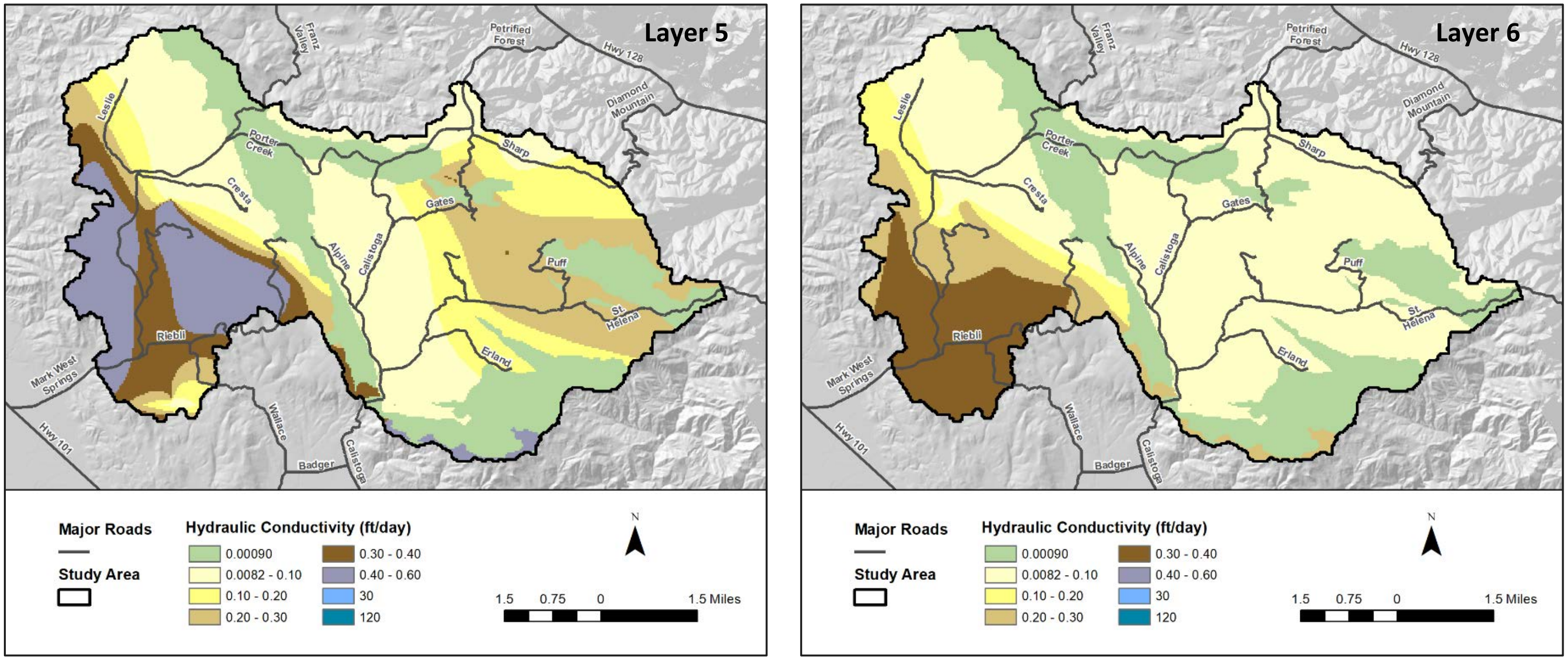


Figure 19: Horizontal Hydraulic Conductivity distributions for model Layers 1 through 6.

Water Use

Water Use Categories and Spatial Distribution

Water uses were calculated on a parcel by parcel basis. We identified the following use categories: Residential, Vineyard Irrigation, Pasture Irrigation, Cannabis Irrigation, Irrigation of Other Miscellaneous Crops, Vineyard Frost Protection, Winery Production and Visitation Use, and Miscellaneous Industrial Uses. The water uses on each parcel were identified using a variety of remotely sensed data and other datasets provided by various governmental entities. Acreages of vineyard, pasture, and other croplands were obtained from the Sonoma County Vegetation Mapping & LiDAR Program's Fine Scale Vegetation and Habitat Map (SCVMLP, 2015). Satellite imagery was reviewed to verify the accuracy of the identified agricultural lands and to identify vineyards planted after 2013 when the underlying LiDAR dataset on which this map is based was collected. In total we found 442.4 acres of vineyard and 12.8 acres of irrigated pasture and other crops (primarily olives).

All vineyards with frost protection systems that use water are required to register with the Sonoma County Agricultural Commissioner's office. Most vineyards in the model domain are located on ridgetops and hillsides where vineyards in Sonoma County are generally less likely to require frost protection than vineyards located on valley bottoms. Additionally, some vineyards may also have permanent or portable fans or heaters for frost protection. A review of the Sonoma County Frost Protection Registration database revealed that three parcels within the model domain are registered as using water for frost protection. One additional parcel with vineyard in the model domain indicated in the SWRCB's 2015 Russian River Information Order (SWRCB Information Order) that they also use water for frost protection. One of these vineyards obtains water from ponds located outside the watershed and three use groundwater from within the watershed. The three vineyards using water from within the watershed for frost protection total 16.9 acres.

Existing cannabis cultivation operations were identified from registration and permit records from the NCRWQCB and the County of Sonoma. It is common knowledge that many existing operations are not identified in the permit system. To account for water use by unregistered cannabis cultivators, we reviewed publicly-available satellite imagery and identified the size and location of all visible cultivation sites in the watershed. In total we identified 47 parcels with outdoor and mixed-light cannabis operations totaling approximately 9.8 acres of cultivation area. Indoor operations could not be identified by aerial imagery and thus this component of cannabis irrigation use may be under-estimated.

The number of residences on each parcel was obtained from the County of Sonoma's parcel GIS coverage. Seven small mutual water companies and the City of Santa Rosa each serve a small area in the southwest portion of the watershed. Information about the well locations and number of residences supplied by each well was obtained from the SWRCB's State Drinking Water Information System (SDWIS) and used to adjust the residential use estimate to account for residences supplied by water from outside the watershed and residences not in the watershed but supplied by water from within the watershed. Census block data from the 2010

U.S. Census provided an estimate of the total population served by water from the watershed. When combined with the corresponding number of residences, this yields an estimate of the average number of people per residence (2.09) which could then be used along with per capita use rates to calculate the total residential use for each parcel. In total there are approximately 2,518 people served by water obtained from within the watershed.

Winery production volumes and annual guest visitation totals were obtained from a GIS dataset provided by the County of Sonoma. Total winery production for the eight wineries in the watershed is approximately 44,300 cases per year. There are only two primary industrial users in the watershed which were handled on a case-by-case basis. Quarterly water use volumes for Mark West Quarry were obtained from reports submitted to the County of Sonoma, and monthly groundwater pumping volumes for Safari West were obtained from the SWRCB Information Order. No use for the Mayacama Golf Club was included since productions wells for the golf club and associated residences are located outside the study area.

Standard Use Rates

Standard use rates were established for the various use categories in the study area using data from the SWRCB Information Order, local municipalities, and literature sources. We examined rates and use categories from the SWRCB Information Order and identified those entries in and around the study area where rates were reported to be based on physical measurements such as totalizer readings or pump fuel usage. In most cases, the method of use estimation was unknown or not based on physical measurements. Given the uncertainty in the accuracy of these estimates, we only relied on those estimates based on physical measurements. In many cases, the reported uses contained a mix of use types (e.g. vineyard irrigation and residential) which prohibited calculation of per acre irrigation or per capita residential use. After careful examination of the data, we were only able to identify four parcels where residential use could be reliably estimated and three parcels where vineyard irrigation use could be estimated.

Total annual per capita use calculated for the four residential parcels in the Mark West Creek watershed for 2014/2015 averaged approximately 23,100 gallons (0.071 acre-ft/yr). We compared the annual use estimates to data from the nearby Town of Windsor. Based on the available data from the SWRCB's Water Conservation and Production Reports from 2014 to 2018, the average annual per capita use was approximately 26,700 gallons (0.082 acre-ft/yr) which is in reasonably good agreement with the Mark West data. Due to the small sample size of the local data, the calculated monthly averages are heavily influenced by individual users, whereas the Windsor data is based on thousands of connections and is therefore expected to provide a better estimate of typical use in the area. We relied on the average per capita monthly data from the Town of Windsor to generate use estimates for the model (Table 9 & Figure 20); it is acknowledged that this method may over- or under-estimate actual residential use in the study area.

Total annual vineyard irrigation use for the three parcels in the Mark West Creek watershed for 2014/2015 (totaling 80 acres of vineyard) ranged from 0.21 to 0.53 ac-ft/ac/yr. As part of a parallel project in the Mill Creek Watershed, we obtained recycled water delivery data for

2017/2018 from the City of Healdsburg for four parcels in the Dry Creek Valley totaling 142 acres which provided a very accurate means of estimating vineyard irrigation rates for the region and validating the estimates derived from the SWRCB Information Order data. The Dry Creek data showed very similar annual rates ranging from 0.17 to 0.55 ac-ft/ac/yr, and the average annual total calculated from the Mark West parcels (0.32 ac-ft/ac/yr) was nearly identical to the average annual total calculated in Dry Creek (0.31 ac-ft/ac/yr). To provide a more robust estimate of the temporal distribution of vineyard irrigation we calculated monthly mean rates from the three parcels in Mark West plus the four parcels in Dry Creek for use in the model, which yields mean annual use of 0.32 ac-ft/ac/yr (Table 9 & Figure 20). In the model, vineyards are irrigated from May through October with irrigation peaking at 0.09 acre-ft/acre/month in June (Figure 20).

Based on guidance provided by the University of California Davis and Sonoma RCD, the timing of water use for frost protection is based on the wet-bulb temperature (Snyder, 2000; Minton et al., 2017). Wet bulb temperature was calculated on an hourly timestep using air temperature and relative humidity data from the Windsor CIMIS station (Stull, 2011). Frost protection is assumed to occur any time the hourly wet bulb temperature is 0.5°C or lower during the typical March 15th – May 15th frost protection season. The rate at which each parcel uses water for frost protection was calculated as the product of vineyard acreage and reported sprinkler and micro-sprinkler application rates as described in the Sonoma County Frost Protection Registration database (Table 9). Based on these assumptions, the annual number of hours of frost protection ranged from one in 2013 to 25 in 2011, the average annual application rate was 0.069 ac-ft/ac/yr, and the maximum rate was 0.18 ac-ft/yr.

Table 9: Standard water use rates and summary of total water use for the various use categories represented in the MWC hydrologic model.

Use Category	Unit Definition	Use per Unit (ac-ft/yr)	# of Units	Total Use (ac-ft/yr)
Residential	Person	0.082	2,518	206.5
Vineyard Irrigation	Acre	0.32	442.4	141.6
Vineyard Frost Protection	Acre	0.069	16.9	1.2
Pasture/Other Irrigation	Acre	2.00	12.8	25.6
Outdoor Cannabis	Acre	1.34	5.9	7.9
Hoop-house Cannabis	Acre	1.53	3.9	6.0
Winery	1,000 Cases of Wine	0.073	44	3.2
Misc. Industrial	Lump Sum	-	-	38.8
Sum				**430.7**

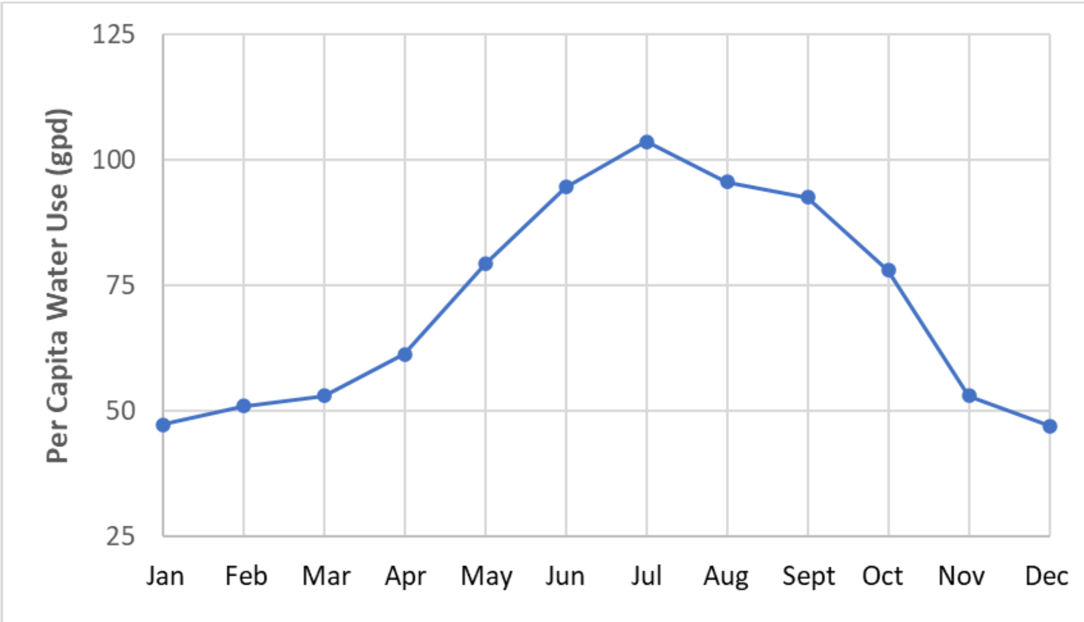


Figure 20: Mean (2014-2018) monthly per capita residential use from the Town of Windsor used to calculate residential use in the MWC hydrologic model.

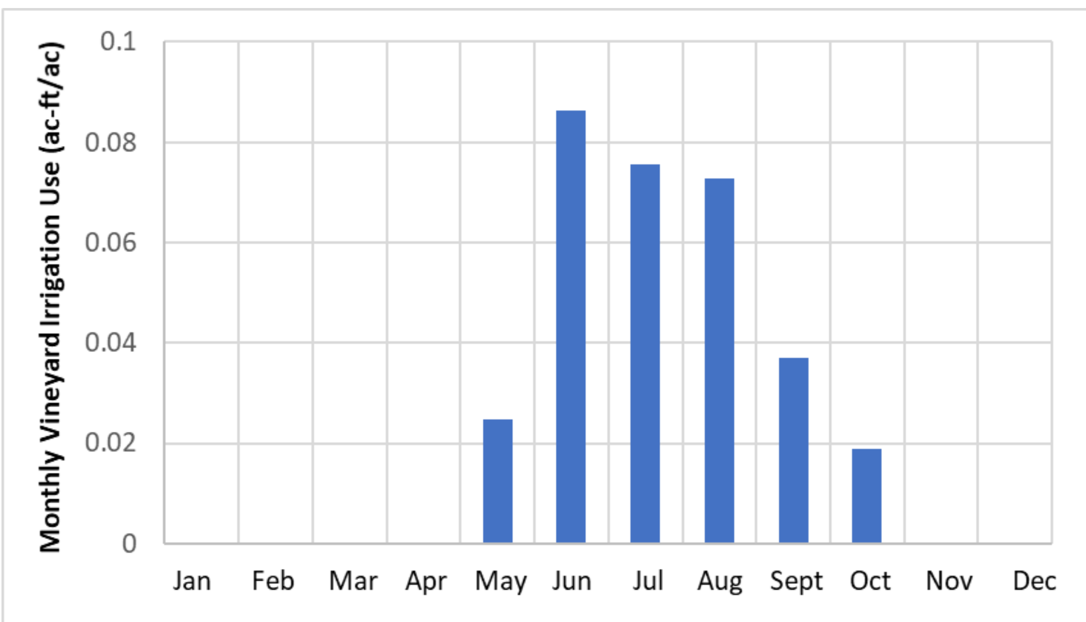


Figure 21: Mean (2014-2015 and 2017-2018) monthly per acre vineyard irrigation use compiled from Information Order data in the Mark West Creek watershed and recycled water delivery data in the Dry Creek Valley and used to calculate vineyard irrigation use in the MWC hydrologic model.

No reliable pasture irrigation rates could be determined from the available data, therefore we relied on a regionally-appropriate value of 2.0 ac-ft/ac/yr (County of Napa, 2015). Based on field reconnaissance and review of available aerial imagery and GoogleEarth Street View products, most orchards within the study area are mature walnut and apple orchards which are typically dry-farmed in Sonoma County. Less than 2 acres each of olive orchard and vegetable crops were identified and were assumed to be irrigated at rates similar to pasture. The total acreage of irrigated pasture, olive orchard, and vegetable crops in the study area is only 12.8 acres.

Cannabis use rates are based on cannabis irrigation data collected by the NCRWQCB for Humboldt, Mendocino, and Sonoma Counties. Typical irrigation rates of 1.34 ac-ft/acre/yr for outdoor cultivation and 1.53 ac-ft/acre/yr for hoop-house cultivation were selected based on a presentation summarizing this data which also provided a monthly distribution of use (Dillis, 2018) (Table 9).

Winery production, employee, and guest water use rates were based on the County of Napa's Water Availability Analysis Guidance Document (County of Napa, 2015) (Table 9). The monthly distribution of winery production was taken from the Winery Wastewater Handbook (Chapman et al., 2001). Winery guest use, which is relatively minor within the study area, was assumed to be constant throughout the year (Table 9). As discussed above Industrial use was based on parcel-specific reported rates from Sonoma County and the SWRCB Information Order rather than on standard rates.

Water Sources

Parcels with surface water diversions were identified from the SWRCB Electronic Water Rights Information Management System (eWRIMS) and the SWRCB Information Order. For unpermitted cannabis cultivation operations where the water source was unknown we assumed surface water use if there was a perennial stream, spring, or pond located on the parcel, which was the case for 9 of the 47 cannabis operations in the study area. For all other parcels we assumed groundwater use. Where multiple wells are located on a given parcel, we divided the total use for the parcel between the various individual wells. When eWRIMS or the SWRCB Information Order indicated that a parcel has both surface water and groundwater supplies, surface water diversions were subtracted from groundwater pumping.

After consolidating duplicate records from the various sources, we excluded diversions reported as inactive or with zero use, as well as those where the SWRCB Information Order states use; however, the reported uses are for evaporation losses and recreation or aesthetics rather than for consumptive uses. We only identified two off-channel ponds with small reported consumptive uses estimated to total approximately 1.3 ac-ft/yr which were accounted for as groundwater use given that the model does not explicitly represent off-stream ponds. For spring diversions, we attribute the location of the diversions to the nearest stream in our model, thus treating it as equivalent to a direct diversion. There are a total of 52 surface water diversions in the model, 24 of these are direct stream diversions, 19 are spring diversions, and 9 are diversions from on-stream ponds represented in the model (Diversion timeseries are based on average monthly diversion volumes. Where possible, reported diversion volumes from eWRIMS and the

SWRCB Information Order were used. If reported diversion volumes from the SWRCB Information Order were not based on physical measurements or if no diversion volumes were reported, volumes were calculated using the standard use rates for the uses on a given parcel.).

Where possible, wells were located at specific locations on a given parcel from location information available on WCRs, the SWRCB Information Order, and in some select cases site visits. The SWRCB Information Order was especially helpful in this regard by providing a means of tying many more wells to specific locations than would have otherwise been possible. Nevertheless, many of the locations reported in SWRCB Information Order data proved to be parcel centroids and it is not possible to locate all wells at a level of detail beyond the parcel scale. More specific location data was used for 458 of the 792 wells in the model. We initially placed all the remaining wells at parcel centroids, but review of the parcels along upper Mark West Creek and Humbug Creek revealed that residences in these areas are generally located much closer to the creek than the centroid of the parcel. There are certainly many exceptions, but wells are often placed in relatively close proximity to the areas they serve, so to avoid over-estimating the distances between wells and streams, we placed theses stream-side parcel wells along upper Mark West Creek and Humbug Creek at the centroids of the residences as indicated by the impervious areas delineated in the Sonoma County fine-scale vegetation mapping data (SCVMLP, 2017).

Well completion details could be determined from WCRs for 189 wells and we associated the wells without WCRs with the nearest well with a WCR within the same geologic terrain to estimate well depth and screened interval information for all wells in the model. About 47% of the wells are screened at least partially within the upper 100-ft of aquifer material but most of these are screened to greater depths with only 5% of the wells screened entirely in the upper 100-ft. About 34% of the wells are screened entirely within the upper 200-ft of aquifer material and about 78% are screened entirely within the upper 400-ft with the remainder screened within the upper 700-ft (Figure 22).

Water Use Timeseries

Surface Water Diversions

Diversion timeseries are based on average monthly diversion volumes. Where possible, reported diversion volumes from eWRIMS and the SWRCB Information Order were used. If reported diversion volumes from the SWRCB Information Order were not based on physical measurements or if no diversion volumes were reported, volumes were calculated using the standard use rates for the uses on a given parcel. The monthly volumes calculated for each diversion are used to calculate a diversion timeseries. These timeseries were calculated on a 6-hour timestep and account for pumps shutting on and off and the estimated capacities of these pumps. A 6-hour timestep was selected to provide a reasonable representation of sub-daily variability while maintaining reasonable computational efficiency. Separate pumping regime assumptions are made for direct diversions and for spring and pond diversions.

Direct diversions were assumed to fill storage tanks completely and then resume once these tanks had been partially emptied. Based on storage tank sizes reported in the SWRCB

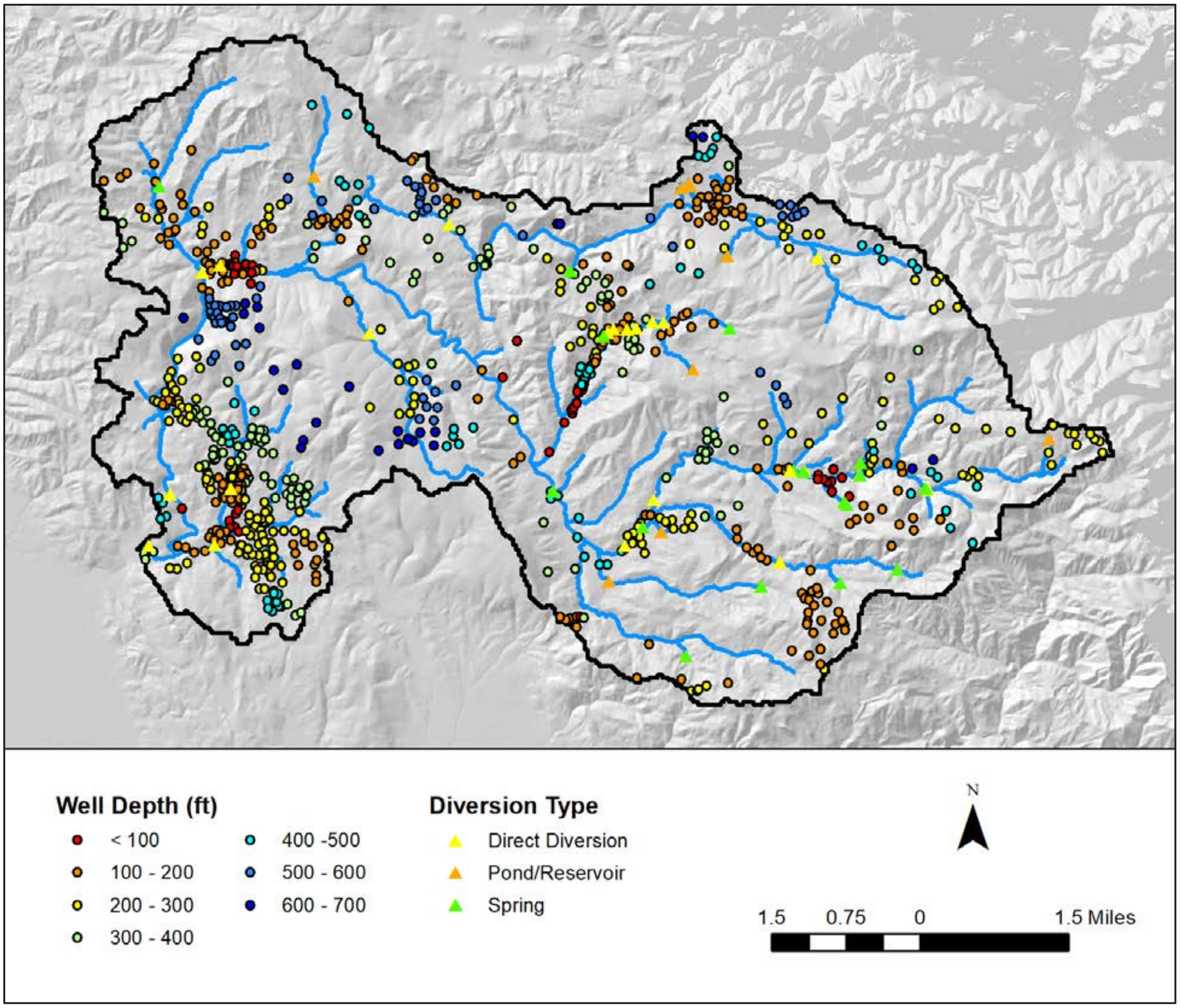


Figure 22: Locations of surface water diversions and groundwater wells in the MWC hydrologic model.

Information Order, the typical tank size for a residence with a direct diversion is approximately 3,000 gallons. Such a tank would need to be filled completely twice a month to supply a typical residence, or approximately four times per month if the tank were only partially emptied. Less data is available for agricultural tank sizes but the limited data supports use of a similar pumping frequency. Consequently, direct diversions were assumed to divert a fraction of the monthly volume on the 1st, 8th, 15th, and 22nd of each month. Some diversion volumes were met using the assumed pumping rates with less than four pumping events per month, in which case they are only active 1-3 times per month depending how quickly the demand is met for each month. For larger demands, the four per month diversion periods were assumed to continue for as long as necessary based on the diversion rate. Typical spring and pond diversions deliver water in near real-time and thus do not require large storage tanks. This results in more frequent, shorter-duration pumping intervals relative to direct diversions. Therefore, daily use was calculated from the monthly volumes and all daily use was considered to be supplied during a single 6-hour timestep.

In addition to developing estimates of the frequency and duration of diversions, it is necessary for modeling to assume a start time. There is likely little to no coordination between diverters regarding the timing of pump activation, and probably some general tendency for coincident pumping due to coincident timing of irrigation demands and work schedules. We made the conservative assumption that all diversions start simultaneously at the beginning of the day, and the diversions on weekly schedules all occur on the same days. These various assumptions result in a maximum instantaneous diversion rate on the 1st of each month, and spikes in rates at regular intervals which is considered to represent a 'worst case' diversion timing scenario (Figure 25).

Where possible the diversion rates used to calculate the diversion timeseries were obtained from eWRIMS or the SWRCB Information Order. However, most diversions rates were either not reported or the reported rates were not realistic given the reported units. Where specific rates were not available, standard rates were used as derived from reported rates in the SWRCB Information Order that were based on actual physical measurements. Standard rates were derived for two diversion types: domestic/small agricultural operations and larger agricultural operations. We combined our analysis of the SWRCB Information Order data for Mark West Creek with analysis of the data for Mill Creek where we are completing a parallel modeling study, and we also restricted the selected entries to include only those based on physical measurements. Based on twelve diversions from the Mark West and Mill Creek Watersheds, the typical residential and small agricultural diversion rate is estimated to be 2.69 gpm (0.006 cfs). Diversion rates for larger agricultural operations varied greatly but typically ranged between 0.01 and 0.03 cfs and a typical diversion rate of 9.0 gpm (0.02 cfs) was used. A monthly timeseries of the total direct and spring diversion volumes and the total pond diversion volumes in the model is shown in Figure 23 and Figure 25, and an example of the 6-hr interval total direct and spring diversion timeseries for July 2010 is shown in Figure 25.

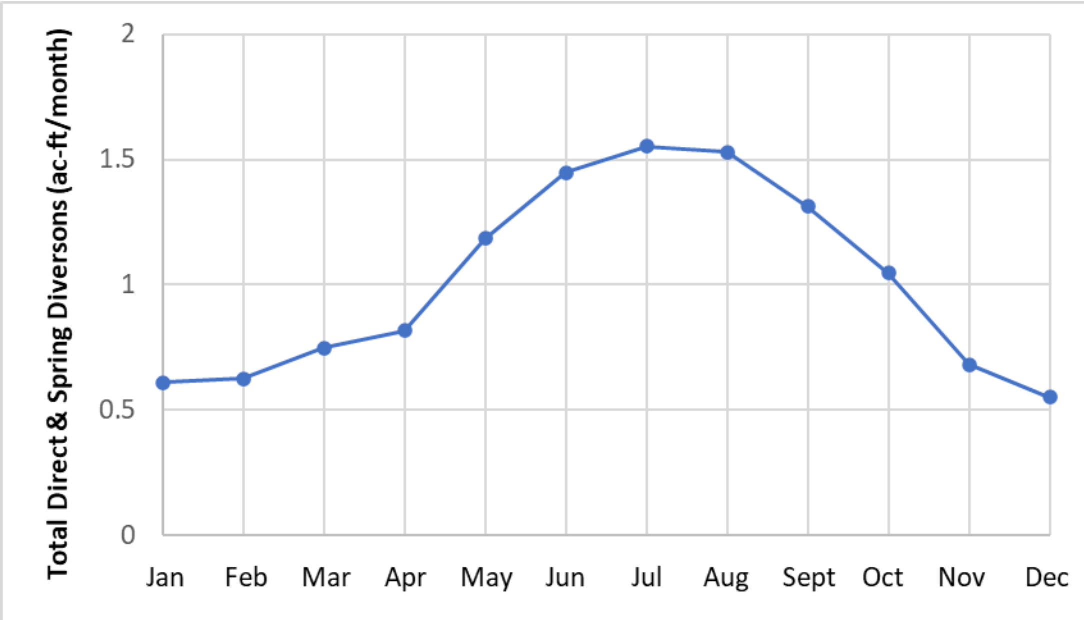


Figure 23: Total monthly direct and spring diversion volumes used in the MWC hydrologic model.

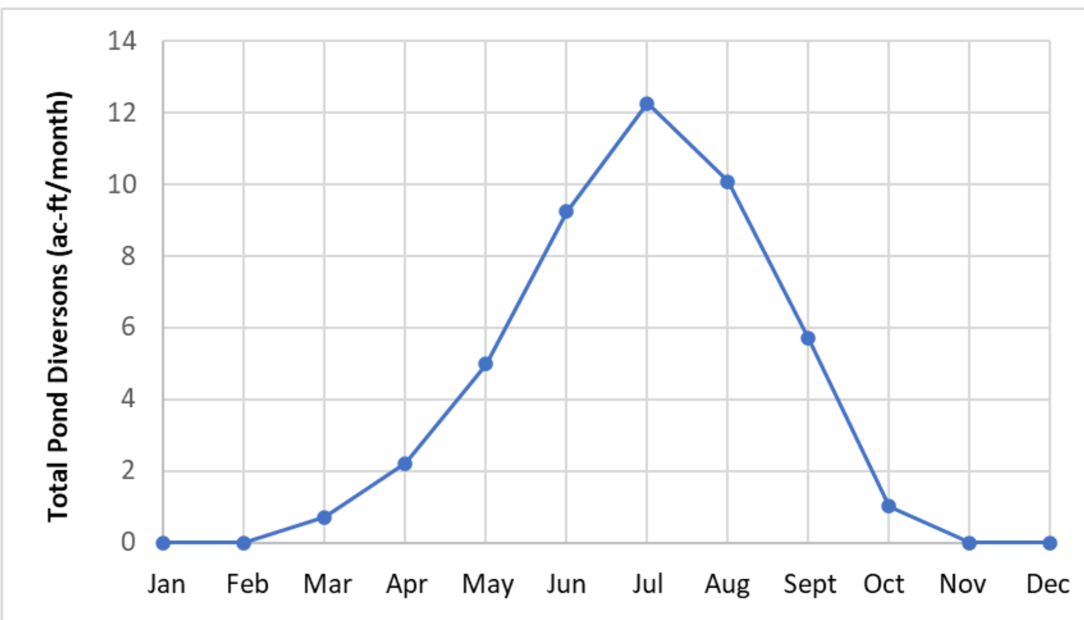


Figure 24: Total monthly pond diversion volumes used in the MWC hydrologic model.

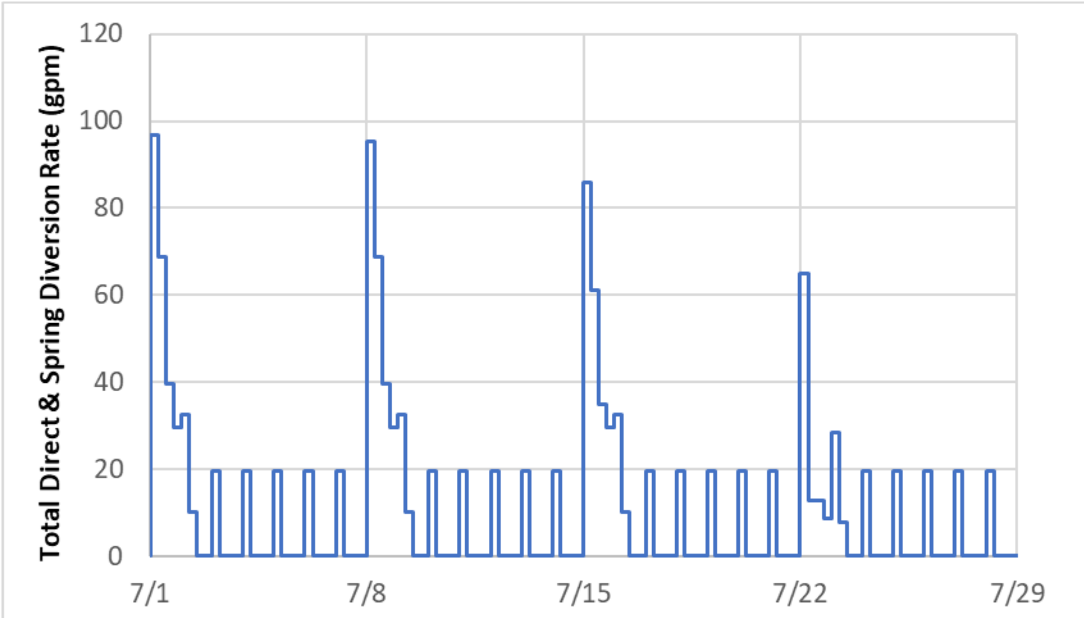


Figure 25: Example of the 6-hr interval timeseries of total direct and spring diversions used in the MWC hydrologic model for July of 2010.

<u>Groundwater Wells</u>

Wells are assumed to be pumped on a daily basis, either supplying water in real-time or topping off a tank. The groundwater pumping timeseries was calculated by converting estimated monthly volumes to a daily demand and pumping each well at its estimated yield until this daily demand was met. This timeseries was calculated on an hourly timestep consistent with the hourly timestep used to drive the groundwater component of the model. Estimated yields are based on pump test data associated with Well Yield Certifications obtained from the County of Sonoma as analyzed and discussed in the Aquifer Properties section above. Typical yields of 13.7 gpm and 6.6 gpm were calculated for the Sonoma Volcanics and the Franciscan Complex respectively (Table 6). Other geologic materials in the watershed including the Quaternary Alluvium, the Glen Ellen Formation, and the Humbug Creek Deposits are not a significant source of water to wells as discussed above under the heading Distribution of Geologic Materials.

Wells supplying large vineyards, used for frost protection, or supplying multiple connections as mutual water company wells are likely have higher than average yields. To account for this, the maximum daily pumping duration is capped at 6 hours per day. If a well cannot supply the required daily volume within this 6-hour window, the pumping rate was increased until it could. The pumping rates used for these wells, up to 78 gpm in the Sonoma Volcanics and up to 37 gpm in the Franciscan, are still within the range of reasonable values for these formations.

The only component of pumping that varies in the model from year to year is the frost protection pumping which accounts for a relatively small component of the total pumping. A monthly timeseries of the total groundwater pumping volumes applied in the model is shown in Figure 26 and an example of the hourly total pumping timeseries for 1 3-day period in early July is shown in Figure 27.

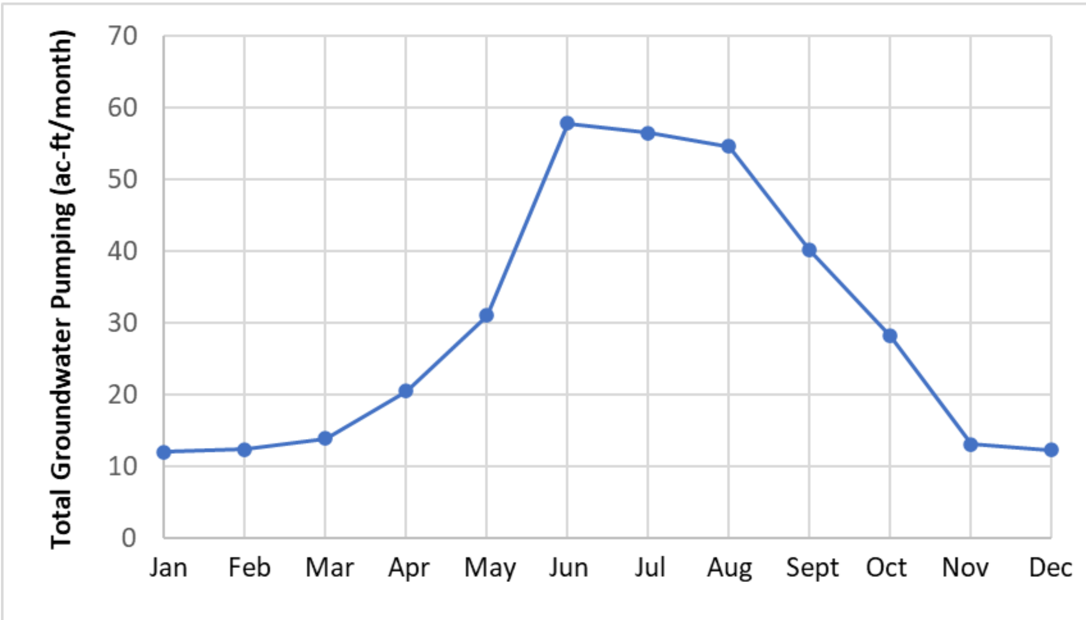


Figure 26: Total monthly groundwater pumping volumes used in the MWC hydrologic model.

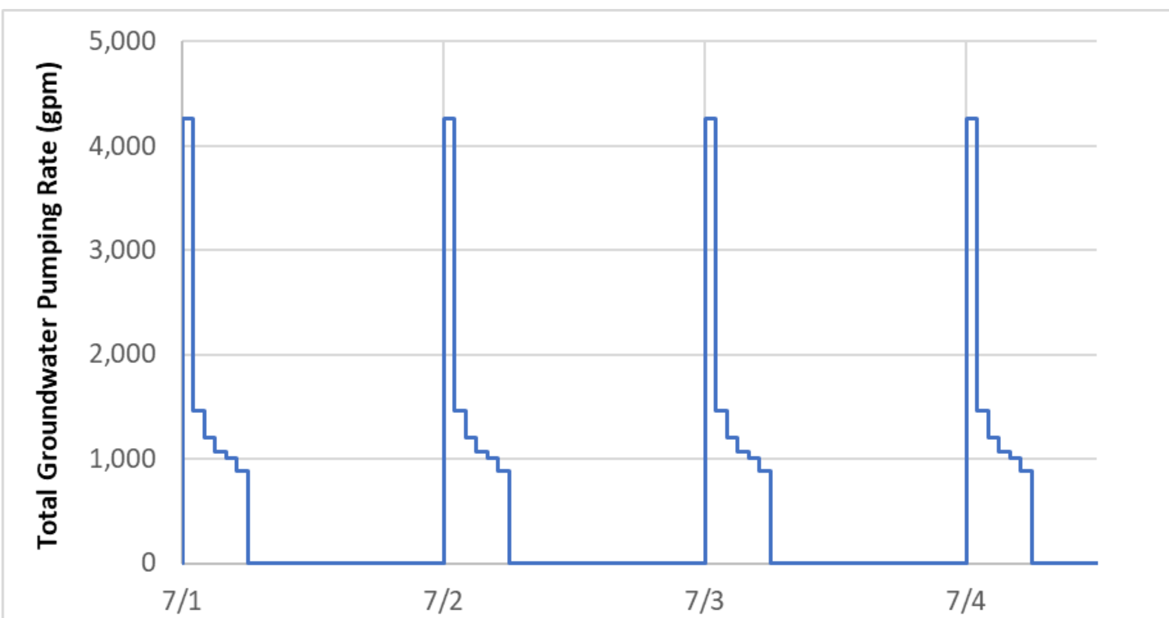


Figure 27: Example of the 1-hr interval timeseries of total groundwater pumping in the MWC hydrologic model for a 4-day period in early July.

Water Use Summary

Total water use from all sources in the watershed is estimated to be approximately 430.7 ac-ft/yr. The largest uses are residential and vineyard irrigation which account for about 48% and 33% of the total water use (Table 9; Figure 28). Industrial uses account for the next largest fraction at about 9%. The remaining 10% consists of irrigation for pasture and other crops (6%), irrigation of cannabis (3%), winery use (<1%), and vineyard frost protection (<1%) (Table 9; Figure 28). About 85% (367.1 ac-ft/yr) of the total use in the watershed is from groundwater with the remaining 15% (63.6 ac-ft/yr) coming from surface water sources. About 81% (51.5 ac-ft/yr) of the total surface water use comes from pond storage, 10% (6.7 ac-ft/yr) comes from direct stream diversions, and 9% (5.4 ac-ft/yr) comes from springs.

Direct stream and spring diversions are concentrated in Humbug Creek, and upper Mark West Creek in and upstream of Van Buren Creek (Figure 22). The highest concentration of wells occurs in the Reibli Creek subwatershed which is generally more urbanized given its proximity to the City of Santa Rosa. Higher concentrations of wells also occur in upper Mark West Creek, upper Porter Creek, and the lower Leslie Creek area (Figure 22). The pattern of development in the watershed has tended to occur along the stream corridors as can be seen in the well distribution with 50% of the wells located within 500-ft of a stream and 73% located within 1,000-ft (based on the modeled stream extent).

Irrigation

The water extracted from wells and surface water diversions for irrigation of vineyards, pasture, and other crops is applied to the land surface as irrigation in the model (see Figure 9 for locations of irrigated crops in the model). The monthly application volumes match the standard use rates as discussed above. Based on previous work with vineyard operators in Sonoma County, vineyards are typically irrigated at intervals of about one week to one month. We assumed a twice-monthly irrigation schedule and developed our irrigation timeseries by distributing the monthly volumes between the two irrigation events each month. We assumed a similar irrigation frequency for pasture and other irrigated crops in the model. Although many vineyard operators use a block rotation schedule for irrigation, the twice-monthly schedule accounts for the temporal effects of irrigation on soil moisture and is decoupled in time from the extraction of that water which is based on assumed pumping rates and tank storage volumes as discussed above. We did not apply water used for cannabis as irrigation in the model since cultivation areas are generally smaller than the 0.5-acre grid scale and many cultivators use pots or fabric bags which limit the potential for interaction with surrounding soils. Water for frost protection of vineyards was also applied back to the land surface as irrigation in the model in real-time based on the calculated demand as discussed above.

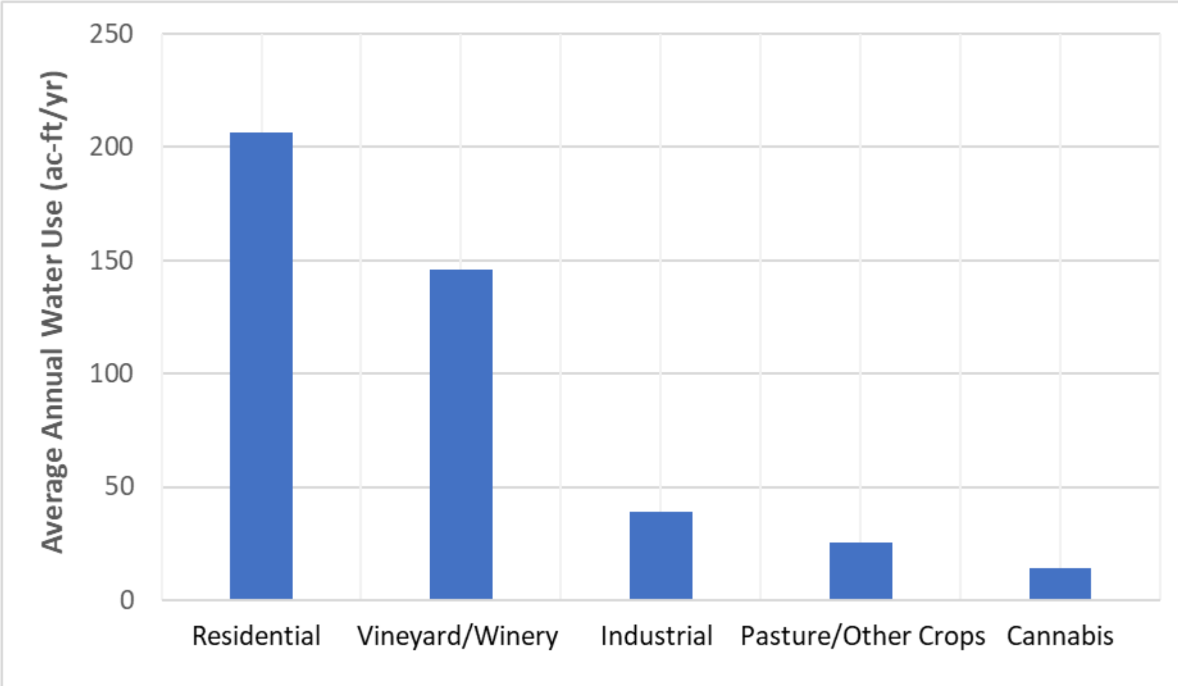


Figure 28: Breakdown of total water use in the MWC hydrologic model by use category.

Chapter 5 – Model Calibration

Calibration of a distributed hydrologic model like MIKE SHE is complicated by the large number of inter-related process and parameters involved. Previous modeling experience has indicated that results are most-sensitive to a relatively small subset of the model parameters including the overland flow Detention Storage and Roughness, unsaturated zone Saturated Hydraulic Conductivity and moisture contents, interflow Drain Levels, groundwater Hydraulic Conductivity, and the streambed Leakage Coefficient. The calibration focused on adjusting these seven parameters within a range of plausible values (to maximize the fit between observed streamflow and groundwater data and mapping information.

Available Data

Several stream gauges have been operated in the watershed at various times over the past ten years including a series of gauges installed in 2010 by the Center for Ecosystem Management and Research (no longer in existence); some of which were re-established by Trout Unlimited (TU) in 2018. In 2018, Sonoma Water established several new gauges to serve as a warning system for potentially hazardous post-fire runoff events and the CRWI installed a gauge on lower Monan's Rill in the upper watershed. Additionally, OEI installed two gauges on upper Monan's Rill tributaries in 2017 and gauging in and near Humbug Creek has also been undertaken by CDFW in recent years.

Despite the relatively large number of stage sensor records available, most of the available data is only from the past few years and only relatively limited development of rating curves and discharge records has occurred. CEMAR and TU collected streamflow measurements and developed low flow (summer baseflow) rating curves at their sites, however rating curves have not been developed for the Sonoma Water sites. Even at the CEMAR/TU sites, no discharge measurements of storm runoff were previously collected, thus prior to this study no continuous rating curves or streamflow records had been developed in the watershed.

We selected three sites for additional streamflow gauging and rating curve development, the CRWI site on Monan's Rill, one of the TU stations in the upper watershed at Rancho Mark West, and one of the Sonoma Water stations in the lower watershed at Michelle Way (Figure 29). We measured discharges at the three sites at approximately monthly intervals between March 2018 and August 2019. For lower flows we used standard wading techniques and a topset rod and flow meter, and for higher flows we used a bridge crane and a flow meter. For all gauging efforts we followed standard USGS stream gauging protocols (USGS,2010).

We obtained the discharge measurements collected by CEMAR for the previous installation at the Rancho Mark West site which operated from March 2010 to December 2014. The original pressure transducer was still installed in the channel near the new instrument that TU installed in February 2018, allowing the older and newer stage records to be combined by applying an elevation offset between the instruments as measured in the field. This made it possible to combine the older CEMAR record from 2010-2014 with data collected from 2018-2019 to develop continuous rating curves and flow records for this site from 3/11/2010 – 12/10/2014 and 2/23/2018 – 7/25/2019.

At Michelle Way, we developed rating curves from our discharge measurements which allowed for the development of continuous flow records from 2/27/2018 – 9/30/2019. We also developed rating curves at Monan's Rill; unfortunately, an instrument malfunction resulted in a large data gap and we were only able to develop continuous flow records for 5/1/2018 – 12/13/2018 and 3/25/2019 – 9/30/2019 which excludes most of the larger runoff events that occurred in 2018/2019. Given the paucity of runoff events captured at this gauge, we focused on the May through September time period for calibration at this location.

In addition to streamflow data, other supplemental sources of calibration data include locations of known springs and perennially-flowing tributaries and wet/dry mapping data collected by CA Sea Grant, CDFW, and Sonoma Water. We compiled the locations of springs and seeps mapped in the field along main-stem Mark West Creek by OEI and CDFW staff in August 2018, spring locations from the National Hydrography Dataset (NHD), springs indicated in the SWRCB's Information Order, springs identified during field reconnaissance and from landowner information, and springs mapped by Pepperwood staff on the Pepperwood Preserve. We also compiled the locations of all flowing tributaries from the August 2018 survey. These data represent all known locations of springs (a groundwater discharge output in the model), but is not a complete inventory of springs and is biased towards showing more springs in locations where detailed spring mapping has been completed such as along main-stem Mark West Creek

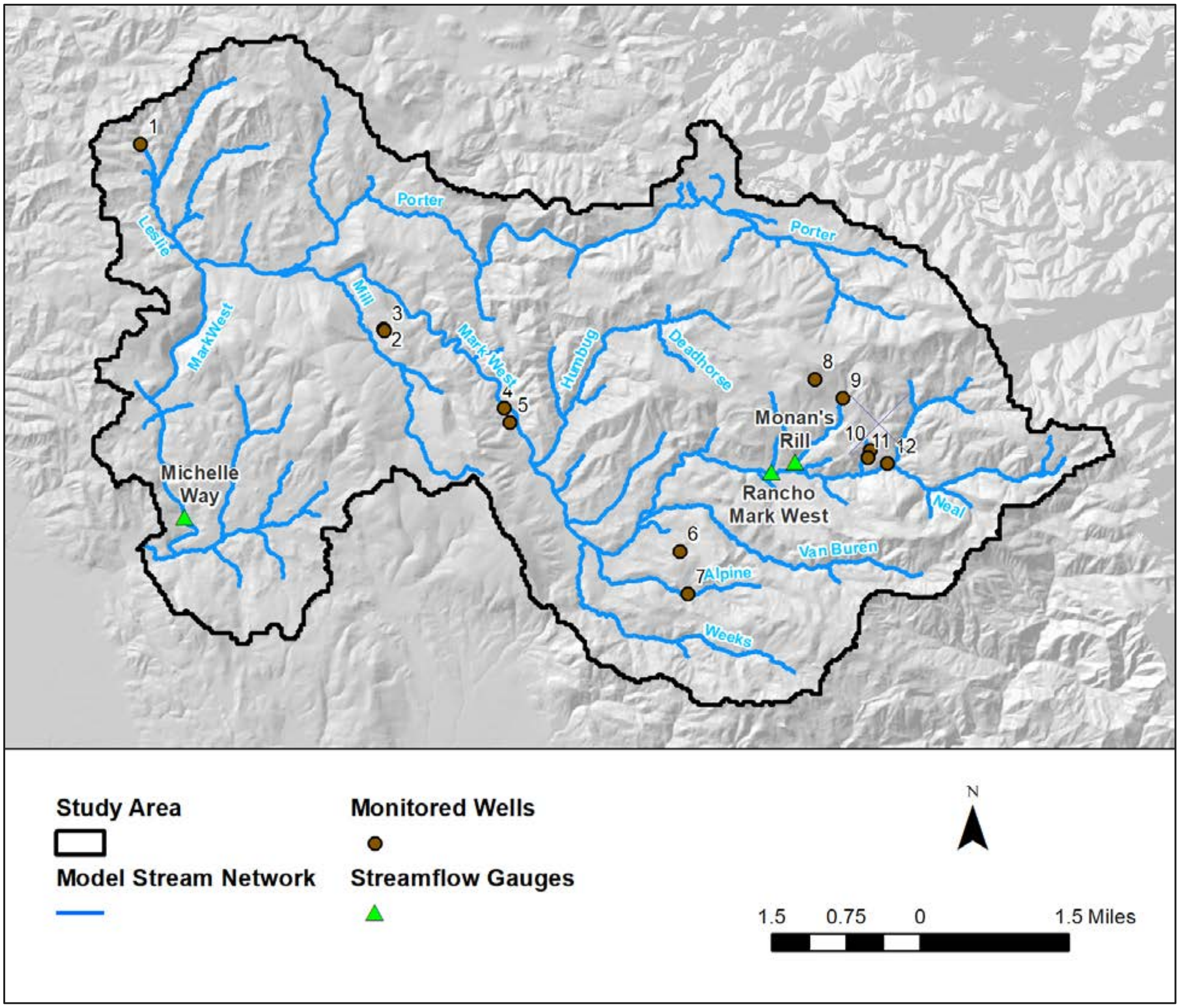


Figure 29: Locations of streamflow gauges and groundwater wells used for calibration of the MWC hydrologic model.

and at the Pepperwood Preserve. Wet/dry mapping data is available for 2012 – 2018 and we focused on the years with the most complete spatial coverage, 2015 – 2018. For purposes of this comparison we considered flows less than 0.01 cfs as equivalent to a field condition of dry and flows less than 0.10 cfs as equivalent to a field condition of intermittent.

Except for a few wells at the Pepperwood Preserve and Monan's Rill, almost no existing groundwater monitoring data was available for the watershed. To develop some field-based understanding of groundwater conditions in the watershed, we established a network of landowners willing to participate in a groundwater monitoring program and collected groundwater elevation data at 16 wells at approximately 5-week intervals between May 2018 and June 2019. Wells are completed in both of the major geologic formations in the watershed, the Franciscan Complex and the Sonoma Volcanics, and they are concentrated in the upper watershed where landowner interest in participation was high. Well casing heights were measured and data was collected relative to top of casing using an electronic sounding tape.

Many of these wells are domestic water supply wells and thus measurements could potentially be influenced by drawdown associated with recent pumping. To minimize such effects, we established a regular monitoring and notification schedule and residents voluntarily abstained from pumping for 24-hrs prior to measurements. The data for four of the wells was not useful for calibration owing to a variety of factors including obvious pumping influences, one seasonally dry hole, and one well located just outside the watershed. Of the remaining 12 wells (Figure 29), we were unable to locate a Well Completion Report for three; given the lack of screened interval information for these wells, we prepared comparisons between simulated and observed water levels but excluded them from the calibration statistics owing to the uncertainty about which model layer is represented by the observations. Seven of the nine monitoring wells used for model calibration are completed in the Sonoma Volcanics and the other two (Wells 4 & 5) are completed in the Franciscan Complex. Three of the wells are screened entirely within Layers 1 & 2 (upper 200-ft), seven are screened entirely within Layers 1-3, and two are completed entirely in Layers 1-4.

Streamflow Calibration

Four 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), the total Percent Volume Error (PVE), and the Nash-Sutcliffe model efficiency coefficient (NSME) (Nash and Sutcliffe, 1970). ME, RMSE, and PVE provide an overall measure of the model bias and have been calculated separately at all three gauges for the full period of record and for the low flow season from May through September. 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. The PVE and NSME have only been calculated for the full period of record since it they are not well-suited for describing data with limited temporal variability such as spring/summer baseflow recessions. To avoid the May through September statistics being dominated by a handful of days with storm runoff, we defined an upper threshold below which to calculate statistics more representative of the model’s ability to predict flow recession and baseflow. The thresholds were 0.4 cfs, 2 cfs, and 5 cfs at the Monan’s Rill, Rancho Mark West, and Michelle Way gauges, respectively.

Due to the limited period of record it was deemed 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 30 through 32 show the comparison between model-simulated and measured discharges at the three gauging sites for the full periods of record, and Figures 33 through 35 show the comparison between model simulated and measured discharges at the three sites for just the May through September low flow season that is most critical from the perspective of salmonid habitat.

The agreement between simulated and measured stream flows was generally good at all three of the gauging locations. The model reproduces the quick flow responses in stream flow during runoff events that is characteristic of the watershed and the overall shape of rising and receding flows. Peak flows are captured reasonably well; however, large differences in peak flows do occur for certain events particularly in the older portion of the record at the Rancho Mark West station. RMSE values for the full periods of record were 13.6 and 68 cfs and NSME were 0.79 and 0.90 at the Rancho Mark West and Michelle Way gauges respectively (Table 10). The total percent volume error was -5.2% at Rancho Mark West and 8.4% at Michelle Way (Table 10). We established targets for successful calibration as a NSME value of 0.60 or greater and a PVE of +/- 10% which are met at both stations.

During low flow periods most critical for understanding coho habitat, the model performance is also generally very good. The shape of the spring flow recessions is well captured but the timing of the flow recession in the upper watershed is delayed in the model by one to two weeks relative to the observed data resulting in over-predicted flows during the May/June timeframe. The flow recession timing matches the observed timing more closely in the lower watershed. Magnitudes of summer baseflow are in reasonably good agreement, but there is a tendency to over-predict late summer flow, particularly in the lower watershed. RMSE values for the May through September low flow period ranged from 0.10 cfs at the Monan's Rill gauge to 0.83 cfs at the Michelle Way gauge (Table 10).

The map of observed springs and flowing tributaries was compared to a map of spring locations and flowing tributary streams as simulated in the model for August 2018 (Figure 36). The model correctly predicts the August 2018 flow condition in all 14 tributaries in the study area greater than 0.3 mi^2 as well as in 7 of the 11 smaller tributaries (Figure 36). The spring location comparison also indicates generally good agreement with a high concentration of springs in the upper watershed in both the observed and simulated maps. The model does not show as many springs in the central reach of Mark West Creek between Porter and Humbug creeks or on the Pepperwood Preserve property as is indicated by the field data. Concentrations of springs in upper Porter, upper Humbug, and lower Mark West Creeks not shown in the observed data likely reflect lack of mapping in those areas rather than lack of springs (Figure 36). Overall, the model appears to reproduce the general locations of groundwater discharge and perennial streamflow in Mark West Creek with reasonable accuracy.

Comparison between wet/dry mapping data collected by CA Sea Grant and Sonoma Water in August and September of 2015 through 2018 and a model simulated wet/dry classification for equivalent dates indicates that both the model and the field data show flow persisting in the majority of main-stem Mark West Creek even during dry years such as 2015 (Figure 37 - Figure 40). Both the model and the field data show dry/intermittent conditions beginning at about the same location in the upper watershed as well as dry/intermittent conditions occurring upstream of the Porter Creek confluence in some water years, however the field data indicates the reach with dry/intermittent flow conditions extends upstream of Porter considerably farther than was captured in the model (Figure 37 - Figure 40).

Table 10: Streamflow calibration statistics for the MWC hydrologic model.

Period	Gauge	Drainage Area (mi^2)	# of Daily Observations	ME (cfs)	RMSE (cfs)	PVE (%)	NSME
Full Record	Rancho Mark West	4.6	2,202	-0.4	13.6	8.4%	0.79
	Michelle Way	35.8	581	-2.6	68.0	-5.2%	0.90
May - Sept	Monan's Rill	0.5	298	0.02	0.10	-	-
	Rancho Mark West	4.6	1,017	0.15	0.28	-	-
	Michelle Way	35.8	290	0.32	0.83	-	-

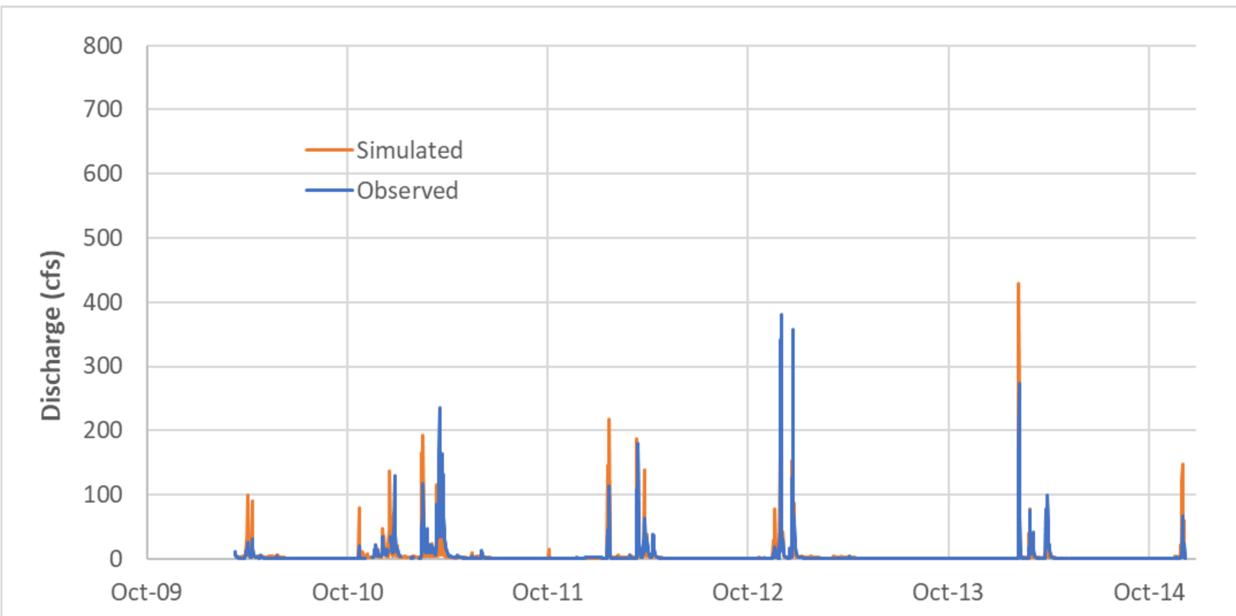


Figure 30: Comparison between model simulated and observed streamflow for the 2010 – 2014 period of record at the Mark West Creek at Rancho Mark West gauge.

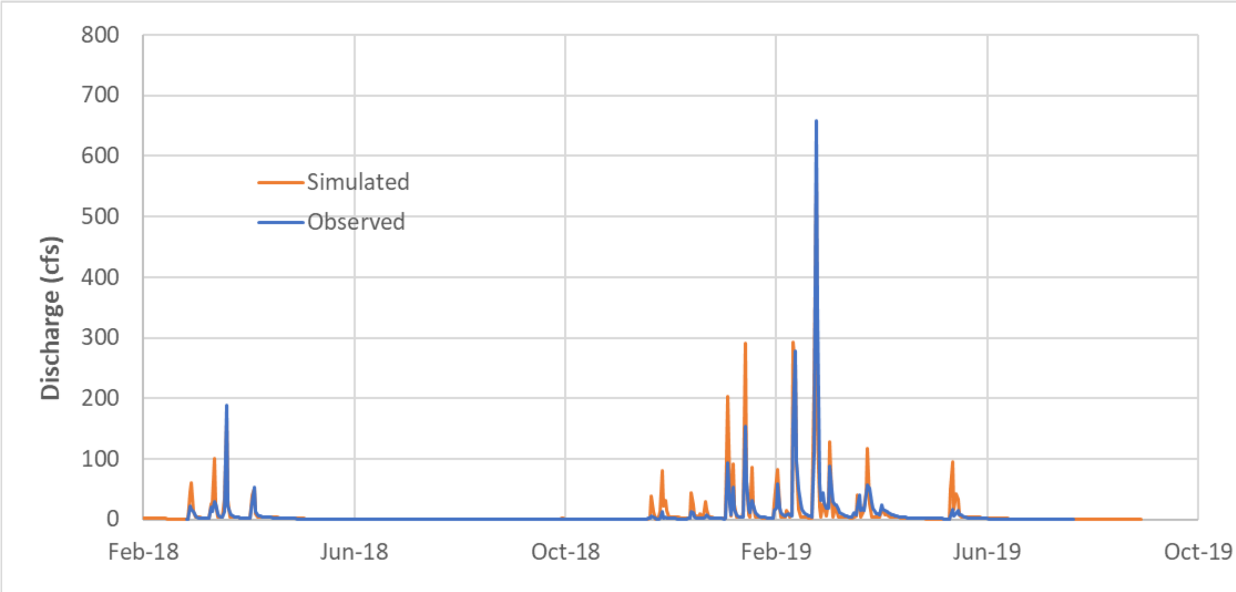


Figure 31: Comparison between model simulated and observed streamflow for the 2018 – 2019 period of record at the Mark West Creek at Rancho Mark West gauge.

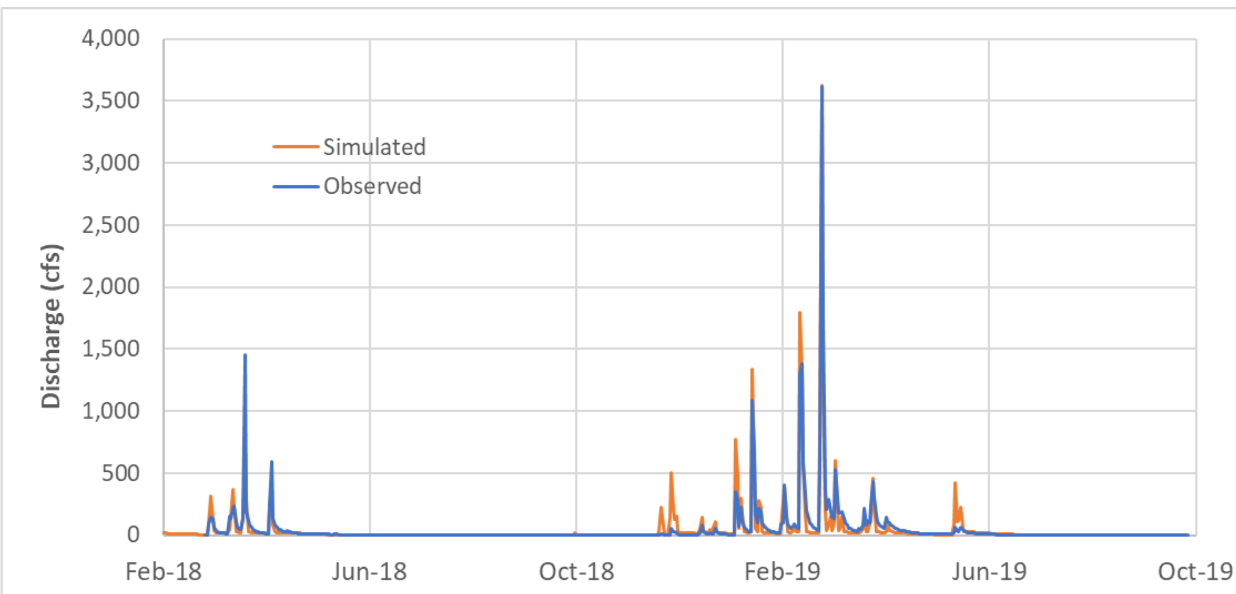


Figure 32: Comparison between model simulated and observed streamflow for the 2018 – 2019 period of record at the Mark West Creek at Michelle Way gauge.

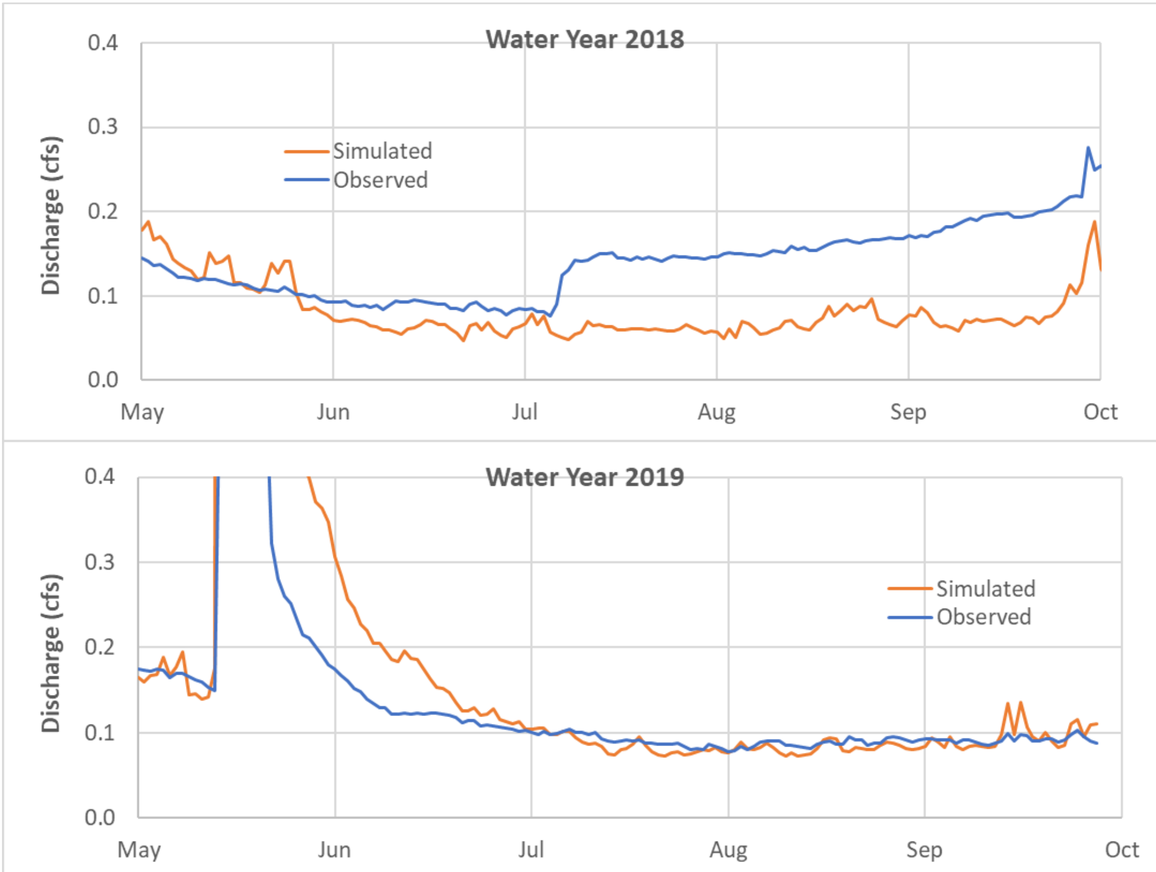
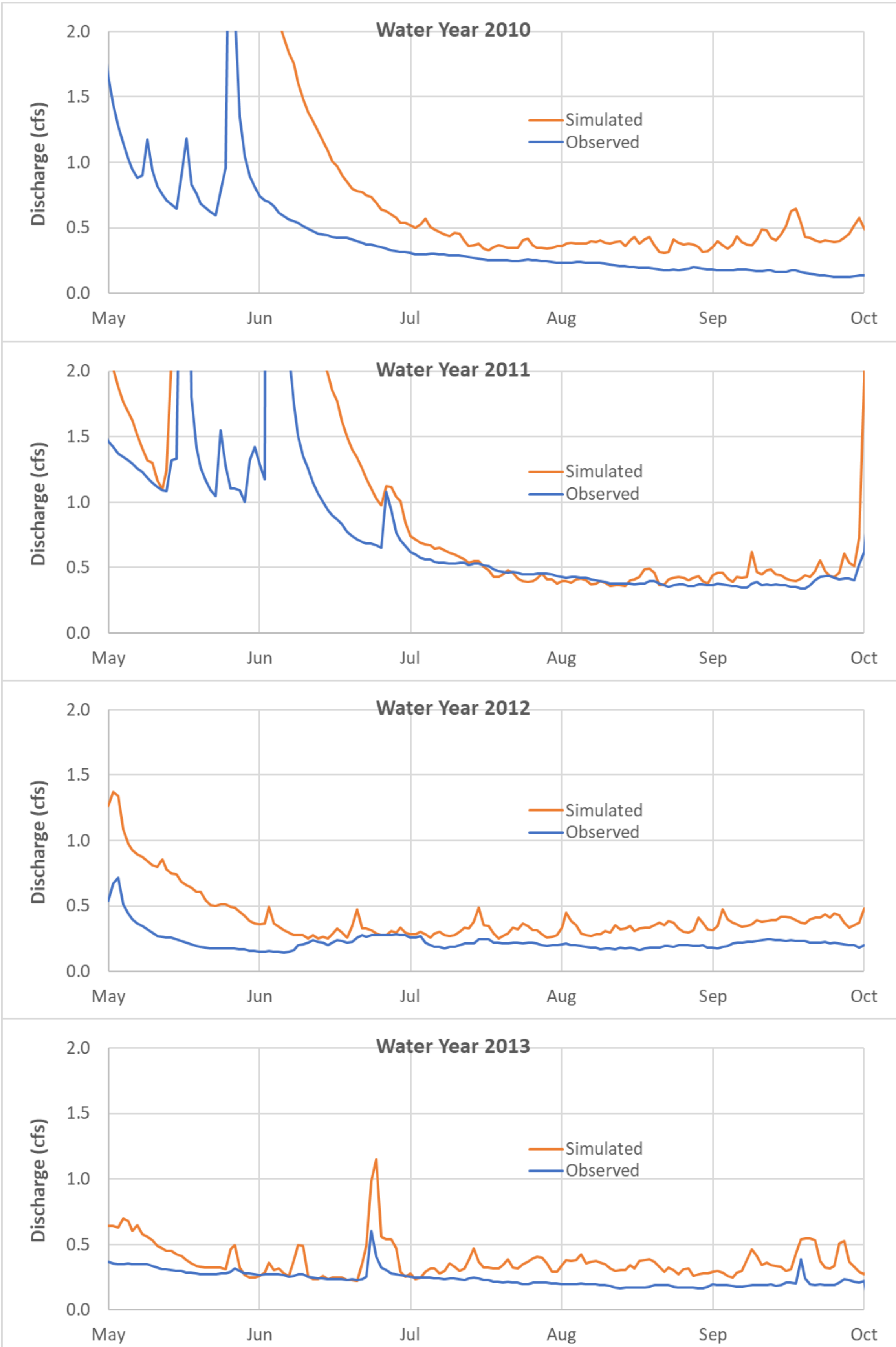


Figure 33: Comparison between model simulated and observed streamflow for the 2018 – 2019 May through September low flow period at the Monan's Rill gauge.


Water Year 2010
Water Year 2011
Water Year 2012
Water Year 2013
Discharge (cfs)
0.0
0.5
1.0
1.5
2.0
May
Jun
Jul
Aug
Sep
Oct
Simulated
Observed

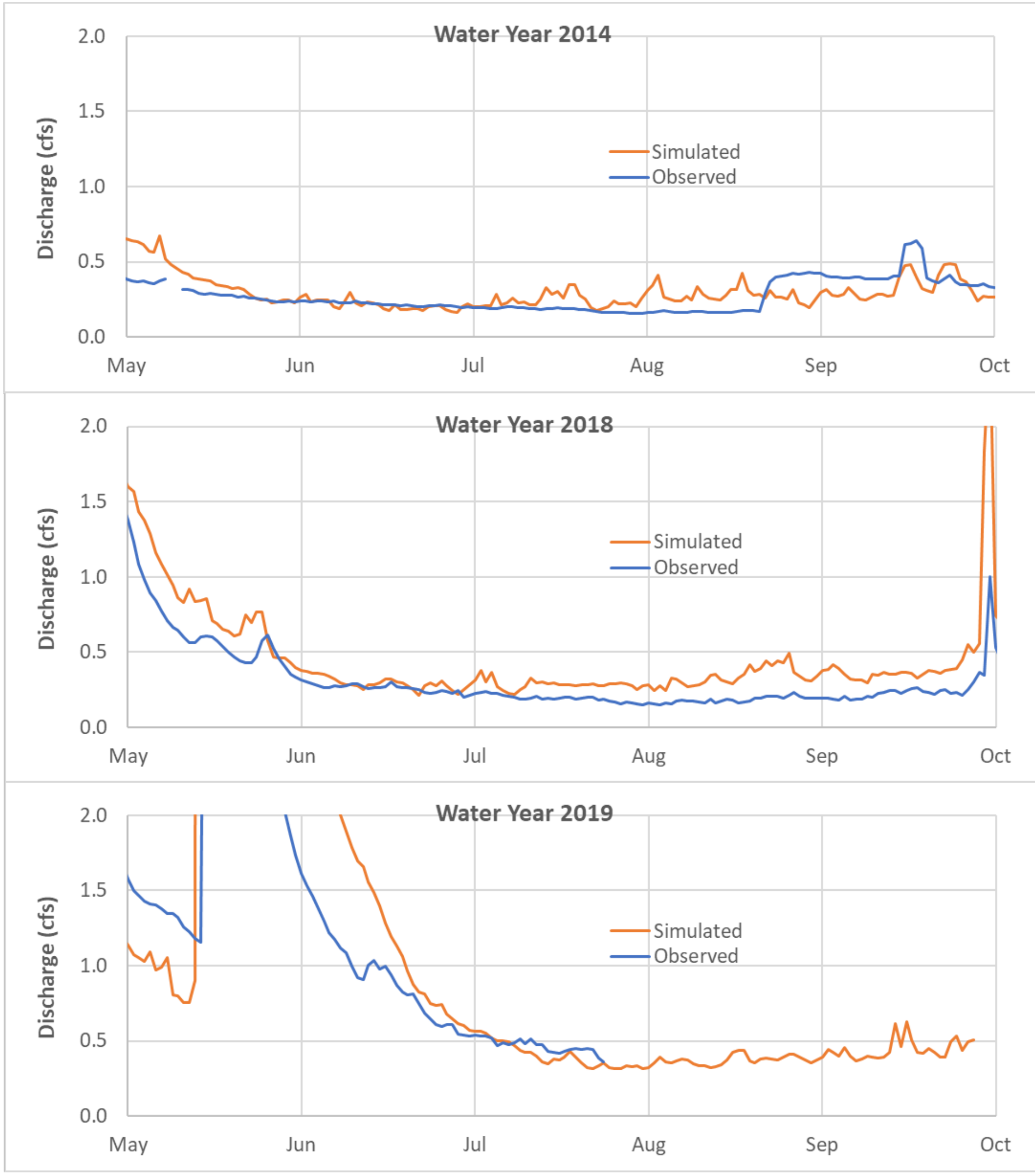


Figure 34: Comparison between model simulated and observed streamflow for the 2010 – 2014 and 2018 – 2019 May through September low flow period at the Mark West Creek at Rancho Mark West gauge.

