Babcock et al. Earth Perspectives (2016) 3:3
DOI 10.1186/s40322-016-0035-x

Earth Perspectives

RESEARCH ARTICLE Open Access

# Stakeholder perceptions of water systems and hydro-climate information in Guanacaste, Costa Rica

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## Abstract

In the face of changing environmental and socio-economic drivers, access to, understanding of, and the use of probabilistic climate forecasts and other sources of scientific hydro-climate information are important for informed decision making in the water sector. This paper characterizes and compares local perceptions of the water system and hydro-climate information in the seasonally dry province of Guanacaste, Costa Rica. Semi-structured interviews were conducted with a total of 40 participants from 7 water-related groups. Interview results were used to compare mental models of the drivers of water systems and water scarcity mitigation/adaptation options, and relate them to stakeholder information needs, accuracy ratings, and use. Our results suggest that: 1) while there appear to be similar perceptions of the drivers of rainfall and groundwater, there is a gap between groups in the use of forecasts, the awareness of management options, and the level of detailed understanding of how the water system works; 2) there are potential mismatches between the information presented in rainfall forecasts and the stated and/or salient information needs of some stakeholders, specifically in the case of groundwater resources; 3) there appear to be different perceptions of forecasts even among groups that rate the accuracy of such forecasts the same; and 4) there appears to be a relationship between the use of forecasts and certain types of management actions such as long-term planning. Our findings warrant further investigation and confirmation and may contribute to the development of communications that help stakeholders make informed decisions about freshwater management in semi-arid regions.

**Keywords:** Stakeholder perceptions, Climate change, Water management, Hydro-climate information

## Introduction

### Background

Successful freshwater resources management is a complex task that involves diverse stakeholder groups and decision making at multiple spatial and temporal levels. Increasingly, changes in climatic patterns, socio-economic pressures, and other large-scale drivers of water systems have created (and are expected to continue to create) contexts in which older water management practices and decision-making strategies are not adequate to meet the demand for freshwater in multiple sectors. Experts, national governments, and international agencies have developed and promoted scientific hydrologic modeling and forecasting tools for use in integrated water resource management, and as part of adaptation plans for water systems under changing climate conditions (Stern and Easterling 1999). Scientific hydro-climate information refers to information that is derived from statistical and modeling analyses that incorporate uncertainty, unlike earlier or traditional approaches. However, it has been shown that many water managers from different sectors and geographic areas do not incorporate this information into their decision-making but rather continue to rely on traditional methods that were developed during (or which assume) a more stationary environment (Rayner et al. 2005; Kirchhoff 2012; Orlove et al. 2004). Without using such information, stakeholders' may not be making *informed* decisions – where the costs, benefits and uncertainties of choices are understood well enough to enable decisions to be made in accordance with values and preferences. This lack of informed decision making may contribute to maladaptive

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decisions for managing socio-ecological systems (SES), especially in arid and semi-arid areas of the developing world where water stress is already elevated and where institutional and physical resource constraints leave such systems more vulnerable to rapid social and ecological change.

A number of specific factors influence the use of scientific climate information in both wealthier and developing nations, including but not limited to: whether the information relates to local conditions and the scale at which the user is operating, the perceived reliability of forecasts and trust in the forecasting agency, the timing of the forecasts, the socio-economic status of the potential user, the specific sector of work the user was involved in, political differences between providers and users, forecast content and the form of communication, institutional standard operating procedures, and the perceived risk from current and future threats to water resources (O'Conner et al. 2005; Rayner et al. 2005; Orlove et al. 2004; Moser and Luer 2008; Letson et al. 2001; Hansen et al. 2004; Lemos et al. 2002). Key factors in the developing nation context include whether forecasts are perceived as appropriate and trustworthy, whether there is access to such forecasts, and whether there are resources to act on that information (Letson et al. 2001; Orlove et al. 2004; Lemos et al. 2002). Furthermore, each of these factors may influence decision making differentially depending on the decision contexts faced by stakeholders acting in different water use sectors (e.g., agriculture, domestic use, energy production, recreational, environmental protection). While it is clear that a number of factors influence the use of climate information, recent research suggests that not all factors are equally influential across all stakeholders. Indeed, a number of additional factors inherent to the decision maker (e.g., who they are; level of expertise/education) and external factors such as context (e.g., water sector decision) and goal (e.g., agricultural production, energy production, recreation, environmental protection) can influence whether a decision maker has access to and can or will make use of such information. Recognizing this, recent work calls for more work on identifying the decision making processes of stakeholder groups with respect to questions of climate adaptation (Kirchhoff et al. 2013; Jain et al. 2015). Therefore, in this paper we ask: What do different groups of water end users think of scientific hydro-climate information and how, if at all, they use this type of information in their decision making.

### Research questions and framework for comparing stakeholder perceptions

Here we explore the perceptions of multiple stakeholder groups in Guanacaste, Costa Rica, that are facing increasing water stress in the face of a changing climate (Kuzdas 2012; van Eeghan 2011). To assess stakeholder perceptions in a systematic fashion, we developed a simplified framework (Fig. 1) that incorporates concepts from Theory of Planned Behavior (Ajzen 1991), the Planned Risk Information Seeking Model (Kahlor 2010), and Protective Motivation Theory (Rogers et al. 1983).[1] This framework takes as its end points the actual implementation of water management actions and/or seeking out and using hydro-climate information. In this framework, a stakeholder's decision to implement management actions is affected by the perception of a threat or opportunity that requires the action, the perception that they have the ability to implement the action, and/or the perception that there is a social pressure to perform that action. Similarly, whether they seek new information and/or use such information is affected by their perceived need for that information, ability to use it, and any subjective norms related to the use of that information. The use of new information in turn can affect the implementation of the management action. Underlying the stakeholder's perceptions of threats/opportunities, information needs, ability, and social norms are their perceptions of the water resources related social-ecological system and of the different aspects of the hydro-climate information. Our focus therefore is on the following main questions:

1. How do various stakeholder groups perceive the freshwater system in their local and regional areas? Specifically how do they perceive the system drivers, states, and responses within the system? What are the similarities and differences between stakeholder groups?
2. How do various stakeholder groups perceive and use hydro-climate knowledge and specific sources of information? Specifically, how do they perceive the information sources; the attributes of the information, including trustworthiness and accuracy; and whether and how the information is used for informing decisions? What are the similarities and differences between stakeholder groups?

