Institute on Science for Global Policy (ISGP)


# Living with Less Water

**Conference convened by the ISGP and the Tucson Working Group**
**February 20–21, 2015**
**at the University of Arizona Tech Parks Arizona**
**Tucson, Arizona**


**ISGP Climate Change Arctic Program (ICCAP) — Tucson**

**Institute on Science for Global Policy (ISGP)**

**("a not-for-profit organization that does not lobby on any issue, but does promote rational thinking")**

# *Living with Less Water*

A conference convened by the ISGP in partnership with
the Tucson Working Group of community leaders, in Tucson Arizona, U.S.
Feb. 20–21, 2015

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

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# Introduction

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and
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**Preface**

The contents of this report were taken from material presented at a conference convened in Tucson, Arizona, by the Institute on Science for Global Policy (ISGP) on February 20–21, 2015, in partnership with the volunteer Tucson Working Group comprised of community leaders. The conference entitled, ***Living with Less Water***, was the first of a new series of ISGP Climate Change Arctic Program (ICCAP) conferences being held around the United States. These ICCAP conferences focus on communities that are concerned with how to mitigate and/or adapt to the anticipated impact of changing climates (e.g., drought, sea level rise, severe storms, warming freshwater). Special attention is given to how changes in climate may alter personal lifestyle choices and the collective decisions made throughout a community. ICCAP conferences attempt to significantly improve the communication of credible scientific and technological (S&T) understanding to both policy makers and to the public *writ large,* required to support progressive policies.

**ISGP**

The ISGP was founded in 2008 on the premise that rational debate between credible scientists and relevant stakeholders is an increasingly critical element in both the public and private sectors where policy decisions involving S&T are being made. To support effective policies, decision makers need to understand the advantages and risks associated with the often-transformational S&T advances.

The ISGP has pioneered the development a new type of international forum designed to provide articulate, distinguished scientists and technologists opportunities to concisely present their views of the S&T options available for addressing major geopolitical and security issues.

All ISGP programs rely on the validity of two overarching principles:

1. Scientifically credible understanding must be closely linked to the realistic policy decisions made by governmental, private sector, and societal leaders in addressing both the urgent and long-term challenges facing 21st century societies. Effective decisions rely on strong domestic and global public endorsements that are based on the active political support required to implement progressive policies.

2. Communication among scientific and policy communities requires significant improvement, especially concerning decisions on whether to embrace or reject specific S&T opportunities continually emerging from global research communities. Effective decisions are facilitated in venues where the advantages and risks of credible S&T options are candidly presented and critically debated among internationally distinguished subject-matter experts, policy makers, as well as private-sector and community stakeholders.

**Tucson Working Group (TWG)**

The TWG is comprised of leaders from various communities within the Tucson area who volunteered to work with the ISGP concerning their shared interest in facilitating constructive, rational, and critical debates about the climate issues facing Tucson and Southern Arizona. Biographies of the Tucson Working Group members are in the Appendix of this report.

**ISGP Climate Change Arctic Program (ICCAP)**
Of the seemingly innumerable challenges associated with science and technology being debated, those connected to "climate change" are among the most intractable. The often-irrational discourse and public uncertainty about climate change defines how complex and challenging such issues can become. While public and political disagreements rage over the existence of climate change, and certainly its relationship(s) to human activities, there are increasing physical indications that changes in climates (local, regional and global) are occurring with a rapidity and severity not anticipated by many credible scientists and societal leaders.

Under these circumstances, there is an increasingly important need to more effectively engage citizens in discussions concerning the reality of climate change and its potential significance in their lives. It is also evident that new models are required to reconcile opposing views in order to obtain practical policies that can be implemented and publicly supported.

To ensure that the societal debates of climate change issues lead to effective governmental and private-sector policies, two types of engagements are needed:

1. It is critical that well-informed, credible scientists and technologists candidly communicate the advantages and risks of practical options for addressing climate changes in the lives of citizens and their communities.

2. Citizens must be able to evaluate recommendations based on the predictions from climate change models against often expensive and difficult alterations in their personal lifestyles. Since citizens legitimately have concerns regarding the credibility of information provided to them from multiple sources, they deserve the opportunity to question specific recommendations based on their own perspectives. Formulating and implementing such policies require broad, sustained public endorsements.

Eventually, the outcomes of such candid debates depend on the degree of certainty citizens attribute to the relationship(s) between climate change and specific human activities. The extent to which citizens believe that uncertainty associated with scientific research justifies their accepting the costs and risks associated with any societal decision is the focal point of the ICCAP conferences. Because these decisions often require changes, and perhaps even retrenchments, in the lifestyles of average citizens and community-wide decisions (e.g., higher-fuel-efficiency transportation, reduced energy consumption, different choices for food and housing), sustained public support is essential to motivate policy makers to act.

***Living with Less Water* conference structure**
At each ISGP conference, internationally recognized subject-matter experts are invited to prepare concise (three-page) policy position papers. Following extensive interviews by the ISGP staff with domestic and international subject-matter experts, three distinguished individuals are invited by the ISGP to prepare policy position papers describing their views of the current realities and the scientific, technological, and policy options available to decision makers in government, the private sector, academia, and the society in general. These policy position papers are distributed to all participants prior to the conference.

In Tucson, a group of 37 debaters, comprised of local scientists, academics, governmental and private-sector representatives, students, and other members of the community, was invited to critically question these experts. (Short biographies of the debaters are included in this Report.)

The first day of the conference was comprised of three, 90-minute sessions, each of which was devoted to a debate of a given policy position paper. In each session, the author was given 5 minutes to summarize her or his views while the remaining 85 minutes were opened to all participants, including other authors and the audience, for questions, comments, and debate. Audience members could submit written questions to the moderator. The debates focused on clarifying understanding among the nonspecialists. The not-for-attribution summaries of each debate, prepared by the ISGP staff from notes and recordings, are presented here immediately following each policy position paper.

On the second day of the conference, all returning participants (audience members, presenters, and debaters) met in small caucus groups to identify areas of consensus and actionable next steps to be considered within government, the private sector, and civil society. 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.

A summary of the overall areas of consensus and actionable next steps emerging from these caucuses is presented in this report.

**Areas of Consensus**

The Areas of Consensus (AoC) and Actionable Next Steps (ANS) presented in this Report summarize the essential themes raised by conference participants in response to information, debate, and discussion about drought and water usage. These statements of AoC and ANS reflect how participants responded to the policy position papers as well as their concerns on related climate/water issues.

The AoC and ANS were prepared by the ISGP and TWC following a careful analysis of the transcripts and notes from the debates and caucuses. These AoC and ANS were sent to all conference participants for review and comment, and that feedback was incorporated into the final statements in this Report.

**Concluding remarks**

This Report is designed to be used throughout society *writ large* including policy makers within citizen groups, public and private-sector organizations, as well as governmental officials wishing to learn about the common concerns of area residents regarding ***Living with Less Water***.

The ISGP, a not-for-profit organization, 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 any topic. Rather, ISGP programs focus on fostering environments that can significantly improve the communication of ideas and recommendations derived from credible scientific understanding to decisions makers in both the public and private sectors. It is hoped that all those responsible for formulating and implementing polices will benefit from the information in this Report in their efforts to effectively serving their constituents.

## Conference conclusions

**Area of Consensus 1**
Tucson and other Southern Arizona communities have implemented several water-management plans (e.g., managing groundwater depletion, water recharge) that have helped prepare for future challenges to water supply. However, Southern Arizona communities, the state of Arizona and the Southwest region are experiencing increased demands on water supply, and are in the midst of a prolonged and widespread drought. In addition, observed global trends and climate science models suggest that climate in the region will continue to become more variable and extreme, resulting in both more extreme droughts and flooding. At the local and state government levels, priority needs to be given to advancing long-range strategic plans and short-range tactical plans for adapting to a protracted curtailment of Colorado River allocations.

**Area of Consensus 2**
Leadership by elected officials is critical to implementing proactive water-management policies. Policymakers need to develop and/or refine local, county and state long-term water management plans that address a range of anticipated future water scenarios. Policymakers need to seek out and integrate recommendations from state academic water experts when crafting water policies, and to provide resources for acquiring the relevant data impacts on which to base policy options. Water management plans need to consider the realistic economic impact of drought, including not only simple cost-benefit analysis but also issues of environmental impact. If water-pricing increases are implemented, provisions must ensure balanced financial impact throughout the economic strata of society. Public investment must be made in programs that provide water education to all state residents, starting in early childhood.

**Area of Consensus 3**
Ongoing education about water availability and conservation needs to be offered to all state residents and visitors (e.g., students, neighborhoods, organizations, military, retirees, religious institutions, tourists, businesses) via publicly funded programs and public-private partnerships. State universities need to develop robust educational outreach programs, and the media and private sector encouraged to ensure relevant, accurate information about water issues is easily accessible and comprehensibly described to a variety of audiences. Residents must be motivated to continue to participate in nonpartisan community conversations about their values and cultural and political priorities. The results of these community-wide conversations are essential to inform water policy decisions and motivate the adoption of effective personal conservation actions.

**Area of Consensus 4**
Recognizing that climate science is not a set of absolute truths, but rather a process of inquiry that generates data based on a specific set of predetermined parameters, policymakers still can utilize projections from climate models as a tool in long-term planning for a variety of rational future climate scenarios. However, it also needs to be recognized that models cannot determine what policies are best to enact in response to projections.

**Area of Consensus 5**
A variety of actions can be taken to reduce water usage and increase water resources in Southern Arizona. “Living with Less Water” participants agree to engage in personally selected actions at the individual, community, and state levels, and to advocate with local and state governments for water-conscious policies.

**Actionable Next Steps**
Examples of actions suggested by conference participants:

- **Individual actions**
  - Agree to pay higher water rates to fund necessary infrastructure to use reclaimed water, or to encourage conservation.
  - Agree to pay higher rates or taxes to fund education about water at all levels of society.
  - Encourage and elect politicians to support sustainable measures.
  - Participate in public forums and educational efforts.
  - Listen more carefully to those who disagree and understand the basis for their positions.

- **Community actions**
  - Utilize the expertise of state universities and other expert advisors in devising water programs and policies. Ensure policymakers are all utilizing the same scientifically credible and current data.
  - Convene regular community forums for water discussions. Ensure younger people are part of the conversation. Develop public commitment to finding long-term strategies for addressing water issues.
  - Develop a community identity that is water-wise, sustainability-wise, community-oriented and green.
  - Require low-impact development that captures runoff.
  - Expand water recharge activities.
  - Expand required water conservation measures for new development and provide incentives to existing homeowners to save water (e.g., through water harvesting, grey water capacity, hot water recirculating pumps).
  - Develop and implement "climate smart" certifications similar to LEED Gold certifications for ecologically smart buildings.
  - Address leaking and inadequate infrastructure.
  - Increase water pricing and fees on groundwater use. Avoid/minimize the burden of higher fees on less-affluent populations.
  - Treat effluent to potable standards.
  - Identify champions in the community to develop incentive programs and provide leadership on difficult issues.
  - Re-think the basis for funding important government functions, because limited water supply is likely to limit growth.
  - Provide household with water audits. Install "smart meters" that give feedback on water usage.

