Institute on Science for Global Policy (ISGP)

Water and Fire: Impacts of Climate Change

Conference organized and convened by the ISGP in partnership with California State University, Sacramento, in Sacramento, California, U.S.
April 10–11, 2016

ISGP Academic Partnership (IAP) with California State University, Sacramento

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An ongoing series of dialogues and critical debates
examining the role of science and technology
in advancing effective domestic and international policy decisions

Institute on Science for Global Policy (ISGP)

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Introduction

Dr. George H. Atkinson
Founder and Executive Director, Institute on Science for Global Policy
and
Professor Emeritus, Department of Chemistry and Biochemistry and
College of Optical Sciences, University of Arizona
and
former Science and Technology Adviser to
U.S. Secretaries of State Powell and Rice

Preface

The content of this book was taken from material presented at a conference organized and convened by the Institute on Science for Global Policy (ISGP) on April 10–11, 2016, in partnership with California State University, Sacramento. This specific ISGP conference, *Water and Fire: Impacts of Climate Change*, was part of the ISGP Academic Partnerships (IAP) program, which is based on collaborations with a variety of distinguished academic institutions. IAP conferences reflect a common commitment to significantly improve the communication of credible scientific and technological (S&T) understanding for both the public and private-sector policy communities and for the public writ large.

The organization of this IAP conference is based on the recognition that climate change has become an international focal point for numerous critical issues which can alter (i) personal lifestyle choices and (ii) collective decisions made within communities at all levels. Societal decisions concerning how to appropriately incorporate the often-transformational scientific advances associated with climate change into public and private sector policies rely on debates that highlight the practicably credible options developed worldwide. ISGP conferences offer rarely encountered environments in which such critical debates can occur among internationally distinguished scientists representing diverse disciplines, influential policy makers, societal stakeholders, and the public.

Current realities

At the outset of the 21st century, most societies face difficult challenges concerning how to appropriately use, or reject, the dramatic new opportunities offered by modern S&T advances. Since scientific research programs, and commercially

viable technologies, are now developed globally, societal challenges related to S&T necessarily involve domestic and international policy decisions, both in the public and private sectors. The daunting challenges to simultaneously recognize immediate technological opportunities while identifying those emerging S&T achievements that foreshadow transformational advantages, and potential risks, are critical governmental and private sector responsibilities. The complexity of these responsibilities reflects the multitude of societal demands, most having conflicting goals. Policy decisions must balance critical commercial interests promoting economic prosperity with the cultural sensitivities that often determine if, and how, S&T is successfully integrated into any society.

ISGP Academic Partnerships (IAP)

The IAP programs recognize that communication between those with S&T expertise and those responsible for ensuring safe, secure, and prosperous societies must be effective and timely. Venues that use concise, accurate presentations of viable S&T options to policy makers while encouraging critical review are essential in identifying effective policy decisions that can be publicly supported and therefore, effectively implemented. Such venues need to promote broad public participation in assessing the advantages and potential risks of all S&T options. IAP events provide such opportunities by engaging both college- and university-level students in helping to organize and convene ISGP conferences on topics of societal importance. The ISGP has pioneered a debate/caucus format that promotes the candid exchanges of ideas and criticism among distinguished S&T professionals, policy makers in government and the private sector, societal leaders, and in some cases, the public. This debate/caucus format is the centerpiece for the pedagogical approach underlying IAP programs at each of the academic institutions.

The academic preparation of the students begins with classroom studies under the supervision of faculty from their respective institutions. In addition to the classroom studies, students are offered opportunities to (i) assist the ISGP staff in interviewing S&T experts worldwide, (ii) help edit the policy position papers used for the debates, (iii) read and analyze the extensive background material available to the ISGP, (iv) participate in the formal debates alongside leading experts in the field, and (iv) guide the caucuses at ISGP conferences used to identify Areas of Consensus and Actionable Next Steps.

The overall educational experience can be viewed as a "practical S&T policy laboratory" designed to (i) prepare the students for active roles in informing and guiding policy makers at the local, regional, national, and global levels and (ii) expose the public to their views through informed debates and caucuses focused

on realistic conclusions. Collectively, the IAP experience seeks to demonstrate the importance of rational thinking in the future formulation and implementation of public and private sector polices.

ISGP format

Extensive interviews by ISGP staff and selected IAP students are used to identify internationally recognized subject-matter experts who are invited to prepare concise (three-page) policy position papers. For the April 10–11, 2016, IAP conference at California State University, Sacramento, three authors were invited to present their views on the current realities, scientifically credible opportunities and associated risks, and policy issues concerning *Water and Fire: Impacts of Climate Change*. Students from the class taught at California State University, Sacramento, by Professor Michelle Stevens, with strong support from Dean Orn Bodvarsson, were involved in these activities. Conference participants from the communities the University serves, included faculty and students, government and public health representatives, private sector and industry leaders, leading researchers from California State University, Sacramento, and related fields, as well as the public.

The conference agenda was comprised of three 90-minute sessions, each devoted to a debate of a given policy position paper. In each session, the author was given 5 minutes to summarize his or her views while the remaining 85 minutes were opened to all participants, including other policy paper authors, for questions, comments, and debate. Written questions were also fielded from the public audience that observed all debates. The debates and subsequent caucuses focused on clarifying understanding among nonspecialists and identifying areas of consensus and actionable policy decisions supported by scientifically credible information.

Following the three debates, small, moderated caucus groups representing a cross section of all participants worked to identify areas of consensus and the actionable next steps to be considered within governments and civil societies in general. Subsequently, a plenary caucus was convened for all participants. While the debates focused on specific issues and recommendations raised in each policy position paper, the caucuses focused on overarching views and conclusions that could have policy relevance both domestically and internationally.

The material presented in this book includes the three policy position papers together with the not-for-attribution summaries of the debates of each paper. The not-for-attribution summaries prepared by the ISGP staff are based on the collective notes and recordings from each debate and are presented here immediately following each policy position paper. These summaries represent ISGP's best effort to accurately capture the comments and questions made by the participants, including

the other authors, as well as those responses made by the author of the paper. The views expressed in these summaries do not necessarily represent the views of a specific author, as evidenced by his or her respective policy position paper. Rather, the summaries are, and should be read as, an overview of the areas of agreement and disagreement that emerged from all those participating in the debates.

The areas of consensus and actionable next steps emerging from this IAP conference are presented immediately following this introduction under the title "Conference conclusions."

Concluding remarks

IAP conferences are designed to provide environments that facilitate publicly accessible debates of the credible S&T options available to successfully address many of the most significant challenges facing 21st century societies. IAP debates test the views of subject-matter experts through critical questions and comments from citizens and nonspecialists committed to finding effective, real-world solutions. Obviously, IAP conferences build on the authoritative reports and expertise expressed by many domestic and international organizations already actively devoted to this task. As a not-for-profit organization, the ISGP has no opinions nor does it lobby for any issue except rational thinking. Members of the ISGP staff do not express any independent views on these topics. Rather, IAP programs focus on fostering environments that can significantly improve the communication of ideas and recommendations, many of which are in reports developed by other organizations and institutes, to the policy communities responsible for serving their constituents in the public.

While IAP conferences begin with concise descriptions of scientifically credible options provided by those experienced in the S&T subject, they rely heavily on the willingness of nonspecialists and citizens to critically question these S&T concepts and proposals. With the introduction of the IAP conference model, now students and the general public can voice their opinions and learn how decisions that undoubtedly will impact their lives are made. Overall, IAP conferences seek to provide a new type of venue in which S&T expertise not only informs the citizen, but also in which realistic policy options can be identified for serious consideration by governments and societal leaders. Most importantly, IAP programs are designed to help ensure that S&T understanding is integrated into those real-world policy decisions needed to foster safer and more prosperous 21st century societies.

Conference Conclusions

Area of Consensus 1

The recognition that societies are responsible to provide access to uncontaminated water as a human right requires municipalities to ensure that the egalitarian allocation of water reflects accepted societal values and science-based information. Such long-term, sustainable access to limited water supplies can be achieved only by integrating the cross-sectorial needs of ecological, municipal, agricultural, and industrial sectors by managing water from its watershed to the end user.

Actionable Next Steps

- Optimize public and private sector investment strategies by supporting both green and gray water infrastructure and expanding the accurate, routine measurement of available supplies, community-wide demand, and contamination levels using effective data management.
- Improve natural and man-made infrastructure to increase the available uncontaminated water sources using wetlands, forest restoration, groundwater recharge and recycling rainwater collection, and flood management in anticipation of an increasing number of extreme weather events (e.g., droughts, floods).
- Improve coordination among governmental agencies responsible for water management (e.g., California Department of Water Resource, State Water Resources Control Board,, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers) to establish an integrated management system that prioritizes the increasingly important impact of drought.
- Implement comprehensive "appreciative inquiry" educational programs characterizing natural versus engineered water sources, competitive human and environmental water needs, and different conservation and management strategies that focus on aiding citizens to evaluate and prioritize water allocation strategies.
- Reconsider water rights system to reflect priorities given to providing safe drinking water and ensuring the stewardship of natural resources.

- Develop financial incentives to support effective water management and infrastructure to meet local and regional interests and based on state, federal, and tribal collaboration.

Area of Consensus 2

The availability of water appropriate for human consumption in sufficient quantities for a rapidly increasing population directly depends on maintaining healthy aquatic ecosystems from headwaters to the ocean, a relationship essential to societal stability and economic prosperity. As competition for water dramatically increases, governmental regulations, management practices, and financial incentives must recognize the integrated needs of humans, healthy aquatic ecosystems, agriculture, and industrial enterprises.

Actionable Next Steps

- Evaluate improvements in existing regulations controlling water rights to identify opportunities to (i) reallocate access to water resources consistent with sustainable aquatic ecosystems, and (ii) make anticipatory, proactive decisions recognizing the importance of changing climatic conditions. Support "net zero" water standards (i.e., consumption at or below local supply levels) by investing in local conservation measures (e.g., tertiary treatment and green infrastructure, effective collection and storage systems, quality standards tailored to specific usages, and incentives encouraging consumer compliance).
- Promote legislation requiring the allocation of water be reviewed by the regulatory agencies (e.g., California Environmental Quality Act, National Environmental Policy Act).
- Implement diverse educational programs (e.g., behavior change and game framework approaches) in K-12 classes and through public, workplace, and stakeholder engagements to prioritize the protection of robust ecosystems by connecting human use of water with the natural cycles of the water systems.
- Initiate real-time data collection to conduct a cost-benefit analysis of how to balance the diverse societal needs for water storage, flood control, and hydroelectric generation with the increased uncertainties of precipitation and weather patterns influenced by a changing climate.

- Focus water management projects and pricing on local/regional needs that fluctuate with changing supplies and demands to establish regional, self-supply districts that define their respective human, environmental, and economic priorities.
- Restore wetland and riparian areas and create set-back levees along riverine and aquatic habitat, integrating the application of local, regional, state, and federal permitting regulations and funding mechanisms.

Area of Consensus 3

Management practices that ensure sustainable forests need to recognize the diversity of forest landscapes, watershed health, regional biogeography, and wildfire management regimes derived from scientific and traditional knowledge observations analyzed collaboratively by all stakeholders. The physical and biological factors impacting wild-land health, private sector priorities, and urban environments are critical when evaluating the advantages and costs of policy and regulatory decisions regarding forest management.

Actionable Next Steps

- Support regional forest management and limit land development in high-fire-hazard and ecologically sensitive areas by permitting forest thinning and controlled burns where appropriate while respecting local planning, zoning, and regulatory strategies at the wild-land/urban interfaces.
- Promote and fund educational programs for diverse stakeholders focused on how effective forest management benefits all citizens (e.g., atmospheric carbon reduction, increased water supplies, long-term forest and watershed health) and how individuals can support fire control practices, comprehensive water allocation decisions, and enforceable land planning.
- Prioritize region-specific forest management (e.g., mechanical thinning, prescribed fires) in ecosystems containing species recognized as providing culturally significant resources. Strategies need to recognize the impact of changes in human population and climate conditions to ensure ecological and societal resiliency and to achieve multiple resource objectives (e.g., uncontaminated water supplies, economically viable timber production, vibrant wildlife habitat).
- Revise interagency policy decisions to avoid competition between fire suppression, forest restoration, and fire prevention priorities. Encourage

public-private partnerships focused on improving forest/ecosystem health and reducing fire danger while defraying the costs of forest management (e.g., the Tuolumne River Land Trust).

ISGP conference program

Sunday, April 10

11:00 – 12:30 **Registration**
Lunch

12:30 – 12:45 ***Welcoming Remarks***

- **Dr. Ming-Tung "Mike" Lee,** Interim Provost and Vice President for Academic Affairs
- **Dr. Orn Bodvarsson**, Dean of the College of Social Sciences and Interdisciplinary Studies
- **Dr. Fraka Harmsen** , Special Assistant to the President on Sustainability
- **Dr. George Atkinson**, Founder and Executive Director of the Institute on Science for Global Policy

Presentations and Debates

12:45 – 14:15 **Dr. Roger Bales, Professor, University of California, Merced**
Foundations for California's Water Security in a Changing Climate

Moderated by Dr. George Atkinson, Founder and Executive Director, ISGP

14:15 – 14:45 *Break*

14:45 – 16:15 **Dr. Christina Swanson, Science Center Director, National Resources Council**
Managing Water for People and Fish, Now and in a Changing Climate

Moderated by Dr. Sweta Chakraborty, Associate Director, ISGP

16:15 – 16:30 *Break*

16:30 – 18:00 **Dr. Jon Keeley, Research Ecologist and Adjunct Professor, U.S. Geological Survey and University of California, Los Angeles**
Global Warming and Future Fire Regimes

Moderated by Dr. Sweta Chakraborty, Associate Director, ISGP

18:00 – 18:15 **Concluding Remarks and Caucus Information**
Dr. George Atkinson, Founder and Executive Director, ISGP

18:30 *Reception and Dinner*

Keynote Speaker
Dr. Frank Lake, Research Ecologist, U.S. Department of Agriculture Forest Service
The Role of Tribal Knowledge Systems in Collaborative Approaches for Addressing Climate, Fire and Water Research and Management

Monday, April 11

7:30 – 8:30 **Registration and Caucus Assignment**

7:30 – 8:30 *Breakfast*

Caucuses

08:30 – 12:00 **Focused Group Sessions**

12:00 – 14:00 *Lunch*

12:15 – 12:30 *The Fire Next Time*, a film by Stephen Most, writer and documentary filmmaker, and Kevin White, director

12:30 – 13:30 **Keynote Speaker**
Chief Ken Pimlott, Director of California Department of Forestry and Fire Protection

13:30 – 14:00 **Sustainability Presentation**
Ryan Todd, CSUS Sustainability Committee Chair

14:00 – 17:00 **Plenary Caucus Session**

17:00 – 17:15 **Closing Remarks**
Dr. George Atkinson

17:15 *Adjournment*

Foundations for California's Water Security in a Changing Climate**

Roger Bales, Ph.D.
Professor, University of California (UC), Merced,
Merced, California, United States
Co-authors: Martha Conklin and Joshua Viers, Professors, UC, Merced;
Andrew Fisher, Professor, UC, Santa Cruz; Graham Fogg, Professor, UC, Davis;
Michael Kiparsky, Director, Wheeler Water Institute, UC, Berkeley

Summary

California's water supplies are facing unprecedented stresses, and the state's water-management systems are struggling to meet both environmental and human needs (agricultural, municipal, industrial). Supplies are highly vulnerable to climate variability and extreme events, limiting options to respond to the combined stresses of a changing climate, population, and land cover. Strategic, coordinated investments in California's water infrastructure, institutions, and information will provide the foundation for a secure, equitable, and efficient water future. The cornerstone of water security, and priority need for California, is a modern, robust water-information system that enables accurate, timely, and transparent accounting through the water-supply and use cycle. This system must extend from mountain headwaters through valley groundwater. Investments are also needed in capacity building for use of water information among institutions and stakeholders across the state. Priority infrastructure improvements are needed for central elements of the state's "green" infrastructure: restoration of Sierra Nevada and other forests in source-water areas, and additional groundwater recharge on farmland and expanded floodplains. With better-informed management, California's existing water supplies could go further to meeting the state's urban, agricultural, ecological, and industrial needs.

