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RÍOS DEL PÁRAMO AL VALLE, POR URBES Y CAMPIÑAS

Building climate adaptation capacity in water resources planning

FINAL REPORT

COOPERATIVE AGREEMENT NUMBER AID-514-A-12-00002 WITH STOCKHOLM ENVIRONMENT INSTITUTE U.S. (SEI-US)

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‘RÍOS DEL *PÁRAMO* AL VALLE, POR URBES Y CAMPIÑAS’

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ACRONYMS

ASOCARs	Asociación de Corporaciones Autónomas Regionales
CAM	Corporación Autónoma Regional del Alto Magdalena
CAR	Corporación Autónoma Regional
CARDER	Corporación Autónoma Regional de Risaralda
CIDERA	Desarrollo y Estudio del Recurso Hídrico y el Ambiente
CENICAFE	Centro Nacional de Investigaciones de Café
CINARA	Instituto de Investigación y Desarrollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico.
CMGRD	Comité Municipal de Gestión del Riesgo de Desastre
CRQ	Corporación Autónoma Regional del Quindío
CVC	Corporación Autónoma Regional del Valle del Cauca
DBO	Demanda Bioquímica de Oxígeno
DEM	Digital Elevation Model
DOR	Average Annual Discharge
ELOHA	Ecological Limits of Hydrologic Alternation
EMCARTAGO	Empresas Municipales de Cartago E.S.P.
ENA	Estudio Nacional del Agua
ERA	Estudio Regional del Agua
GCMs	General Circulation Models
GIRH	Gestión Integrada del Recurso Hídrico
GIS	Geographic Information System
ICWE	International Conference on Water and the Environment
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia
IGAC	Instituto Geográfico Agustín Codazzi
IHA	Hydrologic Alteration
IWRM	Integrated Water Resources Management
m.a.s.l.	Meters above sea level
MW	Megawatt
NCAR	National Center for Atmospheric Research
NGOs	Non-Governmental Organizations
PCH	Pequeñas Centrales Hidroeléctricas
PMEC	Planning, Monitoring, Evaluation & Communication
PMP	Performance Management Plan
POMCA	Plan de Manejo y Ordenamiento Cuenca Hidrográficas
PORH	Plan de Ordenamiento del Recurso Hídrico
POT	Plan de Ordenamiento Territorial
PSMV	Plan de Saneamiento y Manejo de Vertimientos
QUAL2K	River and Stream Water Quality Model
RCP	Representative Concentration Pathways
RIANF	Reduction of unaccounted water (Reducción del Índice del Agua No Facturada)

RDM	Robust Decision Making
SEI	Stockholm Environment Institute
TNC	The Nature Conservancy
UAESPNN	Unidad Administrativa Especial del Sistema de Parques Nacionales Naturales
UNFCCC	United Nations Framework Convention to Combat Climate Change
Univalle	Universidad del Valle, Cali, Colombia
USAID	United States Agency for International Development
UTP	Universidad Tecnológica de Pereira, Colombia
WEAP	Water Evaluation And Planning System
WH	Watt-hour
WWF	Wild World Foundation
XLRM	E**x**ogenous Factors **L**evers, **R**elationships and **M**etrics.

GLOSSARY OF TERMS

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.

Adaptive capacity: The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities.

Baseline/reference: The baseline (or reference) is the state against which change is measured.

Capacity: The combination of all the strengths, attributes, and resources available to an individual, community, society, or organization, which can be used to achieve established goals.

Catchment: An area that collects and drains precipitation.

Capacity building: The practice of enhancing the strengths and attributes of, and resources available to, an individual, community, society, or organization to respond to change.

Climate change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate model: A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved. Coupled Atmosphere-Ocean Global Climate Models (AOGCMs), also referred to as Atmosphere-Ocean General Circulation Models, provide a representation of the climate system that is near the most comprehensive end of the spectrum currently available. There is an evolution toward more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal, and inter-annual climate predictions.

Climate projection: A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative-forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate scenario: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate.

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Deforestation: Conversion of forest to non-forest. For further discussion of the term, see forest and related terms such as afforestation, reforestation, and deforestation.

Decision space: scope within which discussions regarding potentially useful water management adaptations to climate change and other uncertainties take place. It constitutes a framework composed of policies, plans and policy setting processes within which a range of management options are available for decision makers to consider and potentially implement.

Ecosystem: A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.

Forest: A vegetation type dominated by trees. Many definitions of the term forest are in use throughout the world, reflecting wide differences in biogeophysical conditions, social structure, and economics. Particular criteria apply under the Kyoto Protocol. See also afforestation, reforestation, and deforestation.

Downscaling: Downscaling is a method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.

Ensemble: A group of parallel model simulations used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty. Ensembles made with the same model but different initial conditions only characterize the uncertainty associated with internal climate variability, whereas multi-model ensembles including simulations by several models also include the impact of model differences. Perturbed parameter ensembles, in which model parameters are varied in a systematic manner, aim to produce a more objective estimate of modeling uncertainty than is possible with traditional multi-model ensembles.

Exposure: The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.

Flood: The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.

Glacier: A mass of land ice that flows downhill under gravity (through internal deformation and/or sliding at the base) and is constrained by internal stress and friction at the base and sides. A glacier is maintained by accumulation of snow at high altitudes, balanced by melting at low altitudes or discharge into the sea.

Governance: The way government is understood has changed in response to social, economic, and technological changes over recent decades. There is a corresponding shift from government defined strictly by the nation-state to a more inclusive concept of governance, recognizing the contributions of various levels of government (global, international, regional, local) and the roles of the private sector, of nongovernmental actors, and of civil society.

Glacier: A mass of land ice which flows downhill under gravity (through internal deformation and/or sliding at the base) and is constrained by internal stress and friction at the base and sides. A glacier is maintained by accumulation of snow at high altitudes, balanced by melting at low altitudes or discharge into the sea.

Integrated water resources management (IWRM): The prevailing concept for water management which, however, has not been defined unambiguously. IWRM is based on four principles that were formulated by the International Conference on Water and the Environment in Dublin, 1992: 1) fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; 2) water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels; 3) women play a central part in the provision, management and safeguarding of water; 4) water has an economic value in all its competing uses and should be recognized as an economic good.

Management points: locations in the watershed where the amount of water flowing in a river is either measured or manipulation (e.g. stored, diverted, returned). These can be natural points such as rivers junctions which delineate sub-watersheds, or man-made points such as diversions or reservoir locations.

Mitigation (of climate change): A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Projection: A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized, and are therefore subject to substantial uncertainty

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

Scenario: A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from Projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline.

Stakeholder: A person or an organization that has a legitimate interest in a project or entity, or would be affected by a particular action or policy.

Streamflow: Water flow within a river channel, for example expressed in m3 /s. A synonym for river discharge.
Sustainable Development (SD): The concept of sustainable development was introduced in the World Conservation Strategy (IUCN 1980) and had its roots in the concept of a sustainable society and in the management of renewable resources. Adopted by the WCED in 1987 and by the Rio Conference in 1992 as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. SD integrates the political, social, economic and environmental dimensions.
Uncertainty: An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgment of a team of experts.
Vulnerability: Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.
Water consumption: Amount of extracted water irretrievably lost during its use (by evaporation and goods production). Water consumption is equal to water withdrawal minus return flow.

References for Glossary of Terms

Glossary of Terms used in the IPCC Fourth Assessment Report (Glossary of Synthesis Report).

IPCC, 2014: Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130

Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

ACKNOWLEDGEMENTS

Water management in Colombia, as well as in Latin America, is evolving to catch up with growing pressures posed by economic activity and development. As part of that evolution, in 2010 we were contacted by the universities in La Vieja – the watershed where traditionally coffee has been grown in Colombia - who were starting to use WEAP in their efforts to modernize water resources planning and regional support for the water authorities, CARs. In July of that year we met **Carlos Sabas** from Universidad Tecnológica de Pereira (UTP) on a fateful day – his brother had died the day before and the Soccer World Cup Final was capturing the attention of all Colombians. Despite all these extraordinary events, Carlos attended the meeting which was crucial to discuss a joint research agenda and to start networking with local actors. After that day we continued in communication with the La Vieja team, that included **Juan Mauricio Castaño** also from UTP, **Gabriel Lozano** from UniQuindío **Alberto Galvis** from CINARA and **Jorge Marulanda** and **Adalberto Arroyave** from Aguas y Aguas de Pereira. Together we proposed a technical support project to build tools and capacity on water management adaptation to the DGP (Developments Grant Program) of USAID Washington. In early 2011 we met the USAID team led by **Chris Abrahms** who indicated their interest in our proposal, and in May that year we received communication from him about the intention to add two more components to our program: work with CAM to support the climate action plan under the leadership of **Claudia Martinez** from E3 and work with TNC for WEAP technical enhancements for the Magdalena-Cauca initiative under the leadership of **Tomas Walschburger** and **Juliana Delgado**. We finalized the contract in mid-2012 and developed work plans the end of that year. In 2013 we reached out to IDEAM as a key boundary partner, and established contacts with **Omar Vargas, Maria Teresa Martinez** and **Vicky Guerrero** from the different sub directorates leading on hydrology, climatology and adaptation activities respectively. In addition to acknowledging the crucial role of the above mentioned individuals, we acknowledge:

- The hard work of the research technicians and students in La Vieja, including **Juliana Valencia, Norma Castro, Cesar Rodriguez and Maria Fernanda Jaramillo**.
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The actors mentioned in this acknowledgements are leaders in water management in Colombia, and their enhanced knowledge through this program on how to integrate climate into watershed planning will serve Colombia in the adaptation efforts that will be a crucial part of a sustainable peace in the country in years to come.

Sincerely,

Marisa Escobar and David Purkey

EXECUTIVE SUMMARY

The *Rios del Páramo al Valle* program operated from 2012-2015 applying a participatory planning process developed by the Stockholm Environment Institute, SEI, referred to as Robust Decision Support, RDS, in support of capacity building and tool development that can support climate adaptation in Colombian watersheds. This process integrated the contributions from academic institutions and Corporaciones Autónomas Regionales, CARs, and helped create regional and national leaders with long-term capacity to manage and plan the development of watersheds while integrating climate considerations. Working in close coordination with the technicians and decision makers from the CARs, the program evaluated and prioritized a viable set of adaptation alternatives that can reduce climate vulnerability, laying a foundation for sustainable development and the conservation of vulnerable ecosystems.

The RDS process was useful to clarify the steps required to develop useful information about watershed adaptation. By interacting with CARs, it was clear that the rich legal framework for watershed development in Colombia can be overwhelming (Blanco, 2008). Local autonomous authorities' participating in the project complied with national level requirements to the best of their knowledge and capacity by often relying upon contracts with external consultants for support. In contrast, this program's WEAP-based RDS approach sought to enhance CARs participation through capacity building activities that will lead to them obtaining and understanding the building blocks of watershed adaptation analysis. Identifying the decision space – which is defined here as the scope within which watershed actors can discuss potentially useful water management adaptations to climate change and other uncertainties and choose to implement the most promising alternatives -, mapping the regional actors, defining the key scenarios of uncertainty and action, and building tools within the first year of the program gave the initial baseline information. During the second year, the focus was on generating a large dataset of cases, defined by external pressures such as climate and by available adaptation options, in order to understand the key locations of high climate vulnerability and to discover key adaptation options. Sharing this information in useful and dynamic graphs provided a vehicle to communicate complex information with decision makers at the regional and national levels. The complete process responded to the needs to incorporate regional knowledge from actors into decision making about water management (Lynam et al., 2007).

Adaptation actions in the different watersheds ranged from watershed conservation to wastewater treatment plants. Preserving e-flows was highlighted as a necessary option to maintain ecosystem health. In addition to climate, population growth and hydropower development at a small and large scale are increasing the challenges for water systems management.

The process generated impact by promoting the use of WEAP and other program tools in the planning of watersheds outside of the original project case studies, such as Bolo Frayle. Other planning instruments influenced by the project related to the territorial planning of municipalities, as was the case for the Salento EOT. At the national level, the use of the tools for regional water studies - ERAs, and the consideration for use of ENA to support for

the national water studies, demonstrate the potential for scaling of the project outcomes to the country level.

SEI teamed up with TNC to build a model of the Magdalena River Basin using SEI's Water Evaluation And Planning (WEAP) system. Along with ecosystem impacts, the project team set out to study flood risks. The Mompos Depression is highly vulnerable to extreme floods, and in 2010–2013, a particularly wet "La Niña" led to severe floods that caused numerous deaths and widespread property damage in the lower Magdalena basin. Since those floods, several studies have been conducted to identify ways to reduce flood risks, and some identified the development of hydropower dams as a potentially helpful measure. But those studies did not look at flood dynamics in the basin as a whole, nor did they fully consider climate change. Initial results of the WEAP analysis show that hydropower dams could substantially reduce water flows during the dry months, and thus harm wetland ecosystems. But the dams would not protect lowland communities from extreme floods during periodic high flow events, because upstream reservoirs would have to release water for dam safety.

The project had an approach that was gender-focused, which enabled both women and men to influence policy and decision-making; and employ strategies that respond to gender-based vulnerabilities and promote inclusion. In different stages of the RDS process, gender considerations were mainstreamed. In particular, three key aspects were included within specific activities: 1) actor mapping identifying female participation in water management in order to set up a baseline condition, 2) information recording gender to track contributions and interventions at the watershed level, and 3) generating conditions for female participation in technical aspects of the project in order to promote female leadership in watershed management.

All project indicators were achieved and some were exceeded indicating compliance with the project Performance Management Plan - PMP (Appendix 1). In particular, stories of change produced at the request of USAID as part of the Cooperative Agreement (Appendix 2) document the achievement of the main capacity building objectives of the program. Universities and CARs in La Vieja also achieved join work plans for future work applying the WEAP-based RDS framework in response to future water management planning and decision making challenges (Appendix 3). Technical results were reported and published in fact sheets and discussion briefs summarized for technical and lay audiences, including decision makers (Appendix 4). Scientific progress in terms of modelling and tools to support water management decision making was reported upon in peer reviewed articles submitted to scientific journals (Appendix 5).

Lessons learned at different levels of the project suggest possibilities for potential improvements. <u>At the management level</u>, it is clear that a focus on young professionals and on working with academic legacy institutions is important for the continuity of the program in the long term. Also, CARs engagement will have to be revaluated in future applications to ensure stronger commitments to participate by devoting personnel's time to the project.

<u>At the technical level,</u> although the end product of a model building exercise is comparable to having a laboratory for watershed analysis, it is important that the process is streamlined to reduce time spent and avoid frustration. The consolidation of a community of practice may

lead to opportunities to improve the automation of the process, which will in turn contribute to streamlining steps for obtaining results. The lack of data, including socio-economic information, continues to hinder trust in modeling tools; this can be overcome by further characterizing uncertainties associated with data. Finally, the presentation of results to different audiences needs to be further refined to reach larger audiences.

Regarding governance, key recommendations relate to clarifying the linkages between watershed planning and current mandated planning instruments, and to including climate consideration in these instruments. The Colombian water governance system, decentralized to the CARs, creates opportunities for regional management and challenges for integration at the national level, and requires a strengthening of learning exchange between regional and national experiences. For instance, the leadership of IDEAM within IWRM efforts is key. Finally, the exploration of how to navigate adaptation funding would be an important next step for any watershed climate adaptation study.

Building capacity in climate adaptation for watershed planning requires time and effort. Participating actors in this project were exposed to the process in order to gain competence. The learning curve is still on an upward slope and requires additional efforts in order to scale up. The continuity that young professionals and legacy institutions, such as the universities that will continue working to apply the concepts of RDS to support climate adaptation after the program ends as part of their research, teaching and public engagement, can provide will be key to taking those additional steps needed to achieve higher levels of competence in analyzing the best alternatives for watershed adaptation using a set of technically sound tools.

INTRODUCTION

In 1992, participants at the International Conference on Water and the Environment published what has become known as the Dublin Statement on Water and Sustainable Development (ICWE, 1992). This statement, with its references towards defining fresh water as a finite and vulnerable resource, essential to sustain life, which should be managed through broadly participatory approaches, with full recognition of the essential role of women in water management and acknowledgement of water as an economic good, motivated the emergence of Integrated Water Resources Management (IWRM) as a frame for public policy setting involving water resources (Blanco, 2008). Fundamentally IWRM requires a broad and coordinated view of water and watershed management that allows for water allocation to support economic activities, while maintaining ecosystem integrity and the water security of future generations (Jonch-Clausen, 2004).

In Colombia, the response to the Dublin Statement and the emergence of IWRM is evident in the evolving institutional and legal framework related to water and watersheds in the country (Ministerio de Ambiente, Vivienda y Desarrollo Territorial, 2010), leading to the promulgation of several new mandated planning process to be undertaken at the scale of watersheds, and municipalities located within watershed. There still is, however, work to do to achieve the promise of IWRM to coordinate water resources management planning and decision making amongst policy actors and economic sectors (Blanco, 2008). Acknowledging that pending work should not be viewed as an indictment of Colombia and/or Colombian water managers; most countries of the world find themselves in a similar position. Since Dublin, however, efforts to implement IRWM have increasingly confronted the growing recognition that climate change creates a large amount of uncertainty that should, in principle, be considered within the participatory processes anticipated by the Dublin Statement.

The challenges that climate change poses for countries that are pursuing sustainable development related to water, such as Colombia, are real (Steinhoff et al., 2015). They are akin to changing the rules of the game in the middle of a match, as seen most clearly in the decision by the Colombian Ministry of the Environment and Sustainable Development to exclude explicit requirements to consider climate change within recently published guidance documents related to several mandated water and watershed plans. They simply did not feel that they had enough information and insight to craft defensible guidelines at this point in time. As such, the formulation of IWRM-based protocols to identify adaptation strategies to respond to climate change impacts on hydrology, water management and water quality is a pending and necessary task (Ludwig et al., 2014).

At the global level, the Nairobi Work Program of the United Nations Framework Convention to Combat Climate Change (UNFCCC) has initiated an effort (UNFCC, 2009) to compile resources that can support watershed planners, water managers, water utilities, irrigation districts, water users, environmental regulatory agencies and NGO, and stakeholders in general in considering the complexities of climate change in planning and decision making process. Universities and research institutes are key partners in this effort as many have received support to develop the tools required to respond to this complexity. For example, funding from the U.S. National Science Foundation allowed the RAND Corporation to tailor a generic strategic decision making under uncertainty framework (Lempert et al., 2003) referred to as Robust Decision Making (RDM) to the needs of the water management community (Lempert and Groves, 2010). At the core of this effort is the Water Evaluation and Planning (WEAP) system (Yates et al., 2005) developed by the Stockholm Environment Institute. WEAP itself was updated, with support from the U.S. Environmental Protection Agency Office of Global Change Research, to better accommodate climate uncertainty in the evaluation of water management options. In complex water management settings such as California, RDM and WEAP have demonstrated promise in assisting decision makers in implementing IWRM-based processes with full consideration of climate uncertainty.

This report synthesizes three years of experience by the Stockholm Environment Institute, along with a large set of Colombian partners, to explore how these specific tools might contribute to a similar evolution in Colombia. With the support of USAID-Colombia, the SEI team deployed these tools at a number of scales across the Colombian water management landscape. As part of this deployment, substantial attention was focused on (i) building the capacity of Colombian institutions to master these tools, (ii) demonstrating the utility of these tools within formal water and watershed planning and decision making processes in Colombia, and (iii) connecting local experiences using these tools to the national level discourse modifying these formal water and watershed planning and decision making processes to better accommodate the complexity associated with climate change.

The activities documented in this report suggest that a new approach for water resource planning and decision making is emerging that can work across Colombia. The *Rios del Páramo al Valle* project created an opportunity for the exploration of innovative participatory processes, advanced water system modeling and novel communication approaches towards that end. Evidence of increased technical capacity and of an enhanced ability to evaluate adaptation alternatives at the watershed level suggests that the methods and techniques tested in this project can be both replicable and broadly useful in Colombia. This is not, however, a step-by-step guidance document; it is rather a story of change that can illuminate new possibilities for water managers in Colombia, and beyond, as they seek to integrate climate change considerations into their efforts to respond to the ideals contained in the Dublin Statement.

CONTEXT OF THE PROGRAM

Since the creation of the Colombian Ministry of Environment and Sustainable Development in 1993, there has been an evolution of legislation to replace the 1984 Decree 1594 which, along the lines of other clean water legislation in other countries focused on water quality, with new and more extensive powers to plan for the management of water and watersheds. In large measure, these reforms were motivated by the Dublin Statement and subsequent discussions at the 1992 UN Conference on Sustainable Development in Rio de Janeiro, Brazil. Since its creation, the Ministry has crafted several environmental planning instruments related to water, watershed and land use, such as the POMCA (Plan de Ordenamiento y Manejo de Cuencas Hidrográficas – Decree 2759 of 2002), PORH (Plan de Ordenamiento del Recurso Hídrico – Decree 3930 of 2010), POT (Plan de Ordenameinto Territorial – Law 388 of 1997) and PSMV (Plan de Saneamiento y Manejo de Vertimientos – Resolution 1433 of 2004). Guidance for the implementation of these plans provided by the Ministry to the local authorities (mandated to deliver them) make allusion to the importance of participatory processes, and to an integrated approach to improving outcomes related to water quality and quantity, ecosystems, and disaster risk reduction. What these guidance documents do not contain is a mandate to consider climate change as part of the development of these plans. The Ministry simply did not feel confident that they had enough information and insight to propose defensible guidelines at this time.

In addition, the typical manner in which local authorities develop these plans is by contracting with external consultants who seek to implement the Ministry guidelines as closely as possible, focusing the majority of available resources on data collection and an assessment of current conditions. The result is that very little space is left for innovation to consider climate change in the development of these instruments and that little capacity for analyzing the complexity of climate adaptation is created. This is the context within which SEI implemented the *Rios del Páramo al Valle* project. SEI offered a framework and structure that integrated climate change within the principles of IWRM. Based on its prior positive experience using the WEAP-based Robust Decision Making approach, SEI designed the project to focus on deploying this technique at a variety of scales within the Magdalena-Cauca River Basin system.

Within the Magdalena-Cauca Basin, the project focused on two distinct sub-regions: the La Vieja-Otún watersheds in the Cauca Sub-Basin and Alto Magdalena watershed (Figure 1). Both are important coffee growing regions, but they are distinct in many ways. La-Vieja-Otun's major challenges are water quality and ecosystem protection while multi-sector water allocation are the key challenges in the Alta Magdalena watershed. Both watersheds lie within high -performing *Corporaciones Autónomas Regionales* – CARs, regional government organizations in charge of resource use permitting – which are responsible for coordinating water and watershed planning and decision making. This made them ideal locations for the sort of innovation contemplated within the original project design. By focusing on these sub-regions, the project was able to address emerging concerns of numerous important target stakeholders in these watershed systems charged with managing natural resources to the benefit of their constituencies, now and in the face of a changing climate. In particular, key actors such as managers of Colombia's high Andean *páramo* ecosystems, urban residents, representatives from the Colombian coffee industry, and staff from local and national government institutions were part of the project and were engaged at different levels of participation in different activities of the project.

