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Addressing Water Resources and Environmental Quality Programming Needs in Arequipa, Peru

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Abstract: Water resources in historically water scarce regions such as Arequipa, Peru are vulnerable to changing conditions. Population growth and climate change are projected to be major threats to water availability in the region, while urban growth, informal mining, and agriculture threaten water quality. To address these concerns and others, the Arequipa Nexus Institute for Food, Energy, Water, and the Environment (the Arequipa Nexus Institute) was formed as a collaboration between Purdue University and the Universidad Nacional de San Agustín to address key challenges to a sustainable future for Arequipa through research. In this work, a vision for water-related extension programming in Arequipa was developed through three phases of data collection. Phases 1 and 2 involved semi-structured interviews and focus groups with agency personnel, community leaders, and farmers in Arequipa. The water education needs of stakeholders that could be addressed by water and environmental extension programming were identified. In Phase 3, a workshop of researchers from the Arequipa Nexus Institute used the data and their knowledge of institutional capacity to identify opportunities for the Institute to serve as a boundary organization facilitating communication and collaboration between scientists and stakeholders to support water extension and engagement in Arequipa. Water resources extension services provided by this boundary organization would include education about water quality, water allocation, and water use, as well as providing resources to improve public participation in water management. Water extension services could be part of a cross-cutting extension initiative within the Arequipa Nexus Institute, which would be responsible for accumulating research data and connecting them to both formal and informal stakeholders. The dual training nature of the boundary organization will serve to both increase public understanding of water concerns and the capacity of information generators in the university and agencies to engage with the public. This study is unique in combining both sides of the boundary (community needs and scientists' perspectives) in developing the vision for this extension programming.

Keywords: *boundary organization, extension, Arequipa, water resources, engagement*

Population growth in the tropical Andes, particularly in urban centers, is projected to put additional stress on regional water resources by increasing water demand (Buytaert and De Bièvre 2012) and negatively impacting water quality (Wang et al. 2008; Liyanage and Yamada 2017). From 1993 to 2017, the Department of Arequipa has grown by more than 50%, reaching a population of approximately 1,383,000 (INEI 2017a; 2017b). Of those, 1,268,000, or 92%, were living in urban areas in 2017. These increases led to increased need for water for domestic, agricultural, and industrial uses.

In addition to local environmental concerns, climate change is projected to have several impacts in the tropical Andes and act as a threat multiplier in an already stressed region. Vuille et al. (2003) found some decreases in seasonal precipitation in southern Peru since the 1950s, a trend that is expected to continue (Urrutia and Vuille 2009), reducing water availability in some locations during the rainy season. A decrease

Research Implications

- Identified need to develop capacity for public participation in water resources management in Arequipa, based on understanding of both community needs and scientists' perspectives.
- A boundary organization can facilitate communication and collaboration between scientists and stakeholders, supporting end-user participation in water governance.
- The main goals of this organization should be bi-directional to support stakeholders while also informing a culture of applied research. This organization would increase the capacity of information generators at the university and agencies to engage with the public.

in water availability will be compounded by increased evapotranspiration as a result of higher temperatures (Buytaert and Beven 2011). In the Peruvian Andes region, glaciers provide the majority of dry season flow in many watersheds (Viviroli et al. 2011) and have been greatly reduced in recent decades (Racoviteanu et al. 2007; Silverio and Jaquet 2012).

These changing social and environmental conditions mean that local ecological knowledge is less able to support water management decision-making than in the past (Popovici et al. 2020a). Though many farmers have made efforts to adapt, smaller rural and upland communities often do not have the resources or knowledge to utilize the newest information or technology to make effective water management decisions.

The term extension education dates to the mid-1800s, and here we use it in the broad sense to refer to any program of continuing education whose purpose is to share applied, practical information to adult populations (Wu et al. 2011; Prokopy et al. 2017). Extension education has its roots in agricultural extension programs centered on farming practices for smallholder farmers, but here we are specifically exploring programs that help with water management decisions in water scarce environments. Although increased knowledge does not always lead to behavior changes, Dean et al. (2016) and Bowe and van der Horst (2015) found that increased knowledge can increase adoption of water-saving and pollution-reduction behaviors by farmers and homemakers in water-scarce environments.

Globally, there are many different models of extension, depending on the institutional home of extension networks and centers; extension can be tied to public universities, federal or regional government, or the private sector or non-governmental organizations (Prokopy et al. 2017). All models provide technical information in some way, although the method and reach of these services vary. In the U.S. land grant model, extension is tied to public universities, with extension serving as a bridge between university research and community needs (Prokopy et al. 2017). This structure has evolved over time, and increasingly, university extension serves as a boundary organization where scientists and citizens can exchange information needs and techniques to develop new knowledge and management tools together (Cash 2001; Guston 2001). Boundary organizations are entities that facilitate communication among multiple stakeholder groups (including scientists and citizens) and are considered important in generating effective solutions to pressing environmental issues (Cash et al. 2003; Beier et al. 2017). Prokopy et al. (2017) provide multiple examples of the potential for extension boundary organizations to create community-driven approaches to improve community climate resiliency through regional technical advisors that provide technical help, resources, and educational programs to inform decision-making.

