CALIFORNIA
Water Boards

Edmund G. Brown Jr.
Governor

Matthew Rodriquez
Secretary for
Environmental Protection

State Water Resources Control Board

October 2, 2017

Leslie F. Grober
Deputy Director
State Water Resources Control Board
Division of Water Rights
1001 I Street, 14th Floor
Sacramento, CA 95814

SUBJECT: REQUEST FOR EXTERNAL PEER REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTROL BOARD'S DRAFT *CANNABIS CULTIVATION POLICY – PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION*

Dear Mr. Grober,

This letter responds to the attached April 10, 2017 request for external scientific peer review for the subject noted above. The review process is described below. All steps were conducted in confidence. Reviewers' identities were not disclosed.

To begin the process for selecting reviewers, I contacted the University of California, Berkeley (University) and requested recommendations for candidates considered qualified to perform the assignment. This service is supported through an Interagency Agreement co-signed by CalEPA and the University. The University was provided with the request letter and attachments. No additional material was asked for, or provided. The University interviews each promising candidate.

Each candidate who was both qualified and available for the review period was asked to complete a Conflict of Interest (COI) Disclosure form and send it to me for review, with Curriculum Vitae. The cover letter for the COI form describes the context for COI concerns that must be taken into consideration when completing the form. "As noted, staff will use this information to evaluate whether a reasonable member of the public would have a serious concern about [the candidate's] ability to provide a neutral and objective review of the work product."

In subsequent letters to candidates approved as reviewers, I provided the attached January 7, 2009 Supplement to the CalEPA Peer Review Guidelines, which, in part, serves two purposes: a) it provides guidance to ensure confidentiality through the course of the external review, and b) it notes reviewers are under no obligation to discuss their comments with third-parties after reviews have been submitted. <u>We recommend they do not</u>. All outside parties are provided opportunities to address a proposed regulatory action, or potential basis for such, through a well-defined rulemaking process.

Later, I sent letters to reviewers to initiate the review. These letters provided access instructions to a secure FTP site where all material to be reviewed was placed. Attachment 2 to the request memorandum was highlighted as the focus for the review. Each reviewer was asked to address each topic, as expertise allows, in the order given. Thirty days were provided for the review. I also asked reviewers to direct enquiring third-parties to me after they have submitted their reviews.

Reviewers' names, affiliations, curriculum vitae, initiating letters and reviews are being sent to you now with this letter.

Approved reviewers:

1. Thomas Ballestero, Ph.D.
   Associate Professor & Director
   UNH Stormwater Center
   University of New Hampshire
   238 Gregg Hall, 35 Colovos Road
   Durham, NH 03824

   Telephone: 603-862-1405
   E-mail: tom.ballestero@unh.edu

2. James A. Gore, Ph.D.
   Professor (Retired) and Dean Emeritus
   College of Natural and Health Sciences
   University of Tampa
   PH 201, 401 W. Kennedy Boulevard
   Tampa, FL 33606

   Telephone: 813-422-9827
   E-mail: jgore@ut.edu

3. Joe Magner, Ph.D.
   Research Professor
   Department of Bioproducts and Biosystems Engineering
   College of Science and Engineering
   University of Minnesota
   16 Bio Ag Eng Building
   1390 Eckles Avenue
   St. Paul, MN 55108

   Telephone: 612-626-0875
   E-mail: jmagner@umn.edu

4. Diane McKnight, Ph.D.
   Professor and Director
   Center for Water, Earth Science and Technology
   Environmental Engineering Program
   College of Engineering and Applied Science
   University of Colorado Boulder
   ECES 124, 1111 Engineering Drive
   Boulder, CO 80309

   Telephone: 303-492-4687
   E-mail: Diane.Mcknight@colorado.edu

If you have any questions, or require clarification from the reviewers, please contact me directly.

Regards,

Gerald W. Bowes

Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
Office of Research, Planning and Performance
State Water Resources Control Board
1001 "I" Street, 16th Floor
Sacramento, California 95814

Telephone: (916) 341-5567
FAX: (916) 341-5284
Email: GBowes@waterboards.ca.gov

cc: Erin.Ragazzi@waterboards.ca.gov
Division of Water Rights

Daniel.Schultz@waterboards.ca.gov
Division of Water Rights

Andrew.Deeringer@waterboards.ca.gov
Office of Chief Counsel

Lily.Weaver@waterboards.ca.gov
Office of Chief Counsel

Attachments:
(1) April 10, 2017 Request by Les Grober for Scientific Peer Review
(2) Letters to Reviewers Initiating the Review
    (1) Thomas Ballestero, Ph.D.
    (2) James A. Gore, Ph.D.
    (3) Joe Magner, Ph.D.
    (4) Diane McKnight, Ph.D.
(3) January 7, 2009 Supplement to Cal/EPA Peer Review Guidelines
(4) Curriculum Vitae
    (1) Thomas Ballestero, Ph.D.
    (2) James A. Gore, Ph.D.
    (3) Joe Magner, Ph.D.
    (4) Diane McKnight, Ph.D.
(5) Reviews
    (1) Thomas Ballestero, Ph.D.
    (2) James A. Gore, Ph.D.
    (3) Joe Magner, Ph.D.
    (4) Diane McKnight, Ph.D.

CALIFORNIA
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TO: Gerald W. Bowes, Ph.D.
Manager, CalEPA Scientific Peer Review Program
Office of Research, Planning and Performance
State Water Resources Control Board

FROM: Leslie F. Grober
Deputy Director
Division of Water Rights

DATE: AUG 10 2017

SUBJECT: REQUEST FOR EXTERNAL PEER REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTOL BOARD'S DRAFT *CANNABIS CULTIVATION POLICY – PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION*

In accordance with Health and Safety Code section 57004, the State Water Resources Control Board (State Water Board), Division of Water Rights (Division) submits this request for peer review of the State Water Board's proposed interim policy for water quality control titled Draft *Cannabis Cultivation Policy - Principles and Guidelines for Cannabis Cultivation* (Policy). This is the Water Board's interim Policy, which is necessary to establish timely water quality and instream flow requirements for cannabis cultivation activities throughout California. It is anticipated the Policy will be updated[1] over time to modify or add requirements to address cannabis cultivation impacts and incorporate more regional information.

The State Water Board developed the Policy and associated principles and guidelines to address cannabis cultivation legislation. This legislation directs the State Water Board, in consultation with other agencies, to ensure that the individual and cumulative effects of water diversions and waste discharges associated with cannabis cultivation do not affect instream flows needed for fish spawning, migration, and rearing, and the flows needed to maintain natural flow variability. In addition, the State Water Board, is directed to adopt interim and long-term principles and guidelines (requirements) for the diversion and use of water for cannabis cultivation in areas where cannabis cultivation may have the potential to substantially affect instream flows. The legislation requires the State Water Board to establish these principles and guidelines as part of a state policy for water quality control. Per Water Code section 13149, the principles and guidelines:

- shall include measures to protect springs, wetlands, and aquatic habitats from negative impacts of cannabis cultivation; and
- may include requirements that apply to groundwater diversions where the State Water Board determines those requirements are reasonably necessary.

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[1] California Water Code section 13149 (a)(2) states "*The board may update the interim principles and guidelines as it determines to be reasonably necessary.*"

Felicia Marcus, chair | Thomas Howard, executive director

1001 I Street, Sacramento, CA 95814 | Mailing Address: P.O. Box 100, Sacramento, CA 95812-0100 | www.waterboards.ca.gov

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The State Water Board is on an expedited schedule and plans to consider potential changes to the Policy in October 2017. Given the importance of the Policy, the Division requests that peer reviewers provide comments within 30 days of receipt of the peer review package.

The title of the document we request to be reviewed is the ***Cannabis Cultivation Policy – Principles and Guidelines for Cannabis Cultivation***. The supporting document for this proposed Policy is the Draft *Cannabis Cultivation Policy Staff Report* (Staff Report).

Additional background information on the Policy is provided in Attachment 1. Scientific conclusions to be addressed by peer review are listed in Attachment 2. The names of participants involved in developing the proposed Policy are listed in Attachment 3. Primary references are included in Attachment 4 (via FTP site or web link). Attachment 5 is the Draft Policy, dated July 7, 2017. Attachment 6 is the Staff Report, dated July 7, 2017. Attachment 7 is *Estimating Natural Monthly Streamflows in California and the Likelihood of Anthropogenic Modifications* (Carlisie, et. al. 2016). Attachment 8 is *Patterns and Magnitude of Flow Alteration in California, USA* (Zimmerman, et. al. 2017).

Reviewers with expertise in various disciplines will be required to evaluate the conclusions presented in Attachment 2, as follows:

- Conclusion 1: Expertise in instream flow development, water quality, geology, fisheries biology, aquatic ecology, and/or hydrology.
- Conclusion 2: Expertise in hydrologic modeling.
- Conclusion 3: Expertise in instream flow development, fisheries biology, aquatic ecology, and/or hydrology.
- Conclusion 4: Expertise in instream flow development, fisheries biology, aquatic ecology, geology, and/or hydrology.

A sufficient number of reviewers should be chosen to represent each of the disciplines listed above.

If you have questions regarding this request, please contact Dan Schultz at (916) 323-9392 or Daniel.Schultz@waterboards.ca.gov.

ec: **State Water Resources Control Board**

Erin.Ragazzi@waterboards.ca.gov
Division of Water Rights

Daniel.Schultz@waterboards.ca.gov
Division of Water Rights

Andrew.Deeringer@waterboards.ca.gov
Office of Chief Counsel

Attachment 1: Summary of the Cannabis Cultivation Policy – Principles and Guidelines for Cannabis

SUMMARY

The State Water Resources Control Board (State Water Board or Board) is proposing a policy for water quality control to establish principles and guidelines (requirements) for cannabis cultivation activities to protect water quality and instream flows. The proposed *Cannabis Cultivation Policy – Principles and Guidelines for Cannabis Cultivation* (Policy) was developed to satisfy the requirements of statute, which authorizes the Board to ensure that the diversion of water and discharge of waste associated with cannabis cultivation does not have a negative impact on water quality, aquatic habitat, wetlands, and springs. The proposed Policy will establish requirements for cannabis cultivation activities to protect instream flows and water quality, including minimum instream flow requirements, riparian setbacks, and best management practices to control sediment and other discharges of waste.

PROBLEM STATEMENT

In many cases routine cannabis cultivation practices result in damage to streams and wildlife. These practices (e.g., clearing trees, grading and road construction) are often conducted in a manner that causes large amounts of sediment to flow into streams during rains. Cannabis cultivation activities also result in the discharge of pesticides, fertilizers, fuels, trash, and human waste at cultivation sites, that then discharges into waters of the state. In addition to these water quality discharge related impacts, cultivators also impair water quality and aquatic habitat by diverting water from streams in the dry season, when flows are low. Diversion of flow during the dry season often completely dries up streams, stranding or killing native fish. The impacts of these diversions have been exacerbated in recent years by periods of drought. The California Department of Fish and Wildlife (CDFW) has received dewatering reports for at least 19 streams in Northern California, all of which contain anadromous fish listed as threatened or endangered by the state and/or federal government.

Cannabis cultivation has been increasing in recent years, and the expansion is accelerating with the recent passage of the Medical Cannabis Regulation and Safety Act (MCRSA) and the Adult Use of Marijuana Act (AUMA)[1]. A recent CDFW study (CDFW 2015), using aerial surveys of four small watersheds in Humboldt and Mendocino counties found that the number of acres in cannabis cultivation doubled from 2009 to 2012, with an estimated 500 individual operations and approximately 30,000 plants in each of these small watersheds. In the most impacted watersheds, diminished streamflow is likely to: have lethal or sub-lethal effects on state- and federally-listed salmon and steelhead trout; and cause further decline of sensitive amphibian species. CDFW concluded that cannabis cultivation on private land has grown so much in the North Coast region that Coho salmon, a federal- and state-listed endangered species, may go extinct in the near future if the impacts of cannabis cultivation are not addressed immediately. Rare (listed) and sensitive species affected by water diversion for cannabis cultivation in the North Coast region alone include: Coho salmon; Chinook salmon; steelhead trout; coastal cutthroat trout; southern torrent salamander; red legged frog; northern spotted owl; and Pacific fisher. Diversions for cannabis cultivation also are known to occur in hundreds of additional streams with Coho salmon in the North Coast Region and in countless other streams throughout the state with state or federal listed salmon and steelhead, demonstrating that water quality and habitat-related impacts from cannabis cultivation are widespread. Other species throughout the state such as deer, bear, and various birds are also being harmed by cannabis cultivation-related impacts to streams.

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[1] On June 27, 2017, Governor Brown signed Senate Bill 94, which consolidated the provisions of MCRSA and AUMA and established the Medicinal and Adult-Use Cannabis Regulations and Safety Act (MAUCRSA).

POLICY GOALS

California Water Code (Water Code) section 13149 authorizes the State Water Board, in consultation with CDFW, to adopt interim and long-term principles and guidelines (requirements) for the diversion and use of water for cannabis cultivation in areas where cannabis cultivation may have the potential to substantially affect instream flows. Per Water Code section 13149, the requirements: (a) shall include measures to protect springs, wetlands, and aquatic habitats from negative impacts of cannabis cultivation; and (b) may apply to groundwater diversions where the State Water Board determines those requirements are reasonably necessary.

The State Water Board developed the proposed requirements (Attachment A of the Policy), in consultation with CDFW and California Department of Food and Agriculture (CDFA), to meet the goals outlined above. Attachment A of the Policy contains five main categories (or sections) of cannabis cultivation requirements.

Section 1

The general requirements and prohibitions implement existing State Water Board authorities and address issues such as compliance with state and local permits, discharge prohibitions, riparian setbacks, protection of tribal cultural resources, and the State Water Board and Regional Water Quality Control Boards (collectively Water Boards) right to access properties for inspections.

Section 2

The requirements related to water diversions and waste discharge for cannabis cultivation cover the following 12 best practicable treatment or control categories:

- riparian and wetland protection and management;
- water, storage, and use;
- irrigation runoff;
- land development and maintenance, erosion control, and drainage features;
- soil disposal;
- stream crossing installation and maintenance;
- fertilizer and soil use and storage;
- pesticide and herbicide application and storage;
- petroleum products and other chemical use and storage;
- cultivation-related waste disposal;
- refuse and human waste disposal; and
- winterization.

Section 3

The numeric and narrative instream flow requirements address water quality and quantity through the establishment of flow requirements that include three elements: (a) dry season forbearance period, (b) numeric flow requirements (bypass) during the wet season (diversion period), and (c) narrative flow requirements. Instream flow requirements also include dry season flow requirements and provisions for the imposition of a forbearance period for cannabis groundwater diversions in areas where such restrictions are necessary. Section 3 also includes provisions to require cannabis cultivators to install and operate a local telemetry gage in ungaged watersheds or localized watershed areas if the State Water Board determines the assigned compliance gage does not adequately protect instream flows or does not adequately represent the localized water demand.

Section 4

Watershed compliance gage assignments includes the compliance gage instream flow requirements for the14 regions designated in the Policy.

Section 5

Planning and reporting includes requirements that pertain to enrollees under the Cannabis General Order and provides descriptions of the required reports and deadlines by which they must be submitted.

The requirements established by the proposed Policy will be incorporated into and implemented through five regulatory programs:

- CDFA's CalCannabis Cultivation Licensing Program[2];
- State Water Board's Cannabis General Waste Discharge Requirements for Discharges of Waste Associated with Cannabis Cultivation Activities (Cannabis General Order) or any Waste Discharge Requirements addressing cannabis cultivation activities adopted by a Regional Water Quality Control Board;
- State Water Board's General Water Quality Certification for Cannabis Cultivation Activities;
- State Water Board's Cannabis Small Irrigation Use Registration; and
- State Water Board's Water Rights Permitting and Licensing Program.

CDFA's CalCannabis Cultivation Licensing Program is anticipated to begin accepting applications for cannabis cultivation licenses by January 1, 2018. The State Water Board is working to adopt the Policy and establish the requirements statewide prior to January 1, 2018, to ensure the requirements are incorporated into CDFA's CalCannabis Cultivation Licenses. Water Code section 13149 authorizes the State Water Board to develop both interim and long-term requirements and update them as necessary. It is anticipated that the State Water Board will update this Policy over time to modify or add requirements to address cannabis cultivation impacts, as needed.

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[2] Business and Professions Code section 26060(b)(1).

Attachment 2: Description of Scientific Assumptions, Findings and Conclusions to be addressed by Peer Reviewers

The proposed Draft *Cannabis Cultivation Policy – Principles and Guidelines for Cannabis Cultivation* (Policy), dated July 7, 2017, includes interim principles and guidelines (requirements) for cannabis cultivation. Policy background information and rationale for the requirements are located in the Draft *Cannabis Cultivation Policy Staff Report* (Staff Report). The State Water Resources Control Board (State Water Board) developed the requirements expeditiously to address legislative timelines and used the best available information, professional expertise, and professional knowledge.

The statutory mandate for external scientific peer review (Health and Safety Code, section 57004) states that the reviewer's responsibility is to determine whether the scientific portion of any proposed rule is based on sound scientific knowledge, methods, and practices. We request that you make this determination for each of the following conclusions, shown in bold underline, that constitute the scientific portion of any proposed regulatory action.

An explanatory statement is provided for each conclusion to focus the review. It is followed by identification of references, or parts therein, supporting each conclusion.

1. The State Water Board developed the interim requirements contained in the Draft Policy to expeditiously address water diversions and waste discharges impacts associated with cannabis cultivation activities. **The requirements in Draft Policy Attachment A, Sections 1-4 will reduce water quality and water diversion impacts associated with cannabis cultivation.** {Reviewers with expertise in: water quality, geology, fisheries biology, aquatic ecology, instream flow development, and/or hydrology.}

Recent legislation requires the State Water Board to ensure that the individual and cumulative effects of water diversion and waste discharges associated with cannabis cultivation do not affect instream flows needed for fish spawning, migration, and rearing, and the flows needed to maintain natural flow variability. (Business and Professions Code section 26060.1(b)(1).) The Policy generally employs three types of requirements to ensure sufficient instream flows for aquatic resources:

- dry season forbearance period and limitations on the wet season diversion period,
- narrative instream flow requirements, and
- numeric instream flow requirements.

These three protections work in concert to ensure that water diversions for cannabis cultivation do not affect the: instream flows needed for fish spawning, migration, and rearing; natural flow variability; or flows needed to maintain aquatic habitat and support aquatic resources. The instream flow requirements apply statewide and may be modified over time, as needed, as more information becomes available on cannabis cultivation water demand, the location and density of cannabis cultivation, and protectiveness of the interim instream flow requirements.

Further, the State Water Board and Regional Water Quality Control Boards (collectively, the Water Boards) are required to address discharges of waste resulting from cannabis cultivation. In addressing these discharges, the Water Boards must include conditions to address items that include, but are not limited to, the following:

- Site development and maintenance, erosion control, and drainage features
- Stream crossing installation and maintenance
- Riparian and wetland protection and management
- Soil disposal
- Water storage and use
- Irrigation runoff
- Fertilizers and soil
- Pesticides and herbicides

- Petroleum products and other chemicals
- Cannabis cultivation waste
- Refuse and human waste
- Cleanup, restoration, and mitigation

{Policy Attachment A Section 1 – General Requirements and Prohibitions, and Cannabis General Water Quality Certification; Policy Attachment A Section 2 – Requirements Related to Water Diversions and Waste Discharge for Cannabis Cultivation; Policy Attachment A Section 3 – Numeric and Narrative Instream Flow Requirements (including gaging); Policy Attachment A Section 4 – Watershed Compliance Gage Assignments; Staff Report – Overview of Cannabis Cultivation Impacts, pages 26 – 27; Staff Report – Background and Rationale for Policy Requirements for Water Diversion and Waste Discharges Associated with Cannabis Cultivation, pages 28 – 41; Staff Report – Background and Rationale for Instream Flow and Gaging Requirements, pages 42 – 51.}

2. To expeditiously develop numeric instream flow requirements statewide, State Water Board used natural flow statistics developed by the United States Geological Survey (USGS) in collaboration with The Nature Conservancy and Trout Unlimited (USGS natural flow modeling approach). The USGS natural flow modeling approach used a peer-reviewed methodology to develop the flow statistics. **The USGS natural flow modeling approach used appropriate modeling inputs and R scripts, and the modeling outputs stored in the database predict the unimpaired flow statistics as intended.** {Reviewers with expertise in: hydrologic modeling.}

In order to quickly develop numeric flow requirements statewide, a dataset was needed which provided monthly (or more frequent) estimates of unimpaired or natural flow throughout California. To ensure the flow requirements were flexible and adaptable, the dataset had to have sufficient spatial coverage to allow for a compliance point to be moved, as needed, and the flow requirements re-calculated. The State Water Board applied the Tessmann Method using predicted historical flow data sourced from a flow modeling effort conducted by USGS in cooperation with The Nature Conservancy (TNC) and Trout Unlimited. The USGS flow modeling effort developed empirical flow models that predicted the natural (unaffected by land use or water management) monthly streamflows from 1950 to 2012 for the majority of the USGS National Hydrologic Database stream reaches in California (Carlisle, et. al. 2016). The natural monthly streamflow metrics were used to develop the mean monthly and mean annual flows used in the Tessmann Method.

As described in more detail in the USGS *Open-File Report* (Carlisle, et. al. 2016), the concept of the reference-condition was used where a set of reference sites with known gage flow hydrologic record data were used to develop models that were subsequently applied to non-reference sites (such as ungaged stream systems or highly modified systems where hydrologic disturbance is known or suspected). The approach used is based on statistical models of related observed data generally consisting of two types of indicators: static variables that describe watershed features (topography, geology, soils, etc.); and time-series variables, primarily consisting of antecedent precipitation and air temperature.

Six different types of statistical models were compared in developing the final model, including five machine-learning models and one multiple linear regression. The random forest machine learning technique proved to perform substantively better than all other modeling approaches.

A separate model was developed for each month in each region to predict natural monthly flows for any specific year from 1950 to 2012, resulting in 36 separate sub models. The final data matrix for developing models of natural monthly flows included every year for which each reference site had a measured monthly flow value, the set of weather data and modeled runoff associated with each year's measured monthly flow plus the previous 12 months, as well as the full set of static physical watershed characteristics. The USGS natural flow modeling approach was expanded from an initial effort to model natural flows (Carlisle, et. al. 2016) to include additional reference gages, improve spatial coverage, and add flow metrics, including mean, minimum, and maximum monthly flows (Zimmerman, et. al. 2017).

As summarized in the USGS *Open File Report* (Carlisle, et. al. 2016), the "models developed to estimate natural monthly flows performed well and should provide a useful baseline for future studies for how stream flows in California respond to changes in land use, water management, and climate."

{Carlisle, et. al. 2016; Zimmerman, et. al. 2017; Draft Staff Report – Flow Model for Estimating Natural Monthly Streamflows in California, pages 48 – 49}

3. The State Water Board developed interim wet season numeric instream flow requirements throughout California using the Tessmann method. **The Tessmann method is an appropriate method to use to develop interim instream flow requirements in California, was applied correctly, and the Tessmann method spreadsheet calculator correctly calculated the wet season instream flow requirements.** {Reviewers with expertise in: instream flow development, fisheries biology, aquatic ecology, and/or hydrology.}

To meet the timeline, scale, and purpose of this Policy, the State Water Board, in consultation with CDFW, determined that the Tessmann Method is the best methodology to develop interim instream flow requirements that protect aquatic resources and balance other beneficial uses of water, which includes cannabis cultivation. The Tessmann Method develops instream flow requirements by using percentages of historical mean annual and mean monthly natural streamflow. For the development of long-term instream flow requirements, the State Water Board, in consultation with CDFW, will evaluate other scientifically robust methods that are more reflective of regional variability and the needs of target species. The State Water Board applied the Tessmann Method to a predicted historical flow dataset sourced from a flow modeling effort conducted by the USGS in cooperation with The Nature Conservancy and Trout Unlimited (USGS flow modeling data). The interim instream flow requirements were calculated for compliance gages throughout the State. The Tessmann Method and the USGS flow modeling data allow for instream flow requirements to be calculated at additional compliance points throughout the State. The Policy allows the State Water Board to use the Tessmann Method and the USGS flow modeling data to calculate or adjust a flow requirement, as needed, throughout the State.

The State Water Board developed a Tessmann method spreadsheet calculator, which takes the USGS flow modeling data and calculates the minimum instream flow requirement for the location of 306 existing streamflow gages for the months of November through March. Future application of the Tessmann method spreadsheet calculator will allow for the calculation of minimum wet season instream flow requirements at newly identified compliance gages, or at streamflow gages installed as a result of the Policy.

{Policy Attachment A Section 3 – Numeric and Narrative Instream Flow Requirements (including gaging); Policy Attachment A Section 4 – Watershed Compliance Gage Assignments; Staff Report – Methodology for Development of Numeric Flow Requirements, pages 45 – 49.}

4. The State Water Board developed interim dry season groundwater low flow thresholds throughout California to inform the need for additional actions to address impacts from cannabis groundwater diversions. The State Water Board used the New England Aquatic Base Flow Standard (ABF Standard) method to develop the dry season groundwater low flow thresholds. The ABF Standard was slightly modified to only look at low flows when temperatures are high in the late summer period. **The ABF Standard is an appropriate method to use to develop interim groundwater low flow thresholds in California, modification to the ABF Standard is appropriate for California's climate and aquatic resources, the ABF Standard was applied correctly, and the ABF Standard spreadsheet calculator correctly calculated the dry season instream flow**

requirements. {Reviewers with expertise in: instream flow development, fisheries biology, aquatic ecology, geology, and/or hydrology.}

A low flow threshold was developed at each compliance gage during the surface water forbearance period (dry season) to inform the need for additional actions to address impacts associated with cannabis groundwater diversions. The low flow threshold was established in consultation with CDFW. The low flow threshold is established using the USGS flow modeling data to calculate mean monthly flows and applying the ABF Standard methodology at the compliance gages throughout California. The low flow threshold represents the minimum flow that should be in streams during all water year types to support aquatic ecosystems, including juvenile salmonid migration and rearing and water quality. In general, in California, the lowest flows and highest temperatures occur during August, September, and October, therefore the low flow threshold for each compliance gage is calculated based on the median August mean monthly flow, median September mean monthly flow, or the median October mean monthly flow, whichever is lowest. The Policy allows the State Water Board to apply the ABF Standard to the USGS flow modeling data to calculate a low flow threshold requirement at additional compliance points, as needed, throughout the State. The State Water Board will monitor instream flows during the dry season and evaluate the number and location of cannabis groundwater diversions to determine whether imposition of a groundwater forbearance period is necessary. To address potential localized effects of groundwater diversions on surface water flow, the State Water Board will also monitor where significant numbers of surface water diverters are switching to groundwater diversions to evaluate whether imposition of a groundwater forbearance period is necessary.

The State Water Board developed an ABF Standard spreadsheet calculator, which takes the USGS flow modeling data and calculates the low flow threshold for the location of 306 existing streamflow gages. Future application of the ABF Standard spreadsheet calculator will allow for the calculation of low flow thresholds at newly identified compliance gages, or at streamflow gages installed as a result of the Policy.

{Policy Attachment A Section 3 Numeric and Narrative Instream Flow Requirements (including gaging); Policy Attachment A Section 4 Watershed Compliance Gage Assignments; Staff Report – Low Flow Thresholds, Pages 50 – 51.}

The Big Picture

Reviewers are not limited to addressing only the specific conclusions presented above, and are asked to contemplate the following "Big Picture" questions:

- **In reading the Policy and Staff Report, are there any additional scientific conclusions that should be a part of the scientific portion of the proposed Policy that are not described above?**
- **Taken as a whole, is the scientific portion of the Policy based upon sound scientific knowledge, methods, and practices?**

Reviewers should note that some proposed requirements and actions may rely on professional judgement in instances where scientific data and our understanding of the underlying processes are not as extensive as may be ideal. In addition, the State Water Board developed the requirements expeditiously to address legislative timelines. Nonetheless, the evaluation of scientific data and use of professional judgement are appropriate in the context of current scientific knowledge regarding such requirements and actions. In these situations, the proposed requirements and actions are favored over no action.

The preceding guidance will ensure that reviewers have an opportunity to comment on all aspects of the scientific basis of the proposed Policy. At the same time, reviewers also should recognize that the State Water Board has a legal obligation to consider and respond to all feedback on the scientific portions of the proposed rules. Because of this obligation, reviewers are encouraged to focus feedback on the scientific conclusions that are relevant to the central regulatory elements being proposed.

Attachment 3: Names of Participants involved in developing the Cannabis Cultivation Policy

No person may serve as an external scientific peer reviewer for the scientific portion of a rule if that person participated in the development of the scientific basis or scientific portion of the rule.

1. Academia
   - University of California, Davis
     - Jay Lund
     - Samuel Sandoval
     - Belize Lane
     - Sarah Yarnell
   - University of California, Berkeley
     - Ted Grantham

2. Nongovernmental Organizations – current and former staff employed after January 1, 2016
   - The Nature Conservancy – California Region
   - California Trout, Inc.
   - Trout Unlimited – California and Klamath Region
   - Southern California Coastal Water Research Project
     - Eric Stein

3. Local, State, and Federal Agencies Personnel

   To avoid a potential conflict of interest, current and former staff, employed after January 1, 2016, from the list of local, state, and federal agencies provided below should be limited. As stated earlier, the Cannabis Cultivation Policy will establish water quality and flow requirements for cannabis cultivators throughout California. Staff representing agencies that consulted on the Policy, developed information that was used in the development of the Policy, or who may be impacted by its requirements should be excluded.

