UNESCO International Hydrological Programme
Hydrology for the Environment, Life and Policy-HELP

Second International Symposium on

Building Knowledge Bridges for a Sustainable Water Future

SYMPOSIUM COORDINATION COMMITTEE
Shahbaz Khan
Eda R. Soto
Carolina Llovera
Alicia Salas
Emilio Messina

INTERNATIONAL SCIENTIFIC COMMITTEE
Awadhesh Prasad
Francisco Jiménez
Jorge Faustino
Susana Neto
Anny Chaves Quiróz
Rahmah Elfithri
Henrique Chaves
Moisés Darwish
Claudia Candanedo
Mayte González

EDITED BY
Andrés Tarté
Eda R. Soto
Emilio A. Messina

UNESCO
International Hydrological Programme
Hydrology for the Environment, Life and Policy (HELP)

Proceedings of the Second International Symposium on

Building Knowledge Bridges for a Sustainable Water Future

Panama, Republic of Panama

Proceedings of the Second **International Symposium on Building Knowledge Bridges for a Sustainable Water Future**, Panama, Republic of Panama, 21-24 November, 2011.

Published by the Panama Canal Authority (ACP) and UNESCO, 2011.

The publisher is indebted to the Scientific Committee for the invaluable support and services provided in the quality assurance and editing of this volume.

Printed by Punto Gráfico, S.A.

Contents

2. STRENGTHENING GOVERNANCE AND INSTITUTIONS

3. ECOHYDROLOGY FOR HEALTHY ECOSYSTEMS

4. WATER, FOOD AND ENERGY NEXUS

5. WATER EDUCATION AND KNOWLEDGE SHARING

Building Knowledge Bridges and not Walls for a Sustainable Water Future

SHAHBAZ KHAN
Water and Sustainable Development Section, UNESCO Division of Water Sciences, Paris, France
S.Khan@unesco.org

Abstract This paper provides an overview of the key lessons learned from the third phase (2009-2013) of the UNESCO's International Hydrological Program's HELP River Basin Network. It highlights the need for trans-disciplinary science linked with policy-based knowledge bridges to water management. Such an approach can help avoid walls between water scientists, engineers, water managers, water lawyers, and wider stakeholders in a river basin. Twinning of basins to build widely tested decision support systems, joint actions on climate change and hydrological extremes, implementation of good governance practices, and development of shared IWRM tools through comparative studies remain as some of the common areas of action across the HELP river basins.

Key words Evaluation; twinning; IHP; HELP; river basins

1 Introduction

HELP is an acronym for Hydrology for Environment, Life and Policy which is a crosscutting programme under the International Hydrological Program (IHP) of UNESCO. The HELP programme was initiated by the international hydrological research community and adopted by UNESCO and WMO in 1999. HELP is designed to develop and apply scientific research for integrated water resource management (IWRM) through a global network of catchments, in order to improve links between water sciences and the needs of society. It seeks examples of good solution-oriented science which can deliver real outcomes that impact people within the catchments, locally as well as globally.[1]

The first HELP phase (1999-2004) was a pilot phase, and the second phase (2004-2008) gave operational reality to the HELP principles. While the first two phases were very successful in bringing together scientists, policy makers, and stakeholders implementing integrated water resources management, the third phase (2009-2013) is trying to tackle new emerging challenges (the third phase network distribution is shown in Fig. 1). These challenges include:

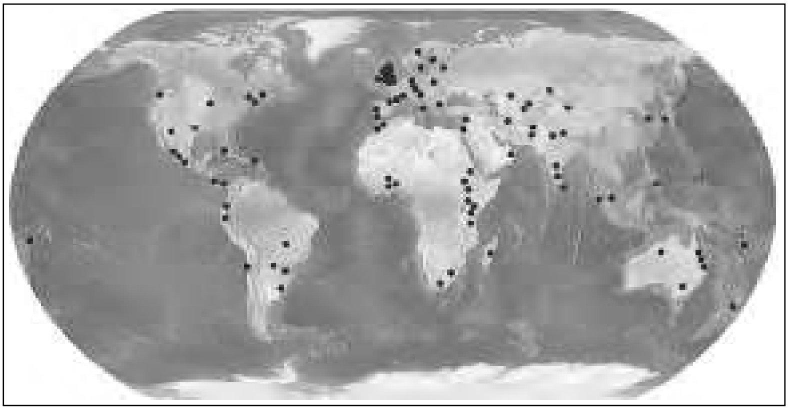


Fig. 1 The HELP River Basin Network.

- Climate change-poverty-water sector adaptations
- Water-poverty-environment nexus
- Energy-water-poverty nexus
- Demand for bio-fuels ensuing competition for land and water resources used for food production
- Globalization and trade policies for food security
- The changing role of state and local actors in the water
- Gender and the feminization of agriculture and other water-intensive sectors

Previous progress on the HELP initiative has been captured in a special volume of *Water South Africa* 34(4) containing selected papers from the 'HELP in Action: Local Solutions to Global Water Problems - Lessons from the South' symposium, held in Johannesburg, South Africa in 2007 (Khan, 2008).

2 Lessons Learned from the Evaluation of the Third Phase Proposals

During HELP's third phase, 47 proposals were received, which were evaluated by a trans-disciplinary committee. The HELP Basins Evaluation Committee (EC) met in Guayaquil, Ecuador (26-29 Jan, 2009) to assess the third round of HELP basin proposals. The Evaluation Committee consisted of the following individuals, with a mix of skills in hydrology, environment, law, and policy disciplines, as well hands-on experience in implementing HELP philosophy at the grass roots level:

- Ms. Anne Browning-Aiken, Senior Researcher and Program Manager, Udall Center for Studies in Public Policy, University of Arizona, USA
- Ms. Pilar Cornejo de Grunauer, Regional Coordinator HELP-LAC, Ecuador
- Mrs. Maria C. Donoso, Regional Hydrologist at the time, UNESCO Montevideo Office and Regional Bureau for Science in LAC, Uruguay
- Mr. Declan Hearne, Program Manager, SurfAid International, Indonesia; currently HELP coordinator in Davao
- Ms. Sarah Hendry, Water Lawyer, UNESCO-IHP HELP Water Law, Policy, and Science, University of Dundee, UK
- Mr. Tariq Rana, Research Hydrologist, Land and Water Division, CSIRO; currently assistant Director, Groundwater Planning, Murray Darling Basin Authority, Australia

The key issues arising from the EC's evaluation of proposals shall guide deliberations about the future of HELP at the 2nd International HELP Symposium, titled "Building Knowledge Bridges for a Sustainable Water Future", to be held from November 21-24, 2011 at Panama City, Panama. These key issues include:

- Suitability of the proposing organization and the river basin for inclusion in the HELP programme
- Relevance of the stated issues, purposes, and outputs to the HELP programme
- Adequacy and feasibility of the proposed activities
- Assurance of commitment to providing resources and cooperation
- Contribution to promoting HELP values

Following the EC meeting, customized feedback to basin proposers was provided. A LinkedIn HELP Forum has also been set up to hold discussions about the HELP philosophy and to answer queries.[2]

3 Key Observations about HELP Basins

Areal scale: With basin size varying from very small to several million km^2, programme objectives varied considerably. Some HELP projects are only dealing with smaller areas within the basins, allowing closer contact with stakeholders. However, scaling up biophysical, social, economic, and integrated learning components remains a challenge. HELP needs to focus on methodologies to address scale problems.

Proposers: Most project teams were from universities or research institutions, except in Latin America, with only a few members from government water agencies. It was observed that HELP needs to promote its aims to government departments and needs to go beyond short term projects. There is also a need to involve NGOs and the public and private sector.

Water Management Agencies: Increasingly, more regulation bodies are being involved in HELP, and therefore represent an important target group for HELP efforts in the context of national water and environmental law and policies.

Stakeholder participation: Water is everyone's business, therefore, there is a need to carefully define stakeholders at a wide range of levels and engage them appropriately. HELP needs to accommodate a total spectrum of stakeholders. How to empower local stakeholders to ensure public participation in law, policy, planning, and implementation of projects remains a big issue across a number of basins. There is a need for targeted social learning, such as twinning of basins by bringing forward best practices as a major action area for HELP. There is a need for sustained actions in local capacity building within a rapidly changing world. Many proposals were weaker on non-institutional stakeholder engagement, and on life and livelihood issues. Many proposers have recognized the need for links between science and law-and-policy, but were not necessarily explicit as to how to activate and improve such links.

Defining HELP issues: Although most proposals did a good job in defining issues in their basin, this was not always reflected in the programmed activities. It is important that awareness of issues translates into appropriate research and implementation activities.

Purpose, outputs, and activities: HELP needs to move from individual research projects to basin planning processes to ensure continuity and sustainability of HELP activities within a long term shared vision for the basin.

Basin HELP champions: Basin champions seem to be the critical catalysts for the success and continuation of HELP activities. Stakeholders need to mould and own HELP principles to ensure continuity and reduce dependence on a single champion.

Monitoring and evaluation: There is a need to monitor and evaluate the impact of HELP plans in the context of a basin's own monitoring and evaluation processes.

HELP Basin teams: Some HELP basin teams did not reflect the full breadth of skills required to truly implement the HELP philosophy.

Budgets and funding: Most funding for HELP related actions seemed to be project based, and there is need for continued integration with basin regulators to ensure sustainability and continuity of HELP efforts. Creative linkages with appropriate bodies and programs are critical to leverage funding and in-kind support to advance and mainstream the HELP agenda. In some basins, volunteerism led to embedding of HELP philosophy in local authority plans.

Twinning: There are a number of opportunities for twinning between basins with similar issues and experiences. This can be a practical and effective way of promoting HELP philosophy and supporting basins. Comparative assessment of water management tools such as DSS, web sites, tool kits, etc. in HELP basins (share experiences and help in evaluation) can shorten IWRM implementation time scales. Comparative assessments of methods of monitoring and evaluation need to be promoted especially in the context of adaptive management and building social capital in HELP basins.

Indicators: There is a need for appropriate indicators to monitor progress towards IWRM. HELP basins can facilitate objective assessment of IWRM indicators to understand their effectiveness and robustness. This needs to be reflected in the future phases of HELP. There is also a need to identify HELP basins that are suitable for monitoring progress towards the Millennium Development Goals in 2015.

Timescale: Most HELP interventions are planned for 3-4 years only, reflecting a realistic time span for currently available funding.

Cross Programme linkages: There is considerable synergy between planned HELP interventions and a number of other national and international programs. In particular, closer collaboration is desired in the context of IHP-VII activities at both the regional and global levels. River basins presented by academic institutions/NGOs present a challenge in terms of the continuity of actions proposed, and consequently, their sustainability; these should be encouraged to establish mechanisms of collaboration with existing official institutions (e.g., local and/or regional governments, IHP National Committees).

Documenting and sharing HELP processes: There is a need to capture HELP learning in setting up collaborative mechanisms and engaging full spectrum of stakeholders in appropriate formats to allow wider sharing of HELP philosophy as a pathway to implementing IWRM. A number of existing basins are ready to document these processes in association with a number of partners.

4 Priority Action Areas for 2009-2013

Addressing climate as a common concern: Managing water resources under climate variability and change (how much, how far, how long) and how it is going to affect people in river basins seems to be of great interest to a number of basins. There is a need to build capacity at a range of levels (science, organizations and community) to help translate climate impacts into local decisions for cost effective actions. In most basins it appears that climate variability and change are important issues, therefore, local adaptation options need to be developed as part of IWRM plans -this is a priority. Flooding and drought events need to be considered with local, social, economic, and environmental realities by taking responsibility for local actions contributing to the management of extremes at the basin and national level, rather than attributing issues to global drivers.

Strengthening water governance: Water management, governance and managing user expectations need to be considered within the context of current and future sustainable development, as well as hydro-climatic regimes across the basins. Therefore, HELP is very relevant to the local development agenda. Some basins have very good access to data and models, and often have good academic networks and good links to institutional stakeholders (governments, regulators, agencies). There is an increasing recognition that governance and participation are emerging issues in many basins. The European Water Framework Directive is having a significant impact on the European, as well on Latin American and Caribbean, river basins, and is a vehicle for data collection, mandatory participation and developing river basin plans where they do not currently exist.

Promoting multipurpose water management: There are new considerations for allocating water, which include social, economic, and environmental services from surface and groundwater. This needs to be reflected in water policy and law. HELP also needs to focus on strategies for improving rural-urban interface and decreasing conflict/competition at a wide range of levels. Some basins are transboundary, which will affect data collection, building consensus, and developing IWRM tools.

Bringing water quality into IWRM planning: Many river basins have listed significant water quality issues due to agriculture and industry waste water, as well as quantity issues. This may lead to poor human health caused by contamination, water shortages, as well as frequent flooding. Therefore, we need to include water quality concerns into the IWRM planning processes.

5 Way Forward

Evaluation of the HELP network third phase proposals clearly showed complex interdependencies within and outside the water systems. Twinning of HELP river basins can promote a transparent and accountable water management platform based on public participation, which can help build bridges between different water sectors (Fig. 2). This will lead to better resolutions for socially acceptable, scientific credible, and economically affordable sustainable water futures in river basins.

Acknowledgements

The author gratefully acknowledges proposals by the HELP network members, as well as the insightful deliberations and synthesis of the HELP Evaluation Committee members.

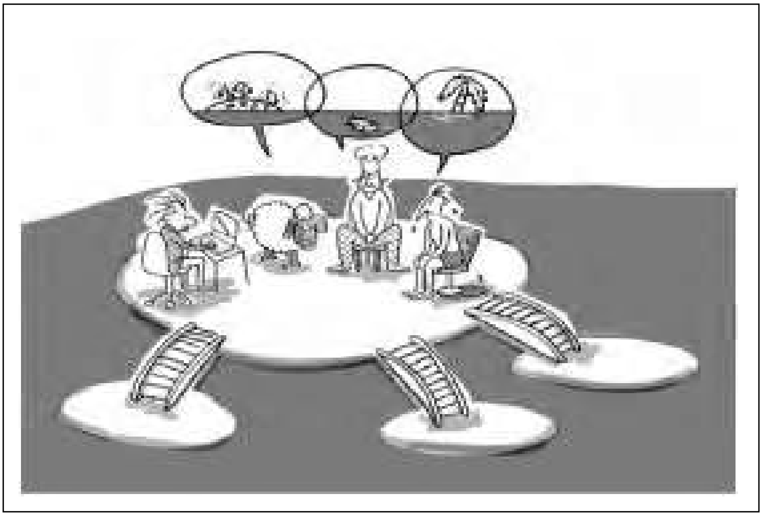


Fig. 2 Building communication bridges for resolving wicked water problems.
Source: Khan, *et al.*, 2010.

REFERENCES

Khan, S. (2008) Turning concepts into community driven catchment water management solutions: Foreword to the special HELP edition *Water South Africa* 34 (4):429-431.

Khan, S., Savenije, H., Demuth, S. and Hubert P. (2010) Tools for Analysing Hydrocomplexity and Solving Wicked Water Problems: A Synthesis. In: *Hydrocomplexity: New Tools for Solving Wicked Water Problems* (Khan, S., Savenije, H., Demuth, S. and Hubert, P. eds.) Pages 1-12.

[1]An overview of the HELP program can be found at: www.facebook.com/UNESCOHELPFORUM.

[2]Available online at: www.linkedin.com/groups/UNESCO-IHP-HELP-3911032.

1. GLOBAL CHANGE IMPACTS ON RIVER BASINS

Institutional Analysis of Water Management, Federal Policy, and the Dynamics between Governmental and Non-Governmental Actors in Problem Solving

ANNE BROWNING-AIKEN & ERNESTO PERLA PLIEGO
University of Arizona.
browing@email.arizona.edu

Abstract The potential for crises arising from inadequate water service and ecosystem failure increases when economic policy contradicts local efforts to maintain community health, when government water institutions have neither the resources nor the opportunity to engage with the community, and when the local cultural history has triggered a sense of public entitlement to water. We analyze the capacity of Mexican water institutions, from the local to the federal level, to address economic, technical, and cultural challenges within the dynamics of problem solving by governmental and nongovernmental actors. We demonstrate that Mexico's water and mining reforms have led the city of Cananea, Sonora into a developmental impasse, in which institutional actors and water stakeholders are unable to repair a broken water delivery or prevent *E coli.* and heavy metals from entering the water system.

Key words Water; institutional analysis; water policy; regional water crisis in Cananea, Sonora, Northern Mexico

1 Introduction

For northern Mexico, water has increasingly become a strategic value, as economic development and migration contribute to exponential growth (Lorey, 1999). Expansion of the mining industry and privatization of municipal water systems has complicated the management and distribution of water in the area. While intensification of agriculture, associated with the increased penetration of global capitalism and transnational corporations into northern Mexico within the last twenty years, has further depleted water resources (Browning-Aiken, 2011). Affordable water in arid northern Mexico is key to the sustainability of regional municipal and agricultural development.

Further, the neoliberal opening to free trade has restructured the way that water resources are managed. While sustainability concerns are now codified into the National Water Law, and regulations reflect Mexico's desire to encourage a 'new culture of water,' the enforcement of sustainability concerns is largely left to new water managers with little assistance from the state and federal governments.

Most people living in the Sonoran portion of the basin reside in the city of Cananea, home to one of the largest open-pit copper mines in the world. The mine, which employs 70 percent of Cananea's residents, controls water use at the headwaters of the San Pedro River (Sprouse, 2005), and represents the single largest water user in the entire transboundary watershed (Browning-Aiken, 2003, 2004). By 2006, due to the proliferation of pumps along the river, which began in 1990, the riparian zone had decreased by 53 percent.

In March 1990, the mining company passed management of the water service to the municipal government (ayuntamiento), which in turn passed water management to the Sonoran state government due to lack of municipal funds and technical expertise. Called Patronato de Agua de Cananea (PAC), the water company has been managed since then by the Sonoran Water Commission (Pliego, 2008). This situation was further supported by the 1992 Mexican Water

Law, which shifted most of the responsibility for water management to the states and local communities, as part of the neoliberal decentralized management of mining and water. Despite the policy change, water management remained top down, with little public participation; the PAC struggled along with "the simultaneous (and contradictory) existence of water management decentralization with centralized resource allocation" (Pineda, 2008: 65).

The PAC tried to increase residential water payments to repair the original equipment, installed in the 1930's, and to cover administration costs, but Cananea r esidents protested because they thought that either the mine or the federal government ought to pay for the management of community water. As a result, during the period from 1990 to 1998, the PAC only collected about 35 percent of its bills, and the system kept breaking down. Two surveys, in 2001 and 2007, indicated that most urban residents and farmers thought that the San Pedro River was too contaminated with heavy metals and *E. coli* to use for crops, and that the lack of reliable drinking water, due to frequent service breakdowns, was increasing. A third survey pointed to the potential for serious health issues due to the presence of heavy metals and organic contaminants in the town's portion of the San Pedro aquifer (Gomez-Alvarez, *et al*., 2009).

At the state level, Sonora has larger and more pressing problems to deal with. The state capital, Hermosillo, dependent upon the stored water from the Sonoran River and the Costa de Hermosillo groundwater, is the focus of a struggle between municipal factions and agricultural producers over water from the Costa de Hermosillo Aquifer (Moreno Vasquez, 2006). From a regional perspective, the problems in Cananea appear sidelined in the light of Hermosillo's water struggles.

2 Political Power Struggle over Land and Water

"Urban water constitutes a vantage point from which to study and test political development. Since water stands as a power instrument, the way decisions about water are made and how water is managed signal critical aspects of intergovernmental relations, local governance, and bottoms-up inputs to policy making" (Pineda, 1999). For example, in 1999-2000 the then Secretary of the Interior, Bruce Babbitt, and Mexican Secretary of the Environment and Natural Resources, Julia Carabias, signed a Joint Declaration called the San Pedro Initiative, formalizing the sharing of funds, information, and conservation expertise across the border for the creation of a new reserve area. $1.5 million was to come from private U.S. interests (U.S. Department of Interior, 2000), but hostility towards the idea remained amongst the Mexican mining company and ranchers, fearing the US taking control of the area. The reserve area, the San Pedro National Riparian Conservation Area (SPRNCA), was created on the U.S. side, but not on the Mexican side.

3 Institutional Analysis

New institutional economics focuses on institutional structures that govern economic behavior, particularly transaction costs that support institutional analysis and determination of prospects for institutional change (Challen, 2001: 3-6). There are three types of institutional structures involved in transaction costs: property rights, entitlement systems, and mechanisms for adjusting resource allocations. In Mexico, water is considered state property, which means that the federal government agency, CONAGUA, is the only agency that can allocate rights to ground or surface water. The community water agency (PAC) allocates water to both the city and the mine, both of which rest on the origins of the San Pedro and Sonoran Rivers. Issues of entitlement in the Mexican portion of the basin emerge most strongly in the beliefs of local Cananea residents, who regard water as a traditional, and possibly a constitutional, right. These beliefs are grounded in the community's status as a mining town (i.e., a "company town") in which delivery of water, and frequently other utilities, typically entailed little or no cost to residents. Since the 1990's, when ownership of the mine changed from public to private hands, the local sense of entitlement directly conflicted with state- and federal-level policies that emphasize primarily local and private financing of municipal water delivery operations. The situation suggests a problem of poor interplay (Young, 2002) between institutions operating at the governmental level and institutions operating at the household level, which emanates from rules based on notions of entitlement.

Furthermore, if we compare the operating and administrative costs of the Cananea PAC, we find that these are three times higher than the actual money collected for the service. Domestic water bills were paid at only an average commercial efficiency of 36.3 percent in 2007. The water director works within a vicious cycle, where service problems are a daily community complaint, but at the same time are impossible to attend to because of the poor record of water service payments. Furthermore, "the rates for water bills are used as political tools by politicians seeking municipal election…, an unsustainable form of water management" (Pliego, 2008: 33).

Participatory procedures can help to ensure that citizens are included in decision-making, that all processes are transparent, and that institutional crisis is not driven by political tenure regimes (Pineda, 2002). At the same time, citizen participation and technological expertise are necessary, but they alone are not sufficient to create water management plan.

Local political factions obstruct the resolution of water conflicts by playing on the fear that environmental issues will defeat economic development. Open debate of all alternatives and an adaptive management approach are needed to address multiple stakeholders' perspectives and to make water resources planning and management an effective learning process for basin stakeholders.

4 Institutional Design Principles

Institutional analysis is inspired by concepts of institutional design for common pool resources (Ostrom, 1990, 2005; Ostrom *et al*., 1994; Agrawal, 2002). Based on years of comparative case studies, Ostrom has drawn up a series of design principles essential to assuring long-term success in resource management. This set of principles stipulates that resource users must (1) define the physical boundary of the common resource and articulate their methods for using that resource; (2) establish a self-monitoring system and a system for resolving conflicts; (3) agree on appropriate sanctions/punishments for breaking the rules; (4) be able to adapt to changing circumstances; and (5) be able to implement their decisions without governmental opposition (Ostrom, 1990: 90-102).

Institutional design hindered by a number of factors, including policy. Despite Mexico's stated intent to decentralize natural resource management to state and local levels, the transition has progressed slowly with regard to water resources. Local entities are encouraged to form watershed commissions and committees, with the support of elected officials and representatives from water use sectors. This is a positive development, but in the absence of sufficient economic support, few institutional changes are emerging. Under these circumstances, Mexico has not yet established a monitoring system or a system for conflict resolution, let alone adapted to additional problems of prolonged drought, as well as a labor strike, which prevents mines' management from effectively participating in basins' management.

5 Institutional and Legal Vulnerability Indicators of Socio-Ecological Resilience

In recent years, research shows that concomitant high levels of groundwater pumping have reduced stream flow and probably transformed the river to a primarily ephemeral stream. Existing institutions are inadequate to the scope and scale of the water management problems. Nowhere is this more apparent than in the efforts to apply resource conservation mechanisms to the protection of the riparian corridor of the San Pedro River, through the development of a Mavavi Reserve.

The vulnerability of any ecosystem and of the human governance systems designed to manage and use this ecosystem as a resource are intricately interdependent; problems in one ripple out as problems in the other. Conflicts over (re)distribution of rights and responsibilities for ecosystem health loom in the horizon unless problems of institutional fit between those who benefit and those who bear the cost in Mexico are overcome. In Mexico, local inhabitants are unable to control the impacts of industrial damage on the health of the ecosystem, and federal and state water agencies lack the strength to enforce the mine's infractions on environmental policy (Browning-Aiken, 2000; Romero Lankao, 2007: 56). "Although Mexico has established key environmental laws and institutions, real spending on the environment shrank ... and the environmental 'side agreement' institution established to help with Mexican environmental problems is not equipped to fill in the gap" (Gallagher, 2004: 13).

6 Presence of a Bridging or Mediation Actor/Organization

While municipal governments struggle to organize a sustainable water service, no one has suggested how to resolve conflicts. When multiple actors, sectors and special interests are involved, some entity with the capacity to moderate conflict is needed. The Mexican San Pedro may need bridging or mediating help to address the complex issues between a large number of players.

7 Possible Responses to Scale Problems

Scale mismatches, especially between environmental management and water resource management, can contribute to a decrease in socio-ecological resilience, including mismanagement of natural resources and a decrease in human wellbeing. In the Mexican San Pedro, economic development is privileged over conservation of natural resources or the environment. In order to repair this mismatch, coordination would be needed at all government levels. In addition, long-term solutions to scale mismatches also depend on social learning and the development of flexible institutions that can adjust and reorganize in response to changes in ecosystems. Social or collaborative/collective learning is a process embedded in institutions, where institutional participants learn how to understand the values of other participants in decision-making, and participants learn from scientists how socio-ecosystems operate (Cumming, *et al.*, 2006); Folke, *et al.*, 2007; Tomkins and Adger, 2004). Frequently, boundary institutions or mediators can help facilitate this process by the formation of watershed governance.

8 Training of a New Culture of Water Managers

Caciquismo and patron-clientelism as a nucleus of local and regional power "continues to generate important mechanisms for maintaining power" (Peña, 1989). The COAPAES directors in Cananea and Naco were selected according to political patronage rather than their education and training in water management. In 2007, the Colegio de Sonora created a program on Integrated Watershed Management to address the politics of watershed governance and the integrated management of hydrologic resources (Moreno and Martinez, 2005). Pliego, co-author of this paper, is one of the graduates of this program.

REFERENCES

Adger, W. Neil. (2000) Social and Ecological Resilience: Are They Related? *Progress in Human Geography* 24 (3): 347-364.

Agrawal, A. (2002) Common resources and institutional sustainability. In *The Drama of the Commons*, pp41-85, eds.E. Ostrom, T. Dietz, N. Dolsak, P. Stern, S. Stonich and E. Weber. Washington, D.C. National Academy Press.

Browning-Aiken, Anne. (2011) Disjuncture between Economic Policy and Sustainable Use of Natural Resources: Water Case Studies in Sonora, Mexico. In *Neoliberalism and Commodity Production in Mexico*, eds. Thomas Weaver, Anne Browning- Aiken, James Greenberg, and William Alexander. Colorado State Press.

Browning-Aiken, Anne. (2000) *The Transformation of Mexican Copper Miners: The Dynamics of the Transformation of Mexican Copper Miners: The Dynamics of Social Agency and Mineral Policy as Economic Development Tools*. Ph.D. dissertation. Tucson: University of Arizona.

Challen, Ray. (2001) *Economic Analysis of Alternative Institutional Structures for Governance of Water Use*. Invited paper to 45th Conference of the Australian Agricultural and Resource Economic Society, Adelaide, Australia. 23-25 January.

Cumming, Graeme S, David H. M. Cumming, and Charles L Redman. 2006. Scale Mismatches in Social-Ecological Systems: Causes, Consequences, and Solutions. *Ecology and Society* 11(1).

Folke, Carl. (2006) Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16: 253-267.

Gomez-Alvarez, Augustin, Diana Meza Figueroa, Arturo I. Villalba-Atondo, Jesus Leobardo Valenzuela-Garcia, Jorge Ramirez-Hernandez and Javier Almendaris-Tapia. (2009) Estimation of Potential Pollution from Mine Tailings in the San Pedro River, 1993-2005. *Environmental Geology* 57: 1469-1479.

Herrera-Carbajal, Socorro, Arturo I. Vilaba-Atondo, and Martin Molinar-Tabares. (2007) Modelación hidrogeológica y evaluación de la sustentabilidad del acuífero transfronterizo del Río San Pedro en Sonora, México. *Revista Latinoamericana de Recursos Naturales* 3(1): 21-30.

Lorey, David. (1999) *The U.S.-Mexico Border in the Twentieth Century*. Wilmington, Delaware: Scholarly Resources, Inc.

Moote, Anne and M. Gutiérrez. (2001) *Views from the Upper San Pedro River Basin: local perceptions of water issues*. University of Arizona Udall Center for Studies in Public Policy, Tucson, Arizona.

Moreno Vasquez, José Luis. (2006) *Por Abajo del agua: Sobreexplotación y agotamiento del acuífero de la Costa de Hermosillo, 1945-2005*. Hermosillo: Colegio de Sonora.

Ostrom, Elinor. (2009) A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325 (5939): 419-422

Pineda Pablos, Nicolás, Anne Browning-Aiken, and Margaret Wilder. (2007) Equilibrio de bajo nivel y manejo urbano del agua en Cananea, Sonora. *La Frontera Norte* 19 (37) 143-172.

Pliego Ernesto Perla. (2008) Tarifas autosuficientes para la prestación del servicio de agua potable Caso: Comisión Estatal del Agua Unidad Operativa Cananea, Sonora. Master's thesis at the Colegio de Sonora.

Scott**,** Christopher A.; Banister**,** Jeff M. (2008) The Dilemma of Water Management **'**Regionalization' in Mexico under Centralized Resource Allocation. *International Journal of Water Resources Development* 24(1):61-74.

Tamayo-Flores, Rafael. (2006) NAFTA-Driven Changes in the Regional Pattern of Economic Growth in Northern Mexico: Profile and Determinants. In *Changing Structure of Mexico: Political, Social, and Economic Prospects*, pp. 119-139. Ed. Laura Randall, London and NY: M. E. Sharpe.

Young, Oran B. Leslie A. King, and Heikeschroeder, eds. (2008) *Summary for Policy Makers. In Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers* pp. xiii-xix.. Cambridge: MIT Press.

Wilder, Margaret and Scott Whiteford. (2006) Flowing Uphill Toward Money: Groundwater Management and Ejidal Producers in Mexico's Free Trade Environment. In *Changing Structure of Mexico: Political, Social and Economic Prospects*, pp 342-358. London: M.E. Sharpe.

Climate Change Adaptation Practices in the Sixaola Binational Basin: Building Governance Capacity from the Local to the National and Regional Level, Costa Rica - Panama

ARIEL AMOROSO
IUCN Mesoamerica and the Caribbean Initiative
ariel.amoroso@iucn.org

Abstract The binational Sixaola watershed has an extension of 280 thousand hectares, and is located in the Caribbean slope of the frontline between Costa Rica and Panama. In the Bribri indigenous territory situated at the middle part of the basin, staple grains, organic cocoa, and banana are grown combined with humid tropical forest. Agricultural systems at the lower basin are traditional plantain, grown by small farmers, and wide extensions of banana produced by transnational companies. In last two cases, natural ecosystems almost no longer exist. The most important climatic threats in this region are related to temporal rain, followed by periods of short dry season. Some climate change scenarios projected the region are coincident with local testimonies of their inhabitants in which not only rain but dryness have risen in intensity, and climatic variability has turned unpredictable. With the objective of assessing these impacts, as a component of the project "good water governance for adaptation" conducted by IUCN, participative tools have been applied, resulting in local climate change adaptation plans designed by local populations. Adaptation practices selected in above cited planning process could be gathered in three components: recovery of protector ecosystems of water spring and flooding lands, agrodiversification as an alternative against plague incidence becoming more often in traditional crops, and last, strengthening of water governance capacity. For applying mentioned adaptation practices, two pilot sites were selected: Middle Sixaola and Lower Yorkin sub-basins. The adaptation strategy adopted by this project were designed in a coordinated platform from local to regional level, as a combination between bottom-up and top-down approaches. For this reason, in the process of implementation, IUCN makes efforts with community-based organizations and indigenous authorities, as well as with the Binational Commission for the Sixaola River Basin and the Secretariat of the Binational Permanent Commission of the Border Cooperation Treaty, signed by Costa Rica Panama.

Key words Watershed; ecosystem approach; water governance; climate change adaptation; livelihood

Climate Change and Anthropogenic Impact on Water Resources of the Lebanese Crests

A. SHABAN & T. DARWICH
National Council for Scientific Research, Remote Sensing Center, Beirut, Lebanon.
geoamin@gmail.com

Abstract The Lebanese crests, the highest of their type in the Middle East region, are constituted over the major surface and groundwater reservoirs of Lebanon. They form over areas with high rainfall rate (>1200mm), and with snow remaining on their slopes and depressions most of the year; they largely contribute to feeding rivers, springs and groundwater aquifers. These crests have remained preserved for a long time with a unique ecosystem. However, alterations are being noticed, given the variability in climatic conditions, which is exacerbated by anthropogenic influence. This is reflected at pediments of these crests on different environmental and socioeconomic regimes in the adjacent regions. As for the climate, there is an obvious turbulence in the rainfall regime, both in rainfall intensity, and a shift in the seasonal intervals. An increase in temperature by about 1.5° C has also been observed. The anthropogenic impact is judged from the degradation of the ecosystem and the interruption of the hydrologic regime. These are caused by the excavation of snowpacks, the diversion of snowmelt water along slopes, and the disintegration of the recharge zones on the crests. To these influences we can add the contamination of the snow cover with animal waste. The volume of water resources in the surrounding regions of the crests has been reduced; hence, the discharge in many issuing rivers has declined by 60%, and several springs have either dried out or are not expected to last long before they do. This, accompanied with quality deterioration, has established a status quo that has been changing both the ecosystem and lifestyle of the surrounding regions. However, there are no legislations to mitigate the uncontrolled human interference over the crests.

Key words High mountains; snow cover; water recharge; water quality; Lebanon

1 Introduction

Lebanon is located on the eastern coast of the Mediterranean Sea. Three major physiographic units characterize it: two uplifted blocks that form the mountain ranges of Mount Lebanon (to the west), and Anti-Lebanon (to the east); and the Bekaa plain, which separates them. The three units trend NNE-SSW (Fig. 1). The existing mountain chains, notably those adjacent to the Mediterranean, create a climatic barrier that receives the cold air masses from west, and results in high precipitation rates that exceed, in many instances, 1500 mm/yr.

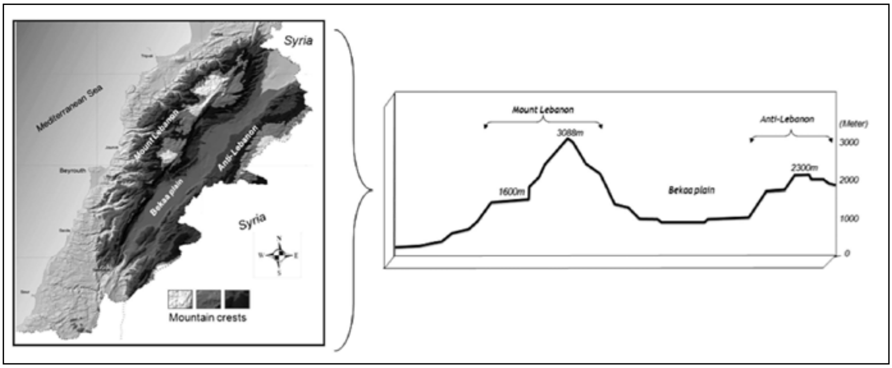


Fig. 1 Location of Lebanon.

Due to this high precipitation rate added to its physiographic setting, Lebanon holds tremendous water resources, and it has been described as the "*Water Tower*" of the Middle East. It is the only geographic location in the Middle East region where snow accumulation remains for several months on mountain crests, covering about 2000 km^2. In addition, Lebanon occupies 12 major rivers (3500 million m^3/year), more than 2000 major springs (1250 million m^3/year), and a groundwater reserve that exceeds 1500 million m^3/year (Shaban, 2003).

Unfortunately, Lebanon has recently become a country under water stress. There have been increased water shortages, and the water deficit is patent everywhere on Lebanese territory. In light of this unfavourable status, efforts have been oriented towards analysing the impact of the variability in climatic conditions, largely ignoring population growth. Still, in the last few decades, the available water resources have suffered an obvious volumetric decrease, estimated at 40% in average (Shaban, 2009).

This study will focus on the factors influencing water resources on the Lebanese mountain crests, since these crests represent the major catchment and feeding zones for surface water and groundwater. It will show that the anthropogenic impact has almost more effects on water resources than climatic variability.

2 Materials and Methods

This study is a preliminary research obtained in the context of a research project carried out by the Lebanese National Council for Scientific Research in Lebanon (CNRS). Most of the methodology followed involves field verification and reporting observations and remarks. Existing measurements concerning water resources exploitation were also used. In addition, a water quality analysis was done on selective sites, mostly from snowmelt. A periodical field survey was done, almost on a weekly basis, in order to monitor short-term changes and applications.

Satellite images of high resolution (1 meter) were an important tool for this study. They facilitated monitoring small-scale terrain features, and thus, the human impact on these features; especially on the existing water bodies. In addition, topographic and geologic maps (1:150,000 scale) were analysed in detail and used as base maps during the field survey.

3 Results

Climate Change and Water Resources

Change in the climatic conditions is a global phenomenon. In fact, dramatic meteorological changes are expected across the globe within the next few decades (IPCC, 2007). However, these changes respond to a regular fluctuation in the regime of meteorological elements that occur from time to time. If we refer to past records we can notice such fluctuations. Recently, the impact of climate change has affected water resources, a vital element of life, and has been considered a major environmental problem. Yet, there is no obvious correlation between water shortage and climatic conditions.

In Lebanon, many have proposed to attribute or partially attribute the water shortage to climate change. Yet, studies have shown little decrease in the precipitation rate. This decrease has been estimated at about 50 mm over the last four decades. This is a negligible value if compared against the average precipitation rate of Lebanon, which ranges between 850 and 950 mm. Besides, rainfall trends are oscillating, with an increasing number of rainfall peaks and a shift in the timing of seasonal intervals. Also, an increase in temperature by about 1.5° C has been reported (Shaban, 2011).

A sharp decrease in the volume of water from different resources has been noted in both surface and groundwater. This was reported from applied illustrations and data interpolation for water discharges from rivers, springs and groundwater. Hence, there is a decrease in the discharge from rivers and springs between 10% and 30% (sometimes even reaching 60%), and several springs have dried or will not last for long before they do. There is a similar case for groundwater. For example, in the area of the Litani River Basin, an average drawdown in the water table was reported as 20-25 m and 5-10 m in the major two aquifers (Cenomanian and Jurassic), respectively (CNRS, 2007).

Anthropogenic Impact

Usually, the impact on water resources is directly linked to the changing climate, whilst the previous section shows that the impact of climate is still uncertain and is almost negligible. Nevertheless, human interference is much more effective in changing the hydrologic regime, and thus, in the interruption of water volume and even its quality. The mountain crests of Lebanon, which are the feeding zones for water resources, show a typical example of human interference on water resources. This interference has several aspects (Fig. 2).

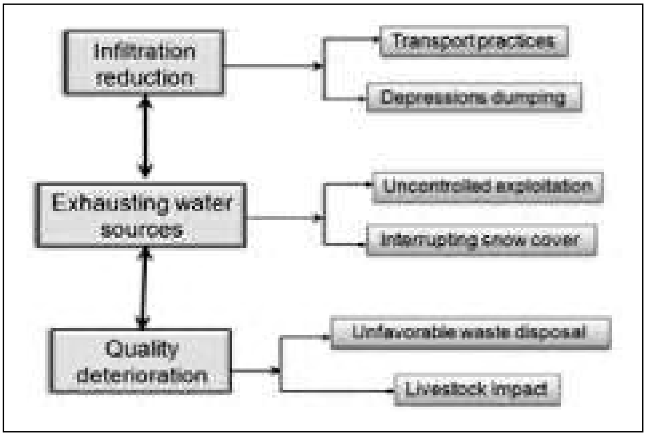


Fig. 2 Major components of anthropogenic impact on the mountain crests of Lebanon.

Infiltration Reduction

The upper zones of the high mountains are almost completely composed of hard carbonate rocks (e.g., limestone and dolomite), which are characterized by intensive fracturing systems and karstification. These hydro-structure properties enhance the infiltration capacity and may exceed 45% of the precipitated water (UNDP, 1970). However, human involvement has recently affected the infiltration capacity of these zones, thus creating an increased risk of run-off flows, overland flows, and evapotranspiration.

The two most critical involvements are: transporting practices and filling of depressions. In the former, humans, livestock and transporting tools affect the terrain. Their presence increases the compaction of the soil cover and transforms it into an impervious layer in which surface water tends to run on the surface of the terrain rather than infiltrate into the substratum. In the latter, the existing lowlands and karstic depressions (e.g., sinkholes) that form on the terrain surface of the high mountains are being filled with soil and rock debris as a result of human and livestock interference. This also affects fractures and fissures, which are the most common elements in water infiltration.

Exhausting Water Resources

In lieu of the appropriate management strategies and legislation to conserve water resources, and due to the exacerbated shortage and increasing demand for water, a number of uncontrolled exploitation approaches have risen in the mountainous regions of Lebanon. This leads to the exhausting of liquid and soil water resources, and in turn interrupts the hydrologic regime. It creates a conflict with the mechanism of water percolation from surface media into the ground reservoirs (Shaban and Darwich, 2011), and affects the storage of groundwater. Table 1 summarizes these extraction approaches.

Table 1 Uncontrolled water exploitation in the mountainous regions of Lebanon.

Water status	Sources	Extraction Approach	Impact*
Liquid sources	River	Direct pumping and diverting water water from upstream zones	High
	Springs	Intensive exploiting of water directly from sources	
	Mountain	Direct pumping and diverting lakes water to lower lands	Moderate
Solid sources	Melting snow	Connecting tubes and diverting water tolower lands	
	Snow packs	Excavation of snow to be collected on site for melting	Slightly high

**Estimated from field observations*

Quality Deterioration

As in the lower regions, the impact on water quality in the mountainous regions of Lebanon has exceeded the unfavourable limits in the last few decades. These regions, which represent the principal recharge zones for freshwater sources, are witnessing severe and easily noticeable pollution. Unfortunately, this pollution is usually derived from the lower lands in the neighbouring areas. It is observed at the distributed small-scale and large-scale landfills, the chaotic waste disposal, and from the contamination practices resulting from pastures.

There are great amounts of solid waste dumped in the remote regions of Lebanon due to the absence of applicable landfills and appropriate waste disposal plans. This waste, in many cases, is derived from remote regions and consists of toxic and biologic residues. Hence, the decay of these residues by water, which infiltrates into substratum, will reach groundwater reservoirs. Yet, there are no empirical studies done on the quality of water in the crests regions of Lebanon, because they are considered as freshwater with pure enough quality. The only research carried by the CNRS in these regions is on the physical properties of snow, with a special emphasis on snow quality. Preliminary results show several anomalous values (e.g., pH = 7.89; conductivity = 17.76 mS/cm; salinity = 11.22 ppm; 40,300 ug/*l*). Nevertheless, the related municipalities have taken no legal implementations, and concerns are very rare.

Another type of water quality deterioration seen in the high regions can be described as "moveable pollution". It is attributed to waste from livestock. This is a common phenomenon, since livestock troops usually move towards cold sites, notably where snow exists (Fig. 3). This is a consequence of the climatic variations that the ecosystem is witnessing in the elevated areas.

The phenomenon has increased and is found to be aggravated when pastoral livestock from other areas come in the dry seasons and settle in the mountainous, relatively cold regions. However, this is not only affecting the quality of melting snow, but also the bioturbation process of the snow that accumulates, since the presence of livestock appears to accelerate the melting process.

Fig. 3 Impact of livestock on snow packs.

4 Conclusion and Discussion

Recently, concerns about water resources have been raised as a global issue. The problem has been taken out of proportion. This is mostly due to the elementary water needs per capita not being fulfilled; correspondingly, there is an absence of proper management approaches in order to conserve this vital resource. This should not occur in Lebanon, a country with tremendous water resources and high precipitated water rate. The change in consumption of water per capita is quite alarming. For example, in Beirut, it ascended from 30, 50, 84, 112 and 200 l/day/ capita for the years 1870, 1912, 1944, 1959 and 2007, respectively (Fawaz, 2007). It indicates a yearly increase of about 1.2 l/day/capita. Yet, the blame has been placed on climate change and the resulting variations in the hydrologic regime. There is not enough research on the hypothesis that climate change is the primary reason behind the water shortage, but there is an obvious ignorance on the negative, direct or indirect, impact of human involvement.

We have observed how the Lebanese population is implementing new techniques to harvest and utilize water at remote and rugged mountainous areas. Many human activities have moved to these remote and elevated areas, and water resources are being freely exploited without any control. Temporary settlements have invaded the mountain crests of Lebanon. They are degrading both the quantity and quality of the water, and more specifically the solid-state water (i.e., snow).

It is of the utmost importance to focus on this crucial issue. The rock bodies of the mountain crests of Lebanon represent major water reservoirs, which are supposedly pure and clear. In addition, these crests are the terrain basin for snow cover, representing a fundamental portion of the Lebanese income and touristic sites. A decision must be taken as soon as possible by the governmental sector to protect these regions and to consider them as natural reserves for both ecosystem and water resources.

REFERENCES

(CNRS) National Council for Scientific Research. (2007) Final Technical Report on the project: *Towards an ecosystem approach to the sustainable management of the Litani River-Lebanon*. IDRC & CNRS & LRA and DSA.

Fawaz, M. (2007) *Towards a water policy in Lebanon.* A book published by ESIB (In Arabic), Beirut, Lebanon. 259p.

IPCC Report. (2007) *The Fourth Assessment Report* (AR4), March 14th 2008. Available at: http://www.ipcc.ch/

Shaban, A. (2003) *Etude de l'hydroélogie au Liban Occidental: Utilisation de la télédétection.* Ph.D. dissertation. Bordeaux 1 Université. 202p.

Shaban, A. (2009) Indicators and aspects of hydrological drought in Lebanon. *Water Resources Management Journal* 23: 1875-1891.

Shaban, A. (2011) Analyzing climatic and hydrologic trends in Lebanon. *Journal of Environmental Science and Engineering* 3 (5).

Shaban, A. and Dawrich, T. (2011) The role of sinkholes in groundwater recharge in mountain crests of Lebanon. Environmental Hydrology Journal 19 (9).

UNDP. (1970) *Liban : Étude des eaux souterraines. Programme des Nations Unies pour le développement*, N.Y. DP/SF/UN, 44, 185p.

Historical Reconstruction of Flow in Northwest Argentina on the Basis of Dendrochronological Records

EDUARDO A. FLAMENCO[1], RICARDO VILLALBA[2] & RAFAEL O. RODRIGUEZ[1]

1 *Instituto Nacional de Tecnología Agropecuaria (INTA), Instituto de Clima y Agua, Buenos Aires, Argentina* eflamenco@cnia.inta.gov.ar

2 *Departamento de Dendrocronología e Historia Ambiental, IANIGLA, CONICET, Mendoza, Argentina*

Abstract To study the climate and its temporal-spatial variation, as well as to help determine the extent to which natural and human factors contribute to this variability, requires knowledge of long-term time series, from centuries to millennia. An analysis of climate variability on the basis of hydrometeorological instrument series, particularly in the northwest of Argentina, where records do not exceed 60 years, would be very limited. Dendrochronology is one of the disciplines that is appropriate to extend series of climatic variables and reconstruct weather, volcanic, archaeological, and environmental events from the growth rings of trees, thus providing continuous series precisely dated at the annual level. In this study, the annual growth rings of native species walnut (*Juglans australis* Griseb) and Tucuman cedar (*Cedrela lilloi* C. DC) have allowed us to reconstruct seasonal flow series since 1791 for a basin in northwestern Argentina. We chose this variable for being an excellent indicator of the hydrologic cycle in nature, integrating precipitation, infiltration, and evapotranspiration over large areas. To link flows and annual growth rings we used a branch of artificial intelligence known as artificial neural networks.

Key words Dendrochronology; climate variability; flow; artificial neural networks

1 Introduction

Studying the climate and its temporal-spatial variation helps determine the extent to which natural and human factors affect this variability. This requires long-term time series, ranging from centuries to millennia, for climate variations to be validated statistically. An analysis of climate variability on the basis of hydrometeorological instrument series, particularly in the northwest of Argentina, where records do not exceed 60 years, would be very limited.

Dendrochronology is a valuable tool to extend series of hydro-climatic variables, as the interannual variations in the thickness of tree growth are related to climatic fluctuations. The *cofechado* (cross-dating) is the basic tool of Dendrochronology. It allows us to compare variations in the width of ring samples from different living and dead trees, so to can identify the exact year in which each ring was formed (Fritts, 1976). Thus, this discipline can generate precise continuous annual logs, which may eventually be extended for thousands of years.

The growth of trees in semiarid environments represents the balance between rainfall and evapotranspiration losses, hence, in many cases the width of the rings can been used as an indicator of seasonal or annual variations in runoff from a watershed (Stockton and Jacoby, 1976; Holmes, *et al*., 1979; Cobos and Boninsegna, 1983; Meko, *et al*., 1995, Lara, *et al*., in press).

As an example of the importance of this technique, the study by Stockton and Jacoby (1976) explained why people in Mesa Verde, Colorado abandoned their cities and moved to other sites due to lack of water. Other example is the study conducted at the Max Planck Institute for Solar System Research (Solanki, *et al*., 2004), which determined the content of the radioactive isotope carbon 14 (^{14}C) trapped in tree rings and used it to reconstruct sunspot activity 11,400 years into the past, in order to evaluate the influence of solar activity on global climate.

It is therefore of interest to use indicators or high-resolution environmental records that may allow for long-term reconstruction of the climate. This will facilitate the possibility of determining the natural cycles of climate change and how they have been affected by human activities in the last 150-200 years.

In this study, we used tree rings, an indicator that provides continuous series, precisely dated at the annual level, to reconstruct the flow of the San Francisco River, a tributary of the Bermejo River, in northwestern Argentina. The dendrochronological series from native walnut species (*Juglans australis* Griseb) and Tucuman cedar (*Cedrela lilloi* C. DC) grown in the region have allowed the reconstruction of a series of seasonal flows in the San Francisco River. Interannual variations in the growth rings of these species are strongly correlated with regional variations in temperature and precipitation (Villalba, *et al.* 1992, 1998), and are a proxy for the regional hydrological cycle, integrating precipitation, infiltration, and evapotranspiration in areas of growth.

2 Materials and Methods

Monthly flow data from 1947 to 2002 has been provided by the Subsecretaria de Recursos Hidricos of Argentina. Monthly rainfall data comes from sources such as Agua y Energía Eléctrica, Ferrocarril General Belgrano, Dirección General de Aguas de Salta y Servicio Meteorológico Nacional.

The tree-ring chronologies used in this study are part of a long-term regional project for drawing up and updating of chronologies of the two species studied. The species chronology for native walnut was developed in the 1980s (Villalba, *et al.* 1985) and updated periodically (Villalba, *et al.* 1987, 1992, 1998). The location of the San Francisco River Basin and the ring sampling sites are shown in Fig.1. The identification of the rings is illustrated in Figures 2 and 3.

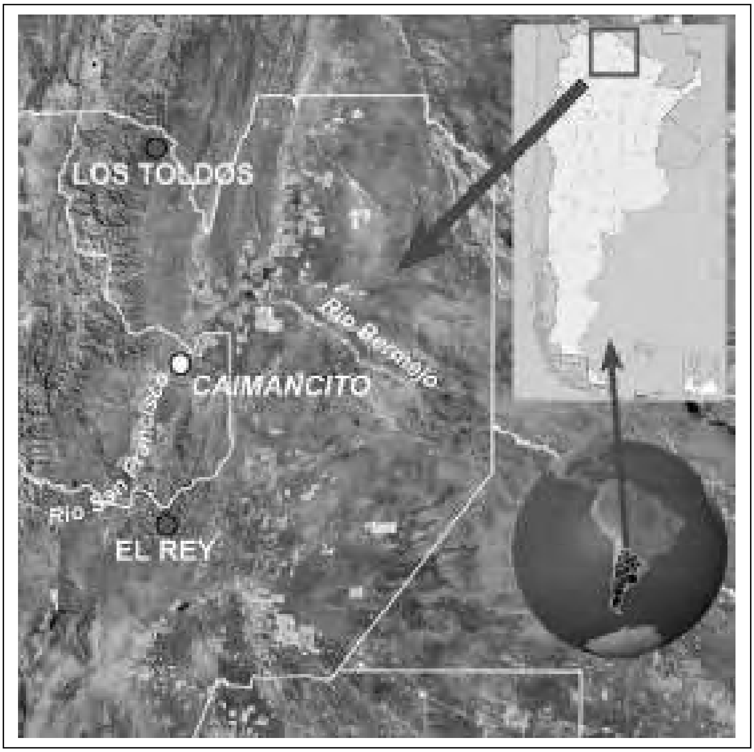


Fig. 1 Location of the San Francisco river basin, tributary of the Bermejo, Caimancito gauging station (23 º 43 'S, 64 º 33' W) and sampling sites of tree rings. Source: NOAA LANDSAT Image.

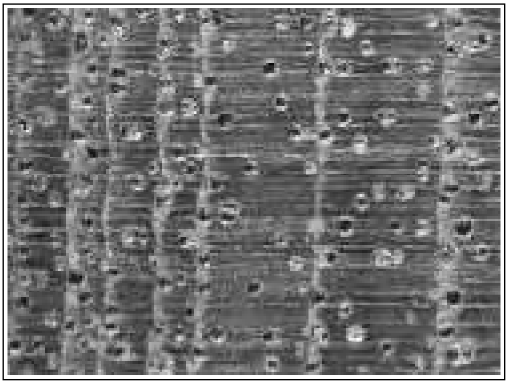


Fig. 2 *Cedrella lilloi.*

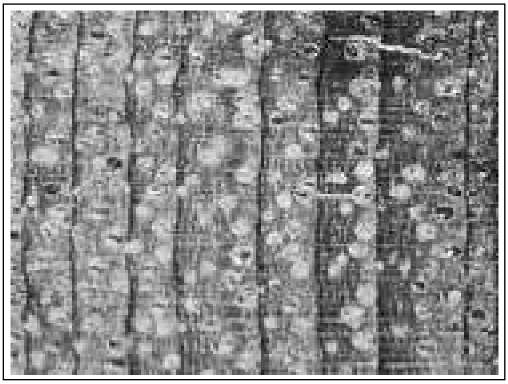


Fig. 3 *Juglans australis.*

The mountainous subtropical region of northwestern Argentina has a marked seasonality regarding water flow, with 83% of annual contributions occurring during the spring-summer (October to April). Fig. 4 shows that the growth rings of native walnut clearly reflect the annual changes in regional climate. The trees were sampled in Los Toldos (22 º 19 'S, 64 º 40' W) and El Rey National Park (24 º 43 'S, 64 º 38' W), in the province of Salta. The distance between both sites is about 250 km. The annual series of rings and the seasonal (October-March) flows of the San Francisco River basin cover the period between 1947 and 1999 in the case of walnut, and from 1947 to 2002 in the case of cedar. To analyze seasonal rainfall (cumulative from October to April), rainfall stations in the basin with enough historical information (1934-1990) were employed.

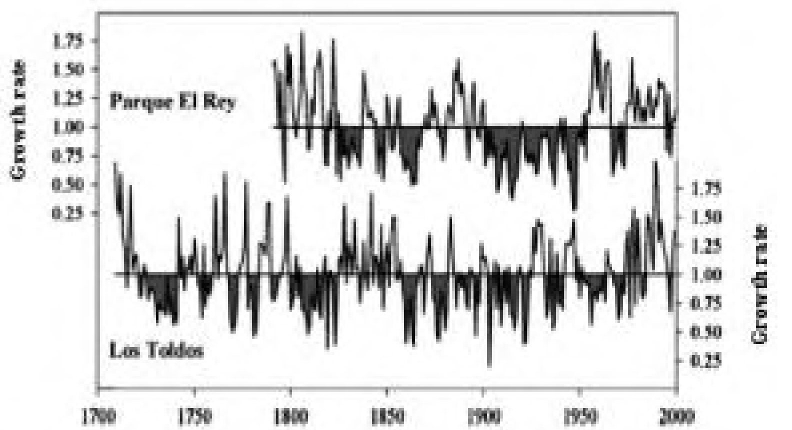


Fig.4 Ring-width chronologies of native walnut (*Juglans australis*) from Los Toldos and cedar from El Rey National Park.

2.1 Cross-correlation Analysis

This analysis was conducted to evaluate the distribution function of scenarios in advance, so as to show whether a relationship exists between runoff and the different ring chronologies of these two species. The analysis confirmed the significant correlation between seasonal mean flows and tree rings, for various periods of development, as well as between mean flows and seasonal cumulative rainfall from October to April in the basins of rivers in the Argentine Northwest.

The significant correlation between seasonal rainfall of different meteorological stations in the San Francisco River Basin and the ring chronologies is observed for both cedar and walnut. Similar patterns of correlation in several meteorological stations of the Bermejo River Basin, such as Picket, Lajitas, Pichanal, Caimancito, and Calilegua were observed.

2.2 Historical Reconstruction of Seasonal Flows

To reconstruct the series of seasonal flows in this basin prior to 1947 we used an artificial neural network. Artificial Neural Networks are a branch of artificial intelligence, where knowledge is built by learning from examples and trying to simulate the structure and functioning of biological neurons.

3 Results and Discussion

Figure 5 shows the observed flow series (1947-1993) and the one estimated with this methodology. The historical reconstruction from 1791 to 1993, expressed in terms of anomally, is illustrated in Figure 6.

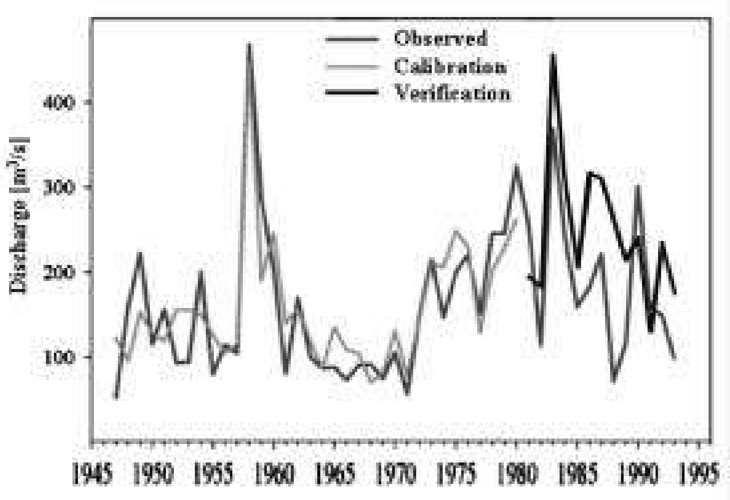


Fig. 5 Seasonal flows in the San Francisco River, at different stages of the Artificial Neural Network used.

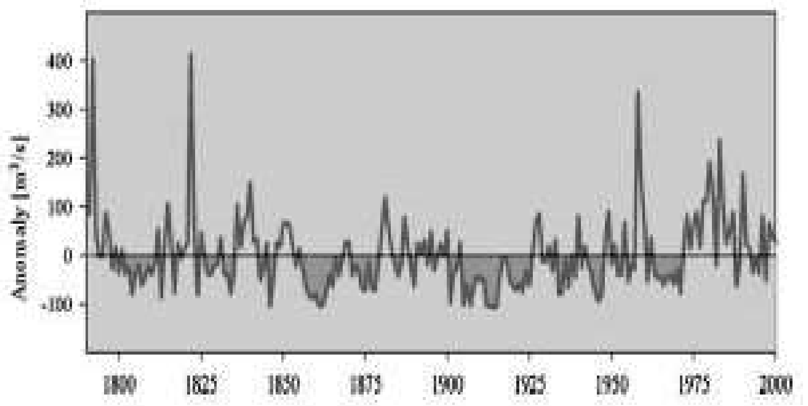


Fig. 6 Historical reconstruction of seasonal flows expressed as anomalies.

4 Conclusions

The aim of this study was to show the enormous importance of dendrochronological records for the reconstruction of hydro-climatic variables. Simple historical observation of the seasonal flow anomalies during the period 1791-1946 (rebuilt series) allows us to identify long periods of flow deficit in the basin, ranging from 10 to 27 years. Also observed were very short cycles with extreme flows, occurring in 1792 and between 1818 and 1823. While this situation is rare, this reconstruction made possible its detection. This type of information will allow analysis of the evolution of the climate system at different scales, which has not been the subject of this paper.

REFERENCES

Cobos, D. R and J. A. Boninsegna. (1983) Fluctuations of some glaciers in the upper Atuel River basin, Mendoza, Argentina. *Quaternary of South America and Antartica Peninsula* 1: 61-82.

Haykin, S. (1994) *Neural networks: a comprehensive foundation*. New York, Macmillan College Publishing Company.

Holmes, R. L.; C. W. Stockton and V. C. La Marche. (1979) Extension of river flow records in Argentina from long tree-ring chronologies. *Water Resources Bull*. 15 (4): 1081-1085.

Fritss, H. C. (1976) *Tree-rings and Climate*. Academic Press Inc. London. 565pp.

Meko, D.; C. W. Stockton and W. R. Boggess. (1995) The tree-ring record of severe sustained drought. *Water Resources Bull*. 31 (5): 789-801.

Rumelhart, D. E.; G. E. Hinton; R. J. Williams. (1986) Learning representations by back-propagation errors. *Nature* 323: 533-536.

Solanki S. K.; I. G. Usoskin; B. Dromer; M. Schüssler and J. Beer. (2004) Unusual activity of the Sun during recent decades compared to the previous 11,000 years. *Nature* 431: 1084-1087.

Stockton, C. W. and G. C. Jacoby Jr. (1976) Long-term surface-water supply and streamflow trends in the Upper Colorado River Basin based on tree-ring analysis. *Lake Powell Res. Project Bull*. 18. Inst. Of Geophys. And Planet. Phys., Univ. of Calif. Los Angeles.

Villalba, R.; J. A. Boninsegna and R . L. Holmes. (1986) *Cedrela angustifolia* and *Juglans australis*: Two new tropical species useful in dendrochronology. *Tree-ring Bulletin* 45: 25-36.

Villalba, R.; J. A. Boninsegna and A. Ripalta. (1987) Climate, site conditions and tree-growth in subtropical north-western Argentina. *Canadian Journal of Forest Research* 17: 1527-1544.

Villalba, R.; R. L. Holmes and J. A. Bonisegna. (1992) Spatial patterns of climate and tree-growth variations in subtropical north-western Argentina. *Jounal of Biogeography* 17: 631-649.

Impacts of Climate Change on the Hydrological Regime and Local Livelihood in the Upper Kaligandaki River Basin, Nepal

JAGAT K. BHUSAL[1] & PREM SAGAR CHAPAGAI[2]

1 *International Hydrological Program National Committee of Nepal, Nepal*
ihpnepal@gmail.com

2 *Department of Geography, Tribhuvan University, Nepal*

Abstract Experience has shown that even relatively small catchments have a wide variety of physical, management, and policy issues relating to process hydrology, water law and policy, water resources management, and stakeholder participation, which can be solved in an integrated manner (HELP, 2000). In this context, some activities related to HELP (Hydrology for the Environment, Life and Policy) were initiated in the Upper Kaligandaki River basin in Nepal. It was found that there are growing concerns on deteriorating livelihoods in the basin, which are worsened by climate variability. Importantly, climate change is altering frequency of snowfall and depth (amount) of snowfall, which results in less water available for irrigation and for traditional agro-pastoral production systems. River sediment and river flows found satisfactorily correlated. This is an indication that with extreme events, hydro hazards, depleting permafrost areas, and glacier melts have close links with river flows and sediment. Several villages settled on the river bank and slopes are likely to disappear within the next few decades if climate continues changing at the present rate. The overall scenario of the basin is that livelihoods are vulnerable and settlements have begun shifting.

Key words Kaligandaki; agro-pastoral; livelihoods; climate change; river sediment; HELP

1 Upper Kaligandaki River Basin

Bordered also with Tibet Autonomous Region of China to the north, east and west, Upper Kaligandaki basin is located in the trans-Himalayan region of Nepal (Fig. 1). Himalayas are geologically young, fragile and hit by continuous denudation. Basin covers an area of 3573 square kilometres with the elevation ranging from 2000m to 8168m from the sea level. Due to deep slopes and cuts by river gorges, settlements are not dense, arable land is limited (NTNC, 2008). The major farming system in the basin is confined to the middle and upper slopes below 3500 meters above mean sea level.

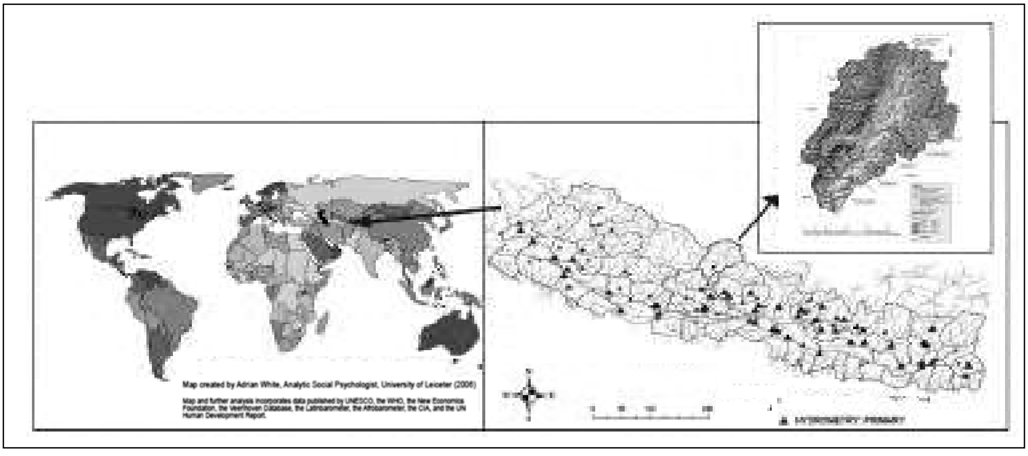


Fig. 1 Location map of Nepal and Upper Kaligandaki River Basin.

Climate and vegetation: Basin lies in the rain shadow area and receives less than 300 millimeters annually (DHM, 1999). The climate is generally dry with strong winds and intense sunlight. Area between from 2000 meter to 3000 meter altitude has cold temperate climate which is the wettest part of the district and is dominated by coniferous forest. Alpine climatic zone varies from 3000 m to 4500m. The area is dominated by shrub, thorny vegetation cover and rich in non-timber forest products. Tundra region ranges above 4500 m and is covered with snow all year round.

Culture and tourism: Over the years, Tibetan missionaries continued penetrating the basin thereby influencing various Buddhism sects and reforming (Simon, *et al.*, 1998). Current era, populations do not belong to one particular culture or traditaion (NTNC, 2008). Since 2010, the vehicle and road network has been opening many opportunities for sustainable livelihoods. But on the other hand, this has also widened economic disparity, accelerate environmental degradation, heighten cultural integration and contribute to the haphazard growth of settlements in the basin (Tulachan, 2001).

Water and culture: Water was highly contested between individuals, communities, and social groups within the basin. Water right was closely tied with the fraternal polyandry system of marriage practiced until recent past in the region. Although this marriage system has almost died by now, the impartibly inheritance system has left the people divided in classes (Basnet, 2007) People indigenous to the basin have much to teach the world about how to adapt, survive, and thrive in the context of global warming and habitat degradation.

2 Climate Change: Annual Precipitation and Temperature Trend

Climate change is a matter of global concern. It is predicted that one degree temperature raise at sea level will correspond to two degree temperature raise in high altitude region like Himalaya (IPCC, 2001). Studies have indicated alarming temperature trends in Nepal which varied roughly between 0.06°C to over 0.08°C. Spatial variation of the annual mean temperature trend analysis showed the increasing trend in almost entire country except on few isolated places (Karmacharya, *et al*., 2007; Practical Action 2009). The mean temperature of basin has a rising trend by about 0.02 per year (Baidya, *et al*., 2008).

The average annual rainfalls in the basin and on overall western regions of Nepal have a positive trend (Baidya, *et al*., 2008). Lower part of the basin which is the wettest part has an increasing trend in annual precipitation with the rate of about 0.70 millimeter per decade (Gauchan A., 2010). The northern part of the basin which is the lowest precipitation region has been experiencing decreasing trend in snowfall.

3 Climate Change: Water Balance, Snow and Glacial Melts and River Sediment

Water balance: Although there are clear indications of climate change effects on hydrological regimes in the basin and study is continued to quantify the alterations in river flows due to such changes. Annual runoff volume that is discharging out through the basin and total annual volume of water falling as precipitation over the basin area (3200 sq. km) is assessed (Fig. 2). The long-term mean annual precipitation is equivalent to 924 million cubic meters whereas the annual water volume discharging out of the basin amounts to 1110 million cubic meters (DHM, 2008). The runoff/rainfall ratio approximates to 1.20. The differences in rainfall and runoff quantity can be explained by the fact that the rainfall over the river basin is not accurately determined due to either lack of representative precipitation records and/or runoff contributing components are also the glacier-melt, snowmelt and groundwater aquifers whose recharge areas could lie outside of the basin.

Snow and Glacier melt: There is about 8.46 % contribution to annual flow from snow and glacier melt, a maximum monthly contribution of 22.52 % in May and a minimum monthly contribution of 1.86% in January in Kosi River in Nepal (WWF, 2009). The assessment made on Upper Kaligandaki river basin indicated that the snow melt contribution could reach up to 40 % (Fig. 3). The worst scenarios as per the present projection are that future flow characteristics of snow fed rivers could appear to be like that of present pattern of non-snow fed rivers. And the reduction in river flows in the basin could be up to 40 % if all snow dries up. However, the situation would be more miserable if temporal and spatial variations become wider due to climate changes in future.

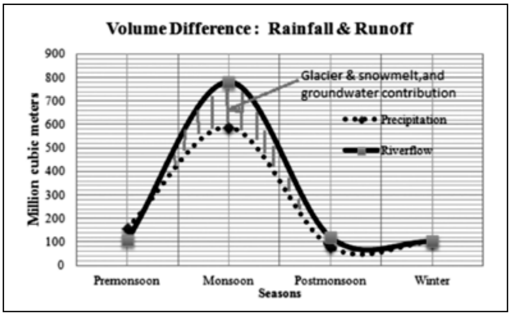


Fig. 2 Annual runoff and rainfall volume.

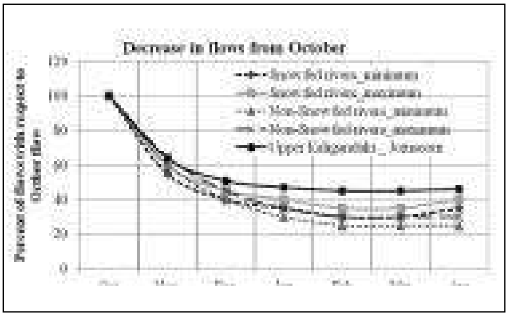


Fig. 3 Flow recession curves.

*River sediment***:** A good correlation is found between measured river flows and suspended sediment concentrations at a river monitoring location within the basin. An appreciable correlation between river flows and suspended sediments transport clearly indicated that the river brings fine sediment all the year round. A preliminary study (Fig. 4) indicated that there is an increase of annual suspended sediment loads by about 0.7 percent

The sediment related risk is inherent in the basin due to continuous uplifting and landscape evolution (Adhikari, 2008). Retreating glaciers, melting of permafrost and annual fluctuation in snow cover areas in the context of rising temperature due to accelerating global and local warming have been changing rate of sediment yields (ICIMOD, 2001; Inman, *et al*., 1999). Unpredicted floods, landslides, heavy soil erosion, river cutting have been witnessed as major risks in the basin. As river cutting is predominant, several villages settled on the bank of Kaligandaki river are likely to face deadly consequences within the next few decades (Fig. 5).

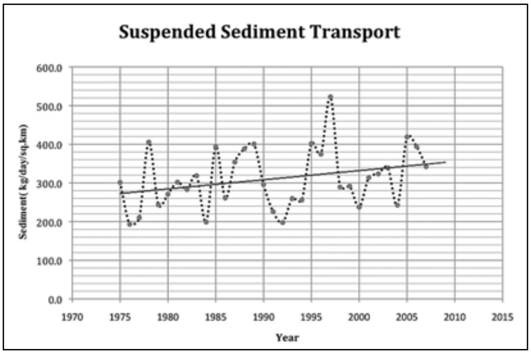


Fig.4 Trend in suspended sediment transport.