Current realities

The effects of drought, a warming climate, changing land cover, and population growth and consequent resource demands, all are creating unparalleled stresses to California's water supplies. Being highly exposed to climate variability and extreme events, options to respond to these combined stresses and reliably meet demands for urban and agricultural supply, hydropower, recreation, and ecosystems are

complex and expensive. For example, much of the state's water system was thought to be capable of withstanding a seven year dry period without severe damage to the economy and environment. However, in the multiyear dry period that began in 2012, some areas struggled to supply adequate water after only one or two dry years (Calif, 2016).

Many of California's water-system services and assets are managed or operated locally and regionally. Surface and groundwater are largely managed and regulated as separate resources, when they are, in fact, a highly interdependent system of watersheds and groundwater basins (Calif, 2014). This heterogeneous approach is an outgrowth of the state's history, with parallel but largely independent mining, agricultural, and urban development. Water rights and the state's hundreds of water-management entities constitute the institutional framework that aims to balance public interest with private claims. The current drought has illuminated weaknesses in both the institutions and data needed to efficiently and fairly allocate water. The state acknowledges unmet data needs to characterize groundwater conditions, operate water-supply infrastructure, achieve water-conservation goals, reduce energy use, and promote water transfers (Calif., 2016). With better management, California's existing water supplies could go further to meeting the state's diverse needs.

Water security can be defined as the reliable availability of an acceptable quantity and quality of water for ecosystem and human health, livelihoods, and production, coupled with an acceptable level of water-related risks, (e.g. flooding, pollution). Sustaining the state's water security in the face of unprecedented changes requires investments in three tightly linked areas: *infrastructure*, *institutions,* and *information* (Figure 1).

Scientific opportunities and challenges

California's water *infrastructure* extends from its headwaters in the Sierra Nevada and other source-water areas through dams, conveyance facilities, groundwater wells, and treatment plants. The first requirement for a sustainable water future is to plan, invest and maintain both this "green" and "grey" infrastructure (i.e., natural versus human engineered infrastructure respectively). Our source-water areas have unsustainable forest densities, as evidenced by increasing high-intensity wildfires that threaten downstream water uses (e.g., greater erosion, loss of snowpack). Adequate water-supply storage is also key to water-security infrastructure, with the state's major stores being surface reservoirs, groundwater, and snowpack. Climate warming is causing declining snowpack storage, and is projected to reduce usable storage behind dams for seasonal water.

The second requirement for ensuring water security is the integration of disparate or individual government efforts into a regional commitment in which the sum becomes greater than any single piece (Calif., 2016). *Institutions* can be broadly defined as the rules, norms, and conventions that influence decisions in society. This includes organizations and agencies, as well as legal, social, cultural, and other influences on decisions. Water-management institutions in California have not evolved to keep pace with yesterday's scientific and engineering developments, let alone the capacity to adapt to 21st century stressors.

The third foundational investment needed is better water *information* to guide decision making, design and maintain infrastructure, and improve water-supply reliability (CCST, 2014). Salient, credible, and legitimate information is increasingly a critical bottleneck for making sound decisions and managing risk. Development and application of innovative, quantitative water accounting and analysis will provide the foundation for better decisions under increasing uncertainties. Tools for high-resolution and real-time monitoring of major water stores and flows (e.g., precipitation, snowmelt, evapotranspiration, recharge, surface and subsurface flows, changes in groundwater storage) will provide accurate, timely feedback in support of adaptive management and infrastructure investments. The power of an informed public with ready access to water-resources information is central to water security.

Policy issues

Strategic, coordinated investments in California's water infrastructure, institutions, and information will provide the foundation for a secure, equitable, and efficient water future:

1. a modern, accurate, timely, and transparent water-resources information and accounting system that covers the extent from mountain headwaters through valley groundwater;
2. capacity building for use of water information among stakeholders across the state;
3. restoration of Sierra Nevada and other forests in source-water areas to sustainable conditions; and
4. additional groundwater recharge on farmland and expanded floodplains.

While some efforts in these areas are underway, more-aggressive and comprehensive approaches are warranted.

Water-information system. Existing technologies can be adapted to more-effectively manage our limited water resources. A modern water-resources information system

can simultaneously enhance flood protection and improve water storage, allocation and delivery by:

1. establishing a network of low-cost, strategically placed snow, snowmelt, rainfall and soil-moisture, and groundwater sensors throughout a basin;
2. incorporating satellite and aircraft imaging that can better determine snow, soil-moisture, and vegetation status;
3. integrating data to more accurately estimate evapotranspiration, across both headwaters and agricultural areas, and to predict runoff; and
4. generating real-time data and information that will reduce key uncertainties, make water-supply forecasts more reliable, and inform water-resource decisions.

Three immediate policy changes and investments can advance this program across the state.

1. Make requirements for basin-scale water accounting much more explicit in the Emergency Regulations for Groundwater Sustainability Plans and Alternatives, under the state's Sustainable Groundwater Management Act.
2. Provide incentives for Integrated Regional Water Management programs to build core elements of a new water-information system through Proposition 1, the Water Quality, Supply, and Infrastructure Improvement Act, proposals. and funds.
3. Develop and demonstrate a prototype cyberinfrastructure system for integrating and serving existing and emerging data in the American River basin as a core element of a new scalable water-information system, through a partnership between agencies, non-governmental organizations and researchers.

Capacity building. Two sustained programs are needed to build the support among institutions and stakeholders for the information and infrastructure investments along with the institutional changes needed by the state to provide a secure water future.

1. Strengthen requirements and provide incentives for water agencies to become primary sources of information within their communities for the priorities and investments needed to: (i) mitigate climate warming (e.g. Assembly Bill 32), and (ii) adapt to climate warming.
2. Expand the state's programs to adapt to climate warming, through: (i) greater technical support from the Department of Water Resources'

climate program, and (ii) additional legislative action as outlined in the 2014 Little Hoover Commission report on the topic.

Forest restoration and management. State, federal, and private-sector partnerships can accelerate restoration of source-water areas and provide a foundation for a new era of sustainable management. Three immediate actions are needed.

1. Form a high-level working group to plan and advocate for sustainable watershed management in source-water areas, as a partnership between the California Resources Agency, water providers, and university; and engage other stakeholders in the process.
2. Expand the vision and plan for sustainable forest management in the next update of the State Water Plan (due in 2017).
3. Sustain ongoing partnerships between land managers, water providers, and researchers to build the knowledge base for predicting and verifying the water implications of forest restoration, management, and disturbance, through multiyear commitments by the Bureau of Reclamation, U.S. Forest Service and California Resources Agency.

Groundwater recharge. Groundwater storage and conjunctive use are potential measures to provide both seasonal and multi-year storage. Two actions can advance these programs.

1. Administrative action can enable federal support through drought-response and grant programs within the Bureau of Reclamation, the Natural Resource Conservation Service, and other agencies.
2. The California Department of Water Resources can partner with water agencies and researchers to develop and sustain testbeds to build the knowledge base for expanded groundwater recharge, storage, and recovery.

References

California Natural Resources Agency, Department of Food and Agriculture, and Environmental Protection Agency (2016). *California Water Action Plan, 2016 Update.*

California Department of Water Resources (2014). *California Water Plan, Update 2013*, Bulletin 160-13.

California Council on Science and Technology (2014) *Achieving a Sustainable California Water Future through Innovations in Science and Technology*.

***** A policy position paper prepared for presentation at the conference on Water and Fire: Impacts of Climate Change, convened by the Institute on Science for Global Policy (ISGP), April 10–11, 2016, at California State University, Sacramento***

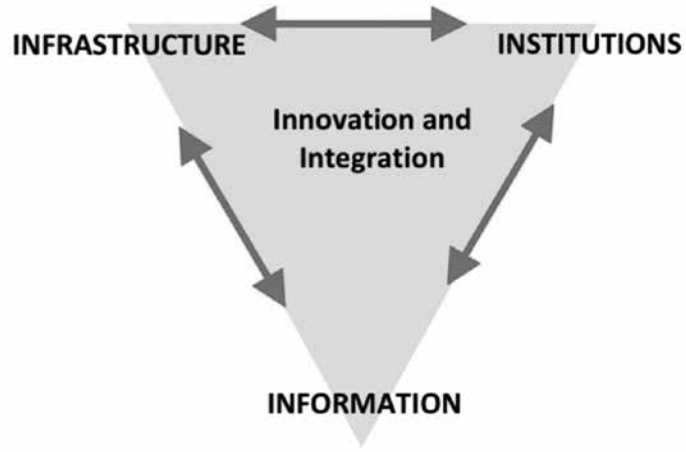

Figure 1. Three key elements of water security are "green" and "grey" infrastructure, institutions that organize water decisions, and water information to guide decision-making. Integration of these can foster innovation, and lead to maintaining and improving water security.

Debate Summary

The following summary is based on the transcriptions of a recording made during the debate of the policy position paper prepared by Dr. Roger Bales (see above). Dr. Bales initiated the debate with a 5-minute summary of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the ISGP's best effort to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Dr. Bales. Although this summary has been written without attribution, the conference itself was open to the public and media and as such, did not restrict participants from attributing remarks to specific individuals. The views comprising this summary do not necessarily represent the views of Dr. Bales, as evidenced by his policy position paper, or those of the ISGP, which does not lobby on any issue except rational thinking. Rather, it is, and should be read as, an overview of the areas of agreement and disagreement that emerged from all those participating in the critical debate.

Debate conclusions

- Since access to timely, accurate, and comprehensive information about water flow, resources, and usage helps to increase supply and improve the sustainability of water systems, collaborative investment in monitoring technology needs to be a priority among local, regional, and state water agencies, as well as in public-private partnerships. Collected data needs to be made available to all stakeholders as they optimize operations, investment strategies (e.g., green versus gray water infrastructure), and policy decisions.
- In recognition of the vital connection between surface water and groundwater, governmental agencies need to implement strategies for land usage and water/forest management that increase the amount of water stored in naturally distributed systems (e.g., snow pack, groundwater basins). Policy issues include (i) setting aside more land for groundwater recharge (especially within flood plains), (ii) restoring and maintaining headwaters, and (iii) preserving forests in pre-fire-suppression condition.
- Although implementation of the Sustainable Groundwater Management Act (SGMA) has significantly improved water security, the rapid depletion of groundwater supplies requires that groundwater protection provisions be accelerated. Compliance with SGMA can be optimized by educating water officials concerning (i) water management provisions, (ii) oversight and enforcement of restrictions, and (iii) existing conservation legislation.
- There is an urgent need to reconsider the water rights system to ensure priorities for (i) providing safe drinking water, (ii) promoting the stewardship of natural resources, and (iii) supporting sustainable water resources. While recognizing the substantial political and economic challenges, water rights reform is essential to creating an equitable system for the distribution of increasingly limited water resources based on credible science and objective data.
- In addressing the causes of global climate change (e.g., greenhouse gas emissions) and the anticipated increase in the number of extreme weather events (e.g., droughts, floods), it is essential to recognize that improved water management, including the increased availability of uncontaminated water sources maintained by natural and man-made infrastructure, is essential for supporting wetlands, forest restoration, recharge and recycling rainwater collection, and flood management.

Current realities

California has the most water security of any semiarid region in the world, but the water system is showing signs of stress due to the effects of climate change, increasing population, and changing land use. While debates about water management tend to focus on operational and implementation decisions (e.g., releasing water from a flood control dam, building a groundwater recharge basin), overarching decisions are more urgently needed concerning the priorities for the state's water system.

Unlike some other areas of the world that are depleting their groundwater basins, California recently prioritized the restoration of water basins to an index level with the passage of the 2014 Sustainable Groundwater Management Act (SGMA). While this is a critical step, many fundamental priorities remain to be determined among human, environmental, and economic interests. Although the state lacks a viable framework within which to effectively prioritize these competing interests, they still must be weighed in current and future decisions about water allocation, usage, and storage.

California's water allocation system comprises hundreds of small water agencies and special districts with local autonomy to determine beneficial usage, even though this structure can result in inequalities and unsustainable practices (e.g., golf courses get irrigated while residents must buy bottled water to drink; land is allocated to development and agriculture rather than to groundwater recharge). Even as water availability decreases, water demand is growing (e.g., in the San Joaquin Valley, corn is being replaced by specialty crops such as almonds that increase stress on groundwater resources). Although the state constitution gives residents the ability to add a definition of "reasonable and beneficial" water usage, this has not been done.

Although operating autonomously, agencies collaborate with each other and the state in large-scale water projects. One example is California WaterFix, a proposed twin-tunnel project designed to improve the reliability of water deliveries from the Sacramento-San Joaquin Delta to the San Joaquin Valley and Southern California. The project, partially financed by Southern California growers, offers the possibility — but not a high probability — of meeting the co-equal goals of sustained water levels in the Delta, healthy saltwater/freshwater ecosystems, and a sustained high level of water delivery to users.

