HAHN & HAHN LLP
LAWYERS
Established 1899

Todd R. Moore
tmoore@hahnlawyers.com

(626) 796-9123
Fax (626) 449-7357
www.hahnlawyers.com

301 EAST COLORADO BOULEVARD
NINTH FLOOR
PASADENA, CALIFORNIA 91101-1977

March 25, 2024

VIA E-MAIL

El Dorado County Planning Commission
c/o Evan Mattes, Planner
2850 Fairlane Court
Placerville, CA 95667
planning@edcgov.us

Re: CCUP21-0004/Single Source (the "Project")

Honorable Members of the Planning Commission:

We are counsel to the Committee To Protect River Pines Estates, a committee of over 50 property owners in the River Pine Estates subdivision that surrounds the Project. This letter constitutes their formal objection to the adoption of a Mitigated Negative Declaration ("MND") for the proposed Project and request that the County obtain an Environmental Impact Report ("EIR") instead. In addition, if the Commissioners opt to adopt the draft MND, the Committee encourages the Commission to deny CCUP21-004 for the reasons discussed in the second part of this letter.

I. The County May Not Adopt A MND Because There Is Substantial Evidence Supporting A Fair Argument That The Project Will Have A Significant Effect On The Environment.

The California Environmental Quality Act ("CEQA") is "a comprehensive scheme designed to provide long-term protection to the environment." (*Los Angeles Waterkeeper v. State Water Resources Control Bd.* (2023) 92 Cal.App.5th 230, 285.) It requires public agencies to undertake an environmental review of proposed projects that require discretionary approval. (Pub. Resources Code, § 21080, subd. (a).) The heart of CEQA lies in the EIR. *(Laurel Heights Improvement Assn. v. Regents of University of California* (1993) 6 Cal.4th 1112, 1123

"[A] public agency must prepare an EIR whenever substantial evidence supports a fair argument that a proposed project 'may have a significant effect on the environment.' [Citations.]" (*Ibid.*)

A. ***Substantial Evidence Supports A Fair Argument That Odors From The Project Will Effect The Environment.***

The Odor Study supporting the findings of "no odor impact" in the Initial Study is badly flawed. This firm has retained the services of Paul Schafer of SCS Engineers & Environmental Consultants. Mr. Schafer is a Vice President of SCS, Project Director, and the firm's national expert on odor management. During his technical career at SCS and SCS Tracer Environmental, Mr. Schafer served in key roles on several nationally significant monitoring efforts, including monitoring odors at commercial cannabis facilities throughout California. He has in-depth experience interfacing with regulatory agencies regarding the performance of monitoring systems and source emission tests. He has had direct working experience with the San Luis Obispo County APCD, San Joaquin Valley APCD, Imperial County APCD, South Coast AQMD, Santa Barbara APCD, San Diego County APCD, California Air Resources Board, EPA Region IX, and the General Services Administration regarding monitoring programs and air quality impact assessments. A copy of Mr. Schafer's analysis of the Odor Study and proposed mitigation measures for the Project is Exhibit "A" to the Committee's Appendix of Exhibits ("Appendix").

Mr. Schafer noted that the Odor Study for the Project is flawed and underestimates the odors associated with the Project in several respects. First, the Odor Study is based on flawed measurements and flawed assumptions about a single cannabis farm during a very short period of time that are not representative of the actual site conditions. Cannabis farms routinely emit more than twice as many odors as modeled by the applicants' consultant. (Ex. "A," p. 2.) As such, it grossly understates the odor impacts of the Project and the odor dilution thresholds that will be present at the Project boundaries and within the Project itself.

Second, the Odor Study does not analyze the odors that will be emitted from the processing and drying operations proposed to take place on site. These emissions are the most significant of the entire Project and the failure to account for them is a serious flaw in the Odor Study that prevents it from being a reliable basis for a finding of "no impact." (Ex. "A," pps. 2-3.)

In addition, Mr. Schafer's analysis of the Project's proposed odor mitigation measures is substantial evidence of a fair argument that those mitigation measures will not be effective at controlling the odors that will affect neighbors and, therefore, not mitigate the environmental impact from noxious odors. For Phase I of the project, the only mitigation measure proposed is an outdoor misting system. No mitigation measures are proposed for the processing and drying facilities for the Project, even though these generate the highest amount of noxious odors. Even the incomplete system will not be effective because it does not provide sufficient contact between the odor control chemicals and the odor plume to effectively eliminate or even materially reduce odors. Such systems have frequently failed to result in public support. (*Id.* at p. 3.) Moreover, the environmental effects of this proposed mitigation measure (such as the impacts of the outdoor release of odor control chemicals intended for personal use or the noise created by fans and sprayers) are not analyzed anywhere in the Initial Study or draft MND. This is a clear violation of CEQA.

In fact, Mr. Schafer's report proves that the proposed mitigation measures will increase, not decrease, the odor and emissions impact of the Project. To the extent the unspecified "odor control" chemicals used in the misting system rely upon fragrances to mask odors, they add far more emissions to the air than are removed. (*Ibid.*)

For Phase II, the proposed mitigation measures include hoop houses and particulate filters. These measures will also not be effective. Mr. Schafer notes that the shade cloth hoop houses are porous and there is no mechanism proposed to force odorous air through an air scrubber. No actual carbon air scrubbing equipment is proposed to be used, only an air conditioner, fans and a particulate filter are proposed to be used. (*Ibid.*) None of these is designed to remove odors or effective at such a task.

B. Substantial Evidence Supports A Fair Argument That The Project Will Exacerbate Already Existing Water Scarcity Problems And Imperil Nearby Pre-Existing Residential Water Uses.

The Initial Study prepared for the County states that the "project premises is not located above a critically over drafted groundwater basin" and has access to a well that produces "35 gallons per minute" so the proposed project would have a "less than significant" impact on groundwater supplies. This finding is unsupported by any evidence and ignores known groundwater conditions surrounding the site.

Every domestic well owner in El Dorado County knows that our wells are not above "a critically over drafted groundwater basin" because wells in the County are not located above any groundwater basin at all. There is no dispute that the Project and surrounding residential properties draw water from small factures in bedrock that hold a finite amount of water rather than a groundwater aquifer. The amount of available water and the recharge rate of the fractures is not quantified anywhere in the Initial Study.

The Initial Study does not contain any estimate of the Project's estimated water usage. The adequacy of the existing well is assumed without any supporting evidence. Consequently, there is no factual basis to determine that the existing water supplies will be adequate to serve the Project and already existing uses.

More importantly, there is substantial evidence supporting a fair argument that the existing intensive water uses at the Project site are already causing groundwater to become scarce and that the existing water supply cannot support the even more intensive proposed use. The initial well production report for the Project site indicates that the well produced 50 gallons per minute in 1999, immediately prior to development of the property for ten acres of wine grape vineyard and a single family home with irrigated landscpaping. (Appendix, Ex. "B.") The Initial

Study indicates that, after more than a decade of that intense irrigation use, the well production fell to only 35 gallons per minute. <u>This represents a decrease of 30% since the intensive vineyard use began</u>.

This troubling decrease in water is not limited to the well serving the Project. A domestic well was drilled at 4881 D'Agostini Drive in 1999, which is contiguous with the Project site. When that well was first put into production, it produced 10-12 gallons per minute. (Appendix, Exhibit "C" [1999 Well Report].) In 2015, after the nearby vineyard had been in production for approximately 10 years, that well's production dropped to only 4 gallons per minute, <u>a 60% decrease</u>. (Appendix, Exhibit "D" [2015 Well Report].) None of this decrease was attributable to use at 4881 D'Agostini because that site had not been developed yet. Several years later, another nearby domestic located well at 4520 D'Agostini Drive, which had been drilled twenty years previously, went dry and had to be replaced with an 800 foot deep new well. (Appendix, Exhibit "E," [e-mail from property owner].)

The cumulative impact of intensive water use in the immediate vicinity of the Project is clear. Water supplies are vanishing. There is substantial evidence of a fair argument that the Project, which further intensifies water use, will negatively impact the availability of water for neighboring property owners and the existing uses on the Project site. The County must obtain an EIR better quantifying these critical impacts. These impacts are capable of being quantified by a qualified groundwater geologist and the County should retain one before proceeding with the Project.

Furthermore, there is substantial evidence supporting a fair argument that the well serving the Project is already inadequate to supply the needs of the site. THC Cannabis cultivation is one of the most water-intensive forms of agriculture. It uses more water than famously water-intensive crops such as cotton and rice. (Appendix, Ex. "F.") No responsible farmer would propose growing such thirsty crops in portions of El Dorado County that have no public irrigation system. According to recent scientific studies, outdoor THC cannabis cultivation in California uses .22 gallons of water per day per square foot of cultivation area during the peak growing season during August and September. (Appendix, Ex. "G.") Given that the planned outdoor cultivation area is approximately 87,120 square feet, the estimated water usage of the Project (excluding all needs of its four full time employees for toilets, handwashing, etc.) is 19,166 gallons per day.

There is also an existing 8 acre vineyard on the site irrigated using the same well. According to University of California irrigation studies, a grape vineyard in California is estimated to require at least 4,500 to 5,000 gallons per acre per day during the dry growing months. (Appendix, Ex. "H.") Consequently, the 8-acre vineyard that remains on the site requires 36,000-40,000 gallons of water per day. The same well also serves a very large single family residence with irrigated landscaping. Conservatively, this home will require 1,594 gallons per day for its occupants and irrigation needs. (Appendix, Ex. "I.")

Water Use	Daily Water Requirement Aug/Sep.
Remaining Vineyard (8 acres)	36,000-40,000 gallons [3,944 gal./acre]
THC Outdoor Cannabis Cultivation	19,166 gallons [9,583 gal./acre]
Single Family Home w/ landscaping	1,594 gallons
TOTAL DEMAND:	56,760-60,760 gallons/day
Well Production: 50,400 gal./day	**Water deficit: -6,760 to -10,760 gal./day**

Given the 35 gallons per minute production stated in the Initial Study, the requirements of the site will exceed the peak production of the well by thousands of gallons per day (50,400 gallons per day produced vs. 56,760 to 60,760 minimum gallons required per day). Based on the estimates of water use per household in El Dorado County discussed above, the proposed developed site would be the *water use equivalent of over 32 single family homes*, nearly more than the entire River Pines Estates subdivision. To permit such an outrageously intensive use of water on a single parcel and in an area without any public water facilities is the very definition of irresponsibility and should be the subject of an EIR, not a MND.

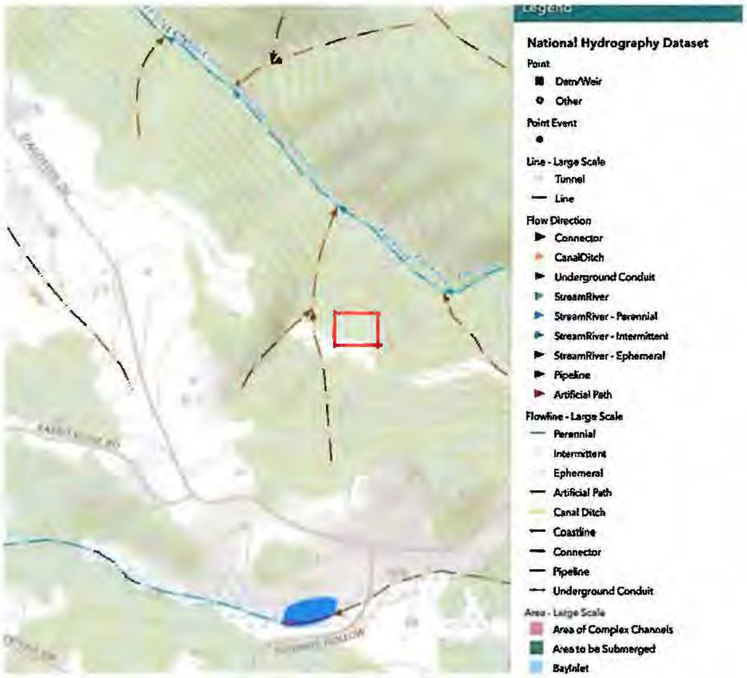
In response, the planning staff or their consultant will likely argue that the Commission may not consider the proposed water usage for purposes of CEQA unless the anticipated use is the equivalent of an even more outrageous number - 500 dwellings units. This argument badly misstates the law. Staff and consultants have previously cited Section 15155, subsection (a)(1)(g) of the CEQA Regulations. Reliance on this section is misplaced. Section 15155 governs when a lead agency is required to seek input from a "public water system" prior to deciding whether to adopt an MND, EIR or negative declaration. (See Cal. Code of Regulations, Title 14, §15155, subd. (b).) Section 15155 does not set a threshold for environmental significance where there is no existing or planned public water system and nothing about that section bars the Commission from considering the negative impacts of a proposed project on private water supplies. Such study is critical to understanding the environmental impact of the Project.

Even if Section 15155 established a threshold of significance for water use, thresholds of significance are not conclusive and do not permit an agency to disregard evidence that an impact may be significant even though the threshold is not exceeded. (14 Cal.Code Regs §15064(b)(2); *Protect Niles v. City of Fremont* (2018) 25 Cal.App.5th 1129.) An agency must prepare an EIR whenever substantial evidence supports a fair argument that the Project has the potential to degrade the environment or cause substantial adverse effects on human beings. (Public Resources Code §21083(b)(1) and (b)(3).)

There is ample substantial evidence supporting a fair argument that the existing intensive irrigation use of the fractured rock water supply is already causing nearby residents to lose their vital water supplies. An EIR should be required to further study the impacts of the Project on water availability.

C. Substantial Evidence Supports A Fair Argument That The Project Will Impact Nearby Streams

The Initial Study only considers the potential impact of the Project on Flat Creek, which is a perennial stream running to the north of the Project site. The Initial Study does not evaluate the Project impact on two ephemeral streams that run in close proximity to the west boundary of the Project. The National Hydrography Dataset published by the U.S. Geological Survey for topographical maps of the Project site demonstrate that these two streams are much closer to the Project than Flat Creek. (The Project cultivation site is outlined in red.)