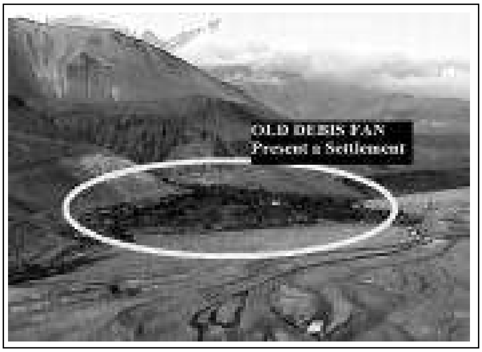


Fig. 5 Settlement on old debris fans at stream confluences.

4 Climate Change Impacts in the Basin

The climate change has been altering not only the spatial and temporal variation in snowfall but also snow accumulation time on the ground. Due to very low moisture holding capacity of the soil, the highland pasture (grazing) productivity has been decreasing. Less water available for irrigation and the traditional agro-pastoral production system which are major source of livelihood (Tulachan, 2001). Decreasing trend in water sources yield (springs and streams) has a greater concern in this basin as people living there are mainly based on the local environmental resources to eke out their living. Many farm-lands are left abandoned due to water scarcity and some populations are going to be climate refugees. There has been a shift in apple farming practices to the higher elevation due to the incidence of new diseases, low productivity (Gauchan A, 2010). Lower part of the basin has experienced higher crop failures due to unpredictable changes in temperature and rainfall patterns. Also the less or no rain means decrease of greener pasture, and so the changes in climatic condition have been a matter of great concern to the farmers' livelihoods.

5 Integrated Water Resources Management Policy

The government of Nepal has formulated and adopted an Integrated Water Resources Management (IWRM) and has also approved National Water Plan-Nepal (WECS, 2002, 2005). Policy principles mentioned in these documents that are relevant and useful to Upper Kaligandaki include: i) developing and managing water resources in a holistic manner, relying in the principle of IWRM; ii) utilizing water sustainably to ensure conservation of resource and protection of the environment; iii) delivering water services in a decentralized manner by involving accountable stakeholders and agencies (public, private, community and user based organizations); and sharing of water resources benefits among the communities on equitable basis; iv) water collecting ponds would help increase the amount of water, and stricter and separate sets of rules during the time of severe scarcity would mitigate the effect of hydrological scarcity; v) adopting best technologies and practices to develop micro-hydro power generation suitable at the local level.

6 Conclusions and Recommendations

- The basin is highly vulnerable to the changing climate. Increased anthropogenic activities, vehicles and road networks have been deteriorating the local environments further. *Preliminary assessments indicated that most of the tapped water sources are going to be dried in future.*
- The river flows and suspended sediments load showed a good correlation which indicated that the river brings fine sediment all the year round. *Several settlements settled on the slopes and on the bank of Kaligandaki River are likely to suffer by climate induced disasters.*
- Traditionally, *villages* were agglomerated with maximum care to preserve productive lands. *But in the changing context, farmers have a trend to built houses within farm lands which has been disintegrating the settlement clusters and diminishing productive land system.*
- Adult male and female have tendency to migrate and this has resulted labor shortages for farming (Tulachan, 2001; Poudel, 2003; Subedi, 2005). Agriculture has been the sole responsibility of women and aged household members. *Policy on livelihood, adaption and shift in farming system that demand less labor and less water is required.*
- The traditional water allocation authorities, property rights, rules, caste system, and other social differentials were dominant in Upper Kaligandaki basin (Basnet, 2007). A change in institutional arrangement for water resources management in one village ties up with an inter-village dispute for pasture land and community owned land. *The success of water resource management of one community cannot be achieved in isolation from other community resources.*

- Annapurna Conservation Area Project (ACAP) is the largest non-profit and autonomous organization which established a close cooperation and partnerships with traditional institutions and community-based organizations like local NGOs, VDCs and District Development Committees (Khadka, 2007). *But still there lacks in mainstreaming the life and environment, economic and social values into the development (planning processes to implementation) for better and sustainable achievements.*
- Policy relevant issues are- (a) Livelihood vulnerability due to insufficient and unavailability water for basic needs and, not having capacity to pay for water, (b) Decrease in production from traditional farming system, bio-diversity diluted and, lives and environments threatened (c) Old mud roofs houses need rehabilitation and restructuring to cope with changed precipitation pattern and for better hygiene; (d) Support to Climate Refugees - relocation and rehabilitation (mechanism of compensation).

REFERENCES

Adhikari, B.R. and Wagreich, M., (2008), "Palustrine limestone in the sedimentary succession of the Cenozoic Thakkhola-Mustang Graben (central Nepal)", Journal of Alpine geology.

Baidya S.K, Shrestha M.L, Sheikh M.M (2008) "Trends in daily climatic extremes of temperature and precipitation in Nepal", J Hydrology and Meteorology 5(1): 38-51.

Basnet G. B. (2007), Water of Discord, Water of Unity: An Ethnography Study of the Struggle for Water Rights in Upper Mustang, Nepal, Graduate Faculty of The University of Georgia, ATHENS, GEORGIA - Ph. D. Dissertation.

DHM (1999), Daily Precipitation Records of Gandaki and Narayani Zone through 1996, Department of Hydrology and Meteorology (DHM), HMG/N, Nepal.

DHM (2008), Stream Flow Summary (1962-2006), Department of Hydrology and Meteorology (DHM), HMG/N. Nepal.

Gauchan Aneeta (2010), "Climatic Risk and Hazards on Commercial Apple Farming in Mustang District", Paper presented on WMO day-2010 Celebration by DHM, Pokhara, Nepal.

HELP Task Force (2000), The Design and Implementation Strategy of the HELP Initiative, (Doc. No. H00/1) [www.unesco.org/science/HELP]

ICIMOD (2001). Inventory of Glaciers, Glaciers Lakes and Glaciers Lake Outburst Floods -,Monitoring and Early Warning Systems in the Hindu Kush Himalayan Region, International Centre for Integrated Mountain Development, Nepal.

Inman, Douglas L. and Jenkins, Scott A, (1999), "Climate Change and the Episodicity of Sediment Flux of Small California River", Journal of Geology, Vol 107, pp 251-270.

IPCC (2001) Third Assessment Report: Climate Change (TAR), The Intergovernmental Panel on Climate Change.

Karmacharya Jagadishwor, Shrestha Archana, Rajbhandari Rupak, and Shrestha, Madan L. (2007) "Climate Change Scenarios for Nepal based on Regional Climate Model RegCM3", APN CAPaBLE, GCISC and Department of Hydrology and Meteorology, Kathmandu, Nepal.

NTNC (2008): Sustainable Development Plan of Mustang; NTNC/GoN/UNEP, National Trust for Nature Conservation, Nepal.

Poudel, P.C. (2003), "Development and Issues in Mountain Eco-tourism: A Case from Pokhara Area, Nepal, The Namche Conference: People, Park, and Mountain Ecotourism, May 24-26, 2003.

Practical Action Nepal, (2009), Temporal and Spatial Variability of Climate change over Nepal (1976 to 2005), Practical Action Nepal Office, Kathmandu, Nepal.

Subedi, B. P. (2005), "The Aged and the Marginal: Social Geography of Older People in Nepal". The Himalayan Review, 35-36 (2004-2005) 1-18.

Tulachan, Pushpa (2001), "Seasonal migration and trade: A strategy of survival by the Lobas of Lo Manthang", in Susanne von der Heide and Thomas Hoffman (eds). Aspects of Migration and Mobility in Nepal. Kathmandu: Ratna Pustak Bhandar.

WECS (2002), Water Resources Strategy of Nepal Water and Energy Commission Secretariat, Kathmandu, Nepal.

WECS (2005), National Water Plan -Nepal, Water and Energy Commission Secretariat, Kathmandu, Nepal [www.moen.gov.np/pdf_files/national_water_plan.pdf].

Rainfall Events and Water Quality in Rivers Employed as Drinking Water Sources: Pacora and Cabra Rivers

JOSÉ FÁBREGA[1], ERICK VALLESTER[1], JOHANA VALDÉS[2], GLORIA GARCIA[3], MARCIAL ARIAS[1], KLEVEER ESPINO[1] & CHAD JAFVERT[2]

1 *Centro de Investigaciones Hidráulicas e Hidrotécnicas, Universidad Tecnológica de Panamá, Panama*
2 *Purdue University, USA*
3 *ITS Panamá, S.A, Panama*
jose.fabrega@utp.ac.pa

Abstract Water quality variations in rivers employed as sources of drinking water can translate in potential downgrades in people's health, as well as problems in the correct operation of drinking water treatment plants. The objective of this work is to study the effect of rainfall events in the water quality of the Pacora and Cabra rivers, located in the Panamá province, Republic of Panamá. The methodology included the sampling and analysis of water in the dry and rainy seasons employing ISCO 6712 automatic samplers. Mainly total solids were analyzed. Findings for the Pacora River include variations in rainfall intensity ranging from 38.95 and 53.34 mm/hr, with durations between 4 and 9 minutes, and total solid values oscillating from 26 to 82 mg/L. For the Cabra River, rainfall intensities were found between 12.19 and 73.15 mm/hr, with durations between 4 and 12 minutes, and total solid values in between 40 and 326 mg/L. It was concluded that there is a trend for total solids to increase for short term events and intensities above 15 mm/hr. For short term events and intensities below 15 mm/hr, the increment in total solids was seen only for cases where pre existing events with intensities of at least 15 mm/hr had already occurred. These results are important due to the lack of intensity/water quality studies in the literature for short term events.

Key words Water supply; total solids; water quality; automatic water samplers; rainfall

The Panama Canal Authority's Flood Control Program

JOHNNY A. CUEVAS M.
Flood Control Program, Water Resources Section, Panama Canal Authority, Panama
jcuevas@pancanal.com

Abstract The Flood Control Program consists of a set of activities carried out by the Panama Canal Authority (ACP) during the season of highest precipitation to identify, mitigate, and respond to various flood conditions that could pose a danger to communities and property located on the shores of the Gatun and Alhajuela reservoirs and, potentially, affect Canal structures and interrupt Canal operations. Water discharge, the most critical activity, is carried out for safety reasons. The rainy season usually begins in August and runs through January, and the ACP carries out different activities to achieve maximum reservoir operating levels that ensure water availability throughout the year, for three main uses: human consumption, ships transit, and hydro-power generation. The Program is dynamic and, in 2005, it began to incorporate potentially flooded communities with a Community Risk Management Plan. The plan guarantees that water discharge operations are conducted in a manner that is safe and appropriate for the communities located both upstream and downstream of the reservoirs, so as to also avoid damage to Canal structures. Risk management drills are important for keeping personnel in different areas of the Canal, as well as the communities at risk, prepared to autonomously face extreme flood events. Without a properly structured plan, the Canal could not have faced, and successfully mitigated, the effects of the storm *La Purísima*, which occurred in December 2010.

Key words Flood control; discharge; communities; risk management

1 Introduction

Plans for Flood Control in an emergency have been developed to reduce the adverse economic, social and physical impacts that major flood events can have on an area. However, it was not until recent decades that these plans were accepted by government agencies and the general public as means to mitigate flood damage (Probst, 1992). The importance of testing the ability of the spillway structures and procedures that the Panama Canal Authority has in place to deal with a flood was duly recognized with the onset of flood control exercises in 1972.

These plans must be updated annually due primarily to anthropomorphic (land use) changes in the watershed that may impact its runoff coefficient. A common problem that is emerging in response to increasing population and its pressure on resources is the incursion of populations in river and reservoir floodplains.

When discharge of the Madden spillway is necessary, there are potential risks, such as erosion of banks and shores, damage to bridges, flooding in communities downstream, strong currents in the Gamboa area, and danger for tourists and residents in the area due to strong currents.

Reservoir management represents a challenge for ACP hydrologists, especially during the last three months of the year, as they have to maintain reservoir elevations as high as possible to cope with the upcoming dry season and there is no reserve left to control flooding (Vargas, 1996). Examples of major storm occurrences over the last months of the year include: October 1923, November 1931, November 1932, November 1966, December 1985, December 2000, November 2004, and more recently, December 2010.

As a result of flood control exercises, questions arose surrounding what was being done in regards to the residents of the communities located downstream from the Madden spillway. In case of flooding due to severe hydro-meteorological conditions, which would cause extraordinary discharge, "how could these communities be supported?"

After identifying the risks posed to these communities, the ACP took the initiative to establish a community-based risk management plan to be integrated into the flood control program. The rationale stated that, in order for the community-based risk management program to be effective, it should have the ability to activate itself, meaning that community members should be empowered to take part in it.

2 Flood Control Program

The Flood Control Program is a set of activities that the Panama Canal Authority (ACP) carries out through its Water Resources Section (EAAR) during the period of highest precipitation to identify, mitigate, and respond to various flooding conditions which might pose a threat to communities and property adjacent to the reservoirs, in addition to affecting Canal operations.

The Flood Control season generally occurs from August to January, and the activities taking place include the review and update of the ACP's Flood Control Manual, the review and update of the EAAR Section's Flood Control Operations Manual, preparation of memoranda designating personnel authorized to request the opening and / or closing of the spillway, update and preparation of lists of notifications to all involved, the hiring of five Hydrology Support Assistants who work rotating shifts, shift preparation and designation of equipment to continuously monitor hydro-meteorological conditions of the Canal Watershed, regular shift change meetings and, when reservoirs are reaching maximum levels of operation, floodplain inspections in communities at risk of flooding due to reservoir discharge. Warning notices or bulletins are prepared and issued to the media, which target communities at risk and the general public, announcing flood risks due to spillway operations and weather conditions.

3 Flood Control Exercises

One of the main activities is the carrying out of Flood Control exercises and drills, which are usually conducted annually during the third week of October. These consist of a coordinated simulation that serves as training for ACP personnel, offering them the opportunity to practice actions and procedures and making them aware of possible problems and solutions. Participants also test and evaluate the flood emergency plans and the lines of communication between the different units involved in operations during a flood. This action includes several steps, namely: meetings, lectures, staff training, the annual exercise itself, and a critique of the exercise.

Since the EAAR section is responsible for the preparation, updating, and publication of the ACP's Flood Control Manual and Meteorology and Hydrology Section's Flood Control Operations Manual, these two manuals are evaluated during the exercise in order to be used during actual flood situations.

The exercise includes the participation of different departments of the (ACP) that may see themselves affected or in urgent need during a severe flood. Additionally, invitations are extended to other government entities that deal with such events.

As an example, in the critique that followed the 2004 flood control exercise, questions arose, such as: In case of flooding in the communities of Santa Rosa and Guayabalito, is there a population census? Is there an evacuation plan? Where will community members be evacuated to? Who should they contact? Is food, blankets, etc. readily available?

4 Support Systems

To enhance the continuous monitoring of hydro-meteorological conditions in the watershed, a telemetry system, which is the backbone of the Flood Control Program and presents the information generated in the field in real time, has been implemented. Other support systems include Satellite/ NOAA Port images, radio survey, meteorological radar (Fig. 1), and a Meteorological and Hydrological Forecast Decision Support System (DSS). Furthermore, floodplain maps of communities at risk of flooding have been defined and updated. All these items allow the hydrology team to make accurate forecasts in order to optimize reservoir management and track extreme hydro-meteorological conditions.

Fig. 1 Doppler style meteorology Radar.

5 Spillway Structures

To adjust the elevation of the Gatun and Alhajuela reservoirs, the Flood Control Program directly depends on a system of dams and weirs. The purpose of these hydraulic structures is to regulate water storage throughout the year, to ensure sufficient water during the dry season.

The three main hydraulic structures that function to control flooding in the Panama Canal are: the Gatun spillway, the Alhajuela/Madden spillway and dam, and the locks' culverts (Fig. 2). The Gatun spillway consists of fourteen (14) vertical sliding gates, the Alhajuela/ Madden spillway has four (4) drum gates and six (6) bottom gates, and in the event of a flooding emergency, there are three (3) culverts available near the Gatun locks, which have a discharge capacity of 27,000 cubic feet per second, and the Pedro Miguel Locks have three (3) culverts with a capacity of 21,000 cubic feet per second.

Fig. 2 Spillway structures of the Panama Canal.

6 From Flood Control to Integrated Flood Management

Although until 2004 there was a well-structured flood control program that guaranteed safe and continuous operation of the Panama Canal, there were still some challenges to deal with, so that the program could be integrated and connected to the communities vulnerable to flooding. This lead to the establishment of a community-based risk management plan.

7 Establishment of the Community Risk Management Plan

The communities of Guayabalito and Santa Rosa, located within the floodplain of the Chagres River, were identified as the most vulnerable to flooding. Activities were initiated through a joint interdisciplinary and inter-institutional effort, where the Community Relations team and the National Civil Protection System (SINAPROC, acronym in Spanish) were invited to participate. The following is a list of activities carried out as part of this Plan:

- Community Assessment in October 2005 and characterization of the communities of Guayabalito and Santa Rosa, January 2006
- Topography of the communities: Re-establishment of the 30.48m (100 ft) elevation markers on the field, at-level curves, location of houses and infrastructure, and mapping, March 2006
- Capacity building workshops to organize and establish the Community Risk Committee, May to July 2006 (Fig. 3)
- School risk workshop in the Santa Rosa school, October 2006
- Informing the residents about the 30.48m (100 ft) elevation mark, 2006
- Preparation of the Flood Risk Control Plan, October 2006
- Validation of the Flood Risk Control Plan in the community, 2006
- Evacuation drills and evaluation, October 2006
- Community environmental management workshop, 2007
- Signing of a cooperation agreement between the Ministry of Government and Justice, through SINAPROC, and the ACP, December 2007
- Workshop to update the Flood Risk Control Plan
- School meeting/workshop on flood risk in the Santa Rosa school, 2007
- Announcement and update of information database for the communities of Guayabalito and Santa Rosa, 2008
- Population evacuation exercise with non-participating observers: National Police, SINAPROC, ACP, 2008
- Community coordinator participation in the introductory presentations for the 2009 - 2010 Flood Control Exercise, in the ACP's Ascanio Arosemena Training Center
- Installation of warning signs in areas at risk of flooding and evacuation routes, September 2009.

8 Results

The activities in the communities of Santa Rosa and Guayabalito provided satisfactory results. Both communities were involved and trained in the culture of risk management, and a risk management plan was created. An updated census of both communities was achieved, points of contact to call in case of emergencies were established, the 100 ft elevation was marked in the field, evacuation routes and the location of accommodation facilities for both communities were signaled, and the active participation of residents in the flood drills was finally achieved.

Fig. 3 Presentation to introduce the Community Risk Management Plan, May 2006.

The Comprehensive Flood Control Program was put to the test on December 7, 8 and 9, 2010, when a storm known as *La Purisima* struck the Panama Canal Watershed and the Madden spillway had to discharge water at 153,000 cubic feet per second (at this flow rate, three Olympic size pools would be filled in two seconds). As a result the following impacts were felt: the water levels reached the 100 ft elevation, so homes located below this level were submerged, several homes in the communities of Santa Rosa and Guayabalito, located in the Chagres River floodplain, were flooded, fortunately there were only material losses (furniture, appliances, household goods, etc. - Table 1); equipment in the telemetry station in Santa Rosa, downstream from the Madden dam had to be removed immediately to prevent damage; traffic on the Panama-Colon highway, near the section of bridge that passes over the Chagres River, was partially restricted; damage was seen in the area of Gamboa, where marine vegetation was swept downstream from the spillway and into the Canal's navigation channel, hence, ship transit through the Canal had to be interrupted for approximately 17 hours.

Table 1 Total number of Affected Families by *La Purísima* Storm**.**

Families	Affected families	Adults	Children	Total people
TOTAL	27	56	43	99
Guayabalito	5	10	9	19
Santa Rosa	22	46	34	80

Source: ACP Inventory. Social Research and Community Relations Team and Environmental Education Team.

9 Discussion

Operations during *La Purísima* were performed following the procedures established under the Flood Control Manual, which strives to provide timely evacuation notices and strict compliance with provisions described in the Community Risk Management Plan for Santa Rosa and Guayabalito. It is quite possible that the drills that were carried out as part of the annual Flood Control exercises prevented the loss of life among residents in these communities. The community responded to the call made due to the extreme discharges, evacuated their homes, and sought refuge in safe shelters that were previously identified and established.

Without a properly designed, structured, and periodically updated plan, added to the annual drills with personnel from the water resources section (meteorologists and hydrologists) and other ACP personnel, well-trained Flood Control operations, the participation of other institutions such as SINAPROC, and undoubtedly, the empowerment of the communities, the Canal could not have faced and successfully mitigated the effects of the storm *La Purisima*.

REFERENCES

Cuevas, J. (2010) *Manual de Control de Inundaciones de la Autoridad del Canal de Panamá.*

Cuevas, J. (2005) *Informe de la Operación de Control de Inundaciones durante la Tormenta del 18, 19 y 20 de noviembre de 2004*. Autoridad del Canal de Panamá, Panama.

Leis, G. (2009) *Manual de Respuesta a Emergencias por Inundación, Poblados de Guayabalito y Santa Rosa, Panamá.*

Probst, S. (1992) *Panama Canal Commission Flood Control Manual*. Comisión del Canal de Panamá.

Vargas, C. A. (1996) *La Administración de Los Recursos Hídricos, Pieza Fundamental para el Funcionamiento del Canal*, Panama.

Response Plan for Flood Emergencies in the Communities of Guayabalito and Santa Rosa

GERARDO LEIS ROMERO
Water Resources Department, Panama Canal Authority, Panama
gleis@pancanal.com

Abstract The Alhajuela reservoir is important for the operation of the Panama Canal, as well as an essential source of potable water for Panama City, and is used for the generation of hydroelectric energy. The inflow of water to the reservoir during the rainy season can provoke significant increases in its water level. The Madden dam possesses a spillway for the drainage of excess water from this reservoir. The draining of these excess water can endanger the lives and possessions of inhabitants and visitors to the communities of Guayabalito and Santa Rosa, located downstream from the Madden dam. The Water Resources Department, with the support of the Community Relations Team (Environmental Division), other areas of the Panama Canal Authority, and organizations such as the National Civil Protection Service (SINAPROC), has implemented actions to minimize the risk to and to train these populations. The Response Plan for Flood Emergencies in the Communities of Guayabalito and Santa Rosa includes the description of the risk area, socioeconomic factors, potential causes of emergencies, detailed floodplain maps, community contact lists, current arrival times, plans for risk reduction and evaluation, action plan schedules, and post-flood actions.

Key words Flooding; emergency response; reservoir; risk

1 Background

The Water Resources Department of the Panama Canal Authority has carried out a Flood Control Program since the year 1972. The reduction of risk in the communities of Santa Rosa and Guayabalito, located downstream from the Madden Dam, has been one of the program's main components in recent years.

Description of the risk zone: The communities of Guayabalito and Santa Rosa are located in the Santa Rosa County, Colon District, in the Province of Colon. The communities are bordered in the east by the Chagres River downstream of the Madden Dam. They are located between the following geographic coordinates: 9°12' and 9°11' North, and 79°34'45" and 79°34'12" West, and between Zone 17 UTM coordinates 1015000m 1017000m North, and 647000m and 648000m East. These communities occupy an area of 63.79 and 7.12 hectares, respectively, in a 1.5 km strip of land parallel to the right bank of the Chagres River (Fig. 1).

Access: The principal access way to these communities is the Boyd-Roosevelt road, from the community of Nuevo San Juan. This road is asphalted. Access by water through the Chagres River is also possible.

Topography: Guayabalito possesses elevations in the range between 26 m (85.28 ft) and 40 m (131.2 ft). It is adjacent to Santa Rosa to the south, which itself has elevations between 27 m (88.56 ft) and 33 m (108.24 ft). Guayabalito contains slopes in the range between 35-45% on its upper western zone, and between 8% and 20% on its eastern sector. Santa Rosa contains a variety of slopes in the range between 8% and 25%. The 30.48m (100 ft) elevation establishes the boundary for the operation of the Panama Canal.

Climate: Tropical, high rainfall. Mean temperatures are between 25.4° C and 27.5° C, and annual mean rainfall is 2090 mm -the rainy season occurs between May and December.

Fig. 1 Regional location of the communities of Guayabalito y Santa Rosa.

Fig. 2 Aereal view of Guayabalito and Santa Rosa and the Chagres River (2007).

2 Hydrographic Features

The communities are adjacent to the Chagres River, between 5.7 and 7.7 km downstream from the Madden Dam. The Dam's spillway can release preventative and extreme discharges in situations of pre-emergency and emergency, depending on the risk presented by hydro-meteorological events. The normal overflow can be up to 2,124 m^3/s (75,000 ft^3/s) and in emergency situations up to 7,079 m^3/s (250,000 ft^3/s).

3 Socio-economic Factors

Santa Rosa has 162 inhabitants (2000 Census), who have electricity and utilize a rural, gravity-fed aqueduct, with its water take in the area of Aguas Claras. The Chagres River is used for transportation, bathing, fishing, and washing clothes. Guayabalito, is located on the western bank of the Chagres River and has a population of 76 inhabitants (2000 Census), of predominantly Afro-Antillean descent. Economic activities are based on Eco-tourism, subsistence agriculture (rice, guandú, ñame, yuca, corn, and others), fishing, and providing services (in Panama City and Colon City). Santa Rosa has as primary school with 2 teachers. When the students reach 7th grade, they commute to the Chilibre County for their high and middle school education needs. The community has a health center, a payphone, 2 local community centers, catholic and evangelical churches, a soccer and baseball field, 2 stores, and 2 kiosks. There is no police station.

Community organizations present in the communities: Parent-Teacher Association, Preschool Committee, Water Committee, Youth Club, Catholic Committee, Farming Settlement, Eco-tourism Committee, and Flood Risk Prevention Management Group.

4 Flood Maps

With the purpose of estimating possible damages done by the overflows of the Madden spillway, a floodplain map was prepared to indicate the water level in the area as a function of discharges from the Madden Dam. These levels were generated using the HEC-RAS model (Hydrologic Engineering Centers River Analysis System) and then entered into a topographical map with 1 m intervals, which was sourced by topographical measuring instruments (Fig. 3). High watermarks in the townships have been placed to indicate the reach of the floodplain at the 30.48 m elevation, as a reference.

Knowing the times of arrival of the discharges from the Madden spillway are important for the estimation of the beginning and end times of an emergency and evacuation plan for the local population. The discharges may take between 20 minutes to 4 hours to reach the communities, depending on the discharge magnitude.

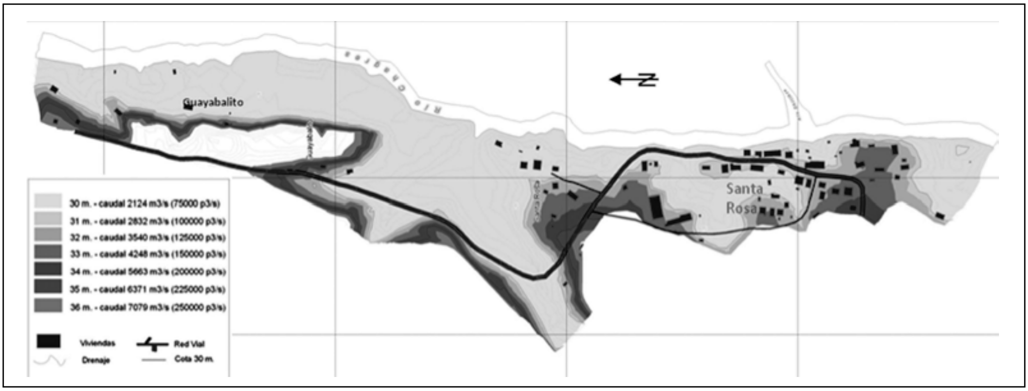


Fig. 3 Floodplain map of Guayabalito and Santa Rosa for different discharges of the Madden Dam (original resolution, 1 meter).

5 Implementation of Risk Reduction and Evacuation Plan

The Water Resources Department (Water Division), with the support of the Community Relations Team (Environmental Division), other sectors of the Panama Canal Authority, and organizations such as the National Civil Protection Service (SINAPROC), has maintained contact with these communities through arranged participatory meetings. Routes, shelters, and meeting points have been established in a systematic way using drawings (Fig. 4). Evacuation exercises, notification lists, and meetings with the communities have been carried out to develop the following aspects:

- Community analysis, 2005
- Community Characterization, 2006
- Topography of the communities: Installation of signs at the 30.48 m (100 ft) elevation, level curves, location of housings and infrastructure, and mapping, 2006
- Capacity-building workshops to organize and establish a Community Risk Committee, 2006
- School risk workshop in the school of Santa Rosa, 2006
- Informing citizens about the 30.48m (100 ft) elevation of, 2006
- Creation of a flood risk control plan, 2006
- Validation in the community of the risk control plan, 2006
- Evacuation exercise, 2006
- Evaluation of evacuation exercise, 2006
- Workshop on community environmental management, 2007
- Signing of a cooperation agreement between the Ministry of Government and Justice, through SINAPROC, and the Panama Canal Authority, 2007
- Workshop to update the flood risk plan, 2007
- School workshop on flooding risk in the school of Santa Rosa, 2007
- Announcement and updating of community information database, 2008
- Evacuation exercise of the citizens with non-participating observers: National Police, SINAPROC, Panama Canal Authority, 2008

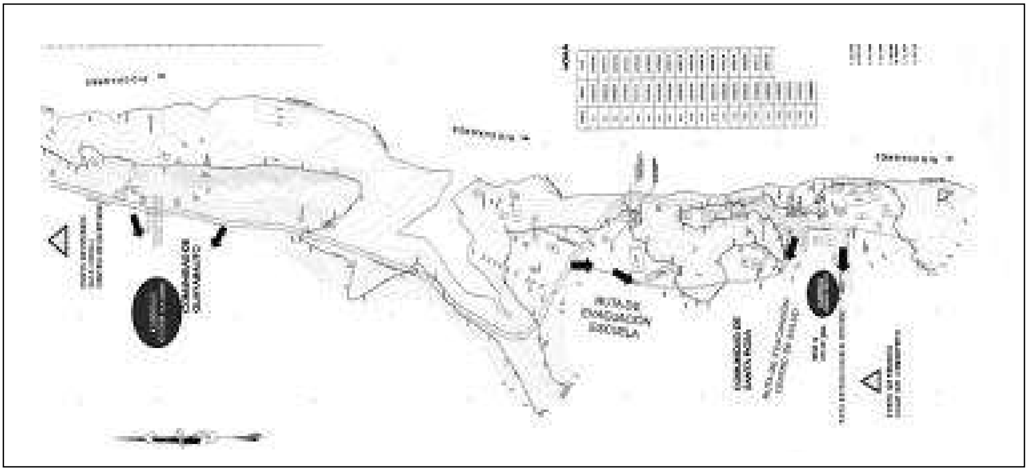


Fig. 4 Drawing with evacuation routes, shelters, and meeting points.

- Participation of community coordinators in a discussion of the Flood Control Exercise, 2009
- Installation of warning signs for areas at risk of flooding and evacuation routes, September 2009

6 Other Essential Components

- Schedule of community actions for risk reduction
- Preparation of communities
- Emergency response plan - procedure prior to Madden discharges
- Base for plan activation
- Notifications
- Public warnings
- Communications
- Operation of alarms or sirens on the Madden Dam
- Action guidelines - populations of Guayabalito and Santa Rosa
- Warnings and actions
- Duration of the emergency

7 Conclusions

The communities that can be affected by flood events can minimize the effects of these events with adequate preparation and training. Tools such as hydrological simulation models permit the establishment of risk zones for known flow levels and can give early warnings to the local populations.

REFERENCES

ACP-SINAPROC. (2006) *Plan de Reducción de Riesgo, Comunidades de GUAYABALITO Y SANTA ROSA, Manual del Participante*.

ACP-Unidad de Educación Ambiental y Relaciones con la Comunidad, Equipo Social. (2006) *Sistematización de la Experiencia GUAYABALITO Y SANTA ROSA, Informe 2006.*

Autoridad del Canal de Panamá-EAAR. (2009) *Manual de Control de Inundaciones*.

US Army Corps of Engineering Center. (1977) *Annotations of Selected Literature on Nonstructural Flood Management Measures.*

US Army Corps of Engineering Center. (1983) *Example Emergency Plan for Blue Marsh Dam and Lake.*

Water Management in the Panama Canal during the December 2010 Extreme Flood

JORGE A. ESPINOSA
Water Division, Panama Canal Authority, Panama
jaespinosa@pancanal.com

Abstract This document examines the measures/decisions taken by Panama Canal personnel during and after the December 2010 storm. Following the standards used by the Panama Canal Authority (ACP) from the Unified Command Protocol of the US Coast Guard, the storm was named "La Purísima", it being the largest three-day storm in Canal Watershed history. The storm was associated to the interaction of a low pressure front with the remains of a stationary front and the intertropical convergence zone on the Canal Watershed's northeastern part. The storm produced a record-high 760 mm of rainfall in 24 hours, and a cumulative steam flow of 235 MMC for three days in the Chico (Chagres River) Station. On December 7th 2010, at 22:20 hours, the flood rendered the Chico Station sensors, located at the Chagres River, out of service; this is a key station for storm monitoring. In order to manage Canal operations, on December 8th, 2010, at local time 10:45, an Incident Command System, formerly the Flood Control Center, was established for the first time in Panama Canal history. Because of landslides, the two roads that connect Panama and Colón City were shut down. The communities of Guayabalito and Santa Rosa, located within the Canal's operation areas, downstream from the Madden Dam, on the Chagres River's floodplain, were flooded due to the volume of water discharged through the dam's spillway. Because of the extreme runoff volumes generated by the storm, 40% PMF, the ACP was forced to use, for the fourth time in its history, the locks' culverts to discharge water, thus stopping ship transit through the Canal for 17 hours. The storm produced over 500 landslides upstream from the Alajuela dam. These lead to a large quantity of suspended sediments, which headed for the dam, right where Panama City's main water supply facilities are located. This situation generated a water turbidity level at the dam of 700 Nephelometric Turbidity Units (NTU), causing the water supply facilities to collapse, leaving a large part of Panama City without access to freshwater for 50 days. The Water Resources Section of the Panama Canal managed the Alajuela Dam by evacuating sediment from the system. The Chagres River's hydrogram at Chico Station was later obtained using two independent methods: the Sacramento model and the HEC-RAS hydraulic model.

Key words Probable Maximum Flood (PMF); Incident Command System; Nephelometric Turbidity Units (NTU); hydrometric test; hydraulic model

1 Water Management in the Panama Canal during the December 2010 Extreme Flood

The Panama Canal Watershed (PCW) is divided into two main sub-watersheds: Alajuela (Madden), with a drainage area of 1026 km^2 (396 mi^2), and Gatun, downstream (below Madden) with a drainage area of 2313 km^2 (893 mi^2) (ACP, 2011d), with seven major rivers, all monitored by The Water Resources Section (WRS) of the Panama Canal Authority (ACP). The rivers Chagres, Pequeni, Boqueron and Indio-Este, located in the northeastern part of the PCW, drain into Alajuela lake, which has a maximum operating level of 76.8 m (252 ft.), while the Gatun, Trinidad, and Ciri Grande rivers drain into Gatun lake, the Canal's navigational lake, which has a maximum operating level of 26.6 m (87.5 ft).

From December 7th through 9th, 2010, the PCW experienced the biggest three day storm in its history. The mean stream flow registered in the 3 consecutive days at Chico station was 908-m^3 s^{-1}, equivalent to 235 Million Cubic Meters (MCM) in those 3 days. According to the Log-Pearson III, the frequency analysis for this volume has a recurrence interval of approximately 300 years; it is the largest recorded in 78 years; the next largest storm, of 556-m3 s^{-1} (144 MCM), occurred in 1935, and has a recurrence interval of 50 years (ACP, 2011b).

The largest storm peak ever recorded at Chico station occurred on November 1966, and peaked at 3606-$m^3 s^{-1}$, with a recurrence interval of 500 years, while this, the second largest storm, La Purísima, peaked at 3501-$m^3 s^{-1}$, with a recurrence interval of 400 years. On both storms, the stilling well on 1966, and the automatic level recording bubbler hose on December 2010, were lost due to the flood wave. In both cases the peak stream flow was estimated by topographic survey of the water level marks left by the flood wave peak. During the December 2010 storm, the flood crest at the Chico station reached 96.2 m or 315.65 ft., approximately 13 m above its base flow level (ACP, 201lb).

Due to the significant runoff produced by the three-day storm, the ACP had to apply, for the first time in its history, the Incident Command System (ICS), in order to manage the flood and protect the Canal's structures and the communities located within its operating areas. The first step taken, once the Incident Command Center (ICC) was established, was to give a name to the event causing the emergency, so the members of the ICC agreed to name this storm "La Purísima" (The Purest). Historically, many of Panama's Caribbean coast farmers have given the name of "La Purísima" to the last major storm of the rainy season, which generally occurs 5 days before or after December 8, day of the "Immaculate Conception of The Virgin Mary" -the Purest-, according to the Catholic calendar. This storm, which occurs before the onset of the dry season, indicates a change in the agricultural practices of the traditional crops.

On December 8, 2010, at 1200 GMT (see Fig. 1) a 1010 low pressure system was located over Panama, while a stationary front extended from the Atlantic Ocean through Espanola, south of which it turned into a trough that went inside northern Panama. These systems produced an intense weather center over the north central part of Panama, on the upper Chagres river sub-watershed, as seen in Fig. 2. Fig. 3 shows the 24-hour rainfall totals for the PCW station network for the maximum 24-hour mean rainfall window associated with the La Purísima storm of December 2010. The Esperanza rainfall station measured 788 mm during the 24-hour window (from 12/7/2010 at 1145 LT through 12/8/2010 at 1145 LT) breaking the all time 24-hour accumulated rainfall record of the PCW. According to the Log-Pearson Type III, the recurrence interval of the consecutive three-day accumulated rainfall for Chico station is 400 years; the next largest rainfall event at Chico occurred in the year 2000 with 290 mm, with a recurrence interval of 50 years.

The water level sensors at the Chico hydrographic station in Chagres River were destroyed by the crest of La Purísima flood at 2300 hours Local Time (LT) on December 7, 2010, thus leaving the WRS without data provided by the main station for monitoring this storm (Fig. 4).

At 1045 LT, on December 8, 2010, the ICC was officially activated and emergency procedures to manage the storm commenced. The decision to utilize the Pedro Miguel and Gatun locks culverts for additional spilling capacity was made. This was the fourth time in the Panama Canal's history that the locks culverts (2 culverts of 3 at Gatun locks, and 3 at Pedro Miguel locks) were used as emergency spilling facilities (Morrow, 1924; PCC, 1924; USA Congressional Record, 1954; ACP, 2011a). Due to the use of the lock culverts for spilling, the Canal was closed to ship navigation for safety reasons, from 1100 LT Dec. 8 through 0400 LT Dec. 9, 2010. The closure of the Canal did not significantly affect ship transit, as they were rescheduled, and by the end of December 10, 2010 all navigation was back to normal.

On December 8, 2010 a record operational spill through the Madden dam spillway (160,000 cfs) was also set. This spilling operation forced the Guayabalito and Santa Rosa populations living in Canal operation areas to comply with the Flood Emergency Plan specifically designed for these types of events for these two towns. The implementation of the Emergency Plan and its frequently practiced evacuation during the ACP's annual Flood Control Exercise proved to be a success, as no casualty was reported during La Purísima event.

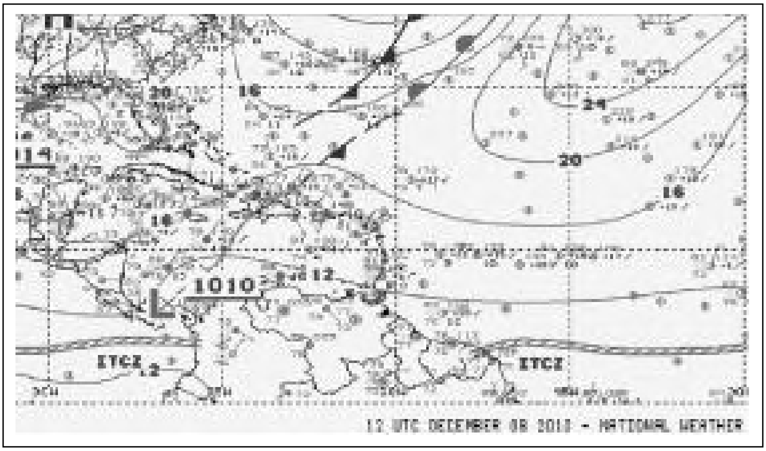


Fig. 1 Surface weather chart for December 8, 2010 at 1200 GMT.
Source: USA National Weather Service.

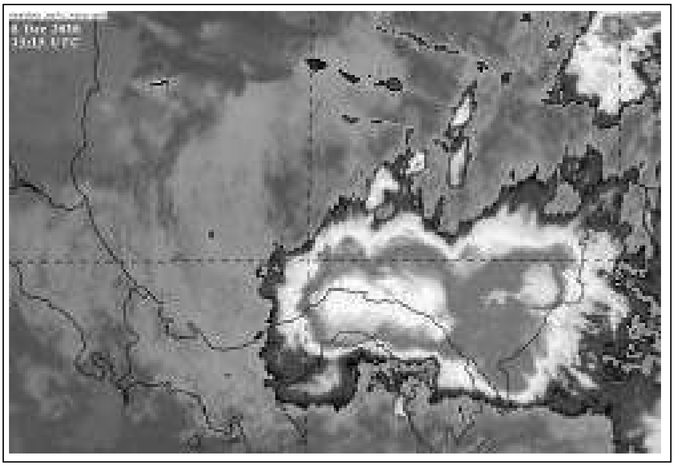


Fig. 2 Infrared satellite image for Dec. 8, 2010 at 1315 GMT.
Source: National Oceanic and Atmospheric Administration (NOAA).

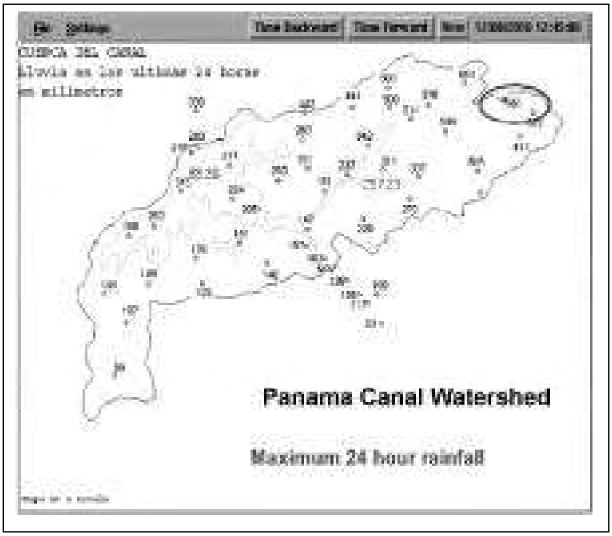


Fig. 3 Rainfall totals for the Panama Canal Watershed rainfall stations for the maximum 24-hour mean rainfall window associated with the La Purísima storm on December 2010.

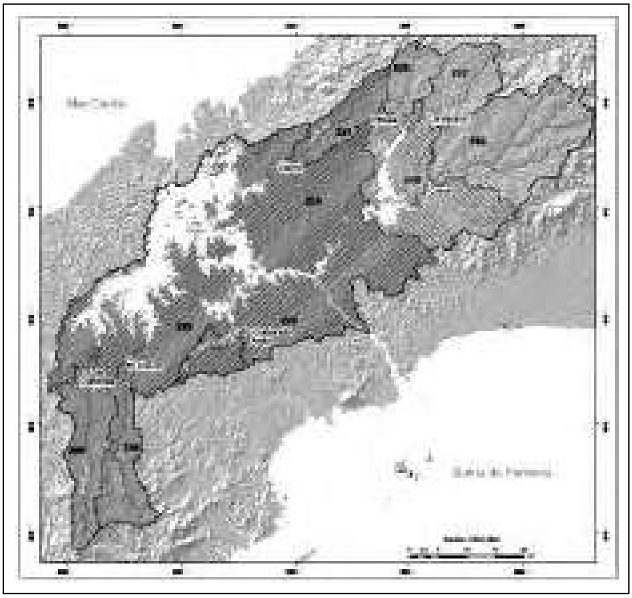


Fig. 4 Panama Canal Watershed suspended sediment production (t/year/km²), 1998-2007. Source: ACP, 2011b.

La Purísima caused so many landslides in the northeastern mountains of the PCW that a significant amount of suspended sediments entered the Alajuela Lake, thus causing the Federico Guardia Conte (FGC) potable water treatment plant to cease operations. The water intake of the FGC plant is located in the Alajuela Lake; designed to routinely process water with 5 Nephelometric Turbidity Units (NTU), it was not able to handle the well over 600 NTU water that was entering the lake during January and February 2011. This situation created a potable water supply crisis in Panama City for over 50 days. A major part of the population had to buy bottled water during this period of time.

Several important findings from investigations of landslides in Puerto Rico can be applied to the PCW, which has a similar tropical climate and similar geology. Larsen and Simon (1993) and Larsen and Torres Sanchez (1998) have found that if more than 200 mm of rain falls in roughly a day's time, and if the terrain is sufficiently steep (> 12 degree slope), then there will be landslides. In the upper Chagres watershed the mountain slopes exceed 45º in 90% of the territory (Larsen, C.L., 1984; Leis, G., 2008).

The ACP's Geotechnical Section, upon request of the WRS, made a hydrometer test which evidenced that more than 50% of the suspended sediments in the Alajuela Lake's water were colloidal clays, and the rest consisted of silts. Based on this result, the WRS decided to continue full hydropower generation at the Madden Plant to flush out the sediments that were entering the lake, without damaging the Plant's turbines, since no abrasive sand particles were found in the water. This decision significantly helped to flush the lake of suspended sediments that otherwise would not have settled due to their small size.

It is important to stress that in tropical areas such as the PCW, the major production of sediments is due to landslides that are a function of rainfall intensity and mountain slopes. Fig. 5 shows that, on average (1998-2007), the higher suspended sediment production in the PCW occurs in the mountains of the Alajuela Lake's sub-watershed (ACP, 2011b), where more than 87% of the land is covered with old-growth forests (Heckadon, et. al., 1999; ANAM-ACP, 2006). While in the lower lands, towards the southwest of the PCW, where the cattle and agricultural activity is more intense, the suspended sediment production is, on average, less.

2 Final Statements

a. La Purísima is the storm that occurred in the Panama Canal Watershed on December 7-9, 2010
b. La Purísima is the strongest 3-day accumulated volume storm that has ever occurred in the Panama Canal Watershed
c. La Purísima caused the use of the Panama Canal locks culverts to spill excess water, causing the suspension of ship transits for the fourth time in its history (1914 - 2010)
d. La Purísima triggered more than 500 landslides in the upper part of the Alajuela lake sub-watershed; a mountainous region covered in 87% by old-growth forest
e. La Purísima is the storm that has put more suspended sediments due to landslides into the Alajuela lake since its creation in 1935, causing the temporary closure of the Federico Guardia Conte Potable Water Treatment Plant
f. The largest amounts of sediments in the PCW are produced in the upper part of the Alajuela lake's sub-watershed; this watershed is the area of high rainfall intensities, where the majority of the mountains have high slopes, and is the least deforested sub-watershed in the PCW.
g. The ACP is carrying on the studies for the design and construction of a new spillway on Gatun Lake

REFERENCES

(ACP) Autoridad del Canal de Panamá. (2011a) *Informe sobre la Tormenta La Purísima*, Departamento de Ambiente, Agua y Energía, División de Agua, Sección de Recursos Hídricos, Corozal Oeste, Republica de Panamá, Septiembre, 2011.

(ACP) Autoridad del Canal de Panamá. (2011b) *Anuario Hidrológico 2011*, Departamento de Ambiente, Agua y Energía, División de Agua, Sección de Recursos Hídricos, Unidad de Hidrología Operativa, Pedro Miguel, República de Panamá, April 2011. http://www.pancanal.com/esp/cuenca/anuario-hidrologico/index.html, accessed on Aug. 30, 2011.

(ACP) Autoridad del Canal de Panamá. (2011c) *Manual de Respuesta a emergencias por Inundación, Poblados de Gauyabalito y Santa Rosa* (Revisión 2011), Departamento de Ambiente, Agua y Energía, División de Agua, Sección de Recursos Hídricos (EAAR), Corozal Oeste, República de Panamá.

(ACP) Autoridad del Canal de Panamá. (2011d) *Manual de Control de Inundaciones*, Departamento de Ambiente, Agua y Energía, División de Agua, Sección de Recursos Hídricos, Corozal Oeste, República de Panamá.

(PCC) Panama Canal Company. (1932) *Annual Report*.

ANAM-ACP. (2006) *Convenio de Cooperación, Monitoreo de la Cuenca Hidrográfica del Canal de Panamá, Programa de Vigilancia de la Cobertura Vegetal, Región Oriental de la Cuenca del Canal*.

Heckadon Moreno, S., Ibáñez D., R., and Condit, R. (1999) *La Cuenca Del Canal: Deforestación, Contaminación y Urbanización*. Panamá, Republica of Panamá, Smithsonian Tropical Research Institute.

Larsen, C.L. (1984) Controlling erosion and sedimentation in Panama Canal Watershed. *Water International*, 161-164.

Larsen, M.C., and Simon, A. (1993) A rainfall intensity-duration threshold for landslides in a humid-tropical environment, Puerto Rico: *Geografiska Annaler*, v. 75A, no. 1-2, p. 13-23.

Larsen. M.C. and Torres Sanchez, A.J. (1998) The frequency and distribution of recent landslides in three mountain tropical regions of Puerto Rico: *Geomorphology*, v. 24, no. 2, p. 309-331.

Leis, Gerardo; Laguna, Diana, *et al*. (2008) *Ordenamiento Territorial de la Cuenca Hidrográfica del Canal de Panamá*, Trabajo Final para la Maestría en Sistemas de Gestión Ambiental Aplicada, MASGA, Louis Berguer Group, Universidad de Panamá.

Morrow, J.J. (1924) *The Military Engineer*, Vol. XVI, No. 86.

U.S.A. CONGRESSIONAL RECORD. (1954) *Proceedings and Debates of the 83rd Congress, Second Session*, May 3, 1954.

Water Management in the Colorado River Basin, a Great Challenge for Mexico and the United States, before Drought and Climate Change

FELIPE ARREGUÍN CORTÉS, MARIO LÓPEZ PÉREZ, JOSÉ GUTIÉRREZ RAMÍREZ & ADRIANA RODRÍGUEZ RODRÍGUEZ
Comisión Nacional del Agua, México, D.F., Mexico
felipe.arreguin@conagua.gob.mx

Abstract The Colorado River satisfies a great part of the water needs of seven States of the United States (US) and two of Mexico. That represents a population of 30 million inhabitants that, according to projections, will reach 38 million in 2020. Over the last 100 years, the total percentage of surface affected by extreme climate droughts in the US has been of 14% annually in average, with a maximum of 65% in 1934. It is widely documented that the allocation, that currently has the water of the Colorado River to the States in the Basin, took place during the wetter period (between 1905 y 1925), in a period of 400 years. Recently, the west of the US has suffered a sustained drought, 30% of the region is subject to a severe drought since 1999, and the Colorado River has had, between 2000 and 2004, the lowest flow registered in a five year period. In addition to that, the US States in the southwest and the northeast States of Mexico are experimenting rapid growth and generating a social, economical, and environmental demand on the water resources, with the consequent legal conflicts.

Key words Management; transboundary basin; drought; climate change

1 Introduction

Given the growing water needs, since early 2008, the governments of México and the US work on joint cooperation actions in topics related with the Colorado River, such as urban, irrigation and environmental uses, the study of the hydrologic system and the potential impacts of climate change, including the effects of the current historic drought in the Colorado River.

Currently, they focus their efforts in the identification of opportunities for water conservation and an increase of the supply through sea water desalination and reuse, as well as in strategies aimed to decrease the variations to the Colorado River system and potential opportunities to make more efficiently the water deliveries to México from the Colorado River.

The objective of the joint cooperation process was to establish an international group of representatives from federal and state governments and users from experts NGO´s experts in Mexico and the US, to explore such topics, aiming to achieve potential binational benefits, in areas of environmental, irrigation and urban uses.

The present document includes a diagnostic of the Colorado River Basin, highlighting aspects such as the availability of water in Mexico, the physical framework and the distribution of water on both countries, relevant aspects of the 1944 Water Treaty are mentioned, the use of water in that region of Mexico is shown and the problematic in terms of the water resources, emphasizing the climate change.

A description of the schemes and the Mexico-US Joint Actions for the increase of water in order to counteract the drought in the Colorado River system analyzed by the US.

An analysis from Mexico´s vision is made about the cooperation in the Colorado River, the opportunities of cooperation and identified projects by the Workgroup, the actions to be followed, the challenges and how to confront them, as a conclusion a final message in which it is emphasized the great efforts that both governments make to achieve that this binational cooperation project, could be considered as an example at the international level, in terms of water integrated management at a basin level.

2 Diagnose

The availability of water in Mexico is very unequal, since while in the southwest there is a per-capita water availability of 24,450 m^3 per year, at the border with the US it is only of 131 m^3 and it is in this region where the largest rates of population as well as economic growth take place.

The Colorado River has a length of 2,300 km, it has ten storage dams, one of them international, irrigates an area of 1.5 million hectares in the US and 170 thousand in Mexico, supplies water to 30 million inhabitants. The availability is 18,500 Hm^3 and the allocation is 20,352 Hm^3, in other words, there is over allocation.

In 1944, the US and Mexico signed a International Treaty of Waters, through which the US government assigns to Mexico, from the waters of the Colorado River, a guaranteed volume of 1,850.2 Mm^3 every year. From the delivered water, 80.6% is used for irrigation; el 8.9% is used for urban water supply, 7% is used by the industry and 3.5% in other uses.

3 Problem

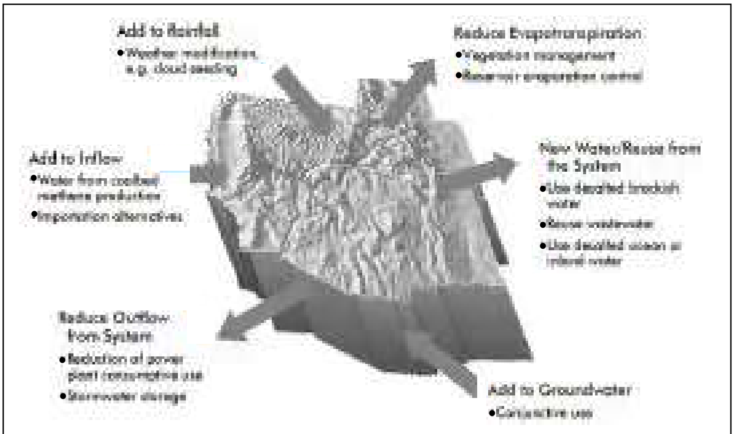
From the total groundwater availability in the region, 60% it's in the Valley of Mexicali and in the "Mesa Arenosa" (sandy plateau) of San Luis Rio Colorado, the first one destined for irrigation within the "Distrito de Riego" (irrigation district) 014 and the second one to supply of border cities from San Luis Rio Colorado, Son., to Tijuana, B.C.

The efficiency in irrigation is very low and there is waste of waste due among other causes to rudimentary irrigation practices, deficient conservation of the hydraulic infrastructure, grading problems and inadequate management of water at parcel level.

In regards to climate change, recent experiences suggest that the conditions are 'critical' in the basin. The variability and the climate change, added to an increasing pressure driven by development, will cause droughts of unknown magnitude for the institutions in the region, and will aggravate the conflicts among the water users.

4 Solution Alternatives

The US analyzes different schemes of water increase to counteract the drought in the Colorado River system, below is an example of the main options for water increase in the Colorado River basin.



Fig, 1 Augmentation Options for the Water Supply of the Colorado River System.

Joint Actions among Mexico-US have been made to increment the offer of water and to counteract the drought in the Colorado River system; with the vision of integrally managing the basin, within the CILA/IBWC it was formed back in 2008 a base group and four working groups with representatives from federal and state governments and users from experts NGO´s in Mexico and the US.

The main objectives of Mexico are to attend the current and future water needs, for urban, irrigation and environmental uses at the Mexico-US border; evaluate the current climatologically conditions, and future conditions of scarcity; identify new sources and increase the storage capacity and programs of binational investments for the conservation of water and environmental improvement.

The main objectives of the US are to attend the current and future needs of water in quantity and quality, for urban, irrigation and environmental uses at the Mexico-US; implement procedures to better management of water in scarce conditions; evaluate the potential exchange of water between Mexico and the US of new sources produced by the development of infrastructure, improvements or other projects and potential impacts of climate change in the Colorado River.

Mexico´s vision about the Joint Cooperation Actions with the US in relation to the Colorado River, is to develop projects that benefit to both countries, such as: increase of water in the system, flexibility in the management of scarcity, improve the ecosystem through allocation of part of the conserved water or generated by both countries to environmental purposes, mainly in the Delta; the utilization of the system in the US to make storages, deliveries, exchanges, transfers or opportunities for mitigation of scarcity, aiming to maintain better levels at lake Mead with the purpose of reduce the possibilities of apply reductions to the delivery of volumes to the users of the lower basin that depend on the levels of storage of that lake; also to increment the abilities on both countries to make a truly planning of the use and a rational and integral water management in the long term, ensuring a sustainable economic growth in the region.

5 Identified Cooperation Projects and in Process of Development

With the lining of 75 Km of the main network of the DR014, there will be a recovery of 46 hm^3/year. Currently there is a pilot binational project, both countries have agreed to equally finance the final design in 2011 and from the results there will be an analysis about the possibility of its implementation. It is expected that the storage water could be used for environmental purposes in the region. Identification of sites for the construction of desaalination plants in Rosarito, B.C., and Puerto Peñasco, Son. In this regard, an on-going study about the feasibility of the Binational Plant in Playas de Rosarito, B.C. is underway, with a capacity of 1,095 lps on a first stage until 2,190 lps as final capacity, the volume of desalinated water will be shared between Mexico and the US. The establishment of five priority conservation areas and a map of the water needs of the riparian environment and the Colorado River Delta. It is underway a pilot binational project that will cost 698 thousand dollars of which 372.5 have already been invested by the Mexican government, the remaining, will be provided by the US starting in 2011.

There is also monitoring of the aquifer, plans in case of scarcity or drought, annual and multi-annual storage in Mexico and the US. There is work being done on the modeling of the complete Colorado River system, in this regard, six scenarios are being simulated, taking in consideration flow to the Delta, savings due to modernization and technification for environmental use, storage in the dams and/or aquifers.

6 Challenges and How to Confront Them

Future scenario characterizes by larger population and economical growth rates at the border region of Baja California - California; growing competition for water resources; adverse scenario of climatic variability (and possible climate change); overexploitation and deterioration of sources.

Trying to balance the water needs at the cities, the agricultural sector, and the environment, is not an easy task, especially with a resources that is over allocated as in the case of the Colorado River. The great challenge to our interests is to find common ground in the water use; this will require good will to adapt from its historical demands.

It is uncertain if this could be reached in the short term, but what it is truth, is that the creative solutions to satisfy the multiple demands in the Colorado River Basin are being implemented now and for the future.

7 Conclusions

The governments of Mexico and the US are characterized by its capacity to joint its efforts in order to strengthen the protection policies to the environment and the natural resources in a sustainable way; the will to cooperate in the search for joint actions that improve the quality of the environment and optimize the quality of life of the inhabitants of the border region that both countries share; as well as the importance of strengthen the cooperation through initiatives about priority issues of common interest; both governments will keep working hard so that this effort of binational cooperation be considered an example at the international level in terms of water integrated management at a basin level.

REFERENCES

International Boundary and Water Commission. (1973) *Minute 242 Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River.*

International Boundary and Water Commission. (1979) *Minute 261 Recommendations for the solution to the border sanitation problems.*

National Water Commission. (2007) *Statics on Water in Mexico*, Chapter II State of Water Resources.

Intergovernmental Panel on Climate Change. *Climate Change and Water.* Technical Document VI.

Treaty Between The United States of the America and Mexico. (1944) *Utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande.* Section III Colorado River.

Integrated Watershed Management as a Land-Use Management Strategy for Climate Change Adaptation in the Panama Canal Watershed

NOEL TREJOS CASTILLO
Autoridad del Canal de Panama, Panama
ntrejos@pancanal.com

Abstract The Intergovernmental Panel on Climate Change (IPCC), through climate simulation models, discusses the main observed and projected changes for the entire planet at the country level. Changes have been observed that might escape from what is accepted as natural climate variability, which will bring grave consequences to various productive sectors, and to the planet's human and environmental systems. For this reason, Integrated Watershed Management offers an alternative to face the challenges and opportunities of climate change in areas of strategic national development, as is the case with the Panama Canal Watershed. The Panama Canal Watershed has an integrated vision on social, economic, and environmental aspects, which include financial mechanisms to implement initiatives that facilitate the implementation of autonomous or planned methods of adaption to climate change in the medium and long term. Taking this into account, the Panama Canal Authority has realized the degree to which the Integrated Watershed Management framework and the hydrologic and forest restoration of watersheds can contribute to increase resilience against the effects of Climate Change.

Key words Integrated watershed wanagement; adaptation to climate change; land management; Panama Canal Watershed

1 Observed Changes due to the Effects of Climate Change

The Intergovernmental Panel on Climate Change (IPCC, 2007) states that global warming is unequivocal and will have severe consequences on our planet's human and environmental systems. According to the scenarios that are drawn by scientific studies, the Latin America and Caribbean region will be one of the most vulnerable to the impacts of climate variability and climate change. This is due in part by Latin America and the Caribbean being located within the hurricane belt, by having numerous island and coastal states, by relying on Andean snowmelt for water supply to urban and agricultural sectors, and for being exposed to floods and forest fires, among other particularities.

In the months of November and December, 2010, the Republic of Panama withstood some extreme climate events that have been associated with Climate Change, specifically with an increase in the intensity of the 2010-2011 La Niña phenomenon. According to many experts, the quick development and the intensity of the 2010-2011 La Niña phenomenon since August 2010 in the Tropical Pacific Ocean, and the intense global warming that has been observed in the waters of the Tropical Atlantic Ocean, led to the development of a series of anomalies in the middle and upper atmosphere in the Americas, which are very complex to document, but which, in one way or another, impacted climate conditions in Central America, including in the territory of Panama.

The persistence of these anomalies brought heavy rainfall for over 21 days, causing large scale impact on human and environmental systems in the country. Said impacts are related to the loss of human life; infrastructural damage due to landslides and flooding, million dollar losses in agricultural and livestock production, and affecting production of potable water in the two most heavily populated provinces of the republic: Panama and Colón.

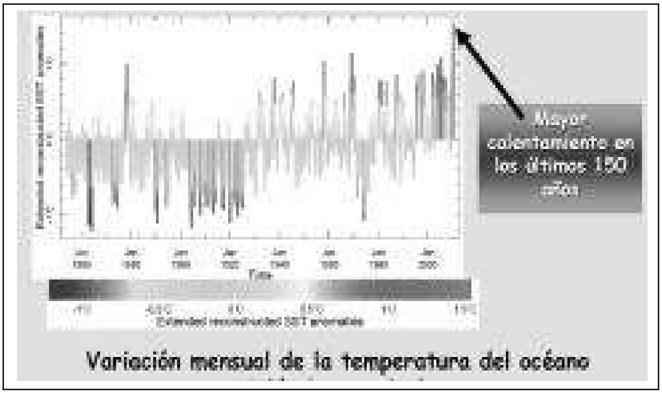


Fig. 1 Monthly temperature Variation in the Tropical Atlantic Ocean.
Source: CATHALAC, 2011.

In the analysis of this event's impacts, the National Civil Protection System (SINAPROC) reports that approximately 1500 people were affected, two children died and one was injured due to a landslide. The Ministry of Agricultural Development reported that the areas of Chepo, Darién and Colón withstood extreme events that caused great economic losses, adding up to more than US$ 2,000,000 in the livestock sector, and more than US$ 1,500,000 in the agricultural sector.

2 Projected Changes due to Climate Change

In the future, the IPCC estimates there will be a greater occurrence of extreme climate events, and projects that desertification and salinization will affect 50% of current agricultural lands, and cause further extensive sectorial damage due to not implementing necessary Climate Change adaptation and mitigation measures.

The available research seems to indicate that intense precipitation events will dramatically increase in numerous regions, some of which will show an overall decrease in precipitation averages (IPCC, 2007). The increased precipitation and water run-off variability poses greater risk of floods and droughts, which raises issues that should be viewed from the standpoint of society, its infrastructure, and its water quality.

The severity and frequency of droughts and floods adversely affect the development of productive activities; the availability of drinking water in the quantity and quality needed for the survival of existing ecosystems, and ultimately, threatens sustainable development. The increase in temperatures will also affect the physical, biological and chemical properties of lakes and rivers, and their effect on numerous freshwater species and on water quality will be predominately adverse.

3 Integrated Management of Watersheds as a Land Management Strategy for Climate Change Adaptation in the Panama Canal Watershed

In accordance with the online magazine Latin*American Network of Technical Cooperation in Watershed Management* (2009), integrated watershed management of has become of great importance, as a way of conserving ecosystems foster economic, social and agro-industrial development within countries in the region. Watersheds offer an immense variety of goods and services (water quantity and quality, soil fertility, landscape, biodiversity, carbon sequestration, among others), and the provision of economic, social and environmental needs of the local communities and stakeholders should be included in watershed management. Along the same lines, watershed management should be included within risk management as a way to confront extreme climate events (cyclones, hurricanes, floods); the impacts on the communities and urban centers can be notably less due to the natural barrier that they offer.

In view of this, the Panama Canal Authority, in collaboration with the United States Agency for International Development (USAID, 2009), completed the study of the *Creation of Maps with Biophysical-Environmental Characteristics of the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' Sub-watersheds*. The results of this study will be part of the creation of the management plans for these sub-watersheds. The main objective is to promote the sustainable use of natural resources and favor the conservation of biodiversity. In the Climate Change Framework, it is expected that this initiative will contribute, in a collaterally strategic manner, to both adaptation and mitigation of Climate Change.

The results of the study are:

- *Map of current land use in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds*: With these results, indicators and monitoring plans were established, with the aim of inferring the land use change tendencies in the aforementioned sub-watersheds, determine which are the factors that have brought such change, and establishing pertinent steps to reverse the process. Fig. 2 shows the distribution of land use in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers.

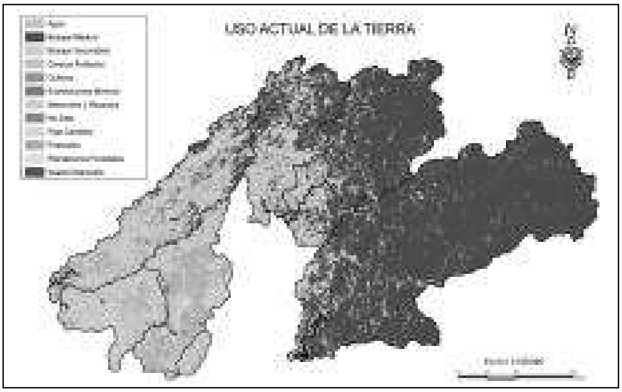


Fig. 2 Map of current land use in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds.
Source: Panama Canal Authority.

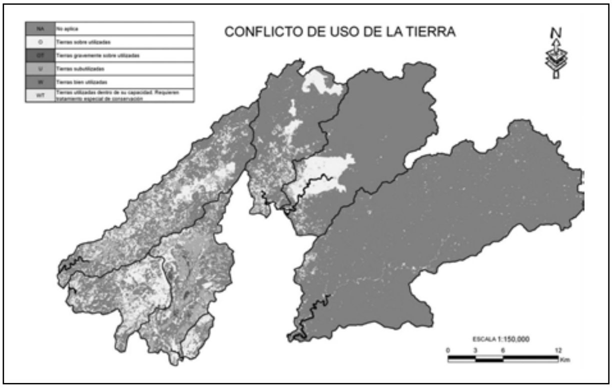


Fig. 3 Map of land use conflicts in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds.
Source: USAID, 2009.

- *Map of land use conflicts in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds:* Based on these results, it was possible to determine the sections of land in the sub-watersheds that were found to be in conflict, that is to say, places where land use is found to be under or over its' capacity, considering its agro-environmental characteristics. In Fig. 3, the results of this analysis are presented.

- *Estimation of riparian forest cover in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds:* The results of this analysis helped to determine which are the rivers and/or riparian areas that require greater attention to protect the water sources from the negative effects of sedimentation and pollution. All types of coverage (mature forest, secondary forest, forest plantations, etc.) within a distance of 20 meters from the riverbanks (10m on each side) were considered (Fig. 4).

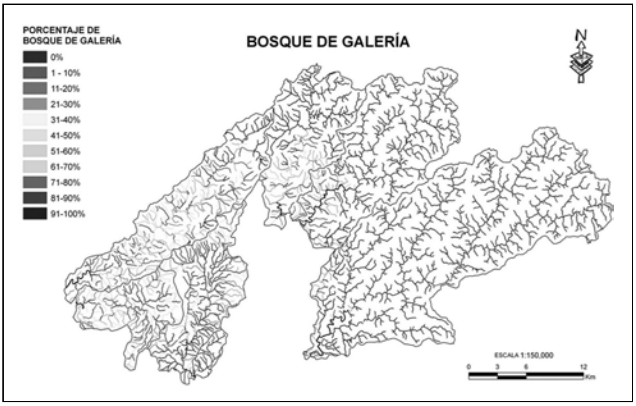


Fig. 4 Map of riparian forest cover percentage for water sources in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds. Riparian forest cover percentage: red = 0-10%; green = 40-70%; blue = over 71%. Source: USAID, 2009.

- *Estimation of sediment content for water sources in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds:* Through this analysis it was possible to identify plots within the studied sub-watersheds that contribute to the increased amount of sediment in the water sources due to the soil's physical characteristics, the topography of the terrain, the coverage and/or use of the soil, and the level of precipitation. The results of the analysis permitted the development of specific hydrologic and forest restoration projects in the study area.

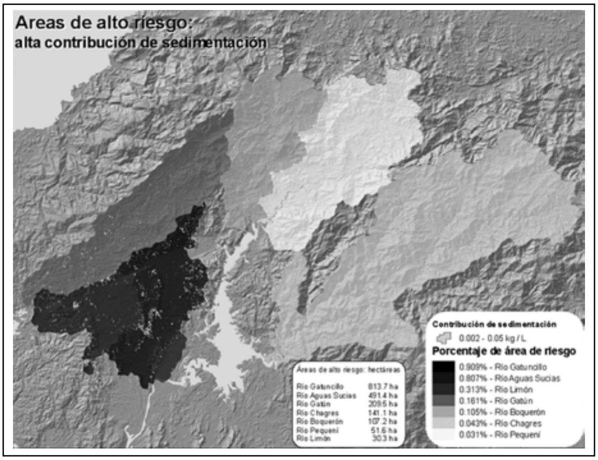


Fig. 5 Map of high risk areas regarding their contribution to sedimentation of water sources in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds.
Source: USAID, 2009.

- *Identification of sediment accumulation areas in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds*: The analysis was able to identify the zones in which sediment accumulates after precipitation. Through this analysis, the potential flood risk zones can be inferred and pertinent preventative measures can be taken.

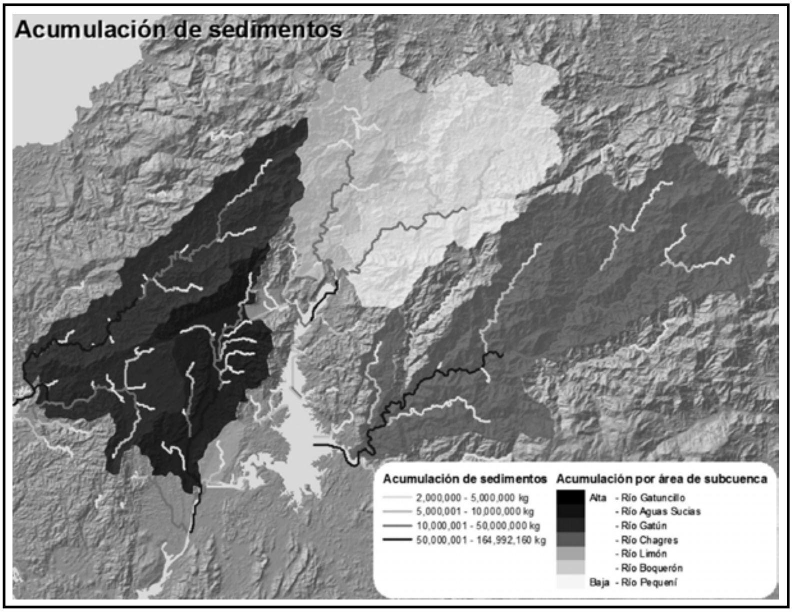


Fig. 6 Map of sediment accumulation areas in the Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón, and Agua Sucia Rivers' sub-watersheds.
Source: USAID, 2009.