   - State Water Resources Control Board
   - Regional Water Quality Control Boards
   - California county, city or local government staff
   - California Department of Fish and Wildlife
   - California Department of Food and Agriculture
   - California Department of Water Resources, State Water Project staff
   - United States Bureau of Reclamation, staff from the California offices
   - United States Geological Survey
     - Daren Carlisle
     - Jason May

Attachment 4: References for Draft Cannabis Cultivation Policy and Staff Report

REFERENCES:

Bauer S, Olson J, Cockrill A, van Hattem M, Miller L, Tauzer M, et al. (March 18, 2015) Impacts of Surface Water Diversions for Marijuana Cultivation on Aquatic Habitat in Four Northwestern California Watersheds. PLoS ONE 10(3): e0120016. https://doi.org/10.1371/journal.pone.0120016

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Attachment 5: DRAFT Cannabis Cultivation Policy

State Water Resources Control Board

DRAFT

Cannabis Cultivation Policy

Principles and Guidelines for Cannabis Cultivation

July 7, 2017

Available online at:
http://www.waterboards.ca.gov/water_issues/programs/cannabis/docs/policy.pdf

Attachment 6: DRAFT Cannabis Cultivation Policy Staff Report

State Water Resources Control Board

DRAFT

Cannabis Cultivation Policy

Staff Report

July 7, 2017

Available online at:
http://www.waterboards.ca.gov/water_issues/programs/cannabis/docs/staff_report.pdf

National Water-Quality Assessment Project

Prepared in cooperation with The Nature Conservancy and Trout Unlimited

Estimating Natural Monthly Streamflows in California and the Likelihood of Anthropogenic Modification

Open-File Report 2016–1189

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	Area	
acre	0.4047	hectare (ha)
	Volume	
acre-foot (acre-ft)	1,233.48	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton, short (2,000 lb)	0.9072	metric ton (t)
ton, long (2,240 lb)	1.016	metric ton (t)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
	Volume	
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
	Flow Rate	
meter per second (m/s)	3.281	foot per second (ft/s)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.0353	ounce (oz)
	Application rate	
kilograms per square kilometer per year ([kg/km^2]/yr)	0.0089	pounds per acre per year ([lb/acre]/yr)

Datum

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Estimating Natural Monthly Streamflows in California and the Likelihood of Anthropogenic Modification

Daren M. Carlisle,[1] David M. Wolock,[1] Jeanette K. Howard,[2] Theodore E. Grantham,[1] Kurt Fesenmyer,[3] Michael Wieczorek[1]

Abstract

Because natural patterns of streamflow are a fundamental property of the health of streams, there is a critical need to quantify the degree to which human activities have modified natural streamflows. A requirement for assessing streamflow modification in a given stream is a reliable estimate of flows expected in the absence of human influences. Although there are many techniques to predict streamflows in specific river basins, there is a lack of approaches for making predictions of natural conditions across large regions and over many decades. In this study conducted by the U.S. Geological Survey, in cooperation with The Nature Conservancy and Trout Unlimited, the primary objective was to develop empirical models that predict natural (that is, unaffected by land use or water management) monthly streamflows from 1950 to 2012 for all stream segments in California. Models were developed using measured streamflow data from the existing network of streams where daily flow monitoring occurs, but where the drainage basins have minimal human influences. Widely available data on monthly weather conditions and the physical attributes of river basins were used as predictor variables. Performance of regional-scale models was comparable to that of published mechanistic models for specific river basins, indicating the models can be reliably used to estimate natural monthly flows in most California streams. A second objective was to develop a model that predicts the likelihood that streams experience modified hydrology. New models were developed to predict modified streamflows at 558 streamflow monitoring sites in California where human activities affect the hydrology, using basin-scale geospatial indicators of land use and water management. Performance of these models was less reliable than that for the natural-flow models, but results indicate the models could be used to provide a simple screening tool for identifying, across the State of California, which streams may be experiencing anthropogenic flow modification.

Introduction

Natural variability in flow is a fundamental physical property of streams and therefore has major relevance to water quality and the health of riverine ecosystems (Poff and others, 1997). In the absence of human influence, the magnitude and duration of streamflows vary seasonally and annually, which constitutes the natural flow regime. The importance of the natural flow regime to maintaining ecological health in rivers and streams is well documented (Poff and Zimmerman, 2010). Modification of watershed hydrology and streamflows from human activity is pervasive in the United States (Poff and others, 2007; Eng and others, 2013b), and quantitative tools are needed to better understand the natural flow regime and to protect stream health.

Central to understanding the causes of poor stream health is the ability to determine the expected natural (we use the term “natural” to indicate the baseline or background condition unaffected by land use or water management) levels of physical and chemical characteristics of a stream, so that an objective assessment can be made as to which factors have been modified by human activities (Hawkins and others, 2010). For contaminants such as synthetic organic chemicals, natural levels in a stream are zero, so the presence of these chemicals can be unambiguously linked to anthropogenic sources. In contrast, anthropogenic modification of streamflows can be difficult to quantify because the natural background conditions are often highly variable temporally (for example, inter-annual) and spatially (for example, across a region or stream network). As a result, streamflow modification has been characterized in a wide variety of ways (Poff and Zimmerman, 2010), which limits the ability to synthesize and generalize how modified streamflows affect stream health and hinders development of standards aimed at restoration and protection of streams. The ability to estimate natural streamflows in a given region is therefore a critical tool for managers and decision makers, particularly in the face of increased water demand and a changing climate (Sabo and others, 2010).

Estimating flows in unmonitored streams (and by extension, estimating natural flows at monitored sites affected by hydrologic modification) is a major frontier in hydrological

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[1] U.S. Geological Survey.

[2] The Nature Conservancy.

[3] Trout Unlimited.

science (Sivapalan, 2003; Sivapalan and others, 2003) and is accomplished with two general approaches: mechanistic and statistical models. Mechanistic models are not considered here, but there is a large amount of literature on published models typically developed for single river basins using process-based understanding. Such models are data intensive and likely are not practical as a predictive tool across large geographic regions. There is much less literature on statistical models (Farmer and Vogel, 2013), which include a wide range of methods reviewed elsewhere (He and others, 2011; Li and Sankarasubramanian, 2012; Shu and Ouarda, 2012; Farmer and Voge,l 2013; Shupe and Potter, 2014), than on mechanistic models.

Another needed management tool is the ability to identify where, across a state or other large geographic area, streamflows are likely to be modified, particularly in areas with sparse streamgaging networks. In most regions, streamflow monitoring is limited to a small subset of the stream network (Poff and others, 2006), largely because of the resources required for gage maintenance. An estimate of the probability of streamflow modification, given readily measured characteristics of a stream basin, would be a useful tool for screening all ungaged stream segments across a region (Eng and others, 2013a). Such a tool would allow decision makers to identify where modified flow, among the many other potential causes, is a likely contributor to poor stream health and where efforts to naturalize streamflows can have the greatest positive ecological outcome.

A study was conducted by the U.S. Geological Survey (USGS) in cooperation with The Nature Conservancy and Trout Unlimited, with the goal of developing statistical models for use in estimating natural streamflow. The purpose of this report is to describe the development of a series of statistical models that (1) predict natural monthly flows each year from 1950 to 2012 for California's streams and (2) predict the likelihood that monthly streamflows are modified by human activity.

Methods

Selection of Spatial Domain

The spatial domain of the study includes aggregated Level 3 Ecoregions (Commission for Environmental Cooperation, 2014) that are present partly or entirely within California. Level 3 Ecoregions represent contiguous geographic areas with similar climate, topography, and natural land cover, which are factors that affect spatial variation in natural streamflow regimes. Prior experience (Carlisle and others, 2010) indicates that statistical models developed at spatial scales for increasingly homogenous environmental settings (for example, similar climate and topography) were less sensitive to broad-scale climatic patterns and more sensitive to catchment-scale physical features, such as soils and geology, than models developed at spatial scales over heterogeneous environmental settings (for example, widely varying climate). In order to achieve balance between an adequate number of reference sites (see section "Identification of Reference Sites") and the environmental homogeneity of a region, Level 3 Ecoregions were aggregated by similar climatic conditions into three large regions (fig. 1): xeric (California Coastal Sage, Chaparral, and Oak Woodlands; Southern Baja California Pine-Oak Mountains; Central California Valley; Mojave Basin and Range; Sonoran Desert; and Central Basin and Range), interior mountains (Sierra Nevada, Eastern Cascades Slopes and Foothills), and north coastal mountains (Klamath Mountains, Coast Range).

The unit of observation for the models in this report is the stream segment and its entire upstream contributing watershed. As defined by the National Hydrography Dataset Version 1.0 (Horizon Systems, 2015), a segment is generally a section of stream bounded by a node (for example, a tributary) on each end. Most segments are less than (<)1 kilometer (km) in total length, and 135,119 segments were identified within the State of California.

General Modeling Approach

Two general principles guided model development. First, we used the reference-condition concept (Bailey and others, 2004), wherein a set of reference sites (that is, least disturbed by human influences) is used to develop models that are subsequently applied to non-reference sites (for example, where hydrologic disturbance is known or suspected) with the goal of predicting expected natural conditions. Second, the approach is based on statistical models of related observed data rather than mechanistic, process-based models (for example, Spruill and others, 2000; Croke and others, 2005). The statistical models contain two general types of predictor variables: (1) static variables that describe watershed features, such as topography, geology, and soils and (2) time-series variables of antecedent precipitation and air temperature. We emphasize that the period of hydrologic and climatic record for this report is 1950–2012. Specifically, the models "learned" the relations among watershed physical features, precipitation, air temperature, and streamflow using observed conditions at reference sites from 1950 to 2012, which has important implications for attempts to use these models in the context of climate variability and change. Finally, monthly mean flows were selected for modeling because they are easily communicated and represent magnitude and timing, which are attributes of the natural flow regime that are relevant to ecosystems and management (Kendy and others, 2012).

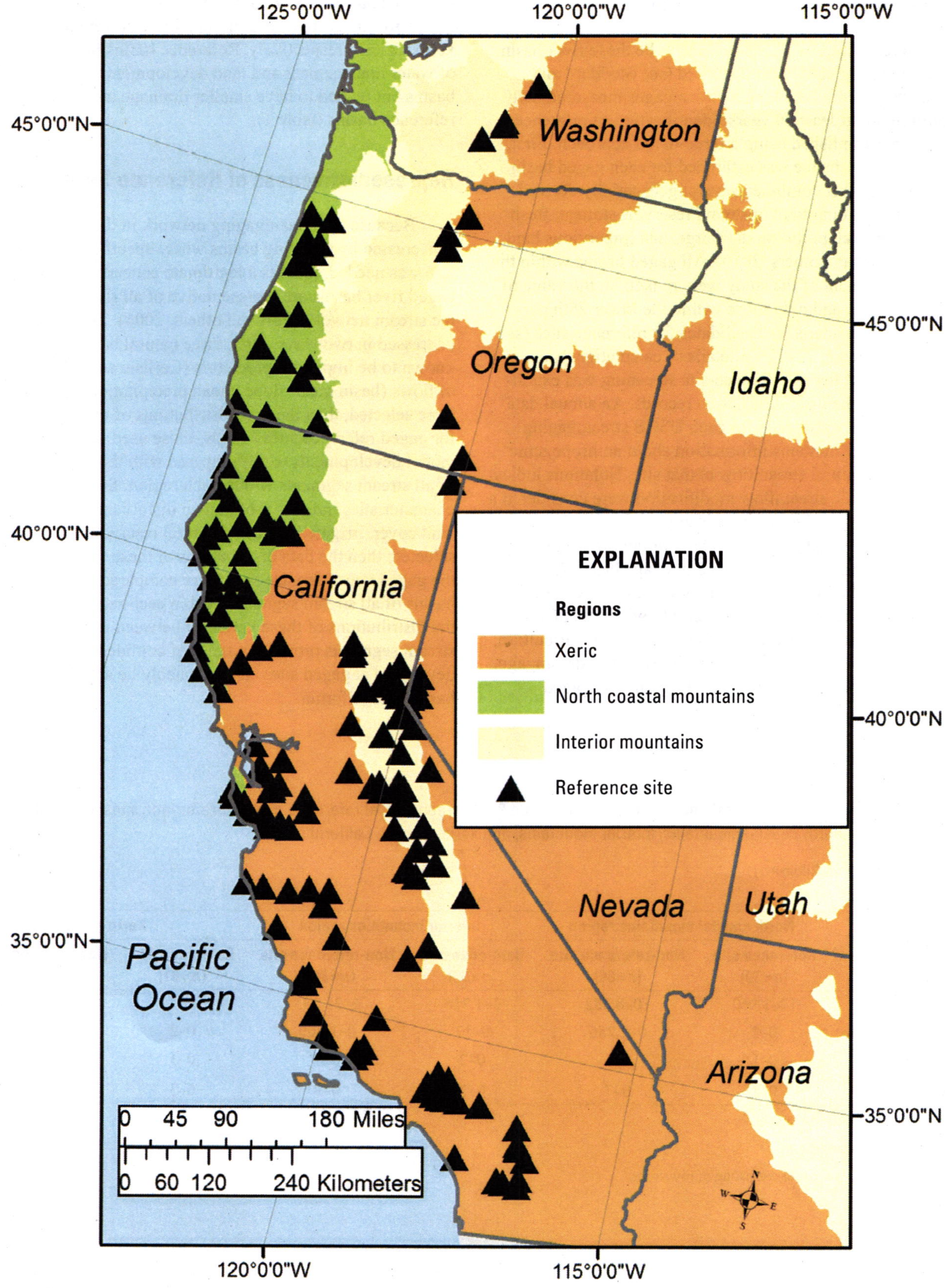


Figure 1. Locations of reference sites in gaged basins and extent of regions used to model streamflows in California.

Identification of Reference Sites

Reference sites were determined to be those river basins that are hydrologically least disturbed (see Stoddard and others, 2006) and where USGS streamgages measured daily streamflow for at least 20 years. Identification of reference sites was accomplished using a three-tiered approach. First, hydrologic disturbance was estimated for each gaged basin using an index that combined several geospatially derived indicators, including total upstream reservoir storage, freshwater withdrawal, pollution discharge, and impervious land cover (Falcone and others, 2010). All gaged basins within the geographic domain of the study were ranked on the value of this index score, and only those within the lower 25th percentile were considered as candidates for reference sites (see Falcone and others, 2010, for details of calculations).

The second tier of reference-site screening was examination of published site-description records. An annual data report is typically produced for each USGS streamgaging station and often contains information about anthropogenic influences on natural streamflow at that site. Notations indicating anthropogenic streamflow modification were considered a reason to classify a site as non-reference.

The third tier of screening was examination of the imagery of each site and its contributing drainage basin. Publicly available satellite imagery and topographic maps were examined for any indication of human activity with the potential to modify streamflows, such as diversions, irrigated agriculture, and wastewater inflows in close proximity to the streamgage. The screening process resulted in 50, 52, and 61 gaged reference basins and 86, 314, and 334 gaged non-reference basins for the north coastal mountains, interior mountains, and xeric regions, respectively. Reference basins had lower levels of water management and land development than disturbed basins but tended to have smaller drainage areas than non-reference basins (table 1).

Representativeness of Reference Sites

Because the streamgaging network in the United States was created by targeting basins where specific water information was needed, there is a legitimate concern as to whether gaged river basins are representative of all river basins within the stream network (Poff and others, 2006). This issue was addressed in two ways. First, three natural basin characteristics known to be important predictors (Carlisle and others, 2010) of flows (basin mean slope, mean precipitation, soil texture) were selected, then the data distributions of these variables for gaged reference sites (that is, those used in natural flow model development) were compared with those of the basins of all stream segments within each region. Second, three basin characteristics indicative of human disturbance (impervious land cover, irrigated agriculture, total reservoir storage) were selected, then the data distributions of these variables for the gaged non-reference sites were compared to those of the basins of all stream segments within each region. Overlap in the distributions of these variables between gaged sites and all stream segments provides a sense of confidence that models developed at gaged sites can reasonably be applied to all river basins in California.

Table 1. Ranges of environmental characteristics, as 1st and 99th percentiles, at reference and non-reference sites in gaged river basins within the north coastal mountains, interior mountains, and xeric regions, California.

[*n*, number; km^2, square kilometer]

Attribute	North coastal mountains region		Interior mountains region		Xeric region	
	Reference site (*n*=50)	Non-reference site (*n*=86)	Reference site (*n*=52)	Non-reference site (*n*=314)	Reference site (*n*=61)	Non-reference site (*n*=334)
Area (km^2)	12–1,962	10–8,382	3–1,758	6–21,145	5–656	7–19,779
Reservoir storage[a]	0–2	0–2,256	0–17	0–1,709	0–2	0–1,663
Impervious[b]	0–1	0–5	0–2	0–4	0–1	0–46
Crop land[c]	0–1	0–7	0–2	0–9	0–3	0–22

[a] Megaliters per square kilometer.

[b] Percent of basin land cover.

[c] Percent of basin land cover consisting of row crops.

Two limitations to the comparisons of basin characteristics were imposed. First, the comparisons were limited to non-gaged basins similar in size to those of gaged basins (table 1). This resulted in the exclusion of many small headwater streams that are present in the stream network but are not represented in the streamgaging network. The second limitation is that the comparisons were qualitative and univariate. Although formal quantitative methods are available for comparing multivarate distributions (for example, Bowman and Somers, 2006), these seemed inappropriate, given that the resulting thousands of statistical tests (for each segment in the stream network) would have limited interpretability.

In all regions, distributions of the six key variables (basin slope, mean precipitation, coarse soils, imperviousness, irrigated agriculture, and reservoir storage) overlapped considerably between reference basins and those of the stream network (appendix 1, figs. 1–1 to 1–3). These findings indicate that, from a univariate perspective, reference basins are largely representative of the natural and human-modified environmental settings of all stream basins in California that are 10–20,000 km^2 in total area.

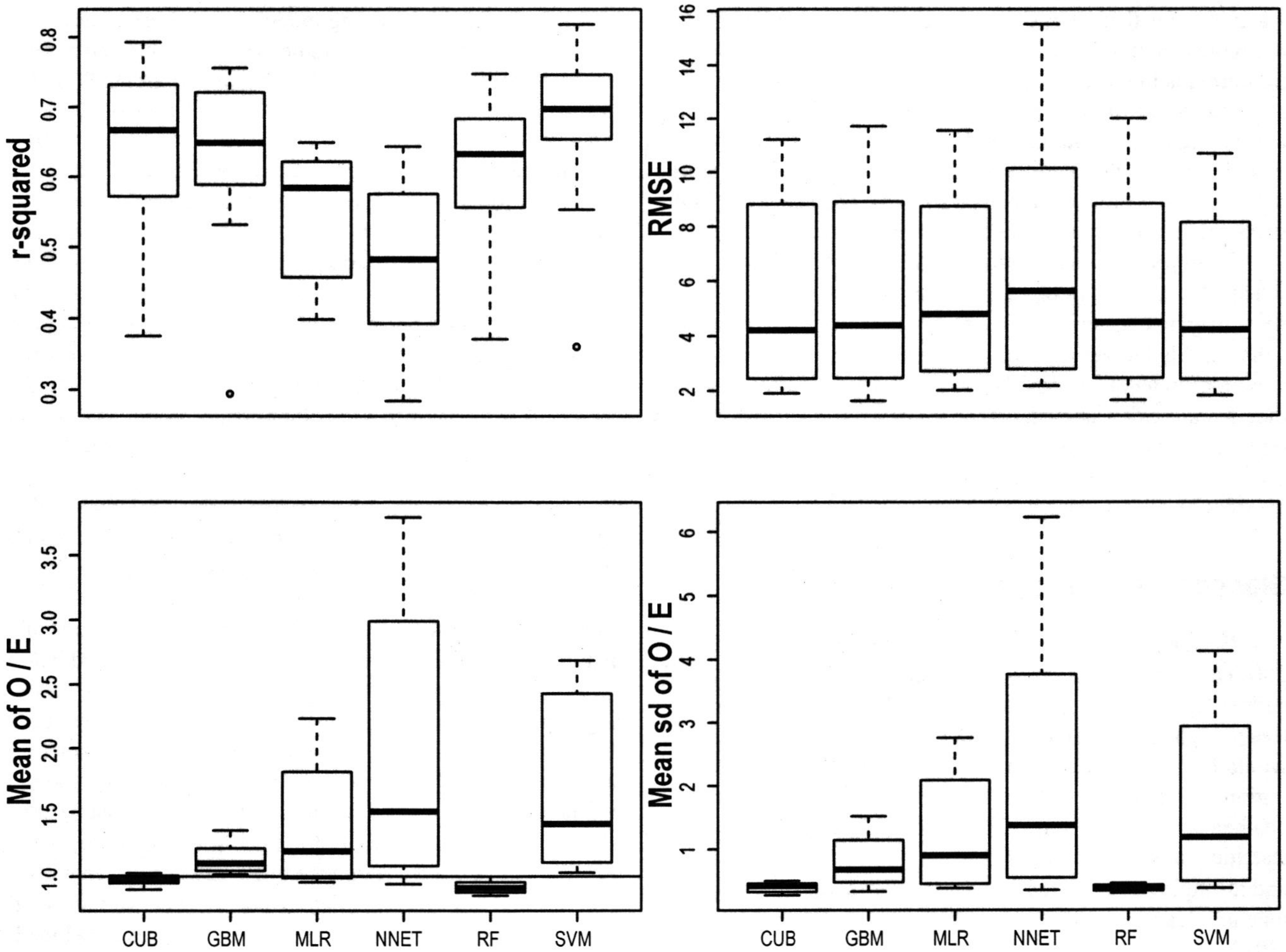
Statistical Modeling Approach

Because a variety of machine-learning methods (Kuhn, 2008) and linear regression have been used to develop statistical models in hydrology (Farmer and Vogel, 2013), alternative modeling approaches were evaluated to determine which would be most optimal for use in this study. Within each region, predictive models were developed (detailed methods below) using reference sites and six different types of statistical models—five different machine-learning models and multiple linear regression. Detailed descriptions of each machine-learning model are provided in Kuhn and Johnson (2013); brief descriptions are provided here. Random forest (RF), general boosted regression (GBM), and Cubist (CUB) are rule-based methods related to classification and regression trees (Hastie and others, 2001). The major difference among these techniques is in how the tree-based models are constructed. RF and GBM build an ensemble of individual tree-based models that are collectively used to make predictions. In RF, each of these individual models is treated independently and contributes equally to the final predictions of the model. In contrast, GBM builds these individual models in sequence and weights their predictions according to their predictive ability. CUB generates a multiple linear regression equation for each partition of the independent variables identified via simple tree-based methods. Support vector machines are a form of nonlinear regression that are robust to outliers and provide flexible model-evaluation rules (Kuhn and Johnson, 2013). Neural networks are a form of nonlinear regression but with the outcome simulated by a set of unobserved variables that are constructed as linear combinations of observed variables (Kuhn and Johnson, 2013).

Most machine-learning models require user-selected settings of various fitting parameters, so we selected a wide range of possible parameter values (appendix 1, table 1–1) and tuned each model with 10-fold cross validation using the caret library (Kuhn, 2008) in R (R Core Team, 2014). For CUB, support vector machines, and neural network models, independent variables were first centered and rescaled, and highly ($|r| > 0.80$) collinear variables were removed (as recommended and described in Kuhn and Johnson, 2013). The tuned models were then re-applied to the reference sites in each region using leave-one-out cross validation. From the resulting data, model performance was measured with the squared correlation and root mean square error of observed and predicted values. Additional measures of model performance (the mean observed (O)/expected (E), and the standard deviation (sd) of O/E) were also computed.

Across all monthly models and regions, RF and CUB models performed substantively better than all other modeling approaches (fig. 2). Because RF predictions consistently exhibited slightly better precision (that is, lower sd of mean O/E) than CUB, we selected RF to generate predictions of natural flows, after additional refinement as described below.

Tree-based methods, such as RF, are a desirable modeling approach because they are free of assumptions that limit linear methods, and they accommodate complex interactions and non-linear relations among independent and dependent variables. Detailed descriptions of RF are given elsewhere (Cutler and others, 2007). In the interest of parsimony, we evaluated how the performance of RF models varied with increasing numbers of predictor (independent) variables—that is, model complexity. First, a full RF model was developed using all predictor variables (table 1–2). RF evaluates predictor variable importance by randomly permuting each predictor in turn, then measuring loss in model performance (Cutler and others, 2007). The relative loss in model performance is used to rank predictor variable importance; variables that cause the greatest loss in model performance, when randomized, are of highest importance. The top 20 important predictors were selected after running the full model. Then beginning with the highest ranking variable, a new RF model was constructed after successively adding each of the top 20 predictors, in turn. Model performance was examined (see description in section "Predicting Natural Flows: Model Development and Performance") for each of the 20 RF models; one was selected that balanced model performance with the least number of predictor variables, thus providing the most parsimonious model.



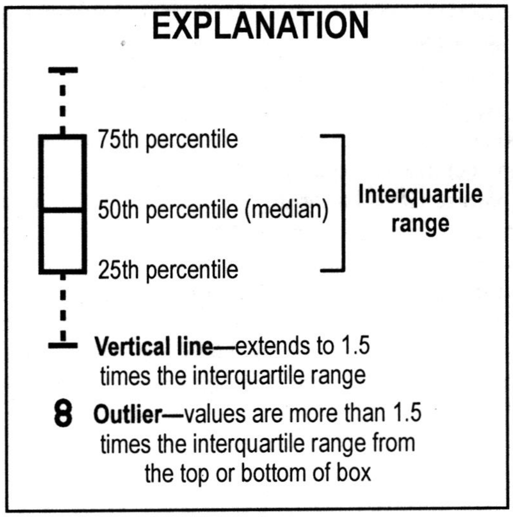


Figure 2. Performance of various machine-learning models for predicting natural monthly streamflows in California's xeric region. Plots for other regions are not shown but exhibited the same patterns of relative performance. Better models have higher r-squared, lower root mean square error (RMSE) and mean standard deviation (sd) of observed/expected (O/E) values, and a mean O/E value near 1. (CUB, cubist; GBM, boosted regression; MLR, multiple linear regression; NNET, neural network; RF, random forest; SVM, support vector machine.) r-squared is the correlation of predicted and observed values of monthly flows. RMSE is the root mean square error. Mean O/E is the average ratio of observed and predicted flows at each reference site. Mean sd of O/E is the mean of the standard deviation of O/E at each reference site.

Predicting Natural Flows: Model Development and Performance

For our first objective, a separate model for each month in each region (36 models) was developed to predict natural monthly flows for any specific year from 1950 to 2012. Measured monthly flow for each year was the dependent variable (U.S. Geological Survey, 2015). The predictor variables included a set of static, physical watershed characteristics and corresponding weather data (table 1–2; Falcone, 2011; Olson and Hawkins, 2014; PRISM Climate Group, 2014). These year-specific weather data included precipitation and air temperature for the month of interest and each of the previous 12 months (Daly and others, 2008). Estimated monthly runoff data from national-scale grids (McCabe and Wolock, 2011) were also used because these estimates indicate the balance between precipitation and evapotranspiration. In summary, the final data matrix for developing models of natural monthly flows included every year for which each reference site had a measured monthly flow value, the set of weather data and modeled runoff associated with each year's measured monthly flow and previous 12 months (39 predictors), and the set of static physical watershed characteristics (113 predictors, Falcone, 2011). The relations between the most influential predictors and the simulated outcome were graphically examined using partial-dependence plots (Cutler and others, 2007). This procedure evaluates how variation in each predictor affects the outcome while holding all other predictors constant (Hastie and others, 2001).

Model performance was evaluated by calculating several statistics (Moriasi and others, 2007) using the observed data and the expected (that is, predicted) monthly data generated by the internal bootstrapping performed by the RF model (Cutler and others, 2007). The squared correlation coefficient (r^2) between observed and predicted monthly flows across all sites was computed. The Nash-Sutcliffe coefficient of model efficiency (NSE) measures the total residual variance (that is, generated from model predictions) relative to the total variance within the data. NSE values near unity indicate that most of the total variance is accounted for by the model, indicating good model performance. Percent bias (PBIAS) estimates the model's tendency to over predict (PBIAS>0) or under predict (PBIAS<0). The root mean square error normalized by the standard deviation of all observations provides a standardized measure of model error. Finally, summary statistics for each site were calculated, including the mean (among years) O/E and the standard deviation (among years) of monthly O/E values.

Predicting the Likelihood of Modified Flows: Model Development and Performance

Objective two was to predict, using geospatial variables, the likelihood of anthropogenic modification of monthly streamflows. Models predicting modified flow were developed with a single dataset of all regions combined because by doing so we maximized the observed variation in affects from human activity, as well as the overall size of the dataset. Initial models for individual regions showed only marginal success in some regions, likely because of small ranges of several geospatial predictor variables. Finally, we had no reason to hypothesize that the relations between human activity factors (for example, freshwater withdrawal) and streamflows would vary by region.

Models described above were applied to all non-reference sites (total n=558) with recent flow records (1990–2010, which generally overlap the time periods of geospatial predictors) to generate a time series of natural monthly flows. Then, O/E was computed and averaged across years to produce a single value for the mean deviation of observed and expected natural flows for each month. Finally, each non-reference site was classified into one of three categories for each month on the basis of that month's mean O/E value: depleted, inflated, or unaltered. Depleted (O/E <0.75) indicates monthly flows that, on average, are reduced relative to natural conditions. Inflated (O/E >1.25) indicates monthly flows that, on average, are augmented relative to natural conditions. Unaltered (all other O/E values) indicates monthly flows that, on average, are similar to natural conditions. Thresholds for defining these categories are arbitrary but based upon a combination of statistical and interpretive reasoning. First, this threshold was within the range of precision (that is, average sd of O/E) of models predicting natural flows. Second, we evaluated model performance at a variety of thresholds and found that ±0.25 O/E units provided the best performance. Finally, a consistently applied threshold defined as a 25-percent reduction/addition of monthly flows is simple to comprehend and communicate.