Further study of the impact of the Project on these ephemeral streams is critical because they may receive runoff of fertilizers and pesticides from the Project as well as carry residue from the odor control chemicals that will be sprayed immediately adjacent to them. (The location of the streams coincides with the location of proposed odor mitigation fans and sprayers.) Neither California water quality law nor the El Dorado County cannabis rules distinguish among ephemeral, intermittent and perennial streams.

D. The Initial Study Underlying The Draft MND Is Not Sufficient To Prove That The Project Will Not Impact Biological Resources

The Initial Study relies upon a biological assessment of the Project Site performed during December and did not examine the potential impact of the Project on any of the nearby ephemeral streams. The appendices to the applicant's biological assessment indicate that many of the threatened or protected species potentially present on the Project site and impacted by the Project are not present during December due to dormancy or migration patterns. Consequently, the biological assessment is grossly inadequate and cannot support a finding of little or no impact. The County should order a new assessment to be performed during the season that threatened plants and animals would be expected to be present, not when they would be absent.

E. The Acoustic And Air Quality Studies Supporting The Draft MND Are Flawed And Do Not Support A Finding Of Little Or No Impact

The Acoustic and Air Quality studies underlying the draft MND were prepared by Earth Groovy Products, LLC. According to California Secretary of State records, this entity is controlled by Rod Miller, who is listed as one of the Project applicants. (Appendix, Exhibit "J.") Mr. Miller is a biased source of information about these important topics. In addition, neither he nor his company have any stated expertise or qualifications to study acoustical or air quality impacts. The firm is a lobbying firm, not engineers or scientists. This is underscored by the fact that neither study considers the noise generated by the proposed odor mitigation measures nor the air emissions from them. A more competent investigator would have studied these.

In summary, there are at least five reasons why the Commission should order the preparation of an EIR rather than adopt the draft MND for the Project. Proceeding on the basis of the inadequate and deeply flawed studies underlying the MND would expose the County to a costly lawsuit challenging its lack of compliance with CEQA. Preparation of an EIR that more fully studies the potential impacts of the Project is a much more reasonable course and is required under California law.

II. **The Commission Should Not Approve The Project Because It Does Not Comply With Applicable County Development Standards.**

Commercial cannabis cultivation is not allowed as a matter of right anywhere within El Dorado County. A conditional use permit to allow the use cannot be issued unless the applicant proves that the proposed project will satisfy each of the cultivation standards set forth in Section 130.41.200 of the County Code. The Single Source application fails to meet these requirements in at least five important respects.

First, the Project does not meet the odor emission requirements of Section 130.41.200(5)(D). This section requires that the applicant prove that "the cultivating, drying, curing, processing and storing of cannabis shall not adversely affect the health, safety, or enjoyment of persons" residing near to the Project. As discussed above and in the supporting analysis of the applicant's Odor Study, the proposed project will have substantial unmitigated odor impacts on surrounding properties. The Initial Study grossly underestimates the cultivation odors generated by the Project and does not account at all for the odors caused by the drying, curing and processing of cannabis that will occur at the Project site. These are among the worse odors that a cannabis site can produce. Furthermore, the proposed odor mitigation measures (which only apply to the cultivation component of the Project), will not be effective to reduce the odors associated even with cultivation. The applicant's own Odor Study confirms that in the absence of effective odor control measures, the dilution threshold required by Section 130 is not met at the eastern and western property lines, where residential development already exists. The Commission must deny the project for failure to comply with odor standards alone.

Second, the Project does not meet the water supply requirements of Section 130.41.200(5)(E). This section states that an application for a commercial cannabis farm "may only be permitted if sufficient evidence . . . demonstrates . . . there is adequate water supply in the watershed and water rights to serve the cultivation site." There is no evidence before the Commission proving the adequacy of water in the watershed surrounding the site. No estimate or projection of the Project's anticipated water use is given nor is there any data substantiating how much water is available in the watershed for both the Project and nearby existing uses. In fact, as discussed above, there is ample evidence that there is not sufficient water for the Project. Domestic wells in the immediate vicinity of the Project and the well serving the Project itself have substantially decreased in production since intensive agricultural water use commenced at the Project site. Indeed, conservative calculations of anticipated water use based upon available scientific data demonstrate that the Project will require more water than the well serving the site can produce.

Third, the Project does not comply with the requirement that it incorporate water conservation measures as required by Section 130.41.200(5)(F). The Project plans are utterly devoid of any specific commitment to employ any of the water conservation measures identified in subsection (5)(F), such as employing underground drip irrigation, soil moisture monitoring or use of recycled grey water even though the existing home on the site produces grey water that could be put to irrigation use.

Fourth, there is no evidence proving that the Project will satisfy the requirement that its electrical needs will be met from a "100% renewable energy" source. (Section 130.41.200(5)(I).) While the Project plans show a photovoltaic solar array, the application contains no data that substantiates a finding that the small array will be sufficient to meet the large power needs of the Project, which includes two batteries of fans along the property lines, multiple air filters, air scrubbers, misters and other equipment needed to mitigate the odor impacts of the Project. Indeed, the odor mitigation and other power needs of the site have not been quantified at all.

Fifth, and most importantly, the Project does not comply with the setback requirements of Section 130.41.200(5)(C). This section requires that the Project be at least 800 feet from any property line and 300 feet from the upland extent of the riparian vegetation of any waterway. The Project is less than 200 feet from property lines and less than 100 feet from ephemeral streams that run immediately adjacent to the site.

The applicant has failed to satisfy the requirements for obtaining a variance from the setback requirements. No variance from the setback requirements may be granted unless "the applicant demonstrates that the actual setback will substantially achieve the purpose of the required setback . . . ." (Section 130.41.100(4)(C).) As noted in the Committee's Odor Analysis, the odors emitted by the Project have been underestimated and will be substantially greater at the property lines than if the Project complied with setback requirements. In addition, the proposed odor mitigation measures increase the overall noise that adjoining property owners will hear and expose them to airborne odor control chemicals that they would not be exposed to if the Project complied with setback requirements. In addition, the project is plainly visible from adjoining properties. The undersigned is the owner of 4881 D'Agostini and attests that the cultivation sight is visible from that property. It would not be visible if it complied with the setback requirements.

In summary, the Commission must order an EIR rather than a MND. Whether the Commission agrees with the evidence or not, there is substantial evidence of a fair argument that the Project will have an effect on the environment. This mandates the preparation of an EIR. The failure to prepare an EIR is certain to result in a costly and meritorious lawsuit against the County to compel it to comply with its legal obligations.

Similarly, even if the Commission finds that it has complied with its obligations under CEQA, it must deny approval of the Project because it does not meet the requirements of the County's Commercial Cannabis Cultivation code. The impact of the Project on surrounding properties is not the same as if it complied with applicable setback requirement. Smells, sounds, light pollution, chemical sprays and other factors are more burdensome on surrounding people than if the site complied with setback requirements. The Project also lacks an adequate water supply, does not employ effective odor control and water conservation measures, and will rely upon non-renewable energy for its needs.

Thank you for your consideration of this important matter.

Sincerely yours,

/s/ Todd R. Moore

Todd R. Moore
of HAHN & HAHN LLP

Attachments

TRM\77777.00324\3865731.1

Appendix of Exhibits

A. Odor Study; Paul Schafer of SCS Engineers & Environmental Consultants

B. Well Production Report for 4941 D'Agostini Drive, 1999

C. Well Production Report for 4881 D'Agostini Drive, 1999

D. Well Production Report for 4881 D'Agostini Drive, 2015

E. Email from property owner, 4520 D'Agostini Drive

F. Zheng Z, Fiddes K, Yang L. A narrative review of environmental impacts of cannabis cultivation, J Cannabis Res. 2021; 3:35; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8349047/

G. Wilson H, Bodwitch H, Carah J. First known survey of cannabis production practices in California. California Agricul. 2019;73(3):119–27; https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0120016

H. Peacock W, Williams L, Christensen L. Water Management and Irrigation Scheduling. Water Management and Irrigation SchedulingUniversity of California Agriculture and Natural Resourceshttps://ucanr.edu › sites › Tulare_County › files

I. EID estimates homes in the County use .56 acre feet per year, or 1,594 gallons per day, on average, Mountain Democract https://www.mtdemocrat.com/news/eid-reviews-consumption/article_f9e6dd8c-16a1-5bc4-bd02-2186c30d8840.html

J. California Secretary of State Statement of Information Earth Groovy Products, LLC

Appendix A

Odor Study; Paul Schafer of SCS Engineers & Environmental Consultants

SCS ENGINEERS Environmental Consultants & Contractors

March 25th, 2024
File No. 24224153.00

MEMORANDUM

TO: Mr. Todd R. Moore, Hahn & Hahn LLP

FROM: Paul Schafer, Vice President, SCS Engineers

SUBJECT: Review of "Updated Notice of Intent to Adopt A Mitigated Negative Declaration" in Regards to Potential Odor Impacts from Project CCUP21-0004/Single Source

1 INTRODUCTION

SCS has been retained by Hahn and Hahn LLP (Client) for support services related to the review of site plans, a dispersion model, odor control plans and the potential impacts of odor emissions from proposed cannabis facility operations in El Dorado County. The project in question is CCUP21-0004/Single Source and the project located on the north side of D-Agostini Drive, approximately 1 mile west of the intersection with Aukum Road, in the Somerset area.

The state of understanding relative to the main cause of odor and, more specifically, the objectionable "Skunky" odor from cannabis emissions and the methods to mediate them from cannabis cultivation is rapidly evolving. Just a few years ago, it was a common perception that the main culprit relative to odors from cannabis operations were terpenes with Myrcene being the main identified culprit. We now know that although Terpenes are a part of the odor profile, they are not the cause of the unpleasant "Skunky" odor character that can be experienced downwind of cannabis operations.

In addition, there are considerable issues and complications that arise when attempting to describe or estimate a facilities potential odor impacts. These include several factors:

1) Cannabis, like most plants, has the potential to emit hundreds of different chemicals. Each at various rates, at widely divergent odor detection thresholds, and dependent on several external variables;
2) Emission rates are not constant throughout the cannabis plants life cycle or within the plant's daily cycle;
3) Emission rates can be influenced by temperature, exposure to light radiation, degree of agitation, plant stresses, among other external factors.
4) The ratios of compounds emitted by cannabis are not constant through the plant's life cycle and the times of highest emissions of certain compounds can be decoupled from other types of compounds.

Finally, there are various technologies that have been used and are being vetted for use in regards to odor mitigation from cannabis operations. From enclosed spaces, the technology of choice has been, and continues to be, scrubbing the effluent point through the use of tried and true carbon scrubbers. However, for vented greenhouses that take advantage of the local climate for temperature and humidity controls, the best technology for use in this space is still up for debate. Vapor Phase odor neutralizers have been used with some success but this technology has limitations and is not looked at favorably by the general public. Standalone carbon scrubbing systems with various pretreatment options have also been shown to be capable of significantly reducing the potential for odor emissions from greenhouse spaces. Each of these technologies, when utilized in open air cultivation/harvesting operations are even less effective as contact with the odorous plume is required.

The following sections review the components of the "Updated Notice of Intent to Adopt A Mitigated Negative Declaration" (MND) in Regards to Potential Odor Impacts and specifically the project – specific Odor Analysis included as Appendix E. This Odor Analysis was the basis of the County's assessment that "No odor Mitigation is required" since the analysis showed impacts less than the County's limit of 7 D/T along project property lines.

2 APPENDIX E: ODOR REPORT REVIEW

Appendix E provides an initial Technical Memorandum (July 21st, 2021) as well as an updated Technical Memorandum dated August 11th, 2023. The first analysis resulted in odors at project property lines exceeding El Dorado County's 7 D/T limit. The project was then revised such that hoop houses would be utilized along with a smaller area of outdoor cultivation. Based on the revised project description, the analysis resulted in compliance with the County's 7 D/T limit.

The modelling study utilized an odor concentration of 20 D/T as the odor baseline. The Model was used to determine the attenuation of odors as they are dispersed from the project. This is not a terrible approach considering there are no published emission rates for cannabis odors and odors from cannabis cultivation are highly variable due to several factors. However, the model needs to account for all odor generating activities, be representative of all site operations, and estimate maximum odor conditions.

SCS has reviewed this analysis and have discovered several flaws that lead to severely under predicting odor impacts to the surrounding community. The following are some of the most critical issues:

1) The foundation of the model is the 20 D/T odor concentration baseline from which all concentrations are then calculated based upon a modelled dilution factor. This value was determined/estimated based upon less than 30 minutes of measurements at a different outdoor farm that is of smaller size than specified by this project.
    a. SCS has recorded D/T values at outdoor cannabis farms in excess of 250 D/T and routinely over 50 D/T.
    b. The 20 D/T baseline estimate was based upon a farm that was 2-weeks out from Harvest. Odor concentrations are likely to increase up to Harvest.
    c. The estimated 20 D/T was based on very limited measurements, conducted over a very short period of time, and there is no quality justification for using this value at this farm.
2) The model did not take into account harvesting and proposed processing activities including on-site drying operations.
    a. Harvesting operations are some of the most odor intensive activities that can be performed at a cannabis cultivation site. This was not taken into account.

   b. Processing activities such as drying, bucking, trimming are very odor intensive activities and are not taken into account in this analysis. It appears this operation is proposed to be performed in a tent within the cultivation area.

3) The analysis states that hoop houses will be installed within the current project and each hoop house would be equipped with a carbon filtration system that would reduce odor intensity below 7 D/T.
   a. It's unclear how the use hoop houses will reduce odor emissions as they are porous, unsealed, and have no control of the emission points.
   b. SCS does not see specifications in the odor analysis for carbon filtration. Various types of conditioning systems, fans, and filters are provided but no specifications for carbon filtration are included.

3 REVIEW OF SET BACK REQUIREMENTS

The following is on Page 22 of the MND.