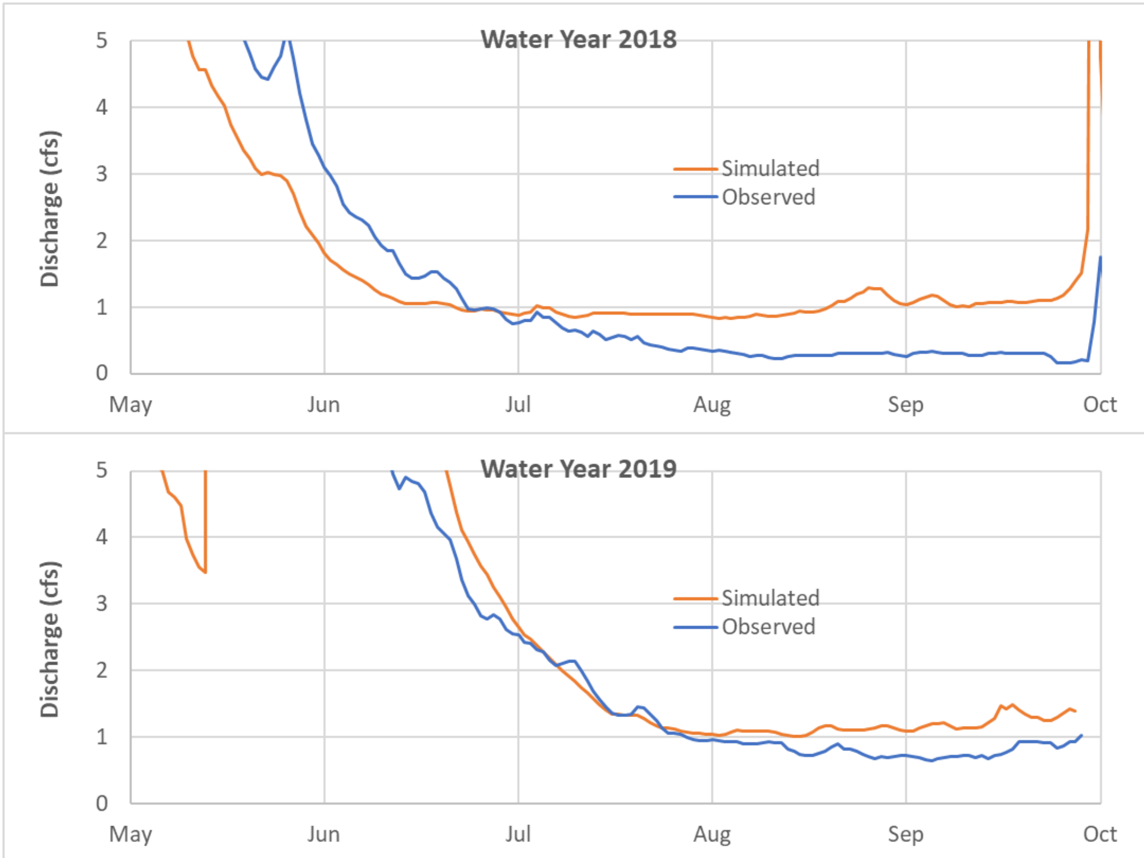


Figure 35: Comparison between model simulated and observed streamflow for the 2018 – 2019 May through September low flow period at the Mark West Creek at Michelle Way gauge.

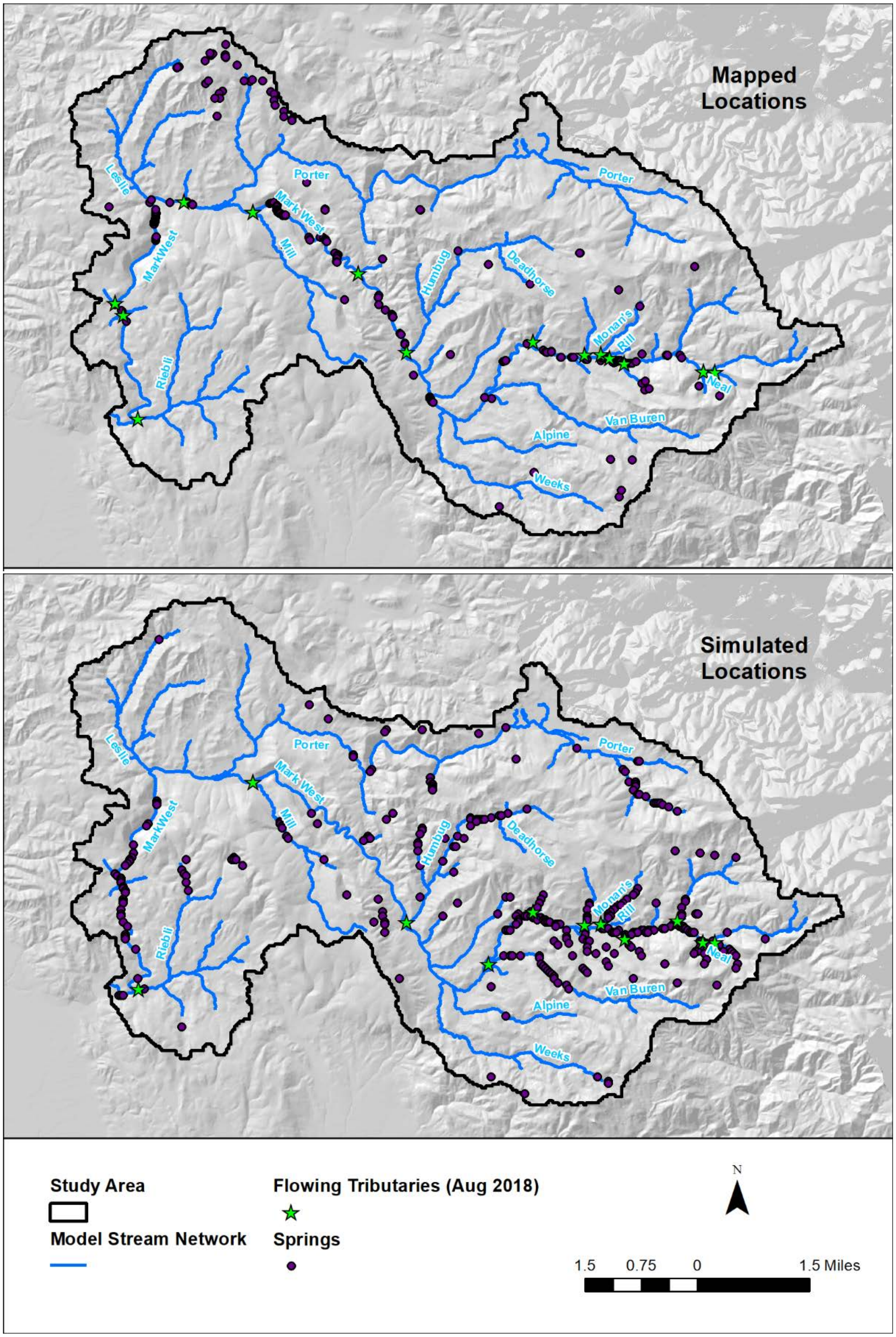


Figure 36: Comparison between known spring locations and locations of perennial springs as simulated in the MWC hydrologic model.

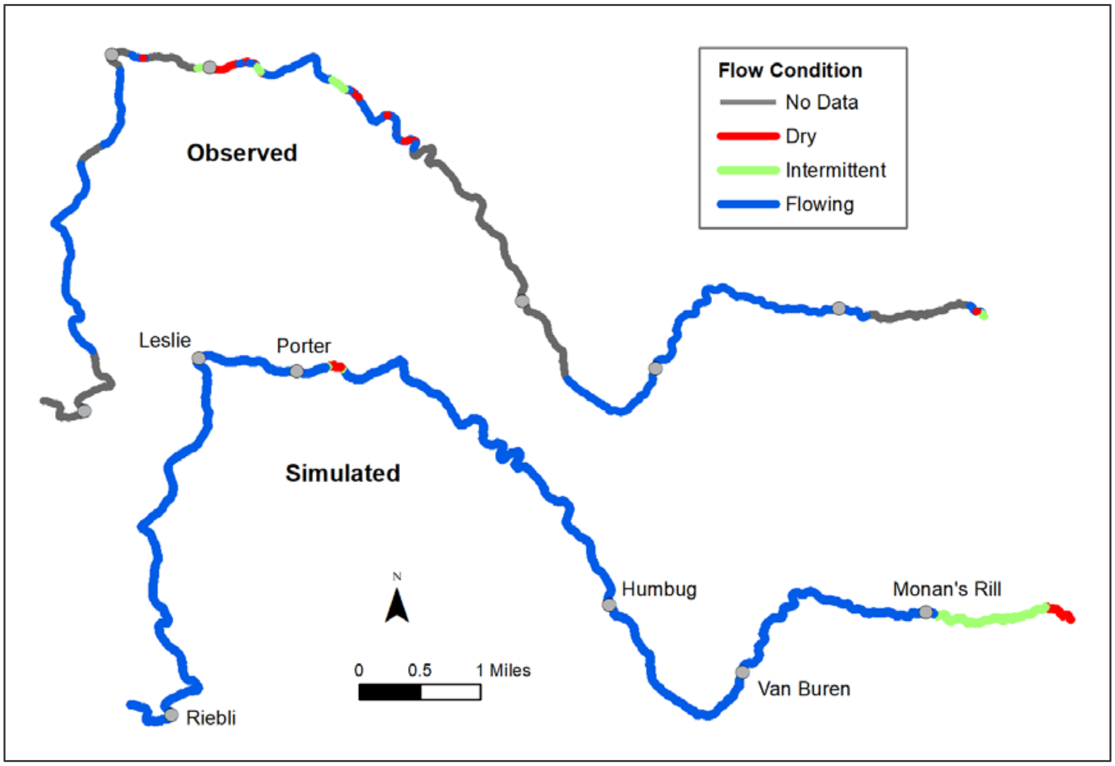


Figure 37: Comparison between observed and simulated late summer flow condition for 2015.

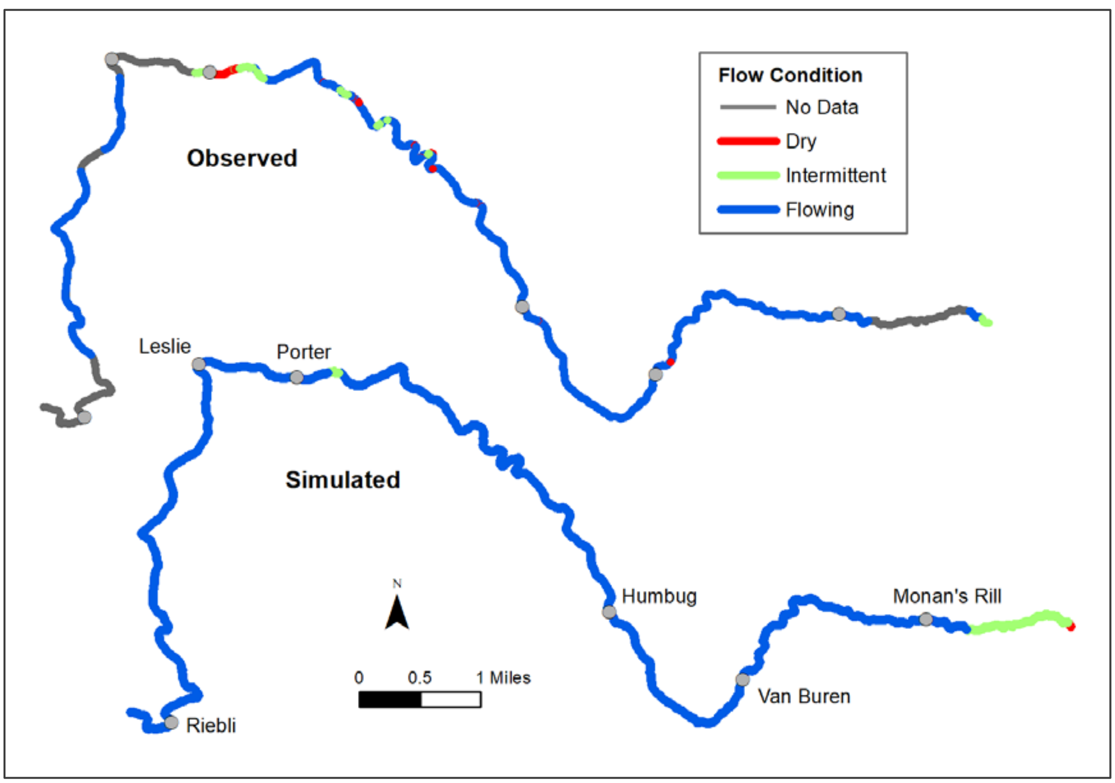


Figure 38: Comparison between observed and simulated late summer flow condition for 2016.

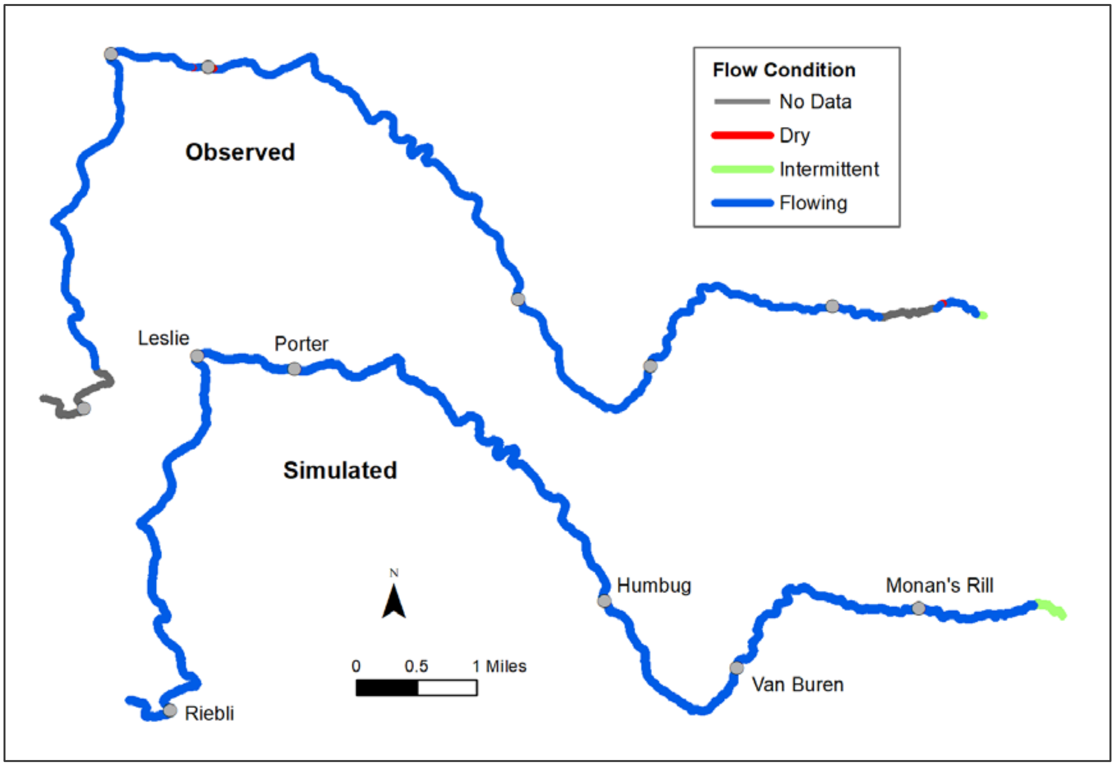


Figure 39: Comparison between observed and simulated late summer flow condition for 2017.

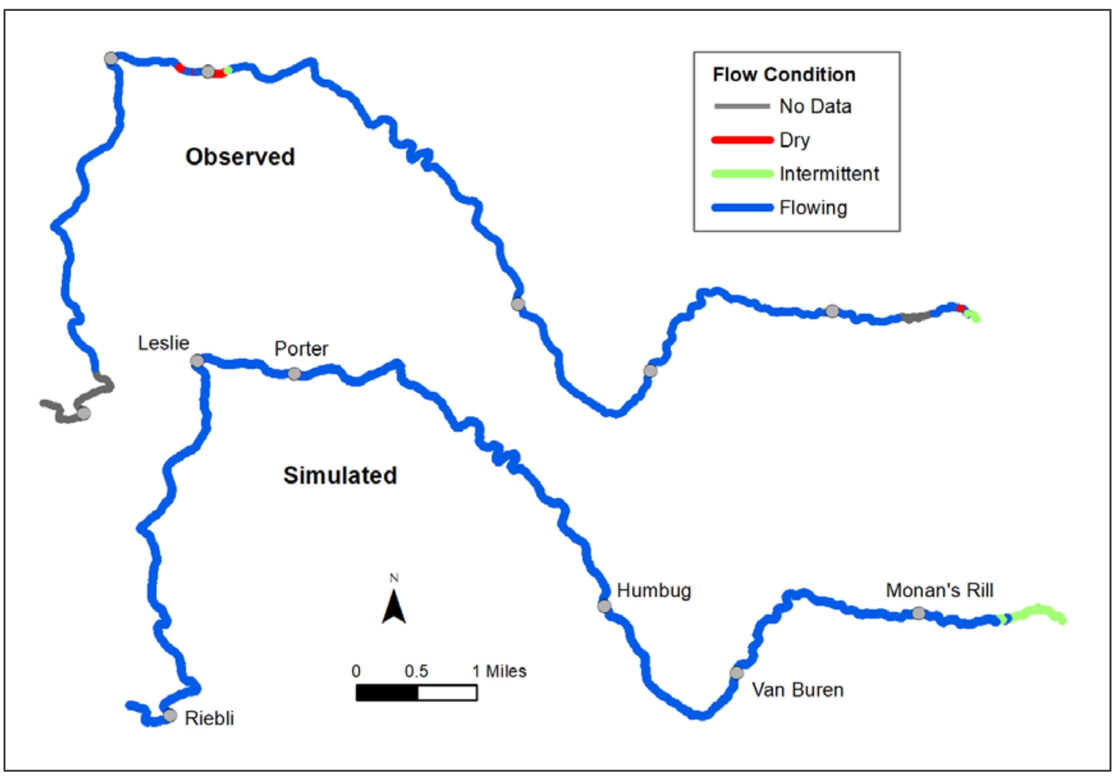


Figure 40: Comparison between observed and simulated late summer flow condition for 2018.

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 nine monitoring wells. Due to the limited periods of record at the available monitoring locations it was deemed 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 monitoring data is available. The composite comparison of simulated and measured groundwater elevations is shown in Figure 41. Figure 42 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 11.

Overall, the observed groundwater elevations are reasonably well-predicted by the model. MEs range from –11.3 to 15.4-ft with an average error of 5.2-ft (Table 11). RMSEs range from 1.1 to 18.6-ft with an average of 9.9-ft. Small seasonal fluctuations occur in all of the wells with maximum elevations generally occurring in March or April and minimum elevations occurring in October or November presumably in response to seasonal recharge patterns. Four of the nine wells (all in the Sonoma Volcanics) show very steady elevations throughout the monitoring period (<3.5-ft annual fluctuation), four show modest fluctuations between 7 and 13-ft, and one shows significant fluctuation on the order of 35-ft (Figure 42). In most cases, the seasonal fluctuations predicted by the model are less than what was observed, with seasonal fluctuations in the model ranging from 0.2-ft to 13.2-ft. Excluding one well with anomalously high fluctuation, the mean seasonal fluctuation simulated in the model was 3.5-ft compared to 6.3-ft based on monitoring observations.

Although the model was able to reproduce observed groundwater elevations with reasonable accuracy, the available monitoring data is very limited both in spatial and temporal extent. Calibration of the groundwater component of the model was also complicated by the difficulties associated with interpreting the observed data which often represents composite head elevations from multiple screened intervals spanning as much as 250-ft. Additional groundwater monitoring from dedicated monitoring wells screened to target specific geologic layers is recommended to support further calibration/validation of the model results with respect to groundwater.

Table 11: Groundwater calibration results for the MWC hydrologic model (see Figure 29 for locations).

Well ID	# Observations	Layer #	ME	RMSE
3	8	2	0.7	3.0
4	11	1	15.0	15.5
5	12	1	-11.3	11.5
7	5	1	-5.7	5.9
8	11	1	15.4	18.6
9	10	1	11.6	12.1
10	11	1	13.9	14.0
11	10	1	7.7	7.8
12	11	1	-0.7	1.1
Mean			**5.2**	**9.9**

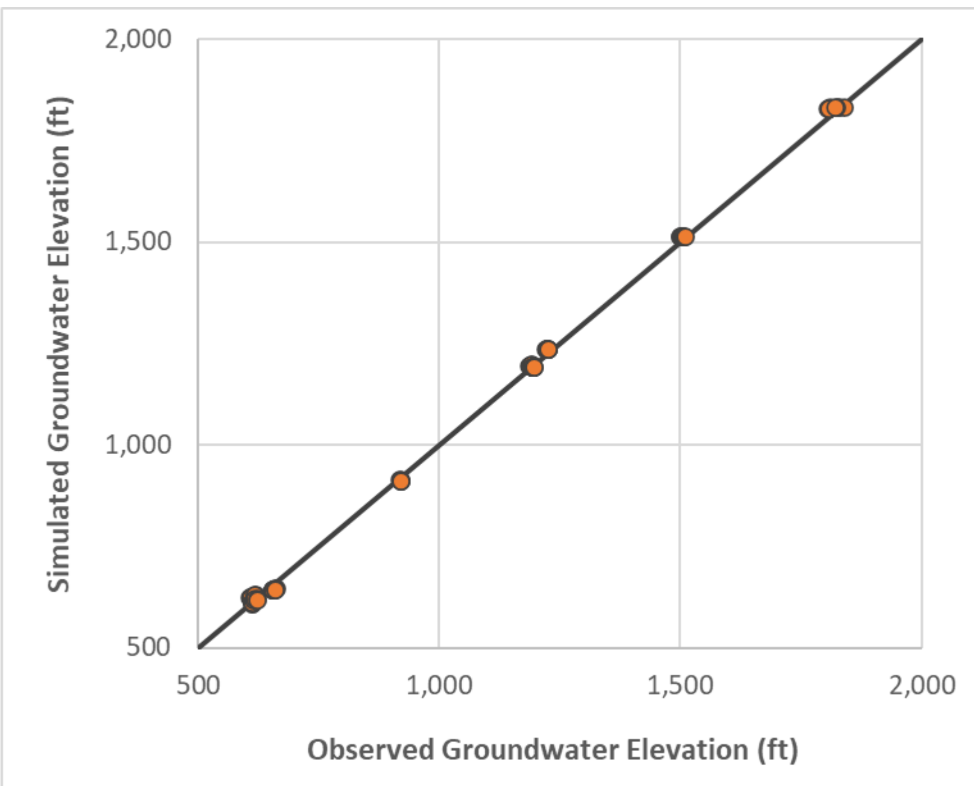
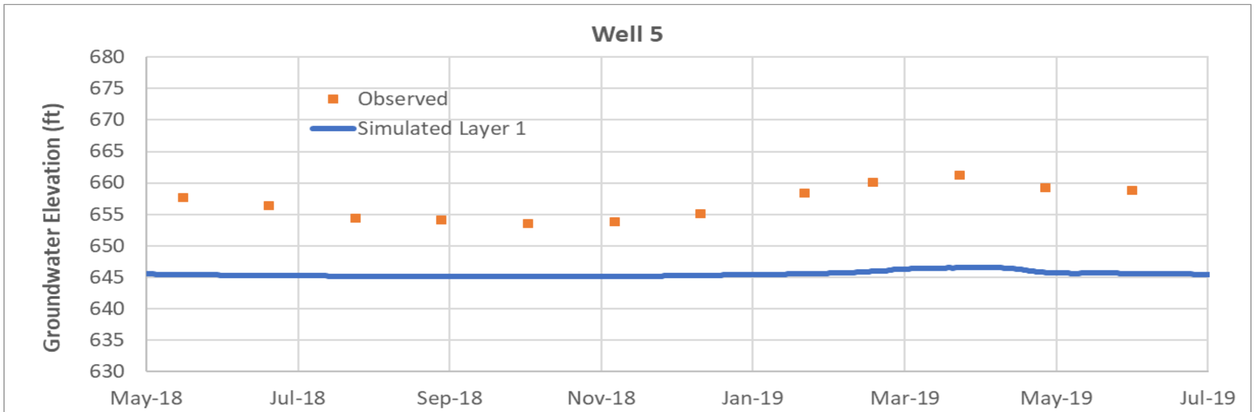
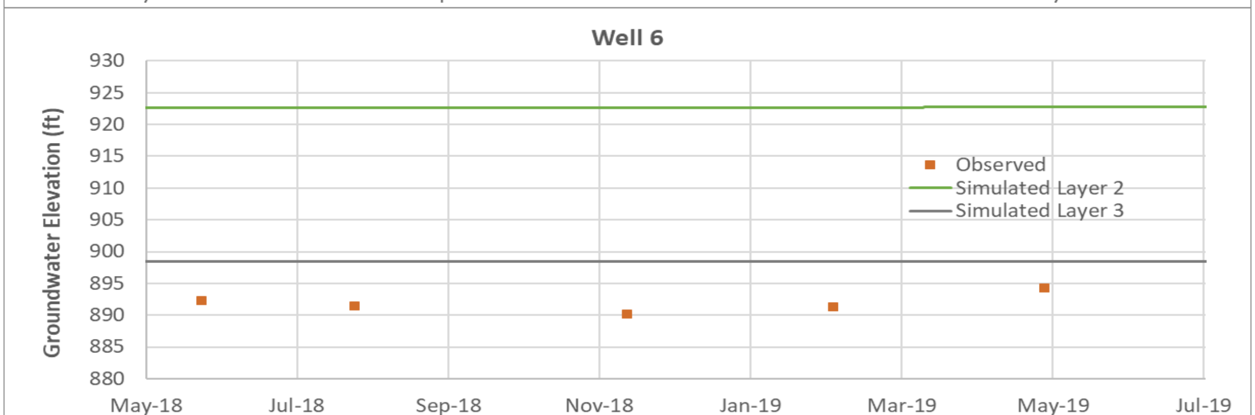
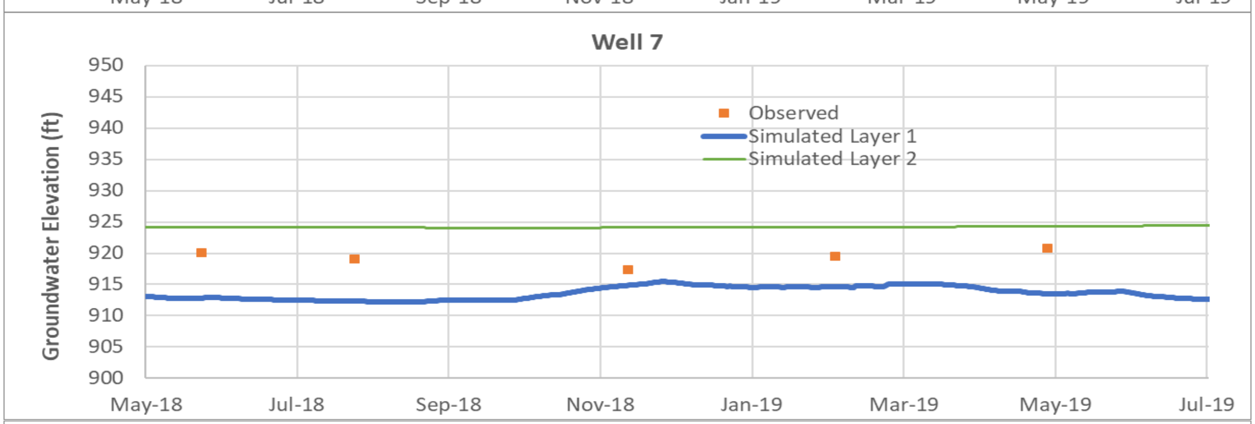


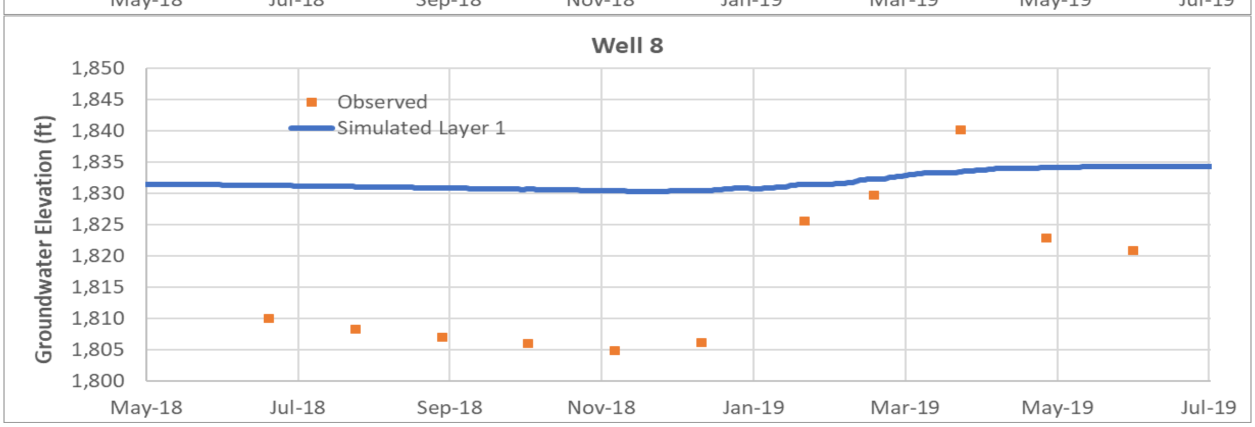
Figure 41: Composite comparison between simulated and observed groundwater elevations (black line shows a 1:1 fit).


Well 1
Groundwater Elevation (ft)
570
565
560
555
550
545
540
535
530
525
520
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19
Observed
Simulated Layer 1
Simulated Layer 2
Well 2
Groundwater Elevation (ft)
650
645
640
635
630
625
620
615
610
605
600
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19
Observed
Simulated Layer 2
Simulated Layer 3
Well 3
Groundwater Elevation (ft)
640
635
630
625
620
615
610
605
600
595
590
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19
Observed
Simulated Layer 2
Simulated Layer 3
Well 4
Groundwater Elevation (ft)
640
635
630
625
620
615
610
605
600
595
590
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19
Observed
Simulated Layer 1


Well 5
Groundwater Elevation (ft)
680
675
670
665
660
655
650
645
640
635
630
Observed
Simulated Layer 1
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19


Well 6
Groundwater Elevation (ft)
930
925
920
915
910
905
900
895
890
885
880
Observed
Simulated Layer 2
Simulated Layer 3
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19


Well 7
Groundwater Elevation (ft)
950
945
940
935
930
925
920
915
910
905
900
Observed
Simulated Layer 1
Simulated Layer 2
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19


Well 8
Groundwater Elevation (ft)
1,850
1,845
1,840
1,835
1,830
1,825
1,820
1,815
1,810
1,805
1,800
Observed
Simulated Layer 1
May-18
Jul-18
Sep-18
Nov-18
Jan-19
Mar-19
May-19
Jul-19

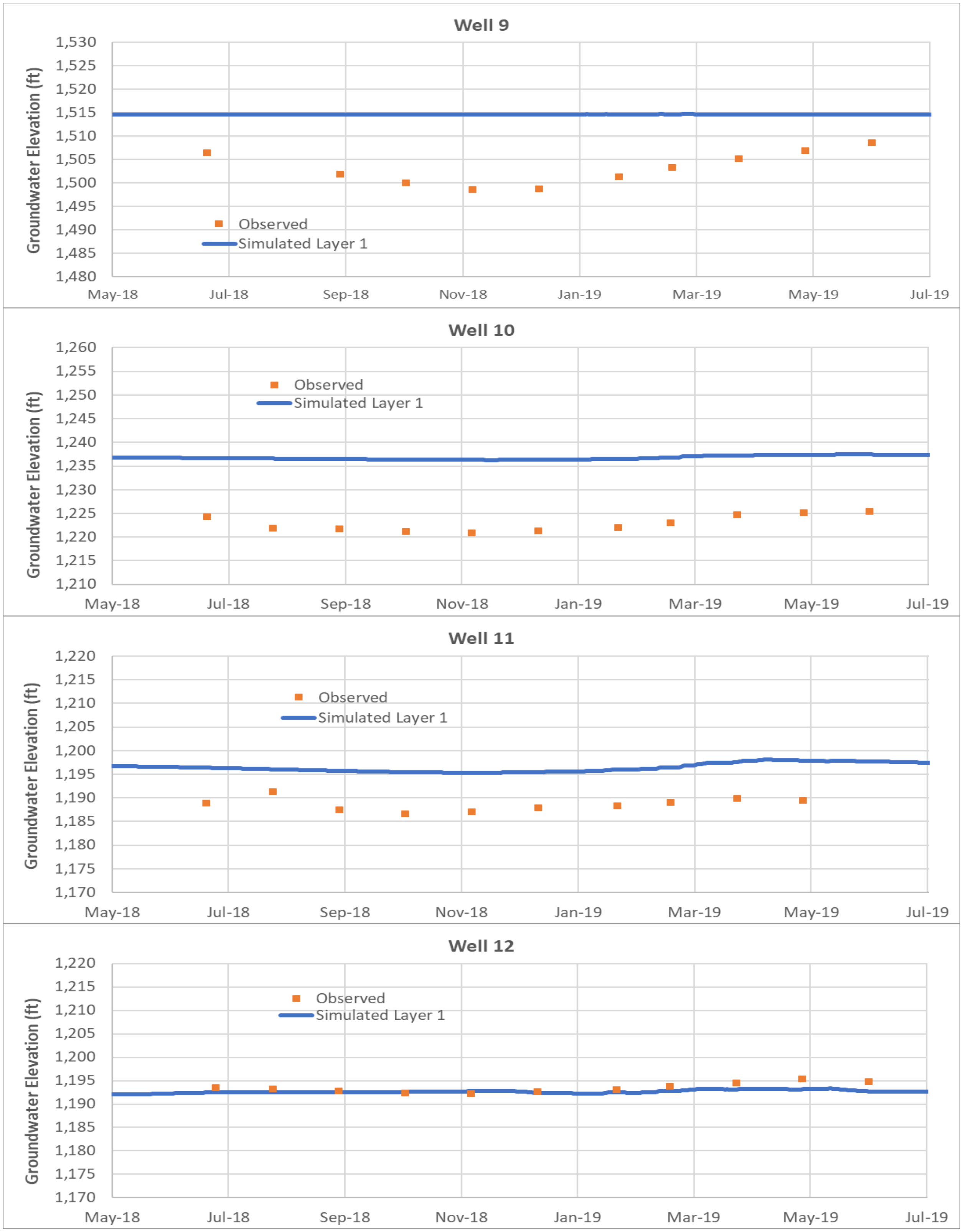


Figure 42: Comparisons between model simulated and observed groundwater elevations (thicker lines indicate simulated data used for calibration).

Chapter 6 – Model Results

Water Balance

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. A water balance may be highly detailed (e.g. decompose ET into interception, evaporation, transpiration from the unsaturated zone, and transpiration from groundwater) or more general, and can be developed for the watershed as a whole or for a specific component of the hydrologic system such as the saturated zone. A general annual water balance for the whole watershed and a more detailed groundwater water balance have been developed for each of the simulated Water Years of 2010 - 2019. A monthly water budget is also presented for selected water budget terms as are maps depicting the spatial variations of key water budget components.

Watershed Water Balance

The primary inflow to the upper MWC watershed is precipitation, which ranged from 19.5 inches in the dry water year of 2014 to 61.2 inches in the wet water year of 2017 (Table 12). Irrigation is a minor additional source of inflow (0.07 in/yr) and it was uniform between water years owing to the way irrigation demands were estimated. Except for the two wettest years of the simulation (2017 & 2019) when streamflow exceeded Actual Evapotranspiration (AET), AET was the largest outflow from the watershed. Variations in AET were significantly less than variations in precipitation and ranged from 14.1 inches in 2014 to 24.1 inches in 2010 (Table 12). Stream flow was the next largest outflow from the watershed, and it varied substantially and in a similar fashion to precipitation ranging from 8.3 inches in 2014 to 32.8 inches in 2017. Groundwater pumping was approximately two orders of magnitude less than AET or stream flow (0.15 in/yr) and was relatively uniform owing to the way water demands were estimated. The watershed boundaries were represented as no-flow boundaries in all components of the model, therefore there are no external inflow or outflow terms in the water budget. Increases in storage of up to 6.9 inches occurred during the wet water year of 2017 and decreases in storage of up to 3.0 inches occurred during the dry water year of 2014 (Table 12).

Groundwater Water Balance

Infiltration recharge represented the largest source of inflow to the groundwater system in the MWC watershed and varied widely as a function of precipitation from 0.8 inches in 2014 to 10.1 inches in 2017 (Table 13). In contrast, streambed recharge was relatively constant ranging from 0.5 to 1.0 inches. In most water years, infiltration recharge is several times larger than streambed recharge. Under drought conditions such as occurred in 2014, streambed recharge becomes a more significant fraction of the total recharge accounting for about 38% of total recharge. Approximately half of the total recharge leaves the groundwater system quickly as interflow, which is the largest source of groundwater outflow varying from approximately 1.1 to 4.3 inches (Table 13). ET from groundwater was the next largest outflow term and was relatively uniform ranging from 0.8 to 1.1 inches.

Springflow and baseflow are also significant outflow terms. Both represent groundwater discharge in the model with the former representing discharge to the land surface or along unsaturated stream banks and the later representing discharge through the bed and wetted banks of the stream. Both of these discharge components were relatively uniform with springflow ranging from 0.5 to 1.0 inches and baseflow ranging from 0.5 to 0.9 inches (Table 13). Baseflow and streambed recharge are approximately equal in magnitude, thus the net gain in groundwater discharge through the bed and wetted banks of streams is near zero when averaged across the watershed; this highlights the importance of springflow as the key mechanism for sustaining summer streamflows in the watershed. Groundwater pumping was a relatively small component (~3%) of the total outflow at 0.15 inches, and there are no subsurface inflows or outflows owing to the no-flow boundary assumption used in the model. Storage decreases of up to 2.2 inches occurred in dry years such as 2014 and storage increases of up to 4.7 inches occurred in wet years such as 2017 (Table 13).

Table 12: Annual watershed water budget simulated with the MWC hydrologic model; all units are inches.

Water Year	Inflows		Outflows			Change in Storage
	Precipitation	Irrigation	AET	Streamflow	Groundwater Pumping	
2010	42.51	0.07	24.06	17.14	0.15	1.23
2011	43.97	0.07	23.13	17.92	0.15	2.84
2012	28.07	0.07	20.07	10.67	0.15	-2.76
2013	28.87	0.07	17.58	12.83	0.15	-1.62
2014	19.46	0.07	14.06	8.30	0.15	-2.97
2015	26.57	0.07	14.94	12.74	0.15	-1.19
2016	33.30	0.07	17.30	13.83	0.15	2.09
2017	61.18	0.07	21.47	32.75	0.15	6.88
2018	26.59	0.07	18.93	9.07	0.15	-1.49
2019	49.77	0.07	21.63	23.44	0.15	4.62
Average	**36.03**	**0.07**	**19.32**	**15.87**	**0.15**	**0.76**

Table 13: Annual groundwater water budget simulated with the MWC hydrologic model; all units are inches.

Water Year	Inflows		Outflows					Change in Storage
	Infiltration Recharge	Streambed Recharge	Interflow	Baseflow	Springflow	ET from Groundwater	Groundwater Pumping	
2010	6.05	0.71	4.29	0.76	0.58	0.82	0.15	0.16
2011	7.49	0.70	4.00	0.80	0.62	0.89	0.15	1.73
2012	2.22	0.57	1.72	0.63	0.84	1.08	0.15	-1.63
2013	2.39	0.58	2.19	0.60	0.68	0.98	0.15	-1.62
2014	0.84	0.52	1.09	0.50	0.76	1.06	0.15	-2.19
2015	2.10	0.66	1.53	0.59	0.67	1.02	0.15	-1.20
2016	4.44	0.60	2.55	0.67	0.48	0.75	0.15	0.44
2017	10.12	1.03	3.39	0.86	0.97	1.07	0.15	4.72
2018	2.87	0.53	1.91	0.62	0.72	1.06	0.15	-1.05
2019	8.17	1.03	3.48	0.83	0.99	0.99	0.15	2.76
Average	**4.67**	**0.69**	**2.61**	**0.69**	**0.73**	**0.97**	**0.15**	**0.21**

Spatial and Temporal Variations of Water Budget Components

The monthly water balance results illustrate the strong seasonality of precipitation and streamflow typical of Mediterranean climates (Figure 43). As a result of the seasonal fluctuations in Potential Evapotranspiration and soil moisture availability, AET was generally lowest during the late fall and early winter and highest during the spring, progressively decreasing throughout the summer months as available soil moisture diminished (Figure 43). During average and wet water years, infiltration recharge occurred in most months between November and April, whereas in the drought conditions of 2014, recharge only occurred during the month of February (Figure 43). The number of days with significant (>0.1-in) recharge varied widely between 4 days in 2014 and 34 days in 2017.

Significant variations in infiltration recharge occur across the watershed with much of the watershed generating less than 2 in/yr and portions of the upper watershed generating more than 20 in/yr (Figure 44). Numerous factors affect the recharge rates, however the spatial variations in recharge appear to be primarily controlled by soil properties, topographic position, and the west to east precipitation gradient. Recharge is concentrated in the upper Mark West Creek watershed upstream of and including the Van Buren Creek watershed, as well as in the upper Humbug Creek watershed (Figure 44). Higher recharge rates also occur locally in portions of the central Porter Creek watershed, and the upper Leslie Creek and upper Reibli Creek watersheds, although recharge rates in these watersheds are generally low. Small negative recharge rates (indicative of net groundwater discharge) occur along valley-bottom areas particularly in the lower watershed (Figure 44). As discussed earlier, recharge only occurred during four days during a single month in the drought of 2014, and much of the watershed experienced negative or near-zero recharge (Figure 45).

As discussed earlier, groundwater discharge occurs in the model both as springflow (subaerial discharge) and as baseflow (subaqueous discharge). Across the entire watershed, springflow is responsible for generating most of the summer streamflow given that net groundwater discharge in the spring and summer months is near zero (e.g. streambed recharge ≈ baseflow discharge). Locations of perennial springflow were discussed previously as part of the calibration discussion in Chapter 5 (see Figure 36). The spatial patterns of surface water/groundwater interaction indicate that gaining conditions predominate throughout the spring and summer months in much the upper watershed upstream of Van Buren Creek, as well as in upper Humbug Creek, portions of upper and central Porter Creek, and lower Mark West Creek below Leslie Creek (Figure 46 & Figure 47). During spring, losing conditions occur in Mark West Creek upstream of Porter Creek, and in the lowest portions of many of the tributary watersheds, notably Porter Creek and Weeks Creek (Figure 46). By late summer, most of the losing reaches in the tributary streams become inactive as streamflows drop to zero (Figure 47). The area overlying the deepest alluvial body in the watershed near and upstream of the confluence of Mark West and Porter Creeks is the most active area in terms of surface water/groundwater interaction. Losing conditions persist throughout the summer months in this area, however the effect on streamflow is localized given that most of the flow loss returns to the stream as baseflow where the alluvium pinches out downstream (Figure 47).

AET varies substantially throughout the watershed, and in most locations rates range from about 10 to 30 in/yr. AET as high as 50 in/yr occurs locally along certain stream channels where transpiration of riparian vegetation is not limited by soil moisture availability due to accessibility of shallow groundwater (Figure 48). Spatial variability of AET is primarily a function of variability in available soil moisture and vegetation water requirements, with the two factors being inextricably linked. Climatic water deficit (CWD) is defined as the difference between PET and AET and is a useful metric for describing the seasonal moisture stress. In the 10-yr average condition the annual CWD ranged from 15 to 40 in/yr across most of the watershed, except locally where rates were near zero due to accessibility of shallow groundwater and associated insensitivity to soil moisture availability (Figure 49). Topographic aspect appears to be a primary control on the spatial variability of CWD with north-facing slopes characterized by lower PET having significantly lower CWD values relative to south-facing slopes. During the drought of 2014, CWD values increased substantially to between 30 and 50 in/yr across most of the watershed (Figure 50). The 10-yr mean CWD across the watershed was 26.0 in/yr compared to 32.7 in/yr in 2014.

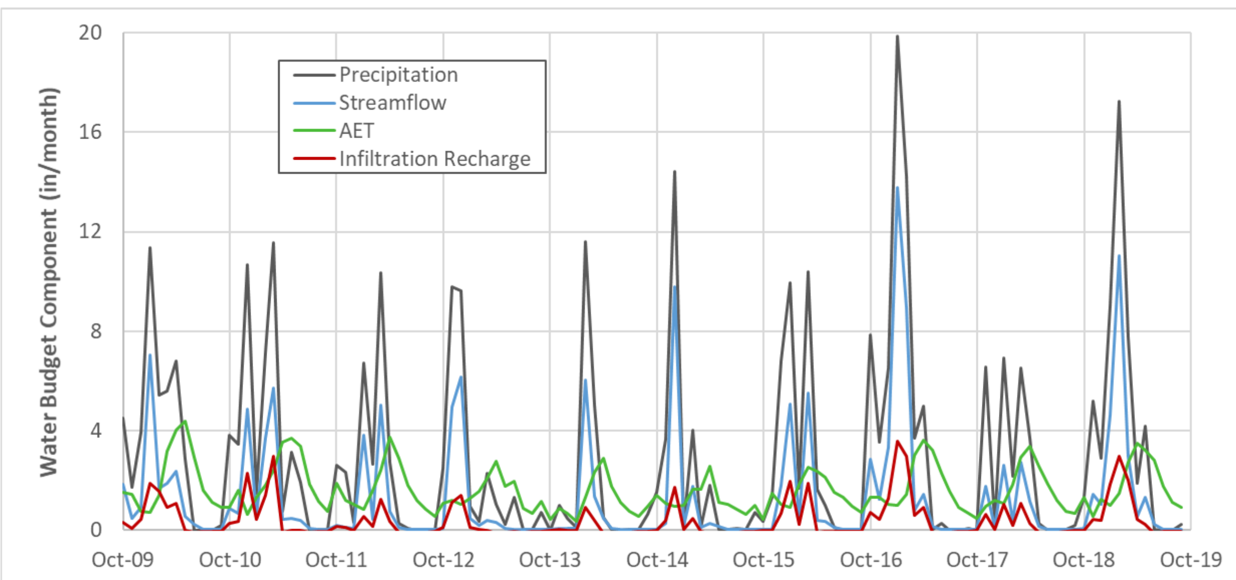


Figure 43: Monthly variation in select water budget components simulated with the MWC hydrologic model.

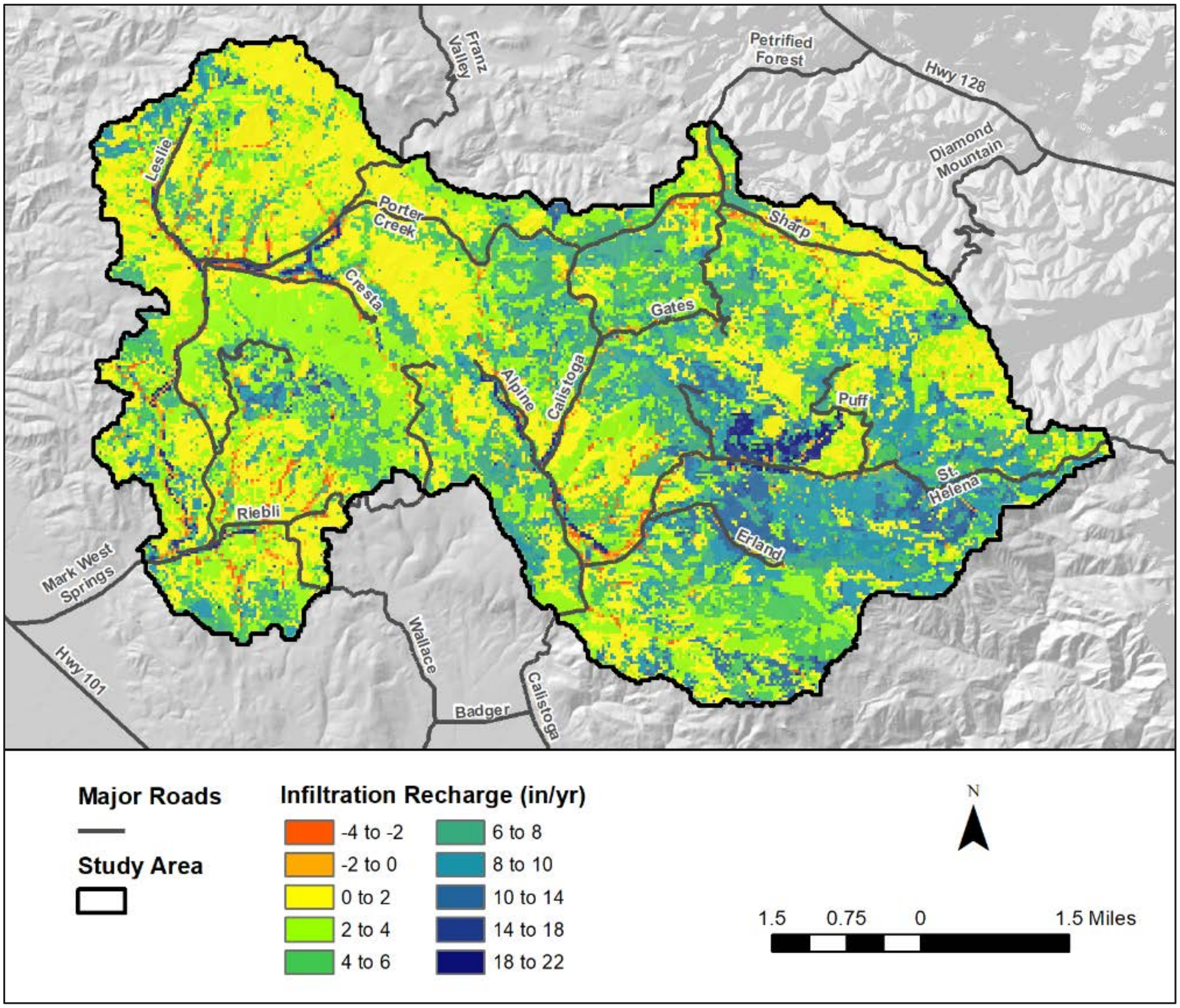


Figure 44: Mean annual infiltration recharge for water years 2010-2019 simulated with the MWC hydrologic model.

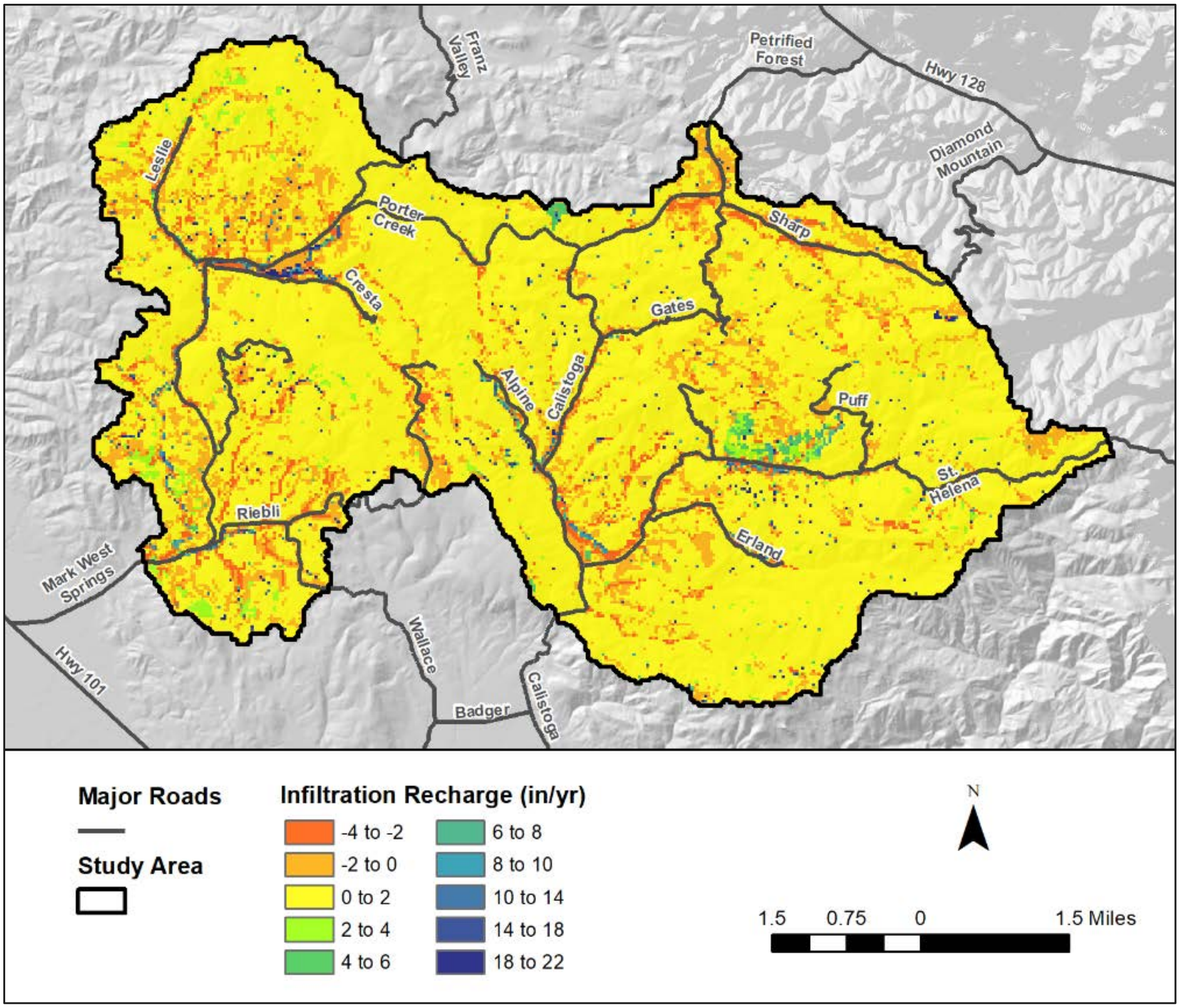


Figure 45: Infiltration recharge for water year 2014 simulated with the MWC hydrologic model.

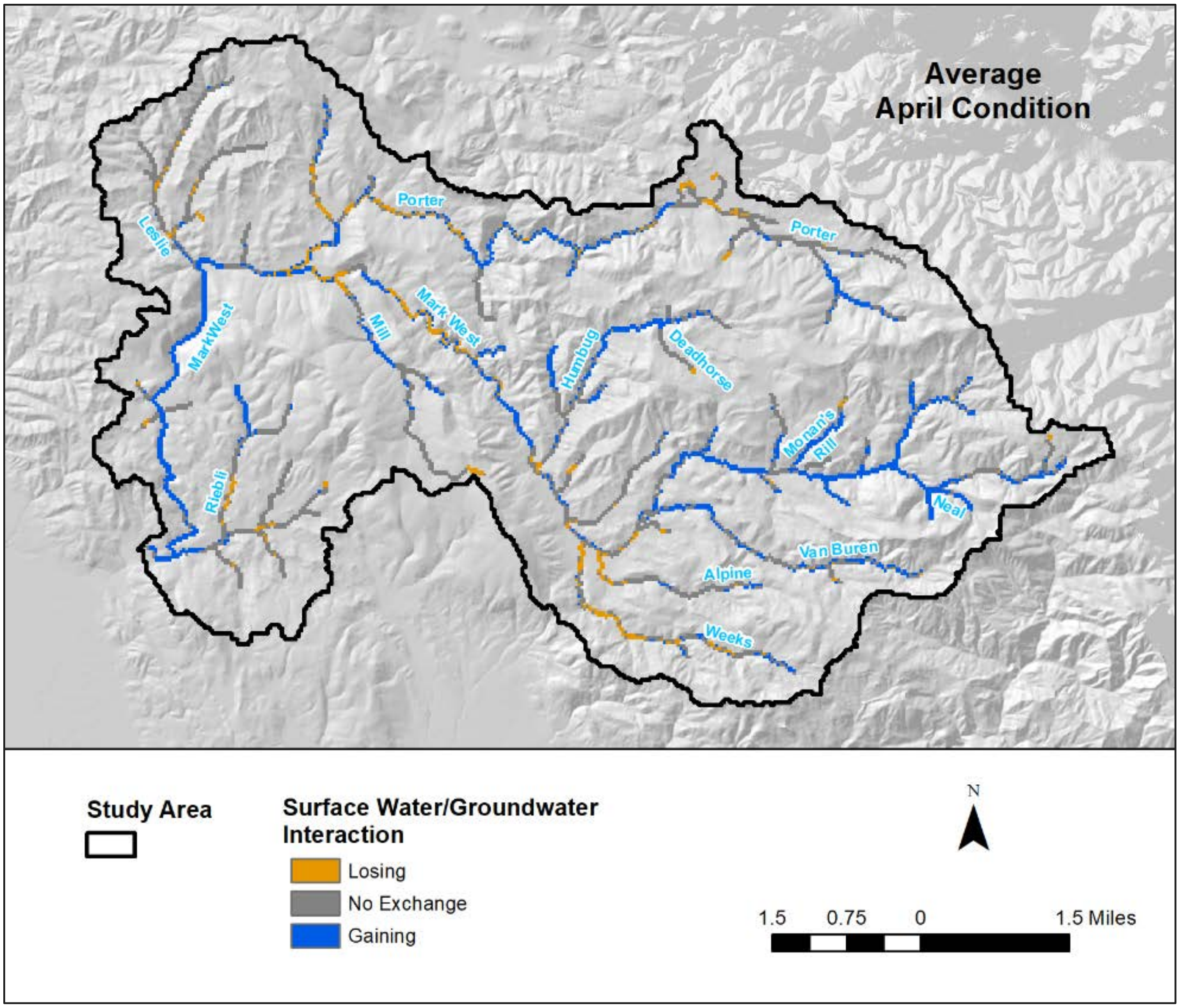


Figure 46: Extent of gaining and losing reaches for the month of April (2010-2019 mean value) as simulated with the MWC hydrologic model.

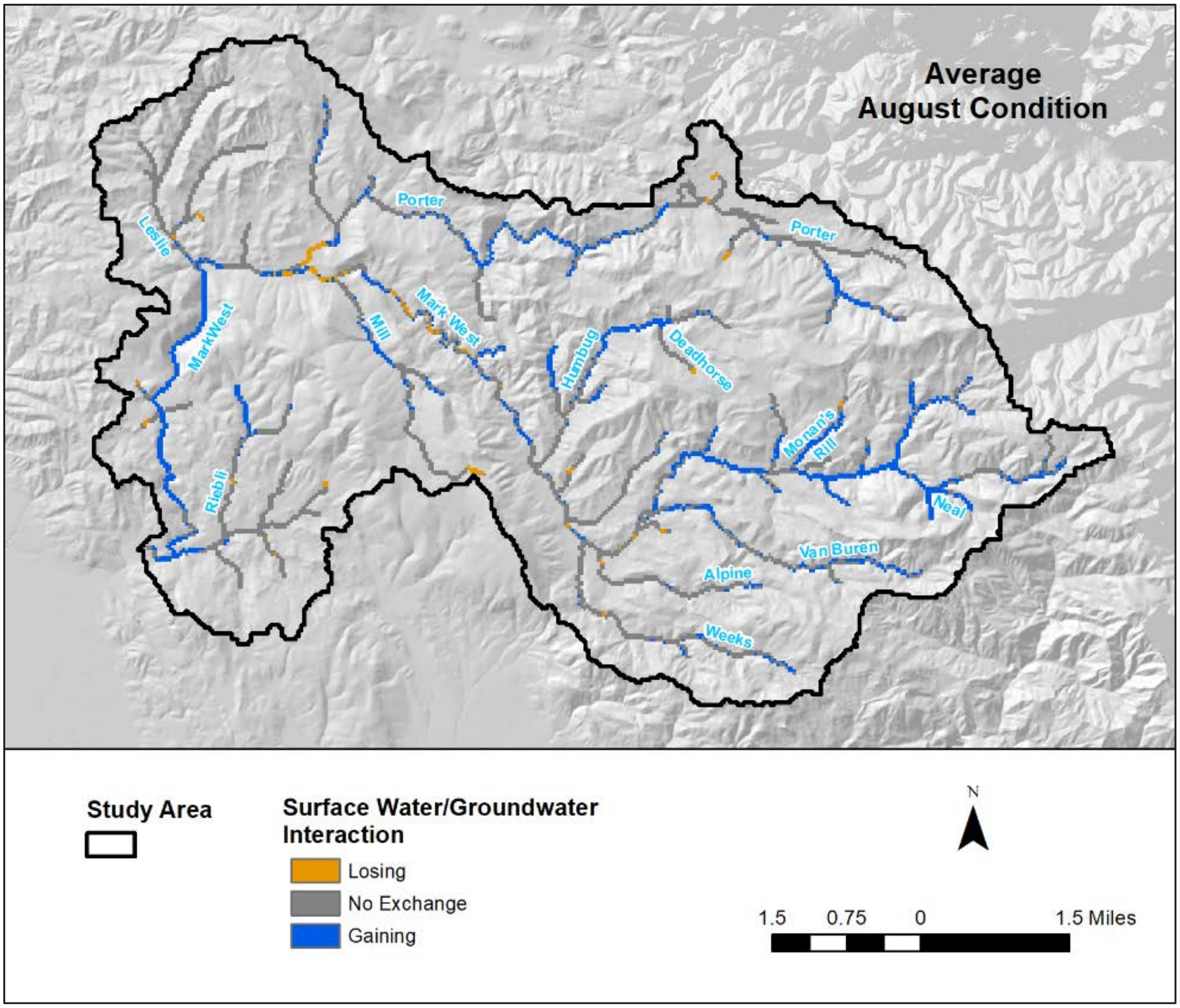


Figure 47: Extent of gaining and losing reaches for the month of August (2010-2019 mean value) as simulated with the MWC hydrologic model.

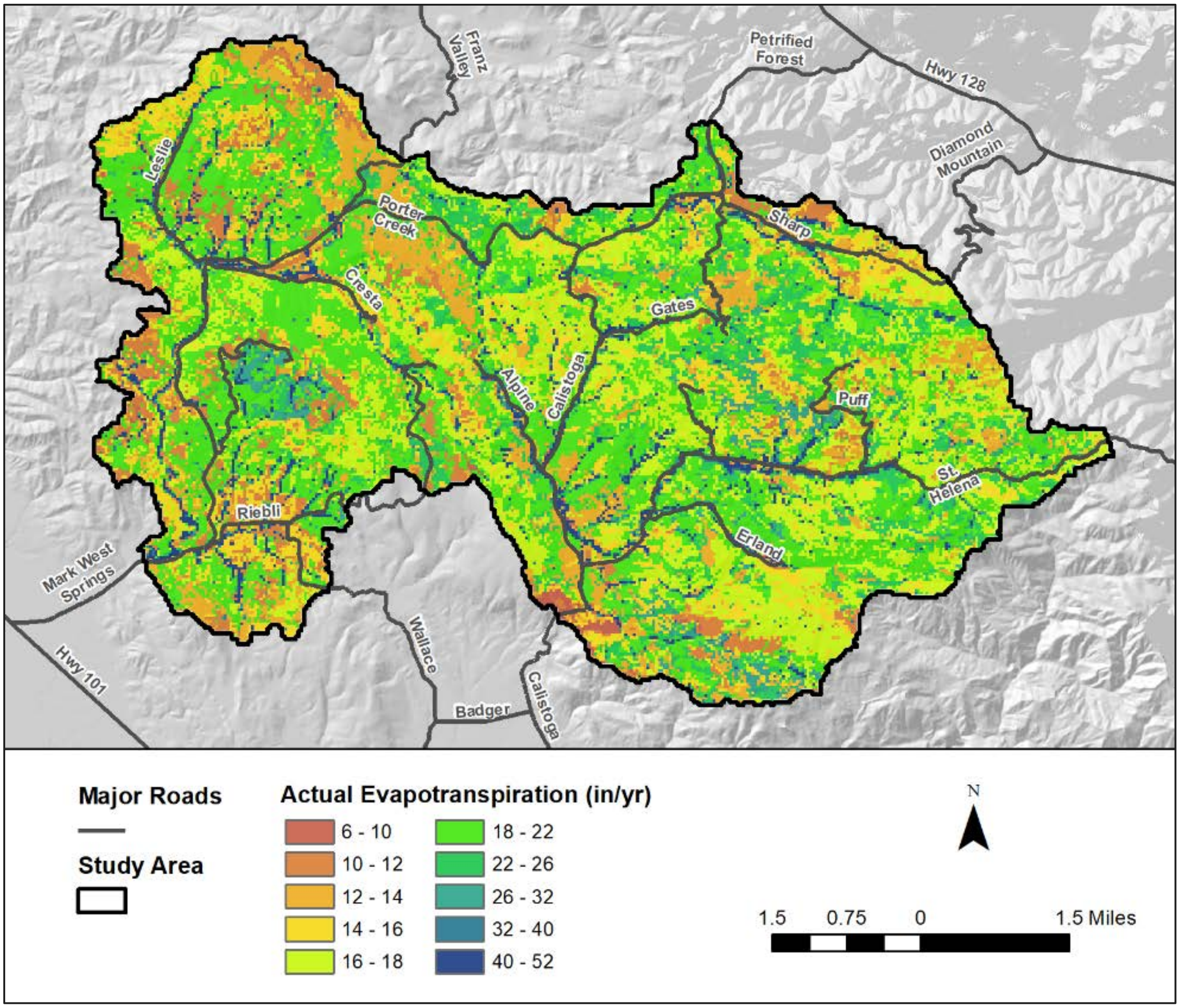


Figure 48: Mean annual Actual Evapotranspiration (AET) for water years 2010-2019 simulated with the MWC hydrologic model.

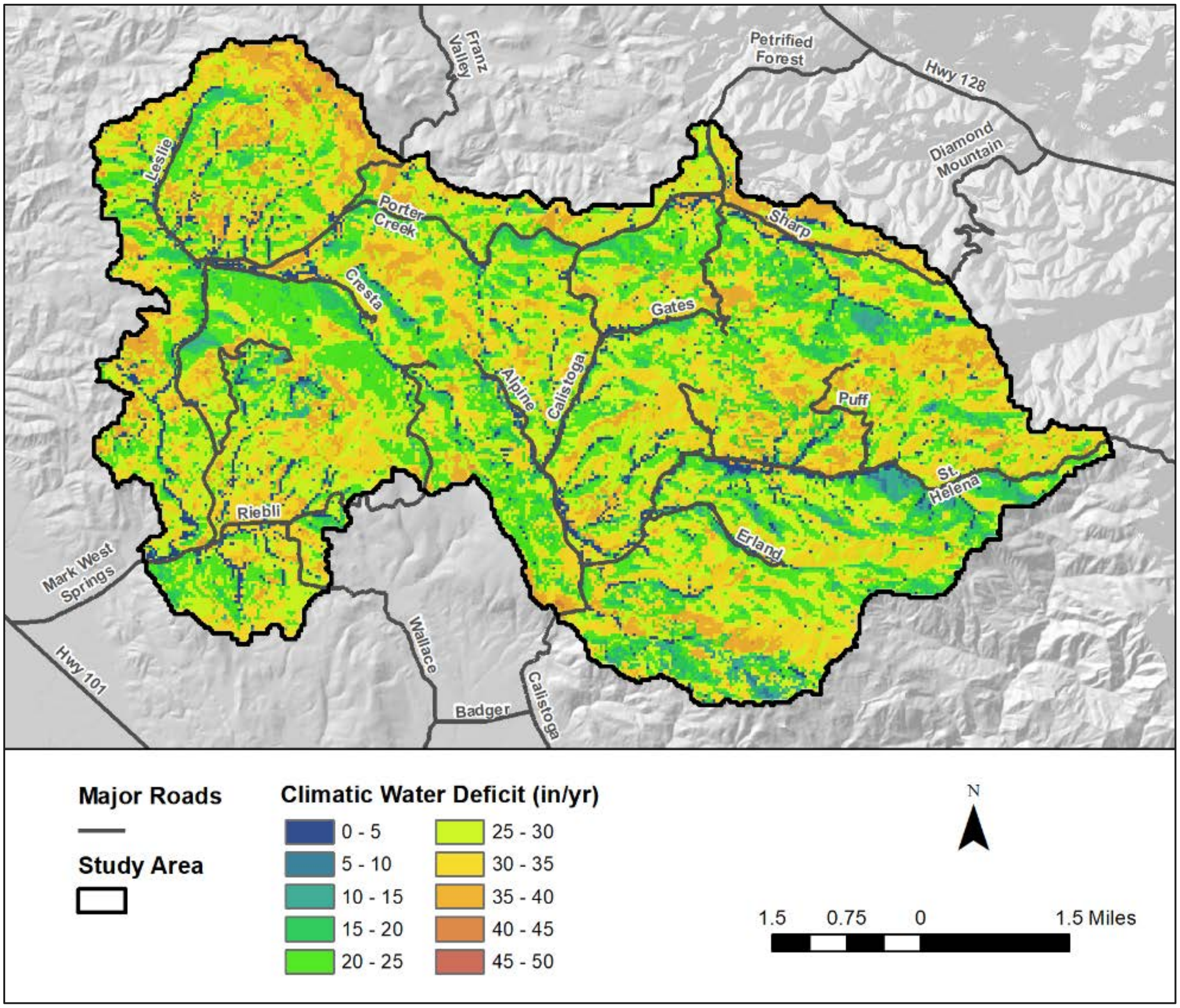


Figure 49: Mean annual Climatic Water Deficit (CWD) for water years 2010-2019 simulated with the MWC hydrologic model.

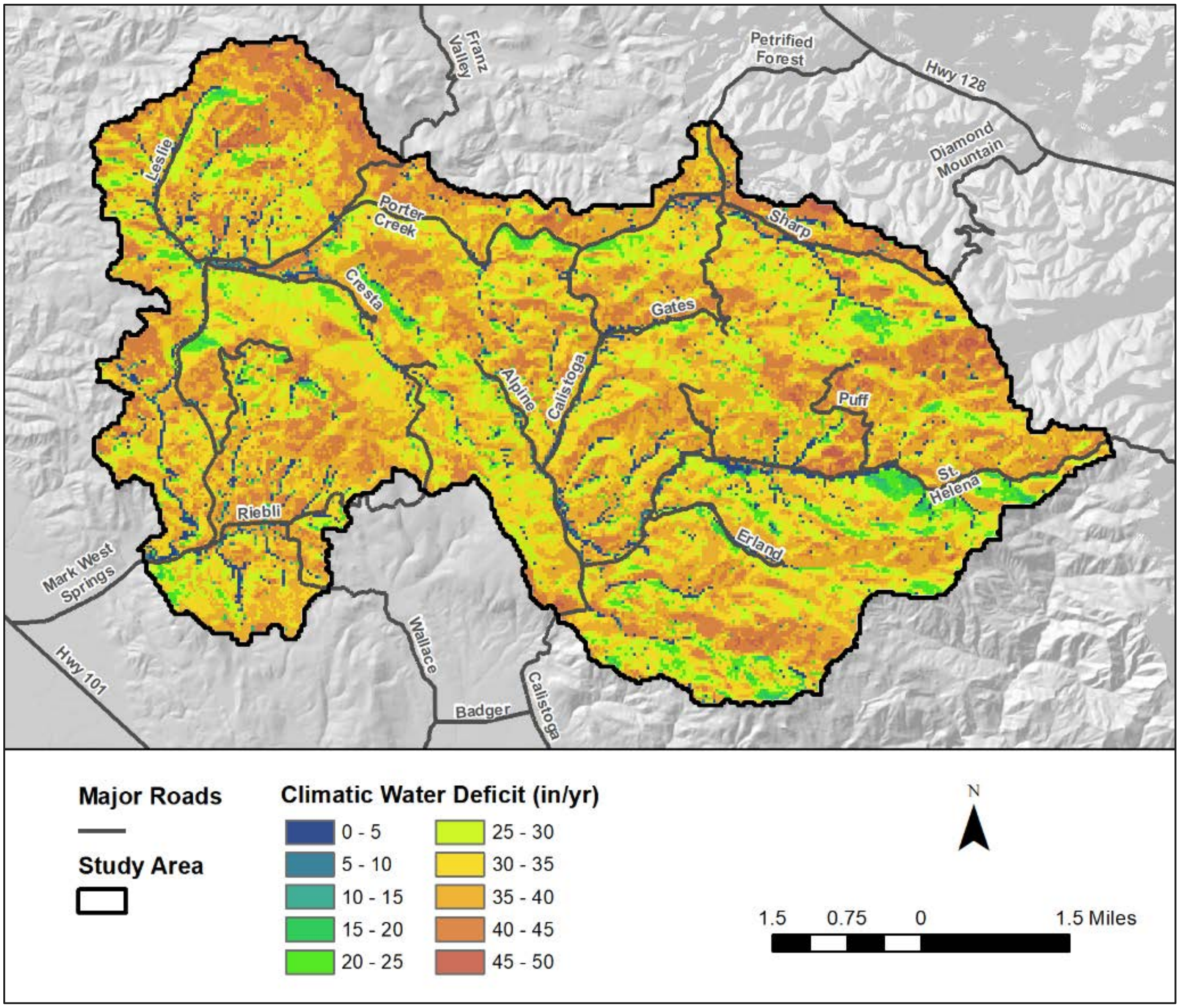


Figure 50: CWD for water year 2014 simulated with the MWC hydrologic model.

Groundwater Flow

Two hydrogeologic cross sections were prepared, one in the upper watershed downstream of Monan's Rill and one in the central watershed downstream of Humbug Creek (Figure 51). These sections show the vertical and horizontal variations in Hydraulic Conductivity, as well as the simulated equipotential lines, and approximate flow directions (perpendicular to equipotential lines) and locations of groundwater discharge predicted by the model. It is important to note that in both cross sections there is a significant downstream (out of the page) component to the flow directions not visible in this one-dimensional cross section view. Equipotentials are based on simulation results for 10/1/2010 but are representative of the regional patterns of groundwater flow throughout the simulation period which do not show significant variation at the regional scale of the cross sections.

The northern portion of the upper cross section (A-A’) passes through the area with the thickest sequence of primarily tuffaceous volcanic materials that was identified from available Well Completion Reports. A transition to more andesitic-dominated materials occurs throughout the cross section with increasing depth, which is typical of our characterization of the volcanics in the upper watershed (Figure 52). Franciscan Complex, which was represented by simple vertical contacts owing to lack of data with which to describe contact orientation, occurs in the southern portion of the cross section. A thin deposit of Quaternary Alluvium is present within a relatively narrow band along the stream channel. Flow is primarily vertical downward within the higher elevation portions of the cross section (Figure 52). Mid-way along the hillslopes above Mark West Creek, the flow directions transition toward horizontal and a vertical groundwater divide occurs beneath the creek with vertical upward flow in the upper ~300-ft (model Layers 1-3) and vertical downward flow in the lower ~500-ft (model Layers 4-6). Springs occur where upward vertical groundwater flow intersects the land surface. This primarily occurs along the lower hillslopes and stream banks in the upper watershed and appears to be associated with horizontal transitions from more tuffaceous to less tuffaceous materials as well as with steep dissected topography (Figure 52).