The next section describes the study area and the development and implementation of the interview protocol. Section 3 describes the qualitative and quantitative results of the interviews, and Section 4 discusses the suggested implications of these results for water management policy in the region and how they may inform future work.

## Methods

### Study area and stakeholders

#### *Freshwater resources in Guanacaste, Costa Rica*

This study is part of the FuturAgua Project in Guanacaste, Costa Rica, a multidisciplinary, multinational research

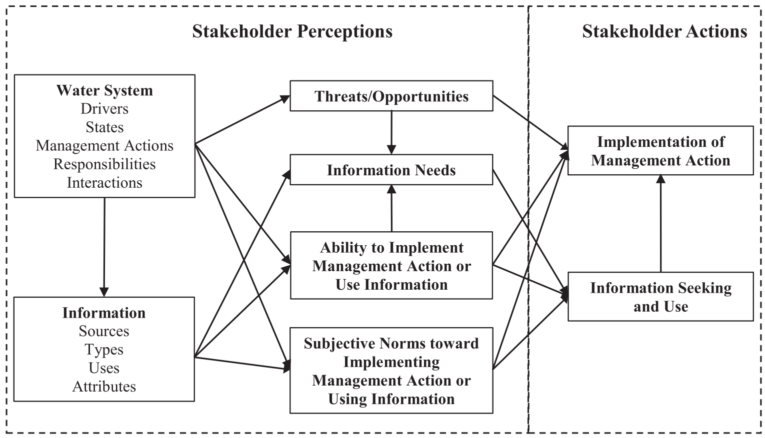


**Fig. 1** Simplified stakeholder perceptions and decision making framework

effort supported by the G8 Belmont Forum to study climate change and freshwater security in developing nations (FuturAgua 2015). Guanacaste is a seasonally dry tropical province, with a yearly rainfall pattern that is typically comprised of a 6-month dry season from late November until May, a smaller rainy season from May to July, a mid-summer drought in July/August, and the main rainy season from August to November. This pattern is significantly affected by the status of the El Niño Southern Oscillation and the North Atlantic Oscillation climate systems. Climate change forecasts and models, such as those included in the Fourth and Fifth Assessment Report of the IPCC, predict changes to the annual cycle of precipitation and increased temperatures, both of which may additionally stress water supplies in the region (Rauscher et al. 2008, 2011; Karmalkar et al. 2011; Ryu and Hayhoe 2014; Neelin et al. 2006; Steinhoff et al. 2014).

Costa Rica guarantees a healthy environment to its citizens in the national constitution and has passed water related laws that establish that freshwater resources cannot be privately owned. The Water Directorate of MINAE, the Costa Rican Ministry of the Environment and Energy, manages concessions of groundwater and river water for use by municipalities, hydroelectric power facilities, and private entities such as farms, off-grid households, and resorts. Within the last 30 years, municipal population growth, changing agricultural activity, increased hydroelectric power production, increased tourism developments, and continuing environmental protection interests all have placed increasing demands on freshwater resources, and there has been a recent history of inter-stakeholder group conflict over water issues (Ramírez-Cover 2008). These conflicts have been shown to occur in part due to underrepresentation of local stakeholders in decision making. In addition, there is a lack of credible or available scientific measures of water quality and quantity, and without these measures the ability to distinguish between the physical lack of water resources and misallocation of such resources has proven difficult (Kuzdas 2012 and van Eeghan 2011).

### *Stakeholder groups*

For this study we separate stakeholders into the following groups: government agencies, large farmers, small farmers, hydroelectric system managers, tourism businesses, village water committees called ASADAs, and the public. The government agencies that make decisions at a local and regional level about water resources or are impacted by such decisions include MINAE as mentioned above, the Ministry of Aqueducts (AyA), the Ministry of Agriculture and Livestock (MAG), and the Ministry of Subterranean Water and Irrigation (SENARA). AyA is mandated to provide potable water to all citizens in the country for domestic use. In the larger towns and cities, AyA manages the water systems, whereas in the smaller less-connected towns the water systems are managed by local water committees or ASADAs. The executive council of each ASADA are volunteers that are voted in by the users every 2–3 years (some ASADAs also pay the administrators and technicians that work on the systems). The volunteer councils are legally responsible for maintaining the water systems and have the authority to collected water use fees, but typically have less technical expertise then the central AyA offices. Almost all municipal water systems in Guanacaste source their water from groundwater or rivers.

The Ministry of Agriculture and Livestock (MAG) is mandated to provide technical assistance to Small Farmers and this outreach includes assistance with irrigation and climate adaptation efforts. Small farmers are either tenants of Large Farms or family enterprises who either raise cattle or grow a variety of crops for local and sometimes export markets (rice and sugar, but also peppers, coffee and vegetables). Large Farms are large estates used either for cattle grazing or for the growing of cash crops such as rice, sugar, and/or melons and employ agronomic engineers as well as large numbers of laborers/tenant farmers. Large and Small farms typically use a mix of direct rainfall, groundwater, and river water depending upon their location and crop. Depending on the farm type they have a mix of irrigation methods installed on their property (this is more widespread on Large Farms, but Small Farms may also have their own systems). In special irrigation districts, SENARA is responsible for providing irrigation water to Small and Large farmers.

Hydroelectric power generation in Guanacaste comes from the ArCoSa system (3 plants in series for a total capacity of 360 MW) operated by the Costa Rican Electricity Institute or ICE, and a two plant system run by the rural electrification cooperative, COOPGUANACASTE. These systems are located in the mountainous region along the eastern border of the Province which receives a larger amount of yearly rainfall and use a mix of reservoir and river water.