The purpose of this paper is to evaluate the requirements and provide a vision for a boundary organization to inform applied water-related research and to extend research results and water resources information to institutions and communities in Arequipa, Peru. To address this goal, we looked at both sides (community needs and scientists' perspectives) in developing the vision for this extension programming by asking the following two questions:

1. What water-related information do local populations and agencies need access to that they currently do not have to make water management decisions? (i.e., What are the unmet needs of stakeholders?); and
2. What is the current institutional capacity

(agency and university) in Arequipa for conducting research and supporting water resources extension programming?

We then discuss how a new boundary organization could fit within the context of current water governance and research in Arequipa. This vision evolved through a three phase, iterative process between extension experts and university personnel in the U.S., collaborators at the Universidad Nacional de San Agustín (UNSA), and stakeholder input.

Background

The Arequipa Nexus Institute

In 2018, UNSA partnered with Purdue University, a land grant institution, to establish the Arequipa Nexus Institute for Food, Energy, Water, and the Environment, a multi-year, multi-phase technical cooperative agreement that will progressively transform UNSA to a regional leader in sustainability and resilience thinking through collaborative research and technical development programs. The Arequipa Nexus Institute's mission includes building university capacity and collaborations needed to address key challenges to create a sustainable future for Arequipa. Research focuses around five centers established at UNSA in 2020 and overseen by UNSA administrators – Sustainable Watershed Management, Soil and Water Quality, Social Sciences and the Environment, Agricultural Innovation and Demonstration, and Sustainable and Adaptive Energy Systems – designed to support UNSA and its mission.

Current Regulatory Structure in Arequipa

In Peru, prior to 2009, water was managed by separate sectors. Water governance fell primarily under the Ministry of Agriculture, which loosely collaborated with the Ministries of Health and Defense (Budds and Hinojosa-Valencia 2012; Pérez 2016). These three Ministries did not work together in a coordinated way. The Water Resource Law of 2009 codified the idea of integrated water resources management with support from the World Bank and Inter-American Development Bank (Congreso de la Republica 2009), which shifted water management from being directly tied to agriculture to explicitly representing other water use sectors. Specifically, the Water Resources Law of 2009 prioritizes water allocation by sector according to the following hierarchy: 1) protecting biodiversity, 2) domestic use, 3) agricultural use, and 4) industrial use and mining. It also defined the river basin as the primary unit of management, within a decentralized national authority. Currently there are 29 river basin units in Peru. River basin councils (*los Consejos de Recursos Hídricos de Cuenca*) are being established, which include regional representatives, as well as members of smaller, local groups. The river basin councils have round table discussions to deliberate and make water resources decisions. Thirteen of the 29 councils are already in place (August 2020), including one in the Quilca-Chili basin in the Arequipa Department.

The National Water Authority (ANA), which is under the Ministry of Agriculture, is the "decentralized national authority" for water management. The Administrative Water Authority (AAA) and the Local Water Authorities (ALA) are entities under the ANA. The AAA and ALA do not have any power to make local rules, as they are set centrally by the ANA. However, the AAA creates water resources plans for local river basins with the assistance of the river basin council. ALA offices implement the plans locally, disseminate information regarding ANA regulations, and help answer questions related to water management from citizens. Additionally, other groups have their own authority over water at some capacity. For example, the Autonomous Authority of Majes (AUTODEMA) was created to develop the Majes Irrigation Project and is now primarily in charge of management and maintenance of its water infrastructure, including collecting, storing, treating, and delivering water from the Colca River to the Majes Irrigation Project. Water users' associations and irrigation commissions are private, non-governmental organizations that operate based on fees from producers. A water users' association may oversee several irrigation commissions, which then work with land-owners. Urban water provisioning and treatment are the responsibility of the Potable Water and Sewage System Service of Arequipa (SEDAPAR), part of the National Superintendence of Sanitation

Services (SUNASS). Through a unique public-private agreement between the Cerro Verde mine and the provincial municipality of Arequipa, Cerro Verde constructed and operates the wastewater treatment plant "La Enlozada" for municipal waste, and in exchange, on average about one half of the treated water (1 m^3/s) is diverted for use by the mine (ANA 2020; ICMM 2020).

Current Extension Programming in Arequipa

While U.S. land grant universities have a three-part mission for research, teaching, and extension, Peruvian public universities have a four-part mission. These four missions include education, research, extension, and social projection. Social projection refers to university participation in the resolution of problems and proposals for societal development, among other activities. Multiple forms of extension programming are in use at UNSA, including expert presentations and training programs, both in person and utilizing the campus television and radio stations. Such methods of delivery are often preferred; written training materials are limited since much of the target population may not be literate, and in-person demonstrations require extensive travel to remote locations. However, despite a mission and experience with extension programming, UNSA currently has limited capacity to transform its science into terms that people can understand to support societal development. Similarly, many local and regional agencies have an interest or role in developing water-related extension materials, with mixed success. The 2009 Water Resources Law establishes the principle of public participation that requires the ANA to create mechanisms for the population to participate in decisions related to the quantity, quality, and opportunity for use of the water, and to strengthen water users' associations (Congreso de la Republica 2009). However, no specific extension programs led by the ANA have been identified.