The cross section below Humbug Creek (B-B’) passes through the relatively thin Humbug Creek Deposits on the northeast side of Mark West Creek which are underlain by primarily andesitic rocks of the Sonoma Volcanics. (Figure 53). A contact between the volcanics and the Franciscan Complex associated with the Maacama Fault Zone occurs near the creek in this reach, and a second contact occurs ~2,000-ft southwest of the creek with a mixture of tuffaceous and andesitic materials occurring in the southwest portion of the cross section. A thin deposit of Quaternary Alluvium is present within a narrow band along the stream channel. Flow is primarily vertical downward within the higher elevation portions of the cross section (Figure 53). A shallow flow path with more horizontal flow occurs mid-way along the hillslope northeast of Mark West Creek, and a somewhat deeper horizontal flow path also occurs at a similar topographic position on the other side of the creek within the Franciscan Complex.

A vertical groundwater divide occurs beneath the creek and adjacent hillslopes with vertical upward flow in the upper ~300-ft and vertical downward flow in the lower ~500-ft. A cone of depression associated with pumping from the well located in the Franciscan Complex is readily apparent and influences the flow directions along the adjacent hillslope (Figure 53). Large persistent cones of depression like this one are relatively uncommon in the model and appear to coincide with wells exhibiting both high production rates and low aquifer Hydraulic Conductivity. Although there is some intersection of equipotentials with the land surface, rates of groundwater movement through these materials are very low and the model does not predict significant springflow in the vicinity of this cross section.

Streamflow & Riffle Depths

The model simulates streamflows and the depth of surface flow across riffles on the stream bed (i.e. riffle depths) throughout the various tributaries in the watershed; however, this discussion focuses on the main-stem of Mark West Creek where nearly all of the available suitable salmonid habitat is contained. The reach shown on subsequent maps extends upstream to the limits of anadromy associated with a natural waterfall as identified in the CDFW Fish Passage Barrier Database.

April through June (hereafter referred to as Spring) mean streamflows varied substantially between water years with the driest conditions occurring in water year 2014 when flows ranged from less than 2 cfs above Van Buren Creek to 6-10 cfs below Porter Creek. The wettest conditions occurred in water year 2010 with flows above Van Buren Creek on the order of 4-8 cfs and flows below Porter Creek in excess of 30 cfs (Figure 54). July through September (hereafter referred to as Summer) mean streamflows were significantly lower than during Spring and also varied much less between water years. The driest conditions occurred in 2015 when flows ranged from less than 0.3 cfs above Van Buren Creek to 0.6-0.8 cfs below Porter Creek. The wettest summer conditions occurred in 2011 when flows ranged from less than 0.7 cfs above Van Buren Creek to more than 1.5 cfs below Porter Creek (Figure 55).

To assist in relating flow conditions to salmonid habitat requirements, we also compiled simulated water depths (hereafter referred to as riffle depths) which were found to be loosely equivalent to riffle crest thalweg depth conditions as discussed in greater detail in Chapter 7. The results were post-processed from model output data by extracting the minimum simulated depth per 1,000-ft of channel length (10 cross sections) to better represent riffle crest conditions observed in the field. Average Spring riffle depths during the drought of 2014 ranged from less than 0.2-ft upstream of Van Buren Creek to 0.2-0.4 ft below Porter Creek. In the wet water year 2017, riffle depths in the upper reaches were above 0.2-ft all the way to upstream about one river mile beyond Monan's Rill (Figure 56). Summer mean riffle depths are significantly lower than Spring depths and are relatively consistent between water years. In typical conditions, depths remain above 0.1-ft in most locations downstream of Monan's Rill, and below Porter Creek depths reach 0.2-0.3 ft in many locations (Figure 57). The simulated spatial distributions of riffle depth reflect both reaches where riffle depths are limited by reduced streamflows, most notably the reach upstream of Porter Creek which loses flow to the alluvium, as well as where depths are limited by geomorphic controls such as the reaches about 1-mile upstream of Riebli Creek (Figures 56 & 57).

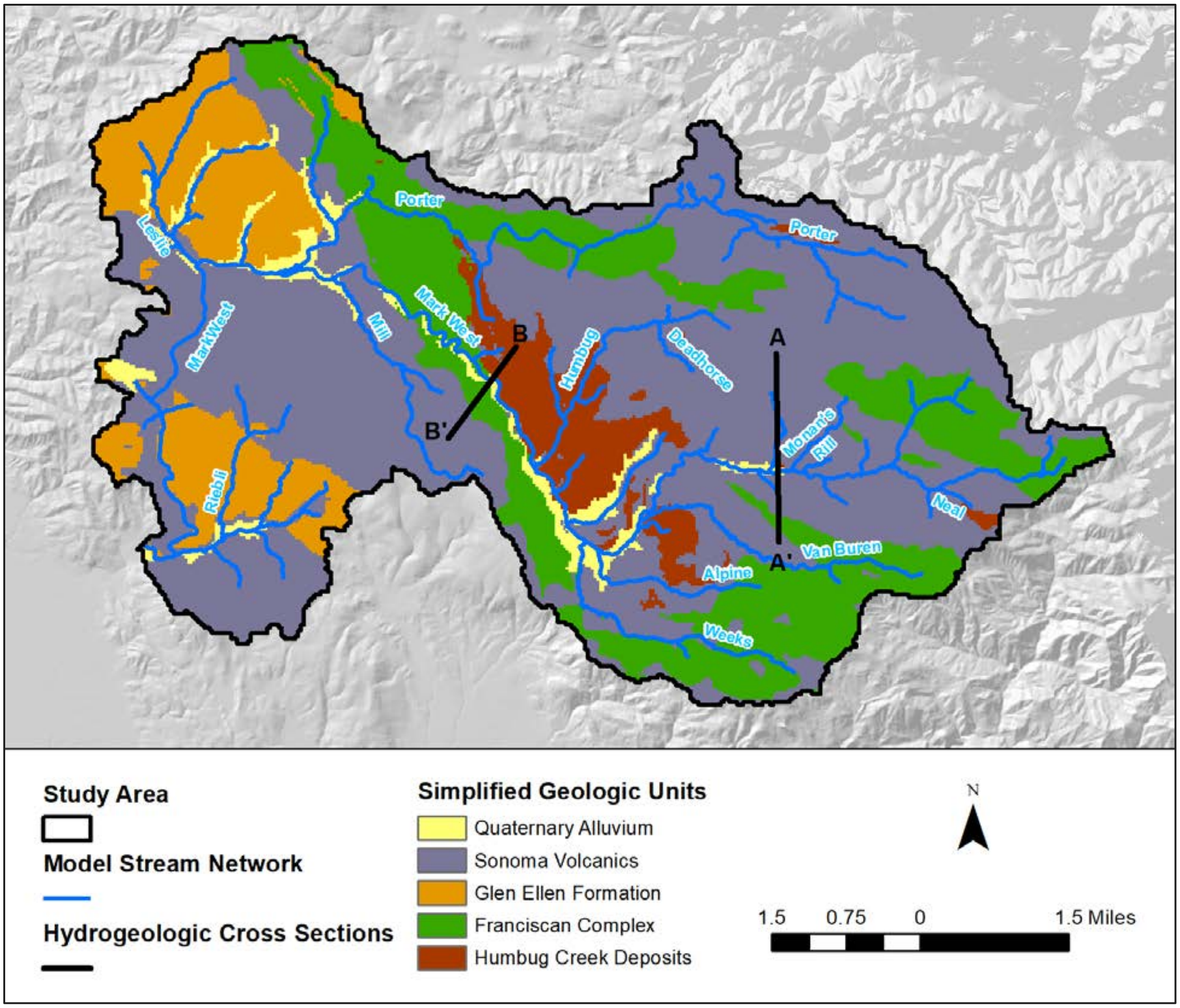


Figure 51: Simplified geologic map and locations of hydrogeologic cross sections A-A' and B-B'.

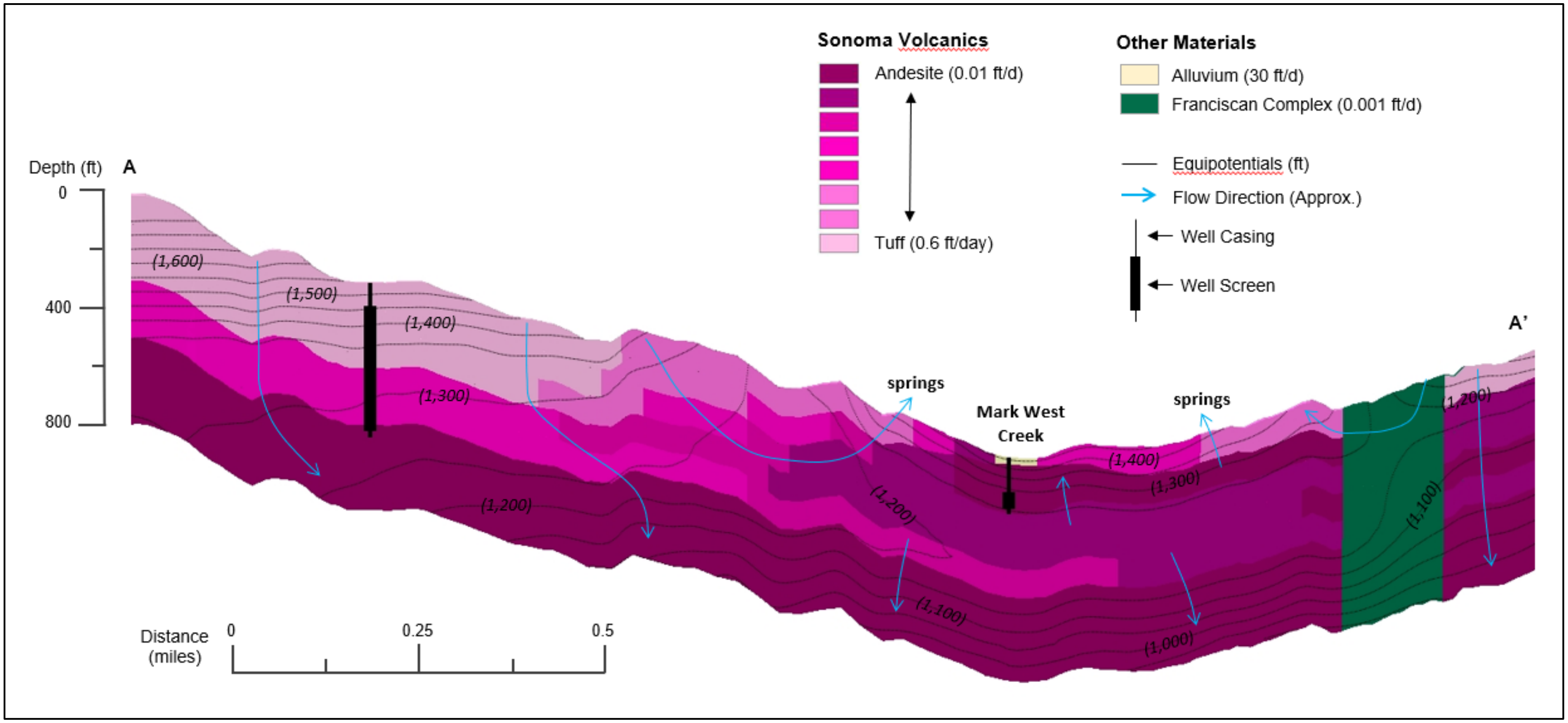


Figure 52: Hydrogeologic cross section A-A' showing hydraulic conductivities, equipotentials, and approximate flow directions as simulated with the MWC hydrologic model (see Figure 51 for location).

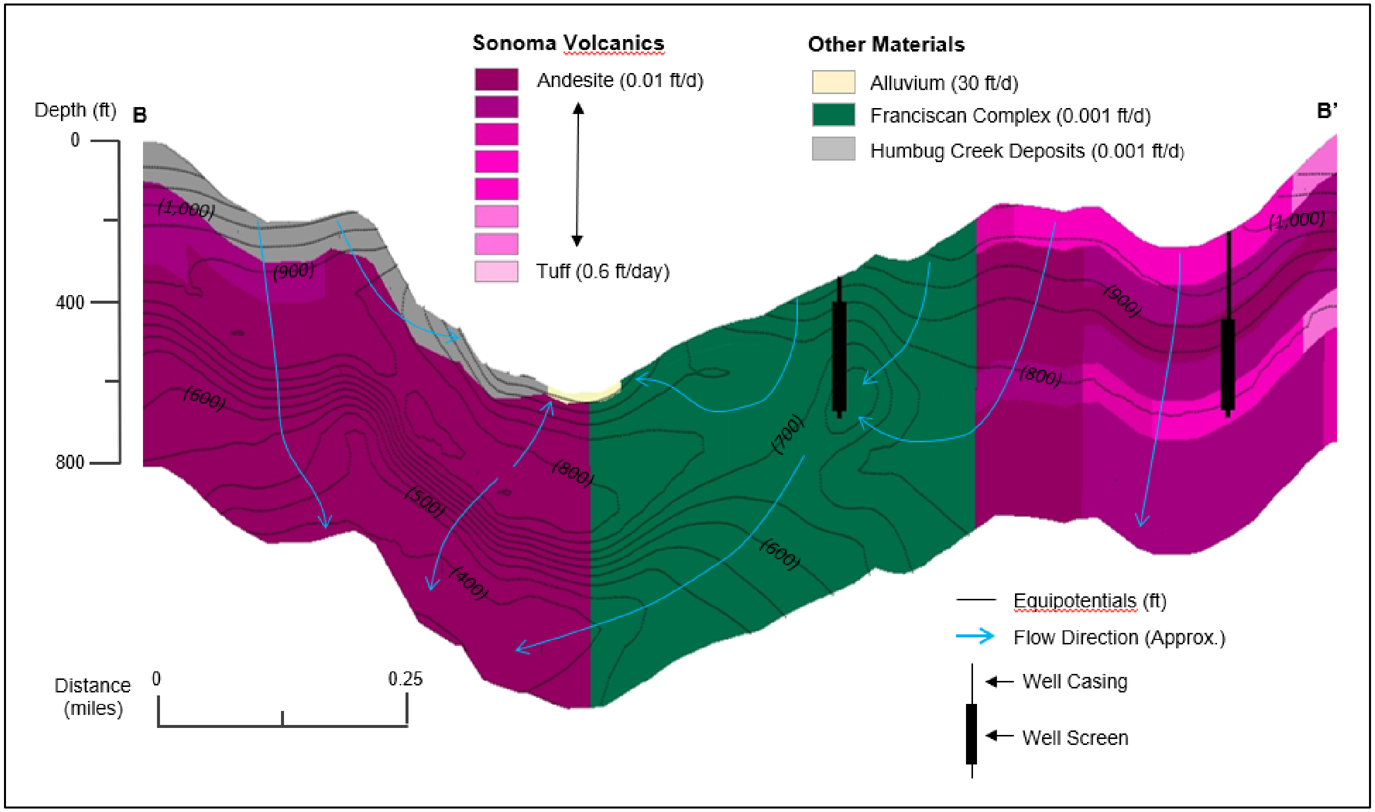


Figure 53: Hydrogeologic cross section B-B' showing hydraulic conductivities, equipotentials, and approximate flow directions as simulated with the MWC hydrologic model (see Figure 51 for location).

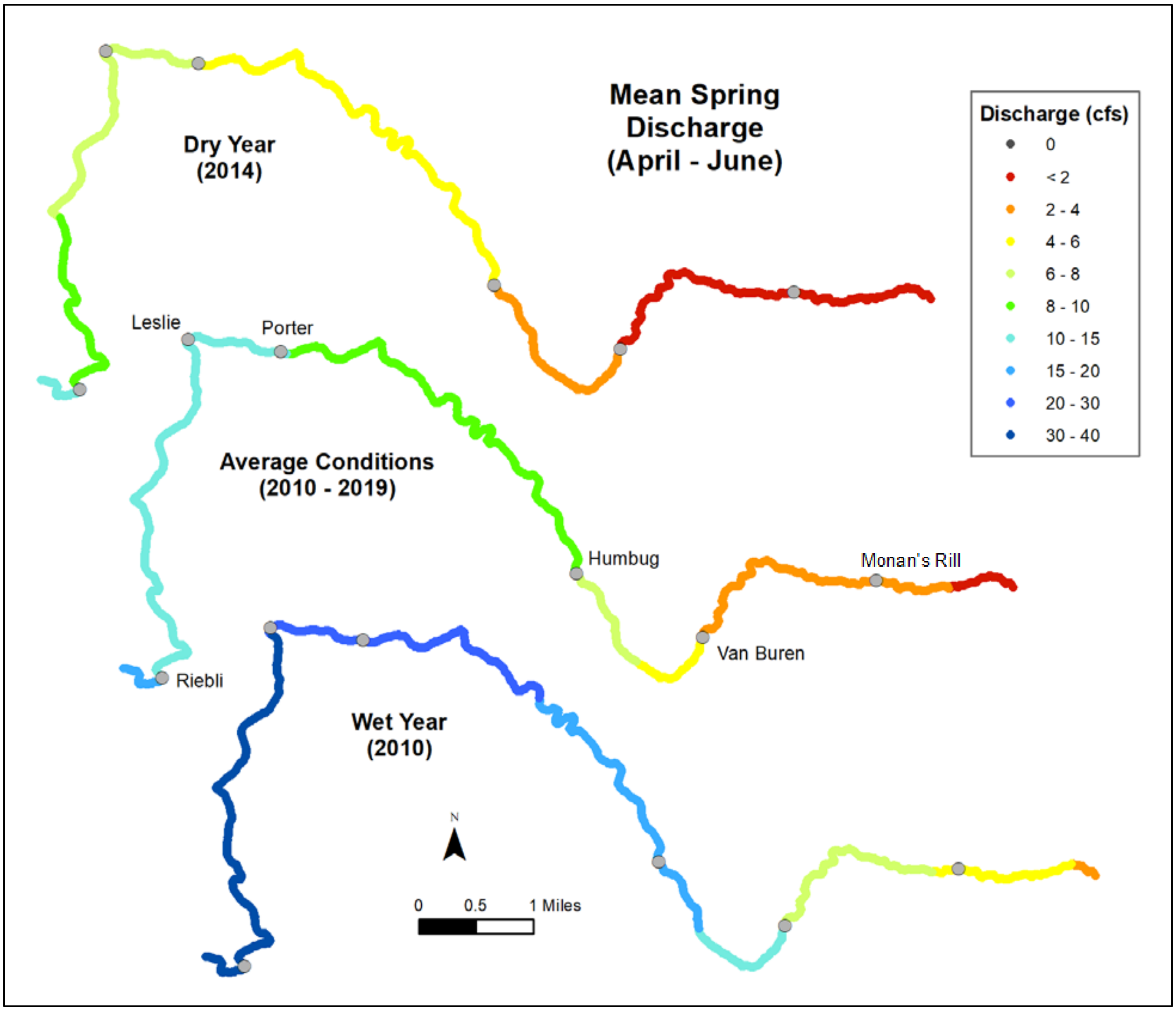


Figure 54: Mean simulated Spring (April – June) streamflows for dry, average, and wet water year conditions.

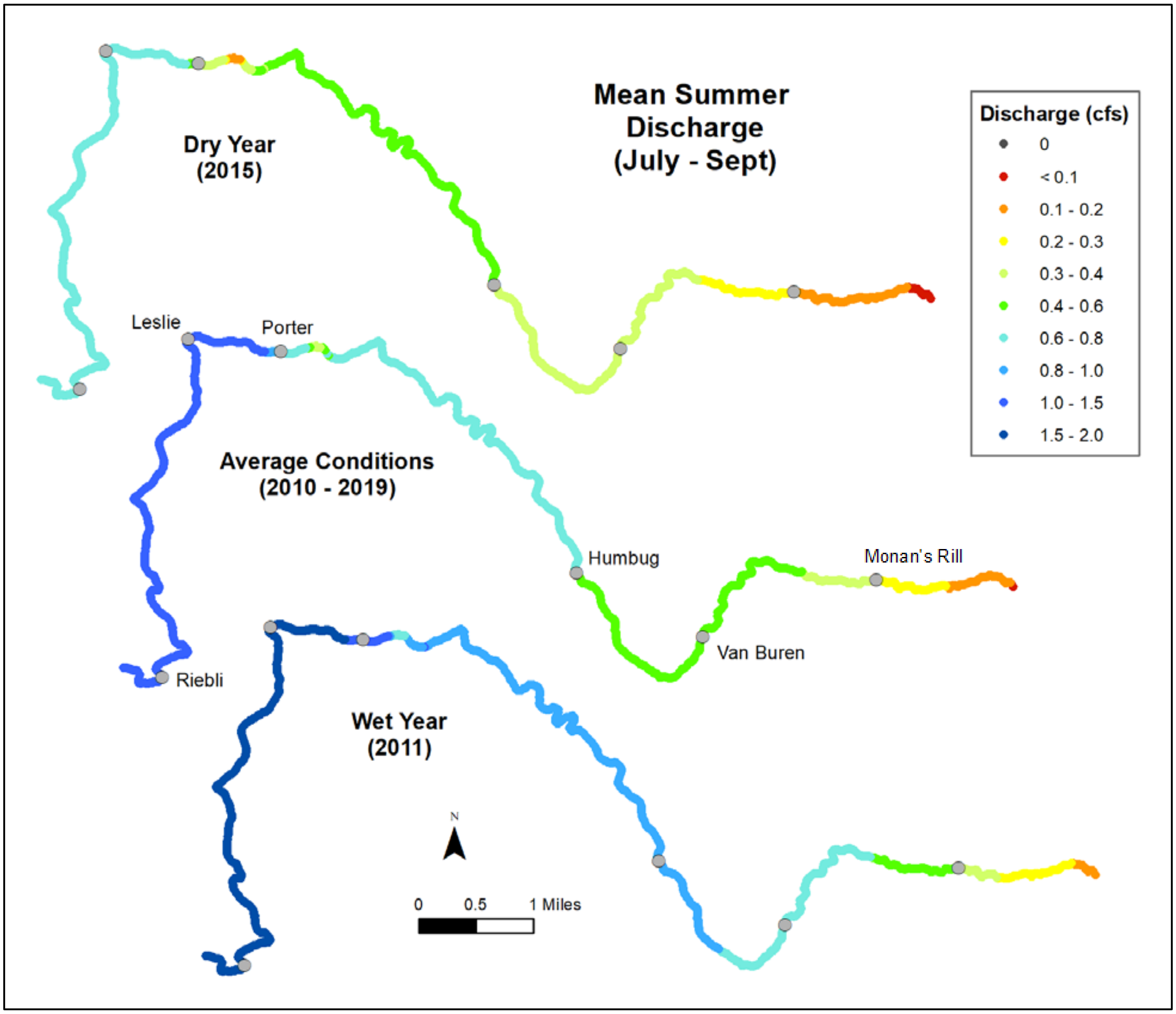


Figure 55: Mean simulated Summer (July - Sept) streamflows for dry, average, and wet water year conditions.

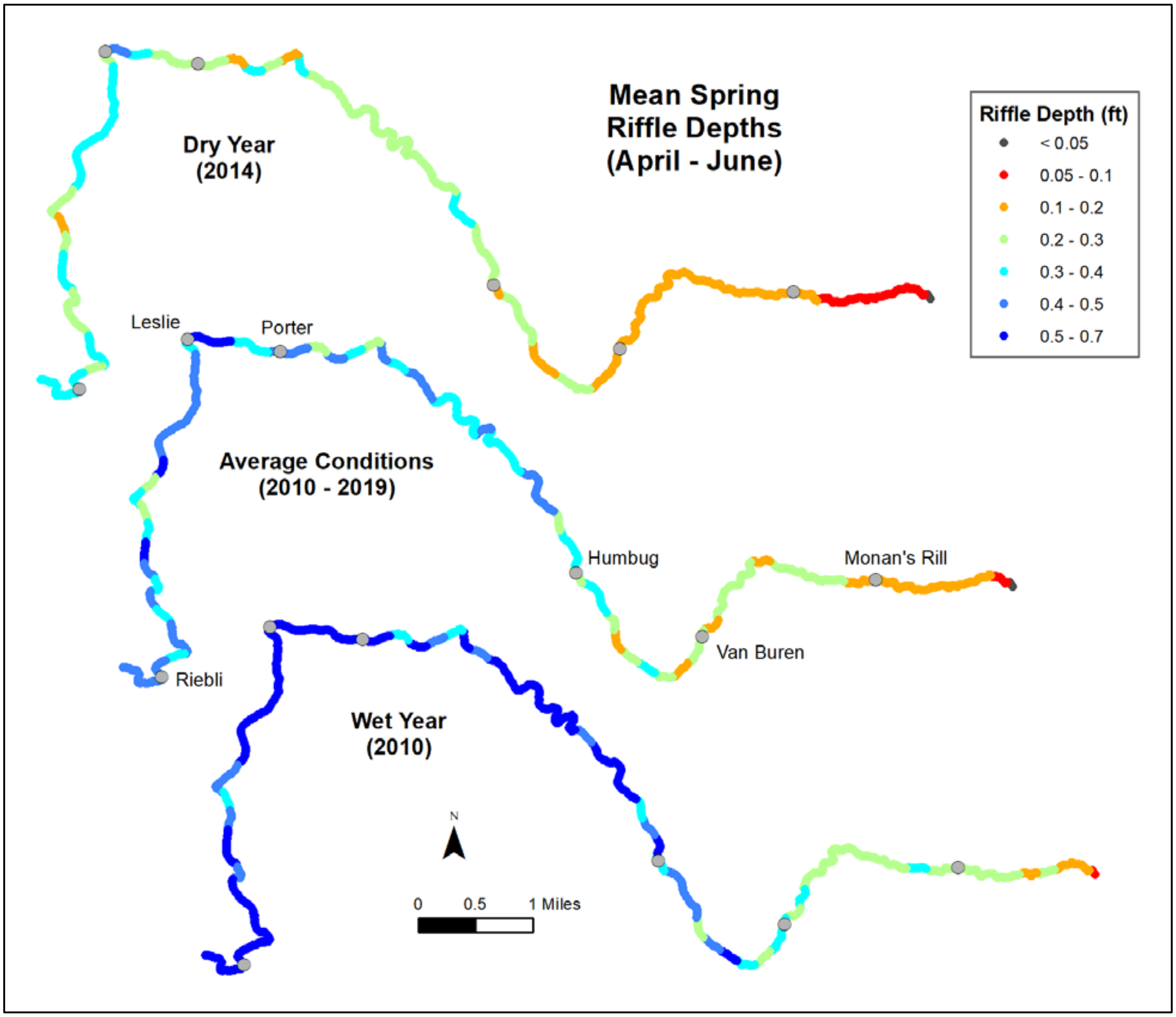


Figure 56: Mean simulated Spring (April – June) riffle depths for dry, average, and wet water year conditions.

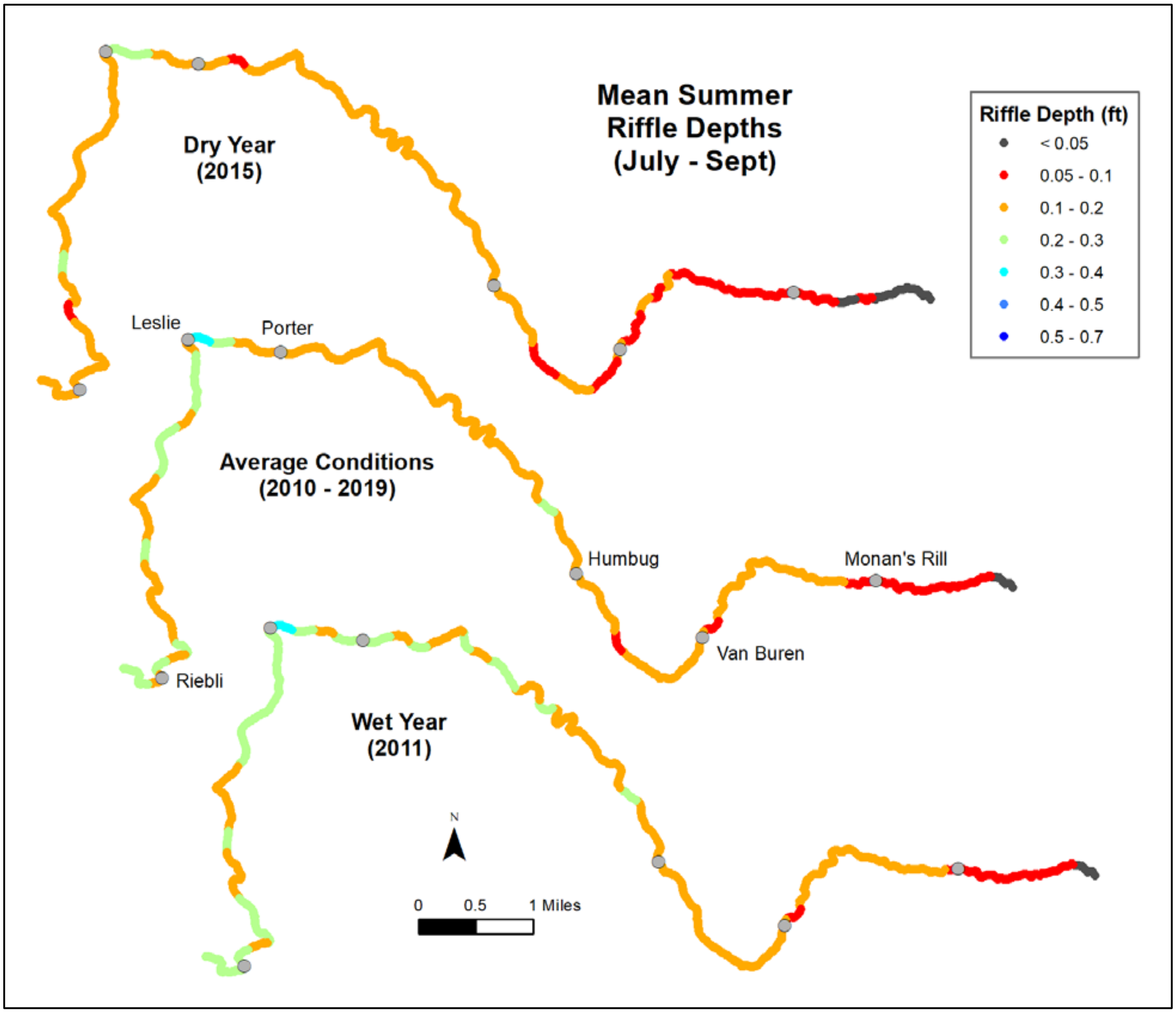


Figure 57: Mean simulated Summer (July - Sept) riffle depths for dry, average, and wet water year conditions.

Chapter 7 – Habitat Characterization and Prioritization

Background

Inadequate 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 (CDFG, 2004; NFMS, 2012). Flows during the spring outmigration period may also be limiting in some cases. 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 & 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 & Trush, 2010).

Regional regression equations produce discharge estimates for Mark West Creek and other Russian River tributaries that are an order of magnitude higher than typical conditions during the summer months. Given that coho persist in these tributaries 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 with respect to streamflow. Direct habitat mapping approaches require extensive fieldwork and site-scale characterization which is beyond the scope of this reginal planning study; a concurrent CDFW Instream Flow Study utilizing such methods is being conducted in upper Mark West Creek.

A simple approach to utilizing hydrologic model results to delineate habitat availability (and the selected approach for this study) is to relate water depths simulated in the model to riffle crest thalweg depths (RCTDs) which have been investigated as important indicators of salmonid habitat suitability. This approach assumes that the simulated water depths are representative of conditions at riffle crests. This assumption is consistent with the limitations of the LiDAR topographic data which does not penetrate water and therefore would be expected to capture riffles and pool water surfaces but not pool geometries. To validate this assumption, we measured riffle crest thalweg depths (RCTDs) at nine riffle crests identified in three reaches of Mark West Creek across a range of typical low to moderate flow conditions and compared the resulting discharge/RCTD relationships to relationships extracted from the model for equivalent locations (Figure 58).

There was generally good agreement between the measured and simulated discharge/RCTD relationships, and the agreement was improved by sampling the cross section within a given 1,000-ft reach with the lowest simulated depths (i.e. finding the cross section most representative of conditions at nearby riffle crests). At most riffle crests observed in the field, maximum depths occur across a relatively narrow width commonly associated with gaps between small clusters of individual cobbles. This level of topographic detail is not captured in the model topography, therefore a small residual depth (0.05-ft) was added to the simulated values to account for the effects of this microtopography. The simulated discharges associated with a RCTD of 0.2-ft ranged from 0.21 to 0.46 cfs based on interpolation between field measurements, and from 0.18 to 0.53 cfs as simulated in the model (Figure 58).

Previous research has demonstrated relationships between RCTDs and various indicators of salmonid habitat suitability including fish passage, water quality, and abundance of benthic macroinvertebrates. Maintaining suitable riffle depths to allow for fish passage is critically important during smolt outmigration (typically mid-February to mid-June) and is also important for facilitating pool selection prior to summer rearing. A minimum passage depth of 0.3 feet has been estimated for juvenile coho (R2 Resource Consultants, 2008; CDFW, 2017). This depth criterion and methodology is somewhat conservative by design and fish passage is thought to occur in Russian River tributaries at shallower depths, therefore it is useful to define a lower criterion below which passage is presumably not possible. For the purposes of this study, that depth was defined as 0.2 feet expressed as a RCTD. It is important to note that we are applying this depth threshold to RCTDs rather than based on CDFW critical riffle methodology. We calculated the flows required to achieve a 0.2-ft depth from our field data following CDFW protocols for performing Critical Riffle Analysis (CDFW, 2017). This resulted in estimates of required flows ranging from 2.0 to 3.2 cfs, which are about 5 to 10 times higher than the typical summer flows experienced in the watershed.

Another key factor in summer survival is the suitability of water quality conditions in the pools that provide rearing habitat for salmonids. Maintaining sufficient flow between riffles is key to maintaining oxygenation in pool habitats, and monitoring in Green Valley Creek has shown that coho survival begins to decline when pools become disconnected with mortality increasing as a function of length of disconnection (Obedzinski et al., 2018). Through extensive field monitoring in Green Valley, Dutch Bill, and Mill Creeks, CA Sea Grant found a statistically significant relationship between RCTDs and Dissolved Oxygen (DO) concentrations in intervening pools, with ~80% of the pools with RCTDs greater than 0.2-ft maintaining suitable DO concentrations above 6 mg/L (CA Sea Grant, 2019). As discussed below in greater detail, water temperature conditions are higher in Mark West Creek relative to the monitored streams nearer the Pacific Ocean in Sonoma County, therefore while we still consider RCTDs to be an important indicator of water quality in Mark West Creek, temperature considerations must be accounted for in more detail.

In addition to suitable water quality, another factor critical summer rearing habitat for salmonids is the availability of a reliable food supply in the form of benthic macroinvertebrates (BMI) which are concentrated in riffle habitats with sufficient flow velocity. Velocities at riffles between about 1.0 and 2.5 ft/s have been shown to be optimal for BMI (Giger 1973, Gore et al., 2001). As part of our riffle crest analysis in Mark West Creek we measured velocities and interpolated relationships between RCTDs and thalweg velocities (Figure 59). At lower flows, depths were too low to measure velocity at more than a few locations across the riffle, however in most cases velocities approaching those at the thalweg only occurred across a relatively small portion of the riffle profile. To ensure that the threshold velocity represents a condition that provides suitable habitat for BMI across larger swaths of the riffle we applied a minimum velocity threshold of 1.5 ft/s and do not consider the upper velocity limit important over the range of summer flows experienced in Mark West Creek. This exercise revealed that 0.2-ft was also a useful threshold for describing the approximate minimum RCTD that corresponded to adequate velocity at riffle crests for BMI (Figure 59).

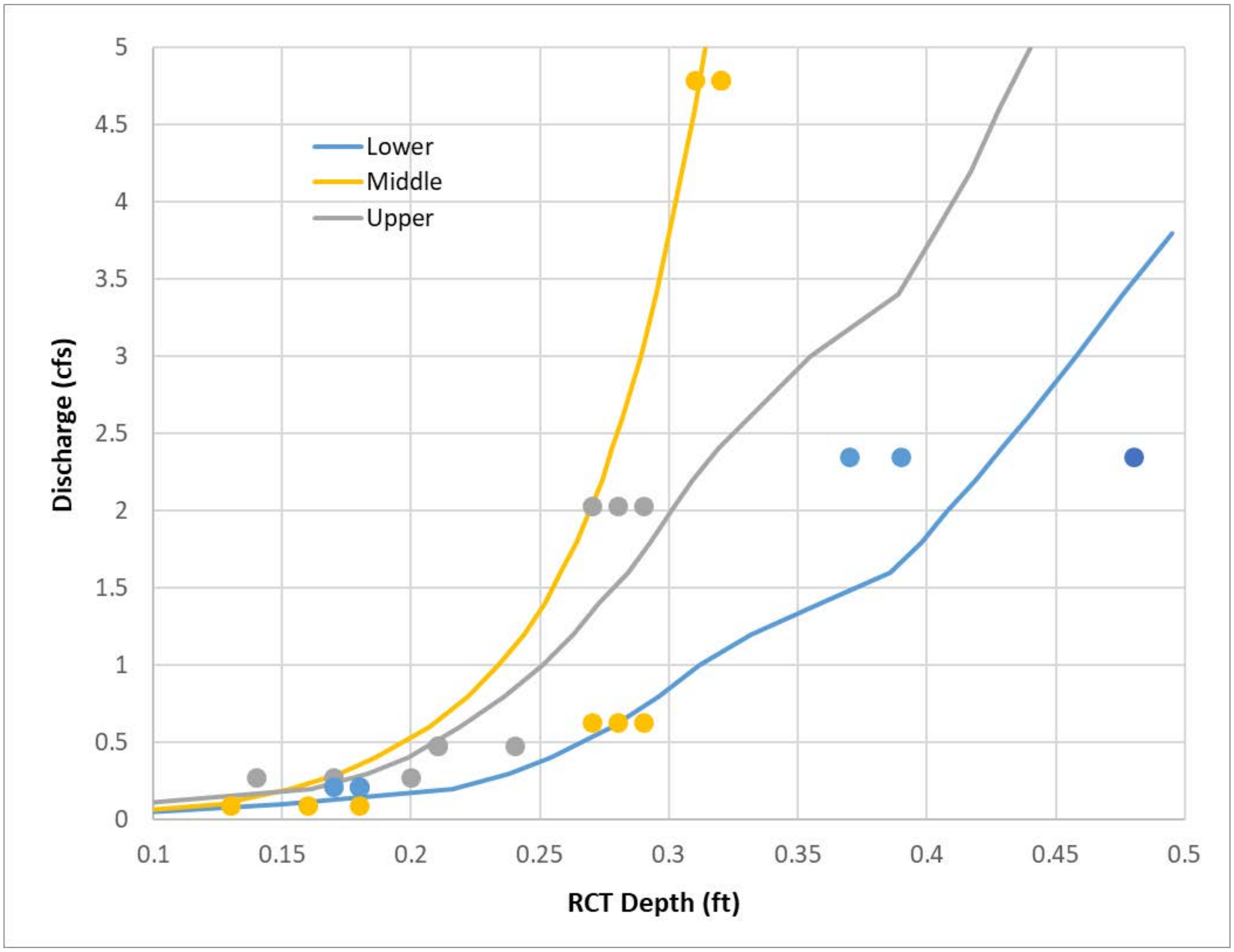


Figure 58: Comparisons between RCTD/discharge relationships measured in the field (points) and simulated with the MWC hydrologic model (lines).

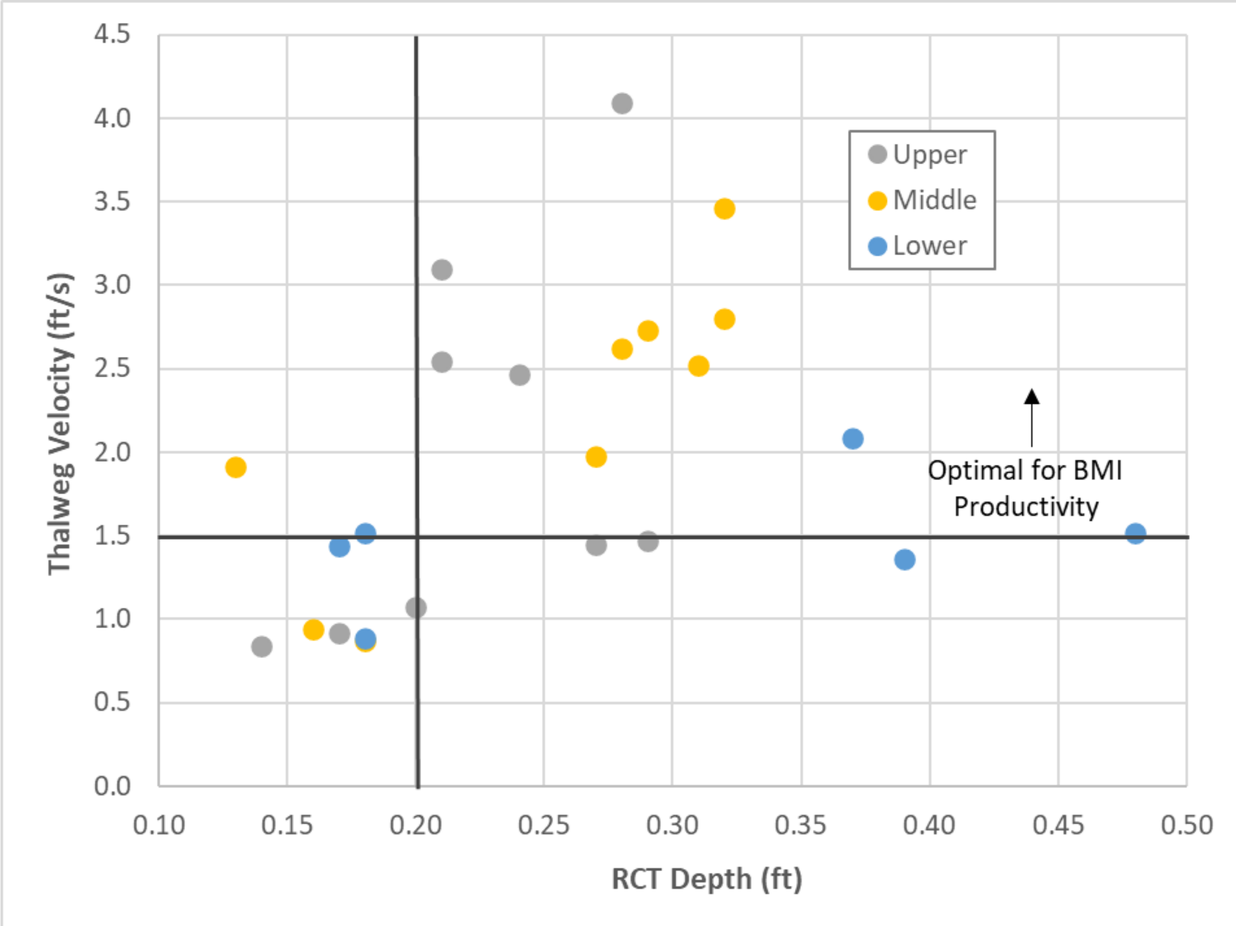


Figure 59: Relationship between RCTD and velocity based on measurements at nine riffles crests in Mark West Creek.

Approach

We developed two streamflow classifications with respect to salmonid habitat condition, one for smolt outmigration and one for juvenile rearing. Both classifications focus on the 0.2-ft RCTD threshold which is intended to represent the minimum flow conditions required to provide suitable (not optimal) habitat for salmonids. It is important to note that the primary goals in defining a minimum flow threshold for this study were to 1) assist in distinguishing between reaches with varying levels of habitat suitability under existing and plausible future flow conditions in the watershed to aid in prioritizing reaches for restoration projects, and 2) to distinguish between conditions that are likely suitable versus not suitable rather than attempting to distinguish between optimal and suboptimal conditions. Optimal summer rearing habitat conditions for salmonids, particularly coho salmon, are rarely found or non-existent in most lower Russian River tributaries.

We obtained smolt outmigrant trap data collected by Sonoma Water in Mark West Creek for 2012-2018. These traps were only deployed during April and May to capture the primary pulse of outmigration. CA Sea Grant has collected data from outmigrant traps in other Russian River tributaries over the full outmigration season from late February to late June. We compared the CA Sea Grant data in Mill Creek for 2014-2019 with the Mark West data and found very similar outmigration timing with peak outmigration occurring between the first week of April and the third week of May in both creeks. CA Sea Grant's analysis of the Mill Creek data (which we believe is representative of Mark West Creek) indicated 80% of the outmigrants had moved by the week of May 21st in a late outmigration year and 99% had moved by the week of June 18th (Nossaman Pierce, personal communication). We developed habitat suitability criteria based on these dates and a RCTD threshold of 0.2-ft as follows:

- Maintain RCTD threshold through week of May 21st in the 10-yr average condition
- Maintain RCTD threshold through week of June 18th in the 10-yr average condition
- Maintain RCTD threshold through week of May 21st in drought years
- Maintain RCTD threshold through week of June 18th in drought years

We followed a similar approach for the juvenile rearing habitat classification focused on July-September conditions. In our previous flow-based habitat classification work in Green Valley/Atascadero & Dutch Bill Creeks, we focused on differentiating between reaches where pools remain connected, become disconnected for short periods of time, and become disconnected for longer periods of time (OEI, 2016). Disconnected pools are relatively rare in Mark West Creek (with the exception of a short reach above Porter Creek), therefore this was not a useful metric for distinguishing between various levels of habitat suitability in this watershed. We developed an alternative and likely more stringent set of habitat suitability criteria for summer rearing habitat conditions as follows:

- Maintain RCTDs threshold for portions of the summer in the 10-yr average condition (always > 0.1-ft)
- Maintain RCTD threshold continuously in the 10-yr average condition
- Maintain RCTD threshold for portions of the summer in drought years (always > 0.1-ft)
- Maintain RCTD threshold continuously in drought years

We then assigned each 1,000-ft stream reach in the model with a score of zero through four based on the number of these criteria that were met to develop flow-based habitat classification maps for smolt outmigration and juvenile rearing.

Although water temperature analysis was not part of our project scope, preliminary review of available temperature data revealed that elevated water temperatures may be an even more important limiting factor for juvenile rearing habitat than flow in this watershed, therefore we compiled available temperature data from Sonoma RCD, CA Sea Grant, Trout Unlimited, and CDFW to facilitate incorporating temperature into the habitat classification. We calculated the Maximum Weekly Maximum Temperature (MWMT) from continuous temperature datasets at 15 locations in Mark West Creek. Each location had between one and five years of data between 2010-2019, however many locations had only one year of data and most years had only a few locations, complicating the interpretation of spatial and temporal patterns. Nevertheless, the data was sufficient to perform a preliminary water temperature classification based on the

MWMT and various levels of temperature impairment. Based on previous work, a threshold of 18.0 °C was used to represent impaired conditions, 21.1 °C to represent severe impairment, and 23.1 °C to represent conditions that may be lethal for salmonids given prolonged exposure (NCRWQCB, 2008). Each reach was assigned a score from zero to three based on the number of the following criteria that were met:

- Maintain MWMT < 23.1 °C
- Maintain MWMT < 21.1 °C
- Maintain MWMT < 18.0 °C

In addition to sufficient flow to enable passage, maintain water quality, and support benthic macroinvertebates, there are many other important factors for maintaining suitable salmonid habitat. These include presence of pools with sufficient depth and cover, suitable spawning gravels, and availability of refugia from high velocity winter flows, among others. To account for some of these factors in our classification, we compiled Stream Inventory Report data collected by CDFW in 1996 and ranked each of the five reaches described in the report based on the relative quality of pool habitat and spawning habitat. Although we did not collect detailed pool or substrate data, we incorporated our general observations of these conditions in our interpretations of the resulting rankings. Our observations suggest that even though the inventory data described conditions more than 20 years ago, the relative quality of habitat conditions between reaches described by the data appears to be fairly consistent with current conditions. Finally, we compiled summer snorkel survey data collected by CA Sea Grant to understand which reaches have been utilized by salmonids in recent years.

We then produced a generalized multi-factor habitat classification map by combining the flow- and temperature-based classifications and making adjustments and interpretations based on the pool and spawning habitat rankings as well as our general observations about other factors such as off-channel habitat availability and potential for redd scour, and recent patterns of salmonid utilization. The resulting maps are intended to delineate the reaches providing the best overall habitat value for salmonids in the watershed as well as the reaches where conditions are likely unsuitable due to one or more critical limiting factors.

Results

The flow-based habitat classification results indicate that most reaches are impaired with respect to flow both in terms of smolt outmigration and summer rearing (Figure 60). Both the juvenile rearing and smolt outmigration classifications show similar patterns overall. Upstream of Van Buren Creek either one or zero of the four flow criteria are met, most reaches between Humbug Creek and Porter Creek meet two or three of the criteria, and most reaches below Porter Creek meet three or four criteria (Figure 60). Notable exceptions to this include short reaches upstream of Porter Creek and between Leslie and Riebli Creeks which are more flow-limited than adjacent upstream and downstream reaches (Figure 60).

Two of the three temperature criteria are met upstream of Van Buren Creek, one of the criteria are met between Van Buren and about 2-miles upstream of Porter Creek, and none of the criteria are met (MWMT > 23.1 °C) in the reach upstream of Porter Creek (Figure 61). No continuous temperature data was available farther downstream. The available water temperature data shows an overall pattern of increasing temperature in the downstream direction with all reaches being temperature-impaired at times to varying degrees (Figure 62). In the upper watershed, maximum water temperatures generally occur in mid-July, whereas the reach above Porter Creek follows a similar trend in general but superimposed on this is a period of elevated temperatures resulting in maximum temperatures about a six weeks earlier in early June; this behavior may reflect a contrast in the timing of response to solar radiation inputs (Figure 63).

We examined the temporal variations in temperatures relative to streamflows observed at the stream gauges in the watershed and found no obvious correlations between flow and temperature at the most temperature-impaired locations. In fact, the highest temperatures in these reaches generally occur during June and begin to improve by August and September, whereas flows are generally declining throughout this period. In the reach above Porter Creek, June/July water temperatures ranged from 14.4 to 23.1 °C when flows were very low (< 0.2 cfs) and exhibited a similar range of variability (14.5 to 24.3 °C) when flows were relatively high (> 1 cfs) (Figure 64). This suggests that flow is not the primary control on temperature and that even significant streamflow enhancement is unlikely to mitigate elevated temperatures.

We also examined the relationship between pool depth and temperature in six pools monitored by CDFW upstream and downstream of Humbug Creek in 2017. Pools with depths greater than 3.5-ft maintained significantly lower temperatures than shallower pools less than 2.5-ft deep (Figure 65). Although based on a limited sample size from a single year, this suggests that deep pools likely provide critical refugia for salmonids in Mark West Creek when extreme temperatures occur in shallower pool habitats (Figure 65).

The CDFW inventory data indicates that the best pool habitat occurs in the reach above and below Humbug Creek (CDFW Reach 5) and above and below Riebli Creek (CDFW Reach 2) (Figure 66). It is important to remember that this is a relative ranking and pool conditions in these reaches are likely still impaired. The CDFW data indicates that these reaches have relatively low shelter ratings (mean of 40), shallow pools (2.5-ft mean maximum depth), and very little Large Woody Debris (1% occurrence) (Table 14). The best spawning habitat as indicated by the CDFW data occurs in the middle and lowest reaches (CDFW Reaches 2 and 4) (Figure 66). Upstream of Van Buren Creek, spawning suitability is limited by high embeddedness and the predominance of bedrock and cobble-sized substrate conditions (Table 14). Not captured in the CDFW data are considerations of potential for redd scour which is likely to increase significantly below Porter Creek due to increased stream power and sediment mobility. Therefore, the most suitable spawning habitat is likely to occur in the reach of Mark West Creek between Van Buren Creek and Porter Creek. It is important to remember that the inventory data is more than 20 years old and as such may not be reflective of current conditions other than in generally describing reach-to-reach variability.

Summer snorkel survey data is available from 2016-2019. Very few (<10) coho were observed in Mark West Creek during 2016 and 2018 and interpreting the data from 2017 is complicated by a spring release of juvenile coho in the upper watershed. Therefore, the 2019 data is the most useful for examining which reaches have been utilized by coho in recent years. Nearly all (98%) of the 734 observed coho were found in pools between Humbug Creek and Porter Creek. Within this reach, coho were highly concentrated in a relatively small number of pools, with 72% of the coho located in just 11 pools and the remaining 28% distributed between 33 additional pools (Figure 67).

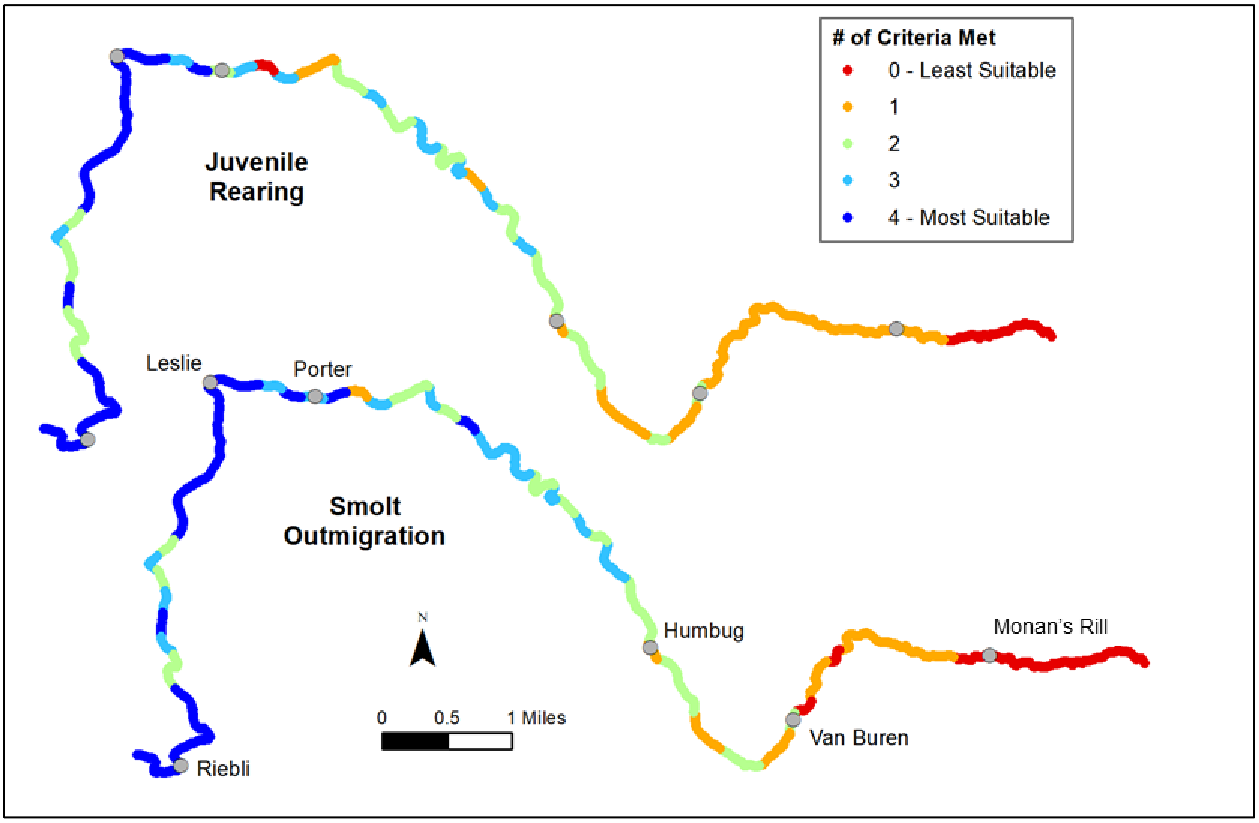


Figure 60: Flow-based habitat suitability classifications for juvenile rearing and smolt outmigration.

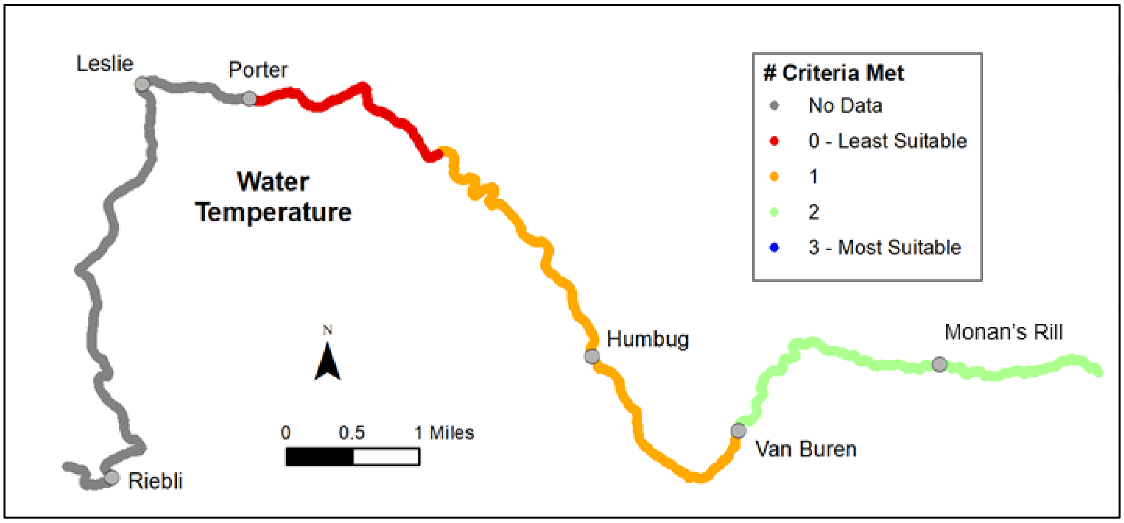


Figure 61: Water temperature-based habitat suitability classification.

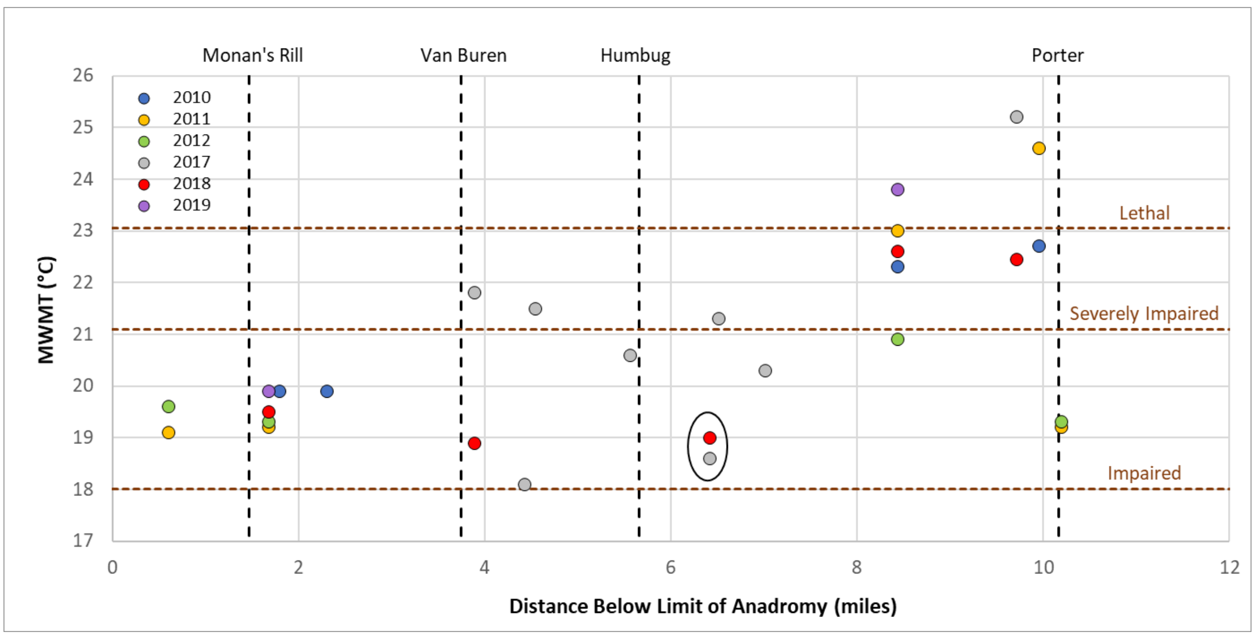


Figure 62: Longitudinal and temporal variations in Mean Weekly Maximum Water Temperature (MWMT) derived from continuous temperature data at 15 stations between 2010 and 2019, black oval indicates location of deep pool cold water refugia; temperature data from CDFW, Sonoma RCD, CA Sea Grant, and TU.

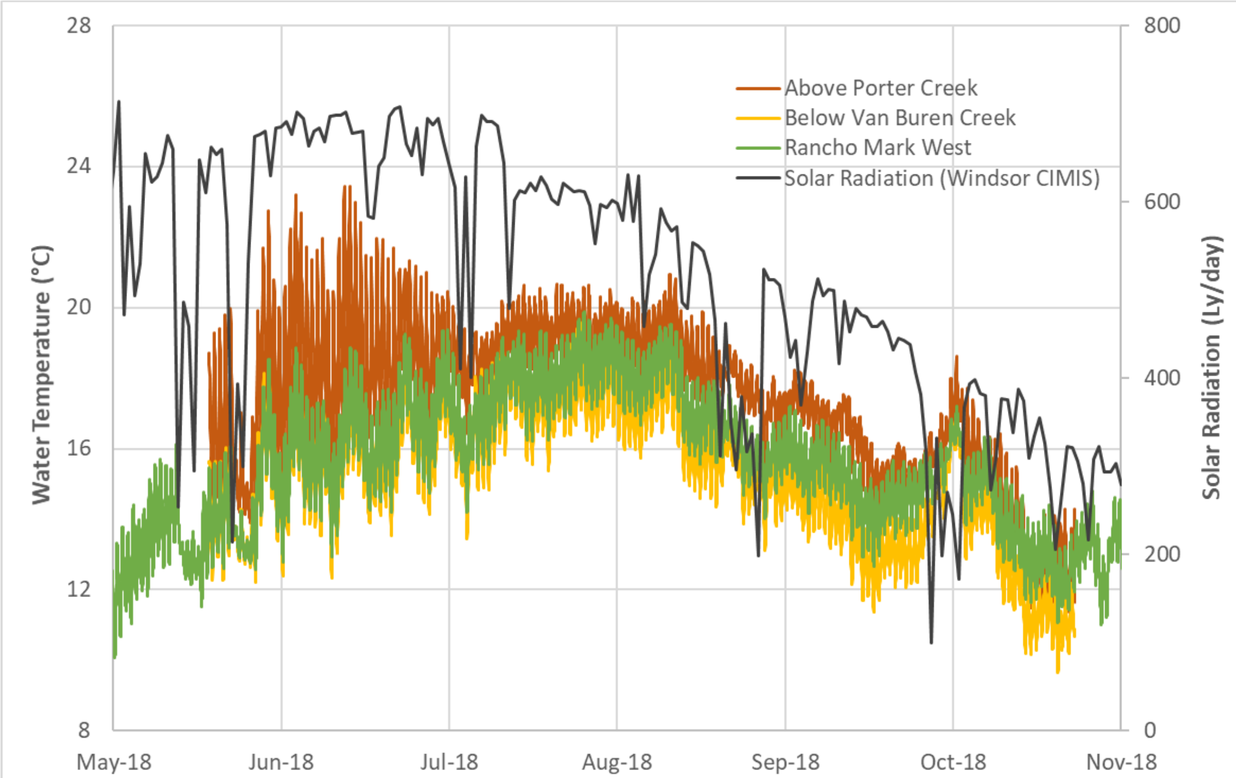


Figure 63: 15-minute interval water temperature data at three locations in Mark West Creek for 2018 and solar radiation data from the Windsor CIMIS station.

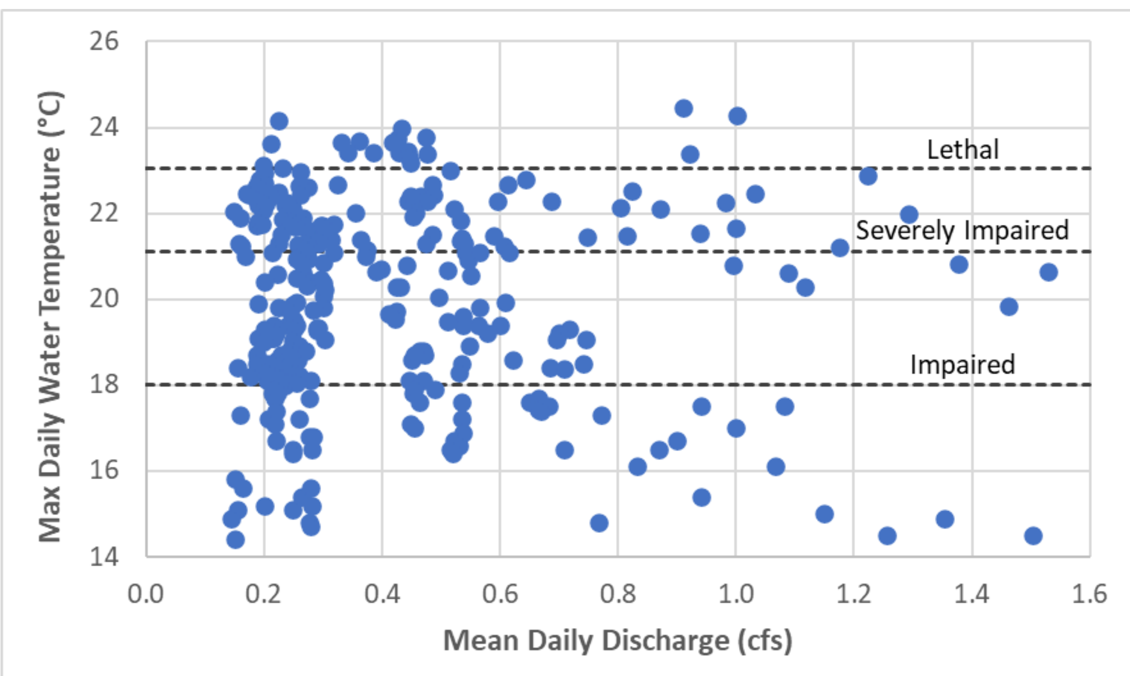


Figure 64: Comparison between Maximum Daily Water Temperature above Porter Creek during June and July of 2010-2012 & 2018-2019 and corresponding discharges as measured at the Rancho Mark West gauge.

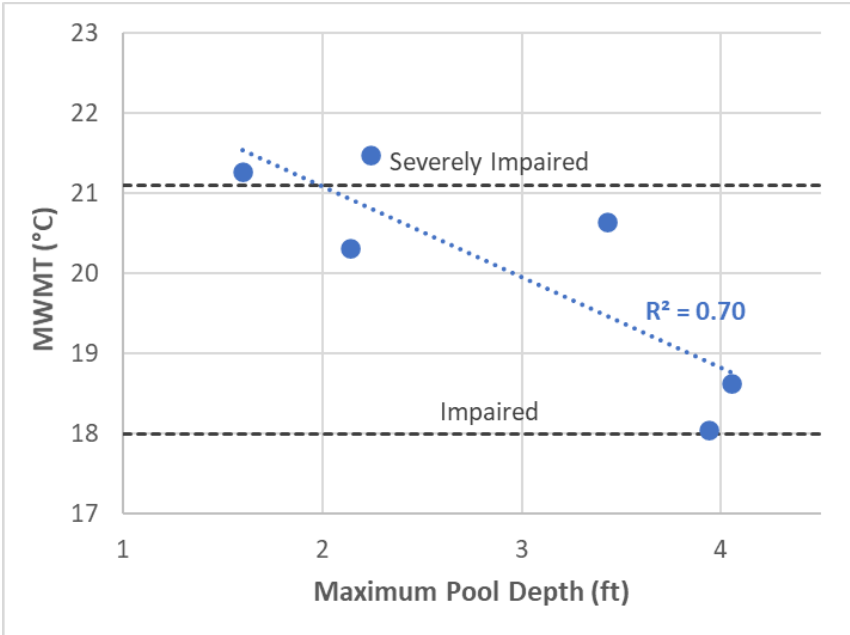


Figure 65: Relationship between maximum residual pool depth and 2017 MWMT for six pools above and below Humbug Creek, data from CDFW.

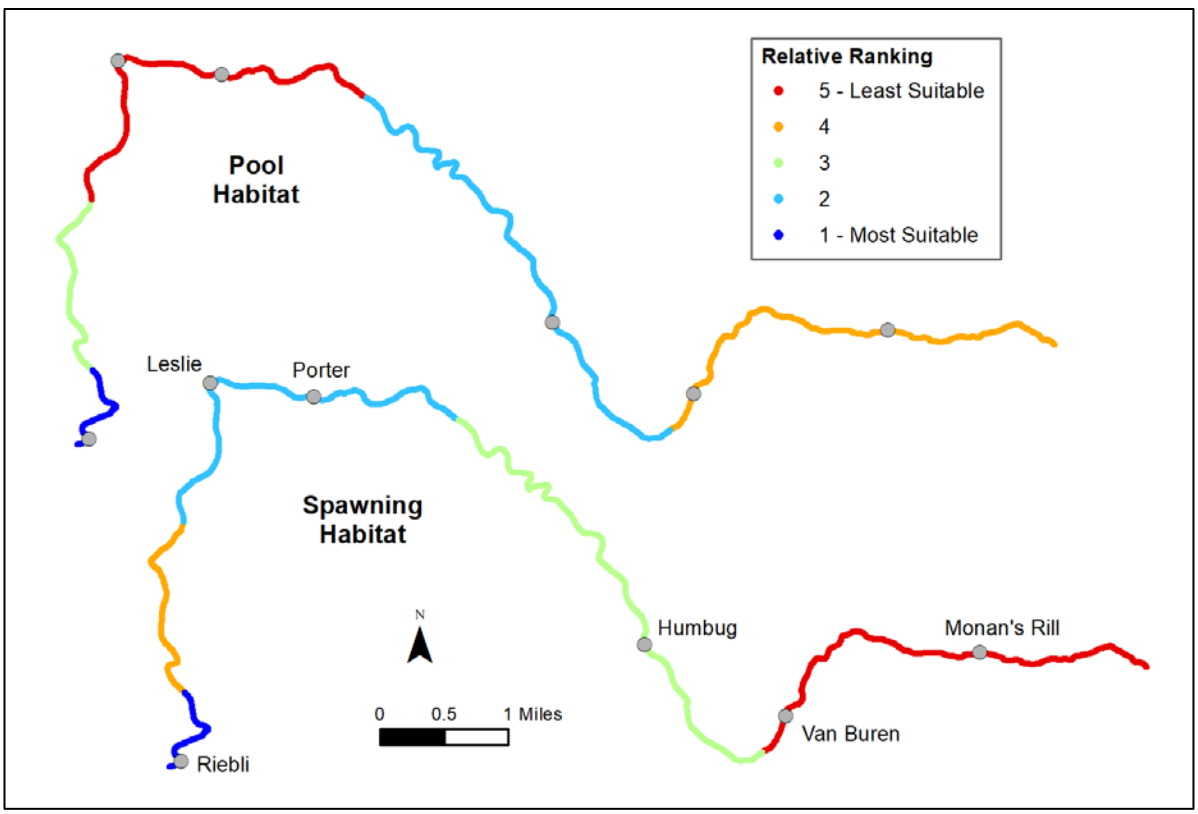


Figure 66: Pool and spawning habitat quality ranking based on the 1996 CDFW Stream Inventory Report.

Table 14: Summary of various pool and spawning habitat indicator metrics compiled from the 1996 CDFW Stream Inventory Report and used to develop the rankings presented in Figure 66.

	Pool Habitat Indicators								Spawning Suitability Indicators		
CDFW reach #	Pools as % of total length	Pools >3-ft as % of total length	Mean maximum residual depth (ft)	Residual maximum depth (ft)	Mean residual pool volume (ft^3)	Mean Shelter Rating	% occurrence of LWD	Pool Ranking	% gravel dominant	% embedded-ness 1 or 2	Spawning Ranking
6	39%	7%	2.0	5.0	379	47	3.1	**4**	14	1	**5**
5	37%	11%	2.5	8.1	751	42	1.0	**2**	12	33	**3**
4	32%	8%	2.2	3.9	784	28	2.7	**5**	32	33	**2**
3	34%	12%	2.7	5.7	1,412	33	0.2	**3**	19	19	**4**
2	49%	11%	2.6	8.9	2,562	38	1.0	**1**	33	64	**1**

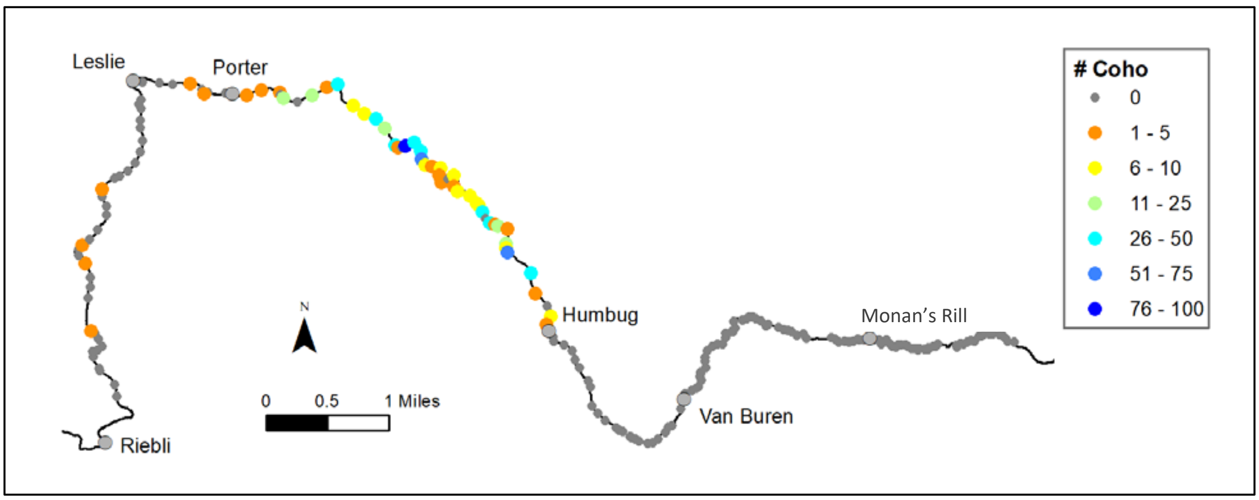


Figure 67: Snorkel survey data showing the distribution of juvenile coho observed in Mark West Creek during June/July of 2019, data from CA Sea Grant and Sonoma Water.

Restoration Prioritization & Recommendations

The overall salmonid habitat classification identifies a ~four mile reach of Mark West Creek between about 0.2 river miles upstream of Alpine Creek (~0.5 miles downstream of Van Buren Creek) and about two river miles upstream of Porter Creek as providing the best overall habitat for salmonids in the watershed (Figure 68). This reach (hereafter referred to as the high priority reach) is considered most suitable because it represents the best combination of flow and water temperature conditions and is also consistent with available data and observations about other indicators of habitat quality such as pool and spawning conditions. Upstream of this reach, no more than one of the four established flow criteria are met, spawning conditions are suboptimal, and natural bedrock controls limit deep pool development and pose migration challenges. The two-mile reach upstream of Porter Creek experiences very high temperatures (>23.1 C) which may be lethal for salmonids and portions of this reach also experience very low RCTDs and periodic pool disconnection making overall conditions problematic for juvenile salmonids. We are aware of anecdotal reports of steelhead trout using the reach upstream of Van Buren Creek, despite the evidence of poor habitat. Less is known regarding temperature conditions farther downstream below Porter Creek, however it is unlikely that conditions improve dramatically and high stream power in this reach is expected to be problematic for spawning success owing to risk of redd scour.

Although the high priority reach we identified (see Figure 68) has the highest overall habitat quality in the watershed, it is still impaired with respect to both flow and temperature, and pool habitat is also likely limited by insufficient cover and large wood. Most of the coho observed in the watershed in recent monitoring were in this reach, further supporting the importance of this reach. Although not the focus of this study, field observations suggest there are multiple opportunities for enhancing off-channel habitat (SRCD has completed a design for an off-channel habitat design project in the reach) and improving pool habitat with LWD projects within this critical reach. We recommend that restoration projects aimed at enhancing both pool and off-channel habitat be implemented in this high priority reach where they are likely to provide the greatest benefits to salmonids.

Additional data and analyses are required to better understand the controls on stream temperatures; nevertheless, our preliminary assessment of available data suggests that daily and seasonal fluctuations in temperatures are driven primarily by fluctuations in incoming solar radiation rather than by quantity of streamflow. Preliminary evidence suggests that deeper pools maintain significantly lower water temperatures than surrounding habitats. The degree of temperature-impairment in the identified high priority reach is severe enough that salmonid survival may only be possible in a relatively small number of deeper pools capable of providing cold-water refugia. Given the importance of water temperature for salmonid survival in Mark West Creek, actions to increase shading through riparian vegetation projects and actions to maintain and enhance deep pools with good cover are likely to provide the greatest benefits for salmonids in Mark West Creek. Additional water temperature investigation is also warranted to better understand the controls on water temperatures and identify the most critical pool habitats within the identified ~4-mile high priority reach.

