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Sustained Dialogue for Ground Water and Energy Resources in Chile

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Abstract: Water conflict arises in interconnected ways. As demand increases in one region or industrial sector, the accompanying shifts in water resource management regimes have impacts at the local level and may carry international implications. Insecure water resources are often the root cause of resistance or social conflict across many political and economic sectors. Integrated Water Resources Management is an emerging transdisciplinary approach to science-based water management that attempts to account for these cross sector effects. This paper presents a case study of Integrated Water Resources Managment methods applied in the El Tatio Geothermal Field basin of northern Chile where tensions from the competing needs of metals mining, tourism, energy development, scientific research, and environmental conservation have created social and political tension. Participatory engagement was conducted with stakeholders in the field through elicitation and group dialogue process. This was combined with design of a cyberinfrastructure system for managing and presenting data. Results suggest that sustained facilitated dialogue and socio-technical systems approaches provide a framework to implement Integrated Water Resources Managment, improve science communication, and engage stakeholders at the center of resource conflict. In the case study, early results are informing the framing of data collection plans, microentrepreneurial ventures, and spurring communication across sectors.

Keywords: *Participatory modeling, ground water management, energy-water dialogue*

Available sources of freshwater and energy are critical to human and economic development. Frequently the benefits of economic development are experienced at a national scale while the impacts are focused at the local and regional levels, particularly in cases with energy-water tradeoffs (e.g., Scott et al. 2011). Global development and population growth are spurring demand for resources, such as copper and other metals, that require secure, stable sources of water and energy. In the Atacama Desert of northern Chile, regions of extreme water scarcity are also experiencing intense economic growth from mining, causing concern for the security of long-term water and energy supplies in that region (Figueroa et al. 1996; Lloyd 1976; Madaleno and Gurovich 2007). Sustainability describes the rates of use for a resource that are considered appropriate for the current generation's benefit, offset by preserving the viability of that same resource for future generations (United Nations 1987). Global demand is driving the mining industry in northern Chile to expand with an increasing reliance on already unsustainable uses of energy and water in the region. Mining has been present in the region since pre-Incan times (Salazar 2010) and the industry is tightly enmeshed with the national Chilean identity. Yet relationships be-tween regional indigenous communities and the mining industry have been strained due to the environmental (particularly water resource related) impacts of mining (Larrain and Schaeffer 2010). In recent times, tensions over these resources have been exacerbated by the need to develop reliable energy generation to support mining. Contemporary events, such as the "Water War" of Bolivia in 2000 and the "Gas War" of northern Chile in 2004 are concrete examples of tensions among industrial, government, and indigenous entities in the Altiplano zones of South America. These have resulted in active conflict and resistance to water and energy infrastructure development (Orihuela and Thorp 2012).

Science can contribute to the topic of water and energy resource allocation by providing information about the workings of these Integrated Water Resources Managment systems and by creating tools to quantify impacts or beneficial aspects of development. Yet, tools alone cannot deliver adequate decision support for complex, ill-structured, and dynamic problems. To address the needs for the application of science and planning, decision-makers and community stakeholders need both computational tools, or models, and soft system methodologies to support dialogue, and deliberative processes to assist with the design, presentation, and evaluation of water management alternatives.

This paper presents a methodological framework to link decision analysis tools with a sustained and facilitated dialogue process in order to establish the basis for transforming relationships across stakeholder groups and enable systematic evaluation of resource management and development alternatives. The decision pathways framework (Pierce 2008) presented in Figure 1 shows the process flow between scientific data analysis, economic valuation, and policy development procedures. Dialogue processes are especially useful during the "Identification" stage, while deliberative process is well-suited to "Evaluation & Choice Routines" as shown in Figure 1.

There are deep-seated conflicts and interdependencies in many water and energy resource cases. Disputes can be compounded by social and political misunderstandings among the various interest groups in a basin, as well as by misconceptions about the meaning of scientific models at how water resources interact and respond to management actions within a basin. The need to identify tough decisions and necessary tradeoffs makes it difficult to gain clarity on both the system behavior and interest group concerns that are critical to identifying possible solutions within a reasonable timeframe.