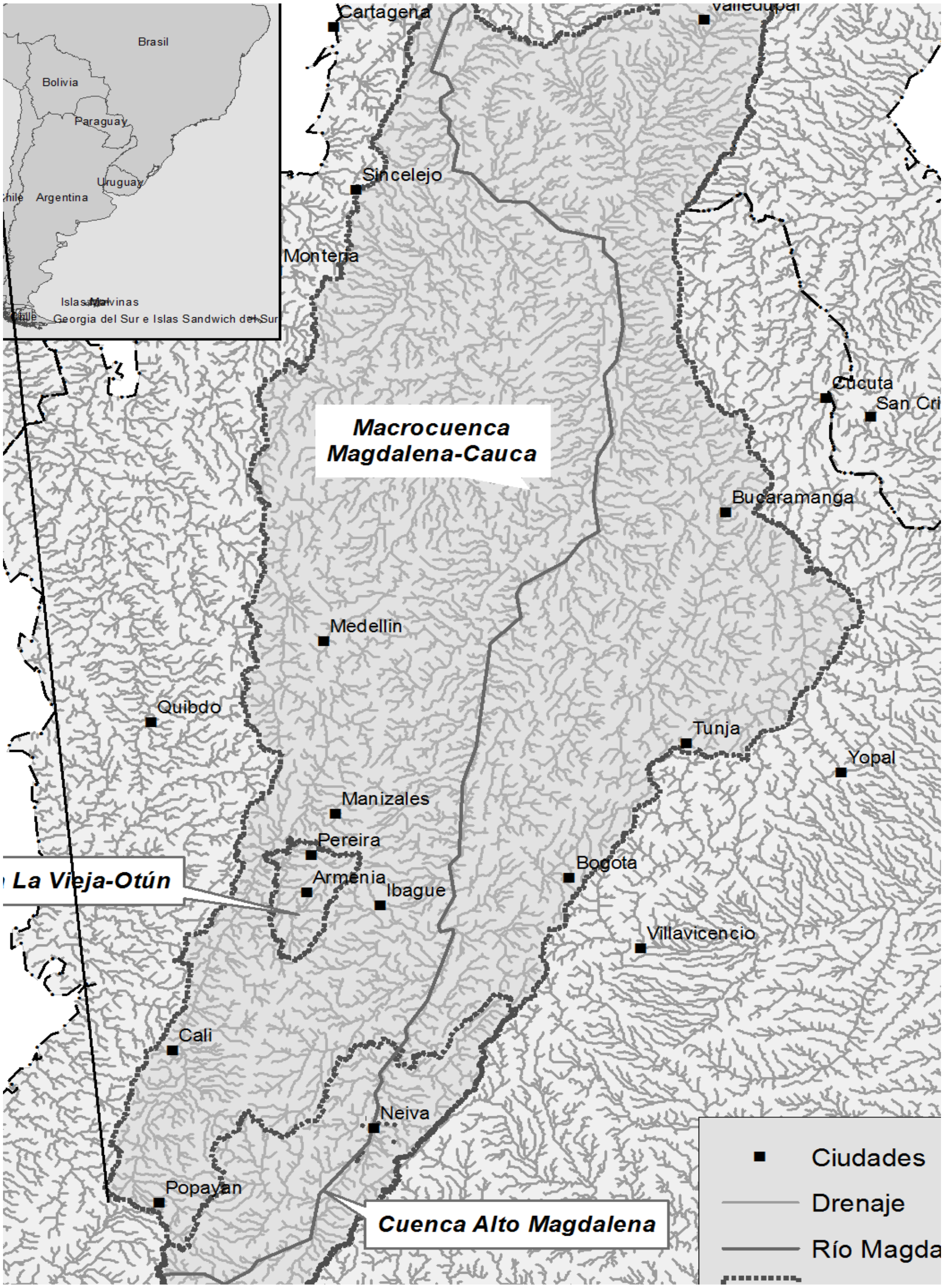


Figure 1. Map with study sites location: La Vieja, Alto Magdalena and Magdalena Cauca

The Rio Otún watershed is the source of water supply for the city of Pereira. The municipal utility, Aguas y Aguas, diverts water for the City of Pereira and other smaller communities, as well for a hydropower producer, and transfers untreated wastewater to the Rio Consota (a Rio La Vieja tributary). The water quality in the Rio Consota is important due to the fact that the river flows into lower Rio La Vieja, which is the source of water supply for the downstream city of Cartago. Including the Rio Otun in the project design allowed for the consideration of two specific issues of significant concern to CARS in Colombia: reversing water quality degradation downstream of urban centers and conserving páramo ecosystems as an effective climate change adaptation. The basin offered a compelling setting to investigate water management and climate change challenges that are common to many regions of Colombia.

In the Rio La Vieja watershed, the project worked with the three CARS (Corporación Autónoma Regional del Valle del Cauca, CVC, Corporación Autónoma Regional del Quindío, CRQ y Corporación Autónoma Regional de Risaralda, CARDER) that have shared jurisdiction for managing the basin. The watershed has a total area of 2,900 km^2 with a main stem river length of 101 km running from south to north through the Eje Cafetero. The total population of 1,140,000 inhabitants within the watershed is distributed across 21 municipalities. The Rio La Vieja has 23 tributaries that descend from the western flank of the Andean Cordillera Central, fed by climate sensitive glacier and *páramo* ecosystems that provide valuable contributions to vital dry season base flows in the watershed. Due to the sensitivity of these ecosystems to changing climatic conditions and to pressure from land use change, the focus on *páramo*s as a priority ecosystem is a good complement to the water quality challenges faced in the La Vieja system.

In the Alto Magdalena watershed, the project focused on supporting the water component of the Climate Action Plan that was being developed by the local CAR. This watershed spans an area of 22,200 km^2 which encompass the whole Huila Department as well as areas from the Cauca Department within the Rio Paez sub-watershed and from the Tolima Department with the Rio Patá and Cabrera sub-watersheds. With a population of approximately 765,000 inhabitants, this region of Colombia is of particular importance at a national level because of the current and potential hydropower production capacity available in the Huila Department. There are also important agricultural productions systems, particularly for coffee, rice, aquaculture, and livestock. Finally, as the source of the vitally important Magdalena River, the Alta Magdalena watershed produces 555 m3/s of water, on average, affording enormous benefit to downstream water users and ecosystems, and to the nation.

A key dimension of the project was its consideration of climate change at the larger Magdalena-Cauca River Basin scale. In particular the project focused on implementing new functionality in WEAP to characterize floodplain inundation as function of flows through time along a river network. Based on information available on recent flooding in the lower Magdalena system, work was carried out to conceptualize, design, implement and test new functionality in WEAP that would allow for assessing how downstream conditions might be impacted by climate change and various water management proposals in the upper watershed, in particular hydropower development. In addition to this focus on downstream floodplains, SEI also enhanced WEAP to link the tool to the Indicators of Hydrologic

Alteration (IHA) software developed by TNC as part of its Ecological Limits of Hydrologic Alternation (ELOHA) initiative. TNC has classified sub-basins within the Magdalena-Cauca system in terms of their ecological integrity and importance and has assessed which IHA indicators are most critical for each classification. Working in close collaboration with TNC, SEI programmed routines into WEAP that permit the estimation of critical IHA metrics under different future climate change and water management conditions. These two enhancements are powerful contributors to efforts to factor ecosystem sustainability into emerging IWRM protocols in Colombia.

The context within which the *Rios del Páramo al Valle* project operated, and the scales at which the project engaged, constitute a powerful learning laboratory for testing a set of decision support processes as well as provides analytical tools that allow local Colombian environmental management institutions to contribute to an emerging national discourse on climate change and water management in Colombia. The success of a national Symposium at which the "bottom-up" experiences of SEI and its partners were presented suggests that the project achieved this goal.

A summary of the watersheds analyzed is presented in Table 1.

Table 1. Summary of watershed areas, population, average streamflow and identified adaptations

Watershed	Area (km^2)	Population (approx. miles)	Average flows (m^3/sec)	Identified Adaptations
Otún	500	400	21.8 (wet) 7.2 (dry)	Watershed conservation E-flows New storage
La Vieja	3000	1,200	149 (wet) 49 (dry)	Improve coffee processing Wastewater treatment plants
Alto Magdalena	22,000	750	555 (wet) 215 (dry)	Small hydropower Irrigation efficiency Reduction in unaccounted for water
Magdalena-Cauca	210,000	30,000	7200	Watershed conservation Wetland management Operation of existing reservoirs

Box. Rios del Páramo al Valle: An agreement that achieved its goal and objectives

The goal of the project was to build regional capacity to support the sustained integration of climate change adaptation into water management plans and strategies within Corporaciones Autónomas Regionales (regional environmental authorities in Colombia) focusing on the Rio La Vieja and Alto Magdalena watersheds, and to extend the benefits of that learning to all Corporaciones in Colombia *(Figure 1)*. The activities included an evaluation of climate change adaptation alternatives for water resources planning, the development of analytical tools and capacity building. As indicated in detail the '**Context of the Program'** section of this report, we worked with several partners to achieve these goals and we briefly restate here what we did, how we did it and with whom. In Rio La Vieja we worked with three main partners. First, **EIS** – a research group within Universidad Tecnológica de Pereira - transferred capacity through workshops and co-learning with CARDER and Aguas y Aguas to build WEAP models to identify climate adaptations for the Otún and La Vieja watersheds. Second, **CIDERA** – a University of Quindío research group – collaborated with CRQ in data transfer and promoted the use of the WEAP systems modeling approach to identify adaptation options in terms of water quantity. Third, **CINARA** from UniValle worked closely with CVC to build capacity in water quality modeling to identify and promote adaptations to improve water quality conditions in urban and rural coffee runoff areas. In Alto Magdalena, we promoted co-learning, cooperation and participative research with **CAM** in the development and implementation of the water component of the Huila 2050 Climate Action Plan. At the Magdalena-Cauca level we worked with **TNC** to build and improve WEAP routines to understand the effect of upstream management and adaptation in downstream flooding of the Mompos Depression. *Figure 19* of the report shows how we collaborated with partners to achieve each component.

In order to meet the project goal, 3 specific objectives were formulated and achieved after project implementation, as described below:

i. Assess current understanding of climate change and variability effects on water resources in the Rio La Vieja and Alto Magdalena watersheds using an innovative, participatory, problem formulation framework.

Current understanding of climate change and variability effects on water resources was achieved by implementing workshops that applied participatory research techniques with a set of stakeholders that were identified as relevant in water management decision making. Stakeholders were guided with questions and conceptual frameworks based on uncertainty characterization, the livelihoods framework and the ecosystem services framework to define key components of the water system to be considered. Such a process led to a complete characterization of the most relevant watershed elements that could be affected by climate change and variability. In the '**Methods'** section of this report we present the details of the methodology applied, in particular the application of the XLRM framework within the Robust Decision Support framework. Components were divided into those that are outside of the control of water managers (Xs in the XLRM framework such as climate change and population growth), those that can be acted upon with adaptation strategies (Ls in the XLRM framework such as infrastructure or páramo conservation), and the metrics to evaluate impacts (Ms in the XLRM framework such as reliability of water supply). In the **'Results'** section of this report there is detail about the watershed characterization that resulted from applying this methods, and a summary of XLRM results for the three basins is presented in *Tables 3, 4 and 6*.

ii. Develop analytical tools based on WEAP to explore links between climate change, the conservation of priority ecosystems and the sustainable management of water resources in the Rio La Vieja and Alto Magdalena watersheds.

Development of analytical tools based on WEAP was achieved by investing a large portion of the grant's time and resources into generating WEAP models of the watersheds under study. The WEAP model building was accompanied by a series of training opportunities tailored to the Corporaciones' needs and availability. Climate information was downscaled and input into the models at the appropriate spatial scale to represent variability within the different parts of the watershed. Climate information was generated during capacity building workshops designed to create awareness of the complexity of climate data and climate model output and to provide approaches to untangle such complexity. Other tools focused on automating the generation of WEAP outputs associated with climatic and non-climatic scenarios, and on visualizing the outputs of big data generated by the multiple scenario model runs. Developing and using these quantitative tools helped in evaluating the climate change implications within watersheds and understanding the most effective adaptation options at the watershed scale. The analysis indicated that most effective adaptations for these watersheds are closely linked to development processes and ongoing conservation efforts in Colombia. In Otún, adaptation priorities are watershed conservation, e-flows prioritization, and new storage infrastructure. In La Vieja, improved coffee processing and wastewater treatment plants are the best adaptation options to improve water quality conditions. In Alto Magdalena, small hydropower, irrigation efficiency and reduction in unaccounted for water were the main adaptations identified (listed in *Table 1* of this report). The details of these outputs are in the **'Results'** section of this report.

iii. Build the capacity of local partners to the point where these partners can contribute to additional capacity building activities and needed institutional articulation of actions for climate change response at the regional and national level.

The RDS process included several steps that required knowledge about approaches to first characterize the watershed context, prepare the required data, and build tools, and second, to investigate the performance of adaptation actions that could be implemented (*Figure 2*). Each step and its associated approach included a capacity building method that helped internalize the concepts. Actor mapping used surveys that highlighted the connections between actors involved in water management. Problem formulation included a participatory workshop that generated knowledge about the key components of the watershed for all participants (mentioned in i). Model construction, climate scenarios definition, ensemble analysis and output exploration included a set of workshops, field visits and events that led to a clear understanding of climatic and non-climatic variables that could alter watershed hydrologic services (mentioned in ii). Capacity building in decision support was achieved by designing regional workshops in Cartago in Dec 2014 and in Neiva in Feb 2015 – that were attended by key watershed stakeholders and decision makers identified in the actor mapping process - and a national symposium in Bogotá in Jan 2015 where decision makers from a range of implicated national level organizations shared their approach to using the information produced to inform decisions about the future planning of the watersheds including climate considerations (a list of key stakeholders involved in these events is located in **Appendix 6** of this report. Also, these events as well as updates about the actors' are continually reported in the project's blog http://weap-lavieja-otun.blogspot.com/). The overall RDS process steps were implemented with the boundary partners leaving them on a path to higher competence levels (*Figure 20*), and also giving them a level of power to use these tools for future analysis (*Table 10*). By linking SEI-US's expertise in water resources adaptation to climate change together with local expertise in the Rio La Vieja, Alto Magdalena and Magdalena-Cauca watersheds, the project responded to needs identified for Climate Change Sector Adaptation activities under the 2011 DGP, including capacity building, tool and guidance development and dissemination, applied research and analysis in support of adaptation activities.

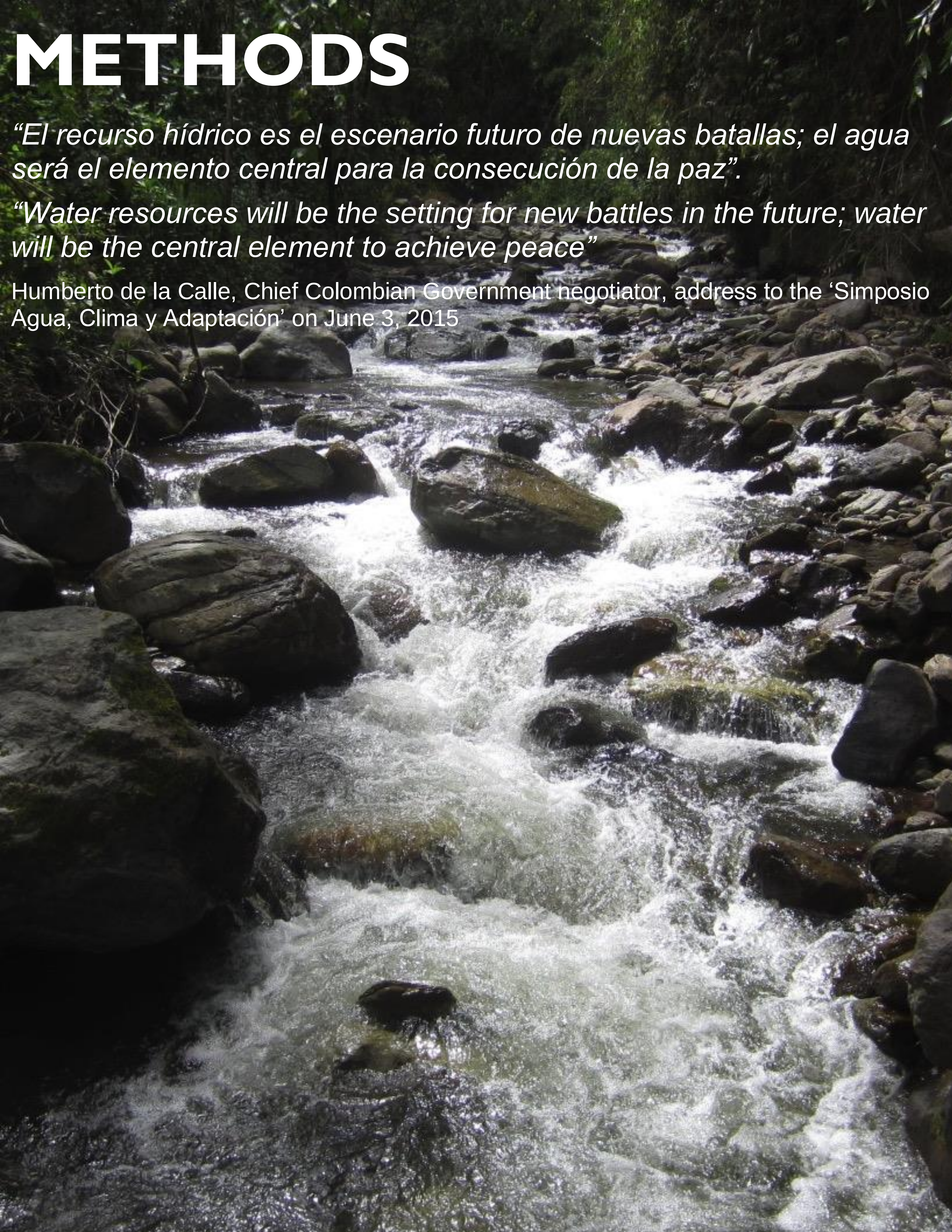
The above goals connected directly to USAID goals and priorities. USAID seeks to support the Government of Colombia in improving living conditions and strengthening the presence and efficiency of the state. Improving the adaptive capacity of Corporaciones in the economically consolidated Eje Cafetero and Alto Magdalena created a platform for similar improvements in regions where increasing the provision of basic services, increasing licit livelihoods and strengthening local institutions is critical. The project also strengthened environmental governance for the conservation of protected areas in Colombia.

METHODS

“El recurso hídrico es el escenario futuro de nuevas batallas; el agua será el elemento central para la consecución de la paz”.

“Water resources will be the setting for new battles in the future; water will be the central element to achieve peace”

Humberto de la Calle, Chief Colombian Government negotiator, address to the ‘Simposio Agua, Clima y Adaptación’ on June 3, 2015



METHODS

As described in the previous section, the context for the project was the need and opportunity to include climate change considerations in the process of water and watershed planning and decision making at various scales in Colombia, with a geographic focus on the Magdalena-Cauca River Basin. The primary goal of the project was to build capacity for partners in the watersheds listed in Table 1, as part of a participatory planning process, to deploy, test, and potentially replicate the experience gained by SEI to help water, watershed and ecosystem managers in other parts of the world identify water management adaptations[1]. Both the prior experience and the efforts in Colombia were based upon the application of SEI's Water Evaluation and Planning (WEAP) system within a participatory planning process referred to as Robust Decision Support (RDS).

The SEI practice of RDS is based on a theoretical decision making under uncertainty framework referred to as Robust Decision Making (RDM). RDM emerged from a program on strategic decision making under conditions of deep uncertainty within the RAND Corporation (Lempert et al., 2003). The starting point for the RDM framework is that traditional decision making approaches based on an assessment of the likely probabilities of future conditions do not respond well to a situation such as climate change, where there is no consensus about the likelihood of specific climate futures. SEI work with RDS has involved applying RDM theory to the challenge of water and watershed planning and decision making under climate change in a way that responds directly to the IWRM appeal for participatory water and watershed planning, based on a large body of literature (Folke et al., 2005; Pahl-Wostl, 2009; Pahl-Wostl et al., 2007).

Before presenting the key features of the RDS approach, it would be useful to present some context for understanding how participation in a project is crucial for incorporating social learning and capacity building (Bouwen and Taillieu, 2004; Lee, 1999; Lynam et al., 2007; Stringer et al., 2006). One useful framework, shown in the legend of Figure 2, defines a progression of levels of stakeholder engagement in a research project. The levels are relevant to analysis carried out in support of decision making processes as well. The lowest, and unfortunately perhaps the most common, level of engagement is characterized as information extraction. While soliciting information from informed stakeholders is necessary to the process of conducting useful analysis, if these stakeholders are not connected to the analysis it is difficult to assign it much relevance or credibility. The highest level, Participatory Action Research, involves granting full control of the design and execution of analysis to stakeholders. Between these two poles, are varying levels of stakeholder engagement in the analytical process. In implementing the RDS approach in Colombia, the project attempted to operate at all the levels of participation from Information Extraction to Participatory Research.

[1] While the project contributed to the identification of specific adaptation actions, the project was not designed to actually realize them on the ground.

The central feature of the RDS practice is to acknowledge and intentionally incorporate the analysis of external factors such as climate change, but also potentially other factors such as population growth and economic development, into the evaluation of the potential benefits associated with specific water management adaptation actions. While grappling with the uncertainty associated with these external factors, decision makers engage in an iterative process of identifying the actions that can be taken at the watershed scale in order to reduce the climate vulnerability and increase the climate resilience of water systems. The steps in the RDS process are shown in Figure 2.

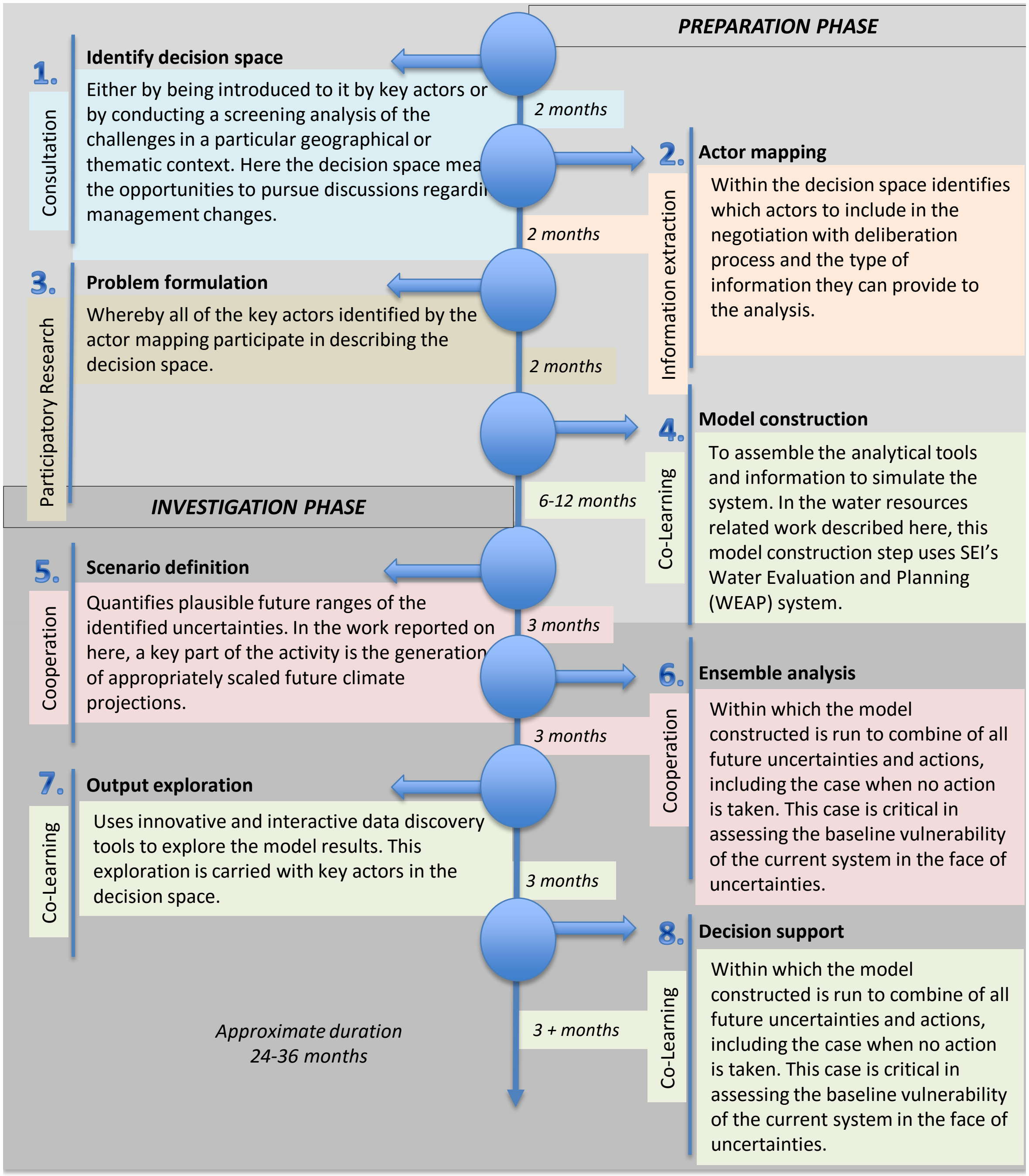
The steps of this process fall into two phases, preparation and investigation. The preparation phase, which generally takes around 12-24 months to complete, is designed to assure that all relevant stakeholders and decision makers are given the opportunity to participate in the critical problem formulation and analytical design process. The lower end of the timing of about 12 months corresponds to situations where a technical level on water modeling expertise exists among stakeholders. The higher end estimate of timing includes working with stakeholders to build capacity on water systems and management modeling. Specific steps in this phase are as follows.

Identify decision space: Either by being introduced to it by key actors or by conducting a screening analysis of the challenges in a particular geographical or thematic context. Here the decision space means the forums within which watershed actors engage in discussions regarding potentially useful water management adaptations to climate change and other uncertainties, and take decisions to implement the most promising options (Pahl-Wostl, 2009). *Level of Participation: Consultation*

Actor mapping: Within a decision space identify which actors to include in the negotiation and the deliberation process and the type of information they can provide for the analysis (Reed et al., 2009). *Level of Participation: Information extraction*

Problem formulation: Whereby all of the key actors identified by the actor mapping participate in describing the decision space via the application of the XLRM problem formulation framework (Lempert et al., 2003). *Level of Participation: Participatory research*

Model construction: To assemble the analytical tools and information to simulate the system. In the water resources related work described here, this model construction step uses SEI's Water Evaluation and Planning (WEAP) system. The model constitutes a laboratory for testing possible watershed futures (Groves et al., 2008). *Level of Participation: Co-Learning*



Increased participation

Participation level legend	Example
Participatory (Action) Research	Research is directed by participants, with the researcher acting as a facilitator
Co-Learning	Working together to define problems and find solutions
Cooperation	Working with people to determinate priorities, but the process is directed by the researchers
Consultation	Local opinions are sought and some dialogue occurs
Information Extraction	Researchers ask people questions and process the information

Figure 2. RDS steps, timing, and participation levels.