"The El Dorado County Cannabis Ordinance, Section 130.41.200 contains a minimum setback of 800 ft from the property line of the site or public right-of-way for allowing cultivation and processing activities. The project components would not be setback by at least 800 ft from the western property line. However, the applicant is seeking a setback reduction waiver from the County"

The basis of this setback reduction waiver is the Odor Report discussed in Section 2. Since the Odor Report was based upon flawed assumptions, the request for this setback reduction waiver should be reviewed as there is a Residence 745 feet to the Southwest.

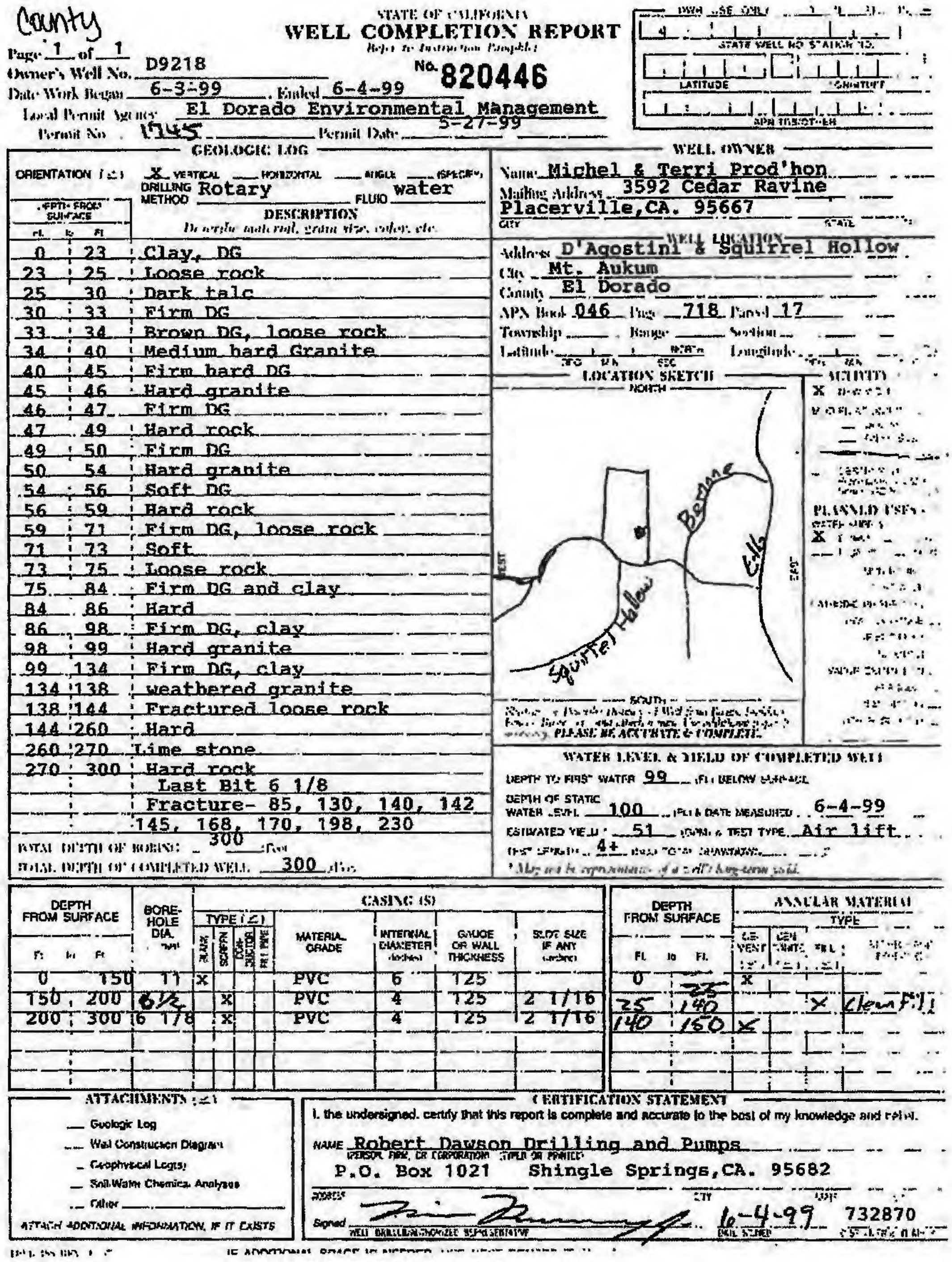
4 PROPOSED ODOR MITIGATION MEASURES

The MND includes standards for maximum allowable odors measured by the County at the property line. It also has provisions for mitigation measures to be installed should County measurements exceed the 7 D/T benchmarks. However, it is unclear how the proposed mitigation measures would actually reduce perceived odors in the surrounding communities. In addition, the schedule for installation of the measures is not provided. The following are some additional recommendations for this section:

1) Odor masking agents or solutions that include fragrance should not be used for odor control. SCS's experience is that community members would prefer cannabis odors to an unknown chemical agent that adds additional fragrance to the air.
2) Require the applicant to specify odor scrubbing/molecular filtration technology to be utilized for odor control in hoop houses along with specifications for odor control efficacy.
3) Schedule County compliance testing during Harvesting and processing activities.
4) Require third-party testing be performed with County oversight of methods to be employed and timing of tests to insure representativeness with worst case odor conditions.

Appendix B

Well Production Report for 4941 D'Agostini Drive, 1999



County

STATE OF CALIFORNIA

WELL COMPLETION REPORT

Refer to Instruction Pamphlet

Page 1 of 1

Owner's Well No. D9218

No. 820446

Date Work Began 6-3-99 Ended 6-4-99

Local Permit Agency El Dorado Environmental Management

Permit No. 1945 Permit Date 5-27-99

DWR USE ONLY

STATE WELL NO./STATION NO.

LATITUDE LONGITUDE

APN/TRS/OTHER

GEOLOGIC LOG

ORIENTATION (✓) X VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)

DRILLING METHOD Rotary FLUID water

DEPTH FROM SURFACE Ft. to Ft.	DESCRIPTION Describe material, grain size, color, etc.
0 23	Clay, DG
23 25	Loose rock
25 30	Dark talc
30 33	Firm DG
33 34	Brown DG, loose rock
34 40	Medium hard Granite
40 45	Firm hard DG
45 46	Hard granite
46 47	Firm DG
47 49	Hard rock
49 50	Firm DG
50 54	Hard granite
54 56	Soft DG
56 59	Hard rock
59 71	Firm DG, loose rock
71 73	Soft
73 75	Loose rock
75 84	Firm DG and clay
84 86	Hard
86 98	Firm DG, clay
98 99	Hard granite
99 134	Firm DG, clay
134 138	weathered granite
138 144	Fractured loose rock
144 260	Hard
260 270	Lime stone
270 300	Hard rock
	Last Bit 6 1/8
	Fracture- 85, 130, 140, 142
	145, 168, 170, 198, 230

TOTAL DEPTH OF BORING 300 (Feet)

TOTAL DEPTH OF COMPLETED WELL 300 (Feet)

WELL OWNER

Name Michel & Terri Prod'hon

Mailing Address 3592 Cedar Ravine

Placerville,CA. 95667

CITY STATE

WELL LOCATION

Address D'Agostini & Squirrel Hollow

City Mt. Aukum

County El Dorado

APN Book 046 Page 718 Parcel 17

Township ___ Range ___ Section ___

Latitude ___ NORTH Longitude ___ WEST

LOCATION SKETCH

PLEASE BE ACCURATE & COMPLETE.

ACTIVITY

X [illegible]

PLANNED USES

X [illegible]

WATER LEVEL & YIELD OF COMPLETED WELL

DEPTH TO FIRST WATER 99 (Ft.) BELOW SURFACE

DEPTH OF STATIC WATER LEVEL 100 (Ft.) & DATE MEASURED 6-4-99

ESTIMATED YIELD * 51 (GPM) & TEST TYPE Air lift

TEST LENGTH 4+ (Hrs.) TOTAL DRAWDOWN ___ (Ft.)

* May not be representative of a well's long-term yield.

CASING (S)

DEPTH FROM SURFACE Ft. to Ft.	BORE-HOLE DIA. (Inches)	BLANK	SCREEN	CON-DUCTOR	FILL PIPE	MATERIAL GRADE	INTERNAL DIAMETER (Inches)	GAUGE OR WALL THICKNESS	SLOT SIZE IF ANY (Inches)
0 150	11	x				PVC	6	125	
150 200	6½		x			PVC	4	125	2 1/16
200 300	6 1/8		x			PVC	4	125	2 1/16

ANNULAR MATERIAL

DEPTH FROM SURFACE Ft. to Ft.	CE-MENT (✓)	BEN-TONITE (✓)	FILL (✓)	TYPE
0 25	x			
25 140			x	Clean Fill
140 150	x			

ATTACHMENTS (✓)

___ Geologic Log

___ Well Construction Diagram

___ Geophysical Log(s)

___ Soil/Water Chemical Analyses

___ Other

ATTACH ADDITIONAL INFORMATION, IF IT EXISTS.

CERTIFICATION STATEMENT

I, the undersigned, certify that this report is complete and accurate to the best of my knowledge and belief.

NAME Robert Dawson Drilling and Pumps

(PERSON, FIRM, OR CORPORATION) (TYPED OR PRINTED)

P.O. Box 1021 Shingle Springs,CA. 95682

ADDRESS CITY STATE

Signed ___ 6-4-99 732870

WELL DRILLER/AUTHORIZED REPRESENTATIVE DATE SIGNED C-57 LICENSE NUMBER

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

Appendix C

Well Production Report for 4881 D'Agostini Drive, 1999

EL DORADO COUNTY ENVIRONMENTAL MANAGEMENT DEPARTMENT

DIVISION OF ENVIRONMENTAL HEALTH

2850 FAIRLANE CT.
PLACERVILLE, CA 95667
(916) 621-5300

REPORT OF WELL PRODUCTION

OWNER OF PROPERTY: WILLIAM THOMAS

ADDRESS OF OWNER: 10101 STATER AVE #120
FOUNTAIN VALLEY CALIF 92708

LOCATION OF PROPERTY: D'AGOSTINI RD
RIVER PINES ESTATES

ASSESSOR'S PARCEL NUMBER: 46-710-19

****

TO BE COMPLETED BY WELL DRILLER

Results of four (4) hour well production test: 12 gpm

Date Performed: 7-15-99

Depth of well 540 ft. Static water level 143 ft.

Diameter of well casing 6 in.

I, HEREBY, CERTIFY THAT THE ABOVE INFORMATION IS TRUE AND CORRECT TO THE BEST OF MY KNOWLEDGE.

Test performed by: David E. [illegible]

State License Number: 453362

READ & RECEIVED
3/12/01
3/12/01

ARROW WELL DRILLING
LIC # 453362
621-1666
P. O. BOX 523
PLACERVILLE, CA 95667

Appendix D

Well Production Report for 4881 D'Agostini Drive, 2015

WELL PRODUCTION TEST

COLT ROER

WELL LOCATION: **D'AGOSTINI RD / LOT 70** DATE: 7/1/2015

Ordered By:	TODD MOORE	Ph:	626-487-9291
	DAN DIXON	Em:	DIXONOTL@GMAIL.COM
Bill To:		Ph:	
		Em:	
		Fx:	
Instructions:		Gate:	

TIME	METER READING	GALLONS PUMPED	PUMP RATE
12:00	47231		
4:00	48365	1134	4.7

Depth of Well:	500	feet	BT/Potability Test:	YES	2-day
Final Yield:	4.7	gpm	Gallons Pumped:	1134	gal
Pump Duration:	240	minutes	Storage System:	N/A	gal
Broke Suction:	NO	y/n	Filtration System:	N/A	y/n

*Pump Operation:	Functional	Deficient	Not Observed X
*Electrial/Well Head:	Functional	Deficient	Not Observed X
*Pressure Tank:	Functional	Deficient	Not Observed X
*Plumbing/Well Head:	Functional	Deficient	Not Observed X
*Storage Tank	Functional	Deficient	Not Observed X
*Booster Pump	Functional	Deficient	Not Observed X
*Filtration System	Functional	Deficient	Not Observed X
*Fire Hydrant System	Functional	Deficient	Not Observed X

Approved By: Colt Roer Date: **7/1/2015**

Rumsey Lang Well Drilling **License #936606**

24-0520 Public Comment
PC Rcvd 03-26-24

Appendix E

Email from property owner, 4520 D'Agostini Drive

Gmail Todd Moore <nopotfarm@gmail.com>

D'Agostini Pot Farm Update

Linette Harris <linette.harris2@gmail.com> Mon, Mar 11, 2024 at 5:31 PM
To: Andrea Cell Harris Jordan <aharrisjordan11@gmail.com>, Michael Harris <shodanmike61@gmail.com>, Todd Cell Jordan <luna.t.rg@gmail.com>, Todd Moore <nopotfarm@gmail.com>

Hi Todd,
Mike & I had to replace our well a few years ago as it went dry & the walls collapsed. We dug a new one much deeper (from a 500+ ft well to an 800+ ft well.)
I'll have to look up when that actually occurred but I'm thinking about 3 years ago. We live at 4520 D'Agostini Dr.
I'll look it up & let you know. We plan to go to the meeting March 28th too.
Thank you,
Linette & Mike Harris

On Sun, Mar 10, 2024 at 8:52 PM Todd Moore <nopotfarm@gmail.com> wrote:

Appendix F

Zheng Z, Fiddes K, Yang L. A narrative review of environmental impacts of cannabis cultivation, J Cannabis Res. 2021; 3:35; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8349047/

Journal of
Cannabis Research
BMC

J Cannabis Res. 2021; 3: 35.
Published online 2021 Aug 6. doi: 10.1186/s42238-021-00090-0

PMCID: PMC8349047
PMID: 34362475

A narrative review on environmental impacts of cannabis cultivation

Zhonghua Zheng,[1] Kelsey Fiddes,[2] and Liangcheng Yang[2]

Abstract

Interest in growing cannabis for medical and recreational purposes is increasing worldwide. This study reviews the environmental impacts of cannabis cultivation. Results show that both indoor and outdoor cannabis growing is water-intensive. The high water demand leads to water pollution and diversion, which could negatively affect the ecosystem. Studies found out that cannabis plants emit a significant amount of biogenic volatile organic compounds, which could cause indoor air quality issues. Indoor cannabis cultivation is energy-consuming, mainly due to heating, ventilation, air conditioning, and lighting. Energy consumption leads to greenhouse gas emissions. Cannabis cultivation could directly contribute to soil erosion. Meanwhile, cannabis plants have the ability to absorb and store heavy metals. It is envisioned that technologies such as precision irrigation could reduce water use, and application of tools such as life cycle analysis would advance understanding of the environmental impacts of cannabis cultivation.