#### *Available hydro-climate information*

The main source of climate forecast information in the region is the Costa Rican National Meteorological Institute (Spanish acronym, IMN). The IMN provides daily and weekly weather forecasts through its website (IMN 2016). The IMN also provides for free on this website monthly climate reports that review the past months precipitation and temperature data and project future precipitation by region typically up to three months ahead (IMN also less frequently releases predictions for the next 6–12 months). Internet coverage in Guanacaste is relatively good and many access the internet through mobile devices (this is more true of younger generations). Additionally all of this information is also transmitted through local and national public media (TV, radio, and newspapers). The IMN also provides more detailed historical data to the public and other government agencies for a fee. The other government agency that has direct access to climate measurements is ICE, though typically ICE does not share this information. ICE also has information regarding reservoir levels that is used in the management of hydroelectric power stations. Many Large Farmers have their own meteorological equipment and have access to NOAA forecast information. Streamflow and groundwater data are more difficult to come by and this lack of information about how much water exists in certain aquifers has been identified as a factor in local water conflicts (Kuzdas 2012 and van Eeghan 2011).

### Interview protocol

In order to elicit stakeholder perceptions, a variation on the mental models approach (Morgan et al. 2002) was employed. This approach includes the use of a formative semi-structured interview that aims to more broadly and openly elicit perceptions from participants. The results of this interview are then used to inform the development of surveys to confirm the prevalence of interview results and test hypotheses generated from the original interview (Klima et al. 2012). Typically this approach has been used to compare risk perceptions and facilitate risk communication between experts and laypeople (Morgan et al. 2002; Hansen et al. 2004). It has also been used to compare climate and adaptation perceptions across experts (Otto-Banaszak et al. 2011). In this study, the approach is used to help compare perceptions of water systems and climate information across multiple stakeholder groups.

Drawing from previous literature and input from other FuturAgua researchers during the winter and spring of 2014, the English language interview protocol was developed. It was then translated into Spanish by the lead author and edited for language by two native Spanish speakers (a coordinator from the FuturAgua project and a member of the local advisory group located in Nicoya, one of the main towns in Guanacaste). In May 2014, the protocol was pilot tested for understanding with two different members of the Nicoya advisory group (an environmental ministry employee and a university professor) prior to the start of the field interviews. The protocol was structured into three main sections: 1) open ended questions about stakeholder perceptions of the social-ecological system (SES); 2) open ended questions about perceptions of water system information and sources and closed questions rating the accuracy of mentioned sources; 3) specific questions about forecasts and climate change (the full protocol can be found in Additional file 1).

### Interview participants and process

A total of 40 participants were interviewed from 7 different stakeholder groups: Agencies ($n = 10$, including government employees of AyA, MAG, MINAE, and SENARA), ASADAs ($n = 7$), Small ($n = 6$) and Large ($n = 4$) Farmers, Hydroelectric power managers ($n = 3$), Tourism-centered businesses ($n = 4$), and members of the Public ($n = 6$). Participants were recruited through a variety of strategies. Members of the Nicoya advisory group, other FuturAgua researchers, or government agency contacts suggested most of the participants and named them as either knowledgeable or interested individuals. Some ASADA members were contacted based on a list of contact information provided by the Aqueduct ministry (AyA) in Nicoya. Other ASADA members were recruited using snowball sampling [34], in which ASADA group interview participants were asked to name other ASADA members to be contacted. All participants from the Tourist and Public stakeholder groups were directly recruited as a convenience sample (Berg 2001) by the lead author in the street, shops, restaurants, businesses or hotels. All potential participants contacted were interviewed with the exception of two (1 hydroelectric project manager and 1 small farmer - both due to scheduling issues). The mix of convenience and snowball sampling in these types of studies is standard practice in the field (see Kirchhoff 2012 and Orlove et al. 2004 as examples), however one possible issue with proceeding in this manner is that the results may not include the views of individuals who live farther away from others or those who have less societal connections.

Interviews were conducted in Guanacaste during June and July 2014[2]. The interviews were recorded and conducted in Spanish except for one (an English-speaking hotel owner who was from the United States and did not want to be recorded). The interviews were performed one-on-one, though occasionally in some interviews there were interruptions and additional comments made by others (family members, neighbors, and in some cases one of FuturAgua's local advisers). Interviews lasted between 25 and 90 min, with most being approximately 45 min long. Participants were not monetarily compensated. After the interview, each participant was given a FuturAgua mug as a thank you gift (participants were not informed of the gift in advance of the interview).

The median age of interview participants was 54.5 years. Overall, 55 % of the participants had at least a college degree. The percentage of stakeholders that had such a degree of education within the Large Farmer, Agency, and Hydroelectric groups was 90 % or above, whereas the percentage in the other groups was 50 % or below. Only 17 % of the participants were female, which, while very low in terms of the general public and elected government positions, is closer to the percentage that are in ASADAs (20 % based on AyA records) or that work for MINAE (25 %) in Guanacaste. Recognizing that the intent of studies employing the mental models approach with in-depth interviews is to discover concepts and suggest hypothesis (not to test them), a sample that includes participants from the targeted groups was sought, but it did not need to be representative.

### Coding and analysis

All interviews were transcribed (Spanish to Spanish) either directly by the lead author or by transcribers recruited through Amazon Mechanical Turk, an Internet platform for crowdsourcing short "human intelligence" tasks (Amazon Mechanical Turk 2015). All Mechanical Turk transcriptions were checked for errors and corrected by the lead author. Interview transcripts were translated into English by the lead author and then, as a quality check, several interview transcripts were back translated from English to Spanish by native Spanish speakers from the broader FuturAgua research team.

The lead author used multiple iterations of an open-coding procedure (Strauss 1987) to inductively find common and interesting themes from the interview transcripts for further analysis. For the one interview that was not recorded, the lead author's notes from the interview were used as the transcript for coding purposes. The codes were separated into groups concerning drivers, states, and uses of the water system, actions taken to mitigate or adapt to water scarcity, and information sources and attributes (a full list of the sub-codes under these categories can be found in Additional file 2).