Given that water storage capacity is vital to water security in semiarid areas, California needs engineered "gray infrastructure" systems (e.g., dams, reservoirs). However, the vast majority of storage capacity is distributed within natural "green infrastructure" systems (e.g., snow pack, soil, ground water, headwaters, forests) and these systems currently are negatively impacted by drought, increased human consumption, changing land use, and climate change.

The proposal to invest in real-time information technology that improves the comprehensive management of gray and green infrastructures and hence increases the sustainability of the water supply is technically possible but politically and economically controversial. Since current water policy is described as "legislation through lobbying and litigation," a shift to dynamic, data-driven water management will create severe disruptions among users accustomed to large, static allocations, and among ecological, agricultural and other special-interest groups with stakes in the outcome. However, access to timely, accurate, comprehensive, and transparent data can provide objective cost-benefit analyses that will better inform decisions and improve water security and sustainability. SGMA requires modeling supported by accurate measurements of the water balance, although some of the vague terms in the law need better definition to ensure effective compliance.

Water management practices would benefit from the collection of real-time data regarding water flow, existing water supplies (e.g., groundwater), and water usage. Within the last decade, the feasibility of real-time information has been realized and it is now possible to obtain distributed data at a lower cost and with greater accuracy, resulting in more exact forecasts and integrative models. Smart meters have been installed on all the wells in the San Joaquin Valley's largest irrigation district, which currently shares the information annually, although it's suggested that monthly is preferable. The amount of water used by the Sierra Nevada forest and crops in the California Central Valley currently is reported every four years, although monthly or annual reports would lead to more effective decision-making.

Access to timely information can lead to proactive decisions by showing correlations (e.g., how water balance is changed when forests are thinned) and by stimulating users to practice watershed management. Data also can show the different vulnerabilities between regions (e.g., due to precipitation, soil type), and can be used to verify hypotheses, especially regarding diverse conditions. The field of forest management is considered to be on the verge of providing verifiable tools that attract private sector investors.

While sensor costs have decreased, concerns exist that installation and maintenance expenses could be high. In addition, past attempts to encourage voluntary self-monitoring were met with low compliance by water users.

It is considered extremely important to address water issues within the overarching framework of the effects of climate change, which continues to be accelerated by manmade factors.

Scientific opportunities and challenges

Even the best ground water managers in the Central Valley are unsure about

the amount of water entering the aquifer, although some may know the total quantities being removed. While numerous solutions have been proposed to increase groundwater recharge, there is a need to measure and compare their effectiveness.

Before investing heavily in large gray infrastructure projects, research is needed to measure the cumulative effects of local projects that enhance water storage in green infrastructure (e.g., recharge in 100 to 200 aquifers near rivers coming off headwaters; restoring forests to pre-fire-suppression condition to increase runoff and snow pack storage; setting aside land for recharge that offsets land that is being developed; moving levies away from river channels to increase flood plains; measuring water that seeps below agriculture irrigation in canals). To prioritize projects to investigate, scientists need to focus on knowledge gaps in forest management and groundwater recharge (e.g., return intervals in headwaters restoration), as these areas are considered especially critical in distributed storage.

Significant challenges exist to increasing green storage capacity (e.g., the possibility of degraded water quality due to contamination, the large amount of energy required to pump water). While renewable energy (e.g., solar, wind) can power the pumps without increasing greenhouse emissions, renewable energy storage technologies still need to be improved.

Another priority for scientific investigation is the utilization of new and emerging monitoring technologies in data collection demonstration projects that inform water supply operations. Hydropower demonstration projects could provide cost-benefit information to elected officials and the hydropower industry, with opportunities to launch a new generation of forecast models that can help to optimize this valuable resource.

Transparent access to objective, comprehensive data is needed to build public support for investments in sustainable water security. Opportunities exist to utilize public talks, op-eds, and mainstream entertainment to effectively communicate data in ways that are useful to the decisions of the public writ large. Given that interest is high among college students to discuss water within a societal framework, such conversations need to be encouraged and supported more broadly. In academia, faculties at all levels need to commit to the pervasive inclusion of sustainability education throughout curricula, so as to raise the climate literacy of kindergarteners through graduate students. Education needs to connect water concerns to larger issues of the effects of climate change. Scientists will need to work with decision-makers to ensure inherently political decisions are based on scientifically credible understanding.

While access to real-time information is widely considered both beneficial and possible, more investigation is sought regarding a proposal to build a comprehensive

water information system, particularly with regard to outcomes from other countries (e.g., Australia), hidden costs, and barriers to success.

Although seawater desalination is often dismissed as a viable water-security strategy because of its high energy and delivery costs and possible environmental effects, it is reasonable to consider its inclusion in planning. The Los Angeles metropolitan area could potentially benefit more from desalinated water than from water from the San Joaquin Delta, providing the desalination is done sustainably using renewable resources.

Policy issues

To enhance water security and sustainability in a time of changing climates, water policies need to be informed by scientifically credible and objective data, and to result in equitable distribution to all users. In recognition of the vital connection between surface water and groundwater, local governments need to develop and implement sustainable community strategies for land usage and water/forest management that conserve and improve distributed water storage within the watershed.

Given that California's system of historical water rights is widely considered outdated and inappropriate for current drought conditions, water rights reform is fundamental to implementing sustainable water policies, notwithstanding the obvious political and economic complications of such an effort. Noting that the California constitution allows water rights to be revised, some have called for a constitutional guarantee of an individual's right to clean water as a strategy that will promote local, regional, and state cooperation in water management strategies.

A comprehensive information system that provides timely data regarding water flow, supplies, and usage can serve as an objective basis for the reform of water rights. Although critical questions are raised about the logistics of financing, coordinating, and managing such a system, a recommended first step is to ensure water data are more readily available to stakeholders. Without reform of historical water rights, however, dynamic water management will be politically impossible to achieve on a comprehensive level.

To enact sustainable water policies, California water users will need to accept that the price of water will increase. Investments are needed in green infrastructure (e.g., restoration of headwaters and groundwater basins, forest thinning), gray infrastructure (e.g., 1,100 miles of Delta levies, water storage capacity), and new technology (e.g., sensors, desalination, tunnels). Forest management restoration, which directly improves distributed water storage, needs investments similar to what is being spent to fight forest fires; once initial costs are realized, however, expenses likely will decrease.

Water districts need to recognize that headwater restoration requires ongoing maintenance rather than one-time investments, as has been done in the past. Public attitudes about investing in environmental services may be slowly changing, as evidenced by water district boards that have allocated money for yearly headwaters maintenance and have not faced recalls.

To fund these investments, collaborations are essential among local water agencies, state agencies, and private beneficiaries. Public investments need to clearly benefit the public, and if the benefits are unequally distributed (e.g., benefitting economic interests more than public interests), the beneficiaries need to contribute to the cost. Residents need to consider a variety of funding options, from taxes and fees, to seeking grants for the carbon sequestration benefits of forest management. Public-private sector partnerships are an integral part of an economically viable adaptable management framework (e.g., recruiting private money to advance forest-thinning restoration projects). California's water information systems, currently used mainly for flood control, represent a cooperative effort among federal/state agencies, and, to some extent, private sector stakeholders. This cooperation is expected to be the model going forward, providing entrepreneurial business opportunities and offsetting taxpayer costs. Existing private sector information systems could be integrated effectively.

Since a sustainable water future will require more land to be set aside for recharge, local governments need to incorporate groundwater recharge into land development plans, as has been done in other parts of the country (e.g., Texas has a program that requires the purchase of land for recharge to offset development in recharge areas).

Despite the autonomy of California's multitudinous water agencies, the passage of SGMA, combined with other existing legislation, provides an opportunity to require local policy makers to adopt groundwater recharge measures. Although SGMA is considered a positive step, there is concern that implementation of groundwater management requirements is too slow and needs to occur sooner than 20 years, due to the ongoing stresses on the groundwater system. Also, SGMA needs to provide more guidelines on reporting requirements, as voluntary reporting has not proven effective (e.g., during the current drought, water rights holders demonstrated low levels of compliance with conservation restrictions and requests to voluntarily report pumping amounts).

Although the California Water Resources Control Board sets water allocation percentages based on per capita water usages, a key policy question is whether residents want to continue to allow local water agencies to decide what constitutes

beneficial water usage, or whether the definition of beneficial usage needs to be considered at the state level.

In light of ongoing effects of climate change, it is recommended that water management planning be based on the assumption of drought, and that any excess water be banked. Investing in water management education for officials of local/regional/state water agencies is a way to increase climate literacy and improve community decision-making. The Integrated Regional Water Management System also can be part of this solution because it has target requirements for greenhouse gas reduction, although the system needs more support and promotion by the state (e.g., the Department of Water Resources).

Managing Water for People and Fish, Now and in a Changing Climate**

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Summary

Recent drought has exposed limitations and flaws in California's water management for humans, aquatic ecosystems, and fish. With climate change, these problems will only get worse. Going forward, sustainable water management must consider the functional connections between the environmental water sources used by humans and healthy aquatic ecosystems. We need to acknowledge the limits to our water supplies and, because current demands exceed sustainable environmental supplies, develop and implement plans to meet our human needs with less water. Science has already provided much of the information we need for improved management and aquatic ecosystem protection, but its application in policy has been hampered by disagreement, denial, and political inertia. Additional scientific opportunities exist for developing and applying regional water budgets, and for using improved models to evaluate alternative management scenarios. New policies are needed to reprioritize allocation of water resources to better protect aquatic ecosystems, accommodate the functional realities of our hydrologic system, encourage conservation and efficient use of water, and promote water management practices that increase water supplies without further damaging our already stressed aquatic ecosystems.

Current realities

California's recent multiyear drought has revealed unwelcome — but not unforeseen — limitations and flaws in our current management of water, fish, and aquatic ecosystems. The state's approach to cope with the dry conditions and maintain stable water deliveries to farms and cities by increasing water diversions from rivers and draining surface reservoirs and underground aquifers is unsustainable, now and in a warmer and potentially drier future. Not only did it fail to meet demands for human use, it drove aquatic ecosystems and native fish species, already stressed by decades of water management practices, pollution, habitat degradation, and other related stressors, to collapse. Scientists now predict imminent extinction of several fish species long considered biological indicators of healthy aquatic ecosystems.

Water, aquatic ecosystems, and fish are all public trust resources in California, managed by the state for public use. Our recent experience confirms that current policies and management are not meeting these public trust responsibilities, particularly for aquatic ecosystems and fish. New policies based on clearer understanding of the functions, requirements, and limits of these resources are needed. Four foundational, intersecting realities — true for California and nearly everywhere else on the planet — govern sustainable management of fresh water, aquatic ecosystems, and the fish and wildlife that rely on them.

First, most water resources used by humans come from the environment, from rivers, lakes, wetlands, underground aquifers, and even the ocean. All of these water sources are connected by the hydrologic cycle: weakening or breaking the hydrologic connections among them impairs their functional availability to humans as water sources as well as their value as habitats for fish and wildlife. For example, excessive diversion of water from a river reduces flows, degrades riverine and adjacent wetland ecosystems, decreases recharge of connected aquifers, and impairs both water quality and the capacity of these ecosystems to provide the natural filtration services that protect water quality. Similarly, excessive groundwater pumping that depletes an aquifer can lead to land subsidence, reduced aquifer storage capacity, and flow reductions in connected rivers, all of which can decrease surface water supplies and ecosystem functionality.

Second, water from the environment is a finite supply that varies from year to year. This supply is not a function of human water demands, but is instead dependent on what is provided through rain, snow, and the equally finite, if somewhat less variable, water supplies in surface and underground reservoirs. However, aquatic ecosystems and fish rely on that same water for river flows and wetland inundation that create habitat and drive essential ecological processes. Excessive water diversions from the environment, which can create chronic drought conditions in aquatic ecosystems, will not support healthy fish and wildlife populations (Figure 1).

Third, all evidence indicates that we — in California and many other regions around the globe — are currently living beyond our water means. Collapsing aquatic ecosystems, fish population declines, deteriorating water quality, water shortages, and depleting aquifers all point to mismanagement and overconsumption of our finite and interconnected water resources.

Finally, the impact of climate change on precipitation, air temperatures, and sea level are expected to significantly affect both environmental water supplies and water needs of humans and ecosystems. In California, predicted declines in mountain snowpack have implications for river ecosystems, cold water flows for salmonids, reservoir operations, flood control, and management of increasingly volatile surface

water supplies for human use and environmental protection. Downstream, where local farms and government water facilities divert water for irrigation and urban use, sea level rise will require increases in river flows to prevent salt water intrusion and preserve water quality, with resultant impacts on upstream water supplies.

Scientific opportunities and challenges

There is already a rich body of scientific literature on water requirements for aquatic ecosystems and fish, including for California's rivers and estuaries. Both regulatory agencies and academic researchers have studied and credibly defined the amounts of water required to protect aquatic ecosystems and fish. However, application of these results is mired in controversy between stakeholders with different interests and regulators who are not immune from political pressure. Several areas of scientific opportunity and/or challenge that flow from the current realities could help inform and advance these and other needed policies.

Managing water is like managing a budget. In California (and many other parts of the globe), we need better quantitative information on our water budget realities. At appropriate regional scales, we need to know: (i) the types and amounts of water supplies, including local surface water, imported water, groundwater, and recycled or desalinated water; (ii) the types and amounts of demands for that water, including for a healthy environment; (iii) whether the supply and demand are in balance and the amount of the deficit (or surplus); and (iv) the opportunities for increasing supply and reducing demand to bring an unbalanced "budget" into balance.

Models can be powerful tools to investigate relationships among multiple variables and alternative scenarios. California water managers use several sophisticated models to evaluate and plan operations of the state's complicated water system. However, most of these efforts focus on a subset of the water resources (e.g., surface water but not groundwater), produce narrowly targeted outputs such as maximizing annual water deliveries, rarely consider effects on ecosystems or species, and incorporate very conservative climate change projections. These approaches are not sufficient to guide sustainable management of water, fish, and aquatic ecosystems now or in our changing world.

The application of science to natural resource management and public policy is rarely simple. It is particularly difficult for issues such as water in California (or other places), which involve competing needs for limited, already over-allocated resources in naturally dynamic and changing systems. Properly defined, science-based decision support tools that integrate research and modeling results from multiple disciplines (e.g., biology, hydrology, economics, climate science) can guide

and provide transparency to the process and serve as a framework for effective adaptive management to refine and improve our management over time.