The El Tatio Geothermal Field presents a case example that exemplifies common relational dynamics and the role of scientific information common to resource issues. The overarching motivation for this work is to develop replicable Integrated Water Resources Managment approaches for this and other systems. These approaches should be capable of improving links between water resource problems and community concerns so that science based information can be communicated in ways that are both meaningful and accurate. Research focuses actively on the use of Sustained Dialogue in the El Tatio Geothermal Field case study to bridge the diagnosis phase of a problem from naming and framing the problem and analysis of cross communication among different stakeholder groups.

The El Tatio Case Study

The El Tatio Geothermal Field in the Atacama region of Northern Chile is the largest geyser basin in the southern hemisphere, and is located in one of the driest places on Earth (Figure 2). Often labeled the Yellowstone of

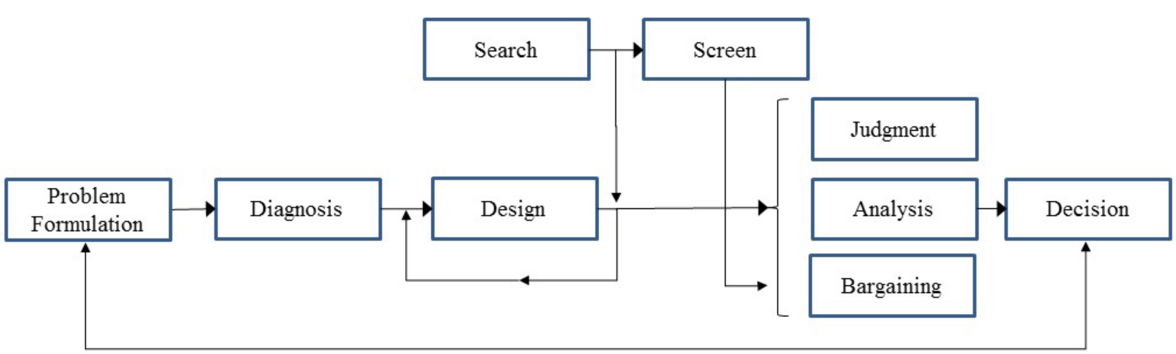

Figure 1. Decision Pathway framework identifies common decision-making stages (from Pierce 2008; modified from Mintzberg et al. 1976).

South America, this unique geyser basin is a rare natural resource that sees heavy visitation by Chilean and international tourists, and it is an important economic resource for the local towns and indigenous peoples. The geothermal springs create an extremophile environment that supports a microbiological community of organisms tolerant to arsenic and ultraviolet light. While the spring features have dynamic microbial ecosystems very similar to Yellowstone, El Tatio Geothermal Field is unlike Yellowstone National Park in that it has limited protection by the Chilean government, and is open to economic development, including for geothermal energy. In the latter half of 2008 the Chilean government issued leases to an international consortium of developers to develop a 100 MW power plant 4 km from the geysers, a plan vehemently opposed by the local indigenous population. Drilling started early in 2009, and included completion of initial production wells, together with retrofitting a set of old test wells from the 1970's, for use as reinjection wells. El Tatio Geothermal Field is now at the center of an international debate centered on the conflict between energy development and water resource preservation. The event driving the current conflict occurred in September 2009 when one of the older wells being retrofitted for reinjection blew out, leaving an open hole to more than 4500 m depth. Steam was venting to a height of 60 m, releasing ground water fluids that are extremely high in naturally occurring arsenic and antimony, and depositing a blanket of arsenic rich salts around the well. This is one of the worst-case scenarios feared by various interest groups in Chile, where an uncontrolled release would contaminate the surface environment while upsetting the thermal and hydraulic balance in the basin itself, possibly drying up unique geyser features.