For each month, two separate RF classification models were developed. One predicted depleted versus non-depleted flows (includes unaltered and inflated flows), and another predicted inflated versus non-inflated flows (includes unaltered and depleted flows). Predictor variables were limited to geospatial indicators of land and water management (table 1–3; Falcone, 2011; USGS, 2008a; U.S. Department of Agriculture, 2012; California Department of Water Resources, 2000; Grantham and others, 2014; USGS, 2008b; USGS 2013). As was done with the models of natural flow, parsimonius models were developed by evaluating model performance at varying levels of model complexity. Model performance was measured using the confusion matrix constructed with observations that were not used in model development (Cutler and others, 2007). The confusion matrix is the summary of the observed versus expected (predicted) classes of each observation used for model validation. Many measures have been proposed to summarize confusion matrices (Kuhn and Johnson, 2013), each with its own strengths and weaknesses. Given our modeling objective, we saw no reason to favor one type of error over another. Failure to detect anthropogenic modification when it actually exists has negative consequences that may be no worse than the consequences of making false detections. Therefore, the percentage of observations that were correctly classified as altered (sensitivity), the percentage correctly classified as unaltered (specificity), and the kappa statistic as a measure of overall classification performance are reported. Kappa accounts for accuracy that would be generated simply by chance given the frequencies of each class in the data.

Results

Predicting Natural Flows

Model performance was marginally higher in both mountainous regions than in the xeric region and relatively consistent among months (fig. 3). For the xeric region (fig. 3*A*), typically more than 60 percent of the variation in observed flows was explained by the model (r^2, 0.41–0.88; NSE, 0.41–0.87), and bias was no more than 5 percent (PBIAS, -5 to -1). Mean O/E values were typically near unity (mean O/E, 0.90–0.98), and the sd of O/E indicated precision was typically 40 percent (sd O/E, 0.31–0.48). For the north coastal mountains (fig. 3*B*), typically more than 80 percent of the variation in observed flows was explained by the model (r^2, 0.84–0.96; NSE, 0.83–0.96), and bias was less than 5 percent (PBIAS, -3 to 2). Mean O/E values were typically near unity (mean O/E, 0.94–0.98), and the sd of O/E indicated precision was typically 29 percent (sd O/E, 0.24–0.34). For the interior mountains (fig. 3*C*), typically more than 70 percent of variation in observed flows was explained by the model (r^2, 0.79–0.96; NSE, 0.79–0.96) and bias was less than 5 percent (PBIAS, -4 to 4). Mean O/E was typically near unity (0.91–0.97), and sd of O/E indicated precision was typically 32 percent (sd O/E, 0.26–0.41).

The performance of statistical models was comparable to that of a wide range of other mechanistic and statistical approaches for monthly flow prediction. The NSE and PBIAS of the models were within the range of those achieved with statistical transfer methods (Farmer and Vogel, 2013). In addition, the r^2 and NSE of the models for the interior mountains region were comparable or slightly better than those (0.67 and 0.65, respectively) of a published mechanistic model for the Sierra Nevada Mountains (Shupe and Potter, 2014) and models for the Sacramento River (NSE, 0.48–0.82) (Ficklin and others, 2013).

Water balance-based runoff of the current month was an important predictor for all months and in all regions (figs. 1–4 to 1–6). Runoff (wb0-wb6) and precipitation (p0-p6, p2sum-p6sum) in the previous 1–6 months were also among the most important predictors for most models and in all regions. In addition to climatic variables, a variety of other physical attributes were important predictors of monthly flows. In the xeric region (fig. 1–4), basin mean slope (SLOPE), soil texture (NO10AVE), and elevation (ELEVATION) were important predictors, particularly for months when precipitation is typically low or nonexistent. In the north coastal mountains (fig. 1–5), precipitation intensity (RFACT) and overland flow (PERHOR), as well as sedimentary geology (sedimentary), were important predictors, particularly for dry months. Precipitation intensity and geologic properties frequently were important predictors for models in the interior mountains region in most months (fig. 1–6).

As expected, precipitation was the most important predictor of streamflow, but the affects of other watershed attributes is evidence that local physical factors affect the relation between precipitation and streamflow (fig. 4). Predicted flow typically increased monotonically with precipitation intensity (R-Factor), as well as with increasing precipitation (antecedent precipitation) and runoff (estimated runoff) in the target and preceding months. Predicted flow increased with increasing basin slope, which reflects the greater tendency for runoff than for infiltration on steeper slopes. In contrast, predicted flow decreased monotonically with the increasing extent of coarse soils, which indicates that greater infiltration in coarser soils results in lower runoff. Predicted flows tended to increase with increasing compressive strength of basin lithology, which indicates that rocks more resistant to weathering allow limited infiltration of precipitation to groundwater sources.

The models for natural flows lacked predictor variables that are direct measures of groundwater contributions to streamflow, but several surrogate variables frequently were important predictors, indicating that the models managed to capture part of this natural process. Antecedent monthly precipitation (2, 3, and 6 months) was an important variable for most months in all regions and may represent the lag time between precipitation and streamflow as a result of shallow groundwater recharge. Similarly, the average base-flow index (BFI) was an important predictor in the north coastal and interior mountains regions. The BFI was generated by a nationwide interpolation of observed streamflow data and represents a broad indicator of the degree to which groundwater contributes to streamflows (Wolock, 2003).

Models predicting natural streamflows could provide a useful baseline for future studies of how streamflows in California respond to changes in land use, water management, and climate. For example, a recent study (Grantham and others, 2014) used statistical models of natural flows combined with geospatial information about sensitive species to prioritize dams where targeted release strategies are likely to have the greatest ecological benefits. In addition, the ability to generate year-specific predictions of natural monthly streamflows will provide a foundation for examining how human activities influence streamflows and stream health, and how those effects may vary in time. For example, if natural monthly flows back to 1950 were generated for streams with long-term flow monitoring stations, trends in streamflow modification can be associated with trends in land use and water management over the last 60 years.

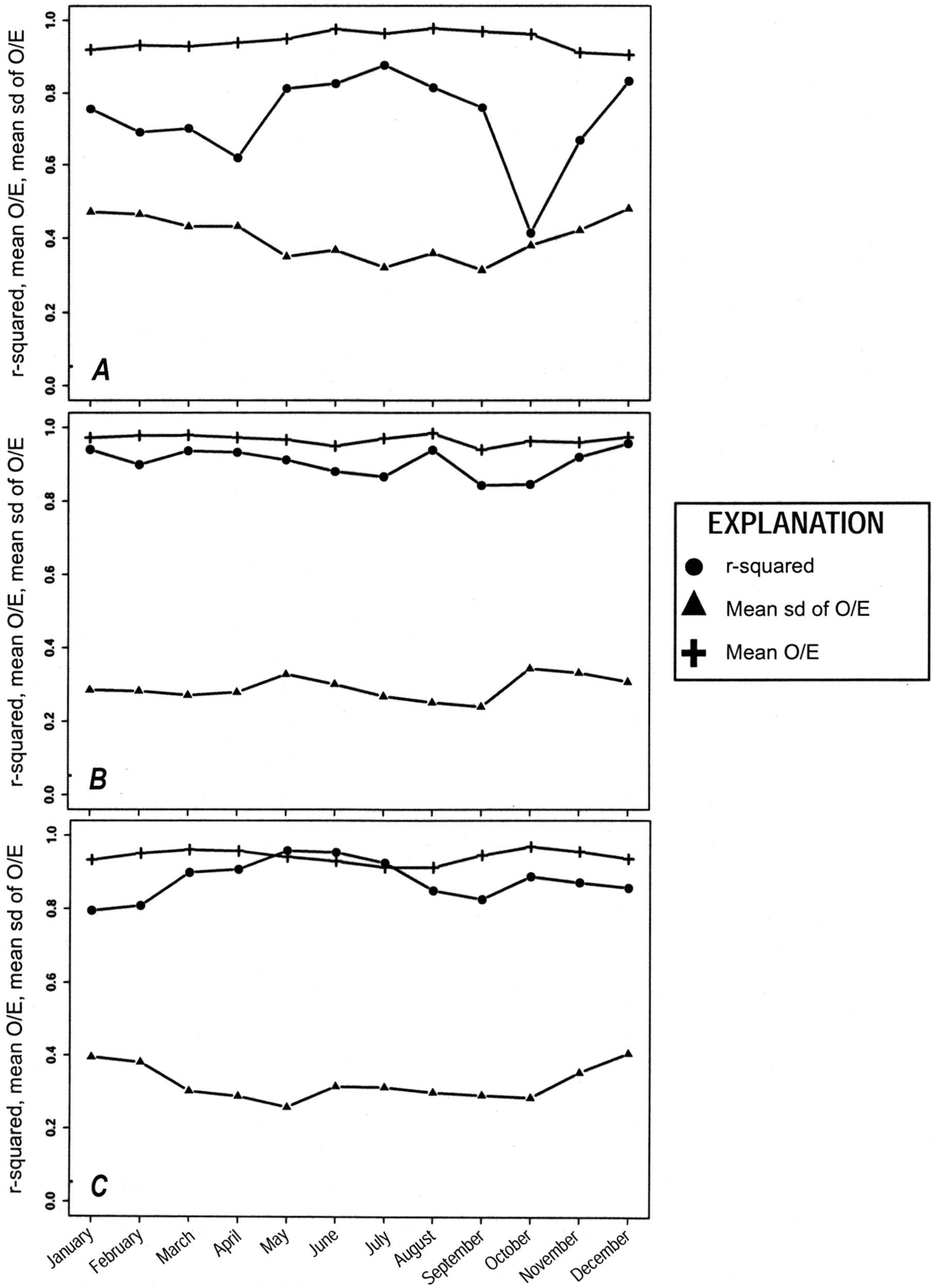


Figure 3. Performance statistics for models predicting natural monthly streamflows in the *A*, xeric; *B*, north coastal mountains; and *C*, interior mountains regions of California (r-squared is the correlation of predicted and observed values of monthly flows; sd, standard deviation; O/E, observed/expected).

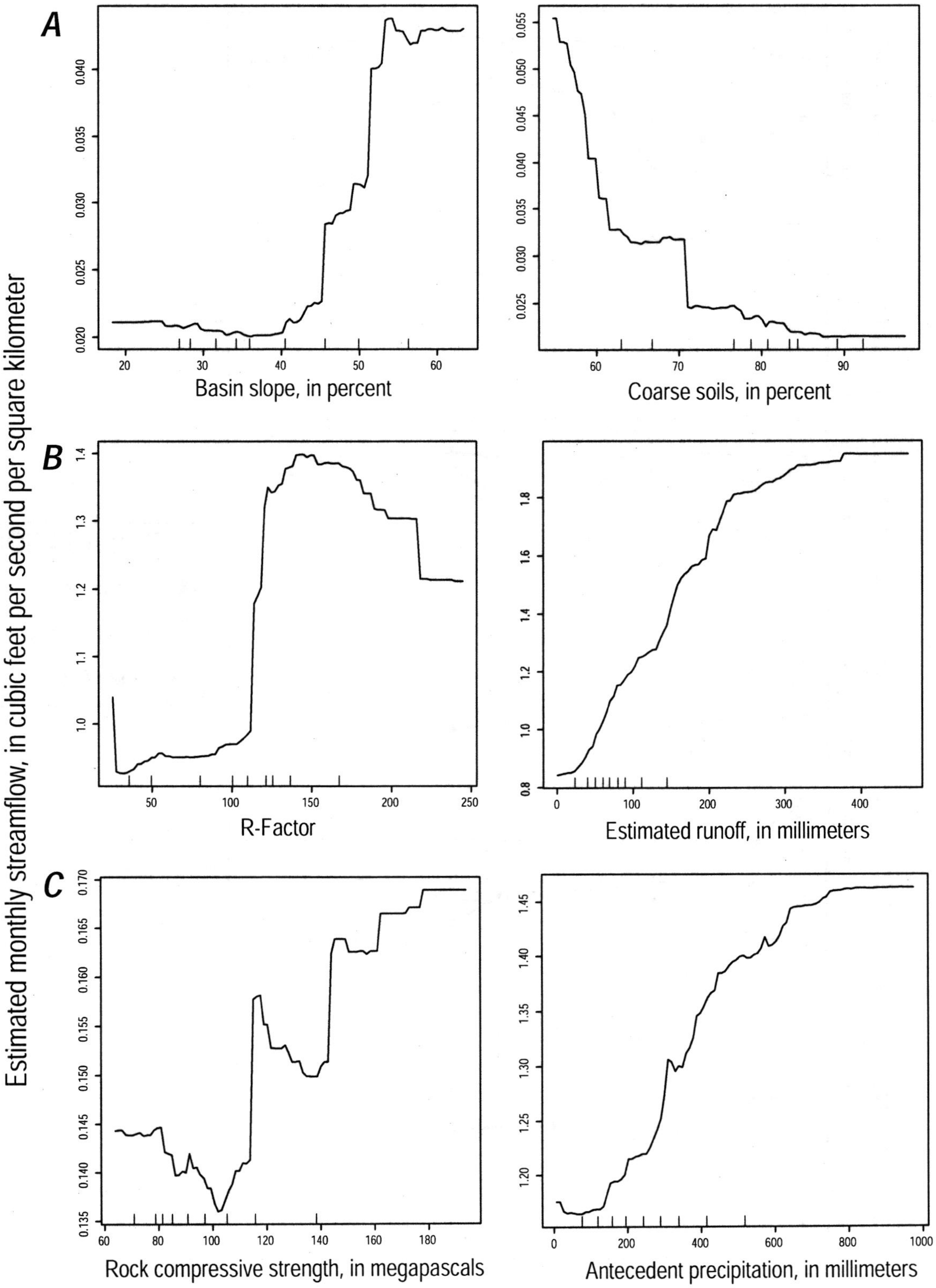


Figure 4. Partial dependence plots showing the relation of predicted natural monthly streamflow to selected predictor variables for the *A*, xeric; *B*, interior mountains; and *C*, north coastal mountains regions, California. Units for R-factor are in hundreds of foot-ton-inches per hour per acre. Estimated runoff is for the target month, and antecedent precipitation is the sum for the previous 6 months.

Predicting Modified Flows

Models predicting modified streamflows had a wide range of performance (fig. 5). Models predicting inflated monthly flows correctly classified, on average, 39 percent of altered sites (that is, sensitivity). The best model was for September (56 percent), and the worst model was for March (13 percent). Ninety percent of unaltered sites were correctly classified (that is, specificity), on average. The average kappa statistic was 0.34 (range 0.15–0.45), and the best models were those for May and June. Various measures of urban development (road stream crossings, impervious area) in the basin or riparian buffer were important predictors of inflated flows in all months (fig. 1–7).

Models predicting depleted monthly flows correctly classified 61 percent of altered sites, on average. The best models were for April (78 percent), and worst were for October (35 percent) (fig. 5). On average, 59 percent of unaltered sites were correctly classified. The average kappa statistic was 0.33 (range 0.25–0.46), and the best models were those for April and May. Various measures of urbanization in the basin were important predictors in all months, but riparian-buffer urban land cover, riparian vegetation height (riparian ht.), fertilizer application (P and N application; phosphate and nitrate, respectively) and freshwater withdrawal (withdrawal) were important predictors of depleted flows for 10 of 12 months (fig. 1–8).

Indicators of urbanization and water use were associated with inflated and depleted streamflows in opposite ways (fig. 6). The probability of inflated monthly flows increased dramatically with increasing impervious cover, which has been abundantly demonstrated in the literature (Paul and Meyer, 2001; Roy and others, 2005; Eng and others, 2013b), but tended to decrease with increasing freshwater withdrawal, which is an indicator of consumptive water use (Maupin and others, 2014). In contrast, the probability of depleted monthly flows increased with increasing freshwater withdrawal, which is also supported by a large body of literature (Jackson and others, 2001), but decreased with increasing urbanization.

The models predicting modified flows using geospatially derived indicators of influences from human activity at the watershed scale have one major limitation. The estimates of water use were based on State records of permitted diversions, which do not reflect the actual quantities of water that are consumptively used (for example, evaporation or export to other river basins) versus quantities returned to the stream or shallow groundwater. As a result, models performed relatively poorly, and typically various surrogates of actual water use (for example, agricultural intensity, impervious land cover) were found to be the best predictors of streamflow modification. Models likely would be improved with future enhancements of geospatially derived indicators of groundwater/surface-water interactions, actual consumptive water use, and return flows. Such data are notoriously difficult to obtain and quantify across wide geographic areas, but pilot programs in arid regions could be used to demonstrate the utility of such data collection efforts.

Although models for some months performed poorly, those for some months performed reasonably well and represent ecologically relevant hydrologic events such as May (spring flows as in Yarnell and others, 2010) and September flows (typically annual low flow). Potentially powerful management tools could be developed by combining predictions of modified streamflows across a large geographic area with other geospatial information, such as water use, sensitive species, or anticipated changes in precipitation owing to climate change.

Published sources of data used in this study and provided in tables 1–2 and 1–3 include the following: Falcone, 2011; Olson and Hawkins, 2014; PRISM Climate Group, 2014. In addition, monthly natural flow data for California stream segments (National Hydrography Dataset, Version 1) generated with models developed in this study are available at Carlisle and others, 2016. In addition, data used to develop models predicting modified flows (objective two) are available at the same source.

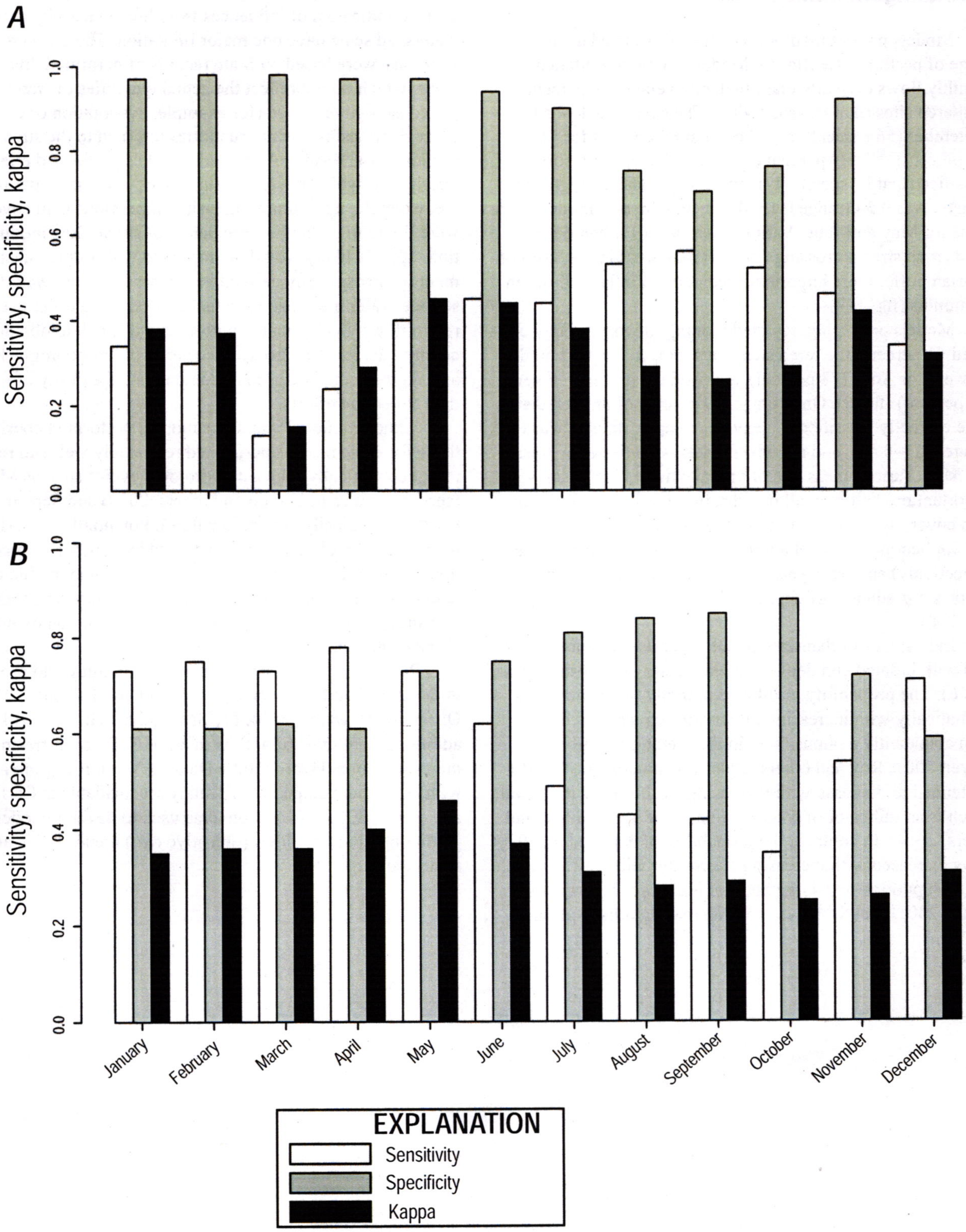


Figure 5. Performance measures for models predicting the probability of *A*, inflated and *B*, depleted flows in California streams.

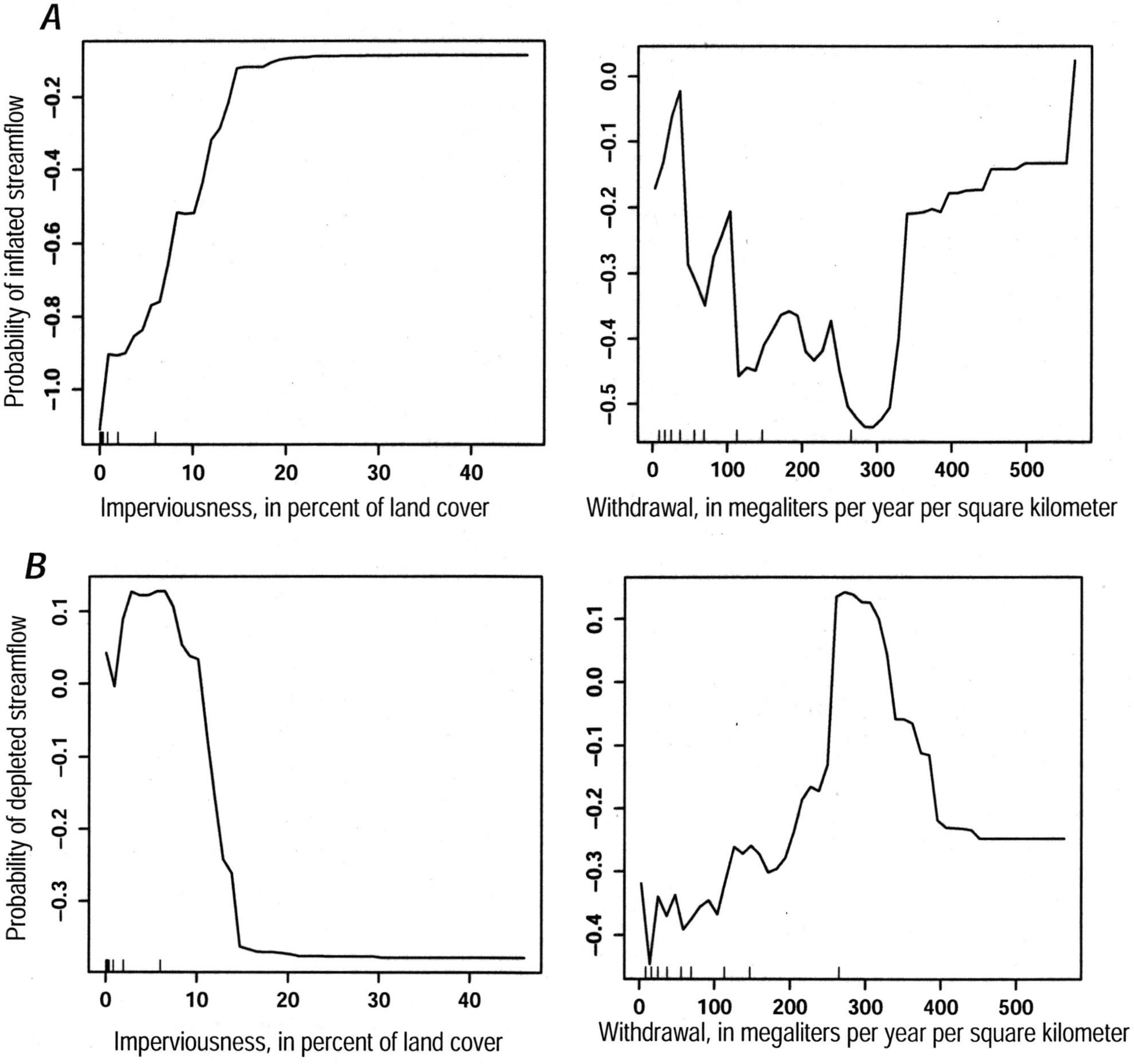


Figure 6. Partial dependence plots showing how the probability (logit of probability / 2) of *A*, inflated and *B*, depleted June streamflows are related to key predictor variables.

Summary

In a study conducted by the U.S. Geological Survey, in cooperation with The Nature Conservancy and Trout Unlimited, models developed to estimate natural monthly flows performed well and should provide a useful baseline for future studies of how streamflows in California respond to changes in land use, water management, and climate. For example, a recent study used statistical models of natural flows combined with geospatial information about sensitive species to prioritize dams where targeted release strategies are likely to have the greatest ecological benefits. In addition, the ability to generate year-specific predictions of natural monthly streamflows will provide a foundation for examining how human activities influence streamflows and stream health, and how those effects may vary in time. For example, if natural monthly flows back to 1950 were generated for streams with long-term flow monitoring stations, trends in streamflow modification can be associated with trends in land use and water management over the last 60 years.

The models that predict the likelihood of modified streamflows performed less reliably than those for natural streamflows but may nevertheless be useful as a general screening tool. Although models for some months performed poorly, those for selected months performed reasonably well and represent ecologically relevant hydrologic events such as May (spring flows) and September flows (typically annual low flow). Potentially powerful management tools could be developed by combining predictions of modified streamflows across a large geographic area with other geospatial information, such as water use, sensitive species, or anticipated changes in precipitation owing to climate change.

Models predicting natural and modified flows likely would be improved with future enhancements of geospatially derived indicators of groundwater/surface-water interactions, actual consumptive water use, and return flows. Such data are notoriously difficult to obtain and quantify across wide geographic areas, but pilot programs in arid regions could be used to demonstrate the utility of such data collection efforts.

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Appendix 1. Supplemental Information

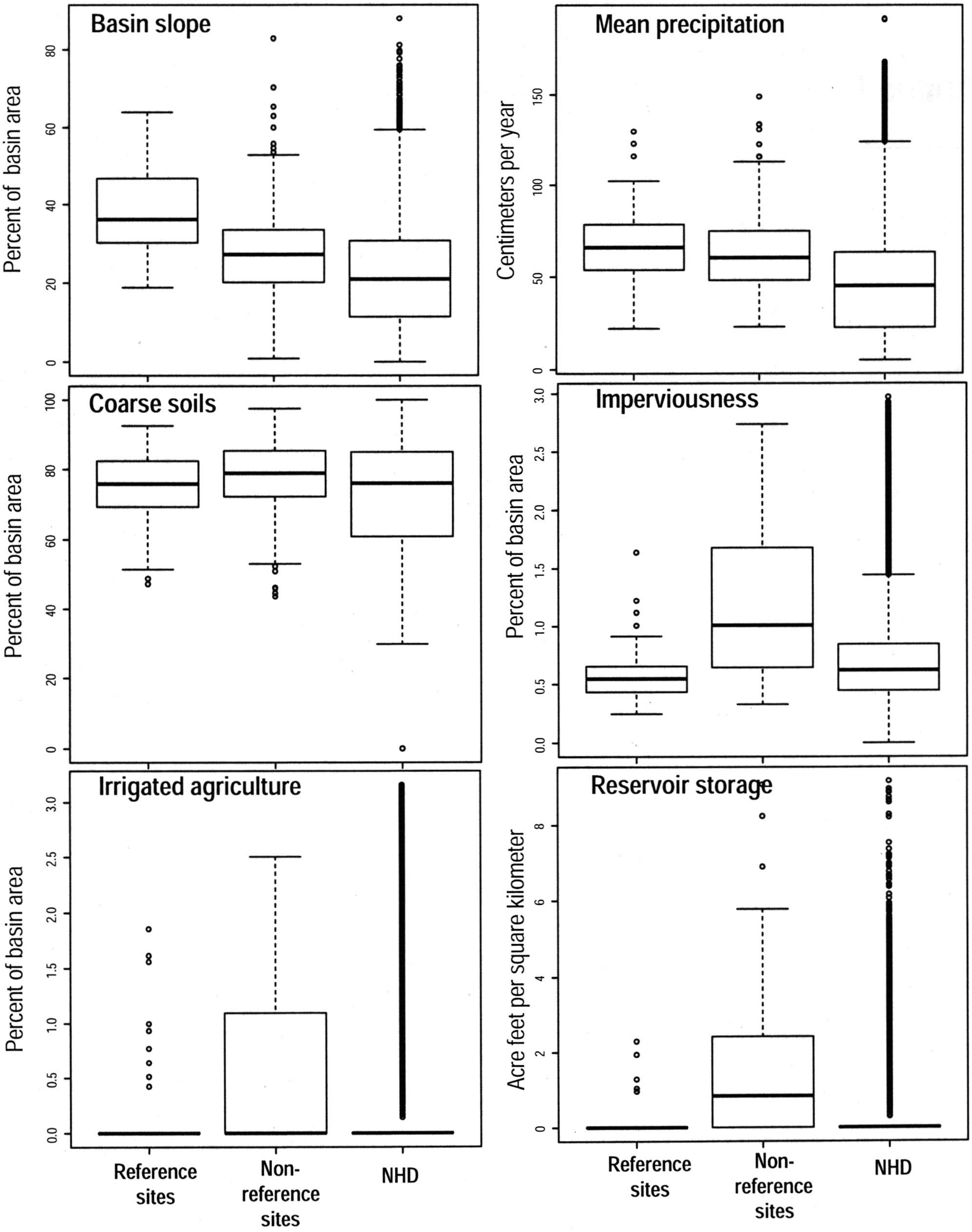

Figure 1–1. Representativeness of gaged basins used in model development relative to all stream segments (NHD= all segments in the National Hydrography Dataset) in the xeric region of California. Descriptions of variables are provided in tables 1–1 and 1–2.