Color coding indicates level of participation according to legend and approximate time for each step is included. Steps are shown in a linear way, but they overlap and can be iterative.

Scenario definition quantifies plausible future ranges of the identified uncertainties. In the work reported on here, a key part of the activity is the generation of future climate projections scaled appropriately for evaluating climate change adaptations at the watershed scale (Peterson et al., 2003).
Level of Participation: Cooperation

Two items referenced in this description of the RDS Preparation Phase warrant further presentation. The first is the XLRM problem formulation framework. XLRM is a tool developed by the RAND Corporation that divides a decision making process into four components.

X (e**X**ogenous factors) represents the uncertain factors outside the direct control of the actors within a particular decision making process but which have the potential to influence outcomes.
L (**L**evers) represents the specific actions that are available to these actors as they seek to improve conditions or outcomes in the face of future uncertainty.
R (**R**elationships) is the suite of analytical tools deployed to capture the exogenous factors and represent the levers identified by the actors, which when deployed produce estimates of…
M (**M**etrics of Performance), which are the means by which individual actors will evaluate the outcomes associated with a specific action considered as part of the decision making process.

The R component of the XLRM framework pertains to the tools used to support the analysis carried out as part of the effort to evaluate the performance specific adaptation actions. These often include models of the watershed/water management system in question. Under the current project, the primary model or analytical tool deployed was the Water Evaluation and Planning (WEAP) system which has been developed and supported within SEI for over 25 years. WEAP is an integrated hydrologic/water resources modeling platform that represents both the natural hydrologic or rainfall-runoff processes in a watershed as well as the physical and regulatory systems put in place to balance available supplies and existing demands as part of a multi-objective water allocation system. Over the years WEAP has been expanded to allow for the representation of groundwater hydrology, surface water quality, plant biomass production and many other processes at play within a watershed. In each of the Colombian watersheds, SEI worked in close collaboration with local technical experts to develop applications of the WEAP software.

At different points in the RDS Preparation Phase, gender considerations were mainstreamed. In particular: 1) the actor mapping exercise was designed to identify the roles that female currently play in the management of water resources within a watershed, allowing for the definition of a baseline condition; 2) the results of the actor mapping were used to promote female participation in the problem formulation exercise and in technical aspects of the project in order to promote female leadership in watershed management; 3) during the problem formulation, contributions were logged by gender in order to differentiate female perspectives from those held by men. Together these efforts led to greater awareness of gender issues among project partners and to greater participation of women on project activities. SEI is very proud of the level to which the project created opportunities for women to lead on the critical issues of climate change and water management.

In the RDS process, once the modeling platform has been constructed and calibrated based on historical climatic and hydrologic data sets, and potential future scenarios have been defined, the process switches to the Investigation Phase. During this phase, which takes approximately 12 months to complete, the models are run for each of several adaptation strategies articulated by the key actors (always including the 'no action' option in order to create a baseline for comparison), under each scenario related to future climate and non-climate (e.g. population growth rate, per capita consumption, regional economic development) uncertainties of concern. A set of scenarios produces a large data base of results covering many dimensions of performance (e.g. demand satisfaction, reservoir storage levels, hydropower generation, and ecosystem health), that are explored using innovative data visualization techniques which provide critical inputs to the decision making process. Specific steps in this phase include:

Ensemble analysis: Within which the model constructed is run to combine all future uncertainties and actions, including the case when no action is taken. This case is critical in assessing the baseline vulnerability of the current system in the face of uncertainties.
Level of Participation: Cooperation

Output exploration: Uses innovative and interactive data discovery tools to explore the model results. This exploration is carried out in a participatory and dynamic fashion with key actors in the decision space.
Level of Participation: Co-Learning

Decision support: Based on the exploration of the outcomes, which are evaluated within the decision space, the performance of specific management actions can be evaluated relative to the no-action baseline and to each other. Upon viewing the results, actors can decide to either reformulate the problem or to accept a particular recommendation for a preferred course of action.
Level of Participation: Co-Learning

The exploration of WEAP outputs is simultaneously the most exciting and the most challenging step in the RDS process. It involves exploring, in close collaboration with watershed actors, the output of multiple model runs covering all combinations of future scenarios and possible adaptation responses, covering several dimensions of performance. The amount of information to digest is substantial and traditional techniques for sharing scientific and technical information with decision makers (maps, X-Y graphs, data tables) are not well suited. In the project, SEI and its watershed partners worked with a leading edge data exploration and visualization software package called Tableau. The sorts of graphics produced to support the evaluation of adaptation actions in project watershed are presented in the results section of this report. In addition to these sophisticated dynamic data visualizations, the project produced a whole series of fact sheets that distilled the key messages into more traditional media. These are found in the Appendices to this report.

In testing the RDS method as part of this project, SEI and its partners tried to directly relate the steps in the process to both the connections between the various water and watershed planning instruments mandated by Colombian Law (POMCA, PORH, POT, PSMV) and to the guidance documents pertaining to the formulation of each individual instrument. As such, the project was able to produce results that are feeding directly into national level dialogues pertaining to climate change and water management in Colombia.

RESULTS

“La modelación son los ojos del futuro. No podemos seguir viendo el país en el presente, no podemos hacer planificación a ciegas, tenemos que planificar con información”

“Modeling gives us a view of the future. We cannot continue seeing the country in the present, we cannot plan blindly, we need to plan with information”

Omar Vargas, Subdirección de Hidrología IDEAM Subdirector of hydrology at ‘Simposio Agua, Clima y Adaptación’, June 3, 2015

RESULTS

Since analytical tools, often models, are central to the scenario-based analysis conducted as part of the RDS process, many of the results presented in this section are derived from WEAP model output built in each project watershed. Before presenting these model output for each watershed, however, some explanation of the WEAP model building process and the type of information produced is warranted. As previously mentioned, WEAP is an integrated hydrologic/water resources modeling platform. As such the model building process involves the construction and calibration of WEAP model elements – such as watersheds, canals, reservoirs, demand sites - that simulate rainfall-runoff processes, water system operation, and river water quality (in the case of the La Vieja model). The steps in the model building process are summarized in Table 2.

Table 2. Summary of WEAP model building and deployment process

Construct hydrologic units to simulate hydrologic processes	500 m Elevation bands were generated with a digital elevation model, or DEM. These bands were intersected with sub watersheds defined using the DEM to obtain polygons that represent hydrologic units or catchments. The number of catchments varies depending on the scale and resolution of each model. As needed, additional hydrologic units can be created to represent special ecosystems such as *páramo* or glaciers. Hydrologic units are characterized based on land cover type. In this particular case, land cover was characterized into glaciers, agriculture, forest, coffee, *páramo*, urban areas, water bodies, and bare soils. The WEAP catchment objects defined via the implementation of these steps are used to simulate rainfall-runoff processes in each modeled watershed.
Model building, water demands and calibration	Existing historic climatic data processed and input for each catchment. Model is run to produce streamflow and water balance components. Water demands characterized based on urban uses and agricultural requirements. Streamflow values produced by the model were compared to observe streamflow values. In the case of the La Vieja model observed water quality values were also compare to simulated values. A calibration process allowed for an adjustment of model parameters to represent the hydrologic behavior of hydrologic units, the operation of installed hydraulic infrastructure and water quality conditions in rivers.
Climate scenarios	A total of 35 General Circulation Models (GCMs) were processed and used to define possible future climate trajectories for the study sites. The time horizon for climate projections was set for 2050, and the most extreme greenhouse emissions path of RCP 8.5 was selected. The downscaling process included the use of data from local hydro-climatological station, to produce spatially varying climate inputs across each modeled watershed for all catchments into the model.
Ensemble of runs and analysis of results	In order to generate a more complete representation of future conditions, possible future trajectories of other uncertain factors were also defined and include in the ensemble analysis. Adaptation measures were represented in the model and the results were compared across the uncertainties to define whether they will reduce climate vulnerability with respect to specific water quantity and quality objectives.

The sorts of results that are produced through the deployment of WEAP as part of a scenario based analysis include:

1. Streamflow values at various points in the watershed.
2. The contributions of various parts of the watershed and various land-use/ecosystem types to these streamflow values.
3. Water storage and diversion patterns associated with the operation of hydraulic infrastructure in order to satisfy demands in the watershed.
4. The level of demand associated with various use of water in the watershed and the level of satisfaction of that demand.
5. The ecological status of river reaches using Indicators of Hydrologic Alteration.
6. River water quality at various points in a watershed.

These are the model outputs that are used to estimate the value of performance metrics articulated by stakeholders as part of the problem-formulation step of the RDS process. Values are generated for each model run, or case, in an ensemble of cases, where a case combines a specific set of assumptions about the future based on the uncertainties identified in the problem-formulation step and a single management response proposed by the stakeholders. The ensemble is designed to generate model output for cases that span the range of uncertainties defined by stakeholders and the set of management responses they propose. The results of these ensembles are presented and analyzed for each project watershed in the following sections.

Otún Watershed

Context Otún Watershed

The Otún watershed is located in the department of Risaralda (Figure 3). Its headwaters have high slopes which generate erosive conditions. In this watershed there are 10,102 hectares of *páramo*, an important ecosystem for the regulation of baseflows, and home to specific endemic species. At a point 66 kilometers from its headwaters, the river becomes a major source of water supply. At El Porvenir, 2.35 m3/s are diverted for the cities of Pereira and Dosquebradas, 5 m3/s are channeled through hydropower generation facilities, and an e-flow of 3 m3/s is left in the river channel. This means the watershed needs to produce 10.35 m3/s of water to meet water management objectives at this point in the watershed.

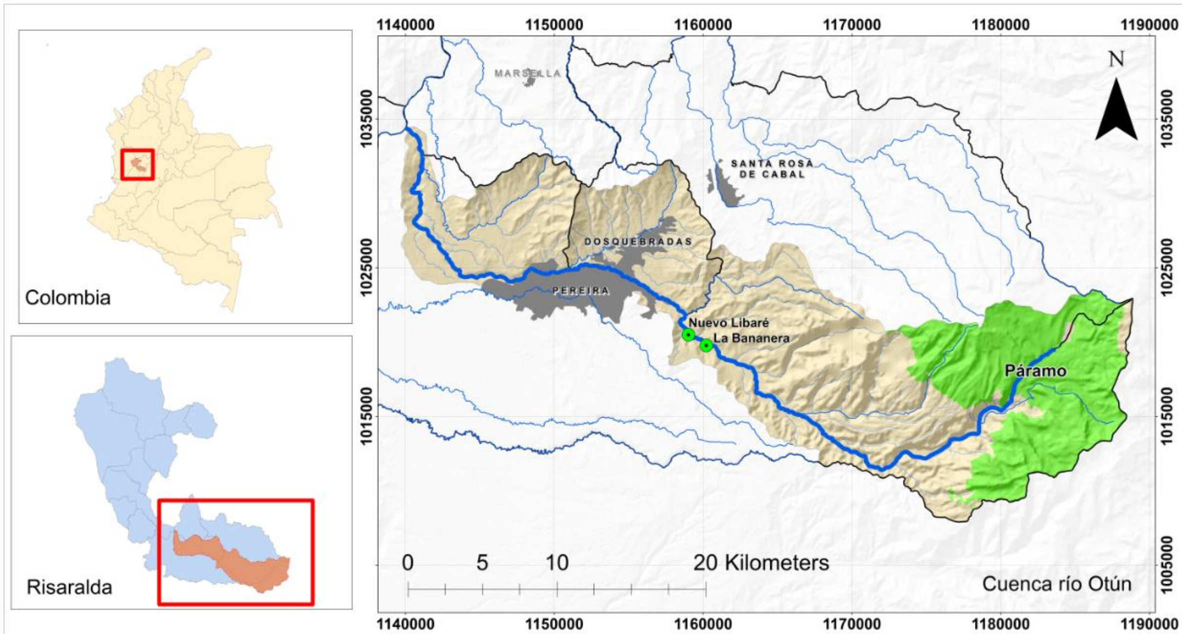


Figure 3. Otún watershed location in Colombia

Map indicates location of the watershed in Colombia and in the Department of Risaralda. Key features such as páramo land cover, location of streamflow measurements, and cities are included.

In this context, where multiple users depend on the watershed for water supply, stakeholders have an inherent interest in the conservation of the watershed. These actors come from multiple groups, including the local Corporación Autónoma Regional (CARDER), a water utility (Aguas Y Aguas S.A. E.S.P. and Serviciudad S.A. E.S.P.), an energy company (Empresa de Energía de Pereira S.A. E.S.P.), a solid waste management company (Aguas y Aseo de Risaralda S.A. E.S.P.), the national parks organization (UAESPNN with the Santuario de Fauna y Flora Otún Quimbaya, the Parque Regional Natural Ucumarí and the Parque Nacional Natural Los Nevados), the municipal government (Área Metropolitana Centro Occidente), planning entities (from the municipalities of Pereira, Dosquebradas and Santa Rosa, and from the Department of Risaralda), along with research groups within universities.

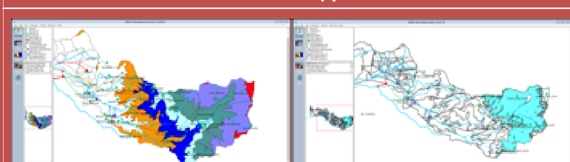
The program - Otún Watershed

The intellectual challenge for work in the Rio Otun watershed was the development of a model for *páramo*s and other Andean wetlands which could lead to an appropriate representation of the hydrology and management of this type of mountain watersheds. This modeling work was consistent with the experience with and interest in Andean hydrology and wetlands held by the local academic group participating in the project.

To achieve a complete representation of the basin, the implementation of the program required that key watershed actors be identified and invited to participate in a watershed participatory planning process that leads to the identification of the watershed physical and institutional context that shape the performance of specific water management actions under consideration. Since the Otún watershed is connected to the La Vieja watershed through the return flows of the city of Pereira, additional actors beyond those mentioned above were convened. A larger set of actors such as other CARs (CVC, CRQ), entities from cities downstream of the city of Pereira (EMCARTAGO E.S.P, CMGRD Cartago), the regional coffee growers association (Comité de Cafeteros del Valle del Cauca), and active NGOs (Fundación Pangea, TNC, WWF) among others, also were invited to participate in a problem formulation exercise.

These participants provided information to complete an XLRM matrix which provided the basis to develop the uncertainty scenarios and management adaptations to be considered. Although most of the information was collected during a specific workshop, many subsequent interactions over the course of a year led to the final characterization of each scenario. The resulting matrix from the participatory process is presented in Table 3.

Table 3. Otún watershed XLRM

X	L
<u>Climate change</u> Precipitation: Max increase / Max decrease /Ave increase ~ 40 mm/month / ~ -41 mm/month / ~ 12 mm/month Temperature: Max increase / Min increase /Ave increase ~ 5.1 oC / ~ 1.3 oC/ ~ 3.0 oC <u>Demographic change:</u> High / Medium / Low <u>Per capita use:</u> High / Low <u>Water losses in distribution system:</u> High/Low	Forest and *páramo* conservation Efficient water use E-flows compliance Changes in priorities between water demands and e-flows: Environmental (1) Human consumption (2) Energy (3)
R	**M**
	Water supply: streamflow at tributaries Domestic, energy and e-flows demand coverage *Páramo* contribution to streamflow at diversion Baseflow / Interflow/ Surface runoff

Note: The R image of the WEAP model is presented here for illustrative purpose to show WEAP model schematics but not to convey information

Data used for characterizing the watershed in the WEAP model included watershed and subwatershed delineation provided by CARDER based on the 1:25.000 IGAC Digital Elevation Model. Key management points which are the locations within a watershed where water flows are either measured or physically manipulated to meet water management objectives (e.g. reservoirs, points of diversion, and points of return flow) were used to delineate subwatersheds. In addition, the SRTM 90 m resolution was used to refine the definition of sub-watershed boundaries.

The resulting monthly hydrology and systems operation model downstream to the point of multipurpose diversion represents the supply system for the cities of Pereira and Dosquebradas, and the energy and ecological requirements. The model was built using climate inputs and physical characteristics to analyze climate change vulnerability in terms of the system's capacity to produce water supply for the city of Pereira, and to meet other management objectives. In addition, a model of daily flows representing the *páramo* hydrology was included to estimate the water contribution of this strategic ecosystem.

The two resulting models for the basin included a monthly model for the Otún watershed, and a daily model of the *páramo* above 3,000 m.a.s.l. Both models include a characterization of uncertainties and strategies that produce outputs for different performance metrics. These uncertainties, strategies and metrics were identified through the XLRM problem formulation process (M in Table 3).

Performance of adaptation options - Otún Watershed

After an analysis of different adaptation options, it was possible to identify that actions already taken in the watershed since 1950 - including the conservation of exiting *páramo* and forest landscapes and efficient water use - are largely maintaining the functionality of the watershed, which in turn is maintaining a water supply and demand balance despite climate and other future uncertainties, with some exceptions under more extreme future scenarios.

In this context, one adaptation strategy evaluated for the future of the Otún watershed was to explore how water allocation priorities could be adjusted to ensure future system performance. This strategy acknowledges a key management challenge in this watershed which is the continuous provision of water services for urban consumption as well as for the needs of instream ecosystem below the main water diversion. The strategy assigned priorities in the following order: 1st to environment, 2nd to water consumption, 3rd to energy. This regulatory adaptation is a change from current conditions where there is an expectation that all uses will be satisfied which translates into confused and ad hoc decision making at moments when supplies are constrained.

Figure 4 shows a Tableau dashboard that illustrates results for the Otún watershed and its assessed vulnerability where this regulatory adaptation strategy is implemented. Each column shows one of the 7 system performance metrics identified by stakeholders and each row shows a combination of external factors about which there is uncertainty, covering a range of possible futures. In this case, the rows incorporate all possible combinations of the four key uncertainties, combining 6 climate projections, 3 demographic change trajectories, 2 per capita use assumptions, and 2 hypotheses related to water losses in the distribution system, for a total of 72 scenarios. The figure's colors denote the level of vulnerability as a percentage of times the system underperforms relative to user-defined performance thresholds. The red indicates failures occurred with respect to a threshold more than 50% of the time and the green indicates failures occurring less than 50% of the time.

Results indicate that with this regulatory adaptation of water allocation priorities, the main vulnerability of the system is for energy provision, as this user would not receive water until the needs of the cities were met and the instream flow requirements were satisfied. The vulnerability map (Figure 4) for this adaptation option maintains e-flow coverage (2^{nd} column), urban coverage of Pereira (3^{rd} column), and urban coverage of Dosquebradas (4^{th} column) at low vulnerability levels (failures much less than 50% of the time under all scenarios). However, the energy coverage (5^{th} column with requirement of 5 m3/s) shows high vulnerability for most uncertainty scenarios.

A close look at the *páramo* contribution to the río Otún estimated at the multipurpose diversion point shows that the *páramo* ecosystem contributes about 40% of the total streamflow (Figure 5). For critical dry years in the climate scenarios, base flow contributions from *páramo* make up to 80% of total flows in the low flow month of September. This highlights the importance of efforts to invest in 'soft adaptation measures' such as land acquisition programs and restoration of associated strategic ecosystems. The low vulnerability of the water supply system for the city of Pereira is evidently a consequence of the historic efforts made by local actors in maintaining a healthy watershed.

Based on the vulnerability analysis results, an adaptation strategy based on maintaining a priority allocation of 1st to environment, 2nd to water consumption, 3rd to energy is recommended. This type of adaptation measure requires continuous concertation of the parties involved. The results obtained are being shared and socialized with key actors to develop concrete operation rules of the system that conform to this recommendation. Other adaptation options designed to reduce the vulnerability of the energy sector are begin explored, such as variable concessions. This type of adaptation would recognize hydrologic variability adjusting operations to generate more electricity in periods with higher average flows, and setting restrictions for production during dry spells in a manner which reduces the financial burden on the power company.

Figure 4. Vulnerability map for Otún River at the diversion point

The matrix indicates the vulnerability of the system after applying the adaptation strategy identified in percent terms for key performance metric. Green denotes below 50% and red above 50% vulnerability for four of the uncertainties evaluated.

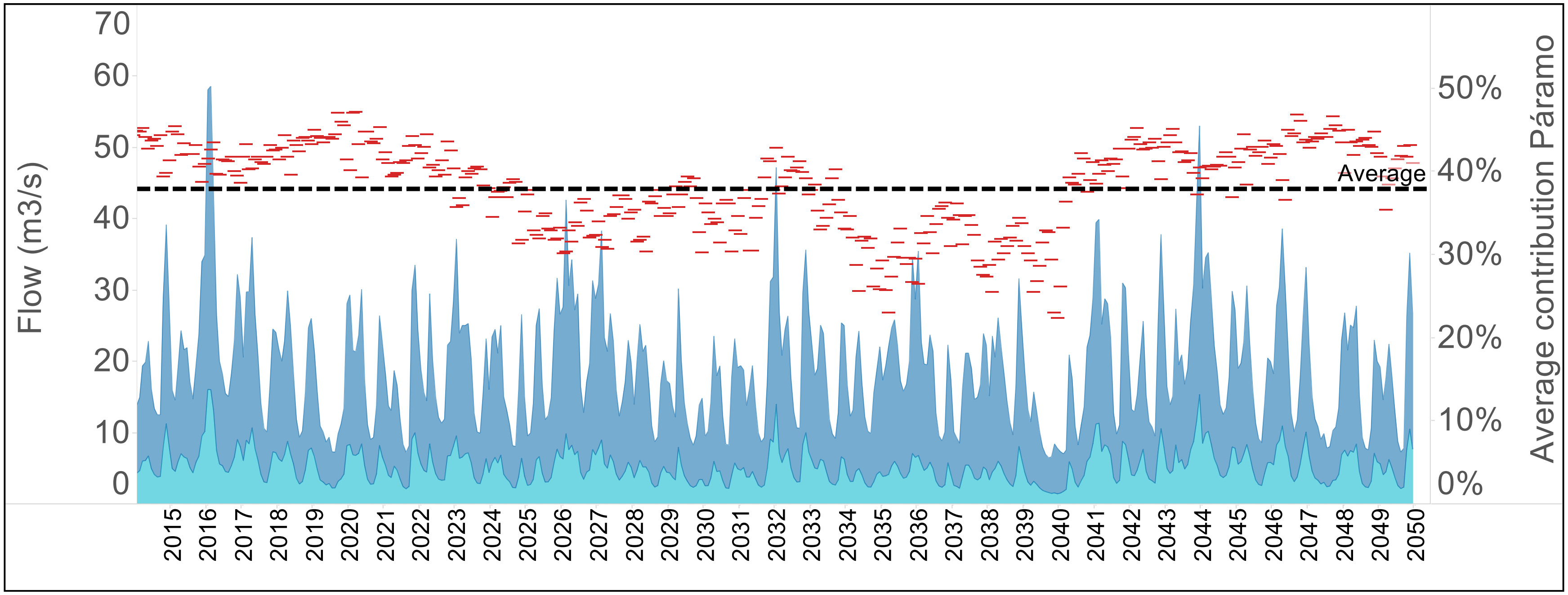


Figure 5. Average of streamflow contribution from *páramo* for the six GCMs used at Nuevo Libaré intake at Río Otún.

The y axes on the left indicate flow, and on the right indicate the average contribution from páramo, which is denoted by red dashes throughout the timeseries. Light blue shows the actual value of streamflow and dark blue the total flows at the point of measurement.

Lessons learned and recommendations

The application of the RDS program in the Otún watershed highlighted the fact that, prior to the project, local institutions and academia did not possess the technical capacities to identify watershed scale climate adaptation options. In addition to the modeling knowledge to produce information for decision making under uncertainty, the learning through the participatory methodology provided sufficient regional knowledge to enable future applications of the RDS process in the region.