QDA Miner Lite software (QDA Miner Lite 2015) was used to "tag" excerpts with one or more codes, allowing the grouping of similar quotes and descriptive comparisons of pairs of codes. A second rater coded a subset of 11 of the transcripts, and there was 69 % agreement between the two raters as to whether a specific code was mentioned in a specific transcript. Literature on inter-rater reliability suggests that a percent agreement of 69 % indicates "substantial agreement" (Landis and Koch 1977). The first coder conducted the interviews and thus likely had a more nuanced perspective of the transcripts and allocated more codes than the second coder. These statements have been added to the manuscript.

Binary frequencies of mention (mentioned in transcript versus not mentioned) were determined for each participant for each single sub-code (e.g., DRIVER-ELNINO) and for select pairs of sub-codes (e.g., did the transcript mention both INFOSOURCE-FORECAST and INFOATTRIBUTE-USED?). Pairing sub-codes allowed frequency counts of interactions such as Driver/State pairings. The percentage of participants within each stakeholder group that mentioned a certain sub-code or pair of sub-codes at least once was then calculated and used for comparing across stakeholder groups.

Transcript excerpts that mentioned the numerical rating of information sources were collected and analyzed with simple descriptive statistics. No inferential statistics were performed as the participants were not randomly selected and there were only a small number of participants in each of the different stakeholder groups.

## Results

### How various stakeholder groups perceive the freshwater system in their local and regional areas

#### *Views on drivers of rainfall amount and duration and groundwater levels*

The main sources of water for stakeholder use mentioned by interview participants from all groups were direct rainfall and/or groundwater (accessed through wells and/or aqueducts). Table 1 shows the perceived drivers of the amount and distribution of rainfall mentioned by interview participants. Global warming-related climate change was the rainfall driver identified by the highest percentage of members within the Agency, ASADA, and Tourism groups. Climate change and the effects of the El Niño Southern Oscillation (ENSO) were both mentioned by the

**Table 1** Drivers of rainfall and groundwater levels mentioned by members of different stakeholder groups

| | % of stakeholder group members mentioning specific driver | | | | | | |
|---|---|---|---|---|---|---|---|
| | Agency (10) | ASADA (7) | Sm. Farmers (6) | Lg. Farmers (4) | Tourism (4) | Hydroelectric (3) | Public (6) |
| Rainfall drivers | | | | | | | |
| Climate Change | **40 %** | **43 %** | **50 %** | **50 %** | **50 %** | **67 %** | 0 % |
| ENSO | 20 % | 29 % | **50 %** | **50 %** | 0 % | **67 %** | **17 %** |
| Nature | 10 % | 14 % | 0 % | 25 % | 25 % | 0 % | 0 % |
| Deforestation | 0 % | 0 % | 33 % | 25 % | 25 % | 33 % | **17 %** |
| Geological/Geographical | 20 % | 0 % | 33 % | **50 %** | 25 % | 33 % | 0 % |
| Ozone Destruction | 0 % | 0 % | 0 % | 0 % | 25 % | 0 % | 0 % |
| God | 0 % | 0 % | 0 % | 0 % | 25 % | 0 % | **17 %** |
| Groundwater drivers | | | | | | | |
| Rainfall | 20 % | **29 %** | **50 %** | **50 %** | 0 % | 0 % | 0 % |
| Climate Change | 20 % | **29 %** | 0 % | 0 % | 0 % | 0 % | 0 % |
| ENSO | 20 % | 14 % | 0 % | 25 % | 0 % | 0 % | 0 % |
| Geological/Geographical | 10 % | **29 %** | 33 % | 25 % | 0 % | 0 % | **33 %** |
| Deforestation | **30 %** | 14 % | 0 % | 0 % | 0 % | 0 % | 0 % |
| Population Growth | 20 % | 0 % | 17 % | 0 % | 0 % | 0 % | 0 % |
| Tourism Use | 20 % | 14 % | 17 % | 25 % | 0 % | 0 % | 0 % |
| Large Farm Use | **30 %** | 14 % | 0 % | 0 % | 0 % | 0 % | 0 % |
| Other Population | 0 % | 14 % | 17 % | 0 % | 0 % | 0 % | 0 % |
| Misuse | 20 % | 0 % | 0 % | 0 % | 0 % | 0 % | 0 % |
| Damage | 10 % | 0 % | 0 % | 0 % | 0 % | 0 % | 0 % |
| God | 0 % | 14 % | 0 % | 0 % | 0 % | 0 % | 0 % |

Bolded values represent the drivers mentioned by the highest percentage of members within the group
() indicate the number of participants in each group
Specific driver definitions can be found in Additional file 2

highest percentage of members within the Small Farmer, Large Farmer, and Hydroelectric groups. Climate change was not mentioned at all by the Public as a rainfall driver, but ENSO, Deforestation, and God were tied for most mentions within this group. Climate change and ENSO were the most mentioned drivers across groups, followed by. Deforestation, Geological drivers, and unspecified Natural cycles.

Table 1 also shows the percentage of each stakeholder group that mentioned different drivers of groundwater levels. Hydroelectric managers did not mention (and were not asked about) groundwater drivers during the interviews, most likely because the source of water for their facilities comes from rivers and reservoirs. Tourism group members also did not mention groundwater drivers, which is of potential interest as the source of water for some of these members is groundwater and some of the political conflict in the region has been over tourist use of aquifers (Kuzdas 2012 and van Eeghan 2011). The most mentioned driver of groundwater resources by several groups was the amount and timing of rainfall. This association clearly has a strong physical basis, especially for shallow (surface) aquifers and wells. The broadest range of drivers were mentioned by the Agency and ASADA group members, which may be a function of the fact that these two groups mentioned groundwater the most out of any other group in general.