Policy issues

For sustainable water management in a changing climate, the greatest challenge for policy makers is not scientific — managing water is, in the end, a mass balance equation. The real challenges are in acknowledging and securing public recognition of the limits of hydrological and ecological systems, prioritizing choices about allocation of the limited resource, and promoting approaches that increase the size of the water supply while preserving our other public policy objectives. Meeting these challenges will require informed engagement of the public and stakeholders and new policies and action by government agencies at all levels that:

- Prioritize allocation of water resources to provide (i) safe drinking water for people; (ii) environmental flows for ecosystem health and hydrological services; and (iii) water for economic uses based on revisions of existing water allocations that correct over-allocation. Such prioritization, and particularly the rebalancing of environmental and economic uses of water, requires changes at all levels of government, including to state law for water use, state and federal regulations for ecosystem, fisheries, and water quality protection, and state, federal and local water contracts.
- Regulate and manage surface and groundwater resources as integrated water supplies throughout government (i.e., federal, state, and local water agencies). Specifically restrict activities that impair hydrologic connectivity (e.g., floodplain development) and manage floods to enhance floodplain habitat creation and groundwater recharge (e.g., by the U.S. Bureau of Reclamation, Army Corps of Engineers, Federal Emergency Management Agency, and related state and local planning agencies).
- Plan for hydrological variability rather than responding to floods and droughts as extreme events. Manage environmental water for multiyear ecosystem protection and water supply reliability instead of maximum annual deliveries, promote realistic expectations by basing permitted or contractual water allocations on projected supplies in dry years rather than wet years, and develop specific plans for ecosystem protection and water supply management during droughts throughout government agencies.
- Protect water quality by reducing or eliminating point and nonpoint source pollution (e.g., agricultural and stormwater runoff, underground injection of contaminated wastewater) and by protecting and restoring

habitats that provide water quality-related ecosystem services throughout governmental agencies (e.g., Environmental Protection Agency, State Water Resources Control Board, and agricultural and urban discharge and stormwater management districts).

- Require and/or incentivize water use efficiency and water conservation by urban and agricultural water users using strategies such as "tiered pricing" and "demand reduction" in all water year types (i.e., both wet and dry years).
- Promote implementation of storm and rainwater capture, water recycling and reuse, and green infrastructure to increase local water supplies, reduce pollution, and recharge local groundwater basins (state and local agencies and water districts).

References

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*** A policy position paper prepared for presentation at the conference on Water and Fire: Impacts of Climate Change, convened by the Institute on Science for Global Policy (ISGP), April 10–11, 2016, at California State University, Sacramento*

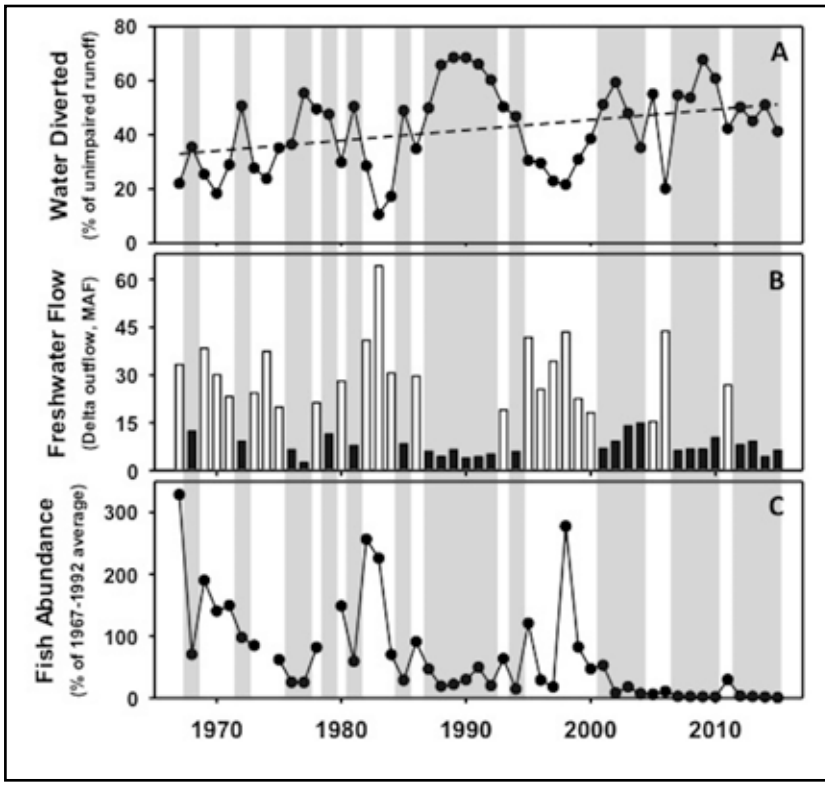

Figure 1. Increasing water diversions from California's Sacramento-San Joaquin watershed and Delta have reduced freshwater flow into the San Francisco Bay, creating chronic, man-made drought conditions in the estuary and upstream, degrading aquatic habitat and driving many fish species toward extinction.

A. Annual water diversions from the Sacramento-San Joaquin watershed and Delta, expressed as the percentage of estimated unimpaired runoff (i.e., without dams or water diversions). Diversions have increased by 30%, from an average of 37% of unimpaired runoff in the 1970s to an average of 49% of unimpaired runoff in the past decade. Diversion rates are highest in years with median and dry hydrological conditions.

B. Annual freshwater flow into the San Francisco Bay estuary, in million acre-feet. Years in which annual flows were less than would have occurred in the driest 20% of years under unimpaired conditions (i.e., natural drought) are shown as black bars and highlighted in gray across the three plots. Based on annual freshwater inflows, the estuary has experienced drought-like conditions in 12 of the last 15 years (80% of years).

C. Abundance of delta smelt, longfin smelt, splittail and striped bass, expressed as the percentage of their average 1967-1992 abundances. Declines in abundance of these estuary-dependent species correspond to low freshwater inflows (gray highlight). Average abundance for the last 4 years was 2% of 1967-1992 levels. Prolonged low flow conditions have driven populations of these species to such low levels that their capacity to recover when conditions improve is substantially reduced.

Data sources: CA Department of Water Resources (Dayflow and Central Valley Unimpaired flow datasets) and CA Department of Fish and Wildlife (Fall Midwater Trawl Survey).

Debate Summary

The following summary is based on the transcriptions of a recording made during the debate of the policy position paper prepared by Dr. Christina Swanson (see above). Dr. Swanson initiated the debate with a 5-minute summary of her views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the ISGP's best effort to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Dr. Swanson. Although this summary has been written without attribution, the conference itself was open to the public and media and as such, did not restrict participants from attributing remarks to specific individuals. The views comprising this summary do not necessarily represent the views of Dr. Swanson, as evidenced by her policy position paper, or those of the ISGP, which does not lobby on any issue except rational thinking. Rather, it is, and should be read as, an overview of the areas of agreement and disagreement that emerged from all those participating in the critical debate.

Debate conclusions

- The evidence attributing declining fish populations in the San Joaquin Delta to manmade reductions in water flow has not by itself motivated new policy decisions since an ongoing debate over the potential contributions from other less-significant factors (e.g., water contamination, destruction of marshes and riparian habitat, invasive plants and fish) has not been resolved. The inability of fish to adapt quickly to rapid environmental degradation caused by low flows and higher water temperatures makes it imperative that mitigation strategies be implemented immediately to repair habitat, improve surface water infiltration, and reduce human demand.
- The health of aquatic ecosystems and the sustainability of secure water resources are governmental and private sector responsibilities that derived from prioritizing the allocation of water for environmental services while recognizing the political and economic challenges associated with long-term investments in environmental infrastructure.
- The recognition that historic water rights are often not appropriate to support current economic or population conditions, especially with respect to maintaining sustainable water resources, requires a comprehensive re-evaluation of existing regulations. Future policies

need to identify opportunities to allocate water resources consistent with sustainable aquatic ecosystem, as well as anticipatory, proactive decisions recognizing the impact of changing climatic conditions.

- The limitations of water as a natural resource, the expensive technical strategies used to create potable water (e.g., wastewater recycling, seawater desalination), as well as their potentially negative ecological impact strongly suggest that changes be made to improve environmental water storage by combining freshwater and groundwater management to reflect the increasing vulnerability to droughts.

Current realities

While California is ahead of the rest of the nation in developing climate-change models to inform development, the recent drought has highlighted the state's mismanagement of its precious water resources. Although the California constitution designates water as a public resource, owned by all and managed for the citizens' benefit by the State, in practice water allocation is being managed according to an archaic water rights system that no longer applies to California's economy or population, and has failed to (i) meet demand for many users and (ii) appropriately protect and manage aquatic ecosystems and fisheries, which suffered severe harm in the drought.

Compared to those years when its water flowed freely without dams or diversions, California's Sacramento-San Joaquin watershed and Delta have experienced chronic manmade drought for 12 of the past 15 years, due to both variable annual flows and the diversion of 50% of the water flow for personal and economic uses. Today, the average amount of water flowing from the Delta into the San Francisco Bay estuary is less than the estuary would have received in the driest 20% of free-flowing years. However, all California rivers (with the exception of some undammed rivers) are flowing at 80% of uninhibited flow, a rate considered necessary to support wildlife habitat, pollution concentration, water temperature, and recreational usage. Estuaries require 75% of free flow, according to a 2010 study by the State Water Resources Control Board. As sea levels rise, higher river flow also is critical to prevent saltwater intrusion in the San Joaquin Delta.

In the Delta, the first to experience the impact of low water flow have been the biological resources that rely on now-depleted aquatic ecosystems (e.g., estuary fish populations, which have steadily declined over the past 50 years). Although salmon and smelt are resilient and adaptable species, decreased flows and dam-blocked access to cooler upper streams have resulted in higher water temperatures, stressing cold-water fish populations. While fish decline and ecosystem degradation are due

in part to water contamination, destruction of marshes and riparian habitat, and invasive plants and fish species, the decreased flow of water is a more significant driver of the problem. Meanwhile, political squabbles over which factor plays the biggest role have stalled implementation of environmental mitigation strategies.

Despite recent progress in sustainable water management (e.g., the 2014 Sustainable Groundwater Management Act or SGMA), environmental water protections were weakened during the drought (e.g., in 2014-2015, the State Water Resources Control Board waived environmental protection in the Sacramento estuary and eliminated the need to provide minimal flow). Other important water protections (e.g., the Clean Water Act's recent revision of the definition of "waters of the U.S.") do not adequately prevent contamination from storm water and agricultural run-off.

Because water policy and management decisions often are based on political concerns rather than scientific understanding, multiple players fiercely compete within the state system to protect their own interests, with agricultural users wielding a disproportionate amount of political clout compared with the sector's contribution to the state's economy. Agricultural usage consumes four times more water than individual, urban, or industrial users, but the agricultural sector largely has resisted voluntarily conservation or measurements of water usage.

The result is that water-management decisions typically prioritize short-term economic water demands over long-term environmental needs, despite evidence that environmental water allocations are necessary to nourish and support the overall water supply for all users. Therefore, current water management practices tend to be reactive rather than proactive, do not encourage conservation behavior from the heaviest users, and are creating a state of water depletion.

A movement to designate water as a human right has emerged and is progressing, driven in part by the uneven distribution of safe drinking water in California and nationally (e.g., lead contamination in Flint, Michigan). This movement could have wide-ranging effects on water management and distribution.

Poor water management that has disadvantaged some communities during the drought may be due in part to the limitations of California's public utilities model that is based on multiple distribution entities, rather than on a model of large utilities with bigger bases that can provide smaller communities with needed resources and oversight.

Protecting and restoring aquatic ecosystems adversely affected by current water management operations is expensive. In the past, public money has been used to fund these efforts because ecosystems are part of the public trust, but the state has neither made sufficient financial commitments to environmental mitigation, nor

asked users who disproportionately benefit from water allocations to bear some of the costs.

Scientific opportunities and challenges

Because revising water rights is described as a "tortuous" process that Californians have avoided so far, the state needs to effectively reprioritize and reallocate water resources within the current water management system. To inform and propel this decision-making, the state needs cost/benefit analyses that consider the critical priorities of individual, environmental, and economic usage (e.g., the environmental cost of polluted runoff in the San Joaquin Valley versus the economic benefit of agricultural products; the costs and benefits of utilizing selected areas for flood plain and recharge versus development).

Multidisciplinary science and engineering collaborations are necessary to devise solutions to challenges affecting multiple stakeholders (e.g., because land development causes water to flow faster through an area and can disrupt the vital surface/groundwater connection, strategies are needed that increase water infiltration, such as setting back levies and repurposing land). While dams block fish access to cold water, they also store cold water, especially in their depths, that can support some fish species. That cold water also can be released to cool the water below the dam. However, such an environmental release reduces the amount of water available for human uses.

Although cold-water fish (e.g., salmon, smelt) are at the edge of their temperature-tolerance limits, they are adaptable and can be managed within the current system and potentially repopulated later. Given that the effects of both climate change and human operations are occurring faster than fish species can adapt, some scientists are developing genetic modifications, sometimes referred to as "assisted evolution," that can help fish thrive in present conditions.

A significant emerging concern for scientists is that there are more chemical pollutants in the water system than can be measured, and many of these contaminants are present in extremely low concentrations but still may affect reproductive capacity, growth, and behavior. Scientists need to pay closer attention to these emerging and low-level contaminants and learn more about their effects.

Although much of the information needed for high-level water management decisions exists, there are critical gaps in scientific knowledge (e.g., the effects of groundwater pumping on surface water). Opportunities exist to better integrate citizens and other end users into improving sustainability by developing local solutions that utilize water more effectively (e.g., storm water capture, green

infrastructure) and provide opportunities for communities to recognize and engage with water issues.

While there are numerous viable strategies for reducing demand (e.g., pricing, regulations, incentives), strategies to increase water supply (e.g., desalination, tertiary treatment of wastewater) often require vast amounts of energy that can be costly and contribute to greenhouse gas emissions. An opportunity exists to simultaneously address the energy required to increase the water supply, and the challenges facing renewable solar and wind energy, which at certain times of day exceeds the energy demands on the power system. Water recycling plants and desalination plants can represent important outlets for excess renewable energy, balancing the energy grid.

With 17,000 seasonal and part-time agricultural jobs lost in 2014 due to the drought, opportunities exists to identify new employment opportunities, and plan for a long-term shift from the current agricultural model to a more sustainable economic model for the state.

Policy issues

Given the integral connections between environmental water flow, the health of aquatic ecosystems, and the sustainability of the water supply for all users, it is necessary for California to reprioritize its allocation of water so that water for environmental sustainability is given a higher priority than water for economic uses. Although it may be scientifically rational to prioritize environmental allocations above human drinking water (because ecosystem allocations contribute to water security), societal values demand that individual human usage be given top priority.