- **Regional and state actions**
  - Manage groundwater and surface water as a single resource.
  - Harmonize existing water and development plans of cities and other regional water users.
  - Create legally defensible and ecologically sound standards for defining and supporting "sustainability."
  - Incentivize decreased usage of scarce resources.
  - Establish a water-use index that is easy to understand, similar to the sun-exposure index.
  - Utilize full-life-cycle costing to ensure that the costs of decisions to future generations and to the environment are more widely considered.

- Promote water-conscious policies at the state level by showing that local implementation is both practical and effective.
- Develop new sources of water (e.g., desalinization via solar power) and expand efforts to convert municipal wastewater for use in irrigation, and industrial and commercial purposes.

## Living with Less Water
## ISGP conference program

**Friday, Feb. 20**

| | |
|---|---|
| 08:30 | **Conference Meetings: Debaters and science presenters** |
| 09:00 – 09:45 | **Registration** |
| 09:45 – 10:00 | ***Introduction***<br>**Dr. George H. Atkinson**, Institute on Science for Global Policy (ISGP) Founder and Executive Director |

**Presentations and Debates**

| | |
|---|---|
| 10:00 –11:30 | **Dr. Elaine Wheaton, Adjunct Professor, University of Saskatchewan, Saskatoon, Canada**<br>*Droughts Challenge Water Resource Management and Policy* |
| 11:30 – 12:30 | *Break* |
| 12:30 – 14:00 | **Mr. Keith W. Dixon, Research Meteorologist, Climate Impacts & Extremes Group, National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, U.S.**<br>*From Global Climate Projections to Regional Planning: Matching What Science Can Supply With Decision Maker Demands* |
| 14:00 – 14:30 | *Break* |
| 14:30 – 16:00 | **Dr. Sharon B. Megdal, Director, Water Resources Research Center at The University of Arizona, Member of the Board of Directors, Central Arizona Project, Tucson, Arizona, U.S.**<br>*Water Resource Management Challenges in a Time of Changing Climate* |
| 16:00 – 16:15 | **Closing remarks and caucus group instructions**<br>Dr. George Atkinson |

**Saturday, Feb. 21**

| | |
|---|---|
| 08:00 – 09:00 | **Caucus-group attendance sign in** |

**Caucuses**

| | |
|---|---|
| 09:00 – 12:00 | **Focused group sessions** |
| 12:00 – 13:15 | *Break* |
| 13:15 – 15:50 | **Plenary Caucus** |
| 15:50 – 16:00 | **Concluding remarks**<br>Dr. George Atkinson and Dr. John Pedicone, Chair, the Tucson Working Group |

# Droughts Challenge Water Resource Management and Policy

Elaine Wheaton, M.Sc.
Adjunct Professor, Climate Scientist, University of Saskatchewan, Saskatoon, Canada

**Summary**
Droughts are among the world's worst hazards and pose serious threats and immense challenges to many people, the economy, and the environment. Major droughts are harsh reminders of the great importance of water. This paper gives an overview of the current realities of drought and implications for program and policy formulation. Three main aspects of the current situation are described, including the peculiarities of drought characteristics, changing drought patterns driven by global warming, and links with policy. The nature of drought continues to be elusive and knowledge gaps exist across drought phases (e.g., onset, peak, decline) as well as for drought origins, areas, migrations, and causes. Drought monitoring, prediction, impacts, vulnerability, and adaptation are receiving some attention in research and policy, but efforts must be improved. One of the greatest challenges is integrating policy with drought/climate science. The goal is to reduce negative effects and exploit benefits. Recommendations are organized by three main topics: (i) present and past droughts, (ii) future droughts, and (iii) adaptation. The most significant goal is to address how individuals and society can best adapt to drought and water scarcity.

**Current realities**
Major droughts are stern reminders of the crucial importance of water. Droughts bring immense challenges, including water scarcity. Current and future climate and socioeconomic trends are increasing pressure on water resources. This places pressure on communities and policy makers to make more informed decisions. Decisions based on the data describing "old" normal and more stable climates are no longer suitable and could be misleading or even dangerous.

Droughts are one of the world's greatest hazards and pose serious threats to society, economy, and the environment. Most other natural hazards (e.g., hailstorms, blizzards, tornados) are different in nature (e.g., have rapid onsets), but droughts can develop slowly. This makes early warning for drought more difficult than with other weather hazards.

Three main aspects of the current situation are (i) droughts can be characterized much better, (ii) drought intensity, frequency, and other characteristics are being driven by global warming, and (iii) drought information can be used better and integrated into programs and policies. Given the necessity of water resources, more attention is needed to accelerate improvement of drought research and the integration of improved understanding into policies and programing. The basic question is how can individuals and society best adapt to drought and water scarcity? Adaptation includes adjustments in natural and human systems in response to actual or expected climatic stimuli or their effects. The goal of adaptation is to moderate harm and exploit opportunities.

**Scientific opportunities and challenges**
Recent research provides several new lessons with important implications for monitoring and adaptation to drought. Some examples include: (i) drought seems to migrate from multiple centers (e.g., from northern United States into the Canadian Prairies), (ii) drought may be expanding its range into areas previously less visited by drought, (iii) drought may peak in the winter and persist into the warm season, (iv) shifts from drought to periods of intense rain can occur; however, this may not end the impacts as some droughts have long lags, and (v) droughts have similarities, but each appears to have differences, such as causes and perhaps changing causes. Drought prediction is difficult, but has increasing importance. The lack of

knowledge about future drought is large and is a barrier to action or an excuse for business as usual.
Climate change is expected to increase the frequency, intensity and extent of moderate to extreme drought in several regions. It is likely that this effect has already been occurring. Future probable droughts are likely to be similar or even longer than the severe and intense drought during 2001 to 2002 that affected much of the Great Plains of North America and western United States (Figure 1). This figure shows only the core of the severe drought, and more moderate drought affected a much greater area. Other surprises could also occur with less stable climates. For example, more intense rainstorms are also possible now because of changes to the hydrological cycle. Extreme rainfall and resultant flooding also results in damage. In summary, society needs to prepare for more extreme wet times and dry times (Figure 2). Uncertainty about the future is often used as an excuse for ignoring the warnings about upcoming drought, but because the future is inherently uncertain, making decisions under uncertainty is necessary.

Droughts can bring a host of other problems in addition to water scarcity. These include increased risks of fire, increased soil erosion, water quality degradation, and habitat deterioration, as well as pests and diseases. Most sectors are sensitive to drought, including agriculture, energy production, tourism, manufacturing, transportation, and health.

All this information and more are required to better plan and prepare for drought. Many research opportunities exist because drought is complex and also appears to be neglected by researchers (e.g., lack of funding and training) and by policy makers. People who make their living from the land, for example, seem to recognize drought earlier than policy makers. Further examination of the nature of droughts include understanding their spatial and temporal aspects, such as onset, peak and declining phases, duration, origin, migrations, areas, and causes. Scientific opportunities and challenges exist in each of the categories of drought characteristics including monitoring, prediction, impacts and vulnerability assessment, and adaptation.

One of the greatest challenges is integrating policy with drought/climate science to protect water supplies and address socioeconomic sustainability. Scientists warn that the nature of drought and other climate extremes seems to be changing and more changes are expected with global warming. Challenges include the need for many more stakeholders (e.g., natural and social scientists, economists, engineers, developers, designers, policy makers) to work cooperatively in teams on both drought and other climate hazards. These teams require institutional and other required support. Future drought may bring several surprises that require much more innovative research, communication, and proactive integration of science and policy to achieve the goal of adaptation.

**Policy issues**
The motivations for policy action on drought are many. Some of the most important include the basics, such as food and water security. Safety is also at risk, with drought-related increases in fire and conflict, for example. A main goal of drought research and monitoring and associated policy development is to ensure sufficient water resources for people, the economy, and the environment. How prepared are current leaders for the next big droughts? The three main questions include: (i) what is the status of past and present droughts and their impacts? (ii) what will drought be like in the future (i.e., next week to next decades)? (iii) what is being done and what more can be done to best adapt to current and future drought? Each of these questions is addressed in turn:

Actions on **current drought** characteristics and impacts require better:

- monitoring and communication capabilities. The most sensitive sectors need to be involved, including agriculture, water, and the environmental departments of all government levels. Severe droughts cause ripple effects from biophysical through socioeconomic sectors, then local to continental levels, so almost everyone is affected. These actions lead to the motivation for the next main steps.

- assessments of past droughts for further information about characteristics and causes.

- tracking of water budgets, including supplies and use.

- social, physical science, and policy teams to use the observed data on drought, its causes and impacts to improve monitoring, modeling, and prediction of drought, impacts, vulnerabilities, and adaptations.

Enhanced understanding of **future possible droughts** and impacts requires improvement of:

- capability to predict droughts (climate) and its impacts, including worst-case scenarios because of the severe impacts of droughts.

- impact assessments, including analysis of possible adaptation options and their effectiveness (question 3).

Preparation to **adapt** to future droughts requires opportunities through enhanced:

- attention and capability to understand and use monitoring and projection information. This requires formal and informal institutions at local to national levels to have additional training and expertise.

- use of the information in many tools, including risk management, decision making under uncertainty, scenario analysis, gaming, and strategic planning.

- natural, social, technical, infrastructure, economic, and other capitals.

- testing and improving adaptations, including planning, preparation, and implementation
- speed of incorporation of new knowledge into policy and programming.

- ways to overcome documented barriers to adaptation, including lack of funds, research, knowledge of water supplies and use, as well as resistance to change, apathy, denial, and over-confidence.

A main challenge is that droughts are irregular, complex, misunderstood, sneaky, and are expected to become worse. It is very disruptive, costly, and dangerous to ignore droughts until they are fully affecting communities, the economy, and the environment. Even with advanced technology, communities and countries are still vulnerable to droughts. Recent Canadian research is documenting local to regional concerns about drought and other climatic extremes. It is clear that drought must be taken much more seriously by policy makers to avoid and/or deal with their impacts. More effort and care is required to monitor droughts and their effects, to be able to predict their occurrences and warn people. Adaptation requires considerable effort and support in many realms of science and policy.

**References**

Bonsal, B, Wheaton, E, Chipanshi, C, Lin, C, Sauchyn, D and L Wen. (2011). Drought research in Canada: a review. *Atmosphere-Ocean* 49(4): 303-319.

Kulshreshtha, S, and Wheaton, E. (2013). Climate change and Canadian agriculture: some knowledge gaps. *International Journal of Climate Change: Impacts and Responses* 4 (2): 127-148.
Wheaton, E, Kulshreshtha, S, Wittrock, V, and Koshida, G.(2008). Dry times: lessons from the Canadian drought of 2001 and 2002. *The Canadian Geographer* 52 (2): 241-262.