The National Meteorology and Hydrology Service of Peru (SENAMHI) maintains a station network to monitor meteorological and hydrological data. They also conduct internal research and develop many products, including gridded weather station data, analysis of El Niño/La Niña climate extremes, and analysis of ecological zones. They have created K-12 outreach materials related to climate change and El Niño. These materials are available online and in print, although in some cases they must be purchased, and they reportedly have some programs for farmer outreach.

At a more regional level, AUTODEMA is involved in the economic development of the Majes region. They conduct internal research and use different methods of extension delivery to help farmers increase farm profitability. For example, AUTODEMA worked together with the water users' associations to develop pamphlets with information on calculating growing degree days for some crops. They have also developed an online tool to estimate irrigation water requirements for specific crops.

Methods

This work involved three phases of qualitative data collection. In Phases 1 and 2, semi-structured interviews and focus groups with agency personnel, community leaders and farmers in Arequipa allowed direct questioning regarding the unmet needs of stakeholders and the institutional capacity of agencies to support water and environmental extension programming to address our two primary research questions. These qualitative data collection approaches are appropriate as they allow the collection of a high level of detail from which to gain insight into experiences based on context (Hammarberg et al. 2016). In Phase 3, a workshop of researchers from the Arequipa Nexus Institute used the data and their knowledge of institutional capacity to identify opportunities to facilitate communication and collaboration between scientists and stakeholders to support water extension and engagement in Arequipa.

The initial research phase consisted of 139 semi-structured interviews conducted in 2018 and 2019 with agency personnel and farmers in the districts of Caylloma, Lari, Yanque, Cabanaconde, and Majes in the province of Caylloma, Department of Arequipa, Peru. As described in more detail by Popovici et al. (2020a), a purposive sampling strategy was used to select interviewees from key organizations involved in water management (Ritchie et al. 2014). Snowball sampling was used to identify additional people and organizations

to interview based on the information collected in previous interviews, until data saturation was reached (Fusch and Ness 2015).

Phase 2 focus groups were conducted in 2019 by members of the Sustainable Water Management (SWM) team of the Arequipa Nexus Institute. A total of eight focus groups were conducted with agency personnel and farmers, including five in the rural districts of Lari, Yanque, Cabanaconde, Chivay, and Majes, and three with different agency audiences in the city of Arequipa. Attendance ranged from one to 40 participants, see Popovici et al. (2020b) for details. During the focus groups, SWM members reported the research findings they had obtained through semi-structured interviews and presented a preliminary set of research ideas to support development of tools for water and crop management. These tools included calculation methods for estimating crop water use and irrigation scheduling; fact sheets on 30-year historic climate trends; information on regional crop quantities, growth stage, and water use using remote sensing; and water quality testing kits.

Researchers from the Arequipa Nexus Institute for Food, Water, Energy, and the Environment who are investigating topics related to water issues in Arequipa convened for a two-day workshop on August 1 and 2, 2019. In this workshop, approximately 40 researchers discussed needs to support diffusion of water and environmental management information in Arequipa, Peru. Content for the workshop included presentations on recent research on water governance and community needs in Arequipa based on the semi-structured interviews and focus groups to provide a common basis of understanding. A trained facilitator led the large group discussion on the target audience for extension programming, appropriate programming structures for Arequipa, and methods of delivery. In addition, participants could opt into a specific small group discussion with a defined purpose, including extension support needs (financial/intellectual/staffing), funding models, advantages and disadvantages of physical centers, and centralized delivery. Volunteer bi-lingual facilitators encouraged and re-directed discussion and note takers participated in each small group break-out section to help recap key discussion points.

Results

Stakeholder Needs for Water-Related Information

It is clear from interviews and focus groups that water scarcity is felt by farmers throughout Arequipa. Additionally, there are issues with proper use of irrigation, whether it be by over-irrigating or lack of knowledge of how to best implement irrigation technology to meet specific needs. Many people believe that water quality is a concern, both from an agricultural and a domestic use perspective. However, some would almost rather not know the quality of their water, for fear of knowing about a problem that they have no control over. Nevertheless, participants in focus groups consistently expressed interest in products that will help to establish risk and best practices, including: information about drinking water quality standards and impacts to human health, a system to communicate water risks to the public using a phone app, and methods for testing irrigation water quality and understanding the limitations of use.

Farmers in traditional high-altitude farming communities such as the Colca Valley are experiencing numerous biophysical and socioeconomic changes that influence their water information needs. Because of the proximity to glaciers (Buytaert and De Bièvre 2012) and more extreme increases in temperature predicted at higher elevations (Bradley et al. 2006), rural and upland indigenous communities are most vulnerable to climate change impacts. Some of these impacts have already been seen; for example, there are reports of small springs drying up and changes in crop performance. It is sometimes unclear if these changes are due to climate change, human influence from mining, or other infrastructure developments.