Keywords: Cannabis cultivation, Water demand, BVOCs emission, Carbon footprint, Soil erosion

Background

The*Cannabis* plant has been cultivated throughout the world since ancient civilizations and used for thousands of years for both medicinal and recreational applications. Cannabis contains a psychoactive compound called tetrahydrocannabinols (THC) that creates a psychogenic effect. It can be consumed through the respiratory tract and digestive tract through smoking and oral ingesting, respectively. In contrast, cannabidiol (CBD), another component derived from cannabis, is a non-psychoactive cannabinoid that has gained popularity for its medicinal values and as a supplement. In the USA, an estimated "30 million Americans use marijuana (cannabis) at least occasionally, and 20 million use it at least once per month" (Osbeck and Bromberg 2017). Despite being used widely, the lack of science-based information due to the legal status of cannabis in the last centuries worldwide (e.g., in the USA) has prevented research.

Cultivation methods have an unavoidable influence on the environment in different degrees. Outdoor cultivation is the traditional and original method of cannabis cultivation. Although with low costs, it is subject to weather and natural resources. Improper soil and water resources management and pest control may induce critical environmental issues. On the contrary, indoor cultivation (including greenhouse cultivation) enables full control over all aspects of the plants, such as light and temperature, but is constrained by higher costs, energy demand, and associated environmental implications. Reducing the global environmental impact of agriculture is vital to maintain environmental sustainability. However, there is a lack of systemic principles towards the sustainable farming of cannabis because its environmental impacts remain unclear. In the wake of the unprecedented legalization of cannabis, there is a pressing need for a complete review of its environmental assessment.

In this paper, we conduct a narrative review of the available literature. We strive to build a better understanding of the environmental impacts induced by cannabis cultivation. This improved understanding can benefit communities, including policymakers, cannabis industry stakeholders, agricultural engineers, ecologists, and environmental scientists. This review covers the environmental effects on water, air, and soil. Energy consumption and carbon footprint are included as well. Possible research directions are also put forward.

Methods and materials

The literature search for this narrative review paper was conducted several times in 2020 and 2021. We searched combinations of keywords such as "cannabis cultivation," "marijuana cultivation," "cannabis water demand," "cannabis emissions," "cannabis energy demand", and "environmental impacts." Papers, reports, and government documents from 1973 to 2021 from Science Direct and Google Scholar databases have been searched in English. We screened over 250 literatures and discarded irrelevant literature for further analysis. A total of 63 literatures were cited in the review.

Water demand analysis

To unify the water demand calculations from different data sources, we conducted the following unit conversions:

$$1 \text{ inch of water} = 27,154 \text{ gallons of water per acre} \qquad (1)$$

$$1\text{acre} = 43,560\text{ft}^2 \qquad 2$$

Similarly, units reported for water demand such as "mm/total growing period" were converted to "gallon/ft^2/day". For example, the water need of cotton is 700 mm per total growing period. The water demand was calculated to:

$$700\text{mm} = 27.56\text{inches} = 748,346 \text{ gallon per acre} \qquad 3$$

Finally, the minimal daily water demand for cotton (shown in Table 1) was calculated using the maximal growing days (195 days):

$$\frac{748,346 \text{ gallon per acre}}{195 \text{ days}} \times \frac{\text{acre}}{43,560\text{ft}^2} = 0.09\frac{\text{gallons}}{\text{ft}^2 \times \text{days}} \qquad 4$$

Table 1

Water demand comparison between Cannabis and commodity crops

Plants	Total growing period (*days*)	Water demand per season (*million gallons acre*$^{-1}$)	Daily water demand (*gallon ft*$^{-2}$ *day*$^{-1}$)	Ref
Cannabis: outdoor	150	1.57 [a]	0.24	(HGA, 2010)
Cannabis: outdoor	August	n.a	0.22	(Wilson et al., 2019)
Cannabis: outdoor	September	n.a	0.17	(Wilson et al., 2019)
Cannabis: indoor	August	n.a	0.18	(Wilson et al., 2019)
Cannabis: indoor	September	n.a	0.22	(Wilson et al., 2019)
Cotton	180–195	0.75–1.39[b]	0.09–0.15	(Brouwer and Heibloem, 1986)
Cotton	/	/	0.14–0.17	(Hussain et al., 2020)
Maize	130–150	0.53–0.86[b]	0.07–0.13	(Brouwer and Heibloem, 1986)
Corn	/	/	0.22 (peak)	(Rogers et al. 2017)
Soybean	135–150	0.48–0.75[b]	0.07–0.13	(Brouwer and Heibloem, 1986)
Soybean	/	/	0.22 (peak)	(Rogers et al. 2017)
Wheat	120–150	0.48–0.69[b]	0.07–0.19	(Brouwer and Heibloem, 1986)
Wheat	/	/	0.19 (peak)	(Rogers et al. 2017)
Rice	90–150	0.48–0.75[b]	0.09–0.18	(Brouwer and Heibloem, 1986)
Rice	/	/	0.11–0.15	(Intaboot, 2017)

Note[a]: The water demand of cannabis is calculated based on 22.7 l (6 gallons) of water per day during the growing season and 200 plants per 5,000 sq. ft (HGA, 2010)

Note[b]: The water demand of crops is based on crop water need from Table 14 in Brouwer Heibloem (Brouwer and Heibloem, 1986). We convert the unit from mm to million gallon acre^{-1} according to the rule of unit conversion where 1 acre inch is equivalent to 27,154.29 gallon

Water demand and pollution

Water demand Cannabis is a water- and nutrient-intensive crop (Carah et al. 2015). Table 1 shows that the water demand for cannabis growing far exceeds the water needs of many commodity crops. For example, cannabis in a growing season needs twice as much as the water required by maize, soybean, and wheat. On average, a cannabis plant is estimated to consume 22.7 l (6 gallons) of water per day during the growing season, which typically ranges from June to October for an approximate total of 150 days (Butsic and Brenner 2016). As a comparison, the mean water usage for the wine grapes, the other major irrigated crop in the same region, was estimated as 12.64 l of water per day (Bauer et al. 2015). Although the average daily water use varies from site to site, depending on many factors such as the geographic characters, soil properties, weather, and cultivation types, it is an agreed-upon truth that cannabis is a high-use water plant. A survey conducted by Wilson et al. (2019) reports the water usage of outdoor cannabis cultivation in California is 5.5 gallons per day per plant (equivalent to 0.22 gallon $\mathrm{ft}^{-2}\ \mathrm{day}^{-1}$) in August and 5.1 gallons per day per plant (equivalent to 0.17 gallon $\mathrm{ft}^{-2}\ \mathrm{day}^{-1}$) in September (Wilson et al. 2019). The indoor cultivation water consumptions are 2.5 and 2.8 gallons per day per plant in August and September. However, the application rates (0.18 gallon $\mathrm{ft}^{-2}\ \mathrm{day}^{-1}$ in August and 0.22 gallon $\mathrm{ft}^{-2}\ \mathrm{day}^{-1}$ in September) are very close to outdoor cultivation (Wilson et al. 2019). In California, irrigated agriculture is regarded as the single largest water consumer, accounting for 70–80% of stored surface water and pumping vast volumes of groundwater (Moyle 2002; Bauer et al. 2015). The great water demand induced by agriculture, amid population growth and climate change, is most likely to exacerbate water scarcity in the foreseeable future (Bauer et al. 2015). Notably, the predicted decrease in water availability downscales in California may adversely affect the value of farmland (Schlenker et al. 2007) and pose a severe challenge to the cannabis industry. As a result, the immense amount of water necessary to keep cannabis plants alive and healthy will continue to burden our environment.

The high water demand presses the need for water sources. Water diversion is a common practice, which removes or transfers the water from one watershed to another to meet irrigation requirements. While the water diversion alleviates the water shortage problem for cannabis cultivation, it also presents new challenges. A study conducted by Bauer et al. quantitatively revealed that surface water diversions for irrigation led to reduced flows and dewatered streams (Bauer et al. 2015). Four northwestern California watersheds were investigated in this study since they are remote, primarily forested, sparsely populated. The results show that the annual seven-day low flow was reduced by up to 23% in the least impacted watersheds of this study, and water demands for cannabis cultivation in three watersheds exceed streamflow during the low-flow period. More recently, Dillis et al. identified well water (58.2%), surface water diversions (21.6%), and spring diversions (16.2%), are the most commonly extracted water source for cannabis cultivation in the North Coast region of California (Dillis et al. 2019). The distributing percentages, however, vary among the counties. For example, the growers in Humboldt County relied more on surface water and spring diversions (57%) than the wells (40.9%), while another study conducted by Wilson et al. showed that groundwater (wells or springs) was the primary water source for irrigation, followed by municipal water, rainwater, and surface water (Wilson et al. 2019).

Water pollution Cannabis cultivation, especially illegal cultivation, may deteriorate water quality. Recent studies have suggested the considerable demands of nutrition such as nitrogen (Saloner and Bernstein 2020, 2021), phosphorous (Shiponi and Bernstein 2021), and potassium (Saloner et al. 2019) for cannabis growth. However, there is limited data on the impact of cannabis cultivation on water quality worldwide or even nationwide. Here we focus on a survey conducted by Wilson et al. (2019) for CA, USA. Based on the survey, more than 30 different soil amendments and foliar nutrient sprays were used to maintain nutrition and fertility (Wilson et al. 2019). The applied pesticides (including herbicides, insecticides, fungicides, nematodes, and rodenticides), due to routine pest and disease controls, make their way into the water without restriction and therefore posing significant risks to the water environment (Gabriel et al. 2013). The transport and fate of the applied fertilizers and pesticides vary. For example, nitrogen and pesticides can get into runoff or leach into groundwater due to rainfall or excessive irrigation (Trautmann et al. 2012). If the polluted water continues to be used, it would add contaminants into soil, surface water, and groundwater. These chemicals may threaten humans and crops through the food chain (Pimentel and Edwards 1982). The other major irrigated crops can also be significantly impacted since the placement of crops is subject to the environmental safety of runoff, groundwater contamination, and the poisoning of nearby bodies of water. However, without the ability to sample water quality and assess the extent to which chemical inputs are entering adjacent water bodies, the ability to link cultivation practices to water pollution is greatly limited (Gianotti et al. 2017). Besides, few environmental clean-up and remediation efforts in the polluted watersheds are accessible due to a lack of resources and staff in state or federal agencies.

Water ecosystem Water diversion and water pollution affect the water ecosystem. The high demand for water due to cannabis cultivation in watersheds affects wildlife such as fish and amphibians in a significant way since cannabis cultivation is widespread within the boundaries of the watersheds, where the downstream water houses populations of sensitive aquatic species. The diminished flows may be notably detrimental to salmonid fishes since they need clean, cold water and suitable flow regimes (Bauer et al. 2015). As the reduced streamflow has a strong positive correlation with increased water temperature, indirectly resulting in reduced growth rates in salmonids, lowered dissolved oxygen, increased predation risk, and increased susceptibility to disease (Marine and Cech 2004). It has been reported that there are 80%–116% increases in cannabis cultivation sites near high-quality habitats for threatened and endangered salmonid fish species (Butsic et al. 2018). Besides, the threat of water diversions and altered stream flows to amphibians cannot be neglected. The desiccation-intolerant species, such as southern torrent salamander (*Rhyacotriton variegatus*) and coastal tailed frog (*Ascaphus truei*), are vulnerable to headwater stream diversions or dewatering (Bauer et al. 2015). The headwater stream-dwelling amphibians also exhibit high sensitivity to water temperature changes (Bury 2008). It is vital to get all the growers on the same page regarding water resources because flow modification is one of the greatest threats to aquatic biodiversity. The cannabis industry is becoming a major abuser concerning water diversions. Studies show that the second-generation anticoagulant rodenticides (ARs) affect many predators in both rural and urban settings (Gabriel et al. 2013, 2012; Elliott et al. 2014). Necropsy revealed that a male fisher had died of acute AR poisoning in April 2009, most likely due to the source of numerous illegal cannabis cultivation sites currently found on public lands throughout the western USA (Thompson et al. 2014). A study examining the effects of Ars on the Pacific fisher reports that four out of fifty-eight deceased fishers examined were killed by "lethal toxicosis, indicated by AR exposure."

Outdoor and indoor air quality

Outdoor air quality Little attention has been devoted so far to study the impact of cannabis cultivation on outdoor air quality. The emission of volatile organic compounds (VOCs) attracts special attention because of the vital role played by VOCs in ozone and particulate matter formation, as well as VOC's health impact (D.R. et al. 2001; Jacob 1999). Amongst the VOCs, the biogenic volatile organic compounds (BVOCs) (Atkinson and Arey 2003), mainly emitted from vegetation, account for approximately 89% of the total atmospheric VOCs (Goldstein and Galbally 2007). Previous studies have identified cannabis plant tissues contain high concentrations of many BVOCs such as monoterpenes (C_6H_{16}), terpenoid compounds (e.g., eucalyptol; $C_{10}H_{18}O$), sesquiterpenes ($C_{15}H_{24}$), and methanol. Hood et al. investigated that the monoterpenes α-pinene, β-pinene, β-myrcene, and d-limonene accounted for over 85% of the detected VOCs emitted, with acetone and methanol contributing a further 10% (Hood et al. 1973; Rice and Koziel 2015; Ross and ElSohly 1996). However, limited systematic studies characterized and accurately quantified volatile emissions during the growing and budding process (Wang et al. 2019b).