The wellhead release created localized impacts to the environment, perceived health risks due to arsenic precipitates from the release, and concerns regarding the relative impacts to basin fluxes due to depressurization of the geothermal complex. Impacts from shifts in the geochemical, hydrological, and thermal fluxes in the basin may result in negative impacts for a range of industries and interests for use of the basin, such as geothermal energy development and international tourism.

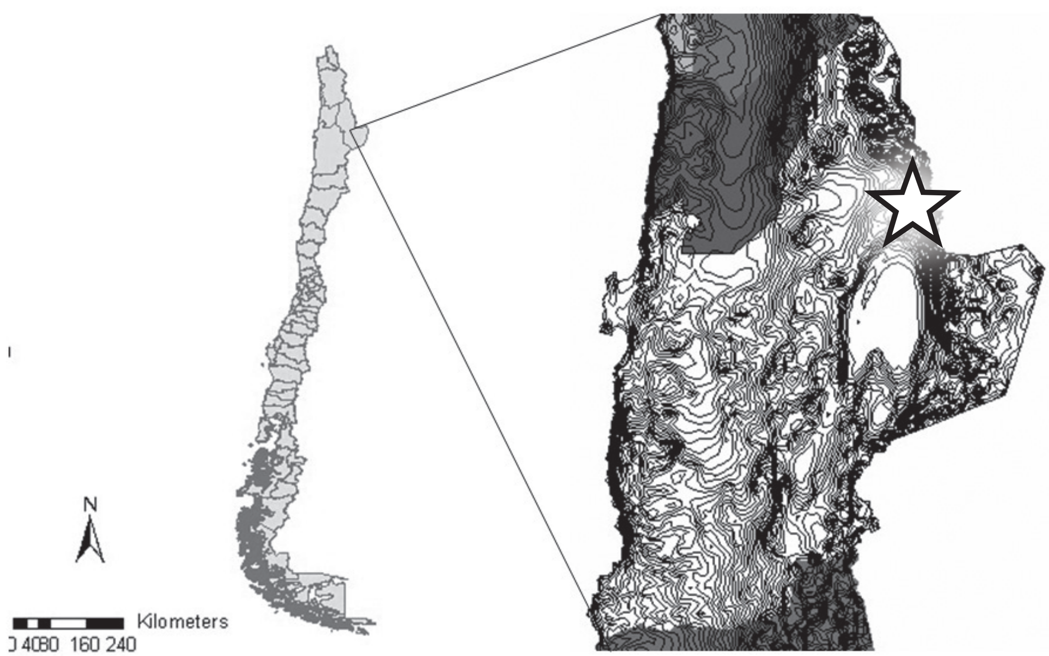

Figure 2. Map of Tatio and Calama basins, Loa Province, Chile with regional and local inset satellite image (modified from Markovich 2012; Direccion General de Aguas 2003).

Physiographic and Geologic Characteristics of the Setting

El Tatio Geothermal Field is situated within the physiographic province of the Cordillera de Los Andes (or Andean Mountain Belt). The geyser complex is located within the larger altiplano volcanic region of northern Chile at approximately latitude of -68.0168 and longitude of -22.3372 (Hauser 1997). The high altitude, approximately 4,250 meters above sea level, and relatively high temperatures at the geysers, between 78-86 ^{o}C (Malin et al. 2011; Lahsen 1988; Lahsen and Trujillo 1976) make this geyser field an extreme environment. In addition, El Tatio Geothermal Field is one of the largest reported in the world with approximate 67 reported geyser features (and potentially many more, unreported) and a total estimated area of 30 km^2 (Glennon and Pfaff 2003; Jones and Renaut 1997).

At the same time, the geyser basin discharges and contributes to the Rio Loa Depression making it an important water resource for the downstream agricultural activities. El Tatio and El Loa (or Calama) hydrologic basins are located within the greater Antofagasta region, or administratively the Second Region of Chile. Surface water and ground water flows from high altitude precipitation and eventually recharge the Loa river which is a major river basin within the country that provides a significant portion of the water demanded by industries, as well as potable water for the more than 400,000 inhabitants of the region (Salazar et al. 2003).