In addition, the current generation of workers are becoming more individualistic, and have less of a sense of helping others in their community (Popovici et al. 2020a). People are migrating out of the Colca Valley into larger cities like Arequipa to find work, and many have multiple jobs. These factors contribute to a less informed population. For example, they do not have time to attend irrigation commission meetings and become informed of water management policies and their

rights in the new integrated water management system. ANA staff also told us that when they travel to communities to schedule training, there is a lack of participation, but they attributed it to lack of motivation from farmers. The need is perhaps greater than ever, but the current training does not accommodate changing lifestyles.

Across all focus groups, a recurrent theme was whether the participants had the knowledge necessary to use the products being discussed. For example, local farmers in Majes expressed interest in testing water sediment load themselves, but at the regional level, agency staff had little confidence that this was possible. For example, one agency representative said:

> *"De nada me sirve a mí llegar con mis unidades de medida, mis cases y todos mis métodos de investigación, si el agricultor no me va a captar absolutamente nada de lo que yo le estoy diciendo."* Translated: *"It is useless for me to arrive with my units of measurement, my containers and all my research methods, if the farmer is not going to retain absolutely anything that I am telling him."*

Focus group participants cited low literacy as a major barrier to use existing data and concepts above the level of what farmers understand from their experiential training/learning. For example, another participant said:

> *"Se han hecho muchas capacitaciones, se han repartido folletos, boletines, gráficos, fotos, pero agricultores que sí lo han captado por el nivel de alfabetización…. Entonces, es complejo la situación... ha traído mucha problemática."* Translated: *"Many trainings have been carried out, brochures, newsletters, graphics, photos have been distributed, but farmers have understood it up to the level of their literacy… So, the situation is complex … it has brought a lot of problems."*

In many cases it was felt that local community members need basic education on the topic areas but may never use decision support products themselves.

Institutional Capacity to Provide Water-Related Information

Participants in the workshop shared that research at UNSA has historically been siloed with little collaboration between professors or with people in the community. As a result, the research undertaken does not necessarily meet the needs of the country and the people impacted are not receiving research results. UNSA does not have the capacity to transform their science into terms that people can understand to support societal development. To move toward impactful, collaborative research, UNSA looked to develop partnerships with established, collaborative research universities, experienced in translating research to application, such as Purdue University. UNSA would like to coordinate their research so that they can better deliver information to citizens.

Many workshop participants had ties to agencies in Arequipa and corroborated what was found in focus groups. Local and regional agencies have developed online products to help users make water management decisions. A common theme across focus groups with regional and municipal agencies was that they wanted support to generate products themselves. So, although the agencies are information generators and extension providers themselves, they are also stakeholders who could benefit from educational programming. For example, they expressed interest in receiving training to run hydrology and hydraulic models, rather than receiving analysis products from research groups. As one focus group participant said:

> *"O sea, la herramienta existe, más que el modelo lo que necesitamos es un poco de capacitación para que haya más gente que pueda tener la idea de cómo se modela y cómo se planifica."* Translated: *"In other words, the tool exists, more than the model what we need is a little training so that there are more people who can have the idea of how to model and how to plan."*

However, there was also a large sense of frustration expressed on both sides regarding the ability of agencies to share information with their target populations. For example, farmers expressed that a tool to predict irrigation water needs would be useful, but we learned through the agency focus groups that AUTODEMA developed a similar tool and tried to promote it through workshop training, but farmers have not

adopted it. It is unclear if the tool did not meet farmer needs, if the training materials were poorly suited to the audience, or if it was the wrong audience (targeting the farm owners rather than the irrigation operators, for example (see e.g., Erwin et al. in review)).

Representatives from the ANA, AUTODEMA, and water users' associations all had examples of challenges in distributing pamphlets, training, and tools with farmers and expressed interest in help with outreach materials. Agency personal admitted that:

> *"...el problema es la difusión de esta información, o sea, hay material de años atrás que hasta ahora no se logra difundir, no logramos, o AUTODEMA como entidad no logra llegar al agricultor."* Translated: *"...the problem is the dissemination of this information, that is, there is material from years ago that until now has not been disseminated, we have not succeeded, or AUTODEMA as an entity has not managed to reach the farmer."*

The ALA and water users' association offices are understaffed and do not have sufficient resources and appropriate training to support communities with a local presence. Another limitation of agencies is the frequent leadership changes which minimizes continuity in outreach programs.

In addition to the outreach, another challenge may exist in the creation of the products themselves. Multiple times in focus groups and interviews we heard that the SENAMHI was working on related products, but they did not meet user needs or were not readily 'shared' with users. For example, products included regional gridded climate data that were at too coarse a resolution for decision-making, compiled extreme weather information that did not incorporate predictions of risk, and projections that did not have consumer confidence. Other complaints included difficulty in accessing data products, access fees, and low quality control. It seems that some of these products could benefit from a boundary organization that could facilitate co-production of the products to better address user needs. Co-production refers to the joint creation of information and collaborative decision-making (Djenontin and Meadow 2018).