As part of this reprioritization, the current system of historical water allocations needs to be shifted to one that is more sustainable, with the State Water Resources Control Board undertaking the difficult task of bringing together all users to adjudicate water rights based on empirical information and pre-established priorities. As an incentive, support is needed in California and nationally for an emerging movement to designate clean water as a human right. While these rights are being worked out, the state's practice of supplying water when local public utilities cannot meet a community's requirements needs to be continued and expanded.

Since water is a finite resource and rights alone don't assure its availability, proactive water management is needed throughout the state that oversees freshwater and groundwater as one unit, and that bases water allocations on the assumption that each year will be a drought year, with any surplus placed in storage.

Although it is extremely costly to mitigate the damage caused to aquatic ecosystems by changing climate and water management (e.g., decreased flow, increased temperature, lost habitat, higher concentrations of contaminants),

taxpayers need to commit to long-term infrastructure investments as a key part of water security, and to seek ways to share these costs with the private sector (e.g., the San Francisco Water Quality Control Board has a monitoring program that is funded by dischargers as part of the cost of doing business).

Numerous criteria can be applied to prioritize water allocations to private sector water users, including: (i) total economic value of the enterprise to the state, (ii) local and national usage (i.e., not for international export), (iii) possibility for water recharge (e.g., some soil within the San Joaquin Valley doesn't drain, creating toxic dumps), (iv) farm size, with preference for family farms, and (v) flexibility of water demand (e.g., orchards have inflexible water demands from year to year, while some crops can be replaced with lower-water-use varieties when necessary). Within these priorities, it is important to ensure there are enough crops to meet demand, and that the state helps agricultural producers and workers transition to new enterprises, including providing job training opportunities.

To improve the vital connection between surface and groundwater, undeveloped flood plains need to remain so, although they can be utilized for agriculture (e.g., the Yolo Bypass flood plain near the Sacramento River).

To increase conservation and reduce demand, both regulations and incentives are needed that empower users to better understand and manage their water resources (e.g., utilizing tiered pricing, which has been shown to be effective at improving water conservation, or following the demand-reduction example of electrical utilities, which pay big users to cut back during periods of reduced supply or peak demand). Given the demonstrated lack of compliance by water users to do voluntary monitoring, the state needs to require (not request) that users report the amount of water used from local streams as a condition of access.

Since policy decisions that are based on economics or societal values without being informed by science may not work and can prove to be both costly and damaging long term, scientifically informed engagement by all stakeholders is essential in water management, particularly political leaders and policy directors.

Global Warming and Future Fire Regimes**

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Summary

Climate and weather have long been noted as playing key roles in promoting wildfires. Global warming is generally expected to exacerbate fire problems. After reviewing the scientific studies of fire-climate relationships, the following conclusions can be drawn. 1) Annual temperature is a crude predictor of ecosystem responses since many processes respond to specific seasonal temperature signals. For example, on landscapes where past climate signals are correlated with fire activity, winter and autumn temperatures are generally irrelevant, but spring and summer temperatures play an important role. 2) Annual fire activity in California has been strongly influenced by climate only in the mid- to higher-elevation forests. However, in lower elevations throughout the state, but most particularly in southern California, fires in shrublands and grasslands have not been strongly correlated with annual variations in temperature during any season. 3) Past fire activity has been strongly influenced by land use activities (e.g., suppression of natural fires or human ignitions) and the impacts have been radically different in the northern and southern parts of the state. These two very different landscapes need to be viewed separately when planning future fire management practices. Global warming is occurring along with a number of other global changes that may have greater influences on future fire regimes, including population growth, changes in land management policy, shifts in vegetation types, and patterns of fire ignitions. All of these factors interact in complicated ways, making future forecasts a challenge.

Current realities

Temperature has always been a key factor in wildfire danger indices, and global warming predictions are a major concern. Historical analyses have shown that the *sine qua non* of a severe fire season in California forests is dry spring weather. It is now widely recognized that this relationship between climate and fire activity has

important implications for climate change impacts on fire regimes of the future. However, it is important to recognize that temperature effects are seasonally dependent. Based on historical analysis of the last 100 years of fire records, it is apparent that warmer winters or warmer autumns have had no discernible effect on fire activity, whereas spring and summer temperatures do play a pivotal role. It cannot be stressed enough that this fire-climate relationship is largely restricted to montane coniferous forest ecosystems. Lower elevations and most elevations in the lower part of the state are generally less responsive to yearly changes in temperature. These latter landscapes appear to be more strongly affected by direct anthropogenic impacts, including timing and location of ignitions.

California covers a greater latitudinal range than any other western state and, as such, comprises a huge range of climates and very diverse fire regimes. In terms of California fire issues, the recent United States Forest Service (USFS) analysis illustrates two distinct regions within the state (Figure 1). Due to the success of a century of fire-suppression policy, forests in the Sierra Nevada and the northern portion of the state have experienced far fewer fires than historically recorded. In contrast, the nonforested landscapes in the southern part of the state, although managed with the same fire suppression policy, have not experienced a deficit of burning. This is in part due the difficulty of suppressing fires in chaparral-dominated landscapes coupled with the greater numbers of human-caused ignitions in this southern region.

Scientific opportunities and challenges

Balancing fire hazard reduction and resource protection poses a major challenge in a state as diverse as California. This equation plays out very differently in northern versus southern ecosystems in the state. Most of California's forests have historically experienced frequent low-severity understory burning, and both understory herbaceous and shrubby species as well as overstory tree species are adapted to this fire regime. Managing these landscapes with frequent prescription burning has the potential for both reducing fire hazard and enhancing these resources.

Research needs for forested landscapes include parsing out the effects of global warming in different seasons and developing models that equate temperature increases with expected fire activity. Because the effect of global warming may have multiple effects, including increases in the length of fire season as well as increasing fire frequency, this research can be complicated. A further complication is that as fire frequency increases, the current ecosystem may be set on a trajectory for a different vegetation type with different fire regime characteristics.

In the southern half of the state there is a need for a better understanding of other global change issues that will potentially have greater impacts than global warming. In particular, there is need for understanding how population growth and patterns of growth will impact future fire regimes, something that is particularly critical in light of the fact that human activity accounts for more than 95% of all fires. Issues in need of research are causes of ignitions and placement of prefire fuel treatments. On these southern California landscapes, humans dominate the ignitions and as ignitions have increased over the past century there has been a well-documented conversion from native shrublands to nonnative grasslands. These latter systems are much more flammable, increasing the length of the fire season and frequency of burning, which feeds back into even greater landscape conversion and resource degradation. Additional issues in need of research are ignition causes and placement of prefire fuel treatments.

Policy issues

The U.S. Geological Survey has been an active player in the development of wildland fire management policy. The Cohesive Strategy developed by federal agencies has focused on using sound scientific evidence when choosing among alternative management approaches.

On an annual basis, California wildfires are responsible for a small portion of the total acreage burned in the Western United States. However they consume the bulk of federal fire suppression dollars. This is largely due to the high population density of metropolitan areas juxtaposed with watersheds of dangerous chaparral fuels. Since the beginning of the 21st century California has averaged a loss of 1,000 homes a year from wildfires mostly in the southern half of the state.

- **Forested ecosystems.** These ecosystems have missed fires due to past fire-suppression policy (Figure 1) that has resulted in substantial increases in forest fuels threatening to change fire regimes to high-intensity crown fires. Forest restoration requires prescription burning or other fuel reduction tactics. One of the primary constraints on burning is air-quality, which applies to both allowing wildland fires to burn, as well as prescription burning. One solution to reducing surface fuels (e.g., leaves, small dead wood) and ladder fuels (e.g., young trees) could be mechanical treatments. Constraints on this approach are the greatly increased costs associated with mechanical treatments plus economic limitations to such tactics on National Park Service lands. Making these treatments pay for themselves

through commercial contracts raises serious issues about trees of value to be removed versus the impact on fire hazard. These are issues in need of serious discussion.

- **Nonforested ecosystems.** These landscapes comprise shrublands, which are the dominant plant community in southern California. Since the California State Legislature mandates a resource assessment of only timber and rangeland, these shrublands are perhaps not as well understood as is needed to assess their fire potential. On these landscapes the important global changes need to be viewed broadly to include more than climate change. Humans account for the vast majority of fires and human growth predictions are an order of magnitude greater than temperature warming in the coming decades.

  Critical concerns do not only involve increased anthropogenic ignitions, but the spatial distribution of ignitions as well. In the south, the majority of fires that become catastrophic are ones that ignite in the interior and are driven by desert-to-ocean offshore winds known as Santa Ana winds. The more that development expands to the interior landscapes, the more likely such fires will increase in size. A closer relationship between fire management practices and land planning decisions could have positive effects.

  Throughout the western U.S. there has been an inordinate concern on landscape-level fuel treatments for handling wildfire issues. In southern California this issue is doubtful because catastrophic fires are driven more by factors such as weather than the state of the vegetation. We currently lack clear evidence that landscape-level fuel treatments change fire outcomes, particularly with respect to property losses. The model that seems to have the most support is that of fire management focused on "the house out," which describes a concern on focusing fire hazard reduction at the house and Wildland Urban Interface (WUI) zone, and decreasing emphasis as one moves out on the landscape. Particularly in these nonforested landscapes, additional research is needed to determine the appropriate strategic placement of vegetation treatments.

  Other issues that need further discussion include the state-mandated "clearance" requirements. Total clearance is not required for defensible space and thus a change in terminology may enhance communication. Recognition that embers are a major source of home ignition points to

the need for more research on specific changes in maintenance required to produce fire safe conditions. The role of evergreen trees as ember catchers needs further research as well.

***** A policy position paper prepared for presentation at the conference on Water and Fire: Impacts of Climate Change, convened by the Institute on Science for Global Policy (ISGP), April 10–11, 2016, at California State University, Sacramento***

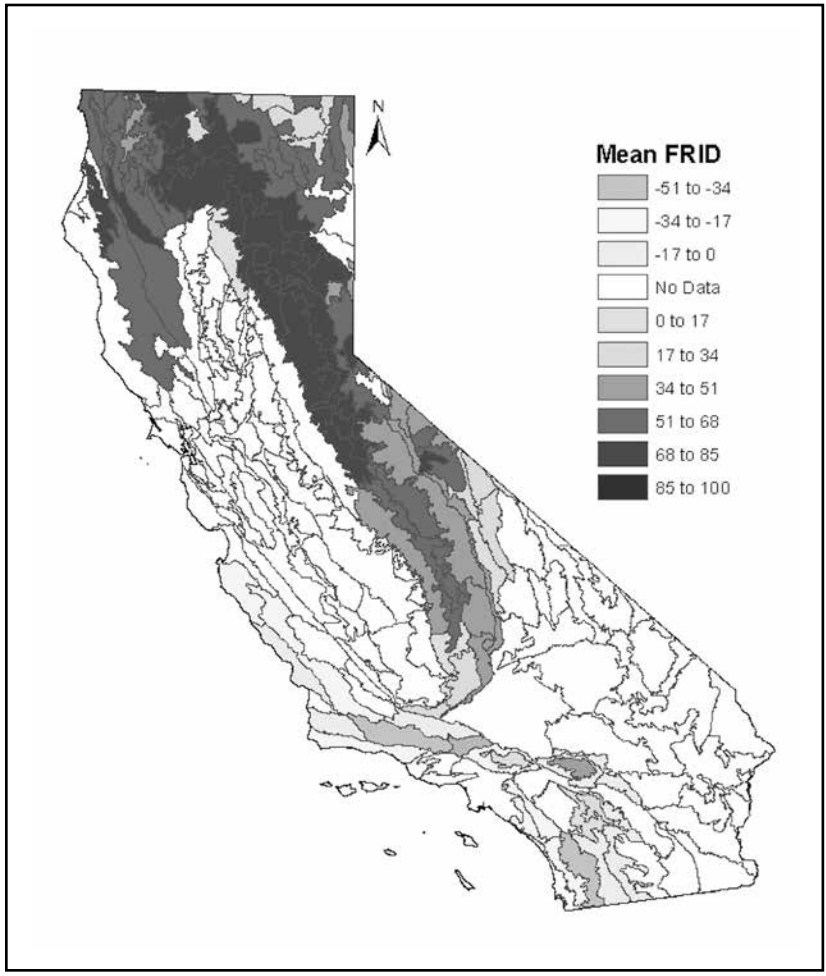

Figure 1: Fire departure map for USFS lands in California. Areas in darkest grays indicate landscapes that, relative to historical fire regimes, have missed fires and are in need of prescription burning or other related vegetation treatments. Lighter grays represent landscapes that, despite a century of fire suppression, have had more fire than historically was the case and 'restoring' fire is not needed (from Safford and van de waters 2014).

Debate Summary

The following summary is based on the transcriptions of a recording made during the debate of the policy position paper prepared by Dr. Jon Keeley (see above). Dr. Keeley initiated the debate with a 5-minute summary of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the ISGP's best effort to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Dr. Keeley. Although this summary has been written without attribution, the conference itself was open to the public and media and as such, did not restrict participants from attributing remarks to specific individuals. The views comprising this summary do not necessarily represent the views of Dr. Keeley, as evidenced by his policy position paper, or those of the ISGP, which does not lobby on any issue except rational thinking. Rather, it is, and should be read as, an overview of the areas of agreement and disagreement that emerged from all those participating in the critical debate.

Debate conclusions

- The broad biogeography in California (high-elevation forests in the north to nonforest landscapes of the densely populated south) require different policy regimes to effectively reduce fire hazards and sustain healthy ecosystems: specifically in the north reducing forest fuel load that both protect natural resources and human health and safety (e.g., prescribed or natural burns, mechanical thinning) and in the south minimizing the increasingly destructive impacts of human-caused fire ignitions (e.g., improved land-use planning, arson prevention).
- The high cost of fire suppression and forest management/restoration activities (e.g., prescribed burning, mechanical thinning, fire prevention) require that the private sector join advocacy groups, government, and forest managers to establish priorities and developing implementation plans for sustainable land-use policies.
- Policy makers need to recognize that while human activities (e.g., arson, land development, forest management strategies) are the primary causes of large, catastrophic California fires, climate changes (e.g., temperature increase, prolonged drought) have exacerbated fire hazards. Enhanced fire prevention efforts are needed that range from implementing simple changes (e.g., fire patrols, roadside barriers that prevent grass ignition)

to regulating land use (e.g., prohibiting heavy-growth development near watersheds), to developing and utilizing remote sensing technology, to provide real-time information about fire conditions.

- The increasing frequency and length of drought and the impact of invasive species on landscape vegetation and plant mortality require that the basis for determining a sustainable and "natural" state for forests and wild lands be urgently reconsidered. Researchers, forest managers, and policy makers need to emphasize flexible adaptation strategies that manage diverse regions, based on their unique needs and stresses, instead of recreating historical fire return intervals and tree densities.