The process also highlighted that climate change is not only a challenge requiring a technical solution. It poses environmental, cultural and political challenges that requires that societies evolve and that institutions transform to confront the adaptation challenges. For instance, technical and participatory process efforts enabled a constructive dialogue with the IDEAM, which evolved from a guarded position in terms of data sharing to an open disposition to cooperate with regional institutions. The willingness to share data, as part of the new National Hydrologic Information System that was being developed by IDEAM in parallel to project implementation, bodes well for the construction of WEAP models in support of RDS processes in other watersheds. However, results also have implications for other key stakeholders, such as those inhabiting the *páramo* areas. Despite the importance of *páramo*s, conflicts associated with land use persist even within protected areas which threatened the current conservation efforts. Since working with communities was beyond the scope of this project, a recommendation is to develop a process oriented to improve water governance that reaches out to those that live in water supply regions of the watershed. These efforts should create greater outreach than existing efforts led by the local CARs and water utilities and is entirely consistent with the recognition that in post-conflict Colombia the ability of residents to ensure livelihoods in rural areas will determine the opportunity for development and stability downstream

Despite the progress made, there are challenges for ensuring the sustainability of the tools for carrying out climate analysis into the future - in particular their need for continuous updating -, and of the capacity built with technical groups within key water management institutions – which require time and support to transition from understanding the modeling and analysis carried out on the project to using it as part of their daily activities.

For the tools to remain useful, it will be necessary to continue updating the WEAP model of the Otún river. Updating of the climate and adaptation analysis tools can be achieved as long as climatic information gathered within the watershed is improved with new instruments. The data produced can be used to improve the calibration and validation of the models. A goal here is to improve analysis of the *páramo*s which currently possess a low density of hydro-climatologic stations leading to a situation where the existing historical information is scarce. The importance of *páramo* for its hydrologic regulation capacity calls for improved quantity, quality and availability of information. It is key that instrumentation programs, which include installing equipment and recording hydro-meteorological data, of these ecosystems are strengthened through monitoring initiatives.

One way to face the challenge of capacity building is to strengthen regional universities. In this particular case, the research center that participated in the project is using the models built and the WEAP training materials available to train new professionals. To date, over 100 students in the 2nd year of a 5 year program have been trained in the basic use of WEAP. This group is also using the models to support new research questions about climate adaptation such as comparative studies of small subwatersheds that have different responses based on land use practices. This type of new analysis may lead to new opportunities to support decision making by CARs and water utilities in their planning efforts.

Major accomplishments

This Otún river component of the project resulted in two models being built, one based on a monthly that provides information at the multipurpose water diversion, and one at daily time step for *páramo* hydrology. Both models are ready to be used, updated and refined for decision-making support.

Regarding capacity building, the project led to a decision to teach WEAP at a hydroclimatologic course available through environmental studies at the university. Through this course, it has been possible to train more than 100 students in the basic modules of the tool. For this, the local university has generated 3 videos for building a base model (Video 1, Video 2, Video 3), which explain the general functions and highlight its potential use in integrated water resources management. Students have shown great interest in deepening their knowledge about WEAP. A total of three students have used WEAP in their theses. In addition to the academic learning, several WEAP training sessions were given to local CAR and water utilities. Basic WEAP modules of model conceptualization were covered during these sessions, including basic water quality modeling and Tableau Visualization. A total of six sessions with an average assistance of eight people were given.

Evidence of impact

One of the mandated water related plans in Colombia is the Water Resources Management Plan (abbreviated as PORH in Spanish). This plan involves a participatory process whereby water allocation and management actions designed to meet water quality and aquatic ecosystem objectives are set. CARDER, the CAR with jurisdiction in the Rio Otún watershed, developed a PORH and decided to contract with UTP so that the WEAP model constructed under the current project, deployed within the RDS framework, could be used to support the development of the plan. That there is both an interest in and the capacity to use these tools in this way confirms the impact of the project in this region. Moreover, the output of this endeavor led to the incorporation of climate considerations in water and territorial planning. Before the project a more standard plan based on guidelines that did not include climate change considerations would have been the only option available to pursue.

Regarding planning instruments, the PORH of the Otún river was contracted and finished in a process parallel to the project, using the WEAP model. This parallel implementation highlighted the importance of incorporating climate analysis and RDS into watershed planning. Although the specifications of this planning instrument required conventional scenario analysis, climate analysis was incorporated using the RDS process. This PORH represents an opportunity for the Otún river planning processes in that this effort led to the construction of a model on a daily timescale for the whole watershed, which built upon the monthly watershed and daily *páramo* models achieved within the scope of the project. This project deepened the RDS learning within the local CAR and allowed for the incorporation of climate uncertainty as a key variable in water and land use planning of the territory. This is the sort of local, bottom-up, learning that can inform national level policy and incorporate climate change considerations into nationally mandated environmental planning instruments.

A unique feature of project activity in the Rio Otún watershed was the participation of the water supply utility for the City of Pereira, Aguas y Aguas. For a number of years, this partner has been considering various water management options to prepare Pereira for changing future conditions defined primarily by population growth and changing regulations related to water quality and environmental flows. As part of the project, these actions were examined through the lens of climate change uncertainty as well, leading colleagues within Aguas y Aguas to consider them not just as potential water management options but as potential climate change adaptation measures (this is detailed in Appendix 1 where project indicators are described and SEI-13 corresponds to the description of these adaptation measures). This analysis, and the associated revaluation of these actions, motivated the decision to include them amongst a set of climate change adaptation actions identified by the project.

La Vieja Watershed

Context La Vieja Watershed

The La Vieja watershed drains the western slope of the central mountain range of the Colombian Andes. This basin is part of the eco-region named the 'Coffee Region', and is shared by the departments of Quindío (68%), Valle del Cauca (22%) and Risaralda (10%). This shared jurisdiction requires that the basin be managed by the three CARs from the three departments which are the CRQ, CVC, and CARDER (Figure 6).

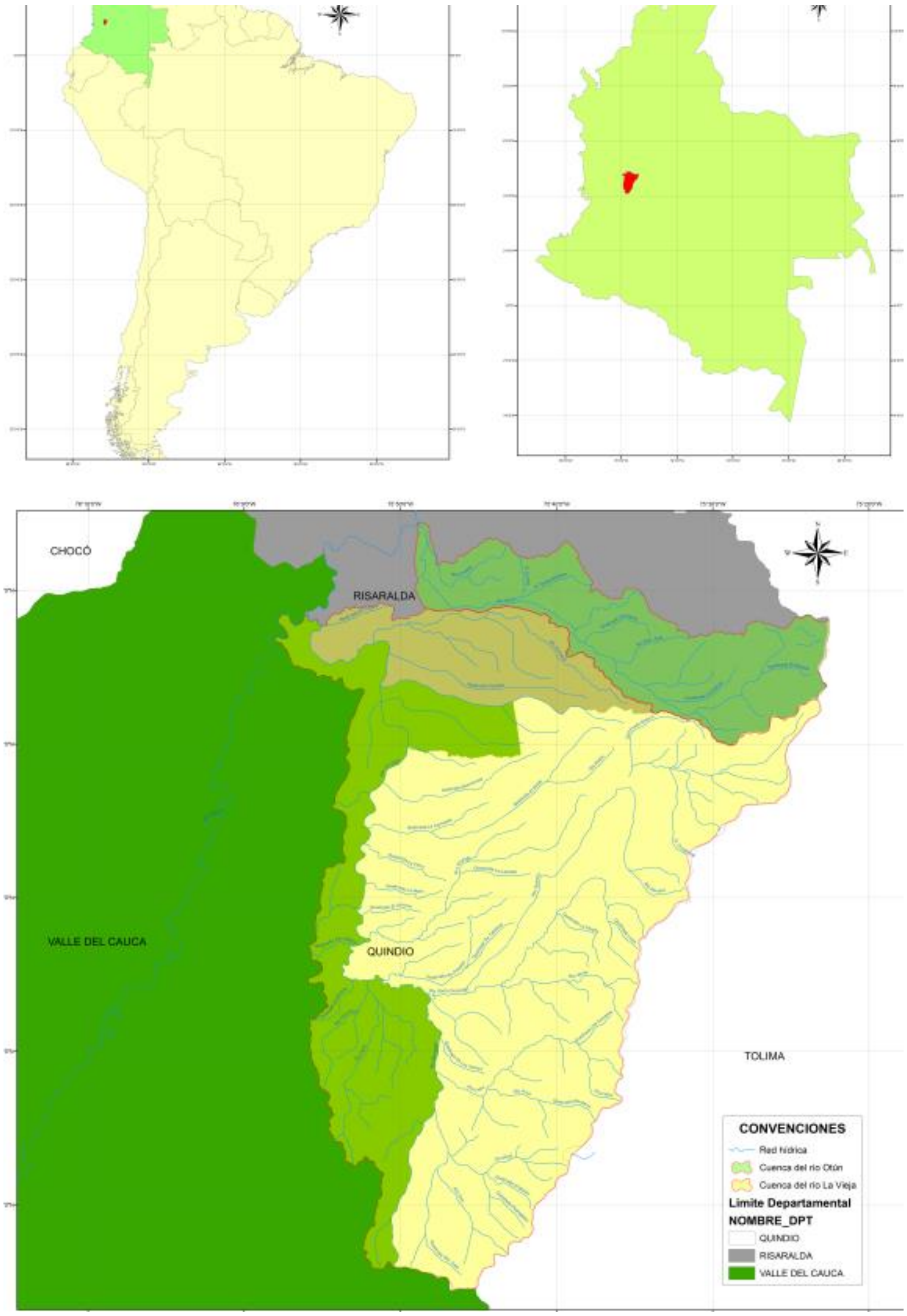


Figure 6. La Vieja watershed location
La Vieja location next to the Otún watershed
highlighting the partition between departmental jurisdictions as indicated by the colors

The La Vieja river mainstem is formed by the confluence of the Quindío and Barragan rivers, and it is one of the main tributaries to the Cauca River, with 360 km of first order drainage which inflow to the main stem, and a water supply production of 34 litters/s/km2 which is equivalent to a hydrologic supply of 2.975,74 Mm3/year.

Actors from the watershed were convened to provide information to contextualize the climate change challenges and adaptation options. Interactions through participatory engagement with a similar set of actors in the Otun River case led to the identification of key watershed features and development trajectories which were classified as either uncertain factors or potential adaptation options. In addition to water utilities, government institutions, and research groups, representatives from the coffee sector provided their perspective and shared information relevant to water use and water pollution associated with coffee production.

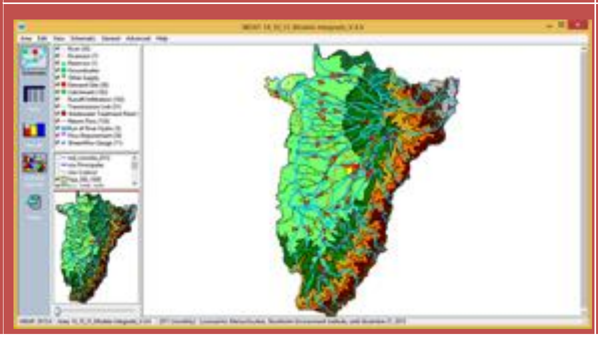
The program – La Vieja watershed

The most relevant aspect of the program in this watershed was the modeling of wastewater treatment and water quality integrated within the quantification of the water supply and demand of the system. This activity required modeling elements – such as watersheds, canals, reservoirs, demand sites - to represent wastewater treatment and water quality in WEAP – in particular the critical elements of the wastewater system of the city of Pereira and of the water intake for the downstream city of Cartago - in addition to the rainfall runoff estimations. The water quality modeling aspect was advanced by CINARA, a research group known nationwide for their experience in water quality and wastewater treatment, while the water quantity component was advanced by CIDERA, a leading Quindío-based research team with experience in water management.

Water quality modeling required representations of wastewater discharges throughout the watershed including those associated with coffee growing and processing. Water quantity modeling required creating a model structure for the Rio La Vieja, connected to the Otún watershed, to represent water demand and supply which then could be connected to the water quality modeling. The two challenges of water quality and quantity required parallel analysis that were ultimately integrated. The model was built as a step towards the consideration of climate uncertainty for this region developed through the application of the RDS participatory process and the subsequent definition of the ensemble of scenarios.

The end result was an integrated WEAP-QUAL2K model that could be used for the evaluation of water quantity and quality of the La Vieja watershed. Using this model enabled the evaluation of the benefits of specific strategies to control water quality impacts at the watershed scale that emerged from the participatory process and the completion of an XLRM contextualization (Table 4).

Table 4. La Vieja watershed XLRM.

X	L
Climate change Demographic change Per capita use Water losses in distribution system Agricultural dynamics	No strategy Wastewater treatment system Domestic Sector Coffee Sector E-flow Reduction of unaccounted for water (RIANF)
R	**M**
	DBO levels Municipal water coverage E-flow coverage

Note: The R image of the WEAP model is presented here for illustrative purpose, not to convey information

Water quantity adaptation strategies identified included reducing unaccounted for water which is a form of illegal withdrawal of water from streams, and enhanced compliance with e-flow requirements. Water quality adaptation strategies identified included the implementation of wastewater treatment plants for the domestic municipal sector and for the coffee sector, given that together these sectors contribute up to 70% of the total point load of the La Vieja river from its tributaries – the equivalent to 11 tons of DBO_5/day. By simulating water quality and considering the implementation of the two strategies for controlling water pollution, it was possible to assess? the combined effect of municipal wastewater treatment plants and of improved wastewater management efforts in the coffee sector.

Performance of adaptation options – La Vieja watershed

As indicated above, the main strategies for water contamination control that were evaluated included wastewater treatment systems for the municipal and coffee sectors. For the urban sector, the treatment plant proposed corresponded to the PSMV or municipal plans for wastewater treatment and sanitation. Each potential municipality's treatment system was assigned a unique initial start-up year, its on level of wastewater coverage and its own efficiency in DBO_5 removal, consistent with available plans. This information was provided by the CARs with jurisdiction within the study watershed. For the coffee sector, the system proposed included an anaerobic wastewater treatment to process waste from coffee production. Small and medium size coffee farms were represented in a distributed form according to their location in the watershed. In the coffee processing steps, the wastewater treatment plan simulated efforts to treat wastewater resulting from processing the cherries to obtain the bean for commercialization. These plants were represented to include a DBO_5 removal efficiency of 70% (Cenicafé, 1999). This strategy envisaged a gradual application of wastewater treatment, assuming that by 2025 50% of small and median size coffee growers had treatment implemented, and by 2050 all had implemented the strategy.

For the 2011-2040 period the scenario in which no wastewater management strategies were implemented shows a visible decline in water quality because of the increase in population (Figure 7 – blue line). This trend is exacerbated by higher municipal residual load and an increase in contaminant load given an increase in coffee production. The evaluation of the DBO_5 for the same period with municipal wastewater treatment plants implemented shows an improvement in the water quality in the river along its profile (red line). Implementing the wastewater system treatment for the coffee sector shows a reduction in DBO_5 and an improvement in water quality along the main stem of the river (green line). This strategy presents better results in terms of reducing DBO_5 than the municipal wastewater system treatment for this watershed. However, the combination of both wastewater treatment strategies show even greater water quality performance along the La Vieja (purple line). With this strategy, DBO_5 is reduced up to 2 mg/L with respect to the no-action trend in the outlet to the Cauca River at the 90th km downstream of the headwaters of the river.

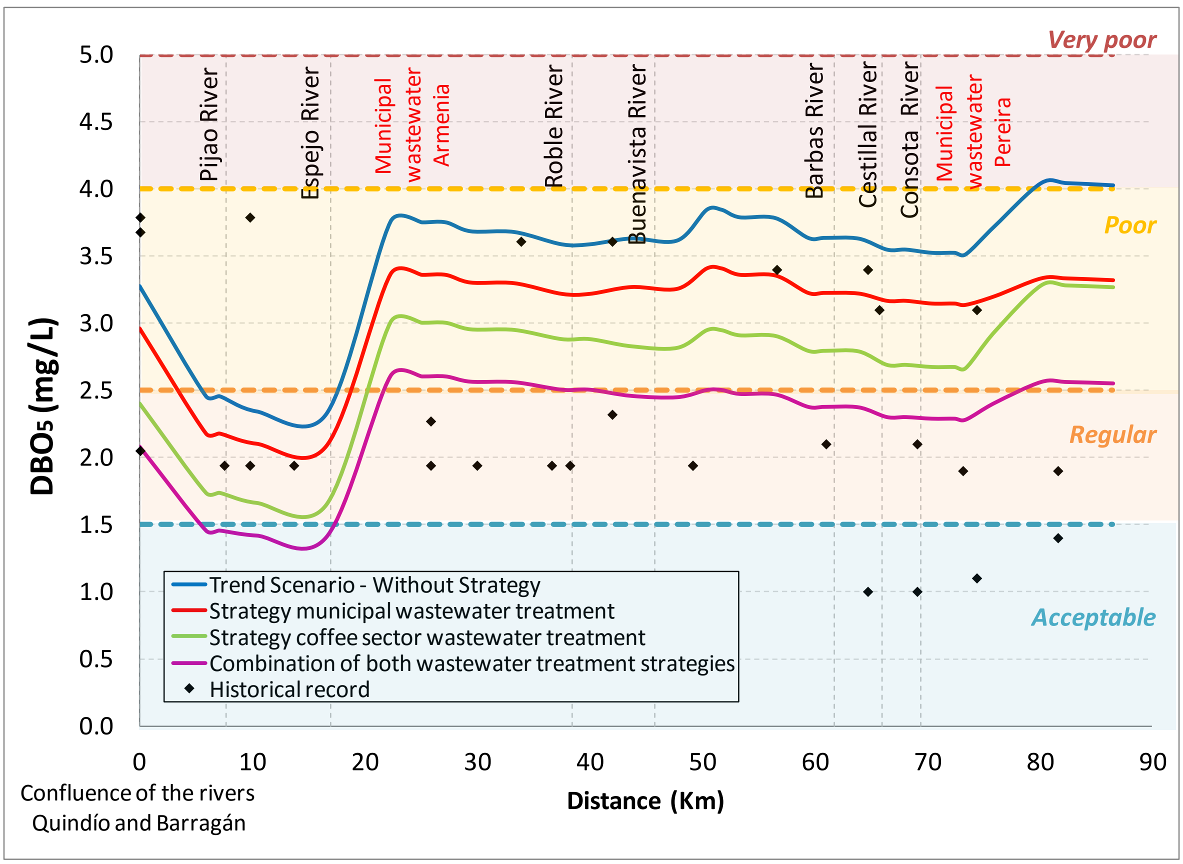


Figure 7. Water quality profile for La Vieja for 2040 with the implementation of strategies

X axes indicate the longitudinal direction of La Vieja River from upstream (left) to downstream (right) to the confluence with Rio Cauca. Each line of the long profile indicates a different scenario as *described by the legend and the colors. Key features are indicated such as wastewater inflows and river confluences.*

For the water quantity analysis, it was necessary to integrate a model that included the Otún and La Vieja watersheds. This model included the same level of uncertainties as those described for the Otún system, but including an additional uncertainty associated to the increase in agricultural areas under coffee production. For the integrated model of water quantity, the reduction in unaccounted for water and enhanced e-flows were included as potential water management adaptations to climate change (Table 4, corresponding to the Ls or strategies).

The integrated model included 37 tributaries to the Rio La Vieja and 17 urban demands, 4 hydropower demands represented by small hydropower plants on the Quindío River, as well as agricultural and coffee production water demands. Allocation priority was given first to e-flows, followed by human consumption and finally to other water uses.

The combination of the uncertainties and adaptation strategies (from Table 4) generated a combination of 1728 possible scenarios, which were run as part of an automated ensemble. The set of scenarios produced a large dataset of outputs for each of the performance metrics identified by stakeholders as part of the participatory process (from Table 4), that were analyzed using a visualization tool.

The main results of the watershed climate vulnerability analysis of the 16 urban demands for the time horizon investigated indicated that the towns of Armenia, Circasia, La Tebaida and Salento have higher vulnerability in terms of supply constraints under most uncertainty scenarios analyzed (Figure 8). . Each column shows one of the 16 system performance metrics, in this case associated with urban demands for the municipalities in Quindío. Each row shows a combination of external factors about which there is uncertainty to encompass a range of possible future scenarios. All the metrics and uncertainties were defined by stakeholders. This graphic incorporated four dimensions of uncertainty; in this case rows incorporate all possible combinations of the four designated uncertainties combining 6 climate alternatives, 4 demographic change scenarios, 2 sets of assumptions related to per capita water use, and 2 hypotheses related to water losses in the distribution system, for a total of 96 scenarios. The figure’s colors denote the level of vulnerability as a percentage of times the system underperforms with respect to a threshold performance level defined by stakeholders. The red scale indicates the level of vulnerability (deep red, higher vulnerability).

Given the projections of vulnerability for the urban demands, various adaptation options were analyzed for possible reductions in vulnerability. In Figure 9, the vulnerability range is represented in the following color scheme: green represents a positive change (reduction in vulnerability), a red color represents a negative change (increase in vulnerability, and gray colors indicate that there were no significant changes associated with the adaptation action in question. The intensity in color varies from dark green (large improvement) to red (large increase in vulnerability). These results provide a dynamic interface to interact with stakeholders regarding the implications of specific adaptation actions. In this particular case, the two adaptation options are presented in the columns and compared against each other.

The RIANF[2] (reduction of unaccounted water) option reduces vulnerability to urban demands, while complying with e-flows would increase it.

Here it is worth noting that the options to increase e-flow requirements would be pursued primarily to improve ecological and water quality conditions in the rivers downstream of the points of water diversion. This is a key performance metric as it is in other rivers in Colombia. Absent any change to either reduce the demands associated with water diversions or to increase the supply of water available at the point of diversion, there would be a direct tradeoff between the diversion of water and the decision to let it pass in order to improve downstream conditions. Fortunately this is not the case as there are opportunities to decrease demands (the case of reducing unaccounted for water was considered as part of this analysis), and investments to improve conditions in the upper watershed could yield more water at the points of diversion during key low flow periods. This strategy will be considered as part of land-use planning efforts being undertaken using the tools developed by this project in collaboration with municipalities located in the upper portions of the watershed (POTs or in the case of smaller municipalities EOTs).

[2] This strategy is well studied in the literature, and includes reducing the unaccounted water by reducing non-authorized water use, improving water use quantification, reducing water meter reading errors, improving data management, and reducing water losses in conveyance systems, among other strategies

Figure 8. Vulnerability map of urban demands in Rio La Vieja

Vulnerability map on a scale from 0-1 and color gradation in reds. Each column indicates a different municipality and the darker colors indicate higher vulnerability to the different sets of uncertainties.

Estrategia	Clima	Poblacion	Consumo	Eficiencia	Armenia	Alcala	Buenavista	Caicedonia	Calarca	Cartago	Circasia	Cordoba	Filandia	Genova	La Tebaida	Montenegro	Pijao	Quimbaya	Salento	Ulloa
Sin Estrategia	Historico	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	0.00%						0.00%				0.00%				0.00%	
	P(+16%) - T(+1.1 °C)	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	0.00%						0.00%				0.00%				0.00%	
	P(-21%) - T(+1.1 °C)	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	0.00%						0.00%				0.00%				0.00%	
QE	Historico	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	0.00%						0.00%				1.67%				0.00%	
	P(+16%) - T(+1.1 °C)	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	0.00%						0.00%				1.25%				1.30%	
	P(-21%) - T(+1.1 °C)	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	0.00%						-0.76%				0.00%				-0.26%	
RANF	Historico	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	-4.92%						-3.40%				-4.17%				-4.36%	
	P(+16%) - T(+1.1 °C)	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	-3.70%						-2.53%				-2.50%				-1.30%	
	P(-21%) - T(+1.1 °C)	Crecim_Alto	Aumento (+10 l/hab-dia)	Perd_actual	-6.52%						-4.53%				-5.15%				-3.93%	

Valores de medidas

-0.1000 0.1000

Figure 9. Change in vulnerability of urban demand with e-flows (QE) and reduction of unaccounted water (RIANF) in the Rio La Vieja

Changes in vulnerability are indicated with color schemes according to the legend. Increased vulnerability due to a given strategy indicate negative effect on certain metrics as shown by red gradations, and vice versa for strategies that can improve the conditions which present a green gradation.

Lessons learned – La Vieja

For the coffee sector, and particularly small and medium coffee farmers, to be able to implement new wastewater treatment strategies it will need to obtain economic resources. Additionally, the evident reduction in climate vulnerability in terms of water quality from coffee treatment wastewater treatment plants, calls for greater control by the environmental authorities over wastewater from the coffee sector to comply with water quality objectives. These may requires mechanisms such as establishing contaminant loads by sector, and implementing programs to incentivize the adoption of treatment technologies.

For the implementation of the combined strategy of the domestic and coffee sectors, it is necessary to develop a financial plan to implement each of the strategies individually. This evaluation should include a cost-benefit analysis of the gradual implementation of the strategies by sector to guide the selection and ultimate financing of the projects.

The water quality analysis could also be complemented by introducing additional water pollution control measures such as domestic wastewater reuse, implementation of low water use devices within households and cleaner production within the industrial sector. The tools and capacity are already in place in the region to continue this analytical process which can provide invaluable information about regional decisions for adaptation. The combination of such strategies, implemented at a watershed scale, could result in a more effective cost-benefit strategy that can help achieve water quality objectives responsive to societal needs.