The Cordillera de Los Andes (The Cordillera) is made up of a north-south trending series of volcanic cones with intermontane basins that constitute the altiplano (or high plains of Chile) (Marinovic and Lahsen 1984). The Cordillera is characterized by Cenozoic volcanics with Cretaceous and Tertiary intrusives. The Tatio geyser complex is located within a graben that is part of a larger regional system of normal faults (Marinovic and Lahsen 1984).

The downgradient Rio Loa Depression is covered primarily by sedimentary sequences of Miocene and Pliocene age, overlain in some locations by unconsolidated Quaternary age sediments (Marinovic and Lahsen 1984). The arid climate limits recharge from seasonal precipitation largely to the upper elevations of the Cordillera (Salazar 2003). Surface water occurrences within the Tatio Basin are generally limited to a 10 km^2 area subject to superficial thermal activity. The central portion of the basin demonstrates anomalous resistivities of less than 10 Ohm/m (Marinovic and Lahsen 1984). Additionally, surface water temperatures at the geyser expressions are generally greater than 70^{o}C and do not tend to exceed the 86 ^{o}C boiling point for the altitude, yet geothermal exploration conducted in the mid-1970's demonstrated that subsurface temperatures ranged between 160 ^{o}C and 265 ^{o}C (Lahsen 1988).

Socioeconomic Demands for the Region

Geothermal Development

Geothermal development of El Tatio Geothermal Field geyser complex has been considered by Chilean government agencies since the mid-1960's. Early estimates of thermal energy production for three exploratory geothermal wells were capable of producing 18 MW of power (Marinovic and Lahsen 1984) and reportedly 10 L/s of freshwater could be produced from each MW of potential power in the basin (Lahsen 1988). Today, the Second Region has developed several power sources, including coal powered and natural gas imported from Argentina, but neither is secure and can be disrupted from international conflicts or transport issues. As the region's population continues to grow, a safe, secure, efficient power source is desirable for continued economic success mostly rooted in mining activities.

Most recently, geothermal exploration and development throughout Chile has become a focal point for conflict with indigenous communities along the Andes. Similar conflicts are emerging throughout the region, particularly in the altiplano regions of Chile and Bolivia (Orihuela and Thorp 2012).

Agricultural Production

An estimated 1,503 hectares were under production within the Loa basin in 2002 with primary crops of alfalfa and carrots. Between both surface and ground water rights, approximately 5,861 L/s are used on average (Direccion General de Aguas 2003). Unfortunately, severe economic restrictions are placed on all agricultural goods produced in the region due to the high levels of arsenic in irrigation waters. Improved water quality discharge from the Tatio basin could have far reaching economic implications for the agricultural industry in the region if produce could be marketed outside the Second Region.

Mining Industry

The mining industry is recognized as the largest water resource demand component in the Second Region, yet the water ministry reports that it does not have complete information regarding the total water usage for mines in the area. Mining stands to benefit from geothermal development due to decreased energy costs for production, but the industry must also consider as yet undetermined benefits from conserving the geyser complex for international tourism, scientific discoveries in the extreme environment, or other sectors. The benefits of energy costs are directly quantifiable, but the unknown value of future research discoveries, which can only be developed if the primary geyser site is preserved, are difficult to predict.

Tourism Industry

The international tourism industry is thriving in the Second Region with El Tatio Geothermal Field providing a site for destination travelers. Protection of the geyser field is important to the retention of the current tourist industry that has developed in the San Pedro de Atacama area and is now expanding into other altiplano pueblos, such as Chiu Chiu, Toconce, and Caspana. Tourism is mentioned among regional stakeholders as a strong offset to the economic drivers urging geothermal development.