4 Final Considerations

Integrated watershed management without a doubt plays an important role in climate change mitigation and adaptation, given that it promotes the coordinated management of water, soil, and other natural resources under a social, economic, and environmental approach, and addresses the challenges and opportunities of climate change in a practical manner. It assesses factors that should be considered at the moment of planning for future changes. In view of this, the Panama Canal Authority has realized the degree to which the Integrated Watershed Management framework for and the hydrologic and forest restoration of watersheds contributes to increased resilience against the effects of climate change.

REFERENCES

IPCC. (2007) Climate change 2007: *The Physical Science Basis, Summary for Policy Makers*, WG-I contribution for the Fourth Assessment Report of the IPCAMBIO CLIMÁTICO (version approved at the 10th Session of the IPCC, France, 2007).

CATHALAC (2011) *Informe de Inundaciones Diciembre de 2010* (online). Accessed on Aug. 29, 2011. www.servir.net/fuertes_lluvias_en_panam%C3%A1_dic_2010.

REDLACH. (2009) *Manejo Integral de Cuencas Hidrográficas en un contexto de Prevención, Mitigación y Adaptación a los Efectos del Cambio Climático* (online). REDALCH webzine. Accessed on Aug. 2010. www.rlc.fao.org/es/tecnica/redlach/boletines/revredlach.pdf

USAID (2008) *Informe Técnico Elaboración de Mapas de Características Biofísicas-Ambientales de las Subcuencas de Los Ríos Chagres, Pequení, Boquerón, Gatún, Gatuncillo, Limón y Agua Sucia.* Unpublished .

Understanding the Impact of Climate Change in the Glaciated Alpine Catchment of the Himalaya Region Using the J2000 Hydrological Model

SANTOSH NEPAL, PETER KRAUSE, WOLFGANG-ALBERT FLÜGEL, MANFRED FINK & BJÖRN PFENNIG
Department of Geoinformatics, Hydrology and Modeling (DGHM), Friedrich-Schiller University (FSU) Jena, Germany
santosh3nepal@gmail.com

Abstract In the context of Global Climate Change, the hydrological regime of an alpine mountain is likely to be affected. This might have serious implications for water availability, both short and long term, for downstream uses. Hence, understanding the hydrological dynamics is vital for estimation of water supply and demand. This paper provides the results of hydrological modeling in a meso-scale glaciated alpine catchment of the Himalayas. The J2000 hydrological model, distributed and process-oriented, was implemented in the study area to simulate stream flow and snow and glacier melt runoff. The model was able to reproduce the overall hydrological runoff dynamics quite well. The low and middle range flows were quite well reproduced, including some degree of peak flows. The maximum temperature showed an increasing trend of 0.047° C/year between 1963 and 2007. The hypothetical rise in temperature scenarios (+2 and +4° C) indicates that the overall streamflow will increase. In snowmelt processes, although the total volume of snowmelt decreases, there will be significant increase during the pre-monsoon period. This indicates that the region is particularly vulnerable to Global Climate Change and the associated risk of water availability to downstream areas in future.

Key words Himalayas; J2000 Hydrological Model; hydrological dynamics; climate change

1 Introduction and Motivation

The glaciated alpine catchment of the Himalaya region is a unique hydrological system, which serves lives and livelihood for millions of people living downstream. The snow and glacier melt have particular significance for downstream communities during the water scarcity period. At the same time, floods during monsoon season always bring havoc to these people (Eriksson *et al*, 2009). The mountainous areas play a key role in hydrology, since they usually receive high amounts of precipitation, store it in the form of snow and glaciers, and gradually release it in the melting process. In the context of Global Climate Change, the future availability of water resources in the region is of high concern. Therefore, understanding of the existing hydrological regime of these river systems is vital. This is possible when the rivers systems are better understood and the relationship between different watershed components (such as soil, groundwater, glacier, and snow) and stream flow is quantitatively assessed (Armstrong, 2011).

The process of understanding the hydrological dynamics of the river systems in the Himalaya region is a challenging task, mainly due to a lack of representative data (Alford, 1992; Sharma, *et al*., 2000), uncertainties (Kattelmann, 1987), and complexities of meso-scale catchments (Krause, 2002; Alford, 1992). However, this is very important, especially giver the expected impacts of Global Climate Change in the water resources, and subsequently in future water availability. For this, the J2000 hydrological model, developed by the Department of Geoinformatics, Hydrology and Modelling, at FSU Jena, (Krause, 2001; Kralisch *et al*., 2007) has been used and adapted in the context of specific catchment requirements, to understand the hydrological system dynamics of the Dudh Kosi river basin in the Himalaya.

The main objective of the study was to understand the hydrological dynamics of the glacierized catchment of the Himalaya region using the J2000 hydrological model. In addition, temperature scenarios were implemented to analyse the impact of Global Climate Change on snow and glacier melt processes.

2 Catchment Description

The Dudh Kosi River basin, located in the eastern part of the Nepalese Himalaya, has been selected for the study. The basin is one of the sub-catchments of the Kosi river basin, which is located in the Himalaya, extending from Tibet to the foreland Gangetic plains of India. The total area of the Dudh Kosi basin is 3,711 Km^2. The basin is characterized by very steep topography and young and fragile mountains (Fig 1). The highest peak in the world, Mt. Everest (8,848 masl) is also located in the basin, which also includes other peaks above than 7000 masl. About 30% of the land is located at altitudes above 5000 m, and 32% of the land is between 3000-5000 m. In recent decades, the glaciers are retreating at higher rate, leading to the formation of many glacial lakes in the Himalaya region (Mool, *et al*, 2001). Therefore, the response of glacier and snow in the context of Global Climate Change is a major concern in the region for sustainable water resources planning. The basin comprises sub-tropical to temperate climates towards the lower altitude. The higher altitude areas exhibit sub-alpine and alpine climate associated with low temperatures (MoFSC, 2002). About 81% of total rainfall occurs during June-September, when the summer monsoon brings the moist air from the Bay of Bengal. During this period, the region receives intense rainfall, which causes floods and widespread damage to property and human lives.

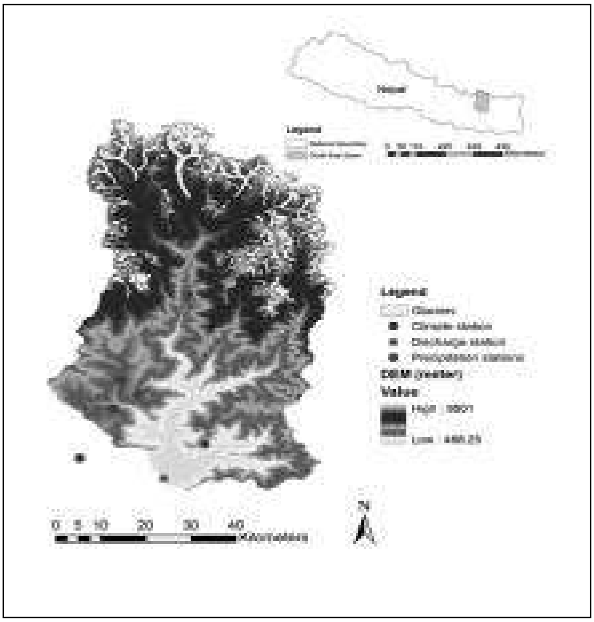


Fig. 1 The Dudh Kosi River Basin in Nepal.

3 The J2000 Modeling System

The J2000 hydrological model (Krause, 2002) is a process-oriented distributed hydrological model to simulate the water balance of large catchment areas, developed within the Jena Adaptable Modelling System (JAMS) framework (Kralisch *et al.*, 2007). The main layout of the model components is shown in Fig. 2. A glacier module is integrated into the modeling system to understand glacier melt runoff in the basin. The glacier module calculates melt water from snow and ice. The ice melt is calculated using improvised degree day factor (Hock, 1999) and has been further modified by taking into consideration the radiation, slope aspect, and debris cover factor. The detailed description of the model and its components are found in Krause, 2001; Krause, 2002, and Krause *et al*., 2006. The J2000 model contains the following modules: snow module, glacier module, soil module, ground water module and flood routing module. All the modules contain a number of calibration parameters that have to be adapted based on the comparison with measured stream flow.

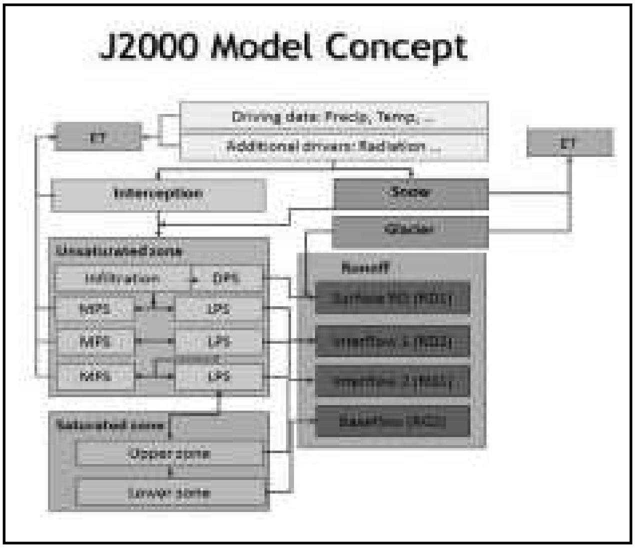


Fig. 2 Principal layout of the J2000 model concept.

4 Input Data

The land cover data was derived from the GlobCover land cover product (May 2005 - April 2006). About 14% of the basin area is covered by glaciers (Fig. 1). The Dudh Kosi basin is one of the most densely glaciated regions in Nepal. It comprises 273 glaciers, with ice volume of 51 Km^3 (Mool *et al.*, 2001). Nearly 50% of the basin is covered by forests, including deciduous, coniferous and mixed forest types. About 50% of the glaciers are located below 5500 masl, which makes them very sensitive to recent Global Climate Change. The soil data is derived from the Soil and Terrain dataset (SOTER).

The input data required for the modeling was provided by observation stations in and around the Dudh Kosi river basin, which is collected and managed by Nepal's Department of Hydrology and Meteorology (DHM). Data from six precipitation stations and one climate station were used for this purpose. The datasets include air temperature, precipitation, sunshine hours, wind speed, and relative humidity. The quality of the dataset was statistically tested by homogeneity using double mass analysis. No abnormal behavior in the data was found during the model run period.

Hydrological Response Units (HRUs) are applied as model entities, which were derived from spatially distributed information about topography, land use, and soil type. HRUs are spatial model entities which are defined as distributed, heterogeneous, structured entities having a common climate, land use, soil and geology controlling their hydrological dynamics (Flügel, 1995). The HRUs were delineated by overlaying DEM, land cover, and soil maps in a GIS arc info environment.

5 Result and Discussion

The average annual precipitation in the basin is 1934 mm. The temperature station at 1720 m showed higher increase in temperature, at a rate of 0.047º C/year from 1963 to 2007. The trend was estimated by using a non-parametric Sen slope estimation (Sen, 1968). The max temperature trend for the whole of Nepal was also found to be increasing at the rate of 0.6º C per decade from 1978 to 1999 (Shrestha, *et al*, 1999). Various studies based on Regional Climate Models (RCM) predict that the temperature in the sub-continent will rise between 3.5 and 5.5º C by 2100 (Rupa Kumar *et al*. 2006). This indicates that the basin is sensitive to climate variability and change, which might impact the basin's hydrological regime.

The model was applied from 1985 to 1997 on a daily basis. The first year was used as an initialization period. The simulated precipitation was 2114 mm. About 71% of the input was used to produce stream flow and 21% was used as evaporation. Nearly 8% of the input is stored in the basin as snow. The total contribution from snow and glacier to the stream flow is about 33%. Of which, glacier alone contributes about 17 % (including 5% from glacier ice melt). Similarly, snowmelt, which occurs in other areas besides glaciers, contributes nearly 16.5%, of which more than 50% is contributed from rain coming down on snow surface. Rain-on-Snow is a phenomenon which is high in lower altitude areas, and the proportion gets lower in higher altitude areas. Fig. 4 shows the contribution of snow and glacier melt to the stream flow. The proportion of contribution during the rainy season (June-September) is about 39%, also including the contribution from rain-on-snow. The contribution in April and May is about 61% and 75% respectively, which indicates the significance of glacier and snowmelt during pre-monsoon periods.

The comparison of average monthly simulated and observed runoff (Fig. 3) shows a reasonably good fit throughout the year. The simulation of low flow periods is quite good, and high flow months are slightly over and underestimated. The simulated and observed daily runoff for the entire period also shows good fit (Figure not included). The low range flows, mostly from the base flow, are well represented most of the time. Similarly, the rising and falling limbs during the pre and post monsoon period are also captured well. The model also simulates flood peaks well, which mostly occur during the monsoon period, although some variation in the form of over and under prediction can be seen. The model is able to reproduce the overall runoff dynamics of the basin quite well. The efficiency results of the model also show good performance between observed and simulated discharge. Overall, the efficiency result is quite satisfactory with values of Nash-Sutcliffe (0.85), Logarithm Nash-Sutcliffe (0.93), coefficient of determination (0.85) and Root Mean Square Error (RMSE) (84) for the entire period.

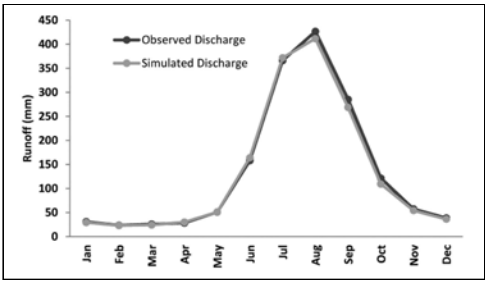


Fig. 3 Average monthly simulated and observed discharge (1986-1997).

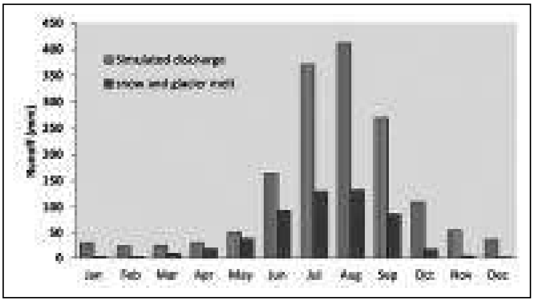


Fig. 4 Contribution of snow and glacier melt to stream flow.

6 Temperature Change Scenarios

A distributed nature of the J2000 hydrological model allows us to assess the temperature scenarios easily in the modeling context. Incremental scenarios or synthesis scenarios describe a technique where particular climate elements are changed incrementally by plausible though random amounts (e.g. +1, +2, and +3° C change from baseline air temperature and +10 and +20% change from the baseline precipitation) (IPCC, 2001). In this study, incremental climate scenarios of +2° C (scenario 1) and +4° C (scenario 2) from the baseline temperature are applied. The rise in the temperature in the modeling context means increase in maximum, minimum and average temperature. A similar range of rise in temperature has been reported in the region in different literature based on RCMS results by 2100 (Rupa Kumar, 2006). The rise in temperature is likely to increase the hydrograph in most of the months. The monsoon season will have higher peaks in the scenarios, with the most visible increase from April to September. In the month of April, the runoff volume will increase by 44% and 105% in scenarios 1 and 2, respectively. On the other hand, in the month of May it is 42% and 85%. The annual streamflow will be increased by 10% and 18% in scenarios 1 and 2 (Fig. 5).

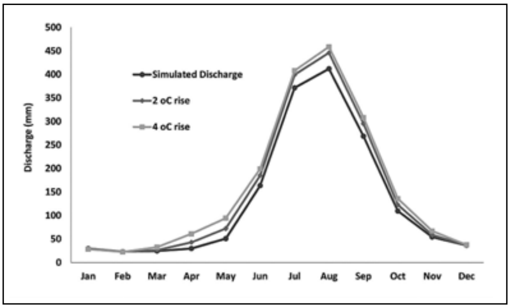


Fig. 5 Change in hydrograph in +2 and +4o C rise in temperature.

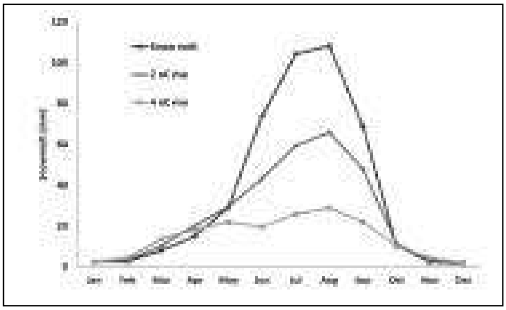


Fig. 6 Change in snowmelt pattern in +2 and +4° C rise in temperature.

The scenarios will change the hydrograph of snowmelt to a large extent (Fig. 6). The snowmelt amount will decrease to - 30 and - 59% in scenarios 1 and 2, respectively. After May, the snowmelt will be decreased heavily in both scenarios, and the magnitude will be higher in scenario 2. In average, during the monsoon season, the snowmelt amount will be decreased to 39% and 73% in scenarios 1 and 2, respectively. This is mainly because higher temperature trends will shift the snowline to higher altitude, and thereby decrease the basin's snow storage capacity. Since the rainy season coincides with the summer period, an overall decrease in snowmelt is likely, since there will be very less snow occurrence in the basin, particularly in lower altitude areas. During the pre-monsoon period (March-May), scenario 1 will produce slightly higher snowmelt than on the baseline conditions. However, in scenario 2, the snowmelt will be higher until April, and thereby gradually decrease. As the months progress towards summer season, the temperature gets higher and less snow occurs. The increase in air temperature is sensitive, which generates overall higher streamflow; however, the amount of snowmelt is decreased.

7 Conclusion and Outlook

The J2000 model showed its ability to simulate the hydrological dynamics of the Dudh Kosi river basin quite well. This study provides a basis for the application of the J2000 hydrological model in the monsoon dominated alpine glaciated catchment of the Himalaya region. The hypothetical rise in temperature scenarios indicate that the total streamflow will be increased. Although the total contribution of snowmelt will be decreased in both scenarios, both increase in snowmelt during pre-monsoon period and heavy decrease during monsoon season is observed. Looking into the snowmelt contribution to the streamflow, the river basin is vulnerable to Global Climate Change. This is mainly because the higher temperature will shift the snowline to higher altitude, and thereby reduce the basin's snow storage capacity. This will have adverse impacts on water availability on the downstream region in the future.

REFERENCES

Alford, D. (1992) *Hydrological aspects of the Himalaya region.* International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

Armstrong, R.L. (2011) *The glaciers of the Hindu Kush Himalaya region, a summary of the science regarding glacier melt/retreat in the Himalayan, Hindu Kush, Karakoram, Pamir, and Tien Shan mountain ranges*.

Eriksson, M; Jianchu X; Shrestha, AB; Vaidya RA; Nepal S; Sandström, K. (2009) *The Changing Himalayas Impact of climate change on water resources and livelihoods in the greater Himalayas.* International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

Flügel, W.A. (1995) Delineating hydrological response units by geographical information system analyses for regional hydrological modeling using PRMS/MMS in the drainage basin of the River Broel, Germany. *Hydrological Processes* 9 (3/4).

Hock, R. (1999) A distributed temperature index ice and snowmelt model including potential direct solar radiation. *Journal of Glaciology* 45 (149), 101-112.

IPCC. (2001) *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

Kattelmann, R. (1987) Uncertainty in assessing Himalayan water resources. *Mountain Research and Development*, Vol 7, No. 3, 279-286.

Kralisch, S., P. Krause, M. Fink, C. Fischer, and W. Flügel. (2007) *Component based environmental modeling using the JAMS framework*, in Proceedings of the MODSIM 2007 International Congress on Modeling and Simulation, edited by D. Kulasiri and L. Oxley, Christchurch, New Zealand.

Krause, P. (2002) Quantifying the Impact of Land Use Changes on the Water Balance of Large Catchments using the J2000 Model. *Physics and Chemistry of the Earth* 27, 663-673.

Krause, P., Bende-Michl, U., Bäse, F., Fink, M., Flügel, W-A. and B. Pfennig. (2006) Multiscale Investigations in a mesoscale Catchment - Hydrological Modelling in the Gera Catchment. *Advances in Geosciences* 9:53-61.

MoFSC. (2002) *Forest and Vegetation types of Nepal*. Ministry of Forest and Soil Conservation, Government of Nepal and Natural Resource Management Sector Assistance Programme (NARMSAP), TISC Document Series, No. 105.

Mool, P.K.; Bajracharya, S.R.; Joshi, S.P. (2001*) Inventory of Glaciers, Glacial Lakes, and Glacial Lake Outburst Flood Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region - Nepal.* Kathmandu: ICIMOD.

Rupa Kumar, K; Sahai, AK; Krishna Kumar, K; Patwardhan, SK; Mishra, PK; Revadkar, JV; Kamala, K; Pant, GB. (2006) High resolution climate change scenario for India for the 21st Century. *Current Science* 90: 334-345.

Sen, P. K. (1968) Estimates of the Regression Coefficient based on Kendall's Tau. *Journal of American Statitistical Association* 63: 324, 1379-1389.

Sharma, K. P., Vorosmarty, C. J., and Moore, B. (2000) Sensitivity of the Himalayan Hydrology to Land-use and Climatic Changes. *Climate Change* 47, 117-139.

Shrestha, A. B.; Wake, C.P.; Mayewski, P.A.; Dibb, J.E. (1999) Maximum Temperature Trends in the Himalaya and Its Vicinity: An Analysis Based on Temperature Records from Nepal for the Period 1971-94. *Journal of Climate* 12: 2775-2787.

2. STRENGTHENING GOVERNANCE AND INSTITUTIONS

The Sixaola Binational River Basin

ALFONSO SANABRIA A.
Integrated Ecoystems Management in the Sixaola Binational River Basin, Changuinola, Bocas del Toro, Panama
sanabria_alfonso@yahoo.com

Abstract The Sixaola Binational River Basin is located on the Panama-Costa Rica border, on the countries' western part, flowing into the Caribbean Sea. It has an area of 289,000 hectares (81% in Costa Rica and 19% in Panama). Its maximum altitude is 3,820 meters above mean sea level. The Basin is divided into three sub-basins: the high basin (204,000 hectares), the middle basin (51,000 hectares), comprising the Talamanca valley, and the low basin (34,000 hectares), where the Sixaola River Valley is located. It includes six protected areas. One of the most important issues in the Binational Basin relates to the water quality that is being delivered to the users, which is directly affected by inadequate management and treatment of the resources at the catchment source and storage tanks. The impacts of these deficiencies are evident in public health measures, they are reflected in high rates of child mortality, diarrhea, and skin disease records. To deal with the challenges that this important Basin presents, the Integrated Ecosystems Management Project in the Sixaola Binational Basin was established.

Key words Binational Basin; Sixaola; integrated ecosystems management

1 Introduction

The Sixaola Binational River Basin is located on the Panama-Costa Rica border. It has an area of 289,000 hectares (81% in Costa Rica and 19% in Panama), ranging from the Talamanca (Costa Rica) and Central (Panama) ridges to the Caribbean coast of both countries. Its maximum altitude (Chirripo Hill) is 3,820 meters above mean sea level. The basin is divided into three sub-basins: the high basin (204,000 hectares), the middle basin (51,000 hectares), comprising the Talamanca valley, and the low basin (34,000 hectares), where the Sixaola River Valley is located.

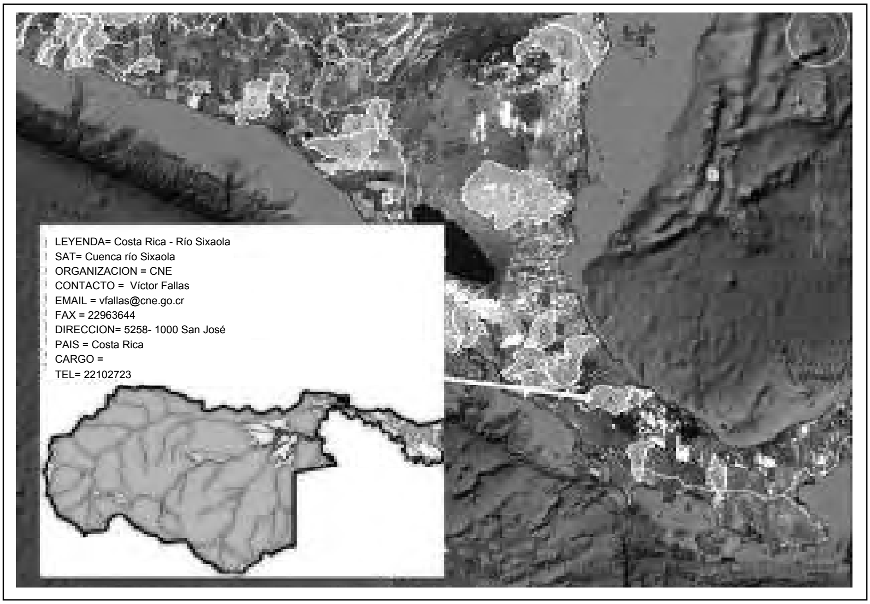


Fig. 1 Geographic Location of the Sixaola River Basin.

Six (6) Protected Wilderness Areas (PWA) are within the basin (143,000 hectares total - 121,000 hectares in Costa Rica and 22,000 hectares in Panama). In Costa Rica: La Amistad National International Park, Chirripo National Park, Hitoy Cerere Biological Reserve, and the Gandoca-Manzanillo Wildlife National Refuge (RAMSAR Site). In Panama: La Amistad International Park (PILA), San San Pond Sack Wetland (RAMSAR Site), and the Palo Seco Protected Forest. Four of these PWAs are transnational. Additionally, there are six indigenous territories that serve as buffer zones for the PWAs, harboring large forested areas and high levels of biodiversity. In Costa Rica (86,698 hectares): Bribri and Cabécar of Talamanca, Bribri of Keköldi, and Cabécar of Telire, legally constituted as Reservations. In Panama (26,090 hectares): Bribri and Naso-Teribe, and recently, members of the Ngöbe-Buglé ethnic groups, neither of which is legally constituted as Reservations.

Population: It is estimated that the Basin is inhabited by 33,500 people, of whom 58% live in Costa Rica (Talamanca Municipality) and 42% in Panama (Changuinola Municipality). 848 inhabitants of the Cabécar and Bri Bri ethnic groups live on the high sub-basin (0.0042 inhabitants/hectare), in the middle sub-basin there are an estimated 8,375 inhabitants (0.16 inhabitants/hectare), 94% of whom are Bri Bri or Cabécar Indians, and the low sub-basin has 24,358 inhabitants (0.72 inhabitants/hectare), mainly Ladinos, and to a lesser extent, Afro-Caribbean and native indigenous groups (Bri Bri and Cabécar) and non-native (Ngöbe-Buglé).

Land Uses: In Costa Rica, the Bri Bri and Cabécar Indians grow organic bananas (2,450 hectares) and manage agroforestry systems (3,600 hectares). In the fertile flood plains of the lower part of the basin there are large plantations of commercial banana (12,400 hectares). In the margins of the Bri Bri and Cabécar territories, as wella as on the Yorkin River Basin, cattle grazing activities are carried out, promoted by Ladinos and indigenous peoples (Ngöbe-Buglé).

In Panama, on the hill slopes and flood plains of the lower sub-basin, we can also see cattle grazing activities. In these areas, not less than 3,340 hectares are subject to a type of land use that generates conflict and contributes to land degradation and soil erosion. In these areas, the slash and burning of the vegetation to create pastures contributes to soil erosion in the heavy rain season.

Water resources and their uses: It is estimated that the Basin forests capture 2,685 mm of rainfall per year, resulting in a multi-annual average flow of 172 m_/s, that is, a volume of 5,456,000 m_/year. In the high sub-basin, the water is generally of good quality, but the waters of the middle and lower sub-basins are affected by pollution, mainly caused by agricultural activities and human settlements.

The Sixaola River is used for navigation, and rural aqueducts have been established to meet the basic needs of some communities. Those who do not have access to these aqueducts must use water directly from the water bodies that make up the basin.

One of the most important issues in the Binational Basin is the water quality that is being delivered to the users, which is directly affected by the inadequate management and treatment of the resources at the catchment source and storage tanks. The impacts of these deficiencies are evident in public health measures, being reflected in high rates of child mortality, diarrhea, and skin disease records.

Environmental Features: The basin provides essential environmental functions. Some of them are sediment filtration, water storage, aquifer recharge, energy dissipation, and serving as habitats for fish and wildlife. Its forest cover protects the fragile soils in the mountainous areas. Also, the forest canopy mitigates the effects of natural disasters such as tropical storms and earthquakes, acting as a regulating *sponge* against torrential rains, while reducing the vulnerability to flash floods, mudslides, and landslides. It also plays a role in the retention and stabilization of steep slopes and upland areas during earthquakes. The forests, in conjunction with the indigenous agroforestry systems, also capture a volume of carbon that is estimated at 647,444 tons (representing 2,374,000 tons of CO_2) per year, helping to mitigate climate change. Finally, the natural beauty provided by these diverse ecosystems, combined with the cultural values represented in the basin, offer unique conditions for tourism.

Biodiversity: As mentioned previously, the La Amistad International Park is located in this Basin. In it we find a wide range of ecosystems, containing exuberant biodiversity. The Jaguar (*Phantera onca*), which is a biological indicator of the good natural state of a site, inhabits the basin.

Protected Areas Management: In Costa Rica, the laws governing protected areas are much more restrictive than those in Panama, and more ambiguous regarding the co-management issue. The National Comptroller's Office does not prohibit the co-management, but acknowledges the need to develop policies and procedures to formalize it. Panamanian law, on the other hand, provides for the co-management of protected areas through grants, and application procedures are relatively clear.

Management of Border Protected Areas: The management of the PILA has been rated as deficient by the Comptroller's Office in both Costa Rica and Panama, and thus has been entrusted to the Environmental Authorities of both countries. The Environmental Authorities, and the civil society organizations that are involved, recognize the need for improved integration of border protected coastal areas (San San Pond Sack and Gandoca Manzanillo), which implies harmonized management plans and joint management activities.

Indigenous Territories: Indigenous territories and the autonomous status of indigenous peoples have been recognized in specific laws, as well as in Agreement No. 169, of the International Labor Organization (ILO), ratified by both countries. In Costa Rica, Act 6172 states that the Indigenous government is constituted by the Integral Development Associations (IDA), and in Panama it has been disposed that each of the territories must define its form of government. Within these territories, the indigenous governments act with relative autonomy.

2 Integrated Ecosystems Management Project in the Sixaola Binational River Basin

This Project is included in the framework of a series of agreements signed by the governments of Costa Rica and Panama. In 1991, the Vice-Presidents of both countries signed Resolution No. 4-91, by which they committed to promote the development of these border areas, for the benefit of regional integration.

During that same year, the two governments signed an agreement on border protected areas, under which the La Amistad International Park (PILA) was officially established, as well as a cooperation agreement for development of the Costa Rica-Panama border. For the latter, a Permanent Binational Commission in charge of strengthening and facilitating integration programs, and to promote the integrated management of the binational area, was established.

In 2003-2004, supported by a grant from the IADB, a Regional Sustainable Development Strategy of the Sixaola Binational River Basin was established. In 2008, a Non-Refundable Financial Agreement from the Global Environment Facility Investment Fund No GRT/FM-10575-RS was signed. After that, implementation of the Integrated Ecosystem Management Project in the Sixaola Binational Basin began.

3 Project Objectives

To contribute to the sustainable use of soil and water resources, and to the conservation of biodiversity, through the creation of a favorable environment for integrated and inter-sectorial management, in the Sixaola River Binational Basin.

4 Project Components

- Strengthening institutional frameworks and technical and operational capabilities, required for an integrated management
- Promotion of production practices compatible with conservation and sustainable use of water and soil resources
- Conservation and sustainable use of biodiversity

5 The Project's Binational Technical Unit

a. Project Coordinator, Alfonso Sanabria,
b. Natural Resource Specialist, Marietta Fonseca,
c. Project Administrator, Edgar Sánchez,
d. ANAM (Panamanian environmental authority) representative, Fernando González
e. MINAE (Costa Rican environmental authority) representative, Marcelo Pacheco

REFERENCES

Inter-American Development Bank. *Costa Rica-Panama, Integrated Ecosystem Management Project in the Sixaola River Binational Basin* (RS-X1017). Loan Proposal Non-Refundable Operation, Financed by the GEF.

The Murray-Darling Basin: Australia's Journey of Sustainability

AWADHESH PRASAD
Murray-Darling Basin Authority, Canberra, Australia
awadhesh.prasad@mdba.gov.au

Abstract The Murray-Darling Basin (M-DB) spreads over five states and is vital to the Australian economy. It is facing many environmental challenges (e.g., salinity and loss of bio-diversity). Several policies (e.g., Cap on water diversions and salinity management strategies) have been initiated to address these challenges. Commendable successes of these policies, however, have not been sufficient to arrest the environmental decline in the Basin. A balance needs to be struck between the consumptive and environmental values of the Basin to achieve sustainability. In a first move towards achieving sustainability on such a scale, a Basin Plan is being prepared, which among other things will set new sustainable diversion limits on both the surface and groundwater diversions, and develop plans for environmental watering and water quality management. An initial Basin Plan proposal for reducing the current diversions by 22-29% was met with angry response from farmers and rural communities. A federal parliamentary inquiry subsequently found that rather than the lack of community support for reform; the Authority's approach to engagement with the community and Basin state governments was responsible for much of the hostile reaction to the initial Plan. Heeding to the feedback, the Authority has been widely consulting with the communities, industry groups and governments on the details of the Plan. The imminent draft Plan, after almost half a year of formal consultation, on adoption by the federal water minister, will become a law binding upon the Basin states, which will have to implement it through their water resources plans. The paper describes the M-DB's fascinating journey of sustainability.

Key words Sustainability; social; economic and environmental values; basin plan; community engagement

1 Introduction

The Murray-Darling Basin (M-DB) in Australia, comprising 23 catchments of the Murray and Darling Rivers, extends over 1 million square kilometres across five states: New South Wales (NSW), Victoria (VIC), Queensland (QLD), South Australia (SA), and the Australian Capital Territory (ACT). More than 2.1 M people live in the M-DB, and another 1.3 M people outside it are dependent on its water. Though only 14% of the land-size of Australia, the M-DB contains 65% of its irrigated areas, consumes 50% of agricultural water use and accounts for 40% of national agricultural produce; generating around $15 billion (MDBA, 2010). The current consumptive use is 15.4 B m^3, comprising 13.7 B m^3 of surface water and 1.7 B m^3 of groundwater (MDBA, 2010). The consumptive use has reduced the average outflow at the Murray mouth to 41% of the flow under natural conditions (MDBA, 2010). The substantial economic benefit of consumptive water use has come at a significant environmental cost. The ecological health of 20 out of 23 catchments is considered 'poor' or 'very poor' (Davies, *et al.*, 2008). It has been realised for a long time that a balance needs to be struck between the consumptive and environmental values of the Basin to achieve sustainability. Achieving balance is challenging, as it involves difficult trade-off decisions that need the community's acceptance. A series of reforms have been undertaken in the M-DB, the latest being a Basin Plan for setting sustainable diversion limits on consumptive water use. However, as the concept of sustainability is not fixed in time and space, but changes with the community's values, achieving sustainability is not like reaching a destination. It is an endeavour, a journey. This paper describes the M-DB's fascinating journey of sustainability.

Evolving Governance

A six-member independent Authority under the federal Water Act currently governs water management in the M-DB. Until 2008, a consensus-based inter-jurisdictional ministerial council and a commission representing the Basin states and the federal government governed it. Some limited inter-jurisdictional governance is still retained in the form of a revamped Ministerial Council and a Basin Officials Committee (BOC). However, on the key issue of sustainable water resources management, both the BOC and the Ministerial Council have only advisory roles and serve as formal forums for engaging with the Basin states' governments. The governance of the M-DB and associated institutions evolved over its century-old history. These changes have followed the evolving focus of water management in the Basin. Blackmore (2002) has identified three phases in the institutional arrangements: (a) *pioneering phase*: 1901-1920; a (b) *delivery phase*: 1921-1970; and a (c) *management phase*: 1971-1990. To this, Baird and McLeod's (2004) fourth, (d) *capping (pre-environmental)* phase: 1991- 2000; and fifth (e) *environmental phase:* 2000 to present; might be added. These phases reflect the drivers, behaviours and relationships prevalent during those times and essentially trace the history of water management and reforms in the M-DB.

Historical Developments and Reforms

The pioneering phase is characterised by a desire to develop water resources for human benefit (irrigation and navigation) without a detailed understanding of its impacts (Blackmore, 2002). In this phase, the foundation for the cooperative management of the M-DB was laid in the form of the River Murray development plan of 1901. Consequently, the River Murray *Waters Agreement* was signed between the three southern M-DB states, NSW, VIC, and SA and the federal government in 1914-15, to share water of the main stem of the River Murray. This agreement established the consensus-based River Murray Commission (RMC), comprising four commissioners (one from each jurisdiction), specified rules for water sharing between the three states, and cost sharing arrangements for the capital work and operations. The formula agreed for water sharing, with minor adjustments, still applies.

The delivery phase is characterised by the construction and management of water regulation infrastructure, e.g., dams, barrages, locks and weirs. The key drivers of this phase were economic development and stability, with other matters being relegated to the background (Blackmore, 2002). Towards the end of the phase, river salinity emerged as an issue leading to awareness of water quality importance and its connection to wider natural resource management. This paved the way for the third phase.

The management phase is characterised by broadening of the management objectives to include a social, economic, and environmental triple bottom line, leading to the necessary trade-offs and associated complexity. The *Waters Agreement* was amended in 1982 and 1984 to broaden the role of the RMC: to include water quality and environmental responsibilities (MDBC, 2006b). However, these amendments proved inadequate in addressing growing inter-state environmental problems (rising land and water salinity). These realisations led to intense negotiations during 1985-1987, resulting in a completely new Murray-Darling *Basin Agreemen*t in 1987; further amended in 1992. The*Basin Agreement* established new institutional arrangements with a Ministerial Council as the top decision making body, a new Murray-Darling Basin Commission (MDBC) as its executive arm and a Community Advisory Committee. A major policy outcome was the establishment of the 'salinity and drainage strategy' to combat the River Murray's salinity. A system of salinity debits and credits was established, making NSW, VIC, and SA accountable for their actions that increased or reduced river salinity. It was one of the first pollution trading systems. QLD and ACT joined the *Basin Agreement* in 1996 and 1998, respectively. This transformed a river authority to a Basin Authority.

The Capping (pre-environmental) phase is characterised by a realisation that water diversion for consumptive uses (mostly irrigation) had reached a level beyond which growth was not sustainable. Diversions increased from 2 B m^3 in the early 1920s to about 12 B m^3 in 1990s. The Ministerial Council in 1995 agreed to a Cap (a limit based on the 1993/94 level of development) on the surface water diversion in response to an audit of water use (MDBMC, 1995) that confirmed that an increasing level of diversions had caused a decline in river health. The two key objectives of the Cap were to maintain and, possibly, improve existing flow regimes and to achieve sustainable consumptive use by developing and managing the water resources to meet ecological, commercial, and social needs (MDBMC, 1996). The Cap was a pioneering decision that tried to balance the competing socio-economic and environmental needs. The review of the operations of the Cap (MDBMC, 2000) concluded that, while the Cap did not guarantee a sustainable basin ecosystem, it was the essential first step in achieving this outcome. Without the Cap, the risk of environmental degradation would have significantly increased.

The environmental phase is characterised by the realisation that only healthy river systems can sustain healthy and prosperous communities. This has come not as a sudden discovery, but as a gradual experience aided by scientific research (commissioned by the MDBC and others). In response to growing evidence that the River Murray's environment was degraded and threatened the well being of communities (their agriculture, industries, natural and cultural values), the Ministerial Council established a significant river restoration program called the Living Murray (TLM) in 2003. Among other things, TLM program committed to returning 500 M m^3 water annually to the river for improving the health of six significant ecological assets along the Murray River.

The environment is now considered a legitimate user of available water in Australia. The National Water Initiative (COAG, 2004) required providing statutory recognition to environmental water, returning over-allocated systems to sustainable levels of use, improving water planning, including through providing water for environmental outcomes, and expanding permanent trade of water. The separate M-DB governments agreement (except for the QLD state government), committed $500 M over five years, starting in 2004, to address water over-allocation and to achieve specific environmental outcomes in the M-DB.

2 Imperatives for Further Reform

Apart from the Cap and TLM program, other significant initiatives aimed at improving the environmental and ecological health of the M-DB Water. These initiatives were: Trading (allowing water to move to higher value uses), the Basin Salinity Management Strategy (extending the enhanced salinity strategy to the whole of the M-DB) and the Native Fish Strategy (for rehabilitating the declining native fish population). The commendable success of these policies was not sufficient to arrest the environmental decline in the M-DB; as is evident by the ecological health of 20 out of 23 catchments being rated 'poor' or 'very poor' (Davies, *et al.*, 2008). The recent worst drought in recorded history aggravated the situation: flow to the Murray mouth ceased, some portion of the nearby Lower Lakes dried up, triggering acidification of the lakebed sediments, and the Ramsar-listed estuarine lagoon developed unacceptable levels of hyper-salinity. This received widespread publicity, creating a lot of community concern. The pace of reform to address over allocation -the underlying cause of the environmental problems- had been slow, and the M-DB's consensus-based governance was being perceived as ineffective. All these factors led to a federal intervention with the announcement of a $10 B National Plan for Water Security (NPWS) in early 2007, and subsequent enactment of the federal *Water Act* in late 2007.

Water Act 2007

As the Australian constitution vests the power over water in the states, the implementation of the NPWS required referral of that power to the federal government. Despite agreement with other

M-DB states, its failure to negotiate referral of this power with the state of Victoria led the federal government to enact the *Water Act* in late 2007, largely using its foreign affairs (international environmental agreements) power. The *Act,* amongst other things, established an independent Murray-Darling Basin Authority (MDBA); the MDBC was left in place. The Authority's mission was developing a Basin Plan to set new sustainable diversion limits on surface and ground water diversions, and an Environmental Water Holder to acquire and manage environmental water.

Following Victoria's agreement to refer its power, the subsequent amendments to the *Water Act* in 2008 resulted mainly in the MDBA. The Basin Plan's provisions largely remained intact, continuing to rely on the foreign affairs power. A Senate Committee (2011) inquiry concluded that the *Ac*t's reliance on foreign affairs power had limited the MDBA's ability to balance the social, economic, and environmental considerations to formulate the Basin Plan -constraining it to give more weight to the environment-, and caused legal uncertainty. The Committee recommended amendments to the *Ac*t to broaden its power base and to enable equal consideration of economic, social, and environmental values; however the Committee's views were not unanimous. The dissenting views stated that amendments to the *Act* were unnecessary, as the *Ac*t had sound legal basis and provided ample scope to appropriately balance economic, social, and environmental considerations. The Senate Committee (2011) report showed that views on the *Water Ac*t were highly polarised: the farming and irrigation community called for the explicit balance of the economic, social, and environmental considerations, while the environmental groups maintained that the balance had earlier been unduly tilted in favour of consumptive users, and should be restored by favouring the environment. It is not surprising that development of the Basin Plan was quite challenging in this emotive environment.

Basin Plan and Sustainable Diversion Limits (SDLs)

The *Water Ac*t specifies the mandatory contents of the Basin Plan, the states' Water Resources Plans (WRP), and the manner in which they must be formulated (including the requirements for consultation with the states and public). The Authority prepared the Plan, which upon adoption by the federal Minster and the federal parliament's approval becomes binding upon the states. The states must implement it through WRPs accredited by the Minister. In making the Basin Plan, the Authority and the Minister must act on the basis of the best available science and socio-economic analysis. Of the three key elements of the Basin Plan -sustainable diversion limits, environmental watering plan, and water quality management plan- the SDL has been the most complex and contentious. To set the SDLs, the Authority must first determine the environmentally sustainable level of take, which the *Ac*t defines as: the level that if exceeded would compromise any of the "key" environmental assets, ecosystem functions, outcomes or the productive base of the water resource. However, the *Act* permitted discretion in determining what is 'key'. In each case, it allows judgement in optimising social, economic, and environmental considerations to set SDLs.

Guide to the Proposed Basin Plan

After almost 2 years of painstaking work, the Authority's *Guide* to the proposed Plan in October 2010 recommended reducing the current consumptive use by 3-4 B m^3 (22-29%) to make way for environmental needs. The *Guide* intended to explain to the community the scientific basis and the policy judgments used to propose the SDLs.

Following the release of the *Guide,* the Authority went straight into community meetings, where it was met with angry outbursts from farmers and rural communities. The Authority's chairman resigned at this time and a new chairman was appointed. A federal parliamentary inquiry was also established to look into the socio-economic impacts of the *Guide*. The Inquiry (2011) found that, rather than the lack of community support for reform, the Authority's approach to engagement with the community and Basin state governments was responsible for much of the hostile reaction to the *Guide*. By adopting a 'closed door' policy during the preparation of the *Guide*, the Authority had failed to consult them. It presented the *Guide* through information sessions rather than through consultation workshops. The *Guide* also failed to explain the need for the Basin Plan and to articulate a vision of how it would be implemented. Other reasons for the community's strong reaction included their feeling of reform fatigue, exacerbated by a decade of preceding drought and undervaluing of the socio-economic analysis (Inquiry, 2011). The Authority's new chairman, distancing himself from the *Guide*, observed that "it showed little respect for the people" and "their desire to be engaged in decision making, and their historic effort in managing water for consumption, production, and environment" (Knowles, 2011).

3 New Approach

The Authority responded by changing its method of engaging with stakeholders and its policy directions. The chairman has been undertaking extensive consultation with the community and Basin states' governments. His consultative efforts have been well received by all.

Shelving the *Guide* proposals, the Authority has indicated a revised 2.8 B m^3 of water recovery for the environment. This new volume is based upon the 'hydrological indicator sites' methodology, which is different from the 'end-of-system flow' approach used in the *Guide*. Considered more thorough, the 'indicator sites' methodology determines the environmental water needs of more than 100 'indicator sites' across the Basin. This is, compared to the rather simplistic approach of 'end-of-system flow', which assumed that if these targets were met, everything upstream would be fine (Knowles, 2011). The lower water-recovery volume has led to protests by environmental groups and criticism by scientists. The Authority maintains that the methodology used is not new and has not resulted from perceived pressure from powerful stakeholders. This detailed analytical work that was progressing during the preparation of the *Guide* has been peer-reviewed twice (Knowles, 2011). To address the concerns of environmental groups and scientists, the Authority asked the National Science Agency, CSIRO, to review the use of the 'hydrological indicator sites' method to determine SDLs. While defending the methodology used, the Authority chairman affirmed that the Basin Plan is not just about science, but also about people (Knowles, 2011). The message here is that to balance the environmental, economic, and social value of water is as much about people as it is about science. Water flows in landscapes that are lived upon and valued by people.

The Authority is negotiating with all stakeholders, including environmental groups, federal and state governments, and communities to craft a plan acceptable to all. Two key outcomes of these negotiations so far are: a 'bridge the gap' commitment by the federal government, and a transition plan to implement new diversion limits. The 'bridge the gap' commitment binded the federal government to buy the water to cover the gap between the current diversion limits and SDLs. The seven-year-long transition plan, with a mid-term review, will establish the new diversion limits under the Basin Plan. The plan finalisation is expected by mid-2012, and its implementation will not start until 2015. By 2019, a review of SDLs will be undertaken considering several matters, including the water recovered and efficiency gained (MDBA, 2011).

The Authority believes that broader issues related to Plan implementation and environmental water delivery need resolution before the draft plan is released. It needs more time to complete these negotiations. The draft Plan due in mid-2011 is now expected in November 2011. The delay has been welcomed by some and criticised by others. Setting aside criticisms, the Authority considers (MDBA, 2011) that “the Plan is too important to rush. It is not about ticking a box, but getting it right.” The Authority has also extended the consultation period for the draft plan by 4 weeks, to 20 weeks total. The whole process for the Plan approval and adoption by the federal minister, including the public consultation, is likely to be completed by mid-2012.

4 Future Challenges

Whatever its final shape, the implementation of the Basin Plan will be very challenging. It will require a lot of technical developments: models, systems and processes for setting targets, compliance, monitoring, evaluation, and reporting. All these will require not only additional financial resources, but also additional human resources (both in the Authority and the states governments). As the M-DB's water management moves from the old ‘state-based’ to a new ‘basin-wide’ regulatory and compliance regime under the Basin Plan, more cooperation than ever before will be required between the states and the federal Authority. The sharing of the water regulatory space -earlier, the states' sole domain- between the Authority and the states, and the need for additional resources, are likely to present new challenges to the federal and states governments.

5 Conclusions

Spread over five of its states, the M-DB is vital to Australia's economy. Governance of its water management has been evolving with the changing focus of water management in the different phases of its century old history. Currently, a federal Authority is developing a Basin Plan that among other things will set new sustainable diversion limits on surface and groundwater diversions. Though quite radical, the Basin Plan is neither a beginning nor an end, but a step in a journey of sustainability. Developing the Basin Plan that aims to balance social, economic, and environmental values has not been easy. Negotiations are continuing in order to achieve an outcome acceptable to all stakeholders. Subject to the federal parliament's disapproval, the Basin Plan as adopted by the Minister (expected mid-2012) is likely to achieve the right balance. Federal leadership will need more cooperation from the states than ever before for the implementation of the Basin Plan.

RERENCES

Baird, J. and McLeod, A J. (2004) Governance Arrangements for Environmental Management in the River Murray, Australia. *Water Law* (15) 3/4, 142-145.

Blackmore, D. (2002) Protecting the Future. In: Connell, D (ed.) *Unchartered Waters*, 1-4, MDBC, 2002 COAG Communiqué.

Davies PE, Harris, JH, Hillman, TJ, and Walker KF. (2008) *The ecological health of rivers in the Murray-Darling Basin 2004-2007, Report of the Independent sustainable Rivers Audit Group,* MDBA.

Inquiry - House of Representatives Standing Committee on Regional Australia. (2011) *Of drought and flooding rains', Inquiry into the impact of the Guide to the Murray-Darling Basin Plan.*

Knowles C. (2011) People at the Heart of the Basin Plan, *Sydney Morning Herald*, 27 July 2011.

(MDBA) Murray-Darling Basin Authority. (2010) *Guide to the Proposed Basin Plan*, MDBA.

(MDBA) Murray-Darling Basin Authority. (2011) *Chair's statement, Progress on the Proposed Basin Plan*, MDBA.

(MDBC) Murray-Darling Basin Commission. (2006a) *Surface Water Resources Fact Sheet*, MDBC.

(MDBC) Murray-Darling Basin Commission. (2006b) *A Brief History of the Murray-Darling Basin Agreement*, MDBC.

(MDBMC) Murray-Darling Basin Ministerial Council. (1995) *An Audit of Water Use in the Murray-Darling Basin,* MDBMC, Canberra.

(MDBMC) Murray-Darling Basin Ministerial Council. (1996) *Setting the Cap*, MDBMC, Canberra.

(MDBMC) Murray-Darling Basin Ministerial Council. (2000) *Review of the Operation of the Cap*, MDBMC, Canberra.

Senate Legal and Constitutional Affairs References Committee. (2011) *A Balancing Act: Provisions of the Water Act 2007*, Commonwealth of Australia, Canberra.

Governance and Water Ethics

DAVID GROENFELDT
Water-Culture Institute, Santa Fe, New Mexico, USA
dgroenfeldt@waterculture.org

Abstract A values approach offers a way of understanding and improving water policies and management practices. The approach applies concepts from environmental ethics and cultural studies to focus on the often hidden values which motivate water behavior. The example of the Santa Fe River (New Mexico, USA) illustrates how deeply held utilitarian values about nature are reflected in policies which are unsustainable from a scientific perspective, yet are supported by an unfortunately effective governance system. Analysis of the Santa Fe case suggests the need for changing water values through governance arrangements that include a broad range of stakeholders, including environmental voices. By acknowledging values and ethics as an explicit dimension of water management, institutions can function more flexibly and water use might become more sustainable.

Key words Ethics; values; environment; governance; Santa Fe River

1 Introduction

What are we governing water for? What are our objectives, and more broadly, what are our aspirations? What are we trying to achieve? Unless we ask these questions, we can easily end up with well-governed rivers that are in ecological decline (Pahl-Wostl *et al*., 2008). As Simon Sinek argues in his recent book, *Start with Why*, we need to be clear not only about our management objectives, but at a deeper level, about the values motivating those objectives (Sinek, 2009).

Water policies and management practices inevitably reflect values and ethical assumptions. Although rarely stated explicitly, the underlying values become visible when water conflicts spill into the political arena. The controversy around large dams, for example, has brought up a range of values about how rivers should be managed, and the relative priorities that should be accorded to environmental considerations and individual human, as well as collective, cultural rights (see the special issue of *Water Alternatives*). The dam controversy demonstrates the powerful range of values implicated by river management decisions, and the interaction between the global level of broad principles, where the World Commission on Dams was operating (WCD, 2000), and the local level, where values specific to local communities and cultures need to be assessed and negotiated.

For the purposes of this discussion, water ethics and values about water use and river management are neither good or bad, right or wrong; they simply exist as part of the context of water governance. Values about water are also problematic, however, for two reasons: (1) values are invisible and easily ignored until they take a visible expression (e.g., in plans for a dam or in demonstrations against the dam), and (2) specialists who study values (anthropologists, philosophers, psychologists) have little involvement in water governance discussions.[1] The message of this paper is that the values underlying water governance deserve systematic and thorough study as part of the process of reforming water governance towards sustainability.

2 The Case of the Santa Fe River

An example of how water ethics and values motivate water governance can be seen in the Santa Fe River in New Mexico.[2] This river is totally impounded by upstream reservoirs built for urban water supply, and as a result is totally dewatered below the dams. Because of this deliberate management strategy of sacrificing the ecology of the river for the water supply of urban residents, the Santa Fe River was declared "America's Most Endangered River" in 2007 by the national environmental group, American Rivers.[3] Who killed the Santa Fe River? I would suggest that the river was killed not by bad governance, but by the local cultural values that see the river's water as a commodity that can be bought and sold, and do not recognize an ethical responsibility for the health of the natural river ecosystem.

The governance of the Santa Fe River reflects the worldview (which is also upheld by state water law) that the river's water rightfully belongs to the human owners of that water. In New Mexico, water rights are private property and dewatering rivers is legal if you own the water.[4] The water in the Santa Fe River is almost wholly owned by the municipal water utility. No water is allowed to escape the water supply reservoirs unless they are nearly full, which in the arid climate happens for only a few months in the year. For the remainder of the year, the Santa Fe River is a dry ditch running through the middle of the historic city founded on the river's banks.

Is this a governance problem? Not entirely. Governance of the Santa Fe River is democratic and transparent. Elected city councilors determine whether to release water from the dam. Local citizens are resigned to the notion that since they live in a dry climate, they cannot expect a wet river. Environmental groups and the city's own water staff have challenged this complacency and are promoting a re-regulation of the river to allow for a minimal environmental flow. There is some hope for a future river, but there is also no denying the recent past. The Santa Fe River has been dry in spite of a reasonably effective governance system.

If good governance is not the path to a healthy river, what is? The answer, in my view, is "ethics". A new ethic about living in harmony with Nature can be the motivation for restoring the river. Sustainable urban development in Santa Fe needs to give priority to the river and build around and with the natural environment. Improving the governance structure of the Santa Fe River could help. A stakeholder council would be a useful check to ensure that a diversity of views get reflected in management decisions. But tinkering with the governance structure can also be a distraction from addressing directly the underlying values (ethics) that motivate behavior.

3 Working with Values

The hidden values that drive water policies and behaviors need to be uncovered and exposed to public debate, where they can be informed by science, religion, politics, and economics. This value-assessment process is part of what good governance should include as standard practice, but explicit attention to ethics has largely been absent in discussions of water governance. Fortunately, that is changing (see Brown and Schmidt, 2010 and Llamas *et al*., 2009). The study of water ethics is slowly emerging as a serious topic. "Getting the ethics right" is just as important to effective water governance as "getting the prices right." Following is a four-step process for working with water ethics:

Step # 1: Identify Existing Values. Identifying the operative values underlying particular behaviors is the first step in the process of "getting the ethics right." Merchant (1997) notes that from a resource management perspective, 20th century ethics were primarily utilitarian and took the interests of society (rather than the individual self) as the impetus for normative legitimacy. This utilitarian view was initially articulated in the United States and has gradually extended internationally (Feldman, 1995, 2007). Even today, definitions of IWRM commonly promote a utilitarian ethic where the goal is to "maximize…economic and social welfare" without compromising the environment (Global Water Partnership, 2000: 22).

Step # 2: Analyze the Values. A values approach allows us to recover the values latent in specific traditions that have been overshadowed by other value systems. For instance, in the Western United States, the doctrine of 'beneficial use' was initially designed to ensure just distributive practices by ensuring that water was diverted for legitimate uses, and that rights could not be bought up by venture capitalists (Schorr, 2005). This materialistic emphasis often interferes with considerations of ecological function which do not have a defined market value. The inconsistencies between the values embedded in water laws and the values of society as a whole, or of particular interest groups (e.g., environmentalists) or of science (e.g., ecology, economics, hydrology) are indicators that the laws need to be re-examined or, conversely, that conflicting values among different social groups need to be debated and negotiated.

Step # 3: Evaluate Alternatives. Values can be evaluated through comparative analysis or historical cases. Environmental historians document the evolving cultural values underlying resource management and may have valuable insights. For example, Blackbourn (2006) traces the evolution of engineering standards applied to the Rhine River, from "command and control" strategies during the first half of the 20th century, to more recent ecosystem-based strategies. The cultural assumptions (values) about the interaction of people and nature have shifted. Ecological principles offer a new paradigm of relating to Nature, which shares many features with indigenous animistic traditions that hold Nature as sacred. In a sense, ecology provides a scientific rationale for indigenous cultural values about rivers.

Step # 4: Propose New Policies. Policy alternatives can be debated among stakeholders on the basis of the community's desired values and outcomes. Governance issues and participatory mechanisms become critical for reaching solutions that are endorsed by the full range of stakeholders. By clarifying the values that the community (or country) wishes to promote, water policies can be formulated to reflect those desired qualities.

4 Applying Ethics to Water Governance

One of the reasons that water values and ethics are not talked about more is that we lack a basic set of terms, and the few terms that we do have are used in conflicting and confusing ways. Take the term, *ethics:* Does this refer to the set of values we would like to see in a sustainable world (*prescriptive* ethics) or does it refer to the set of existing values that are a cause of our currently unsustainable world (*descriptive* ethics)?

Another cause of confusion is determining the object of ethical concern. Are we interested in the ethical management of water bodies (rivers, lakes, aquifers, wetlands), or are we talking about the ethical use of the water that is extracted from those bodies, e.g., for agriculture, urban/municipal supplies, or industry? Are we concerned about individual human rights (e.g., the human right to water and sanitation), or community rights, or cultural rights? The diversity of values and ethical principles adds a dimension of relativity to the study of ethics. A hydropower dam that brings benefits to downstream users might seem unethical to the indigenous community whose ancestral lands will be inundated; indeed, the project might even be deemed illegal under new interpretations of international law.

How can we move from acknowledging discrepancies in values to a constructive policy debate that can harmonize those discrepancies? First, we have to recognize the importance of the values that we care about, and how they conflict with the values embedded in a law or policy. "Unless we have a sufficient grasp both of our own values and of how a law or decision or action affects something we care about, we will not respond. The process of gaining clarity, of discussing the values at stake, may itself promote more reasoned thinking. Deliberation may promote ethical development" (Flournoy, 2003:64).

While this process may sound tautological, it is not the only tool in the arsenal to reform cultural values about water and to promote a more sustainable water ethic. Other approaches include: (1) the application of science both directly (bring in experts) and indirectly through education, (2) new models and conceptual frameworks, such as Integral Theory (O'Brien and Hochachka, 2010), (3) using visual and/or performance art to communicate through aesthetic and emotional channels (Irland, 2007), (4) political action, whether aggressive (e.g, Greenpeace) or diplomatic (e.g., WWF), and (5) governance arrangements that incorporate environmental and cultural stakeholders.

Of these approaches, the last one, governance arrangements, may hold the greatest short-term promise in reforming unsustainable water ethics and resultant water policies. Thanks to the development of sophisticated institutional approaches to water management, governance is an acknowledged priority for policy makers and water managers. Principles of participation and stakeholder involvement are well understood (if not always followed), and the slogan of "making water everybody's business" has been widely communicated. Significant progress could be achieved simply by implementing these concepts more vigorously so that a broader set of stakeholders is included in water decisions.

In New Mexico, water policies were developed by lawyers, entrepreneurs, and engineers. Although elected representatives have ultimate authority, in practice, they go along with the recommendations of the technical water managers. In cases where stakeholders are given official voice, as in a levee reconstruction project along the Rio Grande in central New Mexico, the role of "stakeholder" is defined on the basis of the existing water policies, with the interpretation that only a water rights holder has a "stake" in what happens to the river. This type of governance arrangement precludes environmental organizations (unless they happen to own water) and the vast majority of local residents.

A more generous interpretation of "making water everybody's business" would suggest expanding the concept of stakeholder beyond the economic shareholders to include Indigenous Peoples, environmental voices, and disciplinary perspectives from the arts, humanities and sciences, as well as from engineering and law. For full representation of values, the people and groups holding those values need to be included as stakeholders.

Governance reform to expand the definition of stakeholders is only one part of the ethics puzzle, but it may be the keystone that enables complementary approaches (science, models, art, and policy) to take effect. Values do evolve; we can see this in the history of water development from raw conquest of nature to more peaceful co-existence. But values need to change faster than ever before to keep up with the climatic changes around us.

5 Conclusions

Values are everywhere, and if we make the effort to look for them, we can begin to utilize values as tools for crafting sustainable water (and other) policies. The crisis of climate change adds urgency to the task of "getting the values right" but that crisis also provides experiential lessons about the difference that values can make.

The potential for behavioral change through changes in values and ethics presumes that values can be changed, and that we have some reasonable ideas of how to go about it. I have suggested that the first and most important step is to acknowledge the existence of values hidden within water policies and practices, and only then can we apply creative approaches to transforming those values along the lines we feel would be desirable. The precise outcome is, in my view, less important than the process of identifying, analyzing, and debating alternative values and their implied behaviors. It is critical to maintain a discourse around values and not only around behaviors, because behaviors need to be held accountable to the values they express.

When values are addressed and debated through an open and democratic process, the resultant behaviors are more likely to be sustainable. The danger comes not from democracy (in the ideal sense), but from ossified institutions which lose their resilience to respond to new situations, and then deny the value dimension of their own policies. Values as a moral guide to practical behavior (ethics) serve to lubricate the otherwise sticky gears of institutions. We need institutions, but we also need values. The good news is that both are always present; we just need to look.

Epilogue: A Water Ethics Network

Recently (August 2011), a Water Ethics Network has been established by the Water-Culture Institute (www.waterculure.org) in partnership with several other organizations. The Network's purpose is to bring the study of water ethics into the everyday discourse of water policies and management decisions, so that choices about water use and water ecosystem management are consciously informed by values. The Network facilitates the sharing of experience, ideas, and information about events and activities. Anyone professionally involved in water and/or ethics is invited to join the Network. For more information, and to subscribe to the (free) monthly newsletter, visit: http://waterethicsnetwork.blogspot.com.

REFERENCES

Blackbourn, D. (2006) *The conquest of nature: Water, landscape, and the making of modern Germany*. New York: Norton.

Brown, P. and Schmidt, J. (eds.), 2010. *Water ethics: Fundamental readings for students and professionals*. Washington, DC: Island Press.

Feldman, D. (1995) *Water resources management: in search of an environmental ethic.* Baltimore: John Hopkins University Press.

Feldman, D. (2007) *Water policy for sustainable development.* Baltimore: John Hopkins University Press.

Flournoy, A. (2003) Building an environmental ethic from the ground up. *Environmental Law and Policy Journal* 56:53-80.

Global Water Partnership. (2000) *Integrated Water Resources Management. TAC Background Paper no. 4*. Stockholm: Global Water Partnership.

Groenfeldt, D. (2010) The next nexus? Environmental ethics, water management, and climate change. *Water Alternatives* 3(3): 575-586.

Irland, B. (2007) *Water library.* Albuquerque: University of New Mexico Press.

Llamas, R., L. Martinez-Cortina, & A. Mukherji. (Eds.), 2009. *Water ethics: Marcelino Botin water forum 2007*. London: CRC Press.

Merchant, C. (1997) Fish first! The changing ethics of ecosystem management. *Human Ecology Review* 4: 25-30.

O'Brien, K. and Hochachka, G., 2010. Integral adaptation to climate change. *Journal of Integral Theory and Practice*, 5(1), pp. 89-102.

Pahl-Wostl, C., Gupta, J. and Petry, D. (2008) Governance and the global water system: a theoretical exploration. *Global Governance* 14: 419-435

Sinek, Simon. (2009) *Start with Why: How Great Leaders Inspire Everyone to Take Action.* New York: Portfolio (Penguin).

WCD. (2000) *Dams and Development: A new framework for decision-making*. London: Earthscan.

---

[1] A notable exception to this general rule was the presence on the WCD of Thayer Scudder, an anthropologist, who played a key role on the Commission.

[2] For a more detailed account of this case, see Groenfeldt, 2010.

[3] www.americanrivers.org.

[4] Most other Western states, but not New Mexico, have amended their water laws to provide some protection for environmental flows, and there are ongoing efforts to strengthen these provisions. See the website of the Instream Flow Council for details: www.instreamflowcouncil.org.

Governance Structures for Effective Integrated Catchment Management - Lessons and Experiences from the Tweed HELP Basin, UK

CHRIS J. SPRAY & LUKE COMINS
UNESCO IHP-HELP Centre for Water Law, Policy & Science, University of Dundee, Dundee, Scotland
c.j.spray@dundee.ac.uk

Abstract We report on the development of participatory management at the catchment scale for the Tweed HELP Basin. We contrast the historical management of water within the basin with the current position, and investigate the development and current role of the stakeholder catchment organisation, Tweed Forum, within the context of strengthening governance for sustainability.

Key words Governance; IWRM; participative management; stakeholder engagement; Tweed

1 Introduction

At the Bonn Convention on international freshwaters in 2001, the main issues report identified "Governance, integrated management, and new partnerships" as one of the most important areas for action. Ten years on, we suggest there have been several major developments in the wider context of governance that make this even more relevant now. These are the need to take a catchment approach that transcends national laws and policies; the need to recognise catchments as sources, pathways, and receptors; the realisation of multiple benefits that flow from ecosystem functions and services; the need to access different scientific disciplines and forms of knowledge; and the rise of effective stakeholder engagement and participation. The UNESCO IHP-HELP programme sets out to tackle many of these issues (Bonell, 2004), recognising that integration and stakeholder participation are key. They become especially relevant where society faces what are now termed "wicked" problems, the solution to which requires a systems approach. This needs to encompass multiple perspectives and actions at different scales to effect change. Law and science alone are not enough; implementation requires the acceptance by society of the validity of the aims, methods, and utility of delivery of policy goals (Ison, *el al*., 2007).

2 The Legislative Development of Catchment Management on Tweed

The Tweed basin covers some 5,000 sq km of mainly agricultural land. The river itself flows west to east 160 km, before discharging into the North Sea. The region's population of 130,000 is largely concentrated in valley towns, and the river dominates the landscape, culture, and economy. Salmon fishing alone is worth £18 million/year to the Borders and supports some 500 jobs. The whole river is designated as a Special Area of Conservation under the EU Habitats Directive, and the basin straddles the Scottish border. The estuary and lower catchment (16%) lie in England, such that there are two separate administrations for river basin management, though both parts fall under the single over-arching legislative control of the EU Water Framework Directive (WFD).

Management of river basins in the UK has historically been characterized by separate structures, institutions, policies, and delivery mechanisms. Each dealt with a different area of management -fisheries, water quality, flooding, etc. (Newson, 2009). This approach was driven by the needs of central government and reflected disparate legislative requirements. It was essentially a "top-down" process with little engagement with stakeholder communities. River basins themselves were not seen as very relevant units for management. They often fell between overlapping boundaries of administration and planning, operating at different scales. Historically, management of the Tweed was also “top down”, here focused on salmon fishing. This led to early legislation to protect habitats used by salmon, and the formation in 1807 of the River Tweed Commission (RTC). The RTC has cross-Border powers over the whole catchment to regulate activities to protect the river (especially spawning areas). The RTC’s main focus is on salmon fishing and, although their remit covers more than just salmon, less emphasis was placed on other species of fauna or flora, reflecting the dominant interests of the main fishery owners.

Efforts to tackle other water management issues also developed in response to similar single interests, with their own individual institutions, stakeholders and policies. Spray, *et al.* (2010), for example, describe the development of flood risk management. They highlight the isolated nature of past attempts to protect down-stream, urban areas from flooding, whilst up-stream changes to rivers, drainage, and land use all helped speed water down the valleys towards these same settlements. The situation covering water quality improvements on Tweed broadly followed a similar path. Early regulation by the Tweed River Purification Board and, since 1996, the Scottish Environment Protection Agency (SEPA), was directed at controlling individual point sources of pollution, and focussed on chemical quality, not river ecology. Only with the advent of the WFD was there a move towards a catchment approach, with emphasis on tackling sources of pollution, and better engagement with land managers. The WFD also saw in Scotland the first moves to control water resources, irrigation and extraction, alongside regulation of discharges from reservoirs, and protection zones for drinking water.

Conservation of nature on Tweed was dominated by the designation in 1976 of the whole river as a Site of Special Scientific Interest, and later as a European Natura 2000 site. Scottish Natural Heritage (SNH) and its predecessor agencies played a key role in regulating and promoting species and habitat management. However, historically this focussed on conservation of particular individual species and habitats, rather than on an integrated approach to catchment-wide wetland ecosystems and ecosystem functioning (Spray, 2010). In this, as in the other areas of catchment management, local communities were rarely consulted, and priorities for action largely followed national and international protocols.

3 Integrating River Basin Management and Participative Stakeholder Engagement

The introduction of the WFD gave a major impetus to integrated catchment management in the UK. As well as demanding a catchment-wide approach, river basin management planning (RBMP) demanded a new approach to governance, including much closer working by statutory and voluntary bodies. It further required integration between functions, and between geographical locations, in order to deliver specific measures to improve the ecological status of water bodies across the catchment (Hendry, 2008). Finally, it requires the participation of stakeholders in the process, including the creation of national and area advisory groups (AAG). The new Flood Risk Management (Scotland) Act (2009) similarly recognises that management needs to take an integrated approach to catchment hydrology. A fundamental change occurred from a focus on building structural barriers to defend down-stream urban areas, to one based on management of flood risk through interventions across the whole basin. This approach differentiates between *source areas* (where floods are generated) and *pathways* (river channels and flood plains) alongside defence of *receptor* locations (urban communities). It recognises the potential for reducing flood risk to urban areas by promoting changes in land management practices throughout the whole catchment (Spray, *et al.*, 2010).

With such a well-developed legislative framework, it might be supposed that there would be the associated means for effective local community engagement, at least on a single issue or single site basis. To a certain extent this is now true, but the nature of this engagement is still largely "top-down", and controlled by the institutions responsible for delivery of the respective individual policies. In many cases, the fora created for stakeholder engagement have narrow, set terms of reference. Participation is often by invitation to established representative groups, and the agendas are set by the controlling institutions -in order to deliver their goals-, and to their timetables (Blackstock and Richards, 2007).

4 The Development of Tweed Forum

The development of Tweed Forum, a non-governmental organisation (NGO) represents a very different and highly successful alternative governance model. This has its origins in local community concerns, well before these statutory RBMPs and AAGs existed, and was developed "bottom up". So successful has Tweed Forum been, and so effective their community engagement that, uniquely it was asked to become the Tweed AAG. Elsewhere across the UK, the responsible agencies set up new catchment organisations for each river basin. Tweed Forum began in 1991 in response to a single event -a digger working in the river channel removing gravel. In this respect, it echoes the origins of many NGOs, reacting to an immediate local issue. Its subsequent development occurred in three phases (Collins, 2004), and although the phases overlap, it is important to recognise the different catalysts that led to change. By identifying these, one can understand the barriers and opportunities other catchment organisations face in terms of development and changes to their potential operations and governance.

Phase 1 - the Initial Forum (1991-1999): As noted, the *catalyst* for formation of the forum was a single event that prompted the three statutory environmental organisations locally (Nature Conservancy Council, Tweed River Purification Board, and River Tweed Commission) to bring other interested parties together in a loose association. It began essentially as a "*talking shop*", engaging local cross-border environmental, regulatory, and voluntary groups. *Membership* was mainly the established bodies on Tweed, and was flexible and voluntary. The *aims* were to co-ordinate activities; to clarify regulations and responsibilities; and to improve knowledge exchange around water management at the catchment scale. In terms of *outputs*, key deliverables included a Tweed Fact Pack; a Resource Directory; a range of Technical notes (e.g., use of *midstream* in watercourses) and Advisory notes (e.g., canoeists and angling); and a working protocol for undertaking river works (the original issue).