Urban demands present higher vulnerability in the towns of Salento, Circasia, Armenia and La Tebaiada. These municipalities are all dependent on the Quindío watershed and are of great economic importance to the region in terms of tourism and as economic development centers. As such, the Quindío river presents higher levels of stress over water resources which can have implications for economic activities. The tradeoff is that the scenarios analyzed give a higher priority to e-flows. In this case, based on the uncertainties and adaptation strategies considered, it was possible to maintain e-flows at the points of greater diversions in the Quindío river. However other points of diversions including the Tebaida diversion, PCH El Bosque, PCH Campestre and La Unión were not able to sustain required e-flows within the river below these points of diversion under the different scenarios.

According to the climate scenarios and economic growth trends obtained for La Vieja and its tributaries, if nothing is done there will be implications in terms of reduction of water supply and increases in water pollution levels as a result of socioeconomic activities of the region. This situation should be the departure point to create an action plan that seeks to increase stakeholders' engagement in water resources and the environment planning efforts, and to mobilize funds to support the adaptation actions that they identify.

Major accomplishments

With the La Vieja WEAP model, CRQ, CARDER, CVC now have a management and planning tool to support decisions for water resources, providing a greater understanding of the functions of the water system and enabling a supply-demand analysis at a temporal and spatial scale that encompasses climate effects at the watershed dimension.

The inter-institutional and interdisciplinary work during the implementation of the project was complex and constituted a challenge throughout the project. This reflected the difficulties in terms of coordination to implement integrated water resources management.

Key accomplishments of the project were the strengthening of research team capacities, the production of tools for decision making and the capacity-building to use them for future planning processes. The flexibility of WEAP to work on integrated water quality and water quantity representations led to an integrated model that can help understand the dynamics of a complex, interconnected system.

Evidence of impact

Activity in the La Vieja system produced two key indicators of impact. The first involved a decision to transfer the experience to another location, as demonstrated by the CVC decision to use the WEAP-based RDS approach, through a contract with UniValle, to develop a PORH for the Bolo-Frayle sub watershed. The second involved the decision by single municipality in the La Vieja sub-watershed, Salento, to refine the analysis conducted at the watershed scale in support of a EOT, which is the land use plan for a smaller community. Rather than develop their own analysis of climate change inputs, this important headwater community used the project analysis to carry out a more refined level of analysis. One important evidence of impact is that prior to the project, local water managers had never succeeded in carrying out and integrating water quantity/water quality analysis as part of a watershed planning effort. Now they have important technical capacity in place for future planning efforts.

Finally, an important outcome of the project is the development of research and academic programs. This has created a regional capacity to apply knowledge and tools in academic programs such as sanitary and environmental engineering programs at the undergraduate and graduate levels, as well as in integrated water resources and in environmental modeling.

Alto Magdalena Watershed

Context Alto Magdalena

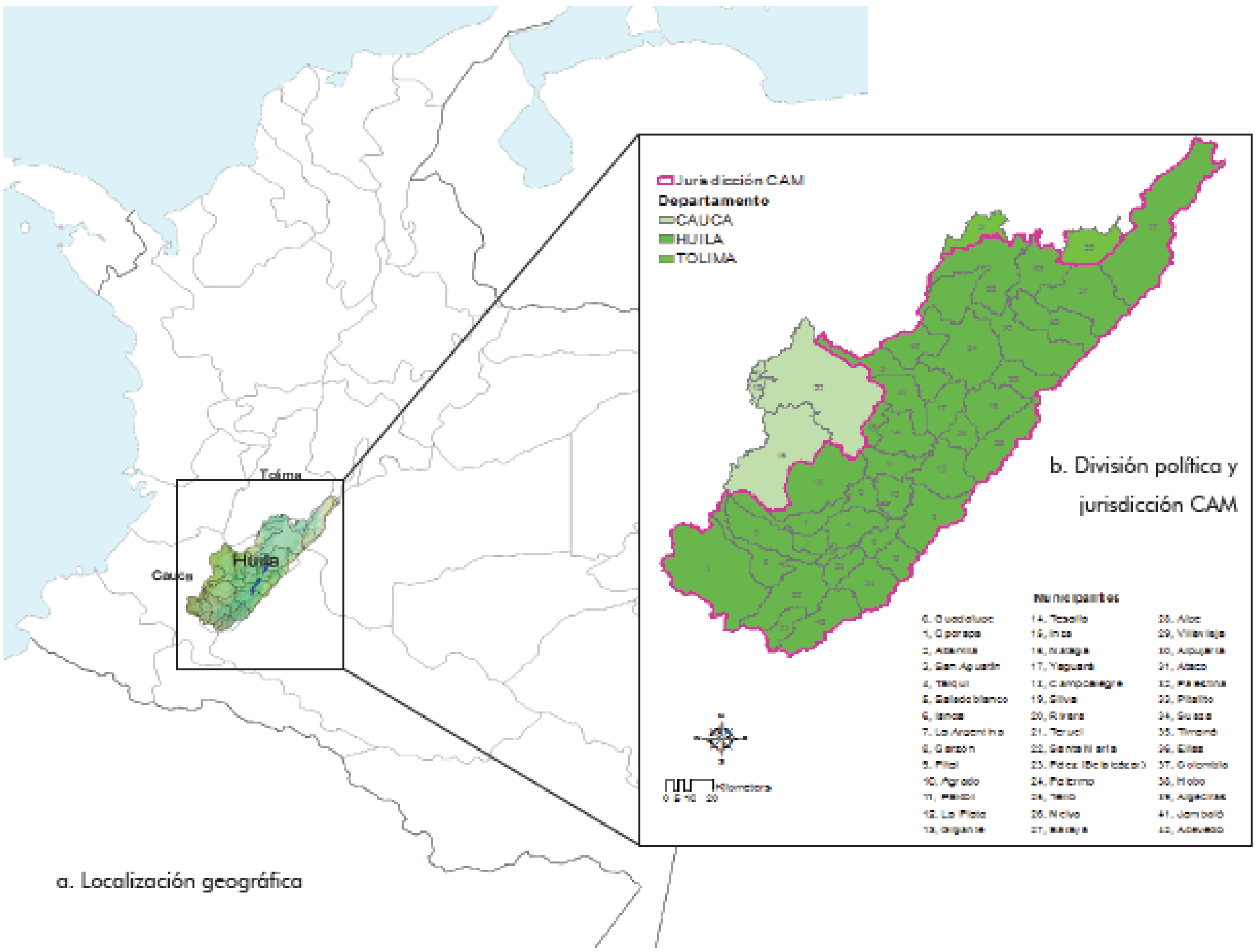


Figure 10. Alto Magdalena watershed location

Alto Magdalena watershed at the headwaters of the Magdalena River. The Huila department and the CAM jurisdiction have an area smaller than the watershed as indicated in the colors.

The Alto Magdalena watershed begins at the ‘Macizo Colombiano’ where the central and eastern mountain ranges of Colombia converge within the Huila Department in the southern part of Colombia (Figure 10). The watershed has an elevation range from 5750 meters above sea level at the Nevado del Huila on the boundary with the Cauca Department, to 325 meters above sea level at the point where the Magdalena River flows into the Tolima department.

The total area of the watershed is 22,171 km^2 which encompasses the whole Huila Department, and parts of the Paez, Patá and Cabrera Rivers shared with the neighboring departments of Cauca and Tolima, respectively. Water supply from this watershed runs at an average of 555 m3/s, with a minimum of 215 m/s during the dry period, which is critical as this water contributes substantially to the larger, and vitally important Magdalena-Cauca basin.

Since the Alto Magdalena is a large area, the development of mandated water and watershed planning instruments is typically defined at smaller scales within subwatersheds where water management institutions, agriculture communities and urban entities can actually exert water management actions to improve water management outcomes. As a result, adaptation measures and watershed modeling were considered not only for the mesoscale of the Alto Magdalena watershed but also for some of its tributaries including: the Río Neiva: the Río Ceibas; and The Río Aipe (Table 5). The problem formulation in these basins was developed during an initial overarching XLRM participatory process that took place in October 2013. As a consequence, the higher level watershed context developed for the Alto Magdalena watershed needed to be scaled down to the individual subwatersheds in which the project set out to support planning processes For this, other participatory processes of consultation, cooperation and co-learning occurred through meetings, visits and work with relevant actors.

Evidence of impact

Colombia invested a great deal of effort in the development of National Water Study (ENA) that attempted to calculate some high level indicators related to the status of water resources within the country. Having done so, the goal was to disaggregate this information by sub-watershed as part of a Regional Water Evaluation (ERA). Both efforts rely heavily on the use of historical data and have limited utility if forward looking estimates of key indicators cannot be linked to model output. For the Rio Neiva sub-watershed in Huila, SEI supported the CAM in estimating changes in ERA indicators from WEAP output under future scenarios. This work was featured at a national workshop on innovation for ERA implementation organized by IDEAM, at which several other CARS expressed their desire to use a similar approach to developing ERAs within their jurisdictions. This prompted IDEAM to include WEAP in a National Water Modeling Center to support the development of ERAs and other plans. This would not have happened without this project.

One example of the detailed work done for the Rio Ceibas watershed shows how the higher level institutional contextualization exercise was scaled down to work with communities. This activity required the adjustment of the technical RDS steps using a more colloquial language to communicate with local actors. The output of this work provided insights into relevant aspects of this watershed as part of the effort undertaken by the local CAR to implement a POMCA in the basin.

Table 5. Alto Magdalena watershed and tributaries under study, and planning processes being supported

Watershed	Area (km2)	Planning process being supported
Alto Magdalena	22,171	Huila Climate Action Plan

Río Neiva	1,062	Regional Water Study (ERA)
Río Ceibas	1,200	Integrated watershed plan (POMCA)
Río Aipe	705	Small hydro development and licensing

The program – Alto Magdalena

The program in the Alto Magdalena watershed followed the structure of the program implemented in the Otún-La Vieja region. The efforts sought to support the development and implementation of the Climate Action Plan for the Huila Department under the leadership of the CAM. Efforts to implement the proposed program had three primary objectives:

1. Develop a set of analytical tools that could be used by the CAM and other regional partners to support the preparation of planning documents for the Huila Department.
2. Build the capacity of experts within the CAM and in other institutions in the Huila Region to use these tools.
3. Work with local academic experts to use the analytical tools to develop the Huila 2050 Climate Action Plan and respond to other regional needs.

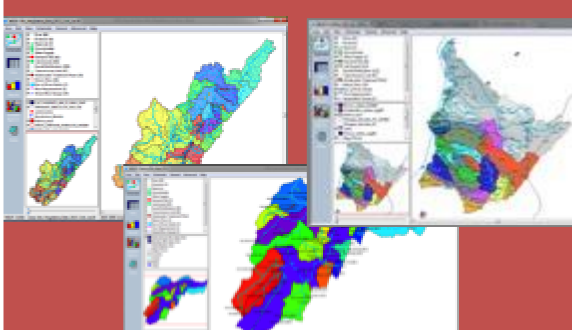
Although the work in this region, as in La Vieja region, followed the RDS approach, the administration of the project was organized through a direct collaboration with the CAM. Activities in Huila between SEI and the CAM led to the creation of a team of CAM technicians that could carry out the technical work in parallel with local universities in Huila, as opposed to being dependent on these academic partners. As a consequence, the CAM involvement in project implementation was much more substantial that the involvement of CARs in La Vieja. The university partner had a more focused technical role – as opposed to the mixed administration, training, and technical role played by the university partners in La Vieja - to support the application of the WEAP software to a specific subwatershed in the Alto Magdalena region to investigate the specific issue of potential climate change impacts on coffee production in Huila.

Due to the focus on the Huila 2015 Plan, the work in Huila was connected to an integrated assessment of climate change mitigation and adaptation opportunities. One of the outcomes of activity in Huila was a contribution to a new planning document: the Huila 2050 Climate Action Plan, which was not legally required by national policy. This document included action lines directly related to the project work in terms of calling for the construction of tools for the evaluation of watershed adaptation actions and the support of efforts to develop mandated water and watershed planning instruments. The action lines of the Huila 2040 plan were supported by the project included modeling of the Alto Magdalena basin under climate scenarios and other future uncertainties, modeling of the Ceibas watershed with a focus on climate adaptation to support the POMCA, and the assessment of hydropower potential under climate change scenarios.

The collaborative development and deployment with the CAM team of the analytical tool kit that considered water management adaptation opportunities in the Huila 2050 Climate Action Plan followed the RDS process. After an assessment and mapping of the key actors, an XLRM evaluation was carried out to identify adaptation strategies. A total of 4 key uncertainties and 5 adaptation strategies were studied.

The Alto Magdalena watershed was divided up into subwatersheds and elevation bands which generated 208 catchments within which rainfall runoff processes were generated. The input datasets included climate information[3], land cover types[4], demand requirements, system operations for Betania (existing), Quimbo (being filled) and Oporapa (possible in the future) reservoirs, 6 small hydropower sites as well as sites where e-flows are defined. The model included 42 water demands associated with cities and towns. A total of 31 points of streamflow observation were used to support model calibration. The historic model ran on a monthly time scale for a period of 1970-2010. The combination of uncertainties and strategies led to the generation of cases within and ensemble run for the 2015-2050 planning (Table 6).

Table 6. Alto Magdalena XLRM

X	L
Historic climate Climate change: three scenarios based on GCMs Population growth: high (3.6%), mid (1.6%), low (0.1%). Two levels of per capita water use: high (200 l/hab*day) and low (150 l/hab*day) Infrastructure: hydroelectric generation of Oporapa	Base case Conservation of protected areas in parks Two levels of reduction in distribution losses: high 20% - low 35% E-flows at reservoir E-flows at PCHs For Ceibas: supply options such as pumping from Rio Magdalena, groundwater pumping up to 67 l/s, diversion from Fortalecillas
R	**M**
	Urban demand coverage Agricultural demand coverage E-flows coverage

Note: The R image of the WEAP model is presented here for illustrative purpose, not to convey information

3 Suministrados por el Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), 146 estaciones pluviométricas y 23 estaciones climatológicas con un periodo de información de Enero de 1970 a Julio del 2011 con datos diarios.

4 *Páramo*, bosque, pastos, café, arroz, cultivos agrícolas, zonas urbanas, suelo desnudo, aguas abiertas.

In addition to the Alto Magdalena model, and through the identification of key planning processes being advanced by the CAM, the project generated windows of analysis with greater detail in some watersheds. Some of these were linked to the action lines of the Huila 2015 Plan. For instance, the Ceibas model focused on supporting the POMCA formulation process by including climate change adaptation elements, and included the Fortalecillas river to consider the development of a potential diversion point. Also, the Aipe model focused on the evaluation of small hydropower and included the indices of hydrologic alteration (IHAs) which are useful inputs for e-flow definitions that might accompany a decision to develop specific small hydropower projects.

Other detailed watershed models were developed in collaboration with the CAM and to support other planning processes. The Rio Neiva model focused on the regional water evaluation (ERA for its acronym in Spanish), a set of indicators that follow IDEAM guidelines that is being implemented as a pilot exercise in the region (Figure 11).

Figure 11 shows how various values of the proposed IDEAM ERA indicators vary according to subwatershed within the Rio Neiva system as a function of different future scenarios, in tabular and map-based formats. Information on the suite of water management options considered using the various model developed in the Alto Magdalena region and the lessons learned in the process is also presented in tables below.

MicroCuenca	IA	IRH	IUA	IVH	IVET
01 - Q. BEJUCAL					
02 - Q. CARAGUAJA					
03 - Q. EL ALBADAN					
04 - Q. EL GUADUAL					
05 - Q. EL QUEBRADON N					
06 - Q. EL QUEBRADON S					
07 - Q. LA CIENAGA					
08 - Q. LA PERDIZ					
09 - Q. LAS DAMAS					
10 - Q. LAS TAPIAS					
11 - Q. LEJIA 1					
12 - Q. LEJIA 2					
13 - Q. LOS NEGROS					
14 - Q. OTAS					
15 - Q. RIVERA					
16 - Q. SANTA LUCIA					
17 - Q. SARDINATA					
18 - R. BLANCO					
19 - R. BLANCO ALTO					
20 - R. FRIO CAMPOALEG					
21 - R. NEIVA_Bajo					
22 - R. NEIVA_Alto					
23 - R. NEIVA_Medio					

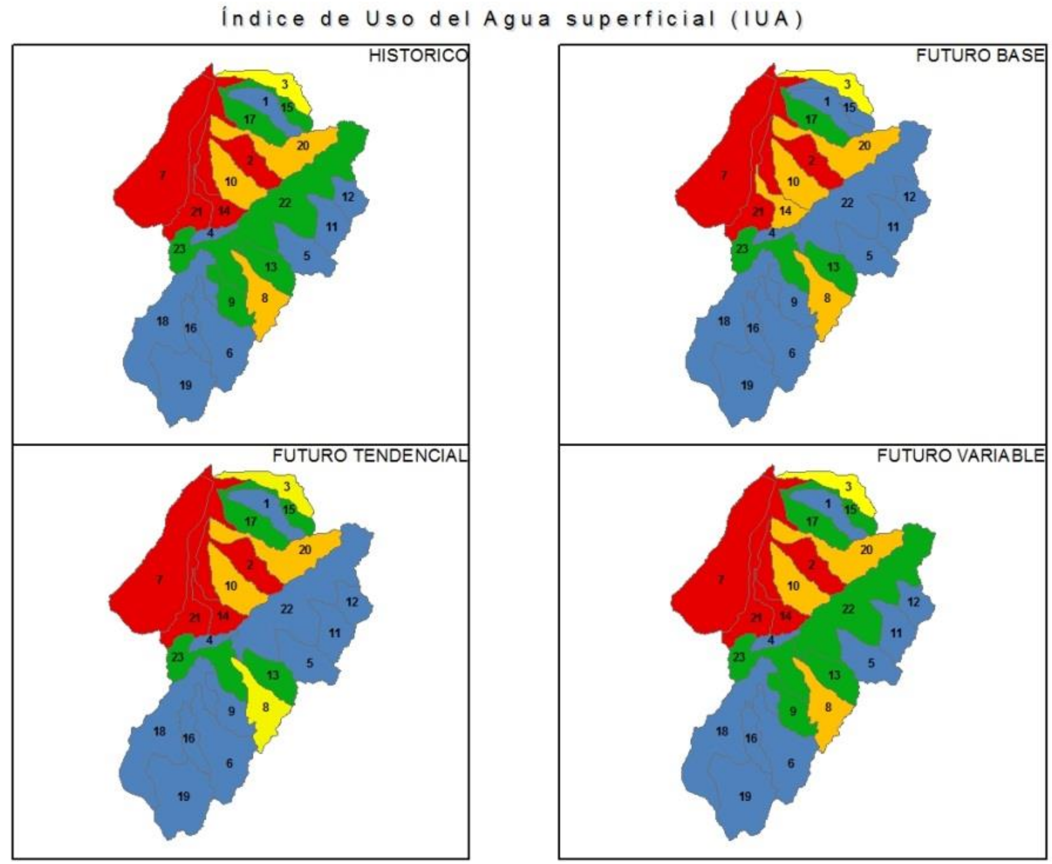


Figure 11. Regional indicators ERA using WEAP, and legend of each indicator.

In Table: IA: Aridity index, IRH: hydrologic retention and regulation index, IUA: water use index, IVH: hydrologic supply vulnerability index, IVET: torrential events vulnerability

Rango (Dh/Oh)*100 IUA	Categoría IUA	Significado
>50	Muy alto	La presión de la demanda es muy alta con respecto a la oferta disponible
20.01 - 50	Alto	La presión de la demanda es alta con respecto a la oferta disponible
10.01 - 20	Moderado	La presión de la demanda es moderada con respecto a la oferta disponible
1 - 10	Bajo	La presión de la demanda es baja con respecto a la oferta disponible
≤ 1	Muy bajo	La presión de la demanda no es significativa con respecto a la oferta disponible

The main ERA indicators are shown for different subwatersheds within the Rio Neiva listed in the table and numbered in the maps. The table shows the indicators for historical conditions, while the maps show the IUA for four different scenarios indicating the trends of this indicators for potential scenarios of climate change

Performance of adaptation options – Alto Magdalena

As the work carried out in the Alto Magdalena study area was multi-faceted, focusing on several different sub-watershed and a range of different scales, the primary adaptation options identified through the development of the WEAP-based RDS approach are summarize in tabular form. As general conclusion that can be reached, however, is that under climate change efforts to balance hydropower development objectives with efforts to maintain and restore environmental flows will take on increased urgency. The use of the new IHA routines within WEAP provide useful in exploring the implications of various options considered.

Alto Magdalena	Conservation scenarios favor ecosystem health and the increase of baseflows and the reduction of peak flows The reduction of losses favorable is max 20% as indicated by the technical document RAS2000 although in some cases this reduction doesn't cover all demands for 100% of population Increase in per capita use affects greatly the water coverage in urban centers. Some simulated PCHs affect baseflow and water availability for other uses, such as the case of Ceibas
Río Neiva	Applying WEAP, it was possible to model 23 streams. The Neiva model included all water demands including rural water use, and agricultural use for rice in the lower part of the basin. The model was useful to generate all the ERA indexes. WEAP does not replace the IDEAM methodology but it is useful to estimate the ERA indexes using an automated procedure
Río Ceibas	Conservation scenarios favor ecosystem health and the increase of baseflows and the reduction of peak flows Although the strategy to reduce losses is favorable, there are still demands that are not satisfied From all options analyzed, pumping water from Magdalena and Fortalecillas is best way to satisfy water demand.
Río Aipe	Small hydro reduces base flows, and climate scenarios make evident that there is greater variability with respect to historic values. Base flow is key for ecological instream health. Simulation without PCHs favor frequency of peak flows and base flows, however the IHA evaluation with PCH indicates that there are higher number of timesteps in which baseflow is low. Stream classification from Infocol and TNC indicates that Aipe is a small, piedmont, rain dependent stream. Baseflow affectation can reduce scour of river bed, favoring the increase in algae diversity.

Lessons learned and recommendations – Alto Magdalena

As in the case of adaptation options, the range over which the WEAP-based RDS approach was applied suggest that lessons learned pertaining to water management in the basin can best be presented in tabular form.

Alto Magdalena	Work on the Alto Magdalena model supporting CAM staff, defining additional details required from the model, and supporting the implementation of scenarios It is key to evaluate strategies to buy land for conservation in strategic zones. It is important to advance an economic estimate of prioritized strategies such as conservation, reduction in distribution system, small hydropower and e-flows. It is key to refine the information about reservoirs operated in series such as Betania and Quimbo
Río Neiva	The validation of WEAP for extracting ERA indicators was reviewed by IDEAM. It has the potential to be implemented in different regions in Huila, as well as in other regions of Colombia.
Río Ceibas	Work on Ceibas model supporting CAM personnel in the definition of climate scenarios derived from the XLRM and on scenario runs The update of watershed land cover to a finer scale will be available within the POMCA process. Climatologic information for 2012-2014 can also be updated in the model Regarding supply alternatives for Neiva, the diversion point could be moved to another point in the basin so the water transfer can happen by gravity. Updating the streamflow and location of local aqueducts Economic evaluation for strategies specially the three options for urban water supply for Neiva.
Río Aipe	Work on the Aipe model supporting CAM personnel in its progress defining IHAs to identify streamflow aspects that could be affected by PCHs and other watershed uses

Major accomplishments

The manner in which the project engaged in the Alto-Magdalena region was dramatically different than the manner in which the project was implemented in the Rio Otun and La Vieja watersheds. The biggest difference was the manner in which the local CAR, the CAM committed staff to work in direct collaboration with the project team, as opposed to relying on partners within local universities to implement the required technical analysis. This meant that while progress on capacity development was less rapid, CAM staff had other responsibilities beyond collaborating with the project, the results are more substantial in terms of the development of capacity within the CAR.

During the last three months of the project, at the requires of the CAM, the project team engaged in developing and supporting the implementation of the work plans whereby the CAM is using the WEAP-based RDS approach to integrate explicit climate change consideration within three POMCAs under development: the Rio Ciebas, the Rio Neiva, and the Rio Suaza. On a regular basis, SEI staff are meeting, via teleconference, with the WEAP team within the CAM to refine the models developed during the project for the task at hand. Collaboration to design POMCA specific data visualization tools in Tableau is also occurring. This is a major accomplishment, as the CAM staff, not external consultants and not partners within local universities, are doing the work to add what will prove to be a unique and innovative set of POMCAs that can be shared with national level authorities as examples of bottom up learning that can advance the manner in which POMCAs are developed across Colombia. In a manner similar to the innovations realized by the CAM with respect to the ERA process being management by IDEAM, the CAM is emerging as a real center of excellence within the CARs community in terms of grappling with the implications of climate change within its standard watershed planning and decision making work flow.