Participants mentioned both perceived direct and indirect drivers of rainfall and groundwater levels. A partial explanation for these results comes from the fact that different participants expressed different levels of specificity and sophistication when discussing these issues. For example, the two quotes below show different levels of detail and knowledge about the role El Niño plays:

> "Depends if it is El Niño or La Niña, and it is a little complex and everything but the El Niño is because of the heating of the Equatorial Pacific Ocean… the climate variability that is a normal process. El Niño has always existed, La Niña also…It's that the storms on the Pacific side, when it rains a lot 5 days, 7 days, 15 days (is when) the Pacific wind tries to go toward the mountain system and it rains a lot. But this year less will be seen, it is expected that 45 % less storms in the Pacific and the wind is hitting here makes it

that the humid breeze from the Pacific backs off and it doesn't rain." (Agency 10)

"Yes. Well they say (there is drought) because of the El Niño phenomena. I don't know when it will be. I don't know." (Public 5)

In general, the participants from the Large Farmer, Hydroelectric, and Government Agency groups were more specific and more confident in describing the relationship between global climate change, the El Niño system, and rainfall than were participants from the other groups.

#### *Views on the state of water resources and appropriate management responses to lack of water resources*

Most participants mentioned that they had enough water at the time of the interview to meet their needs. But, many participants also mentioned that they knew of other areas that did not, or expressed concern and/or uncertainty over whether they would have enough in the future. Table 2 shows the management options mentioned by each stakeholder group for addressing current or future water shortages (additional information about each option can be found in Additional file 2). At least one member of each group mentioned changing the mentality of users and society to be more environmentally friendly, reforestation actions, and finding new water supplies as responses to not having enough water. Table 2 also shows that the more frequently mentioned (and therefore assumed to be most practiced) management options varied by stakeholder group. For example, for Agency, Large Farmer, and Hydroelectric group members, the most mentioned options were grouped under the code "Modify planning" which encompasses changing longer term operations such as the design of future municipal projects or hydropower facilities, phasing out crop types, or expanding agricultural enterprises

Buying insurance as a response to a lack of water resources was only mentioned by farmers, who have experience with the various institutional crop insurance products offered by the government and through cooperatives. One Large farmer (Lg Farmer 1) mentioned an interesting complicating policy factor related to the timing of the rainy season: in order to get crop insurance, farmers have to plant before a certain date. If this date is set too early in a year with a late rainy season then the insurance system may incentivize farmer decisions that result in additional crop loss.

Modification of planning activities (encompassing activities such as changing planting times and power generation schedules) was mentioned by a majority of members of government agencies, hydroelectric managers and large farmers and a minority of other groups.

### Stakeholder perceptions and use of hydro-climate information

#### *Perceived information needs*

A total of 26 participants directly answered the question, "What would you like to know about the state of water resources that you don't already know?" The most common answer (9 participants) was related to how much water was in the aquifer of interest to that participant (including how much was in the aquifer now, how the

**Table 2** Management actions for water shortages mentioned by members of different stakeholder groups

| Management actions | % of stakeholder group members who mentioned specific management action | | | | | | |
|---|---|---|---|---|---|---|---|
| | Agency (10) | ASADA (7) | Sm. Farmer (6) | Lg. Farmer (4) | Tourism (4) | Hydroelectric (3) | Public (6) |
| Nothing can be done | 10 % | 29 % | 0 % | 25 % | 25 % | 33 % | **50 %** |
| Store water | 10 % | 0 % | 0 % | 0 % | **50 %** | 0 % | 33 % |
| Increase efficiency | 50 % | 29 % | 17 % | 75 % | 25 % | 0 % | 33 % |
| Standard operations | 30 % | **57 %** | 0 % | 25 % | **50 %** | 0 % | 33 % |
| Use improved tech. | 30 % | 14 % | 33 % | **100 %** | 0 % | 0 % | 0 % |
| Buy crop insurance | 0 % | 0 % | 17 % | 25 % | 0 % | 0 % | 0 % |
| Modify planning | **90 %** | 0 % | 17 % | **75 %** | 25 % | **100 %** | 17 % |
| Change mentality | 30 % | **57 %** | 33 % | 50 % | 25 % | 33 % | 17 % |
| Make new law/rule | 20 % | 14 % | 0 % | 0 % | 0 % | 0 % | 17 % |
| Protect watershed | 40 % | **57 %** | 33 % | 25 % | 25 % | 67 % | 0 % |
| Find new supply | 70 % | 43 % | **50 %** | 50 % | 25 % | 33 % | 33 % |
| Reforest | 40 % | 71 % | 33 % | 25 % | 25 % | 67 % | 17 % |
| Megaprojects | 40 % | 0 % | 0 % | 0 % | 0 % | 0 % | 0 % |

Bolded values represent the drivers mentioned by the highest percentage of members within the group
() indicate the number of participants in each group
Specific action definitions can be found in Additional file 2

groundwater flowed in or out, and how much would there be in the future). The main reason given for wanting this information was so that they would know if there was going to be enough water for their own use and the use by others. Other direct answers included, in order of frequency, information about groundwater quality (what was the quality and how to treat the water - 5 participants), information about climate change (forecasts and sources – 4 participants), what the rain forecast was going to be (3), information about surface water quality (3), and what the impact of climate would be on plants (2).

### *Awareness and use of different types of forecasts*

During the interviews rainfall forecasts of four different types were mentioned: basic daily/weekly radio/TV/internet forecasts, seasonal 3-month/6-month forecasts created by the IMN or by ICE, year-long forecasts, and multi-year forecasts. Figure 2 shows that only a few participants mentioned multi-year forecasts, members of the Public group only mentioned daily/weekly forecasts, and the highest percentages of use of forecasts were for seasonal forecasts.