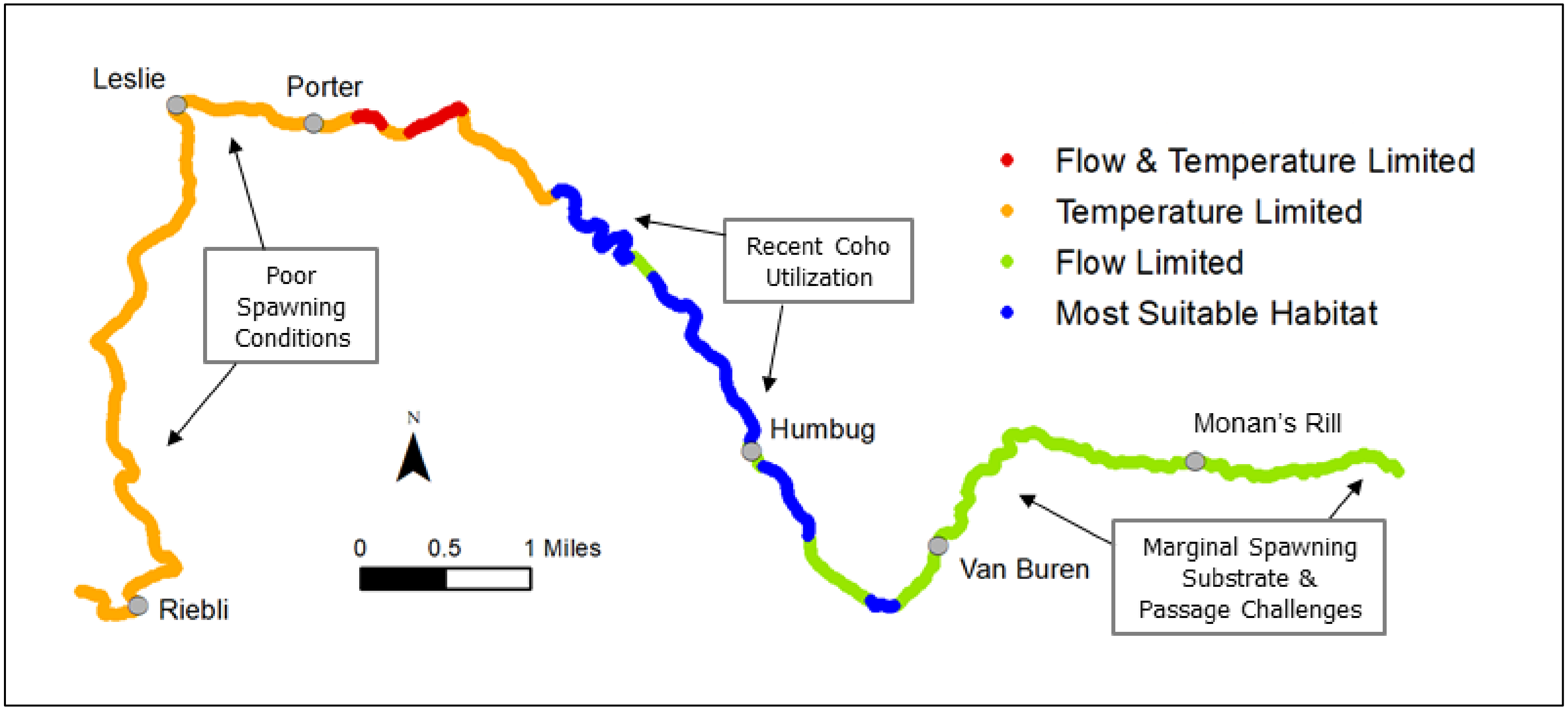


Figure 68: Final overall habitat suitability classification for Mark West Creek identifying the high priority reaches with the most suitable overall habitat conditions in blue.

Chapter 8 – Scenario Analysis

Overview

Efforts to sustain and enhance streamflow conditions have become a recent focus of restoration practitioners working in tributaries of the lower Russian River. Some actions have already been implemented such as pond and flow release projects in Green Valley, Dutch Bill, and Porter Creek (not the Porter Creek in Mark West watershed), and rainwater and diversion storage projects aimed at reducing dry season water use in Mark West Creek watershed and other tributaries. On the other hand, the watershed is subject to increasing water use pressure as new vineyard, winery, cannabis, and residential development projects are proposed, and local and state regulatory agencies are grappling with how best to regulate new groundwater use to avoid detrimental effects on streamflows and associated instream habitat. These challenges are further complicated by ongoing global climate change and the uncertainties associated with future hydrologic conditions. There is a clear need to be able to quantitatively evaluate the relative benefits of various flow enhancement strategies as well as the cumulative effects of land development and water-use on the landscape, and to do so within the context of future climate predictions so that more informed and effective management outcomes can be achieved.

To assist in meeting this need, we developed a series of model scenarios designed to provide an understanding of the hydrologic sensitivity of various hypothetical management and restoration actions as well as the effects of global climate change. There are a total of 19 scenarios grouped in four primary categories: Water Use, Land/Water Management, Climate Change, and Mitigated as described in detail below (Table 15). Each scenario was implemented by changing one or more model inputs and comparing model results to existing hydrologic conditions as simulated with the calibrated model described in previous chapters.

Approach

Water Use Scenarios

Three water use scenarios were developed to estimate the cumulative effects of diversions and groundwater pumping in the watershed: 1-No Diversions, 2-No Groundwater Pumping, and 3-No Water Use. Implementation of these scenarios was a simple matter of turning off well and diversion inputs in the model. Irrigation associated with wells and diversions was also turned off. To examine the factors that influence the degree to which a given well results in streamflow depletion, we developed four additional scenarios where we turned off between 125 and 150 wells (~17% of all wells) based on various criteria (Figure 69). These scenarios included: 2B-wells located within 500-ft of a stream and screened entirely within the upper 200-ft of aquifer material, 2C-wells located within 500-ft of a perennial spring (as simulated in the existing conditions model) regardless of screen depth, 2D-wells screened in tuffaceous materials in the upper 300-ft of aquifer material, and 2E-wells located more than 1,200-ft from a stream or spring, not completed in tuffaceous materials, and not screened in the upper 200-ft of aquifer material. Minor adjustments were made to the selected well distributions to allow for an approximately equal volume of pumping between the four scenarios (Figure 69).

Table 15: Overview of the scenarios evaluated with the MWC hydrologic model.

Scenario Category	Scenario #	Scenario Name	Brief Description
Water Use	1	No Diversions	All surface water diversions turned off
	2	No Groundwater Pumping	All groundwater pumping turned off
	2B	No Pumping Near Streams	Wells within 500-ft of streams and screened in upper 200-ft turned off
	2C	No Pumping Near Springs	Wells within 500-ft of springs turned off
	2D	No Pumping From Tuff	Wells screened in surficial tuffaceous materials turned off
	2E	No Distal Pumping	Wells distal to streams/springs/tuff and not screened in upper 200-ft turned off
	3	No Water Use	All surface diversions and groundwater pumping turned off
Land/Water Management	4	Forest Management	Forest treatment on 7,054 acres of oak and Douglas Fir forests
	5	Grassland Management	Application of organic matter on 2,874 acres of grasslands
	6	Runoff Management	Manage runoff from 310 acres of developed lands to maximize infiltration
	7	Summer Pond Releases	Release water from three ponds with a total release of 0.19 cfs from June 15th to Sept 15th
	7B	Spring Pond Releases	Release water from three ponds with a total release of 0.82 cfs from May 7th to May 28th
	8	Combined Management	Combination of Scenarios 4 through 7
Climate Change	9	CNRM Climate Change	2070-2099 timeframe future climate as predicted by the CNRM model under the rcp8.5 emmisions pathway
	10	CCSM4 Climate Change	2070-2099 timeframe future climate as predicted by the CCSM4 model under the rcp8.5 emmisions pathway
	11	GFDL Climate Change	2070-2099 timeframe future climate as predicted by the GFDL model under the SRES B1 emmisions pathway
	12	MIROC esm Climate Change	2070-2099 timeframe future climate as predicted by the MIROC esm model under the rcp8.5 emmisions pathway
Mitigated	13	GFDL & Pond Releases	Combination of Scenarios 11 & 7 or 7B
	14	GFDL & Combined Management	Combination of Scenarios 11 & 7 or 7B

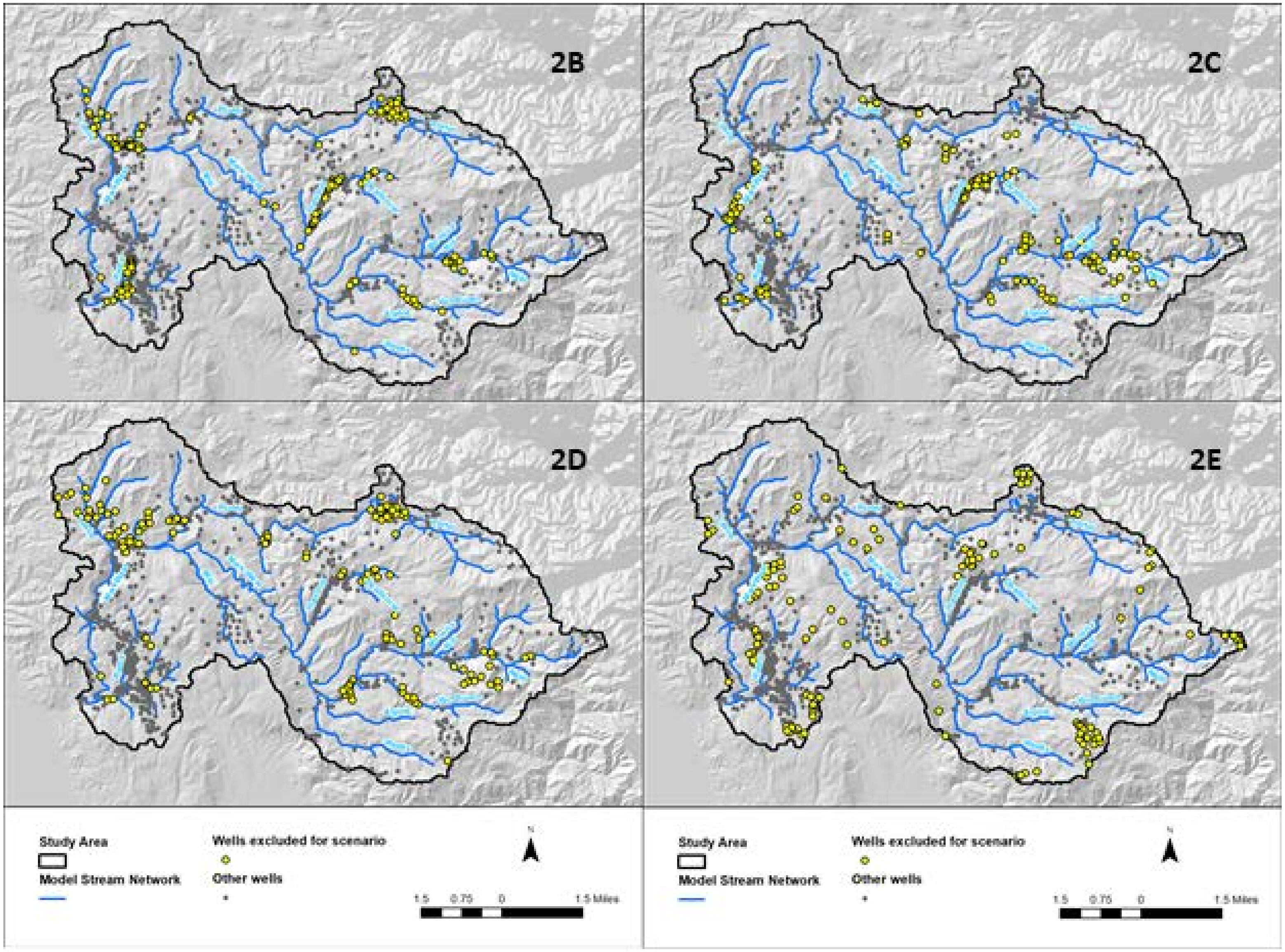


Figure 69: Distributions of wells excluded in Scenarios 2B-2E.

Land/Water Management Scenarios

Six scenarios were developed to evaluate the potential streamflow enhancement resulting from large-scale application of landscape management actions including: 4-Forest Management, 5-Grassland Management, 6-Runoff Management, 7-Summer Pond Releases, 7B-Spring Pond Releases, and 8-Combined Management (Table 15).

Forest Management

In the aftermath of the 2017 Tubbs Fire which burned through a large swath of the watershed and the 2019 Kincade Fire which burned along the north edges of the watershed, there is a very high level of awareness and interest in managing forests for reduced fuel loads. Many of the oak woodlands in the watershed are experiencing encroachment by Douglas Fir, and many Douglas Fir forests are characterized by high tree densities and abundant ladder fuels. This scenario is designed to represent wide-scale application of forest treatment strategies such as thinning and controlled burning (both of which are already occurring in portions of the watershed) and the effects of forest treatment on hydrologic conditions and streamflows.

In consultation with long-time watershed resident and forest manager Rick Kavinoky, we performed a forest condition mapping exercise on the Monan's Rill community property in the upper watershed. We mapped boundaries for nine 0.3-0.7 acre forest stands selected to represent a range of species compositions and treatment needs (determined based on qualitative assessment of tree densities and health, ladder fuel conditions, and presence of encroaching species). We sampled the Leaf Area Index data discussed in Chapter 4 to determine the mean LAI for each of the nine plots. There was a clear relationship between the stand type/treatment need categories and the mean LAI (Table 16). We used these differences to identify forested areas needing treatment throughout the watershed and to adjust the LAI values in the model to reflect implementation of treatment work.

The forest mapping indicated that stands of Black Oak and Oregon Oak not requiring treatment had a mean scaled LAI value of 3.1 and that those stands requiring minor or major treatments had mean values of 4.8 and 9.2 respectively. Douglas Fir stands not requiring treatment had a mean scaled LAI value of 7.3 and those requiring minor or major treatment had mean values of 9.5 and 14.8 respectively. The existing conditions model uses these three forest condition categories for oaks and Douglas fir forests along with these threshold LAI values (see Chapter 4), and the scenario was implemented by simply changing all minor and major treatment areas to no treatment values. Current forest conditions in areas burned by the Tubbs Fire are not captured in the LiDAR-derived LAI data and treatment needs within the burn area are unknown but may be expected to be reduced. We excluded the area of higher severity burn used to represent the Tubbs Fire in the calibration model (see Figure 12) from the identified areas needing treatment.

We used the proportional changes in LAI determined for Black/Oregon Oak and Douglas Fir to delineate treatment categories and estimate LAI for other species of oaks and for mixed Douglas Fir/Tanoak forest which were not included in the mapping at Monan's Rill. We also reduced rooting depths by 10% in the treated areas to better represent changes in transpiration not

Table 16: Forest plots mapped at Monan's Rill and associated treatment needs and Leaf Area Index (LAI) values.

Plot #	Stand Type	Treatment Needed?	Scaled LAI
1	Douglas Fir	No	7.3
7	Douglas Fir	Minor	9.5
3	Douglas Fir	Major	12.9
6	Douglas Fir w/ Tanoak	Major	16.5
5	Black Oak	No	3.0
8	Oregon Oak	No	3.2
4	Black Oak w/ Encroaching Douglas Fir	Minor	4.6
9	Oregon Oak w/ Encroaching Douglas Fir	Minor	4.9
2	Oregon Oak w/ Encroaching Douglas Fir	Major	9.2

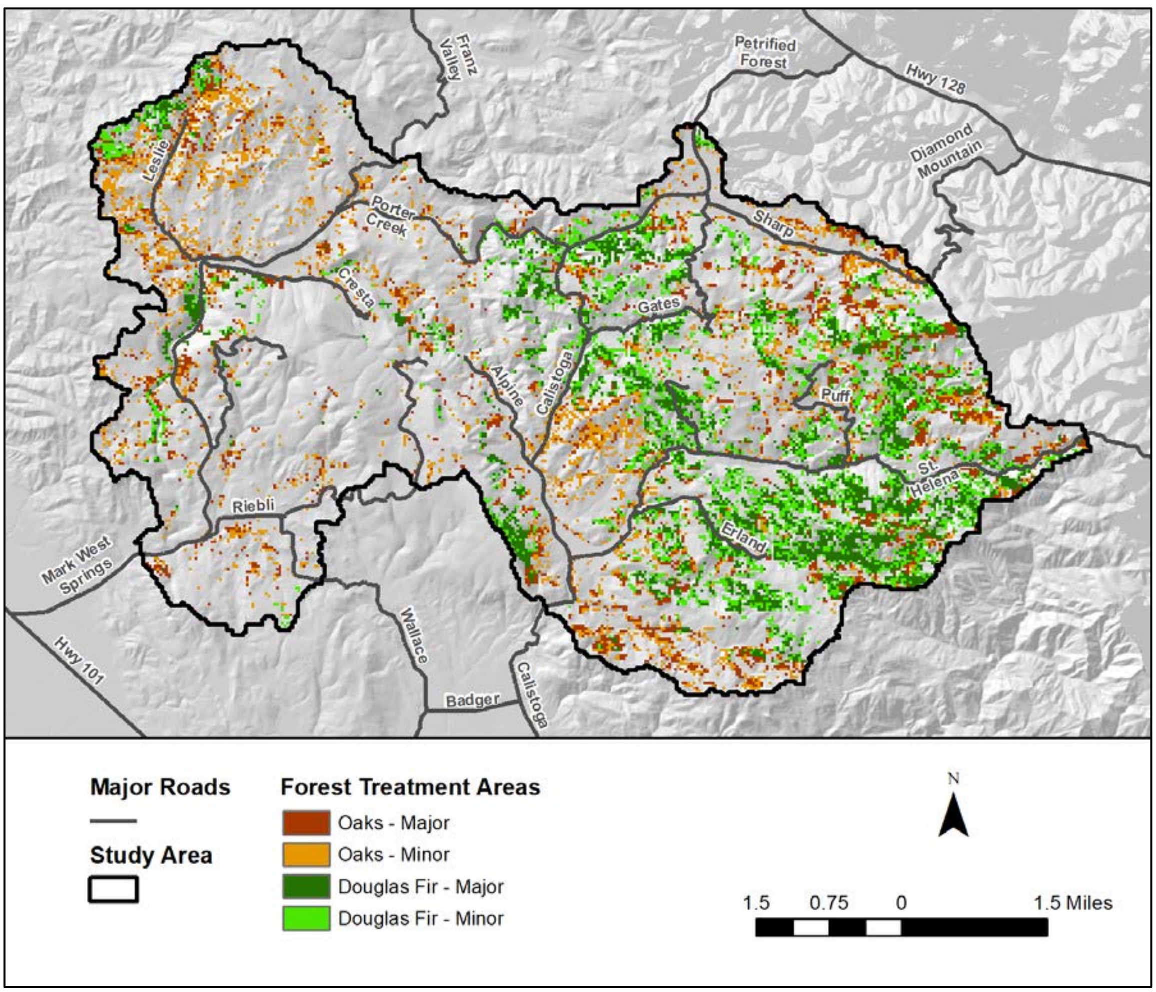


Figure 70: Areas of oak and Douglas Fir forest included as treated in the forest management scenario (Scenario 4).

captured by the LAI changes. The effects of forest treatment on other parameters such as overland roughness coefficients and detention storage are more uncertain and were assumed not to be affected by treatment for the purposes of this analysis. There are a total of 7,054 acres of treated forest represented in the model scenario which was divided approximately equally between various species of oaks (3,428 acres) and Douglas Fir (3,626 acres) (Figure 70).

Grassland Treatment

Increasing Soil Organic Carbon (SOC) on grasslands through compost application or strategic grazing practices has been identified as an important strategy for sequestering carbon (e.g. Ryals & Silver, 2013; Zomer et al., 2017). In addition to carbon sequestration benefits, increasing SOC may result in hydrologic benefits through increases in soil water availability and associated effects on seasonal soil water deficits and groundwater recharge. This scenario is designed to examine the potential hydrologic effects of large-scale adoption of grassland management practices designed to increase SOC. We assumed a 3% increase in SOC would be achievable (Flint et al., 2018) and related that change in SOC to a change in soil moisture contents at saturation, field capacity, and the wilting point based on data from 12 studies compiled by Minasny & McBratney (2018).

We implemented the grassland treatments in all grasslands in the model with more than a 2-acre contiguous area as identified in the fine-scale vegetation mapping (SCVMLP, 2017) covering a total of 2,874 acres (Figure 71). These grasslands were located in 14 different soil types as represented in the model (see Figure 15), and we classified each as fine, medium, or coarse and applied the associated mean estimates of the change in moisture contents from a 1% increase in SOC from Minasny & McBratney (2018). We scaled the estimates up to reflect a 3% increase in SOC which resulted in increases in soil moisture content at saturation, field capacity, and the wilting point of 0.10-0.14, 0.04-0.07, and 0.02-0.03 respectively, and increases in available water capacity (AWC) of 0.044-0.068. These estimates are generally consistent with the changes in AWC estimated for a 3% increase in SOC for soils of similar textures by Flint et al., (2018) which were based on the work of Saxton & Rawls (2006).

Runoff Management

Managing runoff from rooftops and impervious areas around residential and other developed areas to encourage infiltration has been recognized as an important best management practice for new development and is commonly referred to as Low Impact Development (LID). Most developed areas in Mark West Creek watershed were constructed prior to adoption of LID techniques. Traditional runoff management, on the other hand, is more likely to encourage runoff to flow quickly away from infrastructure and towards receiving water bodies via downspouts, drains, and ditches. This scenario is designed to examine the potential hydrologic benefits of large-scale adoption of LID practices on existing developed lands in the watershed.

We identified areas of contiguous impervious surface in the watershed from the developed category in our model land cover data. This spatial data is based on non-roadway impervious areas identified in the fine-scale vegetation map and resampled onto the 0.5-acre model grid.

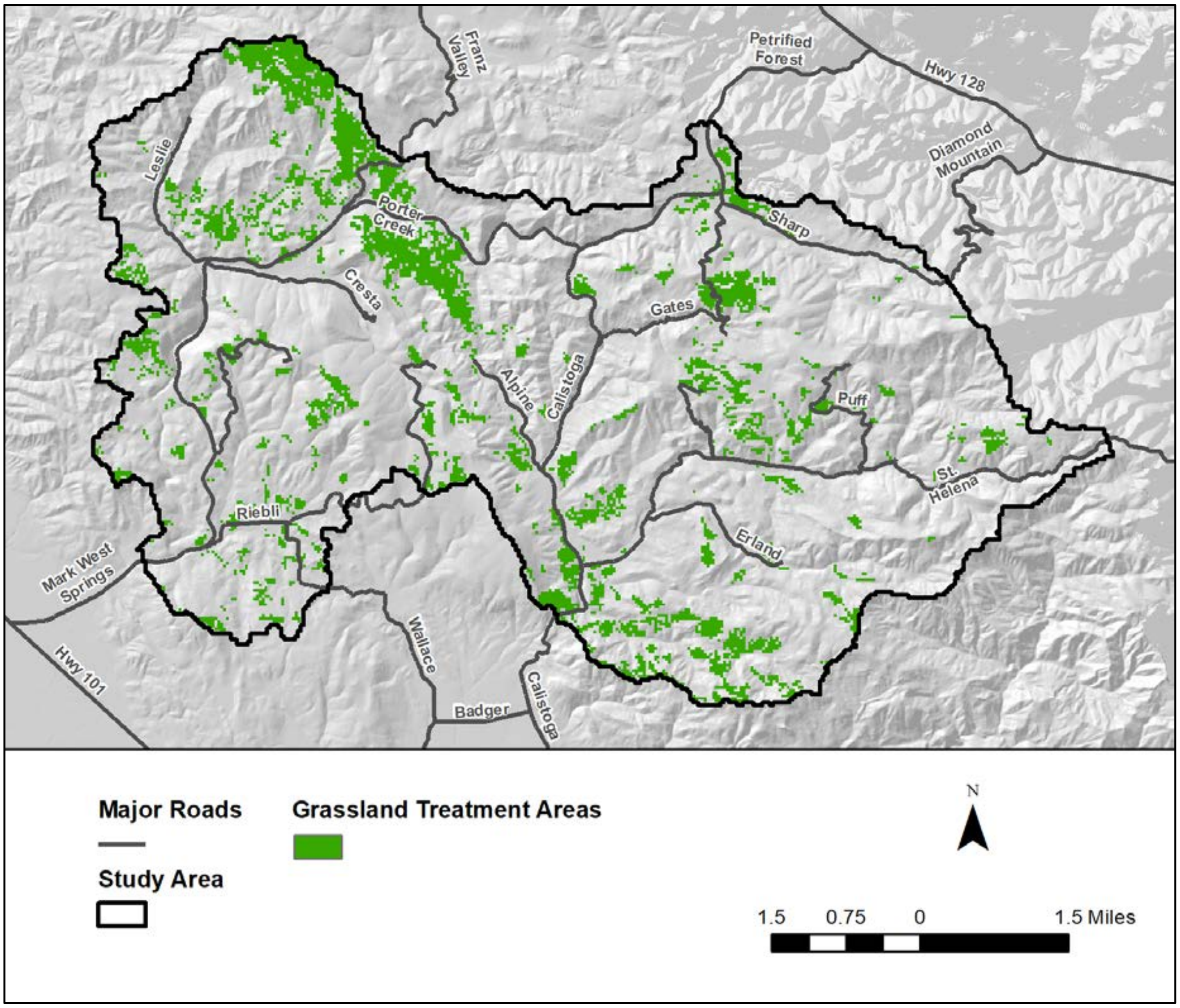


Figure 71: Treated grasslands included in the grassland management scenario (Scenario 5).

The resampling results in the exclusion of smaller impervious areas and the identification of the larger contiguous impervious areas most suitable for runoff management projects with potentially significant benefits. Roads are not represented in the scenario, although large-scale management of road runoff could have significant additional hydrologic benefits beyond what was simulated here. Development is most highly concentrated within the Riebli Creek watershed which is not considered to have high habitat value and contributes flow to Mark West Creek well downstream of the high priority reach. For these reasons, and to avoid dramatically increasing the scale of the scenario for potentially minimal benefit, we excluded Riebli Creek watershed from the analysis.

The developed areas represented in the scenario total 310 acres (Figure 72) which is about 76% of the total non-roadway impervious area in the watershed outside of the Riebli Creek drainage. There are multiple strategies possible for encouraging infiltration of runoff from these lands including use of level spreaders, bioswales, or infiltration basins. The most appropriate strategy

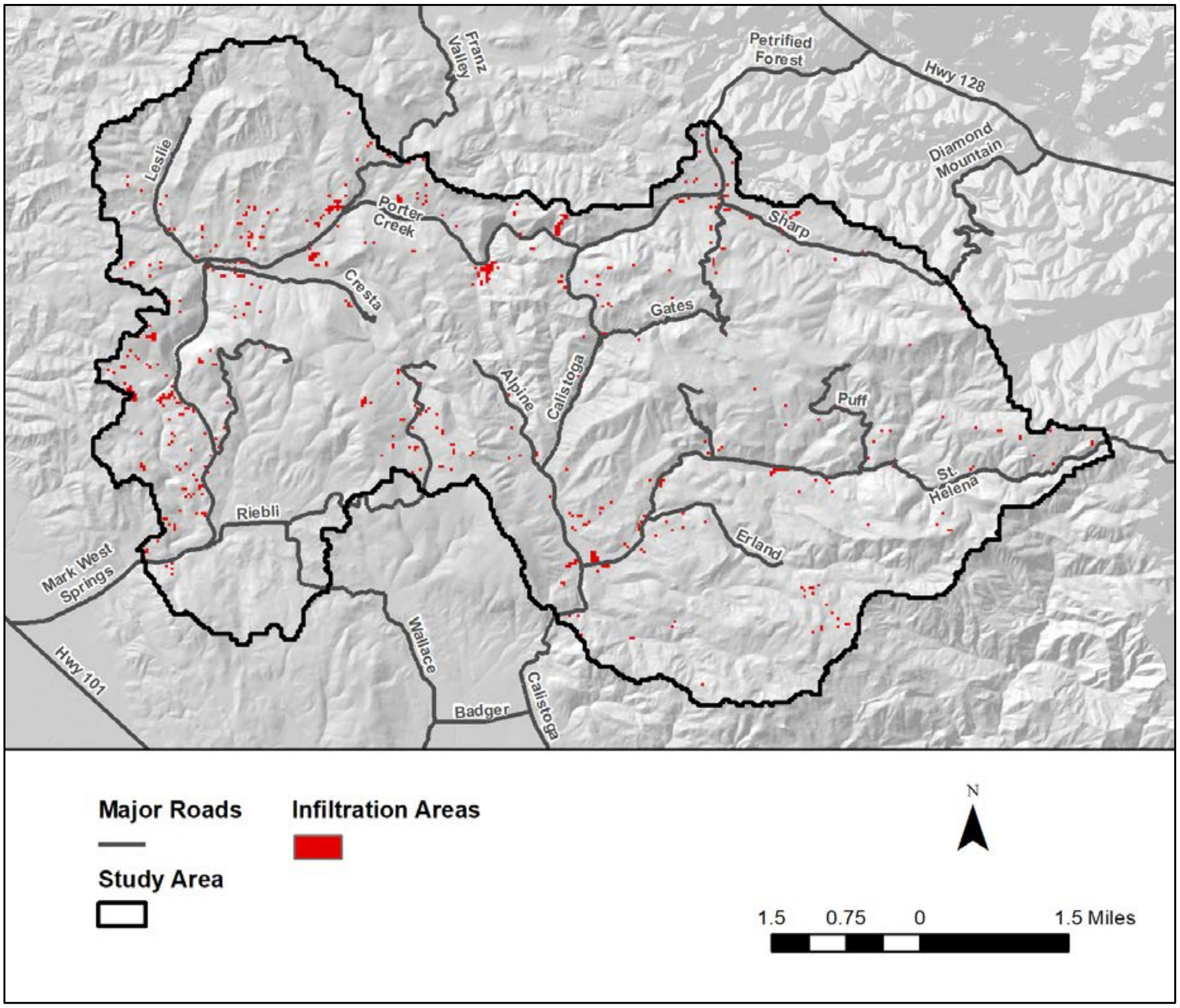


Figure 72: Developed areas included in the runoff management scenario (Scenario 6).

and design for a given location is highly site-specific and implementing the details of these stormwater management features is not practical at the 0.5-acre grid scale used in the model. Thus, for the purposes of this regional planning-level study we simply assumed that practices could be implemented to prevent all runoff generated directly from the identified developed lands from leaving the site. The scenario was implemented in the model by preventing runoff from entering or leaving each area through the use of the separated overland flow area option, and allowing water to pond, infiltrate, and evapotranspire according to the precipitation patterns and soil and evapotranspiration properties present at a given site.

The largest storm event in the 10-yr simulation was approximately a 10-yr event based on comparison to NOAA Atlas 14 precipitation frequency estimates. Thus, for projects to be equivalent to the model scenario they would need to be able to handle the peak flows and runoff volumes from a 10-yr storm. The model results indicate that in the upper watershed the 48-hr volume from this event over a 0.38 acre average per parcel developed area would be about 0.19

to 0.24 ac-ft. This would require a native soil basin on the order of 2,300 ft^2 or a gravel-filled basin of about 6,700 ft^2. These basins are large but likely feasible in many cases given the five acre average parcel size. Runoff management projects of a smaller scale are also possible; however, the goal of this scenario is consistent with the other scenarios in its focus on estimating the maximum potential benefits of runoff management projects.

Pond Releases

Releasing water from existing ponds has been recognized as a potentially important strategy for enhancing streamflows in the lower Russian River and several flow release projects have been implemented in recent years in Green Valley and Dutch Bill creeks among other locations. Most of the ponds in the MWC watershed are too small to allow for a viable release project, but we identified at least four ponds that appear large enough for such projects, and simulated releases for three of them. Out of respect for the privacy of landowners we are identifying these ponds only by their approximate locations. Available storage volumes for releases are approximate and were estimated using the LiDAR-captured water surface elevations as the late-summer residual (after water use and infiltration/evaporation losses) storage levels and a simple relationship between dam height approximated from the LiDAR and pond storage (USACE, 2018).

The three ponds include one in upper Mark West Creek with approximately 31.9 ac-ft of residual storage, one in upper Humbug Creek with approximately 5.2 ac-ft of residual storage, and one in upper Mill Creek with approximately 30.9 ac-ft of residual storage (Table 17). None of these ponds have significant consumptive water uses associated with them, therefore releasing water to augment streamflow is not expected to require new replacement water sources. Landowners we spoke with expressed concerns about fully depleting ponds because of the desire to maintain recreational and aesthetic value and maintain an emergency water source in the event of wildfire. To address these concerns, we have assumed that only half of the available residual storage could be released and the other half would be retained in storage for other uses. We also examined the simulated runoff volumes contributing to each pond and found that there is ample winter runoff to replenish the relatively small released volumes even during drought conditions and under future climate change scenarios.

We developed two flow release scenarios, one focused on enhancing summer juvenile rearing habitat (Scenario 7) and one focused on enhancing spring smolt outmigration (Scenario 7b). The summer release covers a 92-day period each year between June 15th and September 15th and release rates ranged from 0.014 – 0.088 cfs for a total release rate of ~0.19 cfs. The spring release covers a 21-day period each year between May 7th and May 28th and release rates ranged from 0.063 to 0.383 cfs for a total release rate of ~0.82 cfs (Table 17). These periods were selected based on review of historical conditions and targeted to increase minimum flow conditions during summer and the later portion of the primary outmigration period. We did not attempt to optimize the timing and release rates for this regional planning-level study, however it is likely that benefits greater than those simulated in this study could be achieved through adaptively managing releases in conjunction with real-time streamflow data which is available at several locations from Sonoma Water.

Table 17: Overview of the pond release volumes and rates included in Scenarios 7 and 7b.

Location	50% of Residual Storage (ac-ft)	Sceanrio 7 Summer Release Rate (cfs)	Scenario 7b Spring Release Rate (cfs)
Upper Mark West Creek	16.0	0.087	0.383
Upper Humbug Creek	2.6	0.014	0.063
Upper Mill Creek	15.5	0.085	0.371
Total	**34.0**	**0.187**	**0.817**

Climate Change Scenarios

Four model scenarios were developed to evaluate the effects of future climate changes on hydrologic and aquatic habitat conditions in the upper Mark West Creek Watershed. Each of these scenarios was based on projections of future climate for the 2070-2099 timeframe derived from a Global Circulation Model (GCM) scenario. The scenarios reflect changes in precipitation and temperature as predicted by each GCM, but do not address other aspects of climate change that may affect hydrologic and habitat conditions such as long-term changes in vegetation or irrigation demands that may occur in response to a modified future climate regime.

Global Circulation Model Selection

The selection of the four GCM scenarios (‘futures’) was based largely on the recommendations from the Climate Ready North Bay Vulnerability Assessment and the North Coast Resource Partnership’s climate planning efforts (Micheli et al., 2016 & 2018). The vulnerability assessment selected a subset of six GCM futures from an ensemble of 18 futures analyzed by the USGS using the Basin Characterization Model (BCM) (Flint et al., 2013; Flint & Flint, 2014). These 18 futures were selected from the approximately 100 GCM futures included in the Intergovernmental Panel on Climate Change’s (IPCC) Fourth and Fifth Assessment Reports (IPCC 2007; 2014) using statistical cluster analysis. The North Coast Resource Partnership study selected six of the eighteen futures included in the BCM, and our analysis focuses on four of these six (Figure 73 & Table 18).

The selection of these futures was designed to represent the full range of plausible changes to precipitation and temperatures, and to include a scenario representative of the mean projections (Micheli et al., 2016 & 2018). Three of the futures represent the “business as usual” emissions scenario (rcp 8.5) adopted by the IPCC’s Fifth Assessment Report (IPPC, 2014). This pathway assumes high population growth and a slow adoption of clean and resource efficient technologies with atmospheric carbon dioxide concentrations rising to 936 ppm by 2100 (Hayhoe et al., 2017). One of the futures represents the “highly mitigated” emissions scenario (sres B1) reflecting a future with low population growth and the introduction of clean and resource efficient technologies; this pathway is comparable to rcp 4.5 with atmospheric carbon dioxide concentrations rising to 650 ppm by 2100 (Hayhoe et al., 2017).

Table 18: Overview of the four climate change scenarios evaluated with the MWC hydrologic model.

	GCM	Emissions Scenario	Change in Annual Precipitation (%)	Change in Maximum Temperature (°F)
Scenario 9	CNRM	rcp 8.5 (business as ususal)	37%	6.3
Scenario 10	CCSM 4	rcp 8.5 (business as ususal)	8%	5.4
Scenario 11	GFDL	sres B1 (highly mitigated)	-14%	3.7
Scenario 12	MIROC esm	rcp 8.5 (business as ususal)	-21%	11.0

Scenario 9 is a "Warm & High Rainfall" scenario based on the CNRM rcp 8.5 future, which projects a 37% increase in average annual precipitation and a 6.3°F increase in average maximum temperatures by the 2070 - 2099 timeframe relative to 1981 – 2010 (Table 18). Scenario 10 is a "Warm & Moderate Rainfall" scenario based on the CCSM4 rcp 8.5 future, which is close to the ensemble mean of the 18 futures selected for use in the BCM model and projects an 8% decrease in average annual precipitation and a 5.4°F increase in average maximum temperatures. Scenario 11 is a "Warm & Low Rainfall" scenario based on the GFDL sres B1 future which projects a 14% decrease in average annual precipitation and a 3.7°F increase in average maximum temperatures (Table 18; Figure 73). Lastly, Scenario 12 is a "Hot & Low Rainfall" scenario based on the MIROC esm rcp 8.5 future, which projects a 21% decrease in precipitation and an 11.0°F increase in temperature (Table 18).

Methodology

For all scenarios, precipitation and minimum and maximum temperature timeseries were derived from daily data from the World Climate Research Program's Coupled Model Intercomparison Project Phases 3 & 5 (CMIP3 & CMIP5) (USBR et al., 2013). The CMIP provides monthly and daily outputs from the GCMs included in the IPCC's Fourth and Fifth Risk Assessments statistically downscaled to a uniform 1/8th degree grid using a revised version of the bias corrected constructed analog method (BCCA v2).

Several studies have reported that GCMs are biased towards creating "drizzle" days with trace amounts of precipitation (Maurer et al., 2010). Mauer et al. (2010) claims that the BCCA method corrects this issue. However, when compared to observed precipitation records, downscaled precipitation timeseries still contained an un-representatively high number of days with trace precipitation. To address this documented issue, precipitation events with less than 0.02 in/day were removed from the precipitation timeseries. This removed between 50 and 105 trace events per year but changed average annual precipitation totals by only 0.6 – 1.2% over the 2070 - 2099 period. While this approach may not fully resolve the issue, it removes a

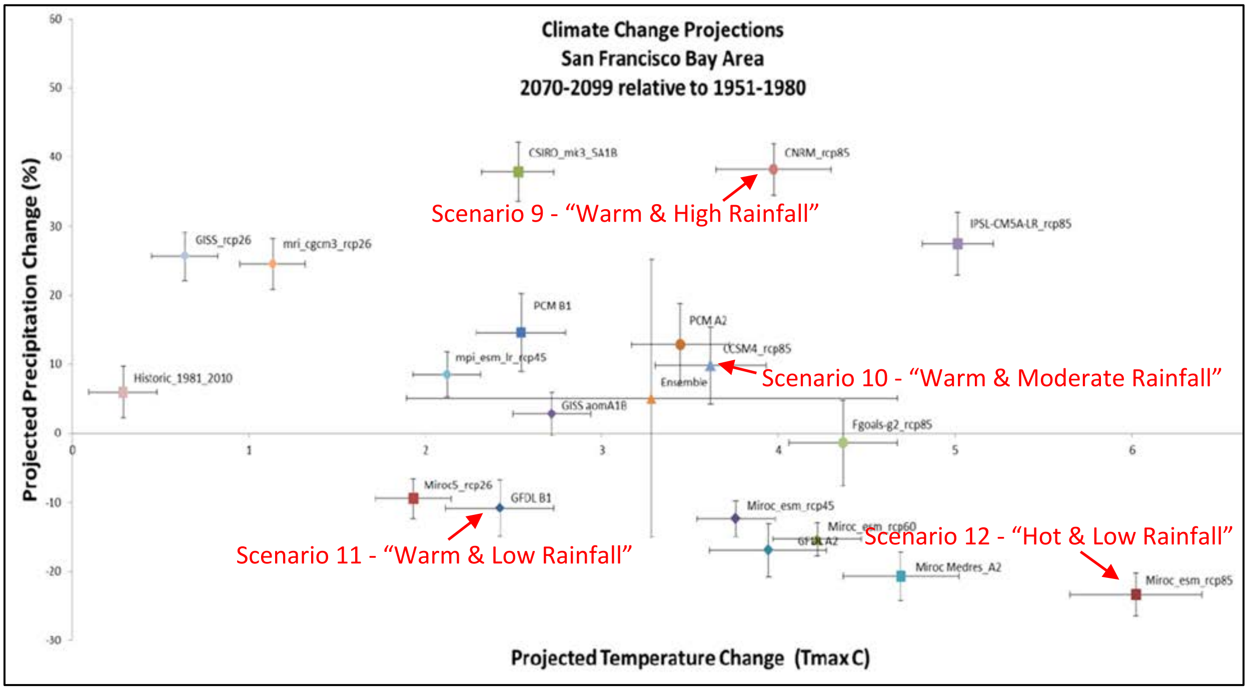


Figure 73: Projected regional changes in average annual precipitation and average maximum summer temperatures for the 18 GCMs analyzed using the Basin Characterization Model (BCM), modified from Micheli et al., 2016 to show the four scenarios included in this study.

significant number of trace precipitation events which if not filtered out could artificially increase simulated canopy interception and evapotranspiration.

Daily Potential Evapotranspiration (PET) timeseries were calculated from the CMIP minimum and maximum daily temperature timeseries using the Hargreaves-Samani Method (Hargreaves & Samani, 1982). These calculations used extraterrestrial solar radiation rates for a flat plane located at the model centroid and a KT value of 0.162 calibrated using reported temperature and evapotranspiration data from the Windsor CIMIS station. More details about the PET calculations can be found in Chapter 4.

As in the existing conditions model, precipitation and PET zone-based distributions were developed to account for the spatial variations in these parameters across the model domain. Precipitation zones are based on 1-inch average annual isohyets derived from the BCM 2070 - 2099 average annual precipitation dataset for each selected GCM future. Future PET distributions were created using the same methodology as the historic distribution discussed in the Chapter 4, in this case using average 2070 - 2099 monthly minimum and maximum temperature distributions from the BCM model. These distributions show similar spatial patterns to the historic distribution, although the range of values across each distribution varies significantly. Precipitation and PET timeseries were applied to these distributions using the same scaling factor approach as for historic conditions.

Scaling factors were calculated as the ratio of the value for each zone and the 2070 - 2099 means for the timeseries. Adjustments were made to the scaling factors applied for precipitation to correct for a high precipitation bias in the BCM dataset relative to historical conditions as observed at local climate stations (see Chapter 4 for further discussion). These adjustments were calculated such that simulated precipitation means preserve the percentage increases in mean annual precipitation between the 1981 – 2010 and 2070 – 2099 normals as estimated by the BCM.

To reduce computational requirements, each climate scenario uses timeseries from a continuous representative 10-year subset of the processed CMIP timeseries from the 2070 - 2099 period. These subsets were selected such that average annual precipitation was within 2% of the average annual precipitation estimated for the 2070 - 2099 normal for each future and such that each subset contained at least one extremely dry and one extremely wet year, as well as a multi-year drought (if present in the original 30-yr period). A summary of the annual and daily precipitation and PET inputs for the selected periods is shown in Figure 74-Figure 77. While the results of these scenarios will be compared against one another, it is not necessary for these time periods to match. GCMs simulate general climatic conditions, not specific weather events, and one would not expect conditions modeled for a given year to be comparable to conditions modeled for the same year using a different GCM.

Inputs Summary

Besides the changes in average annual precipitation and average maximum temperatures shown above in Table 18, the GCMs used as the basis for these scenarios predict several important inter- and intra-annual changes in precipitation and PET. Previous studies of large GCM ensembles have indicated that precipitation will become more volatile, that large precipitation events will become more frequent, and that the seasonal distribution of precipitation will concentrate in the core winter months (e.g. Swain et al., 2018). To assess the degree to which each of the selected GCM futures reflect these projected trends, several statistics were calculated. These include the frequency of historically wet and dry years (defined by the 80th and 20th percentile annual precipitation totals), the magnitude of large precipitation events (maximum 24-hr precipitation), and the seasonal distribution of precipitation (defined by the ratio of precipitation occurring during the core winter months of November - February and the peripheral months of October, March, and April). The baseline for these comparisons is the 2009-2019 simulation period, however as discussed in Chapter 4, conditions during this period are broadly representative of 1981-2010 conditions which is widely used as the baseline period for interpreting future climate changes.

The Scenario 9 (CNRM rcp8.5) future projects a general shift towards wetter conditions. Both the frequency and magnitude of wet years increases, as well as the frequency of higher intensity precipitation events (Table 19 & Figures 74-77). Much of this additional precipitation is projected during the core winter months, leading to a marked shift in the seasonal precipitation distribution. However, despite the large increase in average precipitation, the frequency and magnitude of dry years is projected to remain similar to historic conditions. Despite the low increase in average annual precipitation, the Scenario 10 (CCSM4 rcp8.5) future projects a large increase in annual and seasonal variability (Table 19 & Figures 74-77). It projects the single highest annual precipitation total (80.2 in), the greatest inter-annual variability, and the strongest seasonal shift in precipitation towards the winter months. It also predicts individual dry years of similar frequency and magnitude to historical conditions, but more frequent multi-year droughts.

The Scenario 11 (GFDL sresB1) future projects a general shift towards drier conditions, with increases in both the frequency and intensity of droughts (Table 19 & Figures 74-77). Although the MIROC esm rcp8.5 future projects slightly drier average conditions, the GFDL sres B1 future projects the single driest year, with an average of 11.8 inches of precipitation. This future also projects the lowest precipitation intensities, with maximum daily rainfall totals of less than 2.0 in for most years. The Scenario 12 (MIROC esm rcp8.5) future also projects a general shift towards drier conditions with both the frequency and intensity of droughts increasing (Table 19 & Figures 74-77). Historically dry years are projected to become roughly twice as common and precipitation decreases by up to 30% during the driest years. Although no years with annual totals exceeding the historic 80^{th} percentile are projected, moderately wet years with up to 47 inches of precipitation are still present. During these wetter years, maximum daily precipitation totals are projected to be similar to historic conditions, but much lower during normal and drier years.

Despite the large differences in future projections between the scenarios, all four scenarios share some commonalities. Regardless of the scenario, droughts are predicted to become more extreme and precipitation is predicted to have increased seasonality with more precipitation focused in the core winter months. Additionally, all four scenarios predict increases in PET which vary between scenarios based on the magnitude of the predicted increases in temperatures and represent increases of about 6-14% relative to historic conditions (Table 19 & Figures 74-77).

<u>Mitigated Scenarios</u>

To evaluate the scale of the predicted changes in hydrologic conditions under future climate relative to potential streamflow enhancement actions, we developed two mitigated scenarios. Scenario 13 combines the GFDL future climate simulation (Scenario 11) with the pond release scenarios (Scenarios 7 and 7B), and Scenario 14 combines the GFDL future climate with the combined management scenario (Scenario 8) (Table 15). To keep the number of scenarios to a reasonable level, we only ran the mitigation scenarios using future climate as predicted by the GFDL model. We selected this model because our results showed that it represented the second most extreme predictions of future changes in streamflows which we felt would provide the best overall picture of the degree of climate change induced impacts to streamflows that could be mitigated with the investigated management actions. A higher degree of mitigation would likely be possible if future climate more closely resembles the CNRM or CCSM4 model predictions and less mitigation would be possible if future climate more closely resembles the MIROC esm model predictions.

Table 19: Summary of key climate statistics for each climate scenario evaluated with the MWC hydrologic model.

	Historic	Scenario 9 CNRM	Scenario 10 CCSM4	Scenario 11 GFDL	Scenario 12 MIROC esm
Average Annual Precipitation (in)	36.0	49.3	38.9	30.9	28.6
Maximum Annual Precipitation (in)	61.2	75.2	80.2	46.9	47.3
Minimum Annual Precipitation (in)	19.5	18.6	17.6	11.8	13.3
Interannual Variability (in)	12.9	16.5	20.2	10.6	9.4
Frequency of 80^{th} Percentile Historic Annual Precipitation	-	5	2	0	0
Frequency of 20^{th} Percentile Historic Annual Precipitation	-	2	3	5	4
Seasonal Precipitation Distribution (Core:Periphery)	2.0	4.6	5.3	3.4	3.9
Maximum 24-hr Precipitation (in)	4.7	7.3	5.0	4.5	4.8
Average Annual PET (in)	45.4	50.1	49.5	48.0	51.7

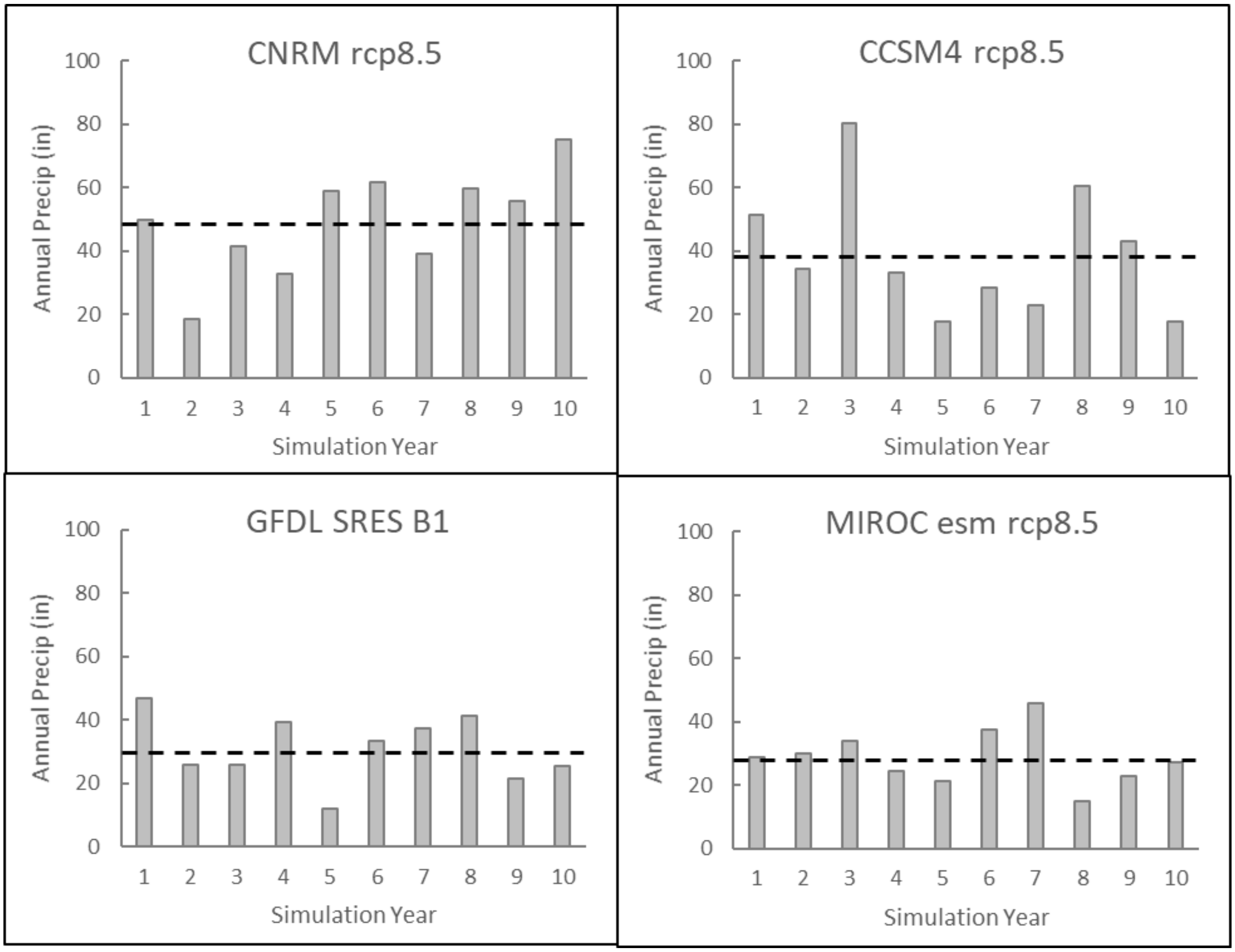


Figure 74: Spatially averaged annual precipitation within the model domain for each of the four selected climate scenarios (dashed black lines indicate the 2070-2099 mean).

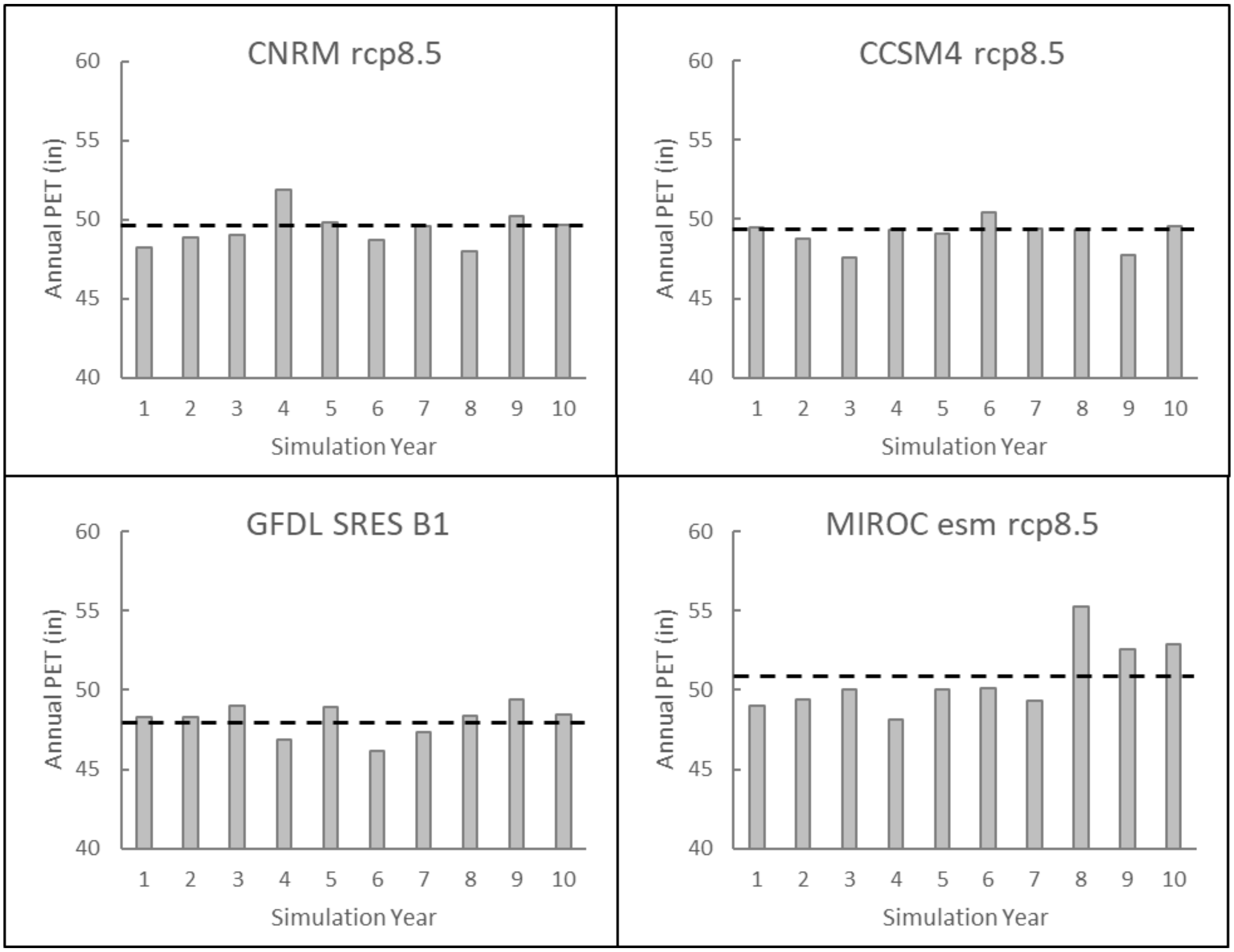


Figure 75: Spatially averaged annual Potential Evapotranspiration (PET) within the model domain for each of the four selected climate scenarios (dashed black lines indicate the 2070-2099 mean).

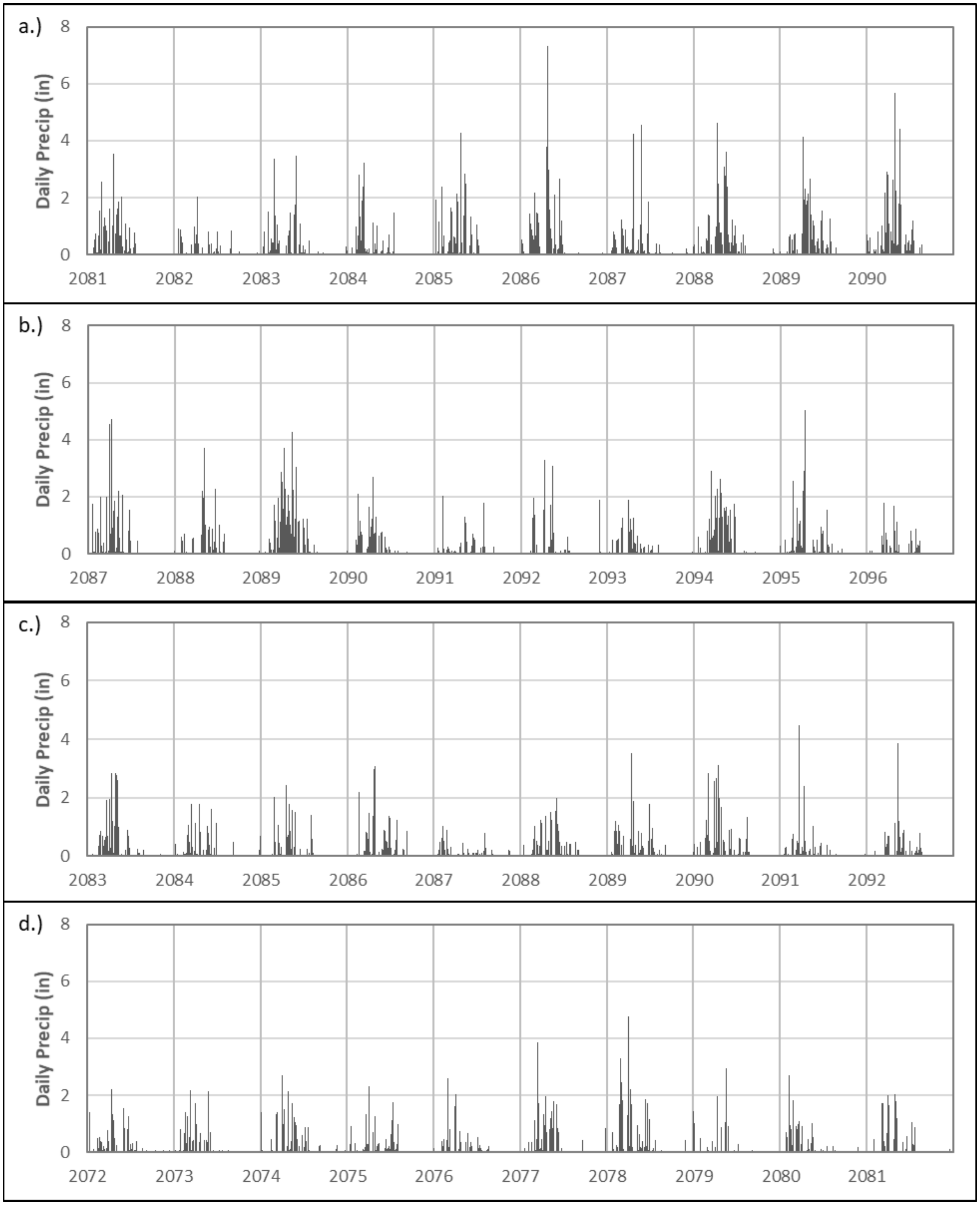


Figure 76: Spatially averaged daily precipitation used in scenarios (a) CNRM rcp8.5, (b) CCSM4 rcp8.5, (c) GFDL SRES B1, and (d) MIROC esm rcp8.5.

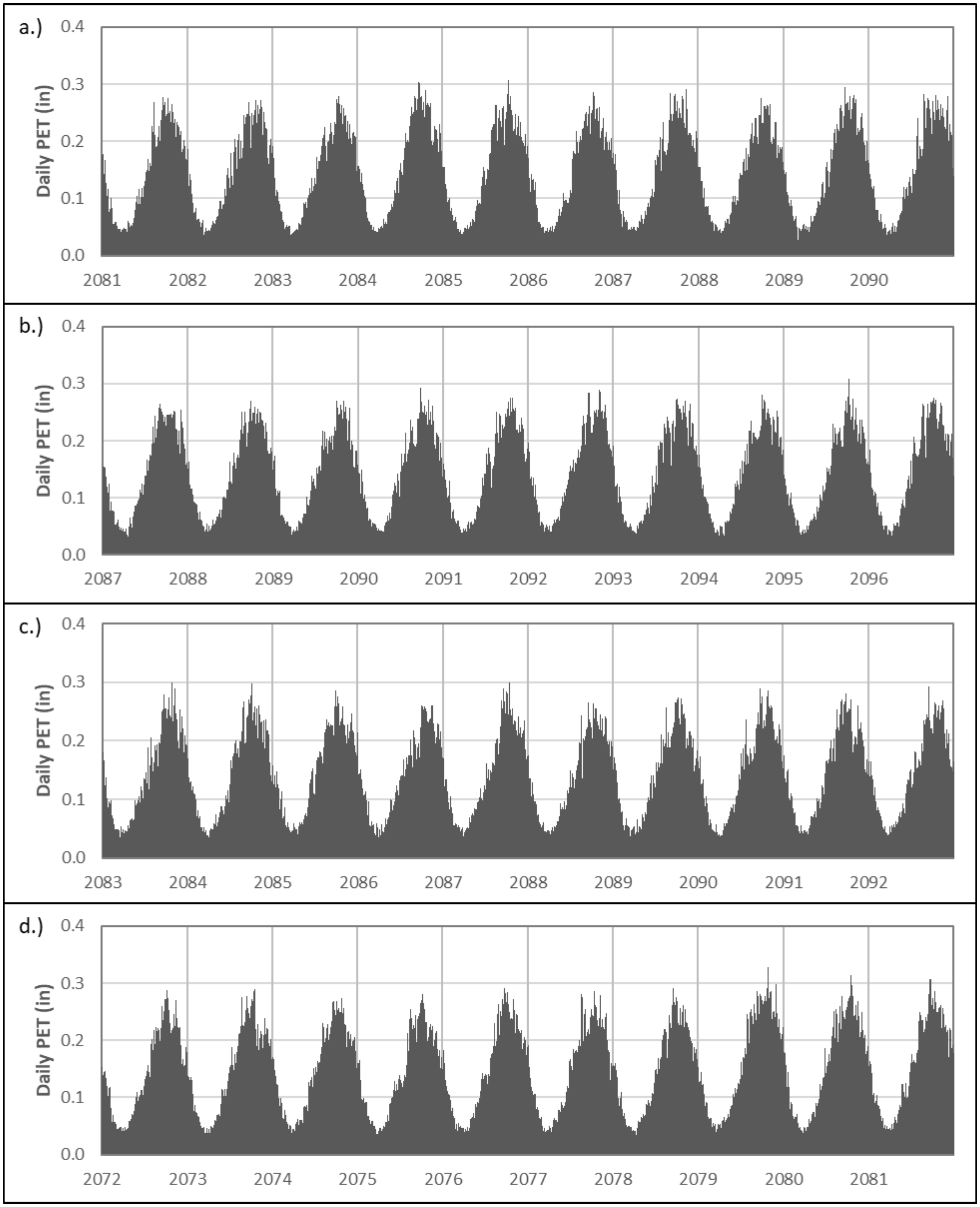


Figure 77: Spatially averaged daily Potential Evapotranspiration (PET) used in scenarios (a) CNRM rcp8.5, (b) CCSM4 rcp8.5, (c) GFDL SRES B1, and (d) MIROC esm rcp8.5.

Results

Water Use Scenarios

The no surface water diversion scenario (Scenario 1) revealed that the sustained cumulative effect of diversions in the watershed is relatively small. With diversions turned off, the average summer discharges increased by less than 0.01 cfs in most of the upper and middle reaches of Mark West Creek and by up to 0.03 cfs in the lowest reaches (Figure 78). The effects of diversions on mean springtime streamflow was similar but slightly greater than the summertime effects, with stream discharge increasing by 0.02-0.04 cfs at most locations downstream of Humbug Creek (Figure 81) with all diversions turned off. We compiled hourly discharge results to evaluate potential short-term diversion effects not captured with the mean summer discharge comparison. This revealed that diversions do have more significant short-term impacts on streamflow, with short-term increases in discharge under Scenario 1 of about 0.05 cfs upstream of Humbug Creek, 0.09 cfs downstream of Humbug Creek, and 0.07 cfs below Porter Creek (Figure 78).

The diversion impacts are discernable but minimal downstream of Monan's Rill and reach a maximum just downstream of Humbug Creek which has a high concentration of diversions (Figure 79). The timing of the simulated streamflow reductions is closely related to the model input assumptions regarding diversion timing and therefore the greatest changes occur on the first of each month when all diversions are active and are near zero during times when few diversions are active. Hence, it is likely that the short-term impacts are exaggerated given that the assumptions of coincident timing create a worst-case scenario. It is interesting to note that the fluctuations in flow throughout the summer due to other factors are generally larger than the fluctuations caused by diversions, therefore it would be very difficult or impossible to discern diversion impacts from examination of streamflow records alone (Figure 79).

The no groundwater pumping scenario (Scenario 2) revealed that the cumulative effect of groundwater pumping in the watershed is larger than that of surface water diversion but of modest magnitude. With groundwater pumping turned off, the average summer discharge increased by less than 0.01 cfs in the upper reaches of Mark West Creek and by up to about 0.06 cfs in the lowest reaches (Figure 80). Mean springtime discharge increases show a similar pattern to the summer increases with slightly larger changes (Figure 81). Examination of the water balance revealed that the aquifer system takes at least several decades to fully adjust to the change in pumping regime, and the reported flow increases represent the 10-yr period following 40-yrs of no pumping. Over the first 10-yr simulation cycle with no pumping, most of the volume that would have been pumped could be accounted for by increased groundwater storage, with only about 18% of the volume manifesting as increased groundwater discharge. During the fifth 10-yr cycle, the changes in storage were minimal and increased groundwater discharge accounted for about 76% of the pumped volume (Figure 82). Most of the remaining volume can be accounted for by increases in AET from the saturated zone and small decreases in recharge which serve to partially buffer the effects of pumping on streamflow (Figure 82).

We also examined the monthly changes in streamflow and other water balance components and found that volumetrically, the largest streamflow depletions occurred during December through April (~0.50 cfs at the watershed outlet) and the lowest rates occurred during July through September (0.06 cfs). This may seem counter-intuitive given that pumping rates peak in June and are at a minimum in January, however it is necessary to consider all of the effects of pumping on the water balance together to gain an understanding of the mechanisms behind the depletion seasonality. The largest month-to-month changes in the water balance occur as changes in storage. With pumping turned off and associated seasonal pumping drawdowns eliminated, not as much water enters storage during the recharge season resulting in more water available to contribute to groundwater discharge (Figure 83). Another significant but lesser effect is that higher groundwater elevations during the dry season result in more water available to riparian vegetation which serves to partially offset summer streamflow depletion through increases in AET from the saturated zone (Figure 83). This analysis suggests that strategies focused on deferring dry season pumping in favor of wet season pumping and storage (which may be effective in alluvial aquifers with short response time-scales) may not be very effective in bedrock aquifer settings like Mark West Creek. It is also important to note that the seasonal storage and AET effects from increasing levels of pumping may be expected to be asymptotic, and that since the total pumping volumes in the watershed are relatively low (~3% of annual infiltration recharge), the seasonality of streamflow depletion may be expected to become less pronounced under higher pumping stresses.

Results of the selective no pumping scenarios (Scenarios 2B-2E) indicate that the magnitude of summer streamflow depletion after 40-50 years of pumping does vary depending on distance from streams and springs, and likely also depending on well screen (perforated well casing) depth and hydrogeologic properties. To account for small differences in pumping volume reductions between the scenarios, we normalized the streamflow results by the change in pumping volume. Mean summer streamflow at the outlet of the watershed increased by 0.026 cfs per 100 ac-ft of pumping decrease for wells located within 500-ft of streams and screened within the upper 200-ft of aquifer material (Scenario 2B) (Table 20). This rate is approximately 137% of the rate determined for all wells from Scenario 2 (0.019 cfs/100 ac-ft of pumping decrease). The highest rate (0.029 cfs per 100 ac-ft of pumping decrease) was for wells located within 500-ft of springs (Scenario 2C). Wells screened within tuffaceous materials (Scenario 2D) showed streamflow effects similar to the average for all wells, and wells located more than 1,200-ft from streams and springs and not screened in the upper 200-ft of aquifer material (Scenario 2E) showed the smallest effects, with a rate of streamflow increase of 0.017 cfs per 100-ac-ft of pumping decrease which represents about 89% of the rate determined for all wells (Table 20).

This analysis suggests that proximity to springs and streams can be useful in determining the relative magnitudes of summer streamflow depletion within the 50-yr timeframe. However, it is important to note that all wells (including those distant from streams and screened at depth) may still be expected to result in streamflow depletion and the rate of depletion from near stream wells screened in the upper 200-ft was only about 1.7 times the rate for distant wells screened at depths greater than 200-ft (Table 20). It is also apparent that the 50-yr simulation timeframe is not long enough for the system to fully adjust to a change in pumping regime, and over longer timeframes it may be expected that the differences between proximal and distal well impacts would decline.

Simulation results from the no water use scenario (Scenario 3) which represents conditions in the 10-yr period following 40-yrs without water use indicate that the cumulative effect of all surface and groundwater uses in the watershed is equivalent to approximately 8% of summer streamflow. With all water uses turned off, mean summer streamflow increased by 0.01 to 0.02 cfs upstream of Van Buren Creek, by 0.02 to 0.04 cfs between Van Buren and Porter Creeks, and by 0.04 to 0.09 cfs in the reaches downstream of Porter Creek (Figure 80).

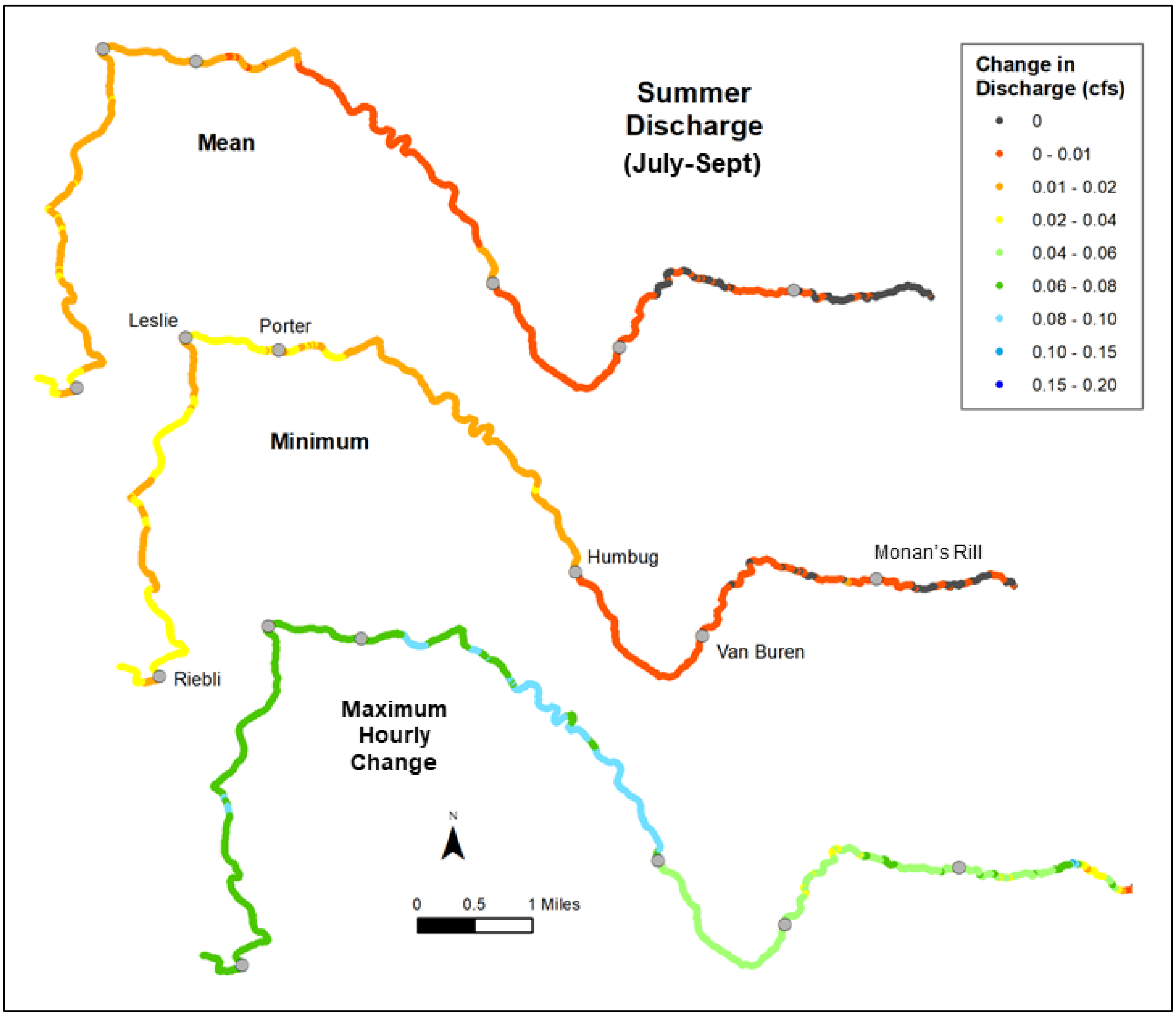


Figure 78: Changes to mean and minimum summer streamflow, and maximum hourly changes from cessation of all surface water diversions (Scenario 1).

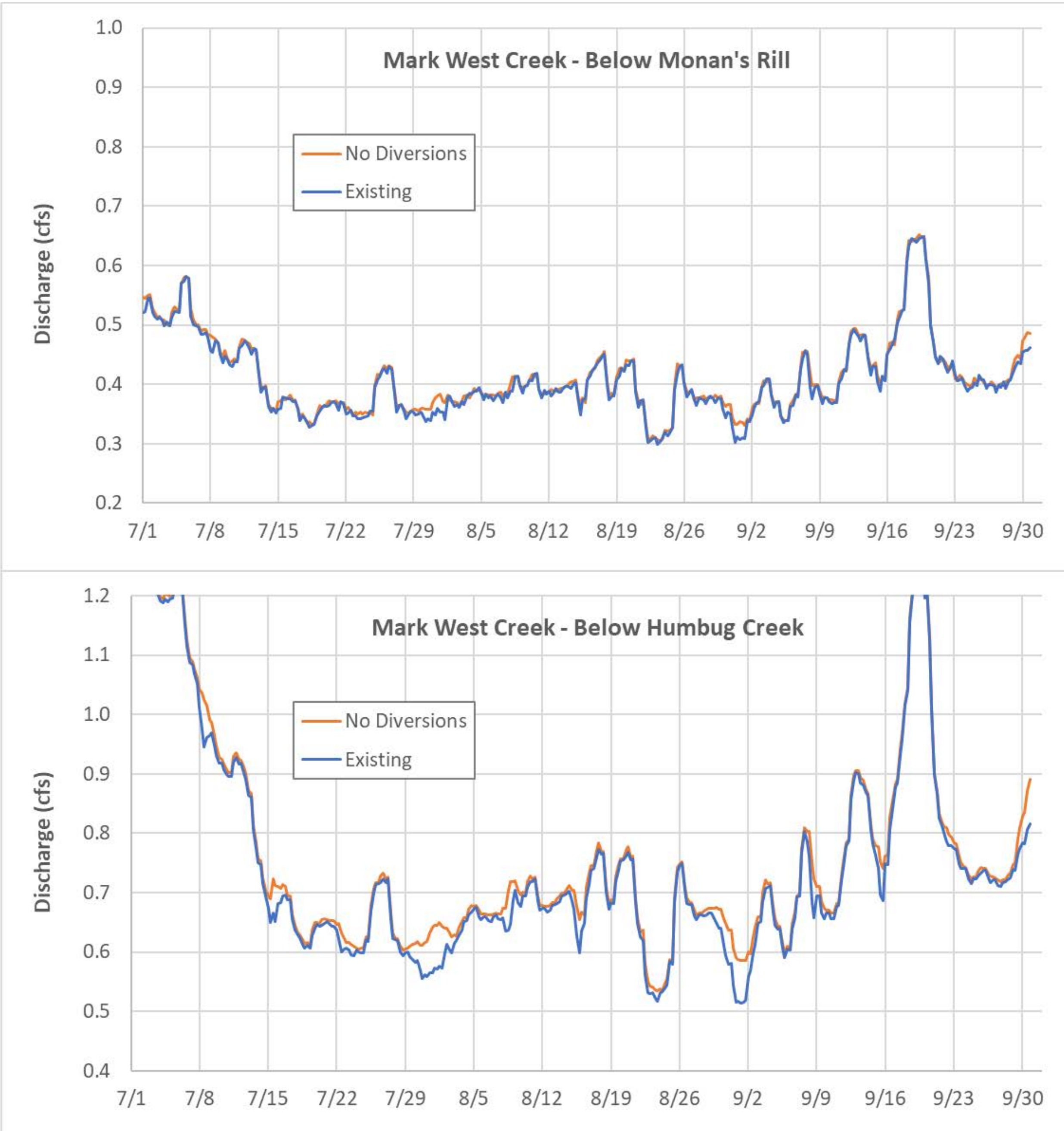


Figure 79: Simulated changes to hourly streamflow in Mark West Creek below Monan's Rill and below Humbug Creek resulting from cessation of all surface water diversions (Scenario 1).