Phase 2 - the Project Delivery Company (1999-2008): In 1999 Forum became a company, the *catalyst* for which was the need to be a limited company if applying for funds from the UK's National Heritage Lottery Fund (HLF). Establishment of the company itself however required resources, and one of the forum members (Northumbrian Water) provided £25 thousand to fund the rental of offices and employment of the first staff. No longer just a talking shop, Forum became a "*project delivery company*". It brought in new partners and facilitated delivery of 50 linked projects across the whole basin. *Membership* was widened, and detailed engagement undertaken with communities to ask them what their priorities were to improve the catchment. Its *aim* was to conserve, enhance and raise awareness of the natural, built, and cultural heritage of the catchment, and to develop recreational opportunities and quality of life in the region. The *outputs* were the delivery, in two phases, of a £9 million series of projects to improve education and interpretation; the built and cultural heritage; access and recreation; and the natural heritage of the Tweed.

Phase 3 - the Stakeholder Institution (2009 -): In 2001, as part of the HLF project, Tweed Forum appointed a Catchment Planning Officer, to begin development of a wider strategy -the Tweed Catchment Management Plan (CMP). This appointment and the launch of the CMP in 2003 acted as a *catalyst* for what was a gradual change. Forum became seen increasingly as *a stakeholder institution focussing on policy and strategy, as well as delivering on the ground*. It also led Forum to look beyond the Tweed, to engage with national policy-makers. *Membership* of Forum was well established, but still open to newcomers, and the creation of the CMP involved catchment-wide consultations and review. Increasingly, Forum was approached by others to assist in developing partnership projects and mediating local initiatives. It was also being consulted by both governments on policy development and stakeholder engagement. The *aims* are now defined in the CMP and progress against these is regularly reviewed (Tweed Forum, 2010). The *outputs* are delivery against these targets, but also a wider series of major projects in which Forum is involved. These include the Eddleston Water restoration, Cheviot Futures, and an eradication programme of non-native species. Finally, with the formation in 2009 of area advisory groups, Forum became an institution in the sense of being the basis of the Tweed AAG.

5 Discussion

The Tweed RBMP takes forward measures to restore water bodies that are currently failing to achieve WFD "good ecological status". On Tweed, most of these failures are due to diffuse agricultural pollution; past changes to river morphology; and to the presence of invasive non-native species. Tweed Forum, as the AAG, works with SEPA to identify and facilitate the delivery of these measures. However, alongside this statutory approach, it works to implement its much wider Tweed CMP, based on the synthesis of extensive stakeholder consultation. This covers six main themes: Water quality; Water resources; Habitats and Species; River works; Flood management; and Tourism & Recreation.

Tweed Forum's main role is to empower local communities to achieve their ambitions, as outlined in the CMP. This it does by: (1) facilitating and enabling partners to come together, defusing potential conflicts, and pooling resources to jointly tackle issues of common interest and concern; (2) seizing opportunities where it may be able to move fast to secure resources; (3) filling gaps where the statutory agencies and local government lack the resources, remit, or current interest in tackling an issue of concern to local communities; and (4) communicating between stakeholders to improve the flow of information, to clarify areas of uncertainty, and to articulate and promote collective concerns, aims, and objectives. These are roles and areas that are generally missed or seen as being of low priority by the agencies and other organizations directing the more formal statutory catchment programmes.

Tweed Forum's success and its current method of working is not only a leading example of strengthening governance for sustainability, but also highlights the importance of basing actions on a strong science evidence base. It works in partnership with universities and institutes across a range of bio-physical and social sciences. In this, it delivers on another of the themes of the IHP HELP programme, with projects that deliver on such areas as climate change resilience; on ecosystem services; and on the use of science and knowledge in management. Increasingly, Tweed Forum is drawn in to linking science and policy, and has come to be seen as an important "voice" for local stakeholders. It has provided input to policy-makers in government, in particular on the development of community partnerships for sustainable catchment management.

The development of Tweed Forum as a catchment organization has taken 20 years. During this process, Forum built up a huge knowledge about the catchment and, more importantly, it also built up trust, both between the members of Forum and, increasingly, between Tweed Forum and the other stakeholders with which it works. Its growth as an organization saw a gradual shift in focus from the initial reaction to a single issue, through delivery of projects, to strategic planning. It now occupies a role as a "trusted intermediary" between local stakeholders and government. It still facilitates and delivers actions on the ground (one of its core strengths) and must continue to do so. At the same time now, it also helps set the strategic agenda locally, and increasingly links in to national water and water-related management and policy-making. It is clear that the transformation of Tweed Forum was only achieved through the timely impetus provided by a series of catalysts. To these opportunities must be added the acquisition of core funds at critical moments to support the organization itself, and the belief of a series of leaders with vision and drive. Core funding remains a challenge, as Tweed Forum continues to maintain its independent position (it has never received direct government funding).

Many other similar catchment organizations now exist, both in Scotland (e.g., Dee HELP basin) and the UK (e.g., West Country Rivers Trust). However, few have developed as a sustainable "third sector" body, alongside the more top-down official governance processes reflected in the WFD. In part this is due to scale, as most operate in a much smaller area than that covered by their respective AAGs; in part no doubt this is due to lack of resources and competencies. It may also reflect time since establishment and where they are in this process. Finally, it may reflect the original model of the organization itself, and its reason for creation (Watson and Collins, 2007). Not all catchment organizations will want, or need to move beyond the first or second phases, however, to achieve an impact, they need to work at the catchment scale, to recognize the interconnectivity of water-related issues, and to fully address the challenges of stakeholder engagement and governance.

REFERENCES

Blackstock, K. and Richards, C. (2007) Evaluating stakeholder involvement in river basin planning: a Scottish case study. *Water Policy* 9: 493-512.

Bonell, M. (2004) How do we move from ideas to action? The role of the HELP programme. *International Journal of Water Resources Development* 20: 283-29

Collins, K. (2004) *The Tweed Forum and the Tweed Catchment Management Plan*, SLIM Case Study Monograph 10 (accessed at: http://slim.open.ac.uk)

Hendry, S. (2008) River Basin Management and the Water Framework Directive: in need of a little HELP? *Journal of Water Law* 19: 150-156

Ison, R., Roling, N. and Watson, D. (2007) Challenges to science and society in the sustainable management and use of water: investigating the role of social learning. *Env. Sci. & Policy* 10: 499-511

Newson, M. (2009) *Land, Water and Development: Sustainable and Adaptive Management of Rivers.* Routledge, London

Spray, C.J. (2010) Targeted species management within a wider ecosystem approach. In: *Species Management - Challenges & Solutions for the 21st century*. Ed: Baxter, HMSO, Edinburgh, 497-515.

Spray, C.J., Ball, T. and Rouillard, J. (2010) Bridging the Water Law, Policy, Science interface: Flood Risk Management in Scotland. *Journal of Water Law* 20 (2/3): 165-174

Tweed Forum. (2010) *Tweed Catchment Management Plan Review,* Tweed Forum, Melrose.

Watson, D. and Collins, K. (2007) *High Level Audit of Participative Water/Catchment Initiatives in England and Wales.* Internal report to Environment Agency, Bristol.

A Review of Watershed Policy Effects in the Upper Watersheds of Davao

DECLAN HEARNE[1] & VERNA MARIE MONSANTO[2]

1 *HELP Davao Network, Philippines*
dhearne76@gmail.com

2 *University of the Philippines, Mindanao, Philippines*

Abstract Policy creation and enactment can be the easy part when it comes to managing land use practices. In watershed management in the Philippines, what happens after a policy is introduced is rarely monitored. In 2007, local stakeholders in Davao City had success in advocating for the adoption of a watershed policy that seeks to balance development and conservation goals. Since then, the focus has remained on the need for implementing the Code, but there has been little focus on what the real effects of the policy have been on land users. While at the City level participation of civil society and business groups is active, marginal upland communities remain recipients of policy rather than participants in governance. This short review looks at the effects of the Watershed Code on two different land user groups. Landscape units at sub watershed scales are recommended to allow more adaptive policies that can integrate productivity and ecosystem goals. Community led approaches that are science-based are recommended to allow deeper participation and sustainable implementation of watershed policies.

Key words Watershed; land use change; landscapes; policy and decision-making

1 Introduction

Effective policy can be a powerful tool for directing socio-economic land use practices, however, if poorly designed or implemented, even a well intended policy can have many unintended outcomes. In Davao City, the Watershed Code of 2007 lays down the provisions for protection, conservation, and management of the watersheds. The Code sets out to achieve this by regulating land use in sensitive areas of the watersheds.

Indigenous Peoples (IP) and agribusiness communities are major land users in the upper watershed of Davao City. There are now apparent indications that the Davao City Watershed Code has, to various extents, alienated both sets of users. Four years after its inception, there are, however, no published works reviewing the impacts of the Watershed Code on the major land users. This presents a risk for water management in the region, considering that without monitoring of policy impacts, it is difficult to direct adaptive policy changes that can reduce unintended consequences and enhance scope for desirable outcomes. This case study therefore looks to assess the effects of current legislation on land use practices of upland communities.

2 Context

While the HELP Davao Network has had successes in advocating change, it is still recognised that the pace of changes in governance approaches may not be keeping up with changes in climate, population and markets. The challenge for Davao is that in the upper watershed the degradation of the ecosystems, including loss of forest cover, soil erosion, and deteriorating water quality, seems to be continuing despite the efforts of the Network and wider watershed stakeholders of Davao. With recent flash floods causing loss of life and economic damage, there is increased risk that upland communities will be blamed by government agencies for causing a loss of watershed functions. In this review, we observe reactions of two predominant land users, Indigenous Peoples (IP) and the agri-business community, since the implementation of the Watershed Code in 2007. Specifically, we look at: a) the range of pressures and societal policy responses to the Davao City Watershed Code; b) understanding power structures governing the uplands; c) defining major user-driven landscape types; and d) seeking to make recommendations that can lead to adaptive and equitable land use policies.

Marilog, a district located in the upper watershed of Davao City, is the focus area of the IP communities, while for the agri-business community the focus is on the banana sector within Davao City. Informal interviews and workshops were used as sources of data and information for the study.

3 Policy and Stakeholder Response

At the City level a Watershed Code was introduced in 2007, and the subsequent Implementation Rules and Regulations (IRR) were approved in 2008. The Watershed Code has imposed restrictions on land uses in areas identified as conservation areas or agro forestry/non-tillage areas. The code regulates the use of 34,000 ha of watershed areas, which are classified into conservation areas, agro-forestry non-tillage areas, and prime agricultural lands. Infrastructural development and mono-crop plantations are banned in the first two of these categories. Three bodies were created to lead the implementation of the code:

- The Watershed Management Council (WMC), the policy-making body, which is headed by the mayor
- The Watershed Multipartite Monitoring Council (WMMC), which would monitor violations and intrusions into conservation areas
- The Barangay Watershed Monitoring Council (BWMC), which is tasked with monitoring agricultural activities and delineation of areas covered by the watershed code

Despite much interest in the policy at the City level, there has been very little evidence of field effort to implement the policy. From 2008 right through to 2010, none of the bodies created under the Code were active. In July 2011 the City Mayor reconstituted the Watershed Management Council (WMC), however, the budget allotted for 2011 is considered insufficient to start real action on the ground. The WMMC and the BWMC have still yet to be formed.

Since the enactment of the code there has been widespread media coverage of resistance from the Banana sector to aspects of the Watershed Code. The banana sectors have voiced concerns over losses in competiveness as the code introduces restrictions that require change in production systems. Changes will incur ‘transition costs’ for plantations. The use of third parties, or middlemen, for banana production and the shifting of the production systems to neighbouring ecosystems outside the City boundaries have both been reported in local media (Balanza, 2006). Under these scenarios, policy has only transferred the issues and not resolved them as intended.

In many IP communities there is poor understanding of the intended outcomes of the Watershed Code. There are examples where IP communities perceive the Watershed Code as a barrier to their cultural or economic development. Within such communities there is little awareness (or care) that the land restrictions have been identified through a scientific analysis of the topography and geological substrata. The communities who haven’t been consulted naturally focus on what might be lost, rather than on what might be gained. This loss aversion results in communities forming positions against the watershed code. The effort required to win back the hearts and minds of the communities may prove to be costly.

4 Power Structures Governing the Uplands

While formal law has the highest legal authority that guides and controls management of natural resources in the Philippines, in many upland and rural communities across the Philippines the actual field level impact of these laws is very limited. Through the Indigenous Peoples Rights Act (IPRA) of 1997 and the Davao City Watershed Code of 2007, formal provisions for integrating IP customs are provided for. However the level of participation in developing and implementing local policy has much room for improvement.

Interventions from NGOs can provide examples of working with IP community members to better recognize the benefits from development of their land in a sustainable and economically viable approach. The Kinaiyahan Foundation, Inc. (KFI) has an ongoing partnership with communities, which has helped nurture the importance of preserving indigenous knowledge systems in order to achieve sustainable and equitable changes in land use practices (Cabrera, 2006). The KFI recognized that in order to empower the communities to understand and care about reversing the negative ecosystem health trends, a social learning process of self-awareness and discovery would have to be embraced. This learning process was not something that the KFI sought to sell to the community, but rather, the KFI realised that if they wanted true partnership with the community, it would have to be a journey that both parties embraced.

5 Defining Landscapes for Focused Actions

Philippine law sets out land classification, which is regulated by the DENR; the Department of Agriculture (DA) maps agriculture use and Local Government Units (LGUs) have the responsibility to develop Comprehensive Land Use Plans, but these formal classifications often do not accurately reflect the local mosaic of the actual land uses and land cover. At a local level, the Davao City watershed code calls for the delineation of prime agricultural areas for use and utilization in human and economic activities. The Watershed Code's ecologically harmful practices are controlled in environmentally sensitive areas, while prime agricultural lands are directed to adopt agricultural practices that can ensure 'food security that can be pursued through sustainable and environment-friendly agriculture in a harmonious balance between economic development and environmental protection.'

The direction set in the watershed code is closely aligned with the *Satoyama*[1] approach of recognising land use systems that are defined by the dominating socio-ecological production uses of the area. The *Satoyama* Initiative defines such land use clusters as 'socio-ecological production landscapes.' Adopting the three main control groups as identified in the Watershed Code we can identify three main landscape types: a) agroforestry subsistence landscapes; b) mixed use agriculture migrant landscapes, and c) agri-business production landscapes.

Defining of socio ecological production landscapes can complement formal land classification. Visual assessments were conducted to aid urban-based policy makers to better understand the spatial interplay between various socio ecological elements in each landscape. However, to develop a deeper understanding of the interplay between pressures and resources, we need to look at how the landscapes have changed over time. Land use change for the upper watershed was mapped using the UNESCO IWRM spiral approach. A key observation from the land use spiral is that changes in the landscape tend to be causally observed over reasonable long time frames (i.e., decades). Unfortunately the time span of elected decision makers is much shorter and this does not encourage consideration for longer-term perspectives.

6 Discussion & Recommendations

The degradation of the upland ecosystems is noted to be impacting the ability of Indigenous Peoples (IP) communities to sustain traditional livelihoods, and it is negatively affecting the health and wellbeing of local communities. This degradation highlights a lost opportunity for potential economic benefits from standing forests and agro-forestry production systems. The degradation of steep slopes in the area has also increased vulnerability of local communities to landslide and the economic burden on downstream communities is escalating due to the increased severity and frequency of flash floods.

Despite the vital importance of ecosystem services, it is commonly noted that leaders in both the private and public sectors have been slow to incorporate these benefits into decision-making processes (Chan, 2006). This slow incorporation traces back to a complex web of factors that goes beyond science, and reflects a need to consider social, cultural, and economic factors. Increasing evidence (Ancrenaz, 2007) is pointing to the fact that for efficient conservation, initiatives need to be undertaken at the landscape level and coupled with consideration for people and ecosystem services.

Banana, and its associated economic opportunities, is a strong driver of change in both cultural and land use practices across the region. The continued growth of the banana sector presents obvious threats, but can also present economic opportunities for the IP communities. The challenge for policy makers will be how to guide the evolution of landscape management practices to reap some of the economic rewards seen in agri-business production models, but still retain desirable levels of cultural and ecological integrity across the region. Policy makers should consider market tools for directing land use practices. Certification processes such as the Rainforest Alliance are growing in Mindanao and provide opportunities to improve social, ecological, and economic models for banana production.

While economics will continue to be a key driver in land use practices, socio-cultural dimensions are also critical to enable more adaptive and sustainable policy actions. From these results, four key lessons are extracted, which are considered valuable tools for decision makers and land use managers to ensure policies are attuned with upland water and land users.

Community-Led Management

Constructive engagement and joint social learning processes with the land user groups (clustered in socio ecological production landscapes) can help policy makers better understand existing land use practices. Better understanding can allow for more appropriate programs and policies to protect critical areas, avoid conflicts, and assist marginalised groups to have a deeper economic appreciation of their lands. The KFI partnership in Marilog is a good example of how community led management can result in field level practices with positive economic and ecological benefits for local and downstream communities. The Barangay Water Management Councils (BWMCs) provide a formal structure that can enable community led implementation of formal policies. Efforts now need to be focused on establishment and capacity enhancement for such community-led councils.

Rights-Based Approaches

Land and water policies that fail to consider such traditional systems can result in costly barriers to implementation at the field level. It is projected that time invested in aligning customary and formal law in the upland ecosystems of the Philippines can result in higher adoption rates, increasing the likelihood of achieving intended policy impacts, and is more likely to be sustained over time than costly enforcement programs of formal law. The BWMC again provides an appropriate structure for integration of rights-based approaches with implementation of formal laws.

Evidence-Based Approaches

Integrated Water Resource Management (IWRM) is an equitable decision-making framework for the allocation of water resources and land use policies at the watershed or basin level. Adoption of a landscape approach can aid the development of appropriate policies for different production systems (e.g., subsistence agroforestry, agribusiness, etc.). These landscapes can be identified as sub watershed units, defined by real field level uses, including the dominant social, ecological, and production systems. Using the UNESCO IWRM spiral can also help policy makers and local communities understand long-term changes in their landscapes and to gauge the expected time frames for policies to achieve change at the field level.

Monitoring Impacts through Partnerships

Negotiation and identifying approaches that link social production systems with ecosystem health trends are procedural and require an ongoing adaptive process. Such processes require active knowledge exchange between user and policy maker. Field extension officers from a range of local and regional government offices (planning, agriculture, environmental, health, and disaster risk management) must be trained to facilitate knowledge exchange, innovation in land use practices, and provide effective feedback to policy makers and managers. Such feedback loops are traditionally not well established in government agencies, and this may be an area where academic, corporate, and civil society partnerships, such as the HELP Davao Network, may play key value-adding roles.

7 Conclusion

In Davao, strong stakeholder participation has resulted in the adoption of formal policies aimed at guiding the development and conservation of water and land resources. To date, this approach has built better social capital; but further action is required in order to unlock the potential of IWRM to enable lower poverty, greener growth, and greater resilience in the face of climate change and other land and water use changes. This lack of measurable gains from policy efforts must trigger the need for reflection and questioning if 'business as usual' is an acceptable way to continue how we manage water and land. Local stakeholders must be ready and open to recognise limitations of ongoing efforts, and must be prepared to identify what has worked and what has not. Stakeholders must continue to look to identify improved pathways to better engage end users to work with policy to build societies that are more productive and in greater harmony with nature.

Acknowledgements

The HELP Davao Network, the Department of Science, Technology Region XI, and the Kinaiyahan Foundation, Inc. are acknowledged for their support in carrying out this study.

REFERENCES

Ancrenaz M, Dabek L, O'Neil S. (2007) The Costs of Exclusion: Recognizing a Role for Local Communities in Biodiversity Conservation. *PLoS Biol* **5**(11): e289.

Cabrera, Z. Gonsalves J. and Queblatin, E. (2006) *Forest Management Through Local Level Action Small Grants Programme for Operations to Promote Tropical Forests*.

Calderon, Reynan P. (2003) *Assessing Benefits and Costs of Commercial Banana Production in the Philippines*. Institute of Strategic Planning and Policy Studies, (ISPPS).

Conception, J.T. (2006). *Marilog Barangay Profile 2007 - 2011,* JSF.

Kai M. A. Chan, M. Rebecca Shaw, David R. Cameron, Emma C. Underwood, Gretchen C. Daily. (2006) Conservation Planning for Ecosystem Services. *PLoS Biol*, Nov. 2006.

Macario D. Tiu. (2005) *Davao Reconstructing History from Text and Memory*, ADDU Press.

[1]The Satoyama Initiative aims to develop societies in harmony with nature, where both biodiversity and human well being are maintained harmoniously.

Improving Local Governance in Watersheds: Some Lessons Learned from Honduras and Nicaragua

HANS KAMMERBAUER
Climate Change and Watershed Program, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica
johann@catie.ac.cr

Abstract Water basins in Central America provide important ecosystem services, especially for water flow regulation, but are increasingly threatened by environmental degradation. Key issues in this process are institution building and local governance. A framework of an adaptive co-management model (ACM) for water basins was validated at four sub watersheds in Honduras and Nicaragua. The model included: (a) formal and informal platforms for decision making; (b) a common territorial agenda; (c) management of critical territories for water flow regulation through an ecosystem services approach; (d) a local common environmental fund; (e) social learning, and (f) relationships of territories through cross scaling. Major benefits of the model have been related to visualizing the complexity of watershed governance in a simple and convincing way, institutional convergence, participation and empowerment of actors and stakeholders, and cohesion and synergies among organizations with increased mutual understanding and trust. Significant changes have been observed in land use and agricultural practices with positive effects on water quality. Whereas, high implementation costs, financial sustainability, and the absence of the private and urban sectors have been some of the constraints and challenges in the models' implementation. Nevertheless, the model allows the active integration of social structures and ecological processes.

1 Introduction

Watershed governance is essentially about conflict resolution and institution building related to water issues. Current institutional conditions, in many cases, are not sufficient to provide solutions for land use and the protection of critical water recharge zones. This is especially true in mountainous regions in Central American countries, where water regulation and water quality may increasingly be affected by climate change (Bates, *et al*., 1998). Main stakeholders in these situations are land owners and water users who normally have no direct institutional relations. In this context, institutions refer to rules and norms that regulate decisions and behavior of organizations and people in natural resource use and management. As water has a strong relationship to territories, from a watershed perspective, it may result in a situation that is known as the *tragedy of the commons* (Hardin, 1968; Dietz, *et al*., 2003) which requires collaborative arrangements among local authorities, local organizations, and other territorial stakeholders to be avoided. A variety of studies in different countries have shown that in certain circumstances, resource users dedicate significant time to generate rules that improve resource conservation, in contrast to other situations (Altrichter, 2008; Antunes, *et al*., 2009; Ostrom, 2009). This means that important social energy may be invested by local people in designing and implementing governance structures at the local level under different resource conditions and common pool contexts. It is expected that arrangements in an adaptive co-management model (ACM) which involve all relevant actors may overcome these dilemmas, or at least reduce conflicts and contribute to develop rules and norms based on public interests and common sense (e.g., Olsson, *et al*., 2004; Plummer & Armitage, 2007).

This paper focuses on governance issues in watershed management based on field experiences at four watersheds in Honduras and Nicaragua. An ACM framework is used to analyze critical factors for successful watershed governance. First, some information is given about the study site and methods. Then, major findings, grouped in benefits and challenges, are presented. Finally, a short discussion is presented, including some conclusions.

2 Study Sites and Methods

The CATIE Focuencas II project implemented actions and research at four sub watersheds in Honduras and Nicaragua, from October 2004 to the current reporting date. An overview of these sites is given in Table 1. These small river basins are representative of the hydrological conditions in Central America, which range from dry tropical zones to semi humid zones in mountainous regions, with altitudes that vary from 700 to 2200 m above sea level. At the four river basins, the predominant economic activity is agricultural production of basic grains, combined with coffee production (in Copan and Jucuapa), and extensive livestock grazing on a mayor scale (in Copan). Tourist activities are present in the urban centers of Copan, known as the *Mayan Ruins of Copan*, and in Valle de Ángeles.

Table 1 Some aspects of the four implementations and study sites in Honduras and Nicaragua.

Sub river basins	Surface (km^2)	Population	Major environmental risks	Social context
Sub river basin of the Copán River; municipalities of MANCORSARIC: Copan Ruins, Cabañas, Santa Rita, and San Jerónimo, Honduras	619	69,000	Contamination of drinking water and vulnerability to flooding and land slides	Rural poverty, migration
Sub river basin of the municipality of Valle de Ángeles (mainly Soledad river); Honduras	107	14,000	Urbanization of forest areas, reduced availability and contamination of drinking water, risks of flooding	Dichotomy of rural poverty and urban wealth, urban pressure
Sub river basin of Aguas Calientes River, municipalities of Somoto and San Lucas, Nicaragua	47	7,200	Draught, scarcity, and contamination of water for drinking, agricultural and livestock use	Rural poverty
Sub river basin of the Jucuapa River, River, municipalities of Matagalpa and Sébaco, Nicaragua	40	3,700	Scarcity and contamination of water for drinking and agricultural use	Rural poverty and water conflicts

The present analysis is based on a review of the technical reports and on an impact study carried out in 2010. An assessment team visited the four study sites and interviewed people using a semi-structured interview technique at the family level, as well as discussions in focus groups with representatives of the watershed committees and local organizations. The assessment considered the following parameters: local, municipal, and national context, participation (gender, poverty, and age), changes in attitudes by water users and providers of environmental services, social cohesion and conflicts, rules and norms, transparency, and accountability of the environmental fund mechanisms. Field observations were made under the same parameters. While researchers analyzed and presented quantitative information, the analysis presented here is inherently qualitative. A general analysis of the *state of the art* in natural resources related to water was made at the beginning, and for some parameters, reconstruction of a baseline was attempted *a posteriori*, to compare with the present state of the watersheds.

3 Results

A framework proposal for an ACM was developed based on the experiences at the four sites. A central hypothesis was constructed based on the incidence in water flow regulation (water quantity) and water quality. Fig. 1 shows the framework for the ACM, which is presented here as a more generic proposal for common pool resources (derived from Kammerbauer, *et al.*, 2011). Formal and informal platforms were important social mechanisms for agreement on processes, where a critical number of relevant and important actors, organizations, and stakeholder groups were legitimately and democratically represented (see further details in: Kammerbauer, *et al.*, 2009). The model proved to be a logical framework and proposal to organize actions and institutional functions related to governance in the achievement of the objectives of public-collective interests in a defined territory. The general perception of people interviewed in each of the four watersheds studied was that watershed management has improved, and that the resource degradation threatening the water cycle has been reduced. The ACM implementation showed benefits, but also some constraints and challenges that must be considered.

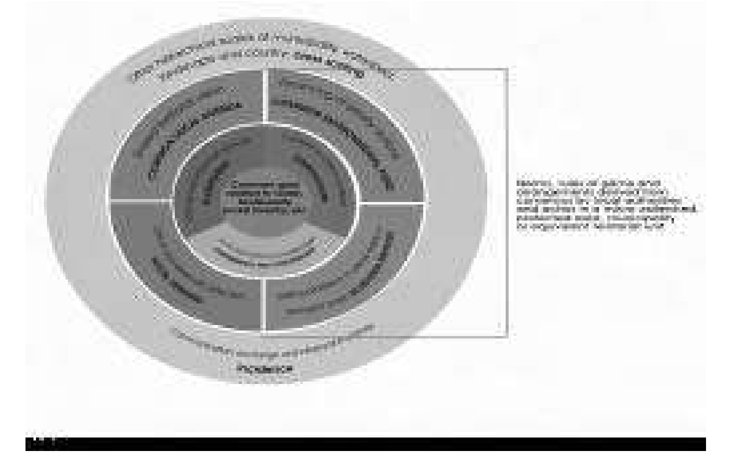


Fig. 1 A generic adaptive co-management model for common natural resources, derived from experiences in four local watersheds in Honduras and Nicaragua.

4 Advantages and Benefits

The proposed ACM allowed the visualization of the complexity of governance issues related to watersheds in a simple and convincing way. A critical number of decision makers, technicians, and members of local organizations at the four sites used the model to describe and relate components, mechanisms, and instruments in an appropriate and logical way for the implementation of actions. Platforms for concerted decision making were established at different spatial scales depending on local contexts at each site. For example, at the inter-municipality level in Copan, a round table for environment and production was created with representation of municipalities, state agencies, local water committees, micro watershed committees, NGOs (Non Government Organizations), and technical cooperation agencies. In Valle de Angeles, a watershed council emerged, based on the community organizations, with a legal registration as a local association for watershed protection. In Nicaragua, watershed committees were set up with representation by the local government, ministries, NGOs, and base organizations; this had strong grassroots connections in communal watershed committees. These organizations were openly structured and modified significantly over the implementation period, starting as a nucleus of local organizations or interested people, and evolving to a more formal structure with official and approved constitutive processes.

The ACM allowed increased participation, including advantaged and disadvantaged social groups. Women's participation increased from a very low level to a significant one during the study period, ranging currently from 15-43%, depending on the site and scale. An enabling factor was the presence of women's organizations at the municipality level, or the involvement of school teachers (predominantly women teachers). At a community level, participation of women, especially young women in local committees, was generally higher (about 40% at three sites, with the exception of Copan). The ACM improved cohesion, generated synergies, and avoided duplication of actions among local organizations using technical and financial capacities in a more integrated way. Major agreements have occurred among local authorities and civil society to more clearly define responsibilities and procedures for implementation of management actions. In a first stage, the model increased transaction costs for the organizations to participate in these platforms. However, this initial increase was followed by a significant cost reduction through coordination and more efficient resource use through sharing infrastructure, transportation, and other costs.

The model contributed to increased mutual understanding and trust among the involved organizations. In general, community organizations had a passive attitude and showed some mistrust of government authorities. It was hard to overestimate the importance of trust in these relationships, as it is the basis for solving the constant stream of internal (e.g., procedures at the municipality) and external challenges (e.g., donor policies) facing water protection and their stakeholders. Besides, municipal authorities had a strong interest in maintaining control over the territory under their jurisdiction, but had only limited legal and technical capacities. For example, the Valle de Ángeles case was particularly interesting, since there was a rapidly advancing demand for urban construction area from inhabitants of the nearby metropolis. When local organizations recognized specific territories as recharge zones for drinking water, they considered them as an asset to development aspirations, and went on protecting these specific zones by imposing a strict control on constructions. Similar protection arrangements were observed for the drinking water systems at the other three sites, implemented mainly by the local water administration committees.

From an impact perspective, some substantial changes in land use, as well as improved practices, have taken place in hydrological zones. Specifically in the Jucuapa watershed, more than a hundred coffee growers joined forces to apply ecological coffee growing practices and to avoid contamination of the river with coffee residues, which currently are used as an organic fertilizer. In the Copan watershed, a promising activity was started with groups of medium sized livestock producers in order to intensify and diversify forage production and thus, transform pasture (about 100 ha) in natural forests and conserve the natural vegetation around water sources that deliver drinking water to neighboring communities. In total, a significant amount of land (about 2000 ha) is now under strict environmental control for hydrological recharge, and about 1700 families are implementing more efficient stoves to reduce firewood consumption at the four sites. Improved watershed management, combined with improved drinking water facilities, has reduced water contamination and consequently, the frequency of intestinal disease in children and adults.

5 Constraints and Challenges

A major constraint in the model refers to high implementation costs and financial sustainability. Major financing came from external sources, complemented through support from local sources. It was assumed that a co-management arrangement is a win-win situation for the involved parties in terms of economic efficiency, and therefore, self-driven social forces were expected to set the stage to continue common environmental funds or equivalent mechanisms, but this remains to be seen. Some financial mechanisms on payments for environmental services, community credit systems, and watershed fees have been implemented, but are still at initial stages. National policies are required for creating enabling conditions for financing institution building as well as for investments.

Defining clear roles and responsibilities of watershed platforms, their actors and organizations, was a major challenge that required a series of analyses. Leadership was especially critical for these linking organizations and institutional performance. The municipal authorities exercised tight leadership, generating dialog and local policies in only two cases. Furthermore, processes were hampered by a change in local governments, with subsequent changes in personnel and policies. Political willingness is a necessary condition for long-term success. A passive attitude from municipal authorities generated apathy and pessimism in some community organizations, and permitted violations of the municipal autonomy by powerful stakeholders. In some cases, development cooperation or technical assistance generated divisions among local actors, who falsely perceived each other as beneficiaries and non-beneficiaries. A massive communication strategy is urgently needed to overcome some of these obstacles.

Complexity increased in the spatial and temporal scale: at the micro level, relationships among stakeholders were evident, but zooming out implied a more distant relationship. Some bureaucratic behavior seemed to be a hindrance to social dynamism and collective learning. The complexity of watershed management requires experimentation and innovation through social learning. Only initial progress was made in relating the sub watersheds to broader territories, as well as in including private enterprises and the urban sector (e.g., to reach regional levels in Honduras or address all of the municipal territories in Nicaragua).

6 Discussion and Conclusion

An ACM is often put forward as an approach for dealing with complexity and uncertainty in natural resources management (Ruitenbeek & Cartier, 2001; Plummer & Armitage, 2007), but implementation requires understanding and a strong appropriation of the concept and framework by social actors and involved stakeholders. The content and implementation logic should be managed by a critical number of members of local organizations, technicians, municipal authorities, state agencies, and other organizations. Social learning is an important ingredient for innovation in integrated water management (Cundill, 2010; Pahl-Wostl, *et al*., 2008; Rist, *et al*., 2007). A sector approach is necessary but not sufficient to deliver appropriate solutions for water as a commons.

Involved parties must have a real interest and commitment to enter into co-management arrangements, which may not always occur, as setting up this process is time-consuming at the beginning (Borrini-Feyerabend, *et al*., 2000). Special attention should to be given to facilitating and conducting social processes for empowerment, without manipulating and becoming involved in decision making. This requires professional competence in moderation and facilitation techniques. Therefore, training in watershed management should include theoretical knowledge about the underlying concepts, as well as practical exercises in institutional management. “Participative democracy” as a guiding principle requires analysis of its legitimate mechanism, and transparent criteria need to be developed. Private enterprises and large landholders may have an important influence on water dynamics and may have to include externalities in their cost-benefit analyses. The present experience was quite limited in this aspect.

Multilevel arrangements have been experienced at the implementation sites, including a municipal association. This type of governance is referred to as a pluri o polycentric governance structure, which may encourage innovation and experimentation (Imperial, 1999; Olsson, *et al*., 2007). A major challenge concerning scale lies in addressing the fit of the governance dimension of ecosystems into the social systems, in order to create dynamic structures (Olsson, *et al*., 2007). Linking different levels and knowledge systems requires an active role by organizations. The scientific community as an interest group should be expected to participate in these arrangements for knowledge generation and identification of limitations. Especially in watershed management, some decisions may be based on the cautionary principle.

National policies should create enabling conditions for collaborative agreements in integrated watersheds related to ACMs. The present experience has been shown to increase efficiency in maintaining or restoring the natural support system for water cycling. It can be concluded that there is a need to understand and actively manage the underlying social structures and ecological processes. The proposed model seems useful, not only to foster dialog and collaboration among actors, but to serve as a framework for identifying important issues and relationships.

Acknowledgements

I would like to express my gratitude to my colleagues, members of the watershed committees, local authorities, and all the others involved for their valuable contributions. The CATIE Focuencas II project was financed by the Swedish International Development Agency (SIDA), Stockholm.

REFERENCES

Altrichter, M. (2008) Assessing potential for community-based managing of peccaries through common pool resource theory in rural area of the Argentine Chaco. *Ambio* 17: 108-113.

Antunes, P., Kallis, G., Videira, N., Santos, R. (2009) Participation and evaluation for sustainable river basin governance. *Ecological Economics*, 68: 931-939.

Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P. (Eds.) (1998) *Climate change and water*, Technical paper VI, IPCC Secretariat, Geneva, 210 p.

Borrini-Feyerabend, G., Farvar, M.T., Nguinguiri, J.C., Ndangang, V.A. (2000) *Co-management of natural resources: organizing, negotiating and learning-by-doing*. GTZ & IUCN, Kasparek Verlag, Heidelberg, Germany.

Cundill, G. (2010) Monitoring social learning processes in adaptive comangement: Three case studies from South Africa. *Ecology and Society* 15(3): 28.

Dietz, T., Ostrom, E., Stern, P. (2003) The struggle to govern the commons. *Science* 302: 1907-1912.

Hardin, G. (1968) The tragedy of commons. *Science* 162: 1243-1248.

Imperial, M.T. (1999) Institutional analysis and ecosystem-based management: The institutional analysis and development framework. *Environmental Management* 24: 449-465.

Kammerbauer, H., León, J.A., Castellón, N., Gómez, S, González, J.M., Faustino, J., Prins, C. (2009) *Plataformas de concertación: una apuesta por la gobernabilidad local en cuencas hidrográficas*. CATIE Tegucigalpa, Honduras, 71 p.

Kammerbauer, H., León, J.A., Castellón, N., Gómez, S., Faustino, J., Prins, C. (2011) Modelo de cogestión adaptativa de cuencas hidrográficas. Propuesta conceptual basada en la revisión crítica de las experiencias en Honduras y Nicaragua. *Recursos Naturales y Ambiente*, 59-60: 117-122.

Olsson, P., Folke, C., Berkes, F. (2004) Adaptive comanagement for building resilience in socio-ecological systems. *Environmental Management* 34: 75-90.

Olsson, P., Folke, C., Galaz, V., Hahn, T., Schultz, L. (2007) Enhancing the fit through adaptive co-management: creating and maintaining bridging functions for matching scales in the Kristianstads Vattenrike Biosphere, Sweden. *Ecology and Society* 12, 28.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. *Science*, 325: 419-422.

Pahl-Wostl, C., Tábara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., Ridder, D., Taillieu, T. (2008) The importance of social learning and culture for sustainable water management. *Ecological Economics* 64: 484-495.

Plummer, R., Armitage, D. (2007) A resilience-based framework for evaluating adaptive co-management: Linking ecology, economy and society. *Ecological Economics* 61: 62-74.

Rist, S., Chidambaranathan, M., Escobar, C., Wiesmann, U., Zimmermann, A. (2007) Moving from sustainable management to sustainable governance of natural resources: The role of social learning processes in rural India, Bolivia and Mali. *Journal of Rural Studies* 23: 23-37.

Ruitenbeek, J., Cartier, C. (2001) *The invisible wand: adaptive co-management as an emergent strategy in complex bio-economic systems*. CIFOR, Bogor, Indonesia.

Basin Organizations in Cuba and Experiences from the National, Territorial, and Specific Watershed Councils

JORGE MARIO GARCÍA FERNÁNDEZ, AUGUSTO LÓPEZ GONZÁLEZ, UBALDE ABALLÍ, VIVIANA CASTRO ENJAMIO & ADA ELSA BIENTS PERDOMO
Instituto Nacional de Recursos Hidráulicos, Cuba
jorgem@hidro.cu

Abstract The National Watershed Council in Cuba, created in 1997, launched a new work style with the introduction of integrated watershed management concepts and practices. This style encompasses the management of water resources and the protection of other natural components, working jointly towards economic development and social progress for sustainable development. With continuous and systematic work, the Council has moved towards maturity, which is reflected in the environmental performance of the 10 national interest watersheds and the 51 provincial interest watersheds. The Council has strengthened its institutional capabilities with an inter sector vision and a legal framework. The Watershed Councils, at the national, regional, and specific levels, plan activities on an annual basis. Meetings and systematic actions are identified throughout 11 sub-programs, with indicators that reflect the work of local actors being assessed annually. Some of these actions include the management of water resources, including networks of hydrological cycle observation, water provision and sanitation, water use planning, as well as increase in forest cover, conservation and improvement of soil, reduction of pollution loads, safety and protection of natural resources, environmental investments, and environmental education, among others. In recent years, advances are reflected by the Simplified Index of Watershed Management, an assessment tool that enables a synthesized evaluation of the management intervention processes that occur each year on a given basin.

Key words Institutionalization; management; integrated; Cuba; watershed

1 Background of Watershed Institutions in Cuba

Starting in 1959, there has been gradual improvement in the formation and intensification of national capabilities in Cuba, as well as a strengthening in the institutional capabilities and organization of the main institutions that deal with the environment. In 1962, the "National Water Resource Institute" was created as the leading institution in country's hydraulic infrastructure, with objectives such as protection against floods and the planning of water resource usage. Its approach followed concepts in watershed management, but not with an integrated vision of all components.

During the following decades, many important actions in the national environmental sphere took place. The National Commission for the Protection of the Environment and Natural Resources (COMARNA) was created, law No.33 for the Protection of the Environment and the Rational Use of the Natural Resources was dictated in 1981, article 27 of the Constitution of the Republic was amended to strengthen the integration of the environment to the economic and social development of the country, and the Ordinance/Law No. 138 that regulates the exploitation, conservation, and mitigation of the rational use of the hydrological resources on territorial waters was implemented in 1993. On that very same year, the National Program of Environment and Development was approved, in accordance to Agenda 21, which already integrated the importance of water basins.

Parallel to this national framework, different international and regional meetings, such as the Earth Summit (Rio de Janeiro, 1992), took place, which contributed to a more thorough understanding of the environment. These are the premises that preceded the creation of the Ministry of Science, Technology and Environment (CITMA, 1994).

Cuban institutions before the 1990s treated watersheds with a limited and partial vision, always in relation to their specific missions, without transcending towards a more integrated and inter sector approach to include natural resource management, economics, and social activities in a comprehensive manner.

On April 1997, the Council of Ministers communicated, in Agreement 3139, the creation of the National Watershed Council (CNCH in Spanish) as the maximum coordinating organization for the planning and management of watersheds in the nation. It is presided by a member of the Council of Ministers.

A couple of months later (in July 1997), Environment Law No.81 was approved, which constitutes a legal instrument of high hierarchy, and originated other ordinances/laws, resolutions and standards in favor of the environment. In its articles 110 and 111 it defines the environmental management responsibilities for Cuban watersheds, granting the National Watershed Council total authority to proceed with the implementation of national policies regarding watersheds.

2 Water Basin Organizations in Cuba: The National Watershed Council

To carry out its functions, the National Watershed Council is structured in as follows: a President and a Vice-president, a Secretary, and permanent members, as indicated in Fig. 1.

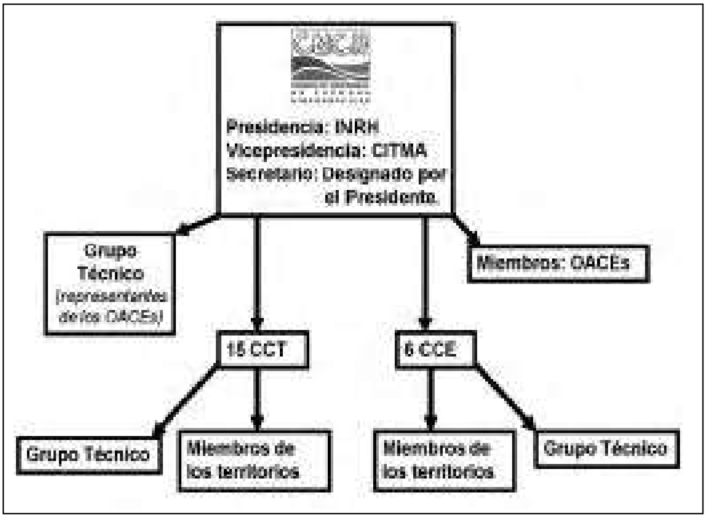


Fig. 1 Structure of the National Watershed Council in Cuba.
Source: Prepared by the authors.

One of the first actions undertaken by the National Watershed Council was the formation of a National Technical Group that integrated experts and specialists of different organizations and institutions. This group selected 10 basins of interest at the national level, taking into account their social and environmental complexity, the level of natural resource degradation, and their local values. Similarly, 51 basins of interest at the provincial level were selected using the same approach. Additionally, at the organizational level, 15 territorial basin councils and 7 specific councils were created, the latter pertaining to basins that are shared between more than one province. These water basin organizations constitute a technical instrument for the Administrative Council of the Popular Power, the provincial government, to control the development and implementation of programs for the basins' integrated management, in close cooperation with the National Watershed Council. They also constitute a framework to launch new standards and effective methodologies in this matter. Representatives of the main ministries are part of the Territorial Watershed Councils at the provincial level.

These accumulated experiences led to the creation, in 2007, of new regulations for watershed management in Cuba. Resolution 52/2007, of the President of the CNCH, and Ordinance/Law 280, of the Council of Ministries, in Chapter III, granted a new scope to the National Watershed Council.

The basin organizations at the national, specific and territorial level, and as a whole, plan their activities annually. They conduct systematic meetings and other activities (workshops, training sessions, inspections, and visits to sites of interest, among others). Their action guidelines are set in eleven subprograms, which contain a group of indicators to assess the work of the local actors involved in watershed management. Every year, these results are evaluated, taking into account the subprograms' performance, and the main actions to be carried out in the following year are identified. The 11 subprograms are:

a. National and local investments dedicated to the protection of the environment in the basins
b. Hydrological resources (networks for the observation of the hydrological cycle, coverage of the infrastructure of drinking water and sanitation)
c. Planning of the use of water in the basin
d. Improvement and conservation of the agricultural soil
e. Increase of the forest surface
f. Forest fires control and combat measures
g. Joint surveillance of natural resources (Protection of Natural Resources)
h. Fight against the contamination and reduction of pollutant load
i. Sustainable use of the biological diversity
j. Environmental education and community participation
k. Science and technological innovation

Each of these subprograms is carried out in coordination with the different central government (OACE in Spanish) organizations who are members of the Council.

3 Added Value in the Creation of the National Watershed Council

Since 1997, the National Watershed Council (CNCH) has met annually with the Executive Committee of the Council of Ministers (CECM), which submits an evaluation of the work completed on that year to the central government. Simultaneously, the main courses of action of the National Watershed Council are approved for the next year. This process is also followed in the Provincial and Specific Basin Councils on an annual basis. As a result of these meetings, some key components of the CNCH's work can be linked to the national environmental policies:

- Environmental management focused on ecosystems, beyond the national, provincial and municipal political divisions
- Integration
- Systematic harmony and coherence
- Coordination among institutions
- Decentralization
- Participation

4 Experiences Achieved with Watershed Management in Cuba

During 14 years of sustained work, the CNCH has made significant progress in the basins' environmental performance, especially on the 10 national interest basins. Some examples, related to the working subprograms, evidence good trends regarding their indicators.

- The network observations for the hydrological cycle operates 411 pluviometers, 7 climate stations, 15 hydrometric stations, 318 hydrogeology stations, and 502 stations belonging to the Water Quality Monitoring Network (RedCal). Pluviometer density is 1 for each 57 km^2, and RedCal station density is of approximately 1 for each 50 km^2.
- The country's rainfall for 2010 averaged 1267.1 mm, which equals 96% of the 1287.0 mm historical average. The biggest value for absolute precipitation in the year was in the Toa basin, with 1672 mm, although, this only represents 66% of the historical average. The biggest relative increase in precipitation corresponded to the Guantánamo Guaso basin (128%) (see Table 1).

Table 1 Annual pluvial behavior in the water basins of national interest.

Name	Average historical rainfall (mm)	2010 average rainfall (mm)	Percent
Cuyaguateje	1475.0	1265.1	86
Almendares-Vento	1514.0	1302.3	86
Ariguanabo	1446.0	1311.0	91
Ciénaga de Zapata	1404.0	1156.6	82
Hanabanilla	1986.0	1366.9	69
Zaza	1427.0	1506.3	106
Cauto	1112.0	1184.5	107
Mayarí	1435.0	1241.8	87
Guantánamo-Guaso	1027.0	1315.0	128
Toa	2518.0	1672.3	66

Source: Management of Water Basins, INRH.

- The percentage of the population in the national interest basins with access to drinking water (considered if the water source is at a distance of 300 meters or less) is around 84.8%.
- Sanitation coverage is around 89.0%, including large and small sewer systems and latrines.
- The ratio of water use to its availability for the water infrastructure was of 37.8%. During 2010, most water from the national interest basins was used for drinking purposes (40%), followed by agriculture (35%), Hydro power (12%), other supplies (8%) and ecological flow needs (5%).
- The conservation and improvement of agricultural soil program maintained a discreet growth every year. At the closing of the year 2010, a total surface of 38,840 hectares of soil had been improved, with progress in the basins of Cuyaguateje and Zaza.
- Seventeen national polygons for the conservation and the improvement of soils and forests were created, with the objective of applying practical mitigation measures and contributing to address the effects of climatic change. Eight of these are located in national interest basins. Additionally, 67 demonstrative areas were established, which are important places to conduct training and communicate the results of the basins' integrated management.
- The Index of Potential Forests (IBP in Spanish) is around 31.6%, and according to recent forest dynamics for the year 2010, the Current Forestation Index (IBA in Spanish) is around 25.0%. This has been achieved through the continuous implementation of reforestation plans. It is worth to note the high coverage obtained using the Normalized Index (IBA / IBP) in the Toa (97.9%), Hanabanilla (94.4%) and Guantánamo - Guaso (94.2%) basins. The basins that still have more area to be forested are the Cauto (581.9 km^2), the Ciénaga de Zapata (305.0 km^2) and the Mayarí (208.06 km^2) basins.

- In 2010, after a complete assessment, pollution in the national interest basins was estimated at 82,469 tons of (DBO_5) / year, with a receptor disposal of 25,182 ton DBO_5 / year. Since the year 2000, the Council has worked on a program that has maintained an annual rate of reduction, except in 3 instances, where the increase has been driven by the loss of efficiency in the treatment systems associated to pig-farming activity. This is summarized in Table 2.

Table 2 Organic Pollution in the National Interest Water Basins.

Year	% of reduction or increase (+) pollutant load	
	Country	Nat. Int. basins
2001	10.9	8.4
2002	10.8	(+) 0.92
2003	9.0	8.4
2004	3.6	3.5
2005	3.7	11.7
2006	(+) 1.4	3.8
2007	(+) 10.7	(+) 12.8
2008	0.5	2.2
2009	2.6	3.7
2010	0.8	(+) 0.1

Source: 2010 National Watershed Council Report.

Conclusions

At present, the National Watershed Council in Cuba is recognized for its excellence as the functional unit that drives the planning, use and protection of water resources. The creation of such councils can be an answer to the problems that are seen today in many countries, and may lead to important adaptation actions to address the impacts of climate change.

The Cuban water management experience since 1997 continues to significantly advance its activities and has achieved maturity, for it has increased and diversified the activities developed by Technical Groups. Throughout their 11 Work Programs (Subprograms) and the application of the Simplified Index of Watershed Management (IsGC in Spanish), the Watershed Councils show a favorable evolution and sustained management of their basins' resources.

REFERENCES

Gaceta Oficial de la República de Cuba. Ed. Extraordinaria. (1997) *Ley 81 de Medio Ambiente, 11 julio 1997. Año XCV. No. 7*. La Habana.

CITMA. (2006-2010) *Estrategia Ambiental Nacional*.

García, Jorge M. (2002) Algunas reflexiones sobre el desarrollo de la gestión ambiental cubana. *Cuba: Medio Ambiente y Desarrollo*, Año 2.

Instituto de Suelos, MINAG. (2001) *Programa Nacional de Mejoramiento y Conservación de Suelos*. La Habana, AGROINFOR

Oficina Nacional de Estadísticas, MEP. (2009) *Medio Ambiente en Cifras*. La Habana, ONE.

PNUMA-CITMA, GEO Cuba. (2009) *Evaluación del medio ambiente cubano*. La Habana.

Secretaría Consejo Nacional de Cuencas Hidrográficas. (2006 a 2010) *Informes de Balances anuales del Consejo Nacional de Cuencas Hidrográficas al Comité Ejecutivo del Consejo de Ministros*. La Habana.

A Conceptual Model for Implementing Integrated Transboundary Water Resources Management (ITWRM)

J. GANOULIS & Ch. SKOULIKARIS
Department of Civil Engineering, Aristotle University of Thessaloniki, Greece
iganouli@civil.auth.gr

Abstract Implementation of Integrated Water Resources Management (IWRM) in different river basins is challenging mainly because of various kinds of borders, not only between countries, in which case there are Transboundary Waters (TW) to share, but also at a national level, where borders exist between different stakeholder groups, regional administrations, institutions, and scientific disciplines and professionals. An example of the latter is the "border" between scientists and decision makers. Weakening this barrier is the main target of the worldwide UNESCO/HELP programme. In this paper, a conceptual model is formulated in order to facilitate implementation of IWRM in Transboundary Waters (ITWRM). The model is based on interactive consultation with all stakeholders and partners involved in the ITWRM process at the river basin level. The multidisciplinary conceptual model consists of seven steps, the first and main one being (1) Stakeholder Consultation. The remaining six steps, which constantly interact with the first, are: (2) Transboundary Diagnostic Analysis (TDA), (3) Data Collection and Sharing, (4) Common Strategic Action Plan (CSAP), (5) Hydrological and Environmental Assessment, (6) Scenario Analysis, including Climate Change, and (7) Applications.

Key words Transboundary waters; integrated management; conceptual model

Introduction

Different kinds of borders and barriers separate not only countries but, at a national level, science and applications, different groups of professionals, researchers and politicians, different institutions and various regional administrators. A leading example of a barrier in water resources management is the locked paradigm between scientists and decision makers, which creates major difficulties for implementing the concept of Integrated Water Resources Management (IWRM). In order to address this issue, UNESCO initiated, in the frame of its International Hydrological Programme (IHP), the HELP global programme, aiming to reduce the gaps between Hydrology, Environment, Life and Policy (HELP).

When surface waters, like rivers and lakes, or groundwater aquifers cross the borders of different countries, the political barriers between them become the main challenge in applying the IWRM framework. In this case, the term "Transboundary Waters" is used synonymously with "Internationally Shared Waters", and in accordance with the terminology used by UNESCO in its international hydrological initiatives, such as the UNESCO/ISARM (Internationally Shared Aquifer Resources Management) and the UNESCO/PC-CP (Potential Conflict-Cooperation Potential) programmes. It is considered a better choice than other similar expressions such as "international waters", "multinational waters" or "regional waters", and avoids misunderstandings due to political sensitivities over national sovereignty in regions located near borders.

According to previous experience gained by the UNESCO Chair/INWEB (International Network of Water/Environment Centres for the Balkans), there are many important obstacles hindering the effective implementation of the IWRM framework in internationally shared waters management, such as:

- Differences in the use of technical standards and specifications for data collection and information sharing

- Lack of harmonisation in methodological approaches involving conceptual and analytical modelling of hydrological, environmental and socio-economic processes
- Differences in socio-economic and cultural levels between riparian countries
- Lack of trust and mutual interests, conflicting objectives and different priorities between countries, in relation to their history, sovereignty and possible territorial claims, and
- Lack of political will

In the literature (UN WWDR, 2006; 2009; Wolf, *et al*., 1999; GWP, 2000), in previous publications (Ganoulis, *et al*., 1996; 2000; 2006; 2008), and in a recently published book (Ganoulis, *et al*., 2011), different models of collaborative activities for TWRM have been suggested. The approach used in these models differs, depending on which particular scientific discipline or professional community has developed the model.

For engineers, hydrologists, hydrogeologists or environmental professionals, emphasis is placed on modelling the physical and ecological transboundary hydro-systems in terms of:

a. delineating their natural borders (hydrologic basins for transboundary rivers and lakes, or hydrogeological boundaries for groundwater aquifers),
b. analysing relationships between physical and ecological variables such as precipitation, river flow, pollutant inputs, water quality, biodiversity or groundwater recharge, and
c. suggesting structural or non-structural measures in order to obtain solutions and improve TWRM.

These models, conceptual or mathematical, are more or less accurate subject to data availability and precision, and the various assumptions and simplifications made. They are useful for understanding how the physical and ecological transboundary systems behave under natural and anthropogenic inputs in terms of water quantity and environmental impacts.

For lawyers and social scientists (geographers, economists, sociologists) emphasis is placed on human factors, which can be very complex and difficult to analyse or predict, such as institutional cooperation, stakeholder participation, and negotiation strategies. For lawyers the emphasis is on regulating provisions and duties of riparian countries in terms of access, utilisation, protection, preservation, and management of transboundary waters. The codification of such legal rules is very useful to the international community, even though this process may be somewhat general and unable to cover all specific cases. The main challenge is whether different national administrations will agree to implement international rules at the national level, and at the same time coordinate their activities with riparian countries through bilateral or regional collaborative agreements. This challenge may be faced by raising public and stakeholders' awareness in participatory processes involving national institutions, academic partners, and international organisations.

In the real world, all the above issues and approaches coexist and are inter-related. In order to achieve effective TWRM, these models, whether descriptive or prescriptive, should merge. There are two main strategies for achieving such integration: (a) through effective capacity building and training in TWRM, and (b) by analysing a general framework of conflict resolution, based on how riparian countries may share benefits and risks. Both these strategies are supported by UNESCO's ISARM and PC-CP programmes, and are detailed in Ganoulis, *et al*., 2011.

Transboundary HELP River Basins

The UNESCO/HELP programme established a global network of experimental basins with the aim of exchanging experience on how to apply the IWRM framework by linking hydrology and policy issues.

A certain number of HELP river basins are transboundary, shared (1) between different riparian countries, or (2) between countries having adopted the same legal system, or (3) between states belonging to a unified federal system. Some characteristic examples of transboundary HELP river basins are the following:

- The San Pedro basin, shared between Mexico and USA (two sovereign countries)
- The Mesta/Nestos basin, shared between Bulgaria and Greece (two countries belonging to the European Union and implementing common directives), and
- The Murray-Darling basin in Australia, shared between four federal states and the Australian Capital Territory.

Bi- and multi-lateral agreements on transboundary river, lake, and aquifer water resources management are important tools for enhancing effective cooperation, involving political commitment, and implementing joint water management plans. Depending on the legal status of the riparian countries, developing multilateral regional agreements has different degrees of difficulty. For example, in centralised independent countries, negotiations and legal issues for developing agreements can be performed more easily. In countries belonging to a unified legal system for water management, like the European Union (EU), the situation is facilitated by the application of common water directives (e.g., the EU Water Framework Directive, EU-WFD). In federal states like the USA, Australia, and Canada, developing such agreements may be more difficult as legal responsibility for water is given by constitution to the individual states.

In order to deal with the complexity of real world problems, where no distinction is made between different dependent physical and socio-economic processes, there is a need for the various approaches described above to be integrated. This process of integration could be facilitated in two main ways. First, through education and capacity building, where special training programmes can show how multidisciplinary approaches can be coordinated in order to achieve an integrated view of a problem and effectively solve it in the real world. Second, by taking into account a general framework for risk analysis in conflict resolution, where risks and benefits could be shared between riparian countries and "win-win" solutions to transboundary disputes can be achieved (Ganoulis, 2009). Both these processes are based on specific programmes developed by UNESCO (Ganoulis, *et al.*, 2011).

A collaborative model for TWRM based on the various contributions to Ganoulis, *et al.*, 2011, is illustrated in Fig. 1. This uses the following seven steps and may be adapted to any particular case study of transboundary waters:

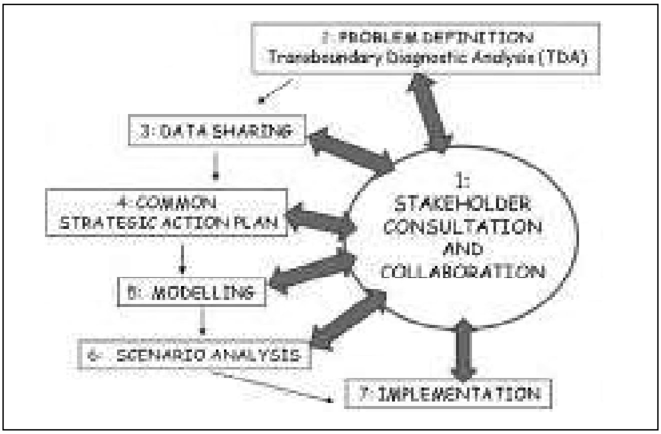


Fig. 1 A conceptual model for effective management of transboundary water resources.

1 *Stakeholder Consultation* and Collaboration, Social Issues, Legal and Institutional Agreements: this step should interact with all the other steps below
2 *Problem Definition*: Transboundary Diagnostic Analysis (TDA)
3 Agree on Data Collection, Common Monitoring and *Data Sharing*
4 Develop a Common Vision and *Common Strategic Action Plan* (CSAP)
5 Physical and Environmental Assessment and *Modelling*
6 *Scenario Analysis* and Decision Support Systems (DSS)
7 Transfer of Models and DSS to Stakeholders, *Applications*

REFERENCES

Ganoulis, J., Duckstein, L., Literathy, P. & Bogardi, I. (eds). (1996) *Transboundary Water Resources Management: Institutional and Engineering Approaches*. NATO ASI SERIES, Partnership Sub-Series 2: Environment, Vol.7, Springer-Verlag, Heidelberg, 478 p.

Ganoulis, J., Murphy, I. L. & Brilly, M. (eds). (2000) *Transboundary Water Resources in the Balkans: Initiating a Sustainable Co-operative Network*. NATO ASI SERIES, Partnership Sub-Series 2: Environmental Security, Vol. 47, Kluwer Academic, Dordrecht, Boston, London, 254 p.

Ganoulis, J. (2006) Water Resources Management and Environmental Security in Mediterranean Transboundary River Basins. In: *Environmental Security and Environmental Management: The Role of Risk Assessment*, (eds B. Morel & I. Linkov), Springer, pp. 49-58.

Ganoulis, J., Skoulikaris, H., and Monget, J.M. (2008) Involving Stakeholders in Transboundary Water Resources Management: The Mesta/Nestos "HELP" Basin. *Water SA Journal* 34 (4) (Special HELP edition): 461-467.

Ganoulis, J. (2009) *Risk Analysis of Water Pollution*, (2nd Edition) WILEY-VCH, Weinheim, 311p.

Ganoulis, J., Aureli, A. & Fried, J. (eds). (2011) *Transboundary Water Resources Management: A Multidisciplinary Approach*, WILEY-VCH, Weinheim, 382 p.

GWP. (2000) *Integrated Water Resources Management*. GWP Technical Committee Background Paper No 4, Stockholm, Sweden. http://www.gwpforum.org/gwp/library/Tacno4.pdf.

UN WWDR. (2006) *Water: a shared responsibility*, UNESCO Publishing, Paris.

http://www.unesco.org/water/wwap/wwdr/.

UN WWDR. (2009) *Water in a changing world*, UNESCO Publishing, Paris. http://www.unesco.org/water/wwap/wwdr

Wolf, A., Natharias, J., Danielson, J., Ward, B. & Pender, J. (1999) International River Basins of the World. *International Journal of Water Resources Development* 15 (4): 387-427.

From Capacity Building to on-the-Ground Action

MARIAN MUSTE[1], JENNIFER FILIPIAK[2] & CHARLES SPITZACK[3]

1 *IIHR-Hydroscience & Engineering, University of Iowa*, USA
marian-muste@uiowa.edu

2 *The Nature Conservancy, Iowa Chapter, USA*

3 *US Army Corps of Engineers, Rock Island District*, USA

Abstract The continued occurrence of destructive flooding in Iowa has triggered a natural reaction of agencies and communities to work across traditional political, geographical and social boundaries and remove the gaps between decision makers, scientists, and communities. Currently, Iowa's institutions and communities are rethinking their relationship with rivers and their watersheds by embracing new ways of managing water resources with flood risk mitigation as a priority. The first capacity building effort along these lines was the designation of the Iowa-Cedar Basin as a UNESCO-HELP Basin in 2009. The HELP Basin creation was shortly followed by the formation of the Iowa-Cedar Watershed Interagency Coordination Team, a nineteen agency partnership focused on the Iowa-Cedar Basin as a model for effective IWRM implementation in Iowa and the Upper Mississippi River Basin. In the spring of 2010, a grassroots body focused on floods was established: The Cedar River Watershed Coalition. It aims at organizing and advocating for practices and policies that target non-structural, watershed-scale solutions to mitigate future flood risk and improve water quality. From its inception, the Iowa Cedar UNESCO-HELP Basin is playing the "translator role" among the scientists, managers and community interests for effective and efficient IWRM implementation. This paper reviews the initial capacity building efforts conducted in the Iowa-Cedar HELP Basin and subsequent on-the-ground activities to attain the well-being of the watershed we live in. It is hoped that sharing these experiences will give useful insights to older, newer, and potential HELP Basins throughout the world.

Key words Floods; Integrated Water Resources Management; decision support system

1 Background

The Iowa-Cedar River Basin (ICB) is a primary tributary watershed of the Mississippi River and is a part of the Upper Mississippi River Basin (UMRB) dominated by agriculture. The fertile soils and climatic conditions existing in the UMRB make this one of the most productive agricultural regions in the world (Filipiak, *et al*., 2011). The current land cover is significantly different than the forest and prairie mix that preceded European settlement. Current land cover and land use have resulted in significantly modified hydrology with direct consequences on surface and groundwater quality, erosion and sedimentation, loss and fragmentation of natural habitat that further affected the diversity and bounty of plants and animals and facilitated the introduction of exotic species. The effect on the system of streams and their watersheds has been significant with flooding and drought events occurring at higher rates and multiple locations. Advancing climate change foretells the likelihood of new challenges in the future. Achieving sustainability of the economic uses and ecological integrity of the UMRB requires addressing the system and floodplain directly, but also through compatible and supportive actions within the tributary watersheds. It requires management by multiple entities, at multiple scales, for multiple purposes through implementation of comprehensive and integrative frameworks such as Integrated Water Resources Management (GWP, 2004).

The 12,600 square mile ICB is located in the Midwestern states of Minnesota and Iowa, as illustrated in Fig. 1. Current land use and land cover is primarily agricultural, with about 93% of the total area being cropland or pasture. Land is largely privately owned. The principal crops are dominated by corn and soybeans, with some hay and oats. The remaining land area consists of about 4 percent forests, about 2 percent urban and about 1 percent water and wetlands. The habitat and hydrology of much of the land in this region has been altered to fit the current land use, which includes urbanization and intensive agriculture (Filipiak *et al.*, 2011).

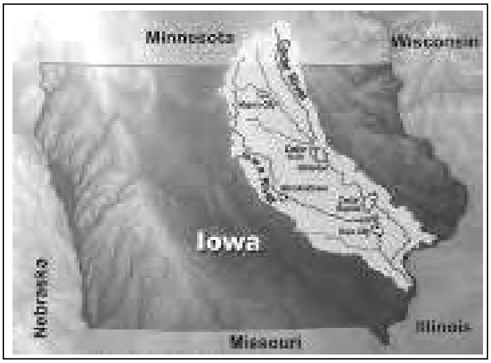


Fig. 1 Iowa-Cedar River Basin location.

Fig. 2 Iowa City during the 2008 Flood.
Source: http://www.peeplo.com

The effects of altered hydrology outside of extreme flood events are evident in the ICB. Stream channel size and shape is governed by the flow regime. It's not just too much or too little water; altered hydrology results in altered flows and flow-driven habitat. Therefore, with the increase of the total amount of water moving through the system as well as the magnitude of the typical 1-2 year flood, the width of the stream channel, as well as the amplitude of its meander pattern, is likely to increase. Channel enlargement has the effect of increasing sediment transport and bedload, much of which comes from the channel streambanks (Skopec, 2010). This is evidenced by incised channels that are undercutting and spreading beyond typical floodplain boundaries to accommodate increased flows. There is evidence that much of the increase in flows is being driven by increased precipitation, but it doesn't explain all of it. A number of national and regional analyses have shown that in Iowa and in many parts of the Midwest we have seen increased precipitation and frequency of intense rainfall events (which is predicted to worsen according to several of the most accepted climate change model scenarios). Several studies relevant to Iowa have looked at stream flow increases in relation to precipitation, and have concluded that increased stream flows are disproportionately greater than the increased precipitation (Novotny & Stefan 2003, Juckem *et al.* 2008).

The impacts of altered hydrology go beyond contributions to major floods. Drainage of urban and agricultural lands through subsurface drains and ditches also causes flows to change. To enable crop production on these once waterlogged soils, thousands of miles of subsurface drainage were installed in crop fields, and surface drainage networks were developed and enlarged via construction of drainage ditches, as well as deepening and straightening of existing natural channels. Ditching and channelizing streams affects hydrology and how streams move and transport sediments. There are other, less intuitive, but broader scale causes of altered hydrology in the ICB: a shift in land cover since the mid 20th Century, and loss of soil organic matter. Current soil structure absorbs roughly half as much rainfall as in the past. Acres devoted to corn are roughly the same as in the 1940's, however, in the northern two thirds of the state, soybeans have displaced small grains (mainly oats, hay, and pasture used for horses and cattle). This loss of perennial crops on the landscape changes patterns of evapotranspiration and leaves soil exposed during spring rains. With a landscape dominated by row crops, evapotranspiration is now the most intense when corn and beans are most active, in late summer. In spring, row cropped areas are not using any water or nutrients, while pasture, trees, and grass, are. An increase in flows that occurs disproportionately in early spring before row crops are established has implications for nitrate loss. Observations of monthly stream flows from pre 1970 gage data compared to post 1970 gage data indicate a temporal shift toward higher flows in March and April. Increased demand for grains is driving continued changes toward more drainage and greater emphasis on row crops - corn and beans. How water moves across and through the landscape is changing, with negative effects on the environment, human health, and our local economy. The consideration above clearly demonstrates that sustainability of the region's social and economic fabric and the ecological integrity of the watershed are at risk. Sustainable solutions must be broad scale, at the scale of the cause -basin-wide- and must accommodate multiple water-related interests.

2 Capacity Building

It is obvious from the above considerations that only an integrated watershed approach can provide a sustainable solution for the future of the ICB. It was the continued occurrence of destructive flooding in Iowa, however, that triggered a natural reaction of agencies and communities to work across traditional political, geographical and social boundaries for improving the watershed well-being. As a watershed facing the near certainty of more massive flood events, affected stakeholders are seeking long-term solutions through a watershed approach. Iowa's institutions and communities are rethinking their relationship with rivers and their watersheds and embracing new ways of managing water resources, with flood risk mitigation as a priority, and using a watershed-wide approach with IWRM as the main guiding framework.

UNESCO-HELP: The first capacity building effort along these lines was the designation of the Iowa-Cedar Basin as a UNESCO-HELP Basin in March 2009. Iowa-Cedar HELP is the most recent addition in the worldwide network of HELP basins, and the first in the Midwest US. The Iowa HELP initiative is focused on addressing the main "paradigm lock" still impeding implementation of IWRM: the gap between the decision-makers interested in land and water scenarios and the scientists interested in improving the understanding of watershed processes. The first major action organized by the Iowa HELP basin was a capacity building and training workshop delivered in October 2009. The capacity building track discussed strategies to initiate the interagency partnership and a common action agenda. The initial focus for the Iowa Cedar HELP Basin is systemic flood reduction. A consensus was reached on the need to develop a Watershed Data and Information System to integrate data from all partners into one common platform (http://iowadis.org). The training workshop provided hands-on experience for setting water data services using advanced data warehousing technologies. The Consortium for Advancement of Hydrologic Science, Inc. (funded by the U.S. National Science Foundation) offered the technical track. More than seventy participants from 18 federal, state, and local agencies, NGOs, and universities attended the plenum meeting. Efforts sponsored through Iowa HELP include participation in UNESCO-HELP workshops (Portland, OR - May 2010; Lodz, Poland - September, 2010). The exposure to other HELP basins experiences were very valuable for us, and lessons learned from HELP workshops are being applied to all of our efforts.

Interagency Coordination and Collaboration: In the fall of 2009, following the designation of the ICB as a HELP basin, the Iowa-Cedar Watershed Interagency Coordination Team (ICWICT) was formed and has emerged as the main collaborative action body (http://iowacedarbasin.org). ICWICT involves federal and local management agencies, research institutions, and stakeholder communities (see Fig. 1).

Fig.1 Current partners in the Iowa-Cedar Watershed Interagency Coordination Team.

The role of the Interagency Team led by the US Army Corps of Engineers and the Iowa Department of Natural Resources is to address water resource problems and opportunities in the basin, in the interest of increasing social and economic value, increasing ecological integrity, and reducing risk. The current action priority for the Interagency Team is flood mitigation using IWRM concepts. Even in its short period of existence, the ICWICT has demonstrated effectiveness in formulating a process for watershed management, taking inventory of the infrastructure and expertise of each individual partner, developing an integrative strategy for place-based collaborative flood mitigation action, hosting community-based “Vision to Action” workshops to create a shared vision for the local watersheds, and attracting and aligning resources. The Interagency Team meets bi-monthly and has created several working groups for development of integrated modeling tools and watershed plans, and for engagement of public officials, stakeholders, and the public.

Grassroots Watershed Management: In the spring of 2010, a new grassroots body was created in the Cedar River Basin with a focus on floods: The Cedar River Watershed Coalition (CRWC). This community-driven group was formed with the purpose of organizing and advocating for practices and policies (federal, state, and local) that target non-structural, watershed-scale solutions to mitigate future flood risk and improve water quality (http://iowacedarbasin.org/cedar). Members of the Interagency Team are closely involved with the CRWC -we see this body as our primary means to reach out to non-traditional partners and the communities at large. We are currently focused on helping this group develop strong leadership and recruit a diverse membership across the urban and rural interface.