Local/Regional/International Industries

Small enterprises, support industries for the larger mining sector, and international import/export activities in the Second Region are driven by the availability of both energy and water. Therefore geothermal development paired with water treatment could potentially result in positive benefits for most organizations within this category. Local indigenous cottage industries, such as an existing Ayquina Goat Cheese Factory, could be expected to increase with improved water resources. Regionally, a decrease in energy costs might encourage entrepreneurial investment and the existing port facilities in Antofagasta could also see increased business if the existing mine operations augmented production.

Domestic Demand

Demand for potable water for use in domestic residences is inevitable. Current potable water demands of approximately 1,600 L/s within the Loa basin are met using surface water only (Direccion General de Aguas 2003). Anecdotal information indicates that demands from the larger city of Antofagasta are augmented with approximately 850 L/s from the altiplano. As the economy of the Second Region and areas near Calama expands, domestic use will also continue to grow. While domestic use rates seem relatively small when compared with industry, when the demand of all populations is aggregated, a significant component of the overall water budget is attributable to this category. In terms of driving economics, the costs for treatment of water to potable standards can be relatively high, while the benefits are extremely difficult to monetize. In relation to the microbial dynamics of the Tatio Basin, if geothermal development incorporated water treatment and arsenic removal (potentially mediated by the very same microbial denizens of the geyser basin) the associated costs and benefits would provide a positive motivation for development.

Methods

This research develops an integrated approach to link science-based information to local knowledge for sense-making stages after a surprise event. Methods begin with elicitive interviews across stakeholder groups using open-ended elicitation and previously successful narrative analysis approaches (Pierce et al., in press) followed by focus group interactions based on sustained dialogue techniques (Saunders 2011). Decisions about how to protect and/or use El Tatio Geothermal Field will pit a myriad of interests (economic, environmental, scientific, cultural) against another. The conflict has intensified because of recent events creating conditions to observe how different stakeholder groups name and frame their concerns and understanding about potential consequences for the resource.

Initial Interviews

Initial socio-technical research for this case began with interviews conducted after the geothermal incident. These interviews were conducted with representatives from municipal governments, environmental interests, energy development, the tourism industry, national government ministries, local pueblo community members, research scientists, and tourists about the perceived impact of the event and the impacts of future development on tourism and the local economy. Two field visits were completed in October and December of 2009 immediately following the uncontrolled release from the 4500 m deep exploration well.

Interview results were used to collect preliminary data on how stakeholders perceive vulnerability and frame the possible consequences and solutions for the management of the El Tatio Geothermal Field. Stakeholder perceptions of the event were then compared with results of direct measurements of the hydraulic and thermal balance of the El Tatio Geothermal Field in October and December 2009. Post event recovery measurements provided a scientific basis for evaluating the actual impact to the basin (flow, temperature, chemistry, heat flux) and interviews captured perceptions (varying from catastrophic impact to no impact across stakeholders).

Qualitative data were collected using open-ended elicitation with a set of participants from interested parties. Preliminary data were evaluated using Value Focused Thinking Techniques (Keeney 1992), sustained dialogue stages (Saunders 2011), and combined evaluation of collective sense-making (Weick et al. 2005) to describe possible science-based uncertainties that are integral to the dialogue surrounding long-term management and decision-making for managing the geothermal basin. Results from interviews were captured with either hand written notes and/or capturing comments using word processing tools on a portable laptop computer. Human subject involvement began October 26, 2009 and participants were asked to self-identify with an interest group category and then selected for inclusion or exclusion using the following criteria:

- Knowledgeable about the situation and/or geothermal basin,
- Willing to participate and give verbal consent,
- Available at the time of the field study and/or willing to participate via teleconference after the field visit is complete, and
- A member of one of the interest groups named above and/or another group with an interest in management of the geothermal basin.