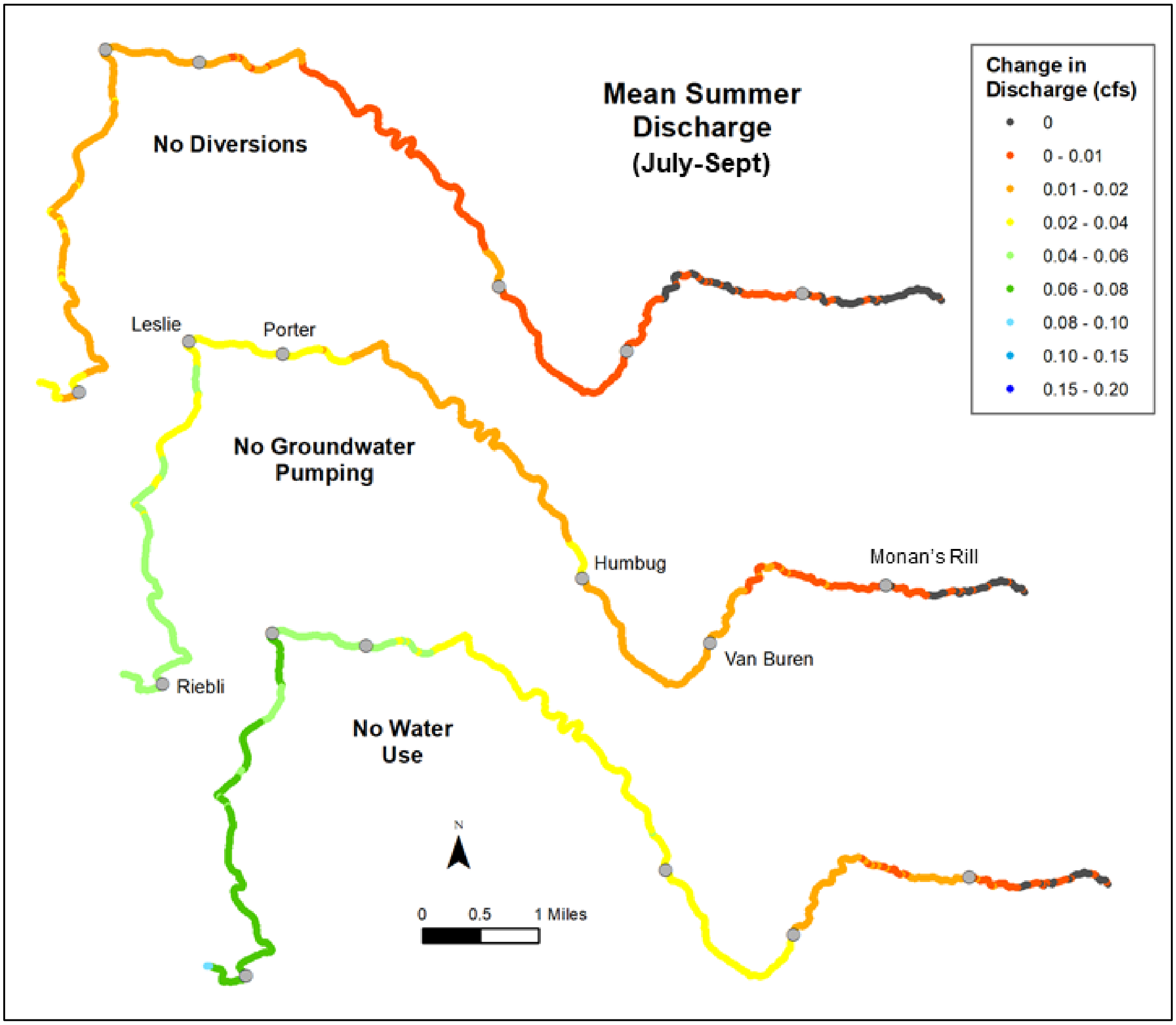


Figure 80: Simulated changes to mean summer streamflow for the three water use scenarios (Scenarios 1-3).

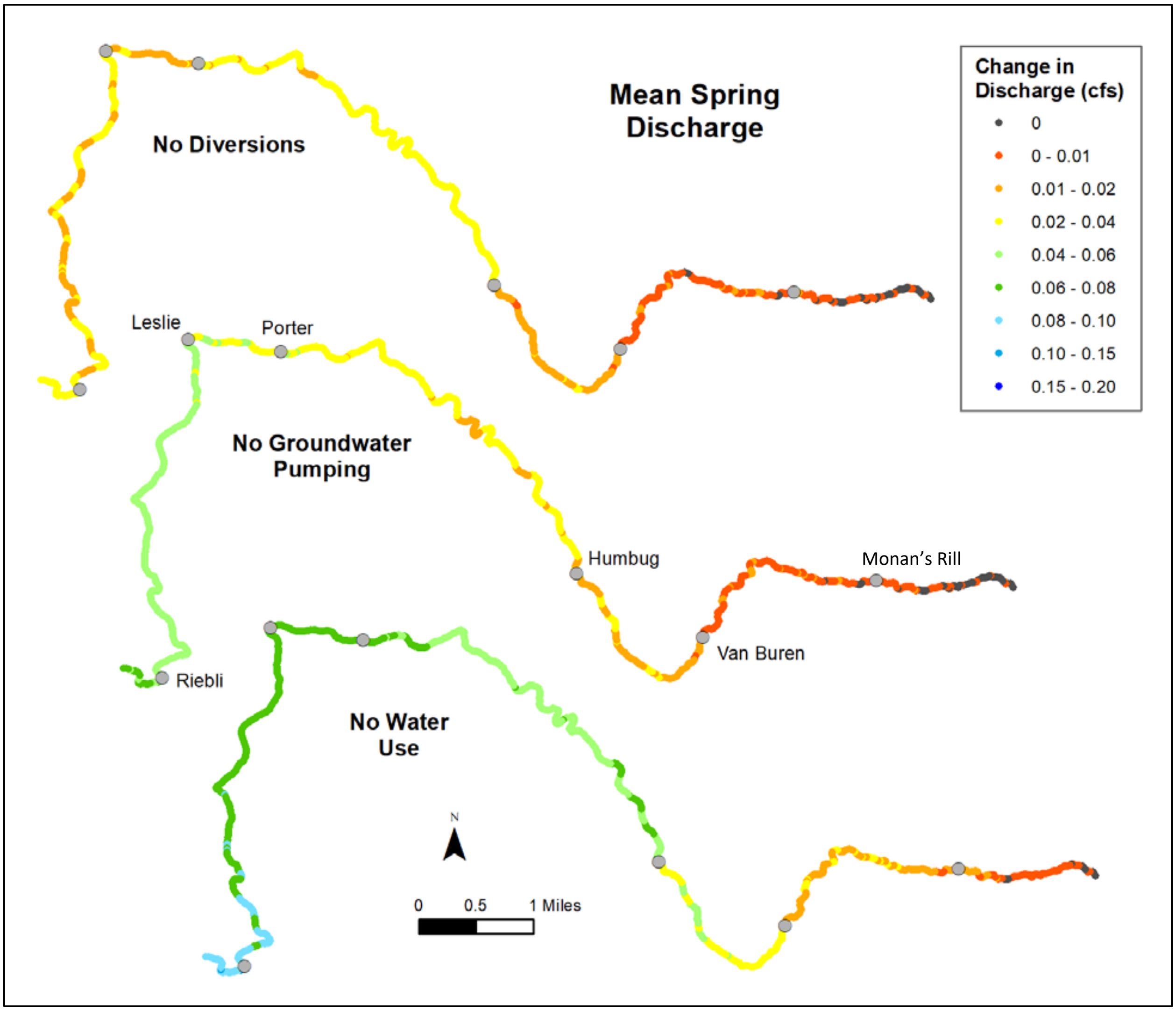


Figure 81: Simulated changes to mean spring streamflow for the three water use scenarios (Scenarios 1-3).

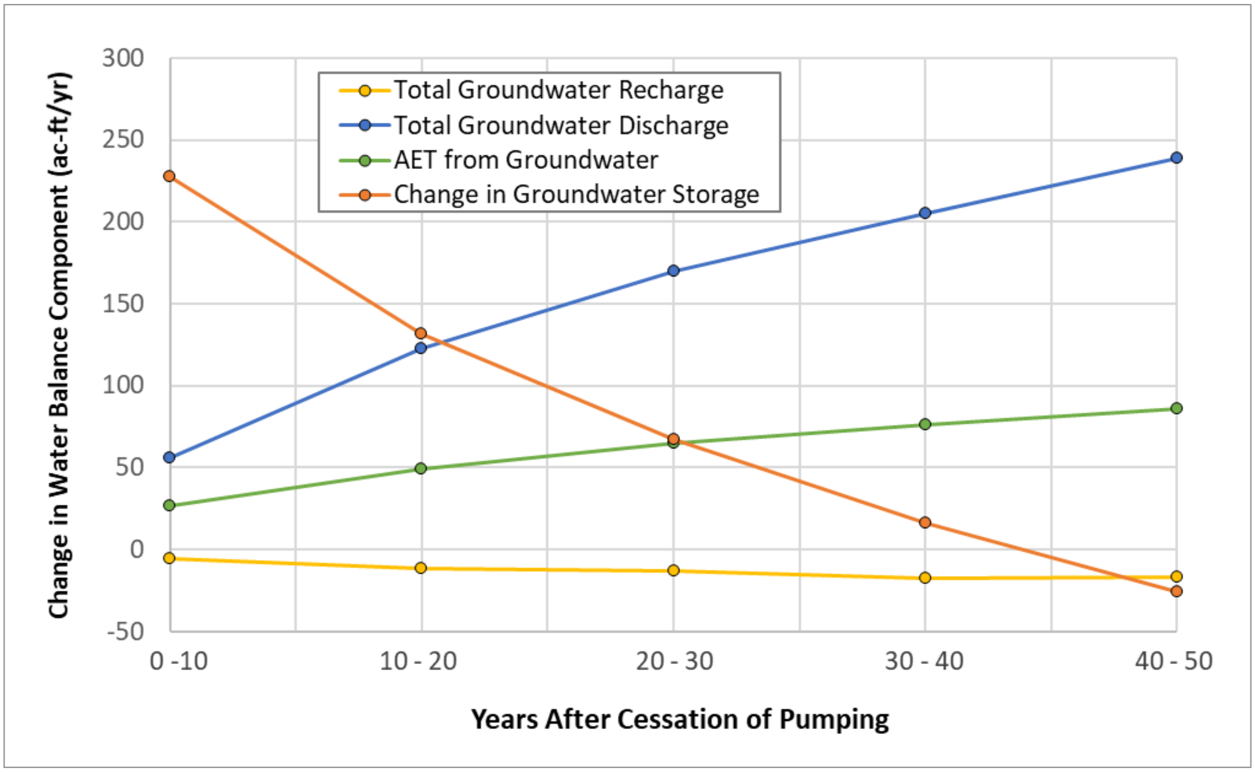


Figure 82: Changes to annual groundwater water balance components resulting from cessation of all groundwater pumping (Scenario 2) for each of the five 10-yr simulation cycles.

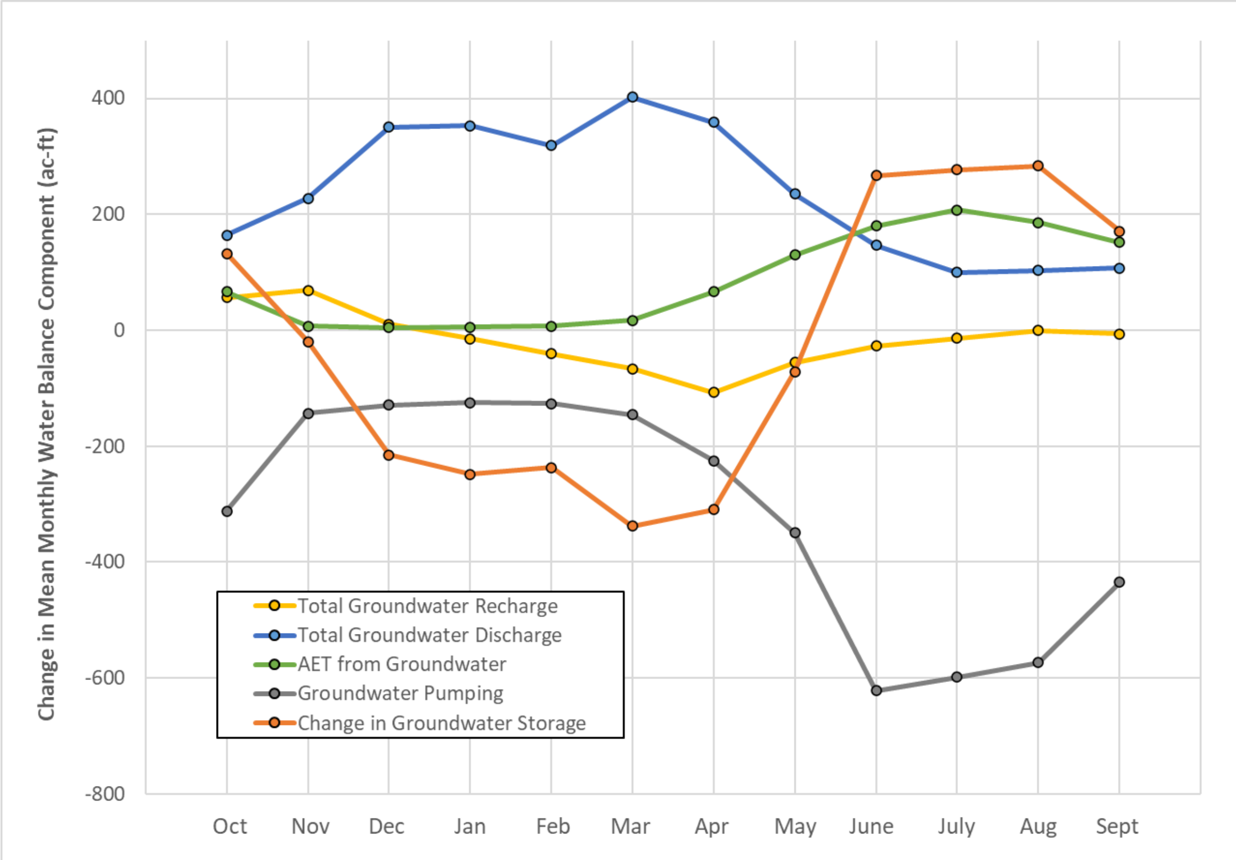


Figure 83: Mean monthly changes in the groundwater water balance resulting from cessation of all groundwater pumping (Scenario 2) for the fifth 10-yr simulation cycle.

Table 20: Summer streamflow depletion normalized by pumping volume for the various no pumping scenarios over the fifth 10-yr simulation cycle (Scenarios 2 & 2B-2E).

Scenario #	Scenario Name	Change in Mean Summer Discharge (cfs/100 ac-ft of pumping)
2	No Groundwater Pumping	0.019
2B	No Pumping Near Streams	0.026
2C	No Pumping Near Springs	0.029
2D	No Pumping From Tuff	0.019
2E	No Distal Pumping	0.017

Land/Water Management Scenarios

Forest, Grassland, and Runoff Management

The forest management scenario (Scenario 4) resulted in modest increases in mean summer discharges of 0.02 – 0.04 cfs throughout most of Mark West Creek upstream of Porter Creek and increases of 0.04 – 0.06 cfs below Porter Creek (Figure 84). These changes are equivalent to a 4-11% increase in mean summer flow depending on the location, and the average change over the full anadromous length of Mark West Creek was ~6%. The grassland management scenario (Scenario 5) resulted in smaller increases in mean summer flows of 0.02 or less throughout Mark West Creek (Figure 84). The runoff management scenario (Scenario 6) resulted in modest increases in mean summer discharges of less than 0.02 cfs upstream of Porter Creek. The majority of the area included in the scenario is located within and downstream of the Porter Creek watershed, and there is a substantial increase in the flow enhancement benefits below the confluence with Mark West Creek with mean summer discharges increasing by 0.06 - 0.12 cfs in the downstream reaches (Figure 86).

Increases in springtime streamflow for the forest management scenario were much larger than the changes for summer streamflow with increases of 0.5 - 0.6 cfs below Humbug Creek and 0.7 - 0.9 below Porter Creek (Figure 85); these changes represent 4 - 6% of the total flow. The changes in springtime streamflow for the forest management scenario are about three to five times larger than the changes for the other management scenarios. Springtime streamflow changes for the grassland management scenario were also larger than the summer changes with increases of 0.06 - 0.08 cfs below Humbug Creek and 0.10 - 0.18 cfs below Porter Creek (Figure 85). The runoff management scenario produced a similar but slightly greater increase in springtime streamflow relative to summer streamflow (Figure 87).

Comparison of the watershed-wide mean annual water balance between existing conditions and Scenarios 4 - 6 indicates that all three strategies (forest-, grassland-, and runoff-management) result in increases in infiltration recharge on the order of 2 - 4% on an annual basis (Figure 88). The mechanisms behind these increases are different for each case. Forest management results in about a 5% decrease in AET on treated lands which equates to a 1.4% decrease watershed-wide (579 ac-ft/yr) resulting in more water available for both runoff and infiltration recharge (Figure 88). In contrast, grassland management results in only minimal changes in AET and runoff and the increases in infiltration recharge are accomplished through increased soil water storage capacity which serves to extend the timeframe over which recharge can occur. Runoff management decreases runoff directly, resulting in both increases in infiltration recharge and AET (Figure 88).

The increases in infiltration recharge for all three scenarios represent a substantial volume of water (230-420 ac-ft/yr) which manifests in part through increases in groundwater discharge to streams as interflow, baseflow, and springflow (Figure 88). The springflow response is of particular interest in that springflow has been identified as the primary process generating summer streamflow in the watershed. The forest management scenario resulted in the largest increases in springflow (6.4%), followed by runoff management (3.9%), and grassland management (1.9%). The relative influence of the management actions on springflow is controlled in part by the spatial distribution of treatment areas. For example, the forest management scenario generates the largest increase in springflow despite generating the smallest increase in infiltration recharge owing to the concentrations of both springs and treatment areas in the upper watershed.

It is apparent that location on the landscape influences how changes in infiltration recharge are expressed, with the forest management scenario resulting in the smallest increases in recharge but the largest increases in springflow due to both treated forest areas and springs being concentrated in the upper watershed. It is also important to note that the acreages involved in the three scenarios are intended to represent large-scale implementation based on existing potential on the landscape, therefore the locations and acreages involved are very different between the scenarios. To compare the relative hydrologic effects of these various management actions it is useful to normalize the results by acres of managed area. This exercise reveals that runoff management is by far the most effective strategy with per area increases in summer streamflow 36 times greater than forest management and 51 times greater than grassland management (Table 21). The level of effort required to manage stormwater from one acre is, however, expected to be significantly greater than the effort involved in management of one acre of forest or grassland. Additional discussion of comparisons between strategies is included below under the heading Summary and Comparison of Scenarios.

Pond Releases

The summer pond release scenario (Scenario 7) resulted in the largest increases in summer streamflow of any of the scenarios discussed thus far. Between the pond release in upper Mark West Creek and the confluence with Mill Creek where the lower release enters, mean summer discharges increase by 0.06 – 0.07 cfs with the exception of localized increases of up to 0.09 cfs just downstream of the confluence of Humbug Creek where the middle release enters. Below the lower release on Mill Creek, discharges increase by 0.14 to 0.16 cfs (Figure 85). Averaged across the full length of anadromy in Mark West Creek, the changes in streamflow represent an increase in mean summer streamflow of approximately 13%.

The predominance of gaining conditions in most reaches of the stream result in only limited flow losses downstream of the releases, which makes this strategy particularly well-suited for this watershed which is characterized by a lack of thick alluvial deposits. The increase in summer streamflow above the middle release at Humbug Creek is equivalent to about 80% of the upper release rate and the increase in streamflow at the watershed outlet is equivalent to about 84% of the total release rate from all three releases. The losing reach below Porter Creek does reduce the increase in streamflow locally by about 0.02 cfs, but this effect does not persist downstream since much of the water that infiltrates through the streambed in this reach discharges back to the stream downstream.

The spring pond release scenario produced a similar but slightly smaller increase in springtime flows (Scenario 7B) than in summer flows (Scenario 7) (Figure 87). The spring pond release scenario was designed to increase flows over a short (3-week) period coinciding with the timing of the end of typical peak smolt outmigration in May. Examination of discharge and riffle depth hydrographs during the 2014 drought shows that the springtime releases substantially increase flows in the high priority reach during this critical time period extending the duration of passable conditions by approximately two weeks (Figure 89). The summer pond release scenario increases riffle depths significantly over the critical summer low flow period, but these changes are not large enough to maintain depths above 0.2-ft (Figure 89).

Combined Management

When all the land/water management scenarios are combined (Scenarios 4 - 7), mean summer discharge in Mark West Creek increased by 0.05 – 0.10 cfs between Monan's Rill and Van Buren Creek and by 0.10 – 0.15 between Van Buren Creek and Porter Creek. Downstream of Porter Creek streamflow increased by 0.25 – 0.35 cfs (Figure 90). These changes are similar but slightly less than the sum of the changes of the four individual scenarios. Averaged across the full length of anadromy in Mark West Creek, the changes in streamflow represent an increase in mean summer streamflow of approximately 23%.

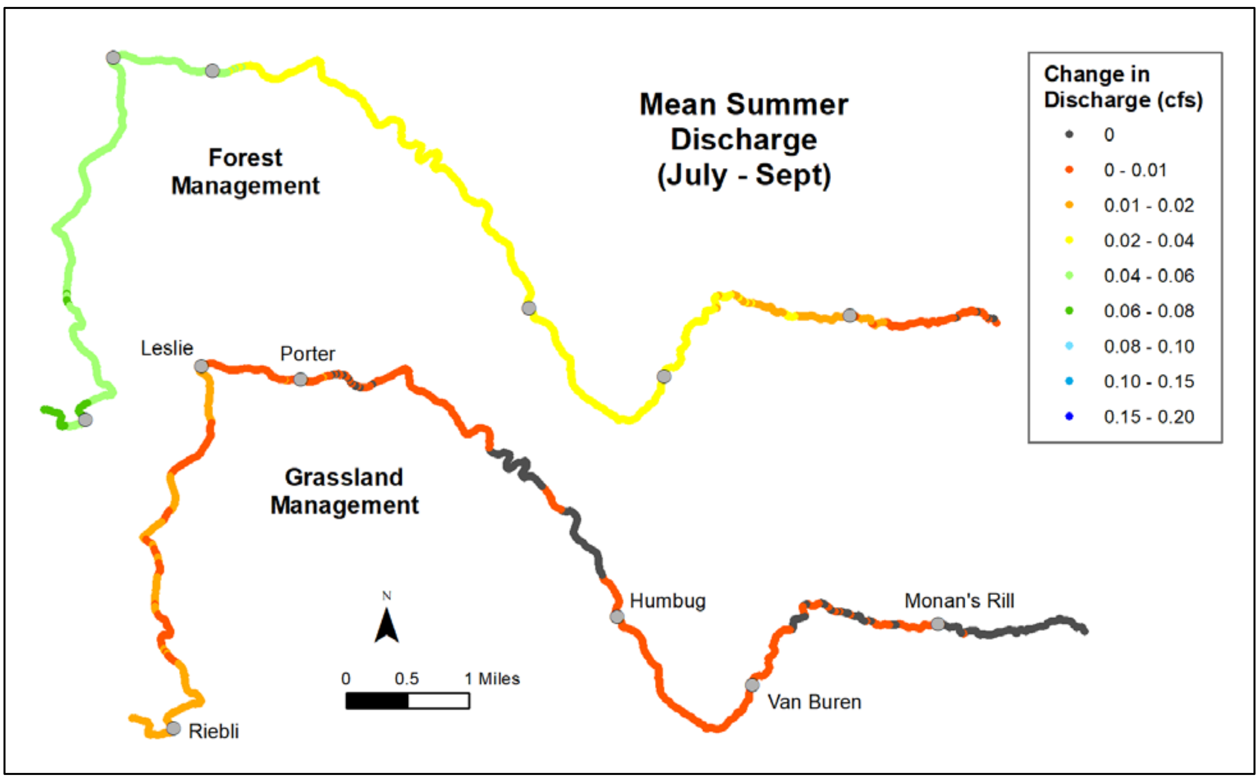


Figure 84 Simulated changes to mean summer streamflow for the forest and grassland management scenarios (Scenarios 4-5).

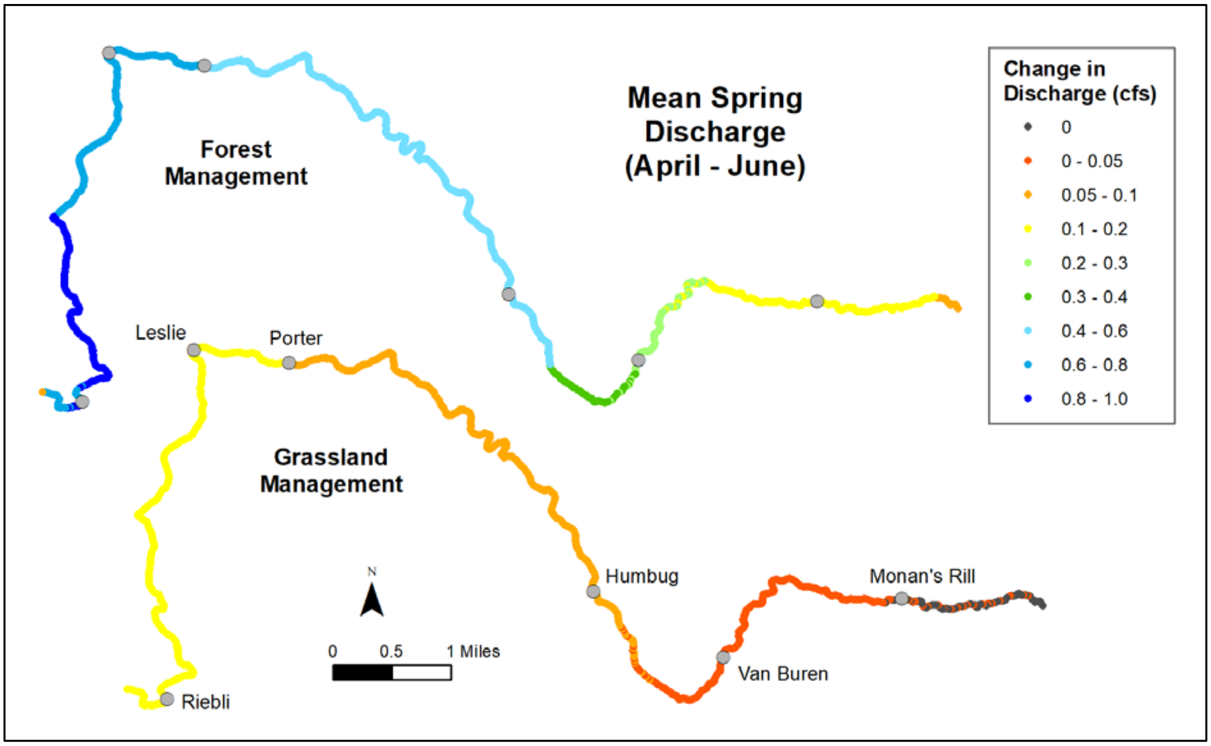


Figure 85: Simulated changes to mean springtime streamflow for the forest and grassland management scenarios (Scenarios 4-5).

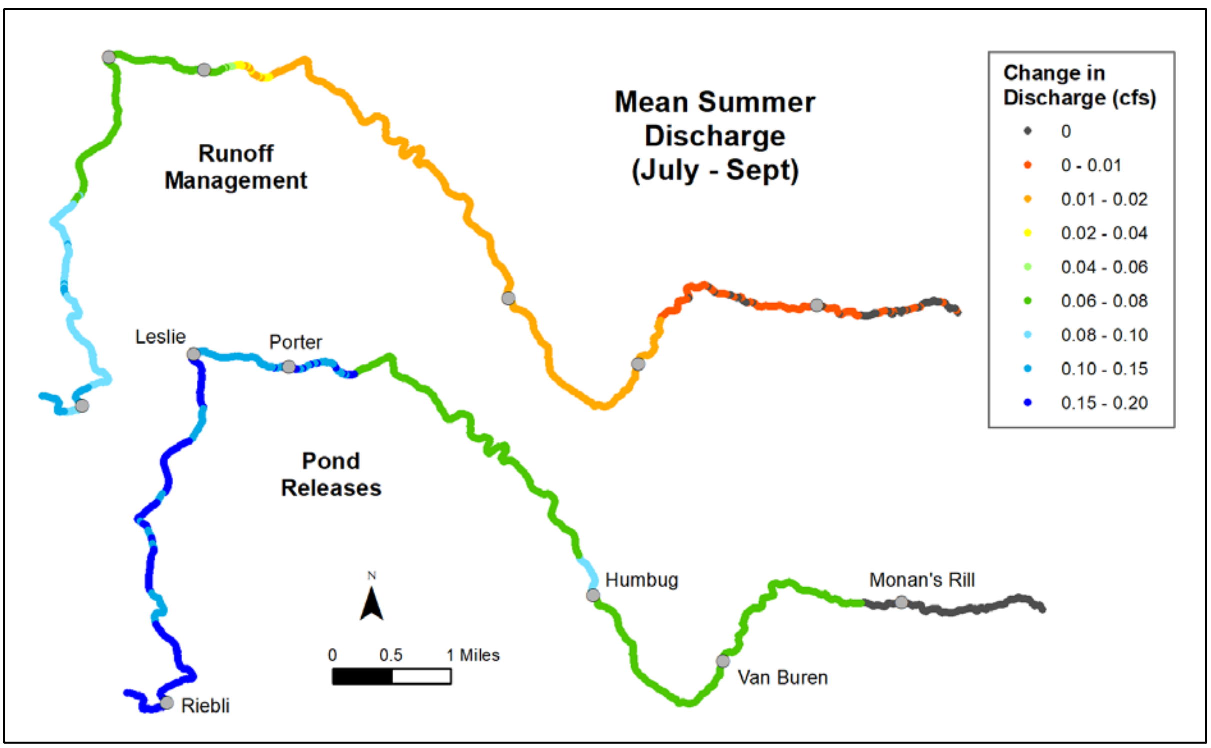


Figure 86: Simulated changes to mean springtime streamflow for the runoff management and summer pond release scenarios (Scenarios 6 & 7).

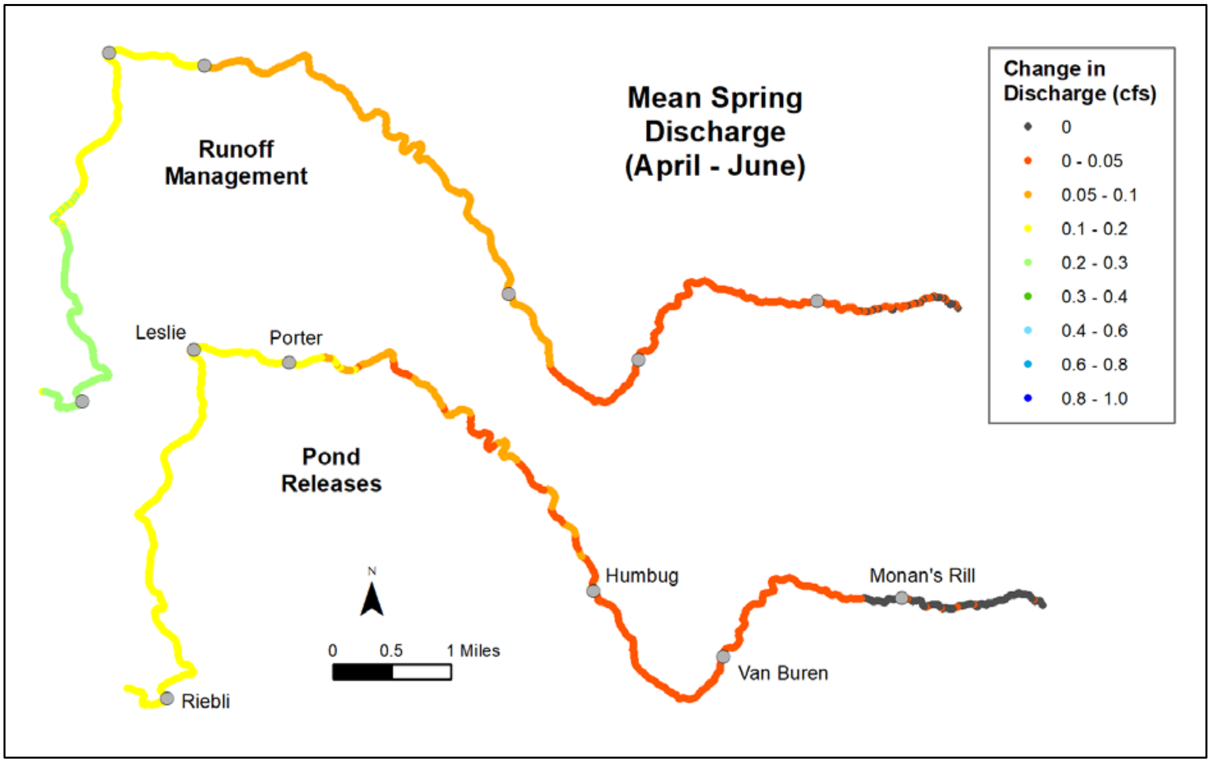


Figure 87: Simulated changes to mean springtime streamflow for the runoff management and springtime pond release scenarios (Scenarios 6 & 7B).

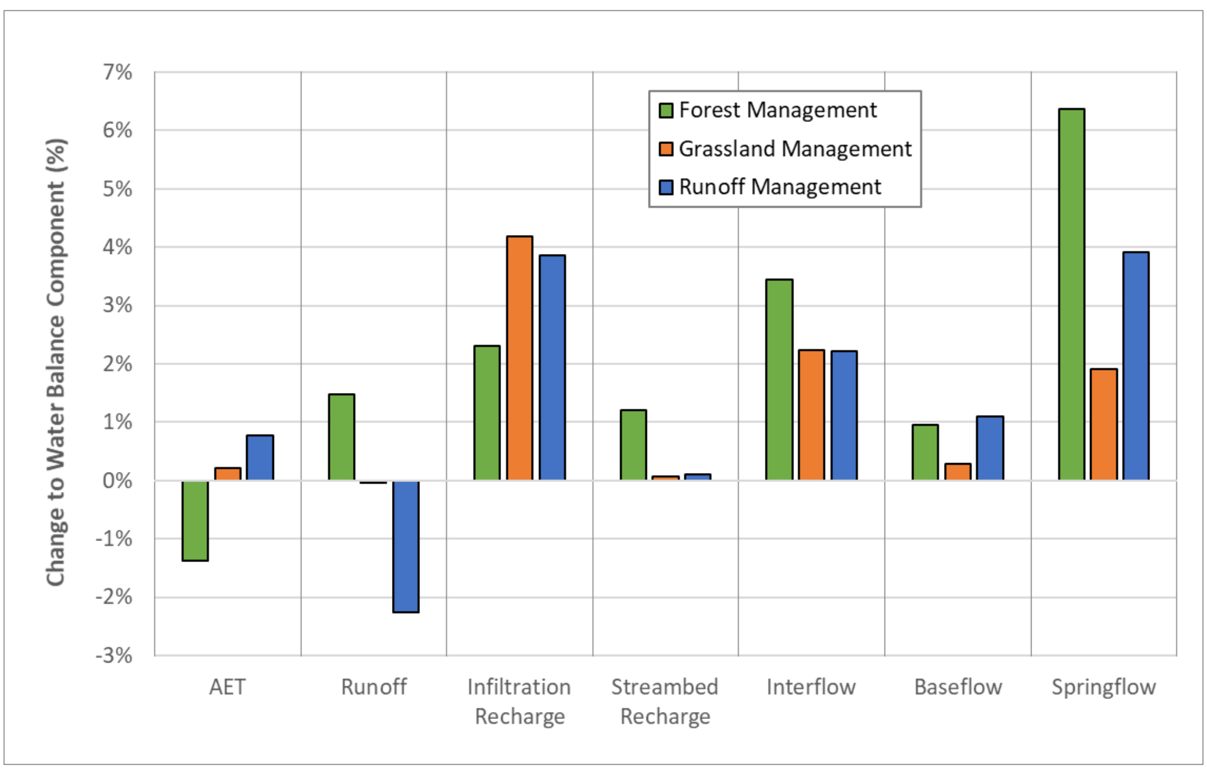


Figure 88: Percent change in select water balance components for Scenarios 4-6.

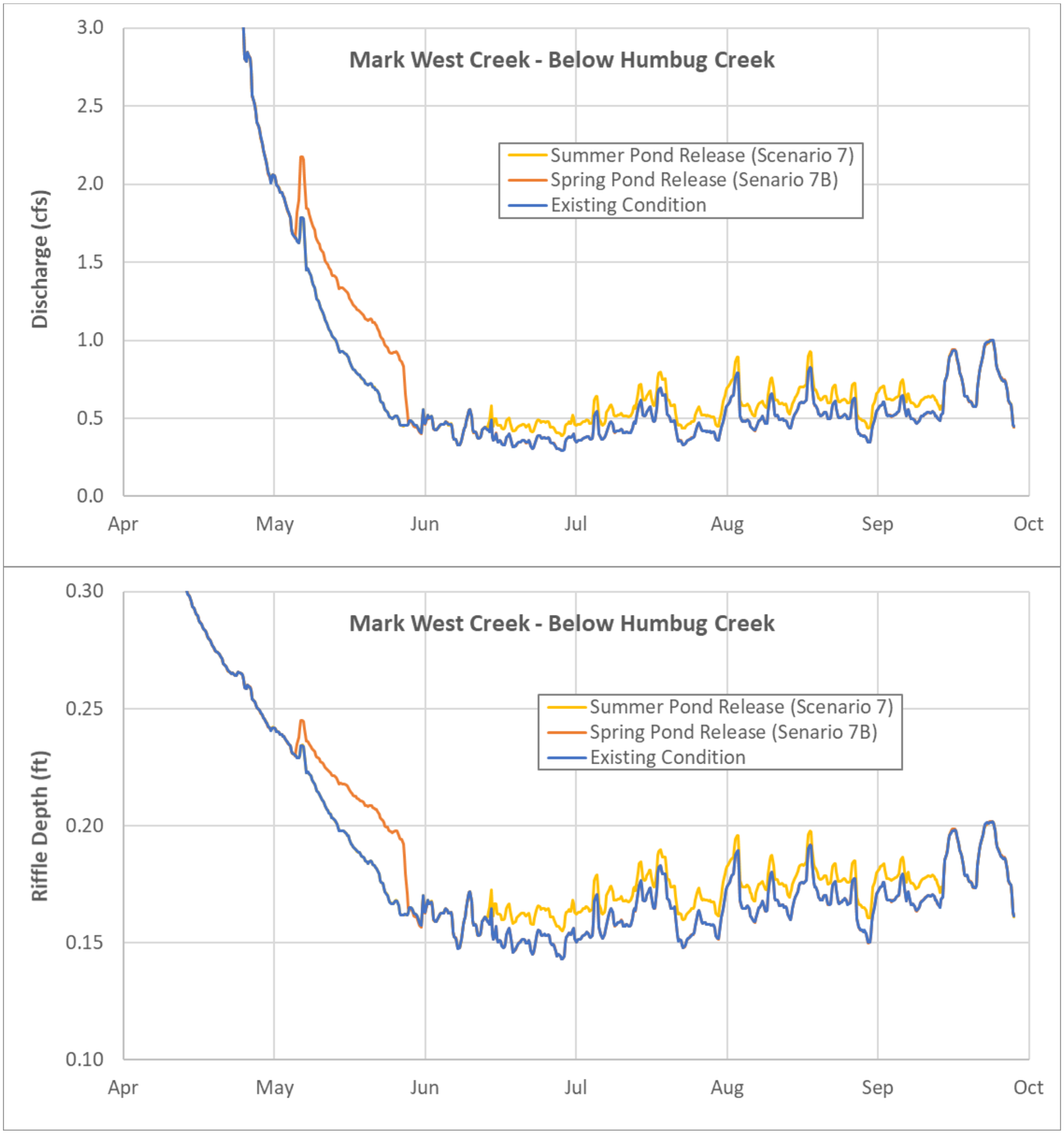


Figure 89: Spring and summer 2014 discharge (top) and riffle depth (bottom) in Mark West Creek below Humbug Creek for existing conditions and the spring and summer pond release scenarios (Scenarios 7 & 7B).

Table 21: Change in mean summer streamflow for forest, grassland, and runoff management (Scenarios 4-6) normalized to a 100-acre treatment area.

Scenario #	Scenario Name	Change in Mean Summer Discharge (cfs/100 acres of treatment area)
4	Forest Management	0.0010
5	Grassland Management	0.0007
6	Runoff Management	0.0355

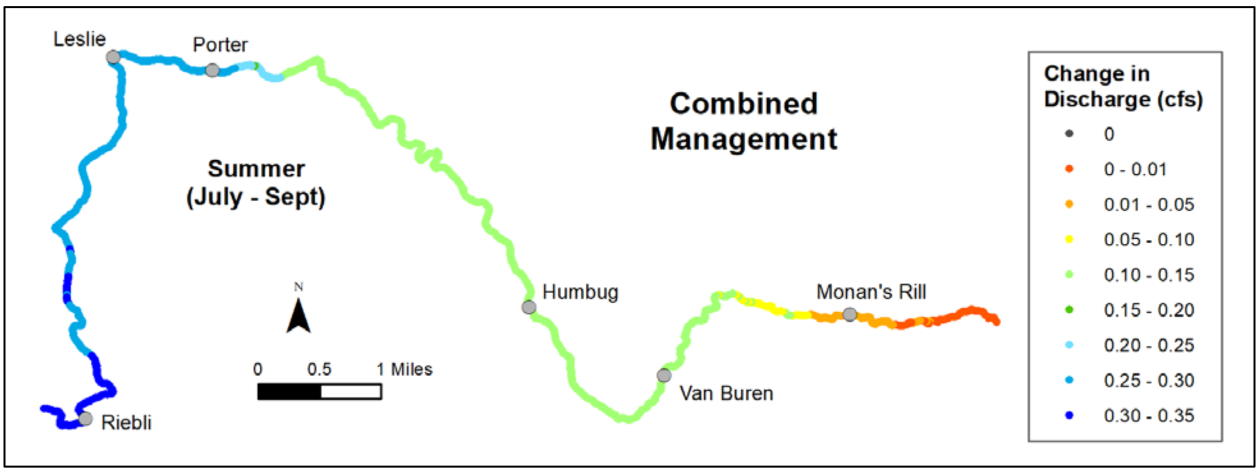


Figure 90: Simulated changes to the 10-yr average mean summer streamflow for the combined management scenario (Scenario 8; note the scale in the legend is different from previous figures for other scenarios).

<u>Climate Change Scenarios</u>

The four climate change scenarios (Scenarios 9-12) generated a wide range of predictions of future (2070-2099 timeframe) changes in discharge in Mark West Creek; nevertheless, there are some commonalities in the predictions of future streamflow trajectories. The average 10-yr mean monthly discharge is predicted to increase during late fall and winter in three of the four scenarios, with mean January flows in the CNRM scenario more than 2.5 times greater than existing conditions (Figure 91). All four scenarios show large decreases in discharge during spring with mean monthly flows during March decreasing by 48-71%. The predictions for summer flows are more variable with two scenarios predicting decreases in the mean monthly August flow on the order of 38-51% and one predicting increases of 26% (Figure 91). The future changes are even more extreme during drought conditions where winter flows are predicted to decrease dramatically in all four scenarios with high streamflow events becoming essentially non-existent in the GFDL scenario (Figure 92). The declines in springtime flows are also extreme with decreases in mean monthly discharge in March of 60-97% (Figure 92).

More careful review of the range of predicted changes in summer flows reveals that mean summer discharges increase in the CNRM scenario by about 0.1 - 0.2 cfs throughout Mark West Creek, whereas in the MIROC esm scenario, discharges between Van Buren Creek and Porter Creek drop from about 0.5 - 0.8 cfs to 0.3 - 0.4 cfs, and below Porter Creek flows drop from about 1.0 - 1.5 cfs to 0.6 - 0.8 cfs (Figure 93). In contrast to the variable predictions in mean summer discharges, all four models predict large decreases in mean spring discharges. The CNRM scenario produces the smallest decreases with flows in Mark West Creek decreasing from 4-10 cfs to 0.5 - 1 cfs between Van Buren and Porter Creeks and from 10-20 cfs to 1 - 2 cfs downstream of Porter Creek (Figure 94). The MIROC esm scenario predicts even more dramatic decreases in springtime discharges with flow of <0.5 cfs between Van Buren Creek and Porter Creek and <1 cfs below Porter Creek (Figure 94).

Examination of the 10-yr mean annual water balance (representative of the 2070-2099 timeframe) reveals that the four climate scenarios predict very different changes to the mean annual water balance. Precipitation changes range from a 37% increase in the CNRM scenario to a 20% decrease in the MIROC esm scenario (Figure 95). The significantly higher precipitation in the CNMR scenario leads to increases in AET of about 13%, whereas the other three scenarios result in modest decreases in AET of between 2 and 7%. Runoff is predicted to increase in the CNRM and CCSM4 scenarios by 26-69% and decrease in the GFDL and MIROC esm scenarios by 25 - 32% (Figure 95). The CNRM scenario predicts large increases in both infiltration recharge (44%) and streambed recharge (33%), the CCSM4 model predicts minimal changes in recharge, and the GFDL and MIROC esm scenarios predict significant decreases in infiltration recharge (29 - 40%) and streambed recharge (17 - 25%). Increased recharge in the CNRM scenario results in increases in groundwater discharge expressed as interflow (32%), baseflow (11%), and springflow (36%). Similarly, groundwater discharge decreases in the scenarios that predict decreases in recharge. The largest decreases are predicted by the MIROC esm scenario where interflow, baseflow, and springflow are predicted to decrease by 30, 21, and 46% respectively (Figure 95).

Comparison of the water balance for the driest of the 10 years in each simulation reveals that the trajectories of the changes in the water balance between the four scenarios are more similar during drought conditions than for long term average conditions. AET is predicted to increase in all four models while runoff, infiltration recharge, and streambed recharge are predicted to decrease (Figure 96). The GFDL drought predictions are extreme with close to a complete loss of both runoff and infiltration recharge. The groundwater discharge results remain variable between the scenarios with the CNRM and CCSM4 scenarios resulting in increased discharge during droughts and the GFDL and MIROC esm scenarios resulting in decreased groundwater discharge reflecting that groundwater discharge responds more to long-term fluctuations in climate rather than individual water year conditions (Figure 96).

All four scenarios indicate increases in Climatic Water Deficit (CWD). The mean CWD for the watershed over the 10-yr simulation period is predicted to increase from 26.0 in/yr under existing conditions to between 30.3 and 33.9 in/yr under future climate conditions. Increases in CWD of this magnitude (17-30%) may be expected to lead to significant changes in vegetation communities and increases in fire risk. It is important to note that these simulations represent the hydrologic effects of changes in climate but do not include secondary effects that may be expected under a significantly altered future climate regime such as changes in vegetation cover and irrigation water demands.

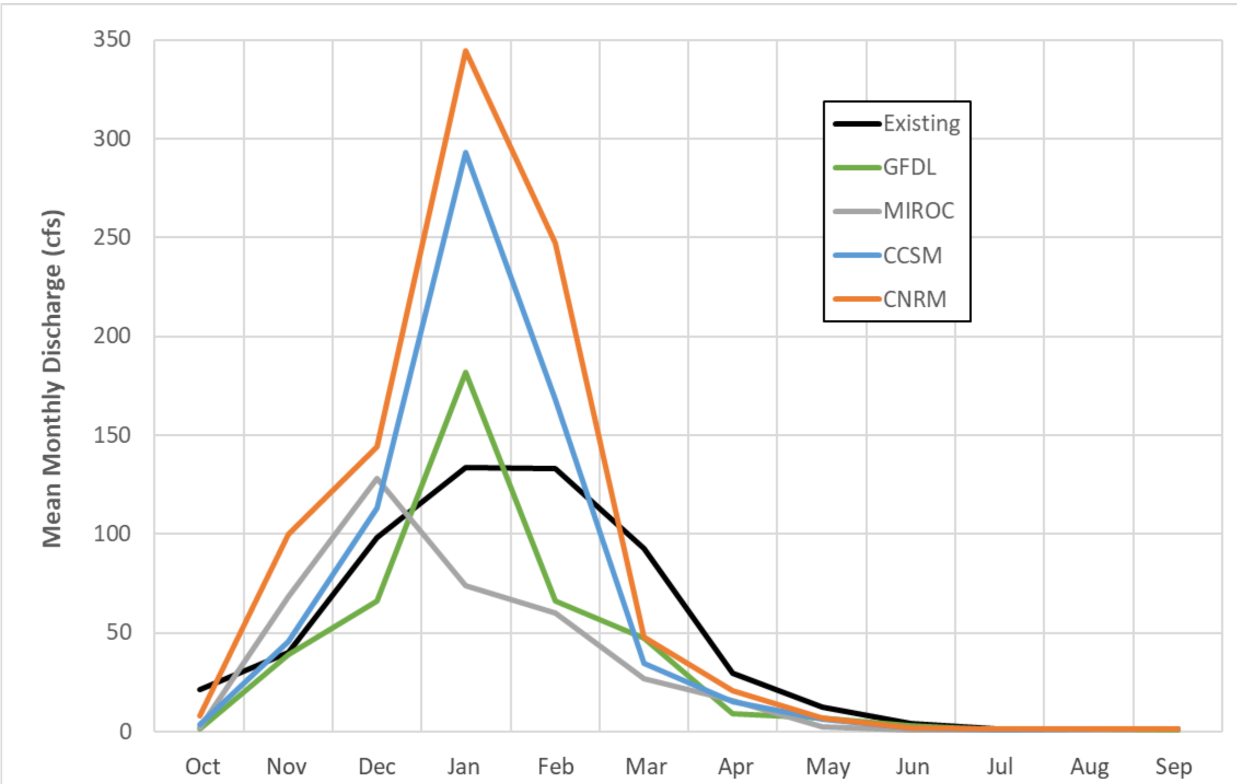


Figure 91: Comparison of mean monthly streamflow averaged over the 10-yr simulation periods for existing conditions and the four climate change scenarios (Scenarios 9-12).

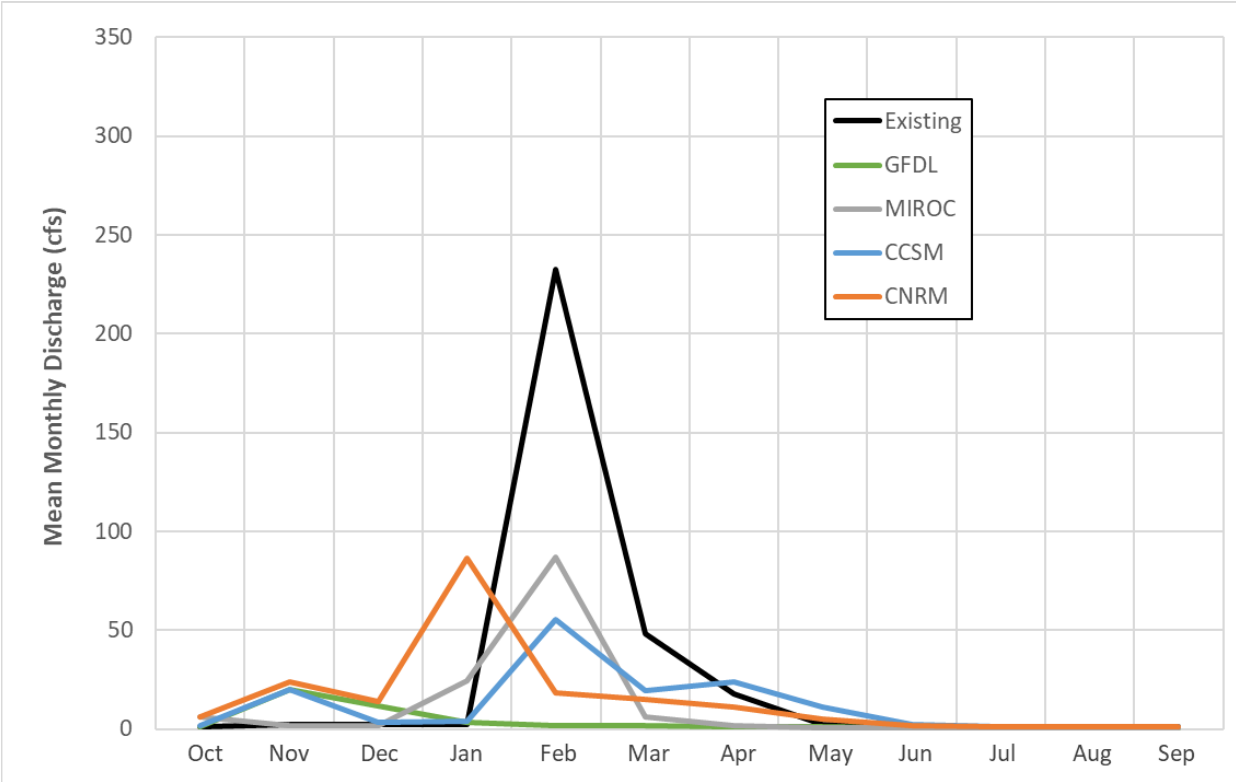


Figure 92: Comparison of mean monthly streamflow for the driest water year in each 10-yr simulation period for existing conditions and the four climate change scenarios (Scenarios 9-12).

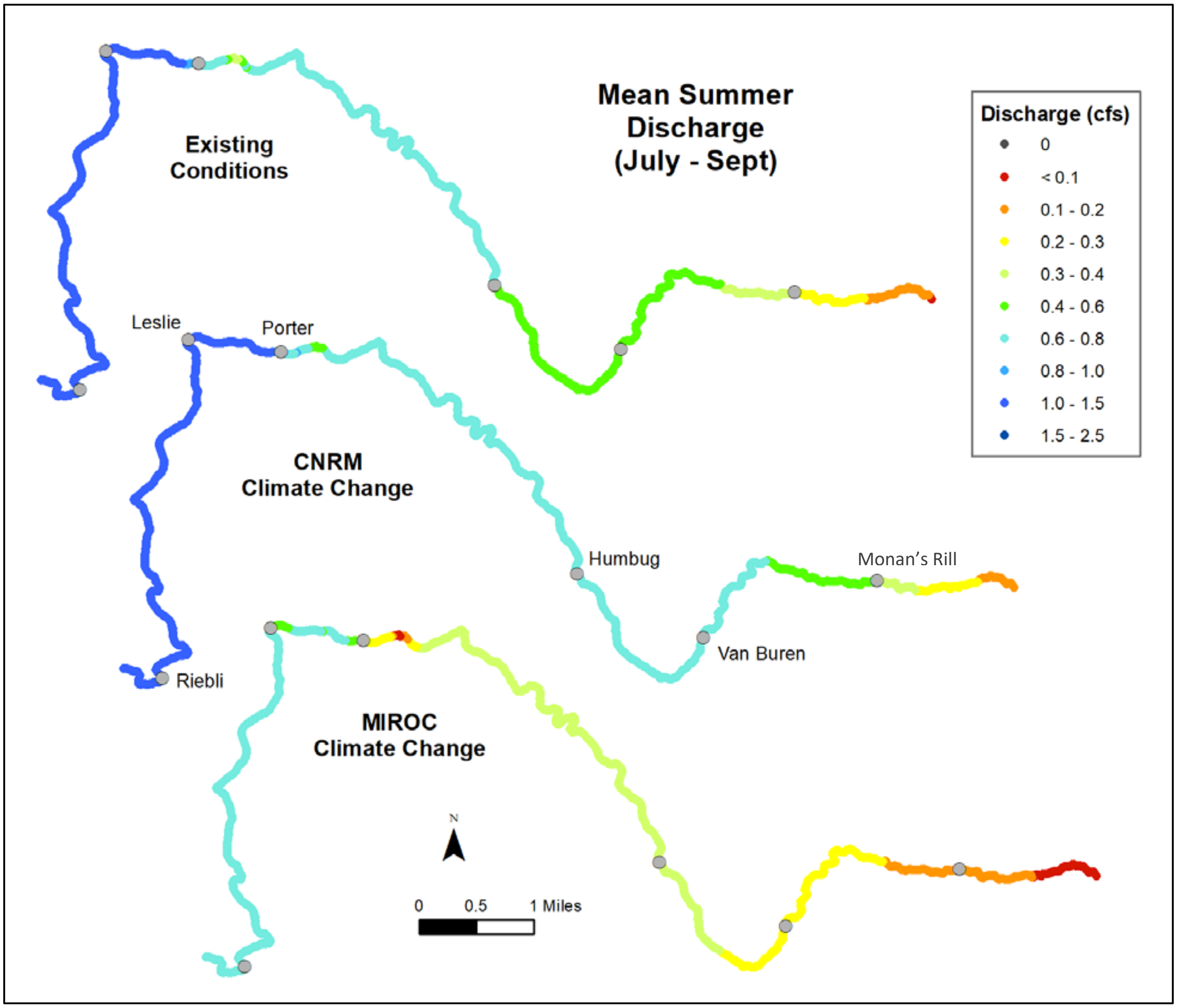


Figure 93: Simulated 10-yr average mean summer streamflow for existing conditions and the CNRM and MIROC esm scenarios (Scenarios 9 & 12) which represent the end-member predictions from the four climate change scenarios.

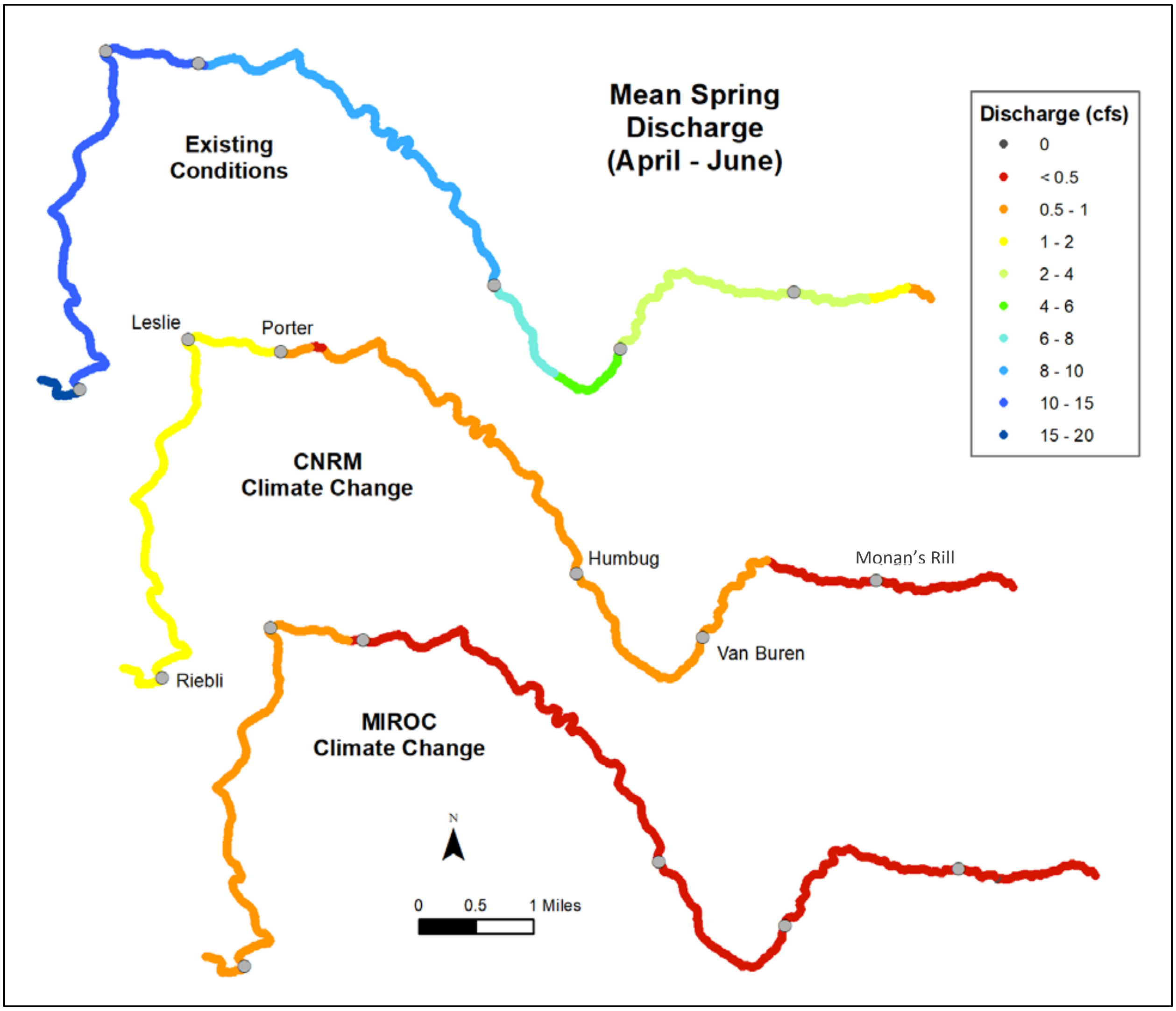


Figure 94: Simulated 10-yr average mean springtime streamflow for existing conditions and the CNRM and MIROC esm scenarios (Scenarios 9 & 12) which represent the end-member predictions from the four climate change scenarios.

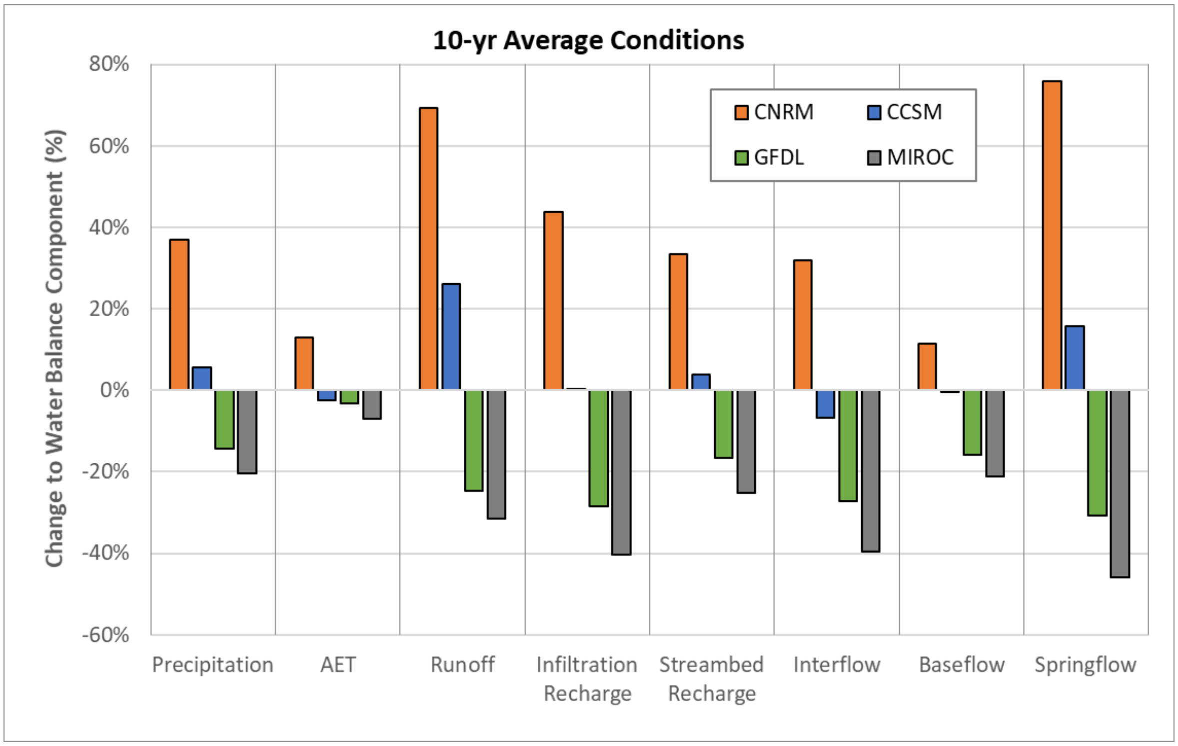


Figure 95: Percent change in various components of the water balance averaged over the 10-yr simulation periods for the four climate change scenarios relative to existing conditions.

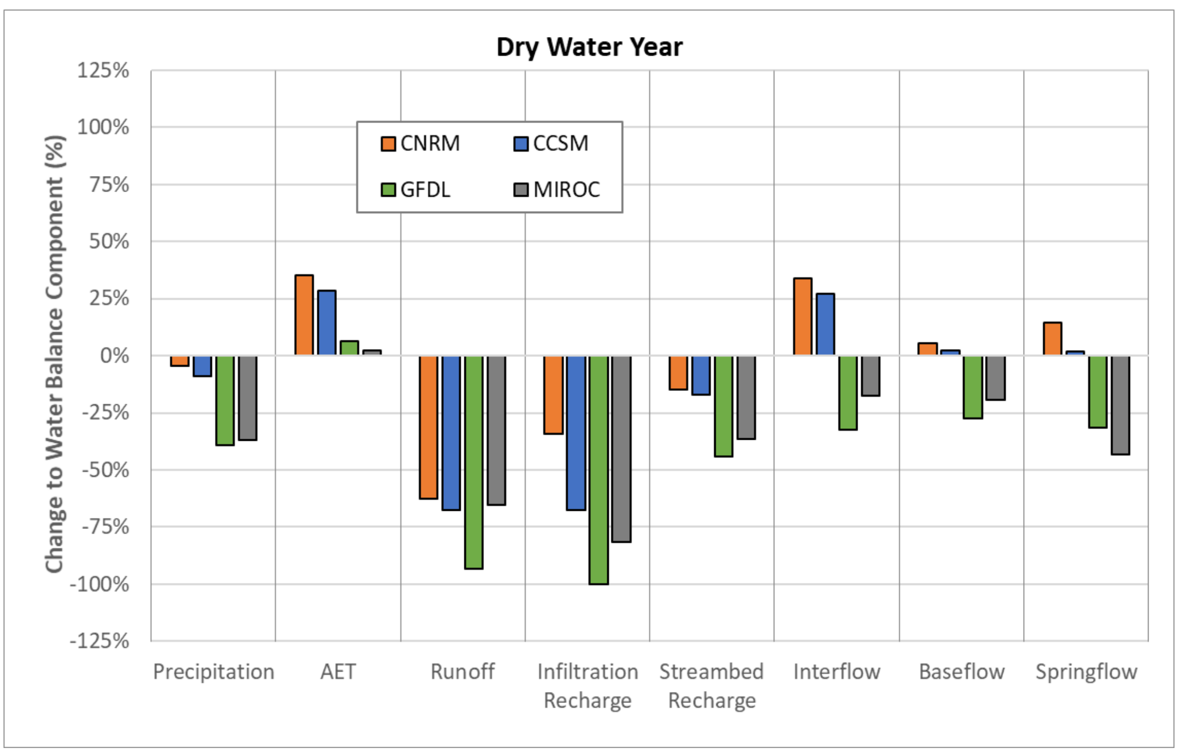


Figure 96: Percent change in various components of the water balance for the driest water year in each 10-yr simulation period for the four climate change scenarios relative to existing conditions.

Mitigated Scenarios

We combined the pond release scenarios (Scenarios 7 & 7B) and the combined management scenario (Scenario 8) with the GFDL climate scenario (Scenario 11) to evaluate the degree to which the various management actions may be capable of mitigating the changes in streamflow associated with future climate. We selected the GFDL model because it represents the second lowest predictions of future spring and summer streamflow of the four climate scenarios which provides a good benchmark for evaluating the scale of the management effects. If future climate more closely resembles the CNRM or CCSM4 scenarios the mitigating effects of the management actions would likely be larger than what is shown here, whereas if future climate more closely resembles the MIROC esm scenario, less mitigation would likely be possible.

The GFDL scenario predicts decreases in mean summer discharge of about 0.20 − 0.42 cfs at most locations in Mark West Creek, and the summer pond releases are large enough to significantly reduce these declines down to about 0.15 − 0.25 cfs (Figure 97). The combined actions of summer pond releases and forest, grassland, and recharge management generate increases in flow that are large enough to fully offset the predicted effects of the GFDL future climate on summer streamflows (Figure 97). None of the actions are capable of fully mitigating against the large decreases in springtime flows predicted by the climate scenarios; nevertheless, springtime flow releases may provide a critical management strategy to provide passable flow conditions for short critical periods of time during smolt outmigration.

Examination of riffle depth hydrographs below Humbug Creek during the driest water year in each 10-yr simulation cycle shows that under the GFDL future climate, riffle depths only reach the 0.2-ft minimum fish passage threshold for brief periods during March through May (Figure 98). This represents a dramatic change in the passage conditions experienced by outmigrants. Under existing conditions depths remain above 0.3-ft until mid-April and above 0.2-ft until early May. Springtime pond releases appear to be large enough to allow for a more sustained (several week) period with riffle depths remaining around 0.2-ft; in this scenario, releases were targeted towards the end of the primary outmigration period in May (Figure 98). Greater riffle depths could likely be achieved over shorter periods by increasing release rates and decreasing durations. The combined actions of summer pond releases, forest, grassland, and runoff management also had an appreciable effect on summer riffle depths generating depths under GFDL future climate that resemble those for existing climate (Figure 98). These findings suggest that aggressive management is capable of offsetting most or all of the summer declines in streamflow predicted for the GFDL future climate.

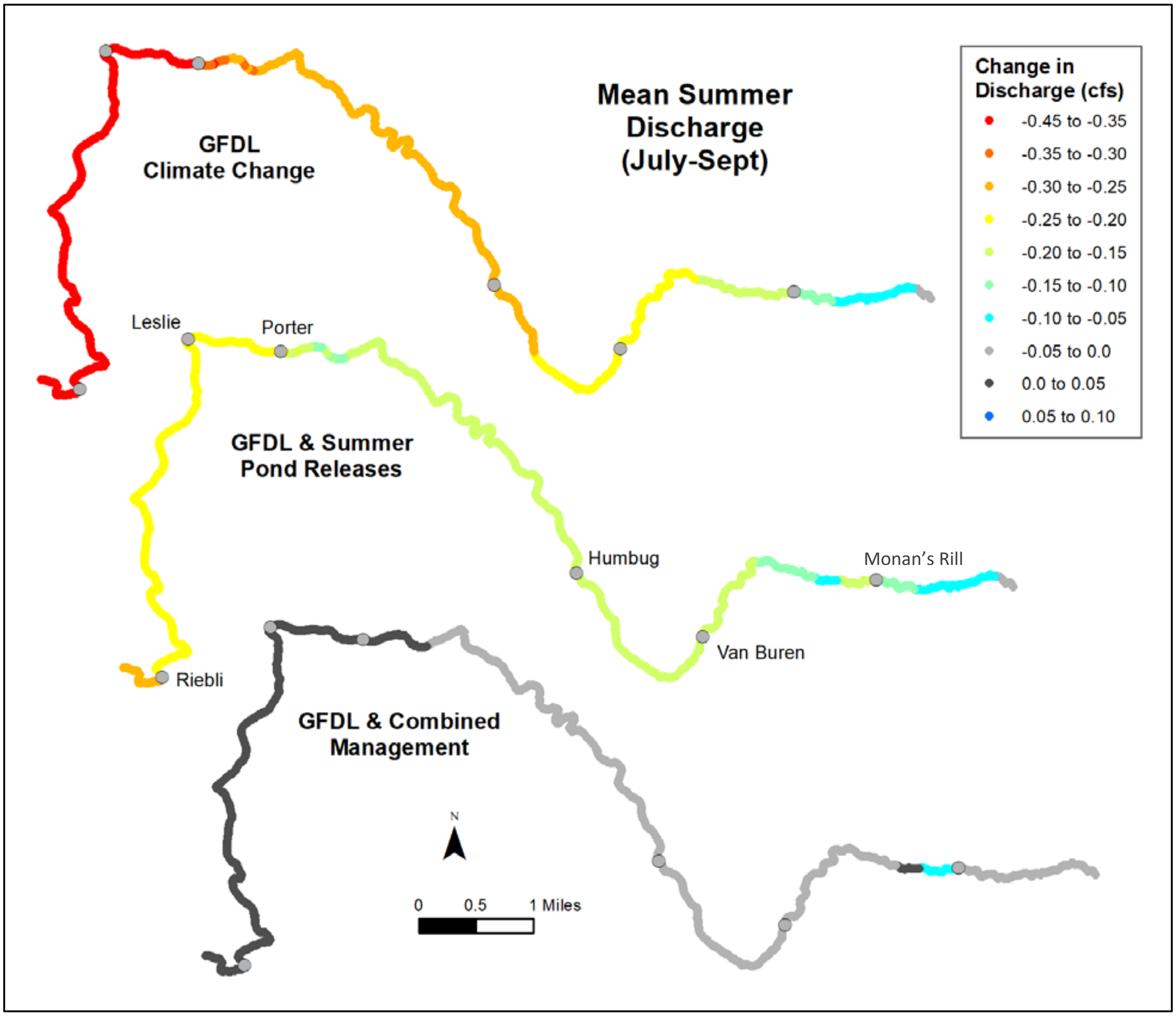


Figure 97: Simulated changes to the 10-yr mean summer streamflow for the GFDL future climate, the GFDL & spring pond release scenario (Scenario 13), and the GFDL & combined management scenario (Scenario 14).

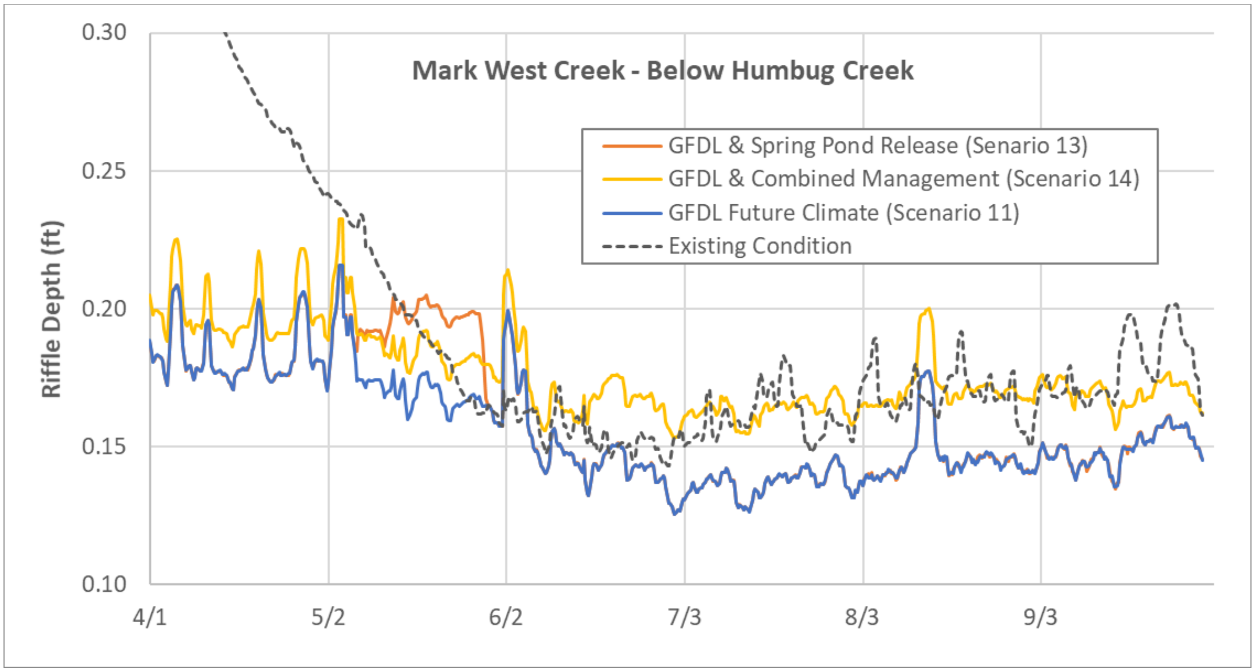


Figure 98: Spring and summer riffle depths for the driest year in the 10-yr simulation in Mark West Creek below Humbug Creek for existing conditions, GFDL future climate scenario (Scenario 11), the GFDL & springtime pond release scenario (Scenario 13), and the GFDL & combined management scenario (Scenario 14).