Involvement of Academia: The ICB has played the role of attractor of activities for scientists in the state universities. For example, a new National Science Foundation award will also be focusing on the ICB for better understanding of the processes that link global-scale climate and socioeconomic drivers to regional-scale responses in land use decision-making, water quality, and water quantity. The study will be placed in the context of sustainability science, with a particular focus on how humans can best adapt in a sustainable manner to climate, socioeconomic, and policy conditions that are changing at multiple spatiotemporal scales. The overarching question of interest concerns the tradeoffs and relations that exist among traditional measures of optimality (e.g., maximizing environmental quality and economic returns) and measures of resilience, adaptability, and sustainability.

Cross Basin Partnerships: Partnerships are being established with entities outside the basin for assimilation of advancements in areas of interest: ecosystem services (Earth Economics, American Rivers); integrated flood management (World Meteorological Organization); river/ rainfall observations and forecasts (NOAA/USGS/USACE’s Integrated Water Resources Science & Service Consortium).

3 On-the-Ground Action

The first on-the-ground collaborative effort uniting the management, public and academic resources and expertise is the Indian Creek study designated as a Watershed for Learning for collaborative action (see Table 1). The ICWICT technical sub-committee is developing and testing an integrated modeling protocol for the analysis of watershed scenarios (different land use, land cover, climate conditions and management actions) applied to Indian Creek through continuous interaction with other stakeholders.

Table 1 Road Map for Indian Creek Study.

Step	Description
1	Conduct outreach activities (visioning sessions, focus groups, etc.) to determine HUC 8 scale "local values" of stakeholders. Form stakeholder group(s) for communications throughout planning phase.
2	Apply alternative scenarios developed through an EPA grant for Upper Mississippi: a) Maximize Commodity; b) Water Quality; c) Habitat Diversity.
3	Input land use scenarios into the Soil and Water Analysis Tool (SWAT) model for the CR to compare the hydrology and water quality at designated locations on the river's main stems. The model is developed by Iowa USGS Water Science Center.
4	Create a central repository to display environmental, economic and social trade-offs using the above scenarios. Inundation maps based on National Weather Service flood stages and DEM data, in conjunction with vulnerability assessment will allow flood risk estimation to be subsequently communicated to the stakeholder group(s) and public.
5	Re-engage stakeholder groups to get input on the model results for alternative land use scenarios (in terms of water quantity, water quality, ecosystem health, agriculture, recreation, etc.). Get stakeholders feedback on the measures of runoff reduction and detention likely to be implemented (i.e. wetlands, filter strips, etc.).
6	Results from #5 are composed in new scenarios collaboratively modeled with SWAT and Gridded Surface Subsurface Hydrologic Analysis (GSSHA) to test the system sensitivity to various land use changes and other best management practices recommended by the visioning groups.
7	Compare scenarios obtained with the same inputs and multiple models. For this purpose GSSHA, HEC-HMS, and HEC-RAS will be developed for Indian Creek watershed. The set of models used in this study will be applied at different basin scales (from Indian Creek to Cedar River Basin) to assess the upscaling feasibility of the investigative/predictive tools.
8	Return to the stakeholder groups(s) to present and discuss the results, and compare them with base scenarios. The ICWICT will use all the inputs above to determine an optimal scenario for the watershed with respect to economic, environmental, and social considerations.
9	The ICWICT will determine which agency has the ability to address the plan components and prioritize land use changes by level of impact (environmental, economic, and social).

The outcomes of the multiple-purpose modeling study conducted in Indian Creek will provide hazard mapping that will be subsequently used in flood risk mapping with considerations of industries, and socio-economic factors that are critical to flood planning. Flood mapping will also delineate areas for water quality modeling and ecological impacts. These models will provide a sound understanding of the physical drivers within the watershed (i.e., impact of tile drains, land use, and other practices for runoff reduction/retention). The overall outcomes of the long-term strategic planning for the basin will be evaluated using performance indicators reflecting management objectives, national and local environmental laws, public perception, and critical floodplain restoration issues (Hooper, 2006).

4 Outlook

Reducing risk from flooding requires a multiplicity of actions, both structural and non-structural, that are compatible with achieving a resilient and sustainable watershed. It will take upstream/upland interests working with downstream/lowland interests to find solutions. Altering use of floodplains, protecting communities with barriers, retaining water, and changing land use practices will all be necessary to reduce flood risk within the ICB. The shift in land use and/or land management practices that will be required for flood mitigation represents a cultural shift for residents in the ICB. The Indian Creek multi-project study will serve as testbed, facilitating observations and inferences on all aspects of an IWRM implementation, from technical (water quantity and quality, flood risk, and ecological) to policy and governance as related to interagency collaboration and public involvement.

We are on a long journey toward implementing an IWRM framework for the Indian Creek and subsequently using the experience, technology, and social learning as a model for other collaborative actions in watersheds across ICB. Success will emerge as a thriving center for communication and coordination, a thriving Coalition with political power, coordinated high level science, a basin plan for maximizing ecosystem services and achieving watershed sustainability supported with legislated programs, and as compatible actions throughout the basin.

REFERENCES

Filipiak, J., Spitzack, Muste M. (2011) *Capacity Building for IWRM Implementation in Iowa Watersheds*, Summer Specialty Conference, American Association of Water Resources, June 27- 29, 2011, Snowbird, UT.

GWP (2004) *Catalyzing Change: A Handbook for Developing Integrated Water Resources Management (IWRM) and Water Efficiency Strategies*, Global Water PArnership, Elanders, Svensk Information, Stockholm, Sweden.

Hooper, B.P. (2006) *Key Perfomance Indicators of River Basin Organizations*, Institute for Water Resources, US Army Corps of Engineers, Alexandria, VA.

Juckem, P. F., Hunt, R.J., Anderson, M.P., and Robertson, D.M. (2008) "Effects of Climate and Land management Change on Streamflow in the Driftless Area of Wisconsin," *Journal of Hydrology* 355, 123-130.

Novotny, E. V. and Stefan, H.G. (2003) *Streamflow in Minnesota: Indicator of Climate Change?* St Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN.

Skopec, M. (2010) "Iowa Floods: the 'New Normal'," *Iowa Natural Heritage*, Fall 2010,
http://www.inhf.org/magazines/2010/fall/2010magfall-images/INHF-Fall2010mag-Flooding-Skopec-web.pdf
Last accessed, November 12, 2010.

Local Water Conflict and Cooperation: Gaps in the Legal and Administrative Water Governance Framework in Bolivia, Mali, Nicaragua, Vietnam, and Zambia

ROBERTO RIVAS HERMANN[1], CATHERINE GALVEZ HOOPER[2] & HELLE MUNK RAVNBORG[1]

1 *Department of Development and Planning, Aalborg University, Aalborg, Denmark*
rrh@plan.aau.dk

2 *Water management independent consultant, Aalborg, Denmark*

Abstract In 2007 the Danish Institute for International Studies (DIIS) launched the research programme "Competing for Water: Understanding conflict and cooperation in local water governance". Along with partners in five developing countries (Bolivia, Mali, Nicaragua, Vietnam, and Zambia), the programme aims to contribute to "*sustainable local water governance in support of the rural poor and otherwise disadvantaged groups in developing countries by improving the knowledge among researchers and practitioners of the nature, extent, and intensity of local water conflict and cooperation and their social, economic, and political impacts, and how this may change with increased competition for water"* (DIIS, 2007). The country research teams developed an overview of the national water governance frameworks at an early stage of the Competing for Water programme period (Bustamante and Cossio, 2007; Djiré, *et al.*, 2007; Gómez, *et al.*, 2007; Nguyen, 2007; Mweemba, C.E., 2007). The purpose of these overviews was to position the research findings on the extent and nature of local-level water-related conflict and cooperation in the context of on-going efforts to improve the policy, legal, and administrative water governance framework in the five countries, and discuss their implications. The present paper synthesizes possible 'blind spots' in the national policy, legal, or administrative water governance frameworks with reference to the identified types of water-related conflictive and cooperative situations identified during the inventories.

Key words Local water governance; conflict; cooperation; institutions; water reforms

1 Introduction

Local water-related conflict and cooperation results from competing water use interests. This paper explores how conflictive and cooperative water-related situations -as those identified as part of inventories of water-related events undertaken in five rural districts as part of the Competing for Water programme[1] (Ravnborg, *et al*., forthcoming; Cossio, *et al*., 2010; Djiré, *et al*., 2010; Mweemba, *et al*., 2010; Nguyen, *et al*., 2010; Rivas Hermann, *et al*., 2010)- are intended to be dealt with as part of the water governance framework in the respective countries. On this basis, it identifies the gaps that make the water legal and administrative framework less efficient in dealing with local-level water-related conflict and cooperation.

2 Namwala District, Zambia

According to the water event inventory by Mweemba, *et al.* (2010), the main issue on these events was competing claims for consumptive different uses (inter-uses). In 35.8% of the events, third parties were called to mediate in conflicts and to warrant equal water access. Frequently, rural domestic water consumers, individual pastoralists, and farmers called for third parties. Local level authorities (headman or chief, community-based organizations) were the most common contacted third parties (Mweemba, *et al*., 2010).

In Zambia, legal and normative gaps do not allow to effectively address water access and scarcity related problems. In the practice, legislation is inadequate regarding the exploitation of water resources, mostly groundwater. This is reflected in the lack of specific norms to tackle water related conflicts in poor rural communities. In particular, the following gaps are identified in the current administrative and legal framework:

- Agencies functions are not clearly differentiated; this leads to duplicity in efforts and functions
- A decreasing economic investment in the services of drinking water supply and sanitation
- Water systems are not sustainable from the economic and functioning point of view, water is considered as a social cost rather than an economic resource
- Lack of logistic capacity for the efficient functioning of water sources
- Women and children's water resource infrastructure and allocation decision participation is marginal (Mweemba, 2007); although a Gender Policy is in place since 2000, this policy has not been put into practice in the water sector

Finally, it is important to stress that the application of regulations in local communities is challenged by customary values. According to these customary values, Zambian water rights are related to land property rights (Chileshe, *et al*., 2005). This perception contrasts with a permit-based water exploitation on a water management approach.

3 Douentza District, Mali

According to the inventory results from the Douentza District (Djiré, *et al.*, 2010), the most common uses involved in water related events were cattle watering, drinking water, and other consumptive purposes.

Parties directly involved were rural and domestic water consumers, community chiefs/headmen, and local government/authority. When competing interests yield to conflict, the problem is reported either during a community meeting, or to the community chief. In some cases, when the problem is not solved locally, the village headman and community leaders call third parties (60% of the events were conflictive when third parties were contacted).

The Malian water legal and administrative framework has limitations and gaps that leave room for conflicts. The following constraints add to the financial burden in the local water governance framework:

- Norms and law enforcement deficiencies: different users' (large and small scale, and local authorities) interests may affect institutional arrangements and law enforcement. This is closely related to the political power of these groups.
- Technical capacity deficiencies: Investments are scarce in capacity building. Specially, local governments do not have a sufficient number of technicians to ensure water resource sustainability (for example, one engineer for every 170 water points).
- Deficient inter-institutional coordination, which causes duplicity of functions.

The Malian water code has limitations with regards to water resource exploitation. The code is not clear on the mechanisms to entangle productivity with protection. Specific limitations of this water code are:

- The water code lacks norm and regulation enforcement mechanisms for local authorities. The code does not state if local authorities will regulate water resource exploitation through ordinances, and which kinds of sanctions will be imposed to infractors.
- Deficiencies concerning water-pricing norms. This entails fee-paying difficulties, especially in rural areas, and thus private investors are more reticent to invest.
- The water code adds to the already existing regulations without bridging connections with them. It lacks an encompassing frame, which could integrate the different strategies, plans, and sectorial policies.

- There is a big overlap of expertise between structures intervening in the water sector.
- There are not clear mechanisms to deal with water related conflicts.
- Rules related to sanitation are not respected and sanitation seems to be a household's responsibility.
- Established structures like Basin committees are not functioning.

4 Con Cuong District, Vietnam

The water competition inventory (Nguyen, *et al.*, 2010) shows that farmer groups, irrigators, and rural water domestic consumers are most interested in contacting conflict resolution third parties. Therefore, community leaders and government local authorities (rural community committee, irrigation committee) participate as conflict mediation and cooperation boost third parties. National authorities (located outside community) are barely requested as third party mediators. Two reasons explain this: the distance that separates the event's communities and the conflict intensity is not strong enough to merit the involvement of these authorities as third parties.

During the 1990s, Vietnam started reforming its legal and administrative water framework. The Water Law of 1998 introduced resource and users distinctions. The main challenge is to reach an adequate decentralization of the water sector that will allow local authorities to cope with the sector's main problems (water quantity, quality, water pollution, water source degradation). Both the water law and the water-related agencies have limitations that impede adequate water management, including:

- Lack of administrative procedures pertaining to the efficient water use and to service provision
- Lack of technical capacities
- Inadequate strategic plans for water resources protection
- Lack of coordination and cooperation between the different stakeholders involved in water resource management at the local, provincial and national levels
- Insufficient investment in operation, maintenance, and management of water infrastructure; this implies a critical water supply and quality performance

5 Tiraque District, Bolivia

Tiraque district's inventory highlights intra-uses, rural drinking water and large and small scale irrigation as the most frequent conflictive and cooperative events. The results also show that third parties were called upon in 12% of the events, and formal demands were submitted to external authorities in 20.5% of the cases. Judges and lawyers are called as third parties when local authorities are not able to mediate in water related conflicts (Cossio, *et al.*, 2010).

Bolivia has a sectoral patched water management with specific regulations for each sector (especially irrigation and drinking water).

The sectoral approach to water management entails several problems. First, this approach boosts an unplanned growth of agencies which are disconnected from the already existing ones. Moreover, irrigation and drinking water sectoral laws have other flaws: irrigation law's water use rights, for instance, are given permanently through family and collective registries to farmers and indigenous groups. Besides, the law does not stipulate water exploitation right revocation procedures. The drinking water and sanitation law was approved in 2000. However, its statutes have not been approved yet. Therefore, until statutes are approved, the law cannot enter into force (Bustamante and Cossio, 2007).

The local water event inventory highlights the State's lack of involvement in rural water management (Cossio, *et al.*, 2010). Local organizations (irrigation, drinking water and users) manage and control the water resource (Cossio, *et al*., 2010). Moreover, at a local level, the mayor and *sub-prefecto* are the most often contacted third parties for conflictive and cooperative events.

Local organizations and district authorities have limitations in their roles as water managers and water-related conflict mediators. Some of these limitations relate to financial shortages, lack of technical staff, infrastructure maintenance, and tariff payback. Similarly, several local organizations sharing the same water source are not coordinated. The most notorious example is in the drinking water systems in peri-urban areas (Bustamante, *et al.*, 2007).

6 Condega District, Nicaragua

The inventory of water related events was carried out in Condega district. Most of the registered events were cooperative (55.6%). In 50% of the events, the parties called upon external parties, primarily community committees, the Water Agency (former rural drinking water service provider), and the mayor or vice-mayor (Rivas Hermann, *et al*., 2010).

The National Water Law[2] stipulates the creation of a national water authority (ANA) to implement the law and coordinate the country's water management. The water law contains some weaknesses in relation to water administration. First, the law does not contain any integration mechanism with other policies. In fact, Nicaragua has a broad water legal framework. This leads to dispersed institutional efforts, contradictions, and overlaps in the legal framework (particularly between the Water Policy of 2001, the Water Law, and its regulation[3]).

At the local level, the Municipalities law (Law 40 and Law 261) empowers local governments to provide water supply services -including maintenance and construction of infrastructure (Art. 7), and to protect water resources (Art. 28). Yet, the concessions of water exploitation must be previously approved by the ANA (according to the Water law of 2007). Therefore, local governments must cope with this and with other problems to handle water resources:

- Few districts carry out territorial planning. This increases the risk of underground and surface water reduction in quality and quantity.
- Insufficient capacity to assure the sustainable use of water resources.
- Conflict resolution mechanisms are not scripted in norms, they are carried out on an *ad-hoc* basis with a "fire-fighter" syndrome.
- Financial resources are insufficient to assure management and monitoring. District governments do not engage in periodical and schematic water exploitation fees, and they do not manage water infrastructure. Therefore, there are no funds coming from water exploitation rights to cover the expenses associated with the resource's management.
- Civil society participation mechanisms are not adequate and are not equal. There are situations in which biased decisions are taken on the grounds of political affiliation.
- Local governments are often left on their own, without technical assistance, training, and advice from central public agencies dealing with water management.

7 Conclusions

Common roots of conflict related water events were water scarcity and challenges to access water. These challenges were caused by an unequal water distribution, deficiencies in water policies and local water administration.

Local governments should have administrative, technical, and financial capacity to cope with conflicts that are generated in their communities. An adequate training can help surmount these deficiencies.

An efficient policy should cover water demand and water offer. Water resource preservation and sustainability should not be bypassed. Such policy should take into account integral elements that allow common participation from all the stakeholders involved in the water sector (users, government, public agencies, civil society and traditional authorities).

Acknowledgements
This article was written in collaboration with: Rocío Bustamante, Abdoulaye Cissé, Vladimir Cossio, Moussa Djiré, Mikkel Funder, Ligia I. Gómez, Phuong Le, Carol Mweemba, Imasiku Nyambe, Huong Pham, and Nguyen T.B. Yen.

REFERENCES

Bustamante. R, Quiroz. F, Heredia. G. (2007) *Análisis institucional: Agua potable y Riego en Bolivia.* Multiple Use Systems Project (MUS), CGIAR Challenge Program Water & Food, IRC - International Water and Sanitation Centre, Programa Agua Tuya, Centro Agua. Cochabamba. Bolivia.

Bustamante, R.; Cossio, V. (2007) *Bolivia, Overview of the national and sub-national water policy, legal and administration context*. Mimeo internal unpublished report. DIIS.

Chileshe. P.; Trotier J.; Wilson L. (2005) *Translational of water rights and water management in Zambia*. International workshop on 'African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa', 26-28 January 2005, Johannesburg, South Africa.

Cossio, V.; Bustamante, R.; and Skielboe, T. (2010) *Cooperation and Conflict in Local Water Management. Conflict and cooperation in local water governance - inventory of local water-related events in Tiraque district, Bolivia*. DIIS Working Paper 2010:11. Copenhagen: Danish Institute for International Studies.

DIIS. (2007) *Competing for water: Understanding conflict and cooperation in local water governance -a comparative and collaborative research program*. Program description DIIS.

Djiré, M.; Cissé, A.O.; Cold-Ravnkilde, S.M. (2007) *Revue nationale du cadre réglementaire et administratif de gestion de l'eau au Mali*. Mimeo internal unpublished report DIIS.

Djiré, M.; Cissé, A.O.; Cold-Ravnkilde, S.M.; Keita, A.; Traoré, A. (2010) *Conflict and Cooperation in Local Water Governance - inventory of water related events in Douentza District, Mali* (DIIS Working Paper 2010:12).

Gomez, L.I; Ravnborg, H.M; Rivas Hermann, R. (2007) *Institucionalidad para la Gestión del Agua en Nicaragua.* Cuaderno de Investigación 30, Managua: Nitlapan.

Mweemba, C.E. (2007) *Overview of the national water policy, legal and administrative context and the context descriptors of Namwala District*. Unpublished internal report DIIS.

Mweemba, C.E.; Nyambe, I.; Funder, M.; van Koppen, B. (2010) *Conflict and Cooperation in Local Water Governance - inventory of water related events in Namwala District, Zambia* (DIIS Working Paper 2010:15).

Nguyen, Y.T.B. (2007) *Overview of the national and sub-national water policy, legal and administration context in Vietnam.* Mimeo internal unpublished report DIIS.

Nguyen, Y.T.B.; Le, P.T.T.; Pham, H.T.M.; Skielboe, T. (2010) *Conflict and Cooperation in Local Water Governance - inventory of water related events in Con Cuong District, Nghe An Province, Vietnam* (DIIS Working Paper 2010:14).

Ravnborg, H.M.; Rocio Bustamante, Abdoulaye Cissé, Signe M. Cold-Ravnkilde, Vladimir Cossio, Moussa Djiré, Mikkel Funder, Ligia I. Gómez, Phuong Le, Carol Mweemba, Imasiku Nyambe, Tania Paz, Huong Pham, Roberto Rivas, Thomas Skielboe, and Nguyen T.B. Yen. (Forthcoming) The challenges of local water governance - The extent, nature and intensity of local water-related conflict and cooperation. *Water Policy.*

Rivas Hermann, R.; Paz Mena, T.; Gómez, L.I.; Ravnborg, H. (2010) *Cooperación y Conflicto en torno a la Gestión Local del Agua en el municipio de Condega, Nicaragua* (DIIS Working Paper 2010:13).

[1] These working papers are available through the research programme website: www.diis.dk/water. The comprehensive synthesis "Overview of national policy, legal and administrative framework for water governance - draft synthesis based on papers produced by the competing for water country research teams" is available at: http://www.diis.dk/graphics/Subweb/Water_internal_files/national_overview_synthesis_DRAFT.pdf

[2] Ley Nº 620, Ley General de Aguas Nacionales [Law 620, General Water Law];

[3] Reglamento de la Ley General de Aguas Nacionales, Decreto Nº 44-2010.

A Regional Initiative for the Hydrological Monitoring of Andean Ecosystems

ROLANDO CÉLLERI[1], PATRICIO CRESPO[1,2], BERT DE BIÈVRE[3] & LUIS ACOSTA[3]

1 *Grupo de Ciencias de la Tierra y del Ambiente, Dirección de Investigación, Universidad de Cuenca, Cuenca, Ecuador* rolando.celleri@ucuenca.edu.ec

2 *Institute for Landscape Ecology and Resources Management, Justus-Liebig University of Giessen, Henrich-Buff Ring Giessen, Germany*

3 *Challenge Program for Water and Food (CPWF), CONDESAN, Quito, Ecuador, and Lima, Peru*

Abstract The design of integrated river basin management plans in Andean headwater basins has faced a number of limitations originated on the lack of knowledge of hydrological processes and the impact of human activities on the hydrological cycle. Nowadays, more people ask themselves what the effects of their land-management actions on water availability are. There is no clear answer to these questions. While the use of hydrological models for scenario analyses can provide a possible solution, the lack of available data to calibrate and validate them at the scales of interest complicates their application. One of the roots of the problem is that, so far, there is limited monitoring of catchments with the aim of knowledge generation. The large variability found in ecosystems, climates and geomorphological settings makes hydrological research a complex task, and therefore, finding answers to these societal problems may take too long, unless a well-coordinated collaboration between research centers, NGOs and local governments takes place. This manuscript outlines the goals of a regional initiative for the hydrological monitoring of Andean ecosystems and describes its first steps.

Key words Mountain hydrology; Andean ecosystems; páramo; montane forests; cooperative environmental monitoring

1 Introduction

Tropical Andean ecosystems, consisting mainly of páramo, jalca, puna, montane, and cloud forests play a key role in the water supply of most Andean cities and towns, (e.g., satisfying 85% and 95% of Quito's and Bogotá's water demand, respectively). Páramo, jalca and puna are high altitude neotropical ecosystems located above the tree line. Geographically, páramo can be found in the region from northern Colombia and Venezuela to northern Perú; jalca is found in northern to central Perú, and puna spans from central Perú to northern Argentina and Chile. Andean montane forests are the typical forests found at elevations above approx. 1000 m in the Andes. In places where cloud presence is permanent, montane forests are called cloud forests. The elevation range where these ecosystems are present is highly variable, mainly depending on the latitude.

However, despite their role as a main water source, the hydrology and water balance of these mountain basins is still poorly understood. The main obstacles for the advancement of hydrological knowledge have been the difficulty to implement and maintain research-grade observation networks in these complex, remote environments, and the lack of acknowledgement of these ecosystems as water providers. Furthermore, regional monitoring networks have been in decline during recent years.

Another major challenge is the large variability found in the basins' bio-physical properties, and most importantly, in the meteorological conditions in space and time (Bendix, 2000; Vuille *et al.*, 2000; Célleri *et al.*, 2007), which complicate data collection for an adequate prediction of precipitation and discharge at operational scales. As an example of this variability, Andean páramos, covering an area of approximately 35,000 km^2, are found between northern Colombia and Venezuela, down to northern Peru. Páramos are located in an altitudinal range spanning between the tree line

(~3000 m a.s.l.) and the permanent snow line (~4500 m a.s.l.), with precipitation varying from below 1000 mm/year to well above 3000 mm/year.

The effects of lack of data and knowledge are two-fold. First, it has hindered the development of hydrological models and has led to the misuse of available models developed for other regions, whose results are accepted without a proper model implementation. Indeed, based on the authors' experience, even model calibration (not to say validation and uncertainty analysis) is still a very uncommon practice in many model applications performed in the region. Second, it has put severe constraints on sustainable water resources management, and therefore, on the the region's development. For instance, nowadays there is an increasing interest in the application of payment schemes for environmental services (PSA in Spanish) (e.g., Asquith & Wunder, 2008; CONDESAN, 2009) as a means for watershed protection and conservation. While water provision is probably the most important service provided by Andean ecosystems, the lack of knowledge of the ecosystems' hydrological functioning is limiting the application of PSA initiatives aimed at water conservation.

During the last decade, a number of research initiatives have been initiated, aiming at better understanding the water yield mechanism of small-scale, pristine, and human-altered catchments. To identify the human impact on the páramo ecosystem (Buytaert *et al*., 2006, Crespo *et al.* 2010), the paired-catchment approach has been used, while the nested-approach has been applied for studying the functioning of montane and cloud forests (Breuer *et al.*, 2006). These and other efforts have yielded important knowledge on the effects of land-use change on storm runoff generation and water yield (e.g., Buytaert *et al*., 2006, 2007; Crespo *et al.* 2011, Fleischbein *et al*., 2006; Tobon, 2008; Wilcke *et al*., 2009). However, given the extreme variability in Andean topography and climate, it is still problematic to derive generic knowledge, to extrapolate findings to non-monitored or data scarce catchments, and to scale up findings to the target scale of interest (Célleri & Feyen, 2009). Additionally, local stakeholders are looking more frequently for answers to their questions (mainly concerning land use and climate change impact analyses), only to find many gaps in the scientific knowledge. Therefore, this manuscript presents a proposal for a regional approach to advance hydrological knowledge and describes its first steps.

2 An Andean Network of Research Basins

Increasing the knowledge of the climate and hydrology of the tropical Andean mountain system requires the establishment of new monitoring networks and their linkage to existing ones, enabling a functional and systematic collection of data. The monitoring tasks, given the extent of the Andean mountain range and the spatial variability, are immense; therefore, research institutions alone will not be able to monitor all target basins suggested by interest groups. A solution to this problem requires a well-designed and coordinated collaborative action between many partners, comprising research groups, as well as local and regional stakeholders.

Whereas research groups collect climate and hydrologic data in specified basins as a function of research their objectives, local and regional stakeholders collect data because of pressing water-related problems. Indeed, research groups are in charge of research-grade monitoring networks in a number of representative basins using process-based monitoring for developing and testing hypotheses and protocols to compute spatially distributed water fluxes over the basin. On the other hand, local stakeholders are starting to implement basic monitoring systems in their basins, or have a strong interest in doing so. The basin scale at which local stakeholders are working corresponds to that of the basin management projects, and usually ranges from hundreds of hectares (e.g., reforestation programs) to less than 10 km^2 (e.g., ecosystem protection). Therefore, reliable predictions at these scales are needed.

To merge and optimize the interest and effort of all stakeholders, a participatory environmental monitoring framework is suggested. In this collaborative framework, research groups and local stakeholders work together to solve the most pressing water-related problems. Research groups assist local and regional stakeholders in network design, instrument selection and installation in well-defined conditions, elaboration of guidelines for station maintenance and data downloading, and data processing, storage, and distribution at several levels, generating reports about the local meteorological and hydrological conditions for distribution among the communities. Local and regional stakeholders (often supported by local NGOs with the necessary expertise) will be responsible for station maintenance, data downloading and transmission to a central database, as well as co-funding research projects. They should make data available to research groups and assist the latter in their monitoring endeavors. It is strongly suggested that all equipment be automatic to avoid manual measurement errors and to minimize time investment.

While data collected in research basins will be used for process knowledge and model development, data collected by local and regional stakeholders will be used for analyzing and developing solutions to water-related problems and, for instance, to test extrapolations and up-scaling hypotheses. Consistency and context of data collection for knowledge generation, model development, and decision-making purposes are needed firsthand.

3 The Initiative

In July 2010 a first meeting of 12 institutions was held in Cuenca, Ecuador. Its main decision was to start the so-called Regional Initiative for the Hydrological Monitoring of Andean Ecosystems. The coordinator of the Initiative is the Consorcio para el Desarrollo Sostenible de la Ecoregión Andina (CONDESAN), a regional consortium of NGOs and research institutes, while the technical coordination lies upon the University of Cuenca, Ecuador, through its Grupo de Ciencias de la Tierra y del Ambiente.

The Initiative is in a stage of set-up and training, gathering interested partners and organizations with existing monitoring initiatives. So far, local interest has far exceeded expectations, with currently about 15 monitoring sites in Venezuela, Colombia, Ecuador and Perú. Local organizations' interest is primarily stimulated by the return of concisely formatted data and easily interpretable information about the behavior of their small catchments, something that is lacking in large monitoring schemes developed by state agencies. Another advantage is the embedding of local efforts within a larger monitoring community, allowing a sharing of experiences and data for regional interpretation and analyses.

Research groups are monitoring small- to mid-size basins (1-100 km^2), from the plot to the basin scale, including hill slopes and small basins (<2 km^2) with different land uses. In this way it will be possible to understand the effects of land-use change on hydrology, as well as testing up scaling hypotheses. While the instrumentation of stakeholders' basins mainly consists of rainfall and discharge stations, research basins will additionally include meteorological stations and sensors to measure state variables, such as soil moisture.

Funding for the implementation of on-site monitoring is provided by national and local projects, such as the recently concluded "Quantification of the hydrological services of Andean basins" PIC-08-460's project, funded by the Ecuadorian Secretary of Science and Technology (SENACYT) and the Universidad de Cuenca. This project establishes two mid-size nested research basins, monitoring basins of sizes ranging from ~1 km^2 -with different land covers (mainly páramo, montane forests and non-native forest plantations)- to ~15 km^2. On top of this, it provides basic rainfall-discharge monitoring to two community-based action research projects situated along the Ecuadorian Andes. The latter are projects managed by local NGOs in their efforts to understand the effects of human interventions on the hydrological cycle and to protect natural forests against deforestation. For these reasons they have realized the importance of measuring discharge (in small experimental and control basins) and precipitation (to remove the effects of climate variability: wet years vs. dry years), in order to determine the impact of their land use practices.

A second meeting of the participant organizations was held in September 2011, in Quito, and as a result a strategic plan for the second year has been prepared.

4 Conclusions

A Regional Initiative for the Hydrological Monitoring of Andean Ecosystems has been initiated as a means to improve the hydrological knowledge of Andean ecosystems. This network will comprise: (a) densely-instrumented basins for identifying and quantifying hydrological processes and their spatial variability, and (b) basic-instrumented basins managed by local stakeholders. Such an approach, founded on the premise that technology has advanced to the extent that local communities can easily be involved in the monitoring process, allows for monitoring in many regions which would otherwise be too expensive or practically infeasible for research institutions alone.

The scientific results provided by research basins in different ecosystems, using a nested approach and monitoring at several scales of hydrological significance from plot scale to basin scale (<100 km^2), including hill slopes and small basins (<3 km^2) with different land cover, will contribute to generating knowledge, testing hypotheses and deriving new models. Small basins will be used to identify the impact of land-use change on the water balance, as well as the mechanisms of runoff generation. On the other hand, basins run by stakeholders will have basic rainfall-discharge monitoring at the scale of the project of interest, normally smaller than 10 km^2. Information from local basins will be used to test and validate knowledge from research basins. Thus, by combining research knowledge and local data, robust solutions to the local groups' problems will be found.

Although data from basic-instrumented basins will likely be of lower quality than data from their research counterparts, improved spatial and temporal coverage (e.g., different rainfall regions and geomorphological settings) may provide information of higher usefulness to researchers and policy makers. Finally, this collaborative research framework will allow bringing real-life problems and quality-controlled data sets to scientists, while providing science-based solutions to societal problems.

Acknowledgements Ideas expressed in this paper were gathered at the workshops on Hydrology of Andean Ecosystems, organized by CONDESAN in Papallacta, Ecuador, on September 2008, and in the Regional Initiative for the Hydrological Monitoring of Andean Ecosystems workshop, held in Quito on September, 2011. Rolando Célleri and Patricio Crespo were funded by the SENACYT-Universidad de Cuenca PIC-11-715 grant.

REFERENCES

Asquith, N. & Wunder, S. (2008) *Payments for Watershed Services: The Bellagio Conversations*. Fundación Natura Bolivia, Santa Cruz de la Sierra.

Bendix, J. (2000) Precipitation dynamics in Ecuador and northern Peru during the 1991/92 El Nino: a remote sensing perspective. *Int. J. Remote Sens*. 21, 533-548.

Breuer, L., Vache, K. & Frede, H. G. (2006) *Hydrogeochemical modelling framework. Project V3.2. Estacion Cientifica San Francisco*. Project description.

Buytaert, W., Celleri, R., De Bièvre, B., Hofstede, R., Cisneros, F., Wyseure, G. & Deckers, J. (2006) Human impact on the hydrology of the Andean páramos. *Earth-Sci. Rev*., 79, 53-72.

Buytaert, W., Iniguez, V. & De Bièvre, B. (2007) The effects of afforestation and cultivation on water yield in the Andean páramo. *Forest Ecol. Manage.* 251, 22-30.

Célleri, R. & Feyen, J. (2009) The hydrology of tropical Andean ecosystems: Importance, knowledge status and perspectives. *Mount. Res. Dev.* 29, 350-355.

Célleri, R., Willems, P., Buytaert, W. & Feyen, J. (2007) Space-time variability of rainfall in the Paute River basin of South Ecuador. *Hydrol. Processes* 21, 3316-3327.

CONDESAN. (2009) *Servicios ambientales para la conservación de los recursos hídricos: lecciones desde los Andes. Síntesis Regional 2008. Producto 2: Estado de la acción sobre la implementación de esquemas de pago por servicios ambientales*. Lima (in press).

Crespo, P., Feyen, J., Buytaert, W., Bücker, A., Breuer, L. Frede, H.G. & Ramírez, M. (2011) Identifying controls of the rainfall-runoff response of small catchments in the tropical Andes (Ecuador). *Journal of Hydrology* 407, 164-174.

Crespo, P., Célleri, R., Buytaert, W., Feyen, J., Iñiguez, V., Borja, P. & de Bièvre B. (2010) Land use change impacts on the hydrology of wet Andean páramo eocystems. In: *Status and Perspectives of Hydrology in Small Basins*. IAHS Publ. 336.

Fleischbein, K., Wilcke, W., Valarezo, C., Zech W. & Knoblich, K. (2006) Water budgets of three small catchments under montane forest in Ecuador: experimental and modeling approach. *Hydrol. Processes* 20, 2491-2507.

Tobon, C. (2008) *Los bosques andinos y el agua*. Publicación de ECOBONA, Quito.

Vuille, M., Bradley, R. S. & Keimig, F. (2000) Interannual climate variability in the Central Andes and its relation to tropical Pacific and Atlantic forcing. *J. Geophys. Res*. 105, 12447-12460.

Wilcke, W., Günter, S., Alt, F., Geißler, C., Boy, J., Knuth, J., Oelmann, Y., Weber, M., Valarezo, C. & Mosandl, R. (2009) *Response of water and nutrient fluxes to improve.*

A Water-Tight Future for India

SRIDHAR THYAGESWARAN
Coimbatore Institute of Technology, Coimbatore, India
mailto:t.sridhar@cit.edu.in

Abstract Relentless population growth, rapid urbanization and booming industrialization have enormously stressed India's water resources in recent times. This paper is a citizen's view on some issues threatening India's water security in the years to come. A few steps that could be taken to avoid water conflicts are explored, in India's context. The study highlights: (1) myopic policies on agriculture and subsidies for farming that have led to uncontrolled extraction of groundwater for irrigation; (2) how the push for attaining high GDP growth rates would greatly increase water demands for energy for infrastructure development needs; and (3) why municipalities are unable to supply potable water round-the-clock in urban India. This underscores a crying need for aggressive measures and policy changes for sustainable water use to prevent severe crises in the near future. Unless the full costs incurred in supplying water are recovered from all consumers, and the costs of treatment and disposal of the wastewater generated are imposed on all users, there will be no compulsion to re-use water, reduce its waste, or prevent its pollution with sewage and effluents. Farming practices best suited to the land, mandatory rainwater harvesting, and graded tariffs that deter excessive water consumption must be implemented.

Key words Government; groundwater; policy; sustainable; water

1 Introduction

It is of utmost importance that water resources be used in a sustainable manner for the well being of any country -for the prosperity of the nation's agriculture and industry- to safeguard the health of citizens, meet energy needs, and protect the environment. For a rapidly developing economy like India, sustainable water use is even more crucial. A vast majority of its burgeoning population of 1.2 billion people lack access to clean and safe water. Nearly 80 per cent of children suffer from water-borne diseases, and millions more are stricken with preventable ailments that can be attributed to unsafe water used for drinking or washing. Despite impressive rates of GDP growth over the past decade or so, and more than 60 years of independence from colonial rule, inaccessibility to safe drinking water and a general lack of basic sanitation facilities and hygiene continue to hamper India's socio-economic development. In many places, people are forced to spend a substantial portion of their daily income for procuring water. Those who cannot afford to, resort to some form of water theft.

1.1 Background

On average, India receives 4000 billion m^3 (BCM) of precipitation; 80 to 90 per cent of which happens during four months of each year. Of its 2.78 million km^2 of river basins (Ministry of Water Resources-MoWR, 2011), the average depth of yearly flow is 0.51 m (Deshpande, 2011). The river run-off in India is nearly 1418 BCM/yr. An additional 432 BCM flow annually through its river systems and replenish groundwater reserves (MoWR, 2009). About 400 BCM/yr of groundwater and 690 BCM/yr of river run-off can be harnessed beneficially, because of various reasons. Due to unrelenting population growth, the per capita water available in India, based on total river run-off and groundwater recharge, has declined from 1816 m^3/yr in 2001 to 1529 m^3/yr in 2010. To feed increasing requirements, annual food grain production (rice, wheat, coarse cereals, and pulses) in India has grown from 50 million tons (MT) in the 1950s to 241 MT in 2010.

By 2025, India's population may exceed that of China, and at least 350 MT/yr of food grain production would be required. In 2010, the total annual demand for water for irrigation, drinking, industry, energy, and other uses was 813 BCM. By 2025, that figure is projected to be 1093 BCM. In years to come, if 70 BCM/yr of groundwater were to be apportioned for domestic and industrial purposes, 330 BCM/yr would be available for irrigation needs.

Floods and drought wreak havoc across India year after year. While 400,000 km^2 of India (1/8th of her area) is flood-prone, 1/6th of her area is drought-prone (Central Water Commission, 2010). According to the Inter-Governmental Panel on Climate Change, in the future, rainfall events may become severe and occur over fewer days during each year. This would certainly increase the risk of crop losses due to excessive floods and droughts in a monsoon-dependent economy like India's. The Food and Agriculture Organization has warned that: (a) by 2050 the world would need water for an additional 2.5 billion people; (b) water use has been growing at twice the rate of human population growth in the past century; and (c) the Himalayan ice cover that feeds many of India's rivers could decline significantly by 2030.

1.2 National Water Policy

India's National Water Policy (NWP) envisions the need for a well-developed information system as the prime requisite for water resources planning. The NWP mentions the need for rainwater harvesting (RWH), water conservation, desalination of sea-water, artificial groundwater recharge, and watershed management though soil conservation, forest preservation, reforestation, protection of catchments and creation of more check dams. It states the need for close integration between water-use and land-use policies, and the water allocation priorities for drinking, irrigation, hydropower, etc. On the issues of inter-basin transfer of river waters, or resettlement and rehabilitation (R&R) of people to accommodate large-sized water projects, the NWP restricts itself to making politically correct statements. The NWP is under overhaul, because it lacks goals with strategies to attain them.

1.3 Purpose and Methodology of the Study

This paper voices a citizen's concern on some of the water-related issues that are bound to influence India's economic development, and some possible ways forward to tackle its impending water crisis. The study is based on information accessed from the web sites of government and non-government agencies, and reports in the print media (e.g., reputed national-level newspapers and journals).

2 Some Major Water-Related Issues

Each year, the Indian meteorological department issues a forecast for the monsoon rains. The forecast is meant for policy makers, planners, economists, farmers, and citizens alike, for the monsoon happens to be India's *de facto* Finance Minister. Everything in India seems to hinge upon a bountiful monsoon: the sowing of crops, the dam storages for irrigation during the remainder of the year, hydropower generation, the assurance of year-round supply of drinking water in cities and towns that are fed by local reservoirs, and the industrial output. Any delay in the onset or progress of the monsoon is a matter of great anxiety for the Indian government. Whether the rains would be normal, in excess, or deficient has always been difficult to predict in spite of many scientific advances. On average, India gets all of her rain in < 100 hours each year. The distribution of the monsoon rains can be spatially non-uniform as well: cities could be flooded, but farmlands a short distance away could remain parched; a group of regional states could be reeling under drought, but in another region the government could be battling floods.

In recent years, India's big push for economic growth via fast-paced industrialization has compounded her water stress. Urban sprawls have rapidly increased owing to increased migration from villages, and the demand for water in cities has grown even more rapidly. Nearly 32 per cent of India's population lives in urban areas today. At 135 daily liters per capita, urban India would need 52 million m3 of water a day. Unable to cater to the demands, many cities are trying to source their water needs from locations further and further away. The people and livestock in such places who are dependent on the same water source are thus left with a smaller share for their agriculture or livelihood. Extraction of groundwater to meet shortages has drastically increased, in part due to govt. schemes for development of groundwater resources. The government offer of free electricity and subsidies on diesel, seeds and fertilizer for agriculture, and improved funding facilities for drilling of bore wells, have led to a boom in the bore well industry. Nearly 230 BCM of groundwater is extracted annually, 92 per cent of which is used for irrigation. Farmers who used to grow crops that survived in low rainfall gradually shifted to paddy, wheat, and sugarcane cultivation, lured by the early promises of groundwater availability and the expansion of canal networks (Kaur, 2009). The situation now is that more than 109 BCM of groundwater has disappeared in the agricultural states of north and NW India, and in places where it is over-exploited the water table has fallen alarmingly. In certain regions of India, high concentrations of arsenic, fluoride, or iron can be found in the groundwater. Indiscriminate use of inorganic fertilizers has resulted in increased levels of potassium and nitrates in groundwater.

There are reports of seawater intrusion into coastal freshwater aquifers due to unsustainable extraction of groundwater.

In 2002, the Supreme Court of India directed the Union Government to reconsider the long-pending proposal for inter-basin transfers of India's river waters as a means of overcoming chronic droughts and floods. The interlinking of rivers (ILR) proposal envisages the transfer of water from basins that have surplus to basins that are deficient; with a Himalayan component (HC) for the rivers flowing in the north, NE, and in the upper half of India, and a peninsular component (PC) for the rivers flowing in the southern half of India. The proposal is technically viable, but very expensive to implement at Rs. 5600 billion, estimated a decade ago, and excluding costs of land submergence, R&R, and running costs. Proponents claim that significant benefits would ensue: 0.34 million km^2 of increased area under irrigation, 34 GW of added hydroelectricity generation, 173 BCM/yr of water saved from run-off to seas, constant water supply for domestic, industry and agriculture needs, creation of new job opportunities, etc. Opponents argue about the possible consequences of river diversion, such as altered sediment loads, changes in river deltas, dislocation of villages, loss of prime farmlands and forest cover to make way for new reservoirs, reduced soil fertility, etc.

India currently faces huge shortages in electricity, which is produced mainly by thermal power plants. To meet ever-growing demands for power, for several massive projects in the near future, India plans to add 100 GW to the total installed generation capacity during her XII Plan -mostly through the thermal route, even as a few new hydropower projects are slowly made operational. Increased thermal power generation would place additional demands for massive amounts of coolant water, to carry away the heat rejected in the thermodynamic power cycle. Surface water and groundwater sources would have to be identified for this purpose; in coastal regions seawater could be used as the coolant. It is unlikely that solar-photovoltaic units and wind turbine generators, which require no coolant water *per se*, but intermittently generate clean renewable energy, would significantly meet the enormous demand for electricity in India in the near future.

In the six most energy intensive industries in India, by 2030, the combined freshwater withdrawal will go up by 40 per cent to 57 BCM, 87 per cent of which would be needed for the power sector (Bhushan, 2010). The growing iron and steel industry would be the next largest user of freshwater. Nearly 32 per cent of the freshwater extracted would be consumed (and the rest discharged after use). There would be a six-fold increase in water consumed by the iron and steel, cement, and aluminum industries taken together, to meet the India's industrial growth.

3 Discussion

It may seem that most of India's water stress could be relieved if the ILR project were to be undertaken. But such an immense project requires highly reliable data on rainfall, water balance, stream flows, groundwater levels, etc. collected over many decades, before all the rivers can be linked (Jain, *et al.*, 2008). Rates of silt build-up, channel seepages, geology, topography, and soil conditions for location of new dams, reservoirs and embankments etc. would have to be considered.

Transfer and spread of effluents and pollutants discharged into rivers elsewhere have to be modeled and analyzed. The effects of interlinking on the ecology of rivers are not yet well understood. Compared to the net river water outflow to the Arabian Sea, the net river water outflow to the Bay of Bengal is much larger. The bay receives more rainfall too. Together, they make for less salty (and less dense) waters, which float as a shallow layer on top. The layer is quickly heated by the sun and supports a north-south gradient in the ocean surface temperatures of the bay. This, in turn, leads to a favorable atmospheric pressure gradient that draws in the moisture-laden monsoon winds from the south-west (Gopal Raj, 2011). By diverting waters to lands westward, and curtailing the normal flows of freshwater into the bay, the ILR could end up severely disrupting the intricate interplay of oceans and atmosphere that drive the Indian monsoons each year.

Most of India's big rivers that would be linked under the HC originate in Nepal and Bhutan, and eventually drain into Bangladesh. There are historical Indo-Nepal treaties on the use of river waters from Nepal for benefit in India. But, over the years, Nepalese policies have hardened in response to India's refusal to allow independent assessments of downstream benefits (Chaturvedy and Malone, 2011). No longer is Nepal keen on developing large hydro-projects that would benefit India or protect Indian lands from floods. In contrast, Bhutan has Indian-designed hydropower facilities operating on her soil. This has led to electricity surplus and socio-economic development in Bhutan; the surplus clean electricity is exported to India. If the ILR project diverts flows in the major NE river basins westward, Bangladesh could lose out on a lot of river water. Before embarking on the ILR project, India must do a lot of diplomatic spadework to pacify her neighbors. Instead of grandiose schemes like ILR, or scouting for water sources located hundreds of kilometers away, other effective and far less expensive measures can be undertaken for tackling India's water problems:

a. On the agriculture front, it is necessary for the experts to critically re-evaluate government policies that encourage bumper harvests year after year to maintain excessive buffer stocks. Due to a crippling lack of adequate grain storage infrastructure nationwide, and bottlenecks within the public distribution system, huge amounts of grain are left to rot in the open (Swaminathan, 2011). With un-remunerative minimum support prices on offer, farmers in India's agrarian states of the Punjab, Haryana, and elsewhere, grow three or more crops a year by over-exploiting groundwater, and indiscriminately use pesticides and inorganic fertilizer. As a result, vast tracts of soils are left distressed, with critical deficiencies of essential micronutrients, or have been permanently damaged. In the Punjab alone more than 27,000 km^2 of land are under paddy -lands more suited for cultivation of pulses. Policy action is needed to convince farmers that they can profit from alternative crops like oilseeds, high-protein corn, or pulses that require much less water to grow than paddy. Neglected by government policies, production levels of pulses have stagnated over the past decades. Only small farmers cultivate pulses nowadays. Farmers must be encouraged to grow drought-resistant or submergence-tolerant varieties of wheat and paddy, to minimize risks of unforeseen crop losses. Practices like system of rice intensification that does not require flooding of the fields and promotes the use of organic fertilizer must be extensively followed. For each kg of food grain that is allowed to rot or go waste, nearly 2 to 4 m^3 of water that went into its cultivation are also wasted. A Supreme Court petition filed in 2010 claims that nearly 18 million tons of harvested food grains were being stored in conditions that could render them unfit for human consumption over time. The corresponding water wasted would be enough to meet the normal drinking requirements of India's 1.21 billion people for 15 days. This does not consider the water that was consumed for production of the fertilizer or for the free electricity used for growing those grains.

b. Municipal water supply in India for domestic use occurs for a few hours daily or, in many cases, for a very limited duration once every few days. Nearly 1/3rd of the water supply is lost through leakages in the urban pipe networks (Seth, 2009). Most municipalities lack funds to replace or repair broken pipelines because municipal water schemes are financed through state budgets. Urban pipe networks are poorly designed with substandard materials that do not meet technical specifications. To surmount the problem of leaks, water utilities reduce the supply pressure or cut the duration of supply. Hence, it is very difficult to identify and fix leaks through proper metering of the water consumed. With leaks and low pressures, the water supply is highly susceptible to contamination. Political parties win elections with empty promises of 24/7 water supply but are reluctant to firmly deal with issues of water pricing, out of the fear of losing their vote banks. With claims of caring for the poor, water tariffs are heavily subsidized and do not take into account the true costs involved in sourcing, treatment, and distribution prior to supply, and in re-treatment and disposal of the wastewater thereafter. In this situation, those who have access to subsidized water indulge themselves with excessive use or its wanton misuse. Houses in poor localities mostly remain unconnected to municipal supply and quarrels over water at public taps are not uncommon. In rural areas where caste-barriers prevail, people of "lower caste" have to form separate queues or are denied their fair share of water by the influential "upper caste". There is a perception that only the government, as custodian of citizen interests, must manage water supply. Privatization of water supply may lead to higher tariffs, but water need not become another commodity, so long as there is strict vigilance. Customers are unwilling to pay more because both the quality and quantity of water received at present are less than desirable. Ultimately, without a reliable 24/7 water supply, people have to invest in underground or overhead tanks, electric motors and pumps, or re-prioritize activities to collect and store their share of water. With no guarantees on water quality, people have to purchase water-purifiers or bottled water, or boil their drinking water. Water-purifiers waste water, plastic water bottles end up in garbage heaps, and boiling requires costly energy inputs. Those who cannot afford any of these options suffer from terrible, avoidable diseases.

4 Conclusions

India's development is negated, significantly, by insufficiencies in the supply of safe potable water. Water demands from Indian industry and agriculture would soon overwhelm supply, unless drastic steps are initiated to ensure sustainable use of water resources. Road RWH could save an additional 500 BCM/yr and replenish depleted groundwater reserves, but the government is yet to make this mandatory. The Water, Land and Trees Act (2002) is supposed to regulate groundwater use, but nobody asks for permission to drill bore wells. Officials do not survey the wells because government departments do not coordinate between each other. There is no provision in the law to meter and levy charges for groundwater consumption. This promotes indifference toward groundwater conservation, which must be corrected.

There is an urgent need to connect the National Water Policy and the Nation Action Plan on Climate Change. Powers for management of water supply should be given to the community, and the emphasis must be on revival of traditional local water resources like *ooranis* (village ponds), or *talapariges* (freshwater springs), and rooftop RWH. Urban water resources management needs coordinated approaches to wastewater, solid wastes, and storm-water management. Similar to electrical appliances, water fixtures and other plumbing must be green-rated. Special incentives could be given to reduce water consumption through verifiable improvements in water use efficiencies or re-use.

REFERENCES

Bhushan, C. (2010) Resource war: India after 2020, *Down To Earth* 18 (23), Centre for Science and Environment, New Delhi.

Central Water Commission. (2010) *Water and related statistics*, Water Resources Information Systems Directorate, New Delhi.

Chaturvedy, R. R., and Malone, D. M. (2011) Hydro-diplomacy: a neglected opportunity for Nepal and India, *The Hindu*, Jun. 28, 2011.

Deshpande, V. (2011) National policy for use of river water needed: conservationist, *The Hindu*, May 30, 2011.

Gopal Raj, N. (2011) The oceans and the monsoon, *The Hindu*, Jun. 29, 2011.

Jain, S. K., Kumar, V., and Panigrahy, N. (2008) Some issues on interlinking of rivers in India, *Current Science* 95 (6): 728-735.

Kaur, R. (2009) A home grown drought, *Down To Earth* 18 (8): 23-29.

Ministry of Water Resources. (2009) *Ground Water Resource Estimation Methodology*, Report of the Ground Water Resource Estimation Committee, Govt. of India.

Ministry of Water Resources, Government of India, (accessed on Jul. 12, 2011) at: http://www.wrmin.nic.in.

Seth, B. L. (2009) Divining round the clock water, *Down To Earth* 18 (11), Centre for Science and Environment, New Delhi.

Swaminathan, M. S. (2011) The Wheat Mountains of the Punjab, *The Hindu*, May 11, 2011.

Building Synergies from the UNESCO-IHP HELP and Ecohydrology Programmes in the Guadiana River Basin

SUSANA NETO[1, 4, 5], LUIS CHÍCHARO[2, 5] & JEFF CAMKIN[3, 4, 5]

1 *Centre of Geography and Regional Planning (e-GEO), Faculty of Social and Human Sciences, New University of Lisbon, Lisbon, Portugal*
susana.neto@netcabo.pt

2 *Faculty of Marine Sciences and Environmental Sciences, University of Algarve, Portugal*

3 *Centre of Excellence for Ecohydrology, School of Environmental Systems Engineering, University of Western Australia, Australia*

4 *UNESCO-IHP HELP Program*

5 *UNESCO- International Centre for Coastal Ecohydrology (ICCE), Faro, Portugal*

Abstract In the context of growing demand, loss of quality, increasing regional scarcity, and global climate uncertainty, sustainable water management, as well as more integrated approaches to water planning, are crucial. This is receiving increasing attention through cross-cutting synergetic cooperation between hydrologists and other disciplines. International agencies such as UNESCO are promoters of this dialogue. UNESCO HELP is a cross-cutting programme aiming to improve the links between hydrology and the water needs for society. Complimentarily, the UNESCO Ecohydrology Programme aims to use knowledge about the integrated relations between hydrologic and biologic processes. The Guadiana River, on Portugal and Spain, is a UNESCO HELP basin, and in July 2009, an international HELP forum brought to the Guadiana experts from all continents to discuss, with the planning team and local community, experiences from river basins around the world. More opportunities for cooperation in the Guadiana basin were created with the additional classification of the basin as a Ecohydrology Reference Basin, in 2010. This paper discusses how this particular synergy can be beneficial to the planning process. Under the European Water Framework Directive, river basin plans must integrate ecological, social and economic dimensions. This challenge has proven to be more difficult than expected for European countries. Programs such as HELP and Ecohydrology can effectively support the planning process by improving dialogue between different disciplines, sectors and perspectives on water, resulting in a much richer consideration of the issues and possible solutions. The paper intends to stress the benefits that can be obtained through synergies between UNESCO programs operating within the same river basin.

Key words IWRM; HELP; Ecohydrology; water planning; WFD

1 Introduction

The Guadiana River is an international river basin, shared by Portugal and Spain, and one of the 91 UNESCO-IHP HELP basins around the world. Located in the Castilla-la-Mancha, Extremadura, Alentejo, Algarve, and Andalucia Regions, it is the most important 'water border' between the two countries. It has a total area of 66,800 km^2 (17% of which is inside Portuguese territory - Fig. 1).

The morphology of the river basin divides the region into three zones: the High Guadiana, the Middle Guadiana, and the Low Guadiana. Climate conditions derive from dry Mediterranean characteristics and are almost homogeneous all over the basin, varying slightly from sub-humid to dry and semi-arid (Low Guadiana). It has hot summers, with an average annual temperature of 16º C, high levels of insolation and evapotranspiration, and average annual rainfall between 500 and 600 mm. The characteristic variability of precipitation in southern Portugal has always led to the need for water storage, which was achieved exclusively through the building of dams and water reservoirs along the rivers.

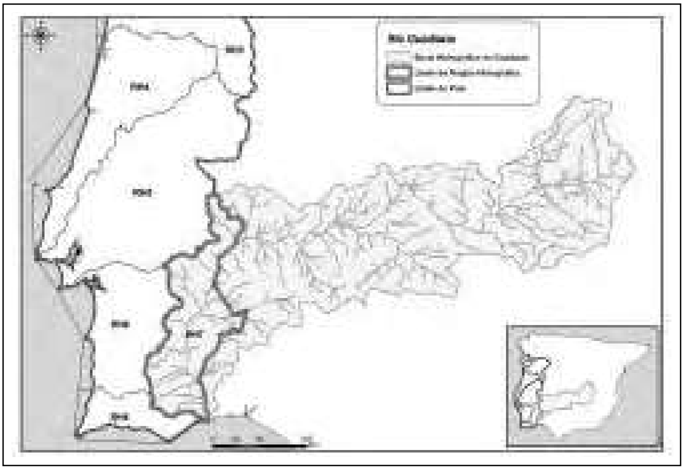


Fig. 1 Guadiana River Basin
Source: ARH Alentejo, 2009.

Increased drought frequency is affecting livelihoods, and over abstraction of groundwater leads to water shortages in summer. The soil erosion and loss process is also a major concern and a serious environmental problem. Awareness of the environmental value of water is an essential consideration in policy adopted, and attention should focus on fostering knowledge about natural processes at the water user level in order to be most effective. However, broader understanding at the river basin, regional, country or even global level also constitutes a learning component in terms of universal and global dialogue.

Desertification is a cause and a consequence of many difficulties in water management in the region. Conflict over different water uses is a major issue for local policies, as well as for central government agencies in the field, with irrigated agriculture representing more than 90% of global uses in the basin.

Additionally, changes in freshwater quantity and quality reaching the coastal area adjacent to the Guadiana estuary are causing changes in coastal primary productivity and causing a shift in fish assemblages, with consequences to commercial fish catches in the area. For example, a shift from planktivorous dominant fish assemblages to demersal-carnivorous fish assemblages has been observed (Chicharo, *et al*., 2005).

2 Institutional Change and Capacity Building in the Guadiana

Under Portugal's 2005 National Water Law, Regional Administrations for River Basins (ARH) were created, establishing a new institutional framework for policy and action. A River Basin Committee was established for the Guadiana to support the river basin's planning process and ongoing management. The Water Framework Directive (WFD) has led to a great change in the current European paradigm on water management. This Directive allows the actions of Member States to be coordinated and gives policies a more comprehensive orientation, striving to approach the available water as a good of high environmental and ecological value, and recognising that all users are responsible for its preservation.

Implementation of the River Basin Plan faces difficulties in coordination between water agencies, due to a very sectoral view of the resolution of water problems and lack of participation of stakeholders in the decision-making process, mainly in the planning activities.

The legislation for Integrated Water Resource Management (IWRM) is not inadequate, but its enforcement is not easy; there are recurrent problems of surveillance and monitoring (either on abusive uses, lack of metering, water quality degradation by effluent discharges, or simply bad practices in agriculture, animal husbandry, etc). The participation of stakeholders can be reinforced through the activation of regional and local levels of discussion, for example, through the existing River Basin Committees. These can become quite a strong instrument for the discussion of expectations and common decision-making, and might help to develop a wider perspective on 'water governance' in the region.

Local governments (municipalities) play a very important role in development processes; their opinions and local policy perspectives are crucial to establishing effective IWRM in the river basin.

3 Water Planning for the Guadiana Basin under the European WFD

IWRM and 'Good Water Governance' in the Guadiana basin means having a better understanding of the main issues that affect social dimensions of water access and the consequences of water stress. It includes managing the impacts and expectations created by interventions like the Alqueva dam, for example, which will cover some water uses (irrigation land, mainly) and not others (loss of property and cultural and patrimonial values, negative impacts). The management of these issues is increasingly becoming a global water concern that must be handled at local and regional levels.

Water systems are permanently changing and exposed to human pressures. Regulation mechanisms may fail at local or regional levels, leading to crises affecting the environment and/or the social systems of larger regions. The incapacity to control water pressures may uncover institutional inadequacies in the management of water systems and insufficient public participation in decision making (Roxo, *et al*., 2008).

The complexity of water management emerges from the need to properly articulate a great diversity of subsystems at very different levels. A multi scale approach allows the simultaneous consideration of local issues, the regional context and characteristics, the national institutional frame conditions and guidelines, and the evolution of land use patterns. Institutions regulate the articulation between the different subsystems of water management at different scales; therefore, the institutional framework in which water management is embedded is a very relevant factor. Some problems must be addressed in a short term perspective at the local level, whereas others (with strategic character) must be addressed at the global level within a long term perspective. The spatial dimension does not only refer to the delimitation of the bio_physical system "water", but also to the social and institutional arrangements that determine the level of human intervention in the system (Neto, 2010).

In the Guadiana basin there is a strong need for 'agency' -for individuals and organisations to demonstrate leadership not restricted to implementing the law- that may overcome bureaucratic mechanisms. There is also a clear need for capacity building of planners, both from a water and spatial planning side, aiming at achieving a deeper understanding of contemporaneous complexity of integrated processes, as well as understanding that planning is a dynamic process. A stronger communication during all planning processes to support alignment of different plans can be an effective way to enhance the integration mechanisms, through dialogue and concerted action (*Ibid*).

4 Discussion

4.1 UNESCO-IHP HELP in the Guadiana

The Guadiana River Basin has been involved in the HELP Program since 2004, and was accepted as a continuing catchment for the third phase (2009-2013). Key objectives for HELP in the Guadiana Basin are:

- Contributing to a better coordination and dialogue among different water and land use planning and management administration entities in the territory of the basin, based on an enlarged social understanding and cooperation towards IWRM aims
- Deepen research on the interaction between upstream and downstream processes as a basis for promotion of sustainable ecosystem uses
- Improve the knowledge base for policies and decision-making processes, at local and regional (river basin scale) levels (institutional framework and necessary changes)

In 2009, an International Seminar was held in Évora, Alentejo, supported by the Regional Administration of Water Resources (ARH), and involving the main sectors working in the field for the River Basin Management Plan (now in its final phase and ready for public discussion). The recommendations for policy change in the Guadiana basin can be summarized in three main points (Neto, 2010):

- Address the lack of linking mechanisms inside the institutional and planning systems, and call for the capacity building of planners, both from the water and the spatial planning side
- Improve awareness on the various sectors and stakeholders that use and benefit from water systems to become effective partners and build common agendas for action
- Strengthen the "agency" role of ARH, involving the other partners and sectors, and building the arena for negotiation of objectives for the water systems management and planning

For any of these areas of intervention, there is clearly a potential for the HELP Programme to provide some guidelines, and to inspire the ARH to play an intermediary role in communication between the Central Administration, the Local Authorities, the local communities, and other actors, thereby promoting change towards an effective IWRM in the Guadiana River Basin.

4.2 UNESCO-IHP Ecohydrology Program in the Guadiana

UNESCO's Ecohydrology Program is focussed on an integrated understanding of biological and hydrological processes at a catchment scale in order to create a scientific basis for socially acceptable, cost-effective, and systemic approaches to the sustainable management of freshwater (UNESCO, 2011). Within this Programme, Ecohydrology Demonstration Sites have been established to recognise places where sustainable, innovative, and transdisciplinary water management practices, based on Ecohydrology principles, are implemented, and to showcase how to identify, quantify, and improve the critical interrelationships between water, biota, and social systems for sustainable water management. These sites are being featured in scientific research and training activities under the program. The objectives of the Ecohydrology network are to: "(1) bridge knowledge gaps for addressing ecohydrological issues relating to water ecosystems under pressure; (2) showcase how better knowledge of the biological and hydrological interrelationships in aquatic ecosystems can promote the long term sustainable carrying capacity of ecosystems, and thus contribute to more cost-effective and environmental-friendly water management, and (3) demonstrate systems solutions and technology transfer opportunities through North-South and South-South linkages by working closely with the UNESCO IHP Water Family" (UNESCO, 2011). The UNESCO IHP 'water family' refers to the global network of UNESCO Headquarters, IHE, World Water Assessment Program, water related Institutes and Centres, UNESCO's Regional and Cluster Offices, and water-related Chairs.

The Guadiana is one of only two Global Reference Projects within the Demonstration Projects Network, and is focussed on sustainable estuarine zone management for control of eutrophication, toxic blooms, invasive species, and conservation of biodiversity in the Guadiana estuary, which is also part of the Guadiana HELP Basin. The Guadiana estuary is affected by the Alqueva Dam, which modified the hydrological regime and ecological function of the river, estuary, and adjacent coastal area. Consequently, scientific activities in this Ecohydrology Global Reference Project are directed towards finding Ecohydrology-based solutions for coastal systems impacted by large dams. Educational activities, coordinated through the International Centre for Coastal Ecohydrology (UNESCO-ICCE) and the University of Algarve, Faro, are framed around demonstration site implementation at the Guadiana saltmarsh area.

The overlap between the Ecohydrology and HELP programs at the Guadiana provides and important opportunity to acquire an overall perspective of the catchment and the challenges and solutions for the Guadiana estuary. With a stronger focus on policy integration and more connections to policy-makers around the world, the HELP program can assist the integration of Ecohydrology principles and activities into water planning for the Guadiana, and by way of demonstration, support policy making elsewhere.

4.3 The UNESCO International Centre for Coastal Ecohydrology

The location of the UNESCO International Centre for Coastal Ecohydrology (UNESCO-ICCE) at the mouth of the Guadiana estuary in Faro, Portugal, provides a unique opportunity for management-focussed research attention on the Guadiana estuary relevant to both the HELP and the Ecohydrology Programs. For example, the UNESCO-ICCE is involved in a project aimed at the harmonisation of methodologies for implementation of the WFD between Portugal and Spain. Further, as part of both the HELP and the Ecohydrology networks, the UNESCO-ICCE is actively involved in the development of new research proposals under the European Research Framework Program 7 (FP7), and the European Neighbourhood Policy (ENPI). These multi-national proposals are being developed in consultation and collaboration with the core water planning organisations for the Guadiana, the Regional Administrations for River Basins (ARH) in Portugal, which are national Partners of the UNESCO-ICCE, and with institutional and other partners in Spain.

The HELP network has also been actively involved in delivery of education through the UNESCO-ICCE and the University of Algarve. In addition to collaborating on this paper, the authors were invited to develop and deliver new courses in Global Water Issues and IWRM (December 2010), and Global Ecohydrology in Action (August 2011), as part of the Erasmus Mundus Master of Science (EMMC) program in Ecohydrology. These courses highlighted the HELP and the Ecohydrology programs, including online presentations to students and interactive tutorials from HELP network members in France, New Zealand, Philippines, Malaysia and Belgium.

5 Conclusions

The substantial benefits that individual UNESCO programs such as HELP and Ecohydrology can bring to local communities was evident from the 2009 HELP forum in Évora. Local water planners and other decision-makers, researchers, and the Guadiana community simply would not have had the opportunity to access a world of possible solutions to their water challenges if the Guadiana was not a UNESCO HELP Basin. Now, the combination of a HELP Basin, an Ecohydrology Global Reference Site, and the International Centre for Coastal Ecohydrology all overlapping at the Guadiana basin provides a unique situation and an even greater opportunity for enhancing research, management, and policy making, not only in the Guadiana but also globally.

The triangulation of UNESCO water programs and institutions, together with others in the region where the Guadiana serves as a field site (including UNESCO World Heritage and UNESCO Man and Biosphere), creates numerous potential synergies. These include the opportunity for more coordinated and effective investment in research, teaching, community consultation, and information management.

The Guadiana is an international river basin in an area particularly vulnerable to climate change, already suffering a wide range of challenges including water scarcity, declining water quality, and social desertification. It is a focal area for the UN Convention to Combat Desertification, and was also a WFD implementation reference basin.

Its diverse range of very significant challenges, current management imperatives, fundamental and applied research needs, and multiple overlapping UNESCO programs and institutions, provide a unique opportunity to develop the Guadiana as an institutional testing laboratory for water governance.

REFERENCES

Chícharo L., Chícharo A., Ben Hamadou R. and Morais P. (2005) 'Ecohydrology in estuaries and coastal areas: the Guadiana estuary case'. In: *Water and Ecosystems: Water Resources Management in Diverse Ecosystems and Providing for Human Needs*. UNU/INWEH publications. 13pp.

Neto, S. (2010) *Water, Territory and Planning. Contemporary Challenges: towards a Territorial Integration of Water Management*. PhD Thesis. September 2010.

Roxo, M.J. (Coord), Neto, S., Nunes da Silva, F. and Gonçalves Henriques, A. (2009) *Analysis of Stakeholders Expectations in Regions with Water Scarcity - Lessons for Water Governance*. Project FCT: PDCT/AMB/57633/2004.

UNESCO (2011) *Ecohydrology for sustainability*. International Hydrological Programme, UNESCO Division of Water Sciences, Paris, France. 2011. 24 p.

Sustainable Water Governance and Institutional Strengthening through Integrated Watershed Management Practices in Andhra Pradesh, India

SUVARNA CHANDRAPPAGARI
Indian Forest Service, Department of Rural Development, Andhra Pradesh, India
suvarnac@yahoo.com

Abstract Andhra Pradesh (AP) is the fifth largest state in India, with large stretches of rain-fed areas under watershed programs since 1994. This study analyzes pro-poor watershed based sustainable approaches and strategies implemented in drought prone districts under two projects: the APRLP (Andhra Pradesh Rural Livelihoods Project), funded by the DFID (Department For International Development of the United Kingdom), and the World Bank funded APDAI (Andhra Pradesh Drought Adaptation Initiatives), in order to understand the quality, impact, and sustainability of watershed activities. The analysis is done by studying the cases, impact assessment, and documents pertaining to the processes, productivity enhancement interventions, institutional innovations, operational strategies, and convergence of institutions. Multiple deprivation (social & material) criteria viz., low potential for irrigation development, household incomes and asset bases, seasonal food distress, land ownership, and natural resource degradation indicators were taken into consideration for selecting areas for treatment. Impact-response matrixes and participatory net planning were extensively used in both the projects, and pilots were initiated in various combinations: diversifying cropping and farming systems, securing access to surface and ground water, and livestock production. Another important aspect was diversifying the portfolio of income opportunities for the poor by providing institutional linkages for micro-credit, and extending revolving funds for arranging household credit to women self help groups and their federations, to promote micro-enterprises. The initiatives resulted in addressing equity and empowerment issues in watershed management. The recommendations include bridging the gaps in watershed projects implementation by focusing more on strengthening the village level institutions, encouraging community groundwater management, diversifying agricultural practices, and adopting new technologies/successful innovations.

Key Words Watershed management; rural livelihoods; community groundwater management; sustainable institutions; impact and response matrix; participatory net planning

1 Introduction

Andhra Pradesh (AP) is the fifth largest state in India, with a population of 76 million, out of which 35 million live in eight drought prone districts. The majority of the people in these districts depend on rain-fed agriculture for their livelihood, but frequent drought years adversely affect the crop and livestock yields. About 60% of irrigated agriculture is groundwater based, due to low and erratic rainfall, thus resulting in the over-exploitation of groundwater from aquifers. Households falling below the poverty line and marginally above the poverty line have become vulnerable to even marginal changes in the environment (CESS *et al.*, 2003; Vijaya Kumar, *et al.*, 2009; MANAGE, 2008).

Watershed development has been implemented as an important strategy in these areas to achieve soil and water conservation by optimizing land use production systems and using sustainable, low cost, location-specific technologies. In the above context, watershed development programs are important instruments in revitalizing rural economy in highly drought prone rain-fed regions of AP. Totally, about 6795 watershed projects have been sanctioned (4242 under DPAP - Drought Prone Area Program, DDP - Desert Development Program, and IWDP - Integrated Wasteland Development Program) by the Government of India (GOI) from 1994-95 to 2006-07, out of which 4560 are still going on in 22 rural districts of AP. Each watershed project covers 500 hectares of rain-fed area. Meanwhile, the watershed guidelines and processes that evolved over due course of time (GOI, 2008) have led to the sanctioning the Integrated Watershed Management Program (IWMP), from 2010-11 onwards, covering 17,450 micro watersheds (approximately 11 million hectares), with a financial outlay of $3.4 billion.

2 Study Objectives

- To analyze pro-poor watershed based approaches and strategies for understanding the quality, impact, and sustainability of various watershed activities.
- To understand the influence of these programmes on policy and scaling up
- To recommend possible measures to be undertaken for successful watershed project implementation.

3 Study Methodology

The analysis was done by studying the cases, impact assessment (TARU, 2007), documents pertaining to the processes (WASSAN, 2009), productivity enhancement interventions, institutional innovations, operational strategies, and convergence of institutions. Relevant details of each project are furnished separately, and conclusions cover salient points from the two projects: the Andhra Pradesh Rural Livelihoods Project (APRLP), and the Andhra Pradesh Drought Adaptation Initiatives (APDAI).