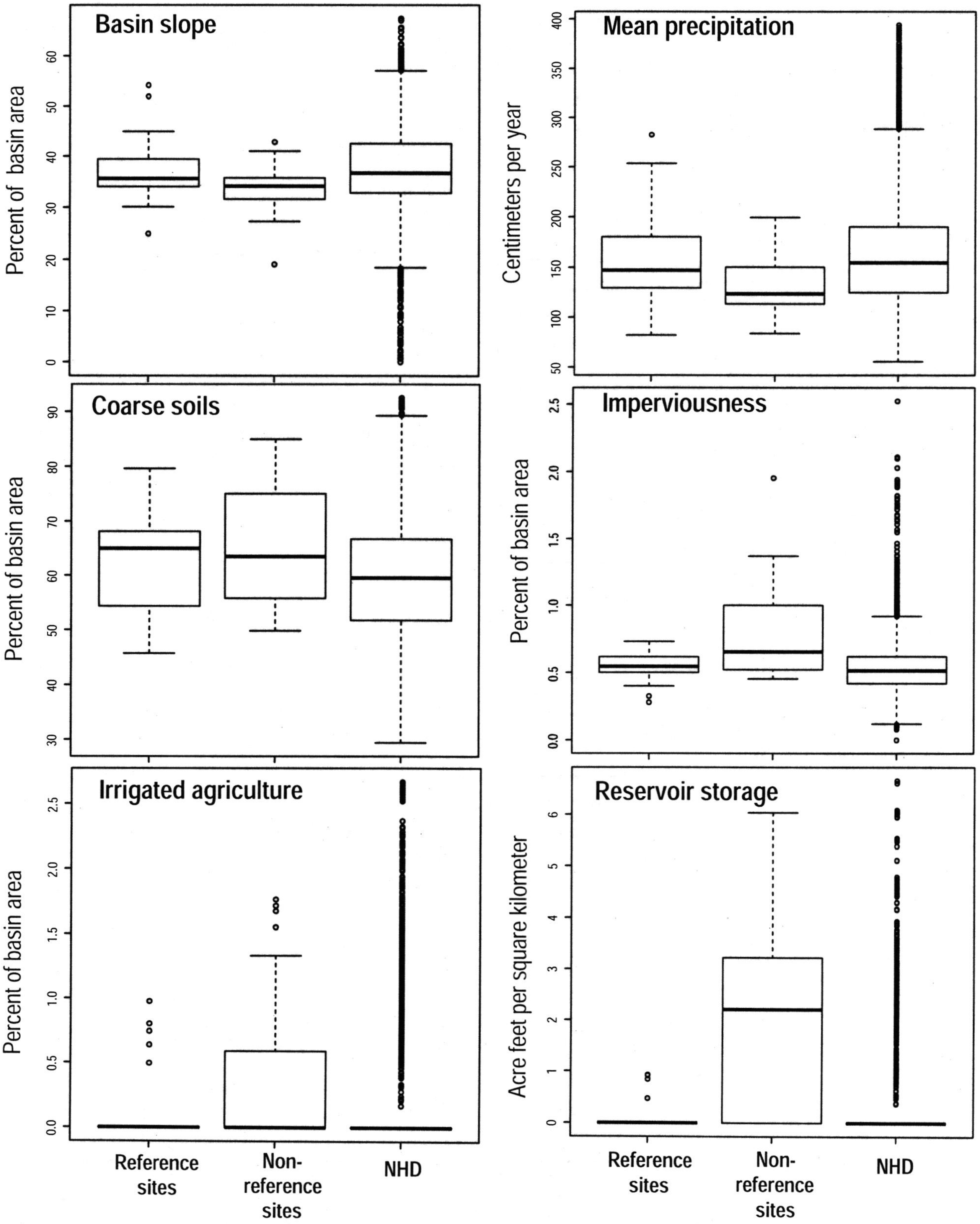

Figure 1–2. Representativeness of gaged basins used in model development relative to all stream segments (NHD) in the north coastal mountains region of California. Descriptions of variables are provided in tables 1–1 and 1–2.

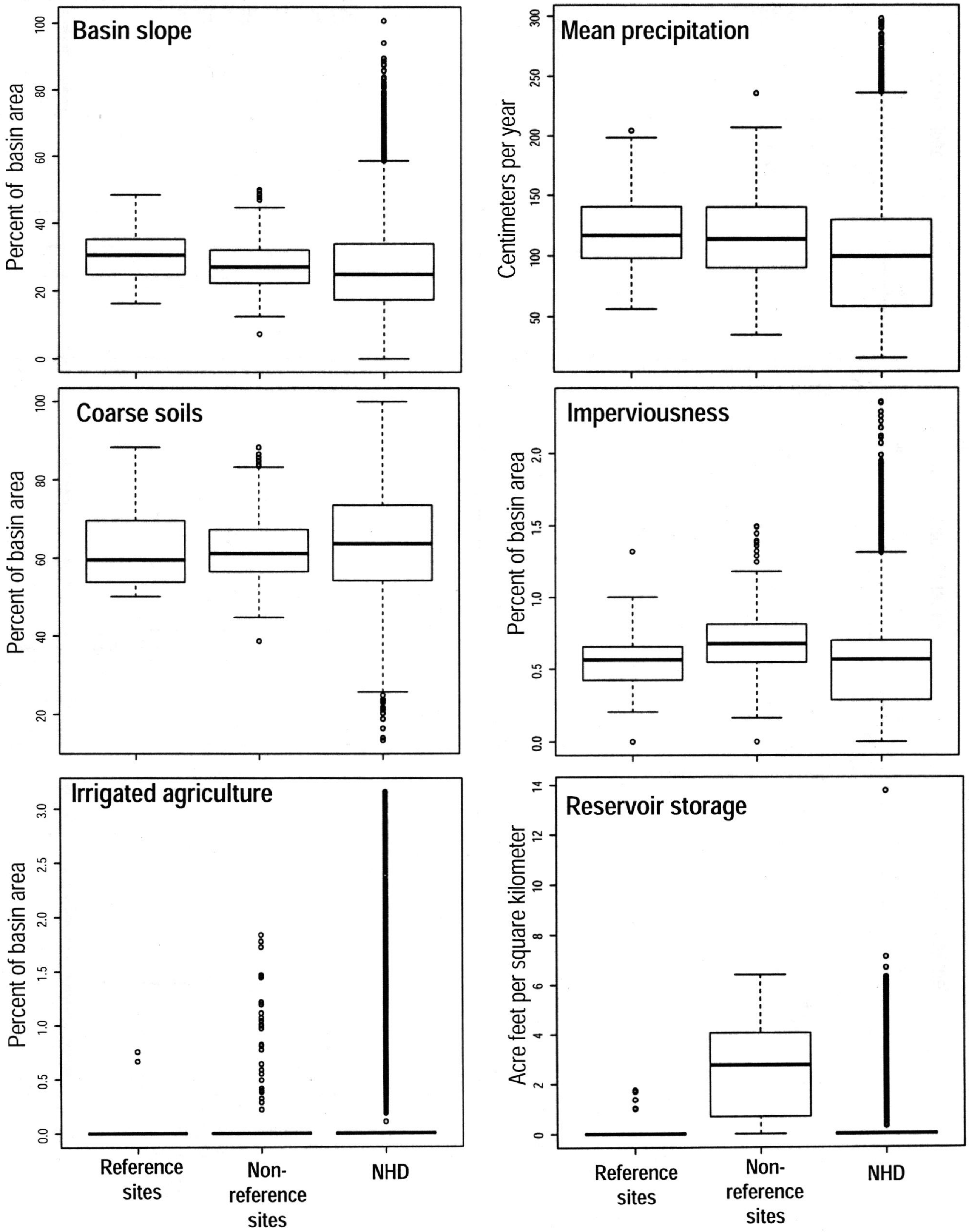

Figure 1–3. Representativeness of gaged basins used in model development relative to all stream segments (NHD) in the interior mountains region of California. Descriptions of variables are provided in tables 1–1 and 1–2.

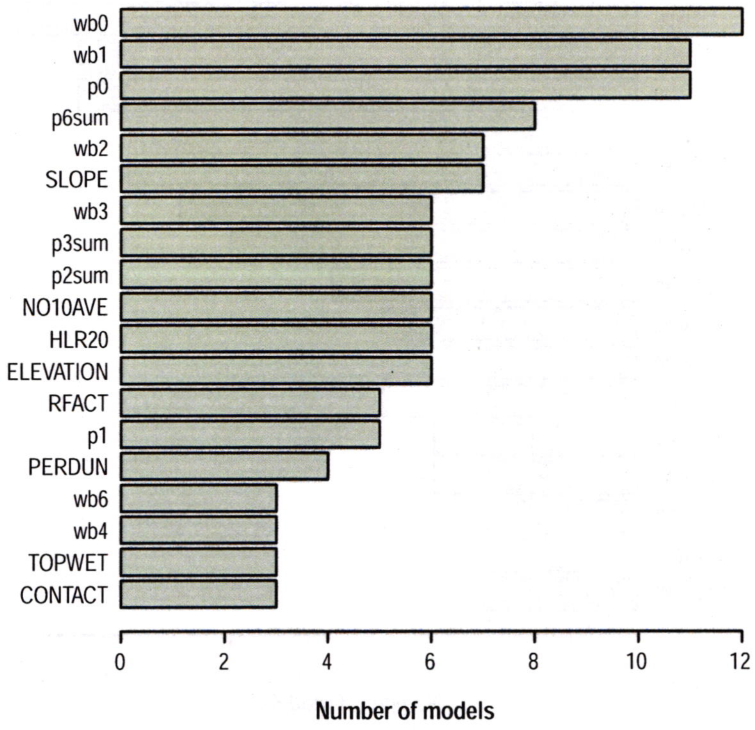

Figure 1–4. Occurrence of variables as important predictors in models of monthly streamflows in the xeric region of California. Descriptions of variables are provided in tables1–1 and 1–2.

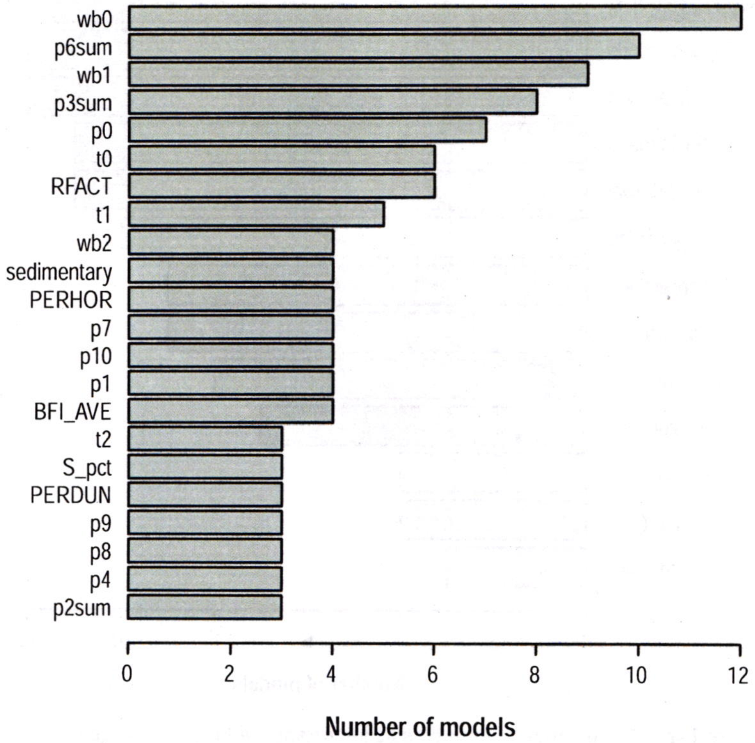

Figure 1–5. Occurrence of variables as important predictors in models of monthly streamflows in the north coastal mountains region of California. Descriptions of variables are provided in tables1–1 and 1–2.

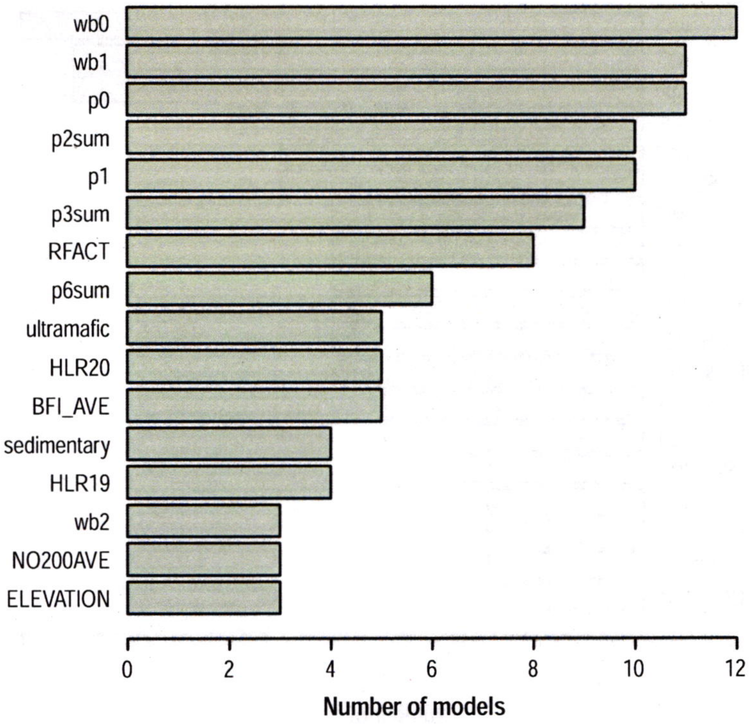

Figure 1–6. Occurrence of variables as important predictors in models of monthly streamflows in the interior mountains region of California. Descriptions of variables are provided in tables 1–1 and 1–2.

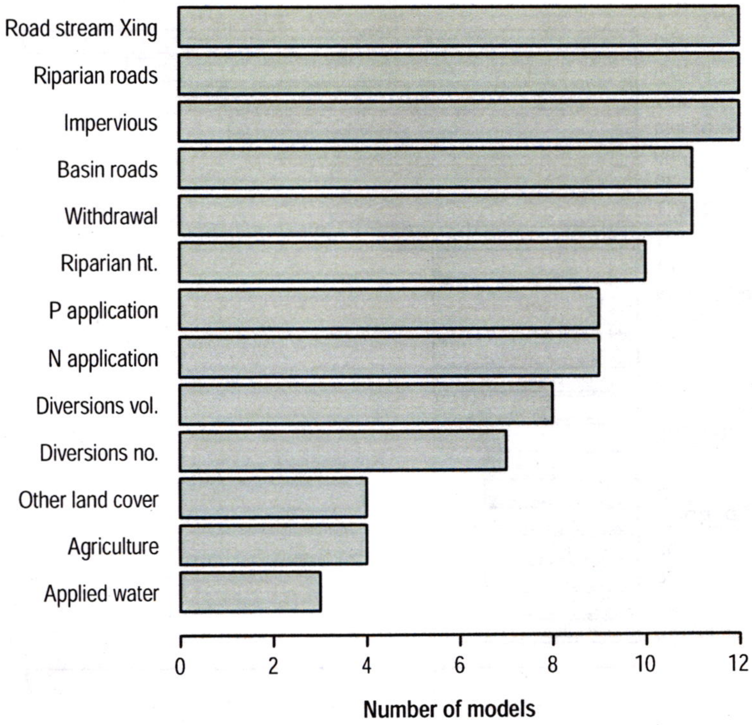

Figure 1–7. Occurrence of variables as important predictors in models predicting the likelihood of inflated monthly streamflows in California. Descriptions of variables are provided in tables 1–1 and 1–2. (ht., height; vol., volume; no., number; P, phosphate; N, nitrate)

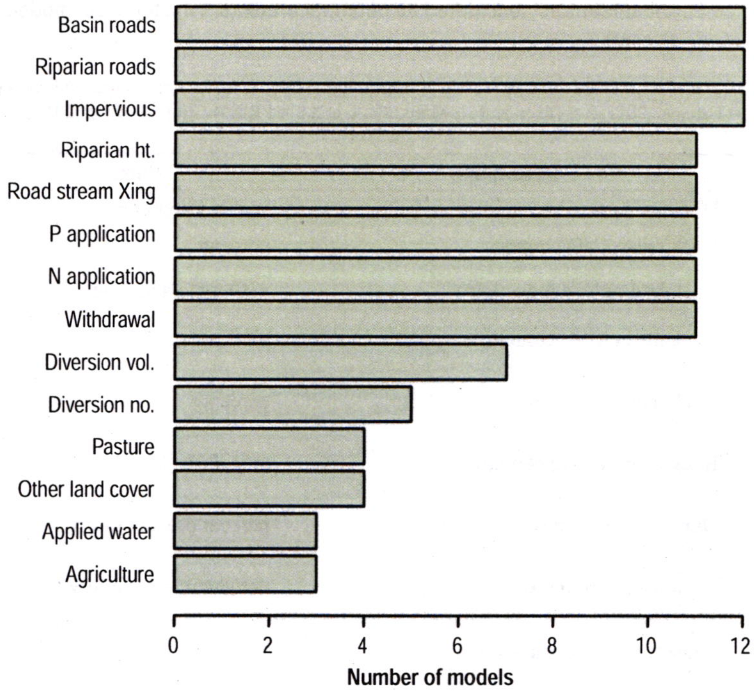

Figure 1–8. Occurrence of variables as important predictors in models predicting the likelihood of depleted monthly streamflows in California. Descriptions of variables are provided in tables 1– 1 and 1–2. (ht., height; vol., volume; no., number; P, phosphate; N, nitrate)

Table 1–1. Machine-learning models and associated tuning parameter settings evaluated for predicting monthly flows in California streams. Settings indicate tuning parameter values that were evaluated. Tuning parameter details provided in Kuhn and Johnson (2013).

Model	Tuning parameter	Settings
Neural network	Decay	0, 0.1, 0.1
	Size	1–9
Support vector machine	Degree	1–3
	Scale	0.01, 0.1, 1
	Cost	0.25, 0.5, 1, 2, 4
Random forest	Number of predictors evaluated at each node	33–57
Boosted regression	Interaction depth	2-12
	Shrinkage	0.01, 0.1
Cubist	Committees	0–100
	Neighbors	0–9

Table 1–2. Watershed physical features considered as potential predictors in statistical models of natural monthly flows in California streams.

[cm, centimeter; hr, hour; m, meter; CaO, calcium oxide; MgO, magnesium oxide; S, sulfur. Data source indicates published source of geospatial data, where 1 = Falcone, 2011; 2 = Olson and Hawkins, 2014; and 3 = PRISM Climate Group, 2014]

Variable name	Description	Units	Data source
DRAIN_SQKM	Drainage area	square kilometers	1
CaO_pct	Rock mean CaO content	percent	2
LPerm	Rock hydraulic conductivity	x10^6 meters/second	2
MgO_pct	Rock mean MgO content	percent	2
S_pct	Rock mean S content	percent	2
UCS	Rock compressive strength	megaPascals	2
PERDUN	Dunne overland flow	percent of streamflow	1
PERHOR	Horton overland flow	percent of streamflow	1
CONTACT	Subsurface flow contact time	days	1
TOPWET	Topographic wetness index	log(meters)	1
BFI_AVE	Base flow index	percent of streamflow	1
CLAYAVE	Soil clay content	percent by weight	1
SILTAVE	Soil silt content	percent by weight	1
AWCAVE	Soil water capacity	unitless	1
PERMAVE	Soil permeability	inches/hour	1
BDAVE	Soil bulk density	grams/cubic cm	1
OMAVE	Soil organic matter	percent by weight	1
HGA	Soil hydrologic group A	percent by weight	1
HGB	Soil hydrologic group B	percent by weight	1
HGC	Soil hydrologic group C	percent by weight	1
HGD	Soil hydrologic group D	percent by weight	1
HGAC	Soil hydrologic groups A and C	percent by weight	1
HGAD	Soil hydrologic groups A and D	percent by weight	1
HGBC	Soil hydrologic groups B and C	percent by weight	1
HGBD	Soil hydrologic groups B and D	percent by weight	1
HGCD	Soil hydrologic groups C and D	percent by weight	1
HGVAR	Soil hydrologic group VAR	percent by weight	1
KFACT_UP	Soil erodibility	unitless	1
ROCKDEPAVE	Soil thickness	inches	1
NO4AVE	Soil material <5 millimeters	percent by weight	1
NO10AVE	Soil material <2 millimeters	percent by weight	1
NO200AVE	Soil material <0.1 millimeters	percent by weight	1

Table 1–2. Watershed physical features considered as potential predictors in statistical models of natural monthly flows in California streams.—Continued

[cm, centimeter; hr, hour; m, meter; CaO, calcium oxide; MgO, magnesium oxide; S, sulfur. Data source indicates published source of geospatial data, where 1 = Falcone, 2011; 2 = Olson and Hawkins, 2014; and 3 = PRISM Climate Group, 2014]

Variable name	Description	Units	Data source
WTDEPAVE	Depth to water table	feet	1
RFACT	Rainfall & runoff erosivity	100s foot-ton inches/hr/acre	1
ELEVATION	Mean watershed elevation	m above sea level	1
SLOPE	Mean watershed slope	percent	1
PPTAVG_BASIN	Mean basin precipitation (1971–2000)	centimeters/year	1
Gneiss	Gneiss	percent of basin	1
Granitic	Granitic	percent of basin	1
Ultramafic	Ultramafic	percent of basin	1
Quarternary	Quarternary	percent of basin	1
Sedimentary	Sedimentary	percent of basin	1
Volcanic	Volcanic	percent of basin	1
Anorthositic	Anorthositic	percent of basin	1
Intermediate	Intermediate	percent of basin	1
SGEO1–SGEO45	Surficial geology classes	percent of basin	1
HLR1–HLR 20	Hydrologic landscape regions	percent of basin	1
BEDROCK_PERM	Bedrock permeability	ordinal rank	1
wb 0-12	Monthly runoff estimates from water balance model, for months at time t=0 through t-12	millimeters	3
p 0-12	Monthly precipitation for months at time t=0 through t-12	millimeters	3
t 0-12	Monthly air temperature for months at time t=0 through t-12	degrees Celsius	3
p 2,3,6 sum	Sum of precipitation from previous 2, 3, or 6 months.	millimeters	3

Table 1–3. Geospatial indicators of human activities used as potential predictors in statistical models predicting monthly streamflow modification in California.

[km^2, square kilometer; NPDES, National Pollution Discharge Elimination System; m, meter. Data source indicates published source of geospatial data, where 1 = Falcone, 2011; 2 = U.S. Geological Survey (USGS), 2008a; 3 = U.S. Department of Agriculture, 2012; 4 = California Department of Water Resources, 2000; 5 = Grantham and others, 2014; 6 = USGS, 2008b; 7 = USGS, 2014; 8 = USGS, 2013]

Variable name	Description	Units	Data source
ARTIFPATH_PCT	Stream length classified as artificial channel	percent of total length	1
ARTIFPATH_MAINSTEM_PCT	Stream length classified as artificial channel	percent of main stem length	1
HIRES_LENTIC_PCT	Lakes, ponds, and reservoirs	percent of basin	1
HIRES_LENTIC_DENS	Lakes, ponds, and reservoirs	number per km^2	1
DDENS_2009	Dam density	number per km^2	1
MAJ_DDENS_2009	Major dam density	number per km^2	1
STOR_NOR_2009	Total reservoir storage	volume per km^2	1
pre1990_DDENS	Dam density prior to 1990	number per km^2	1
pre1990_STOR	Total reservoir storage prior to 1990	volume per km^2	1
CANALS_PCT	Stream length classified as canals	percent of total length	1
CANALS_MAINSTEM_PCT	Stream length classified as canals	percent of main stem length	1
NPDES_MAJ_DENS	NPDES point dischargers	number per km^2	1
FRESHW_WITHDRAWAL	Freshwater withdrawal	volume per km^2	1
PCT_IRRIG_AG	Irrigated agriculture	percent of basin	1
FRAGUN_BASIN	Fragmentation of undeveloped land	unitless	1
DEVNLCD06	Developed land	percent of basin	1
FORESTNLCD06	Forested land	percent of basin	1
PLANTNLCD06	Crop land	percent of basin	1
WATERNLCD06	Open water	percent of basin	1
NITR_APP_KG_SQKM	Nitrogen application	kilograms per km^2	1
PDEN_2000_BLOCK	Population density	persons per km^2	1
rd_km_tot	Road density	kilometer per km^2	2
rd_km_rip	Road density in riparian corridor	kilometer per km^2	2
rd_st_int	Road-stream intersection	number per km^2	2
canal_km	Length of canals	kilometer per km^2	1
canal_st_i	Canal-stream intersections	number per km^2	1
applied_wa	Applied agricultural water	acre feet per year per km^2	3, 4
ag_sqkm	Agricultural lands	percent of basin	1
cnt_stor	Storage reservoirs	number per km^2	5
cnt_hydro	Hydroelectric reservoirs	number per km^2	5
cnt_other	All other reservoirs	number per km^2	5

Table 1–3. Geospatial indicators of human activities used as potential predictors in statistical models predicting monthly streamflow modification in California.—Continued

[km^2, square kilometer; NPDES, National Pollution Discharge Elimination System; m, meter. Data source indicates published source of geospatial data, where 1 = Falcone, 2011; 2 = U.S. Geological Survey (USGS), 2008a; 3 = U.S. Department of Agriculture, 2012; 4 = California Department of Water Resources, 2000; 5 = Grantham and others, 2014; 6 = USGS, 2008b; 7 = USGS, 2014; 8 = USGS, 2013]

Variable name	Description	Units	Data source
ht_stor	Mean height of storage reservoir dams	meters	5
ht_hydro	Mean height of hydroelectric reservoirs	meters	5
ht_other	Mean height of all other reservoirs	meters	5
vol_stor	Total volume of storage reservoirs	acre feet per km^2	5
vol_hydro	Total volume of hydroelectric reservoirs	acre feet per km^2	5
vol_other	Total volume of all other reservoirs	acre feet per km^2	5
rip_ht	Riparian vegetation height within 100 m buffer of stream	meters	6
mine_cnt	Active mines	number per km^2	7
og_well	Oil and gas wells	number per km^2	8
divert_cnt	Water diversions	number per km^2	5
diver_fval	Total volume of diversions	acre feet per year per km^2	5
AnnualFACE_VALUE	Total diversions reported value	acre feet per year per km^2	5
JAN_USE–DEC_USE	Monthly water use	acre feet per month per km^2	5

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For more information concerning this report, contact:
Chief, National Water-Quality Assessment Program
U.S. Geological Survey
413 National Center
12201 Sunrise Valley Drive
Reston, VA 20192
http://water.usgs.gov/nawqa/

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Patterns and Magnitude of Flow Alteration in California, USA

Julie K. H. Zimmerman, The Nature Conservancy, 555 Capitol Mall, Suite 1290, Sacramento, CA 95814, julie.zimmerman@tnc.org

Daren M. Carlisle, National Water-Quality Assessment Program, US Geological Survey, 4821 Quail Crest Place, Lawrence, KS 66049, dcarlisle@usgs.gov

Jason T. May, California Water Science Center, U.S. Geological Survey, Sacramento, CA 95819, jasonmay@usgs.gov

Jeanette K. Howard, The Nature Conservancy, 201 Mission St. 4th Floor, San Francisco, CA 94105, jeanette_howard@tnc.org

Kirk R. Klausmeyer, The Nature Conservancy, 201 Mission St. 4th Floor, San Francisco, CA 94105, kklausmeyer@tnc.org

Larry R. Brown, California Water Science Center, U.S. Geological Survey, Sacramento, CA 95819, lrbrown@usgs.gov

Theodore E. Grantham, University of California, Berkeley, Department of Environmental Science, Policy & Management, 130 Mulford Hall #3114, Berkeley, California 94702, tgrantham@berkeley.edu

DRAFT

Keywords: environmental flows, hydrology, flow modeling, streamflow metrics, reference gages

Summary

The flow regime is a primary factor controlling the health of streams and rivers; thus, understanding the degree to which anthropogenic activities have altered flows is critical for assessing risk to river-dependent biota and for developing effective conservation strategies. Assessing flow alteration requires measurements of existing conditions and estimates of flows expected in the absence of human influence. Although there are several techniques to predict flows in streams and rivers, none have been applied to make predictions of natural flow conditions over large regions and time periods. Here we utilize machine learning statistical models to predict natural monthly flows in California from 1950 to 2015, using time-dependent and fixed watershed variables from reference stream gages. The models are then used to make estimates of mean, maximum, and minimum monthly flows in all stream flows in the state. We also compare expected natural flows with observed flows, measured at 540 stream gages across the state, to quantify the magnitude and character of flow alteration. A gage is considered altered if an observed flow metric falls outside the 90% prediction interval of the modeled flow estimate. We found that 90% of the 540 stream gages in California had at least one month of altered flows over the last 20 years (1996-2015), and 12% of the gages were frequently altered, for which over ⅔ of the months recorded had evidence of altered flows. The type of alteration varied across the state with flows being either depleted, inflated, or a mix of both at different times of the year. High flows (measured as the maximum daily flow for the year) were consistently depleted in the Sierra Nevada and Central Valley, whereas low flows were generally inflated in the South Coast. Understanding the patterns and degree of alteration can aid in prioritizing streams for environmental flow assessment and developing conservation strategies for native freshwater biota.