Summary and Comparison of Scenarios

Comparison of the changes in summer streamflow between the various scenarios indicates that the sustained cumulative effect of surface water and groundwater use are approximately equal and that cessation of all water use would eventually increase mean summer streamflow by about 6% in the ~4-mile high priority reach below Alpine Creek and ~8% at the watershed outlet (Figure 99). The pond release scenario generated the largest increases in summer streamflow of the stand-alone scenarios, with increases of about 13 - 14%. In the high priority reach, the next largest increases were from the forest management scenario, followed by the recharge management scenario (Figure 99). At the watershed outlet this order was reversed owing to the concentration of forest treatment areas in the upper watershed and the concentration of developed areas included in the runoff management scenario in the lower watershed. Runoff management generated about a 3% increase in summer streamflow in the high priority reach and a 10% increase at the outlet, whereas forest management generated about a 6% increase at both locations. The grassland management scenario generated the smallest increases in summer flows on the order of 2% (Figure 99).

The climate change scenarios generated a wide range of predictions with three of the four scenarios indicating decreases in summer streamflow of between 6 and 47% and one scenario indicating increases of about 15 - 19% (Figure 99). The mitigated scenarios indicate that pond releases can likely offset a significant portion of the projected decreases in summer streamflow predicted by some of the models and if combined with forest, grassland, and runoff management, are likely large enough to completely offset the projected decreases (Figure 99). If future climate more closely resembles the predictions of the CNRM or CCSM4 models, pond releases and combined management would be expected to result in flow enhancement above existing conditions.

The various large-scale flow enhancement actions represented by the scenarios and the foregoing comparisons are intended to represent implementation of projects of a given type based on the maximum potential on the landscape. The scenarios vary widely in their scale, feasibility, and expected cost. To better understand the relative streamflow benefits of implementing a given project, we normalized the simulated increases in streamflow based on areas for a 'typical' parcel/project in the watershed (Figure 100). To normalize the surface water diversion scenario results, we assumed a new well would be drilled to replace the entire diversion volume with groundwater pumping. We divided the cumulative diversion effects by the total number of diversions and then subtracted the cumulative groundwater pumping effects normalized by the volume of diversion offset. In most cases it is not possible or practical to completely offset groundwater pumping with rainwater or runoff capture and storage. Installation of storage tanks is a common and practical means of offsetting groundwater pumping and we assumed 10,000 gallons of tank storage offset to normalize the groundwater pumping scenario results. The average per parcel acreages of forest treatment, grassland treatment, and impervious area represented by the scenarios was used to normalize the results for these three scenarios; these acreages were 5.6, 4.6, and 0.38 acres respectively. The pond release scenario was normalized by simply dividing the cumulative enhancement benefits by the number of release projects (three).

We also developed a rough cost estimate for each typical project and normalized the results again based on a $25,000 project cost. The six projects and estimated costs include:

- Groundwater Pumping Offset – installation of a 10,000 gallon rainwater catchment tank and associated reduction in groundwater pumping - $38,000
- Surface Diversion Replacement – replacement of a direct or spring diversion with a new groundwater well - $33,000
- Runoff Management – construction of an infiltration basin sized to capture the 10-yr 48-hr storm volume from a 3,000 ft^2 rooftop or other impervious area - $22,500
- Grassland Management – compost application on 4.6 acres of grassland (average per parcel acreage in the model scenario) - $7,000
- Forest Management – thinning and/or controlled burning on 5.6 acres of forested lands requiring treatment (average per parcel acreage in the model scenario) - $15,000
- Pond Release – summer flow release of 11.3 ac-ft from an existing on-stream pond (average release volume of the three ponds in the model scenario) - $20,000

This comparison revealed that pond releases are by far the most effective strategy for enhancing streamflows (Figure 100). On a cost basis, the streamflow benefits of one flow release project were found to be more than 50 times greater than an average surface water diversion replacement project and more than 500 times greater than an average grassland management project (the second and third most effective strategies). Replacement of direct stream diversions or spring diversions of surface water with new wells is the second most effective strategy. Grassland and forest management showed a similar level of effectiveness on a cost basis and were about 3 - 4 times as effective as runoff management. Offsetting groundwater pumping with storage was the least effective of the six overall strategies considered.

It is important to recognize that runoff, forest, and grassland management may provide significant additional benefits besides streamflow enhancement compared to pond release and diversion replacement projects. These management strategies generate enhanced streamflow primarily via increasing groundwater discharge (see Figure 88), which may be expected to mitigate high water temperature, whereas flow releases from ponds may need to be carefully managed to avoid adverse temperature effects. These strategies also help reduce seasonal vegetation moisture stress which may decreases fire risk somewhat or at least help offset future increases in risk associated with climate change. In particular, the forest management scenario reduces actual evapotranspiration by about 5% on treated lands which represents a fairly large volume of water (615 ac-ft/yr), and the runoff management scenario results in a substantial decrease in the Climatic Water Deficit of about 25% on lands where they are implemented. These various benefits are in addition to the primary non-hydrologic benefits of forest and grassland management projects in reducing fuel loads and sequestering carbon respectively.

All four climate change scenarios representing the 2070-2099 timeframe indicate substantial decreases in springtime flows ranging from 35 - 62% (Figure 101). These changes greatly exceed the potential flow improvements associated with the various enhancement scenarios. Forest management generates the largest increases in mean spring discharges (~5 - 6%), and the other individual scenarios only increase spring flows by ~1 - 2% (Figure 101). As discussed above, while it may not be possible to significantly increase mean discharges during spring relative to the scale of expected decreases resulting from climate change, springtime pond releases lasting several days to weeks do provide a means of creating a period of passable flow conditions during critical outmigration periods which may be essential given the scale of the projected decreases in springtime flows (see Figure 98).

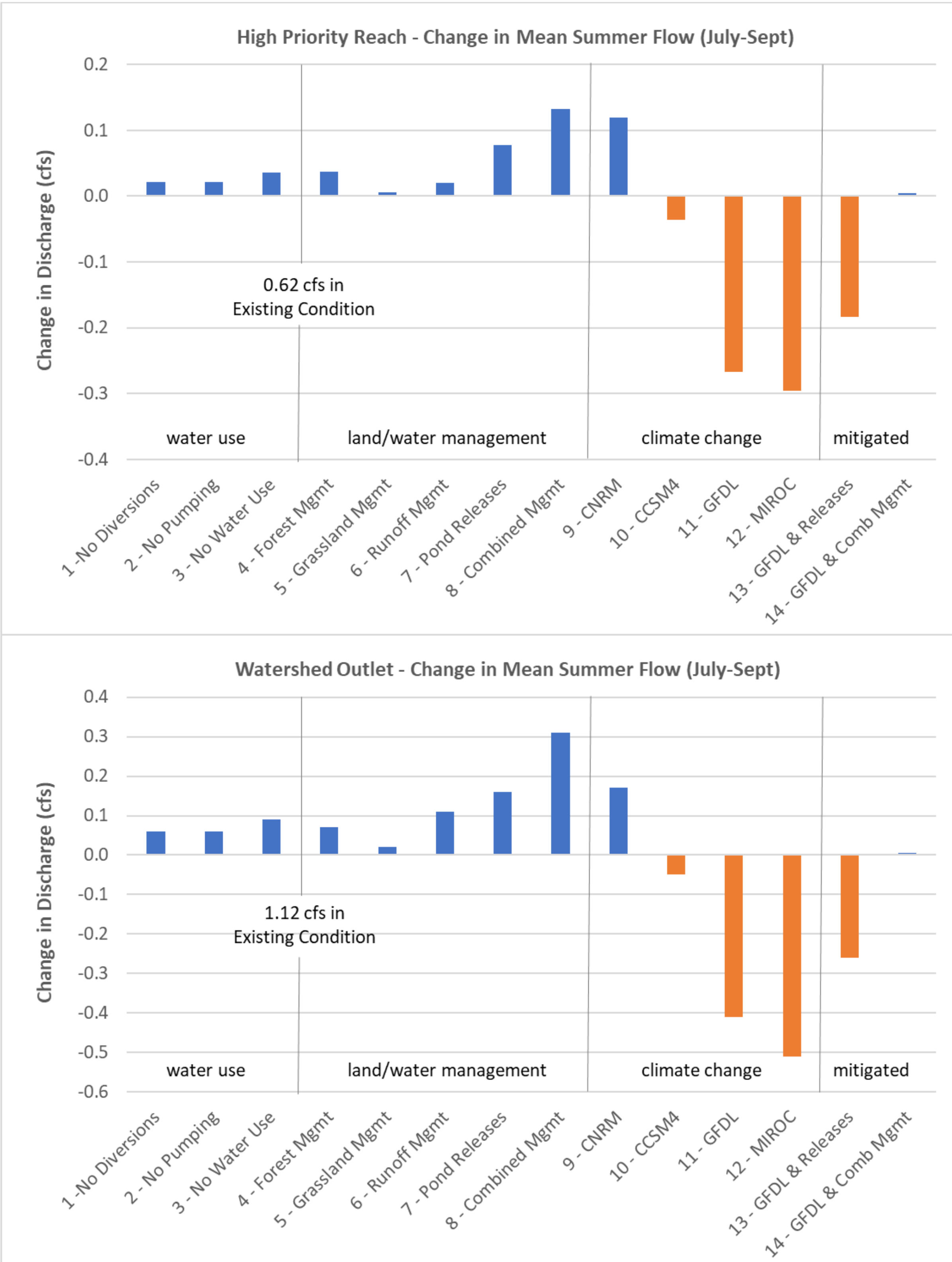


Figure 99: Summary of the simulated changes in mean summer streamflow for Scenarios 1-14 averaged over the high-priority habitat reach (top) and at the watershed outlet (bottom).

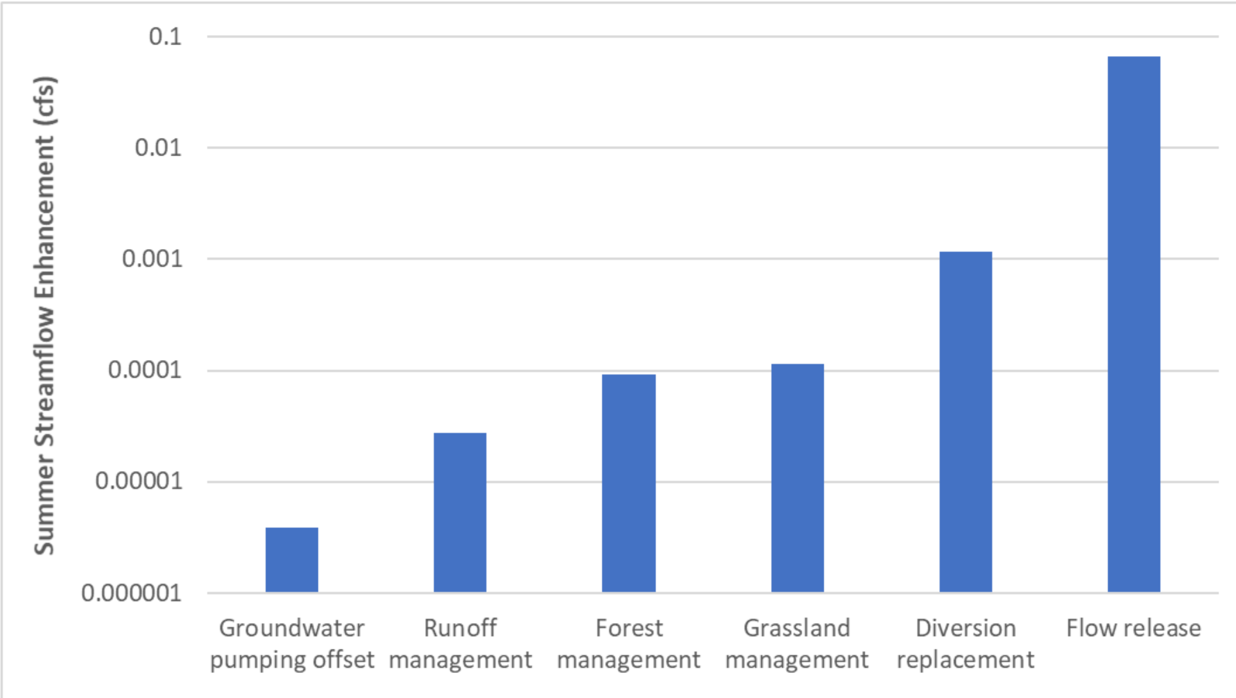


Figure 100: Summary of the simulated increase in mean summer streamflow for the six primary individual flow enhancement actions represented by the model scenarios normalized to a $25,000 project cost.

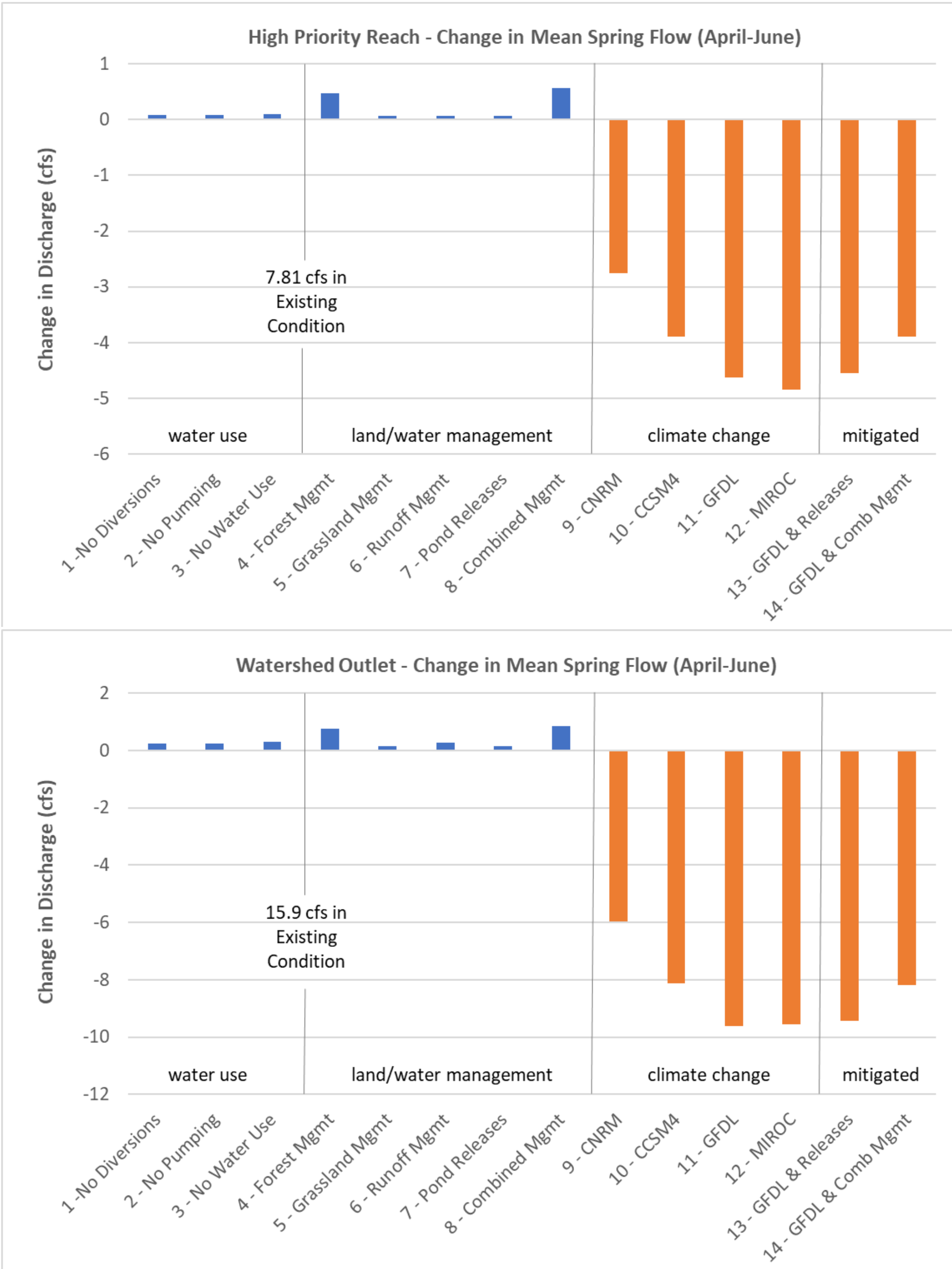


Figure 101: Summary of the simulated changes in mean springtime streamflow for Scenarios 1-14 averaged over the high-priority habitat reach (top) and at the watershed outlet (bottom).

Chapter 9 –Recommendations & Priority Restoration/Management Actions

Habitat Enhancement

Based on simulated riffle depth and observed water temperature data and informed by habitat inventory and fisheries monitoring data, the four mile reach extending from 0.2 miles upstream of Alpine Creek to 2.0 miles upstream of the Porter Creek confluence has the best overall habitat for salmonids (Figure 102). This analysis was focused on juvenile rearing and smolt outmigration; however, the identified reach is also believed to provide better spawning and winter rearing habitat conditions than upstream and downstream reaches. Conditions in the reach are far from optimal with impaired temperatures and insufficient summer streamflows. Nevertheless, the reach has the least impaired habitat conditions with significantly lower streamflows upstream and significantly higher temperatures downstream. We recommend that habitat enhancement projects be focused in this high priority reach where these efforts have the greatest likelihood of improving overall habitat conditions for salmonids.

Based on a limited number of sample sites, water temperatures in the high priority reach appear to remain below severely impaired levels in pools with depths above about 3.5-ft whereas severely impaired temperatures occur in shallower pools (see Figures Figure 62 & Figure 65). More temperature monitoring and pool inventory and analysis is recommended in the reach to identify pools providing critical temperature refugia. A temperature study is also warranted to better understand the factors affecting water temperature and to identify possible mitigation actions. Our preliminary findings suggest that streamflow is not the primary control on temperature and that encouraging formation of stable deep pools and maximizing shading are likely the most important immediate objectives. In-stream large wood (trees and logs) is very limited in Mark West Creek and installation of large wood on a broad scale at sites selected to encourage formation and protection of existing deep pools is recommended. Where needed, projects should also include riparian planting to maximize shading of the summer water surface. Opportunities for development of off-channel habitat projects to enhance winter rearing habitat are also available in the identified reach, and these types of projects are also recommended to support improved conditions in the reach for other limiting life cycle stages.

Flow Protection/Enhancement

Summer streamflow throughout Mark West Creek is generated primarily by spring discharge which most commonly occurs along streambanks with exposures of bedrock of the Sonoma Volcanics. Springflow is concentrated in the upper watershed with the watershed area upstream of Van Buren Creek supplying more than 55% of the total summer spring discharge in the watershed despite representing less than 17% of the total watershed area. We recommend that the various flow protection and enhancement actions described below be focused in the watershed area upstream of the Mill Creek confluence where they are more likely to provide flow benefits in the identified high priority reach. The watershed area upstream of Van Buren Creek could be considered even higher priority for flow protection and enhancement given the disproportionate role the area plays in generating summer streamflow supplied to downstream reaches (Figure 102).

Given that groundwater discharge from the Sonoma Volcanics is the primary driver of summer streamflow, additional monitoring and analysis of subsurface geologic conditions and connectivity of springs and recharge source areas is warranted. Collection of data from a series of dedicated monitoring wells screened in specific geologic units and paired with springflow measurements is recommended to allow for an improved understanding of groundwater processes in the volcanics. Significant prior and ongoing effort has been given to collecting stage data and summer streamflow records, however limited effort has been dedicated to comprehensive rating curve development and generation of continuous streamflow records. Such data is critical to establishing baselines and understanding the effects of flow enhancement actions and ongoing climate change in the watershed and we recommend that a comprehensive long-term streamflow monitoring program be implemented for the watershed.

Releasing water from existing ponds was found to be by far the most effective individual strategy for enhancing streamflow (see Figure 100). The streamflow benefits of a cost-normalized flow release project were found to be more than 50 times greater than surface water diversion replacement projects and more than 500 times greater than grassland management projects (the second and third most effective strategies). Except in the reach upstream of Porter Creek, thick alluvial deposits are uncommon with many reaches of exposed bedrock and predominately gaining conditions persisting throughout the summer. These conditions are ideal for allowing released flows to provide flow benefits that persist in downstream reaches. Examination of existing ponds revealed that there are only three ponds upstream of the high-priority reach with sufficient storage to provide meaningful releases and we recommend that flow release projects be developed for these ponds if possible. There are many challenges that must be overcome to implement these flow release projects including landowner willingness, uncertainty regarding longevity, water quality and invasive species considerations, and permitting and water rights requirements.

There are many existing ponds that could likely be enhanced and new ponds could be built specifically to store water for streamflow enhancement. Given the disproportionate impact that pond releases are expected to have as a mitigation strategy for effects of climate change on streamflow, this somewhat controversial idea should be seriously considered. Water temperature and other water quality considerations should be an important aspect of planning flow release projects since water temperatures are already impaired and it is critical that flow releases do not further increase temperatures. There are various strategies for coping with elevated pond temperatures (e.g. bottom releases, surface shading, cooling systems) to the extent that this poses an issue during planning and design.

Our findings suggest that direct stream and spring diversions may have a significant impact on summer streamflow conditions at least over short periods when diversions are active; however, the cumulative effects of groundwater pumping in the watershed were relatively small. While we did find some relationship between the degree of streamflow depletion and the screen depth and distance of wells from streams/springs, these differences were modest with a rate of depletion from near stream wells screened in the upper 200-ft about 1.7 times the rate from more distant wells screened at depths greater than 200-ft. We did not find any direct relationship between the timing of pumping and the timing of streamflow depletion with the primary effects of summer pumping manifesting largely as changes in water balance dynamics during the recharge season (see Figure 83). These findings suggest that replacing direct stream and spring diversions with storage and/or groundwater pumping is a viable approach for enhancing streamflow conditions but that offsetting groundwater pumping with storage or shifting the timing of pumping from summer to winter is unlikely to lead to appreciable improvements in flow conditions. Of the six general strategies considered, replacement of direct diversions is the second most-effective strategy after pond releases, whereas offsetting groundwater pumping was found to be the least effective strategy (see Figure 100).

Requiring new wells to be screened a set distance from a stream or spring or below a certain depth may extend the length of time before streamflow depletion occurs, but it will not prevent streamflow depletion from occurring. The long response timescale (decades) suggests that a volumetric approach to managing groundwater will likely lead to more successfully managing streamflow depletion compared to approaches focused on location or time of use. It is important to note that the total pumping stress in the watershed is relatively small (~3% of mean annual infiltration recharge) and that the limited degree of streamflow depletion under existing conditions should not be understood to suggest that significant streamflow depletion would not occur were the total volume of pumping to increase substantially in the future.

On a cost-normalized basis, grassland, forest, and runoff management all produced relatively small streamflow benefits with grassland and forest management being approximately 3-4 times as effective as runoff management (see Figure 100). These strategies also have important secondary hydrologic benefits in addition to enhancing streamflows in that they reduce seasonal vegetation moisture stress which may reduce fire risk. Specifically, forest management reduces actual evapotranspiration on treated lands by about 5% and runoff management decrease Climatic Water Deficits (CWD) in infiltration areas by about 25%; grassland management only resulted in a small decrease in CWD of about 1%. These benefits are in addition to the primary non-hydrologic benefits of these types of projects for reducing fuel loads (forest management) and sequestering carbon (grassland management). There are also potential negative consequences of extensive forest management in terms of potential habitat loss for avian and terrestrial species which must be considered, and the forest treatments would only be effective in the long-term if periodically repeated to maintain the intended reduction in fuel load.

We recommend that a planning study be conducted for the upper watershed to identify parcels most suitable for grassland, forest, and runoff management projects and that these projects be implemented where feasible. Given that the streamflow benefits of these strategies are more than an order of magnitude less than those of diversion replacement and more than two orders of magnitude less than those of pond releases, the various types of management projects are considered a lower priority than pond release or diversion replacement projects. That said, the long-term maintenance of streamflow under future climate conditions may require all of the flow enhancement strategies to be implemented and it is important to gain near-term experience with these management strategies and to attempt to monitor their effectiveness.

The optimal design and effectiveness of runoff management projects is highly site specific and it is recommended that projects be focused on parcels with significant impervious area that are currently well-connected to surface water features, have relatively high soil infiltration rates, and sufficient space and site conditions to allow for larger-scale infiltration features. Gravel-filled infiltration basins may be required in some cases to prevent ponding of stagnant waters for more than 72-hrs per Sonoma County vector control requirements. Native soil basins will likely work in some situations, and where space is limited basins can be combined or replaced with bioswales and/or features designed to distribute water evenly across the landscape.

In summary while runoff, forest, and grassland management may not result directly in substantial streamflow improvement, these efforts have multiple benefits and are likely important strategies for managing fire risk and mitigating climate change impacts as discussed in more detail below.

Climate Change Adaptation

Climate change is expected to result in a dramatic decrease in springtime flows particularly during drought conditions. Summer baseflows are also predicted to decrease in some simulations, however the future trajectory of summer flows is less certain with some scenarios predicting limited changes or modest increases. The decline in flows during spring is expected to have significant effects on salmonids particularly with respect to smolt outmigration with some of the climate scenarios predicting that in some years flows will fall below passage thresholds nearly continuously from mid-February through October. The only feasible means to at least partially mitigate this dire threat to salmonids appears to be the implementation of springtime pond releases. While it may not be possible to significantly improve conditions throughout the smolt outmigration period, relatively high release rates could be achieved for a period of several days to weeks to provide a period of passable flow conditions timed to coincide with expected peak smolt outmigration (see Figure 98). We recommend that flow release projects be developed and adaptively managed to provide a combination of larger pulses of streamflow during outmigration and enhanced streamflow during summer baseflow depending on conditions in a given year.

The runoff, forest, and grassland management strategies influence the quantity of streamflow from springs which in general is relatively cold, therefore these approaches may be expected to assist in mitigating elevated water temperatures whereas the more effective strategies (pond releases and diversion replacement) would not be expected to provide temperature benefits (see Figure 88). These strategies also help reduce vegetation moisture stress by increasing the quantity of water available to plants in the case of runoff and grassland management or decreasing water demand from the landscape for the case of forest management. This reduced moisture stress may be an important benefit for wildfire hazard reduction and the increase in wildfire hazard expected as a result of climate change.

In summary, implementation of runoff, forest, and grassland management projects are expected to help build resiliency to climate change by providing multiple benefits beyond potential streamflow improvement and spring and summer pond releases provide a means of adaptively managing flow conditions for salmonids in the face of a changing climate.

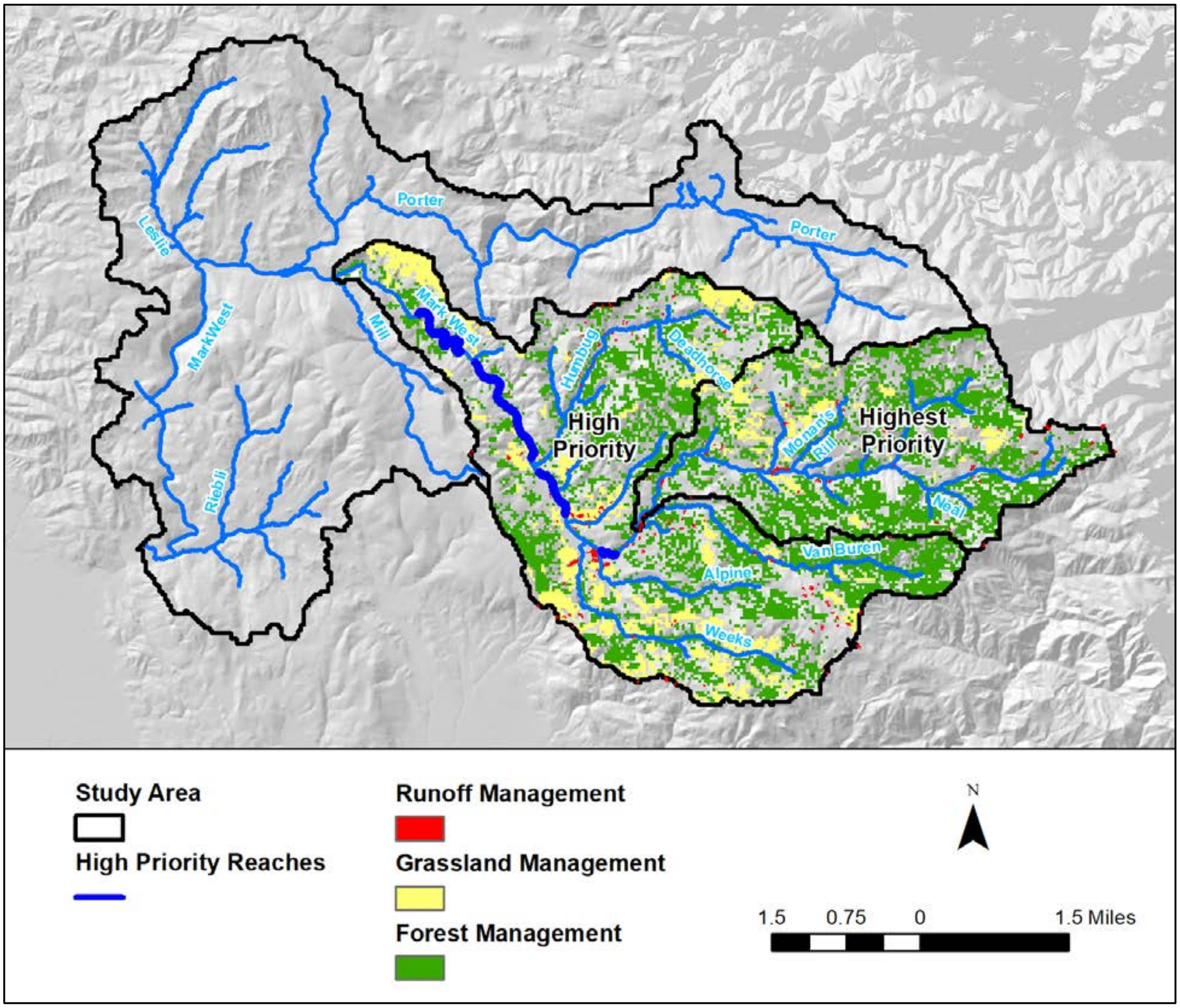


Figure 102: Locations of the identified high priority reaches for habitat enhancement projects and high priority watershed areas for flow enhancement projects.

Chapter 10 – Conceptual Design Development

The final phase of the project involved development of conceptual designs for two site specific streamflow enhancement projects. The projects focus on the approach of runoff management and were selected to take advantage of local site conditions and project opportunities on properties managed by our project partners the Pepperwood Foundation and Sonoma County Regional Parks. The projects illustrate two possible approaches to managing runoff for enhanced groundwater recharge and we anticipate similar approaches as well as other alternative methods could be applied on parcels throughout the watershed.

Goodman Meadow

Site 1 is located within the Pepperwood Preserve at the Goodman Meadow near the headwaters of Leslie Creek in the northwest corner of the watershed (Figure 103). The Goodman Meadow site consists of a relatively flat, approximately 12-acre natural basin perched on a topographic

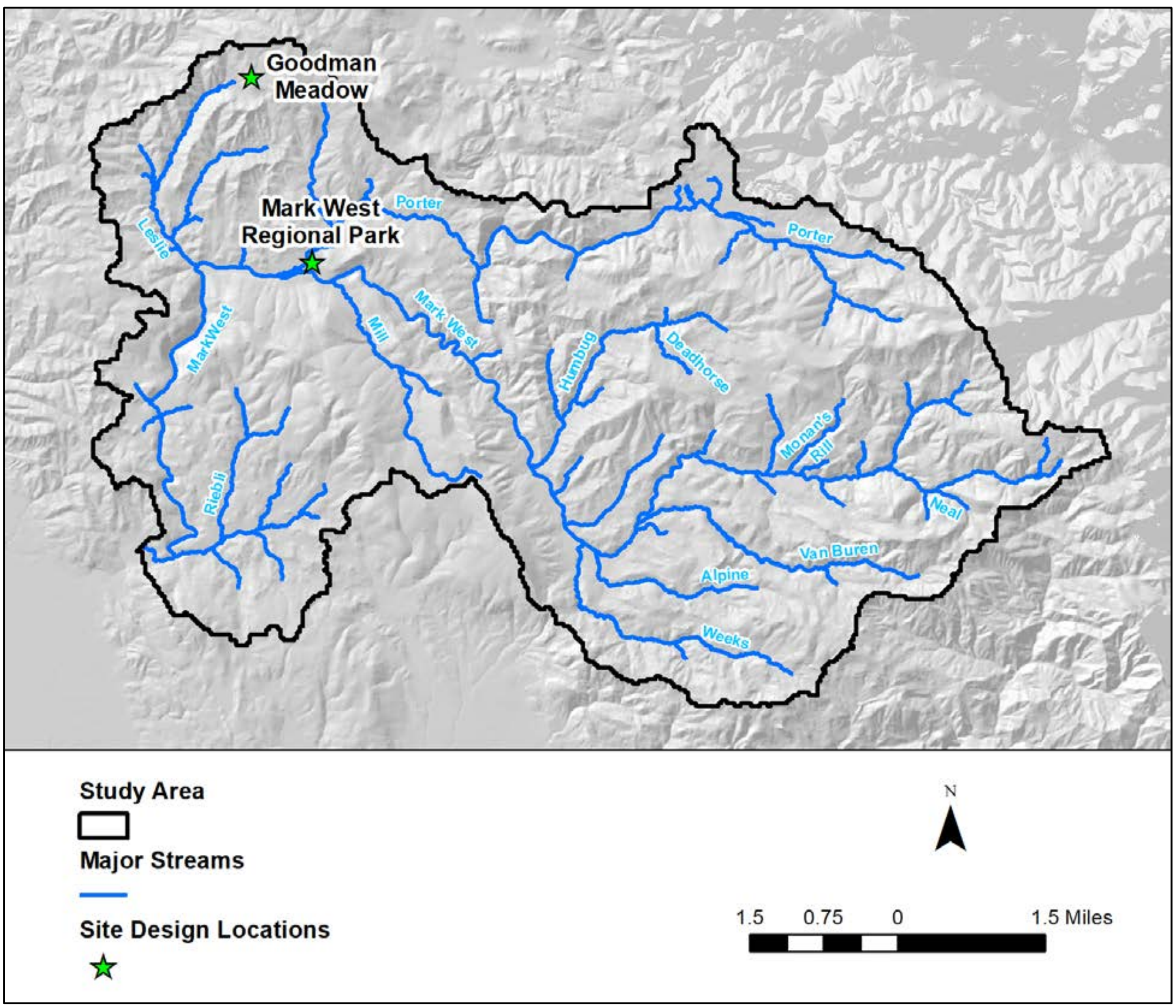


Figure 103: Locations of the two streamflow enhancement sites where conceptual designs have been developed.

bench and drained by an incised channel cutting through its western margin (see Appendix A, profile A to A'). The design consists of constructing a berm across the narrow valley at the basin outlet to retain winter runoff within the meadow and promote enhanced groundwater recharge. A channel exits the basin flowing southwest through a relatively narrow valley (approximately 60-ft wide at the base of adjacent slopes, see Appendix A section B to B') creating an optimal site for a berm or small dam. Approximately 94 acres of watershed area drain to the proposed berm site. The contributing area consists of mostly oak woodland and is not developed outside of an unpaved ranch road which traverses the hillside at the upper end of the meadow.

The basin outlet elevation will control the volume of water captured and stored within the basin. Various types of outlet structures are possible and for this conceptual design we assumed a 50-ft wide broad-crested weir with Low (1,128.0-ft) and High (1,132.5-ft) outlet elevation options (Appendix A). The Low elevation option would create an impoundment area of approximately 0.5 acres capable of storing approximately 1.1 ac-ft of water. Assuming 2-ft of freeboard above the outlet elevation, the Low elevation option would require a berm with an average height at the outlet of 4 feet above the meadow plain and a height of about 7-ft at the outlet above the incised channel bed. Based on existing LiDAR elevation data collected in 2013 (WSI, 2016), an ~98-ft long berm would be required. Assuming a 2H:1V berm side slope and a 4-ft berm top width, this would require approximately 274 yd^3 of fill (Appendix A). The High elevation option would create an impoundment area of approximately 1.4 acres and approximately 5.3 ac-ft of storage. The required berm would have an average outlet height of 8.5-ft above the meadow plain and a height of 11.5-ft at the outlet above the incised channel bed. Based on existing LiDAR elevation data, an ~132-ft long berm would be required. Assuming a 2H:1V berm side slope and a 4-ft berm top width, this would require approximately 692 yd^3 of fill (Appendix A).

A flow release structure should also be included near the base of the outlet to allow for drainage of retained water for maintenance purposes and/or for seasonal drainage if desired. An appropriate release schedule would be guided by Pepperwood Preserve's overall management strategy for the meadow and include consideration of the effects of the changed hydroperiod on grassland communities. These details would be further investigated and determined during subsequent design phases.

To evaluate the anticipated recharge and streamflow enhancement benefits associated with construction of the Goodman Meadow project, we implemented the conceptual design (using the higher of the two outlet elevations) as a scenario in the hydrologic model. The model represents the basin using a stage-storage relationship and calculates daily water levels as a function of simulated inflows from runoff and groundwater and simulated outflows across a broad-crested weir outlet structure and from evaporation and infiltration recharge.

The storage volume of the basin is relatively small compared to the available runoff and it fills to capacity during the first significant rainfall event of each year (typically in November or December). The basin remains near capacity throughout the rainy season with water levels typically beginning to decline in May or early June (Figure 104). Water levels typically reach a minimum in October by which point the upper portions of the basin are dry with 4-6-ft of water

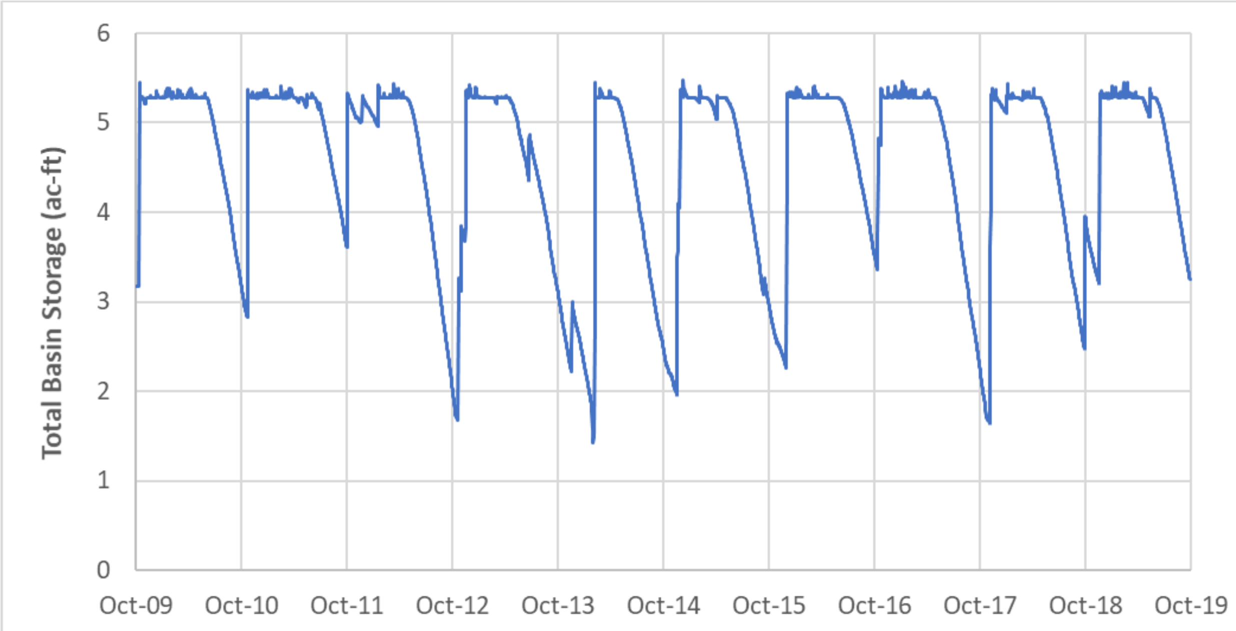


Figure 104: Daily fluctuations in storage in the Goodman Meadow recharge basin over the 10-yr hydrologic model simulation period.

remaining in the lower portions of the basin. The seasonal drawdown is dependent primarily on the duration of the dry season with minimum storage levels ranging from 1.4 to 3.6 ac-ft (26-68% of total capacity) (Figure 104).

Under existing conditions, mean annual infiltration recharge in the basin footprint was ~3.6 in/yr, and under proposed conditions this rate increases to ~18.7 in/yr. The total volume of additional recharge provided by the project is estimated to be about 1.9 ac-ft/yr. This additional recharge generates a modest increase in streamflow downstream in Leslie Creek. The upper reaches of the creek are intermittent and typically dry out sometime between late April and late June. The recharge enhancement serves to extend the length of time that the stream remains flowing each spring by between 12 and 21 days and the 10-yr mean streamflow over the April through June timeframe increases by about 0.01 cfs, representing about a 7% increase in flow.

Mark West Regional Park

Site 2 is located on a terrace on the east bank of Porter Creek just upstream of its confluence with Mark West Creek (Figure 103). The site is slated to be developed as the main entrance and parking area for the newly formed Mark West Regional Park operated by Sonoma County Regional Parks. Park facilities have not yet been designed in detail but are expected to be contained within approximately 3.1 acres currently occupied by a barn structure and an adjacent parking area and gravel road (Appendix B). The stormwater management design described here could become a part of the overall design for the park facilities and consists of collecting runoff from the developed portions of the park entrance in a network of diversion ditches and directing these flows into a series of two linear, gravel filled infiltration basins designed to maximize groundwater recharge. These basins are also expected to provide ancillary benefits by reducing peak runoff and providing filtration of pollutants from the parking area.

The basin alignment corresponds to an existing ditch that runs along the base of the slope southeast of the barn and parking lot. The upper basin is approximately 130-ft in length and runs adjacent to the existing parking area maintaining the existing slope of 0.6%. The lower basin runs approximately 490-ft behind the existing barn and maintains the existing slope of 0.2%. The two basins are separated by a road crossing where a 2.5-ft diameter, 150-ft long culvert is proposed to transport flows (Appendix B).

In addition to runoff collected from the developed footprint, the basins and associated channel will also receive flows from the adjacent hillslope which encompasses approximately 15.4 acres. The main intent of this infiltration basin design is to detain runoff from the developed areas associated with the new Mark West Regional Park entrance facilities and as such the basin has been sized to provide storage for a volume associated with a representative design storm for that area. Typically, infiltration basins are not recommended to receive runoff from drainage areas greater than 2 acres of undeveloped area due to concerns of sediment clogging which, over time could lead to a reduction in basin storage and groundwater recharge potential. Preliminary field observations suggest that runoff from the hillslope likely occurs primarily as sheetflow rather than as concentrated flow which suggests that sediment delivery to the basin may be minimal. Nevertheless, subsequent design work should include measures to minimize concentrated flow and sediment delivery to the basin from the adjacent undeveloped area such as a vegetation buffer with erosion control features along the base of the hillslope parallel to and up-gradient of the basin.

Channel dimensions were based on capacity calculations associated with the 100-yr recurrence interval storm runoff from the combined areas of the developed park and the 15.4-acre hillside. A simple Rational Runoff model for this area estimated 100-yr peak flows from the 3.1 acres of park facility and the adjacent 15.4-acre undeveloped watershed to be approximately 28 cfs. The channel and culvert sizes needed to accommodate this peak discharge were determined using standard open-channel and culvert hydraulic calculations and representative cross sections. The design channel is 2-ft deep, has a bottom width of 5-ft, and has side slopes blending into the existing topography with maximum slopes of 2:1 (Appendix B). A 2.5-ft diameter circular culvert with a slope of 2% connecting the two basins is required to convey the 100-year event (Appendix B).

This design is preliminary and further work by Sonoma County Regional Parks would be necessary to confirm feasibility of this approach. Topographic surveys, soil analysis, and infiltration testing will be necessary to generate construction ready design plans and provide infiltration performance estimates. Typical stormwater retention designs are required to eliminate ponded surface water within 72 hours to prevent mosquitos from breeding; however, this is largely mitigated by the gravel-filled basin design. We did not explicitly simulate this design in the hydrologic model because the scale of the design features is too small to accurately resolve using the 0.5-acre regional model grid. Nevertheless, results from the Runoff Management scenario described in Chapter 8 provide some context regarding the groundwater recharge enhancement and associated streamflow benefits expected from the project.

The regional scenario indicated that management of runoff from 98 acres in the Porter Creek watershed would generate approximately 73.4 ac-ft of additional infiltration recharge. The project design includes a storage volume equivalent to about 1.7% of the storage volume assumed in the regional scenario but only about 0.4% of the surface area. There are many additional factors that may increase or decrease the effectiveness of the design relative to the assumptions of the regional scenario. Nevertheless, these proportions serve as a general guide for estimating the recharge benefits of the proposed project and yield a range of expected additional recharge above background rates of between 0.3 and 1.2-ac-ft/yr.

The reach of Porter Creek adjacent to and downstream of the project site typically goes dry sometime between late May and late July depending on rainfall conditions. The regional modeling indicated that large-scale management of runoff in the Porter Creek watershed could extend the duration of streamflow adjacent to the project reach by 5 to 13 days and increase the mean April through June streamflow by about 0.05 cfs. As discussed above, the project would likely result in less than 2% of the recharge enhancement represented by the regional scenario suggesting that the streamflow benefits of the project by itself would be unlikely to significantly improve flow conditions in lower Porter Creek; though the project's proximity to the intermittent reach of Porter Creek suggests that it may provide greater streamflow benefits than projects located in upstream areas.

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EXHIBIT 3

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
777 Sonoma Avenue, Room 325
Santa Rosa, California 95404-4731

August 30, 2018

Tennis Wick, Director
Permit and Resource Management Department
2550 Ventura Avenue
Santa Rosa, California 95403

Dear Mr. Wick:

This letter communicates NOAA's National Marine Fisheries Service's (NMFS) concerns regarding Permit Sonoma's current protocol for analyzing and permitting cannabis cultivation in Sonoma County, California. NMFS is responsible for conserving threatened and endangered marine species under the federal Endangered Species Act (ESA), and ESA-listed Central California Coast (CCC) coho salmon (*Oncorhynchus kisutch*), CCC steelhead (*O. mykiss*), and California Coastal Chinook salmon (*O. tshawytscha*) reside within many rivers and streams throughout the County. Our concerns stem from the recent proliferation of permitted cannabis cultivation that may have undetermined impacts within watersheds important to the survival and recovery of these salmonid species.

State Water Board regulations concerning cannabis cultivation water usage contain required best management practices (BMP's) highly protective of instream flow volume and fish habitat, such as requiring summer forbearance, winter diversions, and fish friendly bypass flows. However, similar BMP's are not required by the State Water Board for cultivation sites utilizing wells as a source for cannabis cultivation. Because of this discrepancy under state law, the vast majority of cannabis cultivation applications throughout the County are opting for groundwater wells as their water source. We are concerned in particular, that wells are being drilled and pumped without appropriate analysis regarding their potential impact to surface water, especially near-stream wells that may impact groundwater/surface water dynamics and result in streamflow depletion.

NMFS appreciates Sonoma County's required hydrogeological analysis pursuant to General Plan Policy WR-2e, Policy and Procedure 8-1-14, and section 10d of Exhibit A-2 of County Ordinance No. 6189 regarding water availability in Zone 3 and 4 areas.[1] However, after reviewing many hydrogeologic analyses recently submitted to Permit Sonoma as part of individual cannabis cultivation applications, NMFS shares the following comments and suggestions on the analyses, and on Sonoma County groundwater issues in general.

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[1] Sonoma County has produced a map delineating the county into groundwater availability "zones". Based largely upon underlying geologic material. The four zones are: Zone 1 – Major Groundwater Basin; Zone 2 – Major Natural Recharge Area; Zone 3 – Marginal Groundwater Availability; and Zone 4 – Areas with Low of Highly Variable Water Yield. A copy of the map can be found at http://www.sonoma-county.org/prmd/gisdata/pdfs/grndwater_avail_b_size.pdf

Specific concerns regarding the analyses conducted

Appropriate level of coordination and evaluation of cumulative impacts has occurred consistent with the General Plan. According to Sonoma County's "Procedures for Groundwater Analysis and Hydrogeologic Reports":

> *"Prior to conducting the hydrogeologic study, the consultant shall coordinate with Permit Sonoma staff to determine the appropriate cumulative impact area and the projected development within that area. The determination whether or not cumulative impacts have been adequately addressed in the hydrogeologic report will be based upon joint review of the Registered Environmental Health Specialist or the Professional Geologist who responds to the project referral and the Planner, as part of preparing the project Initial Study in accordance with the California Environmental Quality Act (CEQA). If the cumulative impacts in the agreed upon Cumulative Impact Area are determined to be significant adverse impacts or if these impacts are not adequately addresses, the project would be inconsistent with the General Plan".*

In our review of the hydrogeologic analyses included in recent cannabis cultivation applications, there was no mention of coordination between Sonoma County planning staff and the consultant conducting the analysis, or documentation of any coordinated determinations made, regarding cumulative impacts, as required in your procedures. Therefore, we question whether each cumulative impact area was properly identified, and potential adverse impacts determined and adequately addressed.

Lack of identification of existing and abandoned wells within the Cumulative Impact Area. Incomplete consideration of existing and abandoned wells could lead to insufficient data generation when evaluating: 1) interconnections with the nearest surface water bodies and 2) pumping well interference with surrounding wells.

Lack of adherence to well pump test guidelines in water scarce areas. According to the County's Procedures for Groundwater Analysis and Hydrogeologic Reports", test wells are required in Class 4 water scarce areas. Also, the test must be conducted from July 15 to October 1 each year or as extended by the Project Review and Advisory Committee. This time period is referred to as the dry weather pump test period. However, upon review we noted some hydrogeologic reports did not conduct the test during the dry weather pump test period, but instead during the winter/spring period. Adhering to this requirement is critical, since the period when well pumping most impacts streamflow and stream-dwelling salmonids is summer and early fall, when streamflow is naturally lowest.

Adherence to perform proper water balance assessments. Equally important is the water year type chosen for analysis. All water balance assessments should present results for a range of year, including dry years when groundwater pumping impacts are likely greatest. Several of the reviewed hydrogeologic reports present only average water year results. One report roughly simulated a drought condition by assuming 60 percent of the average yearly rainfall, but all other variables in the assessment remained the same (the assumption was not well supported in the analysis). Finally, the range of hydrologic and precipitation data used for analysis varied from report to report; the County should consider providing greater guidance in their protocol documents. For instance, one report only utilized precipitation information from 1945 to 1970. A proper water balance assessment should be calculated with up to date, available data that can be obtained from several sources (*e.g.*, California Irrigation Management Information System (CIMIS), NOAA National Centers for Environmental Information, *etc.*) and should include an evaluation of dry, average and wet years.

Addressing impacts to interconnected surface waters and aquatic habitat. The reports do not properly evaluate significant impacts to groundwater overdraft and potential changes in summer baseflows. It is recommended to analyze the daily hydrological variability during late spring (outmigration), summer and early fall.

Assessing impacts to water temperature. Groundwater discharge provide cool-water environments that protect fish from excessively warm stream temperatures during the summer. Reducing the rate of groundwater discharge to streams by unsustainably pumping hydraulically connected groundwater can warm stream temperatures during the summer and cool stream temperatures during the winter (Barlow and Leake, 2012). The County's required groundwater analysis does not consider this important impact.

General comments relevant to management of ground water in Sonoma County

Chronic lowering of Ground Water levels

The hydrogeologic analysis currently required by County regulations only investigates short-term groundwater dynamics and their potential influence on streamflow depletion. A common misconception is that streamflow depletion stops when pumping ceases. Streamflow depletion continues after pumping stops because it takes time for groundwater levels to recover from previous pumping stress and for the depleted aquifer defined by the cone of depression to be refilled with water (Barlow and Leake, 2012). Analysis addressing this potential impact is required under General Plan Policy WR-2e, which states....

> *Sonoma County must deny discretionary applications in Class 3 and 4 areas unless a hydrogeologic report establishes that groundwater quality and quantity are adequate and will not be adversely impacted by the cumulative amount of development and uses allowed in the area, so that the proposed use will not cause or exacerbate an overdraft condition in a groundwater basin or subbasin. (emphasis added)*

Without an evaluation of long-term trends in groundwater elevation, and how a negative long-term trend, if present, can exacerbate short-term fluctuations caused by well pumping, we question whether impacts to overlying streamflow can be completely assessed, and advise that a hydrogeologic report which fails to address these issues be labeled deficient per County policy.

Lack of coordination between Cannabis Permit Procedures and the Sustainable Groundwater Management Act

As alluded to above, Permit Sonoma does not appear to be considering future groundwater management required under the Sustainable Groundwater Management Act of 2014 (SGMA) when permitting groundwater use for cannabis cultivators and other water users. SGMA requires that groundwater basins that are unsustainably managed (*i.e.,* having one or more of six undesirable results caused by overdraft, of which streamflow depletion impacting beneficial uses is one) must achieve sustainability (avoiding all undesirable results) through developing and implementing a 20-year Groundwater Sustainability Plan. Currently, the County contains three basins requiring groundwater management per the Act, while three additional Sonoma County basins were recently upgraded by the State as exhibiting unsustainable groundwater use and will also require future groundwater management.[2]

Generally speaking, restoring these basins back to sustainability will likely include greater groundwater recharge, less groundwater pumping, or some combination of the two. That Sonoma County is considering permitting groundwater use for cannabis cultivation and other development in overdrafted basins governed under SGMA is concerning, since some of these basins likely suffer from some degree of streamflow depletion currently that is potentially impacting ESA-listed salmon and steelhead. For example, the county has received 38 applications for cannabis cultivation sites overlying the Santa Rosa Plain groundwater basin, which is currently acknowledged as suffering streamflow depletion caused by groundwater pumping. These applications represent a tiny fraction of the over 400 suspected cultivation sites in the basin (Tim Dodson, CDFW, personal communication), so many more applications are likely forthcoming in the near future. In short, adding more groundwater pumping to these basins is inconsistent with restoring these basins to sustainability in the future. In SGMA groundwater basins, Sonoma County should either delay well permitting until SGMA coordination occurs, require the use of public water supplies, or require winter pumping and storage. Moreover, continuing to expand groundwater use in over-extracted basins may create conflict in striving to achieve sustainability amongst various users if future pumping restrictions are necessary.[3]

Exclusion Watersheds

Both Mark West Creek and Green Valley Creek watersheds high priority habitat for salmon and steelhead and support endangered coho salmon and threatened steelhead. Unfortunately, both of these watersheds are impacted by summer low flow caused primarily by groundwater pumping. A hydrology study by CEMAR (2015) concluded that groundwater pumping in Upper Mark West Creek likely results in lower summer baseflow, while low summer streamflow, partially caused by groundwater pumping, led to the State Water Board's 2014 Emergency Order restricting groundwater and surface water use aimed at protecting federal and state-listed

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[2] The Santa Rosa Plain, Sonoma Vallley and Petaluma groundwater basins are currently Medium priority under SGMA. The Alexander Valley, Healdsburg Area, and Wilson Grove groundwater basins are proposed for upgrading to Medium priority.

[3] Unlike surface water, groundwater in California is not governed by the "first in time, first in right" doctrine. Instead, all property owners using groundwater have the same right to the resource regardless of when they first began using the resource, and thus may share in any future restrictions.

salmonids in Green Valley Creek. Moreover, Mark West Creek is one of five California streams prioritized for future flow enhancement and fisheries recovery as part of California's Water Action Plan. Since continued groundwater development in these basins will likely further impair summer baseflows in the future, NMFS recommends Permit Sonoma limit future groundwater development in these basins until the effects of long-term, chronic groundwater depletion and its impact on summer baseflow are properly analyzed. At minimum, NMFS suggests Permit Sonoma require that future groundwater pumping be limited to winter months when streamflow impacts are muted, and that pumped water be stored for summer use (*i.e.,* no summer pumping). We cite the CEMAR (2015) report, which recommended winter storage and summer forbearance as appropriate water resource management in Upper Mark West Creek.

NMFS appreciates the opportunity to present our concerns regarding groundwater development in Sonoma County and ways to minimize its potential impact on streamflow and ESA-listed salmonids. We look forward to working with the County in recovering salmon and steelhead populations while ensuring Sonoma County's economy remains strong. If you have any comments or questions regarding this letter, please contact Mr. Rick Rogers of my staff at rick.rogers@noaa.gov, or 707-578-8552.

Sincerely,

Robert Coey
North Coast Branch Supervisor
North-Central Coast Office

cc. (via email)
Bryan McFadin, North Coast Regional Water Quality Control Board (Bryan.McFadin@waterboards.ca.gov)Corinne Gray, California Department of Fish and Wildlife (Corinne.Gray@wildlife.ca.gov)
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Lisa Hulette, County of Sonoma, Natural Resources Division (Lisa.Hulette@sonoma-county.org)
Daniel Schultz, State Water Board (Daniel.Schultz@waterboards.ca.gov)

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Center for Ecosystem Management and Restoration (CEMAR). 2015. Report on the Hydrologic Characteristics of Mark West Creek. Nov 14, 2014 (Updated Jan 28, 2015). 58 pages. Available at: http://cemar.org/pdf/Report%20on%20the%20Hydrologic%20Characteristics%20of%20Mark%20West%20Creek.pdf

EXHIBIT 4

Environmental Science & Technology
Viewpoint
pubs.acs.org/est

High Time to Assess the Environmental Impacts of Cannabis Cultivation

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On November 8, 2016, four additional U.S. states (California, Massachusetts, Nevada, and Maine) legalized the use of recreational marijuana and four more relaxed medical marijuana laws. This is effectively creating a new industry in United States, one that looks set to rival all but the largest of current businesses with projected income expected to exceed that of the National Football League by 2020. In Colorado sales revenues have reached $1 billion, roughly equal to that from grain farming in the state and a third higher than residential construction,[1] an industry with strict environmental monitoring procedures.

The few studies that have investigated specific practices associated with marijuana cultivation have identified potentially significant environmental impacts due to excessive water and energy demands and local contamination of water, air, and soil with waste products such as organic pollutants and agro-chemicals[2,3] (see Figure 1). *Cannabis* spp. require high temperatures (25−30 °C for indoor operations), strong light (~600 W m^{-2}), highly fertile soil,[2] and large volumes of water (22.7 l d^{-1} per plant,[3] around twice that of wine grapes[3]). A study of illegal outdoor grow operations in northern California found that rates of water extraction from streams threatened aquatic ecosystems[3] and that water effluent contained high levels of growth nutrients, as well as pesticides, herbicides and fungicides, further damaging aquatic wildlife.[3]

Controlling the indoor growing environment requires considerable energy inputs, with concomitant increases in greenhouse gas emissions.[2] It has been estimated that the power density of marijuana cultivation facilities is equal to that of data centers and that illicit grow operations account for 1% of the U.S.'s average energy usage.[2] The carbon footprint of indoor growing facilities, however, is heavily dependent on the power source. For example, illicit growers relying on generators produce more than three times the CO_2 of facilities powered by the grid.[2] There is, therefore, significant potential to reduce both the energy consumption and the carbon footprint through more informed decisions regarding growing conditions, the equipment used and the power source.

Considerably less is known about the potential impacts of this industry on indoor and outdoor air quality. Sampling carried out in conjunction with law enforcement raids on illicit grow operations have measured concentrations of highly reactive organic compounds that were 5 orders of magnitude higher than background.[4] These compounds have clear implications for indoor air quality and thus occupational health, but also on outdoor air quality. In regions where volatile organic compound (VOC) emissions are low relative to those of nitrogen oxides (released from combustion processes), even a small increase in VOC emissions can result in production of secondary pollutants such as ozone and particulate matter. Since these latter compounds are both criteria air pollutants, such a shift in conditions could then lead to nonattainment of the National Air Quality Standards.

Previous studies have been hampered by a lack of reliable data[5] on which to base assessments of the likely consequences of large-scale cultivation and production of marijuana (see Figure 1). The impacts are therefore predicated on conditions and practices prevalent in illicit grow operations. Given that the methods employed in these illegal operations are driven by the need for secrecy, the methods have not been optimized to minimize environmental damage. This speaks to the urgent need for rigorous scientific research and evaluation to aid the new industry and relevant regulatory bodies in assessing the current environmental threats of marijuana cultivation, identifying the opportunities to mitigate such impacts, and developing a framework of stewardship worthy of a modern progressive industry.

Research, both fundamental and applied, is required in the following areas:

Agronomy and plant physiology:

- determine growth rates and cycles of commonly grown *Cannabis* spp. strains;

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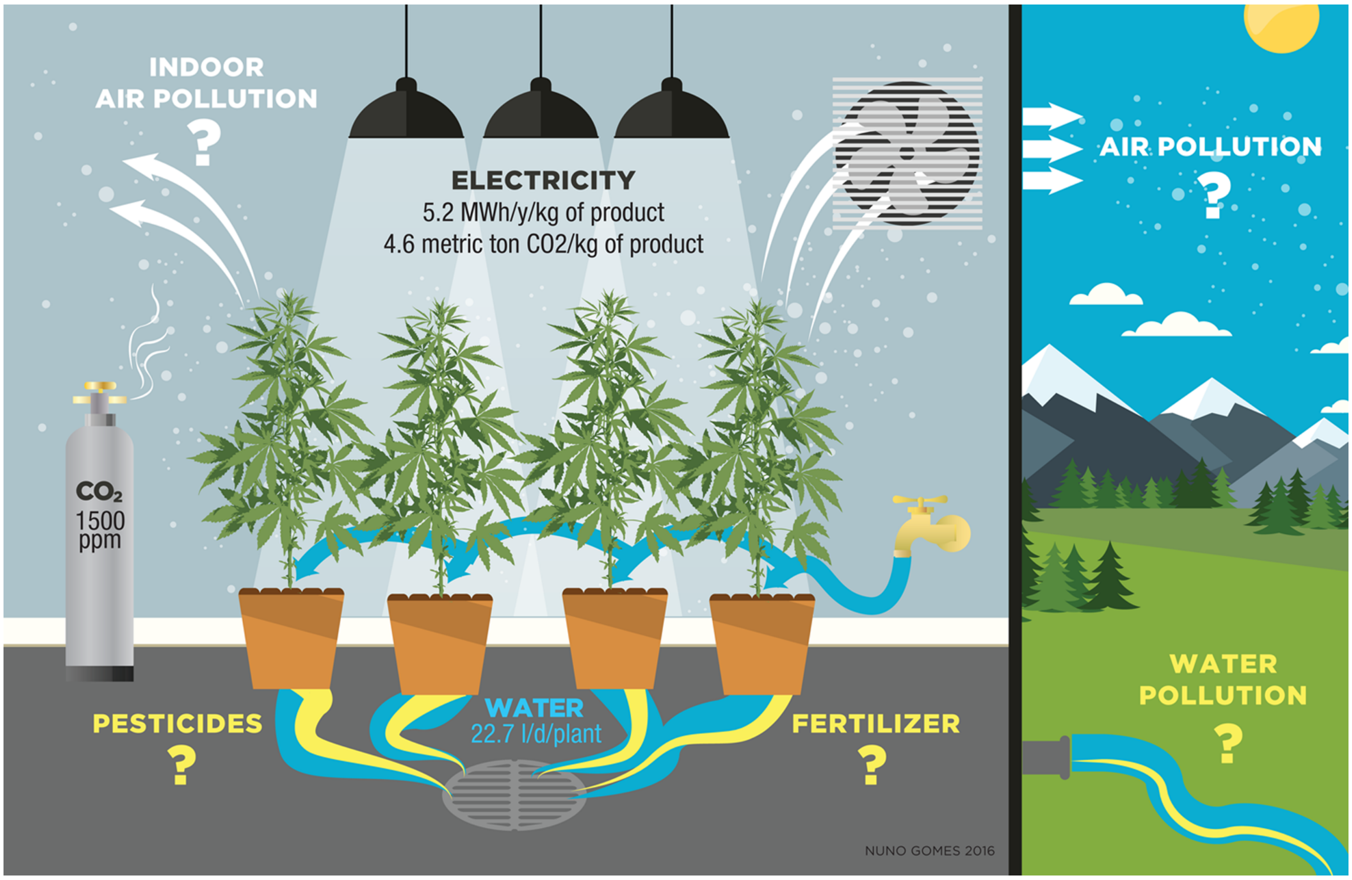

Figure 1. Environmental impacts of indoor marijuana cultivation[1−3] (a question mark indicates that the magnitude of the effect has not been previously estimated). Figure credit: Nuno Gomes 2016.

- determine optimal growth conditions for each stage of the growing cycle;
- identify best practices for minimizing water use and irrigation; and
- identify best practices for minimizing fertilizer, fungicide, and pesticide application.

Waste treatment and management:

- analyze wastewater streams, evaluate pollutant concentrations and explore the possibility of (a) reducing pollution through good agronomy practice and (b) pretreating effluents before discharge; and
- identify best practices for reducing solvent use for processing harvested plant material, and for treating waste prior to discharge.

Outdoor air quality:

- identify and measure emission rates of volatiles from *Cannabis* spp. at different developmental stages and growing conditions;
- identify and measure emission rates of volatiles from soils and plant detritus;
- measure concentrations of trace gases and particles in grow operations and the atmosphere outside such facilities; and
- identify opportunities for reducing emissions.

Occupational health

- identify and quantify the risks to workers exposed to conditions encountered within grow operations.

Such research falls firmly within the remit of U.S. Federal funding agencies, including the U.S. Department of Agriculture, Environmental Protection Agency, National Institutes of Health, and Occupational Safety and Health Administration. The ambiguous legal status of marijuana in the U.S., however, has made it historically difficult for these agencies to actively fund research in this field.[5] We call for this situation to be urgently addressed and funding made available to determine the risk posed to the workforce, the public and the natural environment by this burgeoning industry.

This is an industry undergoing a historic transition, presenting an historic opportunity to be identified as a progressive, world-leading example of good practice and environmental stewardship. Such recognition would lend itself to branding via an "eco-label" scheme that could include formulation of exemplar practices and procedures at every stage of production and supply such as those found in the Marine Stewardship Council's "Certified sustainable seafood." Advanced certification could encourage on-site energy generation from renewable sources, treatment and reuse of irrigation water, and organic growing practices. Such a scheme would provide an incentive for businesses to engage with local agencies, communities and regulators to conduct full environmental impact assessments of marijuana grow operations to minimize risk. This inclusive solutions-based approach would set the bar in accountability and transparency, allowing consumers to make a genuine choice and establishing a progressive business model fit for the 21st century that could act as a roadmap for others to follow.

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Notes

The authors declare no competing financial interest.

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Environ. Sci. Technol. 2017, 51, 2531−2533

EXHIBIT 5

PLOS | ONE

RESEARCH ARTICLE

Impacts of Surface Water Diversions for Marijuana Cultivation on Aquatic Habitat in Four Northwestern California Watersheds

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Data Availability Statement: Most data used are available via public sources (USGS gage data, EWRIMS, and Google Earth), but specific spatial locations of marijuana grows cannot be shared due to legal and privacy concerns. Summary data and all methods/information needed to replicate the study are included in the manuscript. Plant counts and greenhouse counts and measurements for all watersheds are included as Supporting Information (excel spreadsheets).

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Abstract

Marijuana (*Cannabis sativa* L.) cultivation has proliferated in northwestern California since at least the mid-1990s. The environmental impacts associated with marijuana cultivation appear substantial, yet have been difficult to quantify, in part because cultivation is clandestine and often occurs on private property. To evaluate the impacts of water diversions at a watershed scale, we interpreted high-resolution aerial imagery to estimate the number of marijuana plants being cultivated in four watersheds in northwestern California, USA. Low-altitude aircraft flights and search warrants executed with law enforcement at cultivation sites in the region helped to validate assumptions used in aerial imagery interpretation. We estimated the water demand of marijuana irrigation and the potential effects water diversions could have on stream flow in the study watersheds. Our results indicate that water demand for marijuana cultivation has the potential to divert substantial portions of streamflow in the study watersheds, with an estimated flow reduction of up to 23% of the annual seven-day low flow in the least impacted of the study watersheds. Estimates from the other study watersheds indicate that water demand for marijuana cultivation exceeds streamflow during the low-flow period. In the most impacted study watersheds, diminished streamflow is likely to have lethal or sub-lethal effects on state-and federally-listed salmon and steelhead trout and to cause further decline of sensitive amphibian species.

Introduction

Marijuana has been cultivated in the backwoods and backyards of northern California at least since the countercultural movement of the 1960s with few documented environmental impacts [1]. Recent increases in the number and size of marijuana cultivation sites (MCSs) appear to be, in part, a response to ballot Proposition 215, the Compassionate Use Act (1996). This California law provides for the legal use and cultivation of medical marijuana. In 2003, legislation was passed in an attempt to limit the amount of medical marijuana a patient can possess or

Competing Interests: The authors have declared that no competing interests exist.

cultivate (California State Senate Bill 420). However, this legislation was struck down by a 2010 California Supreme Court decision (*People v. Kelly*). As a result of Proposition 215 and the subsequent Supreme Court ruling, the widespread and largely unregulated cultivation of marijuana has increased rapidly since the mid-1990s in remote forested areas throughout California [2]. California is consistently ranked highest of all states for the number of outdoor marijuana plants eradicated by law enforcement: from 2008–2012 the total number of outdoor marijuana plants eradicated in California has ranged from 53% to 74% of the total plants eradicated in the United States [3]. In spite of state-wide prevalence, there is not yet a clear regulatory framework for the cultivation of marijuana, and from an economic viewpoint there is little distinction between plants grown for the black market and those grown for legitimate medical use [4].

Northwestern California has been viewed as an ideal location for marijuana cultivation because it is remote, primarily forested, and sparsely populated. Humboldt, Mendocino, and Trinity Counties, the three major counties known for marijuana cultivation in Northwestern California [5], comprise 7% (26,557 km^2) of the total land area of the state of California. However, their combined population of 235,781 accounts for only 0.62% of the state's total population (United States Census Data 2012). Humboldt County, with an area of 10,495 km^2, has over 7689 km^2 of forestland comprising more than 70% of its land base. More importantly, Humboldt County has 5,317 km^2 of private lands on over 8,000 parcels zoned for timber production [6]. This makes Humboldt County a feasible place to purchase small remote parcels of forestland for marijuana cultivation.

The broad array of impacts from marijuana cultivation on aquatic and terrestrial wildlife in California has only recently been documented by law enforcement, wildlife agencies, and researchers. These impacts include loss and fragmentation of sensitive habitats via illegal land clearing and logging; grading and burying of streams; delivery of sediment, nutrients, petroleum products, and pesticides into streams; surface water diversions for irrigation resulting in reduced flows and completely dewatered streams [2,7–10]; and mortality of terrestrial wildlife by rodenticide ingestion [11,12]. Though these impacts have been documented by state and federal agencies, the extent to which they affect sensitive fish and wildlife species and their habitat has not been quantified. These impacts have gained attention in recent years [7,9] because of the continuing prevalence of "trespass grows," illicit marijuana cultivation on public land. In comparison, the extent of cultivation and any associated environmental impacts on private lands are poorly understood, primarily because of limited access. In addition, state and local agencies lack the resources to address environmental impacts related to cultivation on private lands. In contrast with many MCSs on public lands, MCSs on private lands appear to be legal under state law, pursuant to Proposition 215. Regardless of the legal status of these MCSs, the water use associated with them has become an increasing concern for resource agencies [13].

California's Mediterranean climate provides negligible precipitation during the May—September growing season. In Northern California, 90–95% of precipitation falls between October and April [14]. Marijuana is a high water-use plant [2,15], consuming up to 22.7 liters of water per day. In comparison, the widely cultivated wine grape, also grown throughout much of Northwestern California, uses approximately 12.64 liters of water per day [16]. Given the lack of precipitation during the growing season, marijuana cultivation generally requires a substantial amount of irrigation water. Consequently, MCSs are often situated on land with reliable year-round surface water sources to provide for irrigation throughout the hot, dry summer growing season [7,8,12]. Diverting springs and headwater streams are some of the most common means for MCSs to acquire irrigation water, though the authors have also documented the use of groundwater wells and importing water by truck.

The impacts to aquatic ecosystems from large hydroelectric projects and other alterations of natural flow regimes have been well documented [17–20], but few studies have attempted to quantify the impacts of low-volume surface water diversions on stream flows [21,22]. A study in the Russian River watershed in Sonoma County, CA, concluded that the demand of registered water diversions exceeded stream flows during certain periods of the year, though this study did not quantify unregistered diversions. In addition, this study indicates that these registered diversions have the potential to depress spring base flows and accelerate summer recession of flows [22]. We postulate that the widespread, increasing, and largely unregulated water demands for marijuana cultivation, in addition to existing domestic demands, are cumulatively considerable in many rural Northern California watersheds.

In northern California, unregulated marijuana cultivation often occurs in close proximity to habitat for sensitive aquatic species. Because of this proximity and the water demands associated with cultivation, we chose to focus on the cumulative impacts of low-volume surface water diversions associated with marijuana cultivation. We evaluate these water demands at a watershed scale to determine whether they could have substantial effects on streamflow during the summer low-flow period. In addition, we discuss which sensitive aquatic species are most likely to be impacted by stream diversions and describe the nature of these impacts.

Methods

Methods are presented for the following components of the study: study area selection, data collection, water use estimates, and hydrologic analysis. For the purposes of this study, a MCS is defined as any area where marijuana is grown, either outdoors or inside a greenhouse, based on our aerial image interpretation. Because marijuana cultivation is federally illegal, its scope and magnitude are difficult to measure precisely [2,4,23]. However, the authors have accompanied law enforcement on search warrants and site inspections to evaluate more than 40 MCSs in the Eel River watershed and other watersheds in northwestern California. During these site inspections the number, size, and arrangement of marijuana plants were recorded, as were the water sources, conveyance and storage methods. These on-the-ground verification data were used as the basis for identifying characteristics of MCSs from aerial images.

Study Areas

Four study watersheds were selected—Upper Redwood Creek, Salmon Creek, and Redwood Creek South, located in Humboldt County; and Outlet Creek, located in Mendocino County (Figs. 1–4). Study watersheds were selected using the following criteria: (1) they are dominated by privately owned forestlands and marijuana cultivation is widespread within their boundaries as verified by low altitude survey flights and aerial imagery. (2) The primary watercourse, or downstream receiving body, has documented populations of sensitive aquatic species, such as coho salmon (*Oncorhynchus kisutch*). (3) Watersheds are of sufficient size so as to allow realistic population-scale and regional ecological relevance, but are not so large that conducting an analysis would be infeasible given limited staffing resources. (4) Streams in the watershed had either a flow gage, or nearby streams were gaged, which would allow proxy modeling of the low-flow period in the study watershed.