To determine the BVOCs emission rates, Wang et al. employed an enclosure chamber and live Cannabis spp. plants during a 90-day growing period considering four different strains of Cannabis spp. including Critical Mass, Lemon Wheel, Elephant Purple, and Rockstar Kush (Wang et al. 2019b). They found the percentages of individual BVOCs emissions were dominated by β-myrcene (18–60%), eucalyptol (17–38%), and d-limonene (3–10%) for all strains during peak growth (Table 2). The terpene emission capacity was determined, ranging from 4.9 to 8.7 μg-C per g dry biomass per hour. The estimation with μg-C per g dry biomass per hour for Denver would result in more than double the existing rate of BVOCs emissions to 520 metric ton year^{-1}, leading to 2100 metric ton year^{-1} of ozone, and 131 metric ton year^{-1} of PM (particular matter). However, a high emission can be expected since the better growing conditions contribute to rapid growth and higher biomass yields.

Table 2

Composition of BVOCs

BVOCs	30-day (%)	46-day (%)
β-myrcene	26.6–42.6	18.3–59.4
Eucalyptol	18.5–32.8	16.8–37.6
d-limonene	4.4–17.2	3.0–10.0
p-cymene	2.3–12.8	0.6–4.6
γ-terpinene	2.0–9.7	2.8–14.0
β-pinene	0.4–6.9	1.3–3.5
(Z)-β-ocimene	1.3–5.9	0.0
Sabinene	0.0–5.0	0.2–10.9
Camphene	0.0–4.4	0.0–1.0
α-pinene	0.8–4.3	2.7–3.6
Thujene	0.9–3.1	1.2–3.4
α-terpinene	0.0–2.0	0.5–5.4

Note: *BVOCs* biogenic volatile organic compounds

Data adapted from Wang, C. T., Wiedinmyer, C., Ashworth, K., Harley, P. C., Ortega, J., Vizuete, W. (2019b). Leaf enclosure measurements for determining volatile organic compound emission capacity from Cannabis spp. Atmos. Environ., 199, 80–87. (Wang et al., 2019b)

A recent study conducted by Wang et al. was the first attempt at developing an emission inventory for cannabis (Wang et al., 2019a). This study compiled a bottom-up emission inventory of BVOCs from cannabis cultivation facilities (CCFs) in Colorado using the best available information. Scenarios analysis shows that the highest emissions of terpenes occur in Denver County, with rates ranging from 36 to 362 t year^{-1}, contributing to more than half of the emissions across Colorado. With the emission inventory, the air quality simulations using the Comprehensive Air Quality Model with extensions (CAMx) show that increments in terpene concentrations could results in an increase of up to 0.34 ppb in hourly ozone concentrations during the morning and 0.67 ppb at night. Given that Denver county is currently classified as "moderate" non-attainment of the ozone standard (USEPA 2020), the air quality control of the CCF operation is essential.

In addition to BVOC emissions, like every crop cultivation in water-sensitive zones, the fertilization of cannabis causes deterioration in air quality. As fertilization is one of the most critical factors for cannabis cultivation, the introduction of excessive nitrogen into the environment without regulation can lead to adverse multi-scale impacts (Balasubramanian et al. 2017; Galloway et al. 2003). Ammonia in the chemical nitrogen fertilizer volatilized from cropland to the atmosphere forms PM via the reaction with acidic compounds in the atmosphere. Besides, the wet and dry deposition of reactive nitrogen consisting of ammonia continuously deteriorates the ecological environment. Both soil acidification and water eutrophication risks could significantly increase because of the nitrogen cascade (Galloway et al. 2003; Galloway et al. 2008).

Indoor air quality Although cannabis can be grown outdoors in many regions of the world, sizeable commercial cultivation can also occur indoors or in greenhouses. Ambient measurements collected inside growing operations pre-legalization have found concentrations as high as 50–100 ppbv of terpenes including α-pinene, β-pinene, β-myrcene, and d-limonene for fewer than 100 plants in the cannabis cultivation facility (Martyny et al. 2013; Atkinson and Arey 2003; Wang et al. 2019a). The study conducted by Spokane Regional Clean Air Agency (SRCAA) measured indoor VOCs in seven flowering rooms and two dry bud rooms across four different CCFs, reporting the average terpene concentration was 361 ppb (27–1676 ppb) (Southwellb et al. 2017).

Samburova et al. analyzed the BVOCs emissions from four indoor-growing Cannabis facilities in California and Nevada (Samburova et al. 2019). They reported the indoor concentrations of measured BVOCs could vary among the facilities, ranging from 112 $\mu g\ m^{-3}$ to 5502 $\mu g\ m^{-3}$ (Table 3), for a total measured BVOCs of 744 $mg\ day^{-1}\ plant^{-1}$. The BVOCs characterization partially agrees with the measurements shown by Wang et al. where β-myrcene is one of the dominated BVOCs emitted by Cannabis, but eucalyptol was not a dominating terpene in this study (Wang et al. 2019b). The obtained emission rates ranged between 0 to 518.25 $mg\ day^{-1}\ plant^{-1}$. The largest emission contributors were β-pinene (518.25 $mg\ day^{-1}\ plant^{-1}$, 70% of the total BVOCs) α-pinene (142.92 $mg\ day^{-1}\ plant^{-1}$, 19% of the total BVOCs), and D-limonene (30.86 $mg\ day^{-1}\ plant^{-1}$, 4% of the total BVOCs). Silvey (2019) characterized the overall VOC total terpene mass concentration using sorbent tube sampling and found a higher range between 1.5 $mg\ m^{-3}$ (office) to 34 $mg\ m^{-3}$ (trimming room) (Silvey 2019).

Table 3

Indoor BVOCs concentrations

BVOCs	Sites	Unit in *ppbv*	Unit in *ug* m^{-3}	Ref
α-pinene, β-myrcene, β-pinene, and limonene	Growing room	50–100	n.a	(Martyny et al., 2013; Wang et al., 2019a)
Terpenes	Flowering room	30–1600	n.a	(Southwellb et al., 2017; Wang et al., 2019a)
Total BVOCs	Growing room	n.a	112–5502	(Samburova et al., 2019)
Total BVOCs	Curing room	n.a	863–1055	(Cuypers et al., 2017)
Total BVOCs	Purging room	n.a	1005	(Trautmann et al., 2012)

BVOCs Biogenic volatile organic compounds

The indoor cannabis (marijuana) grows operations (known as "IMGO") also pose a risk of potential health hazards such as mold exposure, pesticide, and chemical exposure (Martyny et al. 2013). For example, cannabis cultivations typically require a temperature between 21 and 32 °C, with a relative humidity between 50 and 70% (Koch et al. 2010)., while the ventilation rate is often suppressed to limit odor emanating, especially for the illegal cultivation. John and Miller suggested that the houses built after 1980 in Canada are at high risk of moisture-related damage if used as IMGO, and increased moisture levels of the IMGO are associated with elevated mold spore levels (Johnson and Miller 2012). The reports by IOM (IOM 2004) and WHO (World Health Organization) showed that the presence of mold in damp indoor environments is correlated with upper respiratory tract symptoms, respiratory infections, wheeze, cough, current asthma, asthma symptoms in sensitized individuals, hypersensitivity pneumonitis, and dyspnea (WHO 2009). Cuypers et al. conducted a study in Europe, showing that pesticide use in Belgian indoor cannabis cultivation is a common practice, putting both the growers and intervention staff at considerable risk (Cuypers et al 2017). They found 19 pesticides in 64.3% of 72 cannabis plant samples and 65.2% of 46 carbon filter cloth samples, including o-phenylphenol, bifenazate, and cypermethrin.

Energy demands and carbon footprint

Indoor cultivation energy demands and impacts As one of the most energy-intensive industries in the USA (Warren 2015), cannabis cultivation results in up to $6B in energy costs annually, accounting for at least 1% of the nation's electricity (Mills 2012).. The cannabis electricity consumption increases to 3% in California (Warren 2015). In Denver, the average electricity use from cannabis cultivation and associated infused product manufacturing increased by 36% annually between 2012 and 2016 (DPHE 2018). As cannabis becomes legalized throughout the country, energy consumption will continue to grow in the foreseeable future.

The energy use of indoor cannabis cultivation arises from a range of equipment, falling into two major categories: lighting and precise microclimate control. For the cannabis plants to thrive and therefore make the growers a profit, several energy-intensive tools are regularly utilized. The energy demand for indoor cannabis cultivation was reported to be 6074 kWh kg-yield^{-1} (Mills 2012). Figure 1 shows the end-use electricity consumption according to a study performed by the Northwest Power and Conservation Council (NPCC 2014). Amongst them, lighting, HVAC (heating, ventilation, and air conditioning), and dehumidification account for 89% of the total end-use electricity consumption.

Fig. 1

End-use electricity consumption

High-intensity lighting is the main contributor to electricity for indoor production facilities. Sweet pointed out that lighting alone can account for up to 86% of the total electricity usage (Sweet 2016). It has been reported that the intensity of the indoor cannabis lamps (25 klux for leaf phase, and 100 klux for flowering (Mills 2012)) approximates that of hospital operating room lamps, which is up to 500 times greater than a standard reading light (Warren 2015). Indoor cultivation facilities typically utilize a combination of high-pressure sodium (HPS), ceramic metal halide (CMH), fluorescent, and/or light-emitting diode (LED) lamps. In addition to the lamp type, lighting system design is also critical to maximizing energy efficiency in the cultivation facilities, and time of use also plays a crucial role.

HVAC Dehumidification system ensures frequent air exchanges, ventilation, temperature, and humidity control day and night. This system can account for more than half of the total energy consumption in an indoor cultivation facility (Mills 2012). Besides, water and energy are inextricably linked, given water and wastewater utilities contribute to 5% of overall USA electricity consumption (Pimentel and Edwards 1982). The grow systems (including automation and sensors), irrigation (including fertigation and pumps), and CO_2 injection also consume an amount of electricity.

Energy production, especially fossil fuel use, is accountable for the environmental impact. Table 4 shows that coal and natural gas make up almost three-quarters of the power supply for Colorado customers in the USA. Considering the environmental impacts of different energy sources, the extensive usages of fossil fuels (coal, natural gas, and oil) causes serious environmental damage and pose effects on (1) humans, (2) animals, (3) farm produce, plants, and forests, (4) aquatic ecosystems, and (5) buildings and structures (Barbir et al. 1990).

Table 4

Power supply mix for Colorado customers

Energy sources	Total generation mix (%)
Coal	44
Natural gas	28
Wind	23
Solar	3
Hydroelectric	2
Others (including biomass, oil and nuclear generation)	0

Data adapted from Dever Publich Health Environment. 2018. Cannabis Environmental Best Management Practices Guide. (DPHE, 2018)

Carbon footprint The term *carbon footprint* refers to "a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" (Wiedmann and Minx 2008). In the context of cannabis cultivation, a carbon footprint can be defined as the total amount of greenhouse gases (GHGs) emitted during the production of cannabis. Denver Department of Public Health Environment broke the GHG inventory down into the three primary scopes: (1) an organization's direct GHG emissions produced on-site; (2) an organization's off-site carbon emissions, or indirect emissions; (3) all other indirect carbon emissions associated with the operation of a business (DPHE 2018). However, a relatively small body of literature pays particular attention to the carbon footprint calculation. Mills estimates that producing one kilogram of processed cannabis indoors leads to 4600 kg of CO_2 emissions to the atmosphere, equivalent to one passenger vehicle driven for one year or 11,414 miles driven by an average passenger vehicle (Mills 2012). Amongst them, the emissions factor (kg CO_2 emissions per kg yield) of lighting is 1520 (33%), followed by ventilation and dehumidify (1231, 27%), and air conditioning (855, 19%). On the other hand, outdoor cultivation can alleviate the energy use for lighting and precise microclimate control but requires other facilities and techniques such as water pumping. Carbon footprint analysis is the first step towards the carbon reduction strategies, which contributes to the reduction of the environmental impacts of the cannabis industry. Future studies are foreseen to improve the understanding of the carbon footprint of cannabis cultivation both indoors and outdoors.

Soil erosion and pollution

Soil erosion Soil erosion is a natural process that occurs when there is a loss or removal of the top layer of soil due to rain, wind, deforestation, or any other human activities. It increases fine-sediment loading into streams and threatens rare and endangered species (Carah et al. 2015). Soil erosion can happen slowly due to wind or quickly due to the heavy rainfall event. Land terracing, road construction, and forest clearing make their ways to remove native vegetation and to induce soil erosion (Carah et al. 2015). Barringer (Barringer 2013) and O'Hare et al. suggested that cannabis cultivation directly contributes to soil erosion (O'Hare et al. 2013). The slope is a useful proxy for erosion potential since soil on steep slopes tends to erosion when cleared or cultivated (Butsic et al. 2018). Butsic and Brenner conducted a systematic, spatially explicit survey for the Humboldt County, California, involving digitizing 4,428 grow sites in 60 watersheds (Butsic and Brenner 2016). About 22% of the clustered cannabis on steep slopes indicates a risk of erosion. Many studies also suggest that cannabis cultivation can result in deforestation and forest fragmentation (Wang et al. 2017), which exacerbate soil erosion. Though greenhouse prevents soil erosion, they are surrounded by large clearings accumulated during construction with exposed soils subject to erosion (Bauer et al. 2015).

Phytoremediation potential Cannabis has gradually garnered attention as a "bioremediation crop" because of its strong ability to absorbing and storing heavy metals (McPartland and McKernan 2017). It can remove heavy metal substances from substrate soils and keep these in its tissues by means of its bio-accumulative capacity (Dryburgh et al. 2018). Usually, it takes up high levels of heavy metals from the soil or growing medium via its roots and potentially deposits into its flowers (Seltenrich 2019). Tainted fertilizer uptake from the soil is often a source of heavy metals contamination such as arsenic, cadmium, lead, and mercury. Singani and Ahmadi reported that *Cannabis sativa* could absorb lead and cadmium from soils amended with contaminated cow and poultry manures (Singani and Ahmadi 2012). Though limited studies discussed the effectiveness of cannabis for heavy metals removal, many studies have addressed the uptake of heavy metals by industrial hemp (Campbell et al. 2002; Linger et al. 2002). It indicates that the cannabis plant is qualified as a phytoremediation of contaminated soils.