Magdalena-Cauca

Context Magdalena-Cauca

The Magdalena River is the most important waterway in Colombia and South America's 5th largest river. Its main course is 1,500 kilometers long, starting among the glaciers and cloud forests of the Andes Mountains in southern Colombia and flowing north to its outlet in the Caribbean at the city of Barranquilla. The Magdalena River is among the rivers with the highest yields of sediment (560 $t/km^2/year$) in South America. High rates of sedimentation have shaped the morphological and hydrological dynamics that determine a complex pattern of water flows in the lower parts of the river and adjacent floodplains (Figure 12).

The Magdalena basin provides 70% of Colombia's hydropower and the majority of the nation's planned hydropower expansion lies within this basin. Currently there are 26 medium and large reservoirs in place in the basin which generate hydropower, with an aggregate capacity of 6,360 MW and an annual average production of approximately 33,400 GWHr. Two major dams are under construction, with a total installed capacity of 2,800 MW, and other planned mid-size projects will contribute an additional 120 MW. An inventory of potential new hydropower projects includes 30 large projects with an anticipated aggregate installed capacity of 8,450 MW. Upstream dams have the potential to change the flow regime and alter the patterns of connectivity between the river and wetlands, jeopardizing their productivity. In addition, there is potential for small hydropower development, which is mainly conceived for regions that have not access to the electric grid with potential capacity of up to 25,000 MW of installed capacity.

The Magdalena and its tributaries to the Mompos depression has two high flow periods in June and in November-December. Flooding of the river associated wetlands of the Mompos Depression is typically an annual event (Figure 12). Variations in sediment transport and discharge contribute to the ecological complexity and species diversity in these lowland wetlands as these ecosystems depend on seasonal nutrients and sediment replenishment carried by the floodwaters. This highly productive system contains more than 200 native fish species (roughly half of which are endemic) as well as a high diversity of mammals, birds, and amphibians. The wetlands and lagoons are critical stopovers for birds in the western hemisphere's migration flyways and rural communities depend on these habitats for fish harvest and other resources.

A recent catastrophic flood (2010-2013) which coincided with an exceptionally wet La Nina period caused widespread property damage and loss of human life in the lower Magdalena. In response, recent studies have focused on identifying structural and non-structural measures to manage and mitigate flood risk in this area, usually without taking into full consideration the implications of climate change or how changes in upstream water management may affect the flooding dynamics of the wetland systems within the Magdalena basin.

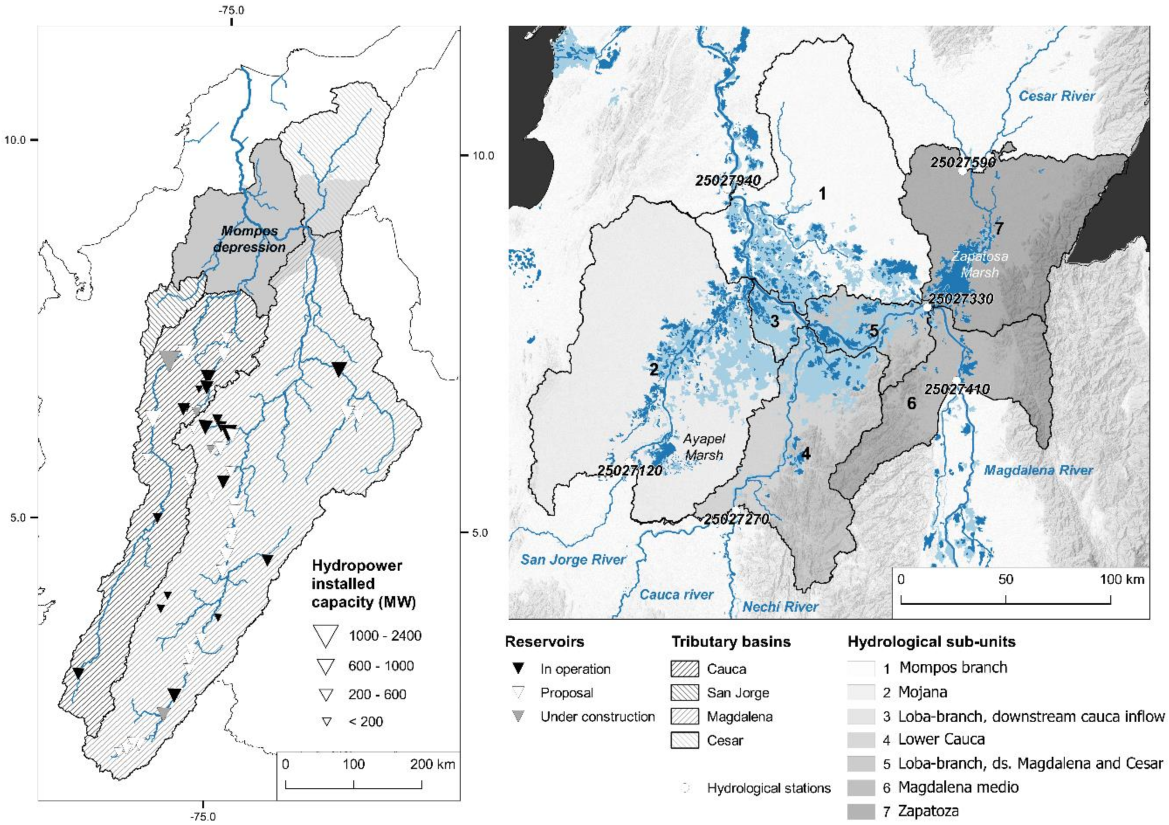


Figure 12. Map of the Magdalena River Basin showing the upstream hydropower reservoirs (existing and projected), location of the low floodplains system, gauge stations referenced in the text.
The maps present reservoirs in operation, under construction and proposed and the inset shows the extent and flooding area of the wetland system in the lower Magdalena.

At the scale of individual subbasins, despite the energy benefits, small hydro can also generate impact on local flow patterns by disrupting the natural flow regime that ecosystems are adapted to. In the process of planning small hydro interventions, it is key to evaluate the potential alterations to the natural flow. Figure 13 shows a Country-wide map for existing and potential small hydro development in the country. The pressure for small hydro development indicates the need to generate analytical tools to define limits of hydrologic alteration at the subbasin level. For instance, in one of the project jurisdictions in the Alto Magdalena there have been at least eight different requests for projects for which the environmental authority needs to advance a licensing process based on information about the local benefits and impacts of these interventions.

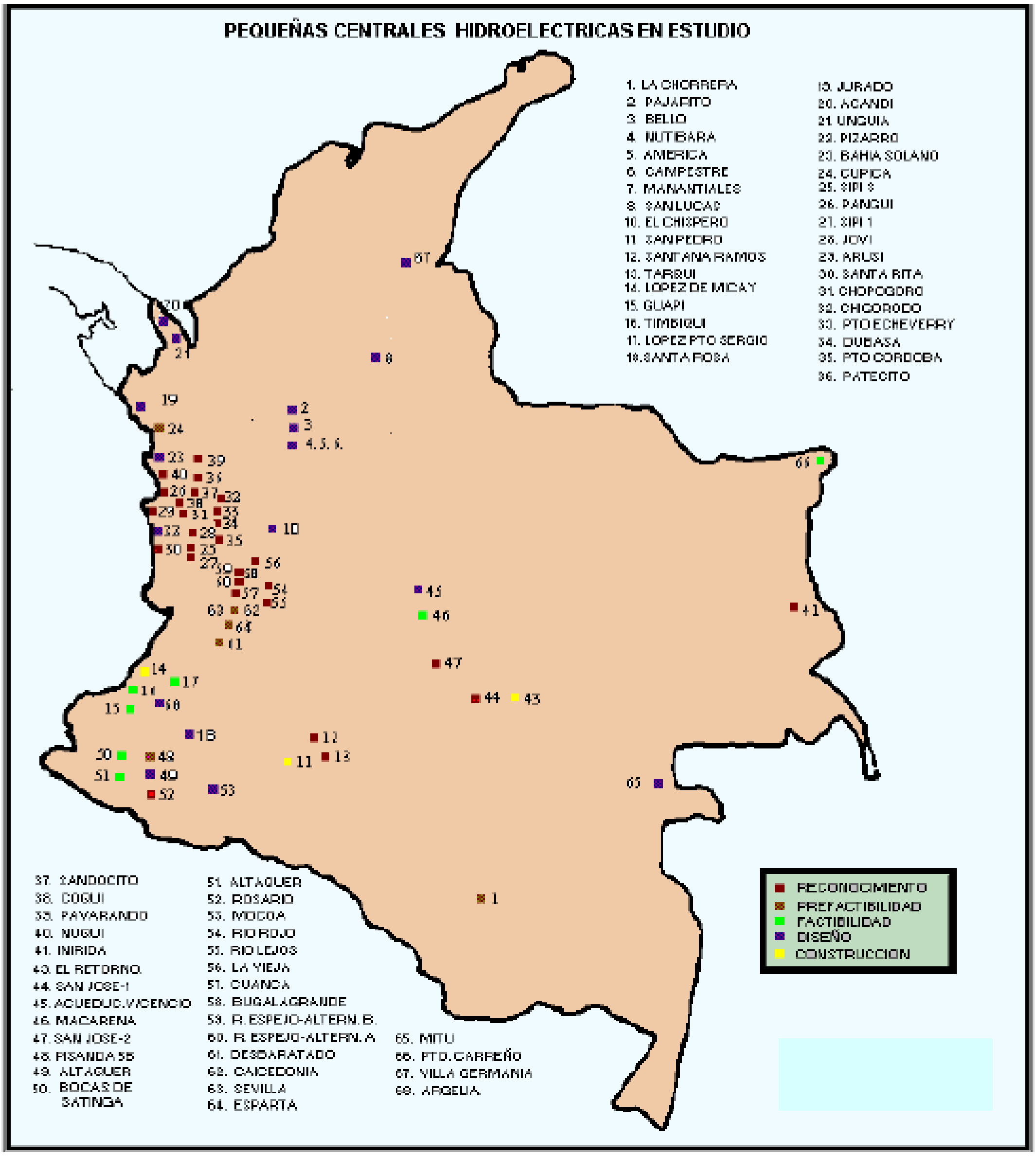


Figure 13. Existing and potential small hydro development in Colombia

Map shows potential locations for small hydro in Colombia as of 2012. These include plants under construction and those in earlier stages of design and feasibility. Source: Research on small hydro in Colombia, by Ernesto Torres Quintero, UniLibre. *http://www.unilibre.edu.co/revistaingeniolibre/revista-12/ar9.pdf*

The program

The program for the Magdalena-Cauca watershed focused on two main components to support the analysis of hydropower pressures in the system. The first component focused on the impact of large scale hydropower by adding functionality to WEAP to enable analysis of floodplain inundation as a function of flows through time along a river network, and potentially other variables of the hydrologic cycle such as evaporation, infiltration and movement between flooding areas. The added WEAP functionality was based on a storage and transfer approach. This divides the river by storage function: main channel, over bank and floodplain and then examines transfers between them. This approach was not intended to provide a precise assessment of river channel and floodplain hydraulics (e.g. flow velocity, flow depth) but rather to provide an accurate depiction of the spatial and temporal extent of flooding under various scenarios. Based on information available on recent flooding in the lower Magdalena system, work was carried out in collaboration with TNC to conceptualize, design, implement and test this new functionality within WEAP.

The second component was focused on small hydro development impact linking WEAP with the Indicators of Hydrologic Alteration (IHA) software developed by TNC as part of its Ecological Limits of Hydrologic Alternation (ELOHA) initiative. As part of an earlier collaboration with SEI, TNC-Colombia had classified sub-basins within the Magdalena-Cauca system in terms of their ecological integrity and importance (Freshwater Ecosystems Conservation Portfolio) and classified the observed flows from hydrological monitoring stations into 23 river types grouped into 6 main river families, based on IHAs. Using expert knowledge input, hypotheses for ecological response to hydrologic alteration were defined in order to generate environmental flows prescriptions for each class. Working in close collaboration with TNC-Colombia, SEI programmed routines into WEAP that allow for the calculation of critical IHA metrics based on simulated flows.

Performance of adaptation actions – Magdalena Cauca

The large-scale analysis of the whole macro-basin was useful to understand the potential impacts of large hydropower development at the Magdalena basin level. From a baseline that included the existing dams and those under-construction, we analyzed the potential impact of increased regulation of water flows from proposed reservoirs upstream of the wetland system. The storage capacity of hydropower reservoirs in 2010 was equivalent to nearly 5% of the average annual runoff volume. In contrast, full development of planned projects - 58 in total - has a potential storage capacity of approximately 30% of the average yearly runoff upstream of the Mompos Depression. The increase in storage capacity would result in total basin generation capacity expansion from 9.3 to 16.9 GW. The big question is these upstream projects could alter the ecologically important wetland and floodplain dynamics downstream.

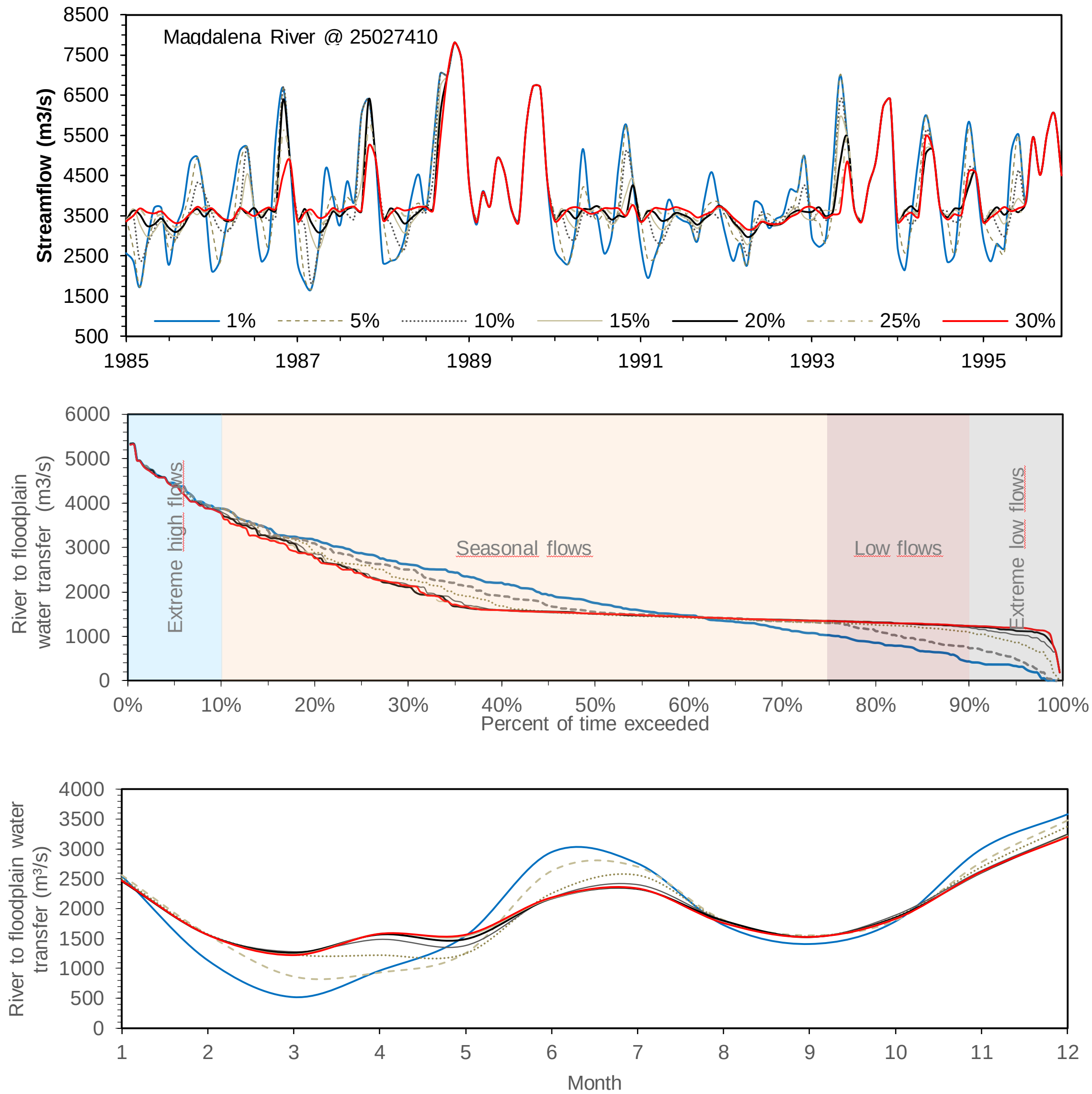


Figure 14. Simulated impacts of upstream regulation between 1% and 30% (expressed as total reservoir volume / average yearly runoff) in wetland dynamics.

A. Simulated monthly hydrographs in the Magdalena river upstream of Zapatosa Marsh and Depression Momposina resulting from hydropower operations. Regulation capacity equivalent to DOR of 1, 5, 10, 15, 20 and 30%. B. Changes in hydroperiod. Extreme high flows, seasonal flows, low flows and low extremes ranges (background colors) of the various flow components are shown. Each of these components has specific relations with the hydraulic and geomorphological dynamics that define the habitats available and therefore define biodiversity and ecological relationships. C. Changes in average seasonal pattern of wetlands regulation

Figure 14 shows one of the main results produced using the enhanced version of WEAP. The higher the level of hydropower development, the more regular the shape of the hydrograph will be upstream of the Mompos depression main tributaries (red line in Figure 14 shows less of the natural variability shown in the blue line). At the highest level of reservoir storage expansion, 30% of the average annual discharge (DOR), reservoir operations substantially reduce the magnitude of seasonal river-floodplain interactions, and virtually eliminate low-flows during dry months where the drainage of floodplains occurs. Alteration of exchange patterns between river and wetlands could have very negative impacts on local ecosystem function as seasonal oscillations are important for nutrient and sediment balance and low flow periods are important for many biodiversity and ecological events, such as reptile reproduction, the propagation of riparian vegetation communities, nutrient and organic matter storage. At the same time, high flow events (10 year return period or higher) would still prompt interactions - associated with extreme wet events, such as the La Niña 2010-2011, - between rivers and adjacent wetlands and floodplains, due to dam safety releases to control flows from upstream reservoirs.

The analysis at the small scale of sub-basins was limited to an exercise in the Aipe basin of the Alto Magdalena. At this scale, the analysis showed that base flows can be considerably reduced by the installation of a PCH. Base flows are a key component of e-flow definitions as any reduction in base flow can alter the scouring effect that renews the river bed substrate for habitats, and can encourage the presence of algae reducing water quality conditions (Figure 15, Figure 16).

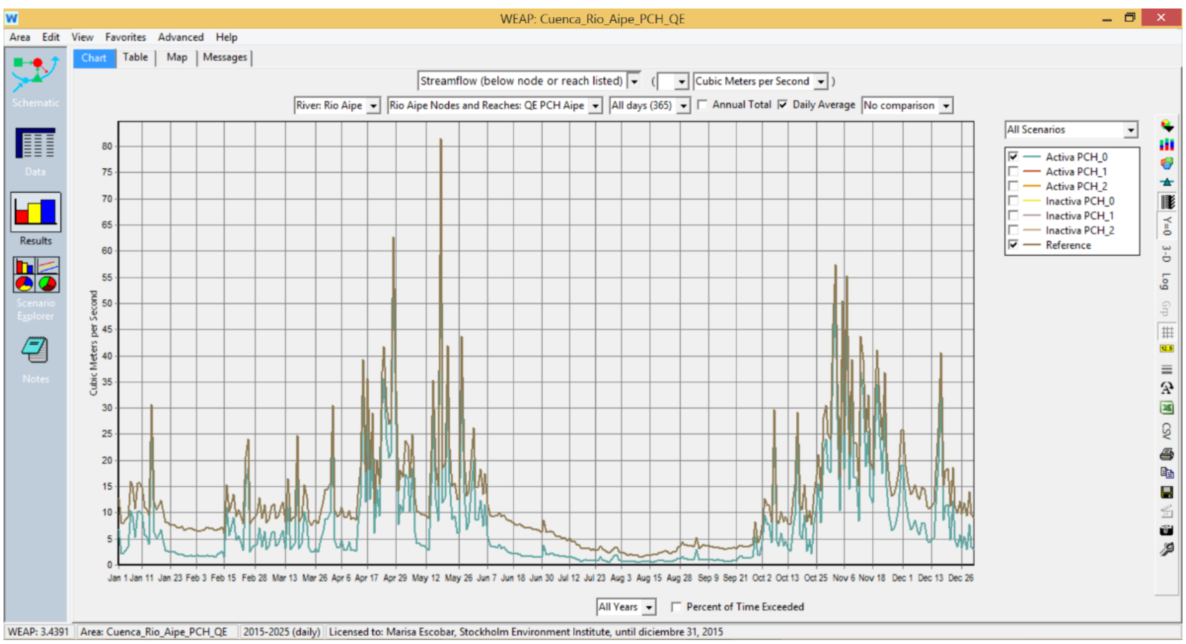


Figure 15. Flow alteration with respect to PCH

This figure from the WEAP interface shows the comparison between daily average flows for the reference case vs the case with active PCH showing a reduction in baseflows downstream of the hydropower plant where e-flows need to be considered.

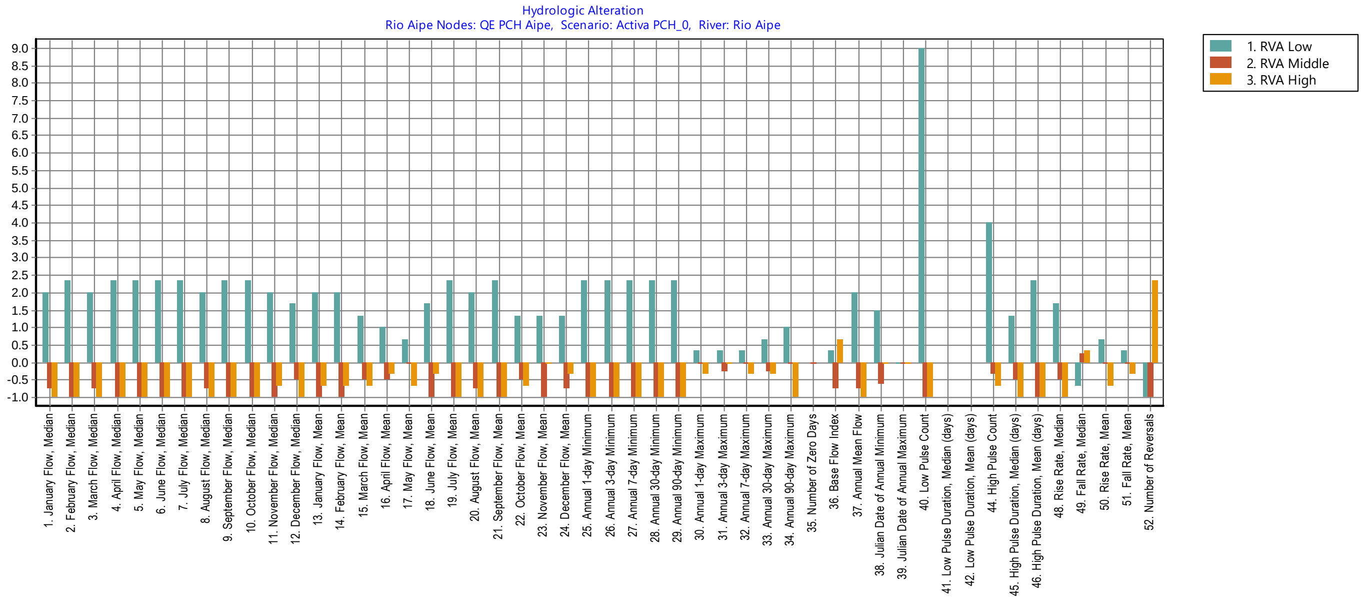


Figure 16. Flow alteration and IHAs due to small hydro in Rio Aipe

This figure is a WEAP result comparing the 52 RVA – Range of Variability Approach – indicators for the pre-and post -alteration on the scenario of a small hydro plant. Positive numbers indicate the increase in frequency and negative values indicate the decrease in frequency of each indicator. This graphs shows a significant increase in the frequency of low flow counts (indicator number 40).

Lessons learned

The case study at the Magdalena-Cauca basin scale reveals that the hydrological dynamics of water storage in the floodplains at a monthly to decadal scale are driven by variations in climate at basin scale and can be represented with enhancements made to WEAP. This makes WEAP the first platform able to successfully resolve the floodplain water balance at medium-to-large scales (~10,000 km2), while linking the simulation of these dynamics to simulated representation of water management practices. In terms of management implications our model estimated that the deployment of existing and potential upstream hydropower infrastructure pose a similar impact to water flows in floodplains in the Mompos as dry periods (~15.000 million m3). This suggests the need to establish basin scale water allocation rules during dry periods to allow for the preservation of floodplain ecosystems dynamics. By providing an improved understanding of the linkages between climate variability, water system operations, and the floodplain dynamics, these new routines provide insights that can guide the implementation of infrastructure development as well as ecosystem conservation projects. Both are critical to the sustainable development of a country like Colombia, and many others.