Habitat

The study watersheds are dominated by a matrix of open to closed-canopy mixed evergreen and mixed conifer forests with occasional grassland openings. Dominant forest stands include Tanoak (*Notholithocarpus densiflorus*) and Douglas-fir (*Pseudotsuga menziesii*) Forest Alliances ("Alliance" is a vegetation classification unit that identifies one or more diagnostic species in the upper canopy layer that are indicative of habitat conditions) [24]. These forests are dominated by Douglas—fir, tanoak, madrone (*Arbutus menziesii*), big leaf maple (*Acer*

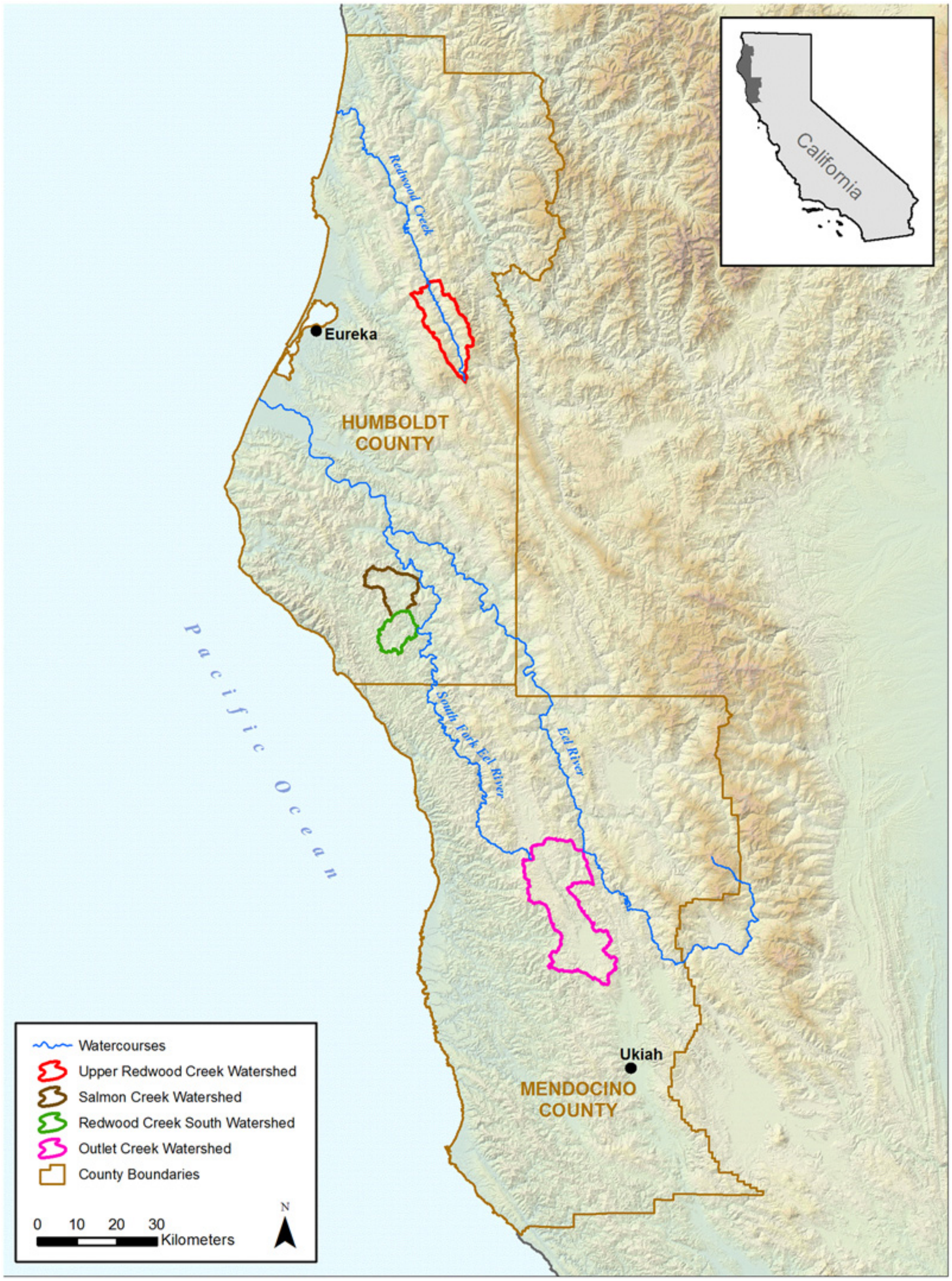

Fig 1. Study Watersheds and Major Watercourses.

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macrophyllum), and various oak species (*Quercus* spp.). The Redwood (*Sequoia sempervirens*) Forest Alliance, as described by Sawyer et al. [24] is dominant in areas of Upper Redwood Creek and in lower Salmon Creek and Redwood Creek South and includes many of the same dominant or subdominant species in the Tanoak and Douglas-fir Forest Alliances. These watersheds, a product of recent and on-going seismic uplift, are characterized as steep

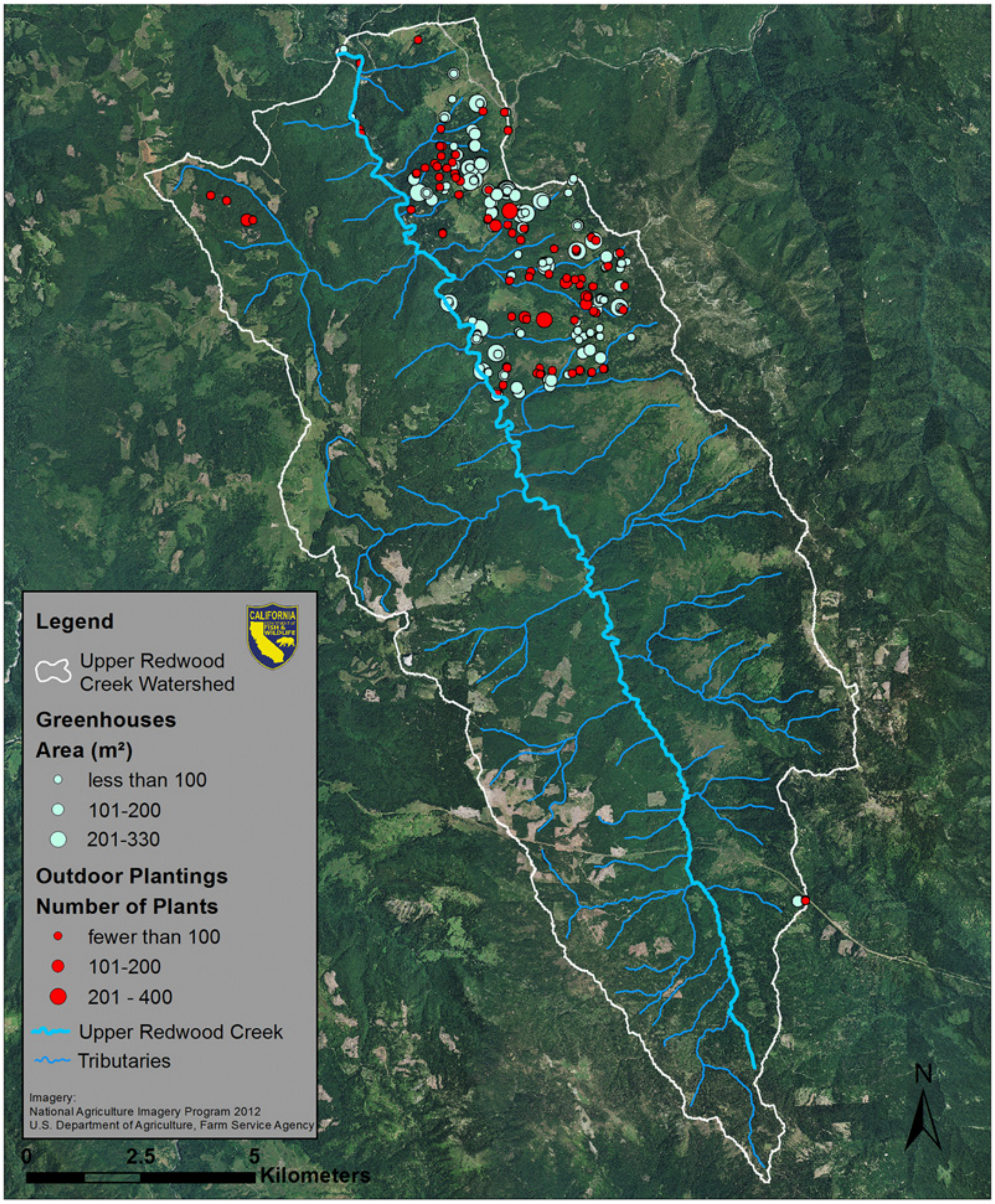

Fig 2. Upper Redwood Creek Watershed. Outdoor marijuana plantings are marked in red and greenhouses are marked in light green.

doi:10.1371/journal.pone.0120016.g002

mountainous terrain dissected by an extensive dendritic stream pattern, with the exception of Upper Redwood Creek, which has a linear trellised stream pattern [25].

Data Collection and Mapping Overview

Study watershed boundaries were modified from the Calwater 2.2.1 watershed map [26] using United States Geological Survey (USGS) 7.5 minute Digital Raster Graphic images to correct for hydrological inconsistencies. These watershed boundaries and a reference grid with one square kilometer (km^2) cells were used in Google Earth mapping program and ArcGIS (version 10.x, ESRI, Redlands, CA). Using Google Earth's high-resolution images of northern California

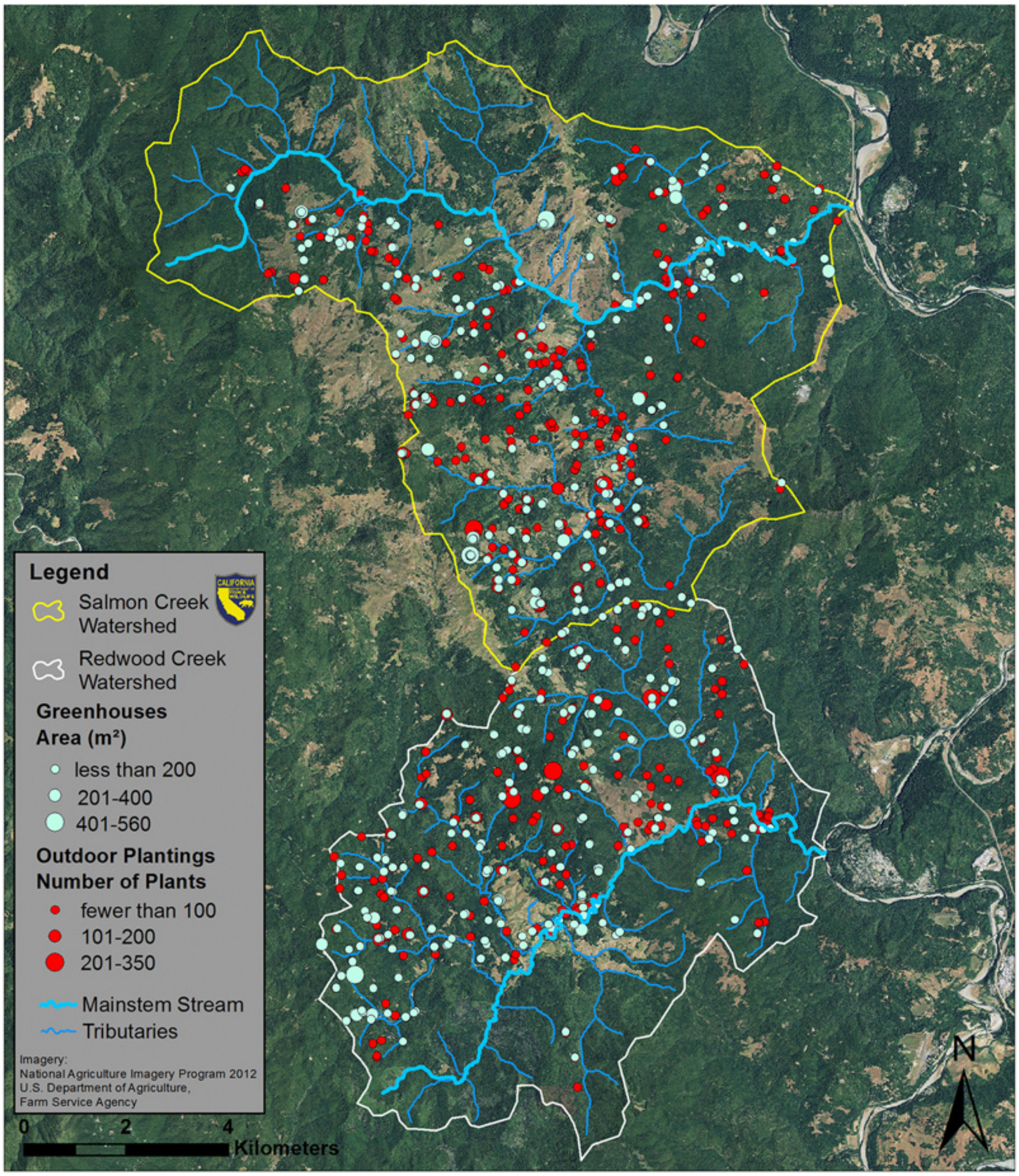

Fig 3. Salmon Creek and Redwood Creek South Watersheds. Outdoor marijuana plantings are marked in red and greenhouses are marked in light green.

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(image dates: 8/17/11, 7/9/12, and 8/23/12) as a reference, features of interest such as greenhouses and marijuana plants were mapped as points in ArcGIS. We identified greenhouses by color, transparency, elongated shape, and/or visible plastic or metal framework. Although we could not confirm the contents of greenhouses, the greenhouses we measured were generally associated with recent land clearing and other development associated with the cultivation of marijuana, as observed in our site inspections with law enforcement. Greenhouses clearly associated with only non-marijuana crop types, such as those in established farms with row crops, were excluded from our analysis. We identified outdoor marijuana plants by their shape, color, size and placement in rows or other regularly spaced configurations. We measured greenhouse lengths and widths using the Google Earth "Ruler" tool to obtain area, and counted and recorded the number of outdoor marijuana plants visible within each MCS. We also examined

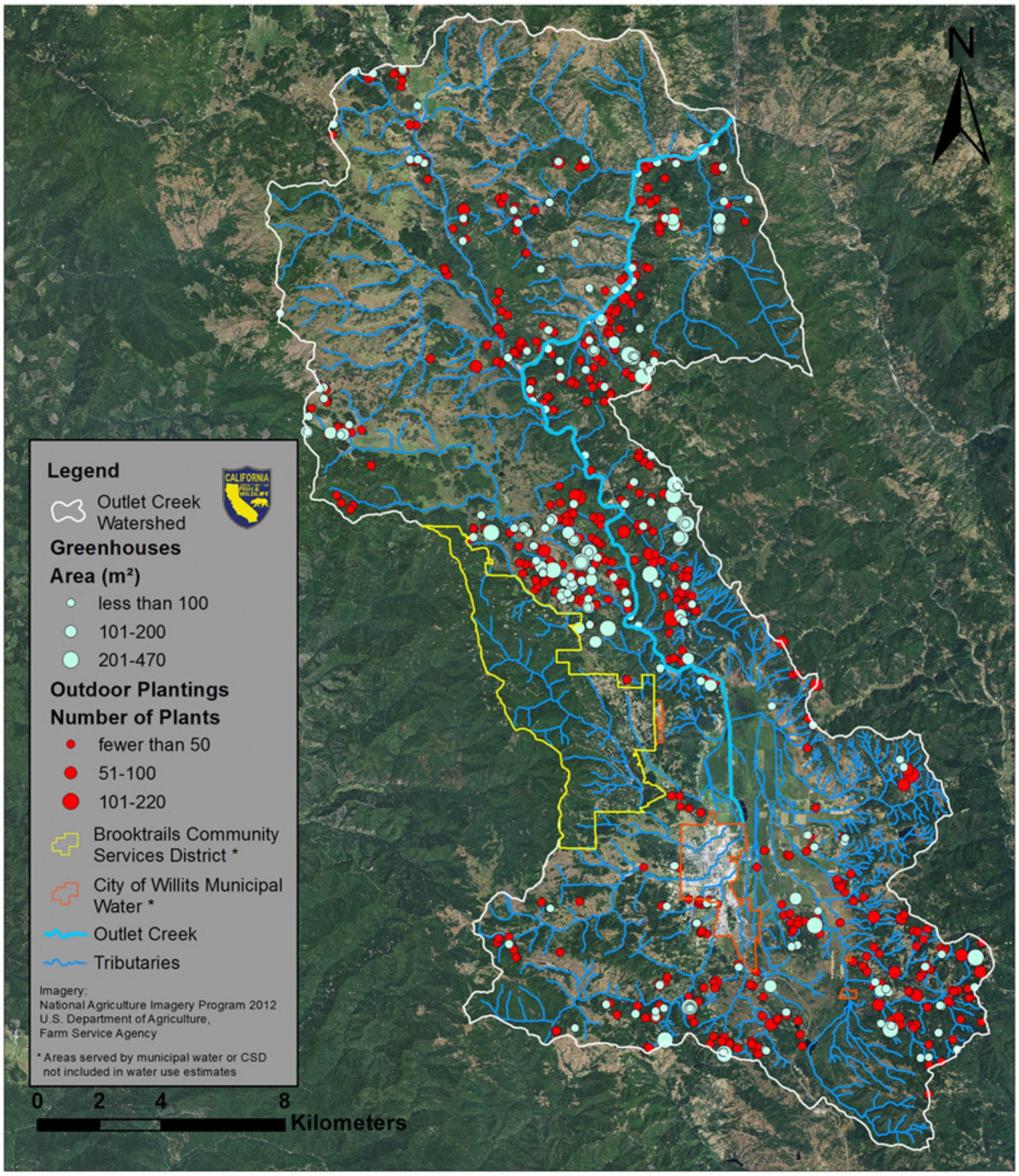

Fig 4. Outlet Creek Watershed. Outdoor marijuana plantings are marked in red and greenhouses are marked in light green.

doi:10.1371/journal.pone.0120016.g004

imagery from previous years using the Google Earth "Historical Imagery" tool to confirm that outdoor plants were not perennial crops, such as orchards.

Plant Abundance and Water Use Estimates

For each watershed, we totaled the number of marijuana plants that were grown outdoors and combined this value with an estimated number of marijuana plants in greenhouses to get a total number of plants per watershed. To develop a basis for estimating the number of marijuana plants in greenhouses, we quantified the spatial arrangement and area of marijuana plants in 32 greenhouses at eight different locations in four watersheds in Humboldt County while accompanying law enforcement in 2013. We calculated 1.115 square meters (m^2) per plant as an average spacing of marijuana plants contained within greenhouses. For the purposes of this study, we assume that the average greenhouse area to plant ratio observed by the authors on law enforcement visits was representative of the average spacing used at MCSs in the study watersheds.

Our water demand estimates were based on calculations from the 2010 Humboldt County Outdoor Medical Cannabis Ordinance draft [27], which states that marijuana plants use an average of 22.7 liters per plant per day during the growing season, which typically extends from June-October (150 days). Water use data for marijuana cultivation are virtually nonexistent in the published literature, and both published and unpublished sources for this information vary greatly, from as low as 3.8 liters up to 56.8 liters per plant per day [7,28]. The 22.7 liter figure falls near the middle of this range, and was based on the soaker hose and emitter line watering methods used almost exclusively by the MCSs we have observed. Because these water demand estimates were used to evaluate impacts of surface water diversion from streams, we also excluded plants and greenhouses in areas served by municipal water districts (Outlet Creek, Fig. 4).

Hydrologic Analyses: Estimating Impacts on Summer Low Flows

The annual seven-day low flow, a metric often used to define the low flow of a stream, is defined as the lowest value of mean discharge computed over any seven consecutive days within a water year. This value varies from year to year. Annual seven-day low flow values for the ungaged watersheds in this study were estimated by correlating to nearby USGS gaged streams. Annual seven-day low flow values for Elder Creek (Fig. 5), a gage used for this correlation, demonstrate the year-to-year variability in the study watersheds. Elder Creek is considered to be the least disturbed of the gaged watersheds, and is also the smallest, with a contributing area of 16.8 square kilometers. The annual seven-day low flow estimates were made by scaling the gaged data by the ratio of average flow of the ungaged and gaged stream, a method that provides better estimates than scaling by watershed area [29]. Regression equations based on average annual precipitation and evapotranspiration were used to estimate average annual flow, providing a more unique flow characterization than using watershed area alone. These methods were developed by Rantz [30]. The gaged data were either from within the watershed of the study area or from a nearby watershed. Correlation with daily average flow data from a gaged

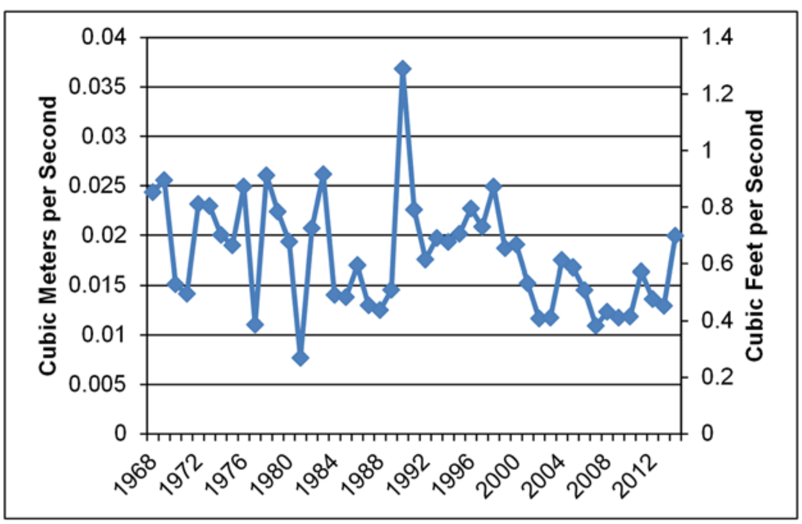

Fig 5. Elder Creek annual seven-day low flow. Values are shown for the period of record (water years 1968–2014).

doi:10.1371/journal.pone.0120016.g005

stream makes sense when the ungaged watershed is considered to be hydrologically similar to the gaged watershed, i.e. similar geology, vegetation, watershed size and orientation, and atmospheric conditions (precipitation, cloud cover, temperature). The accuracy of gaged data at low flows can be problematic because gaging very low flows is difficult and limited depending on the location of the gage and the precision in low-flow conditions, but the method can still provide a rough estimate of low flow by taking into account the range of uncertainty. Data were used from the closest most relevant gaged watershed for correlation to the ungaged sites.

Data for the gaged stations are shown in Table 1. This table includes the estimated average annual flow calculated from both the gaged data and also by use of the regression equations for comparison. The annual seven-day low flow for the period of record of each of the gaged stations is shown in Table 2. This table also shows the minimum, average, and maximum seven-day low flow values over the period of record as a way to represent the variability of the low flow from year to year. To estimate the annual seven-day low flow for the ungaged streams, the average annual seven-day low flow of the gaged stream was multiplied by the ratio of the annual average streamflow of the ungaged stream and the annual average streamflow of the gaged stream. A range of values, including the lowest and highest estimate for each location were calculated to represent the annual variability.

The mean annual streamflow of each ungaged stream was estimated using a regression equation, based on estimates of runoff and basin area developed by Rantz [30] (Equation 1). The mean annual runoff was estimated from a second regression equation (Equation 2) based on the relationship between mean annual precipitation and annual potential evapotranspiration for the California northern coastal area [30]. Mean annual precipitation values are from the USGS StreamStat web site (http://water.usgs.gov/osw/streamstats/california.html), which uses the PRISM average area weighted estimates based on data from 1971–2000. The estimates of mean annual evapotranspiration were taken from a chart produced by Kohler [31].

$$Q_{Avg} = 0.07362 = \left(\frac{m^3}{sec} \times yr \times cm \times km^2\right) \times R \times A \qquad eq.(1)$$

Table 1. USGS stream gages in or near study watersheds.

Watershed	Gage	Period of Record	Area (km^2)	MAP[a] (cm/yr)	PET[b] (cm/yr)	Mean Annual Runoff (cm/yr)	Q[c]avg (CMS[d]), predicted	Qavg (CMS), gaged	% difference
South Fork Eel River	USGS 11476500	10/1/1930–9/30/2012	1390.8	192.8	101.6	129.0	57.8	52.0	-11.1
Bull Creek	USGS 11476600	10/1/1967–9/30/2012	72.5	166.4	101.6	102.6	2.4	3.3	27.1
Elder Creek	USGS 11475560	10/1/1967–9/30/2012	16.8	215.9	101.6	152.1	0.8	0.7	-14.9
Outlet Creek	USGS 11472200	10/1/1956–9/30/1994	417.0	152.9	101.6	89.2	12.1	11.1	-8.8
Upper Redwood Creek	USGS 11481500	10/01/1953–10/1/2013	175.3	231.1	86.4	173.5	9.6	8.5	-12.6
Redwood Creek South	Ungaged	N/A	64.7	157.2	101.6	93.5	0.46	N/A	N/A
Salmon Creek	Ungaged	N/A	95.1	151.4	101.6	87.6	0.48	N/A	N/A

[a]mean annual precipitation

[b]potential evapotranspiration

[c]flow

[d]cubic meters per second

doi:10.1371/journal.pone.0120016.t001

Table 2. Annual seven-day low flow range for period of record.

Gage	Seven-day low flow for period of record in cubic meters per second		
	Minimum	Average	Maximum
SF Eel Miranda	0.3519	0.8829	1.796
Bull	0.0059	0.0310	0.0853
Elder	0.0076	0.0180	0.0368
Outlet Creek	0.0000	0.0162	0.0498
Upper Redwood Creek	0.0265	0.1064	0.2601
Redwood Creek South (based on Elder Creek)	0.004	0.010	0.021
Salmon Creek (based on Elder Creek)	0.005	0.011	0.022

doi:10.1371/journal.pone.0120016.t002

With

$$R = MAP - 0.4(PET) - 9.1$$

Where

$$Q_{Avg} = \textit{mean annual discharge}\left(\frac{m^3}{sec}\right)$$

$$R = \textit{mean annual runoff}\left(\frac{cm}{yr}\right)$$

$$A = \textit{drainage area}(km^2)$$

$$MAP = \textit{mean annual precipitation}\left(\frac{cm}{yr}\right)$$

$$PET = \textit{potential evapotranspiration}\left(\frac{cm}{yr}\right)$$

Estimates of average annual flow made by using these equations range from-15% to +27% below and above the calculated value using the gaged daily average data (Table 1). The Bull Creek gage estimate produced the largest deviation of 27% and may be considered an outlier because of the known disturbances in the watershed due to historic logging practices, and USGS reported "poor" low flow data.

The mean annual flow for each ungaged watershed was calculated using the Rantz method described above. The mean annual precipitation and runoff values are shown in Table 1 with the predicted mean annual flow for the ungaged streams. The annual seven-day low flows for Upper Redwood Creek and Outlet Creek were calculated using data from their respective stream gages. For Redwood Creek South and Salmon Creek, both watersheds with no main-stem gage, the annual seven-day low flow was calculated in the same way by using the data from nearby gaged streams within the South Fork Eel watershed (Bull Creek, Elder Creek, and South Fork Eel near Miranda gage). Fig. 6 shows three different estimates of the duration curves of the annual seven-day low flow for the Redwood Creek South ungaged site based on the three different nearby gages. The variations between these estimated duration curves (Fig. 6) illustrate the relative variability of annual seven-day low flow. Reasons for this

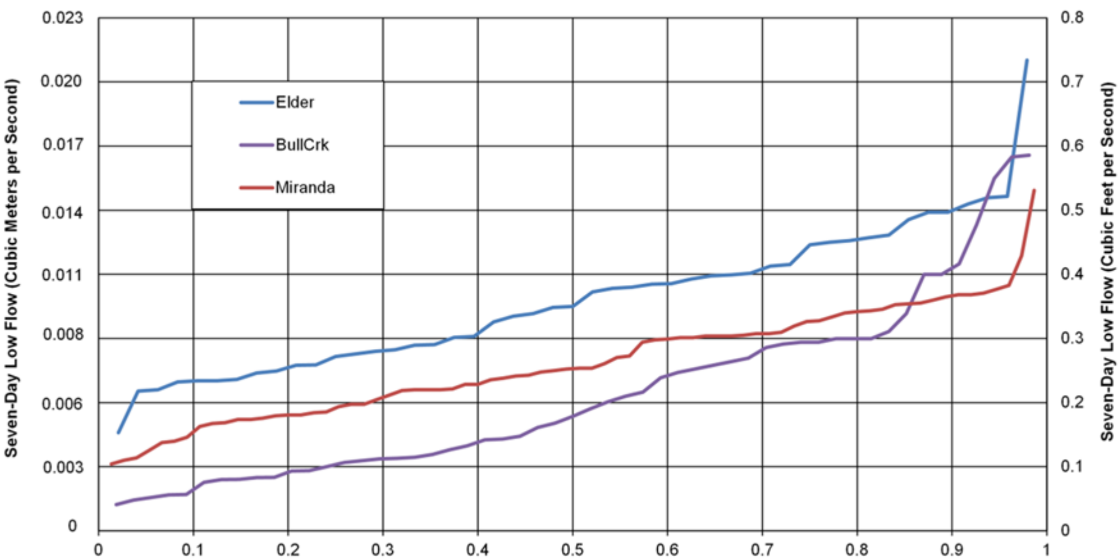

Fig 6. Duration curve of estimates of annual seven-day low flow for Redwood Creek South based on USGS data from nearby streams (Elder Creek, South Fork Eel at Miranda, and Bull Creek).

doi:10.1371/journal.pone.0120016.g006

variability may include the difference in hydrologic response of the gaged watersheds from the ungaged watersheds, differences in withdrawals or low flow measurement error, differences in the atmospheric patterns over the watershed, or differences in watershed characteristics (watershed size, orientation, land use, slope etc.). The gaged watersheds differed from the study watersheds in several ways, such as size (Miranda gage), disturbance (Bull Creek gage), and distance and orientation from the study watersheds (Elder Creek gage). Despite the differences, the Elder Creek gage most likely represents the best data set for correlation to the ungaged watersheds based on its similar size and relative unimpairment. The estimated values represent the upper limit of low flows for the ungaged streams, thus are conservative values and may be an overestimate.

Results

MCSs were widespread in all four study watersheds. In general, MCSs were clustered and were not evenly distributed throughout the study watersheds (Figs. 2–4). Estimated plant totals ranged from approximately 23,000 plants to approximately 32,000 plants per watershed (Table 3). Using the plant count estimates multiplied by our per plant daily water use estimate of 22.7 liters [27] we determined that water demands for marijuana cultivation range from 523,144 liters per day (LPD) to 724,016 LPD (Table 3). We also calculated the daily water use for each parcel that contained at least one marijuana cultivation site (S1 Table). Histograms showing the frequency distribution of daily water use per parcel are displayed for each watershed in Fig. 7. The majority of parcels in this study use an estimated 900 to 5,000 LPD for marijuana cultivation. These water use estimates are only based on irrigation needs for the marijuana plants counted or the greenhouses measured on that parcel, and do not account for indoor domestic water use, which in Northern California averages about 650 liters per day [32]. Thus, our water use demand estimates for marijuana cultivation are occurring in addition to domestic household uses that may occur and are also likely satisfied by surface water diversions.

Outdoor plants and greenhouses were identified from aerial images of Humboldt and Mendocino Counties. Greenhouse areas were estimated using the Google Earth measuring tool and

Table 3. Marijuana mapping summary of four watersheds.

Watershed	Outdoor Plants	Green-houses (counted)	Total area, m^2 (Green-houses)	Estimated Plants in Green-houses	Estimated Total Plants in Watershed	Estimated Water Use per Day (Liters)
Upper Redwood Creek	4,434	220	20749.4	18,612	23,046	523,144
Salmon Creek	11,697	302	20557.5	18,440	30,137	684,110
Redwood Creek South	10,475	324	18703.9	16,777	27,252	618,620
Outlet Creek	15,165	266	18651.1	16,730	31,895	724,016

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an average area of 1.11484 m^2 (converted from 12 ft^2) per plant was used to estimate total number of plants in greenhouses.

Minimum and maximum annual seven-day low flow values in these watersheds (Table 2) ranged from 0.0–0.05 cubic meters per second (CMS) in Outlet Creek to. 03 -. 26 CMS in

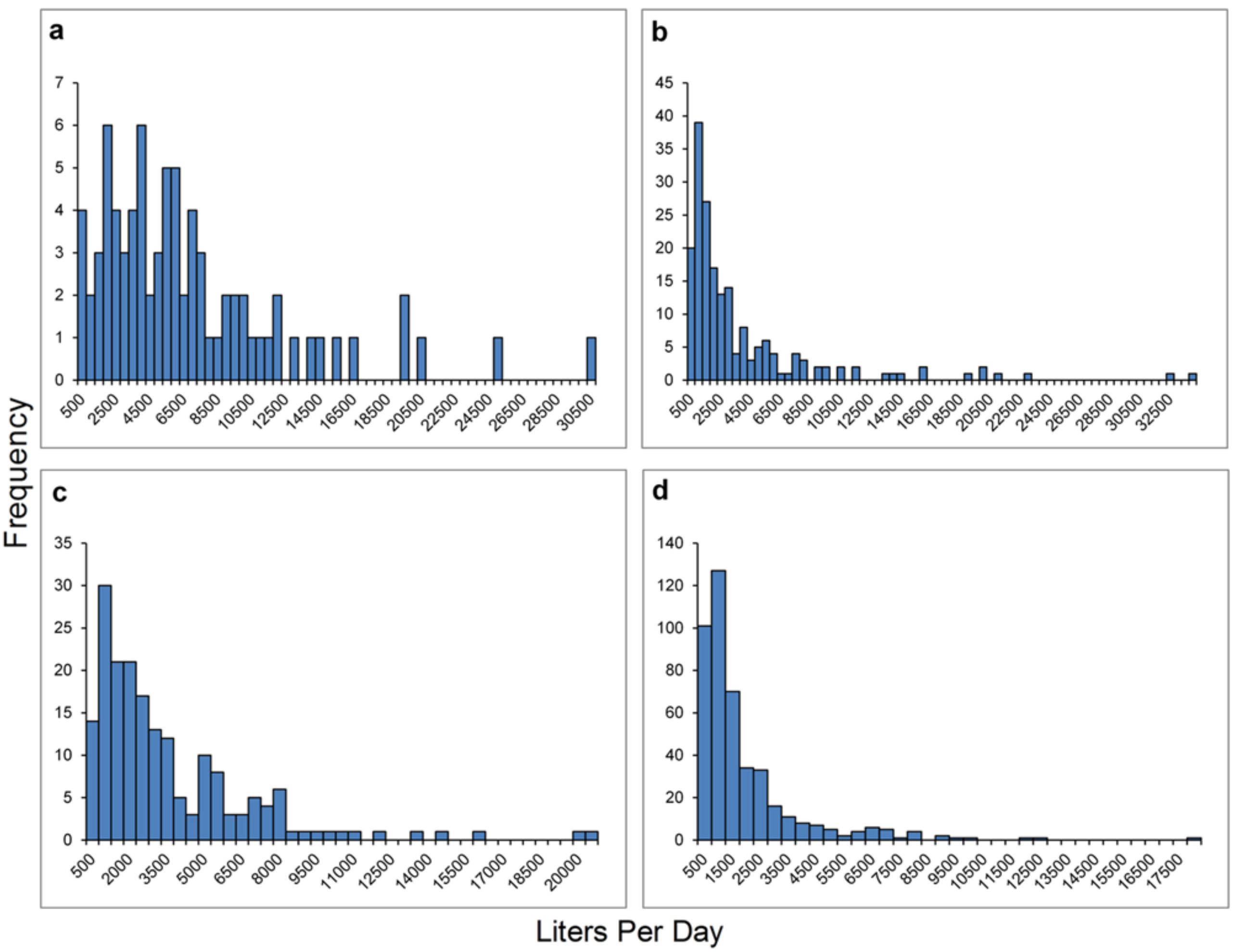

Fig 7. Frequency distribution of the water demand in liters per day (LPD) required per parcel for marijuana cultivation for each study watershed. (a) Upper Redwood Creek watershed, 79 parcels with marijuana cultivation, average water use 6622 LPD, (b) Salmon Creek watershed, 189 parcels with marijuana cultivation, average water use 3620 LPD, (c) Redwood Creek South watershed, 187 parcels with marijuana cultivation, average water use 3308 LPD, (d) Outlet Creek watershed, 441 parcels with marijuana cultivation, average 1642 LPD. See also S1 Table.

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Upper Redwood Creek. By comparing daily water demands to minimum and maximum annual seven-day low flow values, we arrived at a range of values that represent water demand for marijuana cultivation as a percentage of stream flow in each watershed (Table 4, S2 Table). In Upper Redwood Creek, which had the greatest summer flows (Table 2), we estimate water demand for marijuana cultivation is the equivalent of 2–23% of the annual seven-day low flow, depending on the water year. In Redwood Creek South, our data indicate that estimated water demand for marijuana cultivation is 34–165% of the annual seven-day low flow, and in Salmon Creek, estimated water demand for marijuana is 36–173% of the annual seven-day low flow. In Outlet Creek, estimated demand was 17% of the maximum annual seven-day low flow. However, the percent of the annual seven-day low flow minimum could not be calculated because this minimum stream flow was undetectable at the gage (flow <0.00 CMS) in nine of 38 years during the period of record (1957–1994). Due to this minimum annual seven-day low flow of almost zero, marijuana water demand is greater than 100% of the minimum annual seven-day low flow, but we cannot determine by how much.

We also compared the per-watershed daily water demands to the seven-day low flow values for each year of data available in order to better understand the magnitude and frequency of these water demands (Fig. 8, S2 Table). Although substantial demand for water for marijuana cultivation is a more recent and growing phenomenon, by comparing the water use estimates from our remote sensing exercise to historical stream flow data we can better understand how this demand as a percentage of stream flow may vary over the years. Our results indicate that if the same level of water demand for marijuana cultivation had been present for the period of record of the gages, this demand would have accounted for over 50% of streamflow during the annual seven-day low flow period in the majority of years in the Redwood Creek South and Salmon Creek watersheds (based on Elder Creek gage data that spans from water year 1968–2014). In Outlet Creek, the annual seven-day low flow data varied greatly over the period of record (water year 1957–1994) and was too low to measure in nine of the 38 years. The seven-day low flow value was therefore recorded as zero, which means that the water demand was greater than 100% of streamflow, but we could not calculate the water demand as a percentage of stream flow in those years. In Upper Redwood Creek, water demand was much less pronounced in comparison to stream flow, with water demand never accounting for more than 23% of the annual seven-day low flow, and accounting for 10% or greater of the annual seven-day low flow in only 30% of years during the period of record (water year 1954–2014 with a gap between 1959–1972). To summarize, we estimate that in three of the four watersheds evaluated, water demands for marijuana cultivation exceed streamflow during low-flow periods.

Table 4. Estimated water demand for marijuana cultivation expressed as a percentage of seven-day low flow in four study watersheds.

Watershed	Area (km^2)	Plants per km^2	Demand as percent of seven-day low flow	
			Percent of low flow maximum	Percent of low flow minimum
Upper Redwood Creek	175.3	131.6	2%	23%
Salmon Creek	95.1	316.9	36%	173%
Redwood Creek South	64.7	421.2	34%	165%
Outlet Creek	419.1	76.1	17%	>100%*

* The seven-day low flow minimum was measured as 0.0 CMS at the gage.

doi:10.1371/journal.pone.0120016.t004

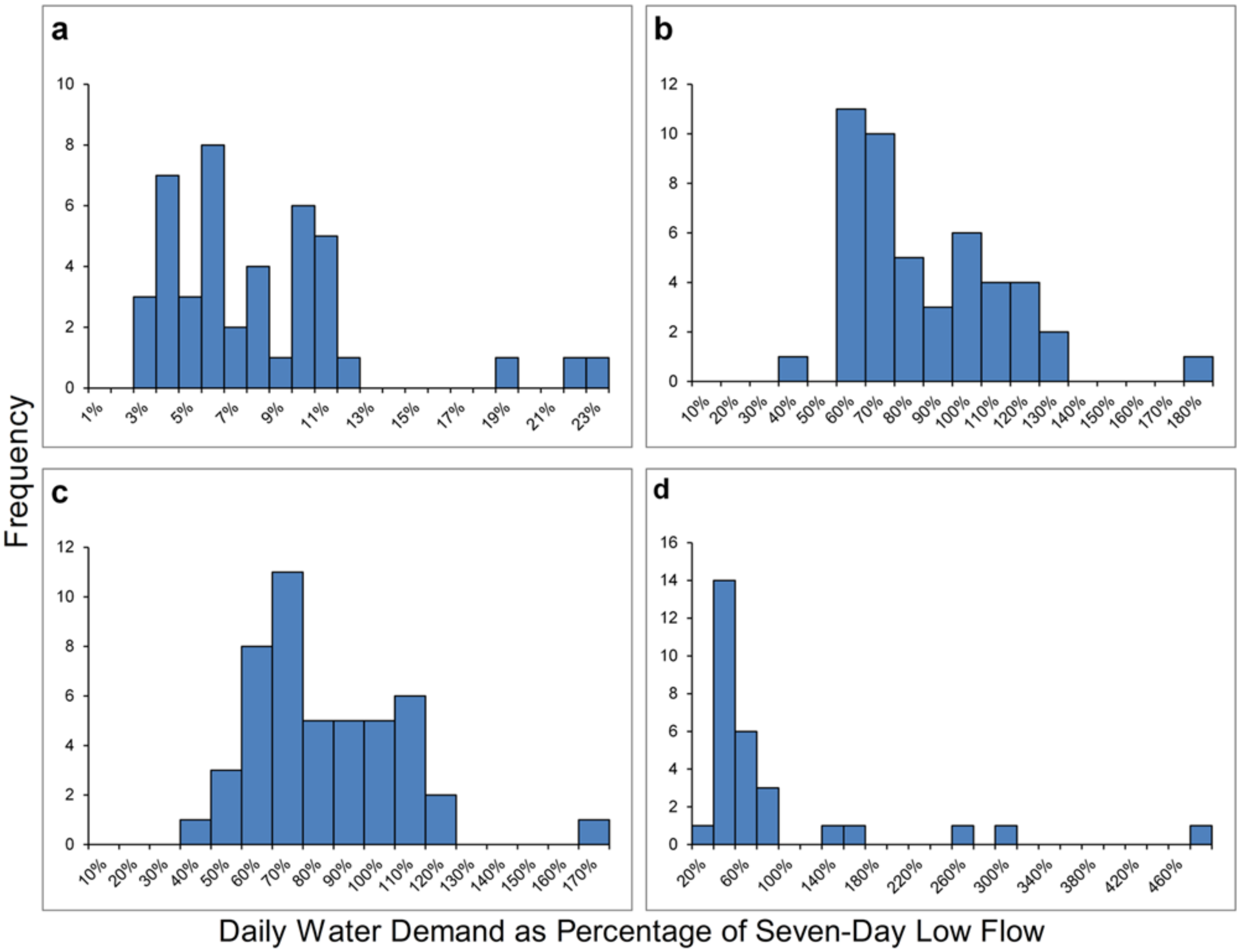

Fig 8. Frequency distribution of the water demand for marijuana cultivation as a percentage of seven-day low flow by year in each study watershed. Water demand data are from a remote sensing exercise using aerial imagery from 2011–2012 and are compared with each year's annual seven-day low flow value for the period of record in each study watershed: (a) Upper Redwood Creek watershed (USGS gage near Blue Lake, CA, coverage from water year (WY) 1954–1958 and 1973–2014), (b) Salmon Creek watershed (data modeled using USGS gage on Elder Creek, CA, coverage from WY 1968–2014), (c) Redwood Creek South (data modeled using USGS gage on Elder Creek, CA, coverage from WY 1968–2014), and (d) Outlet Creek (USGS gage near Longvale, CA, coverage from WY 1957–1994). Data from WYs 1977, 1981, 1987–1989, and 1991–1994 are excluded from Outlet Creek watershed due to seven-day low flow values of zero at the gage. Water demand as a percentage of seven-day low flow would be >100% in these years, but we cannot determine by how much.

doi:10.1371/journal.pone.0120016.g008

Discussion

Aerial Imagery Limitations and Water Demand Assumptions

Due to a number of factors, it is likely that the plant counts resulting from aerial imagery interpretation (Table 3) are minimum values. The detection of marijuana plants using aerial imagery was found most effective for larger cultivation plots in forest clearings greater than 10 m^2 because forest canopy cover and shadows can obscure individual plants or small plots, preventing detection. Some cultivators plant marijuana on a wide spacing in small forest canopy openings in order to avoid aerial detection [7,8]. The authors have also observed a variety of cultivation practices such as the use of large indoor cultivation facilities that could not be detected via aerial imagery. Moreover, a review of Google Earth historical aerial images after field inspections revealed that all MCSs visited in 2013 were either new or had expanded substantially since the previous year. Therefore, it is likely our results underestimate the total number of plants currently grown in these study watersheds and consequently underestimate the associated water demands.

Marijuana has been described as a high water-use plant [2,15] that thrives in nutrient rich moist soil [33]. Marijuana's area of greatest naturalization in North America is in alluvial bottomlands of the Mississippi and Missouri River valleys where there is typically ample rain during the summer growing season [23,33]. Female inflorescences and intercalated bracts are the harvested portion of the marijuana plant. According to Cervantes [15], marijuana uses high levels of water for floral formation and withholding water stunts floral formation. Cervantes recommends marijuana plants be liberally watered and "allow for up to 10 percent runoff during each watering."

There is uncertainty as to actual average water use of marijuana plants because there are few reliable published reports on marijuana water use requirements. As with the cultivation of any crop, variation in average daily water use would be expected based upon many variables, including the elevation, slope, and aspect of the cultivation site; microclimate and weather; size, age, and variety of the plant; native soil type and the amount and type of soil amendments used and their drainage and water retention characteristics; whether plants are grown outdoors, in greenhouses, or directly in the ground or in containers and the size of the container; and finally, the irrigation system used and how efficiently the system is used and maintained [34–36]. However, our water demand estimate of 22.7 L/day/plant based on the limited industry data available [27] comports with the U.S. Department of Justice 2007 Domestic Cannabis Cultivation Assessment [2], which indicates marijuana plants require up to 18.9 L/day/plant.

In many rural watersheds in Northern California, the primary source for domestic and agricultural water is from small surface water diversions [37]. These diversions must be registered with the State Water Resources Control Board (SWRCB), the agency responsible for administering water rights in California. SWRCB registrations are also subject to conditions set by the California Department of Fish and Wildlife in order to protect fish, wildlife, and their habitats. However, when querying the SWRCB's public database, we found low numbers of registered, active water diversions on file relative to the number of MCSs we counted in the study watersheds. The total number of registered, active diversions on file with the SWRCB accounted less than half of the number of parcels with MCSs that were visible from aerial imagery (Fig. 9). In some watersheds, the number was as low as 6%. Since we do not know if the registered diversions on file with the SWRCB belong to parcels with MCSs, it is uncertain if the registered diversions in a particular watershed are connected with any of the MCSs we counted.

Our calculations of water demand as a percentage of stream flow assume that all potential water users are diverting surface water or hydrologically-connected subsurface flow. Historical water use practices and our field inspections with law enforcement support this assumption, although there are few hard data available as there are relatively few active registered water diversions on file with the Division of Water Rights when compared to the potential number of water users in the watersheds (Fig. 9).

Implicit in our calculations is the assumption that all water users are pumping water at the same rate throughout the day, as well as throughout the growing season. In reality, we expect water demand to gradually increase throughout the season as plants mature. This increased water demand would coincide with the natural hydrograph recession through the summer months, creating an even more pronounced impact during the summer low-flow period. In a similar study that monitored flow in relation to surface water abstraction for vineyard heat protection, flows receded abnormally during periods of high maximum daily temperature [21]. These results indicate that water users can have measureable effects on instantaneous flow in periods of high water demand. Our results suggest that similar impacts could occur during the summer low flow period in the study watersheds.

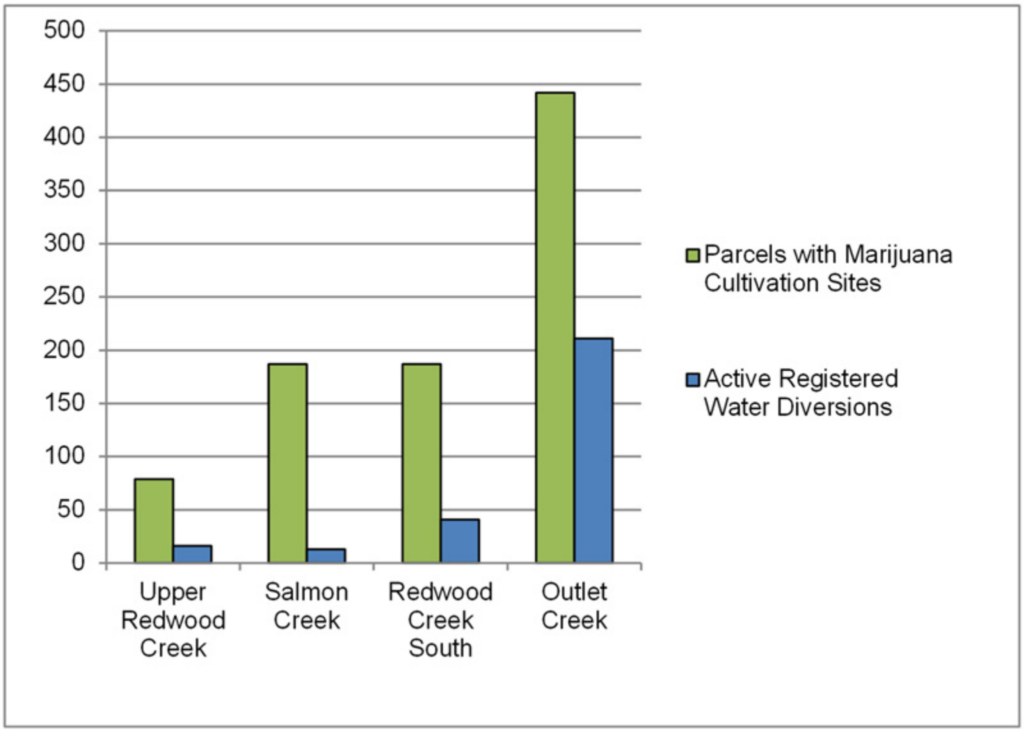

Fig 9. Active water rights in the study watersheds. Parcels with active registered water diversions (on file with California's Division of Water Rights) compared to parcels with marijuana cultivation sites (MCSs) in the four study watersheds.

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Additionally, our analysis assumes the water withdrawals will impact the entire watershed in an even, consistent way. In reality, we would expect water demand to be more concentrated at certain times of day and certain periods of the growing season, as described above. Furthermore, results of our spatial analysis indicate that MCSs are not evenly distributed on the landscape, thus impacts from water withdrawals are likely concentrated in certain areas within these watersheds. Because of these spatially and temporally clustered impacts, we may expect to see intensification of stream dewatering or temperature elevation in certain tributaries at certain times of year, which could have substantial impacts on sensitive aquatic species. Recent data indicate that peaks in high stream temperatures and annual low-flow events are increasing in synchrony in western North America [38], an effect that would be exacerbated by the surface water withdrawals we describe here. Further modeling and on-the-ground stream flow and temperature observations are needed to elucidate the potential extent of these impacts. The minimum streamflow estimates in Salmon Creek, Redwood Creek South, and Outlet Creek are so low that even a few standard-sized pumps operating at 38 liters per minute (LPM), which is a standard rate approved by the SWRCB for small diversions, could dewater the mainstem stream if more than four pumps ran simultaneously in any one area. It follows that impacts on smaller tributaries would be even more pronounced. In addition, on-site observations of MCS irrigation systems, though anecdotal, indicate many of these water conveyance, storage, and irrigation systems lose a substantial amount of water through leaks and inefficient design. This would significantly increase the amount of surface water diverted from streams beyond what would actually be needed to yield a crop. More study is needed to fully understand the impacts of MCS water demand on instantaneous flow in these watersheds.

Given that marijuana cultivation water demand could outstrip supply during the low flow period, and based on our MCS inspections and surface water diversion and irrigation system observations, we surmise that if a MCS has a perennial water supply, that supply would be used exclusively. However, for MCSs with on-site surface water sources that naturally run dry in summer, or are depleted though diversion, it is likely that direct surface water diversion is used until the source is exhausted, then water stored earlier in the year or imported by truck supplants the depleted surface water. It is difficult to determine to what degree imported water and wet season water storage is occurring. However, our on-site MCS inspections support the assumption that the vast majority of irrigation water used for marijuana cultivation in the study watersheds is obtained from on-site surface water sources and water storage and importation is ancillary to direct surface water diversions.

Comparison of Water Demands to Summer Low Flows

Our results suggest that water demand for marijuana cultivation in three of the study watersheds could exceed what is naturally supplied by surface water alone. However, in Upper Redwood Creek, the data suggest that marijuana cultivation could have a smaller impact on streamflow, with demand taking up approximately 2% to 23% of flow (Table 4). This projected demand of flow contrasts with the 34% to >100% flow demand range in the other watersheds, most likely because Upper Redwood Creek has greater mean annual precipitation, less evapotranspiration, and generally higher stream flow than the other watersheds (Tables 1–2). Furthermore, approximately half of the Upper Redwood Creek watershed is comprised of either large timber company holdings or federal lands. As Fig. 2 illustrates, MCSs in Upper Redwood Creek are concentrated within a relatively small area of privately-owned land that has been subdivided. It stands to reason that if all the land within the Upper Redwood Creek watershed was subject to the subdivision and parcelization that has occurred in Redwood Creek South, Salmon Creek, or Outlet Creek, the potential impacts to stream flow would also be greater.

In Outlet Creek, our results indicate a large range of potential water demand as a percentage of streamflow, from 17% in a "wet" year to greater than 100% when the stream becomes intermittent, as it does during many summers. Our data indicate that impacts to streamflow will vary greatly depending on the individual watershed characteristics, whether the year is wetter or drier than average, and the land use practices taking place.

Environmental Impacts

The extent of potential environmental impacts in these watersheds is especially troubling given the region is a recognized biodiversity hotspot. According to Ricketts et al. [39], the study watersheds occur within the Northern California Coastal Forests Terrestrial Ecoregion. This ecoregion has a biological distinctiveness ranking of "globally outstanding" and a conservation status of "critical" [39]. For example, Redwood National Park, 20 km downstream of the Upper Redwood Creek sub-basin, has approximately 100 km^2 of old-growth redwood forest, which is one of the world's largest remaining old-growth redwood stands. The study watersheds also occur within the Pacific Mid-Coastal Freshwater Ecoregion defined by Abell et al. [40]. This ecoregion has a "Continentally Outstanding" biological distinctiveness ranking, a current conservation status ranking of "Endangered" and its ranking is "Critical" with regards to expected future threats [40]. Not surprisingly, numerous sensitive species, including state- and federally-listed taxa, occur in the study watersheds or directly downstream (Table 5).

Our results indicate that the high water demand from marijuana cultivation in these watersheds could significantly impact aquatic- and riparian-dependent species. In the Pacific Coast Ecoregion, 60% of amphibian species, 16% of reptiles, 34% of birds, and 12% of mammals can

Table 5. Sensitive aquatic species with ranges that overlap the four study watersheds: Upper Redwood Creek (URC), Redwood Creek South (RCS), Salmon Creek (SC), and Outlet Creek (OC).

Scientific Name	Common Name	Conservation Status in California	Study Watershed
Oncorhynchus kisutch	coho salmon	State and federally-threatened	URC, RCS, SC, OC
Oncorhynchus tshawytscha	Chinook salmon	federally-threatened	URC, RCS, SC, OC
Oncorhynchus clarki clarki	coastal cutthroat trout	SSC[1]	URC
Oncorhynchus mykiss	steelhead trout	federally-threatened	URC, RCS, SC, OC
Rana aurora	northern red-legged frog	SSC	URC, RCS, SC, OC
Rana boylii	foothill yellow-legged frog	SSC	URC, RCS, SC, OC
Rhyacotriton variegatus	southern torrent salamander	SSC	URC, RCS, SC, OC
Ascaphus truei	coastal tailed frog	SSC	URC, RCS, SC
Emys marmorata	western pond turtle	SSC	RCS, SC, OC
Margaritifera falcata	western pearlshell	S1S2[2]	URC

[1]The California Department of Fish and Wildlife designates certain vertebrate species as Species of Special Concern (SSC) because declining population levels, limited ranges, and/or continuing threats have made them vulnerable to extinction. Though not listed pursuant to the Federal Endangered Species Act or the California Endangered Species Act, the goal of designating taxa as SSC is to halt or reverse these species' decline by calling attention to their plight and addressing the issues of conservation concern early enough to secure their long-term viability.

[2] The California Natural Diversity Database (CNDDB) designates conservation status rank based on a one to five scale, one being "Critically Imperiled", five being "Secure". Uncertainty about a rank is expressed by a range of values, thus a status of S1S2 indicates that there is uncertainty about whether *Margaritifera falcata* ranks as state "Critically Imperiled" (S1) or state "Imperiled" (S2) [41].

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be classified as riparian obligates, demonstrating the wide range of taxa that potentially would be affected by diminished stream flows [42]. The impacts of streamflow diversions and diminished or eliminated summer streamflow would however disproportionately affect aquatic species, especially those which are already sensitive and declining.

Impacts to Fish

Northern California is home to some of the southernmost native populations of Pacific Coast salmon and trout (i.e., salmonids) and the study area is a stronghold and refugia for their diversity and survival. Every salmonid species in the study watersheds has some conservation status ranking (Table 5). California coho salmon, for example, have undergone at least a 70% decline in abundance since the 1960s, and are currently at 6 to 15% of their abundance during the 1940s [43]. Coho salmon populations in all four study watersheds are listed as threatened under both the California and the Federal Endangered Species Acts, and are designated as key populations to maintain or improve as part of the Recovery Strategy of California Coho Salmon [43].

Of California's 129 native inland fish species, seven (5%) are extinct in the state or globally; 33 (26%) are in immediate danger of becoming extinct (endangered), and 34 (26%) are in decline but not at immediate risk of extinction (vulnerable) [44]. According to Katz et al. [45], if present population trends continue, 25 (78%) of California's 32 native salmonid taxa will likely be extinct or extirpated within the next century.

The diminished flows presented by this study may be particularly damaging to salmonid fishes because they require clean, cold water and suitable flow regimes [44]. In fact, water diversions and altered or diminished in-stream flows due to land use practices have been identified as having a significant impact on coho salmon resulting in juvenile and adult mortality [43].

Additionally, all four study watersheds are already designated as impaired for elevated water temperature and sediment by the U.S. Environmental Protection Agency pursuant to the Clean

Water Act Section 303(d). Reduced flow volume has a strong positive correlation with increased water temperature [44]. Increased water temperatures reduce growth rates in salmonids, increase predation risk [46], and increase susceptibility to disease. Warmer water also holds less dissolved oxygen, which can reduce survival in juvenile salmonids [44]. Both water temperature and dissolved oxygen are critically important for salmonid survival and habitat quality [47–50].

Reduced stream flows can also threaten salmonids by diminishing other water quality parameters, decreasing habitat availability, stranding fish, delaying migration, increasing intra and interspecific competition, decreasing food supply, and increasing the likelihood of predation [43]. These impacts can have lethal and sub-lethal effects. Experimental evidence in the study region suggests summer dry-season changes in streamflow can lead to substantial changes in individual growth rates of salmonids [51]. Complete dewatering of stream reaches would result in stranding and outright mortality of salmonids, which has been observed by the authors at a number of MCSs just downstream of their water diversions.

Impacts to Amphibians

Water diversions and altered stream flows are also a significant threat to amphibians in the northwestern United States [52,53]. The southern torrent salamander (*Rhyacotriton variegatus*) and coastal tailed frog (*Ascaphus truei*) are particularly vulnerable to headwater stream diversions or dewatering, which could lead to mortality of these desiccation-intolerant species [54]. To maximize the compatibility of land use with amphibian conservation, Pilliod and Wind [53], recommend restoration of natural stream flows and use of alternative water sources in lieu of developing headwater springs and seeps.

Numerous studies have documented the extreme sensitivity of headwater stream-dwelling amphibians to changes in water temperature [55,56] as well as amounts of fine sediment and large woody debris [57,58]. Additionally, Kupferberg et al. and others [52,59] have demonstrated the impacts of altered flow regimes on river-dwelling amphibians. However, the threat of water diversion and hydromodification—or outright loss of flow—from headwaters streams has not been well-documented in the amphibian conservation literature. This is likely because illegal and unregulated headwater stream diversions did not exist at this scale until the recent expansion of marijuana cultivation in the region. In contrast, timber harvesting, which until recently was the primary land use in forested ecoregions in the western United States, does not typically divert headwater streams in the same manner as MCSs. Timber harvesting operations, at least in California, have state regulatory oversight that requires bypass flows to maintain habitat values for surface water diversions. Thus, the results of our study highlight an emerging threat to headwater amphibians not addressed in Lannoo [60], Wake and Vredenburg [61], or more recently in Clipp and Anderson [62]

Future Water Demands and Climate Change

Flow modification is one of the greatest threats to aquatic biodiversity [63]. As in many parts of the world, the freshwater needed to sustain aquatic biodiversity and ecosystem health in our study area is also subject to severe competition for multiple human needs. The threats to human water security and river biodiversity are inextricably linked by increasing human demands for freshwater [64,65]. In California, irrigated agriculture is the single largest consumer of water, taking 70–80% of stored surface water and pumping great volumes of groundwater [44]. In our study area, agricultural demands account for 50–80% of all water withdrawals [66]. Only late in the last century have the impacts of water diversions on aquatic species become well recognized. However, these impacts are most often assessed on large regional scales, e.g.

major rivers and alluvial valleys, and the large hydroelectric dams, reservoirs, and flood control and conveyance systems that regulate them [67].

Few studies thus far have assessed the impacts of many small agricultural diversions on zero to third order streams and their cumulative effects on a watershed scale [21,22]. On a localized scale, with regional implications, this study detects an emerging threat to not only aquatic biodiversity but also human water security, since surface water supplies most of the water for domestic uses in watersheds throughout Northwestern California [37]. In these watersheds, the concept of "peak renewable water," where flow constraints limit total water availability [68], may have already arrived. In other words, the streams in the study watersheds simply cannot supply enough water to meet current demands for marijuana cultivation, other human needs, and the needs of fish and wildlife.

Due to climate change, water scarcity and habitat degradation in northern California is likely to worsen in the future. Regional climate change projections anticipate warmer average air temperatures, increases in prolonged heat waves, decreases in snow pack, earlier snow melt, a greater percentage of precipitation falling as rain rather than snow, a shift in spring and summer runoff to the winter months, and greater hydroclimatic variability and extremes [69–77]. Consequently, future hydrologic scenarios for California anticipate less water for ecosystem services, less reservoir capture, a diminished water supply for human uses, and greater conflict over the allocation of that diminished supply [70,71,75,78,79]. Climate change is expected to result in higher air and surface water temperatures in California's streams and rivers in the coming decades, which in turn could significantly decrease suitable habitat for freshwater fishes [80–83]. Due to a warming climate, by 2090, 25 to 41% of currently suitable California streams may be too warm to support trout [84].

Already, gage data and climate stations in northwestern California show summer low flow has decreased and summer stream temperatures have increased in many of northern California's coastal rivers, although these changes cannot yet be ascribed to climate change [85]. In an analysis of gage data from 21 river gaging stations, 10 of the gages showed an overall decrease in seven-day low flow over the period of record. This dataset included Upper Redwood Creek as well as the South Fork Eel River, the receiving water body for Redwood Creek South and Salmon Creek [85].

Our analysis suggests that for some smaller headwater tributaries, marijuana cultivation may be completely dewatering streams, and for the larger fish-bearing streams downslope, the flow diversions are substantial and likely contribute to accelerated summer intermittence and higher stream temperatures. Clearly, water demands for the existing level of marijuana cultivation in many northern California watersheds are unsustainable and are likely contributing to the decline of sensitive aquatic species in the region. Given the specter of climate change induced more severe and prolonged droughts and diminished summer stream flows in the region, continued diversions at a rate necessary to support the current scale of marijuana cultivation in northern California could be catastrophic for aquatic species.

Both monitoring and conservation measures are necessary to address environmental impacts from marijuana cultivation. State and federal agencies will need to develop more comprehensive guidelines for essential bypass flows in order to protect rearing habitat for listed salmonid species and other sensitive aquatic organisms. Installation of additional streamflow gages and other water quality and quantity monitoring will be necessary to fill data gaps in remote watersheds. In addition, increased oversight of water use for existing MCSs and increased enforcement by state and local agencies will be necessary to prevent and remediate illegal grading and forest conversions. Local and state governments will need to provide oversight to ensure that development related to MCSs is permitted and complies with environmental regulations and best management practices. Local and state agencies and nonprofit organizations should also continue to educate marijuana cultivators and the public about the environmental threats, appropriate mitigation measures, and permit requirements to legally develop MCSs and best protect fish and wildlife habitat. Finally, local governments should evaluate their land use planning policies and ordinances to prevent or minimize future forestland conversion to MCSs or other land uses that fragment forestlands and result in stream diversions.

Supporting Information

S1 Table. Number of outdoor plants counted, area of greenhouses measured, and estimated water use in Liters per day for each parcel in the study watersheds.
(XLSX)

S2 Table. Per-watershed daily water demands compared to seven-day low flow by year.
(XLSX)

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Author Contributions

Conceived and designed the experiments: SB MVH LM AC JO. Analyzed the data: JO AC MT SB MVH GL. Wrote the paper: GL JO AC MT SB. Collected the data: AC JO SB MVH GL.

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EXHIBIT 6

Laguna de Santa Rosa Watershed

The Laguna de Santa Rosa is the largest tributary to the Russian River and drains a 254 square mile watershed in Sonoma County, California. Major tributaries to the Laguna de Santa Rosa include Windsor Creek, Mark West Creek, Santa Rosa Creek, Blucher Creek, and Copeland Creek. Three hydrologic subareas comprise the Laguna de Santa Rosa watershed: 114.21 Laguna Hydrologic Subarea, 114.22 Santa Rosa Hydrologic Subarea, and 114.23 Mark West Hydrologic Subarea.

This web page provides information specific to the development of Total Maximum Daily Loads for the Laguna de Santa Rosa. Click this link for information on other projects, programs, and efforts in the Laguna de Santa Rosa watershed.

- Map of the Laguna de Santa Rosa Watershed

Impairments

Middle Russian River HA Laguna HSA tributaries to the Laguna de Santa Rosa (except Santa Rosa Creek)	Mainstem Colgan Creek	Oxygen, Dissolved
	Entire water body	Indicator Bacteria
		Sedimentation/Siltation
		Temperature
Middle Russian River HA Mark West HSA mainstem Mark West Creek downstream of the confluence with the Laguna de Santa Rosa	Entire water body	Aluminum
		Oxygen, Dissolved
		Phosphorus
		Manganese

Middle Russian River HA Mark West HSA mainstem Mark West Creek upstream of the confluence with the Laguna de Santa Rosa	Entire water body	Sedimentation/Siltation
		Temperature
Middle Russian River HA Mark West HSA tributaries to Mark West Creek (except Windsor)	Entire water body	Sedimentation/Siltation
		Temperature
Middle Russian River HA Mark West HSA Windsor Creek and its tributaries	Entire water body	Sedimentation/Siltation
		Temperature
Middle Russian River HA Santa Rosa HSA mainstem Santa Rosa Creek	Entire water body	Indicator Bacteria
		Sedimentation/Siltation
		Temperature
Middle Russian River HA Santa Rosa HSA tributaries to Santa Rosa Creek	Spring Lake	Mercury
	Entire water body	Indicator Bacteria
		Sedimentation/Siltation
		Temperature

Not all of the above listings are being addressed at this time. The status of Total Maximum Daily Load (TMDL) development for specific pollutants is presented below.

addressed as part of the larger Russian River Pathogen TMDL development effort. Please refer to the Russian River TMDL page for more information.

- Not under development at this time:
  - Aluminum
  - Manganese
  - Mercury

Further information about the current Clean Water Act Section 303(d) List of Impaired Waters for California and the North Coast Region is available here:

- http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/303d/

Nutrient, Dissolved Oxygen, Temperature, and Sediment TMDLs

A TMDL for high levels of ammonia and low dissolved oxygen concentrations was approved by the US EPA in 1995 as the Waste Reduction Strategy for the Laguna de Santa Rosa. The Waste Reduction Strategy focused on the reduction of nitrogen loading from point and non-point sources.

As mentioned above, efforts are underway by Regional Water Board staff to develop new TMDLs for nitrogen, phosphorus, dissolved oxygen, temperature, and sediment in the Laguna de Santa Rosa watershed to address continuing water quality impairments. These TMDLs will apply to the entire Laguna de Santa Rosa watershed, including Mark West Creek, Santa Rosa Creek, and all tributaries.

The objectives of the TMDL and attendant action plan will be:

1. To improve the quality of waters in the Laguna de Santa Rosa watershed so that water quality standards are attained and beneficial uses like fish habitat and human recreation are fully supported.
2. To set limits on the amounts of nitrogen, phosphorus, dissolved oxygen-demanding substances, controllable temperature factors, and sediments that can be discharged into water bodies in the Laguna de Santa Rosa watershed while still allowing for water quality standards to be attained.
3. To describe the pollutant reductions and implementation actions that will be necessary to attain water quality standards.
4. To describe the monitoring actions that will be necessary to ensure implementation actions are being executed in a manner that attains water quality standards.

Stakeholder & Community Involvement

In order for the Laguna TMDLs to be successful in addressing water quality impairments in the Laguna de Santa Rosa, it is imperative for staff to work with stakeholders and members of the community.

and select "Laguna de Santa Rosa TMDL" on the subscription form.

Nutrient Offset Program and Water Quality Trading Framework

To support implementation of the TMDL, the Regional Board has adopted Resolution No. R1-2008-0061 and Resolution No. R1-2018-0025 establishing the Nutrient Offset Program (NOP) and Water Quality Trading Framework (WQT), respectively. These programs are designed to reduce phosphorus loading into the Laguna and remove legacy phosphorus by creating a market for credits generated through watershed restoration projects and other nutrient reduction actions. More information can be found on the NOP and WQT by accessing the Santa Rosa Nutrient Offset Program Webpage.

Status Updates

Regional Water Board staff provides status updates to the Regional Water Board and the public on an as-needed basis. Updates since July 2010 are available below, listed in reverse chronologic order (most recent first).

- August 12, 2015 – Update on the Development of TMDLs for the Laguna de Santa Rosa (Item 5)
  Executive Officer's Summary Report
  Presentation Slides
- November 20, 2014 – Update on the Development and Early Implementation of the Laguna de Santa Rosa TMDLs for Nutrients, Dissolved Oxygen, Temperature, and Sediment (Item 10)
  Executive Officer's Summary Report
  Presentation Slides
- December 6, 2012 – Update on the Development of the Laguna de Santa Rosa TMDLs for Nitrogen, Phosphorus, Dissolved Oxygen, Temperature, and Sediment (Item 11)
  Executive Officer's Summary Report
  Presentation Slides
- January 27, 2011 – Update on Lower Russian River Core Regulatory and TMDL Efforts (Item 13)
  Executive Officer's Summary Report
  Presentation Slides
- July 15, 2010 – Update on the Status of Russian River Watershed TMDL Development Projects (It
  Executive Officer's Summary Report
  Presentation Slides

Monitoring Plans & Reports

- 2008 Source Analysis Monitoring Report Appendices - December 2008
- 2008 Source Analysis Monitoring Report - December 2008
- 2009 Source Analysis Monitoring Report - November 2010
- 2009 Source Analysis Monitoring Report Appendices - June 2010
- Diel Water Quality Monitoring Report - December - 2011

Technical Memoranda

Several Regional Water Board staff technical memoranda document and describe analyses and assessments to support the development of the TMDLs. These memoranda and their findings and conclusions are subject to change as staff continue to develop the TMDLs. They are listed in reverse chronological order (most recent first).

- Assessment of the Total Nitrogen and Ammonia Nitrogen Goals from the 1995 Laguna TMDL - May 2012
- Assessment of Nutrients Limiting Algal Biomass Production in the Laguna de Santa Rosa - March 2012
- Dissolved Oxygen Model Application for Pre-Settlement Laguna Watershed Conditions - March 2012
- Laguna de Santa Rosa TMDL Linkage Analysis through Application of Water Quality Models - March 2012
- Laguna de Santa Rosa TMDL Linkage Analysis and Loading Capacity Assessment for Total Nitrogen and Ammonia Nitrogen Toxicity - March 2012
- Descriptive Statistics of Diel Water Quality collected within the Laguna de Santa Rosa Watershed during the years 1995 through 2011 - December 2011
- Development of the Laguna de Santa Rosa Watershed Pre-European Settlement Spatial Data Model - December 2011
    - Development of the Land Cover Loading Model for the Laguna de Santa Rosa Watershed - December 2011 (Under Revision)
    - Diel Water Quality within the Laguna de Santa Rosa Watershed during 2001-2002 - October 2011
- Dissolved Oxygen Model Development and Evaluation - June 2011
- Constructing Stream Flow Rating Power Equations for the Pre-settlement Lakes in the Laguna de Santa Rosa Watershed - June 2011
- Sediment Quality of the Laguna de Santa Rosa - May 2011
- Water Quality Model Development History for the Laguna de Santa Rosa TMDL - May 2011
- Pre-European Settlement Spatial Data Model Evaluation - November 2010
- Gradient Analysis of Environmental Variables to Delineate Pre-European Settlement Land Cover Boundaries - November 2010
- (currently under revision)

- Laguna de Santa Rosa Sediment Budget (Main Report) – Tetra Tech (2015)
- Laguna de Santa Rosa Sediment Budget (Appendices) – Tetra Tech (2015)
- Laguna de Santa Rosa Nutrient Analysis – Tetra Tech (2015)
- The Altered Laguna: A Conceptual Model for Watershed Stewardship - A report by Christina Sloop, Joseph Honton, Clayton Creager, Limin Chen, Elizabeth Andrews, and Setenay Bozkurt from the Laguna de Santa Rosa Foundation, Tetra Tech, Inc., and Philip Williams & Associates, Ltd. (2007)
- County Sanitary Survey – Lee (1944)

Mailing Lists

To receive notices and information on the Laguna de Santa Rosa TMDLs via e-mail, please subscribe to our list service by clicking here and select “Laguna de Santa Rosa TMDL” on the subscription form.

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Resources

- TMDLs Start
- Sediment TMDL Implementation Policy
- The Integrated Report - 303(d) List of Impaired Waterbodies and The 305(b) Water Quality Assessment
- TMDL Development
- US EPA TMDLs

- Coastal Pathogens
- Eel River, North Fork
- Eel River, Upper Main
- Eel River, Middle Main
- Eel River, Middle Fork
- Eel River, Lower Main
- Eel River, South Fork
- Elk River
- Freshwater Creek
- Garcia River
- Gualala River
- Klamath River
- Laguna De Santa Rosa
- Lost River, Upper
- Lost River, Lower
- Mad River
- Mattole River
- Navarro River
- Noyo River
- Redwood Creek
- Russian River
- Salmon River
- Scott River
- Shasta River
- Stemple Creek
- Ten Mile River
- Trinity River
- Trinity River, South Fork
- Van Duzen River

(Page last updated 6/25/20)

The California Water Boards include the State Water Resources Control Board and nine Regional Boards
The State Water Board is one of six environmental entities operating under
the authority of the California Environmental Protection Agency

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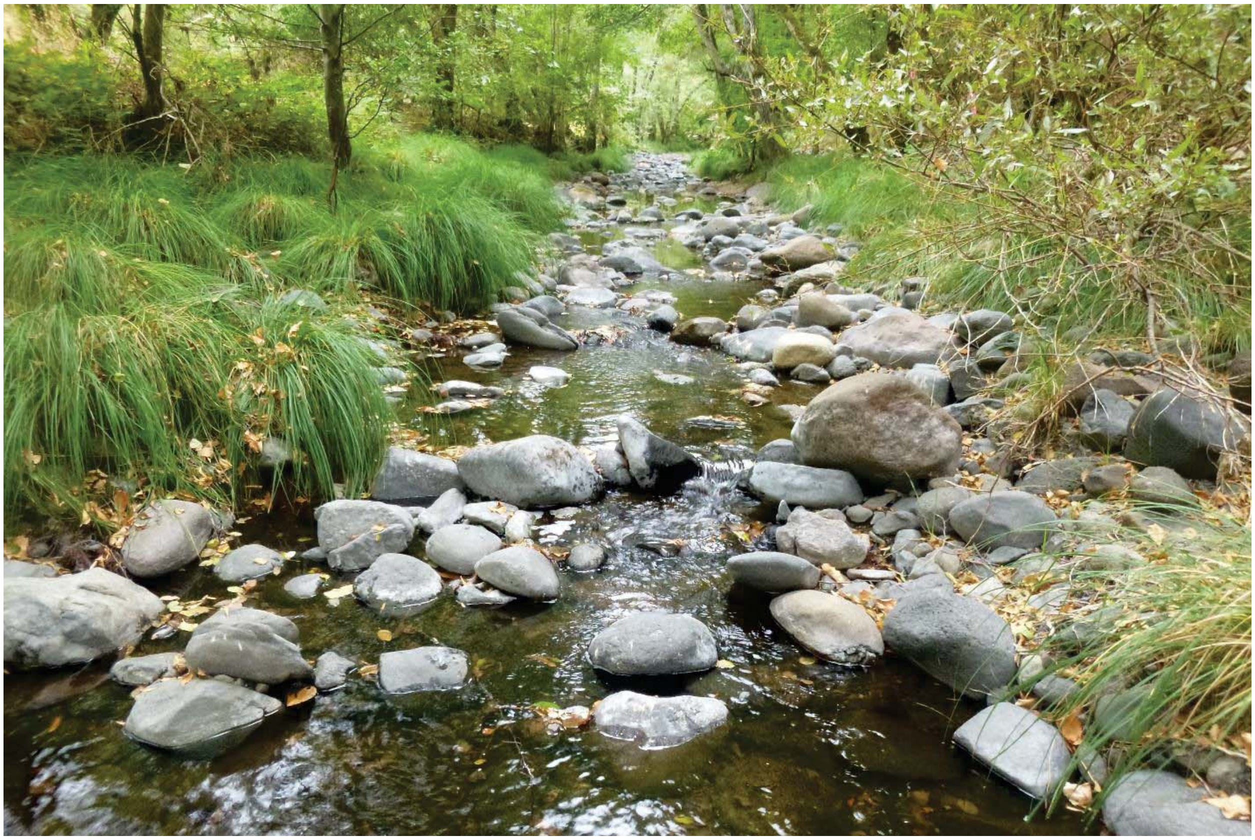
EXHIBIT 7

State of California
Natural Resources Agency
California Department of Fish and Wildlife

STUDY PLAN
Habitat and Instream Flow Evaluation for Anadromous Steelhead and Coho Salmon in UPPER MARK WEST CREEK, Sonoma County



STUDY PLAN

June 2018

Cover photo: Mark West Creek, view upstream.