*** A policy position paper prepared for presentation at the conference on Living With Less Water, convened by the Institute on Science for Global Policy (ISGP), on February 20-21, 2015, in Tucson, Arizona, U.S.*

**Figure 1: Spatial patterns of major droughts in North America using the summer (June, July, August) Palmer Drought Severity Index Isoline of -3 (severe drought).** (Wheaton, E. 2003. Canadian droughts of 2001 and 2002. Comparing the 2001 and 2002 droughts with other droughts. Prepared for Agriculture and Agri-Food Canada. Saskatchewan Research Council, Saskatoon, SK.)

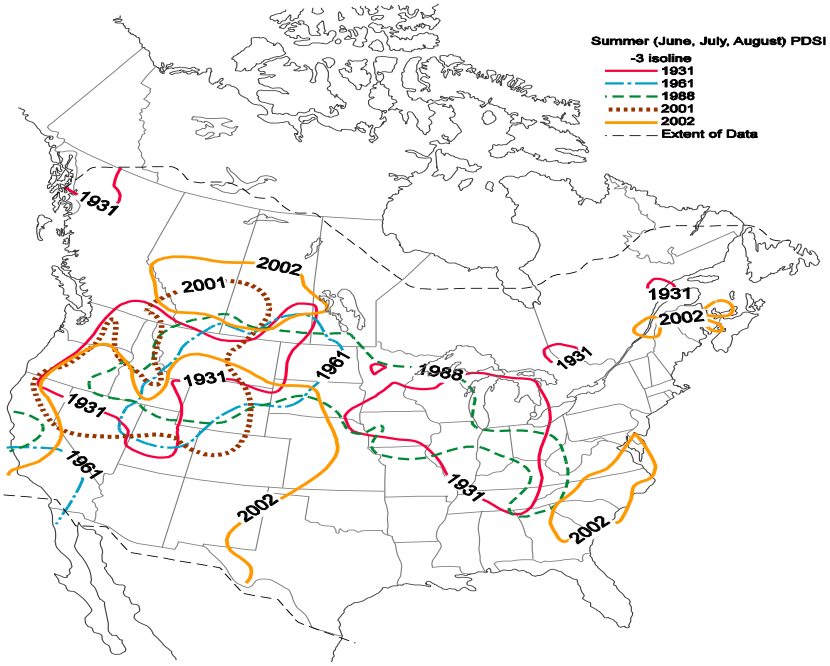
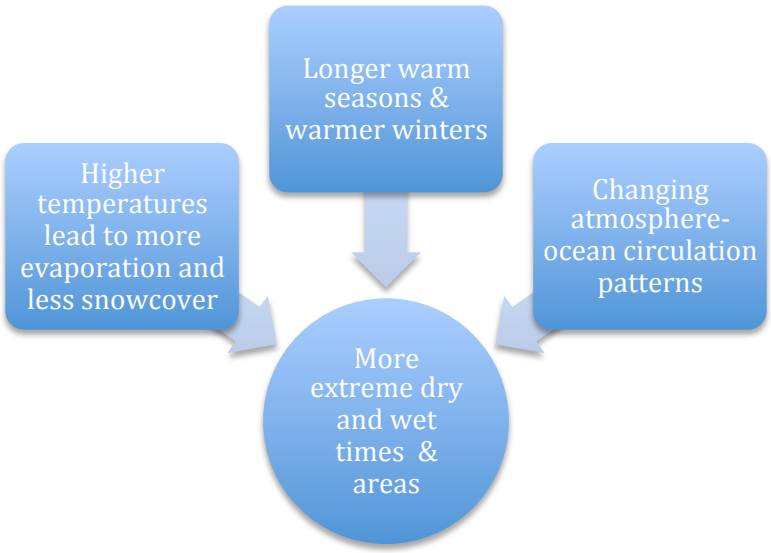


**Figure 2: Global warming indicates that dry times/places become drier; wet times/places become wetter. Adaptation must be much improved to adequately deal with the next droughts.**
(Wheaton, E., Bonsal, B., Wittrock, V. (2013). Future Possible Dry and Wet Extremes in Saskatchewan, Canada. Prepared for the Saskatchewan Water Security Agency. University of Saskatchewan, Saskatoon, SK.)




## Debate Summary

**The following summary is based on notes recorded by the ISGP staff during the not-for-attribution debate of the policy position paper prepared by Elaine Wheaton, titled "Droughts: Challenge Water Resource Management and Policy." Dr. Wheaton initiated the 90-minute debate with a 5-minute statement of her views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute 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. Wheaton. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Dr. Wheaton, as evidenced by her policy position paper. 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**

- Because drought characteristics are not consistent and vary with changes in climate, novel climate-change adaptation strategies being developed by research institutions and government partnerships need to be versatile if they are to be useful in practical applications. Strategies developed from data and indices (e.g., evapotranspiration indices) and their relationship to climate changes (e.g., longer growing seasons, increasing hot spells, food security impacts) need to be reported widely, especially in context meaningful to the public.

- A suite of policy responses needs to be developed to address overall changes in climate as they pertain to drought adaptation. Because drought and climate change are closely interconnected and are widely believed to be caused by the same or similar

anthropogenic activities, integrated policies addressing both drought and climate change is necessary. Stakeholder collaborations (e.g., industry, scientists, government, public) are essential for the successful implementation of such policies spanning both drought and other environmental hazards related to climate.

- Drought mitigation and adaptation policies need to be considered in tandem and based on the results from scientific research focused on the relationship between drought and climate. Public education and outreach need to be a priority in the development of drought and climate change programs.

- Communication among stakeholders (e.g., scientists, governments, private sector, and the public) is required to build effective alliances that proactively promote effective short- and long-term responses to climate changes. Teams of experts (e.g., social and physical scientists, policymakers) need be an important part of these alliances, since priorities within these policies will be directly influenced by social, economic, and cultural issues found within the communities vulnerable to drought.

**Current realities**

Because droughts are elusive and hard to understand, momentum is needed to develop a system of research practices that can be shared and used across the scientific community. Examples include models that more accurately predict drought centers and potential spatial coverage, sudden weather pattern changes (e.g., sudden switches to intense rainfall), as well as seasonal initiation and temporal length (e.g., dry periods that begin and last through cold winter seasons). Climate model deductions (i.e., predictions by scientists) are developed from sets of assumptions that are generally well informed, and these deductions predict not what future drought patterns will be, but what they could be. New studies reveal that the frequency of severe droughts is increasing, and it is also understood that there is variability regarding how droughts begin and evolve.

Drought planning has been gaining momentum across the global community and countries are investing in research that informs actionable policy development. The United States has taken a state-by-state approach to drought planning, which allows individual jurisdictions to tailor drought mitigation and resiliency strategies to meet their specific geographical and resource needs. The National Drought Mitigation Center was established in the U.S. at the University of Nebraska-Lincoln to develop and implement research programs to assist institutions in monitoring drought as well as design plans to minimize societal vulnerability to droughts. Many drought preparedness programs are stressing the need to emphasize adaptation planning and risk management as opposed to crisis response management. South American countries have also been more engaged in drought management practices development, including exploring water deficits and surpluses and how to best distribute resources under water-constrained time periods.

Along with looking at the different causes of droughts, it is necessary to identify how the causes are changing under the shifting climate system and whether these causal differences create new types of drought information that can potentially guide policy approaches. Researchers are looking into potential combinations of causes to identify accurate drought signals and areas affected. It has also been observed that when droughts break with extreme rainfall, other lagging drought characteristics may remain (e.g., groundwater depletion, poor plant growth, insufficient reservoir filling), and these lagging effects should be considered in preparedness management. Furthermore, some drought-breaking rainstorms are localized, so they may not end the drought, except for within a small spatial area.

Although education programs on climate and environment exist, these programs generally are ranked low on the priority list and are allocated scant funding. It is difficult to prioritize climate and environmental funding in general because technology upgrades and infrastructure retrofits are costly but necessary, as is public education and outreach. However, if the public attains higher drought, climate, and environmental literacy, this knowledge can be leveraged to generate aggregated useful data and information (e.g., crowd-sourcing precipitation levels). In this sense, investment in education can be increasingly valuable in terms of long-term benefits. Engaging the public on drought monitoring (e.g., Tucson, AZ, has a cooperative rainfall monitoring network called rainlog.org) and having scientists communicate that they are using these publicly generated data can potentially break down barriers in public outreach on drought planning. This further justifies the need to educate the public on scientific processes and research goals and objectives.

**Scientific opportunities and challenges**

Droughts do not behave in a specific or consistent manner, but rather drought characteristics are morphing with the changing climate system. It is reasonable to assume, based on scientific research, that future droughts may have faster onsets, last longer, or may become more extreme in other circumstances such as area, intensity, and frequency, with interruptions by intense rainfalls. While information on droughts is improving, accurate projections remain difficult and surprises should be expected. Therefore, policymakers can no longer rely on older, established program solutions to respond to current drought impacts. New and more novel adaptation strategies are needed and are currently being developed by research institutions and government partnerships.

One of the most significant challenges is the need to address urban population growth and its increasing water demand, especially under drought conditions that exacerbate water scarcity. Furthermore, agriculture is one of, if not the most, drought-sensitive sectors of the global economy. Food security is especially threatened when water scarcity is coupled with a rapid and continuously increasing global population.

Scientific research surrounding drought monitoring, adaptation, and mitigation must be widely communicated to the public. There was consensus that communication on drought and climate change must emphasize that changes in environmental and societal factors altering the climate are imminent, and the decision require current attention rather than only future considerations. Many dense scientific papers on drought effects must be distilled into accessible, clear information that can reach and inform nonexperts. It was posited that there is an immediate need to create a public understanding of drought behavior, water scarcity threats, and preparedness among the public. This is especially true in developed nations such as the U.S. and Canada, where the public has significant influence over policy decision-making. Data and indices (e.g., evapotranspiration indices that are increasingly important as the growing season lengthens and hot spells increase) need to be reported more widely, as well as explained in context to the public.

It was questioned whether communication gaps exist between the social science researchers and physical science researchers both in understanding each other and how to communicate drought and drought-related impacts (e.g., different definitions of drought used by social scientists and physical scientists can lead to confusion and communication breakdowns). There are opportunities for physical and social scientists to stay current in sharing information, including cutting-edge drought modeling research or adaptation technologies from the physical scientists and community behavior (e.g. water use, political priorities) during drought and nondrought periods developed by the social scientists.

Geoengineered technologies may provide viable options for adapting to climate change, but are accompanied by challenges. For example, solar radiation management strategies require more research and raise global liability issues. Another option with considerable accompanying challenges is water desalination for the purpose of providing additional freshwater resources, especially during eras of water scarcity. Water desalination is costly and energy intensive, which, if scaled, has the potential to cause even higher-than-projected levels of atmospheric greenhouse gas concentrations. Higher greenhouse gases exacerbate climate change, which may lead to more frequent, intensive droughts.

**Policy issues**

Scientific research developed to inform decisions concerning drought mitigation need to focus on policies and strategies to reduce total greenhouse gas emissions, while adaption strategies need to center on how to increase resiliency and reduce societal vulnerability to drought systems occurring within a particular area. Drought mitigation and adaptation policies are considered in their own silos, but they are inherently interlinked and policy development must consider adaptation and mitigation in tandem. Education and outreach, including early childhood education (e.g., K-12), need to be prioritized in drought and climate change program development.