4 Andhra Pradesh Rural Livelihoods Project (APRLP)

The APRLP, a joint initiative of the DFID (Department For International Development of United Kingdom) with the Government of Andhra Pradesh, was implemented from 2001-02 to 2008-09 in five semi-arid and drought prone districts of AP, viz. Anantapur, Kurnool, Mahabubnagar, Nalgonda, and Prakasam, with the aim of strengthening the ongoing watershed development program by adopting a participatory and pro-poor approach to improve rural livelihoods. APRLP was a 'watershed-plus' project that was designed to step beyond natural resource management to address the needs of marginalized and vulnerable groups of people, such as those with no land, women, and the poorest segments of the community. The APRLP set out to consciously learn from, and build upon the past experiences of watershed development in AP. It attempted to ensure a greater focus on poor people's lands, improve participation, shift to cost-effective structures, and improve the quality of natural resource management.

4.1 Diversification and Strengthening of Livelihoods

The APRLP focused on provision of direct livelihood benefits to the landless poor as a priority, by earmarking two separate components: $9000 towards productivity enhancement, and $6600 towards enterprise promotion. The allocated funds were released by the District Water Management Agency according to the Village Organization (VO)'s action plan. This plan was constituted as a revolving fund operated by the VO, which is a federation of women Self Help Groups (SHGs) in the village. Each SHG has 10 to 15 members from homogeneous background. The revolving funds were rotated among the identified families/activities for a set period as decided by the VO. The interest and repayment rates varied across VOs and activities. Micro-enterprise action plans and financial credit plans were prepared for the members of each SHG by taking stock of each member's requirements. The focus was on the identification and promotion of non-farm enterprises and the development of livestock, including small ruminants, through appropriate mechanisms like assured feed, orientation on animal healthcare, and insurance coverage to animals.

4.2 Processes and Institutional Innovations

A nine-point selection criteria was devised for selection of project areas. These criteria integrated natural resource degradation criteria with multiple deprivation criteria (social and material deprivation) in order to get reliable indicators for both technical and social features. Community based organizations and non-government organizations (NGOs) were selected as Project Implementing Agencies. Participatory net planning was done so as to assess the needs of each individual household in the project area. The women SHGs and VOs were actively involved in all processes.

4.3 Productivity Enhancement (PE)

With the overall objective of increasing the impact on poverty through increased agricultural and livestock productivity, as well as improved livelihood opportunities, the APRLP formulated strategies by allocating 30% (about $20,000) of the total project outlay, which spread over sub-components as follows: revolving fund (78%), adoptive trials (11%), and infrastructure development (11%). The revolving fund was mainly utilized for extending loans to purchase seeds, fertilizer, pesticides, low-cost agricultural implements, and milking cattle. The repayment schedule was fixed by the members themselves based on the activity initiated. Adoptive trials were taken up on a limited scale to demonstrate seed production, integrated nutrient management, integrated pest management, low-cost equipment, innovative water saving agronomic practices like SRI (System of Rice Intensification) in paddy, etc. In case of livestock management, artificial insemination, de-worming, vaccination, and fodder production were the focus areas. Low-cost infrastructure such as vermi-compost units, bio-pesticide units, micro-irrigation systems, and new technologies were provided by the project with 10% to 20% contribution by the beneficiaries.

4.4 Impact on Natural Resource Management

The Project recommended several cost-effective structures to meet the conservation and augmentation of four types of water: rain water, soil moisture, surface water and groundwater, so as to increase rain-fed agricultural productivity and enable farmers to withstand dry spells. The project encouraged farmers to grow cover crops on all rain-fed land, in order to provide green manure as well as to reduce soil moisture evaporation, enabling rain-fed crops to withstand drought for a period of 15 - 30 days.

There has been a three-fold increase in the number of surface water sources, notably percolation tanks, followed by check dams. There was a major increase in the number of water availability months in surface water sources, and about 50 percent of the watersheds reported an increase in the groundwater table. Fallow lands were brought under cultivation due to watershed interventions and availability of credit. The project tried to demonstrate approaches to increase crop and livestock productivity by dedicating a portion of the watershed budget to them. Increase in gross cropped area, number of farmers taking up a second crop, and enhanced crop productivity was noted. Loans provided under productivity enhancement were mostly used for purchase of agricultural inputs.

4.5 Impact on Incomes, Food Security, and Livelihoods

Revolving funds for household credit played a crucial role in improving incomes -particularly of target groups such as landless, marginal farmers, and women-headed households. The livestock assets increased, though there was no significant impact on ownership of land or agricultural equipment. The average number of months of food distress was reduced due to the crucial role played by SHGs and VOs, by providing food grains on credit at reasonable rates. However, the overall level of diversification was low, since majority of loans were used for dairying and sheep and goat rearing. Expenditure on food and on debt-servicing constituted a major share of household expenditure, and distress related to food availability was still present in some areas.

4.6 Sustainability of Institutions

The APRLP departed from an entirely subsidy-based approach to watershed development, which had been practiced until then in India, to a credit-based approach, through two key components: Productivity Enhancement and Enterprise Promotion. The creation of revolving funds out of project grants and their placement with VOs ensured an element of sustainability of the project beyond its lifetime. The APRLP approach successfully tackled gender imbalances in representation, participation and decision-making, by providing a central role to VOs and SHGs in the project, and building their capacities to plan and manage natural resources and other livelihood activities through sustainable financial models.

5 Andhra Pradesh Drought Adaptation Initiatives (APDAI)

The APDAI project was started in the year 2006 with financial assistance by a World Bank-executed trust fund and a recipient-executed Japanese PHRD (Policy and Human Resources Development) Climate Change Initiative Grant (CCIG). Two highly drought-prone districts, Anantapur and Mahbubnagar, with heavy dependence on groundwater, were selected for the initiative.

5.1 Interventions

The APDAI was limited to four areas of intervention: (i) production systems, (ii) institutional support and capacity building, (iii) management of common natural resources, and (iv) economic instruments and marketing. A dual focus strategy, based on natural resource conservation and socio-economic improvement, was developed, keeping in mind the above interventions with the aim of improving livelihood.

5.2 Technical Challenges

The technical challenges were defined as: (i) securing access to water, in particular to groundwater for all households to meet their livelihood needs, as well as for critical irrigation of rain-fed crops; (ii) diversifying cropping and farming systems for better drought resilience; (iii) diversifying the portfolio of income opportunities, for the poor in particular, through the livestock and fisheries sectors; (iv) creating resource buffers, in particular for water, fodder and seeds, through localized storage facilities and quick institutional response mechanisms, and (v) integrating innovations into regular government programs as an important condition for up scaling and sustainability.

5.3 Processes

Village institutions, specific stakeholder groups such as farmers, herders, and landless people in the villages, as well as representatives from government departments, were involved in discussions, and an “impact and response matrix” was developed. This matrix systematically identified the expected negative and positive impacts of climate variability and change, the response strategy that would be required to manage these impacts, and specific pilot initiatives that translated that strategy into actionable interventions. In all, 19 pilot initiatives were identified, and almost all intervention measures were related to water management, as water is a limiting factor in dry land natural resource management systems.

5.4 Pilot Strategy and Approach

Since successful drought adaptation strategies should include the creation of employment opportunities outside the agriculture sector, to release the pressure on the natural resource base, issues such as migration policy and remittances become an important part of an inclusive strategy. This policy was complemented by a set of institutional and policy conditions, and the challenges of the pilot strategy were defined as:

- Broaden access to water for all households to meet their livelihood needs, and in particular to groundwater, to allow for critical irrigation of rain-fed crops
- Better management of soil moisture by increasing organic matter in the soils
- Better irrigation agronomy
- Diversify cropping systems, in particular rain-fed systems, by introducing a mix of short and long duration crops, annual and perennial horticultural crops, and by integrating food and fodder crops into the systems
- Diversify the portfolio of income opportunities
- Create resource buffers, in particular for water, fodder, and seeds, through localized storage facilities and/or through quick institutional response mechanisms

5.5 Community Based Groundwater Management

In India, groundwater is a private property, and the existing Laws are not sufficient to manage groundwater effectively. The APDAI addressed the problem of groundwater management by connecting all tube wells through a common pipeline, to which sprinklers were connected, in order to demonstrate to bore well owners the advantages of sharing "their" water with non-bore well farmers. Non-bore well farmers committed themselves not to drill any new wells for at least a ten-year period. The installation of pipelines and sprinklers ensured irrigation on larger areas for bore well owning farmers.

5.6 Livestock Interventions

Up scaling of fisheries cooperatives, breed improvement in sheep, chick rearing centers, and livestock insurance were taken up, which showed positive results by providing enhanced incomes to poor families.

6 Lessons Learned

Strong leadership and civil society organizations are necessary for successful adaptation measures, along with well functioning government structures that are willing to innovate and change. Intensive and inclusive dialogue with all stakeholders is a prerequisite for "thinking innovatively" about adaptation to climate change. A strong synergy between natural resource management and livelihood development is a successful approach. Technical solutions are often simple, but the challenge lies in the enabling environment. For any activity to stand the test of time, it must be economically viable for the individual or group of individuals who undertake it.

7 Conclusions

The APRLP and APDAI's emphasis on capacity building, livelihoods, and participatory pro-poor approaches to natural resource management resulted in greater transparency of the watershed development program and increased responsiveness of village communities. Both programs successfully demonstrated that watershed development could be pro-poor, gender-sensitive and have a livelihood focus. The watershed selection processes, which were a judicious mix of technical and social criteria, and targeting the poorest and most marginalized groups within the selected watersheds also played an important role in making the efforts focused. The process guidelines for watershed development (GoAP 2005a; GOAP, 2005b; GOAP, 2006) successfully combined the APRLP approach with watershed guidelines.

The recommendations of the Government of India's Technical Committee on watershed development and common guidelines (GOI 2008) broadly reflect APRLP's approaches, particularly those relating to production systems enhancement, micro-enterprises, livelihoods, capacity building, and gender. However, some initiatives, like community groundwater management and livestock management, have to be further encouraged.

8 Recommendations

Existing rural employment programs should be dovetailed with watershed programs for enhancing asset creation and employment generation besides scaling up the innovative practices. More stress has to be laid on diversifying agriculture and livestock practices, adoption of new technologies and successful innovations, and making efforts to see that dry land farmers are equally benefited as the farmers that have irrigation facilities. Though adopting community groundwater management universally is a difficult proposition under present circumstances, it should be encouraged as much as possible. The successful interventions need to be integrated into watershed project formulation and planning as a requirement. Village level institutions have to be strengthened through capacity building in watershed related activities with a longer-term perspective. Impact assessment studies have to be regularly carried out so as to bring innovations into the mainstream, or to carry out corrections, if required.

REFERENCES

CESS, AF. SEI and APRLP. (2003) *Watershed based livelihoods approach: A policy action research programme in Andhra Pradesh*. Centre for Economic and Social Studies (CESS), Hyderabad, Accion Fraterna (AF), Anantapur and Department of Rural Development, Government of Andhra Pradesh. pp 1-20.

GOAP. (2005a) *Process Guidelines for Watershed Development*. Issued by Commissionerate of Rural Development, Government of Andhra Pradesh, Hyderabad. pp 10-30.

GOAP. (2005b) *Circular No.8/CLDP/2004*, dated January10, 2005.

GOAP. (2006) *Memo No.19957/RD-II/A1*, dated November 6, 2006.

GOI. (2008) *Common Guidelines for watershed projects implementation*. Issued by Department of Land Resources, Ministry of Rural Development, Government of India, New Delhi. pp 15-40.

MANAGE. (2008) *Farmers' suicidal deaths in Andhra Pradesh state-A diagnostic study*. National Institute of Agriculture Extension Management (MANAGE). Hyderabad. pp 106-112.

TARU. (2007) *Assessing the impact of APRLP on poverty (end-term assessment) Final Report-Volume I*, submitted to Commissioner of Rural Development, Government of Andhra Pradesh, Hyderabad. pp 5-106.

Vijaya Kumar, Raidu and Paramesh shah. (2009) *Ecologically sound, economically viable: community managed sustainable agriculture in Andhra Pradesh, India.* The World Bank. Washington D.C. pp 5.

WASSAN. (2009) *APDAI-Final Report-II of the Lead Technical Agency*, submitted by Watershed Support Services and Action Network (WASSAN), Hyderabad to Commissioner of Rural Development, Government of Andhra Pradesh, Hyderabad. pp 2-85.

An Alternative Compliance Framework for Urban Stormwater Management in California's Central Coast Region

VIOLETTA PRISTEL
Coastal and Watershed Science & Policy, California State University, USA
violettapristel@gmail.com

Abstract The objectives of stormwater management and urban development are often in conflict. Urbanization modifies watershed hydrology, increases stormwater runoff, and impacts the quality of receiving waters. Local governments are increasingly required by state and federal law to regulate stormwater management practices within urban development projects, to offset these impacts. Balancing the need for environmental protection with the need to accommodate an increasing population while encouraging economic growth requires policy tools to cost effectively manage stormwater runoff and urbanization. There is a growing interest in alternative compliance tools, such as credit trading and mitigation banking, to integrate stormwater management and urban planning at the watershed and regional scale. An alternative compliance approach provides off-site compliance options, which allow municipalities the flexibility to meet regulatory requirements to support the optimization of stormwater management, community development, and natural resource protection within a watershed or region. This paper describes the legal and regulatory framework of alternative compliance, including existing policy, legal authority, scope of offset, and fee-based trading options, as well as potential constraints on implementation. The purpose of the research is to help municipalities in California's Central Coast Region assess the feasibility of alternative compliance within their jurisdictions.

Key words Watershed planning; water quality trading; offset mitigation

1 Background

California's Central Coast Region is over 300 miles long and 40 miles wide, extending from Santa Cruz in the north to Santa Barbara in the south. The region has a range of wet and arid climates and is geographically diverse. It includes urban and agricultural land use, and habitat areas such as wetlands, dunes, forests, coastal chaparral, and grasslands. Over 2 million people live in the region, most of them in cities and towns on or near the coast, and development pressure remains an ongoing reality as more people are drawn to the region. Urbanization results in increased impervious surfaces such as roads and parking lots, and brings drainage infrastructure to manage the increased runoff and reduce flood risk. The term "hydromodification" describes alterations of the hydrologic regime as a result of land-use changes. The combination of increasing imperviousness, efficiency of water conveyance, and decreased pervious coverage disrupts the hydrology of a watershed, which can result in adverse impacts to receiving waters. pLarge volumes of rapidly moving stormwater increase peak flows in streams during storm events and cause bank scouring and erosion. Increased imperviousness reduces groundwater recharge and its contribution to stream flow. Urban stormwater picks up pollutants such as bacteria, heavy metals, nutrients, pesticides and sediment from a variety of sources, including lawns, septic tanks, roads, and industry, which degrades water quality. The Central Coast Regional Water Quality Control Board believes protecting watersheds, including groundwater recharge areas, aquatic habitat, and riparian buffer zones, will have the greatest impact on water quality improvement in the region over the long term.

Municipalities in the United States are increasingly required by federal and state laws to regulate stormwater. The National Pollutant Discharge Elimination System (NPDES) program was established in 1972 under the Federal Clean Water Act to control water pollution from point sources. Since 1990, municipal operators must obtain a NPDES permit and develop a stormwater management program to prevent harmful pollutants from being washed or dumped into sewer systems from point and nonpoint sources.

New regulations for development and redevelopment projects will be requiring hydromodification control and Low Impact Development (LID) as part of municipal stormwater NPDES permits. Compliance with LID and hydromodification control requirements revolves around the use of structural and non-structural on-site Best Management Practices (BMPs). On-site requirements aim to address cumulative impacts of site-scale development, encourage watershed-scale restoration/protection of pre-development hydrological processes, and ensure an equitable 'polluter pays' stormwater management system. Hydromodification control requirements are designed to mimic the pre-development runoff characteristics of a site (LID, 2007). Structural LID BMPs are designed to capture or temporarily retain stormwater (e.g., rainwater harvesting, rain barrels), infiltrate stormwater (e.g., biofiltration swales, pervious pavement), and promote evapotranspiration (e.g., green roofs, rain gardens). Non-structural LID practices include site and road design to minimize impervious surfaces, maintaining vegetated areas, and minimizing site disturbance.

Alternative Compliance is a term used to describe a provision offered by municipalities which allows developers to meet new and redevelopment requirements for stormwater control *off-site* of a project. Flexibility in meeting regulatory requirements is often desired by a municipality in order to have a venue to allow developers proposing a development project to pay the municipality a sum of money to implement stormwater controls at a different location within the watershed. Developers may require flexibility in meeting regulatory compliance if LID BMPs are infeasible on-site due to space limitations, soil conditions, depth to groundwater or construction costs. The Central Coast Region lacks a structure to consider alternative compliance off-site options in NPDES municipal stormwater permits. For example, where on-site BMPs are infeasible, a developer may receive a compliance exemption instead of paying for an alternative, which is neither fair, economical, nor achieves water quality or watershed restoration objectives. It may also be a missed opportunity to direct natural resource protection and restoration where it is of highest value in the watershed.

This paper describes the legal and regulatory framework of alternative compliance. The objectives of the ongoing research are to synthesize the legal, environmental, technical, and socioeconomic considerations of alternative compliance to help municipalities in California's Central Coast Region assess the feasibility of alternative compliance within their jurisdictions.

2 Legal & Regulatory Framework

Existing Alternative Compliance Policy

Alternative compliance policies being used in other jurisdictions in the United States generally include two options:

- Offset on-site runoff ('*offset trading'* in this paper) with LID treatment measures at an off-site project. Offset trading should provide hydraulically sized treatment of an equivalent quantity of stormwater runoff and pollutant loading, and achieve a net environmental benefit.
- Pay in-lieu fees ('*fee-based trading'* in this paper) to a regional project (a treatment BMP that collects runoff from multiple projects in the same watershed). An in-lieu fee, a form of offset, is the monetary amount necessary to provide a proportional share of runoff treatment to a regional project. A mitigation bank accumulates fee-based 'credits' in advance and makes them available for purchase later.

Credit trading is a mechanism used to implement alternative compliance programs and provide equivalent mitigation to compensate for a waiver of LID and hydromodification requirements.

The principle of stormwater credit trading is to allow a runoff source that can 'over control' stormwater at a low cost, to sell the over control as credits to a runoff source in another location that is not able to achieve requirements on-site due to site limitations or economic feasibility. The quantity of stormwater credits exchanged might be based on stormwater discharge or best management practices. Credits may also be fee-based, in-lieu of stormwater treatments not implemented on-site. Alternative compliance programs allow developments to proceed provided there are no *net* environmental impacts and can also be designed to achieve net environmental improvements.

Legal Authority

The Federal Clean Water Act authorizes municipal NPDES permits to address urban nonpoint pollution sources such as development through the implementation of BMPs to the 'Maximum Extent Practical' (MEP) statutory standard. The Clean Water Act also provides legal authority for the Environmental Protection Agency (EPA) and States to develop alternative programs to control pollution, and allows regional water boards in California to incorporate alternative compliance provisions into NPDES permits. The California Water Code gives the nine Regional Water Quality Control Boards in California the authority to protect beneficial uses of waters of the State and establish water quality objectives. The Water Boards have broad discretion to implement innovative natural resource protection programs because the California Water Code allows them to regulate any activity that affects the quality of surface water or ground water (LID, 2007).

The two key federal regulations supporting alternative compliance are the Water Quality Trading Policy and Mitigation Memorandum of Agreement. EPA's Water Quality Trading Policy supports offset trading. The policy, promulgated in 2003, is intended to offer an economically efficient alternative means of achieving clean water goals while allowing for community growth (USEPA, 2003). The policy recognizes that different pollutant sources may have different costs for reducing pollution charges, that different activities have different impacts on the economy of a community, and that communities should be allowed flexibility to meet water quality criteria (Trauth and Shin, 2005). The policy allows one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution control costs, with the requirement that no trade can exceed water quality criteria anywhere within a waterbody (USEPA, 2003). The policy provides guidance for using flow as the trading parameter across wet weather sources, which may support a stormwater offset trading program for new development and redevelopment (USEPA, 2007).

The 1990 Mitigation Memorandum of Agreement (MOA) between the EPA and the Department of the Army, under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act, states off-site mitigation is permissible if on-site compensatory mitigation is not practicable (ILF, 2000). The objectives of the MOA are to allow compensatory mitigation projects designed to replace wetlands and other aquatic resource functions and values protected under the Acts and to meet the goal of no overall net loss of wetlands and other aquatic functions and values (ILF, 2000). Off-site mitigation may be performed by the permittee or by a third party. Third party mitigation generally falls into one of two categories: mitigation banking and in-lieu fee mitigation. The objectives of the MOA are not specific to stormwater mitigation; however, it provides a legal framework for fee-based trading.

Scope of Potential Alternative Compliance Solutions

The EPA's Water Quality Trading (WQT) policy provides guidance for offset trading (USEPA, 2003; 2007). The Federal Guidance for the Establishment, Use and Operation of Mitigation Banks (FED, 1995) and the Federal Guidance on the Use of In-Lieu-Fee Arrangements for Compensatory Mitigation (ILF, 2000) provide guidance for fee-based trading. The scope of offset and fee-based trading options are compared below using key sections from the guidance documents, including allowable trading currency, quantification of credits, geographical constraints, and implementation deadlines. The guidelines may be used by municipalities to form their own specific alternative compliance standards.

Trading Currency and Allowable Mitigation Type

• *Offset trading:* Units of trade must be clearly defined for offset trading to occur (USEPA, 2003). A trading currency based on estimated runoff volume or impervious surface area may be acceptable; however, the WQT policy only allows cross trading between commodities with a defined or established translation ratio (USEPA, 2007). For example, trades between runoff and riparian buffer area, or runoff and groundwater recharge area would not be acceptable unless there is adequate information to correlate impacts on water quality.

• *Fee-based trading:* The trading currency of fee-based trading is the aquatic resource functions to be compensated. Fee-based trading guidelines state a preference for 'in-kind' compensation but may allow 'out-of-kind' compensation (cross-trading) if it achieves a greater ecological value (FED, 1995).

Quantifying Credits and Mitigation Equivalency

• *Offset trading:* Offset trading credits are based on the trading currency's impact over time (e.g., stormwater flow) yet compliance requirements are based on the level of BMP implementation during that time (e.g., MEP). The WQT policy recommends developing a protocol to establish a baseline level of BMP implementation for nonpoint source pollution sources such as new development and redevelopment. There must also be an ability to establish trading value equivalence, meaning the equivalence between the location where a pollutant reduction is made (the off-site location or 'credit sending area') and the location where that reduction is used (the on-site location or 'credit receiving area'). Modeling and monitoring BMP effectiveness is recommended to quantify credit values (USEPA, 2003). A trading ratio is a factor-of-safety built into a trade which weights the trade to account for spatial and temporal differences between locations. A trading ratio greater than 1:1 may be used for additional environmental improvements, and to reduce uncertainties regarding water quality impacts and mitigation equivalency.

• *Fee-based trading:* For in-lieu fee arrangements, credit is based on the replacement of aquatic resource functions in perpetuity, and credits are quantified using a fee structure. The in-lieu fee structure is generally a function of the average cost (including operation and maintenance costs) of comparable off-site facility construction in the region in which the project is located (ELI, 2006). For stormwater runoff mitigation, the fee may be standardized per unit of runoff. Mitigation equivalency is assessed by the organization (e.g., municipality) managing the in-lieu fee arrangement and approved by the Army Corps of Engineers (ILF, 2000).

Location of off-site Projects

• *Offset trading:* Credit sending (off-site) locations and credit receiving (on-site) locations should be within the same watershed for offset trading to occur (USEPA, 2003). Because of the EPA requirement that trading cannot result in water quality standards being exceeded anywhere within the waterbody of interest, many trading programs require the off-site location to be upstream of the on-site location, to avoid creating a situation where the increased pollutant discharge upstream results in a violation of water quality standards known as a 'hot spot' (Trauth and Shin, 2005). Alternatively, trading programs may require additional credits be purchased or use location trading ratios to account for project location in a watershed (USEPA, 2007).

• *Fee-based trading:* Compensatory mitigation for fee-based trading consists of restoration/ protection of aquatic resources that are similar to the aquatic resources of the impacted area, therefore, off-site projects should be located in the same geographic area as the impacted area and should be planned and developed to address the specific resource needs of a particular watershed (ILF, 2000). Fee-based trading projects may be sited on public or private lands; however, private land owner participation must be voluntary (FED, 1995).

Implementation Deadlines

• *Offset trading:* Offset credits should not be used before the time frame in which they are generated, and the trading agreement is generally five years duration (EPA, 2003).

• *Fee-based trading:* Fee-based trading projects should be completed no later than two years following fee collection. Trading ratios may be used to limit the generation of credits from an off-site location to account for lag time between the construction of development projects and completion of mitigation projects (ILF, 2000).

Potential Legal and Regulatory Constraints on Alternative Compliance Implementation

Municipalities may assume additional risks, responsibilities, and costs when implementing alternative compliance programs. Alternative compliance programs may draw legal challenges and the degree of uncertainty in establishing equality of trading sites increases a municipality's legal risk. For example, municipalities could be liable under the Endangered Species Act for failure to regulate strictly enough if alternative compliance programs are not equally protective of the environment (e.g., Salmon and Steelhead habitat). Municipalities assume additional liability risk using fee-based trading. For example, if a municipality agrees to construct a regional project but is unable to construct it within an allowed time frame, it risks being out of compliance and may have to refund the money.

The assignment of legal and financial responsibility is a major difference between fee-based trading and offset trading alternative compliance programs. In fee-based programs, the legal and financial responsibility for assuring that mitigation occurs successfully is transferred from the fee payer (the developer) to a third party (usually a municipality). Once a developer makes the cash transfer, they face no further legal or financial liability (Landry, *et al*., 2005). In offset trading programs, however, legal and financial liability for ensuring the water quality offsets are implemented successfully remains with the developer (Landry, *et al*., 2005). Without the ability to transfer liability, buyers of offset credits must use other means to protect themselves from legal and financial risk in case the seller of offset credits fails to deliver the quantity of agreed upon credits on schedule. Contracts and financial assurances can be used to protect buyers of credits, but the perceived risks might constrain offset trading.

A key regulatory issue of an alternative compliance program for new development and redevelopment is the definition of 'Maximum Extent Practicable' (MEP), the statutory standard for BMP implementation. The principle of MEP is to take all the actions that can be reasonably taken in order to prevent water quality degradation from non-point source pollution. The MEP standard represents the 'baseline' for trading and is defined as the pollutant control requirements that apply to a buyer and seller of credits in the absence of trading (USEPA, 2007). An off-site location's ability to 'over control' runoff (beyond MEP) must be quantified in order to authorize a trade. The MEP standard is difficult to quantify and standardize for different locations, and would require that the credit value of alternative compliance trading options be tailored to watershed conditions.

3 Concluding Discussion

The legal and regulatory framework described in this paper suggests there are potential benefit and risk tradeoffs associated with alternative compliance implementation. Alternative compliance programs have the potential to provide communities a means to meet water quality objectives and other natural resource protection/restoration goals, allow development flexibility, and facilitate efficiency (Thurston, *et al*., 2003). Fee-based trading provisions of protection in perpetuity and ‘out-of-kind’ compensatory mitigation supports an integrated watershed planning and management approach, and provides municipalities a tool to meet multiple interests and put limited stormwater management dollars to effective use. Offset trading provides property owners with an economic incentive to build LID BMPs with greater capacity and effectiveness than the minimum regulatory requirements, and may encourage innovation and cost efficiency.

There are potential pitfalls of alternative compliance, such as the difficulty in establishing equivalency (trading value) between different locations in a watershed and risk of inadequate mitigation and localized impacts. For example, wetland mitigation banking has been shown to not fully address losses of wetland function and may facilitate the loss of important ecosystem services from urban to rural communities (Robertson, 2006). The foundation of LID is that stormwater is best managed at the source; directing mitigation to a regional facility goes against this decentralized approach of restoring and protecting hydrological processes. There are also issues of transaction costs associated with collecting and communicating information (e.g., modeling), and with obtaining agreement and regulatory approval (Trauth and Shin, 2005). Alternative compliance may not be appropriate or feasible in all municipalities, and even in appropriate situations may increase liability risks, responsibilities, and costs. Municipalities in the Central Coast Region might consider offering an off-site mitigation program if environmental performance or community benefits can be gained by meeting on-site requirements off-site.

Acknowledgements

This work is supported by California’s Central Coast Regional Water Quality Control Board and the Low Impact Development Initiative.

REFERENCES

(ELI) Environmental Law Institute. (2006) *The status and character of in-lieu fee mitigation in the United States*.

(FED) Federal Guidance for the Establishment, Use and Operation of Mitigation Banks. (1995) *Federal Register* 60 (228): 58605-58614. http://water.epa.gov/type/watersheds/trading/finalpolicy2003.cfm(accessed 16 June 2011).

Landry M, Siems A, Stedge G, Shabman L. (2005) *Applying Lessons Learned from Wetlands Mitigation Banking to Water Quality Trading*. White Paper prepared for Office of Policy, Economics, and Innovation and Office of Water, U.S. Environmental Protection Agency.

(LID) Low Impact Development Center, Maryland (2007). *A review of Low Impact Development policies: Removing institutional barriers to adoption*.

Robertson MM. (2006) Emerging ecosystem service markets: trends in a decade of entrepreneurial wetland banks. *Frontiers in Ecology and the Environment* 4: 297-302.

Thurston HW, Haynes CG, Szlag D, Lemberg B. (2003) Controlling stormwater runoff with tradable allowances for impervious surfaces. *J. Water Resources, Planning, Management* 129 (5): 409-418.

Trauth KM, Shin Y. (2005) Implementation of the EPA’s Water Quality Trading Policy for stormwater management and smart growth. *J. Urban Planning and Dev*. 131(4): 258-269.

(ILF) U.S. Department of the Army, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration. (2000) *Federal Guidance on the Use of In-Lieu-Fee Arrangements for Compensatory Mitigation under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act*.

(USEPA) U.S. Environmental Protection Agency. (2003) *Water quality trading policy.*

(USEPA) U.S. Environmental Protection Agency. (2007) *Water quality trading toolkit for permit writers*. EPA833-R-07-004, Washington, D.C.

Maintaining, Testing, and Monitoring Water Quality in Rural Water Supply Systems in Sri Lanka

W.B.G. FERNANDO & T.W.S. PERERA
National Water Supply and Drainage Board. Sri Lanka
agmrural@gmail.com

Abstract Rural water supply systems (RWSS) operated and managed by user communities have been in existence for several decades in Sri Lanka. However, many of them were gravity schemes and point sources in remote villages, which didn't demand a comprehensive water quality testing and monitoring system. This situation was drastically changed in the 1980's when many piped RWSS were constructed. Presently, there are about 3200 RWSS, providing safe water coverage of about 12%. With the increasing number of RWSS, a comprehensive mechanism for water quality maintaining, testing, and monitoring was seriously needed. Many RWSS used shallow dug wells, springs, streams, tube wells, and rain water as sources of water. With the rapid urbanization and industrialization, pollution of water sources is also increasing. Testing of water quality at regular intervals is also an important task. However, this is limited due to high cost, limited number of laboratories available, and inadequate attention. An effective monitoring system for water quality is compulsory to achieve long term sustainability of the RWSS. Being the leading institution in water supply, the National Water Supply and Drainage Board (NWSDB) has already formulated a system to address this situation. Rural Water Supply Units (RWSU) at the district level are established by the NWSDB to provide necessary assistance and guidance in this regard. This includes guidance in maintaining water quality, facilitating low cost and readily available water quality testing, and managing effective water quality monitoring systems. This paper describes in detail new strategies proposed maintaining, testing, and monitoring for water quality in the RWSS.

Key words Rural; water; quality; maintaining; testing; monitoring; sustainability

1 Introduction

Sri Lanka is a small country on the Indian Ocean, extending to approximately 64,000 km^2. It has a population of 20.4 million, according to a census carried out in 2011. Within this population, 72% is estimated to live in rural communities. Today, safe drinking water coverage in the country is about 86% (UNICEF, 2010), while the rural coverage is approximately 40% (Central Bank of Sri Lanka, 2010).

For several decades, rural communities have depended mainly on shallow ground water extracted from dug wells, streams, and other natural sources. Starting in the 1980's, a large number of tube wells has also provided drinking water for the rural communities. During early days, these sources were used individually, or commonly shared among a group of families, without any organized mechanism. Organization of rural water supply systems came in the 1980's. Since then, about 3200 RWSS have been constructed in the country. These were provided mainly through the assistance from government and non-government organizations.

Water quality supplied through the RWSS was of not much concern at the initial stages. However, with the increasing number of RWSS, and possible pollution of water sources with rapid urbanization, the quality has become an important issue today. The following sections describe the importance of water quality and possible pollution sources. They also elaborate on the steps already taken to ascertain water quality, and on institutional mechanisms that are being adopted to address the situation.

2 Importance of Maintaining Water Quality

Maintaining of the water quality at an acceptable level in a RWSS is of paramount importance. It is the usual practice in Sri Lanka to accept World Health Organization (WHO) standards as the preliminary requirement of water quality. Although it is difficult to maintain all the conditions in WHO standards at a desirable level, efforts should be taken to achieve the permissible level, at least in the most important parameters. If the quality deteriorates, users may not be able to find suitable drinking water, and investments made for the provision of the RWSS would be wasted. Even though quality is acceptable for drinking, certain substances may be harmful for health in the long term. There is evidence that the high content of iron and fluoride has created serious health problems in certain rural areas of Sri Lanka.

3 How Quality Deteriorates

Water may generally be contaminated in extraction, transmission, storage, distribution, or in domestic usage. Although possible contamination in domestic usage is irrespective of the water source, ways and means of contamination in other instances are largely dependent upon the particular RWSS. Depending on the sources, RWSS can be basically categorized into three types:

- Piped RWSS with a surface or underground water source
- Individual or common dug well or tube well
- Rainwater harvesting system

The ways of possible contamination in the above three systems have been summarized in Table 1. Figures 1, 2, and 3 show an unprotected dug well, the essential components of a protected dug well, and the components of a rainwater harvesting system, respectively.

Table 1 Possible causes for water pollution.

Piped RWSS	Dug well or tube well	Rain water Harvesting System
Inferior raw water	Inferior raw water	Catchments pollution
Transmission	Outside contamination	Storage
Storage	Corroded riser pipes and buckets	Corroded taps
Distribution	Transporting	Transporting
In house	In house	In house

Fig. 1 Unprotected Dug Well.

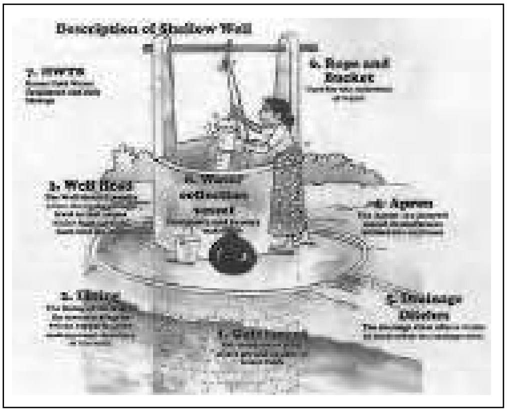


Fig. 2 Components of a Protected Dug well.

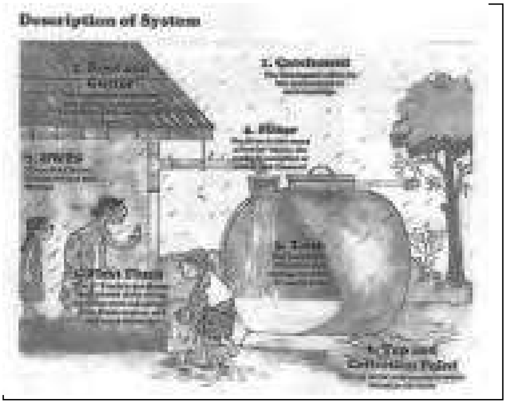


Fig. 3 Components of a Rainwater Harvesting System.

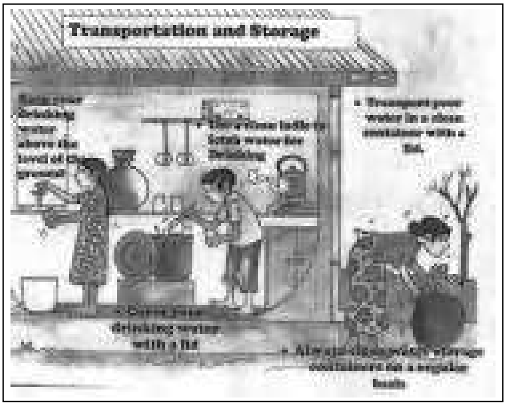


Fig. 4 Pollution of water in house.

Water can also be contaminated in the house, whatever the source may be. Fig. 4 shows simple corrective measures that could be taken to avoid water contamination in house.

4 Prevention of Water Quality Deterioration

Methods for the prevention of water quality deterioration are based mainly on the RWSS used. Except for the prevention of water quality deterioration in house, the possible steps that can be taken for safeguarding the quality of water in other instances are summarized in Tables 2, 3, and 4.

Table 2 Possible causes for water pollution & proposed remedial actions for Piped RWSS.

Cause of Pollution	Proposed Remedial Action
Inferior raw water	Selection of a better source / low cost treatment
Transmission	Use of high quality pipes / Avoid leakages / attending repairs promptly
Storage	Regular cleaning / attending repairs promptly
Distribution	Use of high quality pipes / Avoid leakages / attending repairs promptly / disinfection (adding Chlorine)

Table 3 Possible causes for water pollution & proposed remedial actions for individual or common Dug Wells.

Cause of Pollution	Proposed Remedial Action
Inferior raw water	Selection of a better well / low cost treatment
Outside contamination	Wall around well /Apron
Corroded riser pipes and buckets	Avoid metal buckets / Use high quality riser pipes
Transporting	Use plastic buckets

Table 4 Possible causes for water pollution & proposed remedial actions for Rain Water Harvesting Systems.

Cause of Pollution	Proposed Remedial Action
Catchment pollution	Clean roof before rainy season / Drain out water from first few rains / Good quality roof / small filter at the mouth of the tank
Storage	Cleaning the tank
Corroded taps	Use high quality taps
Transporting	Use plastic buckets

5 Institutional Mechanism

The National Water Supply and Drainage Board (NWSDB) has clearly understood the importance of establishing a comprehensive mechanism for water quality monitoring and management in order to sustain the RWSS in the country. Fig. 5 shows a Rural Water Supply Unit (RWSU) established in the district of Kegalla.

Fig. 5 Sample RWS Unit.

The following actions will be implemented through the already established Rural Water Supply Units:

a. Create awareness in the community on the importance of water quality management, and educate members on simple household water treatment systems, such as Chlorination and Sodis (Solar Water Disinfection). A very effective means of communication is through school children. Poster and art competitions, as well as theatrics, can also be used in this process. This campaign is further facilitated by village level health workers, like public health inspectors and midwives.

b. Communities face severe difficulties in checking the water quality on the schemes they manage. In order to overcome this situation, the NWSDB is in the process of strengthening the existing laboratories and establishing new ones next to its district offices throughout the country. This will facilitate easy access to water quality measuring, at a reduced cost. Furthermore, the NWSDB has recently started testing a limited number of water samples for Community Based Organizations (CBOs), free of charge.

c. Popularization of simple water testing methods, such as H2S kits, among rural people, so that costly water testing can be avoided.

d. Action has been initiated to amend local authority by-laws, in order to empower them authority for protecting RWSS catchments. This is very essential, because at the moment, the capacity of CBOs is not adequate for this task.

e. Generally, the traditional water quality monitoring systems are not effective in RWSS due to their high cost. On the other hand, this is a “reactive” attitude, rather than a preventive one. Hence, the NWSDB has initiated preparation of water safety plans for RWSS. This will provide a powerful tool for the drinking water supplier to manage the supply safely.

f. Establishment of a water quality surveillance system with the participation of all sector stakeholders. While health authorities will lead water quality surveillance activities, all service providers, including the NWSDB and CBOs, will be partners in the process. It is proposed to have water surveillance committees at various levels. This process has already started, and committees at the lowest levels are being established (Water Quality Surveillance, 2010).

6 Challenges

Since about two decades ago, rural communities have been using domestic sources of water. Back then, demand was low and the environment was clean and healthy. Therefore, there was not much need to pay attention to water quality issues. However, due to increasing demand and pollution of the environment, today it has become necessary to keep a close look on the quality of water. In order to implement the aforementioned actions, many challenges have to be faced:

a. The majority of rural communities still do not understand and accept the importance of water quality
b. Improved health facilities have reduced the need for best water quality
c. Members of rural communities still consider water quality to be an individual responsibility, and do not acknowledge need for combined efforts.
d. The majority of people in rural communities are farmers. They consider the use of pesticides and herbicides for their cultivars to be more important than protecting water sources
e. There is a lack of proper institutional frameworks for water quality monitoring
f. Low cost water treatment methods are scarcely available, and awareness about the few methods available is low
g. There is a lack of coordination between responsible government organizations
h. Policy makers poorly acknowledge the role to be played by NGOs

7 Recommendations

The demand for safe drinking water in rural communities in Sri Lanka will not be reduced during in the next few decades, which adds to the difficulty in finding suitable water sources and required capital funds for large scale water supply schemes. Hence, the maintaining of water quality in RWS schemes is highly important. Although it is a difficult process, to establish a proper water quality testing and monitoring system is very important people's health. The challenges described in the preceding section are not impossible hurdles. Better coordination among the responsible government and non government intuitions, with necessary financial support, would definitely bring successful results in this endeavor.

REFERENCES

Central Bank of Sri Lanka. (2010) *Annual Report*.
Water Quality Surveillance (2010) *Policy Draft*.
UNICEF. (2010) *JMP Report*.

The Cuyaguateje Watershed (HELP Cuba): Experiences in Integrated Management

ZEIDA ROMERO PALMERO & MATÍAS R. PÉREZ DUARTE
National Institute of Water Resources, Pinar del Río Provincial Division, Cuba
zeida@pri.hidro.cu

Abstract The Cuyaguateje hydrographic watershed is located in the province of Pinar del Río, in the western part of the island of Cuba, and is one of 10 Basins of National Interest for its economic, social, and environmental importance, as well as for its historical and cultural values. It has an area of 875 km^2, with a population of approximately 48,370 inhabitants. It is the largest basin in the western region, with high vulnerability to hurricanes. It is a part of the International Hydrological Program (HELP Basin) since 2009. The Territorial Watershed Council (CCT) was created in 1998, as a government instrument to deal with watershed problems. Its functions include: coordinating and implementing an ecosystems approach in integrated water resource management; recommend, coordinate, and assess integrated programs that combine the sustainable use of natural resources with economic and social activities; and assess behavior and trends of economic, social, and environmental indicators, as well as identify problems and find ways mitigate or solve them, and generally contribute in the decision making process. A large number of projects and actions have been developed since the CCT's creation, and the results show improvement trends in the indicators assessed for 11 working subprograms.

Key words Basin; Cuyaguateje; experience; integrated management; ecosystem

1 Introduction

The Cuyaguateje water basin is located in the Pinar del Río Province, on the western part of the Island of Cuba, and it is one of the 10 Basins of National Interest for its economic, social, and environmental importance, as well as for its historical and cultural values. It has an extension of 875 km^2, with an approximate population of 48,370 inhabitants. It is the largest basin in the western region, with high vulnerability to hurricanes. Since 2009 it is part of the International Hydrological Program's HELP network. It is characterized for:

- Geological complex structure and varied lithology. It is considered that 60% of its area is affected by Karst processes, which are visible in the high and middle parts of the basin.
- Varied relief features: in the high and middle parts, mogotes and hills can be distinguished, with steep slopes in the river beds; in the lower part the relief is flat. This basin is also characterized by having very unique landscapes, such as the Saint Tomas Cave System, the biggest cave system in Latin America.
- Mean annual precipitation for the basin is 1580 mm, and mean annual temperature is 25.1º C. The Cuyaguateje River is 112.4 km long. The presence of underground water in the form of springs is a feature that stands out.
- Developed hydraulic infrastructure: it has dams, a small hydroelectric power plant, aqueducts, and a network to monitor hydrological cycle variability, which belongs to the National Institute of Water Resources (INRH).

2 Objective

To present the main projects being carried out in the Cuyaguateje watershed, which indicate a general improvement in the performance of indicators, assessed for 11 integrated management subprograms.

3 Developed Projects

3.1 Methodological Proposal of a Viable Strategy for Ecological Restoration of Marshes in Deteriorated Areas of the Cortés Sector

This project is part of a reforestation program. Its objective is to propose a strategy of ecosystem restoration, according to the biophysical features in the study area, so that the gradual and integral restoration of the marshes is achieved. It includes strong community participation.

The reforestation and forest management actions that are being carried out in the Cuyaguateje basin have led to the continued increase in forest cover area (natural and plantations). However, the mangrove ecosystems (known to be fragile ones) in the Cortés Sector are in a state of deterioration regarding mean ecological integrity. The species *C. erectus* and *L. racemosa* are most deteriorated ones, due to the entropic activities that local residents carry out, such as: illegal pruning, production of coal with mangrove species, and dumping solid waste in the area.

Samoin and other investigators from the University of Pinar del Río have developed and applied a methodology to manage them, which entails biophysical diagnosis with community participation. Their proposed conservation strategy is feasible for the study area because it contemplates the characteristics and current conditions of the marshes' vegetation and the local population's influence. The ecosystem recovery activities involve community members, who have been previously educated about the importance of the coastal environment.

3.2 Gully Rectification for Soil Recovery in the Cuyaguateje River's Protection Forest Strips

This project is a part of the work, improvement, and conservation of soils program. Its objective is to assess the results obtained in gallery forest rehabilitation and protection activities, which include rectification of gullies, and to propose measures to reduce the emergence of new gullies.

One of the tasks carried out in the project was to classify the existing gullies into different categories, large, medium, and small, according to Soto's methodology (2004). Among the causes that favor gully formation in the basin is the high grade of slopes, which facilitates surface runoff to a higher speed, thus removing large soil volumes. The measures taken to diminish gully erosion are:

- The use of dead covering in the different cultivations with steep slopes
- Implement cultivations in contour with slopes (to plant following the contour lines)
- To use live covering such as: comb, pumpkin, sweet potato, bean, etc.
- To use live barriers in areas with slopes of 5%
- To use only in forest and fruit-bearing plantations in areas where the slopes are larger than 30%

Positive environmental impacts were felt from the start:

- Attenuation of polluting factors, since the water reaching the river has less soil particles and other agents that could contaminate it
- Improvement and reestablishment of native biodiversity in the study area, observed in the survival of species like *Gliricidia sepium*, *Bursera simaruba, Spondias mombin*
- Enrichment of the rural environment and its socioeconomic efficiency, as well as the creation of an esthetic landscape that respects the balance of nature

3.3 International Collaboration Project to Increase Cognitive and Technical Capacities in the UNAH (Agrarian University of Havana) and the CENHICA (Center for Hydrology and Water Quality) for Soil and Water Conservation in the Cuyaguateje River Basin

This project is a part of the work, improvement, and conservation of soils program.

It was planned to be developed in a 5-year period. Partial results of this project have been presented in different events and workshops; also, several M. Sc. theses have been developed from it.

In 2009, a workshop was carried out in the middle part of the basin, with remarkable participation by the community. This year, the workshop was carried out again, as part of the project closing activities, in a different part of the basin. The workshop's objectives were to:

- Illustrate and explain water erosion, and to analyze the different phenomena that influence the process
- Present the work carried out during the years of project implementation
- Illustrate the influence of precipitation as an erosive factor in the Cuyaguateje River basin, and to demonstrate the effects that soil protection has on crops
- Carry out an open exchange with the communities and to hear their approaches and suggestions

3.4 Determination of the Water Quality Index for Underground Water in the Cuyaguateje Watershed

This project is a part of the work program for Hydraulic Resources. Its objective is to determine the Water Quality Index (ICA) in the basin, to assess the natural quality of the underground waters. The methodology employed was suggested by the National Institute of Water Resources (INRH), which is based on the one proposed by Gutiérrez and other specialists (1981). The scale for assessing the quality is shown in Table 1. To carry out the study, the INRH's Water Quality Network database was used. Physical-chemical and bacteriological data from the main monitoring sources in the basin were assessed.

Table 1 Classification of water quality according to ICA results, proposed by Gutiérrez, *et al*.

Class	Classification of the body of water	Index of Water Quality (ICA) value
1	Excellent quality	90.00 a 100.00
2	Acceptable quality	80.00 a 89.99
3	Lightly polluted	70.00 a 79.99
4	Polluted	60.00 a 69.99
5	Very Polluted	50.00 a 59.99
6	Terrible Quality	≤ 49.99

Results

- High part of the basin: Lightly polluted with an ICA = 77.10
- Middle part of the basin: Lightly polluted with an ICA = 75.75
- Low part of the basin: Lightly Polluted with an ICA = 74.35

The study indicates that underground waters in the Cuyaguateje basin are, in general terms, lightly polluted. The median value of the ICA is 75.56, where 62,5% of the analyzed sources ranked as lightly polluted, 25% as polluted, and only 12.5% acceptable.

REFERENCES

Gutiérrez J., J. M. García, O. Beato. (1979) *Un índice de calidad para las aguas subterráneas*. Reporte del Instituto de Hidroeconomía.

Gutiérrez, J. (1981) *Mapa de la calidad de las aguas subterráneas.* Reporte de Investigación del Instituto de Hidroeconomía.

Soto, A. (2004) *Indicaciones prácticas de conservación de suelos para los agricultores.* (Ingeniería Medio Ambiental).

3. ECOHYDROLOGY FOR HEALTHY ECOSYSTEMS

Biodiversity of the Reventazón River Watershed: Knowledge for Management

ANNY CHAVES, CARLOS GAMBOA, LUZ MARINA RODRÍGUEZ, JORGE LEIVA, ALEX MOLINA, CARLOS ARRIETA & SUSY SEGURA
Instituto Costarricense de Electricidad. PO Box 10032-100, San José Costa Rica.
achaves@ice.go.cr

Abstract The Reventazón river watershed is situated on the Costa Rican Caribbean slope. It was incorporated, as Watershed HELP - UNESCO, in 2009. With an area of 2950 Km^2 it has 59% coverage of prime vegetation. The river, at its longest fetch, is 180 Km long and drains the Cartago urban zone on its left hand margin while the right bank is made up of important protected wildlife areas. With an irregular relief, the watershed covers altitudinal stratum raging from sea level to 2800 m.a.s.l, representing 10 life zones with areas of high precipitation (7000mm) in the south, sectors of relatively low precipitation in the north (1500mm) and a combined runoff of 2614mm. The confluence of these elements results in an area of remarkable biodiversity, in the terrestrial component as well as that of the aquatic system. As a function of hydrological resource exploitation, the Costa Rican electrical authority, (Instituto Costarricense de Electricidad (ICE)), is undertaking biological studies along the length of the watershed, with a view to evaluating, mitigating and controlling the effects that the various operating hydroelectric plants (as well as those proposed or under construction) have on the biodiversity system. The results of the last ten years of study, as it pertains to the documentation of the biological richness, show that 33% of Costa Rican Biodiversity is present in Reventazón basin. A proposal to integrate, from a biology conservation perspective, knowledge and biodiversity management into the current Watershed Management Plan is presented.

Key words Biodiversity; watershed management; conservation biology; Reventazón River; Costa Rica

1 Introduction

The Reventazón river watershed was incorporated, as Watershed HELP - UNESCO, in 2009. It has an area of 2950 Km^2 it maintains a 59% coverage of prime vegetation. The river, at its longest fetch, is 180 Km long and drains the Cartago urban zone on its left hand margin while the right bank is made up of important protected wildlife areas such as the Tapanti National Park. With an irregular relief, the watershed covers altitudinal stratum raging from sea level to 2800 m.a.s.l, representing 10 life zones (Bolaños and Watson, 1993). Within a straight-line distance of 18km, one finds areas of high precipitation (7000mm) in the south, sectors of relatively low precipitation in the north (1500mm) and a combined runoff of 2614mm (Rodríguez, 2007).

The conjunction of these elements results in an área of impressive biodiversity, as much in the terrestrial compones as the acuatic, accentuating the need to incorpórate investigation and management into the strategic planning of the basin. As a function of exploiting the hydroelectric resource within the basin, biological studies are undertaken along the length of the river so as to evaluate, mitigate and observe the effects that the various installed and proposed plants may have on the systems biodiversity.

The Costa Rican electrical authority, (Instituto Costarricense de Electricidad (ICE)) has installed three hydroelectric plants in the upper basin and is currently building the Reventazón HP in the middle basin. In order to maintain monitoring of environmental conditions in the basin, ICE conducts studies that include biotic, social and water quality in the catchment areas of these plants and projects while coordinating the necessary management actions with the Reventazón Basin Management Committee (COMCURE).

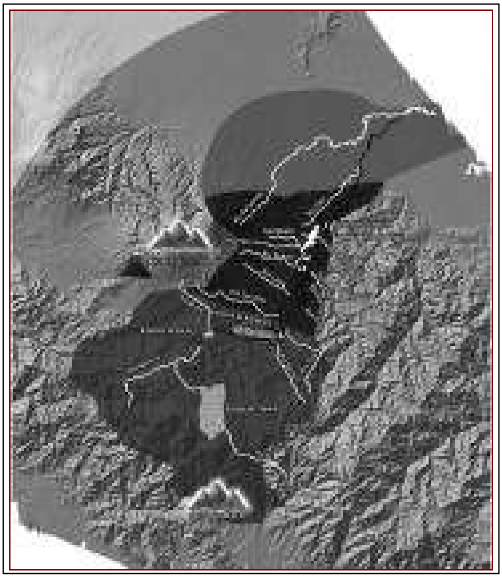


Fig. 1 Cuenca del Río Reventazón.

2 Methodology

Biological studies conducted over the past 10 years in the Reventazón River Basin, have allowed the documentation of biological species richness in both the aquatic system and terrestrial wildlife as related to the river (Chaves y Gamboa 2008, Segura 2006, Villalobos y Rodríguez 2003).

The studies were conducted in 25 sampling sites distributed in a strip 500 m wide along the River, from the mouth and estuarine area up to 1100 m above sea level, upstream of the Cachí dam. The sampling sites are related to areas of influence of the hydroelectric projects of the Instituto Costarricense de Electricidad (ICE). Also included are the species documented during the rescue of wildlife in the Angostura reservoir filling (Barrantes et al, 2000), the species identified in studies of theCachí and Angostura plants and species harvested by clearing land for the Reventazón works currently under construction. For terrestrial vertebrates, samples were collected and observations were conducted both day and night. The identification for each group was made with the existing field guides for Costa Rica (Stiles and Skutch 1998, Savage 2002, Carrillo et al 1999). For fish collections using various fishing gear, including nets such as seine, cast nets, and electrofishing, the identification was made based on Bussing (1998) and the lists are updated according to the nomenclature in the database of FishBase (www.fishbase.org). For aquatic macro-invertebrates, collections were performed using D-type nets in the various tributaries and at the same sites sampled in the ichthyological study in the main channel. The identification was made using specialized keys for the region and the country. Macro-invertebrate information only presents data at the taxa level of quality index BMWP-CR.

Since 2006, a monthly water quality control has been performed with the monitoring of 18 parameters, initially in two seasons and has led to five sampling stations (1 on the upper basin, two in the middle basin and one in the lower basin). The index of water quality (ICA), commonly called ICAFNS, developed in 1970 by the National Foundation of health of the United States of America (FNSEUA), which can be used in the determination of the quality of the water from a river over a period of time and be able to compare the quality of water in different parts of a river, was used for analysis. This ICA is composed of 9 physiochemical and bacteriological parameters (Deininger, r. 1980). For the Reventazón sites, a modified ICA was applied where only 6 physiochemical parameters are taken into consideration: - Percentage of saturated oxygen, pH, BOD, total phosphates, nitrates and total solids.

As a complement, the work of Segura (2006) in the pre-feasibility study for the Reventazón project, where the BMWP´ CR index wasapplied, based on the composition of the communities of aquatic invertebrates and their characteristics as indicators for pollution for some tributaries and points in the main channel of the Reventazón river. As part of the biological studies for the Reventazón EIA, sampling of aquatic invertebrates in January and February 2008 were undertaken and this sameinformation applied to the indexof sites that were used for the fish study.

3 Results

The documented terrestrial fauna reveals that the Reventazón watershed holds at least 33% of the terrestrial vertebrate biodiversity of Costa Rica (table 1), with a total of 501 species recorded so far. The middle basin shows a greater diversity in almost all groups. However, it is important to take into account that, due to the location of the Reventazón project in this sector, a greater study effort was undertaken. Likewise, results from information derived from collections of fauna rescued at the construction works, show an increases in the number of species that are difficult to observe in traditional sampling**.**

Table 1 Number of species of terrestrial fauna by group, documented for the lower, middle and upper basin of the Reventazón River system and their relationship to the diversity of the country.

GROUP	LOWER BASIN	MIDDLE BASIN	UPPER BASIN	TOTALSP REVENTAZÓN /SP IN COSTA RICA	%*
AMPHIBIANS	12	41	20	45/ 178	25
REPTILES	29	32	35	57/ 228	25
BIRDS	158	218	189	338/ 864	39
MAMMALS	34	54	29	64/ 236	27
				501/1506	33

Source: Prepared by the author, INBIO (http://www.inbio.ac.cr).

The wealth of birds and mammals within the basin is associated with the diversity of the life zones, the wide variety of resources related to the coverage of forest in areas close to the river and the possibility of connectivity between the existing wilderness areas, also allows for altitudinal movement to many of these species.

For amphibians and reptiles, the existing status and relationship between bodies of water and vegetation is a decisive situation for diversity. The Reventazón middle watershed represents conditions of very high diversity and has 91% of amphibians reported throughout the basin. Especially important, is the area around the Guayacán stream, in the Reventazón project, with 31 species of amphibians which represent 68% of the amphibians of the basin. A total of 84 species of fish have been documented in the Reventazón Riversystem, of which 22 species are marine and only found in the estuary. The remaining 62 species are from the freshwater system. Estuarine habitat (48 sp) and the lower basin (47 sp) are those that represent the most diversity with many shared species. This is the part of the system is not sectioned by the presence of dams, but does receive the annual impact of the reservoir cleaning activities. However, the environmental management of the energy production activities and actions performed to minimize sediment production in the basin has resulted in the mitigation of impacts on the aquatic system. The middle (29sp) and upper (19 sp) basin have fewer species affected by the decrease in water temperature and the presence of two dams and their respective reservoirs.

While commercial fishing of river species is not practiced, some fish species are very important to subsistence and sport fishing. Such is the case of the machaca (*Brycon guatemalensis*), tepemechín (*Agonostomus monticola*) and bobo (*Joturus pichardi*) fish, which is an icon of the region, and a favorite of the nearby river towns. The estuarine system provides subsistence and sport fishing of Tarpon (*Megalops atlanticus*) and a number of other marine species. There are reports of the presence of exotic species such as rainbow trout (*Oncorhinchus mykiss*) that are bred in captivity and who have escaped to the natural system in the upper basin. Also found are tilapia (*Oreochromis niloticus and Tilapia mosambica*) throughout the system and plecóstomos in the canals, possibly liberated from aquaria.

Despite existing agricultural activities and urban development, the water quality of the main channel is found to be acceptable. The parameters analyzed monthly are within accepted quality standards. When using some of the samples for the implementation of the modified ICA, as noted, that ICA varies between 81.66 and 90.66 during the year, which relates generally to good quality water. This can be improved to an excellent condition, as may be seen occasionally. The turbulence and energy characteristics of the River explain this condition in the main stream.

The results of studies using biological indicators allow for evaluation regardless of the time of a sample, due to the composition of the invertebrate populations, reaching conclusions on the conditions to which they have been exposed. According to the results of Segura (2006) and Chaves and Gamboa (2008) with biological indicators for contamination, sampling sites located in the restoration of the machine room of the Cachi and Angostura plant, show a BMWP'CR value of 96 and 79 respectively, corresponding to the color green, which is interpreted as regular water quality with moderate pollution. For the middle basin portion of the river, at the site of the reservoir and the dam of the Reventazón project, index values of 51 and 60 respectively are found. Those indicate a yellow condition, which is interpreted as low quality and generally polluted water. Samples taken from the tail waters of the reservoir of the Reventazón project (rio Bonilla, q. Lajas and q. Rubio) presents a green status. The Sibon, Tres Amigos and Guayacán creeks, located in the middle basin, downstream from the dam site, have a value between 103 and 122, in the blue category, which is a very good condition. Rivuluscreek, located in the Reventazón project was the only one in blue category (value 149), which is of excellent quality. The sections that feature a yellow status are populated areas in the lower basin, where agricultural and livestock activities are undertaken on the banks of the river.

The sites that presented the best conditions are those tributaries surveyed in the upper part, exhibiting a slight deterioration closer to populated centers. The sections of the main channel at the level Florida (dam site) presented an Orange condition, likewise, the sampling site near the town of Carmen (lower basin). This condition is classified as poor quality polluted water. The quality of the water fluctuates, improving or deteriorating depending on the state of the tributaries, therefor, after displaying a quite critical condition in Florida, characteristics recover after receiving good quality waters from streams such as the Rivulus, Sibon, Tres Amigos and Guayacán. Again, the quality deteriorates when it passes through Carmen (the Cocal site).

The ASPT values reveal that most of the sites have heterogeneous pollution-tolerant and pollution-intolerant communities. A few sites present homogeneous communities intolerant to pollution, such as the Guayacán creek at its confluence with the Reventazón and others present pollution-tolerant homogeneous communities.

4 Conclusions and Proposal

The biological wealth of the Reventazón has merit for its declaration as a HELP basin, but at the same time constitutes a commitment and a responsibility for the country (and ICE) to ensure the environmental conditions, despite intervention to use the hydraulic resource to maintain the national electric system.

The existence of the Reventazón Basin Commission (COMCURE), involving government agencies, community organizations, universities and ICE allows the coordination of actions to improve the quality of life of the inhabitants of the basin and the monitoring of various environmental aspects. In 10 years of COMCURE activity, it has already been possible to demonstrate the benefits in improved tree coverage and use of the land (Fields, C. 2010). In the same way, by having a baseline of biodiversity and water quality, it is possible to monitor the impact of other direct actions on habitat quality. A proposal is underway to launch a campaign of vegetation restoration on the riverbanks. Habitat management actions that incorporate communities working with COMCURE, with the aim of increasing the level of connectivity of corridors along rivers, are envisioned. Likewise, these corridors will serve as a barrier for the transport of sediments and contaminants. The existing biodiversity information is a starting point for the monitoring and control of change in habitat conditions. COMCURE member institutions such as ICE, the State universities and non-governmental organizations working in the area, would be charged with carrying out research and monitoring of environmental conditions.

REFERENCES

Barrantes, R., A.Chaves y F. Aguilar. (2000) *Informe de Rescate de Fauna del PH Angostura*. Instituto Costarricense de Electricidad.

Bolaños R. y V. Watson (1993*) Mapa Ecológico de Costa Rica Según el sistema de clasificación de zonas de vida del mundo de L. R. Holdridge. San José*, Costa Rica. Centro Científico Tropical- Instituto Geográfico de Costa Rica.

Bussing, W.A. (1998) Peces de las aguas continentales de Costa Rica, 2 ed. San José, Costa Rica. Editorial de la Universidad de Costa Rica.

Chaves, A y G. Gamboa. (2008) Diagnóstico Biológico para el PH Reventazón. En Carías D (ed). *Estudio de Impacto Ambiental del PH Reventazón*. ICE

Campos, C. (2010) Análisis de los Cambios de Cobertura de la Cuenca Alta y Media del Río Reventazón, Costa Rica, Período 2000-2010. *Tesis de Licenciatura.* Escuela Ingeniería Forestal. ITCR

Carrillo, E, Wong, G y J.C. Sáenz. (1999) *Mamíferos de Costa Rica.* San José, Costa Rica. Editorial INBio.

Deininger, R.A.(1980) A water quality index for rivers.Wat. Int. September: 16-21

Rodríguez, CR. (2008) Diagnóstico Aguas Superficiales. En D. Carías(ed). *Estudio de Impacto Ambiental del PH Reventazón*. ICE

Savage, J.M. (2002).The amphibians and reptiles of Costa Rica. Chicago, USA. The University of Chicago press.

Segura, S. (2006) Caracterización Biológica del Proyecto Hidroeléctrico Reventazón. En: A. Vargas (ed) *Informe de Avance a la Factibilidad del P.H. Reventazón*. Documento interno. Instituto Costarricense de Electricidad.

Stiles, F.G y A. Skutch. (1998) Guía de aves de Costa Rica. 2 ed. San José Costa Rica, Editorial INBio.

Villalobos J y Rodríguez L. (2003) Diagnóstico de biología del AP y AID de la Línea de Transmisión Cachí -Angostura, *Informe técnico para formulación del Plan de Gestión Ambiental UEN Proyectos y Servicios Asociados*, Instituto Costarricense de Electricidad, 38 pp.

Calibrating a Hydrological Model to determine the volume of water flowing in a Tropical Rainforest: the Panama Canal Watershed

DAVID VEGA
Center for Hydraulic and Hydro-technical Research, Technological University of Panama, Panama
david.vega@utp.ac.pa

Abstract The Center for Hydraulic and Hydro-technical Research (CIHH, acronym in Spanish) of the Technological University of Panama (UTP), in conjunction with researchers from the New Mexico Institute of Mining and Technology (NMT) and the University of Wyoming (UW), is in the last phase of this research, which seeks to find more reliable hydrological parameters that influence the use of hydrological models used to estimate the volume of water supplied to the Panama Canal Watershed, located within a tropical rainforest. The specific objectives are: 1) develop a field database of basic hydrological variables, 2) test the hypotheses developed in previous studies, 3) calibrate existing hydrological models for use within tropical watersheds, 4) develop national capacities in the area and transfer technology, and 5) disseminate the results through various activities. This research is being conducted in the area of Cerro Pelado, in Gamboa, on land owned by the UTP, located within the Canal Watersehed. Within this zone, a 40-meter high meteorological tower, with instrumentation capable of measuring wind speed and direction in 3 dimensions, as well as evapo-transpiration, precipitation, solar radiation, relative humidity, and temperature, has been installed to study a micro-watershed area of approximately 1 km^2. In the long term, the establishment of a Tropical Hydrology Experimental Laboratory in Cerro Pelado is expected.

Key words Humid tropical rain forest; hydrological model; Gamboa; Cerro Pelado; tropical hydrology; Panama Canal Watershed

1 Background

The existing volumes of water in the different components of the Panama Canal Watershed can only be estimated by conducting hydrological simulations. Hence, water resource management in this strategic region of our country will depend on the accuracy of the mathematical models employed.

Although two thirds of the forest area in the Panama Canal Watershed are currently protected under National Parks or Natural Monuments, changes in forest protection and pollution control are necessary. This project has global significance due to the fact that the humid tropics cover 22% of the planet's land area, and is home to 33% of the global population. Contrary to popular belief, water sources in these regions are often insufficient to meet demand, due to population growth and increasing living standards.

If we add to this the existing rate of deforestation, changes in precipitation patterns, and the negative effects of climate change, (i.e., increased frequency of devastating hurricanes), we face the need to further study the hydrological cycle of tropical forests.

The hypotheses assessed in this study are the product of a multidisciplinary study conducted over a period of three (3) years in the Chagres River Watershed, which resulted in, among other things, the publication of a book titled "The Chagres River: A Multidisciplinary Profile of a Tropical Watershed". This project involved researchers from CIHH-UTP, the NMT, and had the support of other institutions, such as the Panama Canal Authority (ACP, acronym in Spanish) and Panama's National Environmental Authority (ANAM, acronym in Spanish).

This proposal includes an investigative component and an educational component. The first one aims to improve the calibration of hydrological models in their application to tropical watersheds, through field measurements and assessment of previously developed hypotheses.

The site that will be used as a laboratory is in Cerro Pelado, Gamboa, within the Canal Watershed. It has an area of approximately 1 km^2, and was granted by the former Inter-oceanic Region Authority (ARI) to the UTP and the University of Panama. The site presents the characteristics of a small watershed in a humid tropical area, with features similar to those found in the study of the Upper Chagres River Watershed. On this site, our US partners (Doctors Ogden and Hendrickx) have installed run-off and infiltration sensors, equipment for measuring groundwater flow; in addition, there is a 40-meter tall meteorological tower capable of measuring wind speeds in 3 dimensions, as well as evapo-transpiration, precipitation, and solar radiation. The information from these devices is collected by the Technological University of Panama. In the short term, two weirs will be constructed on the site to measure water flow at the outlet of the watershed under study.

However, despite the equipment installed in the area, more instrumentation is required to perform more accurate measurements, and more personnel is needed to process and analyze this information. In conversations with staff from the ACP's engineering division, hydro-meteorological models (the NWSRFS[1] System has been modified to include PANMAP[2] and PANFCST[3] models) need to be enhanced by field data collected in this project.

The educational component aims to introduce students from participating universities to tropical hydrology, through internships or courses taught by the researchers involved in the project. For researchers, especially those from the UTP, there will be a training component to learn new techniques, through both field work and short internships in the United States.

In the medium term, the objective of this research is to develop other projects on an international level, using the institutional and research capacity gained in this project by local researchers involved. In the long term, the project seeks to create a Tropical Hydrology Experimental Laboratory in Cerro Pelado, which will provide continuous, complete, and reliable information on a Humid Tropical Watershed. This laboratory will be very useful to both local and foreign researchers.

2 Benefits and Main Beneficiaries

This project offers benefits such as:

- Knowledge transfer and exchange between local researchers and foreign experts in hydrological aspects.
- The acquisition of valuable information by the ACP and ANAM, both from a technical standpoint, and from the perspective of establishing policies for water resource use within the Canal Watershed
- The procurement of missing infrastructure, in order to complete an on-site tropical hydrology laboratory in Panama.
- The development of capacities on an institutional level, thus allowing our researchers to advise other researchers in the region and improve the management of other tropical watersheds.

This project's main beneficiaries are the following institutions/groups:

A. *The Panama Canal Authority.* The greatest contribution and benefits from this project will be for the Panama Canal Watershed, which will allow for more accurate readings of water volumes in different parts of said watershed.

B. *The National and International Scientific Community.* This project involves a calibration of a hydrological model in a tropical watershed that has been studied very little.

C. *Tecnological University of Panama.* The creation of technical capacity building in the UTP will allow for the calibration of a hydrological model, in addition to the measurement of hydrological and meteorological parameters using the humid tropical rain forest as a case study. The transfer of technology by international experts from the University of Wyoming (UW) and the New Mexico Institute of Mining and Technology (NMT) with experience in this area.

D. *New Mexico Tech and the University of Wyoming.* When conducting similar research, these institutions will benefit from the information obtained from this project, given that our research will be done under conditions different to those found in their institutions' campuses.

E. *National Environmental Authority (ANAM).* This study will offer a better scientific basis for policy development by the ANAM, which involves the optimal use of water resources in tropical watersheds.

3 Expected Impact

The impact on the country's scientific base is significant for several reasons: a) the transfer of knowledge derived from working with foreigners who are experts in this field, b) the ACP and the Panama Canal Hydrographic Watershed Inter-Institutional Commission (CICH) acquiring valuable information from a technical standpoint, and from the perspective of establishing policies for the use of water resources in the Canal Watershed, c) the procurement of infrastructure that is missing in order to complete an on-site tropical hydrology laboratory in our country, d) the development of capacities at an institutional level, thus allowing our researchers to advise other researchers in the region and improve the management of other tropical watersheds in the country.

Knowledge Transfer. We will work with experts from the New Mexico Institute of Mining and Technology and the University of Wyoming in the United States, who bring to the project their experience in both field work and in creating model simulations. Doctors Jan Hendrickx and Fred Ogden have extensive experience, not only in hydrology, but conducting research in Panama, specifically in the upper watershed of the Chagres River, as well as in the area where this project is proposed.

Useful Technical Information for Panama. This research seeks to improve the understanding of the behavior of water resources in humid tropical forest areas, specifically in the Panama Canal Hydrographic Watershed. Project results will enable the Panama Canal Authority to more accurately predict the behavior of the hydrological cycle, since the mathematical models currently used for this purpose use variables that do not correspond to the reality of our climate.

Experimental Tropical Hydrology Laboratory on a Regional Scale. Another favorable aspect of this project is the fact that this research has a strong educational component, which seeks to create an on-site laboratory, which would allow for on-going work in the area with professionals from Panama and other countries in the region.

Capacity Building. A problem that our country has is the lack of institutional capacities in several scientific areas. This research would help meet these needs in the field of hydrology, by creating an international excellence hydrology program at the UTP.

4 Project Objectives

General Objective

To determine, with greater reliability, hydrological parameters that influence the use of hydrological models used to estimate the volume of water that is supplied to the Panama Canal Watershed in situations typical of a humid tropical rainforest.