The case study application of IHA at the scale of the Aipe sub-basin is a simple demonstration of an analysis derived from this new functionality. Knowing the potential impact of small hydro in one region could facilitate large scale analysis of the cumulative effects of multiple small hydro using the existing tools.

Major accomplishments

A conceptual model including a wetland and floodplain storage component that includes interactions between a river and adjacent flooded areas was developed as an enhancement to the existing Water Evaluation and Planning (WEAP) system. The model has the capacity to assess how water resource management practices, including reservoir operations, or changes in the connectivity between river and wetland systems or inundated floodplains impact wetland and floodplain dynamics.

The enhancements implemented in WEAP included two modifications: the inclusion of surface water storage in the soil moisture model, and the representation of connections between surface storage and the river network (Figure 17). The mathematical details of the water balance equations can be found in an accompanying peer review paper under publication.

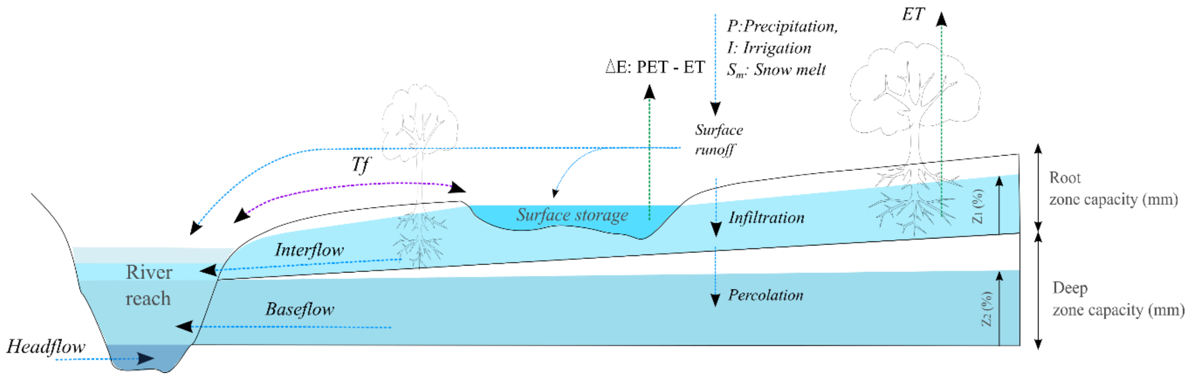


Figure 17. Schematic of the two-layer soil moisture model including a surface storage component, showing the different hydrologic inputs and outputs.
The schematic shows the interactions between the river, base flow, interflow, surface storage, runoff, precipitation, irrigation, and evapotranspiration. Tf is the transfer function that determines the flow towards the floodplain or vice versa given the variable conditions between the flow in the river and in water depth in the floodplain.

The model can be applied to multiple river reach and floodplain connections, allowing for the representation of complex interactions between wetlands, river reaches and floodplains. For example, it is possible to represent a case where a floodplain is fed by the overflow from multiple river reaches, or where the return flow from the floodplain occurs to multiple reaches of the river.

The testing of the model focused on the Mompos Depression and adjacent low lands, with an approximate area of 32,198 km², or 11.8% of the total area of the entire Magdalena basin (Figure 12). This area receives water from the Magdalena, Cauca, San Jorge, and Cesar rivers. The region includes hydrological monitoring stations which, despite shortcomings in terms of record completeness, allow for inferring patterns of circulation of water within the basin. The surface water storage model was tested based on different sets of conditions depending on different definitions of hydrological units within the Mompos system. The model was calibrated and validated by comparing simulated runoff from each hydrologic unit with observed runoff over a 20 year period (1985-2005). The resulting statistics fell within acceptable ranges for the calibration and validation periods.

Much of the functionality of the stand-alone version of IHA has been incorporated into WEAP. Indicators of Hydrologic Alteration (IHA) is a software program that provides useful information for those trying to understand the hydrologic impacts of human activities or trying to develop environmental flow recommendations for water managers. Nearly 2,000 water resource managers, hydrologists, ecologists, researchers and policy makers from around the world have used this program to assess how rivers, lakes and groundwater basins have been affected by human activities over time – or to evaluate future water management scenarios.

In WEAP, an IHA analysis can either look at streamflow statistics for a single period, or can compare statistics for two different periods or two scenarios. The two-period analysis typically splits the record into a period before substantial alteration of the historic streamflow ("pre-impact"), which could be caused by reservoir construction or re-operation, withdrawals from the river, land use or climate changes that would influence runoff to the river, and a period after the alternation had begun ("post-impact"). In this way, historical changes to streamflow can be quantified and characterized. If a historical streamflow record is not available, it is possible to use WEAP's catchment hydrology to reconstruct the natural streamflow that existed before alteration. In a two-scenario analysis, it is possible to construct scenarios of change and use IHA to analyze their impact on historic or current flows. This involves choosing the scenario that will be the reference scenario (typically, this will represent the pre-impact state, or a baseline to compare against). Flows from the reference scenario are then used to calculate the Environmental Flow Components thresholds for the RVA analysis, which is the Range of Variability Approach that leads to identifying the boundaries of historical variation and compares that the variation of given scenarios.

Flooding and IHA analysis in WEAP are available to all users that download and use WEAP. With a user base of 18,000 people, an average of 10 WEAP downloads per day, and a total of 950 WEAP users in Colombia, these enhancements are likely to have a high impact for water management practitioners. The WEAP 2015 version available now has these enhancements, and a user guide that explains how to use them.

Evidence of impact

Collaborative work with the TNC at the scale of the Magdalena-Cauca River Basin has prompted several initiatives that have used SEI tools and expanded the impact of this project. Partners in Antioquia have applied WEAP in several other sub-watersheds in the basin, extending the level of coverage of modeling at the sub-watershed scale. Modeling work at the basin and sub-watershed scales has prompted IDEAM to contract with CENIGAA, a project partner in the Alto-Magdalena work, to develop protocols for the inclusion of WEAP models with an National Water Modeling Center being launched by IDEAM. The development of planning protocols is a lengthy process, involving conversations between actors at various levels. The project has certainly shaped this discourse as the WEAP-based RDS process is being applied beyond the limits of the project watersheds.

MONITORING AND EVALUATION

The information contained in the prior results section is compelling and useful as it demonstrates how the project watersheds may be vulnerable to climate change and other uncertainties and how various water management action might reduce this vulnerability. It also shows the degree to which project partners were able to take on the task of deploying the WEAP model within the RDS framework in a manner which allows for explicit consideration of climate change and other uncertainties. From a technical perspective these results offer solid evidence of capacity development in Colombia. This section analyzes how this capacity development corresponds to the objectives originally laid out for the project and offers lessons learned and recommendations on best practice that will enable the impact of the project to be increased at both the watershed and national scales.

The Project Performance Management Plan

The official Project PMP was tracked via regular updates to the USAID MONITOR system and complemented by the use of an internal SEI system PMEC (Planning, Monitoring, Evaluation and Communications) that must be used to implement any SEI project. The PMEC system is based on an Outcome Mapping approach[5], which utilizes a series of logical steps easily embedded within a structured, web-based tool. Essentially, interactions with this website at various points in the project implementation process generate a relational database containing information on the overall aims and of the project, progress towards meeting the aims of the project evaluated against agreed milestones and success criteria, linked to actions taken by the project team. A key feature of the PMEC system is its reference to Boundary Partners, to which specific changes realized through project implementation are ascribed. As PMEC includes several reporting dimensions related to Boundary Partners that are not explicitly tracked in MONITOR, information from PMEC has been used as part of the evaluation of project impact.

With respect to the official Project PMP, as reflected in the USAID MONITOR system, the primary focus for the project was to respond to Development Objective 4 (DO-4) *Colombian Efforts to Sustainably Manage the Country's Environmental Resources Reinforced*. Within DO-4, the pertinent SubIRs were IR 4.1 *Environmental governance strengthened* and 4.2 *Climate change mitigation and adaptation improved*. To these official USAID SubIRs several SEI indicators related to specific Boundary Partners included in the project PMEC have been added. The combination of USAID SubIRs and SEI indicators, along with progress towards each of the project targets, are shown in Table 7. The information contained in this table is expanded upon in Appendix 1, which includes narrative descriptions of how progress was achieved with respect to each USAID SubIR and SEI Indicator.

[5] Outcome mapping (OM) is a methodology for planning and assessing development programming that is oriented towards change and social transformation.
For more information: http://www.outcomemapping.ca/

Table 7. Project Indicators, targets and cumulative numbers

Partner	Name	Disaggregated level	Target	Cumulative
Academia	SEI-1 Research paper including climate change considerations produced by the universities	National	3	5
	SEI-2 Courses that include teaching of WEAP	Participating municipalities and departments	55	379
	SEI-3 Students or technicians in research groups interacting directly with CARs	Quindío, Cartago, Pereira, and Huila	13	16
CARs	SEI-4 Information used for water resources management	National	4	8
	SEI-5 Use of climate change information	National	4	4
	SEI-14 Sub-IR 4.1 Environmental governance strengthened	National	4	9
	SEI-6 Sub-IR 4.1.1 Improved environmental policies for conserving bio-diversity and for mitigation impacts of global climate change	Municipalities and participating departments	4	6
	SEI-7 Sub-IR 4.1.2 Improved capacity to quantify ecosystem services, such as GHG sequestrations, and other climate change mitigation elements resulting from biodiversity conservation	Participating municipalities and departments	4	7
National Meteorological Institute	SEI-9 Participation in capacity building activities	National	4	9
	SEI-10 Reception of feedback from CARs on national policies	National	2	4
Private Sector	SEI-11 Participation in workshops	Participating municipalities and departments	12	18
Water utilities	SEI- 12 Information used for water resources management	Pereira	4	7
	SEI-13 Definition of climate adaptive measures	Pereira	8	12
All boundary partners	SEI-8 Sub-IR 4.2.2 Climate change adaptation capacity improved in target regions	Participating municipalities and departments	4	6
	SEI-15 Sub-IR 4.2.2 Number of stakeholders* with increased capacity to adapt to the impacts of climate change as a result of USG assistance (* "stakeholders" refers to individuals)	National	36	95

In assessing the impact of the project, as summarized in Table 7 and Appendix 1, it is important to recall that the primary objective of the project, as captured in the name of the project itself, was building climate adaptation capacity in water resources planning. Stories of change reported in Appendix 2 show some of the most relevant impacts of the project. In meeting the capacity building objectives, many lessons have been learned that inform the recommendations on how to extend the achievements of the project to actual national level policy reform related to water management and climate change in Colombia and the implementation of actual on-the-ground adaptation actions at the local level. These opportunities, and the challenges that must be overcome to realize them, are explored in the next section where lessons learned from across all the project watersheds and recommendations are explored.

One of the key indicators that demonstrate assimilation by Colombian water managers of the tools is the number of WEAP downloads (Figure 18). Each year, the number of people using the software is increasing, indicating the possibility for consolidation and replicability of the program in the country.

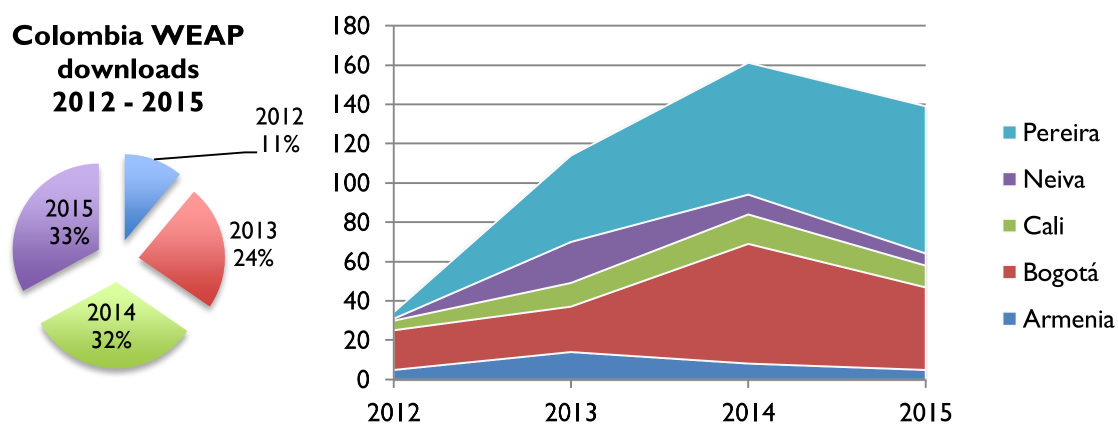


Figure 18. Number of WEAP Downloads per year in Colombia and in project cities.

Note. 2015 downloads are counted until September 2015

EVALUATING OUTCOMES, LESSONS LEARNED, AND RECOMMENDATIONS

2012 - 2013


July 2012, A&A, Pereira


March 2013, Pereira


June 2013, Armenia


July 2013, IDEAM, Bogotá


October 2013, CRQ,

2014


February 2014, Salento

April 2014, California


July 2014, Manizales

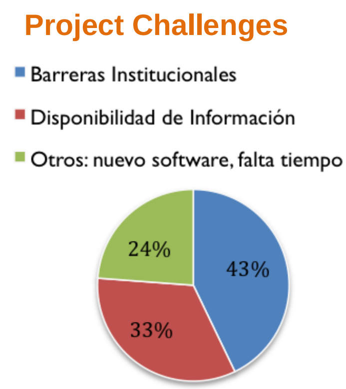

August 2014, CARDE

2014 - 2015


August 2014, CVC, Cali


October 2014, DWR, California


June 2015, Bogotá



How partners overcame project challenges

"The challenge to obtain information was overcome through strengthening trust between institutions and through transparency in the use of information"

"Looking for spaces within the institution to socialize the potential of the tool and its applications, in particular spaces where it is possible to find technical and directive teams"

"We have learned the concept of 'adaptive management', which has been shared in the project. The project administrative team has shown that these processes require flexibility and the capacity to adapt to the circumstances to continue making progress"

EVALUATING OUTCOMES, LESSONS LEARNED AND RECCOMENDATIONS

After nearly three years of collaboration on the project, which involved partners from universities, local CARS, and other water management entities, a number of valuable lessons have been learned that are relevant to continued efforts to better integrate climate change considerations into water resources planning and decision making in Colombia. These can be organized into three distinct categories: Managerial lessons; technical lessons; and governance lessons. Each of these categories are explored individually in the following sections based on information derived from different sources. These sources include: anecdotal experiences, a formal project satisfaction survey, and a specific survey on lessons learned circulated amongst the project partners at the end of project implementation.

Managerial lessons learned

In order to provide a context for the presentation of managerial lessons learned, some description of how the project was managed is required. The project was managed through a cooperative agreement, under which USAID interacted directly with the project management team within SEI. USAID reviewed and approved annual work plans, suggesting adjustments to increase the likelihood of achieving our objectives and meeting our indicators. SEI's project management team included a Program Coordinator, a Technical Backstop, and a Financial Administrator. Other technical staff from SEI were involved in different stages of the project to support WEAP software enhancement (floodplain routines, IHA integration), WEAP model building in the project watersheds, model output visualization, and program monitoring and evaluation. SEI does not have a permanent presence in Colombia, but its implementation approach is consistent with SEI's organizational profile as an international research institute possessing substantial in-house capabilities of long-term research staff located in its research centers around the world. This is in contrast to a perhaps more typical USAID project business model whereby managerial leadership and technical expertise is secured through a team of contracted short-term hires posted in country.

That said, SEI did contract with a number of young Colombian professionals to implement various parts of the project, particularly those implemented in the Alto Magdalena sub-watershed. This represented an important management arrangement as it gave SEI a more permanent presence in Colombia. Perhaps more importantly, however, this arrangement contributed to the kernel of a cohort of technical experts that will continue to implement WEAP-based RDS methodology after the project ends. This kernel was further enhanced in the La Vieja-Otun set of activities, through the establishment of formal sub-contracting arrangements with three universities which in turn hired 2-3 young professionals to work on the project. In both regions, these on-the-ground partners worked in close collaboration with colleagues within the local CARs and other local water management agencies to implement the WEAP-based RDS approach, supported by visits from SEI in-house staff at key moments in the implementation of the process (e.g. XLRM problem formulation workshop, climate scenarios workshop, regional results workshops, national dialogues).

The management structure for the work carried out at the scale of the Magdalena-Cauca River Basin was different, as it was based on an informal collaboration with another USAID-Colombia grant recipient, The Nature Conservancy-Colombia. Here SEI took on more of a technical support role whereby WEAP enhancements were designed, implemented and tested through early model application work carried out jointly with TNC technical staff. The use of the results of these early enhanced model runs to support water management planning and decision making at the scale of the Magdalena-Cauca River Basin was left largely up to TNC.

A graphical presentation of these management arrangements and the lines of communication they imply are shown in Figure 19.

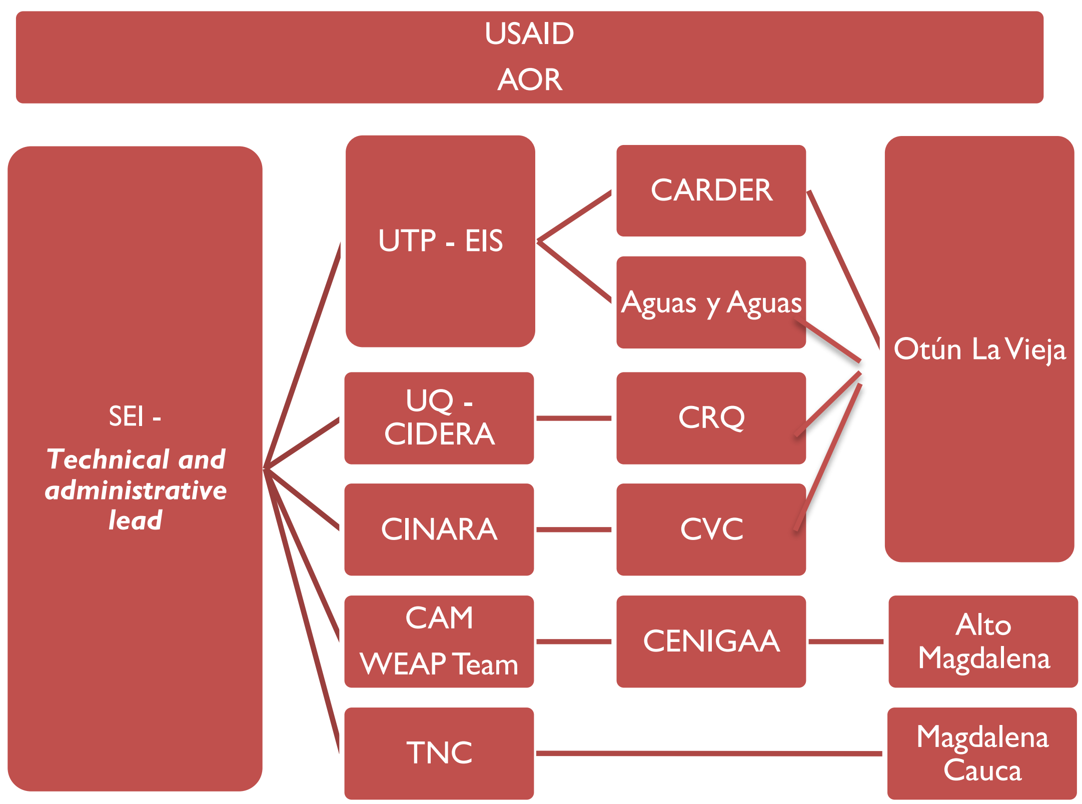


Figure 19. Management and administration structure
SEI was the technical and admin lead, and local representation was in charge of universities and CARs for each of the project components.

While the organizational structure of this project is interesting, more important are the managerial lessons learned it prompted. These include the following.

<u>A focus on building the capacity of early career young professionals is useful</u>
On this project ten different young Colombian professionals were engaged in project implementation, either through direct contracts with SEI or as part of teams assembled by universities contracted by SEI. Each of them made great strides in assimilating the skills needed to implement the WEAP-based RDS approach and some of them have taken these skills and applied them to other similar activities beyond those undertaken as part of the project. In addition, they have established professional and inter-personal connections amongst themselves which creates a nascent professional network working on climate change and water management in Colombia. Beyond this core group of 10, additional actors included other young professionals within the local CARs, the Ministry of the Environment and Sustainable Development, and IDEAM who participated in many of the events organized by the project. As these young professionals advance along their career trajectories they will bring the experienced gained on the project with them to increasing high levels of engagement and responsibility.

<u>Working with universities creates legacy institutions</u>
Engaging universities as project partners poses both challenges and opportunities. Challenges stem mainly from the fact that the primary function of a university is to generate new knowledge, less to applying existing knowledge to concrete problems. As such it is sometimes difficult to align the incentives of a researcher with those held by a water manager. Increasingly, however, universities in Colombia and elsewhere are being asked to justify the relevancy of their research through collaboration with actual managers and decisions-makers. In Colombia, a number of CARS and other water management entities have actually developed very strong and productive relationships with universities (e.g. CARDER and UTP; CVC and UniValle). Assuming that these trends continue, universities can play the role of legacy institutions for the learning achieved during project implementation, particularly if they capitalize on opportunities to develop classroom and research opportunities for students on the subject, as all of the project's university partners have done. Young professionals benefitting from these opportunities should be connected to the nascent professional networks created by the early career young professionals associated with the project.

<u>As CARs are key to on-the-ground change, their engagement needs to be strengthened</u>
However substantial a role universities can play in supporting the consideration of climate change in Colombian water resources planning and management, in the end the ultimate responsibility for these functions rests with government institutions, specifically CARS with jurisdiction over individual watersheds and municipalities located within them. Given the important role played by the CARs, the experiences gained during project implementation suggest that the manner in which they engage in the application of the WEAP-based RDS process needs to be re-evaluated. In particular, technical staff within the CARs need to be more active participants in the process so that the technique can be taken up instead of

simply being understood. This would require more substantial and sustained capacity building directed towards key technicians with the CARs, and a commitment from their management to allow these staff to engage in the process to a much higher degree. As part of the commitments derived from the project, universities and CARs put together work plans and recommendations that are reported on Appendix 3. This sort of work is akin to the way the integration of GIS into the internal capacity of the CARs evolved a decade or so ago. What once seemed like an innovative technology is now part of the standard workflow within a CAR. The WEAP-based RDS approach needs to experience a similar evolution.

Technical lessons learned

Most of the technical results are presented in previous sections in this report, and were also published in the form of fact sheets or discussion briefs that served as communication tools with stakeholders and higher level decision making bodies. The Appendix 4 and 5 contain fact sheets and submitted peer review articles that compile the details of the technical work done. Also, Table 8 compiles published information produced by the project with relevant hyperlinks. While the Results section of this report and the Appendices clearly demonstrated that a high level of technical capacity was achieved by a cohort of young Colombian professionals to implement the WEAP-based RDS process, a number of important lessons related to the technical process itself did emerge. This is to be expected, for as previously mentioned the integration of climate change considerations into participatory IWRM efforts at the watershed scale remains a work in progress, both in Colombia and around the world. As part of an evolution of the project impact, the following conclusions can be drawn.

<u>Constructing a watershed model takes work; opportunities exist to streamline the process</u>
The work required to construct an integrated hydrologic/water resources model such as WEAP is not inconsequential. Much of the time invested by the young Colombian colleague contracted by the project was spent working on model construction, calibration and deployment in response to the problem formulation developed in collaboration with key actors in each project watershed. A large part of the effort was associated with gathering and processing the spatial information and time series data required to construct a model. SEI has developed a set of tools and techniques for accomplishing these required tasks, which were shared with the partners in Colombia. There is a real opportunity to automate some of these tasks within the software itself in order to facilitate the model building process. Automating the model building process based on available information and data sources in the Colombian context would facilitate the uptake of the tool within the CARs.

Table 8. List of selected publications and hyperlinks

This table presents selected publications, and links to the location of these resources on the internet.