Policy makers need to make decisions and build programs to address the changing climate system based on drought science research. Communication among the scientific community, the pubic, and governments can build alliances to understand how and when to act proactively, as well as what to do when solutions are needed for immediate responses. Teams of experts (e.g., social and physical scientists, policymakers) need to be formed in communities, particularly those vulnerable to drought.

Different communities will have different priorities that will be influenced by social, economic, and cultural factors. Decision-making on how to prioritize uses of scarce water will require input from all stakeholders (public, industry, government, NGOs). Stakeholder involvement is essential for the success of policies that address drought and other environmental climate hazards. To develop successful policies, short- and long-term forecasts on industry development and other local and regional economic drivers, as well as urban planning (e.g., zoning policies, infrastructure retrofits and development, public transportation), need to be considered to create a holistic approach to climate change mitigation and adaptation.

# From Global Climate Projections to Regional Planning: Matching What Science Can Supply With Decision Maker Demands**

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**Summary**
Access to high-quality and comprehensible climate information is key if policy makers are to make well-informed decisions on a range of topics. When considering 21st-century climate projections, the multistep process of transferring and translating information and knowledge from the realm of large-scale climate science to regional scale impacts, or other policy-relevant interests, poses several scientific and communication challenges. Communication hurdles exist not only between scientists and policy makers, but also between different science and engineering communities. While transferring data sets is relatively simple, reliably translating knowledge across disciplines so that strengths, limitations, and contexts are appreciated is more difficult. However, such transfers are needed if a stakeholder's information demands are to be matched with an appropriate supply of credible climate information. The quality of climate information available to policy makers can benefit both from improvements in the upstream source (i.e., climate science advancements in general, and especially improved projections) and from improved mechanisms that support cross-disciplinary information and knowledge exchanges. Accordingly, one can envision an increased role for policy-neutral boundary organizations — multidisciplinary entities designed to enhance collaboration, understanding, and communications among and between researchers and decision makers.

**Current realities**
In recent years, advances in climate observations, scientific understanding, and computer models of our planet's global climate system have contributed to three broad findings about multi-decadal climate trends on large spatial scales — findings that have placed the topic of climate change on many policy makers' radar. The three key science-based messages are: (i) multiple lines of observational evidence detect that Earth's climate is warming; (ii) analyses of observations and models show that significant amounts of change in several observed large-scale climate features can be attributed to human activities; and (iii) climate model projections indicate that, for most plausible future greenhouse gas emissions scenarios, human-induced climate change will continue during the 21st century, quite possibly at a rate greater than that seen during the 20th century. The climate science community has delivered these messages in several forms, including international and national assessment reports, as well as statements and publications from numerous national academies and professional societies.

In some policy-making circles, the realization that past climate records alone are not necessarily reliable guides for the 21st century has led to demand for more specific information about future climate projections, including guidance regarding uncertainties. Currently, whether, and to what extent, the climate science community is able to supply credible information to meet the specific demands of various decision-making groups differs greatly. In the climate impacts arena, information sought from climate projections often vary by the application of interest (e.g., significance for agriculture, water resources, human health, ecosystems, national security). These projections also depend on the geography and the time line being considered. Even among those interested in how climate variations and trends impact Arizona's water resources, the relative importance of changes in multiyear averages, seasonality, or extreme events can differ greatly, and hence the requirements for climate information and guidance differ as well.

Global Climate Models (GCMs) are complex computer programs that simulate the Earth's three-dimensional climate system (i.e., the physical atmosphere, ocean, land, and ice components,

and increasingly, elements of the biosphere). GCMs are physics-based scientific tools used to generate climate projections on time scales extending over centuries. Originally developed as research tools, today's GCMs are used to advance climate science understanding and for decision-support purposes. Developing and running state-of-the-art GCMs requires multidisciplinary scientific teams and some of the most advanced, high-performance computing capabilities available. A 2012 National Research Council (NRC) report identified three global climate modeling efforts in the U.S., with similar groups existing in approximately 10 other nations. Additional climate modeling efforts, smaller in scope and often focusing on regional climate, exist at universities and other institutions.

Sources of uncertainty in GCM projections include, but are not limited to, questions about the rate that greenhouse gases will be emitted into the atmosphere over time and how the climate system will respond in detail to a given emissions scenario. An expression of these uncertainties is evident in the range of results generated by different combinations of GCMs and future emissions scenarios. While a large number of data files derived from dozens of climate model projections are freely available, for many climate impacts studies undertaken to support regional decision-making, the information contained in GCM output files is deemed inadequate due to a lack of spatial detail or systematic biases. Using GCM data files as input, a variety of processing methods referred to collectively as "downscaling" can be applied to generate climate projection products designed to be more suitable for climate impact studies. However, the dilemma for those seeking projections to aid in a decision-making process often is not the lack of projections, but rather "how to choose an appropriate data set, assess its credibility, and use it wisely."

**Scientific opportunities and challenges**

Significant challenges exist regarding the effective transfer and translation of high quality, policy-relevant climate science information from the realm of large-scale climate science to various decision-making applications. To provide policy makers an opportunity to make well-informed decisions, there is a need to better match an appropriate supply of credible climate science information with policy-relevant demands. Data servers and high-speed Internet connections allow large volumes of data to be shared, but data file transfers alone are insufficient to bridge transdisciplinary knowledge gaps. But to whom does the responsibility of filling those gaps fall?

Just as it is unrealistic to expect users of climate projections to become experts in the strengths, weaknesses, uncertainties, and nuances of climate model projections, it is likewise unrealistic to expect climate scientists to learn enough about various user needs to provide detailed guidance for particular applications. Within the U.S. government, some relatively modest department- or agency-level efforts exist that aim to enhance the use of climate science information in decision-making via the establishment of boundary organizations that straddle aspects of research, communications, and policy (e.g., U.S. Department of Interior Regional Climate Science Centers, National Oceanic and Atmospheric Administration Regional Science Integration and Assessments Program, U.S. Department of Agriculture Climate Hubs). The 2012-2021 strategic plan for the interagency U.S. Global Change Research Program encompasses aspects of this effort under the banner of advancing science and informing decisions. Efforts by universities, professional societies, and public and private sector entities similarly aim to initiate or encourage transdisciplinary dialogue and information exchange on climate science and policy issues. As noted in the 2012 NRC report, "addressing the wide spectrum of user climate information needs is outpacing the limited capacity of people within the climate modeling community."

Additional challenges include determining how enhanced information and knowledge exchange capabilities can be pursued without detracting from critical, ongoing climate science R&D efforts.

Some climate scientists are wary of being perceived as being too closely linked to policymaking efforts, lest the scientist's objectivity be drawn into question.

**Policy issues**

The following items can contribute to developing a balanced portfolio that advances the production of high quality, policy-relevant climate science information while simultaneously promoting the effective communication to allow well-informed policy decisions.

- **Cross-disciplinary communications regarding policy-relevant climate projections:** This item is consistent with the 2012 NRC report's statement citing "the need for qualified individuals who can provide credible information to end users based on current climate models, wherever they work (public or private sector)." Key elements include collaborative development of boundary organizations capable of bridging gaps between decision-makers and climate scientists as well as between scientists and engineers in different disciplines. Promoting coordination among multiple boundary organization efforts could enhance consistency and reduce duplication of efforts. The rigorous implementation of policy-neutral practices could bolster the credibility of the process.

- **Development of the next generation of policy-relevant climate projections**: The climate modeling community continually seeks to improve climate model projections, especially on the regional spatial scales of interest to many stakeholders (e.g., the representation of El Niño in the tropical Pacific and the North American monsoon that have been linked to Arizona's precipitation). In the U.S., pursuit of this goal depends on the availability of advanced computing resources and personnel associated with the nation's major global climate modeling efforts, as outlined in the 2012 NRC report. Additionally, the downscaled climate projections used in many decision-support studies have not been analyzed as much as have the GCM projections from which they are derived. This suggests that increased efforts to systematically assess this less-studied segment of the climate information exchange chain could potentially reap sizable benefits.

- **Foundational climate science research and development:** The topic of human-induced climate change became a noteworthy policy issue only after decades of climate science research. Such foundational research was and continues to build upon several activities that are not directly associated with generating future climate projections. They include: gathering, improving and analyzing observations; developing and testing theories of how the myriad components of the climate system interact; and creating numerical models of the climate system (i.e., virtual Earths) that allow scientists to perform experiments that cannot be done in the real world. Improved policy-relevant projections and advancing the understanding of uncertainties will continue to depend upon broad-based advancements in climate science.

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*** A policy position paper prepared for presentation at the conference on Living With Less Water, convened by the Institute on Science for Global Policy (ISGP), on February 20-21, 2015, in Tucson, Arizona, U.S.*

## Debate Summary

**The following summary is based on notes recorded by the ISGP staff during the 90-minute not-for-attribution debate of the policy position paper prepared by Keith Dixon. Mr. Dixon initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute 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 Mr. Dixon. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Dixon, as evidenced by his policy position paper. 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**

- While recent technologies have improved climate change predictions, climate models still are subject to uncertainties, many of which are due to the environmental variability of climate. Because the scientific community has fallen short of effectively communicating the causes and effects of these uncertainties to the general public, many members of the public are skeptical of climate models.

- To improve communication between the public and scientists, it is critical that scientists themselves become more effective in more accurately articulating credible scientific information to both the media and the public. Simultaneously, the public needs to more candidly convey its concerns and questions to the scientific community. Such two-way communication not only aids in framing the scientific information in terms of issues that have priority to the public, but also potentially generates the broad public support needed to effectively implement progressive policies.

- Among the many concerns associated with effective science communication (e.g., relevance to the public, model uncertainty, lack of trained communicators), is the shifting public-to-private debate over climate issues, which has historically diminished the availability of accurate, unbiased climate information.

- To ensure that climate change policies relevant to society are developed, there first needs to be improved communication among scientists, policymakers, and communities. Methods for improving communication include (i) organizing a group of "translators" between scientists and communities, (ii) making climate data relevant to the daily lives of the intended audience, whether that audience consists of policymakers or the general public, (iii) implementing discussions of current needs and effective adaptations to climate change, and (iv) supporting boundary organizations (i.e., multidisciplinary entities designed to enhance collaboration, understanding, and communications among and between researchers and decision makers) so they are better equipped to effectively achieve their goals.

**Current realities**

The uncertainties of climate models were the subject of a great deal of discussion. Climate models use experiments that cannot be practically tested in the real world. Within these models, errors exist, which over time can cause the accuracy and relevance of the results to degrade.

There are two different types of problems frequently referred to in the field of climate science: i) initial value problems, and ii) boundary value problems. The former usually refers to the weather, while the latter deals with climate and leads to many of the climate-model uncertainties, which can negatively affect the value of climate science to the general public. These differences are exhibited in describing their effects on short-term forecasts (i.e., weather predictions) and longer-term forecasts over years. Errors embedded in the initial data are inevitable and have significant impact of the accuracy of short-term predictions. Predicting changes years in the future is affected by factors that constrain climate over the long term, such as the amount of carbon dioxide in the atmosphere.