Approvals

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Regional Manager, Bay-Delta Region

Gregg Erickson ____________________ Date 6/21/18

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PREFACE

This study plan outlines the approaches that may be used by the California Department of Fish and Wildlife (Department) to evaluate instream flow needs for anadromous steelhead and Coho Salmon in upper Mark West Creek, Sonoma County. The California Water Action Plan[1] (CWAP) outlines ten actions and associated sub-actions to address water management challenges and promote reliability, restoration, and resilience in the management of California's water resources. Action Four of the CWAP, to protect and restore important ecosystems, directs the Department and the State Water Resources Control Board (State Water Board) to implement a suite of actions to enhance instream flows within at least five priority stream systems. Mark West Creek, a tributary to the lower Russian River, is among these first five priority streams. The Department plans to begin work on the upper Mark West Creek study in 2018 as part of the suite of actions to address instream flow enhancement for anadromous salmonid species present within upper Mark West Creek.

The Department is the Trustee Agency for California's fish and wildlife resources and a Responsible Agency under CEQA §21000 *et seq*. Fish and wildlife resources are held in trust for the people of the State of California under FGC §711.7. As Trustee Agency, the Department seeks to maintain natural communities and native fish, wildlife, and plant species for their intrinsic ecological values and for their benefits to all citizens in the State. This includes habitat protection and maintenance of habitat of sufficient amount and quality to ensure the survival of all native species and natural communities. The results of the study may be used to assist with flow enhancement activities in upper Mark West Creek through the CWAP and other salmonid restoration and recovery efforts.

[1] More information about Proposition 1 and the California Water Action Plan can be found at http://resources.ca.gov/california_water_action_plan/

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ABBREVIATIONS

°F	degrees Fahrenheit
1D	one-dimensional (physical habitat simulation model)
2D	two-dimensional (physical habitat simulation model)
BMI	benthic macroinvertebrate
CC	California Coastal
CCC	Central California Coast
CCR	California Code of Regulations
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife (previously CDFG)
CEMAR	Center for Ecosystem Management and Restoration
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CNFD	California Natural Flows Database
CWAP	California Water Action Plan
cfs	cubic feet per second
DPS	distinct population segment
DWR	Department of Water Resources
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FGC	Fish and Game Code
FN	Froude number
FR	Federal Register
FRAP	Fire Resource Assessment Program
ft	foot/feet
ft/s	feet per second
GIS	geographic information system
GPS	Global Positioning System
HEC-RAS	Hydrologic Engineering Center’s River Analysis System
HRM	Habitat Retention Method
HSC	habitat suitability criteria
HTS	habitat time series
HUC12	12-digit hydrologic unit code
IFP	Instream Flow Program
LiDAR	Light Detection and Ranging
MANSQ	Manning’s stage discharge
NMFS	National Marine Fisheries Service
NRCS	Natural Resources Conservation Service
PACT	Priority Action Coho Team
PHABSIM	Physical Habitat Simulation Model
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RCD	Resource Conservation District
RIVER2D	River2D Model
RRCWRP	Russian River Coho Water Resources Partnership
RRISRP	Russian River Independent Science Review Panel

RTK	real time kinematic
SCWA	Sonoma County Water Agency
SEFA	System for Environmental Flow Analysis
SOP	standard operating procedure
SRPBAP	Santa Rosa Plain Basin Advisory Panel
SRPHM	Santa Rosa Plain Hydrologic Model
SWRCB	State Water Resources Control Board
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WPM	Wetted Perimeter Method
WSEL	water surface elevation
WY	water year
WSP	water surface profile
VAF	velocity adjustment factor
VDI	Voluntary Drought Initiative

CONVERSIONS

1 cubic foot per second ≈ 2.83×10^{-2} cubic meters per second
1 inch = 2.54 centimeters
1 foot ≈ 30.48 centimeters
1 square mile ≈ 2.59 square kilometers
1 mile ≈ 1.61 kilometers
1 foot ≈ 0.31 meters
°C = (°F - 32) ÷ 1.8

1.0 INTRODUCTION

The Russian River watershed, to which Mark West Creek is a tributary, currently supports several species of anadromous salmonids, including anadromous Rainbow Trout (commonly known as steelhead; *Oncorhynchus mykiss*), Chinook Salmon (*O. tshawytscha*), and Coho Salmon (*O. kisutch*). Salmon and steelhead populations within coastal California watersheds, including those found within the Russian River watershed have declined significantly due to habitat modification, overfishing, and environmental stressors (Steiner 1996; CDFG 2004; NMFS 2008; NMFS 2012; CDFW 2015b; NMFS 2016). The National Marine Fisheries Service (NMFS) has consequently made several listing determinations pursuant to the federal Endangered Species Act (ESA) for the Distinct Population Segments (DPS)/ Environmentally Significant Units (ESU) of the respective species. These determinations cover all anadromous salmonid species found within the Mark West Creek subwatershed: Central California Coast (CCC) steelhead, listed as threatened in 1997 (62 FR 43937); California Coastal (CC) Chinook Salmon, listed as threatened in 1999 (64 FR 50394); and CCC Coho Salmon, listed as endangered in 2005 (70 FR 37160). CCC Coho Salmon north of San Francisco Bay were also listed as endangered under the California Endangered Species Act (CESA) in 2005.

Despite the CESA/ESA listings, populations of anadromous salmonid species continue to decline in the Russian River watershed and throughout their ranges. The Russian River population of Coho Salmon was nearly extirpated in the late 1990s (CDFG 2004; NMFS 2008). In response to the decline, county, state, and federal agencies formed the Russian River Coho Salmon Captive Broodstock Program (Broodstock Program) in hopes of preventing imminent extirpation. This collaborative effort has been supporting species recovery by breeding Coho Salmon from local genetic stocks and releasing juveniles into streams historically inhabited within the Russian River watershed, including Mark West Creek.

The degradation and loss of freshwater habitat, caused by a decrease in water quality and insufficient water quantity, is one of the leading causes of salmonid decline (CDFG 2004; NMFS 2012). Water diversions, modifications to riparian vegetation, and sediment delivery to streams that provide critical habitat to salmonid species in the Russian River watershed have contributed to the degradation and loss of habitat (NMFS 2008; Sonoma RCD 2015). This instream flow study conducted by the Department of Fish and Wildlife (Department) will provide information to help support the recovery of anadromous species within upper Mark West Creek by identifying the flow regimes necessary to support salmonids and the habitats upon which they depend.

2.0 PROJECT BACKGROUND

The Mark West Creek subwatershed provides habitat for listed anadromous salmonid species including CCC steelhead, CC Chinook Salmon, and CCC Coho Salmon as well as various other aquatic species of special concern such as the California Roach (*Lavinia symmetricus*), Northwestern Pond Turtle (*Actinemys marmorata*), and Foothill Yellow-Legged Frog (*Rana boylii*). One of the primary motivations for this flow study is the California Water Action Plan (CWAP). Released by Governor Brown in 2014, the CWAP directs the Department and State Water Resources Control Board (State Water Board) to initiate a suite of actions to enhance water flows in at least five stream systems that support critical habitat for anadromous fish species. Mark West Creek was established as a priority CWAP stream. In addition to being a CWAP priority stream, limiting factors and recovery actions identified in recovery plans for the listed salmonid species inhabiting Mark West Creek (CDFG 2004; NMFS 2012; NMFS 2016) provide contextual background for this instream flow study.

Prior assessments (e.g., NMFS 2008; Grantham et al. 2012; Obedzinski et al. 2016) have indicated that impaired streamflow is a factor affecting steelhead and Coho Salmon survival in the Russian River watershed. The State's Steelhead Restoration and Management Plan (CDFG 1996) suggests that water diversions have led to insufficient flow conditions within the Russian River watershed, contributing to the decline of steelhead populations. Part of the difficulty in managing the impacts of water diversions, the plan stated, stems from the lack of studies to determine the instream flow requirements for salmon and steelhead within the Russian River and its tributaries (CDFG 1996). The Department's Coho Salmon Recovery Strategy (CDFG 2004) suggested that altered flow regimes were likely presenting an obstacle to Coho Salmon recovery within the Russian River watershed. Finally, both the CCC Coho Salmon Recovery Plan (NMFS 2012) and Coastal Multispecies Recovery Plan (NMFS 2016) identified insufficient baseflow conditions as a limiting factor facing rearing juveniles within the Russian River and Mark West Creek focus populations, respectively. To aid in the prioritization of recovery actions from the Coho Salmon recovery plans, the Department and NMFS formed the Priority Action Coho Team (PACT). The PACT identified Mark West Creek as one of the top ten streams north of San Francisco Bay in which flow enhancements could benefit the recovery of the species.

In 2014, prolonged drought conditions and the likelihood of significant impacts to listed salmonid species prompted the Department and NMFS to develop the Voluntary Drought Initiative (VDI) Program[2]. Mark West was identified as a priority watershed in which to implement the VDI Program, one of four within the entire CCC steelhead DPS and CCC Coho Salmon ESU. In 2015, as poor conditions persisted, the State Water

[2] Governor Brown declared a State of Emergency in 2014 due to ongoing drought conditions and subsequently issued an Executive Order directing the Department to coordinate with other agencies and landowners to minimize the combined impacts of the drought on listed species within priority watersheds. The VDI Program aimed to incentivize landowners to reduce water use and "prevent unreasonable impacts to fishery resources."

Board adopted an emergency regulation titled "Enhanced Water Conservation and Additional Water User Information for the Protection of Specific Fisheries in Tributaries to the Russian River" (CCR Title 23 Section 876). This regulation applied to the four Russian River subwatersheds identified in the VDI effort (i.e., Dutch Bill, Green Valley, Mill, and Mark West creeks), and mandated that landowners reduce water use and provide water use information on surface and subsurface diversions.

The Russian River Coho Water Resources Partnership (RRCWRP) identified Mark West Creek as one of five critical subwatersheds within the Russian River basin where important water management strategies could help restore the Coho Salmon population (RRCWRP 2017). In order to help address the low-flow limiting factor, developing an understanding of flow regimes and the relationship between streamflow and available salmonid habitat within upper Mark West Creek is required. This study will develop these habitat-flow relationships and identify the flows necessary to provide suitable habitat to support species recovery and guide future management decisions.

3.0 PROJECT DESCRIPTION

Department staff will conduct the instream flow study within upper Mark West Creek. Department Water Branch staff will coordinate and carry out data collection, data analysis, and generate a technical report (Table 1). Given the diverse nature of interests within the watershed, stakeholder coordination and outreach will be a vital component of the project. Bay-Delta Region staff will identify key outreach opportunities and will be supported by Water Branch staff participation. Bay-Delta Region, Conservation Engineering, and the Fisheries Branch will review the study plan, technical project components, and reports produced by the Water Branch.

Table 1. Roles and responsibilities in the Department's Mark West Creek study.

Department Lead	Role
Water Branch	Technical Study Project Coordination Study Planning Field Data Collection Engineering Data Management and Analysis Data Reporting
Bay-Delta Region	Project Context and Objectives Study Plan Review Field Data Collection (resources permitting) Project Review
Shared (Water Branch and Region)	Study Design Stakeholder Identification, Coordination, and Outreach Landowner Access
Conservation Engineering	Study Plan Review Project Consultation and Review
Fisheries Branch	Study Plan Review Project Review

3.1 Study Goals and Objectives

The goal of this study is to develop relationships between streamflow and salmonid habitat in upper Mark West Creek. Information developed will identify important flow thresholds for the protection and maintenance of anadromous steelhead and Coho Salmon juvenile rearing, and may be used to generate Department flow recommendations.

The objectives of this study are to:

- Identify and develop relationships between streamflow and available salmonid habitat using a combination of empirical approaches and hydraulic habitat modeling.
- Determine flows needed to maintain rearing habitat and connectivity for juvenile salmonids.
- Identify flows that support productive riffle habitats for benthic macroinvertebrates, an important food source for juvenile salmonids.
- Monitor water quality conditions, including temperature and dissolved oxygen.

3.2 General Approach

Relationships between streamflow and habitat within upper Mark West Creek will be developed using a combination of scientifically defensible methods, which may include hydraulic habitat modeling and empirical approaches described by the Instream Flow Council in *Instream Flows for Riverine Research Stewardship* (Annear et al. 2004). The resulting relationships will serve as a basis to help identify important flow thresholds for the conservation, restoration, and protection of salmonids and other aquatic resources within the watershed. Study components include assessing rearing habitat, riffle productivity and connectivity flows in upper Mark West Creek. In addition, monitoring of temperature and dissolved oxygen will be conducted to evaluate water quality conditions.

4.0 WATERSHED DESCRIPTION

Depending on the source of information, the boundary of the Mark West Creek subwatershed can vary. The U.S. Geological Survey (USGS) National Hydrologic Dataset and the Sonoma County Water Agency (SCWA) define Mark West Creek as a tributary to the Russian River (Nishikawa 2013). However, several other sources identify Mark West Creek as a tributary to the Laguna de Santa Rosa, which then flows into the Russian River (Sloop et al. 2007; Baumgarten et al. 2014; CEMAR 2015). The discrepancy stems in part from the complex lower reaches of the creek. Lower Mark West Creek's channel has undergone natural course migrations across its alluvial fan, but has also been subject to substantial anthropogenic modifications since the late 1800s (Baumgarten et al. 2014). For the purposes of this study, we are defining the Mark West Creek subwatershed using a modified USGS 12-digit hydrologic unit code (HUC12) boundary[3] and Mark West Creek as a tributary to the Russian River. Mark West Creek enters the Russian River near river mile 24 (Figure 1).

[3] Quantum Spatial developed these hydrologic data products for the Sonoma County Vegetation Mapping and LiDAR Program based on high-resolution LiDAR data collected in 2013.

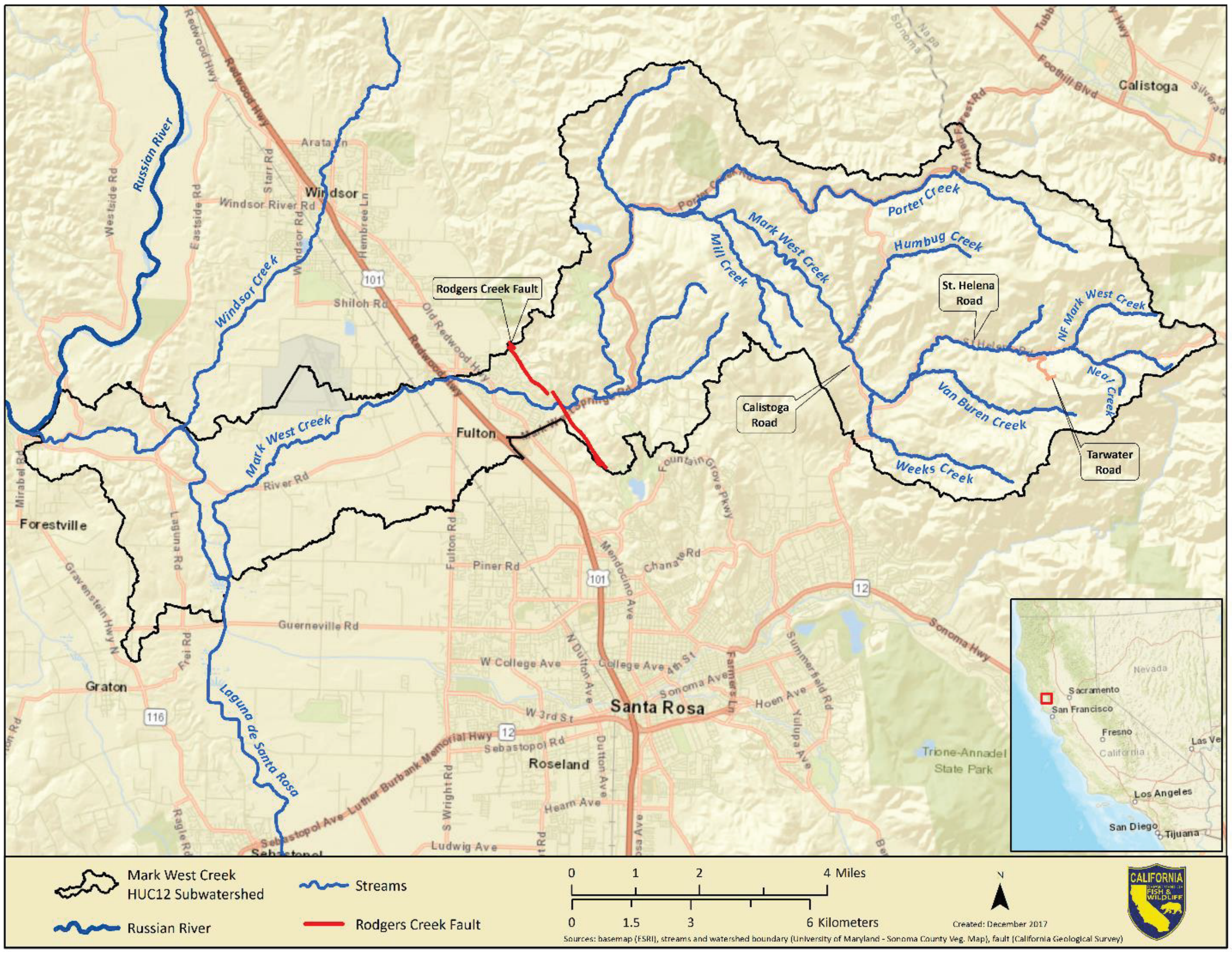

Figure 1. Mark West Creek HUC12 subwatershed.

Situated about five miles north of the City of Santa Rosa along the eastern boundary of Sonoma County, the Mark West Creek HUC12 subwatershed is the second largest in the Russian River basin, draining an area of approximately 59 square miles. Mark West Creek stretches roughly 34 miles from its confluence with the Russian River to its headwaters in the Mayacamas Mountains. The three main tributaries to Mark West Creek are Windsor and Porter creeks, and the Laguna de Santa Rosa. Smaller significant tributaries include Mill, Humbug, Weeks, Van Buren, North Fork Mark West, and Neal creeks.

With a maximum elevation of approximately 2,350 feet, the watershed drains a portion of the Mayacamas Mountain Range in a general westward direction towards its confluence with the Russian River, which occurs at an elevation of roughly 30 feet. Longitudinally, the watershed's topography varies greatly. Towards its western boundary, the watershed encompasses a low relief valley area. The Rodgers Creek fault that runs northwest and lies approximately mid-watershed marks a noticeable topographic boundary at the foot of the Mayacamas Mountain Range (Figure 1; Sloop et al. 2007). From this point, the watershed begins to climb into rolling foothills and ultimately terminates in the steep-walled, narrow valleys of the mountainous headwater region along its eastern boundary (Honton and Sears 2006).

The watershed's land uses and land cover differ between the lower valley and upper mountainous region. Around the mid-19th century, the lower watershed underwent a conversion from a landscape dominated by oak savannah, seasonal and perennial wetlands, to a landscape structured around grazing and ranching; this later shifted to dairy farming, orchards, hay fields, and row crops (Honton and Sears 2006; Sloop et al. 2007). In the mid-20th century, rapid urbanization began to shift land use from agriculture (Sloop et al. 2007). Today, most of the lower watershed's land cover is dominated by urbanized land and irrigated cropland (predominantly vineyards), and to a lesser extent native hardwood forests, riparian forests, and grassland (CEMAR 2015).

Ranching and timber harvest were the major early land uses in the eastern mountainous region of the watershed (i.e., the upper watershed; Sonoma RCD 2015). Mirroring population growth and changes in the lower watershed, land use in the upper watershed began to shift in the mid-20th century when parcels were subdivided, allowing for the expansion of rural residential development (Sotoyome RCD 2008). Like the lower watershed, vineyards emerged as a dominant crop towards the end of the 20th century (Sonoma RCD 2015), although vineyard land cover by percentage area is far smaller in the upper watershed as compared to the lower watershed with approximately 2% and 37%, respectively[4]. Coniferous forest, hardwood forest, grassland, and shrubs presently dominate land cover in the upper watershed (CEMAR 2015; Sonoma RCD 2015). Approximately 90% of the land within the Mark West Creek subwatershed is privately owned.[5]

4.1 Target Species and Life Stages

Collectively, CCC steelhead, CC Chinook Salmon, and CCC Coho Salmon utilize the Mark West Creek subwatershed year-round to carry out the freshwater stages of their life histories. CCC steelhead and CC Chinook Salmon are both listed as threatened under the federal ESA, while CCC Coho Salmon are listed as endangered under both the ESA and CESA. Bjorkstedt et al. (2005) and Moyle et al. (2008) concluded that CCC steelhead within Mark West Creek exist as an essential, potentially independent population within the steelhead DPS. CCC Coho Salmon in lower Russian River tributaries, including Mark West Creek, exist as part of a single, functionally independent population that is at high risk of extirpation (NMFS 2008). NMFS (2008) suggests that, historically, CCC Coho Salmon populations in the lower Russian River were the most abundant population source for other streams within the CCC ESU. Accordingly, the persistence of CCC steelhead and CCC Coho Salmon populations in

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[4] Vineyard land cover estimate from GIS analysis using the fine-scale vegetation and habitat map data from the Sonoma County Vegetation Mapping and LiDAR Program.
[5] Land ownership estimate from GIS analysis using data from the California Department of Forestry and Fire Protection, Fire Resource and Assessment Program (FRAP).

the Russian River is necessary to support the recovery of the species within their respective DPS/ESU (NMFS 2008). The Department identified the juvenile life stages of steelhead and Coho Salmon as the focus for this instream flow and habitat assessment project. Because the juvenile life stages of these species rear in the creek throughout the summer and fall months (Table 2), maintaining adequate streamflow conditions during this period is essential to support the species' recovery (NMFS 2008).

Table 2. Generalized seasonal periodicities of target salmonid species in upper Mark West Creek.

Species and Life Stages	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
CCC steelhead												
Adult												
Juvenile												
CCC Coho Salmon												
Adult												
Juvenile												
Legend:												
	Present											

Sources: Steiner (1996); R2 Resource Consultants, Inc. and Stetson Engineers, Inc. (2007); NMFS (2012); NMFS (2016).

Long-term systematic fish surveys are lacking within the Mark West Creek subwatershed (NMFS 2016). Several short-term studies have been conducted and observations have been noted during periodic habitat analyses conducted by the Department and other entities. Historically, steelhead were observed over a wide range of Mark West Creek where habitat remained wetted through the summer and fall seasons (CDFG 1953, 1966, 1969, 1971), though current densities are thought to be significantly reduced from observations noted through the 1950s to 1970s (NMFS 2016). Information on the historical presence and distribution of Coho Salmon within the Russian River watershed, and Mark West Creek, specifically, is much more limited (Spence et al. 2005; NMFS 2008). Nonetheless, both Brown and Moyle (1991) and Spence et al. (2005) found evidence from past stream surveys to conclude that Coho Salmon populations historically existed in Mark West Creek.

In the early 2000s, the Broodstock Program conducted surveys in the lower Russian River and found limited numbers of wild juvenile Coho Salmon in only five creeks, including Mark West (Conrad 2006). A study conducted by Merritt Smith Consulting (2003) during the summer and fall months from 1993-2002 observed small numbers of Coho Salmon across their three Mark West Creek study reaches in 2001 only. Steelhead were observed in moderate numbers in each of the study reaches in most years, with greater abundances in the upper watershed (Merritt Smith Consulting 2003). The SCWA also conducted electrofishing distribution/abundance surveys in Mark West

Creek to detect steelhead and Coho Salmon in 2001 and found only steelhead throughout the creek, with numbers increasing from the most downstream to upstream survey sites (Cook and Manning 2002).

4.2 Habitat Suitability and Biological Criteria

Accurate representation of available habitat in relation to discharge requires linking stream channel hydraulics, over a range of flows, with known habitat suitability criteria (HSC) for the target species and life stages (CDFG 2008). The target species and life stage for this project have been identified as juvenile CCC steelhead and juvenile CCC Coho Salmon. Appropriate HSC are a critical element of hydraulic habitat modeling. No site-specific HSC have been developed for the above listed species in the Russian River watershed.

The creation of suitable HSC requires a minimum sample size of fish observations (typically greater than 150 per life stage/species, mesohabitat category, and microhabitat component) while also accounting for the influence of habitat availability on observed habitat use (Bovee 1986). HSC are developed by associating fish observations with water depth, velocity, cover, and other important site-specific microhabitat components, ideally in systems that have a minimally altered flow regime. To accomplish this, field-based techniques including fish snorkel surveys and measurements/classification of physical habitat attributes are employed based on methods described by Holmes et al. (2014). General guidelines for HSC development can be found in Bovee (1986), Bovee and Zuboy (1988), and CDFG (2008).

Obtaining representative and unbiased information is an important step in developing HSC. There are two factors that make the development of HSC uncertain in Mark West Creek. First, Mark West Creek has an impaired hydrograph and can be subject to sustained low flow conditions. Because of this, hydraulic habitat availability and associated fish behavior observed in a HSC study may not be representative of ideal conditions since fish are unable to utilize preferred habitat. Second, estimates of current Coho Salmon populations within Mark West Creek have been very low and it would likely be difficult to observe the required sample size. Instead, HSC from two coastal California watersheds will likely be used to support the habitat analysis of juvenile CCC steelhead and CCC Coho Salmon life stages in Mark West Creek: the Big Sur River (Holmes et al. 2014) and the South Fork Eel River (to be completed in 2018/2019).

4.3 Hydrology

The watershed’s Mediterranean climate is characterized by arid to semi-arid summers and punctuated storm events during the winter and spring months. Long-term meteorological data coverage in the Mark West Creek subwatershed is limited and records from existing monitoring stations often have short periods of record, contain significant data gaps, or are situated in the lower elevations of the watershed making it difficult to characterize precipitation patterns in the mountainous upper watershed (Woolfenden and Nishikawa 2014). Because precipitation within the watershed is strongly influenced by topography (Nishikawa 2013), many analyses rely upon PRISM (Parameter-elevation Regressions on Independent Slopes Model) datasets, which use elevation and nearby meteorological stations to interpolate precipitation values for ungaged locations. Average yearly precipitation values vary from about 30 inches in the valley floor to about 47 inches in the Mayacamas Mountains, with a watershed average of approximately 40 inches[6] (800m PRISM 30-year normal, 1981-2010). In a 2015 report, the Center for Ecosystem Management and Restoration (CEMAR) presented information from a landowner in the upper watershed who recorded an annual average of approximately 65 inches (1965-2011), indicating that the PRISM normals are likely underestimates, at least in the upper watershed (CEMAR 2015). Although winter temperatures may be conducive to snow formation at the higher elevations, nearly all of the precipitation in the watershed falls as rain (Nishikawa 2013). Rantz (1972) analyzed streamflow and precipitation records (1931-1970) in relatively undeveloped watersheds including nearby Mill and Santa Rosa creeks, and found that roughly half of the precipitation that fell in those watersheds was converted into streamflow.

Springs and seeps such as those that contribute to Neal Creek, a small tributary in the headwater region of Mark West Creek, play an important role in maintaining water connectivity and perennial flows within the upper watershed (Nishikawa 2013; CEMAR 2015). Some of the tributaries to Mark West Creek also maintain minimal perennial flows through the dry season, though the majority undergo significant drying and generally lose surface connectivity with Mark West Creek (SRPBAP 2014). Baseflow, which comprises only a small portion of the hydrograph in Mark West Creek, is an extremely important component of flow during the dry season (Nishikawa 2013). Results from the USGS Santa Rosa Plain Hydrologic Model (SRPHM)[7] indicate that surface runoff is the main component of the hydrograph in Mark West Creek from November through April, while baseflow is dominant from May through October (Woolfenden and Nishikawa 2014). CEMAR (2015) indicated their multiyear streamflow monitoring conducted in upper Mark West Creek showed that, while consistently low, flows were relatively more stable over the course of each dry season compared to other Russian River tributaries in their monitoring network.

As with many streams subject to the seasonality of Mediterranean climates, the timing of higher streamflow in Mark West Creek and other Russian River tributaries in the late winter and spring does not coincide with the high demand in the summer and fall dry seasons (Deitch and Dolman 2017). CEMAR (2015) found that total annual rainfall and discharge generally surpass demand; however, demand in the summer and fall exceeds surface water availability leading to a reliance on wells and springs to meet dry season

[6] PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed September 2017.

[7] The SRPHM is a groundwater-surface water model that was developed by the USGS. It is used to characterize a water balance including streamflow, groundwater recharge and storage, and the impacts of diversions on these hydrologic components. The model utilized information and data collected during a hydrologic characterization of the Santa Rosa Plain completed by the USGS in 2013 (Nishikawa 2013).

water needs (Deitch and Dolman 2017). This reliance upon wells and springs can have cumulative impacts on baseflow and likely contributes to the low flow conditions observed throughout the dry season, especially during extended periods of low rainfall (SRPBAP 2014; CEMAR 2015; Sonoma RCD 2015). Results from the 2015 informational order (see Section 2) show dense concentrations of groundwater wells along areas of Mark West Creek and its tributaries (Figure 2).

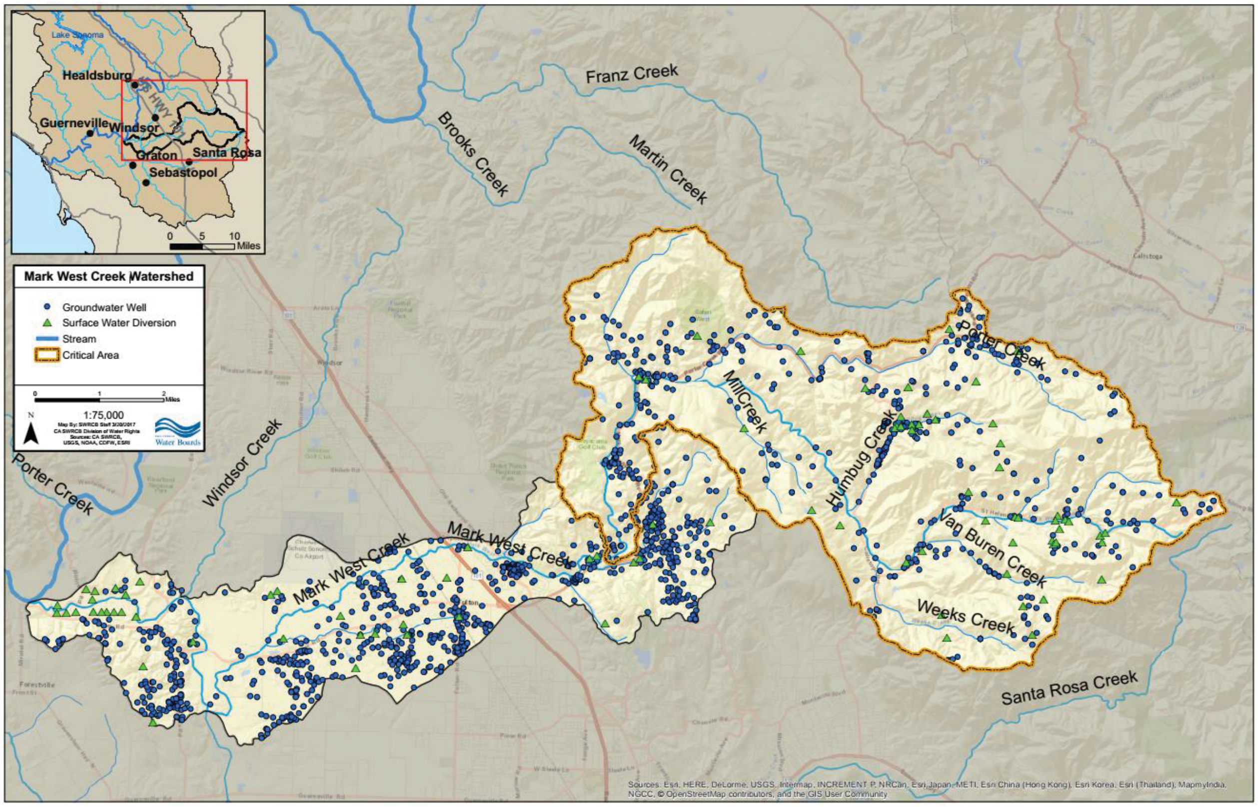

Figure 2. Diversions within the Mark West Creek subwatershed. Figure from SWRCB (2017).

Numerous streamflow gages have been operated across the Mark West Creek subwatershed (Figure 3 and Table 3), though meaningful hydrologic analysis is constrained by short periods of record, data gaps, and seasonal data collection (Sloop et al. 2007; Nishikawa 2013). A USGS gage near Mirabel Heights (USGS 11466800) has the longest period of record within the watershed, with approximately 12 years of data starting in the 2006 water year (WY). This gage is located downstream of Mark West Creek's confluence with two large tributaries, the Laguna de Santa Rosa and Windsor Creek. The lack of flow information for these contributing tributaries means the amount of flow originating from upper Mark West Creek cannot accurately be discerned. CEMAR has operated three gages to varying lengths during WY 2010-WY 2017. One of these gages, MW01, is located high in the watershed near Tarwater Road. This gage provides the best available indicator of conditions in the upper watershed during the dry season. Average daily streamflow at MW01 has generally dropped below 1 cubic foot per second (cfs) by May or June. The minimum and maximum average daily summer flows captured at MW01 over the period of record were 0.06 and 11.8 cfs, respectively. The mean and median average daily flows during the same period were 0.41 and 0.22 cfs, respectively. The lack of a long-term, year-round gage network throughout the watershed makes it difficult to assess flow regimes and to understand how the range of flows can affect biological processes and species recovery in the creek (Honton and Sears 2006).

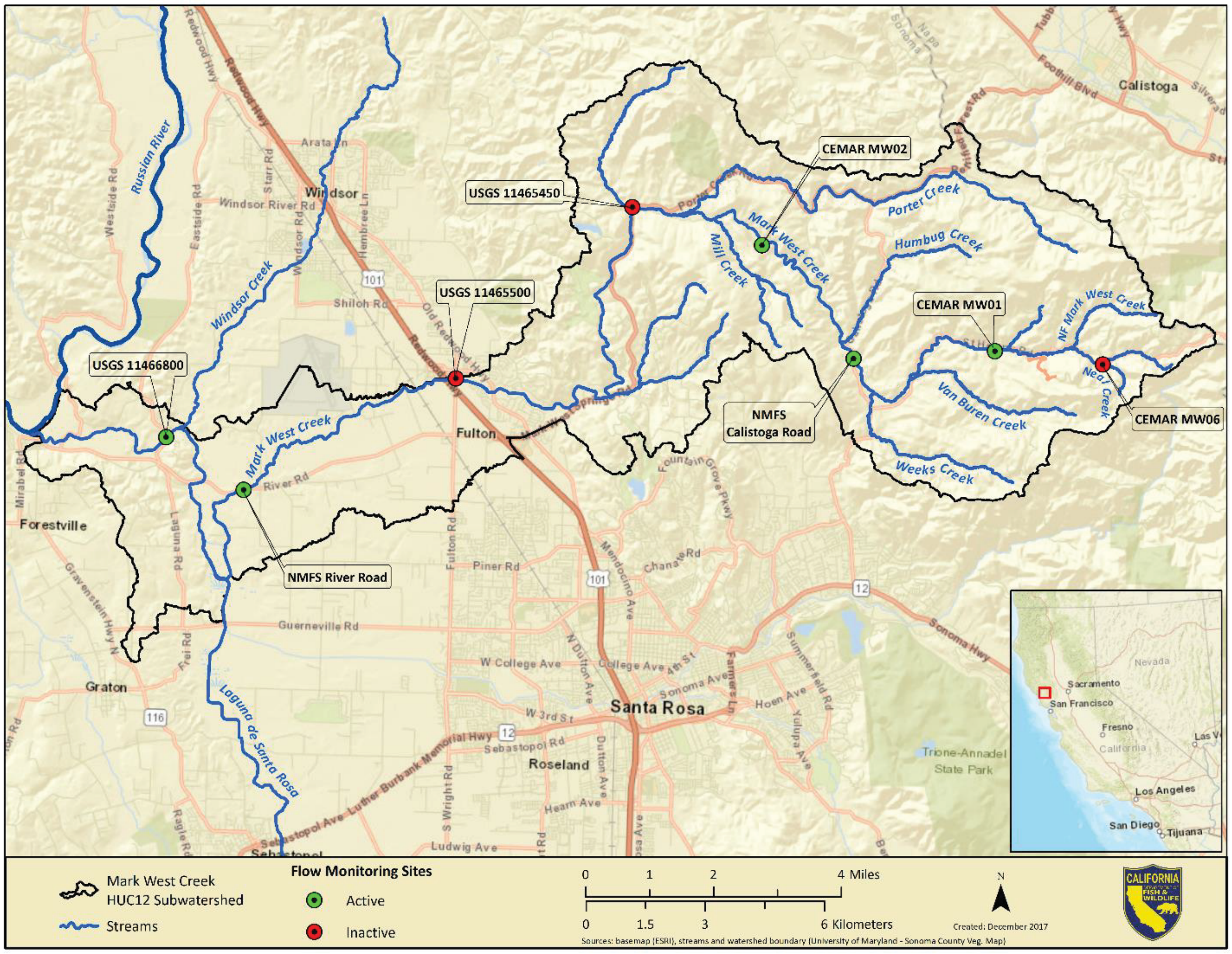

Figure 3. Streamflow monitoring gages in the Mark West Creek subwatershed.

Table 3. Streamflow monitoring gages within the Mark West Creek subwatershed.

Operator	Gage Identifier	Period of Record	Notes
USGS	11466800 Mark West Creek near Mirabel Heights	October 2005-Present	Some small data gaps in record, and a large gap for most of WY 2010. Gage sometimes influenced by backwatering from Russian River during high flows.
NMFS	Mark West Creek at River Road	November 2011-Present	Significant data gaps.
USGS	11465500 Mark West Creek near Windsor	October 2006-April 2008	Significant data gap in second half of WY 2007.
USGS	11465450 Mark West Creek at Mark West Springs	1958-1962	Peak annual discharges only.
CEMAR	MW02 Mark West Creek above Porter Creek	May 2010-Present	Record covers mostly low flow periods. Significant recent data gaps.
NMFS	Mark West Creek at Calistoga Road	October 2011-Present	Discharge extrapolated above 30 cfs. Some data gaps.
CEMAR	MW01 Mark West Creek below Tarwater Road	March 2010-Present	Early records were mostly year-round with discharges estimated below 50 cfs only. Some small data gaps. Since WY 2015, only seasonal low flow measurements taken.
CEMAR	MW06 Mark West Creek at Neal Creek	June 2011-November 2014	Record covers mostly low flow periods. Some small data gaps.

Long-term unimpaired streamflow records are generally used by the Department IFP to aid in the determination of a range of representative target flows for field data collection. The lack of long-term gages in the Mark West Creek subwatershed, as well as the surrounding watersheds, complicates the unimpaired streamflow determination. Given this, to identify target flows for data collection in upper Mark West Creek the Department intends to select an appropriate range of flows based on unimpaired average monthly flow estimates (1950-2015) from the California Natural Flows Database[8] (CNFD; Zimmerman et al. 2017). The unimpaired average monthly flow estimates in the stream reach (COMID 8272495) located near the CEMAR MW01 gage will serve as the basis for a flow duration analysis, which estimates the likelihood of a particular discharge value being equaled or exceeded (referred to as an exceedance flow; CDFW 2013b; Searcy 1969). The unit of time used to calculate exceedance flows affects the utility of the flow duration curve (i.e., a shorter time unit will result in a greater representation of flow variability). The CNFD only provides average monthly unimpaired flow estimates. While exceedance calculations using the average monthly estimates may result in diminished flow variability, the CNFD provides the best available information for calculating target flows. Target flows for data collection on upper Mark West Creek will likely fall within the 20 to 80 percent exceedance flow range (CDFW 2013b). The 20, 50, and 80 percent exceedance flows estimated for this reach of upper Mark West Creek are 23.5, 2.9, and 0.5 cfs, respectively.

4.4 Groundwater Hydrology

The Mark West Creek subwatershed overlies three groundwater subbasins identified in the Department of Water Resources' (DWR) Bulletin 118 (DWR 2003), though the subbasins' areal extent within the watershed varies. The upper Mark West Creek subwatershed overlies small sections of both the Rincon Valley Subbasin (1-55.03) and the Alexander Subbasin (1-54.01). Most of the lower Mark West Creek subwatershed overlies the Santa Rosa Plain Subbasin (1-55.01). In addition to these named subbasins, small, localized aquifers likely exist within the alluvial deposits along the stream channels in the middle watershed (Nishikawa 2013). The Sonoma Volcanics, which comprise a significant portion of the Mayacamas Mountains in the upper watershed, can also contain disconnected aquifers within fractured or porous strata (Cardwell 1958; Nishikawa 2013). Groundwater that discharges from springs and seeps provides a significant source of baseflow in parts of Mark West Creek (Nishikawa 2013), especially within the Sonoma Volcanics (Cardwell 1958).

The geologic heterogeneity surrounding Mark West Creek, especially in the mountainous upper watershed, results from the numerous fault zones that traverse the area as well as the interaction between the North American and Pacific tectonic plates that formed the Mayacamas Mountains and northern California Coast Ranges (SRPBAP 2014; RRISRP 2016). The interactions that result from the juxtaposition and

[8] The California Natural Flows Database was a collaborative effort between the USGS and The Nature Conservancy to develop estimates of natural (unimpaired) flows for all of the streams in California from 1950-2015 (Zimmerman et al. 2017).

interfingering of these geologic units can affect groundwater flow and yields (Nishikawa 2013). For example, evidence suggests that Mark West Creek likely gains streamflow near the Rodgers Creek fault zone, where shallow groundwater originating in the mountainous upper watershed mounds and discharges to the creek as a result of the horizontal flow barrier (SRPBAP 2014).

Several surficial geologic units are present in the upper Mark West Creek subwatershed including Quaternary Alluvium, the Sonoma Volcanics, and the Franciscan Assemblage (Nishikawa 2013; CEMAR 2015); the Sonoma Volcanics are the dominant unit in terms of areal coverage (Nishikawa 2013). The Sonoma Volcanics are generally porous and can be highly fractured in areas, allowing for development of wells (RRISRP 2016), though their yield is highly variable and is dependent upon the extent of fracturing (Cardwell 1958; Nishikawa 2013). Due to the inconsistent fracturing within the Sonoma Volcanics, determining the direct impacts of groundwater pumping is difficult (CEMAR 2015). Although domestic wells have tapped into areas of fractured bedrock that underlie the Sonoma Volcanics, the existence of groundwater within the Franciscan complex is much more limited and the wells consistently have low yields (Nishikawa 2013). Where wells exist in the upper Mark West Creek subwatershed, the alluvial deposits generally consist of coarse material (Nishikawa 2013), which leads to higher streambed conductivities and a greater potential for groundwater-surface water interactions (SRPBAP 2014).

Lower in the watershed, both the Sonoma Volcanics and the Glen Ellen Formation outcrop in the area surrounding the Rodgers Creek fault zone (SRPBAP 2014). In the lower Mark West Creek subwatershed, the valley is comprised of quaternary alluvium and loosely consolidated alluvial deposits of the Glen Ellen Formation (SRPBAP 2014). Well pumping yields within the Glen Ellen Formation are highly variable (DWR 1975) and the alluvial deposits are generally comprised of finer material than those found in the upper Mark West Creek subwatershed, leading to lower conductivities and infiltrative capacity (SRPBAP 2014).

4.5 Connectivity

Low streamflow can limit the hydrologic connectivity of riverine habitats, impacting water quality, food production, and critical salmonid life history strategies. Salmonids have learned to survive in systems with long low flow periods by rearing in deep pools and runs throughout the summer and fall months (Moyle 2002; CDFG 2004). Disconnected stream segments can prevent juvenile salmonids from relocating to suitable over-summer holding habitat having adequate cover and water quality conditions. Due to various factors such as climate, water diversions, antecedent precipitation, and groundwater-surface water interactions, sections of Mark West Creek become disconnected during the dry season. Merritt Smith Consulting conducted seasonal fisheries surveys from 1993-2002 along three reaches of Mark West Creek and observed that the reach in the upper watershed downstream of Calistoga Road occasionally became intermittent in the late spring and summer months, forcing fish to rear in isolated pools (Merritt Smith Consulting 2003).

The watershed's Mediterranean climate and lack of precipitation during summer months is a significant factor contributing to seasonal low flows and intermittence in Mark West Creek (CEMAR 2015). Additionally, springs and seeps that help maintain stream connectivity in the upper watershed are frequently diverted during the dry season when streamflow is already naturally low. While unintentional, baseflow may be impacted by the cumulative impact of diversions, depending on the extent of groundwater-surface water interconnection (CEMAR 2015).

In 2013, the UC Cooperative Extension added Mark West Creek to their list of streams monitored for wetted habitat conditions (wet/dry mapping)[9] during the low flow period. The objective of the wet/dry mapping effort is to document the extent and location of wet, dry, and intermittent instream habitat during the driest period of the year, which usually occurs in September. The effort has indicated that Mark West Creek remains wetted through most of the middle and upper watershed, though streamflow remains low. In the alluvial reach near the Porter Creek confluence (middle watershed), Mark West Creek has experienced dry or intermittent conditions each year since 2013, with the exception of 2014.

4.6 Geomorphology

The Mark West Creek subwatershed is situated within the Northern Coast Range geomorphic province. The Mayacamas Mountain Range that comprises much of the terrain in the upper Mark West Creek subwatershed was formed as a result of complex tectonic interactions between the North American and Pacific plates. Mark West Creek and its tributaries have eroded the Mayacamas Mountains over time, transporting and depositing sediment into the mountain valleys and alluvial fan in the valley below. The northwest trending Rodgers Creek fault zone acts as a rough boundary between the sediment production zone of the upper watershed and the depositional zone in the valley floor (Sloop et al. 2007).

Hydrologic soil group classifications (NRCS 2007), which are based on soil properties such as permeability and soil thickness, can be a useful tool in understanding a watershed's response to precipitation. In general, soils in the lower portion of the watershed have low-moderate runoff potential, while soils in the mountainous upper watershed are thinner with a significant amount of exposed bedrock, leading to a moderate-high runoff potential (Nishikawa 2013). Landscape alteration and disturbance can also affect runoff, erosion processes, and sediment transport. Historical landscape changes in the Mark West Creek subwatershed such as road development, timber harvest, and rural subdivisions, as well as shifting land use practices (e.g., grazing and vineyard development), have contributed to higher rates of runoff and sedimentation (Sloop et al. 2007; Sonoma RCD 2015).

[9] Information on wet/dry mapping available at: https://caseagrant.ucsd.edu/project/coho-salmon-monitoring/flow-and-survival-study.

The upper and middle portions of the watershed are comprised of moderate gradient channels that drain steep hillsides (Nishikawa 2013). In the valley floor, as Mark West Creek traverses its alluvial fan, the channel assumes a more modified character with a relatively straight, channelized, and entrenched channel (RRISRP 2016). An analysis of generalized stream typologies presented in the 2016 RRISRP report, developed by Walls (2013), suggests that five different stream types exist within Mark West Creek: dissected alluvium, unconfined alluvial, alluvial fan, semiconfined alluvial, and bedrock canyon. The alluvial channel forms are dominant in the valley floor up to the transition zone near the Rodgers Creek Fault. With the exception of a dissected alluvium channel downstream of the Porter Creek confluence, bedrock canyons and semiconfined alluvial channels dominate the upper watershed (RRISRP 2016).

Few on-the-ground assessments of the stream channel have been completed in Mark West Creek; the most recent watershed-wide mainstem survey was conducted by the SCWA in 1996 (CDFG 2006). The surveyors identified six different reaches and channel types from the downstream extent up to the Neal Creek confluence: F4, F2, B2, B3, C3, and B1-2 (Table 4). Flatwater habitat was the dominant Level II habitat type and comprised approximately 50% of the stream length, followed by approximately 40% pool habitat, 8% riffle habitat, and 1% dry channel (CDFG 2006).

Table 4. Mark West Creek channel types, presented from downstream to upstream.

Channel Type	Description
F4	Entrenched, meandering riffle/pool channel with low gradient and high width/depth ratio; gravel-dominated substrate
F2	Entrenched, meandering riffle/pool channel with low gradient and high width/depth ratio; boulder-dominated substrate
B2	Moderately entrenched, riffle-dominated channel with moderate gradient; boulder-dominated substrate
B3	Moderately entrenched, riffle-dominated channel with moderate gradient; cobble-dominated substrate
C3	Low-gradient, meandering, riffle/pool alluvial channel with well-defined floodplain; cobble-dominated substrate
B1-2	Moderately entrenched, riffle-dominated channel with moderate gradient; boulder- and bedrock-dominated substrate

Source: Rosgen (1994).

Following two landslides that contributed large amounts of fine sediment to upper Mark West Creek in the mid-2000s, Li and Parkinson (2009) assessed instream habitat in a small section of the upper watershed from Tarwater Road up to the confluence with North Fork Mark West Creek. In this assessment, pools were identified as a the dominant Level II habitat type and comprised approximately 68% of the stream length, followed by approximately 20% riffle habitat, 11% flatwater habitat, and 1% dry channel (Li and Parkinson 2009).

4.7 Water Quality

Pursuant to section 303(d) of the Clean Water Act, the State Water Board is responsible for assessing, protecting, and restoring surface water quality and submitting a list of impaired water bodies to the U.S. Environmental Protection Agency (EPA). The State Water Board has listed Mark West Creek and its tributaries upstream of the confluence with the Laguna de Santa Rosa as 303(d) impaired water bodies for sedimentation and temperature. Downstream of the confluence with the Laguna, Mark West Creek is also impaired for aluminum, dissolved oxygen, phosphorous, and manganese.

The NMFS Multispecies Recovery Plan (2016) also rates the entirety Mark West Creek as poor for temperature and watershed processes/sediment transport as they relate specifically to the rearing life stage of juvenile steelhead. Because juveniles rear in the creek throughout the year, Moyle (2002) and NMFS (2008) highlight the importance of maintaining temperatures below approximately 57°F, the maximum optimal temperature for rearing steelhead and Coho Salmon. Additionally, Reiser and Bjornn (1979) and Moyle (2002) note that high levels of suspended fine sediments can adversely impact rearing habitat and food availability, and can negatively impact survival by damaging the gills of juvenile fish. In an attempt to help address impairments caused by sediment, Pacific Watershed Associates assessed approximately half of the unpaved roads in the upper Mark West Creek subwatershed for potential sediment delivery sites (Sonoma RCD 2015). Other water quality related assessments in the watershed have generally been short-term and sporadic in nature, focused mainly on temperature. In general, targeting the causes of temperature-related impairments has been difficult. The Sonoma Resource Conservation District (RCD) noted that temperature loggers deployed over several years in reaches along St. Helena Road have consistently recorded water temperatures below 70°F through the low flow season, whereas temperatures lower in the creek near the Porter Creek confluence are significantly warmer, typically surpassing 70°F by mid-June (Sonoma RCD 2015). In the lower reaches, it is suspected that the higher temperatures result from lack of riparian canopy cover (NMFS 2016) and cold-water spring inputs (Sonoma RCD 2015).

4.8 Tubbs Fire

In October 2017, the Tubbs Fire burned approximately 57 square miles across sections of Napa, Sonoma, and Lake counties, including approximately 22 square miles (37%) of the Mark West Creek subwatershed. The burn area spanned the entire north-south extent of the watershed and was concentrated from just west of Highway 101 to Calistoga and Petrified Forest roads to the east. In addition to water quality and biological impacts, the fire may affect the hydrology of Lower Mark West Creek. Depending on the upslope burn severity, CalFire (2017) predicted that the 10%

exceedance flow (CDFW 2013b) in reaches of Mark West Creek could increase anywhere from 9-25%. Due to the likelihood of channel instability (e.g., channel aggradation) after the Tubbs fire, the potential study area has been constrained to the reaches of Mark West Creek above Calistoga Road (Figure 4).

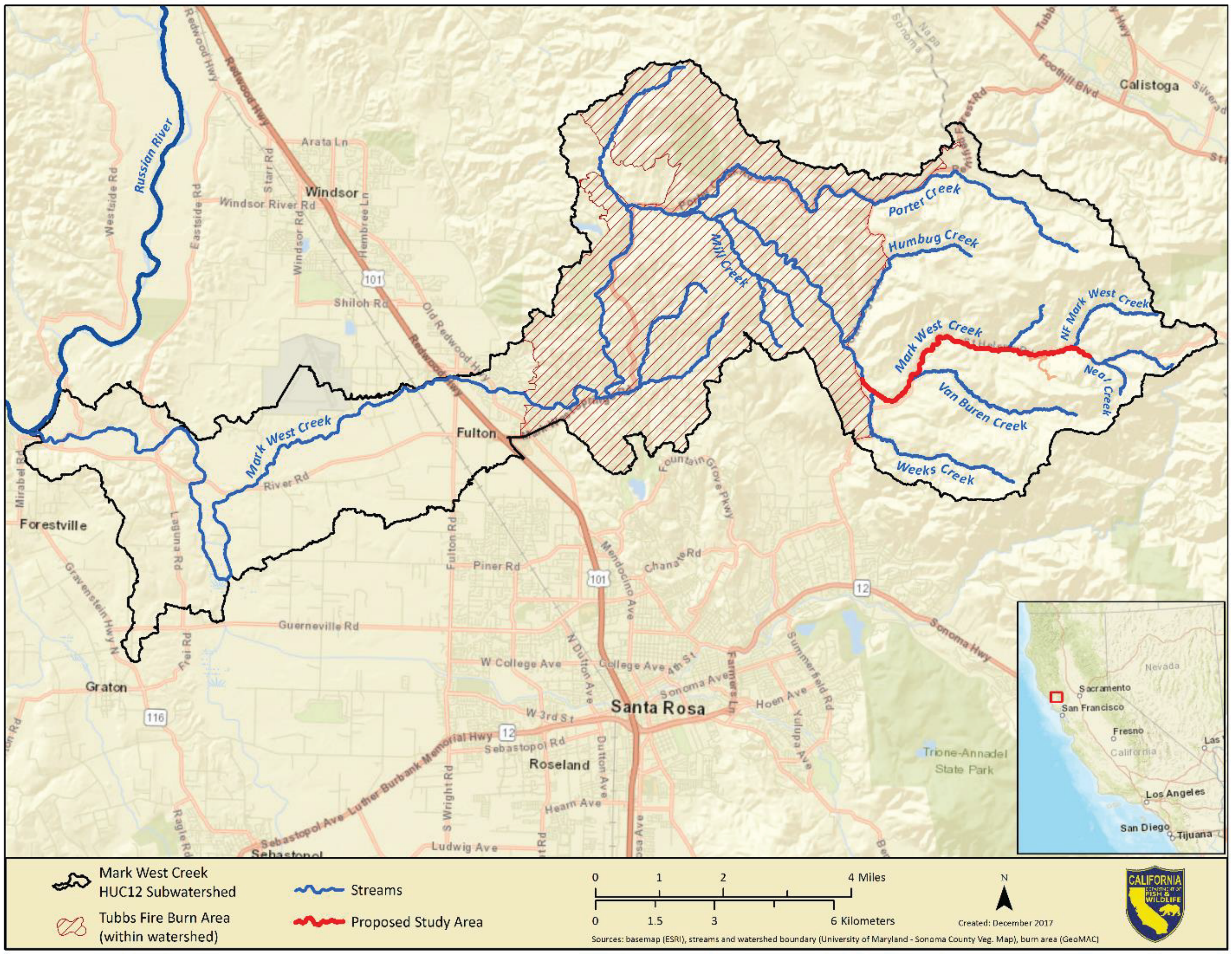

Figure 4. Map of the Mark West Creek subwatershed showing the Tubbs Fire burn area and the proposed study area.

5.0 METHODS AND PROTOCOLS

Department staff will conduct a stream survey within upper Mark West Creek following the Level III-IV (i.e., modified Level III) habitat type survey classifications, as described in the *California Salmonid Stream Restoration Manual* (Flosi et al. 2010) to identify mesohabitat types (CDFW 2015a). A corresponding discharge measurement (CDFW 2013a) will be measured each day of the survey; data will only be collected where landowner access is granted. Upon completion of the survey, the modified Level III mesohabitat classifications will be grouped into riffle, pool, run, or glide categories. The classification of different habitat types is based on characteristics such as channel morphology, gradient, substrate composition, and hydraulic characteristics. The assemblage and overall proportion of each mesohabitat type will help guide site selection for hydraulic habitat modeling (CDFW 2015c).

Mesohabitats were mapped using the on-the-ground method and are typed to the most detailed level III-IV typing as described in Flosi et al. (2010). This level of habitat delineation allows data to be used for other studies or aggregated into less detailed levels depending on the needs of individual studies (e.g. hydraulic habitat modeling). These surveys entail the identification of habitat types using specified criteria, along with measurements of habitat unit length and maximum pool depth for pool units. In addition, landmarks such as road crossings, bridges, and significant streambank alterations are noted.

Each habitat unit will be characterized as modelable or unmodelable according to the limitations of standard one-dimensional (1D) and two-dimensional (2D) hydraulic modeling methods. Modelable, in this context, is a term used to characterize a habitat unit's hydraulic properties and refers to whether the unit's water surface along a hypothetical transect would remain steady and flat over a broad enough range of flows to develop a predictive model. This characterization is necessary for the dataset to be compatible with stratified study site and transect selection techniques, where unmodelable mesohabitat units may be rejected prior to the selection process.

Below is a list of modified Level III mesohabitat types containing sufficient detail for the purpose of transect placement, hydraulic data collection, and transect weighting consistent with stratified sampling for hydraulic habitat modeling. The following mesohabitat types are generally considered modelable and should be retained for study site and transect selection:

- Pool (e.g., mid-channel, lateral scour, channel confluence)
- Glide
- Run/Step-run
- Pocket Water
- Low-Gradient Riffle

The following mesohabitat types are generally considered unmodelable and should be excluded from study site and transect selection:

- Cascade
- Chute
- High-Gradient Riffle

For hydraulic data collection, cascade and chute types are not sampled. High-gradient riffles may occasionally be sampled, but the determination must be done on a case-by-case basis.

Ideally, surveys will be conducted under flow conditions at which the mesohabitat types are readily apparent. That is, not when flows are so high that it appears as though all unit types are either runs or riffles or so low that there are only pools with undifferentiated riffles in between. For safety purposes, the survey team(s) will consist of at least two staff members familiar with salmonid habitat requirements. Team members will already have experience with or will have received recent training in habitat typing methods. At least one member of each survey team should be sufficiently experienced with hydraulic habitat modeling to classify each mesohabitat unit as modelable or unmodelable, irrespective of mesohabitat unit type.

5.1 Single Transect Hydraulic Based Habitat Methods

Single transect hydraulic based habitat methods require site-specific data to be collected along one or more transects within a stream reach. The site-specific data are used with a computer program to model hydraulic parameters. Single transects are placed across the shallow portion (i.e., hydraulic control) of representative riffles. Single transect hydraulic based habitat methods assume that if adequate conditions are maintained over the shallow portions of a stream reach, then the hydraulic habitat in other parts of the stream reach will also be sufficient (Annear et al. 2004).

5.1.1 Habitat Retention Method

The Habitat Retention Method (HRM; CDFW 2016) is a single-transect biology-based method (Nehring 1979) used to estimate hydraulic characteristics (i.e., average depth, average velocity, and percent wetted perimeter) over a range of flows. The HRM quantifies a minimum flow, sufficient to provide a basic survival level for fish during times of the year when streamflow is at its lowest (Annear et al. 2004). With a goal of sampling at least three representative riffles per reach, the method assumes that if a prescribed flow adequately meets hydraulic criteria at the shallowest part of the riffles (i.e., the hydraulic control), then conditions throughout the remainder of the reach should also be sufficient (Nehring 1979; Annear et al. 2004). The HRM may also be used to evaluate fish passage and/or habitat connectivity flows at riffle sites.

5.1.2 Wetted Perimeter Method

The Wetted Perimeter Method (WPM) is used to determine flows that support the maintenance of benthic macroinvertebrate (BMI) habitat and productivity in riffles with rectangular streambed profiles. The WPM is typically applied during the summer and/or fall low flow months (Annear et al. 2004, CDFW 2013d). The wetted perimeter refers to the perimeter of a cross-sectional area of the wetted streambed along a transect, which varies according to discharge. After collecting WPM data and corresponding discharges, a relationship between discharge and wetted perimeter can be developed. Historically, application of the WPM required collecting data over an expansive range of discharge events to determine the relationship between wetted perimeter and discharge at each site. Recent applications of the WPM generally use computer-based water surface profile modeling programs based on the Manning's equation to develop this relationship (Annear et al. 2004). Using the graphical relationship between wetted perimeter and discharge, the inflection point on the wetted perimeter/discharge curve is identified as a threshold where it is assumed that the corresponding flow can protect BMI production at an adequate level to sustain fish populations (Annear et al. 2004).

5.2 Hydraulic Habitat Modeling

Hydraulic modeling, in conjunction with depth, velocity, and substrate/cover criteria for the target fish species and life stage(s) can be used to determine the relationship between streamflow and suitable habitat. One-dimensional or two-dimensional hydraulic-based habitat models are designed to predict hydraulic conditions within a reasonable range of flow levels that are not sampled. Study site selection for 1D or 2D modeling will depend on reach access, the need for applying a 2D model, and channel complexities identified through habitat mapping.

Any currently available standard software package that meets the standards set by Waddle (2000) can be used for 1D habitat modeling. Except in reaches with highly complex channel hydraulics, reaches of most river channels can be adequately evaluated with standard 1D hydraulic models such as those found in PHABSIM (Waddle 2001), SEFA (Payne and Jowett 2012), or similar programs.

In highly complex channels where depth and velocities cannot be accurately predicted using a single transect approach, a 2D hydrodynamic model is often used to predict flow characteristics and features of ecological importance (Crowder and Diplas 2000; Waddle 2010). While virtually any available 2D model can be used for hydraulic assessment, the modeling software River2D (Steffler & Blackburn 2002) is frequently used by the Water Branch. River2D has the ability to evaluate fish passage criteria for depth and velocity along with site-specific topographic features to produce relationships between flow and habitat suitability or passage conditions.

5.3 Single Transect Hydraulic Based Habitat Method Data Collection

Department staff identify representative riffle sites for HRM and WPM that are representative of the overall geomorphic structure and shape of the reaches of interest within the study area (CDFW 2016). Once sites are selected, cross-sectional transects are established along the hydraulic control of each riffle with a measuring tape and a headpin and tailpin positioned on the left bank and right bank, respectively. The pins are placed at or above the bankfull elevation. For the purposes of this method, bankfull elevation is defined as the location where the vegetation emerges at the toe of the bank, there is a change in slope along the cross-sectional channel profile, and/or there is a change in substrate composition from coarser to finer material (CDFW 2016). Bed elevations are measured along each transect using an auto level and surveying stadia rod at one-foot intervals following the procedures set forth in the Department’s standard operating procedure (SOP) for Streambed and Water Surface Elevation Data Collection (CDFW 2013c). Smaller increment measurements are taken in areas with highly variable bed topography. In addition, water surface elevations (WSELs) are measured mid-channel and near each bank to determine the water surface profile along the transect (CDFW 2013c). The length of the riffle along with WSELs measured near the left and right bank at the downstream extent of the riffle are used to compute the water surface slope. A temporary staff gage is used to monitor the stage at the beginning and end of each data collection event to ensure that flow levels do not fluctuate during the course of data collection. A discharge measurement is taken for each transect using a flow meter and top setting wading rod (CDFW 2013a), or if one exists, flow data from a nearby stream gage can be paired with the date and time the transect was surveyed. Discharge measurements are then associated with the survey data to estimate hydraulic properties using Manning's equation for open channel flow.

Along with the measured discharge (Q) and calculated channel slope (S), the bed elevation data are used to calculate the flow area (A), wetted perimeter (P), and hydraulic radius (R) for the cross-section. These values are then used to calculate the Manning's roughness coefficient (n) using the Manning's equation for open channel flow, given below:

$$Q = \left(\frac{1.486}{n}\right) A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

While several programs are capable of modeling these hydraulic parameters, the Department generally uses the commercially available software program Hydraulic Calculator (HydroCalc; Molls 2008). HydroCalc is based on the Manning's equation and can be used to develop discharge rating curves in addition to estimating the listed hydraulic parameters (see HRM SOP for procedures; CDFW 2016).

For HRM, when the criteria for average depth and at least one other parameter are met (Table 5), flows are assumed to be adequate for habitat connectivity and aquatic ecosystem habitat maintenance. For the WPM analysis, a relationship between discharge and wetted perimeter is developed (CDFW 2016). The breakpoint and incipient asymptote (curve inflections), are identified as thresholds of desired habitat conditions. These curve inflections (i.e., the breakpoint and incipient asymptote) are used to determine the instream flow needs necessary to maintain riffle habitat and production of benthic macroinvertebrates.

Table 5. Key flow parameters used to determine flow criteria in riffle habitats using the HRM.

Bankfull Width (ft)	Average Depth (ft)	Average Velocity (ft/sec)	Wetted Perimeter (%)
1-20	0.2	1.0	50
21-40	0.2-0.4	1.0	50
41-60	0.4-0.6	1.0	50-60
61-100	0.6-1.0	1.0	70

Sources: Nehring 1979; CDFW 2016

5.4 Hydraulic Habitat Modeling Data Collection

The number and range of river flows, mesohabitats, reaches, and transects sampled within river segments influence the extrapolation range, representativeness, applicability, reliability, and utility of any model. It is critical that discharges, mesohabitats, and microhabitats are effectively sampled in order to develop usable 1D and/or 2D simulations. The Department's standard for 1D analyses is to include: a) sampling of at least three distinct river flows; b) sampling of three units of each significant mesohabitat type within each generally homogeneous river segment; and c) for simulations, at least three transects within each mesohabitat unit. The actual number of flows, mesohabitats, or transects sampled may be dependent upon the complexity of riverine conditions, the length of homogeneous reaches, the study objectives, and landowner access. In specific cases, it may be appropriate to sample less or more than three replicates of each mesohabitat unit, three microhabitat transects per unit, and/or water depth and velocity characteristics at a range of at least three flows.

Hydraulic and structural parameters are measured using a combination of standard techniques from the U.S. Fish and Wildlife Service (USFWS) methodology (Trihey and Wegner 1981; Bovee 1982; Bovee 1997; Bovee et al. 1998; USFWS 2011). The data collected at the upstream and downstream transects at each site (i.e., site boundaries) include: 1) WSELs; 2) wetted streambed elevations; 3) dry ground elevations to points above bankfull discharge; 4) mean water column velocities measured at the points where bed elevations are taken; and 5) substrate and cover classification at locations where wetted streambed and dry ground elevations are surveyed (CDFW 2013c; CDFW 2015c). If there is a hydraulic control downstream of a given transect, differential leveling is used to survey the stage of zero flow, which is found in the thalweg downstream of the transect.

Each cluster of transects, or each transect if need be, should have a corresponding discharge that accurately represents the conditions at the time of survey. A temporary staff gage is used to monitor the stage at the beginning and end of each data collection event to ensure that flow levels do not fluctuate during the course of data collection.

Continuously recording water level loggers may be deployed in certain reaches to monitor changes in stage during calibration measurements. Bed topography, substrate data, instream/overhead cover, water surface elevations, velocity profiles, and associated discharges are collected.

Two-dimensional hydrodynamic models use depth-averaging techniques to simulate water depth and velocity in sites with complex flow patterns. Data collection for 2D models consists of detailed bed elevations, horizontal position, estimates of substrate composition, and instream/overhead cover. Transects at the upstream and downstream extent of a site are established and used to define the boundary conditions, which are determined by water stage, flow, and channel roughness. Channel roughness is an important hydraulic parameter that is characterized in the model by the bed topography and, to a lesser degree, the substrate size estimates. The upstream boundary requires an accurate inflow amount and the downstream boundary requires a corresponding WSEL for the given inflow. The bed topography data are collected with a total station and/or Real Time Kinematic Global Positioning System (RTK GPS) surveying equipment. Bed topography data are collected at a higher point density in areas with highly variable topography and patchy substrate and cover, and at a lower point density in areas with more uniform topography, substrate, and cover. Topography data are collected at a distance of one channel width upstream of the upstream transect to improve the accuracy of the flow distribution at the upstream end of the sites.

5.5 Hydraulic Habitat Modeling

One-dimensional hydraulic modeling procedures, appropriate to the study site, will be used to model water surface elevations and velocities at each selected cross-section. For WSELs, these procedures include the development of stage-discharge rating curves using log-log regression, hydraulic conveyance (MANSQ or similar), and/or step-backwater models (e.g., WSP, HEC-RAS); direct comparison of results; and selection of the most appropriate and accurate method. Water velocities will be simulated using the Manning's n method of velocity distribution across all transects, with calibrations generally consisting of correction of over- or under-simulated velocities at individual sample points (i.e., velocity adjustment factors, or VAFs). Data file construction, calibration, simulation, reporting, review, and consultation will follow standard procedures and guidelines.

Mesohabitat types are weighted and combined to develop a representation of hydraulic characteristics and fish habitat suitability for each 1D reach or sub-reach. Mesohabitat weighting is based on the relative proportion of each of the modeled mesohabitats within the reach or sub-reach. A final habitat index for each study site is produced by combining hydraulic simulations over a range of flows with HSC for the target species and life stage(s). Any currently available standard software package that meets the standards set by Waddle (2000) can be used for 1D habitat modeling.

Two-dimensional model calibration consists of adjusting the roughness values in the model until a reasonable match is obtained between the simulated water surface elevations and the surveyed water surface elevations as well as the channel's wetted edge measurements taken along the study site at a given flow. Models may be calibrated at a single flow and then validated at the two other flows, or the model can be calibrated at each measured flow.

Once calibrated, the downstream water surface elevation and the inflow to the 2D model site are changed to simulate the flows of interest. Each modeled flow is then run to a steady state solution. That is, for a constant inflow to the site, the model is run until there is a constant outflow and the two flows are essentially equal. Typical convergence tolerance is 1% of the inflow. Another measure of convergence is the solution change. Ideally the solution change will become sufficiently small (e.g., 0.00001) once converged. In some cases, the solution change will reach a relatively small value and refuse to decrease any further indicating a small, persistent oscillation at one or more points. This oscillation is often associated with a shallow node that alternates between wet and dry. This oscillation may be considered acceptable if the size of the variation is within the desired accuracy of the model (Steffler and Blackburn 2002).

At least 50 randomly selected paired depth and velocity measurements are collected (in addition to the depths and velocities measured along the upstream and downstream transects) to validate the 2D model[10] (USFWS 2011). The locations of the validation measurements will be distributed randomly throughout the site. The flow present during validation data collection will be determined from gage readings, if gage data are available. If gage data are not available, staff will measure the flow during validation data collection.

The fish habitat component of River2D is based on the same habitat index utilized in standard 1D models. The habitat index for the entire site is calculated by expanding the composite suitability index for every point in the model domain with the area associated with that point, and then summing those values for all points. The composite suitability is calculated as the product of suitability values for depth, velocity, and channel index (cover and substrate codes). The output includes node characteristics of habitat suitability values for depth, velocity, channel index (substrate and/or cover), and combined parameters at a number of flows for each species and life stage of interest. Model outputs at selected flows will also include image files of the plan view showing any change in suitability for each habitat parameter for each species and life stage.

The habitat index versus discharge function is a static relationship between discharge and habitat that does not represent how often a specific flow/habitat relationship occurs. For this reason, in many cases the index alone should not be considered the final result of a 1D or 2D model. A more complete analysis is known as a habitat time series (HTS) analysis. A HTS analysis integrates the habitat index versus flow function with hydrology to provide a dynamic analysis of flow versus habitat. Results of the HTS are

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[10] 2D model calibration and validation will follow USFWS (2011) standards, as discussed in Section 6.1 Quality Assurance.

most useful when the broadest possible range of hydrology is used for the model. For this reason, it may be necessary to extend the stage-discharge rating curve beyond 2.5 times the highest calibration flow with additional stage-discharge measurements made during field data collection to support the analysis.

5.6 Temperature Monitoring

Water temperature data may be collected and evaluated as part of this study. Water temperature data would be recorded at a frequency of no less than hourly measurements at key locations throughout the study reaches using digital HOBO®, Solinst®, or TidbiT® data loggers. TidbiT® data loggers are used where water depths are anticipated to be too shallow to use the larger HOBO® or Solinst® loggers. Calibration, placement, sampling interval, and data processing of the logger data is done in a manner consistent with guidance provided by the U.S. Department of Agriculture (Dunham et al. 2005). Data loggers are generally placed in secured stilling wells or anchored to exposed roots along the banks of the creek in pool habitats using plastic cable zip ties. Suspending the loggers prevents them from being buried by sediment and keeps the instruments out of sight to avoid tampering by humans and/or animals. Any temperature data collected may be combined with existing temperature monitoring data when appropriate to assess temperature and discharge relationships during the rearing period.

6.0 QUALITY ASSURANCE/QUALITY CONTROL

All field equipment, including the Marsh-McBirney and HACH FH950 flow meters, will be calibrated according to manufacturer's instructions before data collection begins. Discharges will be measured following the protocols set forth in the SOP for Discharge Measurements in Wadeable Streams (CDFW 2013a). Velocities will be measured to the nearest 0.01 cfs. Water surface and bed elevations will be measured to the nearest 0.01 ft using standard surveying techniques (i.e., differential leveling) as described in the Streambed and Water Surface Elevation SOP (CDFW 2013c).

Wetted streambed elevations will be determined by subtracting the measured depth from the surveyed WSEL at a measured flow. WSELs will be measured at a minimum of three locations along each transect. WSELs measured along each transect for each survey event will be averaged together unless the surface is found to be sloped along the transect line or if a portion of the surface is determined to be unrepresentative of the water surface with respect to the transect stage-discharge relationship. The WSELs measured at each transect will be evaluated and a single representative WSEL will be derived consistent with the guidance provided in the PHABSIM User's Manual (Waddle 2001). WSELs will be collected at a minimum of three relatively evenly spaced calibration flows, spanning approximately an order of magnitude. Model calibration flows will be selected so that the lowest simulated flow is no less than 0.4 of the lowest calibration flow and the highest simulated flow is at most 2.5 times the highest calibration flow. If a 2D model is used for the study, the accuracy of the 2D bed topography elevations collected should be 0.1 ft and the horizontal accuracy should be at least 1.0 ft (USFWS 2011).

The Department will use the USFWS (2011) standards for calibrating and validating any two-dimensional hydraulic habitat model, if used. The standards include:

- Mesh Quality: the quality of the fit between the final bed profile and the computational mesh, as measured by the Quality Index value, should be at least 0.2.
- Solution Change/Net Flow: when the model is run to steady state at the highest flow simulated, the solution change should be less than 0.00001 and the net flow should be less than one percent.
- Froude Number (FN): the maximum FN for low gradient streams should be less than one.
- Water Surface Elevation: if developing a 2D model, WSELs predicted at the upstream transect should be within 0.1 foot of the WSEL predicted by PHABSIM for the highest simulated flow (or observed at the highest measured flow).
- Velocity Validation: the correlation between at least 50 spatially-distributed measured and simulated velocities should be greater than 0.6.

Data sheets will be checked in the field by a designated field team lead to ensure that all data and relevant information has been collected for the given method(s) being used. All data are transferred from field data sheets into an electronic format upon returning from field data collection events, and quality control checks will be conducted for every electronic data sheet to ensure that the data were translated correctly. If data collection errors are discovered, the Project Coordinator will review the issues with the appropriate personnel to develop a plan for corrective action so that resampling, if required, can be scheduled during the same sampling season.

7.0 DATA MANAGEMENT AND REPORTING

Field data will be collected by Department staff from the Water Branch and, with resources permitting, Bay-Delta Region staff. Water Branch staff will prepare a final technical report with assistance from Bay-Delta Region staff. The Bay-Delta Region, Department Engineering, and Fisheries Branch will review the technical report.

7.1 Target Audience and Management Decisions

The Department has the responsibility to conserve, protect, and manage fish, wildlife, native plants, and their associated habitats. Accordingly, the Department has an interest in assuring that water flows within streams are maintained at levels that are adequate for long-term protection, maintenance, and proper stewardship of fish and wildlife resources. Using criteria generated from the flow study, the Department intends to develop flow recommendations for juvenile steelhead and Coho Salmon in upper Mark West Creek. These recommendations are not requirements that will be self-executing. Rather, they will represent beneficial uses relating to fish and wildlife preservation and enhancement to be considered by the Water Board in any future proceedings that the Water Board may or may not hold regarding applications for new diversions, permit requests, or other proceedings as set forth in Section 1257.5 of the California Water Code.

7.2 Coordination and Review

To the extent possible, entities or stakeholders that have an interest in the results and interpretation of the study may be involved in study scoping and implementation.

7.3 Data Management and Reporting

All data generated by this project will be maintained in field log books and/or data sheets, as well as in an electronic spreadsheet format. The Department will store the hard copies and electronic data. Final documents, including the technical report, will be posted on the Department's website.

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