General	Results (WEAP – ADR)
1. Relevancia y utilidad del proceso ADR y del sistema WEAP para la formulación de Planes de ordenamiento y Planes de manejo de cuencas y ríos en Colombia (POMCAs y PORHs). 2. El desarrollo legislativo para la gestión del agua en Colombia: Leyes, actores, y desafíos. 3. Instrumentos de Planificación y Apoyo a Decisiones Robustas (ADR) en la Gestión del Agua en Colombia. 4. Blog del Proyecto: Gestión del Recurso Hídrico y Cambio Climático.	1. Modelación hidrológica del recurso hídrico en la cuenca del Alto Magdalena en Colombia, "Ríos del páramo al valle, por urbes y campiñas" 2. Implementación del modelo WEAP para el estudio de la calidad del agua en la cuenca del río La Vieja. 3. Forjando capacidad de adaptación al cambio climático en la gestión de recursos hídricos en la cuenca del río Otún 4. Modelación del recurso hídrico en la cuenca del río La Vieja en Colombia
Manuals	**Courses**
1. Modelación Hidrológica y de Recursos Hídricos de las cuencas de los ríos La Vieja y Otún mediante el modelo lluvia escorrentía de la humedad del suelo del sistema soporte de decisión (SSD) WEAP; Una herramienta para la adaptación al Cambio Climático. UTP, UniQuindío 2014 2. Modelación de la calidad del agua de la Cuenca del río La Vieja. Instituto CINARA 2014 **3.** IHA en WEAP – Tutorial step by step. SEI 2014	1. Módulo WEAP (4 semanas) en el Curso de Hidroclimatología en el pregrado de Administración Ambiental – UTP 2. Pregrado Ingeniería sanitaria - UNIVALLE 3. Posgrado Ingeniería Sanitaria - UNIVALLE 4. Diplomado en Gestión Integral del Recurso Hídrico y Modelación Ambiental - UNIVALLE

The development of a community of practice related to watershed modeling is key

It should never be assumed, however, that the development of a good watershed model will ever become a push button exercise. Such a level of automation based on readily available information and data would never foreclose opportunities for individuals with extremely relevant local knowledge to contribute useful and important insights to the model building process. Gaining access to the collected experience/insights held by these individuals would be greatly facilitated, however, through the creation of a WEAP/RDS community of practice. In some respects the emerging network of young professionals associated with the project already operates as an informal community of practice, as these individuals were in regular communication during the project. Formalizing these relationships through on-line platforms or periodic user conferences could improve the quality of information exchange and the efficiency of the model building process. As more technical staff within the CARs take up the approach, they could be connected to this community of practice. Appendix 6 compiles the complete list of partners that constitute the community of practice generated by the project, including those that were directly involved as boundary partners in the project through contracts, and other key partners that participated throughout the project, and that were exposed to the results presented during the Symposium on Water, Climate and Adaptation in June 2015.

Care needs to be taken to characterize uncertainties created by a lack of monitoring data

While Colombia is by no means the worst case in terms of the availability of the information required to construct and calibrate a model such as WEAP, there are gaps in the existing data and constraints in the ability of technical analysts to access what is available. While progress could be made in improving access to existing data, to which the development of IDEAMS National Water Information Platform is contributing greatly, Colombia, like all parts of the world, will never possess all of the data required to construct a perfect model. As such, greater care should be taken in the future to develop techniques to convey to decision makers the uncertainty in model output stemming from incomplete model input data. This was not a central activity of the current project based on the assumption that the uncertainties associated with climate change and other factors were greater than the uncertainties produced by the quality of the model input data itself. Still this assumption should be tested and more clearly justified in the future as it has implications for decision making.

Socio-economic metrics need to be included in the evaluation of adaptation options

During the implementation of the project, a great deal of time was spent characterizing the vulnerability of the current systems within the project watersheds to climate change and other uncertainties with respect to hydrologic, ecologic and water management metrics of performance. From this baseline vulnerability assessment the ability of specific management responses to reduce the level of vulnerability with respect to these current conditions was assessed. The exercise made it possible to analyse how specific adaptations could improve future levels of performance with respect to metrics such as the ecological condition in key river reaches, the level of satisfaction of specific demands and water quality; and to compare these improvements across the suite of proposed actions. The comparison across potential management actions, however, requires that some consideration be given to the financial costs and benefits associated with each evaluated course of actions, along with some consideration of metrics related to social equity. In the future, these sorts of indicators should be more fully evaluated as part of the implementation of the WEAP-based RDS approach.

<u>Different ways of presenting model results to different audiences are needed</u>
The use of WEAP within an ensemble of model runs, that generates a range of cases defined by different future scenarios and management responses, produces a large amount of data. One of the most challenging, and most exciting, parts of the RDS process is the development of data visualization tools that support participatory and dynamic exploration of these model outputs as part of a process of co-learning amongst key stakeholders regarding promising adaptation actions. During the project, the Tableau software was used to build these data exploration tools, to great success when the target audiences were technical partners and technical collaborators within the CARs. There needs to be a recognition, however, that non-technical audiences, specifically politicians and policy makers, may not have the time to dedicate to understanding expansive data exploration. Different communications approaches are required to transmit learning about climate change and water management to these actors. While the project experimented with new media approaches such as blogging and old approaches such a publishing fact sheets, more work could be done to identify the most promising communication techniques for each critical audience.

Governance lessons learned

The number of academic papers published on approaches to integrate climate change considerations into water resources planning and decision making suggests that this topic constitutes a compelling, and pressing, research agenda (Bouwen and Taillieu, 2004; Folke et al., 2005; Lempert and Schlesinger, 2000; Nilsson et al., 2009; Pahl-Wostl et al., 2007). This project, however, was not intended to be a pure research endeavor. The Project PMP included a group of indicators related to actual policy setting and governance, with the expectation that over time governance mechanisms would be created to realize actual on-the-ground water management adaptations to climate change. As such, several governance related lessons can also be articulated.

<u>The linkages between water and watershed planning instruments needs to be clarified</u>
There are a number of mandated planning instruments of relevance to the water and watershed planning in Colombia. Four of particular relevance include the POMCA, the PORH, the POT and the PSMV, although others touch upon the themes of water and watersheds as well. As part of the implementation of the current project, SEI and its partners invested a great deal of effort in understanding how these various plans fit together and how the WEAP-based RDS approach could help to strengthen the connections between them. The output of this thinking was a fact sheet, found in Appendix 4, which lays out how this might occur. The key conclusion is that while there are practical reasons for keeping these plans separate, there is a great deal of overlap that must be recognized if the IWRM aspiration of integrated, multi-actor, multi-objective water management is to be achieved in

Colombia. Key questions of information flows between the plans, and issues of subsidiarity, need to be clarified if these plans are to meet that objective. A strong case could be made that a consistent watershed model developed on a platform such as WEAP could provide a valuable shared foundation upon which individual plans could be constructed.

Technical guidelines associated with these instruments need to include climate change

As previously mentioned, the Ministry of the Environment and Sustainable Development in Colombia considered including climate change considerations in recently published guidance documents associated with the POMCA and the PORH, only to decide against doing so based on the conclusion that the proper protocols are not yet well enough formulated. This was a logical decision, but one which creates real opportunities for innovation. More important than mandating specific climate change analytical protocols for the POMCAs and PORHs is whether climate change considerations can be gradually incorporated within the steps described within guidance documents published by the Ministry. In particular, innovative analytical tools and participatory processes developed and tested at the local watershed level, such as those described in this document, need to be encouraged and accommodated. As part of the project, SEI published a fact sheet that lays out how the WEAP-based RDS process could help create the scalable framework for considering climate change, while also supporting the current promulgated steps in the plan formulation processes. There is ample opportunity to test this approach in a watershed where the project engaged, in particular in the Alto-Magdalena region where the local CAR remains in communication with SEI about using the WEAP-based RDS approach as part of ongoing POMCA development efforts.

Co-learning between local level experience and national level policy is nascent

In the last months of the project, SEI and its partners organized a set of dialogues with national level actors working in the field of water and watershed management and climate change around the activities carried out in each of the project watersheds. The forum provided an opportunity for the experience gained by project partners at the local level to be shared with those responsible for setting national level policy. The reaction was extremely positive. One consistent theme from the dialogues, which touched upon both the technical details of the work conducted and on its relevance for water governance, was that learning accomplished at the local level can usefully contribute to the national level discourse on appropriate policy responses to climate change. The Ministry is hungry to know about these experiences. Still the connection between bottom-up and top-down learning is nascent. There is an urgent need to connect these poles, however, as another theme of the dialogues was the importance of local land and water management in a post-conflict Colombia. This point was reinforced during the meeting by the government delegation involved in on-going peace negotiations who pointed out the central role that natural resources and the environment are playing in the emerging terms of the peace agreement. While nascent, the connection between national goals and local experience needs to be cultivated by connecting staff within national level institutions with colleagues working in local watersheds.

IDEAM play a key role in efforts to consider climate change within IWRM activities

One key actor in the strengthening of these connections is IDEAM. As the organization with the mandate to generate and supply information relevant to local water and watershed planning, SEI and its partners took pains to include IDEAM in the activities undertaken at the local level. Two important examples include the organization of a climate scenarios workshop at which the IDEAM staff responsible for developing national scale climate projections for Colombia had the opportunity to hear about the needs local water managers have for climate projections with an appropriate spatial and temporal resolution to support watershed planning. The workshop connected both sets of actors with colleagues within the National Center for Atmospheric Research in the United States who have a long experience of downscaling large-scale GCM output for use in watershed level models such as WEAP. This connection continues to develop. A second example of how the experience of the project connects to the objectives of IDEAM stemmed from the use of WEAP in the Alto-Magdalena region to support the development of an ERA (Estudio Nacional de Agua) in the Huila Department. The ERAs are an IDEAM initiative designed to develop a disaggregated set of indicators that can serve as a baseline for the various water and watershed plans mandated in Colombia. Based on the local experience in Huila, IDEAM is now planning to include WEAP in the National Water Modeling Center it is developing to support the development of ERA and other watershed level investigations. The connections forged with IDEAM pertaining to the WEAP-based RDS method during project implementation must be cultivated.

The creation of capacity to secure funding for promising adaptation actions is required

While the project accomplished much in terms of building the capacity of local partners to introduce climate change considerations into water and watershed planning, and contributed usefully to emerging national level discourse on the subject, the fact remains that participatory processes, analysis and plans will be needed to motivate real, on-the-ground changes that can reduce the vulnerabilities created by climate change. A number of international, regional, and national funds have been set up to provide funding for adaptation. The process of setting up these funds has brought the issue of additionality to the fore, namely the need to demonstrate that any specific action offers climate change adaptation capacity beyond the normal set of benefits that would accrue from any particular project. This is a high standard, and one that is increasingly based on some level of technical analysis. As part of its broad set of activities in the Andean Region, SEI has deployed in-house staff with high levels of experience and knowledge of emerging climate adaptation funds to help argue how the WEAP-based RDS approach can be used to strengthen adaptation plans and therefore to secure necessary adaptation funding. This argument need to be refined and transferred to local water managers so that they can translate the promising actions highlighted in the Results section of this report into on-the-ground projects.

A compilation of the some key elements of these lessons learned, from all three categories, is shown in Table 9.

Table 9. Lessons learned per component from indicators

Component	Lesson Learned
Capacity Building	Research groups can strategically involve technicians, researchers and students in local and regional processes. Research groups as partners can serve as regional legacy groups that extend research impacts into the future. For research groups to support CARs with information for climate adaptation needs, there needs to be administrative and technical capacity. Persistence presence of the project through workshops and training plans, and the identification of technicians within CARs is key to generate the knowledge and appropriation of the tools for their use in ongoing planning processes. The individuals with greater assimilation of the tools should be promoted to devote more time to work in defining adaptation measures using this information
Decision Making	Additional resources to strengthen the participation of IDEAM in regional water resources planning can strengthen the link between national and regional climate information needs. it is important to keep in balance different aspects of the project such as operations, technical analysis, environmental considerations, social and cultural components and finances, to warrantee the sustainability of investment programs. The relationship among these aspects increases the integrality of adaptation programs, but at the same time it increases the complexity and uncertainty in decision making. As a consequence, it is key to count with a RDS-type analysis that lead to a better management of water resources by water utilities in Colombia. It is important to maintain the RDS framework in the formulation of 'Planes de Saneamiento y Manejo de Vertimientos' by water utilities, which will need to be revised and approved by regional environmental authorities.
Water Management	Technicians within CARs are extremely busy overseeing the implementation of other projects. More than deep learning of any tool, these technicians need frequent exposure to information so they can keep on their radar the appropriate tools for appropriate climate adaptation analysis. Commitment from CARs Directors is important to understand the time and resources required for the use of this information, and in so doing, generate the space for technicians to do this work. Regional governance is strengthened by partnering between institutions and academia, with the role of outside organizations like SEI as the catalyzing think tank. CARs technicians are busy with administrative work, and have little time to devote to technical activities. An increase in CAR personnel is required to allow technicians to focus on technical work. Institutions are represented by individuals that need to be connected It was not possible to involve other water utilities in the project since no explicit efforts were made to outreach to them from local project partners. Explicit work with stakeholders through task orders or 'convenios' (formal agreements) guarantees greater commitment to internalize tools for their use at the regional level
Tools Development	The use of WEAP and associated models developed during project should be seen as internal institutional tools to corroborate any information produced by outside consultants. At the level of MADS it may be possible to generate greater momentum for the use of WEAP in POMCAs and PORHs if they are named explicitly as options in national guidelines.

Recommendations regarding best practices

As with any new challenge, Colombia's journey towards a full consideration of the risks posed by climate change and other uncertainties to water management will move along a series of steps as indicated in Figure 18. While a decade or so ago the global water management community was largely unaware of these risks, represented by the ground floor of 'unconscious incompetence' in terms of the looming challenges, when the current project was initiated the Colombian water management community found itself on the first step, that of 'conscious incompetence'. There was a general awareness of the problem but little resolution on what should be done. The decision of the Ministry of the Environment and Sustainable Development not to explicitly include climate change considerations in its guidance documents for the formulation of POMCA's and PORH's reflected this. The efforts, undertaken with partners in the project watersheds, was an attempt to move up to the level of conscious competence, where actual approaches for responding to the challenges posed by climate change were understood and accepted as useful. This has been accomplished, which for a project where capacity building was the primary objective, constitutes an enormous success.

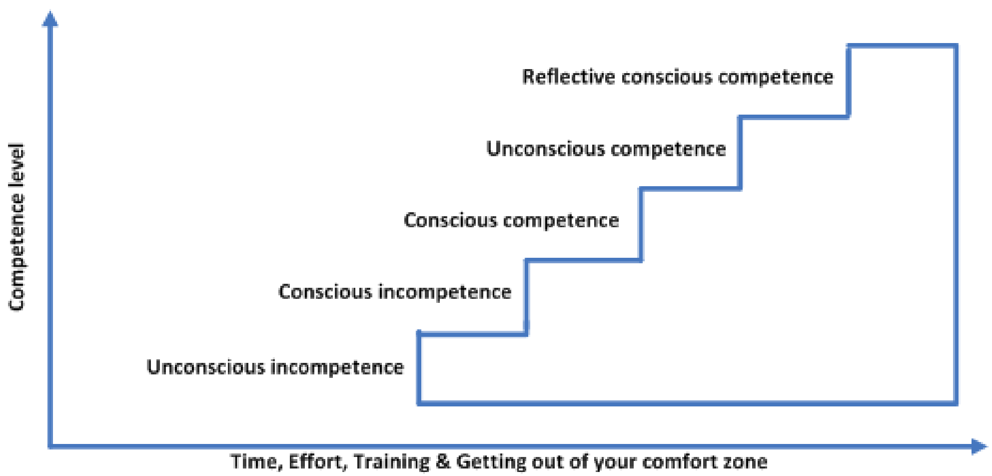


Figure 20. Levels of competence and resources investment to build capacity applied to RDS

Moving to the next level of 'unconscious competence' is still a work in progress (Figure 20). What will this look like? It would see the agencies and stakeholders involved in implementing Colombia's IWRM aspirations actually integrating climate change considerations into their normal workflows and discussions. More specifically, it would see the WEAP-based RDS approach being seamlessly integrated into the planning and decision-making processes underway in Colombian watersheds in response to clear guidance from national policy makers that makes this sort of effort mandatory, rather than discretionary. Once experience is gained along these lines, Colombia will be primed to move to the final step of 'reflective conscious competence' whereby consensus is reached around the best courses of action to reduce water management vulnerability to climate change and resources can be mobilized to implement these actions on the ground.

This section on recommended best practices has been constructed with an eye towards moving the water management community in Colombia up these two final steps. If successful, Colombia would take its place as one of the world leaders in the water and climate arena. In order to get to the level of ‘unconscious competence’ from the current ‘conscious competence’, several best practices should be followed.

Identify key technical personnel within each institution: If the use of tools like WEAP is to become part of the standard work flow within CARs, much as GIS analysis has become, staff will need to be assigned to the effort. These staff will need to have a background training in hydrology and water resources and some experience using models. They will also need to be allocated time and resources by the Directors of the CARs to work on this activity so as not to be diverted onto other projects.

Organize milestone training events: Under the current project some effort was made to train technicians within the CARs on the use of WEAP within the RDS approach, to varying degrees of success. The most successful case was that of Alto-Magdalena where the local CAR actually assembled a WEAP team to work regularly on the project in collaboration with the SEI team. Still, if this approach is to be fully internalized with CARs, more formal and sustained training will be required. The partner universities, acting as legacy institutions, or the emerging IDEAM National Water Modeling Center could develop a curriculum of activities that provides a depth of knowledge on key concepts (i.e. climate uncertainty, watershed modeling) and within a period r of roughly 6-12 months that would provide enough time for the concepts to be assimilated.

Maintain presence at the CAR: To support the integration of the WEAP-RDS approach into standard workflows within the CARs, it is advisable to maintain a persistent presence within the organizations for some time. The person could be dedicated to assisting in-house staff to define work plans, monitor progress and solve problems that are encountered. Such an individual could be engaged through external project funding, as part of a university outreach function, or within the new IDEAM National Water Modeling Center.

Plan regular meetings with CARs Directors: The Directors of CARs in Colombia occupy a complex position defined by technical realities and political complexities. Many of them have a legal background or management training, and are not typically well versed in issues related to modeling. If the approach is to become part of the standard work flow and discussions within watershed, however, these Directors need to be conversant with the approach and understand how it facilitates the consideration of climate change within the standard CAR’s functions. Quarterly, half day updates with technical teams within the CARs are advised.

Generate opportunities for exchange of ideas about climate adaptation at the watershed level: The emerging community of practice fostered through the project is a critical component of future success. This community of practice should facilitate knowledge exchange between watersheds where the approach is being applied, and across policy scales. On a technical level exchanges of experience between watersheds could focus on modeling techniques or on the sorts of adaptation actions that are emerging as promising in different locations. On a policy level, such exchanges could focus on how learning at the watershed level can contribute to the refinement of national policy and the creation of national level systems to support climate informed water management at the watershed level. In this sort of community of practice, an organization such as ASOCARS could play a central role.

Draw stories of change to highlight the impact in terms of planning before and after: One of the key outcomes of the project is the existence of 40 individuals fully aware of the RDS process and with capacity to articulate climate adaptation needs in Colombia. By bringing together a set of stories of change from these individuals, and providing them opportunities to showcase these, it is possible to, in the words of one project partner 'give an answer to the community as to whether a project is viable or not in terms of it climate adaptive capacity'. The effort to disseminate these stories of change can be facilitated through more intentional use of new media such as blogs and Twitter feeds.

Once the practice of considering climate change is integrated into the standard workflows and discussions surrounding climate change and water management in Colombia, the stage will be set for taking the last step in the development of competence, 'reflective conscious' capacity. Best practices required to make this step will include:

Make water central to the national debate: Colombia is rich in water resources with 6 times more water supply per capita than any other country in the world, and 3 times more than others in Latin America (Blanco, 2008). However, some rivers have been greatly altered: the Magdalena and Cauca have witnessed a 40% reduction in water supply and rivers in the Chocó region present high levels of mercury contamination. Despite an appropriate legal framework provided by the 99 Law of 1993 and the creation of the CARs, problems remain. The largest water user in the country is the agriculture sector with 54%, followed by the urban sector with 29% and industrial sector with 13%. It needs to be recognized that in spite of the rich endowment of water, Colombia must manage its resources in order to provide water of sufficient quantity and quality to support these activities. All the more so in post-conflict Colombia, where improving rural livelihoods will be critical.

Recognize how land use planning is going to impact on water management: Land use and land distribution is at the core of the conflict in Colombia and it is also at the core of the peace process. Colombia has 114 millions of hectares, and could use 20 for agricultural production. However, the country is using only using 5 million hectares. 40 millions of hectares are being used to support extensive cattle ranching, which could be accomplished on 5 million of hectares if livestock production systems were improved. There are 35 million of hectares that could be used for other activities, such as the conservation of ecosystems that underpin water resources in the country. Among the proposed activities in the post-conflict era are actions to coordinate land use planning. The focus on land use planning highlights one of the key challenges for water management, which is to recognize its close relation to land use planning.

Connect program themes to realities of the peace process in the country: All regions in Colombia are witnessing the peace process and are expectant as to its outcomes and final resolution. In this particular case, connecting the symposium themes of water and adaptation to the peace process generated the opportunity to increase awareness about the importance of watershed planning for more sustainable progress. The management of land and water resources must be a focal part of implementing the peace.

Prepare a clear, written articulation of the priorities and how these have been developed: Once the importance of water and watershed management is firmly established in post-conflict policies in Colombia, the stage will be set to begin the sorts of actions and adaptations identified through the implementation of the WEAP-based RDS process as implemented by local CARs. Templates should be developed which clearly articulate how these actions fit within national policies and are justified in terms of the concept of additionality required to secure adaptation funding support from various sources.

Maintain contact with national government focal points for adaptation fund: The national focal points for the various sources of adaptation funds are key actors with whom relationships must be developed and maintained. As CARs develop proposals for water management adaptations to climate change, grounded in emerging national policies and in the implementation of peace agreements, these focal points should be briefed on the proposed actions and the manner in which the WEAP-based RDS process justifies their selection for funding support.

If these best practices are followed it should be possible to (i) enable CARs and other local water management institutions to identify promising adaptation actions to reduce the vulnerability of watersheds to climate change and other uncertainties; and (ii) connect these actions to emerging national policy initiatives in a post-conflict Colombia in a manner which motivates financial support from sources of climate adaptation funding.

DISCUSSION AND CONCLUSIONS

As part of USAID's efforts to support Colombian efforts to reinforce the management of the countries' environmental resources, the *Rios del Páramo al Valle* program established a participatory and technical process to strengthen environmental governance and to improve climate adaptation. The process, derived from SEI's RDS practice, filled in a gap in the ability of partners to provide a broad, coordinated view of watershed management that integrates climate adaptation considerations. The application of the process led to (i) building the capacity of Colombian institutions to master a set of tools for climate adaptation analysis, (ii) demonstrating the utility of these tools within formal water and watershed planning and decision making processes in Colombia, and (iii) connecting local experiences using these tools to the national level discourse on formal water and watershed planning and decision making processes and the need to better integrate the impact of climate change.

To illustrate the empowerment achieved by Colombian institutions using the tools, we offer an analogy from practical applications of management theory about empowerment (Apello, 2014). The RDS steps were shared through consistent capacity building efforts in order to achieve full assimilation by local groups. However, empowerment in the use of the tools comes with time. Empowerment happens as each individual, or institution, moves from lower stages of assimilation to higher levels of capacity to act on a certain component of the process. In this particular case, the components of the RDS can be ranked at different descriptive levels, and varying for each institution, as the technical assistance moved from informing about the process to delegating full responsibility for implementation to the local actors.

The RDS steps towards empowerment can be categorized as follows:

a) Informed institutions about the tools and the approach
b) Shared with institutions the usefulness of the tools, providing examples from elsewhere
c) Consulted with institutions for their input to improve the process and to decide
d) Agreed with technical teams the terms of the model and of the scenarios
e) Advised the institutions to continue to evaluate potential applications of the tools in other watersheds, or to improve the existing applications
f) Questioned the institutions about their decisions so they can review and assert their steps forward
g) Empowered the local institutions to continue applying the process

Table 10. Qualitative assessment of levels of empowerment of RDS steps. Example for CAM

RDS stage	Inform	Share	Consult	Agree	Advise	Question	Empower
1. Decision space							
2. Actor mapping							
3. Problem formulation							
4. Model building							
5. Scenario development							
6. Ensemble runs							
7. Visualization							
8. Robust decision analysis							

Higher levels of empowerment are happening at universities which are advanced in defining research agendas based on the process. Among CARs, the CAM is the more advanced thanks to the commitment and creation of a strong technical team (Table 10). Although not all institutions have achieved the highest level of empowerment, the team continues working and communicating with SEI to move forward in the use of the RDS process. SEI is supporting their efforts as they move forward to provide continuity.

In our view, while the full capacity to act on each of the stages may not have been achieved by all involved parties, the trajectory has been set. We observe that the momentum created by the effort will guarantee a path towards higher levels of empowerment in the application of the RDS process of the actors involved, and the consequent replication in other regions of Colombia for better planning of watershed adaptation. Whereas a decade or so ago, water managers in Colombia and other parts of the world had only a limited idea that climate change needed to be considered within IWRM based water and watershed planning processes, an exciting community of practice has been created in Colombia that is now committed to meet the challenge.

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