Boundary organizations, such as the U.S. Department of Interior's Regional Climate Science Centers, the multi-institutional South Central Climate Science Center based at the University of Oklahoma at Norman, the Southwest Climate Science Center at the University of Arizona, and the U.S. Department of Agriculture's Climate Hubs, are tasked with helping translate climate science data. However, there is little unification among these organizations. More interaction among boundary organizations, as well as multidisciplinary collaborations, is needed to more clearly determine the certainties and uncertainties of the scientific results.

Because scientists often fall into one of three categories: (i) those that have no interest in interacting with the media and the public, (ii) those who do outreach and feel an obligation to do so, and (iii) those who are solely interested in advocacy and working in boundary organizations, it was generally agreed that there is a need for people who have firsthand experience and knowledge of political processes to act as climate "translators." Climate translators could convey scientific data to the public, and express the public need for information to scientists. Multidisciplinary collaborations among experts also are needed, as is more education across all segments of the population about climate changes. The Pima County Cooperative Extension program was cited as a model for imparting climate change information to citizens.

Another factor in the public's ability to comprehend and have access to climate data is that climate consulting, which provides hard data about climate changes, has been shifting from the public to the private sector. This shift has created significant challenges for the dissemination of data on climate change because much of the data gathered by the private sector is under nondisclosure agreements and not readily available to the public outside of those organizations.

Tools such as national academy reports, national assessments, and the Intergovernmental Panel on Climate Change are essential in condensing published reports, making them more comprehensible for the public. While the media is an important source of information on climate science for the general public, a significant amount of the information distributed is inaccurate, largely because of the decline in specialists working in the media.

The City of Tucson has a general water sustainability plan that has received support but some dissatisfaction was expressed as to how climate change has been incorporated into budgeting and infrastructure investments. The Southwest is in a unique position to lead the way in developing policies that respond to climate change, in that much of the effects of climate change are being experienced in that region first.

**Scientific opportunities and challenges**

Natural occurrences (e.g., the Milankovitch cycles, which describe the collective effects of changes in the Earth's movements upon its climate) can cause changes in atmospheric conditions, creating uncertainties in climate models. Climate models become more uncertain as the focus narrows to a local scale. Because the nature of those ambiguities is difficult to convey, much of the public is skeptical of predictions and recommendations generated by these models.

There was broad agreement that this skepticism creates many challenges for those who are delivering climate science findings to the public.

Opportunities exist for scientists to work in partnership with museums and other groups that communicate with the public, creating alliances that aid in the dissemination and deciphering of climate data for the general public. Such boundary organizations also can create liaisons between scientists and stakeholders via bidirectional communication. There is an opportunity for individuals from varied disciplines to work together to serve as liaisons and render data into relevant information that answers questions of the intended audience.

It was generally agreed that communication between scientists and the public needs to be bidirectional. To properly communicate with an audience, it's necessary to first determine their needs and then use that information as an opportunity to improve the exchange of information.

A significant challenge exists in the lack of science "translators" who can serve as skilled intermediaries in this bidirectional communication. It was noted that only a small number of scientists are willing to work as translators of scientific data, in part because translation work is not valued and there are not many incentives for performing that function. There was concern that the number of people with experience in the field is rather small. This challenge creates an opportunity to develop training and/or certification programs for nonscientist "climate translators."

Doubts regarding climate models create challenges beyond communication. There is potential for public resistance to the use of federal funds to fund climate science research because the public considers the answers it wants and needs are not being provided by researchers.

Another challenge that arises when translating climate science to the public is that there will always be individuals who will deny the validity of the information because it threatens the financial interests of their respective organization or violates deeply held beliefs, not because of the science itself.

Challenges arise when speaking to politicians and policy makers about climate change because these individuals often have no objective means by which to evaluate the data. Recently, a number of politicians have repeated a stock answer to questions about climate change: "I am not a scientist." Such a blanket dismissal makes it difficult to conduct informed conversations about public policy. It was argued that there is a need to make the science more relevant for policy makers.

There was strong agreement that the media presents a large amount of misinformation about climate change. Because the media is necessary to disseminate information, opportunity exists to confront the media's inaccurate reporting. Much of the misinformation is because there are fewer trained science journalists in the media. Members of the media need to be educated about climate science so that information provided is presented as accurately and clearly as possible. Some of this work is being done by the independent organization Climate Central, which provides scientifically accurate climate change information to the media. Opportunities also exist to train and teach both children and adults through a wide range of educational programs.

The Southwest region is in a unique position in that it is experiencing the effects of climate change before other areas of the United States. There is an opportunity to take advantage of this distinctiveness and create adaptations that can be used as models elsewhere, making the region an example to other areas.

**Policy issues**

Accurate communication and information exchange are essential to creating effective policies to address climate change. Because communication skills often are not valued by scientists, many are not interested in doing the work. Creating incentives for scientists to be involved in translation work is necessary. Policies that encourage science translators would add value to the work as well as aid in the transfer of accurate information and provide a larger pool of people to perform the work. Certification programs for nonscientists involved in climate change communication were heavily supported.

It was suggested that the agricultural extension system operated by land-grant colleges and universities provides an effective framework for building a cadre of people to help with science communication. Extension agents often phrase questions in such as way as to create a starting point for bidirectional communication in which the scientists learn from stakeholders and then impart the relevant science to address current concerns.

While boundary organizations meant to act as middlemen between scientists and communities have been created, many of these organizations are newly formed and are not unified entities. Policies need to be designed to shore up these organizations, providing them with multidisciplinary teams to gain credibility and perform much-needed work.

Sustainability plans could be incorporated into both daily and long-term government policy. Many of the climate change regulations regularly discussed and debated concern mitigating future climate change and reducing its impact, but there are fewer conversations about enacting policy that incorporates current scientific data and helps communities respond to current effects of climate change.

Although the field of climate science has advanced since its early days, there exists a need for updated technology. Policies that aid in the development of more accurate climate science technologies are crucial in allowing scientists to gain more useful data and answering those questions that are of societal relevance.

# Water Resource Management Challenges in a Time of Changing Climate **

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**Summary**
Water is scarce relative to demand in Arizona and the Colorado River Basin. Despite 14 years of drought, the likes of which have not been seen for over 900 years, Arizona is not in a crisis. However, central Arizona is particularly vulnerable to Colorado River shortage declaration due to the lower priority of Colorado River water delivered through the Central Arizona Project (CAP). While climate change is projected to impact water supplies and influence water demands, water decision makers must take actions to meet future demands, regardless of the cause of any shortfalls. A suite of policy options is presented, along with a recommendation for engagement of both expert stakeholders and the general public.

**Current realities**
Water supplies are scarce relative to demands in Arizona and the Colorado River Basin. According to most recent numbers released by the Arizona Department of Water Resources, groundwater, which nature replenishes less quickly than we use it, is pumped to meet about 40% of Arizona's water demands. Water from the Colorado River, including that delivered via the CAP canal, makes up another approximately 40%. The Salt River Project delivers Salt and Verde watershed surface water to the Phoenix area. Reuse of treated wastewater and other surface water supplies make up the rest. In 2011, a special state water resources commission projected that the statewide shortfall between water supplies and demands would reach 1 million acre-feet (MAF) by 2060. One acre-foot of water is 325,851 gallons. In 2012, a U.S. Bureau of Reclamation study offered projections based on alternative assumptions for climate and growth in water demands. For the Colorado River Basin, including Arizona, an average gap in 2060 of 3.2 MAF was projected for the study area, which excluded the Mexico portion of the basin and any detailed study of Native American water uses. Figures 1 and 2 depict the boundaries of the Colorado River Basin and the study area for Reclamation's 2012 study, respectively. Figure 2 shows in crosshatch the communities outside the basin that rely on Colorado River water.

The Colorado River Basin is entering its 15th year of drought conditions. In Fall 2014, Lake Mead, which provides Colorado River storage for the Lower Basin states (i.e., Arizona, California, and Nevada), was at its lowest level since filled and only six feet above the trigger level for a shortage. A declaration of shortage on the Colorado River has never been made. Though climate models project higher temperatures for Arizona and changing precipitation patterns, it is difficult to conclude whether the extended drought reflects climate change or cyclical climate variability. Regardless, a video released by the CAP and available on YouTube, titled "Challenged but Unbroken: Sustaining the Colorado River," reports the sobering reality that the river system faces unprecedented threats. Notably, based on tree ring studies, the flow for the past 14 years is the lowest in any comparable period in over 900 years.

Arizona had to accept lower priority than California for CAP water to secure federal funding. Thus, central Arizona, including Tucson, is in a seriously vulnerable situation if drought conditions persist and become more severe. Arizona's entire CAP entitlement could be curtailed before California experiences any cutback in Colorado River water deliveries. Yet, unlike California, which has experienced severe drought conditions, Tucson and Arizona generally have not faced mandatory cutbacks in water use. There is no local perception of crisis here, which is due to several factors. Arizona municipalities are not subject to cutbacks of

CAP deliveries until water levels in Lake Mead decline below the first shortage trigger level of 1,075 feet. Moreover, enabled by Arizona's comprehensive water storage and recovery statutes, the Arizona Water Banking Authority has been storing water since 1997 for "firming" municipal deliveries should a shortage necessitate curtailment of municipal and industrial priority allocations. Importantly, careful planning by water utilities, coupled with compliance with rules requiring physically, continuously, and legally available water for 100 years before new developments can be approved, has enabled utilities to meet the demands of a growing population. In addition, water use in many municipalities has fallen on a per capita basis, resulting in the stretching of existing supplies to meet growing populations.

**Scientific opportunities and challenges**

Whether transported from afar, diverted from nearby rivers or streams, or drawn from aquifers, the quality of the water is a concern. Although the federal government establishes drinking water quality standards and controls the quality of water discharged into U.S. waters, there are constituents that have no standards. Groundwater, invisible water of great importance to Arizona, resides in aquifer conditions that vary considerably. Therefore, scientific endeavors to monitor, quantify, and treat water quality are of high importance, as are efforts to quantify groundwater in storage and the rate at which it is replenished. Localized drawdown of aquifers is of concern in many areas. Quantification of rates of recharge, whether through natural or artificial means (e.g., spreading basins, which are used extensively in Arizona), is also important. Groundwater quality must also be characterized and groundwater pollution can be difficult to correct. Carbon sequestration in aquifers requires full investigation, especially because deep aquifers are potential future sources of water for human use.

The engineering and science of treatment alternatives provide opportunities for expanding the usability of water supplies. As better membrane treatment systems have been developed, the economics of seawater and brackish (high salinity) groundwater desalination have improved. However, there remain two main issues associated with desalination: (i) the significant energy requirements and (ii) the disposal of the brine. Scientific and economic issues associated with treating wastewater to potable standards are also at the forefront of attention, as are the effects of changing land cover and forest fires.