Conclusions and envisions

A summary of the environmental impacts of cannabis cultivation is shown in Fig. 2. Water demand and usage will continue to be a major concern. Illegal cannabis cultivation and improper operation may raise water pollution issues. Studies on cannabis' physiological properties will guide to determine water demand. Besides, identifying and applying best management practices, such as precision irrigation and enhanced climate control, will be critical to minimize the environmental impacts on water. Energy consumptions mainly come from the equipment operation of the indoor cultivations such as lighting, HVAC, and dehumidification. Carbon footprint can be calculated both indoors and outdoors based on energy consumption. Quantitatively accounting for the energy assumption across operations at scales is the key to better estimating the carbon footprint. Techniques such as life cycle energy assessment and life cycle carbon emissions assessment would offer informative guidance to reduce the environmental impacts. Few studies have focused on the impacts of cannabis cultivation on air quality. Evidence has emerged that BVOCs and fertilization may contribute to outdoor air quality issues. Indoor air pollutants, i.e., BVOCs emission, mold, pesticide, and chemicals pose a risk of health hazards. Field or chamber studies on determining the species and emission rate of BVOCs, trace gases, and particles from the plant, plant detritus, and soils are important. Much work will be needed to include this information in the emission inventory for air quality modeling. Investigation concerning the contribution of those species to regional, even global air quality, is useful for policymakers and the public. Besides, a better understanding of indoor pollutant concentration and emission ensures the safety of indoor operation. The environmental impact of cannabis cultivation on soil quality has two sides, and it needs to be treated dialectically. On one side, cannabis cultivation directly contributes to soil erosion. On the other side, cannabis has a strong ability to absorb and store heavy metals in the soil. Further studies on the soil mechanics and dynamics of heavy metals in plant-soil interactions are needed.

Fig. 2

Summary of cannabis environmental impacts

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Abbreviations

ARs	Anticoagulant rodenticides
BVOCs	Biogenic volatile organic compounds
CAMx	Comprehensive Air Quality Model with extensions
CBD	Cannabidiol
CCFs	Cannabis cultivation dacility
CMH	Ceramic metal halide
CSA	Controlled Substances Act

GHGs	Greenhouse gases
HPS	High-pressure sodium
HVAC	Heating, ventilation, and air conditioning
IMGO	Indoor Marijuana Grows Operations
LED	Light-emitting diode
NIH	National Institutes of Health
OSHA	Occupational Safety and Health Administration
PM	Particular matter
SRCAA	Spokane Regional Clean Air Agency
THC	Tetrahydrocannabinols
USDA	Department of Agriculture
VOCs	Volatile organic compounds
WHO	World Health Organization

Authors' contributions

Dr. Zheng worked on sections including outdoor and indoor air quality, energy demand and carbon footprint, and soil erosion. Miss Fiddes worked on water demand and pollution. Dr. Yang supervised Dr. Zheng and Miss Fiddes in completing this project. The author(s) read and approved the final manuscript.

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Appendix G

Wilson H, Bodwitch H, Carah J. First known survey of cannabis production practices in California. California Agricul. 2019;73(3):119–27; https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0120016

Impacts of Surface Water Diversions for Marijuana Cultivation on Aquatic Habitat in Four Northwestern California Watersheds

Scott Bauer, Jennifer Olson, Adam Cockrill, Michael van Hattem, Linda Miller, Margaret Tauzer, Gordon Leppig

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Correction

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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.

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Data Availability: 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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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 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.

Fig 1. Study Watersheds and Major Watercourses.
https://doi.org/10.1371/journal.pone.0120016.g001

Fig 2. Upper Redwood Creek Watershed.
Outdoor marijuana plantings are marked in red and greenhouses are marked in light green.

https://doi.org/10.1371/journal.pone.0120016.g002

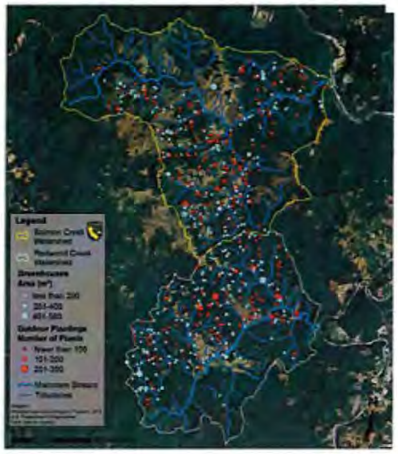

Fig 3. Salmon Creek and Redwood Creek South Watersheds.
Outdoor marijuana plantings are marked in red and greenhouses are marked in light green.
https://doi.org/10.1371/journal.pone.0120016.g003

Fig 4. Outlet Creek Watershed.
Outdoor marijuana plantings are marked in red and greenhouses are marked in light green.
https://doi.org/10.1371/journal.pone.0120016.g004

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 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 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 (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 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 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.

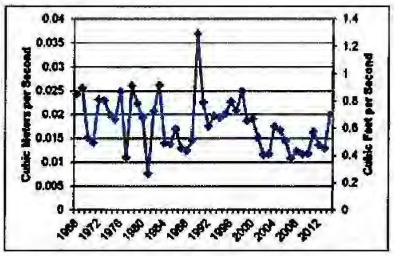

Fig 5. Elder Creek annual seven-day low flow.

Values are shown for the period of record (water years 1968–2014).
https://doi.org/10.1371/journal.pone.0120016.g005

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.

Table 1. USGS stream gages in or near study watersheds.
https://doi.org/10.1371/journal.pone.0120016.t001

Table 2. Annual seven-day low flow range for period of record.
https://doi.org/10.1371/journal.pone.0120016.t002

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].

$$Q_{Avg} = 0.07362 \times \left(\frac{m^3}{sec} \times yr \times cm \times km^2\right) \times R \times A$$

eq. (1)

With

$$R = MAP - 0.4(PET) - 9.1$$

eq. (2)

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 mainstem 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 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.

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).

https://doi.org/10.1371/journal.pone.0120016.g006

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.

Table 3. Marijuana mapping summary of four watersheds.

https://doi.org/10.1371/journal.pone.0120016.t003

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 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.

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.
https://doi.org/10.1371/journal.pone.0120016.g007

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 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.

Table 4. Estimated water demand for marijuana cultivation expressed as a percentage of seven-day low flow in four study watersheds.
https://doi.org/10.1371/journal.pone.0120016.t004

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.

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.
https://doi.org/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.

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.
https://doi.org/10.1371/journal.pone.0120016.g009

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.

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).

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).
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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 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.

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(XLSX)

S2 Table. Per-watershed daily water demands compared to seven-day low flow by year.

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(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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Appendix H

Peacock W, Williams L, Christensen L. Water Management and Irrigation Scheduling. Water Management and Irrigation SchedulingUniversity of California Agriculture and Natural Resourceshttps://ucanr.edu › sites › Tulare_County › files

University of California **Cooperative Extension** **Tulare County**

Pub.IG9-98

Water Management and Irrigation Scheduling

Bill Peacock, Larry Williams, and Pete Christensen

Water Management

Seasonal evapotranspiration (ET) or water use of a mature raisin vineyard can vary from 19 to 26 inches (483-1143 mm) in the San Joaquin Valley depending on canopy size. ET is a combination of the water evaporating from the soil surface (E) and transpiring from the leaves (T). Evaporative demand varies very little from season to season within the geographical boundary of the raisin industry.

The total amount of irrigation water applied, however, is often more than vineyard ET. An additional 6 to 8 inches (152 - 203 mm) of water may be needed some years for leaching salts and providing frost protection, and the efficiency of the irrigation system must be taken into account. Winter rainfall can offset irrigation requirements by 3 to 6 inches (76 - 152 mm) depending on the timing of the rainfall and the ability of the soil to store water. Typically, raisin vineyards are seasonally irrigated with 24 to 36 inches (610 - 914 mm).

In developing an irrigation strategy for grapevines, canopy development and the timing of the vine's growth stages should be taken into consideration. Water use by grapevines begins with budbreak. It gradually increases as the canopy develops and evaporative demand increases. The canopy is fully developed by early to mid-June, and peak water use will occur in June, July, and August. The effect of irrigation on vine growth and fruit development is best discussed by dividing the season into four stages. The irrigation stages depicted in this chapter should not be confused with the three stages of berry growth discussed elsewhere.

The first irrigation stage (**Stage One**) covers the period from shortly after budbreak to bloom (April 1 to May 10). The water requirement during this period is low with only 2.5 inches (64 mm) used during the 40-day period. Moisture stored in the soil from winter rains is usually adequate to meet vineyard water requirements during this time frame. Even with no spring irrigation, grapevines rarely exhibit symptoms of water stress during this period. The exceptions are vineyards on very sandy or shallow soils with limited soil water storage, or vineyards with cover crops. Irrigations that occur during Stage One are primarily for frost protection or to add to stored soil moisture. The danger of frost is high until mid-April after which the probability of frost diminishes rapidly.

The second stage (**Stage Two**) covers the period from bloom to veraison (May 10 to July 1). Veraison is the point when fruit begins to soften and usually occurs in late June or early July in the San Joaquin Valley. Grapevines use 4 to 7 inches (102 - 178 mm) of water during this period. Proper water management is critical during this time as cell division and elongation are occurring in fruit. Water stress at this time will reduce berry size and yield.

AGRICULTURAL BLDG., COUNTY CIVIC CENTER, WOODLAND AND W. MAIN STREETS, VISALIA, CALIFORNIA 93291-4584 — TEL (209) 733-6363, FAX (209) 733-6720
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The third irrigation stage (**Stage Three**) covers the period from veraison to harvest (July 1 to September). Thompson Seedless vineyards, when harvested in early September, use 7 to 9 inches (178-229 mm) during this 60-day time frame. Raisin growers generally terminate irrigations 2 to 6 weeks prior to harvest, depending on soil type, to allow time for terrace preparation. Drip irrigation of raisin vineyards may continue up until a few weeks before harvest. Irrigations may be cut back in order to impose moderate stress and reduce shoot growth in vigorous vineyards between veraison and harvest. Excessive irrigation during this period can delay fruit maturity, encourage bunch rot, delay or reduce wood maturity.

The last irrigation stage (**Stage Four**) is the postharvest period that concludes with leaf abscission (early November). The length of this period depends on harvest date. Water use during this 60-day period (for Thompson Seedless harvested early September) is 4 to 6 inches (102-152 mm). Irrigations at this time should be applied in amounts to maintain the canopy but not encourage growth. Excessively vigorous vines will continue to grow or start new growth after harvest and fail to ripen wood if supplied with excessive water. Mild to moderate water stress may be beneficial by stopping shoot growth and promoting wood maturity; however, vines should not be allowed to defoliate. In late October or early November, when temperatures are too low to encourage shoot growth, a heavy irrigation is recommended to replenish some of the soil water reservoir and satisfy the leaching requirement. Vines that are extremely water stressed during this time period may have delayed shoot growth the following spring.

The approximate water use or ET of a Thompson Seedless raisin vineyard during the four above-mentioned irrigation stages can be found in Table 1. Tables 2 and 3 give seasonal water use on a daily basis for a small canopy vine shading 50 to 60 percent of the land surface (a vineyard using a single wire trellis) and a large canopy vine shading 75 percent of the land surface (a vineyard using a crossarm trellis). The seasonal water use for raisin vineyards, Tables 2 and 3, is based on historic reference ET (ET_o) and was developed by research in commercial raisin vineyards and using a weighing lysimeter at the Kearney Ag Center. This water use information can effectively be used to schedule irrigations, particularly drip irrigation.

Scheduling Furrow Irrigated Vineyards

The principle of scheduling furrow irrigations can best be discussed using a water budget. The water budget balances vineyard water use with the size of the soil water reservoir. Irrigations should occur when 30 to 50 percent of the soil water reservoir has been depleted by vine ET, and irrigation should be sufficient to refill the reservoir. The soil water reservoir is based on the available water-holding capacity of the soil (which varies with soil texture) and the depth of the root system.

Available soil water content, rooting depth, and allowable depletions for several different soil textures are given in Table 4. Available water is the difference in volumetric water content between field capacity and the permanent wilting percentage (or point) of the soil. Allowable depletion represents the amount of water that can be readily extracted by the grapevines, before stress begins to occur. For a mature vineyard with a fully developed root system, the allowable depletion is about 2 inches (51 mm) for a sandy soil and 4 inches (102 mm) for a loam or fine sandy loam soil.

The ET of a large canopied vineyard during the month of July is about 0.2 inch (5 mm) per day (Table 3). Therefore, vines growing on sandy soil will require irrigation about every 10 days to avoid water stress (2 inches [51 mm] allowable depletion for a sandy soil/0.2 inch [5 mm] per day). In contrast, a vineyard on a fine sandy loam can go 20 days between irrigations (4 inches [102 mm] allowable depletion for a fine sandy loam soil/0.2 inch [5 mm] per day).

The above examples illustrate an important point: the water use of vines (with similar canopy) is the same regardless of soil type. It is much more difficult to efficiently furrow irrigate vineyards on sandy soil compared to a finer textured soil: more water is lost below the root zone. This difference in irrigation efficiency gives the false impression that the water use of vines on sandy soil is higher than on finer textured soils. Typical irrigation efficiency, allowable depletion, amount of water applied each irrigation, number of irrigations per season, and total water applied for different soil texture classes are given in Table 5.

Irrigation Cutoff

Irrigations must be cut off early enough before harvest to allow drying of the soil surface for preparation of a dry terrace by harvest: irrigations should be cut off 2 to 4 weeks for sandy soil and 4 to 6 weeks for fine textured soils (Table 6). An early cutoff date to purposely impose severe stress to the vine does not promote more total grape sugar or improve raisin grade. A cutoff date that is too early results in some leaf defoliation occurring by harvest, and defoliation is excessive by the time raisins are boxed. This level of stress, if repeated yearly, can weaken the vineyard, reduce production, and should be avoided.