DRAFT

NOTE: This paper is currently in revision for submission to Freshwater Biology. The following excerpts are relevant to the unimpaired flow modeling, but do not represent the entire paper or the finished manuscript.

DRAFT

Introduction

The importance of the natural flow regime to stream and river health has received growing attention over the last two decades. Quantifying natural river flows has become an essential component of water resource planning, including assessments of water supplies (Vicuna et al. 2007; Wurbs 2005), reservoir operations (Hejazi, Cai, and Ruddell 2008), and drought risk (Meko et al. 2001). Understanding the natural flow regime is also crucial for managing stream ecosystems. Many studies have demonstrated that alterations of the natural flow regime are associated with changes in biological assemblages(Pringle, Freeman, and Freeman 2000; N. L. Poff and Zimmerman 2010; Miller, Wooster, and Li 2007) and altered hydrology is one of the dominant factors reported to affect the composition and health of aquatic species(Moyle and Mount 2007; Brown and Bauer 2010; N. L. Poff and Zimmerman 2010; Roy et al. 2005; Konrad, Brasher, and May 2008; Brooks et al. 2011). Managing river flows in a manner that preserves features of the natural hydrograph is thought to be essential for the long-term maintenance of river ecosystem health(N. Leroy Poff et al. 2010; Arthington et al. 2006; N. Leroy Poff et al. 1997; Yarnell et al. 2015)[JKH1] , and can also sustain benefits to society, such as water supply and hydroelectric power(Arthington et al. 2006; N. Leroy Poff et al. 2010).

The flow regimes of streams in mediterranean-climate regions such as California are characterized by particularly high seasonal and inter-annual variability (Gasith and Resh 1999). In fact, California has higher variability between wet and dry years than any other state in the USA, due to a small number of winter storms providing the bulk of the state's precipitation(Dettinger 2011). California is also characterized by strong spatial gradients in water availability – approximately 90% of the state's runoff comes from 40% of its land surface, predominately in the northern region and mountainous Sierra Nevada region to the east (Hanak 2011). California has managed this hydrologic variability with extensive water infrastructure that reduces temporal and spatial variation in water availability(Kondolf and Batalla 2005; Dettinger 2011). Operations of water infrastructure and human use of water has resulted in decreased variability in flows for many of California's rivers and streams(Kondolf and Batalla 2005); including both a reduction in high-magnitude flows and an increase in low-season flows in many rivers.[JKH2] The water management system has also intensified the effects of drought, by artificially reducing flows below that would be expected under natural conditions(He et al. 2017). Collectively, alteration to natural streamflow patterns has been documented to have negative effects on California's aquatic biota, and there is evidence that restoring components of natural hydrology can provide substantial ecological benefits(Kiernan, Moyle, and Crain 2012; Brown and Ford 2002; Kupferberg et al. 2012).

Managing streamflows for ecosystems objectives requires an understanding of the natural flow regime, the current (altered) flow regime, and an estimate of how much of a departure from the natural flow regime is acceptable for a set of ecological indicators(Carlisle, Wolock, and Meador 2011; Carlisle et al. 2010; Falcone et al. 2010). However, natural flow data are limited. The network of stream gages across the state is sparse in many areas and does not comprehensively represent all stream types (Lane et al. 2017). Most gages are located on streams that are already highly modified by human activities (e.g., upstream dams and diversions) and gage records prior to stream impacts are often limited. These limitations can be overcome using modeling approaches to make predictions of "expected" natural hydrologic conditions. For example, statistical models have been developed to predict monthly flow metrics (hereafter, "flow metrics") based on associations with natural basin characteristics(Carlisle et al. 2016, 2010). Monthly streamflow attributes are straight-forward to communicate in management contexts(Kendy, Apse, and Blann 2012), and have been shown to be ecologically relevant(Carlisle, Nelson, and May 2016a).

To better understand natural/unimpaired conditions, we developed flow models to predict monthly natural flows for all California streams from 1950 to 2015. We expanded on an initial effort to model natural flows(Carlisle et al. 2016) to include additional reference gages, improve spatial coverage, and add flow metrics, including mean, minimum, and maximum monthly flows. Our objectives were to: (1) quantify natural flow regimes for California streams by modeling monthly unimpaired flow statistics for all streams and rivers, gaged and ungaged, (2) assess the likelihood/frequency of hydrologic alteration for watersheds with gages using modeled natural and observed flow metrics; (3) identify the dominant type of alteration by hydrologic region.

DRAFT

Methods

Study area

We developed predictive models of natural flows (i.e., without the effects of water management or land use) for all stream segments in California. We followed the approach of Carlisle et al.(2016) and stratified the state into three regions for model development (Figure 1). These modeling regions were aggregations of Level 3 Ecoregions(Omernik 1987; US Environmental Protection Agency 2015), including the "xeric" (Central Basin and Range, Central California Foothills and Coastal Mountains, Central California Valley, Mojave Basin and Range, Sonoran Basin and Range, Southern California Mountains, Southern California/Northern Baja Coast), "interior mountains" (Cascades, Eastern Cascades Slopes and Foothills, Sierra Nevada), and "north coastal mountains" (Coast Range, Klamath Mountains/California High North Coast Range). For reporting purposes, we synthesized results into eight reporting regions based the California Department of Water Resources hydrologic regions (Ca. Dept. of Water Resources 2013) : North Coast, San Francisco Bay, Central Coast, South Coast, Sacramento River, San Joaquin and Tulare (combination of the San Joaquin River and Tulare Lake regions), North Lahontan, and Desert (combination of South Lahontan and Colorado River regions) (Figure 1).

DRAFT

The California Department of Water Resources divides the state into ten hydrologic regions: North Coast, San Francisco Bay, Central Coast, South Coast, Sacramento River, San Joaquin River, Tulare Lake, North Lahontan, South Lahontan, and Colorado River. Most precipitation falls in the north and east mountains, producing the highest runoff volumes for the North Coast and Sacramento River regions (>20 MAF in 2010) and lowest volumes for the North and South Lahontan, Central Coast, and San Francisco regions (<2 MAF in 2010). In contrast, water demands are concentrated in urban centers in San Fransisco Bay, Central Coast, and South Coast, and in agricultural regions including the San Joaquin River, Tulare Lake, and Colorado River.

General Modeling Approach

Reference sites are located in river basins that are hydrologically "least disturbed"(sensu Stoddard et al. 2006), and were identified using distinct approaches. The first approach relied on a published database of USGS streamgage watershed attributes (Falcone et al. 2010) that contains designations of least-disturbed sites. Those sites were identified through a 3-step screening process, described in detail by

Falcone et al. (2010), and summarized here. In step 1, hydrologic disturbance is estimated for each gaged basin using an index that combines several geospatially derived indicators, including total upstream reservoir storage, freshwater withdrawal, pollution discharge, and land cover. Gaged basins are then ranked on the value of this index, and only those within the lower 25th percentile are considered as candidates for reference sites(see Falcone et al. 2010 for details of calculations). In step 2, annual data reports for each gaging station are inspected for any notation indicating anthropogenic streamflow modification results in the designation of the site as "non-reference". In step 3, the land use within each basin upstream of the gage site is visually inspected. Publicly available satellite imagery and USGS topographic maps are examined for any indication of human activity with the potential to modify streamflows, such as diversions, irrigated agriculture, and wastewater inflows in close proximity to the stream gage. Of the reference gages identified by Falcone et al. (2010) through the 3-step screening process, 146 were located within our study area.

To increase the number and spatial density of reference sites for this study, we used two additional screening approaches. First, we identified 548 USGS gaging sites in California that had been excluded from the 3-step reference-site screening efforts described above(Falcone et al. 2010) because the period of streamflow record was < 20 years. Because contemporaneous land cover and hydrologic data are unavailable for most of these sites (i.e., pre 1980s), we modified the GIS-based screening step (step 1) used by Falcone et al. (2010) exclude sites that had experienced any increases in urbanization or agricultural land cover between 1974-2012 (Falcone 2015). For the remaining gages, we applied the Falcone et al. (2010) screening steps 2 and 3, as described above. This approach yielded 45 new reference sites (11-yr average length of flow record post 1950, minimum 5 yrs) in the study area.
We then considered gages in California that had been classified as non-reference (n=641) by Falcone et al.(2010), but contained periods of flow record that preceded substantial anthropogenic influences.

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USGS published annual data reports (i.e., Falcone et al. 2010 step 2 above) and data inventories were examined to determine whether periods of record existed prior to discrete (e.g., reservoir construction) or recent (e.g., urbanization) anthropogenic influences. This final screening process yielded 59 additional reference sites (25-yr average length of record post 1950).

In total, 250 reference sites were identified within the study area, including those previously identified by Falcone et al.(2010) (n=146) and those added according to the methods described above (n=104) (Figure 1). For each of these reference sites, we obtained observed monthly streamflow statistics, downloaded from the National Water Information System(US Geological Survey 2016), including:

1. Monthly mean flow (mean of daily flows for all months, 1950-2015, excluding months with < 20 daily values)
2. Monthly minimum and maximum flow (minimum and maximum daily flow value for all months, 1950-2015, excluding months with < 20 daily values).

Evaluating Representativeness of Reference Sites

We evaluated how environmentally representative the reference gaged basins were with respect to non-reference gaged basins and the population of stream basins in California (as defined by NHD). Three basin variables known to be important predictors (Carlisle et al. 2010) of flows (basin size, mean annual precipitation, aridity--defined as the difference between mean annual precipitation and mean annual potential evapotranspiration) were selected and their distributions compared among gaged reference sites, gaged non-reference sites, and the basins of all stream segments of the NHDPlus (V2) network [JKH2] (ADD NHDPlus REFERENCE HERE). We also compared the distributions of three variables indicative of human disturbance: reservoir storage volume, cultivated land cover, urban land cover. Significant overlap in the distributions of these variables among gaged sites and all stream segments suggests that models developed at gaged reference sites could reasonably be applied to gaged non-reference sites, as well as to the entire California stream network.

Two limitations to the comparisons of basin characteristics were imposed. First, the comparisons were limited to non-gaged basins similar in size to those of gaged basins (Table 1). This resulted in the exclusion of many small headwater stream segments that are present in the stream network but are not represented in the stream gaging network.

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Modeling Baseline Conditions

Separate statistical models were developed to predict monthly streamflow statistics in each of the three model regions (i.e., 12 months x 3 monthly statistics x 3 regions = 108 models). We considered a broad set of predictor variables for potential inclusion in the models, including 113 static, physical watershed characteristics described in Carlisle et al.(2016) and Supplementary Table XX, and monthly climate data [JKH1] concurrent with, and antecedent to, the respective monthly flow period(University Center for Atmospheric Research 2017). These climate data included monthly total precipitation and mean monthly air temperature(Daly et al. 2008), as well as estimated monthly runoff volume(McCabe and Wolock 2011), for the month of interest and each of the previous 12 months. By including monthly precipitation for the 12 months prior to measured flow, we are attempting to approximate the influence of groundwater storage on streamflow. In summary, the initial training dataset for each model included every annual observation for which each reference site had a measured monthly flow statistic, the set of climate and runoff variables associated with each year's monthly flow statistic and the previous 12 months (39 predictors), and 113 static variables representing physical watershed characteristics (Supplementary Table XX).

Model training followed procedures described by(Carlisle et al. 2016) using random forests (RF)(Cutler et al. 2007), an aggregated tree-based (e.g. classification and regression trees) statistical modeling approach(Hill, Hawkins, and Carlisle 2013; Olson and Hawkins 2013). The first step in model training was to restrict the number of predictor variables. To do so, we ran each model 40 times, each using a different, randomly-selected subset (90%) of the reference sites and recorded the relative importance of all predictor variables, based on their Gini score (Cutler et al. 2007). Predictors with the highest score are those that when excluded from the models, cause the largest loss in of model performance, as measured by a decrease in mean square error. For each model run, the top-15 ranked predictors were recorded and the resulting list from the 40 iterations (typically 10-20 total predictors) was used in the final model. This approach to predictor selection has the advantage of being objective and robust (due to measuring variable importance on different subsets of the calibration data), but still required an arbitrary decision to consider only the top 15 (vs. 5 or 10) predictors of each RF model, and may still not have identified the most parsimonious set of predictors (e.g., Stroble and others, 2007). Nevertheless, given the general robustness of RF to overfitting (Kuhn and Johnson 2013) and the large numbers of observations in calibration sets, the approach balances the risk of overfitting with obtaining the best predictive performance for the models as possible. All models were developed using the Random Forest package (Liaw, 2015) within the R computing environment (R Core Team 2016).

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Model Performance

Final RF models were fit with the restricted set of predictors and performance was again assessed by generating 40 randomly selected calibration (90% of reference sites sampled, without replacement) and validation (10% of reference sites) datasets, using several model performance statistics(Moriasi et al.

2007). These included the squared correlation coefficient (r^2) between observed and predicted monthly flows and the Nash-Sutcliffe coefficient of model efficiency (NSE), which measures the total residual variance (that is, generated from model predictions) relative to the total variance within the data. NSE is an indicator of how well observed and predicted data would fit on a 1:1 line. Similar to the squared correlation coefficient, NSE values near 1.0 are generally accepted as indicative of good model performance. We also computed percent bias (PBIAS), which estimates the model's tendency to over predict (PBIAS>0) or under predict (PBIAS<0), and the root mean square error normalized by the standard deviation of all observations, which is a standardized measure of model error. Finally, summary statistics for each validation site were calculated, including the mean (among years) ratio of observed and predicted flow (i.e., O/E), and the associated standard deviation. Computation of O/E for model performance statistics were made after adding a constant to both O and E to avoid zeros. All model performance statistics were averaged across the 40 iterations of the validation models.

Using the final, trained models, predictions of natural monthly flow statistics for each month and year (1950-2015) were made at each NHD stream segment(Horizon Systems 2015) within the boundaries of CA (n=139,912) for which the same set of static physical and climate variables used in model development were calculated. Each RF model was composed of 1,000 trees, each of which generates a prediction for the respective monthly flow statistic. We calculated the mean value of the predictions, as well as the 10th and 90th percentile files to represent lower- and upper-confidence bounds for the flow statistic in each month and year.

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Results

Unimpaired flow models

Overall, the natural flow models accurately predicted observed monthly flows at reference sites, although performance varied by region and flow statistic (see Table S1 in Supporting Information). Across all models, reference sites withheld for validation exhibited mean O/E values from 0.73 to 1.03 (median = 0.94); r-squared of observed and predicted values ranged from 0.33 to 0.94 (median = 0.80); and percent bias ranged from -80 to 9 (median = -3). In general, models for the interior mountains and coastal mountains performed better than those for the xeric region, and models for minimum and mean monthly flows performed better than those for maximum monthly flows. For information on how to access the full database of unimpaired flow data, see Text S1 in Supporting Information.

With some exceptions, natural environmental features of the watersheds of reference basins were similar to those of non-reference (i.e., hydrologically disturbed) watersheds, as well as features of the stream network as a whole (Table 1). With respect to drainage area, reference watersheds had a similar range of size as non-reference and the NHD. However, most watersheds in the NHD are much smaller (even after removing basins < 1km2) than gaged sites, as evidenced by a median size ~20x smaller than that of reference and non-reference gaged watersheds. The distribution of mean annual precipitation was generally similar among reference, non-reference, and the NHD. In contrast, reference and non-reference sites had similar levels of aridity, but both types of basins tended to be much less arid than the NHD. These results indicate that arid basins are underrepresented in the streamgaging network of California, and that our flow predictions for the NHD network in arid areas should be interpreted with caution. Nevertheless, given the low likelihood that additional stream gages will be installed in arid areas, our predictions represent the best available estimates of natural flows for the time being.

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Tables

Table 1. Basin characteristics of reference and assessed USGS gages in California, USA relative to the National Hydrography Dataset (NHDPlus Version 2) stream network (n=139,912 segments) statewide. Aridity index is the difference between mean annual precipitation and mean annual potential evapotranspiration.

		USGS Gages		
Variable	Percentile	Reference (n=250)	Assessed (n=540)	NHD Network
Drainage area (km^2)	1	2	7	1
	25	57	78	3
	50	185	247	9
	75	656	1,025	54
	99	21,949	29,382	21,653
Mean ann. precipitation (mm)	1	25	27	11
	25	59	60	42
	50	88	94	67
	75	122	125	114
	99	234	211	255
Mean aridity index (mm)	1	-644	-604	-1,222
	25	-132	-117	-356
	50	220	326	-28

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	75	672	721	538
	99	1,710	1,517	1,951
Reservoir storage (Ml / km^2)	1	0	0	0
	25	0	0	0
	50	0	2,868	0
	75	0	125,701	0
	99	2044	5,235,493	5,224,768
Cultivation agriculture (pct)	1	0	0	0
	25	0	0	0
	50	0	0	0
	75	0	0	0
	99	1	25	64
Urban development (pct)	1	0	0	0
	25	0	0	0
	50	0	1	0
	75	1	4	1
	99	10	75	71

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Supporting Information

Figure S1. Regions used for statistical model development. These regions are based on groupings of the U.S. Environmental Protection Agency Level 3 ecoregion.

Table S1. Performance statistics of models predicting natural maximum, mean, and minimum monthly flows in California regions.

Text S1. Online Data Repository and Visualization.

Due to space limitations, we were unable to provide figures of hydrographs for all stream gages in California. Instead, we built an online interactive visualization that allows a user to select one or several stream gages and see the corresponding hydrograph of observed and expected flows overtime. The URLs for the online visualizations are here:

Mean monthly flows: https://public.tableau.com/views/California_Stream_Flow_Alteration/mean

Maxium and minimum annual flows:

https://public.tableau.com/views/California_Stream_Timing_Alteration/minmax

We have also uploaded the full dataset of observed flows for all stream gages, and expected flows for all stream segments in California. This database is too large to download in its entirety, so we have built an application programming interface (API) to access the data. For the full documentation and examples of how to access the data through the API, visit this URL: https://rivers.codefornature.org

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CALIFORNIA
Water Boards

Edmund G. Brown Jr.
GOVERNOR

Matthew Rodriquez
SECRETARY FOR
ENVIRONMENTAL PROTECTION

State Water Resources Control Board

September 7, 2017

Thomas Ballestero, Ph.D.
Associate Professor & Director
UNH Stormwater Center
University of New Hampshire
238 Gregg Hall, 35 Colovos Road
Durham, NH 03824

SUBJECT: INITIATION OF REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTROL BOARD'S DRAFT *CANNABIS CULTIVATION POLICY – PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION*

Dear Professor Ballestero:

The purpose of this letter is to initiate the external peer review.

All components for the review are posted at a secure FTP site. They include:

1. August 10, 2017 memorandum from Leslie Grober, Deputy Director of the Division of Water Rights. The subject of the memorandum is "Request for External Peer Review of the California State Water Resources Control Board's Draft *Cannabis Cultivation Policy – Principles and Guidelines for Cannabis Cultivation* transmitting the following attachments:

   - Attachment 1: Summary of the Cannabis Cultivation Policy – Principles and Guidelines for Cannabis
   - **Attachment 2: Description of Scientific Assumptions, Findings and Conclusions to be Addressed by Peer Reviewers** (You have indicated you can address Conclusion 4 with confidence; you are free to address other conclusions where you can provide insight, as well as the Big Picture section at the end of Attachment 2)
   - Attachment 3: Names of Participants Involved in Developing the Cannabis Cultivation Policy
   - Attachment 4: References for Draft Cannabis Cultivation Policy and Staff Report
   - Attachment 5: Draft Cannabis Cultivation Policy Principles and Guidelines for Cannabis Cultivation – July 7, 2017
   - Attachment 6: Draft Cannabis Cultivation Policy – Staff Report – July 7, 2017

- Attachment 7: USGS: National Water Quality Assessment Project – Estimating Natural Monthly Streamflows in California and the Likelihood of Anthropogenic Modification
- Attachment 8: Patterns and Magnitude of Flow Alteration in California, USA

2. January 7, 2009, Supplement to the Cal/EPA Peer Review Guidelines.

Comments on the Foregoing

1. January 7, 2009, Supplement. In part, the Supplement provides guidance to ensure the review is kept confidential through its course. It also notes reviewers are under no obligation to discuss their comments with third-parties after reviews have been submitted. We recommend they do not. All outside parties are provided opportunities to address a proposed regulatory action through a well-defined regulatory process. Please direct third parties to me.

Questions about the review, or material, should be for clarification, in writing – email is fine, and addressed to me. My responses will be in writing also.

Access to secure FTP site:

https://ftp.waterboards.ca.gov/

Username: PRFTP
Password: Water123

Please send your reviews to me by September 27, 2017. I will subsequently forward all reviews to Leslie Grober, Division of Water Rights, with Curriculum Vitae for each reviewer. All this information will be posted at the State and Regional Water Boards' Scientific Peer Review website, and at the Division of Water Rights program website for this proposal.

Your acceptance of this review assignment is most appreciated.

Sincerely,

Gerald W. Bowes

Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
Office of Research, Planning and Performance
State Water Resources Control Board
1001 "I" Street, 16th Floor
Sacramento, California 95814

Telephone: (916) 341-5567
FAX: (916) 341-5284
Email: GBowes@waterboards.ca.gov

CALIFORNIA
Water Boards

Edmund G. Brown Jr.
GOVERNOR

Matthew Rodriquez
SECRETARY FOR
ENVIRONMENTAL PROTECTION

State Water Resources Control Board

September 1, 2017

James A. Gore, Ph.D., Dean
College of Natural and Health Sciences
University of Tampa
PH 201, 401 W. Kennedy Boulevard
Tampa, FL 33606

SUBJECT: INITIATION OF REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTROL BOARD'S DRAFT *CANNABIS CULTIVATION POLICY – PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION*

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   - Attachment 1: Summary of the Cannabis Cultivation Policy – Principles and Guidelines for Cannabis
   - **Attachment 2: Description of Scientific Assumptions, Findings and Conclusions to be Addressed by Peer Reviewers** (Earlier, you indicated you could address conclusions 2 and 3 with confidence, but feel free to address other conclusions where you feel you could provide insight).
   - Attachment 3: Names of Participants Involved in Developing the Cannabis Cultivation Policy
   - Attachment 4: References for Draft Cannabis Cultivation Policy and Staff Report
   - Attachment 5: Draft Cannabis Cultivation Policy
     Principles and Guidelines for Cannabis Cultivation – July 7, 2017
   - Attachment 6: Draft Cannabis Cultivation Policy – Staff Report – July 7, 2017

- Attachment 7: USGS: National Water Quality Assessment Project – Estimating Natural Monthly Streamflows in California and the Likelihood of Anthropogenic Modification
- Attachment 8: Patterns and Magnitude of Flow Alteration in California, USA

2. January 7, 2009, Supplement to the Cal/EPA Peer Review Guidelines.

Comments on the Foregoing

1. January 7, 2009, Supplement. In part, the Supplement provides guidance to ensure the review is kept confidential through its course. It also notes reviewers are under no obligation to discuss their comments with third-parties after reviews have been submitted. We recommend they do not. All outside parties are provided opportunities to address a proposed regulatory action through a well-defined regulatory process. Please direct third parties to me.

Questions about the review, or material, should be for clarification, in writing – email is fine, and addressed to me. My responses will be in writing also.

Access to secure FTP site:

https://ftp.waterboards.ca.gov/

Username: PRFTP
Password: Water123

Please send your reviews to me by September 28, 2017. I will subsequently forward all reviews to Leslie Grober, Division of Water Rights, with Curriculum Vitae for each reviewer. All this information will be posted at the State and Regional Water Boards' Scientific Peer Review website, and at the Division of Water Rights program website for this proposal.

Your acceptance of this review assignment is most appreciated.

Sincerely,

Gerald W. Bowes

Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
Office of Research, Planning and Performance
State Water Resources Control Board
1001 "I" Street, 16th Floor
Sacramento, California 95814

Telephone: (916) 341-5567
FAX: (916) 341-5284
Email: GBowes@waterboards.ca.gov

CALIFORNIA
Water Boards

EDMUND G. BROWN JR.
GOVERNOR

MATTHEW RODRIQUEZ
SECRETARY FOR
ENVIRONMENTAL PROTECTION

State Water Resources Control Board

September 1, 2017

Joe Magner, Ph.D.
Research Professor
Department of Bioproducts and Biosystems Engineering
College of Science and Engineering
University of Minnesota
16 Bio Ag Eng Building
1390 Eckles Avenue
St. Paul, MN 55108

SUBJECT: INITIATION OF REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTROL BOARD'S DRAFT *CANNABIS CULTIVATION POLICY – PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION*

Dear Professor Magner:

The purpose of this letter is to initiate the external peer review.

All components for the review are posted at a secure FTP site. They include:

1. August 10, 2017 memorandum from Leslie Grober, Deputy Director of the Division of Water Rights. The subject of the memorandum is "Request for External Peer Review of the California State Water Resources Control Board's Draft *Cannabis Cultivation Policy – Principles and Guidelines for Cannabis Cultivation* transmitting the following attachments:

    - Attachment 1: Summary of the Cannabis Cultivation Policy – Principles and Guidelines for Cannabis
    - **Attachment 2: Description of Scientific Assumptions, Findings and Conclusions to be Addressed by Peer Reviewers** (Earlier, you indicated you could address all four conclusions with confidence, but felt Conclusion 1 was the best fit. I recommend you cover all conclusions where you feel you can provide insight).
    - Attachment 3: Names of Participants Involved in Developing the Cannabis Cultivation Policy
    - Attachment 4: References for Draft Cannabis Cultivation Policy and Staff Report
    - Attachment 5: Draft Cannabis Cultivation Policy Principles and Guidelines for Cannabis Cultivation – July 7, 2017

- Attachment 6: Draft Cannabis Cultivation Policy – Staff Report – July 7, 2017
- Attachment 7: USGS: National Water Quality Assessment Project – Estimating Natural Monthly Streamflows in California and the Likelihood of Anthropogenic Modification
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Your acceptance of this review assignment is most appreciated.

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Gerald W. Bowes

Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
Office of Research, Planning and Performance
State Water Resources Control Board
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Telephone: (916) 341-5567
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CALIFORNIA
Water Boards

Edmund G. Brown Jr.
GOVERNOR

Matthew Rodriquez
SECRETARY FOR
ENVIRONMENTAL PROTECTION

State Water Resources Control Board

September 1, 2017

Diane McKnight, Ph.D.
Professor and Director
Center for Water, Earth Science and Technology
Environmental Engineering Program
College of Engineering and Applied Science
University of Colorado Boulder
ECES 124, 1111 Engineering Drive
Boulder, CO 80309

SUBJECT: INITIATION OF REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTROL BOARD'S DRAFT *CANNABIS CULTIVATION POLICY – PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION*

Dear Professor McKnight:

The purpose of this letter is to initiate the external peer review.

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• Attachment 1:	Summary of the Cannabis Cultivation Policy – Principles and Guidelines for Cannabis
• **Attachment 2:**	**Description of Scientific Assumptions, Findings and Conclusions to be Addressed by Peer Reviewers** (Earlier, you indicated you would be able to address with confidence Conclusions 1 and 2).
• Attachment 3:	Names of Participants Involved in Developing the Cannabis Cultivation Policy
• Attachment 4:	References for Draft Cannabis Cultivation Policy and Staff Report
• Attachment 5:	Draft Cannabis Cultivation Policy Principles and Guidelines for Cannabis Cultivation – July 7, 2017
• Attachment 6:	Draft Cannabis Cultivation Policy – Staff Report – July 7, 2017

- Attachment 7: USGS: National Water Quality Assessment Project – Estimating Natural Monthly Streamflows in California and the Likelihood of Anthropogenic Modification
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1. January 7, 2009, Supplement. In part, the Supplement provides guidance to ensure the review is kept confidential through its course. It also notes reviewers are under no obligation to discuss their comments with third-parties after reviews have been submitted. We recommend they do not. All outside parties are provided opportunities to address a proposed regulatory action through a well-defined regulatory process. Please direct third parties to me.

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Please send your reviews to me by September 27, 2017. I will subsequently forward all reviews to Leslie Grober, Division of Water Rights, with Curriculum Vitae for each reviewer. All this information will be posted at the State and Regional Water Boards' Scientific Peer Review website, and at the Division of Water Rights program website for this proposal.

Your acceptance of this review assignment is most appreciated.

Sincerely,

Gerald W. Bowes

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Manager, Cal/EPA Scientific Peer Review Program
Office of Research, Planning and Performance
State Water Resources Control Board
1001 "I" Street, 16th Floor
Sacramento, California 95814

Telephone: (916) 341-5567
FAX: (916) 341-5284
Email: GBowes@waterboards.ca.gov

January 7, 2009

Supplement to Cal/EPA External Scientific Peer Review Guidelines – "Exhibit F" in Cal/EPA Interagency Agreement with University of California

Gerald W. Bowes, Ph.D.

Guidance to Staff:

1. Revisions. If you have revised any part of the initial request, please stamp "Revised" on each page where a change has been made, and the date of the change. Clearly describe the revision in the cover letter to reviewers, which transmits the material to be reviewed. The approved reviewers have seen your original request letter and attachments during the solicitation process, and must be made aware of changes.

2. Documents requiring review. All important scientific underpinnings of a proposed science-based rule must be submitted for external peer review. The underpinnings would include all publications (including conference proceedings), reports, and raw data upon which the proposal is based. If there is a question about the value of a particular document, or parts of a document, I should be contacted.

3. Documents not requiring review. The Cal/EPA External Peer Review Guidelines note that there are circumstances where external peer review of supporting scientific documents is not required. An example would be "A particular work product that has been peer reviewed with a known record by a recognized expert or expert body." I would treat this allowance with caution. If you have any doubt about the quality of such external review, or of the reviewers' independence and objectivity, that work product – which could be a component of the proposal - should be provided to the reviewers.

4. Implementation review. Publications which have a solid peer review record, such as a US EPA Criteria document, do not always include an implementation strategy. The Cal/EPA Guidelines require that the implementation of the scientific components of a proposal, or other initiative, must be submitted for external review.