Global and downscaled (i.e., refined) climate models can inform water planning and management. Scientific issues related to water and climate change have to do with understanding its implications for precipitation events, including intensity, amount, and seasonality. Timing of runoff/evaporation of snowpack and rain events affects surface water availability. Changing temperatures, particularly higher temperatures, affect usable water quantities as well as demand for water for such things as outdoor watering and the energy to power air conditioning. How higher overnight temperatures associated with heat islands affect water use is a climate change phenomenon. It is well recognized that energy use and water use are inexorably linked. The amount of water used for energy depends on the type of energy generation. Water delivery and treatment require energy. The third significant nexus item is food. Scientific developments related to food, including the issue of drought-tolerant genetic modification of crops, are relevant to the world's ability to produce food for a growing population. Although water is essentially local (or nearly local), food and forage, with the water embedded in it, are readily transported.

The science of assessing the water needs of the environment — our natural systems — provides both opportunities and challenges. Only limited portions of Arizona's river systems have been sufficiently characterized in terms of the timing, intensity, and amount of water needed to sustain their health. Finally, but no less importantly, the human dimensions of water use, valuation and stewardship are increasingly subject to scientific scrutiny. In addition, study

of water governance and robust approaches to stakeholder engagement are at the forefront of local, regional, and international efforts to improve water management. Social scientists see opportunities for transferability of good practices and for better decision-making based on better understanding of consumer perceptions and the water-use options.

**Policy issues**

Policy is at the heart of managing water under changing climate conditions. Policy decisions depend on many factors, such as the legal structure, including case law, and the degree of (de)centralization of authorities. Many agree that the barriers to implementation of water management solutions have more to do with public perceptions than issues of science, engineering, or even finance. The region has made extensive use of aquifer recharge to reduce costs of using surface water, replenish groundwater, and store water for future use. In the process of relying on a system of storage and recovery, Tucson Water has developed one of the more drought-resilient delivery systems in the region. The Colorado River Basin states have come together with some innovative agreements (e.g., 2007 Shortage Sharing Guidelines, December 2014 agreement to leave water in Lake Mead). Agreements with Mexico have created additional storage in Lake Mead, international shortage and surplus sharing, and the unprecedented March 2014 pulse flow release of water at the border, which flowed to the Colorado River Delta. In the complex setting of the Colorado River and locally, policy choices that do not depend on fundamental legal changes are the more likely pathways forward.

Southern Arizona tends to focus on water scarcity. Actions are needed to close the supply/demand gap, regardless of cause (e.g., climate related or the growth in population and the economy). Consideration of options should include the impacts of alternative options on natural systems, along with their costs, water yield, and time frame for implementation. Financing options, including public-private partnerships, also require careful scrutiny and debate. Although significant changes to law and institutional arrangements may be difficult to accomplish, modifications of governance approaches, such as regional collaboratives, may assist. Solutions development must involve expert stakeholders from within and outside of the water community, along with the general public. While the particulars of the options and trade-offs may vary by location, the suite of policy options is similar and includes combinations of the components listed.

- Reductions in water demand through increased deployment of multifaceted conservation programs and water pricing that encourages conservation.

- Increasing usable supplies through one or more of the following:
  - Reuse (recycling) of treated wastewater. This is a locally controlled rather than an imported resource, which, upon proper treatment, can be used for potable purposes.
  - Rainwater and storm water harvesting, particularly to match the quality of the water with the intended use. This can reduce the demand on the potable system.
  - Desalination of brackish groundwater and/or seawater and also enhanced treatment of poor quality groundwater. Desalination of seawater could benefit Arizona through trade of Colorado River water for payment for desalinated seawater or possible transportation of desalinated water from Mexico. This is a longer-term option. Seawater desalination options clearly are more complex and depend highly on the decision of non-local entities.
  - Water augmentation through development of water banking and storage projects, water transportation projects. These options are highly developed in the Tucson region. Weather modification is an option some discuss.

- Voluntary water transactions. Options are dependent on the water rights framework.

- Reducing systems losses. Utilities strive for low system losses. Improved technologies for metering, sensors, and advanced warning systems are assisting utilities.

*** A policy position paper prepared for presentation at the conference on Living With Less Water, convened by the Institute on Science for Global Policy (ISGP), on February 20-21, 2015, in Tucson, Arizona, U.S.*

Figure 1. Colorado River Basin Boundaries

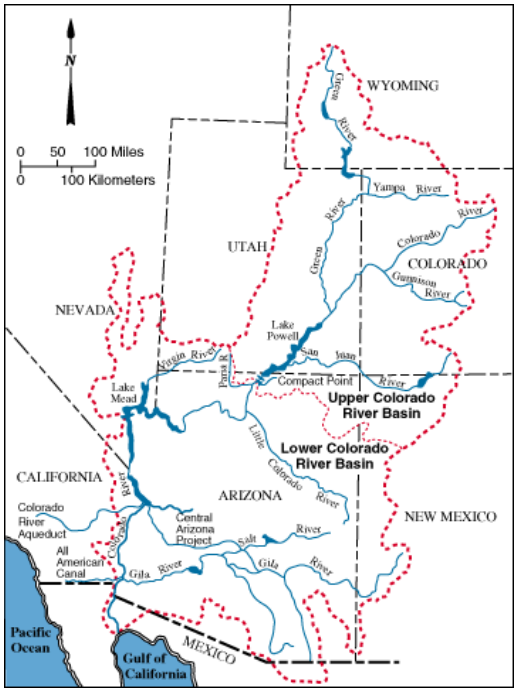

Figure 2. Study Area for Colorado River Basin Water Supply and Demand Study http://www.usbr.gov/lc/region/programs/crbstudy.html


## Debate Summary

**The following summary is based on notes recorded by the Institute on Science for Global Policy (ISGP) staff during the debate of the policy position paper prepared by Dr. Sharon Megdal (see above). Dr. Megdal opened the 90-minute debate with a 5-minute statement of her views and then actively engaged the conference participants throughout the remainder of the 90-minute period. This Debate Summary represents the best effort by ISGP staff to accurately capture the comments, challenges, and questions posed by all participants, as well as responses from Dr. Megdal. The views comprising this summary do not necessarily represent the views of Dr. Megdal, as evidenced by her policy position paper. Rather, it is, and should be read as, an overview of the areas of agreement and disagreement that emerged from all those participating in this critical debate.**

**Debate conclusions**

- Although Tucson and Southern Arizona, as well as Arizona *writ large,* are at the forefront of groundwater management, more needs to be done to effectively plan for unpredictable future climate conditions, increased user demand, and "worst-case scenarios." Implementing a variety of strategies, including strategies focused on water conservation and water treatment and reuse, is necessary to effectively manage local water supplies.

- Water policies and water-saving strategies need to be informed by a holistic view that considers not only the costs and benefits to businesses and individual consumers, but the effects on groundwater reserves, watershed and riparian areas, and food prices.

- Sustained and widespread education about drought and water policy options is needed to combat public apathy and ignorance about the current water situation. These attitudes are caused by the unpredictability of drought conditions, relatively low water prices, and the fact that there have not yet been cutbacks in allocations of Central Arizona Project (CAP) water. However, water prices and the CAP allocation are likely to change given current and projected conditions.

- Because there is a severe lack of political leadership on water policy at the state level in Arizona, water stakeholders (i.e., all Arizonans) must become more educated regarding the situation, engage in community dialogue to discuss options, consult academic water experts when considering policy issues, and share their views with policy makers from the local to the state level.

**Current realities**

Tucson and Southern Arizona face two major uncertainties: a drought with no predicable end and uncertain future demands and stressors on shrinking water supplies. There was wide agreement that uncertainties related to the area's water situation are among the biggest challenges in motivating the public to take water issues seriously.

Several U.S. states and the Mexico use the water in the Colorado River. There has been a drought on the Colorado River watershed for the past 15 years and the river is under severe stress both from over-demand relative to long-term flows and from potential decreases in the flows associated with climate change. In addition, it is difficult to know when a drought is over. Short periods of heavy rainfall are not enough to alleviate the area's drought — even a year of good rainfall at the headwaters of the watershed would not alter the current situation.

An in-state study, through the Water Resources Development Commission, projected about a million acre-foot gap between future human demands and future supplies within less than 25 years. This does not include the impact of groundwater loss on watersheds (i.e., areas that are inundated or saturated by surface water or groundwater) and riparian areas (i.e., vegetated ecosystems along a water body).

Multiple stakeholders have rights to the Colorado River water and there are differences of priority among these stakeholders, and even within stakeholder groups. Arizona Native American tribes are major stakeholders regarding water in the state, the Central Arizona region, and Tucson. Tribes are sovereign with respect to water management (i.e., they are not bound by rules and regulations imposed at the state level). The tribes are partners in the Central Arizona Project (CAP) as well as partners with cities. There is a large partnership between the Salt River Project and the Gila River Indian Community for storage of Central Arizona Project water.

On an interstate level, California has a higher priority than Arizona for receiving allocations of Colorado River water, meaning Arizona's CAP deliveries could be cut to zero before any shortage would be realized by California. This trade-off was part of the deal required to get Congressional funding for the CAP.

There is deep concern about potential cutbacks to Arizona water users. Despite the drought, cutbacks have not been implemented because the water stored in Lake Mead has not dropped to 1,075 feet above sea level, the "trigger" level at which an official declaration of shortage is declared. The lowest level reached thus far was 1,081 feet in October 2014.

Although not immediate, a declaration of shortage seems inevitable, especially if the trend toward drier winters continues. When a shortage is declared, the first cuts will occur to non-Indian agricultural water (i.e., Central Arizona farmers who are using CAP water in lieu of using ground water).

A major concern is that when CAP water is cut back, farmers will switch to using more groundwater, which is cheaply priced, rather than implementing water-saving strategies, such as changing cropping patterns and irrigation practices or land fallowing (i.e., leaving land unseeded and unplowed for a season). On average, the state receives about 40% of its water from groundwater. Some communities are wholly reliant on groundwater and others, such as Phoenix, hardly reliant at all. Agriculture consumes about 70% of Arizona's allocation of Colorado River water. The over-usage of groundwater reserves, which can be effectively measured through satellite imaging, is a source of concern not only in Arizona, but also in communities around the world affected by drought.

Curtailing CAP water deliveries to agriculture not only may increase groundwater pumping, but also will likely increase food prices. In addition, having fewer water users results in fixed costs of the water system being spread among the remaining users, increasing their rates. Consequently, municipal users likely will experience a price increase during a shortage, even though the cities will not be the first to receive cutbacks.

Despite its problems, Arizona is at the forefront of effective water-use planning, through such legislative tools as the 1980 Groundwater Management Act. A recent example is a pilot study in the Yuma Mesa Irrigation and Drainage District, in which land is being fallowed and water is being saved in Lake Mead. While water storage is part of long-range drought planning in the state, as demand grows, the water available for storage decreases. It was generally agreed that, despite Arizona's significant planning thus far, there is a need to strategize for worst-case scenarios.