Discussion: A Vision for the Boundary Organization

Based on findings from existing programming, stakeholder needs, and institutional capacity, it was determined at the workshop that there is an opportunity for a boundary organization to provide water resources extension services in Arequipa. This boundary organization could be created through the development of an extension hub that operates through the Arequipa Nexus Institute.

The Hub's Role

At the workshop, a broad discussion was held of the different target audiences in Arequipa and the types of programming that are appropriate. It was agreed that a boundary organization needs to support the differing needs of both informal and formal actors. Formal actors include national and regional agencies, such as the SENAMHI, AUTODEMA and ANA, and the university, while informal actors include farmers, individual communities, and community groups, such as irrigation commissions, livestock and product associations, women's groups, and water users' associations. The type of information needed by informal actors varies depending on the geographic location, level of urbanization, and income generation methods, among others, but will include training and information to support personal water management decisions, such as when irrigation water is safe to use. Formal actors can consult with the boundary organization to guide their applied research initiatives and learn how to effectively co-produce information products and tools.

During the workshop, different extension models were discussed involving different primary information generators and different information distributors. It was expressed that information distributed by a university-affiliated organization would be perceived with higher validity by the end users than information from agencies. Given distrust of government agencies, and past inability of agencies to allocate resources to community education, a university-affiliated extension office may be more effective at working directly with community level organizations.

The Arequipa Nexus Institute is uniquely poised to fill the current shortcomings of extension

education in Arequipa. As a part of UNSA, a public institution, it can simultaneously interact with high level agencies, businesses, not for profit organizations, and local populations, and it has also already begun to deepen its relationship with many institutions. However, to function as a boundary organization, the extension hub would need to expand the Arequipa Nexus Institute's current efforts of research and innovation to include extension as an additional role. This extension hub would be cross-cutting throughout the Arequipa Nexus Institute, addressing aspects of all five of the established Nexus Research Centers.

This relationship would function by UNSA (including the Arequipa Nexus Institute) generating new information from current research (Figure 1). This information could be passed to the water extension hub to be shared with formal institutions (agencies) at both regional and local levels as end users for in-house decision-making. However, these agencies are also substantial generators of information. This audience would benefit from training and consultation provided by the extension hub on *how* to co-produce and disseminate information and products themselves to better meet the needs of target audiences.

By allowing the extension hub to be an intermediary of information, data and research generated by UNSA and agencies can be evaluated for applicability before being shared with end users. The extension hub can play the role of transforming information into a form that stakeholders can understand and facilitate the relationship between content generators and end users. Products can be distributed directly from the hub, through agencies such as AUTODEMA that are equipped for extension, but also through existing local users' groups and organizations, which can provide a targeted method of reaching individuals.

Extension Hub Needs

As described above, a bi-directional boundary organization can help to translate generated information into useful tools, trainings and products, and to guide future directions of inquiry. The primary need is to build the capacity to co-produce water management products between UNSA, agencies, and society to allow Arequipa to fully embrace the integrated water management approach mandated by federal law. A new boundary organization would greatly benefit from staff trained in social science techniques who can provide training and resources on increasing participation in integrated water management. In addition, there is need to increase capacity for extension within the water agencies, and increase access to hands-on training programs.