5. Identity of external reviewers. External reviewers should not be informed about the identity of other external reviewers. Our goal has always been to solicit truly independent comments from each reviewer. Allowing the reviewers to know the identity of others sets up the potential for discussions between them that could devalue the independence of the reviews.

6. Panel Formation. Formation of reviewer panels is not appropriate. Panels can take on the appearance of scientific advisory committees and the external reviewers identified through the Cal/EPA process are not to be used as scientific advisors.

7. Conference calls with reviewers. Conference calls with one or more reviewers can be interpreted as seeking collaborative scientific input instead of critical review. Conference calls with reviewers are not allowed.

Guidance to Reviewers from Staff:

1. Discussion of review.

   Reviewers are not allowed to discuss the proposal with individuals who participated in development of the proposal. These individuals are listed in Attachment 3 of the review request.

   Discussions between staff and reviewers are not permitted. Reviewers may request clarification of certain aspects of the review process or the documents sent to them.

   Clarification questions and responses must be in writing. Clarification questions about reviewers' comments by staff and others affiliated with the organization requesting the review, and the responses to them, also must be in writing. These communications will become part of the administrative record.

   The organization requesting independent review should be careful that organization-reviewer communications do not become collaboration, or are perceived by others to have become so. The reviewers are not technical advisors. As such, they would be considered participants in the development of the proposal, and would not be considered by the University of California as external reviewers for future revisions of this or related proposals. The statute requiring external review of science-based rules proposed by Cal/EPA organizations prohibits participants serving as peer reviewers..

2. Disclosure of reviewer Identity and release of review comments.

   Confidentiality begins at the point a potential candidate is contacted by the University of California. Candidates who agree to complete the conflict of interest disclosure form should keep this matter confidential, and should not inform others about their possible role as reviewer.

   Reviewer identity may be kept confidential until review comments are received by the organization that requested the review. After the comments are received, reviewer identity and comments must be made available to anyone requesting them.

   Reviewers are under no obligation to disclose their identity to anyone enquiring. It is recommended reviewers keep their role confidential until after their reviews have been submitted.

3. Requests to reviewers by third parties to discuss comments.

   After they have submitted their reviews, reviewers may be approached by third parties representing special interests, the press, or by colleagues. Reviewers are under no obligation to discuss their comments with them, and we recommend that they do not.

   All outside parties are provided an opportunity to address a proposed regulatory action during the public comment period and at the Cal/EPA organization meeting where the proposal is considered for adoption. Discussions outside these provided avenues for comment could seriously impede the orderly process for vetting the proposal under consideration.

4. <u>Reviewer contact information</u>.

The reviewer's name and professional affiliation should accompany each review. Home address and other personal contact information are considered confidential and should not be part of the comment submittal.

THOMAS P. BALLESTERO

Professional Preparation

The Pennsylvania State University	Civil Engineering	B.S.	1975
The Pennsylvania State University	Civil Engineering	M.S.	1977
Colorado State University	Civil Engineering	Ph.D.	1981

Appointments

University of New Hampshire	Associate Professor, Water Resources Engineering	1983-present
University of New Hampshire	Director, UNH Stormwater Center	2002-2004, 2012-present
University of New Hampshire	Director, Water Resources Research Center	1986 – 1999
USFWS	Hydrologist (IPA)	2007-2012

Products Closely Related to the Project

1. Kirshen, P., Christy Miller Hesed, Ruth, Matthias. Michael J. Paolisso, Ballestero, Tom. Ellen Douglas, Chris Watson, Philip Giffee, Kim Vermeer, Chris Marchi, Bosma, K, 2017, Engaging Vulnerable Populations in Multi-Level Stakeholder Collaborative Urban Adaptation Planning, Journal of Planning Education and Research. Submitted March 2017.
2. Ballestero, Thomas P., 2013, Trees Incorporated into Urban Stormwater Management, in Urban Forestry: Toward an Ecosystem Services: A Workshop Summary, Katie Thomas and Laurie Geller, Rapporteurs, Research Board on Atmospheric Sciences and Climate; Division on Earth and Life Studies; National Research Council, The National Academies Press, ISBN 978-0-309-28758-6
3. Parasiewicz, P., Ryan, K., Vezza, P., Comoglio, C., Ballestero, T. and Rogers, J. N. (2012), Use of quantitative habitat models for establishing performance metrics in river restoration planning. Ecohydrol.. doi: 10.1002/eco.1350
4. Roseen, Robert, Nicolas DiGennaro, Alison Watts, Thomas Ballestero, James Houle, 2010, Preliminary Results of the Examination of Thermal Impacts from Stormwater BMPs , in Proceedings of World Environmental and Water Resources Congress 2010: Challenges of Change by Richard N. Palmer, Ph.D., P.E., D.WRE, (editor), Reston, VA,(doi 10.1061/41114(371)352)
5. Barbu, I.A., T.P. Ballestero, and R.M. Roseen. "LID-SWM practices as a means of resilience to climate change and its effects on groundwater recharge." *EWRI – 2009 World Environmental & Water Resources Congress: the 6th Urban Watershed Management Symposium*, ASCE Conf. Proc. 342, 134, **2009**. DOI: 10.1061/41036(342)134

Other Significant Products

1. Ballestero, Thomas P., 2013, Trees Incorporated into Urban Stormwater Management, in Urban Forestry: Toward an Ecosystem Services: A Workshop Summary, Katie Thomas and Laurie Geller, Rapporteurs, Research Board on Atmospheric Sciences and Climate; Division on Earth and Life Studies; National Research Council, The National Academies Press, ISBN 978-0-309-28758-6
2. Parasiewicz, P., K. Ryan, P. Vezza, C. Claudio, T. Ballestero, and J.N. Rogers. "Use of quantitative habitat models for establishing performance metrics in river restoration planning." Ecohydrology, online first, 2012. DOI: 10.1002/eco.1350
3. Roseen, R.M., L.K. Brannaka, and T.P. Ballestero. "Thermal Imagery And Field Techniques To Evaluate Groundwater Nutrient Loading To An Estuary." *Conference Proceedings for American Geophysical Union Spring Meeting, Special Session: Groundwater Flux at the Land-Ocean Margin: Physics, Chemistry, and Ecology*, Boston, MA, March, **2001**.
4. Roseen, R.M., T.P. Ballestero, J.J. Houle, P. Avellaneda, G. Fowler, and R. Wildey. "Seasonal performance variations for stormwater management systems in cold climate conditions." *J Environ*

Eng, **135**(3): 128-37, **2009**. DOI: 10.1061/(ASCE)0733-9372(2009)135:3(128)

5. Avellaneda, P., Ballestero, T.P., Roseen, R.M., and J.J. Houle. "On parameter estimation of an urban stormwater runoff model." *J Environ Eng,* **135**(8): 595-608, **2009**. DOI: 10.1061/(ASCE)EE.1943-7870.0000028
6. Ballestero, T.P., Roseen, R.M., and G.F. Bacca-Cortes. "Land use influence on the characteristics of groundwater inputs to the Great Bay Estuary, NH." In *Watershed Management to Meet Water Quality Standards and Emerging TMDL (Total Maximum Daily Load) Proceedings of the Third Conference, Atlanta, GA, 5-6 March, 2005.* St. Joseph, MI: American Society of Agricultural and Biological Engineers, **2005**.

Synergistic Activities

1. *Flood susceptibility hydraulic analyses for the following projects*: Route 4 at Bunker and Johnson Creeks, Durham, NH; Route 1 at Sagamore Creek, Portsmouth, NH; Route 4 at the Bellamy River.
2. *Supervised modeling effort of the Piscataqua River estuary* (from the General Sullivan bridge to the ocean). The focus of the study was hydraulic and sediment transport modeling. *Technical advice* on port location, construction, and sediment consequences for the Port of Pecem in Ceará, Brazil, as well as on coastal erosion protection at the US Coast Guard Humboldt Bay Coast Guard Station.
3. *Stream restoration and designs for aquatic organism passage* performing all aspects of stream restoration including: field geomorphic measurements; stream restoration designs; wetlands restoration designs; stream restoration construction supervision; dam removal; fish bypass designs; hydraulic analyses of stream restoration alternatives; hydrologic studies; and assessment of stream channel instabilities (bank erosion, loss of islands, inability to move sediment). Projects include Bowman Creek, Quaker Run, Berry Brook, Crooked Creek, Johnson Brook, and Bentley Creek. Collaborators include Trout Unlimited, NH Fish & Game, and US Fish & Wildlife Service.
4. *Started a field demonstration/research facility for the study of stormwater technologies*. The site is located on UNH property. There, stormwater from a nine-acre parking lot is collected and distributed to various stormwater treatment technologies. In addition, additional sites have been constructed and other technologies tested. The UNH facility is a nationally unique site able to produce data on treatment effectiveness.

Collaborators and Co-Editors*: Pedro Avellaneda (U Nat Colombia), Iulia Barbu (AECOM), Larry Brannaka (USFWS), Joshua Briggs (UNH), Claudio Comoglio (DIATI, Italy), Mark Eberle (USACE), Diane Foster (UNH), George Fowler (UNH), Kevin Gardner (UNH), James Gruber (Antioch), Jeff Gunderson (freelance editor), James Houle (UNH), Todd V. Janeski (Virginia Comm U), Heather Jensen (USACE), Steve Jones (UNH), Julie LaBranche (Rockingham Planning Comm), Ernst Linder (UNH), Daniel Medina (Cornell), Fred Paillett (UME), Piotr Parasiewicz (UMass), David Putnam (USFWS), Corey Riley (GBNERR, Joseph N. Rogers (UMass), Robert Roseen (Geosyntec), Kathleen Ryan (UMass), Michael Simpson (Antioch), Paul Stacey (GBNERR), Paolo Vezza (DIATI, Italy), Alison Watts (UNH), Robert Wildey (UNH)

* GBNERR = Great Bay Nat Estuarine Research Reserve	UNH = Univ New Hampshire
USFWS = US Fish & Wildlife Service	USACE = US Army Corp of Engineers

Graduate Advisors and Postdoctoral Sponsors: Arthur C. Miller (Penn St U), Vujica Yevjevich (dec.)

Thesis Advisor and Postgraduate-Scholar Sponsor:
Graduate students advised (57): Jose Edberto da Silva (U Fed de Pernambuco, Brazil), Pedro Avellaneda (U Nat Colombia), Iulia Barbu (UNH), Josh Briggs (Geosyntec), Heidi Borchers (UNH), Melinda Bubier (UNH), Sergio dos Santos (U Fed Ceará), Renee Fitsik (Geosyntec), Rob Flynn (USGS), George Fowler (Woidt Engineering), Matt Hergott (GZA GeoEnvironmental), Kristopher Houle (Horsley Witten Group), Kevin MacKinnon (Vanasse Hangen Brustlin, Inc), Edberto Silva (U Fed Pernambuco), Megan Wengrove (UNH), Robert Wildey (UNH)

Post-graduate scholars sponsored (1): Hironori Hayashi (Kyushu U)

James A. Gore, PhD
Dean *Emeritus*, College of Natural and Health Sciences
Professor of Biology (*Retired)*
University of Tampa
Email: jgore@ut.edu

B.A.	(Zoology),	University of Colorado (1971)
M.A., Ph.D.	(Zoology)	University of Montana (1976, 1981)

Recent Professional Experience

- Professor of Environmental Science (2004-2009), University of South Florida St Petersburg; [**Interim Dean** (2006-2007)], College of Arts and Sciences, University of South Florida St Petersburg; [**Chair** (2004 – 2007)], Environmental Science, Policy and Geography, University of South Florida St Petersburg [Tenured 2004]
- Associate Professor/Professor (1996 – 2004), **Director**, Graduate Program in Environmental Science, **Chair**, Department of Environmental and Health Sciences, Columbus State University, Columbus, GA [Tenured 1998]

Relevant Publications

Gore, J.A., J. Banning, and A.F. Casper. 2016. River Resource Management and the Effects of Changing Landscapes and Climate. Pp. 295-312. *In*: D.J. Gilvear, M.T. Greenwood, M.C. Thoms, and P.J. Wood (eds.) *River Science: Research Applications for the 21st Century*. Wiley Blackwell, Chichester.

Lamouroux N., **Gore J.A.**, Lepori F. & Statzner B. (2015) The ecological restoration of large rivers needs science-based, predictive tools meeting public expectations: an introduction to the Rhône project. *Freshwater Biology* DOI:10.1111/fwb.12553

Casper, A.F., B. Dixon, J. Earls, and **J.A. Gore.** 2011. Linking a spatially explicit watershed model (SWAT) with an in-stream fish habitat model (PHABSIM): A case study of setting minimum flows and levels from a low gradient, sub-tropical river. *River Research and Applications* 27: 269-282.

Kelly, M.H., and **J. A. Gore**. 2008. Florida river flow patterns and the Atlantic Multidecadal Oscillation. *River Research and Applications* 24: 598-616.

Gore, J.A., and J. Mead. 2008. The Benefits and Dangers of Ecohydrological Models to Water Resource Management Decisions. Pp. 112 – 137. *In:* D. Harper, M. Zalewski, and N. Pacini (eds.) *Ecohydrology: Processes, Models and Case Studies. An approach to the sustainable management of water resources.* CABI Publ., London.

Gore, J.A., J.B. Layzer, and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: a role in stream and river restoration. *Regulated Rivers* 17: 527-542.

Gore, J.A. 2001. Models of Habitat Use and Availability to Evaluate Anthropogenic Changes in Channel Geometry. Pp 27-36 *in:* J. Dorava (ed.) **American Geophysical Union Monograph** *Geomorphic Processes and Riverine Habitat*. Water Science and Application, Volume 4.

Timchenko, V., O. Oksiyuk, and **J.A. Gore**. 2000. A model for ecosystem state and water quality management in the Dnieper River delta. *Ecological Engineering* 16: 119-125.

SHORT CURRICULUM VITAE

Dr. Joseph Anthony Magner
Research Professor
Department of Bioproducts & Biosystems Engineering
University of Minnesota (UM)
1390 Eckles Ave., St. Paul, MN 55108
ORCID ID: 0000-0001-8775-5112; ResearchGate score, 22.68
jmagner@umn.edu

ACADEMIC PREPARATION & REGISTRATION:

B.S. (with honors) - Soil & Water Science, University of Wisconsin, River Falls, 1979.
Ph.D. - Hydrology & Watershed Management, University of Minnesota, St. Paul, 2006.
Watershed-Stream Restoration Engineering; 500 hours training from 1996-1999.
AIH - Registered Professional Hydrogeologist - 1988
State of Minnesota - Licensed Geoscientist (Soils) - 1998
State of Wisconsin - Licensed Hydrologist – 1999

ADDITIONAL APPOINTMENTS:

Fulbright Specialist, Council for International Exchange of Scholars, USA State Dept.
(*Invited* – Visiting Professor, Khazar University, Baku, Azerbaijan)
Visiting Professor, Fu Jen University, Taipei, Taiwan; 2015
Visiting Professor, Qingdao University, Qingdao, China; 2014
Visiting Professor, University of the Free State, Bloemfontein, South Africa; 2013,
Graduate School Appointments: WRS, NRSM and BBSEM

INSTRUCTIONAL EXPERIENCE:

Environmental and Ecological Engineering (1-credit, UM)
Hydrology and Water Quality Field Methods (3-credit, UM)
Water Quality of a Natural Resource (3-credit, UM)
Assessment & Diagnosis of Impaired Waters (3-credit, UM)
Agroforestry in Watershed Management (3-credit, UM)

PROFESSIONAL EXPERIENCE:

2011- present: Research Professor UMN; Direct water research projects and manage 10-15 graduate and civil service staff; Teach Fall and Spring Semesters.
2006-2013: Principal Research Scientist, MN Pollution Control Agency (MPCA), Impaired Waters Nonpoint Source Management Program.
2006- present: Water Resources Consultant; clients include: EPA Grant Review, David Letterman Ranch, Choteau MT, Mizoram State Government, India, Environmental Defense Fund and state and local units of government in Minnesota.
1979-2006: Research Hydrologist, MPCA, Clean Water Research

RELEVANT RESEARCH PROJECTS & GRANTS:

PI: Quantifying Cropland-Riparian Water Management: 2016-2019; $283,787; EPA 319

Co-PI: Global Spotlight award focusing on agriculture, climate change and human development in Mizoram: 2014-2015; $100,000; UMN international funds.
PI: Implementing the "watershed approach" in Beargrass minor watershed, central Indiana: 2014-2018; $1,200,000; NRCS CIG and Walton Foundation providing match.
PI: Defining and measuring water quantity & quality in Dobbins Creek watershed using a treatment train to trap and treat: 2014-2018; $333,952 via State, District and EPA 319.
Co-PI: Quantifying hydrologic impacts of drainage under corn production systems in the upper Midwest: 2014-2017; $496,740 with MN Corn Growers Association.
PI: Developing the One Watershed One Plan Land Use Management Strategy: 2013-2017; $225,000; MN Board of Water and Soil Resources.
PI: Nutrient sequestration & flood management in the Red River Basin using engineered flood impoundments; 2014-2018: $288,394; Environmental Trust Fund and EPA 319.
Co-PI: Baseflow restoration in Minnehaha Creek with storm water infiltration: 2012-2014; $100,000; Minnehaha Creek Watershed District.
Co-PI: Tile Outlet Treatment Trains in Elm Creek: 2013-2016; $165,000; EPA 319.

RELEVANT PUBLICATIONS:

Brooks, K.N., Ffolliott, P.F. and **Magner**, J.A.: (2013). HYDROLOGY AND THE MANAGEMENT OF WATERSHEDS, 4th edition, Wiley-Blackwell, Hoboken, NJ.

Krider, L., J. **Magner**, B. Hansen, B. Wilson, G. Kramer J. Peterson, and J. Nieber. (2017) Improvements in fluvial stability associated with two - stage ditch construction in Mower County, Minnesota. *Journal of the American Water Resources Association* doi: 10.1111/1752-1688.12541.

Dolph, C., Vondracek, B. Eggert, S. **Magner**, J. Farrington, L. (2015) Reach-scale stream restoration in agricultural streams of southern Minnesota alters functional responses of macroinvertebrates. *Freshwater Science* 34: DOI: 10.1086/680984.

Krider, L. **Magner**, J. and Perry, J. (2013) Air-water temperature relationships in the trout streams of Southeastern Minnesota's karst landscape. *Jour. of Amer. Water Res. Asso.* 49:896-907 (DOI 10.1111/jawr12046).

Magner, J., Hansen, B., Sundby, T., Wilson, B. and Nieber, J. (2012). Channel evolution of southern Minnesota ditches. *Environmental Earth Sciences* 67: 2359-2369, (DOI 10.1007/s12665-012-1682-3).

Lenhart, C., K. Brooks, S. Verry and J. **Magner.** (2012). Adjustment of a prairie pothole stream to land-use, drainage and climate change: past history and active processes. *River Research & Applications* DOI: 10.1002/rra.1549

Magner, J.A. (2011). Tailored Watershed Assessment and Integrated Management (TWAIM): A Systems Thinking Approach. *WATER* 3:590-603. (INVITED)

Asmus, B., **Magner**, J.A., Vondracek, B., Perry, J., (2009). Physical Integrity: the missing link in biological monitoring and TMDLs. *Environmental Monitoring and Assessment,* 159: 443-463.

Green, M.B., Nieber, J.L., Johnson, G., **Magner**, J.A., Schaefer, B., (2007). Hydrologic influence on N: P ratios in two headwater streams: A paired watershed study. *Journal of Geophysical Research-Biogeosciences.* Vol. 112, G03015, doi: 10.1029/2007JG000403.

Komor, S. and J.A. **Magner**., (1996). Nitrate in ground water and water sources used by riparian trees in an agricultural watershed: A chemical an isotopic investigation in Southern Minnesota. *Water Resources Research,* 32:1039-1050.

Statzner, B., **J.A. Gore**, and V.H. Resh. 1998. Monte Carlo simulation of benthic macroinvertebrate populations: Estimates using random, stratified, and gradient sampling. *J.N. Am. Benthol. Soc.* 17: 324-337.

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Honors/Awards

FULBRIGHT SENIOR RESEARCH FELLOWSHIP - Council for the International Exchange of Scholars - Freshwater Research Unit, Univ. of Cape Town, South Africa - regulated river management projects - Jan 1989 - Sept 1989

U.S. Dept. of Energy/Assoc. of Western Universities Faculty Research Participation Award - Laramie Energy Technology Center, Univ. of Wyoming - toxicology research - Summer, 1983

Assoc. of Western Universities/ U.S. Dept. of Energy Fellowship - Western Research Institute, Univ. of Wyoming - toxicology of treated synfuel effluents - Summer, 1984.

Columbus State University – Faculty Research and Scholarship Award – 2000
Columbus State University – Faculty Research and Scholarship Award – 2004

Lifetime Achievement Award – August 2015 - International Society for River Science

Recent Professional Service

1999-Present	Scientific Advisory Board – United Nations/UNESCO – International Hydrology Program (IHP) – section on ecohydrology
2006-2015	Board of Directors – International Society for River Science
2010-Present	Delta Science Program – Analysis of the collapse of the Sacramento River Fishery – Sponsored by the National Marine Fisheries Service and the US Fish and Wildlife Service

Diane M. McKnight, Professor

Institute of Arctic and Alpine Research
University of Colorado
1560 30th Street
Boulder, CO 80309-0450
Tel: (303) 492-4687
Fax: (303) 492-6388
email: diane.mcknight@colorado.edu

Education
Massachusetts Institute of Technology Mechanical Engineering B.S., 1975
Massachusetts Institute of Technology Civil Engineering M.S., 1978
Massachusetts Institute of Technology Environmental Engineering Ph.D., 1979
U. S. Geological Survey, NRC Fellow Hydrology 1979-1980

Professional experience:
Professor of Civil, Environmental and Architectural Engineering, University of Colorado, 1999-present
Fellow of INSTAAR, University of Colorado, 1996-present
Associate Professor of Civil, Environmental and Architectural Engineering, University of Colorado, 1996-1999
Research hydrologist, National Research Program, U. S. Geological Survey, 1980-1996

Recent related publications:

Miller, M. P., Boyer, E. W., McKnight, D. M. , Brown, M. G., Gabor, R. S., Hunsaker, C. T., Iavorivska, L., Inamdar, S., Johnson, D. W., Kaplan, L. A., Lin, H, , McDowell, W. H., Perdrial. J. N. 2016. Variation of organic matter quantity and quality in streams at Critical Zone Observatory watersheds, Water Resources Research, 52, 8202–8216, *doi:*10.1002/2016WR018970.

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Synergistic activities: 1: American Geophysical Union, (Acting President of Biogeosciences Section, 2000-2002), 2: Editor, JGR-Biogeosciences, 2004-2009, 3: AGU Chapman Conference on Lakes and Climate Change, member of steering committee, 2008, 4; Long Term Ecological Research Network, Chair of Editorial Committee of the Schoolyard Book Series, 2003-present, and 5: Member, National Academy of Engineering, 2012.

Collaborators and other affiliations:
Graduate advisors: S.W. Chisholm, F.M. M. Morel
Collaborators: R. Anderson, S. Anderson, J. Barrett, C. Blodau, W. Bowman, E. Boyer, Y. Chin, P. Doran, C. Foreman, A. Fountain, M. Gooseff, A. Howkins, W. B. Lyons, D. Nemergut, J. Priscu, R. Runkel, M. Sanclements, T. Seastedt, C. Takacs, R. Virginia, M. Williams, D. Wall,.

Students (of 14 Ph.D, and 26 M.S.): A. Bomblies, K. Cawley, R. Cory, K. Cozzetto, M. Gooseff, A. Hickey, J. Koch, M. Miller, N. Mladenov, D. Niyogi, D. T. Scott, S. Spaulding, L. Stanish, A. Todd.

Review of the California State Water Resources Control Board's DRAFT Cannabis Cultivation Policy – Principles and Guidelines for Cannabis Cultivation

Thomas P. Ballestero, PhD, PE, PH, CPGW, PG
Director, UNH Stormwater Center
University of New Hampshire
29 September 2017

This review first addresses the fourth focus area of Attachment 2 dealing with aquatic base flows and groundwater diversions. Following that section, appear comments on other Attachments as well as brief responses to Overview (Big Issue) questions.

1. Attachment 2: Conclusion 4

The ABF Standard is an appropriate method to use to develop interim groundwater low flow thresholds in California, modification to the ABF Standard is appropriate for California's climate and aquatic resources, the ABF Standard was applied correctly, and the ABF Standard spreadsheet calculator correctly calculated the dry season instream flow requirements.

The Application and use of the New England Aquatic Base Flow (NE ABF) methodology and applied to California (CA) hydrology is an appropriate method. There is sufficient documentation to understand the method and data that were used to develop the CA ABF. The development of the policy for surface diversions (Attachment A, Section 4, Table 1) is understandable and supported by the analyses presented in the Staff Report. What is not clear is how the Groundwater Instream Flow Requirements in the same Table 1 were developed. No mention of groundwater appears in the Policy for Maintaining Stream Flows in Northern California Coastal Streams (Instream Flow Policy) (State Water Board 2014). In the North Coast Instream Flow Policy (R2 Resource Consultants, Inc. and Stetson Engineers, Inc., 2007), the study specifically ignored groundwater pumping: "*…does not consider the indirect effects of shifting water extraction from surface water diversion to alternate sources, such as groundwater pumping…*" The Carlisle paper (Carlisle, D.M., Wolock, D.M., Howard, J.K., Grantham, T.E., Fesenmyer, Kurt, and Wieczorek, Michael, 2016) was the methodology employed to develop mean monthly flows from which the CA ABF flows were derived, but this document also does not address groundwater diversions and how they affect stream flows. Existing groundwater diversions are most likely built into the Carlisle model; however the model does not predict surface water reductions as a result of future groundwater diversions or switching from surface water to groundwater diversion.

No documentation was presented to clearly follow how the groundwater diversion thresholds were established and why they vary compared to the surface water diversion values. Additionally, no evidence was provided to support the general lag between groundwater diversion and the effect in nearby streams.

"*The State Water Board will monitor instream flows during the dry season and evaluate the number and location of cannabis groundwater diversions to determine whether imposition of a groundwater forbearance period is necessary. To address potential localized effects of groundwater diversions on surface water flow, the State Water Board will also monitor where significant numbers of surface water diverters are switching to groundwater diversions to evaluate whether imposition of a groundwater forbearance period is necessary.*" The way that the policy reads is that a period of monitoring the implementation of this policy will be performed, and then at some point in the future a more adaptive strategy will be developed. An adaptive strategy is understandable given the site specific relationships between groundwater and surface water. Given the original vagueness on the technical aspects of how groundwater diversion thresholds were developed, the adaptive strategy is also thin on details. For example, What type of data infers the need to modify the proposed Rule? No documentation was supplied to support the logic behind future adaptations.

2. Attachment 1: Summary

First paragraph under Problem Statement indicates practices and consequences but provides no references or data.

3. Attachment 5. Draft Cannabis Cultivation Policy

Page 10, Surface Water Diversion Forebearance Period paragraph, third line from the bottom of the paragraph. "breeding ques"? Not clear what this is.

Page 10 after the text, "streamflow[7]" there is an extra period.

Page 15, fourth line, word missing, suggested text in italics, "… activity, and also present a lower *risk* to water quality…"

The groundwater forebearance concept in the DRAFT rule relies solely on surface water data without much attention paid to physical watershed hydrology. This concept is certainly understandable in that the response of surface water flow due to groundwater diversions are delayed and muted in time and space. The DRAFT rule recognizes that hydraulic connection between surface waters and groundwaters may exist and that groundwater withdrawals have the potential to reduce surface water flows in a delayed fashion, contrary to direct surface water withdrawal. However shallow and deep groundwater flows are a complex system. The draft rules recognize that *high surface water-groundwater connectivity; large numbers of cannabis groundwater diversions; and/or groundwater diversions in close proximity to streams* may affect instream flows. It is understood that the rules were developed in expeditious fashion, which is pointed out various times in the documents. However the holistic principles of watershed hydrology may be oversimplified while at the same time recognizing that applicants who fall under this policy require site level regulations. This has bearing on the location of compliance gages with respect to each site of groundwater withdrawal: the hydraulically further the site from the compliance gage, the less likely that controls (reduced groundwater pumping) during the allowable groundwater period will have in instream flows. In other words, the groundwater pumping period, for use as a water management strategy, is variable to each groundwater withdrawal and its site specific hydrologic relation to each compliance gage. There is no supporting analysis to reveal how the groundwater threshold flows were determined other than to say the NE ABF method was used, which is curious because the NE ABF describes surface water flow: diversions are then regulated in order to meet the ABF. Exactly what was performed to yield the ultimate threshold flows is unknown.

It is not clear why the enterprises under the section Exemption for Indoor Cultivation Activities are exempt. Do they not require water withdrawals that potentially affect instream flows?

Page 19, Enforcement section, last sentence: "*Appropriate penalties and other consequences for violations prevent cultivators that do not comply with the Requirements from obtaining an unfair competitive advantage and help ensure public confidence in the regulatory framework*". While competitive advantage control is a laudable objective, one would think that the penalties and other consequences are more importantly enforced to promote receiving water ecosystem characteristics: water flow, water quality, aquatic habitat, riparian habitat, wetlands, and springs. Additionally, that water use is not unreasonable.

Attachment A, page 6, Soil Materials. There seems to be an errant underscore prior to the first word in the definition.

Section 3.5. In addition to Narrative Flow Requirement 4, at all times the cannabis cultivators shall bypass a minimum of 50 percent of the surface water flow past their point of diversion, as estimated based on visually observing surface water flow at least daily. Visual estimation of streamflow in order to comply with policy is not an accurate or reliable method to manage surface waters. In addition, no limiting size to stream or watershed is given for this metric. This 50% flow bypass metric seems entirely subjective.