### *Perceptions of rainfall forecast accuracy*

The most consistently mentioned information source related to water resources in Guanacaste was the short-term (weeks) and long-term (months/years) forecasts of rainfall provided by the IMN. The forecast accuracy was judged on a scale from 0 (completely inaccurate) to 10 (fully accurate). Based on participants' comments, the main reasons for high ratings were that the participant thought that the forecast matched what the participant actually experienced and that the people in charge of making the forecasts were skilled professionals/experts. As some participants put it:

> "Like I said it is a trusted source, they take a lot into account. Maybe we don't make decisions only based on what they say but yes it forms an important part of the decision we make on our farm." (Lg Farmer 1)

> "Okay based on the last 3 years' experience I would say very good precision for example from 1 to 10 I would put a 9. At least in that they have said, "Here comes a dry period" and it is certain that there have been dry years. For example, this year…they predicted that May, June, and July were going to be dry but the percentage in June was drier than they thought it was going to be. Nevertheless yes they were right that there were dry months. I really… I have trust in the IMN." (Agency 10)

Even participants who had a positive opinion on the accuracy of the forecasts usually also discussed some limitation to them:

> "I would give between a 7 and 8. For example it fails. So they say in these 3 months it is going to rain 100 mm, 25-50-25, but maybe it rains 100 but 5-70-25, you understand that, or the total rain is more or less certain. I believe it is impossible that they do it so… In this they are not certain but it works very well." (Lg Farmer 1)

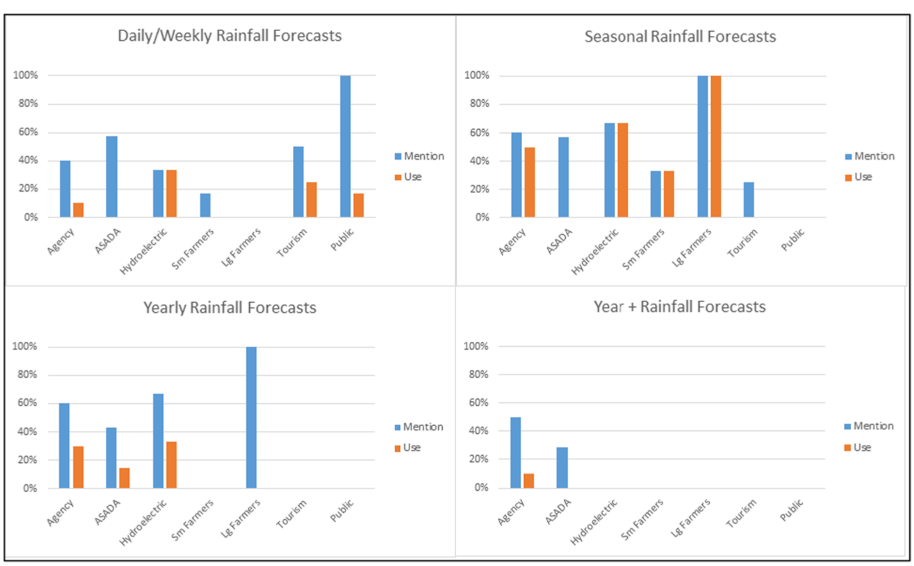


**Fig. 2** Percentage of each stakeholder group that mentioned forecasts of different types

> "No, I give them a 7 about there, yes, yes, yes. But for the 3 month forecasts. They that make these (forecasts) take data from the different meteorological stations. So, to 3 months it is close enough with the projection, but equally they also are very responsible to say that for example the projections for 1 year are not as confident because in reality they are variable or so uncertain that it is a projection nothing more." (Hydroelectric 1)

Participants often mentioned a mismatch between the spatial and temporal scales of the forecasts and the information they need to assess their water management decisions, and many participants mentioned that the farther into the future the forecast goes, the less accurate it will be. The reason for the spatial discrepancy that was most mentioned was that forecasts are given on the scale of the entire region, not on the scale of the sub-region, town, or farm level. Some participants from the Large Farmer and Agency groups stated that while 3-month-ahead average rainfall forecasts were useful, having a forecast that could describe the distribution of rainfall over those 3 months would be even more helpful.

For those assigning low accuracy ratings, the main reasons given included that the participants felt the forecast did not match what they actually experienced or more generally that reality was too variable for the forecasts to be accurate. As one participant said:

> "They are not trustworthy. Sometimes they say it is going to rain in the afternoon and it is dry, sometimes they hit the target and sometimes they don't." (ASADA 7, rated accuracy of 5)

This last quote and the quote from Agency 10 are representative of several that basically say, "Sometimes what the forecast predicts occurs, and sometimes it doesn't." The results show that whether this statement is used to justify a high rating or a low rating varies across stakeholder groups – it seems that large farmers, government agencies, and hydroelectric managers give high ratings and other groups give low ratings (see Fig. 3).

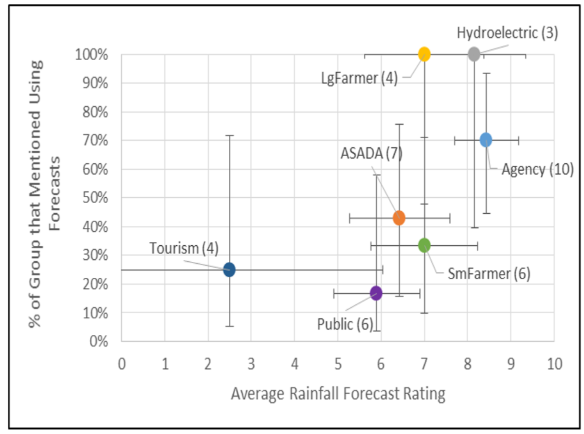


**Fig. 3** Percentage of group that mentioned using forecasts vs. Average Rainfall Forecast Accuracy Rating. *Horizontal error bars* are 2 SD. Vertical error bars are 95 % CI on binomial p distribution. The (#) is the total sample size in the group used to calculate the % of group that mentioned using forecasts. The average rainfall accuracy is averaged only over those participants in each group that gave a numerical rating (and therefore can be less than (#))

### *Use of rainfall forecasts*

Figure 3 also shows the average rainfall forecast accuracy rating calculated for each stakeholder group compared against the percentage of group members that mentioned using the forecasts. The results suggest that higher average accuracy ratings for rainfall forecasts are associated with a greater stated use of such forecasts, though significant variation is present within groups. This tendency would be in agreement with previous results: Orlove et al. (2004), in their study of the fishing sector in Peru, similarly found that their results, "supports the long-established claim that perceived accuracy influences forecast use" and that, "subpopulations differ significantly in their use of this information."