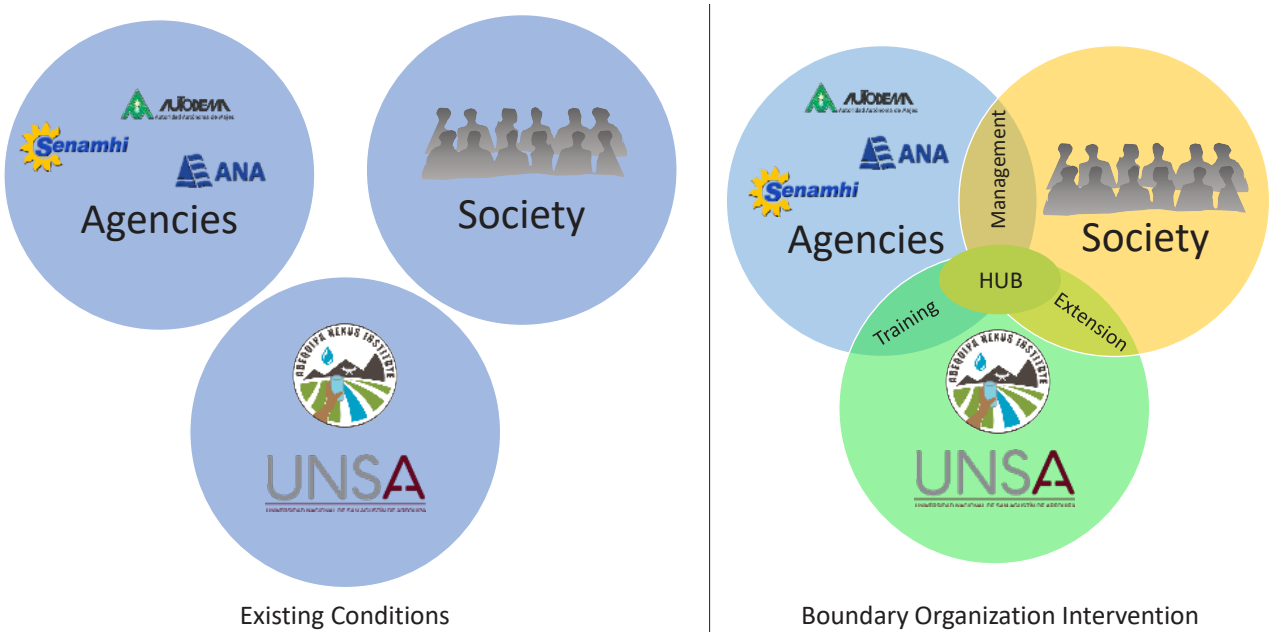

Figure 1. The situation of the Water Resources Extension Hub as a boundary organization that closes the gaps between researchers in the university, information generators in government agencies in Arequipa, Peru, and society.

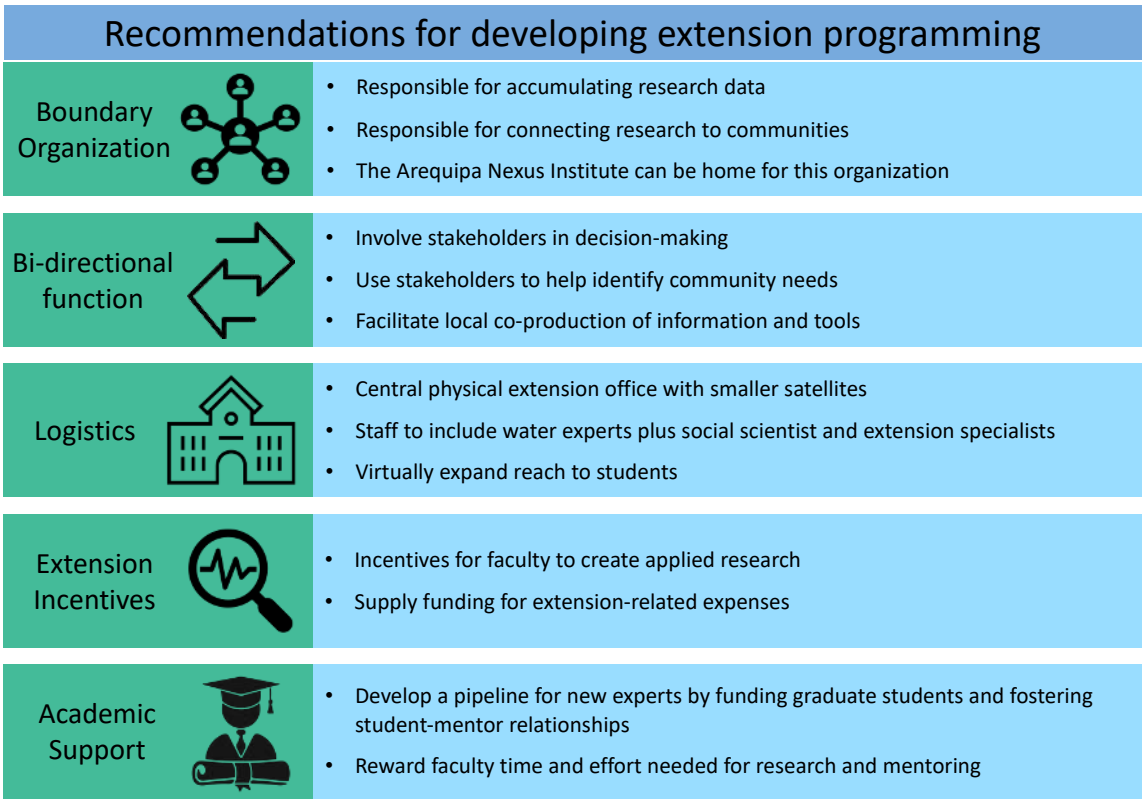

Figure 2. Recommendations for needs to develop effective extension programming were identified at the two-day workshop. These include the creation of a boundary organization with a bi-directional function, a dedicated office and staff, and incentives and academic support for faculty to develop applied research.

To create the research pipeline to support an extension program, it is necessary to continue to develop internal university incentives and infrastructure for applied research and to increase collaboration between the university and water agencies (Figure 2). Research projects should be developed involving UNSA students who can use the research to work toward their theses. This mentored development of research products involving faculty and students working together is not the norm at UNSA. Although research theses are required at the bachelor, professional, and graduate levels, there is no formal support or supervision of this research. There should be a reliable graduate student funding source, as these students are the basis of research in many places. Support for developing advisor-student relationships is needed to create reliable research that is carried out by graduate students. Lines of research need to be defined to have clearer goals based on the five Nexus research centers. An extension hub can develop research capacity by helping to identify research needs that are relevant to local communities, in addition to translating research results to make them understandable for lay people.