Attachment A Section 3.7, page 43. "*The State Water Board has developed Numeric instream flow Requirements (minimum instream flow requirements) for each compliance gage in Section 4, Table 1 through Table 14, to ensure that individual and cumulative effects of water diversion and discharge associated with cannabis cultivation do not affect the instream flows needed for* *fish spawning, migration, and rearing, and the flows needed to maintain natural flow variability…*" Where is the technical support for this paragraph? There are no references, citations, etc. to direct the reader to the technical basis for Requirements or the developed values.

Attachment A Section 3.8, page 43. "*This Policy establishes a low flow threshold, calculated by applying the New England Aquatic Base Flow Standard, as one mechanism to help monitor whether groundwater diverters are having a cumulative negative impact on surface flows.".* As with the previous comment, it is not evident upon which reports, documents, etc. the groundwater diversion flows are developed.

Attachment A Section 3. Gage Installation, Maintenance, and Operation Requirements, page 44. It may seem trivial, but "inspection" is not mentioned in this paragraph which covers operation and maintenance. Inspection must be clearly spelled-out and discussed in any O&M plan.

Attachment A Section 4. Tables 1, 2. The ABF method was developed using USGS streamgages with drainage areas of 50 mi^2 or greater. Gage drainage areas should appear in these tables.

In addition, up until this point of the Rule, there is no clear rational demonstrated for the Groundwater Low Flow Threshold.

4. Attachment 6. Staff Report

Table 3. Water Quality Contaminants and Percent Impairment in the Nine Policy Priority Regions. Note that for first three listed regions in this Table, Temperature is a major impairment. This is relevant because a hydrologic issue overlooked in the Policy and the Staff Report is that when groundwater diversions do replace surface water diversions, although there may be a zero net effect on watershed flow, temperature will be a casualty in the cold water fisheries: by leaving warmer surface water and removing groundwater base flows, logically the result will be warmer overall surface waters. In addition, groundwater discharge zones would be expected to shrink, potentially adversely affecting hyporheic fluxes.

Page 31. BACKGROUND AND RATIONALE FOR POLICY REQUIREMENTS FOR WATER DIVERSION AND WASTE DISCHARGES ASSOCIATED WITH CANNABIS CULTIVATION. Section on Turbidity. Only sediment is discussed. Excess nutrient loads have the potential to increase algae and other plant species, also thereby affecting turbidity.

Page 44, BACKGROUND AND RATIONALE FOR INSTREAM FLOW AND GAGING REQUIREMENTS, Diversion Rate Section. The maximum 10 gpm diversion at this juncture seems arbitrary and unsupported, especially since it seems to apply to all streams of any watershed size and climatic zone.

Page 50 Low Flow Thresholds. There simply is not sufficient detail to understand how the NE ABF method was used to ultimately develop the specified groundwater low flow thresholds in Policy Attachment A, Section 4: "Watershed Compliance Gage Assignments.

Page 50-51, BACKGROUND AND RATIONALE FOR INSTREAM FLOW AND GAGING REQUIREMENTS. Methodology for Development of Dry Season Low Flow Threshold Values Section. The description of the ABF method is accurate. What is silent is if there is a minimum watershed size on which to apply the ABF default flows on ungaged streams. However the CA intent is at the watershed scale at Compliance gages, at which each potential cannabis cultivator plays a role. As previously mentioned, the drainage areas for each Compliance gage should be included in the table of Policy Attachment A, Section 4: "Watershed Compliance Gage Assignments. The stream flow database (USGS/TNC) employed to develop the CA ABF, based on mean monthly flow values, is consistent with the NE ABF method development. The CA ABF went further and developed the CA ABF on the lowest median monthly flows on a regional basis in order to accommodate a more accurate timing (month of lowest median flow), which is also consistent with the intent of the NE ABF method. What is missing is the fundamental data for each Compliance gage (monthly flow probability distributions, monthly flow statistics, etc.) from which the ISF and groundwater thresholds are developed. The methodology that is described is technically sound for the ISF and surface water diversion Policy. The groundwater low flow thresholds of Policy Attachment A, Section 4: "Watershed Compliance Gage Assignments remain a mystery in the Staff Report.

Big Picture Questions

In reading the Policy and Staff Report, are there any additional scientific conclusions that should be a part of the scientific portion of the proposed Policy that are not described above?

The details of the Groundwater Low Flow Threshold need to be presented and supported.

Taken as a whole, is the scientific portion of the Policy based upon sound scientific knowledge, methods, and practices?

Overall, very good scientific basis was employed to develop the instream flows identified in the Policy.

24 September 2017

External Review of Conclusions 2 and 3 of the State Water Resources Control Board's proposed *Cannabis* Cultivation Policy

James A. Gore, PhD
Emeritus Dean
College of Natural and Health Sciences
Professor of Biology (*Retired*)
University of Tampa
Tampa, Florida 82606

NOTE: Those areas highlighted in blue are commentary provided by the State Water Board with my evaluation below those comments.

"2. To expeditiously develop numeric instream flow requirements statewide, State Water Board used naturalflow statistics developed by the United States Geological Survey (USGS) in collaboration with The Nature Conservancy and Trout Unlimited (USGS natural flow modeling approach). The USGS natural flow modeling approach used a peer-reviewed methodology to develop the flow statistics. **The USGS natural flow modeling approach used appropriate modeling inputs and R scripts. and the modeling outputs stored in the database predict the unimpaired flow statistics as intended."**

"3. The State Water Board developed interim wet season numeric instream flow requirements throughout California using the Tessmann method. **The Tessmann method is an appropriate method to use to develop interim instream flow requirements in California, was applied correctlv, and the Tessmann method spreadsheet calculator correctlv calculated the wet season instream flow requirements."**

The Tessman method (modified from the Tennant method), comes from a body of models referred to as unlinked intermediate models using hydrographic techniques (Gore and Mead 2008) and local biological opinion. These techniques largely assume that gauged hydrographic records reflect flows that support aquatic life in that system (Wesche and Rechard 1980). That is, even with input of local biologists, that the existence of flowing water are sufficient to maintain ecosystem integrity. Tennant chose to divide the water-year into several components and recommend flows for each increment. The Tessman method (developed for northern Great Plains prairie rivers) follows a similar protocol but uses different component blocks. This is similar to other modifications (see, for example, the Arkansas method for warmwater rivers [Filipeck *et al.* 1987]). The greatest differences between all of these models is the separation of component blocks and the protocol for determining mean monthly flow allocations.

However, the assumptions of these models only apply where streams are undeveloped or where development has been stable for a sufficiently long period of time to supply an adequate post-development hydrographic record (Stalnaker *et al.* 1995). Where development is on-going or will significantly change in the future, it is possible to reconstruct the natural hydrograph from gauging records, when accounting for current diversions and withdrawals, but this requires that the water manager make some significant assumptions and speculations about the condition of the fishery prior to disturbance (Bayha 1978). Among the body of intermediate unlinked models, the Tennant or Tessman modification are considered to be the most generous of minimum flow / instream flow / environmental flow allocations to protect the riverine ecosystem.

Assuming that the USGS model to estimate natural flows is sufficient for the state of California, then the State Water Board report indicates an adequate application of the Tessman method has been achieved and I believe that the minimum flows predicted by the method adequate, on an *interim* basis. The operative word in this rule is "*interim"* and should not be considered to be adequate for a final minimum flow allocation as it does not link biological requirements of target species to the flows as they exist, even when a wetted perimeter is maintained.

A sufficient body of evidence exists that flow related habitat criteria are unique and specific to almost all biota existing in a lotic environment. These flow-related criteria (velocity, depth, near-bed hydraulics, and substrate/cover) have worked together over time to influence body morphology, physiological success, and foraging ability (Gore *et al.* 2008; Statzner and Higler 1986; Statzner *et al.* 1988). So, the final determination of an adequate minimum / environmental flow should be predicated upon a comprehensive analysis of ecohydrological requirements by the biota. As an additional analysis to the existing *interim* methodology and recommendation, State Water Board may want to consider a *stop-gap* analysis to address at least some biological criteria; that is, by assuring that connectivity is maintained to ensure the ability of likely target species to move upstream or downstream over the course of a year. The State Water Board report acknowledges that this is a concern, even on an interim basis. I suggest that State Water Board may want to consider analyzing flow records to maintain fish passage depth criteria, generally considered to be 0.6 ft, for salmonid species (Thompson 1972; Hupalo *et al.* 1994). An example of this relatively rapid analysis (using HEC-RAS) has been demonstrated by the Southwest Florida Water Management District (2002) who combined wetted perimeter criteria with minimum fish passage criteria to arrive at a minimum flow recommendation. Although this technique has been abandoned for subsequent minimum flow recommendations, it is adequate on an *interim* basis.

"For the development of long-term instream flow requirements, the State Water Board, in consultation with CDFW, will evaluate other scientifically robust methods that are more reflective of regional variability and the needs of target species."

Appropriately, the State Water Board has indicated that more "robust methods" that tie hydrologic and hydraulic requirements to target species habitat requirements must be accomplished in order to recommend long-term instream flow requirements. It is imperative that the *interim* recommendations not be the final recommendations.

I suggest that the State Water Board consider a building-block approach (Postel and Richter 2003), that attempts to partition the water year into identifiable habitat blocks (for example, wetted perimeter, targeted spawning requirements, floodplain inundation, etc.) (Gore et al. 2016). This method creates an integrated approach to maximizing water availability yet retaining a natural hydrograph and ecological integrity.

Regardless of the type of approach to defining ecological flows in riverine ecosystems, five elements must be considered before an adequate decision can be made. These are: (1) the goal (such as restoring or maintaining a certain level of ecosystem structure), (2) the resource (target fish species or certain physical conditions), (3) the unit of achievement (how achievement of the goal is measured; such as a certain discharge, in cfs), (4) the benchmark time period (over 20 years of hydrographic record, for example), and (5) the protection statistic (a mean monthly flow or a mean daily or weekly flow) (Beecher 1990).

The appropriate habitat model, as a component of the building blocks to determine special habitat needs, is yet to be chosen and ranges from a relatively simple and effective one-dimensional model such as the physical habitat simulation (PHABSIM) (see Stalnaker *et al.* 1995) to simple statistical approaches (Lamouroux and Capra 2002).

Regardless of the choice of habitat model, the State Water Board should also consider carefully, the appropriate benchmark time period. In my opinion, it is no longer appropriate to choose the previous 20-years as the period of record for analysis (even to include the "natural flow statistic" already described by the State Water Board in item 2 (above). Analysis of longer periods of record, encompassing multi-decedal shifts in weather pattern will provide the most effective representation of natural flows. These analyses will have significant affect upon time-series analysis of habitat availability and significant ecological harm.

A number of oceanic temperature anomalies that affection continental precipitation and runoff patterns at a regional scale have been recognized (Pekarova *et al.* 2003; McCabe and Wolock 2008; Nunn *et al.* 2007) and these long-term, but oscillating shifts, should have an affect on choice of benchmark time period. Historically, it has been assumed that annual variation in rainfall and thus streamflow is a more or less random event; thus, the previous 20 years of record (or any other interval) is a representative segment of hydrographic history. On the North American east coast, the Atlantic Multi-decadal oscillation (AMO) has significant impact on streamflow patterns as a regular, cyclical event (Enfield et al. 2001; Kelly and Gore (2008). The AMO has such strong influence on streamflow patterns that the Southwest Florida Water Management District chose to create management strategies based upon AMO-influenced wet-hydrographic periods and dry-hydrographic periods (see Kelly and Gore 2008 and Gore *et al.* 2016). It can be demonstrated that significant shifts in biotic community composition occur during these multi-decadal patterns and that different water withdrawal and diversion strategies must be considered (Gore *et al.* 2016). Mantua *et al.* (1997) noted that there is a statistical relationship between El Nino (ENSO), the Pacific Decadal Oscillation (PDO) and the AMO, meaning that they are not actually independent events. Consideration of the impacts of the ENSO and PSO [and to a lesser degree, the AMO] on California natural flow regimes and instream flow evaluations should also be a high priority. I suggest that the creation of the natural flow statistic described in the report make assurances that long-term precipitation cycles also be incorporated.

The State Water Board report describes a number of ungauged watersheds that will also be important to consider for future instream flow evaluations. Although it might be expensive to implement gaging records at this time and inappropriate to wait until at least 20 years of record are available to make an initial attempt at an instream flow evaluation, there are alternative GIS-based techniques to provide instream flow evaluations (Casper *et al.* 2011).

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UNIVERSITY OF MINNESOTA

Department of Bioproducts and Biosystems Engineering
College of Food, Agricultural and Natural Resource Sciences
College of Science and Engineering

BBE North
Kaufert Lab
2004 Folwell Avenue
St. Paul, MN 55108-6130
612-624-1293
Fax: 612-625-6286

BBE South
BioAgEng Building
1390 Eckles Avenue
St. Paul, MN 55108-6005
612-625-7733
Fax: 612-624-3005

E-mail: bbe@umn.edu
Web: www.bbe.umn.edu

September 26, 2017

Gerald W. Bowes, Ph.D.
Manager, Cal/EPA Scientific Peer Review Program
Office of Research, Planning and Performance
Stat Water Resources Control Board
1001 I Street, Sacramento, CA 95814

RE: **EXTERNAL PEER REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTROL BOARD'S DRAFT *CANNABIS CULTIVATION POLICY – PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION*** and presented as per **Attachment 2: Description of Scientific Assumptions, Findings and Conclusions to be addressed by Peer Reviewers.**

Reviewer Charge: External Review Sections – I have divided the review into several sections: *Page 1*, **Attachment 2 – Conclusion 1I**) items from the draft policy and staff report which need additional clarification or more detail to ensure that the policy will be digestible for cannabis cultivators as well as consultants that may be asked to provide guidance to the cultivators, *Page 6*, **Attachment 2 - Conclusion 1II**) comments on the individual parts of the staff report, *Page 9*, **Attachment 2 – Conclusion 2**) review of Carlisle et al., 2016. USGS Open-File Report 216-1189 and the concordant draft manuscript titled "Patterns and magnitude of flow alteration in California, USA" by Zimmerman et al., (in review), *Page 12*, **Attachment 2 – Conclusions 3 and 4**, Big Picture questions that I feel are necessary to contemplate before permitting takes place to achieve the goal of being protective of water quality and quantity for both surface water (SW) and groundwater (GW) in California, and References cited in the review. I also provide examples from the Minnesota experience with SW and GW quality and quantity; these are issues due to large scale agricultural production and industrial use—relevant to this review.

Attachment 2: Description of Scientific Assumptions, Findings and Conclusions to be addressed by Peer Reviewers

1) The requirements in Draft Policy, Attachment A. **Sections 1- 4 will reduce water quality and water diversion impacts associated with cannabis cultivation.** I respectfully disagree with this statement based on detailed comments presented for the Policy and Principles document (Attachment 5), and the Staff Report (Attachment 6).

I) Draft California Cannabis Cultivation Policy - Principles, and Guidelines

Overall impressions of the policy - The report does a good job of identifying potential issues foreseen with cannabis cultivation in California. The draft policy provides an expectation for cultivators to follow and suggested measures to prevent pollution and instream flow maintenance for protection of water quality and quantity. I appreciate the acknowledgement that California has a varied topography, climate, precipitation regime, and stream types, wherein different management needs and restrictions may be required. Further, I understand that the timeline for review and implementation of this policy is a short window for consideration of outside review comments and big picture concerns. Nevertheless, I hope that some of the big picture and other items mentioned here can be thought about and concerns addressed prior to implementation of the policy to ensure that cannabis cultivation in California "does not have a negative impact on water quality, aquatic habitat, riparian habitat, wetlands, and springs."

Comments on individual parts of the policy

Page 6 – *"Water Code section 13149 authorizes the State Water Board to develop both interim and long-term requirements* ***and update them as necessary****. It is anticipated that the State Water Board will update this Policy* ***over time*** *to modify or add requirements to address cannabis cultivation impacts, as needed."*

What is the anticipated timeline for additional review? 2 years, 5 years? Might be important to set up an expectation for this to occur, to ensure that it does occur and pre-develop a means to track decisions and the concordant response.

Page 27. *45 -* ***Cannabis cultivators shall only divert water such that water does not scour the channel bed or banks at the downstream end. Cannabis cultivator shall divert flow in a manner that prevents turbidity, siltation, and pollution and provides flows to downstream reaches. Cannabis cultivators shall provide flows to downstream reaches during all times that the natural flow would have supported aquatic life. Flows shall be of sufficient quality and quantity, and of appropriate temperature to support fish and other aquatic life both above and below the diversion. Block netting and intake screens shall be sized to protect and prevent impacts to fish and wildlife.***

This is a critical piece of the policy to ensure that aquatic life is protected from pollution, has sufficient flow, as well as securing a stable channel. Will cultivators know how to interpret this information? Would a training session be sufficient, or would this require a watershed consultant that is familiar with fluvial geomorphology, hydrology, and habitat quality? How will cultivators know if temperatures in waterbodies are appropriate above and below diversions? Will they or someone else be monitoring this? If not done already, these items should have more detail on how this is to be interpreted and who will be responsible for training, monitoring, and management.

Page 30 - 64. ***Cannabis cultivators shall not disturb aquatic or riparian habitat, such as pools, spawning sites, large wood, or shading vegetation*** *unless authorized under a CWA section 404 permit, CWA section 401 certification, Regional Water Board WDRs (when applicable), or a CDFW LSA Agreement.*

How will cultivators know how to identify these aquatic features? Road crossings will likely occur in shallow areas that may be riffles and spawning areas for federally listed and endangered fish and other species. Will or should a professional be consulted when placing road crossings on streams?

Page 31 - 72. *Cannabis cultivators shall ensure that all water diversion facilities are designed, constructed, and maintained so they do not prevent, impede, or tend to prevent the passing of fish, as defined by Fish and Game Code section 45, upstream or downstream, as required by Fish and Game Code section 5901.* ***This includes but is not limited to the supply of water at an appropriate depth, temperature, and velocity to facilitate upstream and downstream aquatic life movement and migration.*** *Cannabis cultivators shall allow sufficient water at all times to pass past the point of diversion to keep in good condition any fish that may be planted or exist below the point of diversion as defined by Fish and Game Code section 5937. Cannabis cultivators shall not divert water in a manner contrary to or inconsistent with these Requirements.*

Again, similar question. How will cultivators know what is an appropriate depth, temperature, and velocity? A watershed consultant familiar with aquatic species requirements will likely be needed to ensure compliance.

Page 31 - 74. *Water diversion facilities shall include* ***satisfactory means for bypassing water to satisfy downstream prior rights and any requirements of policies for water quality control, water quality control plans, water quality certifications, waste discharge requirements, or other local, state or federal instream flow requirements. Cannabis cultivators shall not divert in a manner that results in injury to holders of legal downstream senior rights. Cannabis cultivators may be required to curtail diversions should diversion result in injury to holders of legal downstream senior water rights or interfere with maintenance of downstream instream flow requirements.***

This seems to be a large responsibility to know and respond appropriately by individual cultivators. Will the State Water Board staff be responsible for oversight and ensure that the cultivators are collectively abiding by all federal, state, and local water use policies and restrictions? To me, this sounds like it will require some watershed wide oversight, such as a watershed wide water usage monitoring manager or a more comprehensive water management plan or agency.

Also, given that it will take time for a water usage restriction to be implemented, is there an alert system that can be developed to inform water users that a restriction has a high probability of occurring? For example, within 5-to-10% of the minimum flow threshold? This would allow cultivators time to plan and prepare for water use restrictions, as well as alert staff to be prepared to enter watersheds to ensure that the flow restrictions are being followed. How will these water use restrictions for junior users be enforced? Will senior users also yield to restrictions on their usage when other junior users are not complying with the restrictions? The recent drought in California has shown that senior users do not feel they need to comply before junior users are in full compliance (Boxall, 2015). Low compliance rates and the timeline for due process (e.g., oral notification, letter to comply, court case) will likely mean that the instream flows will go much lower than minimum low flow thresholds and will not be protective of instream habitat conditions for aquatic species. Therefore, lack of compliance with water use restrictions could be a real issue that may result in everything the low flow threshold was intending to prevent, e.g., stranded fish due to dewatered streams and disconnection of pools and riffles, higher temperatures, low dissolved oxygen. Perhaps set a higher low flow threshold to act as a buffer for protection of the minimum flow requirement, akin to the "margin of safety" that is used for TMDLs. Develop an alert system when the instream flow requirement is nearing this margin of safety.

Page 39 127. ***Cannabis cultivators shall implement all applicable Erosion Control and Soil Disposal and Spoils Management Requirements in addition to the Winterization Requirements below by November 15 of each year, or earlier, if needed to prevent waste discharges that result in water quality degradation.***

With loss of perennial vegetation and the protection of soil, land is more likely to be eroded during winter rain and snow melt events. Winterization and erosion control measures are part of the permit, but how much attention will cultivators pay to this and implement winterization measures, especially on large tracts when it costs staff time and money in materials? Perhaps add a requirement that the cultivator will email when winterization is completed along with photos of erosion control measures in place. This would provide a way to track without staff having to visit each site. Additionally, I would recommend staff visits to all or a percentage of cultivation plots to see that winterization measures have indeed been completed as planned.

Page 42- 4. *Cannabis cultivators that divert water from a waterbody with an assigned compliance gage in Section 4 of this Policy* ***are required to ensure that the real-time daily average flow,*** *as published on a designated compliance gage website identified by the Deputy Director for Water Rights,* ***exceeds the minimum monthly instream flow Requirement at the cannabis cultivator's assigned compliance gage. Cannabis cultivators shall verify and document compliance with the applicable Numeric Flow Requirement on a daily basis for each day of surface water diversion.***

Will individual cultivators or consultants make daily observations and know how to interpret the gage information to make these decisions? Will there be training provided to cultivators on how to interpret and implement this part of the policy - as well as the many other areas of the policy? It may serve in their best interest to hire a watershed wide hydrologist to monitor, and keep records to ensure daily flow requirements and documentation. Training provided to individual cultivators before they receive permits. Perhaps suggest that collectively, the cultivators hire a consultant to assist in interpretation and implementation of all policy requirements, as well as advice on diversion times and other instream flow requirements.

Page 42 - 5. *In addition to Narrative Flow Requirement 4,* ***at all times the cannabis cultivators shall bypass a minimum of 50 percent of the surface water flow past their point of diversion, as estimated based on visually observing surface water flow at least daily.***

How will this be managed and monitored? How will cultivators be able to interpret this 50% visual observance? Will one time a day be sufficient when multiple cultivators begin diversions on the same day? How will this be documented? Again, training for cultivators and their watershed consultants on how to implement and record observations. Photographs of the instream water conditions just at or downstream of their point of diversion.

Page 43 - 7. *The State Water Board has developed Numeric instream flow Requirements (minimum instream flow requirements) for each compliance gage in Section 4, Table 1 through Table 14, to ensure that individual and cumulative effects of water diversion and discharge associated with cannabis cultivation do not affect the instream flows needed for fish spawning, migration, and rearing, and the flows needed to maintain natural flow variability.* ***If the individual and cumulative effects of diversions result in unanticipated impacts, however, the State Water Board may revise the narrative and/or numeric instream flow Requirements to better protect instream resources, habitat, and natural flow variability.***

Who will be reviewing the instream flow requirements? Adverse impacts of instream habitat and flow variability will likely occur – this looks like a research project for a graduate student?

Pages 43 - 44 *The Deputy Director for Water Rights (Deputy Director) may require cannabis cultivators to install and operate a local telemetry gage in ungaged watersheds or localized watershed areas if the Deputy Director determines that use of the assigned compliance gage does not adequately protect instream flows or does not adequately represent the localized water demand. The Deputy Director may also require the installation and operation of a local telemetry gage in watersheds with no gage assignment if the Deputy Director determines that a gage is necessary to adequately protect instream flows. . ..*

This is a good requirement. However, the policy as written does not specify when the gage should be installed. While there are many gages at the outflow of larger rivers, there appears to be many headwater sub-watersheds where there are no flow gages currently in place. The policy outlines the requirement for the producers to install gages within these headwater watersheds, when it is determined that one is needed. However, what is the required timeline for this to take place? Should this be a requirement to have gages installed and operating *before* clearcutting and other cultivation activities begin? I would suggest the Board make it a condition that *before* a permit is granted, that the gage is installed and operational. Require at least one year of monitoring to establish understanding for what allowance there maybe for additional SW and GW usage. The Deputy Director, as well the cultivators could use this time to understand how much water might be available for irrigation, and insure that they will not invest in a large undertaking before they estimate the probable water availability in an ungaged watershed.

Page 44 - *Prior to October 31, during each water year of gage operation, an annual maintenance and operation summary report* **prepared by a qualified professional***, as defined above in this Requirement, shall be submitted to the Division of Water Rights that includes, at a minimum: qualifications and names of entities responsible for maintenance and operation; maintenance activities or operational issues for the prior water year of operation; quality assured gage stage and flow data collected and analyzed for prior water year;* **rating curves for prior and upcoming water year of operation***; data collected to establish rating curves for prior and upcoming water year of operation; and any anticipated maintenance plans or operational issues for the upcoming water year. The gage data shall be provided to the Division of Water Rights in a format retrievable and viewable using Microsoft Excel, Microsoft Access, or other software program authorized by the Deputy Director.*

Hiring a qualified professional to handle this area of the policy is a good requirement. This level of detail in reporting and creation of rating curves will require a high level of expertise.

Page 45 - . . . *The State Water Board is developing an online mapping tool to assist cannabis cultivators with determining which compliance gage applies to them and whether they may divert water.* *It is anticipated that the online mapping tool will allow cannabis cultivators to enter their address or otherwise locate their point of diversion to identify their assigned watershed compliance gage.* ***The compliance gage assignments may change as more information becomes available. To ensure cannabis cultivators are reporting in accordance with the appropriate gage, the cannabis cultivator is required to check the website for their compliance gage assignment at least daily and prior to diverting water to ensure water is available to divert at that gage*** *(i.e., the real-time daily average flow is greater than the Numeric Flow Requirement at the assigned compliance gage).*

Will this online mapping tool be available before permits are being received and granted? It might be important for cultivators to view the current flow conditions in some of these watersheds. The tool would also allow permit reviewers to see if cultivators are in gaged watersheds, or alert the Deputy Director that there are cultivators that are interested in currently ungaged watersheds. The Deputy Director should be involved in the permitting process to determine if gage implementation is a conditional requirement that needs to be met prior to granting the permit. See comments referencing Page 43-44 above.

Page 68 - *Summary of Technical Reports Required by Tier and Risk Level*
I'm unable to really provide much here; the policy document received did not contain Appendix D for review of the details needed for these reports. The Site Management Plan, Site Erosion and Sediment Control Plan, and Disturbed Area Stabilization Plan are required to be submitted within 90 days of the issuance of receipt. Does this mean the application has been received but the permit is not yet granted? Who will review these plans? What is the turnaround time for review of these reports? Perhaps some of this information is answered in Appendix D that provides details of these reports and plans. The draft policy document received did not contain Appendix D, so I did not review or comment on the details included and required in these reports.

II) Comments on individual parts of the staff report

The Instream Flow Policy research also concluded that traditional agricultural diversions permitted to divert during the dry season would be reduced or ceased by October 1 of each year, which would further diminish the impacts from cannabis cultivation diversions occurring after this period. No sooner than November 1 was selected as the beginning of the diversion period for the Policy to allow time for:

After reading several times, this paragraph is confusing. Are these two dates supposed to be the same (November 1) or what does October 1 mean and how is it different from "No sooner than November 1"? More clarification is needed here. Or, rather should October 1 be October 31 instead?

Issue 1 – Protection of springs and wetlands.

Are spring and wetland locations already known and recorded in ArcGIS? Given the ephemeral nature of these waterbodies, would there need to be better identification of these water body features to know where riparian setbacks are required and where cultivation cannot occur? Would this be part of the application review process?

Issue 2 & 3 - Current GW and SW permitting, irrigation, and over use.
Given the already sensitive status of California stream and GW availability, how will additional permitting reviews and permit issuance be managed? Are there areas where GW and SW sensitivity will mean there will be no opportunities for additional GW and SW extraction for cannabis irrigation? Will there be enough staff to handle both application review and overseeing usage? It appears to me that the private sector will be needed to help this effort run smoothly. The Minnesota Dept. of Natural Resources (MnDNR) oversees GW quantity and issues permits for larger users. There has been criticism that there is not enough monitoring and management for sustainable water levels and little enforcement of over extraction. Some permittees are over extracting 240% to 1,500% of their permitted use (Steil, 2013). Many users have been found to be over extracting GW, above what they are permitted, even in times of drought. Considering this criticism, MnDNR in the past has said that given the huge workload of permit applications, current MnDNR staff are overloaded and cannot provide adequate time for reviews and enforcement; management said it was not the current priority (Steil, 2013). The MnDNR was also recently sued by a local lake association for allowing unsustainable over allocation and usage of GW for White Bear Lake, MN. (Sepic, 2017). The judge agreed with the suit, saying that MnDNR did not do enough to monitor sustainable levels of GW use and allowed over extraction. The entire Midwest is seeing high GW extraction rates associated with corn production that is not sustainable (Harball, 2013). **The point; can government be trusted to keep public water resources safe?**

Identifying watersheds upfront that are already experiencing unsustainable GW and or SW levels, either by climate change or by current usage, and limit or restrict permitting of additional users in those areas. Where additional users may be permitted, I would advise considering a phase-in approach using a lottery or other method to allow a certain number of permits or acreage to be in production per watershed in a given year. Monitor groundwater stage, stream flow, usage, and compliance with water use restrictions before additional cultivators or increase in cultivated acreage is allowed.