Current realities

California has the highest fire-suppression costs of all Western states, with a dollar amount that is out of proportion to the total area burned. Because the state has a broad biogeography, ranging from the high-elevation forests of the north to the chaparrals of the heavily populated south, strikingly different fire challenges confront forest managers.

Because fire frequency in Southern California is higher than has been experienced historically in the region, the landscape lacks the accumulation of highly combustible fuels that is present in northern forests. Although the area's chaparral landscapes thrive with periodic high-severity fires, those areas have instead experienced low-severity fires, resulting in a conversion to invasive grasses that further suppresses fire severity. When chaparral is transformed to exotic grasslands via these low-severity fires, the fire season lengthens from six months to year-round, watersheds become unstable, and there is less carbon storage in vegetation.

By contrast, Northern California's forests historically thrive with low-severity fires that do not kill the forest canopy trees. However, fire severity in Northern California has increased, in part as a result of a suppression policy that has led to a massive build up of fuels (e.g., parts of Sequoyah National Park have not had a fire for 125 years, although tree ring records historically show fire intervals every 10 to 30 years).

While not the only factor, climate change has an effect on fire hazard. Research by Anthony Westerling at the University of California, Merced, has shown that large fires in high northern forests are correlated with temperature increases in the spring and summer — an inferred impact of global climate change. However, no such link exists between climate change and fire activity in Southern California. Although deadly fires occur in Southern California during the annual 50-to-60-mile-per-hour Santa Ana winds, those fires generally are human caused and are not the result of

climate change, nor is there an apparent correlation between wind severity and the changing climate.

While not the primary cause of large fires, increased temperatures as a result of global climate change exacerbate other fire-hazard factors, particularly droughts. Estimates suggest that warmer temperatures increased the severity of the most recent drought by 10% to 15%. Projections indicate temperatures will rise by 4% to 5% within the next 30 years. In a reverse effect, fires may be contributing to climate change. The 2013 Rim Fire, the largest, highest-severity wildfire in the Sierra Nevada, emitted the equivalent amount of greenhouse gas as California Assembly Bill 32 (i.e., the California Global Warming Solutions Act of 2006) sought to reduce in 2½ years.

Despite discussions of climate change effects on fire, 95% of Southern California fires are human caused, and area population is projected to increase by 50% within the next 30 years. Human-caused fires (i.e., arson or accidental) also are changing fire timing, as is seen in the deadly large fires that occur during the Santa Ana winds, when, historically, fires did not occur. The problem of arson-caused fires in Southern California has been partially addressed through neighborhood fire patrols (e.g., during the Santa Ana winds) and the judicial system (e.g., arsonists responsible for fire-related deaths have received the death penalty). However, at the same time, municipalities are allowing land development in and around watersheds, which have hazardous fuel loads, increasing the potential for human-caused fires.

In Northern California, fire suppression policies have almost eliminated fires in the forests, creating extremely high fuel loads. To effectively address fire danger in the fuel-laden northern forests, two strategies are recommended: prescribed burning and mechanical thinning. Each has limitations.

Although prescription burning is utilized regularly in state and national parks, the program is small compared with the size of area to be managed, and park managers do not believe there is any way they can restore historical fire intervals to the system. While forest managers have prioritized certain areas for prescription burning (e.g., Sequoia National Park's giant Sequoia groves have been burned repeatedly in the last 30 years), prescribed burns frequently need to be cancelled because of a lack of fire crews or air quality regulations that prohibit prescribed burns if conditions cause smoke in inhabited areas. Air quality regulations also can require forest managers to extinguish lightening-caused fires that managers would prefer to let burn to reduce fuel.

Fuel loads also can be reduced through mechanical thinning projects, in which private companies buy the rights to cut and remove timber. However, the practice can be expensive and is not always attractive to private industry because large trees (e.g., more than 30 inches in diameter) cannot be harvested.

Indigenous forest management practices worldwide generally seek to return forests to a pre-settlement state, and are an important management tool that can result in a resurgence of cultural practices, traditional knowledge, and biodiversity. While Western forest management also attempts to replicate historical (i.e., pre-management) fire frequency based on the belief that this is a sustainable frequency, these plans are not necessarily based on Native American burning practices, which would work in some areas (e.g., the Sierra Nevada) but not in others (e.g., Southern California).

Scientific opportunities and challenges

Since the 1980s, when there was a peak in fires, ignitions have been decreasing throughout California, although the reasons for both the peak and the decline are unknown. Behavior change caused by public education regarding fire prevention (e.g., Smokey-Bear-type messages) could be at least partially responsible for the decline.

Scientists are challenged to better understand the effects of global climate change on fire occurrences in many areas, as well as the compounding role of nonhuman factors, such as:

- **Temperature**: While increasing temperatures are correlated with higher forest fire activity, it's not known whether the correlation is a result of temperature effects on the snow pack, or soil moisture, or other factors. The duration of optimal fire temperatures also appears to be a significant factor, as is its timing. Research by Anthony Westerling has found that higher spring and summer temperatures, as well as an earlier onset of spring, are strongly correlated with large forest wildfire occurrences in the western U.S.
- **Drought**: While it is known that high temperatures exacerbate the effects of drought, and that drought can lengthen the fire season even absent of temperature increases, it is less clear whether the current drought cycle — which has significantly lengthened and expanded over the last few decades — is influenced by global climate change or is part of a natural cycle.
- **Snow pack**: Although snow pack can play a role in fire risks by affecting soil moisture and the moisture of dead fuels, definitive evidence is lacking of the direct role of snow pack in fire occurrence, and the implications of changes in precipitation and temperature.

- **Ecosystem changes**: Although Southern California vegetation is predicted to move upslope in elevation and northward in latitude, such movements have been occurring for millennia and are not unnatural. Nonetheless, such changes in the ecosystems present scientists with challenges.
- **Sustainable states for forest**: Given that the drought has caused high levels of tree mortality and is driving changes in vegetation, how should a "sustainable state" for forests be defined? How should forest management change given that the native tree densities measured in 1911 are too high for a warmer, drier climate? Scientists and managers are challenged to distance themselves from a static focus on recreating historical fire return intervals, because while those strategies may be appropriate in some cases, in others (e.g., Cedar Grove, Kings Canyon National Park) that static focus has resulted in an increase in invasive plants.

Although the California Division of Forestry focuses on managing and removing forest fuels to make fires less catastrophic, this strategy does not always address the factors that cause a fire to rage out of control. Since the devastating Rim Fire easily jumped across at least 20 large clear cuts, it is apparent that fuel management is not enough to counter the effects of drought and wind, raising the need for more attention to a relatively unexplored area: fire prevention. Simple prevention solutions may be best (e.g., in Southern California, lining roads with traffic barriers could prevent grasses from igniting and spreading into wildfires).

While alert citizens equipped with cell phones have made fire detection easier, opportunities remain for developing and utilizing remote sensing technologies that can relay valuable information about fire conditions (e.g., Light Detecting and Ranging [LiDAR] systems for measuring vertical structure of forest canopies, satellite monitoring for detecting fires, remote sensing systems that can monitor short-term changes in dead fuel in drought-stricken areas, or chlorophyll measurements to identify areas of abundant grass growth).

Given that it may be possible to change wildfire losses in Southern California simply by changing land-use patterns, new models are needed that analyze future development, its effect on ecosystems, and the ways in which development can increase in density rather than expanding outward. In addition, collaboration among environmental advocates, fire managers, and land planners could achieve the separate-but-related goals of fire-hazard reduction and conservation planning through the strategic purchases of land for conservation purposes that also minimizes fire hazard to citizens.

Scientists working with the public and policy makers regarding fire and water policies have an opportunity to connect these issues to climate change, the impact

of human lifestyle choices in driving those changes, and the choices available to reduce that impact.

Greater knowledge of current indigenous fire management practices is needed to better support and study the effectiveness of these strategies.

Policy issues

Restoring the health and resiliency of California's forests is a significant priority, but to succeed will require a balance of resource conservation and protection of people and property. Collaborative efforts are needed to achieve this goal, including collaborations among (i) diverse local groups working together with local and state government to restore and sustainably manage area forests and watersheds, and (ii) governmental agencies unifying efforts to lower costs (e.g., through fire prevention aimed at arson-caused fires, which potentially could have a large impact on fire suppression costs). Business groups need to be invited into collaborative planning, as there are connections between the health of forests and the health of urban areas affected by smoke. Policy makers need to take advantage of current public interest in drought and fire to develop funding mechanisms that strengthen the urban-rural connection, with the beneficiaries of forest ecoservices helping to pay for restoration and management costs.

Federal and state agencies need to explore ways in which mechanical forest thinning can be made cost effective for private industry. Past projects have been costly, it has been difficult to find private partners willing to remove only midsize and small trees, and federal partners have been unwilling to pay for mechanical removal, especially given the huge area the requires thinning. There have been examples of profitable, sustainable private thinning projects in experimental and nonexperimental forests (e.g., Stanislaus National Forest) in which mid-size trees (20-25 inches in diameter) were harvested followed by prescribed burning that removed excess fuel load without the need for government subsidies. These projects worked because (i) the U.S. is currently a leading importer of lumber, (ii) communities have become more accepting of mechanical thinning within the past four to five years, because it is viewed as preferable to destructive blazes; and (iii) companies and forest managers cooperated to find a mutually agreeable course of action. The key to finding agreement among contending groups has been to act locally. On a larger level, however, the success of mechanical thinning relies on changing National Park Service policy prohibiting mechanical thinning in the parks.

To lower fire occurrence in Southern California, state and federal fire agencies need to work with local planners to discourage development in areas with high fire risks. However, reducing fire occurrence by limiting public access to remote forest

areas through road closures is politically unpopular and hard to enforce.

As much as fire management is a practical policy matter, it also is a philosophical issue and managers need to be clear about their goals and priorities. For example, in Cedar Grove, dying ponderosa pines were replaced in campgrounds with tall gray pines, even though the short pinion pine is more native to the area and is the most likely tree to naturally replace the towering ponderosas as well as being better adapted to surviving changing conditions in that area. The decision to plant the gray pines illustrates the choice facing planners and policy makers charged with managing the national parks: Are the parks meant to preserve natural processes and landscapes or human preferred landscapes, such as campgrounds shaded by tall trees?

Acknowledgments

Numerous individuals and organizations have made important contributions to the Institute on Science for Global Policy (ISGP) program on climate change. Some of these contributions directly supported the efforts needed to organize the ISGP conference, *Water and Fire: Impacts of Climate Change,* convened in partnership with California State University on its campus in Sacramento, California, April 10–11, 2016. Other contributions aided the ISGP in preparing the material presented in this book, which includes the three invited policy position papers and the not-for-attribution summaries of the views presented in the discussions, critical debates, and caucuses that ensued at California State University, Sacramento.

The willingness of those in the scientific and policy communities to be interviewed in the preparation for the conference is appreciated, as are the efforts of the three subject-matter experts invited to present their views concerning water, fire, and fish in their policy position papers. The willingness of these authors to engage all conference participants in the vigorous debates and caucuses that comprise all ISGP conferences was especially noteworthy. The biographies of these three authors are provided here.

The success of every ISGP conference critically depends on the active engagement of all participants in the often-intense debates and caucuses. The exchange of strongly held views, innovative proposals, and critiques generated from questions and debates fosters an unusual, even unique, environment focused on clarifying understanding for the nonspecialist. Since these debates and caucuses address specific questions related to formulating and implementing effective public and private-sector policies, ISGP and California State University, Sacramento, are greatly indebted to all those who participated in the conference.

The efforts made by the faculty, students, and administration of California State University, Sacramento, in collaboration with the ISGP to organize and convene the fifth conference within the ISGP Academic Partnership (IAP) program were uniformly recognized as outstanding and are appreciated. The results of their efforts served the interests not only of the academic community, but of the communities engaged with California State University, Sacramento. The brief biographies of the faculty and students from California State University, Sacramento, involved are presented here.

The members of the ISGP Board of Directors also deserve recognition for

their time and efforts in helping to create a vital, increasingly relevant not-for-profit organization that is addressing many of the most important societal questions of our time. The ISGP remains a not-for-profit organization that does not lobby on any issue except rational thinking. The brief biographical backgrounds for the ISGP Board members are presented here.

The energetic, highly professional work of the ISGP staff merits special acknowledgment and appreciation. The staff's outstanding interviewing, organizing, and writing skills remain essential to not only organizing the conference itself, but also to recording the often-diverse views and perspectives expressed in the critical debates, capturing the areas of consensus and actionable next steps from the caucuses, and persevering through the extensive editing process needed to assure the accuracy of the material published here. Biographical information on all the ISGP staff involved is presented here.

ISGP programs are financially supported by government agencies and departments and through gifts from private-sector entities and philanthropic individuals. Specifically, the IAP conference on *Fire and Water: Impacts of Climate Change* received funding from the College of Social Sciences and Interdisciplinary Studies, and the Provost's Office at California State University, Sacramento. The ISGP benefited greatly from generous gifts provided by the Sloan Foundation, MARS Corp., and Edward and Jill Bessey.

Dr. George H. Atkinson
Founder and Executive Director
Institute on Science for Global Policy
April 2016

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www.scienceforglobalpolicy.org.

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ISGP conferences on, or related to, Emerging and Persistent Infectious Diseases (EPID):

- *EPID: Focus on Antimicrobial Resistance,* convened March 19–22, 2013, in Houston, Texas, U.S., in partnership with the Baylor College of Medicine.
- *21st Century Borders/Synthetic Biology: Focus on Responsibility and Governance*, convened December 4–7, 2012, in Tucson, Arizona, U.S., in partnership with the University of Arizona.
- *EPID: Focus on Societal and Economic Context*, convened July 8–11, 2012, in Fairfax, Virginia, U.S., in partnership with George Mason University.
- *EPID: Focus on Mitigation*, convened October 23–26, 2011, in Edinburgh, Scotland, U.K., in partnership with the University of Edinburgh.
- *EPID: Focus on Prevention*, convened June 5–8, 2011, in San Diego, California, U.S.
- *EPID: Focus on Surveillance*, convened October 17–20, 2010, in Warrenton, Virginia, U.S.
- *EPID: Global Perspectives*, convened December 6–9, 2009, in Tucson, Arizona, U.S., in partnership with the University of Arizona.