Participants in the workshop voiced support for both physical, in-person programming and virtual models, both of which have benefits and drawbacks. Physical centers have more value for locally relevant hands-on learning and local access, and the visual presence will increase awareness of the center. On the other hand, virtual centers provide a broader reach, especially in a geographically diverse region such as Arequipa in which travel can be difficult. In addition, virtual centers are less costly to start up, and can better reach new audiences (Dromgoole and Boleman 2006). An OECD survey of virtual learning has shown that almost a quarter of adults in Latin American countries who wanted to participate in training were unable to, but new technologies may provide new opportunities to engage adults who find traditional in-person training difficult to

access or ineffective. However, it was also found that in Latin America virtual adult education tended to reinforce and potentially amplify existing knowledge gaps, with more educated individuals more likely to benefit. Given that the proposed extension hubs will have two types of stakeholders, both trained, agency personnel and untrained community members creating a model that combines physical centers and virtual information seems desirable in Arequipa (OECD 2021).

Conclusions

There is a great need to develop capacity for public participation in water resources management in Arequipa to support management decisions at all level and scales. The 2009 Water Resources Law charges the ANA with the goal of creating mechanisms for public participation in integrated water management, but this service has not yet been implemented. Similarly, other agencies and university researchers are developing research and services that may help communities, but they lack the resources and knowledge to engage with these communities and provide training and resources that will be utilized. Although many entities put at least some effort into extension, community education needs are not being fully met. There is a need for a boundary organization that can support end-user participation in water governance, while helping to disseminate materials from agencies and universities.

To more effectively share water resources research with local stakeholders, efforts should be consolidated by allowing the boundary organization to act as a central extension entity. The main goals of this extension hub should be bi-directional to support and inform stakeholders while informing research and management. Stakeholders' needs should be further explored to steer research and problem-solving in the region, while UNSA and the Arequipa Nexus Institute continue to develop a culture of applied research to support the information needs of the extension center. Extension programming will focus on the co-production of water resources knowledge to involve end-users in water resources decision-making. In Arequipa, a model that combines physical hubs and virtual information is the most logical. Staff should include both biophysical water experts, as well as social scientists and extension specialists to support the co-production needs.

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References

Autoridad Nacional de Agua (ANA). 2020. Visor de Estaciones. Available at: http://snirh.ana.gob.pe/visors2/. Accessed October 6, 2020.

Beier, P., L.J. Hansen, L. Helbrecht, and D. Behar. 2017. A how-to guide for coproduction of actionable science. *Conservation Letters* 10(3): 288-296.

Bowe, C. and D. van der Horst. 2015. Positive externalities, knowledge exchange and corporate farm extension services; A case study on creating shared value in a water scarce area. *Ecosystem Services* 15(C): 1-10.

Bradley, R.S., M. Vuille, H.F. Diaz, and W. Vergara. 2006. Threats to water supplies in the tropical Andes. *Science* 312(5781): 1755-1756.

Budds, J. and L. Hinojosa-Valencia. 2012. Las industrias extractivas y los paisajes hídricos en transición en los países andinos: Análisis de la gobernanza de recursos y formación de territorios en Perú. In: *Agua, Injusticia y Conflictos*, R. Boelens, E. Isch, F. Peña (Eds.). Lima, Peru, CBC.

Buytaert, W. and K. Beven. 2011. Models as multiple working hypotheses: Hydrological simulation of tropical alpine wetlands. *Hydrological Processes* 25(11): 1784-1799.

Buytaert, W. and B. De Bièvre. 2012. Water for cities: The impact of climate change and demographic growth in the tropical Andes. *Water Resources Research* 48(8): W08503.

Cash, D.W. 2001. "In order to aid in diffusing useful and practical information": Agricultural extension and boundary organizations. *Science, Technology, & Human Values* 26(4): 431-453.

Cash, D.W., W.C. Clark, F. Alcock, N.M. Dickson, N. Eckley,…and R.B. Mitchell. 2003. Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences of the USA* 100(14): 8086-8091.

Congreso de la Republica del Perú. 2009. Ley de Recursos Hídricos N° 29338. Lima, Peru. Available at: https://leyes.congreso.gob.pe/Documentos/Leyes/29338.pdf. Accessed September 8, 2021.

Dean, A.J., K.S. Fielding, and F.J. Newton. 2016. Community knowledge about water: Who has better knowledge and is this associated with water-related behaviors and support for water-related policies? *PLoS ONE* 11(7): e0159063. Available at: https://doi.org/10.1371/journal.pone.0159063. Accessed October 8, 2020.

Djenontin, I.N.S. and A.M. Meadow. 2018. The art of co-production of knowledge in environmental sciences and management: Lessons from international practice. *Environmental Management* 61(6): 885-903. Available at: https://doi.org/10.1007/s00267-018-1028-3. Accessed September 16, 2020.