An earlier cutoff date is advisable when in past years vines are still growing vigorously at harvest. Fruit maturity can be delayed when shoots continue to actively grow from veraison to harvest. Also, vines that continue to actively grow until late in the season may develop many poorly matured canes (not woody). This can make it difficult for a pruner to find a sufficient number of mature, fruitful canes. Poor cane maturity can be a serious problem with young, excessively vigorous vineyards. To manage this problem, irrigations should be cut off early enough to slow or stop most shoot growth by harvest.

Postharvest Irrigation

By mid-October, the vineyard is normally terraced back, disced, and prepared for a postharvest irrigation. In some instances vines may have gone for 2 months without an irrigation. Sixty percent or more of the available water in the root zone will have been depleted by October, and vineyards will exhibit symptoms of water stress, in varying degrees. Thus, an irrigation after harvest in October is recommended to replenish soil moisture in the root zone and/or leach salts.

Vineyards on sandy or shallow soils have a much smaller soil water reservoir; therefore, they may be stressed by the time harvest is complete. These vineyards should be irrigated immediately after harvest. In contrast, excessively vigorous vineyards on deep soils with high water-holding capacities should not be irrigated postharvest until late October or November. This will help reduce late season growth and improve cane maturity. Postharvest irrigation can be delayed on vineyards that have been defoliated by insects or mites to prevent excessive late season growth.

Scheduling Drip Irrigations

There is much less soil water storage with drip (one-third to one-fourth as much as with furrow irrigation) which makes frequent irrigations necessary to avoid water stress. By June, about 30 percent or less of the root system may be found in the wetted soil volume directly beneath the emitter. Less than 15 percent of the root system may be wetted if the soil has slow infiltration characteristics. Drip irrigations should be applied frequently (every 1 to 4 days during the summer months) and with enough water to satisfy the vine's water use over that interval.

The drip irrigation schedules (Tables 2 and 3) indicate how much water should be applied on a daily basis during the season. The schedule given in Table 2 provides daily water use for a vineyard with a 50 to 60 percent canopy which is typical of most raisin vineyards using a single wire trellis system. Table 3 gives daily water use for a vineyard with a 75 percent canopy which is typical for vineyards using a crossarm trellis system.

It is easy and practical to use Tables 2 or 3 to schedule drip irrigations. For example, to schedule irrigations during the first week of July for a large canopied vineyard, use Table 2. The schedule indicates that the vineyard's water use is 3550 gallons per acre (33,202 liters/hectare) per day; therefore, irrigate with 3550 gallons per acre every day (plus an efficiency adjustment - see below) to replenish the soil water extracted. To schedule irrigations every other day, apply 7100 gallons (66,404 1/ha) plus the efficiency adjustment (2 days x 3550 gallons); to schedule irrigations every fourth day, then apply 14,200 gallons (132,808 1/ha) plus the efficiency adjustment (4 days x 3550 gallons). During summer months, irrigation intervals should not exceed every 4 days because of restricted soil water storage and the potential for vine stress between irrigations. To calculate gallons per vine per day, divide the gallons per acre value by the number of vines per acre. For example, if the vineyard has an 8 x 12 ft. (2.4 x 3.6 m) vine and row spacing, then divide 3550 (gallons per acre per day) (33,202 1/ha) by 454 (vines per acre) (1,122 vines per ha) which equals 7.8 gallons (29.6 liters) per vine per day.

Irrigation amounts shown in Tables 2 and 3 do not account for irrigation efficiency of the drip system. Most drip systems have an emission uniformity or water application efficiency of 70 to 90 percent. Schedule amounts given in Tables 2 and 3 must be increased accordingly to compensate for the efficiency of the drip system. For example, the schedule indicates that 3550 gallons per acre (33,202 1/ha) per day should be applied the first week in July, and the emission uniformity of the drip system is 90 percent. Therefore, 3944 gallons per acre (36,887 1/ha) per day should be applied. This is calculated as follows: 3550 gallons (33,202 liters)/ .90 = 3944 (36,891).

Drip irrigations should be cut back beginning July or early August to 50 to 75 percent of schedule amounts (Tables 2 and 3) to slow shoot growth in vigorous vineyards. Drip irrigations are usually discontinued 1 or 2 weeks before harvest to allow for the preparation of a dry terrace. Irrigating during harvest is risky since a rupture in the system could result in flooding and damage to the raisin crop, although some growers on very sandy soils will irrigate during the sun drying process.

After raisins are boxed, drip irrigation should commence by applying enough water to rewet the soil to 3 or 4 feet (0.9 - 1.2 m) beneath the dripper. This may take 15,000 to 30,000 gallons per acre (140,290 - 280,581 1/ha) for sandy or fine sandy loam soils, respectively. After rewetting the root zone, begin drip irrigation using amounts shown in the schedule (Tables 2 and 3). Less water (50 percent of schedule amounts) or no water should be applied to vigorous vineyards showing active shoot growth until late October when low temperatures no longer encourage growth.

Irrigation Scheduling Using Current Weather Information

Seasonal evaporative demand remains fairly constant from year to year in the San Joaquin Valley; therefore, the irrigation schedules found in Tables 2 and 3 provide a practical guide in scheduling irrigations. When using these tables, irrigation amounts can be increased during unseasonable hot weather and decreased during unseasonable cool weather by 15 to 25 percent: Common sense should prevail and tensiometers or other soil/plant based irrigation monitoring tools should be used to verify the accuracy of the irrigation schedule.

If more precise irrigation scheduling is required, current (or real-time) ET_o data can be used and are available from the California Irrigation Management Information System (CIMIS). The information needed in scheduling irrigations throughout the current growing season are daily ET_o values and reliable crop coefficients or RDI factors. The seasonal crop coefficients at full ET and RDI factors for Thompson Seedless grapevines were developed at the Kearney Ag Center (Figure 1). Daily vine ET equals ET_o multiplied by the crop coefficient or RDI factor for that day. The uppermost data set in Figure 1 represents the crop coefficient for vines growing in the weighing lysimeter (100% of ET). However, since yields were maximized with water application amounts at 80 percent of full vine water use, most raisin growers would use the seasonal 80 percent RDI_F. For vineyards that are weak or the vines are smaller, the seasonal 60 percent RDI_F may be more appropriate. Therefore, the following equation can be used to schedule irrigations in raisin vineyards:

$$ET_C = ET_o \, RDI_F$$

The specific RDI_F to be used can be found in Figure 1. Using this method to determine vine water use, one is able to compensate with a fair degree of accuracy for changes in daily evaporative demand during the current growing season and canopy size or trellis type used.

Water Use In Vineyards With Cover Crops

The irrigation schedules presented in Tables 2 and 3 and the crop coefficients and regulated deficit irrigation factors presented above are for vineyards without cover crops. Additional water should be applied when cover crops are grown to avoid vine water stress, unless it is the grower's objective to purposely slow the growth of an excessively vigorous vineyard.

Studies at the Kearney Ag Center showed that the amount of additional water will vary with the type of cover crop and management of the cover. In one study a continuous cover crop (bromegrass seeded during the winter, followed by resident vegetation in the summer) increased water use 46 percent compared to the bare soil surface treatment. Bromegrass, killed after seed shattering (in May) increased water use 19 percent compared to no vegetation. A rye/vetch cover crop incorporated into the soil the second week of July required 35 percent more irrigation water.

Evaluation Of Irrigation Scheduling And Amounts

There are several methods to validate irrigation schedules and/or amounts. Symptoms of water stress in vineyards are usually not visible in the San Joaquin Valley until mid-May to early June. The approximate date is dependent upon soil texture and rooting depth in the vineyard. The first visible sign of water stress is a decrease in the angle formed by the axis of the leaf petiole and the plane of the leaf blade. As water stress increases, shoot growth slows and internode growth is inhibited. As water stress becomes more acute, the shoot tips and tendrils die. Finally, under extreme water stress leaf abscission occurs, originating with the most mature leaves and progressing towards the shoot tip. This level of stress is usually not observed in the San Joaquin Valley until late June or early July.

A tensiometer can be an important tool for monitoring the accuracy of irrigation scheduling. Tensiometers measure the soil's matrix potential. Shoot growth will slow when tensiometer readings average -40 centibar in most of the root zone, and defoliation will begin when readings exceed -80 centibar (the upper limit of a tensiometer). Waterlogged conditions are indicated when tensiometers read below -10 centibars. Two tensiometers should be placed side by side with one monitoring the 18- to 24-inch (0.45-0.6 m) depth and the other monitoring the lower soil profile, the 36- to 48-inch (0.9-1.2 m) depth. Tensiometers should be placed down the vine row; one tensiometer site for every 20 acres (8 ha) is adequate.

When drip irrigations are effectively scheduled, tensiometers will give a constant reading of -10 to -20 centibar (kPa) until irrigations are cut back or terminated prior to harvest; then the readings will become more negative. This is consistent with the principle of drip irrigation, frequent irrigations with steady state soil moisture. With furrow irrigation, soil moisture levels and, subsequently, soil matrix potential fluctuate considerably in the root zone, corresponding to the water budget principle of scheduling furrow irrigations. Typically, vines are furrow irrigated when soil matrix potentials at the 2-foot (0.6 m) depth approach -40 to -50 centibars, and after a successful irrigation, the soil matrix potential will increase to -10 to -15 centibars indicating the soil reservoir was recharged. Monitoring tensiometers placed at both 2 and 4 feet 0.6-1.2 m) below the surface will indicate the depth of water penetration.

There are several other methods to validate and/or schedule irrigations in vineyards. Soil water content can be monitored with a hydroprobe. One would base the next irrigation event when a predetermined minimum soil water content was measured. Plant-based measures of vine water stress, such as predawn or midday leafwater potential measurements, have been used for other crops. One would irrigate when a predetermined value of leaf water potential was measured. Grapevines are generally not considered to be stressed if midday values of leafwater potential are no lower than -10 bars (-1.0 MPa).

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Table 1. Approximate raisin vineyard water use during four seasonal irrigation stages.[1]

Irrigation stage	Phenological events	Approximate dates	Days in Irrigation stage	Vineyard water use during irrigation stage (inches/acre)[6] Small canopy	Large canopy
One[2]	Budbreak to Bloom	(April 1) (May 10)	40	2.0	2.5
Two[3]	Bloom to Veraison	(May 10) (July 1)	51	5.6	7.5
Three[4]	Veraison to Harvest	(July 1) (Sept 1)	62	8.0	10.7
Four[5]	Harvest to Leaf fall	(Sept 1) (Nov 1)	61	3.8	5.1
Total vineyard water use for season				19.4	25.8

[1] Based on Thompson Seedless.

[2] Water requirement during irrigation Stage One is supplied primarily by soil moisture stored from winter rains (except for vineyards on very sandy or shallow soils). It is difficult to stress vines during this stage. Withholding irrigations may help improve berry set.

[3] Don't stress vines during irrigation Stage Two: cell division and berry growth is occurring during this period and the fruit is very susceptible to sunburn at this time.

[4] Deficit irrigation during irrigation Stage Three (50% to 75% of ET) will have minimal or no effect on yield. Excessive irrigation can increase rot and delay fruit maturity.

[5] Apply enough water to maintain canopy during irrigation Stage Four. Avoid excessive growth or premature defoliation.

[6] Multiply inches/acre by 62.8 to calculate centimeters/hectare.

Table 2. Drip irrigation schedule (vine water use) for a small canopy vineyard or one using a single wire trellis system in the San JoaquinValley.[1,2]

		Gal/Acre/Day[3,4,5]			Gal/Acre/Day[3,4,5]
APRIL	1-7	500	JULY	1-7	3550
	8-14	750		8-14	3700
	15-21	1000		15-21	3800
	22-30	1200		22-31	3750
MAY	1-7	1550	AUG	1-7	3650
	8-14	1800		8-14	3550
	15-21	2050		15-21	3400
	22-31	2300		22-31	3300
JUNE	1-7	2650	SEPT	1-7	3100
	8-14	2900		8-14	2850
	15-21	3200		15-21	2650
	22-30	3350		22-30	2400

[1] Vineyard canopy covers 50% to 60% of the land surface during summer months.

[2] Schedule amounts must be increased according to the efficiency of the drip system.

[3] Divide values by number of vines per acre to determine gallons/vine/day.

[4] Divide values by 27,154 to calculate inches/day.

[5] Multiply values by 9.35 to calculate liters/hectare.

Table 3. Drip irrigation schedule (vine water use) for a large canopy vineyard or one using a trellis with a crossarm.[1,2]

		Gal/Acre/Day[3,4,5]			Gal/Acre/Day[3,4,5]
APRIL	1-7	700	JULY	1-7	4700
	8-14	1000		8-14	4900
	15-21	1300		15-21	5050
	22-30	1650		22-31	5000
MAY	1-7	2050	AUG	1-7	4900
	8-14	2400		8-14	4800
	15-21	2700		15-21	4550
	22-31	3100		22-31	4400
JUNE	1-7	3550	SEPT	1-7	4100
	8-14	3900		8-14	3800
	15-21	4250		15-21	3500
	22-30	4500		22-30	3200

[1] Vineyard canopy covers 75% or more of the land surface during summer months.

[2] Schedule amounts must be increased according to the efficiency of the drip system.

[3] Divide values by number of vines per acre to determine gallons/vine/day.

[4] Divide values by 27,154 to calculate inches/day.

[5] Multiply values by 9.35 to calculate liters/hectare.

Table 4. Representative values for available water content, rooting depth, and allowable depletions for different soil types.

			Allowable depletion	
Textural class	**Available water (in/ft)[1,4]**	**Root zone depth (ft)[5]**	**Percentage[2]**	**Amount (in)[3,6]**
Loamy sand	0.8	4.5	50	1.8
Sandy loam	1.6	3.5	50	2.8
Fine sandy loam	2.4	3.5	50	4.2

[1] Available water can be thought of as the difference in volumetric water content between field capacity and permanent wilting percentage. Values within textural classes should be considered rough estimates.