Open-ended elicitation interviews lasted 20-60 minutes depending on the length of participant responses to questions. Questions during non-structured elicitation using open-ended questions related to:

- Historic connection with the geothermal basin;
- Perceived level of vulnerability in the basin to use and/or management options;
- Description of primary concerns or objectives for resource management;
- Description of primary controls for management;
- Description of possible best and worst case outcomes or consequences for the basin;
- Identification of the highest perceived values to society from the basin; and
- Perception of the impacts specifically related to the September 21, 2009 well release incident.

Interview results supported the research design for a follow on group dialogue forum as described in the next section.

Sustained Dialogue and Group Forum with Indigenous Stakeholders

Values that consider non-market aspects of resource problems, such as environmental and long-term sustainability (or intergenerational equity) values and economic forces associated with a problem are difficult to measure. Initial interview processes provide insight into the key concerns, objectives, and social constraints for any resource problem, but moving from identification to transformation of group dynamics is a challenging process. Sustained Dialogue is a descriptive framework that recognizes the phases that every group goes through to resolve a conflictive issue and it also sets out a set of principles and tenets that mediators or facilitators can use to inform group engagement (Saunders 2011; Stewart and Saunders 2009). Sustained Dialogue formed through decades long processes of conflict resolution conflict negotiation teams working on behalf of the US Department of State to broker peace in many of the most volatile situations around the world. Although readers are referred to publications by Saunders (2011) for more detailed information on this complex process, key elements include five general stages (shown in Figure 4) that reflect the topics that groups need to address during any conflict resolution process. The discussion is not a linear process, it is iterative, but any group seeking to achieve resolution must address each of the five stages. The case reported here is in the Stage I and II framing and early problem identification stages of dialogue. One tenet that Sustained Dialogue practitioners are urged to follow, is disallowing the group to discuss alternatives or solutions until they have addressed the first stages of any problem. These early stages are also the starting point to bridge science and society knowledge, because Stages I and II provide for sound problem diagnosis for a scientist interested in constructing an Integrated Water Resources Managment model.

Results

The results reported in this research present initial steps for creating a long-term engagement strategy with a community group. Initial problem formulation and fact-finding were completed through individual interviews across stakeholder groups. The results of interviews informed the design of a participatory process to engage with a target stakeholder interest group, in this case the indigenous community members of northern Chile. These initial steps provide early problem formulation and social learning opportunities in the broader process of decision support to long term Integrated Water Resources Managment in the Second Region. As the process continues, additional stakeholder groups will be engaged and dialogue processes are expected to continue. The following sections discuss specific results of early engagement processes.

Interview and Scientific Results

Results of the stakeholder interviews demonstrated several important considerations about the perceptions of scientific knowledge and conditions in the El Tatio and El Loa basins. This section focuses on perceptions reported by indigenous community members and government agency representatives, because analysis indicated that the greatest levels of misunderstanding and miscommunication exist between these two groups.

Results of interviews with indigenous community members highlighted their perception of severe impacts to the El Tatio Geothermal Field basin during and after the geothermal blowout event, which is directly at odds with results of scientific measurements after the event (Malin et al. 2011). Core concerns raised by indigenous community members demonstrated that they are firmly locked in the Stage I aspects of a Sustained Dialogue that represents a sense of direct threat to identity and power imbalances with all other sectors in the region. In relation to scientific information, participants reported that they see science as a "weapon" that can be used against them locally, while international scientists are viewed as allies to help the group advocate for their case. Importantly, the indigenous community members indicate that they reject all government authority over environmental, water, or energy resources in the region. Community members led a protest march against government control of El Tatio Geothermal Field. In response to the protest, the Chilean Senate passed a moratorium on leases for geothermal exploration for several months.

Government representatives reported perceptions that are directly connected to Stage II aspects of Sustained Dialogue demonstrating that they feel they are in a top-down environment with control over activities and events in the El

Table 1. Stages of Sustained Dialogue process and showing primary concerns addressed in these stages of a process (Saunders and Stewart 2009).