Dromgoole, D.A. and C.T. Boleman. 2006. Distance education: Perceived barriers and opportunities related to extension program delivery. *Journal of Extension* 44(5): 5RIB1. Available at: https://archives.joe.org/joe/2006october/rb1.php. Accessed September 8, 2021.

Erwin, A., Z. Ma, R. Popovici, P. Salas, L. Zanotti,… and G. Arce. In review. Integrating migration into community resilience: A case of the Majes Canal. *Land Use Policy.*

Fusch, P.I. and L.R. Ness. 2015. Are we there yet? Data saturation in qualitative research. *The Qualitative Report* 20(9): 1408-1416.

Guston, D.H. 2001. Boundary organizations in environmental policy and science: An introduction. *Science, Technology, & Human Values* 26(4): 399-408.

Hammarberg, K., M. Kirkman, and S. de Lacey. 2016. Qualitative research methods: When to use them and how to judge them. *Human Reproduction* 31(3): 498-501.

Instituto Nacional de Estadistica e Informatica (INEI). 2017a. Evolución de la Población Censada Urbana, Según Departamento y Año Censal. Censos Nacionales de Población y Vivienda 30 Aug. 2019.

Instituto Nacional de Estadistica e Informatica (INEI). 2017b. Población Censada, Según Departamento y Año Censal. Censos Nacionales de Población y Vivienda 30 Aug. 2019.

International Council on Mining & Materials (ICMM). 2020. Creating Shared Value for Business and Communities. ICMM Guidance

Case Studies. Available at: https://guidance.miningwithprinciples.com/case_study/creating-shared-value-for-business-and-communities/. Accessed October 6, 2020.

Liyanage, C.P. and K. Yamada. 2017. Impact of population growth on the water quality of natural water bodies. *Sustainability* 9(8): 1405.

Organization for Economic Cooperation and Development (OECD). 2021. Making the Most of Technology for Learning and Training in Latin America. Available at: https://doi.org/10.1787/ce2b1a62-en. Accessed September 5, 2021.

Pérez, E.G. 2016. Evolución histórica de la gestión de los recursos hídricos en el Perú. *Revista Iberoamericana del Agua* 2(i–iv).

Popovici, R., A. Erwin, Z. Ma, L. Prokopy, L. Zanotti,… and G.R.A. Larrea. 2020a. Outsourcing governance in Peru's integrated water resources management. *Land Use Policy* 101:105105. Available at: https://doi.org/10.1016/j.landusepol.2020.105105. Accessed September 9, 2021.

Popovici, R., K.E. Mazer, A. Erwin, Z. Ma, J.P. Pinto Cáceres,…and L.S. Prokopy. 2020b. Coproduction challenges in the context of changing rural livelihoods. *Journal of Contemporary Water Research and Education* 171: 111-126. Available at: https://doi.org/10.1111/j.1936-704X.2020.3348.x. Accessed September 8, 2021.

Prokopy, L., W.-L. Bartels, G. Burniske, and R. Power. 2017. Agricultural extension and climate change communication. *Oxford Research Encyclopedia of Climate* Science. Available at: https://doi.org/10.1093/acrefore/9780190228620.013.429. Accessed September 8, 2021.

Racoviteanu, A.E., W. Manley, Y. Arnaud, and M.W. Williams. 2007. Evaluating digital elevation models for glaciologic applications: An example from Nevado Coropuna, Peruvian Andes. *Global and Planetary Change* 59(1): 110-125.

Ritchie, J., J. Lewis, C.M. Nicholls, and R. Ormston (Eds.). 2014. *Qualitative Research Practice: A Guide for Social Science Students and Researchers*. SAGE, Los Angeles, California.

Silverio, W. and J.-M. Jaquet. 2012. Multi-temporal and multi-source cartography of the glacial cover of Nevado Coropuna (Arequipa, Peru) between 1955 and 2003. *International Journal of Remote Sensing* 33(18): 5876-5888.

Urrutia, R. and M. Vuille. 2009. Climate change projections for the tropical Andes using a regional climate model: Temperature and precipitation simulations for the end of the 21st century. *Journal of Geophysical Research* 114: D02108.

Viviroli, D., D. Archer, W. Buytaert, H.J. Fowler, G.B. Greenwood,…and R. Woods. 2011. Climate change and mountain water resources: Overview and recommendations for research, management and policy. *Hydrology and Earth System Sciences* 15(2): 471-504.

Vuille, M., R.S. Bradley, M. Werner, and F. Keimig. 2003. 20th century climate change in the tropical Andes: Observations and model results. *Climatic Change* 59: 75-99.

Wang, J., L. Da, K. Song, and B.-L. Li. 2008. Temporal variations of surface water quality in urban, suburban and rural areas during rapid urbanization in Shanghai, China. *Environmental Pollution* 152(2): 387-393.

Wu, H.-Y., Y.-K. Lin, and C.-H. Chang. 2011. Performance evaluation of extension education centers in universities based on the balanced scorecard. *Evaluation and Program Planning* 34: 37-50.