The results presented in Fig. 3 also may suggest that Large Farmers, Hydroelectric Managers, and Government Agency group members use rainfall forecasts more than ASADAs, Small Farmers, and members of the Public and Tourism industry. It also tentatively suggests that while Small Farmers and Large Farmers provided similar accuracy ratings for the rainfall forecasts, the percentage of group members mentioning using forecasts may be much higher among Large Farmers than among Small Farmers. This may be due to the Large Farmers potentially having more access or awareness of different types of rainfall forecasts.

More widespread use of forecasts within a group may be related to whether those forecasts are used to inform the modification of planning activities (changes in planting or equipment schedules, changes in energy production, etc.). Figure 4 shows that again there appears to be a distinction between Large Farmers/Hydroelectric Managers/Government Agencies and the other stakeholders, with the groups reporting the use of forecasts also reporting planning modification options for their water systems. These results could suggest either or both directions of influence: that these groups are responding with modifying planning activities because they use forecasts, or that they seek out and use forecasts because they are already modifying longer-term activities.

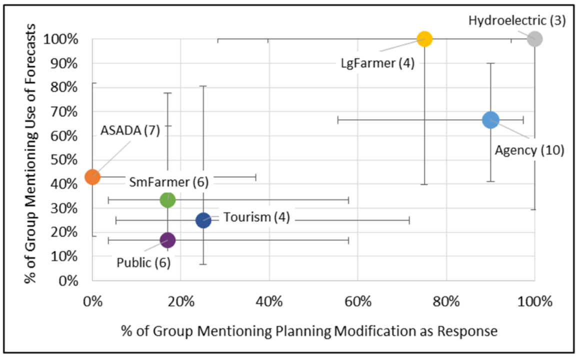


**Fig. 4** Percentage of Group Mentioning Planning Modification Type Responses vs. Average Rainfall Forecast Accuracy Rating. *Horizontal* and *vertical error bars* are 95 % CI on binomial p distribution

## Discussion and conclusions

### Main research findings and study limitations

Our results suggest that most stakeholder groups are similar in their identification of climate change and ENSO as the major drivers of rainfall and groundwater resources, though they differ in their ability to explain the interactions between drivers and water resource states. Stakeholder groups also differ in the types of management responses they are most aware of, with some groups (Large Farmers, Hydroelectric, and Agency members) emphasizing longer-term planning. The timing of the rainy season and the amount of rainfall during the rainy season were identified as important factors in the water system, though individual stakeholders differed to a large extent in their awareness of different rainfall forecasts, their rating of forecast accuracy, and their mentioned use of forecasts. Participants from the Large Farmer, Hydroelectricity, and Government Agency groups rated forecast accuracy as higher and mentioned using forecasts to a larger extent than other groups.

As this study is based on a limited number of interviews, the results presented above should be considered tentative and the actual prevalence of these beliefs and actions requires further testing with larger populations. Also, the results are all self-reported and therefore in some cases may not be accurate. In addition to working with larger populations, the use of other corroborating evidence (census and ministry information and observations, network analysis etc.) will help increase the confidence in these results and their usefulness.

### Implications for policy and future research

Our results tentatively suggest a split between two groups of stakeholders in the sophistication and specificity of descriptions of the interactions between water resource drivers, states, and management actions, in the perception and use of rainfall forecasts, and in the variation of opinions expressed on these issues within each group. This is important because as shown in the framework in Fig. 1, these perceptions impact whether a specific threat is perceived and whether the stakeholder perceives they have the information and the ability to act in the face of this threat. Stakeholder groups we call the Large type (the Agency, Large Farmer, and Hydroelectric stakeholder groups) seem to express a clearer and more descriptive understanding of the physical drivers of rainfall and groundwater, use rainfall forecasts to a larger extent, and have less variation in their opinions than groups from the Small type (Public, Tourist, Small Farmer, and ASADA)[3]. In addition to differences in education levels, one general distinction between Large and Small groups that may factor into these results is that the Large groups most likely have more direct institutional connections and longer term relationships with the National Meteorological Institute. For example, while the IMN releases its 3-month and El Niño forecasts publically on their website, and such forecasts are mentioned in the public media, only members of the Large Farmer, Hydroelectric, and Agency groups mentioned having direct meetings and specialized presentations with the IMN. These types of connections have been identified in previous literature as beneficial to the use of forecasts, specifically the “Interaction” part of Lemos et al.’s “Fit, Interplay, and Interaction” model (Lemos et al. 2012). “Interaction” opportunities that improve the use of forecasts such as co-production, long-term relationships, and two-way communication, appear to be more prevalent between Large Farmers, Agency, Hydroelectric groups and the IMN. The split in perceptions of the water system between Large and Small stakeholders may become problematic in cases where Large and Small groups interact, as in the case where the Ministry of Agriculture (MAG) is mandated to provide education and guidance on climate change and water management to small farmers. A similar relationship exists between the ASADAs and the Ministry of Aqueducts (AyA). An important implication for policy is that the educational material and communication practices of Large groups, should be developed and tested with Small groups to ensure understanding and usability of information to enhance the management of freshwater resources (Wong-Parodi et al. 2014).

Previous literature has emphasized the importance of providing information that helps answer the questions stakeholders actually have to deal with/are aware of (Moser and Luer 2008; Lemos et al. 2012; Fischhoff 2013). For example, in Moser and Luer’s study of coastal managers (2008), they argue that, “the overarching message emerging from the information needs identified by coastal managers is that climate change science still needs to be translated into types of information that are salient to the manager”. Our results suggest that rainfall and climate forecasts are not being translated into information about the more salient water resource concern, which in this case may be groundwater (based on the interest expressed in obtaining additional information about it as mentioned in the results section ). In our results, while rainfall was perceived as a major driver of groundwater, information on groundwater levels and flows was directly identified as a need more often than climate and rainfall forecasts. If groundwater levels are information that people want and need in the study area, then perhaps communicators of climate information need to be able to do a better job of translating climate forecasts into a type of groundwater forecast (the feasibility of which depends greatly on how well the groundwater, surface water, and precipitation interactions are monitored and understood). If modeling of the groundwater levels or storage is too difficult to achieve this translation, then an alternative would be to try to understand better and communicate to stakeholders how increased groundwater withdrawals during dry periods can exacerbate the effects of rainfall deficits on groundwater (a total of 7 interview participants from the Agency, ASADA, Small Farmer, and Large Farmer groups mentioned the relationship between the lack of rain and increased withdrawals as causes for concern). Future exploration and testing of stakeholder's understanding of the relationship between rainfall and groundwater levels may also assist in designing more salient and effective communication of climate forecast information.