Specific Objectives

The specific objectives planned for this stage and presented in the Memorandum of Understanding (MOU COL06-013) are:

- Develop a field database of basic hydrological variables
- Test hypotheses developed in previous studies

- Calibrate existing hydrological models for use in tropical watersheds
- Develop national capacities in the area and transfer technology
- Disseminate the results through various activities

REFERENCES

Bonell, M. (2005) Runoff generation in tropical forests. In: M. Bonell and L.A. Bruijnzeel (Editors), *Forests, Water and People in the Humid Tropics.* Cambridge University Press, Cambridge, pp. 314-406.

Elsenbeer, H., Newton, B.E., Dunne, T. and de Moraes, J.M. (1999) Soil hydraulic conductivities of latosols under pasture, forest and teak in Rondonia, Brazil. *Hydrological Processes* 13(9): 1417-1422.

Elsenber, H. (2001) Hydrologic flowpaths in tropical rainforest soilscapes - a review. *Hydrol Process* 15: 1751-1759.

Elsenbeer, H., Cassel, K. and Castro, J. (1992) Spatial analysis of soil hydraulic conductivity in a tropical rain forest catchment. *Water Resour Res* 28(12): 3201- 3214.

Elsenbeer, H., Newton, B.E., Dunne, T. and de Moraes, J.M. (1999) Soil hydraulic conductivities of latosols under pasture, forest and teak in Rondonia, Brazil. *Hydrol Process* 13: 1417-1422.

Elsenbeer, H. and Vertessy, R.A. (2000) Stormflow generation and flowpath characteristics in an Amazonian rainforest catchment. *Hydrol Process* 14: 2367-2381.

Bonell, M.M. Hufschmidt and J.S. Gladwell (Editors), *Hydrology and Water Management in the Humid Tropics - Hydrological Research Issues and Strategy for Water Management*. UNESCO, Paris.

Hargreaves, G.H. and Samani, Z.A. (1985) Reference crop evapotranspiration from temperature. *Appl Eng Agric* 1(2): 96-99.

Harmon, R.S. (2005) An introduction to the Panamá canal watershed. In: R.S. Harmon (Editor), *The Río Chagres, Panamá: A Multidisciplinary Profile of a Tropical Watershed*. Springer, Dordrecht, pp. 19-28.

Harris, R.D. (2000) *Water level accuracy and correcting for errors due to gravitational acceleration and liquid density.* In-Situ Inc., Fort Collins.

Harrison, B.J., Hendrickx, J.M.H., Vega, D. and Gobbetti, L.C. (2005) Soils of the upper Río Chagres basin, Panamá. In: R.S. Harmon (Editor), *The Río Chagres, Panamá: A Multidisciplinary Profile of a Tropical Watershed*. Springer, Dordrecht, pp. 97-112.

Hendrickx, J.M.H. *et al*. (2005) Hydrology of hillslope soils in the upper Río Chagres watershed, Panamá. In: R.S. Harmon (Editor), *The Río Chagres, Panamá: A Multidisciplinary Profile of a Tropical Watershed.* Springer, Dordrecht, pp. 113-138.

Niedzialek, J.M. and Ogden, F.L. (2005) Runoff production in the upper Río Chagres watershed, Panamá. In: R.S. Harmon (Editor), *The Río Chagres, Panamá: A Multidisciplinary Profile of a Tropical Watershed*. Springer, Dordrecht, pp. 149-168

Ogden, F.L. (2003) *Rating curve for the Río Piedras stream gaging station upstream from Río Chagres in the watershed of the Panamá Canal*. University of Connecticut, Storrs, pp. 18.

Alka, E.J. (2005) A geographic overview of Panama: Pathway to the continents and link between the seas. In: R.S Harmon (Editor), *The Río Chagres, Panamá: A Multidisciplinary Profile of a Tropical Watershed*. Springer, Dordrecht, pp. 3-18.

Priestley, C.H.B. and Taylor, R.J. (1972) On the assessement of surface heat flux and evaporation using large-scale parameters. *Mon Weather Rev* 100: 81-92.

Rutter, A.J., Kershaw, J.A., Robins, P.C. and Morton, A.J. (1971) A predictive model of rainfall interception in forests, I. Derivation of the model from observations in a stand of Corsican pine. *Agr Forest Meteorol* 9: 367-384.

Scatena, F.N. (1990) Watershed scale rainfall interception on two forested watersheds in the Luquillo Mountains of Puerto Rico. *J Hydrol* 113(1-4): 89-102.

Schellekens, J. (2000) The interception and runoff generating processes in the Bisley catchment, Luquillo Experimental Forest, Puerto Rico. *Phys Chem Earth* 25(7-8):659-664.

Senarath, S.U.S., Ogden, F.L., Downer, C.W. y Sharif, H.O. (2000) On the calibration and verification of two-dimensional, distributed, Hortonian, continuous watershed models. *Water Resour Res* 36(6): 1495-1510.

Shuttleworth, W.J. (1988) Evaporation from Amazonian rainforest. *Proceedings of the Royal Society of London Series B* 233(321-346).

Shuttleworth, W.J. (1993) Evaporation. In: D.R. Maidment (Editor), *Handbook of Hydrology*. McGraw-Hill, New York, pp. 4.1-4.53.

National Weather Service River Forecast System.

Meteorlogical model designed for the Panama Canal. PAN = Panama, MAP = Mean Area Precipitation.

Hydrologic model that uses the results from the PANMAP to forecast flow and lake elevation for Gatun and Alhajuela lakes.

Ecological Degradation of Marsh Wetland Habitats due to Global Climate Change and Human Disturbances in Northeast China

DEMIN ZHOU & XIAOJUAN LI
College of Resources, Environment, and Tourism, Capital Normal University, Haidian District, Beijing, China
deminzhou@yahoo.com

Abstract This paper describes a case study in the Ecohydrology of marsh wetlands in the Northeast portion of the Sanjiang Plains in China. In this area, ninety percent of the marsh landscape has been lost in the past 30 years. The integrated approach employed during this study developed a relationship between the loss of soil moisture and the characteristics of the wetland plant habitats using remote sensing technologies. Based on this study's findings, researchers have been able to predict possible ecological consequences of hydrological alteration due extensive drainage in the area. The predominant distribution of the typical marsh communities in the yearly saturated zone is diminished into the larger distribution of the wet meadow in the seasonal saturated zone, and then replaced by the predominant distribution of the wet meadow. These natural ecosystems are significantly disturbed by human activity rather than by climate change. This study has shown that it is possible to carry out spatio-temporal assessments of wetlands and to develop knowledge based strategies which can help maintain healthy wetlands, or repair wetland ecosystems damaged by global and regional changes.

1 Introduction

"Wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which at low tide does not exceed 6 meters" (Ramsar Convention, 1971). Wetlands provide service as a habitat for highly endangered wild life. Hence, wetlands have been described as a "Storage Area of Natural Genes" (Mitsch and Gosselink, 1986). The continued loss of marsh wetlands and their ecological degradation have received much attention from scientists. Within the Sanjiang Plain, over 80% of the marsh wetlands has been lost in the past 50 years (Liu, *et al*., 2004). The loss of wetlands is mainly associated with extensive local agricultural activities, specifically by reclamation, which fragments the wetland. Though most of the remaining area is now protected as natural reserves, the wetland habitats are still under a multitude of threats, causing irreversible loss of biodiversity (Liu, *et al*., 2002).

Eco-hydrologists wish to understand and analyse the correlation between ecology and hydrology in riparian areas (Rodriguez 2000; Acremanm, 2001). To confront the threats to the marsh wetland ecosystems from both human interventions and global climate change, a case study in marsh wetland degradation occurrence over the last 30 years is presented. An integrated eco-hydrological analysis was carried out to gain a better understanding of the loss of moisture characteristics of the wetland plant habitats, from which the researchers can predict the possible ecological consequences caused by hydrological alteration (Zhou, *et al*., 2006). Ultimately, a better assessment of wetlands and knowledge based strategies can be employed to maintain healthy wetlands or to repair damaged wetland ecosystems due to global and regional changes (Capon 2005).

2 Materials and Methods

The study area of this research is located in the Northeast portion of the Sanjiang Plain, an extensive plain between three large rivers: the Heilong River, the Songhua River, and the Wusuli River.

Widespread flooding is aided by a network of cross channels on the low topographic gradient of the area (average slope grade of less than 1:10,000). The study area covers 2416 km^2. Surrounded by three local farms, the Honghe National Nature Reserve (HNNR) is on the International Important Wetland list for being a typical inland wetland and fresh water ecosystem in the North Temperate Zone.

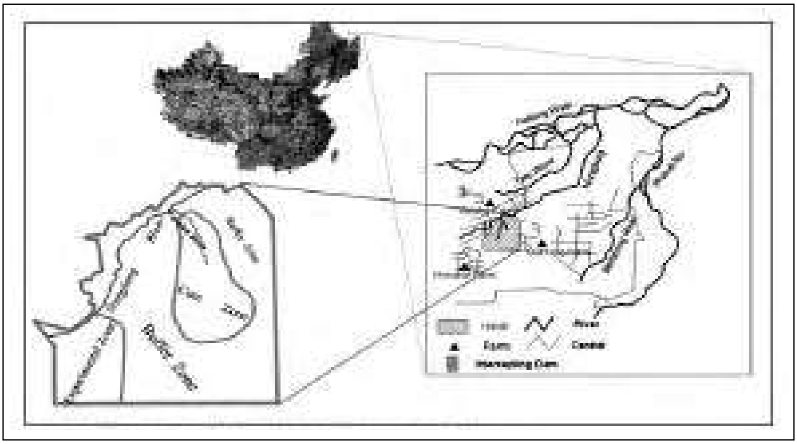


Fig. 1 Geographic position of the Honghe National Nature Reserve in China.

One cloud-free Landsat MSS image and two Landsat TM 7 images of the study area were acquired for the 1975, 1989, and 2006 growing seasons. An original contour map covering the HNNR at scale of 1:10,000, with 1 metre elevation intervals, is used for DEM generation. Climate data from 1982 to 2002 at Honghe came from a climate station supported by the Field Station of Wetland Ecology of the Chinese Academy of Sciences, and form the Honghe Farm, 17 km southwest from the HNNR. Statistical data for the crop land area and rice land area from 1966 to 2002 came from the statistical yearbooks of local farms.

The regional classification mapping in the specific dates was carried out using the Erdas 8.6 platform to interpret the enhanced pre-processed TM images with colour composites. A digital river network and the sub-catchment delineation were generated from the grid DEM by using the hydrological analysis module within ArcGIS 9.2. All above digital information was validated with both GPS waypoints and the relief map. Within the HNNR, a hydro-ecological analysis was done by coupling the 13 wetland community compositions with the two hydro-geomorphic zones. The wetland landscape patterns were coupled with the hydro-regime zones for the other hydro-ecological analysis in the HNNR (Zhou, *et al*., 2008).

3 Results and Discussion

Ninety percent of the marsh landscape has been lost in the study area in the past 30 years. Most of the marshland has been claimed by the cropland. The wetland reclamation has slowed down from 1989, while a large area of dry cropland has been changed into paddy field with the support of an extensive irrigation system. These irrigation networks in the surrounding three farms have altered the hydrological conditions that are required for the maintenance of marsh wetlands in the HNNR; therefore, over 50 percent of the marsh wetlands has been degraded into the meadow landscape due to the drier plant habitat, from 1975 to 2006.

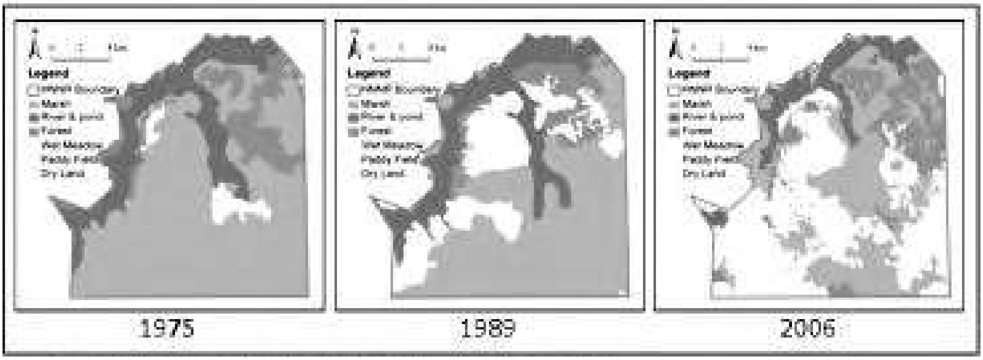


Fig. 2 Change of the wetland landscape in the HNNR within the past 30 years.

The ecohydrological research results show that the distribution of wetland vegetation types follows a specific pattern along a hydro-geomorphic gradient in the HNNR. The spatial patterns of vegetation match soil moisture distribution very well due to a natural ecological response. The predominant distribution of the typical marsh communities in the perennially saturated zone is diminished into the larger distribution of the wet meadow in the seasonal saturated zone, and then replaced by the predominant distribution of the wet meadow, with fewer marshes in the perennially unsaturated zone (Zhou, *et al.*, 2008). Within the HNNR, the decrease of both flooding frequency and its extent makes the wetness gradient fall back along the geomorphological gradient, which lessens the area of marsh habitats with suitable wetness. Consequently, non-marsh plants expand along the geomorphological gradient by replacing typical marsh plants. The distribution of the typical marsh has accordingly shrunk into the limited shallow riverway or low-lying land.

A linear regression on yearly average temperature data shows that local temperature warms up at a rate of 0.374° C per 10 years since 1982. Application of a similar method indicates that local yearly precipitation has decreased at a rate of 2.039 mm per year in the past 20 years. The natural ecosystems are significantly disturbed by human activity rather than by climate change. Statistical data from local farms shows a 10-fold increase in crop area, and a nearly 40,000-fold increase in the rice area since 1996 (Zhou, *et al.*, 2009). In the Sanjiang Plains, every local farm has established a systematic irrigation network, which greatly disturbs the local natural water system. Established reservoirs or dikes limit water supplies from rivers to wetlands. Not only do they cut off the hydraulic relationships between wetlands and nearby rivers or lakes, but water sources from the wide catchment to the wetland are also cut off by irrigation works such as dams, canals, and dikes used for flood control. Some limited observational data indicate that there have been significant changes in shallow groundwater in the past few years in the HNNR. Monitoring data indicates an annual mean reduction of 6 cm of the surface water level in the core area from 1993 to 2002, as well as an annual mean reduction of 80 cm of the ground water level from 1997 to 2002 (Zhou, *et al.*, 2006).

4 Conclusions

There are two types of the ecological crisis affecting marsh wetland habitats in the Sanjiang Plains. First, most marsh wetland habitats have been lost due to local reclamation for economic purposes, and this is visible and constantly happening. Second, the lack of water resources is causing the marsh wetland to degrade into a meadow wetland, due to both agricultural activities and global climate change. This process is recessive, slow, and continuous if human interventions are not halted and the trend of global change is not reversed. Climate change provides an additional stress to the degradation of wetland ecosystems. Human interventions, however, speed up the degradation significantly. Marsh wetland degradation is magnified when coupled with natural factors. Further research of wetland eco-hydrology needs to concentrate on a better understanding of the ecological degradation processes linked with the change in hydrological regimes due to the disturbances from both natural and human factors.

Acknowledgements

This study was funded by both the National 863 high-tech project of China (2007AA12Z176) and the National Natural Science Foundation of China (NSFC40871241), awarded to Dr. Demin Zhou. Both the Sanjiang National Research Station of Wetlands Ecology and the Honghe National Nature Reserve gave valuable support to the research by providing facilities to conduct field work.

REFERENCES

Acremanm, C. (2001) *Hydro-ecology: Linking Hydrology and Aquatic Ecology.* IAHS Publ.

Capon, S.J. (2005) Flood variability and spatial variation in plant community composition and structure on a large arid floodplain. *Journal of Arid Environments* 60: 283-302.

Liu, H.Y., Zhang, S.K. and Lu, X.G. (2004) Wetland Landscape Structure and the Spatial-temporal Changes in 50 Years in the Sanjiang Plain [J]. *ACTA GEGGRAPHICA SINICA* 59(3): 391-400.

Liu, X.T. and Ma, X.H. (2002) *Natural Environmental Change and Ecological Protection in the Sanjiang Plain*. Beijing: Science Press, China. 135-151pp.

Mitsch, W.J. and Gosselink, J.M. (1986) *Wetlands.* New York: Van Nostrand Reinhold Company Inc.

Ramsar Convention. (1971). Available from: http://www.ramsar.org/key_conv_e.htm.

Rodriguez, I. (2000) Eco-hydrology: a hydrological perspective of climate-soil-vegetation dynamics. *Wat Resour Res* 36: 3-9.

Wheeler, BD. (1999) Water and plants in freshwater wetlands. In: Baird, A.J. & Wilby, RL. (eds.), *Eco-Hydrology: Plants and Water in Terrestrial and Aquatic Environments*. 127-180. Routledge: London and New York.

Zhou D., Gong H., Liu Zh. (2008) Integrated wetland ecologic assessment of environmental condition in water catchments: Linking hydro-ecological modelling and Geo-information techniques. *Ecological Modeling* 214: 411-420.

Zhou D., Gong H., Luan Zh., Hu J., Wu F. 2006. Spatial Patterns of Water controlled Wetland Communities in the Sanjiang Floodplain, Northeast China. *Community Ecology* 7(2), 223-234.

Zhou D., Gong H., Wang Y., Khan S., Zhao K., (2009). Study of Driving forces of Wetland Degradation in the Honghe National Nature Reserve in the Sanjiang Floodplain, Northeast China. *Environmental Modeling & Assessment* 14:101-111.

Modeling Groundwater Flow using Chemical Tracers in a Micro Basin: Gamboa, Cerro Pelado, Panama Canal

ERICK VALLESTER, EUCLIDES DEAGO, JOSÉ RODRÍGUEZ, JEIMI CERRUD
Hydraulic and Hydrotechnical Research Center, Universidad Tecnológica de Panamá
erick.vallester@utp.ac.pa

Abstract The Panama Canal operations depend on the amount of water flowing into its watershed and on the proper control of the water levels in Lakes Gatun and Alajuela. To estimate the amount of water available for the operation of the Panama Canal, it is important to establish groundwater flows and interactions between surface water and the underlying aquifers. For this purpose, we monitored, during the dry season, a 1-hectare micro watershed in Cerro Pelado to determine groundwater flow behavior in the unsaturated zone. This paper presents the results of field measurements obtained with a Soil Moisture Conductivity/Temperature Sensor**,** and likewise, presents the mathematical model of groundwater flow using 2D/3D HYDRUS. The estimated velocity of groundwater flow in saturated soil conditions with field data was 0.07094 m/h. With the field results and the initial and boundary conditions, several models were run, accurately representing the direction of flow and the speed in this area of study, using the finite element method in MATLAB, to complement the results previously obtained by HYDRUS 2D. The results obtained in this study allow us to better understand how groundwater behaves in a tropical rainforest. To get a complete picture of the flow of water entering a watershed, it is necessary to incorporate variables such as evapotranspiration.

Key words Panama Canal; groundwater; unsaturated zone; mathematical modeling; HYDRUS 2D/3D

Modeling of Biological Denitrification of Water Using Canal Grass (*Saccharum spontaneum*) as Carbon Source

EUCLIDES DEAGO[1], GONZALO PIZARRO[2] & ERICK VALLESTER[1]

1 *Centro de Investigaciones Hidráulicas e Hidrotécnicas, Universidad Tecnológica de Panamá, Panama*

2 *Departamento de Ingeniería Hidráulica y Ambiental, Facultad de Ingeniería, Pontificia Universidad Católica de Chile, Chile*

euclides.deago@utp.ac.pa

Abstract Groundwater contamination with nitrate is a problem primarily caused by the excessive use of agrochemicals. To address this situation, in recent years we have studied the biological denitrification (BD) of nitrate using natural organic solid substrates (NOSS) as an alternative source of organic carbon, obtaining encouraging results. However, despite progress in this area, little is known of the behavior of the processes that control BD using NOSS. In this study we investigated the use of canal grass (*Saccharum spontaneum*) as NOSS as an alternative for BD. We present the results of the study carried out in batch reactors and mathematical modeling of the processes involved in BD. In this research we obtained kinetic parameters necessary for mathematical modeling: net return “Y” (0.668 mg VSS / mg COD), the maximum rate of nitrate consumption “qmax” (1.3 mg NO3-N / mg VSS - day) the Monod affinity constant “Ks” (5.7 mg NO3-N / L). These parameters are within the range obtained by other authors for denitrification processes. With these results and the initial and boundary conditions we made several runs of the model, which accurately represented the nitrate removal rate and the release of carbon from NOSS. We note that mathematical modeling is an excellent tool for studying BD using NOSS, because it allows the system to predict how it will respond, depending on operating conditions. It is required to study BD in continuous systems, e.g., in filtration columns and *in situ*, as it would better resemble reality.

Key words Biological denitrification; *Saccharum spontaneum*; SSON; mathematical modeling

A Panama Canal Watershed Experiment: The Agua Salud Project

FRED L. OGDEN[1,3], ROBERT F. STALLARD[2,3], HELMUT ELSENBEER[3,4] & JEFFERSON HALL[3]

1 *Department of Civil & Architectural Engineering, University of Wyoming, USA*
2 *U.S. Geological Survey, Boulder, Colorado, USA*
3 *Smithsonian Tropical Research Institute, USA*
4 *Institute of Geoecology, University of Potsdam, Potsdam, Germany*
f.ogden@uwyo.edu

Abstract Does reforestation result in more or less dry-season runoff in the seasonal tropics? The Agua Salud project, managed by the Smithsonian Tropical Research Institute (STRI), aims to answer this question. Our study is being undertaken within the Panama Canal watershed, on lands adjacent to the old regrowth Soberanía National Park, which is in the former U.S. Canal Zone. Over the past two years we have planted over 150,000 trees, both native timber species and teak, in catchments that were until recently grazed pastures. We have instrumented these plantation catchments as well as control catchments that consist of pasture, old re-growth forest, early secondary succession, and an invasive grass species *Saccharum spontaneum*. Instrumentation installed to date includes 16 on-stream weirs in catchments that range from 8 to 400 ha, a network of triple rain-gages, two eddy-covariance systems, a surface energy balance station, 10 shallow groundwater monitoring wells, and automated water quality samplers. Studies completed to date include throughfall studies and soil analysis, a 25-year chronosequence in 108 secondary succession plots, and LiDAR overflights. Work in progress includes above- and below-ground carbon analyses, monitoring of all hydrologic and meteorological variables, and tracer studies using both natural and introduced tracers, as well as observations of shallow subsurface flow using electrical resistivity tomography at the hillslope scale. We are also educating large numbers of undergraduate, graduate, and post-doctoral students in the important field of tropical hydrology, in collaboration with Panamanian universities. Data and observations will guide the development of conceptual and physics-based hydrologic models to enable predictions of the effect of reforestation on the water-balance at time scales ranging from single-events to annual. Models will be used to up-scale knowledge developed at the plantation and catchment scale to the entire Panama Canal watershed. Knowledge gained and models developed will help aid in land-use management decisions in Panama, the Caribbean basin, and much of the mountainous seasonal tropics. Our project is working in close cooperation with the Panama Canal Authority and the National Environmental Authority of Panama.

1 Introduction

Due to the construction of the Panama Canal, the Canal watershed has the distinction of being the only substantial watershed on the planet that discharges into two oceans. A second distinguishing feature is that it has the longest and most complete hydrological and land-use change record of any watershed of comparable size in the tropics. This makes it an appealing site for tropical research on hydrologic behavior, function, and ecosystem services. Our project builds upon a significant body of prior work in the Panama Canal Watershed, including the Panama Canal Watershed Monitoring Project, which was a joint project between the Panamanian Government and the U.S. Agency for International Development (Heckadon Moreno, *et al.*, 1999; Condit, *et al.*, 2001; and Ibáñez, *et al.,* 2001).

The largest river in the Panama Canal Watershed is the Río Chagres, which was dammed to create Lake Gatún, and thus create the trans-isthmian water crossing at a 26 m (85 ft) elevation. The upper Río Chagres is a protected natural park that is 98% old-growth forest (Ibáñez, *et al*., 2001). The Upper Río Chagres watershed was studied by a multi-disciplinary group of researchers in 2002-2003, as summarized in Harmon (2005). The entire Canal basin is covered by a dense network of hydrological monitoring stations, including approximately 30 streamflow gages, more than 70 rain gages, 20 meteorological stations, twice-daily weather balloon soundings, and an S-band weather radar. The Panama Canal Authority (ACP) performs regular annual assessments of land cover within the Canal watershed.

With enough time, the intense weathering of igneous rocks in the seasonal humid tropics produces soils dominated by aluminum and iron sesquioxides (Stallard, 1988). Precursor soils are Acrisols and Ferralsols, with the latter typically older and dominant on continental cratons. The study area and much of the eastern Canal Basin are underlain mostly by basaltic and andesitic rocks of a Cretaceous island arc (Stewart, *et al.*, 1980; Wörner, *et al.*, 2005). The soils are broadly classified as Acrisols and are up to 20 m in thickness. These soils are dominated by the clay minerals kaolinite and halloysite, with small amounts of illite, smecitite, and interlayered illite/smectite (Harrison, *et al*., 2005). Deeper weathering profiles with higher proportions of clay are present primarily in upper slope positions (Harrison, *et al*., 2005). The soils of the tropics have been poorly mapped in general, so the exact coverage of these soils is uncertain. Together, Acrisols and Ferralsols cover 1,960,000 km^2 or 57% of the humid tropics (Richter and Babbar, 1991; Kaufman, *et al*., 1998; see Fig. 1). The main difference between these two soils is an increase in clay content with depth in the case of Acrisols. Near the land surface, Acrisols and Ferrisols have similar porosity and plant available moisture, and are frequently well drained and structured (Kaufman, *et al*., 1998; Elsenbeer, 2001). Tropical vegetation, which we hypothesize is the major driver of the rapid flow capacity, is highly diverse across the tropics. Thus, we expect that our results will be applicable to some degree in areas of the tropics covered by Acrisols and Ferralsols.

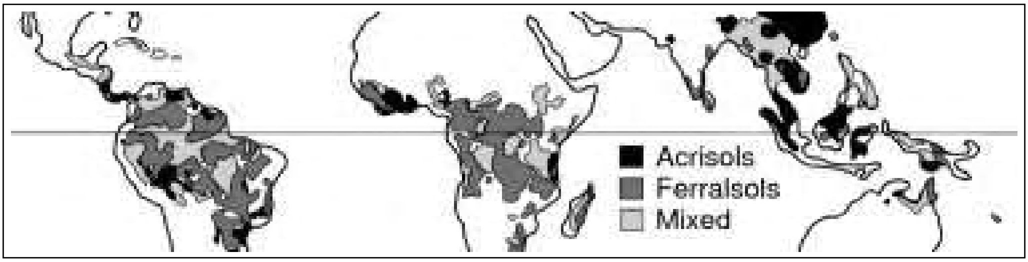


Fig. 1 Distribution of Acrisols, Ferralsols, and dominant mixes of the two throughout the tropics (after FAO-GIS, 1998).

Macropores and pipes are produced by roots, soil fauna, or desiccation cracking. They provide pathways for water to bypass the soil matrix and to move downslope to the shallow aquifer at velocities of several mm/sec (e.g., Beven and Germann, 1982; Mosley, 1979, 1982). Soil physics dictates that water will enter soil pipes or macropores only under positive pressure (Hillel, 1998). Once water is inside the macropore network, it can be transported downslope through otherwise unsaturated soils. Many studies indicate that the importance of macropore flow increases with the amount of event precipitation.

An abundance of macropores (both desiccation and tension cracks) and pipes was observed in all soil pits opened at three sites in the Upper Río Chagres watershed during a reconnaissance study conducted in 2002 (Harrison, *et al*., 2005; Hendrickx, *et al*., 2005), as well as those dug near Gamboa (Niedzialek, 2007; Niedzialek and Ogden, 2005). Subsurface pipes were observed by Hendrickx, *et al.* (2005) with diameters up to about 10 cm. The abundance of macropores and pipes in the Upper Río Chagres watershed is much larger than ever observed in soils in the more temperate regions of western Europe and New Zealand (J.B.J. Harrison and J.M.H. Hendrickx, pers. comm.). Señor P. Rojas, a park ranger in the Río Chagres watershed, has often observed jets of water from macropore pipes during heavy precipitation events (Hendrickx, *et al.* 2005) indicating that the pipe network is hydraulically well connected. The exfiltration of water from pipes on tropical hill slopes has also been reported by Bonell, *et al*. (1984), Elsenbeer and Cassel (1991), and Niedzialek (2007) at a high landscape position at Cerro Pelado near Gamboa, Panama, during a 4-hour, 100 mm rainstorm in November, 2006.

2 Study Sites

The STRI Panama Canal Watershed Experiment takes advantage of new and existing hydrologic infrastructure. The weirs shown at Ciudad del Árbol in Fig. 2 where built in the 1920's. We located these long-neglected weirs and re-activated them in support of our project. We have also installed over thirty rain gages at ten locations across the study area.

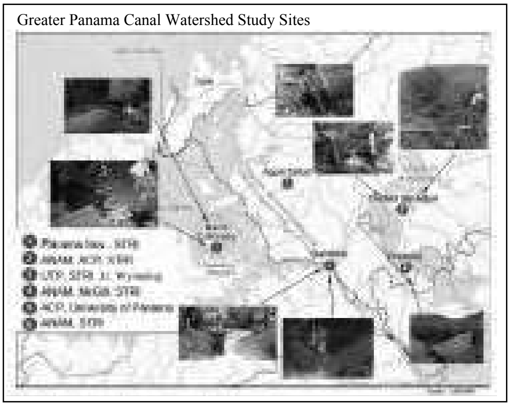


Fig. 2 Study sites and weirs in the greater Panama Canal Watershed.

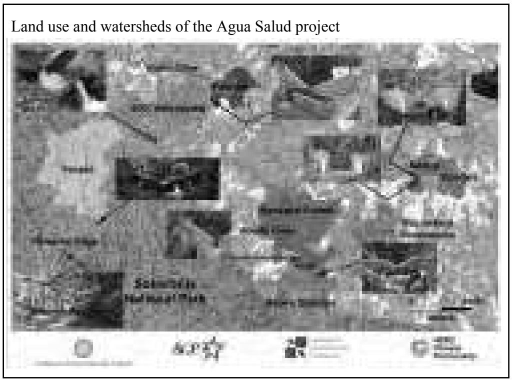


Fig. 3 Study catchments in the Agua Salud project showing land-use, plantations and weirs. Darker greens are forest.

The plantation, old-regrowth, managed forest, and pasture study sites of the Agua Salud project are shown in Fig. 3, together with a background of land-use. The forest in the catchment labeled 50% deforested is a mosaic of regrowth due to non-interventional succession. The pasture catchment is being maintained in active grazing. The teak and native-species plantations are being fertilized annually, and the grass and competing native vegetation are being manually trimmed on a regular basis.

One of the hypotheses being examined in the Agua Salud project is that reforestation of pasture will increase infiltration and ground water recharge. Increased ground water recharge will increase dry season river flows. One of the tools being used to test this hypothesis is electrical resistivity tomography (ERT). Fig. 4 shows results of an ERT test using slightly salty water (500 mg/l NaCl), which resulted in a 400% increase in electrical conductivity, applied at the upslope end of the study hillslope. Five hours after the start of the test, the electrical conductivity in the upper soil layer showed approximately a 20% increase in conductivity. Approximately 20 mm of rain fell during this test, revealing the vertical structure of the active flow layer in the soil.

3 Conclusions

The STRI Agua Salud project aims at improving our understanding of the ecosystem services provided by tropical watersheds including production of consistent high-quality supplies of water for human consumption and Canal operations. Fig. 5 shows significant differences between dry-season streamflow behavior as a function of land-use in closely paired catchments. The forested catchment attenuates flood peaks, and results in increased base flow during the dry season. Our experiment is fully operational and beginning to yield useful results. Better yet, the project infrastructure is positioned to observe a significant period of aforestation in a tropical watershed.

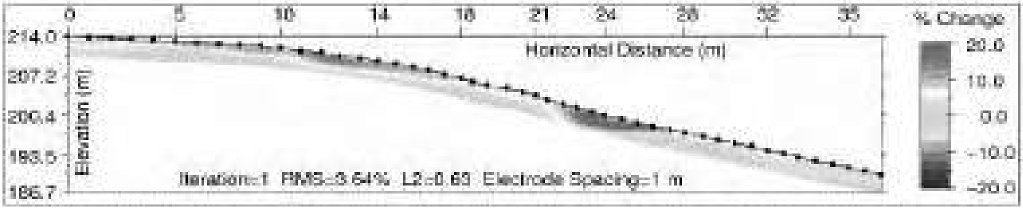


Fig. 4 Results of the Electrical Resistivity Tomography (ERT) test conducted using an applied salinity contrast in the Agua Salud project teak plantation in July, 2009, showing percent change in electrical conductivity 5 hours after application at x=0. ERT array electrodes are shown as black dots on the surface. The active flow layer is readily visible.

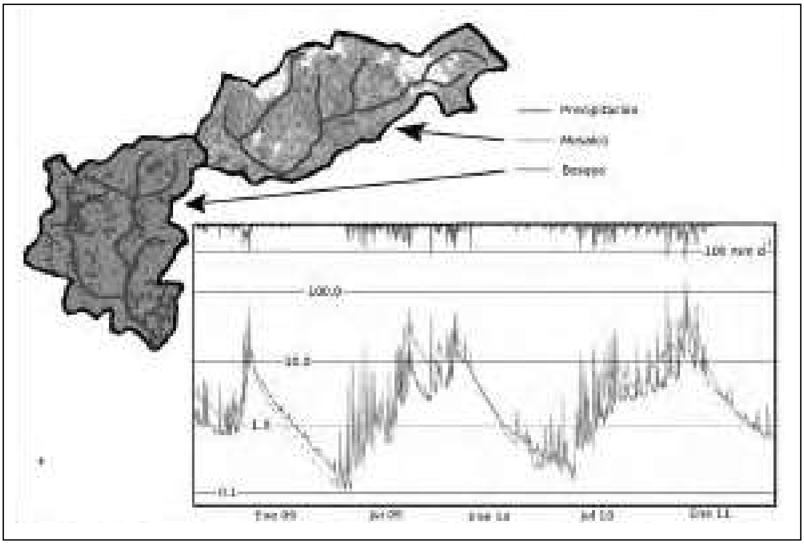


Fig. 5 Significant dry-season flow differences between old-regrowth forest and approximately 50% reforesting mosaic watersheds.
Translation: Precipitación = Precipitation; Mosaic = Mosaic; Bosque = Forest.

Acknowledgements

Primary funding for the STRI Agua Salud project comes from the HSBC Climate Partnership. The project would not be possible without the aid of numerous U.S. and Panamanian agencies. Funds for hydrometeorological instrumentation have been provided by the U.S. Army Research Office through Grant 55573-EV-RIP to the first author. The Panama Canal Authority provides significant support through funding for native-species plantations, operation of two meteorological stations in the Agua Salud study area, and through data sharing and technology transfer. The Panamanian Environmental Authority has provided support through permitting and access to the Soberanía National Park catchments. Other sources of funding include the University of Wyoming, the U.S. Geological Survey, and the University of Potsdam, through the German National Science Foundation. We also acknowledge the support of undergraduate, graduate, and post-doctoral students too numerous to mention.

REFERENCES

Beven, K., and P. Germann. (1982) Macropores and Water-Flow in Soils. *Water Resour. Res.* 18: 1311-1325.

Bonell, M., Cassels, D.S. and Gilmour, D.A. (1984) Vertical soil water movement in a tropical rainforest catchment in north-east Queensland. *Earth Surf. Processes Landforms* 8: 253-272.

Condit, R., Robinson, W.D., Ibáñez, D., R., Aguilar, S., Sanjur, A., Martinez, R., Stallard, R.F., Garcia, T., Angehr, G.R., Petit, L., Wright, S.J., Robinson, T.R., and Heckadon Moreno, S. (2001) The status of the Panama Canal Watershed and its biodiversity at the beginning of the 21st Century: *Bioscience* 51(5):389-398.

Elsenbeer, H. (2001) Hydrologic flowpaths in tropical rainforest soilscapes, a review: *Hydrol. Proc.* 15:1751-1759.

Elsenbeer, H. and Cassel, D.K. (1991) The mechanisms of overland flow generation in a small catchment in western Amazonia. In: B.P.F. Braga and C. A. Fernandez-Jauregui (Editors), *Water Management of the Amazon Basin*. UNESCO, Montevideo, Uruguay, pp. 213-220.

Harmon, R.S. (2005) *The Río Chagres Panama - Multidisciplinary Profile of a Tropical Watershed*, Springer.

Harrison, J.B.J., Hendrickx, J.M.H., Vega, D., Calvo-Gobetti, L.E. (2005) Soils of the upper Río Chagres Basin, Panama. In R.S. Harmon (Ed.), *The Río Chagres Panama - Multidisciplinary Profile of a Tropical Watershed*, Springer, 97-112.

Heckadon Moreno, S., Ibáñez D., R., and Condit, R. (1999) *La Cuenca Del Canal: Deforestacion, Contaminacion y Urbanizacion*. Panama, Republic of Panama, Smithsonian Tropical Research Institute.

Hendrickx, J. M. H., D. Vega, J. B. J. Harrison, P. Rojas, L. E. C. Gobbetti, and T. W. Miller. (2005) Soil hydrology along steep hill slopes in the Río Chagres watershed. in R. S. Harmon, editor. *The Río Chagres: A multidisciplinary profile of a tropical watershed*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Hillel, D. (1998) *Environmental soil physics*. Academic Press, San Diego, CA.

Ibáñez D., R., Condit, R., Angehr, G.R., Aguilar, S., Garcia, T., Martinez, R., Sanjur, A., Stallard R.F., Wright S.J., Rand A.S., and Heckadon Moreno S. (2002) An ecosystem report on the Panama Canal: Monitoring the status of the forest communities and the watershed: *Envir. Monitoring and Assess.* 80:65-95.

Kaufman, S., W.G. Sombroek, and S. Mantel. (1998) Forest Soils in the Humid Tropics: Characteristics and Classification, pp. 9-20 in *Soils of Tropical Forest Ecosystems: Characteristics, Ecology, and Management*, A. Schulte and D. Ruhiyat (Eds.), Springer, ISBN 3-540-63607-2.

Mosley, M.P. (1979) Streamflow Generation in a Forested Watershed, New Zealand. *Water Resour. Res.* 15:795-806.

Mosley, M.P. (1982) Subsurface flow velocities through selected forest soils, South Island, New Zealand. *J. Hydrol*. 44(104):65-92.

Niedzialek, J.M. (2007) *Unusual Hydrograph Characteristics, Upper Río Chagres, Panama*, Ph.D. Dissertation, University of Connecticut, Storrs, CT 06268 USA, 261 pp.

Niedzialek, J. M., and F. L. Ogden. (2005) Runoff production in the upper Río Chagres catchment, Panama, in R. S. Harmon, ed., *The Río Chagres: A multidisciplinary profile of a tropical watershed*, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Richter, D.D., and L.I. Babbar. (1991) Soil Diversity in the Tropics, in *Advances in Ecological Research* 21, Begon, M., A.H. Fitter, and MacFadyen, eds., Academic Press Inc. San Diego, CA 92101 USA.

Stallard, R.F. (1988) Chapter 1: Weathering and erosion in the humid tropics, in *Physical and Chemical Weathering in Geochemical Cycles*, Lerman, A. and Meybeck, M., editors: Kluwer Academic Publishers, Dordrecht, Holland, p. 225-246.

Stewart, R.H. and Stewart, J.L., with collaboration of Woodring, W. P. (1980) *Geologic map of the Panama Canal and vicinity, Republic of Panama*, US Geological Survey, IMAP-1232.

Wörner, G., Harmon, R.S., Hartmann, G., and Simon, K. (2005) Igneous geology and geochemistry of the Upper Río Chagres Basin, in R. S. Harmon, editor. *The Río Chagres: A multidisciplinary profile of a tropical watershed*. Kluwer Academic Publishers, Dordrecht, The Netherlands, 65-81 pp.

Innovative Water Management for Lakeside Communities in Uganda: The Eco-Hydro-Social Health Approach

FREDERICK KAKEMBO
Uganda Christian University, Uganda
fkakembo@ucu.ac.ug

Abstract This paper explores an integrated water management framework for safe water provision and waste disposal for lakeside communities in 3 districts in Uganda. The communities experience high water stress, which leads to ill-health and poverty. It is premised that fixing these problems goes beyond technology, equipments, and physical infrastructure, and calls for innovative management systems. Guided by the hydro-social-health perspective, existing water management issues are analysed and the innovative management frameworks are demonstrated. The paper describes the linkages between human health, management patterns, technical issues, and socio-cultural issues. Existing literature suggests a return of between US$3 and $34 for every dollar invested in safe water and sanitation. Given that the government lacks adequate financial resources for water management, it is suggested that Public Private Partnerships (PPP) be used as viable management models. Besides PPP, the paper analyses socio-economic incentives in promotion of communities' involvement in water resources management. It examines polluting sources/activities; health risk perceptions; existing water treatment options; attitudes towards possible sludge reuse; existing policy/regulatory frameworks; willingness and capacity to pay for safe water and waste disposal; local managerial/technical skills; and local capacity to mobilize capital. Based on the findings, an integrated and sustainable water management framework is proposed, with particular reference to re-use of sludge to boost agricultural outputs. It is concluded that community education and training could be instrumental in capacity building for PPP, and in promoting community involvement and participation.

Key words Safe-water; waste-disposal; eco-hydro-social-health; management; Public-Private-Partnerships

1 Introduction

The provision of safe water and sustainable disposal of wastewater in Uganda calls for innovative approaches. The growth rates of urbanisation at 20%, and the 15% growth of manufacturing (UBOS, 2008) could translate into increased contamination of Lake Victoria and other natural water sources. Untreated domestic and industrial wastes are discharged from Kampala, Jinja, Entebbe, and other small towns. The main pollutants are industries, hospitals, schools, and households within urban and peri-urban areas of Kampala, Mukono, Jinja, and Entebbe. The daily discharge from Kampala city alone amounts to 6.34 tonnes of Biological Oxygen Demand (BOD), 1 tone of Phosphorous, and 1.5 tonnes of nitrogen (Banadda, *et al*., 2009).

The increasing saturation of Lake Victoria is exemplified by watercolour changes and the growth of algae. Other destinations of untreated wastewater are wetlands, natural drainage channels, and other unoccupied areas (MWE, 2010). This paper, however, focuses on the districts of Mukono, Kayunga, and Buikwe, which up to two years ago were under the Mukono district.

The study area lies between longitudes 32∞ 30' 30" and 33∞ 25' E, and latitudes 1∞ S and 1∞ 30' 30" N. It is surrounded by rivers in the east and west, Lake Victoria in the south, and Lake Kyoga in the north. About 90% of the communities are rural, with agriculture as their main economic activity. The lakeside communities in the study area are among the 124 fishing shoreline settlements on Lake Victoria. It is estimated that the population in the settlements is about 92,000, but their pit-latrine coverage is less than 20%. Much of the wastes (approx. 2 tonnes of DOB, 0.25 tonnes of nitrogen, and 0.13 tonnes of phosphorous) are dumped into (or close to) natural water sources

(MWE, 2010). This untreated or partially treated wastewater contains pathogens, organic chemicals, and heavy metals that are hazardous to human health, and which may ultimately lead to poverty.

2 Conceptual Framework

It is premised that fixing the issues of water quality and waste disposal goes beyond technology, equipment, and physical infrastructure; and calls for innovative management approaches. This view is based on the continued deterioration of water quality despite numerous regional and global initiatives over a couple of decades. It appears that a number of projects concentrate on physical infrastructure and focus on quantitative targets, such as number of households provided with water/sanitation, and on time-frames for attaining targets. As pointed out by Swyngedouw (2009), true water scarcity goes beyond the physical absence of water; it is an issue of economy and politics.

This paper discusses a multi-dimensional approach to water provision and wastewater disposal. The approach examines the inter-linkages between physical, ecological, technical, economic, and socio-cultural factors. Given that inadequate sanitation does not stand in isolation, it is imperative to explore diverse factors that influence human behaviour, particularly the adherence to ideal practices. To be effective, any intervention may have to address physical, ecological, economic, policy, and socio-cultural issues. Existing approaches seem to work well in a typically hydrologic cycle (describing physical processes of the movement and distribution of water through its various forms). It is proposed that water resources management adopt a Hydro-Social health cycle that describes the relationship between ecosystems, human activities, and health.

The Hydro Social health approach is a re-definition of the landscape of water resources management that focuses on political-economy and political-ecology of water and water circulation (Castro 2006; Loftus 2005; Kaika 2005). It focuses on correlations between the hydrological cycle and the social, political, economic, and cultural factors (Swyngedouw 2004). Water circulation is a convergence of physical and social processes because nature and society are inseparably fused (Swyngedouw, 2006a). This approach challenges the traditional fragmented perspectives that look at the social and physical spheres as separate entities (Bakker 2003; Heynen, *et al.*, 2005). This paper therefore discusses water accessibility and wastewater in light of the Eco-Hydro-Social-health cycle.

The study was based on the assumption that socio-economic incentives and Public Private Partnerships (PPP)[1] may improve water accessibility and wastewater disposal. The expectation is that individuals would adopt ideal practices if they know the associated social and economic benefits. For instance, one of the assumed economic benefits of sustainable wastewater disposal is improved agricultural outputs. Wastewater has nutrients such as nitrogen, phosphorous, potassium and zinc, which act as manure for plants, and which improve other soil qualities (FAO, 2011). This value becomes particularly important in light of global shortages of phosphorous (NETWAS, 2011). Applying wastewater instead of natural irrigation water enabled farmers in Mexico to save US $150 per hectare relative to use of chemical fertilizers (Van der Hoek, *et al.*, 2002). It was also premised that resources of the private sector could make up for inadequate government human and financial resources. The feasibility of PPPs is reflected by studies that suggest a return of between US $3 and US $34 for every dollar invested in safe water and sanitation (Schuster-Wallace, *et al.*, 2008). On the basis of the Eco-Hydro-Social-health cycle, a number of factors are likely to influence the role and effectiveness of socio-economic incentives and PPPs for improving water resources management. The factors include: supportive policy frameworks, community risk perceptions, attitudes to wastewater treatment options, local willingness and capacity to pay for the water-related services, local capacity to mobilize capital, and availability of local managerial and technical skills. The focus of the study was to determine whether and how these factors influence safe water provision and wastewater disposal in the study area. The findings are expected to be the foundation of comprehensive studies at the next stage: determining the feasibility, cost-effectiveness, and cost-benefit analysis of various water management options in the study areas.

3 Study Objective

The main purpose of the study was to establish parameters to be used in a subsequent study that will assess the feasibility, cost effectiveness, and cost-benefit analysis of various water management options in the same areas.

4 Methodology

The study was typically exploratory applying a limited range of qualitative data collection tools when investigating the factors that influence the accessibility of safe water and disposal of wastewater in the districts of Mukono, Buikwe, and Kayunga. The research was partly based on critical analysis of data from current studies on water and sanitation in the three districts and in the country at large. It was also based on analysis of documents at the national and district offices of the National Water and Sewerage Corporation (NWSC). In-depth interviews were conducted partly to validate the existing data and to generate additional insights. The respondents included: NWSC staff within the districts and at the national headquarters, administrative staff at the various levels of local government in the districts, private (water related) service providers, community leaders (manning the water projects), and selected beneficiaries of water related services.

5 Results

This section describes the insights generated during the study on how various policy, economic, and socio-cultural factors converge to influence the provision of safe water and the disposal of wastewater.

Convergence of Economic and Policy Limitations

While regulatory instruments are in place to protect water sources from pollution, central and local governments do not have sufficient human and financial resources to observe compliance (MWE, 2010). The resources do not match the rapid and unplanned development of towns and industries, which are the main sources of untreated effluents. Out of the 89 companies, institutions, and organisations that were issued water discharge permits, only 39 have valid permits (MWE, 2011).

Apparently, the quality of water continues to deteriorate because of the widening demand-supply gap in the service delivery. For instance, while NWSC Statute 1995 mandates the NWSC to handle all domestic and industrial wastewater, the latter does not have adequate resources to handle the service by itself (NETWAS, 2011). Incidentally, high connection costs hamper private operators and industrialists from connecting to NWSC sewer systems. Cesspool operators charge a fee (15,000-20,000) for discharging treated wastewater into the Jinja plant (*ibid*). This induces industrialists and other private operators to discharge untreated wastewater into natural water sources. Furthermore, private operators are occasionally let down by electricity irregularity and poor roads, which are beyond their financial and mandatory scope. For instance, whenever electricity supply from the national grid is disconnected, the Uganda Christian University (Mukono), which operates a water treatment plant, incurs in large generator-fuel costs.

Most of the existing statuary instruments are focused on compliance with set discharge standards other than promoting alternative management options. The issues addressed are: safe storage, treatment, discharge, and disposal of wastewater. The instruments include: the National Environmental health policy (2005); the National Environment Standards for discharge of effluent into water or on land, and the National Environment (Waste Management) regulation 1999. The policy gaps in wastewater disposal could be bridged by alternative water resource management options such as PPPs. However, making PPPs operational is challenged by occasional failure by local and central government authorities to reconcile their socio-economic responsibilities with private providers' interests. For instance, private cesspool operators face undue competition from their counterparts in public institutions such as the police fire brigade, the army, educational institutions, and hospitals. While the private operators pay taxes, public providers do not pay taxes and they occasionally serve the same clients. Private operators therefore find themselves in a disadvantaged position. The other challenge is about demarcating and defining the key roles and responsibilities of consumers, regulators, NGOs/CBOs, private service providers, and local/central governments.

Town authorities in Mukono, Buikwe, and Kayunga have not yet enforced the setting up of service lanes to ensure access of cesspool trucks to septic tanks and latrines. Besides, unlike their counterparts in the Mityana town council, the administrators in the study areas have not enforced construction of water borne toilet facilities (in areas accessed by piped water). Given the high economic costs entailed, it has not yet been possible to set up sewer systems, and therefore the areas have to depend on cesspool trucks. The statuary instruments are silent about the re-use of wastewater. The only reference on the subject is the Kampala city council urban agriculture ordinance (2006). It prohibits people from using untreated human waste for agricultural purposes because of the associated health risks. The application of wastewater sludge is currently restricted to flowers, trees and other non-food crops (NETWAS, 2011).

Enabling Policy Environment and Community Involvement

The Water Act (1999) provides for the formation of Water User Groups and Water Associations. Group/association memberships are expected to be drawn from community beneficiaries. Their primary duties are to ensure maintenance by way of levying user charges. On the basis of these provisions, initiatives for improving water accessibility have been undertaken. This paper describes two initiatives to illustrate how enabling the policy environment enhances social inclusion and community participation.

The DANIDA-supported Rural Water and Sanitation (RUWASA) project empowered communities to participate in the construction and management of protected spring water wells. The communities provided: local materials such as sand, clay, gravel, hardcore; manual labour by way clearing the drains, fencing areas behind retaining walls; and handling storm water/ runoffs. Water User Committees (WUC) of six members and two caretakers (where one had to be a woman) were set up and mandated to: supervise caretakers, propose/enforce by-laws approved by the water users, ensure active participation, monitor activities, promote sanitation, and undertake hygiene education. The government responsibility was to produce guidelines for community based operations and maintenance activities, facilitate training of WUC and caretakers, pay the masons and supervisor, and transport materials and provide cement, pipes, iron bars, and other locally unavailable materials. It is estimated that the monetary value of the government contribution and that of the community were equivalent.

The second initiative is the UNU-INWEH-supported project in Kiyindi. It was aimed at increasing accessibility to the water supply. The initiative expanded an existing reservoir for water (coming out of a natural spring), which hitherto was not enough for the population of up to 20,000. Previously, local households competed for the same water with the Beach Management Unit (BMU), which needed large volumes to clean fish. The initiative involved setting up a management committee, made up by 50% women and representatives from the BMU. The outcome is that 700 (20 L) jerry cans could be sold daily using four water kiosks with meters. The project has helped to reduce the cost of water in the area from between 300-500 schillings to 100 shillings. The saving (in terms of time and money, is remarkable for the lakeside communities whose incomes are not regular.

In both of these initiatives however, the achievement can only be described in terms of quantity but not quality of water accessed. Perhaps because of practical financial issues and sustainability considerations the initiatives did not include a water treatment component. The water is therefore susceptible to health risks, even when it comes from natural springs. A study is imperative to determine whether communities can afford the water if treatment is incorporated.

Economic Issues in Safe Water Provision and Wastewater Disposal

As indicated before, many of the existing water provision initiatives lack a treatment component. The Uganda Christian University is one of the few organisations that supply treated water (inside and to a few areas outside the university). The biggest limitation appears to be costs and sustainability. With regards to the wastewater disposal, there are no sewer systems in the study areas. Industries, institutions, and households depend on the costly cesspool trucks for drainage. The exception is the Uganda Christian University, which has a central sewer system. On the reuse of sludge, very few farmers in the study areas apply it for farming. All these factors mean that there is little incentive not to dump wastewater into (or near) natural water sources. In the few cases where sludge is used for trees and flower nurseries (in Kampala), preference of small scale farmers is based on the lower costs entailed, relative to commercial fertilizers (GTZ, 2010). Willingness by medium scale farmers to use it depends on the availability of distribution networks (NETWAS, 2011). Large scale farmers would be ready to use it if transport costs were low (GTZ and CIDI, 2009). Wastewater reuse therefore could be promoted if it is availed nearer to potential users. Given that sludge from domestic sources contain less heavy metals (WHO, 2006), treatment costs (for pathogens) are likely to be lower compared to that from industrial urban areas. In case awareness of sludge value is created, farmers in the Kayunga district (near the Jinja plant) could get it for free, except for the transportation costs (which, according to figures used in Kampala, are UGX 15,000). Farmers in the Mukono district (near Uganda Christian University) could obtain it at a lower cost.

Socio-Cultural Concepts of Safe Water and Wastewater Disposal

Communities' health risk perceptions influence the management of water resources because willingness to meet costs of safe water depend on the understanding of safe options. Lakeside communities have a traditional saying, "*Enyanja tenoga*" (the lake is too big to be saturated with impurities). Others believe that taking treated/boiled water reduces their immunity to waterborne infections. Perhaps the changing colour of the water can now be proof that it is not safe for drinking (if untreated/un-boiled). On the reuse of wastewater, its application is quite low despite its potential value (GTZ, 2009). People decline to buy food from farmers who are known to use urine as fertiliser (NETWAS, 2011; GTZ, 2010). Faeces, faecal sludge, and wastewater sludge are socially and culturally considered to be dirty. Nevertheless, the application of urine in crops is a growing practice (NETWAS, 2011). Rural farmers are willing to pay for urine at a cost of UGX 5,000 for a 20 litre jerry can (GTZ, 2010). Besides, a general lack of awareness of the value and availability of wastewater sludge and urine limits the would-be buyers/users. Agricultural technical staff and other local government officials are among the people who are ignorant about this resource. On the whole, the use of fertilizers in Uganda (regardless of the type) is quite low (at 3%) (NETWAS, 2011).

6 Conclusion

Safe water provision and wastewater disposal are seamlessly intertwined to the extent that it may not be easy to handle one aspect without addressing the other. Perhaps without pollution many of the water sources would be relatively safe. In the light of the Hydro-Social-health cycle, the starting point is to identify and understand factors that converge to limit accessibility to safe water. Being the principle cause of pollution and being at the core of the remedies, humans happen to be at the centre of the Hydro-Social-health cycle. Appropriate strategies are those that address inter-linkages between ecological, physical, economic, and socio-cultural factors. Raising awareness about the value of wastewater creates an incentive to use it profitably and sustainably, other than discharging it into natural water sources. Awareness could also be raised about associated risks and likely mitigation measures. As suggested before, resources of the private sector could supplement government efforts in ensuring safe water. It has been illustrated, however, that PPP faces a number of challenges. One of the realities emerging from the findings is that innovative community education initiatives could be central in developing capacity for water resources management. The role of community education would be different for different stakeholders: communities for creating socio-economic incentives for sustainable wastewater use, formation of and maintaining water resource management structures; private sector/service providers to handle innovative management tools and approaches, handling user charges to cover operational/ maintenance costs, mitigation of financial risks, resource management, financial management, developing communication channels with clients and government; and local governments for making PPPs operational, setting tariffs and upgrading service.

REFERENCES

Banadda, E., *et al*. (2009) *Land use- based non point source pollution: A threat to water quality in Murchison Bay, Uganda.*

Bakker, K. (2003) *An Uncooperative Commodity - Privatizing Water in England and Wales*. Oxford University Press.

Castro, E. (2006) *Water, Power and Citizenship: Social Struggles in the Basin of Mexico.* New York: Palgrave.

FAO. (2011) *The safe use of water in agriculture.* http://www.fao.org/news/story/en/item/44899/icode/ Accessed Feb. 20th 2011.

GTZ (2010) *Marketing Human Excreta: A study of possible ways to dispose of urine and faeces from slum settlements in Kampala, Uganda.*

GTZ, (2009) *Marketing Human Excreta: A study of possible ways to dispose of urine and faeces from slum settlements in Kampala, Uganda.*

Heilman, J. and Johnston. (1992) *The Politics of Economics of Privatization*. University of Alabama Press, p. 197.

Heynen, N *et al*. (2005) Urban Political Ecology - Politicizing the Production of Urban Natures. In: *The Nature of Cities - Urban Political Ecology and the Politics of Urban Metabolism*, eds. N. Heynen, M. Kaika and E. Swyngedouw. London: Routledge.

Kaika, M. (2005) *City of Flows*. London: Routledge.

Loftus, A. (2005) *The Metabolic Processes of Capital Accumulation in Durban's Waterscape.* In: *The Nature of Cities - Urban Political Ecology and the Politics of Urban Metabolism*, eds. N. Heynen, M. Kaika and E. Swyngedouw. London: Routledge.

(MWE) Ministry of Water and Environment. (2009) *Water sector performance report 2009.*

(MWE) Ministry of Water and Environment. (2010) *Water sector performance report 2010.*

NETWAS UGANDA. (2011) *Market Study on Demand for Use of Wastewater, Excreta and Faecal Sludge and Other Related By-products*; Final Report.

Schuster-Wallace, *et al.* (2008) *Safe water as the Key to Global health.* The United Nations University International Network on Water, Environment and Health (UNU-INWEH).

Swyngedouw, E. (2004) *Social Power and the Urbanisation of Water. Flows of Power*. Oxford: Oxford University Press.

Swyngedouw, E. (2006) Circulations and Metabolisms: (Hybrid) Natures and (Cyborg) Cities. *Science as Culture* **15** (2): 105-122.

Swyngedouw, E. (2009) Political Economy and Political Ecology of the Hydro-Social Circle. *Journal of Contemporary Water Research & Education*, Issue 142, Pages 56-60, August 2009.

(UBOS) Uganda Bureau of Statistics. (2008).

Van der Hoek W. *et al.* (2002) *Urban wastewater: A valuable resource for agriculture*. A case study from Haroonabad, Pakistan. Research Report -63, International Water Management Institute, Colombo, Sri Lanka.

(WHO) World Health Organisation. (2006) *WHO guidelines for the safe use of wastewater, excreta and greywater.*

[1] PPP is defined as "The combination of a public need with private capability and resources to create a market opportunity through which the public need is met and a profit made." (Heilman and Johnston, 1992).

Ecological and Eco-hydrological Solutions for Sustainable Management of the Citarum River Basin Oxbows in Indonesia

GIUSEPPE ARDUINO[1], EVA MIA SISKA[1], MARCO BONETTI[1], RAMSIS SALAMA[2] & JOSE MIGUEL RUIZ VERONA[2]
1 *Hydrological/Geological Unit, UNESCO Office Jakarta, Indonesia*
2 *SWITCH-in-Asia Consultant*
g.arduino@unesco.org

Abstract This paper presents the preliminary components of the proposed project "Ecological and Eco-hydrological solutions for Sustainable Management of Citarum River Basin Oxbows in Indonesia". The target area is located along the upper part of the Citarum River Basin, West Java, considered the most strategic river basin of Indonesia, as well as one of the most polluted watersheds in the world, covering over 13,000 km, hosting 9 million people and supporting a population of more than 28 million. Downstream of Bandung city there are 11 oxbows, remaining meanders of the river that have been cut off in order to regulate/ divert the flow of the Citarum. The project focuses on 2 oxbows, namely Dara Ulin (50 ha) and Mahmud (16 ha), located in the Bandung Regency. The poor sanitation of the settlements in the catchment area, the existing high environmental dependency, the effects of climate change, and the water flow regulation works, have severely disturbed and degraded the natural environment of the Basin. These two oxbows still present relatively preserved ecosystems worth to be sustained and enhanced, in order to protect the genuine Citarum environment. On the oxbows' shores and in the adjacent area lives a population of approximately 3,000 inhabitants; the poor sanitation conditions in the area, combined with small industrial and agricultural activities, are a threat to water quality and to the environment of the Oxbows. UNESCO, in view of this situation, has promoted a participatory process, involving several UN agencies, universities, research institutes, government institutions, and NGOs, for the implementation of a pilot project in the framework of the SWITCH-*in-Asia* programme, an integrated and innovative programme for Sustainable Water Management in Asian Cities. The approach includes the development of demonstration sites, awareness raising, training, R&D support to provide local and national stakeholders with capacities and tools to generate solutions that are tailored to the specific needs encountered, as well as turning Citarum Oxbows from waste dumps into ecosystem service providers for the Citarum River Basin.

1 Background

The Citarum river basin is an important water resource in Indonesia. It is the most strategic river basin in the country, with a population of almost 28 million people in 2004 (more than 72% of the provincial total). There are three hydroelectric dams located at the upper section of the basin, producing an aggregate of 1,400 megawatts hours. The total area of irrigated agricultural land is over 400,000 km^2. The Citarum River system also supplies 80% of Jakarta's raw water. The water resources of the rivers and groundwater systems in the basin are critical to the country's social and economic development. They are essential for urban and industrial development (particularly in the Jakarta and Bandung areas), including export industry, agricultural production through major irrigation systems, rural water supplies, electricity generation though hydropower, and fisheries. While the water resources of the Citarum River Basin are relatively abundant (on average), competition for these resources has increased significantly over the past 20 years, leading to a situation of acute water stress and depletion of aquifers in some places. Rapid urbanization has significantly increased the exposure to flood risk and the generation of pollution. Environmental degradation has reached a level that compromises public health and livelihood, particularly for the urban and rural poor, and incurs additional economic and financial costs related to water supply and its treatment. There has been a lot of research and discussions on improving the condition of the Citarum river basin, especially with regards to the pollution problem, but so far there has been no significant improvement. Since the area is so large, it involves a variety of stakeholders, thus creating very severe and complex conflicts among their interests.

In October 2008, Indonesia and the ADB signed a Framework Financing Agreement (FFA) for a $921 million Multitranche Financing Facility (MFF) to support, through an Investment Program (IP), the implementation of a Road map for Integrated Water Resources Management in the Citarum River basin (RCMU, 2010). The roadmap has showed that the Integrated Citarum Water Resources Management Investment Programme (ICWRMIP) will need a total USD 3.5 Billion up to 2023.

The present project has been accepted in the Citarum road map as part of the "Other Donor" contributions.

Water Quality in the Citarum River

Pollution of surface water in the Upper Citarum basin (upstream of the Saguling reservoir) has reached an alarming stage. BOD content at all locations in the upper Citarum is relatively high, and ranges from 11 mg/l to 36 mg/l. The highest BOD content of 36 mg/l was observed at Curug Jompong, at the inlet of the Saguling reservoir (West Java EPA, 2008). Concentration of pathogen bacteria, dissolved oxygen, ammonia, phosphorous, and heavy metals, normally exceeds water quality standards, especially in the dry season (May-October).

Citarum Oxbows

Oxbows are the meandering parts of the river which have been cut off from the main river due to engineering works aimed at regulating/diverting the flow of the Citarum River. There are 11 such Oxbows located along the upper part of the Citarum River. For example, the Oxbow area on the Citarum River near the Dayeuh Kolot and Bojongsoang District is now a swamp filled with trash and mosquito nests, continuously causing disease to the community and ecosystems around it. Nevertheless, these oxbow bodies could become ecosystem services providers if their hydrologic and ecological function is restored and enhanced, rather than remain a major liability to the community and to the environment.

SWITCH-in-Asia Solutions

In the framework of the SWITCH-*in-Asia* programme, an integrated and innovative programme for Sustainable Water Management in Asian Cities, UNESCO has promoted a participatory process, involving several UN agencies, universities, research institutes, government institutions, and NGOs. Using the three SWITCH-in-Asia approaches: action research, development of demo-sites, and awareness raising, the pilot project aims to turn the Citarum oxbows from waste dumps to ecosystem service providers.

2 Project Locations

To facilitate the participatory process, in May 2009 UNESCO gathered several government offices, i.e., the Ministry of Public Works (PU), the Indonesian Institute for Sciences (LIPI), the West Java EPA (BPLHD), and several universities, to carry out a two-day workshop in order to define where the project would be located and which activities would be implemented; it was then agreed to focus on the oxbows of the upper Citarum River Basin.

The Project site is located within two particular oxbows, Dara Ulin (50 ha) and Mahmud (16 ha), which resulted from a past river diversion (normalisation) (Fig.1). Both oxbows are relatively preserved ecosystems, worthy of being sustained and enhanced as former pristine sites of the Citarum environment. The threats upon their water quality and environment obviously come from poor sanitation in the surrounding settlements.

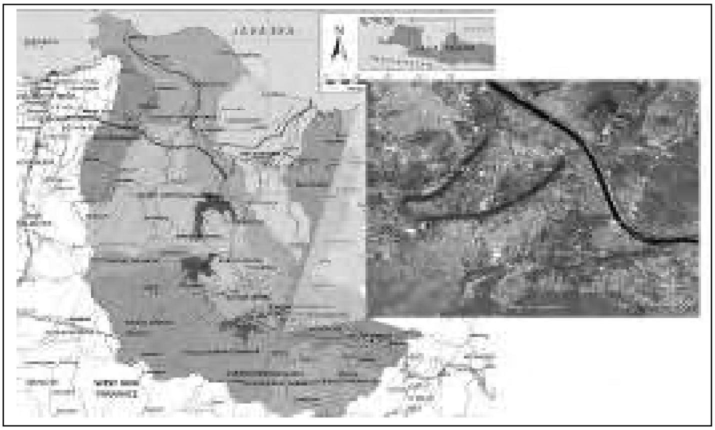


Fig. 1 Project Location.

Some efforts have been made in the Dara Ulin Oxbow involving a local NGO named Warga Peduli Lingkungan (WPL), which incurred in fruit tree planting, awareness raising, and construction of a communal septic tank with its primary pipelines for 200 households (1000 people). The facility and system services have been to-date managed by the community, who was trained by the NGO prior to the septic tank construction. Inhabitants gradually constructed their own toilets and made connections to the system at their own cost. Today there are almost 160 households already connected to the system. However, the existing facility has several drawbacks; the small holding capacity of the compartments and the excessive effluent flow do not allow enough residence time for settling and processing of the waste. Another problem is that the untreated effluent from the septic tank is directly discharged to the oxbow, and as such, the septic tank has actually increased pollution to a higher level, rather than reducing it.

The Mahmud Oxbow is a religious tourist spot, with communal toilets discharging wastewaters directly into the oxbow. There have been no efforts so far to treat the wastewater from the Mahmud community; therefore, the quality of water in the oxbow is expected to decrease in time.

3 Main Objective

Turning Citarum Oxbows from Waste Dumps into Ecosystem Service Providers for the Citarum River Basin.

4 Project Approach

The project aims to adopt a community approach for the provision of three types of ecosystem services, using Ecoh-ydrology principles along the oxbows:

- Provisioning services: food, freshwater, raw materials, genetic resources, and medicinal resources
- Regulating services: water regulation, water purification, erosion control, pest regulation, natural hazard regulation, and soil quality regulation
- Cultural services: aesthetic value, recreation, and ecotourism and cultural values

5 Project Components and Activities

The project will be carried out based on the main three SWITCH-in-Asia components: action research, demonstration, and capacity building.

The project components will be supported by a Learning Alliance[1], as a platform to support the innovation, research, dissemination of knowledge, and optimization of relationships among research, governmental, and educational organizations in the field of Urban Water Management. Learning Alliances have emerged in response to the widespread failure of much of conventional research efforts to have significant impact. It also emerges in response to the acknowledgement that new products and processes are brought into use not just through the activities of researchers, but through the activities of a number of widely different actors and organizations. This groups of interconnected players typically include public sector institutions (e.g., line ministries, utilities, regulators, educators, research institutes), private sector organizations (e.g., industry, financial services), and civil society players (e.g., NGOs, media, professional bodies and unions, advocacy organizations).

The learning alliance is aiming at facilitating communication and experience sharing among the partners (within a country as well as within a region). The regional programme will work to develop, apply, and demonstrate a range of tested scientific, technological, and socio-economic solutions and approaches that contribute to the development of effective and sustainable Urban Water Management (UWM) schemes in Asian Cities, human settlements, and corresponding catchments.

Several field surveys, as well as desk studies, have been carried out in the oxbows to define the action research component. The results show that the area is mainly covered by flood plain and alluvial fan deposits of Holocene Age underlain by Pleistocene volcanics (Sunardi, 1997). The porosity and permeability of the alluvial deposits are very high. Recharge from precipitation varies from about 30 to 50 percent reaching the shallow aquifer, and 10-20% reaching the deep aquifer, (Pulawski and Obro, 1976; IWAO-WASEO, 1991).

The main groundwater pollution sources, especially in the shallow aquifer, are domestic wastewater and small industrial activities, and to a lesser extent agricultural activities, being predominantly dependent on groundwater extraction; depth to groundwater, permeability, and type of materials through which water infiltrates will determine the amount and type of pollutants reaching the aquifer.

The action research component will focus on the hydrological, hydro-geological, hydro-chemical, and eco-hydrological interactions, as well as on the assessment of social patterns and the existence of regulations applicable to the oxbows.

The capacity building and community empowerment component will play an important role in the sustainability of the project. In particular, the project will increase the awareness of local communities about conservation, utilisation and protection of natural resources following the principles of the 4Rs (Reduce, Reuse, Recycle, and Redesign), cleanliness, sanitation, and proper disposal of waste, and about the importance of water purity. It will also encourage participation in the planning and management of water resources, watersheds, and waste, increase the public knowledge with regard to ecosystems, eco-technology, and eco-hydrology through the development of 'green school' concepts, and create awareness on Disaster Risk Reduction.

Four interrelated steps should be considered in the management of sewage and sanitation services: (1) reduce water use and therefore wastewater production; (2) treat wastewater with the aim to recover and reuse valuable resources (nutrients, energy, and water); (3) recycle waste water after purification (e.g., for irrigation purposes), and (4) redesign collection, purification, distribution, and storage systems to locally fit and use renovated eco-hydrological methods (self-purification capacity of phytoplants in natural water bodies).

The demonstration component will focus on developing and implementing eco-technologies (Figures 2 and 3) for sewage and effluent treatment towards a rational use of water, allow effluent treatment in combination with resource recovery, and reuse, develop, and implement eco-hydrology concepts and principles (Fig 4). This will be achieved by stimulating the natural self purification processes in the oxbows, as well as constructing simple sanitation facilities for effluent collection and disposal, and developing solid waste collection and recycling facilities.

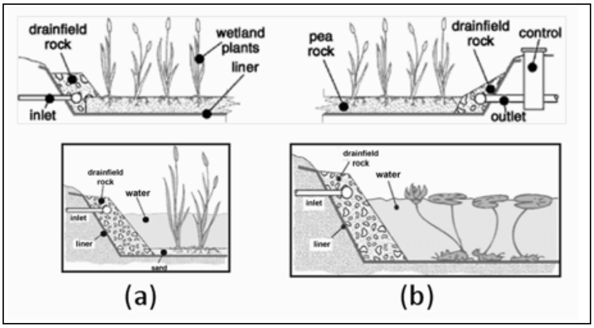


Fig. 2 Subsurface Flow Constructed Wetland (Above) and Surface Flow Wetland (Below), (a) Open Water and (b) Hydroponic.

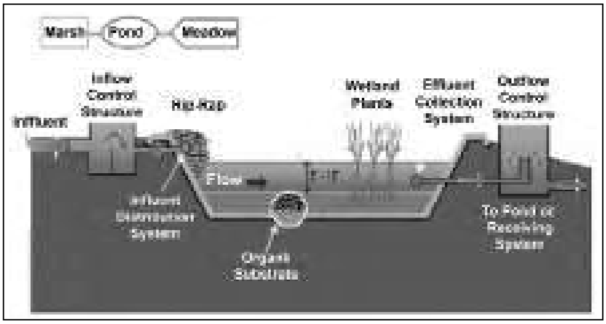


Fig. 3 Conceptual design of a biofilter using phytotechnologies with sedimentation, biogeochemical purification, and biofiltration components.