Arizona's water studies and policies in general do not include consideration of the water needs of the environment, specifically watersheds and riparian areas that are dependent on groundwater flow. There has been little deliberation regarding noneconomic costs and benefits associated with water-saving options and there does not appear to be political support for considering about environmental consequences of drought. It was agreed that Arizona's environment is on the verge of significant degradation if environmental water needs are not considered and addressed. The "Roadmap for Considering Water for Arizona's Natural Areas," by the Water Research and Planning Innovations for Dryland System (Water RAPIDS) program at the University of Arizona Water Resources Research Center, provides solutions to avoid further degradation and help improve some of the natural areas.

There exists a level of apathy and lack of awareness among area residents regarding the critical nature of the water situation in the region. It was stated that people need to hear about water shortages and to understand cutbacks are a real probability. Although a variety of educational efforts are underway, such as the successful Arizona Project WET program for teachers, it remains a challenge to get people interested and engaged in the topic when there is no perception of a crisis existing.

It was noted that community town hall meetings held by Tucson Water regarding water rates rarely are attended by more than a few dozen people. The three most common comments made at these meetings are (i) "water is too cheap," (ii) "my bills are too high," and (iii) "you asked me to conserve and then you raised my rates."

**Scientific opportunities and challenges**
Scientific opportunities exist to utilize various water-reduction strategies, and to test and evaluate strategies based on their overall effectiveness. Challenges include providing credible science education about drought and sustaining the public's interest and willingness to make difficult policy choices when drought is so variable and uncertain.

A number of strategies have been discussed over the years as ways to increase water supplies, such as desalinating seawater from the Sea of Cortez and transporting it to the Tucson area. While cloud seeding has been mentioned as an option, research has shown its effectiveness is not significant.

It was generally agreed that a variety of strategies need to be tried simultaneously, especially strategies focused on increasing water supply via water reuse and utilizing treated wastewater. Better conservation methods also are part of the strategy to close the gap between supply and demand.

Scientific opportunities exist for research into the impact of various strategies on increasing or preserving water supplies. An example of such research is the Ground Water Replenishment District of the Central Arizona Project, which has embarked on a pilot fallowing effort with Yuma Mesa Irrigation and Drainage District. The project includes research on water savings, cost, and the impact on third parties (e.g., the environment, other water users).

It was widely agreed that scientific opportunities exist for more research into the effect of water overuse on riparian environments and watersheds apart from human uses.

The difficulty in effectively educating the public regarding drought was cited as a significant scientific challenge. The challenge is due in part to the variability and uncertainty of drought. Short-term climate oscillations with five to seven wet years, cause people to lose interest in the topic of drought and water conservation, making if difficult for policy makers to make decisions regarding increasing water rates or investing in water-saving infrastructure.

Because of climate change, large floods on the Colorado River are a much higher probability than they were in the past, presenting both an economic risk and a risk to water supply.

Another challenge is the need to ensure all variables are included in studies that attempt to predict water supply and demand. For example, The Colorado River Basin Water Supply and Demand Study performed by the Bureau of Reclamation and released in 2012 attempted to project into 2060 the demands and supplies of water for the study area. However, the incorporation of changes in flow caused by climate change was very limited and the study did not include a thorough analysis of Colorado River water usage by Arizona Native American tribes or by Mexico.

**Policy issues**
In the current political environment, it was generally agreed that water rights are unlikely to be changed to cope with the effects of drought and shrinking water supplies. It will take voluntary agreements and transactions to work through the many complex and sensitive policy issues that surround water rights and allocation.

Water governance and management are largely decentralized in the United States. The federal government sets water quality standards for drinking water and discharges, but, with the exception of interstate rivers and waters, individual states determine their own regulations.

Arizona laws currently do not offer much protection for the environment or ecosystem, or even acknowledge them as entities needing protection.

Arizona also does not recognize the legal connection between ground water and surface water rights (i.e., a groundwater user can inadvertently, but legally, have a negative impact on the water rights of a surface-water user, or vice versa). The surface water/groundwater interface is a complicated policy issue and requires a holistic view by policy makers that considers the overall hydrologic cycle. Many factors are hard to "monetize" or put into a cost-benefit ratio, especially when it concerns maintenance of watersheds that are essential to riparian areas. It was suggested that life-cycle costing, not just a cost-benefit analysis, should inform resource policy decisions.

Agricultural subsidies can enable farmers to grow high-water-use crops such as alfalfa that are largely exported as cattle feed, rather than human food crops. While it is unlikely that the subsidies in place could be changed quickly, a call was made for voluntary creative solutions where "gainers can compensate losers."

The question of incorporating higher water prices into water policy provoked some debate. It was broadly agreed that higher water prices can "spread the pain" and induce water users to conserve. However, higher prices hurt agricultural producers, who have seen substantial increases in production costs because of the drought. This in turn raises the cost of food, which significantly affects lower-income populations.

Lack of political leadership was cited as a serious challenge to effective water policy development. A sense of urgency among state legislators is lacking, there is little bipartisan effort, and it seems to take a crisis before action occurs. More public awareness is needed regarding water policy at the state, county, and local levels. All citizens are water stakeholders and can influence decision makers. There is a need for the public to participate in policy deliberation and to consider a wide variety of concurrent options.

Tucson and area municipalities can conserve water by addressing aged and leaking infrastructures. In addition, a certification system for water policies needs to be created that is similar to LEED certification for environmentally sound buildings, enabling the public to judge the effectiveness of policies in conserving water. Research could be incorporated into new policies (e.g., models could include a feedback loop in which the strategy is assessed for effectiveness, cost, impact, return on investment, and other factors), enabling area water policies to become more effective over time.

It was emphasized by many that effective communication and education are necessary to long-range water planning. Several options suggested:

- More dialogue between experts and policy makers. For example, when the Tucson City Council is discussing Tucson Water's rates, water experts need to inform that conversation. Arizona's state universities have great expertise, but often are not called upon by policy makers.

- Better science communication and education. It was generally agreed there is a need for widespread and sustained educational efforts. Individuals need to know the source of their water beyond the tap. Some water-producing strategies, such as membrane reverse osmosis treatment, are costly and the public must have a good understanding of the costs and benefits to make a decision on funding. It was stated that in times of cost cutting, education is often the first to be cut.

- More forums for discussion. Arizona lost important forums for water discussions with the closure of the Arizona Department of Water Resources Active Management Area office and the Southern Arizona Water Resources Association. Replacements must be found for these forums, which brought together water managers, consultants, agency people, and other highly interested individuals.

## Acknowledgments

Numerous individuals and organizations have made important contributions to the Institute on Science for Global Policy (ISGP) Climate Change Arctic Program (ICCAP) *Living with Less Water* conference. Some of these contributions directly supported the efforts needed to organize the invitation-only conference, convened in partnership with the Tucson Working Group at the University of Arizona Tech Parks Arizona, Feb. 20-21, 2015. Other contributions aided the ISGP in preparing the material presented in this report, including the three invited policy position papers, the not-for-attribution debate summaries, and a record of the results, without attribution, of the views presented in the discussions and caucuses that ensued.

Of special significance were the efforts of the three distinguished experts invited by the ISGP to present their views in each of the three concise policy position papers that were debated. The biographies of these three authors are provided in this ISGP report. The ISGP also greatly appreciates the willingness of those in the scientific and policy communities who agreed to be interviewed by the ISGP staff as potential conference presenters.

The success of every ISGP conference critically depends on the active engagement of all invited 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, and even unique, environment focused on clarifying understanding for the nonspecialist. These debates and caucuses address specific questions related to both formulating and implementing effective public and private sector policies. The ISGP is greatly indebted to the wide range of policy makers, scientists, and community members who engaged in the vigorous debates and caucuses that compose all ISGP conferences.

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 focused on addressing many of the most important societal questions of our time. Their brief biographical backgrounds are presented at the end of this report.

The Tucson Working Group merits special acknowledgment for their efforts to help organize and convene this ICCAP conference. Their contributions in planning the conference and assembling the diverse and knowledgeable debaters seated around the table are greatly appreciated. Their brief biographical backgrounds are provided in this report.

The energetic, highly professional interviewing, organizing, and writing skills of the ISGP staff were essential to not only structuring the ICCAP conference itself, but also to recording the often-diverse views and perspectives expressed in the critical debates, accurately 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. Their biographies are provided in this report.

Also deserving acknowledgment are the volunteers from Rincon, Sunnyside, and Palo Verde high schools, Pima College, the University of Arizona, and graduate students studying Soil, Water and Environmental Science at the UA. Center. A list of these individuals is included in this report.

ISGP programs are financially supported by government agencies and departments and through gifts from private-sector entities and philanthropic organizations and individuals. Specifically, the ICCAP conference on *Living with Less Water* received funding for the general activities of the ISGP as generous gifts provided by the U.S. Department of State, the MARS

Corp., Edward and Jill Bessey, R.B. "Buck" O'Rielly, Butch and Denise Ryan, and Sperry and Donnalyn Van Langeveld. In-kind donations to the ISGP in support of the ICCAP conference were generously made by the University of Arizona Tech Parks Arizona, the Economic Development Authority for the Tohono O'odham Nation, The Doubletree Hotel, the Pima Monthly Meeting of the Religious Society of Friends, AZ Cine Equipment, and Eurest Catering.

Dr. George H. Atkinson
Founder and Executive Director
Institute on Science for Global Policy
July 1, 2015

**Books from ISGP conferences**

**Books and reports listed below are available to the public and can be downloaded at no charge from the ISGP Web site: www.scienceforglobalpolicy.org.**
**Hardcopies of these books are available through Jennifer Boice, jboice@scienceforglobalpolicy.org.**

**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.

**Food Safety, Security, and Defense (FSSD):**

- *FSSD: Focus on Food and the Environment,* convened October 5–8, 2014 in Ithaca, New York, U.S., 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.*

**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 Academic Partnerships**

- *EPID: Focus on Pandemic Preparedness*, convened April 11–12, 2014 in Collegeville, Pennsylvania, U.S., in partnership with Ursinus College.

# Appendix

## Biographical information of scientific presenters

**Keith Dixon, M.S.**
Mr. Keith Dixon, research meteorologist and climate modeler at the National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory located in Princeton, New Jersey.. His expertise lies in the uses and limitations of state-of-the-art computer climate models to simulate the Earth's past, present, and future climate.

**Sharon B. Megdal, Ph.D.**
Dr. Sharon B. Megdal, Director of University of Arizona Water Resources Research Center, and C.W. and Modene Neely Endowed Professor in the College of Agriculture and Life Sciences. Her work focuses on water resources management and policy, and how to reform institutional structures.

**Elaine Wheaton, MSc**
Ms. Elaine Wheaton, climate scientist, adjunct Professor at the University of Saskatchewan (School of Environment and Sustainability) and Researcher Emeritus at the Saskatchewan Research Council (SRC). Her expertise is climate change impacts (especially droughts and excessive moisture), adaptations, hazards, and vulnerabilities.

## Biographical information of the Tucson Working Group

**John Pedicone – Chair**
Dr. John Pedicone is the retired superintendent of Tucson Unified School District (TUSD), the largest public school district in Tucson. He oversaw the academic and operational functions of TUSD, which has approximately 50,000 students and 9,000 employees, serving a half-a-million citizens over 230 square miles. He served as vice president of the Southern Arizona Leadership Council and was Master's Degree Program coordinator for educational policy studies and practice, University of Arizona College of Education.