Stage I	Stage II	Stage III	Stage IV	Stage V
Define	Identity interests	I to We	Collaborate	Communicate
Who	Power	Alternatives	Transform the Problem	Implememnt
Engage	Misperceptions -Interaction		ID Actions	

Tatio Geothermal Field basin. Participants in this stakeholder category indicated that they needed more hydrologic information to make sound decisions and that from more technical information they would be able to craft a limited communication plan and control outcomes for El Tatio Geothermal Field. This planned change perspective is at odds with the indigenous community's rejection of government authority.

Notably, the physical measurements and comparisons using forward-looking infrared, geochemical, and flow datasets indicate that the El Tatio Geothermal Field system recovered rapidly from the exploration incident in 2009 (Malin et al. 2011) and this corroborates the findings of the official report by the United Nations Development Program's panel of experts (UNDP Chile 2010).

These results provided important information to guide the next elements of the research so that sustained dialogue sessions could be initiated to bridge between science, policy, and communities. Because the indigenous group is squarely situated in Stage I phase, the research team decided to initiate a group dialogue using the Sustained Dialogue techniques to initiate and inform an early framing and problem diagnosis process and open opportunities to bridge a dialogue process with government representatives in the future.

Forum Results

The initial group dialogue session was hosted as a "Seminario Cientifico-Etnico" (Ethnic Science Seminar) with 19 participants from four northern regions in Chile over the course of 12 hours (See Figure 5 for a photo of participants during the forum).

The process combined narrative and deliberative approaches to generate substantive discussions among participants. Scientific participants provided brief capacity-building lectures about available information sources for water data through the Chilean government, GIS and mapping resources, and the macroscopic context of water resources in the north of Chile.

At the conclusion of the meeting, participants defined three initiatives to:

1. Create an indigenous management environmental and water resource monitoring network;
2. Develop a science-based training program for indigenous tour guides using water topics initially; and
3. Explore potential for an indigenous-led alternative energy cooperative.

Each of these initiatives is underway since the culmination of the group forum. Some important constraints were placed on topics by the participants, who refused to discuss geothermal energy and only allowed presentation of water resource information, which may indicate that water is an entry point for dialogue on more divisive topics for this region. Additionally, the group agreed to clear actions in relation to the three initiatives and also requested a future seminar to discuss geothermal energy and ground water.

The group forum supports scientists with an improved understanding of the level of knowledge about water resources in the region and the primary concerns of the indigenous community members. This new understanding can support the development of educational materials for future interactions and inform development of decision support models for Integrated Water Resources Managment efforts.

Conclusions

Truly sustainable water and energy resource management will not optimize a single indicator to define a long-term management regime. Rather, integrated water resources management that takes into account the various biophysical, hydrologic, environmental, economic, cultural, and legal factors can be expected to generate the most appropriate strategies for all parties concerned. Energy and ground water management is a significant, complex real world challenge that requires thoughtful consideration of scientific and social aspects before selecting a recommended course of action.

English and Dale (1999) recognized that future research and work in the area of decision support development can be expected to flourish in areas that:

1. Develop new tools that are increasingly transparent to the user groups;
2. Improve the integration of tools into daily use by decision-makers (i.e., keeping the tools off the shelf and in use); and
3. Continue collection of input parameter data and improve data measurement.

This study presents a replicable process for the early stages of decision problem formulation that may provide an avenue for addressing the areas identified by English and Dale (1999) and improve com-munication with regard to water resource conflicts, as demonstrated by El Tatio geyser complex. At the same time community conflicts that involve complex systems with critical scientific information, are unlikely to be resolved without clarity in the naming and framing of issues to be addressed during a dialogic or deliberative process.

Socio-technical tools and methods are capable of systematically bridging the boundaries between science and social regimes. It is necessary for professionals across the range of water and energy resource management and research to create a common understanding and level of communication in order to improve the outcomes of planning and policy implementation.

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Figure 5. Photo of sustained dialogue participants during January 2013 Seminario Cientifico-Etnico.

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