ISGP conferences on Food Safety, Security, and Defense (FSSD):

- *FSSD: Equitable, Sustainable, and Healthy Food Environments*, convened May 1–4, 2016 in Vancouver, British Columbia, Canada, in partnership with Simon Fraser University.
- *FSSD: Food Security and Diet-linked Public Health Challenges*, convened September 20–23, 2015 in Fargo, North Dakota, in partnership with North Dakota State University.
- *FSSD: Focus on Food and the Environment*, convened October 5–8, 2014, in Ithaca, New York, in partnership with Cornell University.

- *FSSD: Focus on Food and Water,* convened October 14–18, 2013, in Lincoln, Nebraska, U.S., in partnership with the University of Nebraska–Lincoln.
- *FSSD: Focus on Innovations and Technologies,* convened April 14–17, 2013, in Verona, Italy.
- *FSSD: Global Perspectives,* convened October 24, 2012, in Arlington, Virginia, U.S., in partnership with George Mason University.

ISGP Academic Partnership (IAP) conferences

- *Water and Fire: Impacts of Climate Change*, convened April 10–11, 2016, in Sacramento, California, in partnership with California State University.
- *Communicating Science for Policy*, convened August 10–11, 2015, in Durham, North Carolina, in partnership with Sigma Xi, The Scientific Research Society.
- *FSSD: Food Security: Production and Sustainability*, convened April 24–25, 2015, in St. Petersburg, Florida, in partnership with Sigma Xi, The Scientific Research Society, and Eckerd College.
- *FSSD: Safeguarding the American Food* Supply, convened April 10–11, 2015, in Collegeville, Pennsylvania, in partnership with Sigma Xi, The Scientific Research Society, and Ursinus College.
- *EPID: Focus on Pandemic Preparedness,* convened April 11–12, 2014, in Collegeville, Pennsylvania, U.S., in partnership with Ursinus College.

ISGP conferences on Science and Governance (SG):

- *The Genomic Revolution* convened September 6, 2014, in cooperation with the Parliamentary Office on Science and Technology of the British Parliament within the House of Lords. London, United Kingdom.

ISGP reports from ISGP conferences on Global Challenges are available to the public and can be downloaded from the ISGP Web site: www.scienceforglobalpolicy.org:

- *ISGP Climate Change Program (ICCP): The Shore's Future: Living with Storms & Sea Level Rise*, convened November 20–21, 2015, in Toms River, New Jersey, in cooperation with the Toms River Working Group, Barnegat Bay Partnership, Barnegat Bay Foundation, and the Jay and Linda Grunin Foundation.

- *ICCP: Sea Level Rise: What's Our Next Move?*, convened October 2–3, 2015, in St. Petersburg, Florida, in cooperation with the St. Petersburg Working Group.
- *ISGP Climate Change Arctic Program (ICCAP): Sustainability Challenges: Coping with Less Water and Energy,* convened June 5, 2015, in Whittier, California, in cooperation with the Whittier Working Group.
- *ICCAP: Living with Less Water*, convened February 20–21, 2015, in Tucson Arizona, in cooperation with the Tucson Working Group.

Biographical information of Scientific Presenters and Featured Speakers

Scientific Presenters

Roger Bales, Ph.D.

Dr. Bales is Director of the University of California (UC) Water Security and Sustainability Research Initiative, and Director of the Sierra Nevada Research Institute. A Distinguished Professor of Engineering and founding faculty member at UC-Merced, Dr. Bales also is a researcher in the Center for Information Technology Research in the Interest of Society. Active in water- and climate-related research for over 30 years, Dr. Bales' current focus is on building the knowledge base about water issues in California, with the goal of encouraging policies that adapt water supplies, ecosystems, and the economy to the impacts of climate warming. A fellow in the American Geophysical Union, the American Meteorological Society, and the American Association for the Advancement of Science, he has published well-cited papers in multiple disciplines, including hydrology, glaciology, paleoclimate, atmospheric chemistry, geochemistry and environmental engineering, and has led the development of regional, national and international measurement programs that increase scientific understanding of climate change.

Jon E. Keeley, Ph.D.

Dr. Keeley is a Senior Scientist (ST) for the U.S. Geological Survey, an adjunct professor at the University of California Los Angeles, and former director of the ecology program for the National Science Foundation. His research focuses on the ecological impacts and history of wildfires in Mediterranean-climate ecosystems, particularly how climate and other global changes will impact future fire regimes. The senior author of "Fire in Mediterranean Climate Ecosystems: Ecology, Evolution and Management" (Cambridge University Press, 2012), Dr. Keeley has more than 350 publications in national and international scientific journals and books, and has garnered more than 15,000 citations. Awarded a Guggenheim Fellowship in 1985, he is a Fellow of the Ecological Society of America, and the Southern California Academy of Sciences. Dr. Keeley has served on the Los Angeles County Department of Regional Planning Environmental Review Board, and the State of California Natural Communities Conservation Program Board of Scientific Advisors.

Christina Swanson, Ph.D.

Dr. Swanson is Director of the Science Center at the Natural Resources Defense Council (NRDC), where she works to expand the organization's scientific capabilities and support its legal and policy work across a range of environmental, public health and sustainable management issues. She is an expert in fish biology, aquatic ecosystem protection and restoration, ecological indicators and water resource management. Much of her work has been in California, but she has also worked and conducted research in Hawaii and, as a Fulbright Scholar, in the Philippines. Prior to joining NRDC in 2011, Dr. Swanson worked with The Bay Institute, serving as the organization's fisheries scientist and, from 2008-2011, as executive director and chief scientist. The author or co-author of more than 20 peer-reviewed articles and numerous technical and policy memoranda and reports, Dr. Swanson served as President of the Western Division of the American Fisheries Society in 2012-2013, and of the California-Nevada Chapter in 2004-2005.

Featured Speakers

Frank Kanawha Lake, Ph.D.

Dr. Lake is a Research Ecologist working on tribal and community forestry and related natural resource issues with the United States Department of Agriculture Forest Service, Pacific Southwest Research Station Fire and Fuels Program, in Orleans, California. Dr. Lake's research focuses on restoration ecology and traditional ecological knowledge related to tribal management and fire ecology in the Pacific Northwest and northern California, with an emphasis on the Klamath-Siskiyou bioregion. He has a particular interest in wild-land fire and management effects on cultural resources and tribal values. Recently his research has focused on how tribal traditional ecological knowledge can be incorporated into scientific climate change research to support tribal adaptation and mitigation strategies. Dr. Lake is the chair of the TEK section of the Ecological Society of America, the Tribal-Climate Change contact for the Pacific Southwest Research Station, and lead coordinating scientist for the Redwood Experimental Forest and Western Klamath Restoration Partnership landscape collaborative. He received his Bachelor of Science in 1995 from University of California-Davis in Integrated Ecology and Culture, with a minor in Native American Studies, and earned his doctorate in 2007 from Oregon State University Environmental Sciences Program.

Ken Pimlott

Chief Pimlott, Director of the California Department of Forestry and Fire Protection, is also California's State Forester. Chief Pimlott began his fire service career nearly

30 years ago as a seasonal reserve firefighter with the Contra Costa Fire Protection District. His subsequent years of service include 28 years with CAL FIRE, where he served as Deputy Director of Fire Protection with responsibility for CAL FIRE's statewide fire protection programs, including Command and Control Operations, Cooperative Fire Protection, Conservation Camps, Fleet Management, Aviation Management, Training and Safety. Chief Pimlott's resource management and fire protection positions include Pre-fire Management Division Chief, Fire Chief for the City of Moreno Valley and program manager for CAL FIRE's Cooperative Fire Protection Programs. He served as co-chair of the 2010 Strategic Fire Plan Steering Committee within the Board of Forestry and Fire Protection, and is the incoming chair of the Council of Western State Foresters. Chief Pimlott holds an Associate of Arts degree in Fire Technology from American River College, a Bachelors degree in Forest Resource Management from Humboldt State University, and is a registered professional forester.

List of Conference Debaters

Terrence Adelsbach
Student, California State University, Sacramento
Wildlife Biologist and Regulatory Specialist, Michael Baker International

Mike Albrecht
Project Manager
Tuolumne County Tree Mortality Task Force

John Amodio
Rim Fire Recovery Consultant
Tuolumne River Trust

Kathleen Ave
Climate Program Manager
Sacramento Municipal Utility District

Gregor Blackburn
Flood Management & Insurance Branch Chief
Federal Emergency Management Agency

Steven Brink
Vice President - Public Resources
California Forestry Association

Chris Brown
Principal
Chris Brown Consulting

Mark Brown
Professor, Department of Government
California State University, Sacramento

Peter Buck
Director of Natural Resources
Sacramento Area Flood Control Agency

Dudley Burton
Professor Emeritus, Environmental Studies
California State University, Sacramento

Ronald Coleman
Professor, Biological Sciences
California State University, Sacramento

Roger Dickinson
Former Assemblyman
Attorney, Greenberg Traurig

Austin Dunn
Student
California State University, Sacramento

Jeffery Foran
Professor, Chair of Environmental Studies
California State University, Sacramento

Rebecca Fox
Student
California State University, Sacramento

Zachary Frese
Student
California State University, Sacramento

James Goldstene
Adjunct Professor, Environmental Studies
California State University, Sacramento

Fraka Harmsen
Special Assistant to the President on Sustainability Initiatives
California State University, Sacramento

Andrew Hawkins
Student
California State University, Sacramento

Tim Horner
Professor, Chair Geology Department
California State University, Sacramento

Frank Lake
Research Ecologist
USDA Forest Service

Ben LePage
Remediation Manager
Pacific Gas and Electric Company

Amber Mace
Deputy Director
California Council on Science & Technology

Henry McCann
Research Associate
PPIC Water Policy Center

Kate Meis
Executive Director
Local Government Commission

Annalise Metzger
Student
California State University, Sacramento

Jeffrey Michael
Executive Director, Center for Business and Policy Research
University of the Pacific

Cristina Munguia
Student
California State University, Sacramento

Simon Nicholson
Director, Global Environmental Politics Program
American University

Matt Owens
Student
California State University, Sacramento

Samuel Palmquist
Student
California State University, Sacramento

Michael Paparian
Counselor
InterEnvironment Institute

Ericka Picazo Soto
Student
California State University, Sacramento

Judy Robinson
Sustainability Manager-Principal Planner
Sacramento County

Jason Roush
Student
California State University, Sacramento

Juana Sanchez
Student
California State University, Sacramento

Lucas Sanchez
Student
California State University, Sacramento

Michelle Stevens
Associate Professor, Environmental Studies
California State University, Sacramento

Martha Turner
Co-founder, Board of Directors
350 Sacramento & Fossil Free California

Eric Vega
Ethnic Studies Lecturer
California State University, Sacramento

Megan Weiss
Student
California State University, Sacramento

Lauma Willis
Senior Environmental Scientist
California Department of Water Resources

Jennifer Wood
Chapter Leader
Citizens Climate Lobby

Biographical information of California State University Sacramento (CSUS) faculty and staff, and student participants

Faculty and staff

Örn B. Bodvarsson, Ph.D.

Örn Bodvarsson is Dean of the College of Social Sciences and Interdisciplinary Studies and Professor of Economics at CSUS. Prior to coming to CSUS, he served as Dean of the School of Public Affairs at St. Cloud State University and founded and directed the Master of Science in Applied Economics degree program there. The co-author of The Economics of Immigration: Theory and Policy (Springer, second edition 2013), his primary research focus is the distributional effects of immigration and the determinants of internal and external migration. He earned his Bachelor and Master of Science degrees from Oregon State University, and his doctorate in Economics from Simon Fraser University.

Lora Bowler, A.A.

Lora Bowler is an Administrative Support Coordinator in the CSUS College of Social Science and Interdisciplinary Studies Women's Studies Department. In addition to her duties in Women's Studies, she works on special projects for the College of SSIS. Her latest project was the *Water and Fire: Climate Change Conference*.

Dr. Michelle Stevens, Ph.D.

Michelle Stevens, an Associate Professor in Environmental Studies at CSUS, served as campus coordinator of the *Water and Fire: Impacts of Climate Change* conference and taught the IAP class. As a wetlands ecologist and ethno-ecologist with more than 30 years in policy, restoration, management and education, she is currently studying ecological and cultural resiliency within the context of climate change in the Mesopotamian Marshes of Iraq and riparian and mountain meadow wetlands in California.

Student participants

Terrence Adelsbach, B.S.

Terry Adelsbach, who is completing a Master's degree in Conservation Biology at CSUS, has more than 18 years experience in the industry, working with the California Department of Fish & Wildlife, U.S. Fish & Wildlife Service, and ECORP Consulting, Inc. He is currently a senior biologist with Michael Baker International, and a Ph.D. candidate in ecology at the University of California, Davis.

Austin Dunn

Austin Dunn, CSUS Class of 2017, is working toward a Bachelor of Science in Environmental Studies while interning with the Sacramento County Environmental Management Department and working in their Small Water System program. His interests lie in public health and the social and environmental implications of policies.

Rebecca Fox

Rebecca Fox, a member of the Class of 2017, is earning a Bachelor of Science in Environmental Studies from CSUS.

Zachary Frese

Zachary Frese CSUS Class of 2016, is earning a Bachelor of Science in Environmental Studies. Building on a lifelong interest in the natural world, his goals focus on the wellbeing of the planet's biodiversity. Mr. Frese served as an ISGP intern.

Andrew Hawkins

Andrew Hawkins, CSUS Class of 2017, is earning a Bachelor of Science in Environmental Studies while also working in the insurance industry and pursuing wildlife photography. Mr. Hawkins served as an ISGP intern.

Annalise Metzger, A.A.

Annalise Metzger, CSUS Class of 2017, has Associate's degrees in Math and Science and is finishing a Bachelor of Science in Environmental Studies at CSUS. She works as an ELISA lab technician in a genotyping and molecular botany lab.

Cristina Munguia

Cristina Munguia, a member of the Class of 2017, is working toward a Bachelor of Science degree in Environmental Studies from CSUS.

Matthew Owens

Matthew Owens, CSUS Class of 2016, is earning a Bachelor of Science in Environmental Studies, and conducting research on strategies for controlling invasive species. He has a strong interest in water management policy and restoration ecology. Mr. Owens served as an ISGP intern.

Samuel Palmquist

Samuel Palmquist, CSUS Class of 2017, is working toward a Bachelor of Science degree in Environmental Studies, with a particular focus on wetland and agricultural ecology.

Jason Roush, A.A.

Jason Roush, Class of 2016, holds an Associate's degree in Anthropology, and is pursuing a Bachelor's degree in Environmental Studies at CSUS. His focus areas include environmental policy, conservation, sustainability, and emerging environmental technologies.

Juana Sanchez, A.A.

Juana Sanchez holds an Associate's degree in Biology and Chemistry and is earning a Bachelors of Science in Biology from CSUS in 2017. Her career goals are in Aquatic or Marine Biology.