[2] Percent allowable depletion represents how much available water that can be extracted before the next irrigation. Irrigation should occur when 30% to 50% of the available water is depleted throughout the root zone to avoid stress: 50% depletion is used in this example.

[3] Values obtained by multiplying available water x root zone depth x % allowable depletion. Irrigation must take place after the vineyard has used this amount of water to avoid stress. Inches x 27,154 equal gallons/acre allowable depletion.

[4] Multiply values by 7.74 to calculate centimeters per meter.

[5] Multiply values by 0.305 to calculate meters.

[6] Multiply values by 2.54 to calculate centimeters.

Table 5. Recommended irrigation amounts for varying soil types and corresponding irrigation efficiency.

Textural class	Irrigation efficiency (%)	Allowable depletion[2,5] (inches)	Irrigation amount[3,5] (inches)	Irrigation amount[4,6] (gal/a)	Number irrigations per season	Total water applied for season (inches)[5]
Loamy sand	50	1.8	3.6	97,000	11	40
Sandy loam	60	2.8	4.7	126,000	7	33
Fine sandy loam	70	4.2	6.0	162,000	5	30

[1] Irrigation efficiency is defined as the percentage of applied water that remains in the root zone and is available for crop uptake.

[2] Values obtained from Table 4.

[3] Values obtained by dividing allowable depletion by irrigation efficiency and indicate how much water should be applied each irrigation.

[4] Values obtained by multiplying acre-inch by 27,000 gals/acre-inch to determine gallons. Working with gallons rather than inches is sometimes more useful. For example: to apply 125,000 gallons per acre using a pump discharging 450 gals/min will require 277 minutes. By keeping a record of the number of hours a pump is used on a block of grapes, the application amount can be easily determined.

[5] Multiply values by 2.54 to calculate centimeters.

[6] Multiply values by 9.35 to calculate liters per hectare.

Table 6. Suggested irrigation cutoff dates for raisin vineyards in the San Joaquin Valley.

Soil type/rooting depth	Cutoff date
fine sandy loam (deep)	July 15 to 22
sandy loam (deep)	July 22 to 31
loamy sand or shallow (hardpan)	August 1 to 10

NOTE: Irrigations must be cut off early enough to allow preparation of a dry terrace by harvest (2 to 4 weeks for sandy soil and 4 to 6 weeks for fine textured soil).

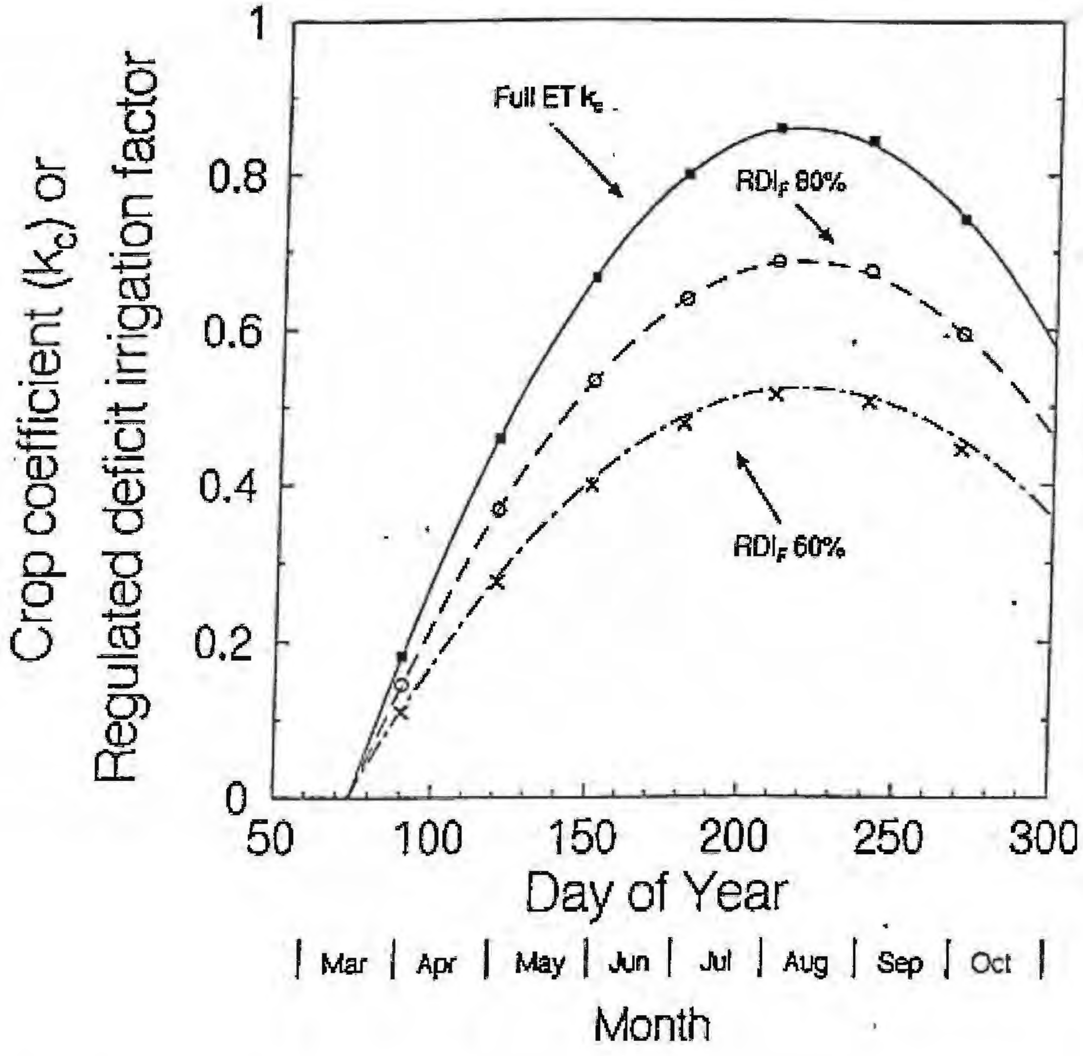

Figure 1. The seasonal crop coefficients for non-water-stressed Thompson Seedless grapevines grown in a weighing lysimeter at the Kearney Agricultural Center (full ET k_c). The seasonal regulated deficit irrigation factors (RDI$_F$) were obtained by multiplying the seasonal k_c by either 60 or 80%. The following equations were obtained for each data set:

Full ET $k_c = -1.11 + 0.0181x - 0.0000416x^2$
RDI$_F$ 80% $= -0.89 + 0.0145x - 0.0000333x^2$
RDI$_F$ 60% $= -0.67 + 0.0109x - 0.0000249x^2$

where x equals day of year. Day of year 1 is January first.

Appendix I

EID estimates homes in the County use .56 acre feet per year, or 1,594 gallons per day, on average, Mountain Democract https://www.mtdemocrat.com/news/eid-reviews-consumption/article_f9e6dd8c-16a1-5bc4-bd02-2186c30d8840.html https://www.mtdemocrat.com/news/eid-reviews-consumption/article_f9e6dd8c-16a1-5bc4-bd02-2186c30d8840.html

EID reviews consumption

By Michael Raffety
Jun 21, 2021

• Directors to consider drought declaration June 28

By dividing the El Dorado Irrigation District into three climate zones, water consumption is identified for each zone and approximate populations are also sorted out, according to an Urban Water Management Plan presented June 14 to the district's board of directors.

The plan is updated and submitted at five-year intervals.

The hottest location is El Dorado Hills, which is also the most populous.

El Dorado Hills had 16,683 single-family connections with EID in 2020. Along with seven other classes of connections, total connections were 23,103.

Total population of El Dorado Hills residents in the El Dorado Irrigation District was 75,349 in 2020. Each residence in El Dorado Hills uses 0.5 acre-foot annually. Those getting recycled water for landscaping only use 0.16 acre-foot annually. New residences in El Dorado Hills are even more efficient, consuming 0.44 acre-foot per year. Total water consumption was 11,078 acre-feet.

The western area includes Lotus-Coloma, Cameron Park and the Crystal Boulevard and Logtown area along Highway 49. Residents in this area consume 0.48 acre-foot annually per single-family customer. New EID customers consume 0.41 acre-foot annually.

There are 6,628 service connections in the area. All seven customer classes total 7,911 connections. The population of this area of EID in 2020 was 25,503 and total water consumption in 2020 was 5,388 acre-feet.

The eastern area, from Placerville to Pollock Pines, had 8,944 single-family connections that each used 0.29 acre-foot annually. All seven classes totaled 9,846 connections and used 5,246 acre-feet of water. New customers consume 0.25 acre-foot annually.

Total district water consumption in 2019 was 26,283 acre-feet. EID has 81,494 acre-feet of water available, which includes a separate supply for Outingdale, which draws water from the Middle Fork of the Cosumnes River.

In 2035 EID will add 7,500 acre-feet of Fazio water to its portfolio, bringing total supplies to 88,994. However, the average year planned availability of water in 2035 will be 78,594. In a single dry year that will drop to 67,429. If dry years persist for five years in a row, total supplies will shrink to 55,863.

In 2035 total system demand for potable water, including system losses, is forecast to be 36,680.

Water conservation requirements from a state law passed in 2015 require 241 gallons per person per day, which includes landscape irrigation or small farms. EID exceeded that goal, using 208 gallons per person per day.

El Dorado Hills has 2.95 persons per household; ditto for the western region, while the eastern region has 2.58 persons per household. Total population in the eastern region of EID in 2020 was 28,205.

Dry-year forecasts also involved the EID Drought Action Plan. In a single dry year EID could call for up to 15% of water conservation, though it will not likely do that this year. But Folsom Lake water use could get its own water conservation call as well as Outingdale.

Currently EID receives permission from the State Water Resources Control Board to provide 1 cubic foot per second from Jenkinson Lake in Sly Park to the North Fork of the Cosumnes River and from there on to the Middle Fork, supplying Outingdale.

A drought declaration will be considered at the June 28 meeting of the EID board. Also scheduled for that same date will be adoption of the Urban Water Management Plan.

Stages of drought could call for 30% savings, then 50% and in stage 4, greater than 50%.

Stage 1 would involve irrigating early in the morning or later in the evening and not refilling swimming pools.

New pools already built will have to be filled "or they'll pop out," said Director Alan Day. He said replastering a pool will have to be put off.

Director George Osborne asked that staff notify pool construction firms.

"Last time (2012-16) people let mature trees die. They provide shade. It doesn't save that much water to let mature trees die," Day said.

The board approved the revised drought action plan unanimously.

Appendix J

California Secretary of State Statement of Information Earth Groovy Products, LLC

Secretary of State
Statement of Information
(Limited Liability Company)

LLC-12

22-A53814

FILED

In the office of the Secretary of State
of the State of California

JAN 27, 2022

This Space For Office Use Only

IMPORTANT — This form can be filed online at bizfile.sos.ca.gov.

Read instructions **before completing this form.**

Filing Fee - $20.00

Copy Fees - First page $1.00; each attachment page $0.50;
Certification Fee - $5.00 plus copy fees

1. Limited Liability Company Name (Enter the **exact** name of the LLC. If you registered in California using an alternate name, see instructions.)

EARTH GROOVY PRODUCTS, LLC

2. 12-Digit Secretary of State Entity Number 201735510255	**3. State, Foreign Country or Place of Organization** (only if formed outside of California) CALIFORNIA

4. Business Addresses

a. Street Address of Principal Office - Do not list a P.O. Box	City (no abbreviations)	State	Zip Code
6170 OAK RIDGE CIRCLE	El Dorado	CA	95623
b. Mailing Address of LLC, **if different than item 4a**	City (no abbreviations)	State	Zip Code
6170 OAK RIDGE CIRCLE	El Dorado	CA	95623
c. Street Address of **California** Office, if Item 4a is not in California Do not list a P.O. Box	City (no abbreviations)	State	Zip Code
6170 OAK RIDGE CIRCLE	El Dorado	CA	95623

5. Manager(s) or Member(s)

If no managers have been appointed or elected, provide the name and address of each member. At least one name and address must be listed. If the manager/member is an individual, complete Items 5a and 5c (leave Item 5b blank). If the manager/member is an additional managers/members, enter the names(s) and address(es) on Form LLC-12A.

a. First Name, if an individual - Do not complete Item 5b	Middle Name	Last Name	Suffix
Rodney	Andrew	Miller	
b. Entity Name - Do not complete Item 5a			
c. Address	City (no abbreviations)	State	Zip Code
6170 OAK RIDGE CIRCLE	EL DORADO	CA	95623

6. Service of Process (Must provide either Individual **OR** Corporation.)

INDIVIDUAL – Complete Items 6a and 6b only. Must include agent's full name and California street address.

a. California Agent's First Name (if agent is **not** a corporation) Rodney	Middle Name Andrew	Last Name Miller	Suffix

b. Street Address (if agent is **not** a corporation) - **Do not enter a P.O. Box** 6170 OAK RIDGE CIRCLE	City (no abbreviations) EL DORADO	State **CA**	Zip Code 95623

CORPORATION – Complete Item 6c only. Only include the name of the registered agent Corporation.

c. California Registered Corporate Agent's Name (if agent is a corporation) – Do not complete Item 6a or 6b

7. Type of Business

Describe the type of business or services of the Limited Liability Company

consulting

8. Chief Executive Officer, if elected or appointed

a. First Name	Middle Name	Last Name	Suffix

b. Address	City (no abbreviations)	State	Zip Code

9. Labor Judgment

Does a Manager or Member have an outstanding final judgment issued by the Division of Labor Standards Enforcement or a court of law, for which no appeal therefrom is pending, for the violation of any wage order or provision of the Labor Code?	☐ Yes ☑ No

10. By signing, I affirm under penalty of perjury that the information herein is true and correct and that I am authorized by California law to sign.

01/27/2022	Rodney Andrew Miller	Managing Member	
Date	Type or Print Name	Title	Signature