Issue 4 – Increased land application of nitrogen fertilizer. Potential increase in nitrate-nitrogen pollution to GW and SW depending on the hydrologic pathway.
The Staff Report (page 31) includes suggested application rates of fertilizer that is approximately 1.4 times plant uptake. This will mean that it is expected that at least 1/3 of the applied nitrogen will be more than plant uptake and be lost; mostly likely by leaching beyond the root zone where it may percolate to deep GW. That may amount to a large addition of nitrate-nitrogen to SW and GW which could lead to concerning levels for drinking water and human health and be detrimental to sensitive aquatic organisms, either indirectly by increasing aquatic plant production and lowering levels of dissolved oxygen or being directly toxic to sensitive species. What are the current standards for nitrate-nitrogen in SW and GW and does California have nutrient standards in development for protection of aquatic life in both warm and coldwater streams? What would an aquatic life nitrogen standard mean for future cannabis cultivation?

With increased corn production in Minnesota, nitrogen applied fertilizer increased to meet crop demand. Minnesota has communities with GW and SW nitrate levels far exceeding safe drinking water standards (10 mg/l nitrate-nitrogen). For example, in Central Minnesota, 40% of domestic use wells tested above the drinking water standard; Southwestern Minnesota had 20% of domestic use wells test above the standard (Kroening and Ferrey, 2013). The SW in Minnesota shows a trend of higher nitrate-nitrogen with cropland accounting for 70% of the total nitrogen source to SW (Figure 6; MPCA, 2013). With increasing levels of nitrate-nitrogen over the last decade some local units of government are investing in reverse osmosis technology (e.g., Hastings - http://www.health.state.mn.us/divs/eh/water/com/waterline/featurestories/hastings.html) or need to dilute high nitrate groundwater with surface water (e.g., Lewiston, Worthington). These removal or dilution methods are costly to municipal users (https://www.mda.state.mn.us/protecting/waterprotection/~/media/Files/protecting/waterprotection/dwps2.ashx). As costs of nitrate-nitrogen removal for drinking water increases and become more prevalent, cities and rural GW users may begin litigation on nitrate-nitrogen sources, including nitrogen fertilizer use industries that pollute upstream waters, e.g., Des Moines, Iowa (Des Moines Register, 2013).

Effects to dissolved oxygen - Nitrogen also contributes to plant growth in aquatic species. When plants die, decomposition uses up dissolved oxygen in streams which may create low-diel dissolved oxygen levels that are stressful to aquatic organisms. From the Staff Report, there appears to be several streams already impaired for dissolved oxygen. Given reduced flows at certain times of the year, there will likely be problems. The USEPA encourages states to develop numeric nutrient criteria to be protective for aquatic life. What is California's timeline for development of these criteria for phosphorus and nitrate-nitrogen for warm and coldwater streams and rivers? What are the current background levels for SW and GW for areas that already have land application of nitrogen sources? (e.g., manure, fertilizers, etc.).

Minnesota has draft aquatic life standards for nitrate-nitrogen that were developed in consultation with literature sources (Monson, 2010). The proposed standards include: draft acute value (maximum standard) calculated to be 41 mg/L nitrate-nitrogen for a 1-day duration; draft chronic value is 4.9 mg/L nitrate-nitrogen for a 4-day duration for warmwater streams and a draft chronic value of 3.1 mg/L nitrate- nitrogen (4-day duration) for coldwater streams. These were intended to be protective of 95% of aquatic organisms during various life stages (e.g., larvae, egg, hatchlings).

These aquatic life draft standards for Minnesota are currently in review by USEPA. USEPA has requested additional toxicological testing which is expected to be completed sometime in 2017. I anticipate that if these aquatic life draft standards are applied, hundreds of additional streams in Minnesota will be 303(d) listed for exceeding the nitrate-nitrogen standard.

Shallow groundwater aquifers are more at risk to nitrogen contamination from land applied fertilizers and other sources. Where shallow aquifers occur, limit cannabis production in these areas based on a **detailed nitrogen budget** (Manifold, 2015). Like corn production, additional research on more productive timing and amount of nitrogen fertilizers should be performed using research plots. Maintaining deep rooted perennials will help to utilize excess applied nitrogen during the non-cannabis growing season.

Issue 5 - Sedimentation, channel instability, and instream habitat.
With increased clearcutting, increased sedimentation is likely even with riparian buffer setbacks and winterization measures, due to deforestation of both natural lands as well as lands restored already for improvements and protection of instream fish habitat. When forests are converted to annual summer growing vegetation, there will be more storm related runoff moving toward streams and likely less GW infiltration. Climate related issues are raised below under the Carlisle review; nevertheless, there will be a fluvial response to changes in hydrologic pathways and processes.

In addition to min, max and average monthly, what about the natural hydrograph per storm event? It would appear to me they will become exacerbated by climate change and clearcutting where the perennial woody and grass vegetation is no longer transpiring antecedent soil moisture during the early spring snow melt and rainfall. This could lead to channel instability in terms of stream bank erosion and over-widened channel geometry with exacerbated aggradation in some reaches. Someone needs to ask: what is the condition of the stream geometry in this system? Stable or unstable? When the channel cross-sectional area changes, due to increased width, the water depth becomes shallower, slower and warmer. Though discharge remains constant, sediment transport and concordant sediment size changes. This can cause excess sedimentation and smothering of redds and fish eggs, and limit hyporheic oxygen exchange with GW and SW. **Who will measure if redds are being adversely impacted?**

Conversely, in certain watersheds, rainfall and snow melt may be less than current due to climate change. Typically, the spring snow melt and storm hydrograph peaks for about a week during which critical channel forming flows and sediment scouring takes place. This peak may be dampened if winter diversions lower the base-flow and if there is less snow melt or rainfall in the spring due to climate change. This will likely cause excess sedimentation and burying of redds or reduce the hyporheic exchange with groundwater. Under future climate change scenarios and additional SW and GW usage during the winter, **will the spring flushing flow still be adequate to maintain redds in these watersheds?**

Someone must work with California fisheries department to monitor instream condition of redds and annual recruitment of juvenile fish. Consider pebble counts or other measures to determine if flow conditions are sufficient for flushing and maintaining spawning beds. Observe storm and snow melt hydrograph to see how clearcutting is altering the natural hydrograph. In addition, pay attention to modeling outputs where climate change may alter the degree of snow storage and rain events. Phase in clearcutting to allow time to determine the level of impact and sensitivity of the watershed before additional clearcutting and road building. Limit additional clearcutting in areas where federally listed fish are present to protect or provide time to effectively restore habitat conditions. Provide options for cultivators to pay to enhance watershed woody and perennial grass cover, where appropriate, in highly sensitive watersheds that may already have been illegally clear-cut and cleared to allow for additional cultivation in areas that are considered less sensitive to erosion and rainfall.

2) **<u>The USGS natural flow modeling approach used appropriate modeling inputs and R Scripts and the modeling outputs stored in the database predict the unimpaired flow statistics as intended.</u>** True, but this method does not account for climate change.

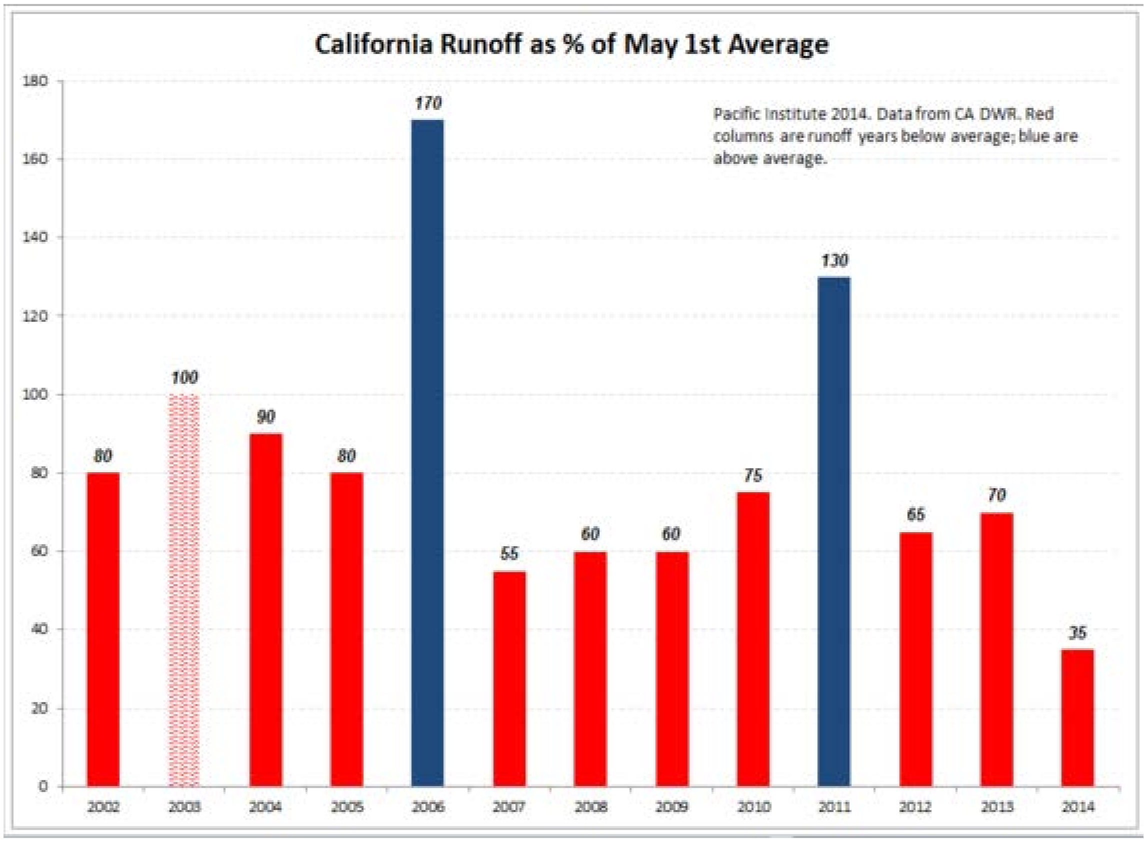
III) Review of Carlisle et al, 2016. USGS Open-File Report 216-1189 and the concordant draft manuscript titled Patterns and magnitude of flow alteration in California, USA by Zimmerman et al. (in review)

This work by the USGS and The Nature Conservancy provides an important frame work in California for defining streamflow. As defined by the authors, “natural” streamflow refers to the baseline or background conditions unaffected by land use and water management. By the study site selection the authors have done that to the extent possible. The method used for selected sites is justified and reasonable, using Level 3 Ecoregions and least disturbed reference conditions etc. The statistical tools; static descriptors and time-series variables coupled with machine-learning represents state-of-the-art. The authors did a great job in explaining and communicating the results of their work. Yet the work is specifically about prediction of natural monthly flows each year from 1950-2012 for California streams and predicting the likelihood that monthly streamflows are modified by anthropogenic activity. In the prediction of modified depleted monthly flows, the best models were for April and May; a time critical for plant establishment.

However, a data caveat was identified; modifications were based on state permitted diversions and not actually volumes diverted. Further, the authors state that groundwater resurgence and exchange with surface water would greatly improve the models. All models performed best at larger scales because of the rich robust data sets. Small drainage areas (<25 km^2) lacked sufficient gage data to fully capture hydrologic response. Intensive land use in headwater areas will have a larger amount of epistemic uncertainty. Lastly, Zimmerman et al. point out model performance for the xeric region was less robust than mountain and costal models. They warn that results for arid areas should be used with caution. Overall the work performed and reported was of excellent quality given the typical use of such models.

However, given climate change, the 1950-2012 calibration period may not reflect future flow conditions in California. Milly and others (2008) make the case for the death of “Stationarity”. Stationarity refers to the use of probability density function (pdf) as a statistical tool used over decades to plan and manage water. They argue that looking at past streamflow records and predicting future flows will not work based on the 12 IPCC climate changes models. Instead they suggest “combining historical and paleohydrologic measurements with projections of multiple climate models, driven by multiple climate-forcing scenarios” be used in a predictor model (Milly et al. 2008). The use of 1950-2012 meets the “historical” but not the “paleo”.

The western states of Nevada, Arizona and California, show a strong decrease in runoff volume projected to occur by the middle of the 21st century (Milly et al., 2008). Serinaldi and Kilsby (2015) and others have challenged Milly et al. (2008); the point is that scientists can disagree about conclusions reached in a peer reviewed publication. Yet Milly et al. (2015) did offer a published response – this quote sums up best where we are left in 2017: “it follows from thermodynamics that the water cycle is now undergoing fundamental change, albeit one whose structure is poorly known. We find ourselves in a situation where the science suggests a substantial and growing ACC (*refers to anthropogenic climate change*) signal, yet the observable change may currently be indistinguishable from the chaotic internal variability and naturally (e.g., volcanically) forced variability of the climate system. However, because the ACC effects are growing in magnitude, they cannot readily be assumed to be negligible over the decades-long design horizon of engineered water systems. In such a situation, because there is reason to suspect that a trend exists, one should be sensitive to the substantial possibility of type-II errors: the probabilities of failing to recognize a trend—a signal hidden amidst overwhelming noise—when it does actually exist." (Milly et al., 2015). Further Milly et al. (2015) states: "Should the enormous body of research on ACC amount to nothing when water decisions are made? It is not our suggestion that ACC effects should be identifiable from the observational record alone; this would be quite a challenge [Serinaldi and Kilsby, 2015]. Rather, we envision a major role for estimates of ACC trends that are informed by combination of climate theory, models, empirical analysis of hydrologic data, and expert opinion." It is this last point that I would like to highlight; every cannabis operation should have an annual review by a recognized expert to determine if a critical threshold of change has occurred that will adversely influence water quality and aquatic life.



Data and discussion from Pacific Institute's Peter Gleick suggests: "The problems with California's water are that it is highly seasonal, highly variable, and poorly managed. Now, halfway through the second decade of the 21st century, we've hit the wall. California is in a drought — some call it the third year of a drought, but it could also be called the 10th dry year out of the last 13 (see Figure above). Even if next year brings some relief, our water problems will remain. The problem is that even in wet years, California has passed the point of "peak water." We have maxed out the renewable water available in our rivers — allocating to users more than nature provides even in a wet year. We are unsustainably overdrafting our groundwater — turning a renewable resource into a non-renewable resource — and we are plunging toward an economic, social, and political catastrophe in the groundwater basins of the Central Valley. We are past the point of "peak ecological water" — the point where our use of water now causes far more ecological harm than it provides benefit. Overall, on average, we use at least 6 million acre-feet a year more than we should." (Gleick, 2014)

It is important to note that California will not be without water to grow crops like cannabis; the issue is more about intensity, duration and magnitude of future precipitation. More recent work by Prein et al. (2017) suggests much of the future precipitation may come in extreme events; "We show that hourly precipitation extremes are also increasing in regions such as the Pacific Southwest, where no positive relationship between precipitation and temperature is observed. This implies that observed scaling rates cannot be used directly to assess climate change projections." All the figures presented in Prein et al. (2017) illustrate that at least portions of California could see statistically significant change.

In summary applying this work to cannabis related water management in small watersheds requires best professional judgment (expert opinion), by a registered American Institute of Hydrology professional or equivalent with expertise in watershed management. The reason for this specific recommendation is that California licensed engineers, geologists and hydrogeologists may lack sufficient understanding of soil-plant-water dynamics. Engineering and geologic disciplines are not required to study plant physiology.

3) **The Tessmann method is an appropriate method to use to develop interim instream flow requirements in California, was applied correctly, and the Tessmann method spreadsheet calculator correctly calculated the wet season instream flow requirements.** Yes – but epistemic uncertainty about future climate, may negate the usefulness of the tool. "The Tessmann Method develops instream flow requirements by using percentages of historical mean annual and mean monthly natural streamflow". The fundamental problem is "natural" for the future does not exist! For future management of watersheds and specifically cannabis cultivation, anthropogenic and paleoclimatic cycles make historic "natural" irrelevant in California and many other locations across the globe e.g., India. The tool should still be applied, but must have professional judgement and interpretation that acknowledges climate extremes into management decisions.

4) **The New England Aquatic Base Flow Standard (ABF) Standard is an appropriate method to use to develop interim groundwater low flow thresholds in California, modification to the ABF Standard is appropriate for California's climate and aquatic resources, the ABF Standard was applied correctly, and the ABF Standard spreadsheet calculator correctly calculated the dry season instream flow.** Yes – but epistemic uncertainty about future climate, may negate the usefulness of the tool. Further, the SW-GW exchange relationship understanding in most headwater watersheds is poorly

> understood at best. I have spent over two decades exploring SW-GW exchange in different hydrogeologic settings; the more sites I have examined the more I'm convinced that simple models are helpful but always wrong. Heterogeneity most often drives the unique interplay of water exchange both temporally and spatially. The bottom line: a professional trained in SW-GW exchange will need to guide acceptable land use actions above and beyond the use of ABF.

Big Picture Questions

As an external reviewer of the policy from outside of the state, I am not fully aware of all California policies already in place that are provided for other cultivators (e.g., vegetable production, corn production, feedlot and dairy operators). I hope that there would be a recognition and attempt to remedy current water pollution and water quantity issues before additional cultivation and land clearing takes place, especially given recent drought, wildfire, adverse and apparent effects of climate change, illegal land clearing and cultivation, existing concerns about water quantity and quality. A few big picture questions:

Should there be one Comprehensive California water policy that considers cumulative effects?

Should cannabis cultivation be allowed in watersheds with currently impaired waterbodies, streams with federally listed species, and dewatered streams? Could clean up of these waters be incentivized by requiring a certain amount of rehabilitation/restoration to take place *prior* to permitting?

Will there be enough Water Board staff to handle permit applications, training, and enforcement of these policies? Will inspectors have the level of expertise and training required to know how to identify each area of non-compliance and know who to contact when non-compliance issues come up, the multiple agencies involved in the management of soil, water usage, endangered species habitat, etc? Will cultivators diligently monitor all parcels to ensure that measures installed to be protective of water quality are still operating or will replace if needed? (e.g., erosion control measures, proper waste disposal, pesticide and fertilizer storage, winterization measures are sufficiently working after large rain events). **Should the private sector have a key role – such as Watershed Service Providers – similar to Technical Service Provider for conservation practices?**

What will happen if legal production of cannabis supply outpaces demand? Any market research to date on the anticipated demand and projected costs of legally grown cannabis? Would a phase in approach minimize effects of boom/bust economics and prevent large scale legacy issues with forest clearing and provide better protection of SW and GW water quality and quantity?

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Please let me know if I can provide any additional information to you.

With best regards.
Sincerely,

Dr. Joe Magner, Ph.D., P.H., P.S.S., P.Hg.
Research Professor
Dept. Bioproducts & Biosystems Eng.
University of Minnesota
1390 Eckles Ave
St. Paul, MN 55108.
E-mail: jmagner@umn.edu
Telephone: 612-626-0875

University of Colorado
Boulder

Institute of Arctic and Alpine Research
1560 30th Street
Boulder, CO 80309

303 492 7909
450 UCB
instaar.colorado.edu

Dr. Gerald W. Bowes
Manager, CaIEPA Scientific Peer Review Program
Office of Research, Planning and Performance
State Water Resources Control Board

Dear Dr. Bowes,

I am glad to provide the enclosed external peer review of the California State Water Resources Contol Board’s Draft *Cannibis Cultivation Policy- Principles and Guidelines for Cannibis Cultivation*. I am providing a review related to Conclusions 1 and 2.

Sincerely,

Diane M. McKnight

Diane McKnight

Professor, University of Colorado at Boulder

Department of Civil, Environmental and Architectural Engineering

Member, National Academy of Engineering

EXTERNAL PEER REVIEW OF THE CALIFORNIA STATE WATER RESOURCES CONTOL BOARD'S DRAFT CANNAB/S CULTIVATION POLICY - PRINCIPLES AND GUIDELINES FOR CANNABIS CULTIVATION

1. Review of Conclusion 1- The requirements in Draft Policv Attachment A. Sections 1-4 will reduce the water qualitv and water diversion impacts associated with *cannabis* cultivation.

Overall, the draft Policy takes a comprehensive, balanced and scientifically robust approach towards achieving the objectives of the Policy for reducing water quality and water diversion impacts due to cannabis cultivation in the State of California. At the same time, the draft Policy presents a sufficient and tractable level of detail in the draft measures and guidelines for practical implementation. The draft Policy addresses in an integrated manner the different ways in which cannabis cultivation can cause deleterious impacts on water quality and aquatic biota. Specifically, the draft Policy presents measures for mitigation of disturbance of stream ecosystems through excess sedimentation, restriction and mitigation of contaminant inputs, protection of riparian zones and maintenance of instream flows required for sustaining suitable aquatic habitats throughout the year. In addition, the draft Policy includes several specific measures to protect fish populations, such as the prohibition of instream impoundments for water storage. This integrated and holistic aspect of the Policy is an important overarching strength. My review supports Conclusion 1 as elaborated below.

The draft Policy is strongly based on the scientific understanding of the sustained impact of disturbance in structuring aquatic ecosystems. For stream ecosystems, the long-lasting effects of episodic inputs of large quantities of sediments are well-established. Throughout Sections 1 and 2 of Attachment A of the draft Policy, strategic measures are presented that can be expected to limit or mitigate input of excess sediment and resulting turbid conditions in the adjacent and downstream habitats of vulnerable aquatic biota. These measures are to be applied for the construction phase of a cannabis cultivation projects and for their operation as well. For example, under General Requirements and Prohibitions, item no. 5 (pg. 9) land disturbance activities are prohibited during the period when most of the rainfall occurs in California, and these activities are restricted to the period from April 1 to November 15. Further, item no. 7 (pg. 10) requires the cannabis cultivator to monitor the weather forecast during land disturbance activities and cease such activities and implement erosion control measures if the forecast indicates a 50% or greater chance of rain. There are numerous other protective measures to limit sedimentation and streambed disturbance related to watercourse crossings, e.g. items no. 38-57 (pgs. 26-29), that are precise and practical to implement. Similarly, item no. 60 (pg.29) protects stream habitats by requiring storage of erodible soils and soil amendments in a secure manner. Finally, the measures related to winterization, items no. 127-135 (pgs. 39-40) are also likely mitigate excess erosion and sedimentation. Taken as a whole, these requirements can be expected to avoid large episodic inputs of sediments and contribute in a major way to achieving the objectives of the draft Policy.

In addition to problems associated with turbidity and sedimentation, the draft Policy identifies excess nutrients, fertilizers, pesticides, and petroleum products as contaminants of concern. This selection of contaminants of concern are based on a well-established findings in stream ecology.

For example, high nutrient concentrations can cause excess growth of algae that can disrupt aquatic food webs necessary to support salmonid populations. An even greater concern occurs if excessive nutrients promote blooms of toxic algae that pose risks to livestock and pets. Furthermore, excess growth of algae can cause excessively high pH values during mid-day that can be toxic. The deleterious effects of organic contaminants associated with agricultural activities are also well established. These ecological effects can be long-term as the contaminants can be bio-magnified in food webs, with highest concentrations occurring in the tissues of aquatic organisms at higher trophic levels.

In addition to the strong scientific justification for focusing on the draft set of water quality contaminants (pgs. 28-33 of the Staff Report), the section on water quality impairment in the Overview of Policy Regions of the Staff Report presents definitive information on the current status of the percent of area impaired with respect to a given water quality contaminant. The potential for expanding cannabis cultivation to impact water quality in the Priority Regions without regulatory measures is evident by the existence of impaired conditions in 10-27% of the area for both nutrients and pesticides for more than half of the Priority Regions. Clearly, a balanced approach that mitigates both sediment impacts and water quality impacts is warranted. The requirements of the draft Policy include several specific measures that can be expected to limit contaminant inputs, e.g. items no. 106-108 (pg. 36).

The consistency of the requirements in the draft Policy to limit and mitigate sediment inputs are also reflected in the protections for riparian zones in the Sections 1 and 2 of Attachment A of the draft Policy. In addition to mitigating sediment inputs, riparian zone vegetation can contribute to stream health by regulating temperature through shading and by providing a source of allochthonous coarse particulate organic matter (e.g. leaf litter) that serve as a food resource for benthic invertebrates and other prey for fish populations. The “goods and services” provided by riparian zones are protected in the draft Policy by establishing clear riparian setbacks, for example.

The importance of flow regime in determining stream ecosystem health has been established in numerous scientific studies. Further, over the past several decades a strong conceptual basis has been developed to consider these relationships between flow regime and the maintenance of viable populations of native aquatic biota in streams. The reproductive success of native species of anadromous fish may be tied to sufficient flows and connectivity in a stream/river network to support upstream migration for spawning. As described in the Staff Report, the reduction of flow, as well as dewatering of streams, during the summer low-flow season associated with cannabis cultivation in more remote watersheds of California has been a serious concern for threatened and endangered anadromous species. Appendix 2 of the Staff Report clearly describes the life histories of the salmonids to be protected by the Policy. The strong scientific basis for these concerns associated with the summer low flows and dewatering that have been caused by cannabis cultivation and the thorough documentation of salmonid life histories work together to establish a robust scientific basis for the restriction of water diversions for cannabis cultivation during the low-flow period.

2. Review of Conclusion 2-The USGS natural flow modelinq approach used appropriate modelinq inputs and R scripts, and the modelinq outputs stored in the database predict the unimpaired flow statistics as intended.

The practical implementation at the local or regional scale of the current scientific understanding of the importance of flow regime for stream ecosystem health must be based upon a quantitative knowledge of natural flow regimes for the streams of concern. The USGS natural flow modelinq approach used for this Policy has a strong scientific basis and employs in an effective manner the extensive streamflow record available in the State of California in a systematic and robust manner to develop statewide instream flow requirements. My review supports Conclusion 2 as elaborated below.

Of the two general approaches that could have been taken to estimate natural instream flows, the choice to develop an empirical model rather than a mechanistic model is excellent. Mechanistic models are primarily useful for evaluating hypotheses for underlying processes that control flow regimes. In particular, a mechanistic model can be constructed to simulate a flow record from a well-studied watershed for which sufficient ancillary data are available and can be used to parameterize such a mechanistic model. The results from mechanistic models can then be used to inform the choice of measured parameters to include in the development of empirical models. In particular case of the USGS natural flow modelinq approach employed for the State of California, the empirical approach takes advantage of records that begin as early as 1950 and continue to 2012. The empirical approach was based on static and variable parameters and there was not a requirement that all records considered cover the same period of time. As illustrated in the document describing the modeling approach in detail, this approach can be extended to include additional streamflow record, e.g. up until 2015, which will provide the ability to revise and upgrade the Policy in the future.

The steps taken in the development of the USGS natural flow modelinq approach are all well-justified and supported by rigorous comparison with alternative statistical approaches and models. First of all, this empirical model is based upon a well-conceived reference condition approach that employed three steps (or tiers) to identify a set of reference sites. At the first step, geospatial data were summarized in an index corresponding to the degree of human disturbance in the gauged streams. The second step relied upon qualitative information recorded during the operation of the stream gauge to identify sites subject to human disturbance. Finally, the remote sensing imagery of potential reference sites were examined to identify a subset of reference sites from the set of gauged sites. One clear strength of this three step approach is that a wide range of available data were used in a systematic and reproducible way to identify the reference sites, upon which the next steps in the USGS natural flow modelinq approach are based.

Another strength of the approach taken was to evaluate potential bias in reference site selection by comparing important basin characteristics, such as basin mean slope, of the identified reference sites with those for all of the stream segments in a region. The representativeness of the reference sites was then assessed by comparing the overlap in the range of the selected characteristics. As the USGS natural flow modelinq approach is applied in the future, these steps for identifying reference sites can also be used to establish criteria for re-categorizing reference sites as being subject to human disturbance if landuse changes in a basin, for example.

In the USGS natural flow modelinq approach, the choice of the statistical approach for developing an empirical model was based on a thorough evaluation of several statistical approaches. For the different regions in California, the random forest (RF) approach was found to produce a model that had higher r-squared and other favorable statistical characteristics. This evaluation of other statistical approaches provides strong support for the RF approach that was taken for modelling natural flows.

There are several other strengths of the USGS natural flow modelinq approach that deserve mention. The choice of Level 3 Ecoregions was well-considered and based on past research demonstrating the limitations of applying statistical approaches for small regions where the basin characteristics were quite homogenous. These regions also mesh well with the regionalization approaches that have been developed in the State based on both climate and hydrologic regime, as described in the Staff Report.

Another well-considered aspect of the USGS natural flow modelinq approach was to model at a monthly scale. Predicting average monthly flows in ungauged basins captures the seasonal pattern in high and low flows, which are key aspects for salmonids and other native stream biota, while avoiding predictions at finer time scales that would be less practical from a management perspective. This monthly level of resolution is tractable for communication with stakeholders in an applied context. Further, the monthly approach will be useful in determining the need for establishing a gauge in an ungauged basin.

Another consideration for future use of the USGS natural flow modelinq approach is to evaluate the model for influences overtime that may be associated with changes in the reference site response to climatic and hydrologic drivers that are independent of encroaching human disturbance. There may be changes over time that are related to shifts in vegetation or other watershed characteristics due to steady changes in climate. It may be worthwhile in the future to evaluate the USGS natural flow modelinq approach for any issues of non-stationarity. Given the flexibility of approach, these issues could be addressed potentially by modifying the temporal span of flow records considered to put less weight on earlier records for example.

Comments in response to “Big Picture questions:

In readinq the Policv and Staff Report, are there anv additional scientific conclusions that should be a part of the scientific portion of the proposed Policv that are not described above?

In my opinion the Policy and Staff Report thoroughly consider the scientific aspects of managing cannabis cultivation to protect water quality and aquatic biota. As noted in my comments related to conclusion 2, the issue of gradual landscape changes in vegetation can be addressed in the future within the framework of the USGS natural flow modelinq approach, as long as the streamflow records are maintained.

Taken as a whole, is the scientific portion of the Policv based upon sound scientific knowledge, methods, and practices?

In my opinion, the scientific portion of the draft Policy is based on well-established scientific understanding of stream ecology and on relationships climate, landscape characteristics and hydrology.