Ericka Picazo Soto

Ericka Soto, CSUS Class of 2016, is earning a Bachelor of Science in Environmental Studies and a minor in Biology, with a particular focus on environmental justice. Ms. Soto helped lead the community outreach task force for the *Water and Fire* conference, and served as an ISGP intern.

Lucas Sanchez

Lucas Sanchez, CSUS Class of 2017, is pursuing a Bachelor of Science in Environmental Studies, with a minor in Philosophy. Mr. Sanchez served as a field research intern for Caltrans and the U.S. Forest Service in a small-mammal conservation project.

Megan Weiss

Megan Weiss is earning a Bachelor of Science in Environmental Studies at CSUS. She played a significant role in developing the website and marketing materials used for the *Water and Fire* conference. A breeder of purebred White Dorper Sheep, her goal is to own and manage a small sustainable organic farm. Ms. Weiss served as an ISGP intern.

Biographical information of ISGP Board of Directors

Dr. George Atkinson, Chairman

Dr. Atkinson founded the Institute on Science for Global Policy (ISGP) and is an Emeritus Professor of Chemistry, Biochemistry, and Optical Science at the University of Arizona. He is former head of the Department of Chemistry at the University of Arizona, the founder of a laser sensor company serving the semiconductor industry, and Science and Technology Adviser (STAS) to U.S. Secretaries of State Colin Powell and Condoleezza Rice. He launched the ISGP in 2008 as a new type of international forum in which credible experts provide governmental and societal leaders with understanding of the science and technology that can be reasonably anticipated to help shape the increasingly global societies of the 21st century. Dr. Atkinson has received National Science Foundation and National Institutes of Health graduate fellowships, a National Academy of Sciences Post Doctoral Fellowship, a Senior Fulbright Award, the SERC Award (U.K.), the Senior Alexander von Humboldt Award (Germany), a Lady Davis Professorship (Israel), the first American Institute of Physics' Scientist Diplomat Award, a Titular Director of the International Union of Pure and Applied Chemistry, the Distinguished Service Award (Indiana University), an Honorary Doctorate (Eckerd College), the Distinguished Achievement Award (University of California, Irvine), and was selected by students as the Outstanding Teacher at the University of Arizona. He received his B.S. (high honors, Phi Beta Kappa) from Eckerd College and his Ph.D. in physical chemistry from Indiana University.

Dr. Ben Tuchi, Secretary/Treasurer

Dr. Tuchi is chairman of the board of directors of the Arizona Research Park Authority. He received his B.S. and M.S. degrees in Business Administration from the Pennsylvania State University and his PhD in Finance from St Louis University. His full-time teaching career began in 1961 at St. Francis College and continued until 1976 at West Virginia University. From 1976 through 1996 he served in cabinet levels at West Virginia University, The University of Arizona, The University of North Carolina at Chapel Hill, and finally as Sr. Vice Chancellor for Business and Finance of the University of Pittsburgh. During those assignments he was simultaneously a tenured professor of finance. He retired from the last executive post in 1996 and returned to a full-time teaching position as Professor of Finance at the University of Pittsburgh, until his retirement in 1999. For the two years prior to his retirement he

was the Director of Graduate Programs in Business in Central Europe, at Comenius University, making his home in Bratislava, The Slovak Republic.

Dr. Janet Bingham, Member

Dr. Bingham is President of the George Mason University (GMU) Foundation and GMU's Vice President for Advancement and Alumni Relations. GMU is the largest university in Virginia. Previously, she was President and CEO of the Huntsman Cancer Foundation (HCF) in Salt Lake City, Utah. The foundation is a charitable organization that provides financial support to the Huntsman Cancer Institute, the only cancer specialty research center and hospital in the Intermountain West. Dr. Bingham also managed Huntsman Cancer Biotechnology Inc. In addition, she served as Executive Vice President and Chief Operating Officer with the Huntsman Foundation, the private charitable foundation established by Jon M. Huntsman Sr. to support education, cancer interests, programs for abused women and children, and programs for the homeless. Before joining the Huntsman philanthropic organizations, Dr. Bingham was the Vice President for External Relations and Advancement at the University of Arizona. Prior to her seven years in that capacity, she served as Assistant Vice President for Health Sciences at the University of Arizona Health Sciences Center. Dr. Bingham was recognized as one of the Ten Most Powerful Women in Arizona.

Dr. Henry Koffler, Member

Dr. Koffler is President Emeritus of the University of Arizona (UA). He served as President of the UA from 1982-1991. From 1982 he also held professorships in the Departments of Biochemistry, Molecular and Cellular Biology, and Microbiology and Immunology, positions from which he retired in 1997 as Professor Emeritus of Biochemistry. His personal research during these years concentrated on the physiology and molecular biology of microorganisms. He was Vice President for Academic Affairs, University of Minnesota, and Chancellor, University of Massachusetts/Amherst, before coming to the UA. He taught at Purdue University, where he was a Hovde Distinguished Professor, and the School of Medicine at Western Reserve University (now Case Western Reserve University). Dr. Koffler served as a founding Governor and founding Vice-Chairman of the American Academy of Microbiology, and as a member of the governing boards of Fermi National Accelerator Laboratory, the Argonne National Laboratory, and the Superconducting Super Collider Laboratory. He was also a board member of the Association of American Colleges and Universities, a member and Chairman of the Council of Presidents and a member of the executive committee of the National Association of Land Grant Colleges and Universities. He was also Founder, President and board

member of the Arizona Senior Academy, the driving force in the development of the Academy Village, an innovative living and learning community. Among the honors that Dr. Koffler has received are a Guggenheim Fellowship and the Eli Lilly Award in Bacteriology and Immunology.

Mr. Jim Kolbe, Member

For 22 years, Mr. Kolbe served in the United States House of Representatives, elected in Arizona for 11 consecutive terms, from 1985 to 2007. Mr. Kolbe is currently serving as a Senior Transatlantic Fellow at the German Marshall Fund of the United States, and as a Senior Adviser to McLarty Associates, a strategic consulting firm. He advises on trade matters as well as issues of effectiveness of U.S. assistance to foreign countries, on U.S.-European Union relationships, and on migration and its relationship to development. He is also Co-Chair of the Transatlantic Taskforce on Development with Gunilla Carlsson, the Swedish Minister for International Development Cooperation. He also is an adjunct Professor in the College of Business at the University of Arizona. While in Congress, he served for 20 years on the Appropriations Committee of the House of Representatives, was chairman of the Treasury, Post Office and Related Agencies subcommittee for four years, and for his final six years in Congress, he chaired the Foreign Operations, Export Financing and Related Agencies subcommittee. He graduated from Northwestern University with a B.A. degree in Political Science and then from Stanford University with an M.B.A. and a concentration in economics.

Dr. Charles Parmenter, Member

Dr. Parmenter is a Distinguished Professor Emeritus of Chemistry at Indiana University. He also served as Professor and Assistant and Associate Professor at Indiana University in a career there that spanned nearly half a century (1964-2010). He earned his bachelor's degree from the University of Pennsylvania and served as a Lieutenant in the U.S. Air Force from 1955-57. He worked at DuPont after serving in the military and received his Ph.D. from the University of Rochester and was a Postdoctoral Fellow at Harvard University. He has been elected a Member of the National Academy of Sciences and the American Academy of Arts and Sciences, and a Fellow of the American Physical Society and the American Association for the Advancement of Science. He was a Guggenheim Fellow, a Fulbright Senior Scholar, and received the Senior Alexander von Humboldt Award in 1984. He has received the Earle K. Plyler Prize, was a Spiers Medalist and Lecturer at the Faraday Society, and served as Chair of the Division of Physical Chemistry of the American Chemical Society, Co-Chair of the First Gordon Conference on Molecular Energy Transfer, Co-organizer of the Telluride Workshop on Large Amplitude Motion and

Molecular Dynamics, and Councilor of Division of Chemical Physics, American Physical Society.

Mr. Thomas Pickering, Member

Mr. Pickering is Vice Chairman of Hills & Co, international consultants, and Strategic Adviser to NGP Energy Capital Management. He co-chaired a State-Department-sponsored panel investigating the September 2012 attack on the U.S. diplomatic mission in Benghazi. He served as U.S. ambassador to the United Nations in New York, the Russian Federation, India, Israel, El Salvador, Nigeria, and the Hashemite Kingdom of Jordan. Mr. Pickering also served on assignments in Zanzibar and Dar es Salaam, Tanzania. He was U.S. Under Secretary of State for Political Affairs, president of the Eurasia Foundation, Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs, and Boeing Senior Vice President for International Relations. He also co-chaired an international task force on Afghanistan, organized by the Century Foundation. He received the Distinguished Presidential Award in 1983 and again in 1986 and was awarded the Department of State's highest award, the Distinguished Service Award in 1996. He holds the personal rank of Career Ambassador, the highest in the U.S. Foreign Service. He graduated from Bowdoin College and received a master's degree from the Fletcher School of Law and Diplomacy at Tufts University.

Dr. Eugene Sander, Member

Dr. Sander served as the 20th president of the University of Arizona (UA), stepping down in 2012. He formerly was vice provost and dean of the UA's College of Agriculture and Life Sciences, overseeing 11 academic departments and two schools, with research stations and offices throughout Arizona. He also served as UA Executive Vice President and Provost, Vice President for University Outreach and Director of the Agricultural Experiment Station and Acting Director of Cooperative Extension Service. Prior to his move to Arizona, Dr. Sander served as the Deputy Chancellor for biotechnology development, Director of the Institute of Biosciences and Technology, and head of the Department of Biochemistry and Biophysics for the Texas A&M University system. He was Chairman of the Department of Biochemistry at West Virginia University Medical Center and Associate Chairman of the Department of Biochemistry and Molecular Biology at the College of Medicine, University of Florida. As an officer in the United States Air Force, he was the assistant chief of the biospecialties section at the Aerospace Medical Research Laboratory. He graduated with a bachelor's degree from the University of Minnesota, received his master's degree and Ph.D. from Cornell University and completed postdoctoral study at

Brandeis University. As a biochemist, Dr. Sander worked in the field of mechanisms by which enzymes catalyze reactions.

Mr. Richard Armitage, Special Adviser

Mr. L. Armitage is the President at Armitage International, where he assists companies in developing strategic business opportunities. He served as Deputy Secretary of State from March 2001 to February 2005. Mr. Armitage, with the personal rank of Ambassador, directed U.S. assistance to the new independent states (NIS) of the former Soviet Union. He filled key diplomatic positions as Presidential Special Negotiator for the Philippines Military Bases Agreement and Special Mediator for Water in the Middle East. President Bush sent him as a Special Emissary to Jordan's King Hussein during the 1991 Gulf War. Mr. Armitage also was Deputy Assistant Secretary of Defense for East Asia and Pacific Affairs in the Office of the Secretary of Defense. He graduated from the U.S. Naval Academy. He has received numerous U.S. military decorations as well as decorations from the governments of Thailand, Republic of Korea, Bahrain, and Pakistan. Most recently, he was appointed an Honorary Companion of The New Zealand Order of Merit. He serves on the Board of Directors of ConocoPhillips, ManTech International Corporation, and Transcu Ltd., is a member of The American Academy of Diplomacy as well as a member of the Board of Trustees of the Center for Strategic and International Studies.

Biographical information of ISGP staff

George Atkinson, Ph.D.
Dr. Atkinson is the Founder and Executive Director of the Institute on Science for Global Policy (ISGP) and is an Emeritus Professor of Chemistry, Biochemistry, and Optical Science at the University of Arizona. His professional career has involved academic teaching, research, and administration, roles as a corporate founder and executive, and public service at the federal level. He is former Head of the Department of Chemistry at the University of Arizona, the founder of a laser sensor company serving the semiconductor industry, Science and Technology Adviser (STAS) to U.S. Secretaries of State Colin Powell and Condoleezza Rice, and past president of Sigma Xi, The Scientific Research Society. He launched the ISGP in 2008 as a new type of international forum in which credible experts provide governmental and societal leaders with the objective understanding of the science and technology that can be reasonably anticipated to help shape the increasingly global societies of the 21st century.

Daniela Baeza, B.A.
Ms. Baeza, ISGP Senior Fellow, holds bachelor's degrees in Global Affairs/ International Relations and Political Science. With a focus on interdisciplinary cooperation between the scientific community, the private sector, and the public sector for international development, she has worked on various domestic and international research projects assessing development strategies, the latest evaluating the effects of economic development on living standards in Singapore.

Jennifer Boice, M.B.A
Ms. Boice, ISGP Program Coordinator, worked for 25 years in the newspaper industry at the Tucson Citizen and USA Today, and was the Editor of the Tucson Citizen when it was closed in 2009. Ms. Boice received her M.B.A. from the University of Arizona and graduated from Pomona College in California with a degree in economics.

Sweta Chakraborty, Ph.D.
Dr. Chakraborty, ISGP Associate Director, received her doctorate in Risk Management from King's College London, and has more than 22 published articles, has contributed to three books, and is author of the forthcoming book "Pharmaceutical Safety: A Study in Public and Private Regulation." She is a former

adjunct assistant professor at Columbia University and a current program associate at Oxford University's Centre for Socio-Legal Studies.

Torsten Fiebig, Ph.D
Dr. Fiebig, ISGP Senior Fellow, is Founder and Chief Executive of Advanced Optix Research, LLC. He holds two doctorate degrees in science, and has been a professor and conducted research at various academic institutions, including the California Institute of Technology, Northwestern University, and the Max Planck Institute for Biophysical Chemistry (Germany). His research interests include energy sciences, medical optics and biological physics.

Christina Medvescek, B.A.
Ms. Medvescek, ISGP Program Administrator, holds bachelor's degrees in Journalism and Psychology from Valparaiso University. An internationally published journalist and editor, she is former Vice President of Publications for the Muscular Dystrophy Association, an EEO mediator for the U.S. Postal Service, and a mediator, facilitator and instructor for the Center for Community Dialogue, Tucson, AZ.

Joseph Roberts, Ph.D
Dr. Roberts, ISGP Senior Fellow, earned his doctorate in social psychology from The Ohio State University in 2011. His research has examined the influence of mindsets on self-control, planning, and decision-making in health and public policy domains. In addition to his work for ISGP, he teaches courses in psychology, statistics, and research methods at The Ohio State University in Columbus, Ohio.

Cleo Warner, B.A.
Ms. Warner, ISGP Senior Fellow and social media manager, is a 2015 Eckerd College graduate with a degree in Literature and Environmental Studies. Her love for studying food systems is leading her through farming adventures all over the globe before eventually pursuing her graduate degree.