**Kristin Almquist**
Ms. Kristin Almquist, a second-generation Tucsonan, currently is a consultant for nonprofit and private-sector marketing, sales and community engagement. Formerly she was director of the Southern Arizona Office for Arizona Governor Janet Napolitano. She is a member of the Arizona Public Media Community Advisory Board, which advises Arizona Public Media Radio and Television station management on a wide variety of issues relating to southern Arizona public broadcasting. Ms. Almquist also has worked for Habitat for Humanity and the Pima Council on Aging.

**Linda Ellinor**
Ms. Ellinor is a co-founder of The Dialogue Group and co-author of "Dialogue: Rediscover the Transforming Power of Conversation." She is currently authoring a book and blog on the topic of “Dialogue as a Way of Life” and offers workshops on this theme and others in which she encourages participants to integrate a sustainable and holistic worldview in their day-to-day lives through conversation with self and others. Her workshops and learning groups help participants identify and apply their personal passions in service of shaping our collective future.

**Richard Grijalva**
Mr. Richard Grijalva is the Chief Executive Officer of the Economic Development Authority for the Tohono O’odham Nation. The Tohono O’odham Nation (Desert People) is a federally recognized Native American Tribe and is the second-largest reservation in the United States, comprising 2.7 million square miles in the Sonoran Desert. Mr. Grijalva was president and major stockholder in Tucson Blueprint Co. for 25 years. He also served as an adjunct faculty member of Pima Community College for 30 years.

**Kathy Jacobs**
Dr. Kathy Jacobs is director of the Center for Climate Adaptation Science and Solutions (CCASS) and professor in the department of Soil, Water and Environmental Science. She has served as an assistant director in the U.S. Office of Science and Technology Policy (OSTP) in the Executive Office of the President, and was the director of the National Climate Assessment, leading a team of 300 authors and more than 1,000 contributors who wrote the Third NCA report. She also was the lead advisor on water science and policy and climate adaptation within OSTP. She has served as executive director of the Arizona Water Institute and as a water manager for the Arizona's Department of Water Resources.

**Henry Koffler**
Dr. Henry Koffler is President Emeritus of the University of Arizona (UA), having served as President of the UA from 1982-1991. 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. He also is 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 in Tucson.

**Ken Marcus**
Mr. Ken Marcus is responsible for the finances and operations of the University of Arizona Tech Park and UA Tech Park - The Bridges. Earlier in his career, he worked for the University of Arizona Agriculture Extension Service on research projects, and served as controller for Bell Howell Cope Company and as Interim Executive Director of Finance for Tucson Unified School District. He graduated from the University of Arizona in 1982 with a BS in agriculture and completed his MBA at the University of Phoenix in 1990.

**C. Mary Okoye**
Ms. Mary Okoye heads the Tucson office of the public affairs firm Scutari and Cieslak. She formerly was Director of Intergovernmental Relations for the City of Tucson, where she led teams of public, private, and community leaders in the successful pursuit of federal and state funding for downtown efforts, including the Modern Streetcar project. A graduate of the University of Arizona College of Law, she has worked in private practice, served as a Tucson City Court Magistrate, was Pima County Public Fiduciary, and has facilitated town halls, public meetings, and numerous focus groups on behalf of the Tucson Unified School District. She currently serves on numerous boards including the Community Foundation of Southern Arizona.

**Butch Ryan**
Mr. Butch Ryan worked in school district business administration for eight years. He founded, developed and managed the software development company Via Media Inc., which provided products for the education market for 28 years. He has lived in Tucson, Arizona, since 1966 and is currently semiretired.

**Ben Tuchi**
Dr. Ben Tuchi serves on the boards of four nonprofit organizations, including serving as chairman of the board of directors of the Arizona Research Park Authority, and Secretary/Treasurer of the board of directors of the Institute on Science for Global Policy (ISGP). He has held teaching and cabinet-level positions 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. For the two years prior to his retirement in 1999, he was the Director of Graduate Programs in Business in Central Europe, at Comenius University, making his home in Bratislava, the Slovak Republic.

**Sperry van Langeveld**
Dr. Sperry van Langeveld's career has included positions in polymer research and senior management in large suppliers to the automotive and other industries. In 1984, he established a personal computer manufacturing business that he and his wife operated until their retirement in 1999. He holds diverse graduate degrees; his doctoral thesis formed the basis for Du Pont's "Design of Experimentation" program, utilizing statistics to predict reaction optima with minimal experimentation. Sperry is a life member of Sigma Xi and has participated at board level in environmental and educational organizations. He studies and teaches at the University of Arizona and is interested in statistical modeling.

## Biographical information of conference debaters

**Ryan Anderson**
Planning, Transportation & Sustainability
Tucson City Mayor's Office

**William Ardern**
Colonel USAF, retired.
Former air wing commander,
Davis-Monthan Air Force Base

**Glenn Bacon**
Teacher, computer science, retired

**Victor Baker**
Professor, University of Arizona
Institute on the Environment

**Amanda Barth**
Teacher, science, Tanque Verde
School District

**Adam Burgess**
Professor of social risk research
University of Kent, United Kingdom

**G.A. Clark**
Archeologist, Arizona State University
Regents Professor Emeritus

**William Lynn Engles**
Bureau of Indian Affairs, U.S.
Department of the Interior, retired

**Christopher Fullerton**
Attorney; University of Arizona Water
Policy graduate certificate program

**Joan Gilbert**
Science educator, Tucson Unified
School District

**Cathy Green**
Maritime archaeologist, National
Oceanic and Atmospheric Agency

**Robert Grove**
Senior scientist and oceanographer
Southern California Edison, retired

**Lisa Hopper**
CEO and founder,
World Care

**Theodore Hullar**
Biochemist, professor emeritus University
of California; Cornell University

**Jill Jackson-Mandel**
Docent, Tucson Botanical Gardens
Volunteer, U.S. Forest Service

**Kathy Jacobs**
Director, Center for Climate Adaptation &
Solutions; professor, University of Arizona

**John Kai, Jr.**
Kai Farms, Avra Equipment
and Supplies

**Madeline Kiser**
Community Water Coalition & Southern
Arizona Green for All Coalition

**Jim Kolbe**
Consultant, former U.S. congressman
ISGP Board of Directors

**Marie Light**
Hydrogeologist, Pima County
Environmental Quality

**Ben Lomeli**
Hydrologist, Bureau of
Land Management

**Gary Lynch**
Water utility executive,
Park Water Company

**Conrad McCarthy**
Geologist,
Rio Rico, Arizona

**Amy McCoy**
Water consultant, Tucson Watershed
Management Group

**Francie Merryman**
Wealth strategist,
Northern Trust Bank

**Fernando Molina**
Public information officer,
Tucson Water

**Gary Nabhan**
Agro-ecologist, farmer, writer, educator
University of Arizona

**C. Mary Okoye**
Government relations consultant,
Scutari and Cieslak

**Don Pope**
Civil engineer, water
management, retired

**Michael Ray**
President, Nurse Tree Arch Design,
L3C and Netorganizing Consulting

**Joellen Russell**
Associate professor, University of
Arizona Department of Geosciences

**David Schaller**
Scientist, U.S. EPA; Tucson Green
Chamber of Commerce

**Norman Scott,**
Biological and environmental engineering
Cornell University

**Scott Stonum**
Chief of Science and Resource
Management, Saguaro National Park

**Sheldon Trubatch**
Attorney, physicist,
educator; retired.

**Karin Uhlich**
Ward 3 Council Member,
Tucson City Council

**Alfred Urbina**
Attorney General,
Pasqua Yaqui Tribe

**Claire Zucker**
Director, Sustainable Environment
Pima Association of Governments

## Biographical information of ISGP Board of Directors

**George Atkinson, Chairman**
Dr. George 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. A past president of Sigma Xi, The Scientific Research Society, he also 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.

**Ben Tuchi, Secretary/Treasurer**
Dr. Ben 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.

**Janet Bingham, Member**
Dr. Janet Bingham is former President and CEO of the George Mason University (GMU) Foundation and GMU's Vice President for Advancement. 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.

**Henry Koffler, Member**
Dr. Henry 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.

**Jim Kolbe, Member**
For 22 years, Mr. Jim 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.

**Charles Parmenter, Member**
Dr. Charles 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.

**Thomas Pickering, Member**
Mr. Thomas 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.

**Eugene Sander, Member**
Dr. Eugene G. 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.

**Richard Armitage, Special Adviser**
Mr. Richard 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.

## Biographies of ISGP staff

**Jennifer Boice, ISGP Program Coordinator**
Ms. Boice 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. She received her M.B.A. from the University of Arizona and graduated from Pomona College in California with a degree in economics.

**Samantha Cermignano, ISGP Senior Fellow,**
Ms. Cermignano received her Bachelor of Science in Biology with a concentration in Pre-Health from Ursinus College, Pennsylvania. She previously held a position at the University of Pennsylvania as a visiting undergraduate researcher in hematology, and has been published in the journal *Blood*. She will be entering medical school in fall 2015.

**Sweta Chakraborty, ISGP Associate Director**
Dr. Chakraborty received her doctorate in Risk Management from King's College London, and has more than 20 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 currently an adjunct assistant professor at Columbia University and a program associate at Oxford University's Centre for Socio-Legal Studies.

**Christina Medvescek, ISGP Program Administrator**
Ms. Medvescek is an internationally published journalist and editor specializing in health, human development and conflict resolution. She also serves as an EEO mediator for the U.S. Postal Service, and as a volunteer mediator, facilitator and instructor at the Center for Community Dialogue, Tucson, AZ.

**Ramiro Soto, ISGP Fellow**
Mr. Soto graduated in May 2015 from University of Arizona College of Science with a degree in General Applied Mathematics and a minor in Hebrew Studies. He plans to enter a doctoral program to further his studies in mathematics.

**Andrea Vazquez, ISGP Fellow**
Ms. Vazquez is a student at Arizona State University pursuing her bachelor's degree in social work. She also serves as a college prep assistant at a Tucson, Arizona, high school. Her goal as a social worker is to advocate for people who are vulnerable and oppressed, especially youth.

## List of *Living with Less Water* volunteers

Nicole Dutiel
Pima Community College

Leticia Fischer
University of Arizona

Christopher Fullerton
University of Arizona

Adolfo Jimenez
Sunnyside High School

Maritza Jimenez Chavez
University of Arizona

Sara Jimenez
Pima Community College

Zaira Jimenez
Pima Community College

Caitlyn Hogan
Palo Verde Magnet High School

Shine Little-Sagg
University of Arizona

Martin Christopher Lopez
University of Arizona

Alan Mata
Rincon High School

Ron Medvescek
Community volunteer

Veronica Miranda
Pima Community College

Brian O'Neill
University of Arizona

Mayram Velazquez
Pima Community College

Basant Virdee
University of Arizona

Susan Ward Harris
University of Arizona

Kayla Williams
Pima Community College

Donnalyn van Langeveld
Community volunteer

Greg Harris
Community volunteer