An unexpected finding from the interviews that suggests an opportunity for further policy analysis and improvement is that crop insurance mandates regarding when planting must start may incentivize farmers not to adjust their planting schedules to changing rainfall patterns, resulting in crop loss. This finding suggests future work should include attempts to determine how important insurance is to farmers in the region (e.g., through follow-up surveys). If found to be important, then the process by which the providers of crop insurance determine their cutoff dates should be reviewed and possibly updated.

Looking across Fig. 1 at how perceptions of information may influence the ability to use such information (and the subsequent use of that information), the differences between groups in the rating of forecast accuracy, whether forecasts are used, and how they are used suggest some additional questions about stakeholder decision making that could be tested in the Guanacaste and other contexts as part of future work. While it could be that the distinction between Large and Small type group stems solely from the inability of smaller groups to act due to the lack of opportunity or resources ("nothing can be done" was the most mentioned response for the Public), the fact that members of the ASADA, Small Farmer, and Tourism groups did mention actions that they take which could potentially be enhanced by forecast information (see Table 2) may indicate that other aspects are important. For example, signal detection theory, combined with an understanding of how stakeholders differ in their prior beliefs and motivational biases, could be used to better explain the finding that groups which basically agree on the fact that forecasts are not entirely certain rate the forecast accuracy differently (Green and Swets 1966; Small et al. 2014). It could be that the two groups see the distinction between how well the forecast matches reality the same way (same sensitivity), but one group's decision point for calling something "accurate" (different biases) and having a subsequent positive feeling about the forecast is higher or lower than the other's decision point. Another explanation for the discrepancy could be that some groups simply understand the forecast information or the underlying ideas of uncertainty less than others. Future studies that directly test such understanding may help determine if this is the more important determinate of accuracy perception. A different avenue to pursue based on our results involves exploring why the 3-month/6-month rainfall forecasts were the most well known and most used of the various types of forecasts used. For example, it could be that the perceived ability to use these types of forecasts is high because these forecasts fit the already established management schedules of different stakeholder groups (planting seasons, energy production projections, etc.).

### Conclusions and next steps

Our findings support existing literature that those who have more resources (e.g., economic resources, organizational connections, etc.) are also those who tend to use forecasts (Lemos et al. 2002; Kirchhoff et al. 2013). Similarly, those who rate forecasts as more accurate also somewhat tend to use forecasts more as mentioned above (Orlove et al. 2004). We also find that other factors may be important such as recognition of groundwater levels in people's understanding of water availability, the potential for crop insurance to provide perverse incentives, and the differences in perceptions of forecast accuracy between different stakeholder groups. Indeed, these findings warrant further investigation and confirmation and may contribute to the development of communications that help stakeholders make informed decisions about freshwater management in Guanacaste and other semi-arid regions.

## Endnotes

[1]There have been attempts to integrate these various factors into summary frameworks such as Lemos et al.'s model of "fit, interplay, and interaction" which concentrates on the interaction between climate information providers and end-users (Lemos et al. 2012). Others have investigated these factors (and factors related to adaptation decision making and activity in general) using modified versions of established decision making, information

seeking, and behavior frameworks such as the Theory of Planned Behavior (TPB) (Ajzen 1991), the Risk Information Seeking and Processing (RISP) model (Griffin et al. 1999), the Planned Risk Information Seeking Model (PRISM) (Kahlor 2010), and Protective Motivation Theory (PMT) (Rogers et al. 1983). For example, Truelove and colleagues use a modified version of the PMT they named the Risk, Coping, and Societal Appraisal (RCS) framework to study adaptation to climate change in the farming sector (Truelove et al. 2015) and Yang and colleagues have used RISP and PRISM to investigate and compare the seeking out of climate information between different groups (Yang et al. 2014a, b). These frameworks all tie into the idea that in order to improve informed decision making, producers of scientific information must identify the specific decisions, perceptions, and decision environments faced by those stakeholders (Fischhoff 2013).

[2]It should be noted that while most often this time of the year would have been the beginning of the wet season in Guanacaste, in 2014 this period was very dry and the government was in the process of issuing El Niño alerts (which may have primed some participants to bring up El Niño during the interview).

[3]It should be noted that 2 of the 3 Hydroelectric group participants also work at government agencies.

## Additional files

**Additional file 1:** Full Interview Protocol (English version). The full English-language version of the protocol used to guide the mental model interviews. (PDF 248 kb)

**Additional file 2:** Full List of Codes and Sub-Codes used with descriptions. The full list of codes and sub-codes used in analyzing the interview transcripts, with descriptions. (PDF 255 kb)

### Competing interests
The authors declare that they have no competing interests.

### Authors' contributions
MB conceived and designed the data collection, performed the data collection, analyzed the data, and wrote the paper. GWP, MS, and IG conceived and designed the data collection and wrote the paper. All authors read and approved the final manuscript.

### Acknowledgements
The work presented in this article was funded through FuturAgua, a multinational, multidisciplinary Belmont Forum-G8 Initiative Collaborative Research project. Support for Carnegie Mellon's participation in FuturAgua was provided by the US National Science Foundation (ICER1342941-NSF). We would like to thank the other members of FuturAgua for their research and administrative support. We also especially would like to thank the study participants from Guanacaste for their participation.

Received: 15 January 2016 Accepted: 23 June 2016
Published online: 04 July 2016

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