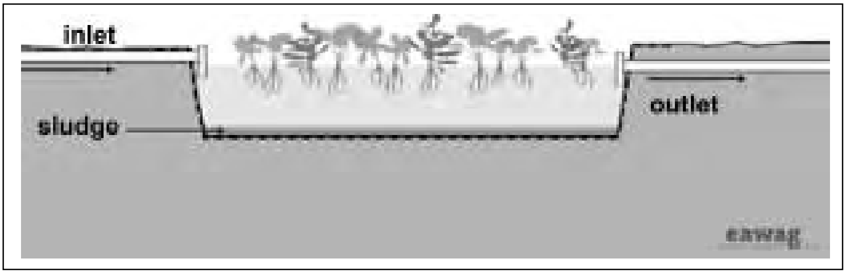


Fig. 4 Floating aquatic plant biofilter.

REFERENCES

Pulawski and Obro. (1976) Groundwater study of a volcanic area near Bandung, Java, Indonesia. *J. Hydrology* 28, p. 53-72.

IWAO-WASEO. (1991) *Bandung hydrogeological study, West Java provincial water sources master plan*, Jakarta, 111p.

Sunardi. (1997) *Magmatic polarity stratigraphy of the plio-pleistocene volcanic rocks around the Bandung basin, West Java, Indonesia*. Doctoral thesis, Osaka University, unpublished, 5-11p.

Rofiq Iqbal. (2010) *Strategies on Establishment of Bio-Eco Engineering System for Watershed Management* (2010 proposal).

Roadmap Management and Coordination Unit (RCMU). (2010) *Integrated Citarum Water Resources Management Investment Program Summary.*

[1] A learning alliance is a grouping of constituent organizations from a given system, which seeks to take relevant innovation to a larger scale. The more representative the alliance is, the better it will capture the organizational complexities that constitute the realities of the innovation system.

Micro-Hydroelectric Systems and Micro-Watershed Management as a Tool for Community Development and Biodiversity Conservation

NELSON ULLOA
Proyecto Promoviendo Manejo Integrado de Ecosistemas y Recursos Naturales en Honduras, Honduras

Abstract The GEF-UNDP sponsored project "Promoting Integrated Ecosystems and Natural Resources Management in Honduras" (Ecosystems project), executed by the Forest Conservation Institute (ICF in Spanish), submits the following presentation summary to the 2011 Global Symposium "Building Knowledge Bridges for a Sustainable Water Future. The Rio Platano Biosphere Reserve is located in eastern Honduras, a region of high biodiversity. Despite its status declared by UNESCO, the reserve and biodiversity that dwell within are being threatened by agricultural activities, poor logging practices and poaching. The Sico-Paulaya Valley is part of the Rio Platano buffer zone; Ecosystems Project is working with two pilot communities to combat environmental degradation through the declaration of micro-watersheds and their community-based management. In order to contribute to local development, the project along with other actors has implemented two 11 and 15 kW micro-hydroelectric systems in these two remote communities outside the national electric grid. The benefits of micro-hydroelectric systems are not limited to the provision of light. While both communities currently bring fuel for lighting, their agro-forestry cooperatives also need it to process certified mahogany (FSC) that is sold for Gibson and Taylor guitars necks. Clean energy generated facilitates the use of better technology at a lower cost, helping cooperatives improve their product and hence their profitability and economic sustainability. In total, there is an annual reduction of about 4.800 gallons of fossil fuel use, protection of 2,500 hectares on average. When settling on the benefits that a healthy ecosystem brings with it, the local population committed themselves to conserve the forest and to use natural resources sustainably. Beyond this, this mechanism for local development and ecosystems conservation is being institutionalized at the national level through policy designed by the Forest Conservation Institute.

Key words Management; provision and socio-economic benefits of biodiversity and ecosystem services

Vegetation Ecological Risk Assessment and Prediction under the Impact of Groundwater Exploitation in the Wulannao Area, Ordos Basin, China

SU XIAOSI & WANG WEI
Institute of Water Resources and Environment, Jilin University, Changchun, China
suxiaosi@jlu.edu.cn

Abstract The Ordos Basin, an important base for energy resources and chemical engineering in China, is in an arid area with shortage of surface water. Groundwater is the essential water source to meet the need of regional development. When the drawdown of groundwater is a bit more than the suitable water-level of native vegetation, risks affecting vegetation will be triggered. Quantitative evaluation of the ecological risk can provide guidance for the ecological protection of vegetation and sustainable exploitation of groundwater resources. In this study, the Wulannao groundwater source area in China is selected as an example to analyze the mathematical relationship between depth and groundwater-level, and groundwater burial depth has been chosen as a variable to establish a vegetation ecology risk index. The vegetation ecological risk of the study area is analyzed with the support of GIS and Visual Modelflow. According to the risk level assessed, the study area has been divided into different risk areas.

Key words Groundwater numerical simulation; suitable ecological water-level; vegetation ecological risk; groundwater exploitation

1 Introduction

The Ordos Basin is rich in coal, oil, natural gas and other mineral resources, and has become an important energy base in China. Because this basin is in an arid and semi-arid area, which lacks surface water resources, groundwater is the main water source used to meet the need of regional development. The Wulannao groundwater source area, which is located in the northeastern Ordos basin, west of Yijinhuoluo County, Ordos City, Inner Mongolia Autonomous Region, has plentiful groundwater resources and is a potential groundwater exploitation site for the Shenhua energy base.

Previous studies show that the exploitation of groundwater resources will change the natural state of the groundwater system. The groundwater hydrology process change will have an inevitable effect on local vegetation and the ecological environment, and bring about ecological risks. The risks are mainly reflected in the groundwater-table change (Zhang Mao-shengÅC2008). The drawdown of groundwater will cause the degradation of vegetation or even its replacement. In this research, the Gaussian analysis method has been utilized, based on the mathematics of vegetation ecology, to set up the relationship between the groundwater table and the occurrence of vegetation, then, a numerical groundwater flow model has been simulated, and the future groundwater table has been predicted under expected exploitation, to finally estimate the ecological risk caused by such exploitation.

2 Hydrogeological Settings

The Wulannao groundwater source area is located west of Ordos City, Inner Mongolia Autonomous, Region (Fig. 1). The study area is 1665 km^2. It is a part of the Ordos denudation plateau, with an elevation range of 1300-1500m.This area has an arid and semi-arid continental climate, with annual precipitation averaging 321.16 mm, and annual average evaporation at 2350.4 mm.

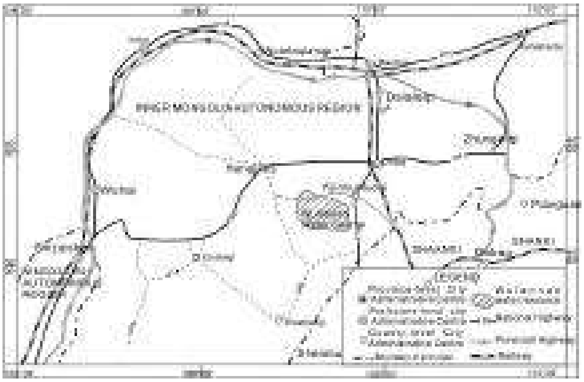


Fig.1 Location of the study area.

The strata in this area are composed of lower Cretaceous sandstone and Quaternary unsolidated deposits. The main aquifers of the study area are Quaternary aquifer and Cretaceous aquifer. The Quaternary aquifer is always 1-5 m thick, and contains a lake sediments aquifer, aeolian sediments aquifer, and alluvial sediments aquifer. The Cretaceous aquifer is made up of Huanhe aquifer formations and Luohe aquifer formations. The Huanhe aquifer formation is the target aquifer of groundwater supply, due to its large thickness. Combined with hydro-geological drilling data and geophysical prospecting results, the aquifer system in the study area has been divided into unconfined aquifer and confined aquifer. The unconfined aquifer is composed of a Quaternary aquifer and the upper part of a Cretaceous aquifer; the confined aquifer is composed by the lower part of the lower Cretaceous aquifer. Between the two aquifers is an aquitard, whose lithology is mudstone and muddy siltstone.

3 Gaussian Model Distribution of Vegetation Ecology

The quantitative ecology research shows that the majority of vegetation and environmental factors fit the non-linear quadratic curve models, and the Gaussian model is the most representative, as shown in Equation 1. Each type of vegetation has its own suitable ecological groundwater burial depth interval. When the groundwater burial depth is in this interval, vegetation growth can be best achieved. But when the interval is exceeded, vegetation growth is inhibited (ZHANG Jin-tun, 2004).

$$f(x)=\frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \quad (1)$$

where x refers to groundwater burial depth, $f(x)$ refers to abundance of vegetation, and m,s refers to the parameters of the gaussian model. This equation can also be written in the following form:

$$f(x)=e^{-\frac{x^2}{2\sigma^2}+\frac{x\mu}{\sigma^2}-\left[\frac{\mu^2}{2\sigma^2}+\ln\left(\sqrt{2\pi\sigma}\right)\right]} \quad (2)$$

Equation 2, in turn, shows that the biomass and environmental factor are in line with the exponential model form, like this:

$$f(x)=e^{ax^2+bx+c} \quad (3)$$

4 Change of Groundwater Burial Depth under Exploitation

The whole study area has been selected as the model region. The groundwater site is around Wulannao and Qihenao (Fig.1). Based on the hydrogeological conditions, the aquifer system can be generalized into unconfined aquifer and confined aquifer. The unconfined aquifer is composed of Quaternary aquifer and upper part of the lower Cretaceous aquifer, with a thickness of 30-50m. The confined aquifer is composed of the lower part of the lower Cretaceous aquifer, with a thickness of 200-300m.

For the unconfined aquifer, the northern, eastern, western, and south-eastern boundaries are groundwater divides, and the southwestern boundary is perpendicular to the equipotential line of unconfined water, the boundary of unconfined water is defined as the no-flow boundary. But for the confined aquifer, the southwestern, northern, and eastern boundaries are parallel to the equipotential line of groundwater, these boundaries are defined as specific-head boundaries, and the others are parallel to water flows, and far from water resource, so the exploitation of groundwater will not affect these boundaries, and thus they have been set as no-flow boundary.

The upper boundary of the groundwater system in the study area is the water-table -precipitation and evapotranspiration happen through it. The unconfined aquifer and confined aquifer exchange water through aquitard. The thickness of the Cretaceous aquifer is large, and now the depth of exploitation is only within 350 m, below which is also Cretaceous sandstone, so a depth of 450 m is defined as the no-flow boundary. The hydrogeology parameters of the study area are obviously different, so the aquifer parameters are regarded as heterogeneous and isotropic. The water flow in aquifer is in accordance with Darcy's law, and the groundwater flow is in a transient flow state.

Visual Modflow 4.0 has been used to establish the numerical model and solve the differential equation. The study area has been subdivided into 6660 cells, and cell size is 500 m 500 m. After model calibration and verification, the difference between simulated water level and measured water level on 17 observation wells' was less than 0.5 m. The simulated flow net and the measured flow net are similar.

5 Vegetation Ecological Risk Assessment and Prediction under Groundwater Exploitation

Risk Assessment Index

The persistent exploitation of groundwater will cause water level decline when the depth of the groundwater table exceeds a certain interval. Vegetation growth will be restricted and vegetation communities will be at risk of decline. In order to quantitatively descript this kind of risk, groundwater burial depth has been selected as a variable to establish a vegetation ecological risk assessment index, according to the relationship model of total vegetation abundance and depth of the groundwater table. See Equation 4:

$$R = \frac{f_N - f_P}{f_S} \times 100\% \tag{4}$$

where fN is total abundance of vegetation under current depth of the groundwater table, fP is total abundance of vegetation under predicted depth of the water table, fS is total abundance of vegetation under suitable depth of the groundwater table, $fN- fP$ expresses the change of total abundance of vegetation caused by the change of groundwater level, and R is the risk index (%).

The risk index (R) can show the change in vegetation under water level change. In this equation, when the groundwater level does not change, R will be equal to 0. In large groundwater depth areas where R is smaller than 0.1, the water demand of vegetation growth relies on rainfall and condensation water -groundwater level change does not affect vegetation growth. When the depth of the water table is between 3-5m (R is larger than 0.5), groundwater drawdown will cause a significant degradation of local vegetation. According to R values representing the severity of vegetation changes, the study area has been divided into a high-risk zone ($R > 0.5$), a middle-risk zone ($0.3 < R < 0.5$), a low-risk zone ($0.1 < R < 0.3$), and safe zone ($R < 0.1$).

Vegetation Ecological Risk Assessment

From the numerical simulation results, the vegetation ecological risk assessment results under groundwater exploitation are shown in Fig.2. High-risk zones are mainly located around the groundwater source site. After 10 years os exploitation of groundwater, the water level in the central area of exploitation in the confined aquifer has dropped down to 9-16 m, and the unconfined water level has dropped 2-4 m, with a burial depth of the water table of 4-5m, which is larger than the suitable groundwater burial depth for low humidity vegetation. The current vegetation will be degraded and the vegetation type and quantity will obviously drop. Middle-risk zones are mainly on the outside of the central area of exploitation, along the lake beach, where the low humidity vegetation can grow and there will not be major change in vegetation ecology. Low-risk zones are mainly distributed in the northern and northeastern areas of the study area, and the vegetation here is expected to continue its normal growth. Safe-zones are mainly distributed in the bedrock ridge, and the groundwater burial depth is deeper than in other areas where the vegetation is independent on groundwater.

Through risk analysis and assessment, we can say that groundwater exploitation in Wulannao has little ecological impacts on vegetation, except the central area. Artificial cultivation and prohibition of grazing can effectively prevent deterioration of the ecological environment.

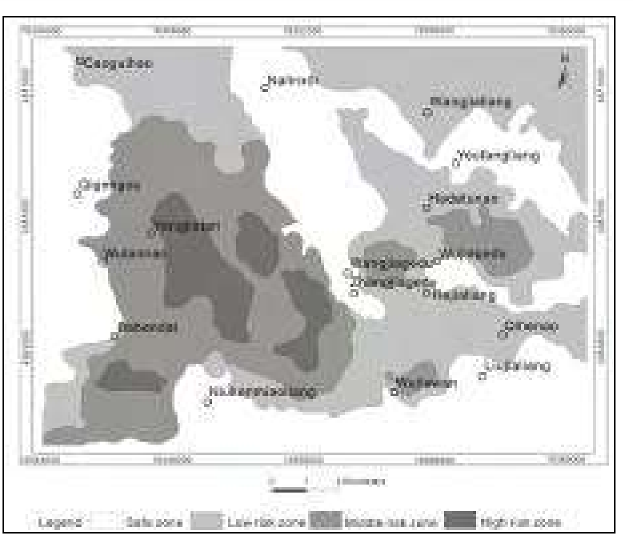


Fig. 2 Vegetation ecological risk zoning map.

6 Conclusions

- Groundwater burial depth is an important factor controlling vegetation ecology, and the quantitative ecology method is useful in establishing the quantitative relationship between vegetation and groundwater level in arid and semi-arid areas.
- According to the prediction results, the ecological risk caused by groundwater exploitation is little.
- Artificially planting drought-resistant vegetation can effectively avoid the losses caused by environmental degradation.
- Vegetation ecological risk assessments are of significance to the ecological protection of vegetation.

REFERENCES

ZHANG Mao-sheng, LU Na, CHEN Jin-song. (2008) Ecological effects of vegetations during groundwater exploitation in the Northern Shaanxi Energy & Chemical Industry Base, China [J]. *Geological Bulletin of China* **27**(8):1299- 1312.

ZHANG Jin-tun. (2004) *Quantitative ecology* [M], Beijing , Science Press.

4. WATER, FOOD AND ENERGY NEXUS

Renewal of hydrology in the Gagas River Basin: Community-Driven Strategies

ANITA PAUL & KALYAN PAUL
Pan Himalayan Grassroots Development Foundation, Uttarakhand, India
apaul@grassrootsindia.com

Abstract Mountain communities are known to be resilient and capable of coping with changes in the ecological landscape. Indigenous knowledge systems based on reverence regarding the 'bounties of nature' have guided their patterns of life for generations. The Pan Himalayan Grassroots Development Foundation has been spearheading a community-driven program in the Gagas river basin in the Indian Himalayan Region for almost a decade, and this idea has been endorsed by UNESCO-HELP since its inception. Over the years, it is being increasingly demonstrated that communities, led largely by womenfolk, have been able to organise themselves to renew the hydrological cycle in this river basin through adoption of a de-centralised approach, wherein each village in various ecosystems within the river basin have been galvanised into action. The ideas and actions which have evolved in this river basin, regarding urgent measures for adaptation and mitigation of climate change and ways to secure sustainable livelihoods for future generations, provide lessons for several other languishing river basins.

Key words Hydrology renewal; community-driven Strategies; ecological security

1 Introduction

This case study is anchored in Gagas River Basin, in the state of Uttarakhand in the Central Indian Himalaya region. With a geographical area of 53,000 km^2, this is the fourth largest Himalayan state. Its population is 8.5 million, which represents 22% of the total Indian Himalayan Region (IHR). The paper attempts to bring together the field experiences of community-driven strategies for the renewal of the hydrological cycle in the river basin and restoring a fresh balance to people's lives in times of climate change.

Climate Change is exposing the basin's residents to increasing natural hazards, environmental stress in terms of biotic pressures on scarce resources, and depleting water resources at unprecedented rates, much beyond the natural ability to adapt. Quality of life seems to have been impacted profoundly, leading to socio-economic-ecological, changes which will impact future generations. The crisis in this river basin could be described as typical, in view of several other languishing river systems in the Indian Himalaya.

In order to address these issues in a comprehensive manner, The Pan Himalayan Grassroots Development Foundation (*Grassroots* from now on) has been involved in the eco-restoration of the Gagas River Basin in Almora, district of Uttarakhand, India for almost a decade. Its work has been endorsed by UNESCO-HELP as part of its global efforts for restoring languishing river systems.

Grassroots is established as a non-profit volunteer organization with the primary aim of initiating people's action at the grassroots level for restoration of ecological security in languishing river basins through holistic mountain development programs, in order to improve the people's quality of life. The loss or lack of titles to environmental assets is viewed, by Grassroots, as an additional component of poverty, leading to the conclusion that environmental conservation is actually a fundamental requirement to poverty alleviation. Concepts like sustainable mountain development will never cease to be a mirage in the desert, unless forest ecosystems are restored for adequate hydrological and nutrient recycling functions.

2 Geographical Features of the Gagas River Basin

The Gagas River basin covers an area of approximately 510 km^2 and lies between the latitudes 29° 51' 55"N and 29° 35' 49"N, and longitude 79° 20' 36" and 79° 33' 15" in the Almora district of Uttarakhand, India. This basin holds a total of 373 villages, with a population of 1,200,000, which has a high literacy rate of 74 percent. The land-use pattern in the basin is as follows:

a.	Village Forest (Community Commons)	5,800 hectares = 12 %
b.	Reserved Forest (Government)	10,500 hectares = 21 %
c.	Agriculture Land	19,200 hectares = 38% (only 7 % irrigated)
d.	Cultivable Wasteland	8,700 hectares = 17 %
e.	Not available for cultivation	5,800 hectares = 12 %

The topography of the region varies from 2746 m above sea level at the head waters, in the north-eastern part of the basin, to 762 m above sea level at the mouth of the river, in the western part of the basin.

3 Ecological, Social, and Economic Impacts

Historically, the vegetal cover in the river basin has been classified as temperate, dominated by Oak (*Quercus leucotrichophora*), an evergreen broad-leaf tree which grows best on moist soils. The substitution of native species with almost a monoculture of Pine (*Pinus roxbughii*) forests seems to have led to a distinct change in hydrology, soil conditions, as well as in the prevalence of associated plant species in the basin. Increase in forest fires over the past two decades is further hampering biodiversity conservation, which is essential for hydrology renewal. Data collected by hydrologists in the various hydro-met stations reveals that the number of rainy days has decreased over the years, and the resulting dry phase is perhaps responsible for the increase in forest fire incidence.

4 Water Resources

Naulas (stone-pitched water-storage structures which trap shallow sub-surface water capillaries) and springs were traditionally used for meeting domestic water requirements. Ample evidence exists regarding the decline in availability of water for domestic consumption and non-functional upland irrigation systems based on fragile primary water resources. This has resulted in reduced crop outputs and created a vicious cycle of impoverishment, along with a rise in water-borne diseases.

In recent times, water conflicts are a regular feature in the river basin. The situation worsens with the onset of the dry summer months, when the demand for water is at its peak, due to increase in tourist traffic, the wedding season, and agricultural requirements.

Livestock management has also suffered and led to indiscriminate grazing of hill slopes by cattle and goats in search for fodder. This, in turn, has led to the ecological devastation of vast tracts of hill slopes adjoining village lands. This also has led to increased run-off and soil erosion during the monsoon, and to reduced re-charge of groundwater.

Appraisal of seventy villages on either bank of the river reveals the plight of primary water resources. Only about 56% of the naulas are functional, and the rest have dried-up, as the ecological status of the fragile catchment areas are not allowing infiltration of rain water to recharge the water resources. Furthermore, only 23% of the functional water sources provide water for the entire year, which adds to the drudgery of women and children who now have to travel longer distances to meet their daily water requirements.

5 Livelihoods Issues

Data on 18 villages illustrates the situation across the river basin: irrigated farmland has been reduced from 9% to less than 1%, and food production is down from 94 kg to 15 kg per unit of land. Shortage of quality feed and fodder, along with hardships faced by women when fetching water for domestic cattle has impacted upon livestock rearing -average cattle heads have reduced from six to just three per family within a decade. Draught cattle are now reared by very few households, with the result that several farmers are unable to plough their fields. Milk and related milk products are no longer part and parcel of the food habits. This reduction in the number of cattle heads has also led to insufficient quantities of farm yard manure.

This ecological degradation of forest areas has led to pine needles being used as composting material, which in turn has introduced several obnoxious pests, and also changed the moisture regime of crop lands adversely. Soil test reports reveal that soil is mostly acidic, making it in-conducive for beneficial microbes to thrive. Only 30% of soil samples reveal the presence of adequate carbon. Since carbon is the backbone for microbial activity, the availability of natural nitrogen and phosphorus has also been impacted, thus resulting in crops succumbing to diseases.

This scenario of reduced food security has led to significant emigration, in order to supplement family incomes. This in turn is leading to severe strains on local societies where significant responsibilities have to be borne by women alone. Data from just these 18 villages in two drainage basins (gadheras) would perhaps explain the climate induced dislocation within communities:

- 70 of 800 households have migrated permanently from the river basin - 10 percent
- 20 percent of adult males have migrated temporarily to urban sweatshops

Migration is also said to be having a negative impact on the communities' psycho-social health. The elderly members of this basin are facing major hardships with no help for domestic chores or during times of illness, leading to severe mental depression.

6 Action at the Grassroots

Based on the vulnerability of the residents of the Gagas river basin, Grassroots has been engaging with them to work towards restoring the ecological security. Marginalized communities have been galvanised to form appropriate institutional structures at the grassroots -self help groups of women at the hamlets have led to the creation of a dynamic basin-level federation, which in turn has been able to initiate an effective dialogue for sharing experiences regarding ecological restoration in the following manner:

- Providing a fresh vegetal cover on degraded commons and renewal of traditional methods for soil and moisture conservation
- Swift spread of appropriate technologies in cross cutting sectors like drinking water, environmental sanitation, renewable energy, and rainwater harvesting
- Improving food security and livelihoods through land-use optimisation and establishment of market linkages directly between producer-farmers and consumers

Intra and inter basin dialogue is evolving strongly as a new feature through regular meetings, capacity building workshops, cross-visits, and social audit of physical and financial matters. The emergence of change, development, and leadership at the basin level is slowly leading to affecting policy changes, viz., the hydrology renewal within the confines of the reserved forest areas, which define the largest and most critical land masses in the river basin.

The bedrock of change and development in the river basin is intensive community organization, resulting in a three-tier institutional structure at the grassroots, consisting of self help groups, gadhera bachao samiti (village development committees), and an apex body, called the Gadhera Bachao Manch (drainage basin federation) .

This structure at the grassroots has enabled and empowered local community-managed institutions to outline action plans regarding establishment of nurseries, tree-planting, renewable energy, organic farming, food processing and marketing - measures which assist people in adapting to changing times.

Over the past five years, community led efforts have resulted in the following outcomes:

- 480 farmers are promoting organic farming systems. Market linkages are being established for promoting cultivation of traditional rain-fed, and some value added crops, for enhancing farm incomes.
- Experiments and training programs are enabling farmers to improve the quality of farm yard manure (vermi-composting) and reduce water consumption for agricultural purposes, especially for growing paddy.
- Horticulture is being adopted in the basin for enhancing household incomes.
- 262 households have adopted biogas as an appropriate technology option for meeting their domestic energy requirements, resulting in positive impacts on women's health, by providing clean smokeless energy, saving time, and reducing drudgery.
- 150 hamlets have adopted infiltration wells as a source of potable drinking water, resulting in the improvement of quality of life for 20,800 individuals, or over 20 % of the basin population. Alongside, 1640 individual toilets have been constructed for improving sanitary conditions.
- 250 households have also adopted rain water harvesting as a means for augmenting the availability of water for domestic consumption.
- 500,000 saplings of native broad leaved tree species have been planted.
- Contour trenches and percolation pits are being dug to intercept surface runoff and aid percolation.
- Communities are engaging to finalise annual action plans focussed on eco-restoration, volunteering time to implement the proposed action items, and make conservation a part and parcel of their daily lives.
- Celebration of International Women's Day, followed by World Water Day, enables the residents across the river basin to meet and share lessons.
- Acknowledging the role of local leaders has led to significant growth of human capital in the basin.

7 Policy Issues

The Government of India has recently given the Indian Himalayan Region its due importance as one of the critical Missions in its National Climate Change Action Plan (NAPCC). In fact, the GOI clearly desires to promote community based management of ecosystems through incentives to community based organisations for protection of village commons, forest lands, and water resources. The aim is also to maintain two thirds of the IHR under forest cover, in order to prevent erosion, land degradation, and ensure the stability of the fragile ecosystem.

Best Practices focused on governance for sustaining Himalayan ecosystems as a broader framework for adaptation strategies highlight the importance of achieving water security through rejuvenation of springs and catchments. This feature is of utmost importance, as the downward spiral of hydrological conditions in most river basins is reaching alarming levels -impacting food security, livelihoods, and the health of mountain communities (Governance for Sustaining Himalayan Ecosystem).

A shift in energy policy towards renewable sources would also lead to significant improvements in the health of forests and people. Sixty five percent of households in the IHR are said to be using firewood as the primary source of domestic energy.

Keeping in view that the government, in principle, has provided an enabling environment in terms of policy directives and financial allocations, it would be prudent to mention that organisations like Grassroots have been playing a key role in pioneering a way forward for enabling mountain communities to participate as the primary stakeholder in the process of change and development. Assistance from UNESCO-HELP in terms of documenting and organising knowledge bridges for various stakeholders of the IHR could assist other stakeholders in adopting similar choices.

REFERENCES

Governance for Sustaining Himalayan Ecosystem. *Guidelines & Best Practices*. MOEF, Government of India.

Government of India. *National Action Plan for Climate Change*.

Use of Native Species in Land Reforestation in the Panama Canal Watershed

ARTURO CEREZO
Environment Division, Panama Canal Authority, Panama
acerezo@pancanal.com

Abstract The Panama Canal Authority (ACP), through the Department of Environment, Water and Energy's Environment Division, is developing a new Sustainability Program for the Panama Canal Watershed and its inhabitants. The key strategy is the Environmental Economic Incentives Program, which aims to protect and conserve the Basin's water resources in harmony with the activities of the Basin's inhabitants. This 20-year-term program aims to reforest 6,560 ha in the first five years through agroforestry and silvopastoral systems, and reforestation with commercial species. Other compensation schemes, such as the Reduction of Emissions from Deforestation (REDD +) will be included. Reforestation of continual areas and forest enrichment is being developed in national parks, protected areas, and their buffer zones. The goal is to conserve soil and water resources. Planting native species mimics the diversity found in nature, facilitating the development of biodiversity, the gradual recovery of green areas intervened by humans, the reduction of erosion in order to improve surface runoff, and has direct impact on controlling invasive weeds, such as *Saccharum spontaneum*.

Key words Panama Canal; native species; reforestation; *Saccharum spontaneum*

1 Introduction

In 1987, the Panama Canal Comission (PCC) began a reforestation project in the Canal Operating Areas using nonnative species acacia (*Acacia mangium*) and melina (*Gmelina arborea*), because of their seed availability and rapid growth characteristics. Since 1998, the now Panama Canal Authority (ACP) has continued the reforestation project, with an innovative approach to ecological restoration, using only native species (Jones *et al*., 2004; Montagnini *et al*., 2008). Since 2001, the ACP has engaged in a strategic partnership with the Reforestation with Native Species Project (PRORENA), a scientific research project led by the Smithsonian Tropical Research Institute (STRI) and Yale University**,** in order to collect data on the behavior of the native species used in ACP Projects (PRORENA, 2004; Jones *et al*., 2004).

One of the reforestation projects, developed since 2006 by the ACP, is known as Ciudad del Árbol (Tree City), which consists of a 200-hectare estate administered by the University of Panama (UP) (Auroridad del Canal de Panamá, 2007; Montagnini *et al*., 2008). From 2006 to 2008, the 200 hectares were planted with a mixture of 90 native species**,** in order to mimic the local environment. Through this project, the University of Panama, the National Environmental Authority (ANAM), and the Panama Canal Authority promote the environmental recovery of this area, which was originally invaded by the weed known as Paja Blanca (white straw), an undergrowth with the scientific name *Saccharum spontaneum*. In 2006, a monitoring plot of 1000 m^2 was established to research and assess the plantation's growth and development. This paper presents results of that research.

2 Objective

To promote the restoration and protection of forest coverage for water conservation**,** in harmony with activities in the Panama Canal Watershed, in order to achieve environmental restoration in the Ciudad del Árbol project, using a gene pool of native Panamanian species.

3 Methodology

Site Location

Culebra Cut, Camino de Cruces and Soberanía national parks, Agua Salud, and Ciudad del Árbol, are the areas where reforestation with native species has been established. Ciudad del Árbol is located in the community of Chilibre, close to Madden Dam, 40 km from Panama City. It is a buffer zone for the Alhajuela Lake and Chagres National Park (Autoridad del Canal de Panamá, 2007). It also has some steep slopes, and the average annual rainfall is between 2000 and 2500 mm.

Establishment

Learning experiences from reforestation projects implemented by the Panama Canal Authority were applied in Ciudad del Árbol. These experiences are based on the principle that plants are indicators of the pedological and climatic conditions in which they grow and develop, and that forests are highly heterogeneous and dynamic. This was the reason for reproducing its diversity.

Pioneer species, such as periquito (*Muntingia calabura*), balsa (*Ochroma pyramidale*) and cortezo (*Apeiba tibourbou*), with no commercial value, were selected from secondary and mature forests; others like jobo (*Spondias mombin*) and guava *(Inga* sp.) which are wild fruits, were used to produce interaction between the area's flora and fauna.

For the initial cleansing work, the concept of "selective cleaning," was applied. This involves the removal of undesirable weeds, mainly *Saccharum spontaneum* and flemingia (*Flemingia strobilifera),* while keeping native tree species that had established themselves naturally, especially hardwood trees that are potential colonizers. Also, undergrowth and natural regeneration are administered, which means that species disseminated by the wind, birds, bats or other terrestrial wildlife, are allowed to grow freely. This particular form of plantation management is dynamizing plant growth and development, similarly to natural forest vegetation. Organic and chemical fertilizers and microorganisms were used to strengthen the root system and enhance nutrient absorption. Seedlings were combined in a 3x3 m area, to avoid the concentration of the same species.

4 Results and Discussion

Between 2006 and 2008, 200 hectares were planted with a mixture of native species in Ciudad del Árbol, and a monitoring plot of 1000 m2, with 124 plants from 24 species, was established. From 2007 to 2008, 14 plants and two species died.

By 2008, some of the species' average growth was as follows: Balso (*Ochroma pyramidale*), 11 m; Nazareno (*Jacaranda* sp.), 7.5 m; Negrito (*Annona spraguei*), 5.5 m; Guácimo Negrito (*Guazuma ulmifolia*), 5.32 m., and Jobo (*Spondias mombin*), 5.0 m. The survival rate for the plants planted in 2007 was 93%, and in 2008 it was 89% (Table 1 and Fig. 1).

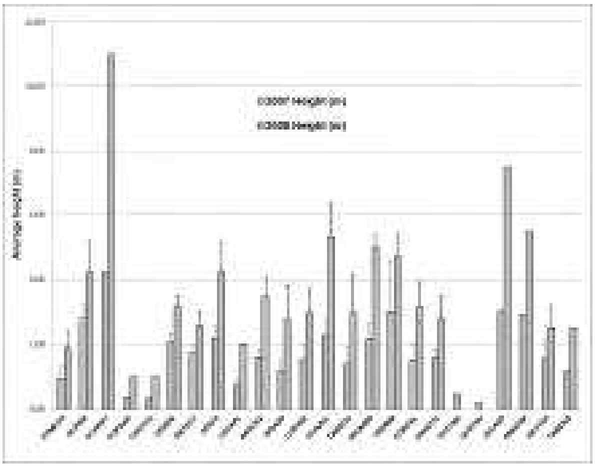


Fig.1 Mean height (m) of native species in the Ciudad del Arbol Project 2007-2008.

Table 1 Mean height (m) and basal diameter (cm) of native species in Ciudad del Arbol Project 2007-2008.

007	2008	Species	Scientific name		2007 Height (m)	Stan. Dev.	2008 Height (m)	Stan. Dev.	2007 Diameter base(cm)	2008 Diameter base(cm)	2007 DAP (cm)	2008 DAP (cm)
2	2	Algarrobo	*Hymenaea courbaril*	HYMECO	0.94	0.374766594	1.88	0.530330086	1.20	3.50		
6	5	Balo	*Gliricidia sepium*	GLIRSE	2.78	0.44907312	4.22	0.960858991	5.37	9.74	2.13	5.44
1	1	Balso	*Ochroma pyramidale*	OCHRPY	4.20		11.00		7.40	19.58	5.20	16.71
1	1	Cabimo	*Copaifera aromatica*	COPAAR	0.35		1.00		0.50	2.23		
1	1	Caimito	*Chrysophyllum cainito*	CHRYCA	0.33		1.00		0.50	2.55		
5	5	Ceibo	*Ceiba pentandra*	CEIBPE	2.06	0.279284801	3.17	0.297069016	5.86	13.87	1.48	6.03
6	6	Corotu *cyclocarpum*	*Enterolobium*	ENTECY	1.75	0.233580821	2.57	0.402492236	3.25	5.57	1.38	3.21
6	6	Cortezo	*Apeiba tibourbou*	APEITI	2.16	0.380823669	4.22	0.909212113	5.68	11.99	2.32	6.37
4	2	Cuipo	*Cavanillesia platanifolia*	CAVAPL	0.73	0.17670597	2.00	0	1.91	6.21		1.59
11	11	Espave	*Anacardium excelsum*	ANACEX	1.60	0.245442087	3.45	0.610640498	3.58	7.41	1.14	3.60
2	2	Guabo	*Inga sp.*	INGASP	1.17	0.325269119	2.75	1.060660172	1.75	7.62		3.10
19	19	G. Colorado	*Luehea seemannii*	LUEHSE	1.53	0.429500594	2.96	0.733502771	4.05	7.22	0.86	3.05
15	15	G. negrito	*Guazuma ulmifolia*	GUAZUL	2.26	0.535123484	5.31	1.065442005	3.96	9.53	1.99	5.32
5	5	Guayacán	*Tabebuia guayacan*	TABEGU	1.39	0.531526105	2.95	1.177921899	2.11	4.81	0.50	3.10
2	2	Jobo	*Spondias mombin*	SPONMO	2.15	0.487903679	5.00	0.353553391	5.65	11.06	3.05	7.08
5	5	Jordan	*Trema micrantha*	TREMMI	3.00	1.573238698	4.70	0.671751442	3.20	7.72	2.07	4.21
14	14	Laurel	*Cordia alliodora*	CORDAL	1.50	0.496677422	3.13	0.795833933	2.64	5.85	1.35	3.38
2	2	Marañon	*Anacardium occidentale*	ANACOC	1.57	0.275771645	2.75	0.707106781	2.70	5.57	1.30	3.18
1	0	M. Curazao	*Syzygium malaccense*	SYZYMA	0.47				0.30			
1	0	Membrillo	*Gustavia superba*	GUSTSU	0.20				0.20			
1	1	Nazareno	*Jacaranda sp.*	JACASP	3.00		7.50		0.30	1.27		
1	1	Negrito	*Annona spraguei*	ANNOSP	2.90		5.50		4.80	9.55	2.00	7.32
3	3	Palo santo	*Erythrina sp.*	ERYTSP	1.56	0.550121199	2.50	0.661437828	4.10	8.86	1.20	3.18
1	1	Roble	*Tabebuia rosea*	TABERO	1.16		2.50		2.70	5.41		2.55

2007 saw the regeneration of 91 plants in thirteen species, of which seven were new species recorded in the plot. Regeneration rates stand out in guácimo colorado (*Luehea seemanii*), with 35%, and jordan (*Trema micranta)*, with 25%. Also notable is the growth of pioneer species such as balso (*Ochroma pyramidale*) and guarumo (*Cecropia* sp.) with 7.0 m. in average; poro poro (*Clochlospermunm vitifolium*), 5 m.; Jordan (*Trema micranta*), 4.59 m; periquito (*Muntingia calabura*), 4.58 m., and guácimo negrito (*Guazuma ulmifolia*), 4.25 m. A type of species used by farmers, carreto (*Erithroxylum citrifolium*), showed an average height of 3.0 m. The survival rate of plants regenerated in 2007 to 2008 was 95%, indicating excellent adaptation of plants and species scattered throughout the area (Fig. 2).

In 2008, 148 plants of sixteen species were regenerated, of which two were new species in the plot. Regeneration rates stand out in balo (*Gliricidia sepium*), with 59%, guarumo (*Cecropia sp*), with 13%, and guácimo colorado *(Luehea seemanii*), with 8%. The analysis of the survival rates for species planted in 2006 and species regenerated in 2007 indicates the existence of 206 plants at the place of measurement. For 2008, the total count indicated the existence of 344 plants (Table 2).

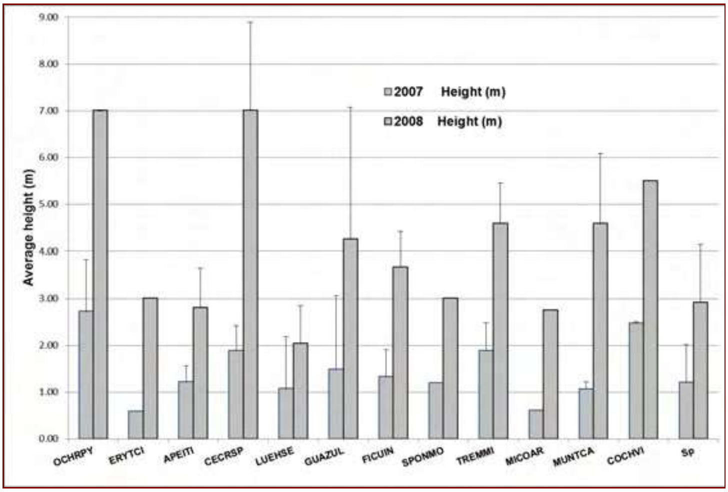


Fig. 2 Mean height (m) of native species regeneration in the Ciudad del Arbol Project, 2007-2008.

The growth shown by native species in spite of disturbed conditions found it difficult to establish a forest plantation, which contrasts with the perception that native species are slow growing. *Hura crepitans* is the species that so far has presented the earliest flowering, starting three months after established. The early flowering of other species, like tronador (*Hura crepitans*), periquito (*Muntingia calabura*), balo (*Gliricidia sepium*), guavas (*Inga sp*.), guácimo negrito (*Guazuma ulmifolia*) and cortezo (*Apeiba tibourbou*) and other understory allow interaction between the flora and fauna, as an important step in the recovery process logged areas.

The energy of rain is absorbed in contact with the canopy, which reduces the erosive force of runoff, one of the major objectives of reforestation project. This trend, coupled with the management of the understory and regeneration of seeds dispersed by many natural agents like wind, land animals, and birds, gradually promotes the recovery of plant cover, which will result in decreased erosion processes and allow the conservation of water resources.

Table 2 Number of individual and species planted in 2006 survivor (%) and regenerated native species Ciudad del Arbol Project 2007-2008.

Species planted 2006			Regeneration 2007		Regeneration 2008	Observation
2006	**2007**	**2008**	**2007**	**2008**	**2008**	
124						No. Individual Planted 2006
			91		148	No. Regeneration
	115	110		86		No. Survivor
	9	5		5		No. Dead
	93	89		95		% Survivor
			73	69	119	% Regeneration
			206	196	344	Planted + Regeneration
			166	158	277	% Planted + Regeneration
24	24	22	13	13	16	No. Species
		2				No. Species Dead
			7		2	No. New Species
			31		31	No. Total Species
	62	100	31	71		DAP

5 Conclusions

Planting heterogeneous species, managing ground cover and allowing natural regeneration, progressively foster the development of new vegetation and the increase of the biodiversity in sites invaded by *Saccharum spontaneum*. The two species that showed the most growth in two years were: balsa (*Ochroma pyramidale*) and nazareno (*Jacaranda* sp.). Others like negrito (*Annona spraguei*), guácimo negrito (*Guazuma ulmifolia*), jobo (*Spondias mombin*), jordan (*Trema micrantha*), balo (*Gliricidia sepium*), and cortezo (*Apeiba tibourbou*) displayed intermediate growth. Our recommendation to land managers, policymakers, non-governmental organizations, and interested parties is to consider these species for their reforestation programs, since they have been shown to grow rapidly. Also, the selective cleaning technique used in the maintenance of the plantations, together with the management of ground cover and natural regeneration, has allowed scattered species such as balso (*Ochroma pyramidale*), guarumo (*Cecropia* sp.), poro poro (*Clochlospermunm vitifolium*), jordan (*Trema micranta*), periquito (*Muntingia calabura*), and guácimo negrito (*Guazuma ulmifolia*) to grow freely in a natural manner, exhibiting dynamic growth and development, very much like natural forest vegetation.

REFERENCES

Autoridad del Canal De Panamá. (2007) *Ciudad del Árbol. Proyecto para la recuperación ambiental para la reserva genética de especies nativas de Panamá*. Universidad de Panamá y Autoridad del Canal de Panamá.

Canal Zone Experiment Gardens. (1939) *Annual Report*. The Panama Canal, Press. Mount Hope, C. Z., July 20, 1939.

Jones, E. R.; Wishnie, M. H.; Deago, J.; Sautu, A.; Cerezo, A. (2004) Facilitating regeneration in *Saccharum sponteneum* (L.) grassland within the Panama Canal Watershed: effects of tree species and tree structure on vegetation recruitment patterns. *Forest Ecology and Management* 191 (2004) 171-183.

Missouri Botanical Garden. (1948) *Missouri Botanical Garden Bulletin*. Volume XXXVI.

Montagnini, F.; Cerezo, A.; Lant Bent, H. S.; Kim, T. J.; Finney, Ch. (2008 Reforestation for control of invasive grass and watershed protection in the Panama Canal. *Revista Forestal YVYRARETA 15* (2008) 33-38.

PRORENA. (2004) *Investigaciones sobre reforestación con especies de árboles nativos en las Zonas de Operación del Canal de Panamá: 2001-2004*. Un trabajo colaborativo entre la Autoridad del Canal de Panamá (ACP) y el Proyecto de Reforestación con Especies Nativas (PRORENA). Informe final del contrato: ACP-STRI # SAA-82784. 20 p.

Prerequisites of Water Management Institutions for Contrast Scenario Between Water Availability and Poverty Level: A Case Study from the Ganges River Basin, India

BISHAKHA GHOSH & E.B. UDAY BHASKAR REDDY
Centre por Economic and Social Studies
Hyderabad, Andhra Pradesh, India

1 Introduction

Water as a natural resource plays an important role in the human well-being and human wellbeing exists in a continuum of poverty . Lack of availability for drinking water itself is an indicator of poverty but the role of water in human wellbeing becomes complex when water availability influences and gets influenced through food crop production, agro processing, fishing, health, and access to water use (CGIAR, 2006). India is characterised by non-uniformity in poverty along with level of awareness, socio-economic development, education, practices and rituals which add to the complexity of providing water (Khurana and Sen, 2008). To be more precise, it is well known that the country is suffering from regional disparity in the incidence of poverty in terms of per capita expenditure, state domestic product, and agricultural wages. Disparity exists within states, between states, and especially within urban and rural areas (Deaton and Dreze, 2002).

2 Water and Poverty

Water supports livelihoods of people through water consuming agriculture and industrial activities, through domestic consumption and sanitation and through ecosystem services. Lack of adequate water supply hampers health and output and again, even with adequate supply of water, poor cannot have access to it due to their low income. (Lawrence *et al* 2002). In short, water is a key element of human life and major element in explaining poverty. As rivers are a major source of water, people tap the river basins to meet water needs, including agricultural, industrial, domestic, and others. It is often assumed that availability of water from rivers in any geographical area can bring benefits in human life, leading to wellbeing as well as poverty reduction (Lawrence *et al* 2002, CGIAR, 2006, MEA, 2005). However, a closer look into the data on poverty and water availability across river basins in India presents a different picture. For instance, much of the rural poverty is concentrated in a few states that fall in the Ganges river basin (Sharma et al, 2008) though the Ganges River has the highest water potential (in terms of annual average surface water flow, CWC, 2005).

3 Study Area

The study area is confined to the Ganges basin. The Ganges, which is the largest basin of the Ganga Brahmaputra Meghna (GBM), is the 41st longest in the world and 20th longest river in Asia (Sharma *et al*, 2008). According to central water commission report 2005, this basin has the highest amount of estimated utilisable surface water among the river basins of the country. About 40 per cent of Indian population lives in Ganges basin, but the basin has remained as home of the largest number of people living in poverty. (Upali *et al*, 2005).

Much of the rural poverty is concentrated in the few states of India that fall in the Ganges basin (Sharma *et al*, 2008). This kind of a situation requires a more detailed analysis of the data in order to understand the relationship between water availability and poverty which seem to be not a straightforward one. There could be other determining factors as well, among which access to water resources is an important one. The Ganges covers Uttar Pradesh, Madhya Pradesh, Bihar and West Bengal with Monsoonal climate and in east Haryana, Rajasthan with arid climate.

Madhya Pradesh, Bihar, and West Bengal are the states with high poverty incidence (Narayanmurthy, 2007). It is significant to note that there are several adjacent districts within the basin which show higher differences in rural poverty head count. The majority of those districts are from different states. Table below gives the details of adjacent districts within a state with high poverty gap in the Ganges Basin.

Table 1 Details of adjacent districts within a state with high poverty gap in the Ganges Basin.

State	Adjacent Districts	Rural % of Poor in the district	Difference in Rural % of Poor between adjacent districts
Utter Pradesh	Siddharthnagar	66.3	-
	Shrawasti	56.1	10.2
	Balarampur	18.6	37.5
Utter Pradesh	Mathura	41.0	-
	Aligarh	19.8	21.2
West Bengal	Murshidabad	55.9	
	Nadia	18.3	37.6

Source: Rural % of Poor in the district has been taken from NSSO 61st Round Survey, 2004-2005 (Chowdhury and Gupta, 2009).

In the case of West Bengal, the difference in level of rural poverty is highest in two adjacent districts. West Bengal state is located at eastern part of India; and it has two parts. There are three districts at the Northern part is Himalayan region: Darjeeling, Jalpaiguri, Kochbihar. The level of poverty is from 10 to 30 per cent in this part. The other one is Gangetic delta part consisting of eastern Bhagirathi plain, western Bhagirathi plain, Mayurkhshi plain, Rupnarayan plain, Damodar, Kangshabati, Kanthi, and Medinipur plain. The Gangetic delta is watered by the Ganges river and its branches. The level of rural poverty varies from 10 per cent to more than 55 per cent in this part. At the district level, the highest level of rural poverty is found at Murshidabad district (55.9 per cent) and lowest rural poverty at the Nadia district (18.3 percent). Table 2 shows important characteristics of these two districts.

Table 2 Geographic, Social and demographic characteristics of Nadia and Murshidabad District.

District		Nadia	Murshidabad
Total geographic area		3927 Sq. Km	5324 Sq. Km
Rural area		97.58%	94.65%
Number of population in the year 2006		5035674	6526499
Rainfall in July		272.1 mm	303.1mm
From the year 2000-2006, annual average annual rainfall		1039.71mm	1495.85mm
Livelihood		Agriculture	Agriculture
*Population Density (2001)		Total-1173, Rural-975, Urban-4661	Total-1102, Rural-988, Urban-5685
Land Tenure		Percentage of cultivated area is 79.06 and for non- cultivated land it is 20.63	Percentage of cultivated area is 79.82 and for non-cultivated land it is 23.03
Land Holding	No. of operational holding Area of operational holding (in hectare)	594925 438912	418238 350589
	Average size of operational holding(in hectare)	0.74	0.84
Local river		Jalangi	Bhagirathi
**Water availability in river (in lakh hec. Mtr.)		Surface- 3.707 Ground- 1.35	Surface- 13.643 Ground- 3.37

Source: www.wbagrimarketingboard.gov.in, Accessed on 22nd April, 2010
*Source: www.indiastat.com .** Sech Patra, 1994, Department of irrigation and water ways, Government of West Bengal.

The District of Murshidabad is bigger than Nadia district in terms of geographic area and population. However, the percentage of rural area is almost the same for both of the districts. Also both districts have the same soil type, temperature, and livelihoods. Rainfall is higher in Murshidabad compared to Nadia. Both the districts have same land tenure and holding pattern.

Against this background, the present study attempts to understand the relationship between water and poverty in the Indian context using both secondary and primary data.

4 Objectives

a) To study access to water for domestic use at households belonging from different level of poverty.
b) To estimate opportunity cost of domestic water collection at household level.
c) To explore the issues related to constrained access to domestic water.
d) To find out relevant policy implications to reduce level of rural poverty.

5 Methodology and Data

For collecting primary data from the households we first selected one village from each district. The procedure adopted for selection of villages and households are given below.

a) *Selection of villages*. We selected one village from each of the districts. For this, we first visited various government department and offices such as the Department of Irrigation and Waterways, Department of Water Investigation and Development, Circle office, Government of West Bengal, and Jalangi Bhavan Nadia, to get secondary information on surface water flow of Jalangi River. Information has been collected to select the area in the Nadia district where surface water flow of the river is low. Accordingly Bahadurpur village of Dhubulia II block has been selected for primary data collection (It has been reported from the above mentioned Government sources that on an average Jalangi river has surface flow of water with 8 meters height but in the selected area the height is 6 meters).

In addition to the above offices for Murshidabad and Central Water Commission, Lower Ganges Division, Murshidabad have been visited to get secondary information on surface water flow of the Bhagirathi River. Information has been collected to select the area in the Murshidabad district where surface water flow of the river is high. It has been reported from above the sources that as Bhagirathi has been a controlled river by the Farakka dam, the flow of water is more or less same throughout is course. Pirtala village of Jiyagunj district has been selected as width of river in this area is comparatively high.

b) *Selection of sample households*: At first, a pilot survey has been done in both the villages for collecting household level information about landholding. It was found that the number of household in Bahadurpur village is 1211 and that of Pirtala village is 365. Among them 250 households in Bahadurpur village are primarily or secondarily engaged in farming whereas it is 189 in Pirtala village. We decided to collect primary data from 15 per cent of households, that is, 38 from Bahadurpur and 28 from Pirtala engaged in farming from each village. According to size of agricultural land held, households in each village have been divided in three groups (up to 1 acre, 1 to 2 acres, greater than 2 acres).

We used a structured questionnaire to collect data. The questionnaire was prepared on the basis of the insights received from the focus group discussions conducted among key informants in the villages. The questionnaire was finalised after field testing. Apart from household socio economic and demographic characteristics, questions related to water for domestic use and peoples' perspective on constrained access to water and its' further consequences were included. Poverty has been considered on the basis of agricultural land held by households. A household having lesser amount of own agricultural land has been considered as poorer. Descriptive statistics, cross tabulations have been used to analyse the data. Access to domestic water has been estimated using Access Sub Index of Water poverty Index for each group of households.

6 Results and Discussions

a) Access to water for domestic use at households belonging from different level of poverty: Households have more access to water in Bahadurpur village of Nadia district compared to Pirtala village of Murshidabad district. It is evident from the results that access to water increases with the increase in landholding size up to 2 acres and thereafter steadily declining in Bahadurpur village but in Pirtala village the relation between landholding size and access to water is directly proportional.

b) Opportunity cost of domestic water collection at household level: Households holding bigger amount of agricultural land have the source of domestic water within their residential compound in the form of bore wells/ well. In both the villages, average time spent for collecting domestic water is more for households with less agricultural land as the source is located far off. The land holding size in these villages is grouped under 3 categories - 1 category (land holding up to 1 acre), 2 category (land holding more than 1 up to 2 acres), and 3 category (more than 2 acres). Average time spent within group for domestic water collection is more in Pirtala village than Bahadurpur village. Opportunity cost of domestic water collection for people with less amount of agricultural land is high compared to people with large amount of agricultural land because they couldn’t find the time to engage in income generating activities like poultry management, bidi binding (country made cigars), or fodder management.

c) In both villages across different groups domestic water is mainly carried by women of households: Water related diseases as well as social hazards like Low water level, sexual harassment, daily quarrel with neighbour, facing at the time of water collection are more for the groups having lesser own agricultural land in Pirtala village and has been reported as zero in Bahadurpur village.

Table 3 Water consumption in study villages.

Attributes	Size of agricultural land holding (in acres)											
	Bahadurpur				Pirtala				Bahadurpur and Pirtala			
	~ 1	> 1-2	>2	Total	~ 1	> 1-2	>2	Total	~ 1	> 1-2	>2	Total
Water Consumption (in litres)	40.88	46.74	45.5	42	31.2	36	53.6	35	37.4	40.48	50.37	39.4

Source: Primary Survey.

7 A Summary

Pirtala village is facing less access to domestic water although it has surplus water in the local river. According to the primary survey, the basic reason for less access to water in Pirtala village than Bahadurpur is the extensive use of ground water for irrigation.

8 Policy Implications

There is a need for utilising more surface water in Pirtala village of Murshidabad district. For domestic water use there is a need for Government intervention. The head of the Pirtala village

Panchayat opined in the Focus Group Discussion that they have petitioned to the authorities to sanction an over -head water tank which would meet water demand. There is a need for Government as well as Non-Government intervention to minimise gender inequality in responsibilities of gathering domestic water and giving women more scope to get engaged in income generating activities.

REFERENCES

Chaudhury S and Gupta N (2009). Levels of Living and Poverty Patterns: A District - Wise Analysis for India. *Economic and Political Weekly,* 44(9):94-110.

Cook S. and Gichuki F (2006). Agricultural Water Productivity Issues, Concepts and Approaches. CGIAR Basin Focal Project Working Paper No 1.

Cook S. and Gichuki F (2006). Mapping Water Poverty: Water, Agriculture and Poverty Linkages. CGIAR Basin Focal Project Working Paper No. 3.

Deaton A. and Dreze J (2002). Poverty and Inequality in India A Re-Examination. *Economic and Political Weekly*, 43(6):43-49.

Khurana I and Sen R (2008). Drinking water quality in Rural India: Issues and Approaches. Water Aid Background Paper.

Lawrence P., Meigh J., Sullivan C (2003). The Water Poverty Index: An International Comparison', Keele Economics Research Papers.

Millennium Ecosystem assessment report 2005.

Sharma R .B., Upali A.A., Sikka A (2008). Indo- Gangetic River Basin : Summary Situation Analysis. IWMI Publication.

Upali A., Bharat R.S., Noel A., Scott C; Valdamir S, Fraiture C.D (2005). Spatial Variation in water supply and demand across River basins of India', IWMI Research Report 83.

Linking Farmers' Livelihoods with Trees and Soil-water Processes for Good Catchment Management Practices

LAURA BENEGAS NEGRI[1,3], VICTOR MEZA PICADO[2,4], ANDERS MALMER[3] & BENNO POKORNY[4]

1 *Tropical Agricultural Research and Higher Education Center (CATIE), Costa Rica*
lbenegas@catie.ac.cr

2 *National University of Costa Rica, Costa Rica*

3 *Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Sweden*

4 *Institute of Silviculture, University of Freiburg, Germany*

Abstract The presence of trees in the landscape under agroforestry or silvopastoral systems is typically considered a good practice in Catchment Management. However, empirical data about trees, soil, and water relationships have been scarce in tropical regions, as well as data related to local management practices compatible with tree presence in the landscape. In order to clarify the role of trees, we focused on the relationship between trees and infiltration as one of the main processes for groundwater recharge in agroforestry and pasture landscapes in the Central American tropics. Two case studies were analyzed: a coffee plantation under an agroforestry system in Aquiares, Turrialba, Costa Rica, and a pasture landscape (cattle farm) in Copan, Honduras. In Aquiares, there was no difference in infiltration between tree and non-tree conditions (tree mean = 898 mm/h, and nontree mean = 1.124 mm/h, p = 0.105), suggesting that a coffee plantation without trees -other than coffee- is better than one with trees in terms of groundwater recharge. In Copan, trees increased infiltration (Mood median test, p = 0.009; clump of trees median = 146 mm/h, open pasture median = 47 mm/h). Because case study 1 involved only one farm and trees were not significant to infiltration, we chose only case study 2 to explore which aspects of people's livelihoods influenced their decision to keep trees on their farms. This was done through the analysis of livelihoods surveys, using a total of 47 variables. The results showed the degree of association between the number of trees they kept and the corresponding reasons for doing so. On the Copan livestock farms, current land use ($p<0.0004$, coffee plantation = 107 trees/ha ±100, livestock = 19.74 trees/ha ±22) and altitude ($p<0.0089$, associated with high altitudes where the coffee plantations are found) are the most important reasons to have trees on farms.

Key words Community capitals; farmer's choices; hydric ecosystem services

1 Introduction

Among various services derived from ecosystems, water supply, under the functions of storage, retention, and regulation (Costanza, *et al*., 1997; de Groot, *et al*., 2002), is referred to as the hydric ecosystem service (HES). Agroforestry offers this and various ecosystem services, which need to be fully explored (Jose, 2009).

To understand HES, the hydrological-cycle process of infiltration offers the first step. Infiltration by rainfall affects quantity and quality of soil and groundwater systems (Wu, *et al*., 1996). It is the natural input of moisture on the groundwater table, and the main factor enabling its sustainability (Grinevskii and Novoselova, 2011). Therefore, research efforts have been directed to the infiltration process because it is considered the key to the hydrological changes derived from agricultural practices (Chapman, 1990).

To increase sustainable productive systems, current and past development projects have been promoting the increase of trees in farmers' systems. In them, agroforestry and silvopastoral techniques were the most common change linked with catchment management best practices. Although development and conservation projects focused their efforts on restoring forest as a land use that provides the most environmental services, they were not a complete success. Among other reasons, because this land use goes against the local context of agricultural systems managed by smallholders (for example for livestock 9.84 ha ±22.41; coffee= 3.86 ha ±3.03 for Copan River catchment) and subsistence farmers. Also, in such development projects the dimension of the mutual dependence between farms and families was not considered from the onset (Gray, 1998). Management is a key factor to understand the social theory of soil and land resources constructed through time (Barrera-Bossals, *et al*., 2006), from which it is possible to identify patterns (Chen, *et al*., 2010) or preferences taken by local farmers.

Even if it is well-known that agroforestry systems -the inclusion of trees in the agricultural system- facilitates the provision of environmental services, particularly those that include perennial crops like coffee or cacao that are fairly widespread in the Neotropics (Rapidel, *et al*., 2011), they still have to compete with several agricultural systems that avoid tree inclusion on the farm. For example, extensive livestock farming, pineapple and oil palm plantations in Central America. Thus, a strictly-forest land use is not a feasible possibility. Increasing the number of trees on farms is a more realistic option for conservation approaches.

This work first seeks to clarify the role of trees in groundwater recharge through promotion of agro-silvo-pastoral systems, among best management practices for catchments, to provide hydric ecosystem services in the Central American tropics. Secondly, it seeks to define linkages and boundaries in the relationships between the farmers' perceptions and the style of an agricultural system that maintains more trees in the catchment.

2 Methodology

Context of the Two Case Studies

Coffee plantation under an agroforestry system in Aquiares, Turrialba, Costa Rica

The coffee plantation is located in the Aquiares farm, one of the largest in Costa Rica (6.6 km^2). This area belongs to the Turrialba river subcatchment on the slopes of the Turrialba Volcano, which drains into the Reventazón River catchment in the central Caribbean region of Costa Rica, and ends in the Caribbean Sea. This farm has been under Rainforest Alliance TM certification since 2003. The experiment was held as part of the Coffee-Flux platform, situated in the Mejias Creek microcatchment between the coordinates 83˚44' (west longitude) and 9˚56' (north latitude), with an extension of 0.9 km2, elevation ranges between 1020 to 1280 m.a.s.l, mean slope of 20%, permanent streams of 5.6 km, with a drainage density of 6.2 km/km^2 (Gómez-Delgado, *et al*., 2011).

The Aquiares farm is homogeneously planted with coffee (*Coffea arabica L.,* var *Caturra)* on bare soil, shaded by free-growing tall *Erythrina poeppigiana* trees. Shade trees have a density of 12.8 trees ha_1, with a mean of 12.3% canopy cover and 20 m canopy height. Soils belong to the order of andisols according to the USDA soil taxonomy (USDA, 1999), which are soils developed from volcanic ejecta, under weathering and mineral transformation processes -very stable, with high organic matter content and biological activity, and very large infiltration capacities. The climate is tropical humid with no dry season, according to the Köppen-Geiger classification (Peel, *et al*., 2007). In the study region for the period 1973-2010, the average precipitation was estimated at 3,014 mm at the Aquiares farm station.

Natural Pasture Landscapes from the Copan River Catchment, Honduras

The Copan River flows in a transboundary catchment between Honduras and Guatemala, which drains into the Motagua River and then the Caribbean Sea. This territory is shared by five municipalities, Copan Ruinas, Santa Rita, Cabañas, San Jeronimo, and Concepción. The first four organized under a community of municipalities known as MANCORSARIC. This catchment extends about 620 km2 between 14°43' to 14°58' north, and 88°53' to 89°14' west. Data for 2007 indicates that pastures are the main land use in this catchment, covering 30% of the territory.

The soil type of this area, known as Malcote Association, is classified as Typic Argiustolls, according to the USDA (1986). It is characterized by deep soils with good drainage, developed under intrusive rocks. The superficial soil extends 20-30 cm in depth; its textures are between clay-loam and loam (FAO-PESA and CATIE, 2007). According to the Holdridge life zones, the climate is described as dry tropical forest (Holdridge, 1978). In this region, the average annual precipitation was 1,772 mm for the last 32 years (data provided by the local stakeholder, Victor Bueso Lopez).

We selected tree farms of the communities of El Malcote, Sesesmiles, and El Zapote, all located in the Down-Copan River subcatchment. In all cases, these farms have been under cattle pasture for the past 20 years, with native grass species mixed with improved ones (*Cynodon dactylon, Cynodon plectostachyus, Panicum maximum*, and *Brachiaria brizantha)* as well as old native clumps of trees sparsely distributed around the pasture and live fences of newer introduction (*Gliricidia sepium*), used as farm boundaries. We conducted infiltration tests (double-ring method) below some clumps of *Byrsonima crassifolia, Lonchocarpus hedyosmus, Spondias purpurea, Ficus colibrinae*, and *Lippia sp.* As a reference, the mean animal load was 1.8 UA/ha in Sesesmiles, where the reference for a sustainable livestock management is between 1 to 1.3 UA/ha with supplements like gramineous forage banks (Cristobal Villanueva, personal communication). We estimate that on the other farms (El Malcote and El Zapote) this animal load can be even higher; thus, in all cases we observed signs of soil degradation due to trampling.

Experimental Setup

We established transects representing a paired condition of (i) tree or clump of trees in the pasture landscape, and (ii) open pasture in case study 2 (natural pasture landscapes from Copan River catchment, Honduras). A similar paired condition of (i) trees plus coffee and (ii) only coffee in the gaps of the agroforestry system was established in case study 1 (coffee farm in Aquiares, Turrialba, Costa Rica). For the transects, which started from the central point of a tree (for case study 1) or a clump of trees (for case study 2), we randomly chose in which direction (north, south, east, west) to move to make the infiltration tests.

We measured infiltration on every meter (1 m) with five repetitions in what we called the "the transect tree part", doing the same in the coffee-only part. A total of 60 infiltration tests were run for case study 1. In the pasture landscapes, we used the clump of trees as the transect beginning, also doing five repetitions under the tree canopy. For the open-pasture part of the transect, we used the height of the highest tree of the clump as a distance for the first infiltration test; then twice the height and finally three times this height. A total of six replications were run in the open-pasture part -for a total of 80 infiltration tests for case study 2. The tests were done using a double-ring infiltrometer (diameter: 25 cm for inner ring and 35 cm for outer ring, keeping a constant water head of 10 cm). Tests were applied until reaching a steady state, and the resulting data were modelled using the Philips Equation (Philips, 1957).

The statistical analysis conducted were: 1) the paired t test for case study 1, where the dataset was normally distributed, and 2) nonparametric analysis in case study 2, to account for the difference between tree and open-pasture conditions. Data were analysed with Minitab statistical software.

Livelihoods Surveys

We used data collected for the baseline of the MESOTERRA project in the region of case study 2. This CATIE project seeks to promote sustainable management of degraded lands in Central America.

The survey was organized to collect data under the approach of livelihoods and community capitals (Emery and Flora, 2006). We selected 47 variables that represented these aspects in order to analyse the relationship between the number of trees (variable of interest) with several variables representing the natural, social, cultural and financial capitals of the communities; integrated by 63 stakeholders (*n*). We applied multivariate statistical analysis in order to identify the main reasons behind farmers' decisions to keep trees on their farms. Through contingency table analyses, Chi square tests and the classification tree analysis, we managed to show what variables explain the farmers' decision to keep trees in their productive systems. Data were analysed with the Infostat statistical software.

3 Results and Discussion

In Aquiares (case study 1), there were no differences in infiltration between tree and nontree conditions (Fig. 1; p = 0.105; no-tree mean = 1,124 mm/h, tree mean = 898 mm/h), suggesting that coffee plantation without trees is better than one with trees in terms of groundwater recharge. This high infiltration is typical of andisols on volcanic rock (Gomez-Delgado, 2011). In Copan (case study 2), trees increased infiltration (Mood median test, p = 0.009; clump of trees median = 146 mm/ha, open pasture median = 47 mm/ha). All infiltration values in Aquiares are above maximum prevailing rain intensities (maximum rain intensity in one hour = 46 mm/ha in the wetter month of June 2009). Most of the infiltration values in Copan are below maximum, prevailing rain intensities (maximum rainfall intensity in one hour = 50 mm/ha in the annually wetter month of June in 2010), especially where there are no trees.

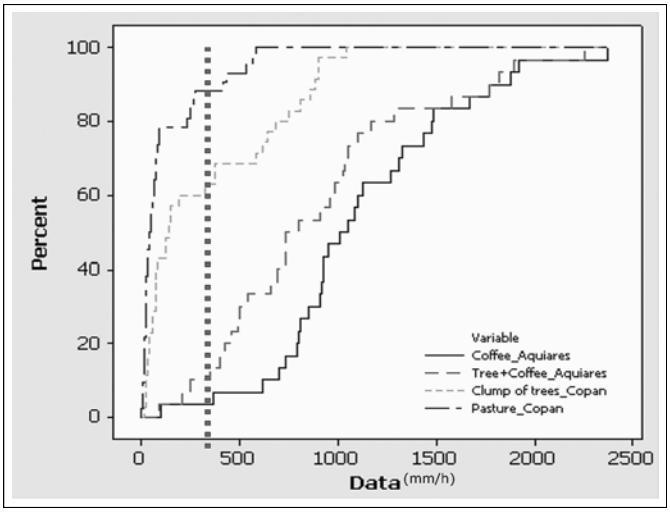


Fig. 1 Cumulative frequency distribution of the infiltration values in the Aquiares coffee farm and the Copan silvopastoral landscape**.** The vertical dotted line indicates the upper limit (100 mm/ha) for rain intensity in the Tropics (Jackson, 1986).

For the analysis of the livelihood survey applied to the case study 2 region, we divided the variable of interest (number of trees per hectare) into three categories; where C1 represents the lower number of trees and C3 the higher. Through the tree classification method we identified which variables were generating the separation between categories (number of trees per hectare). Fig. 2 shows that the first separation variable is the current land use (a group of 27 farmers have pastures and the remaining 36, coffee). The group of 36 farmers is successively divided by slope, where there is a group located at slopes <= 77.5% (n = 33) and another located at slopes > 77.5% (n = 3). The variables that manage to separate the categories of number of trees per hectare are biophysical variables. Some minor groups are explained by prices of coffee production, altitude and previous land use.

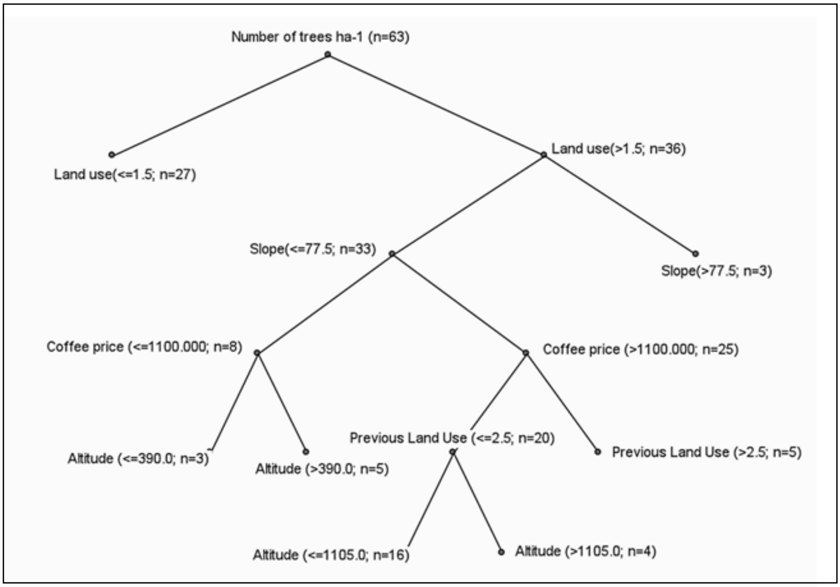


Fig. 2 Classification tree analysis explaining the number of trees per hectare according to local agricultural context. Copan, Honduras.

The variables typically recommended to explain preferences in land use -such as organization level, education, formal training, income level, among others (47 variables, mainly socioeconomic)- have little to do with the presence of trees on farms. This result could be attributed to the social structures and networks that further modulate economic factors to create a highly diverse pattern that is temporally, spatially, and socially specific (Start and Johnson, 2004). As a result, each actor or user group is far from homogeneous (Berkes, 2009).

The farmers' decisions to keep trees on their lands respond to their own internal logic, and for this case study, the results of the contingency table allow us to show the degree of association between the number of trees they kept and their corresponding reasons. Here, current land use ($p<0.0004$, coffee plantation = 107 trees/ha ±100, livestock = 19.74 trees/ha ±22) and altitude ($p<0.0089$, with high altitudes where coffee plantation are found) are the most important reasons to have trees in their farms.

4 Conclusions

In the context of case study 2 (pasture landscape in the Copan River catchment), trees effectively contribute to increase infiltration that favours groundwater recharge, especially in degraded pasture lands; however, this land use continues to be the less favourable to keep trees in the landscape.

The trajectory and cultural history of coffee production systems in this region have demonstrated that they are compatible with tree increment in catchments; apparently it has been less influenced by external factors (association, organization, training). In the case of livestock systems, which are the ones reflecting more benefit from trees for groundwater recharge, their management practices do not include increasing trees in the catchments.

Under the current Central American agricultural context -small farms and smallholders subsistence goals- there is a need to shift from imposed conservation practices to promote forestry, toward an approach for increasing trees on farms and, ultimately, in catchments.

Acknowledgments

We would like to thank professors Fernando Casanoves and Ulrik Ilstedt for their suggestions and support for the statistical analyses; Karen Banegas for her help collecting the livelihoods surveys; Hugo Brenes for his support processing the database. Also our gratitude to Cirad UMR Eco&Sols and Coffee-Flux platform (http://www5.montpellier.inra.fr/ecosols/Recherche/Les-projets/CoffeeFlux) for logistics and meteorological instrumentation; to Hacienda Aquiares for field access, to the Barquero family for their constant support in field campaigns in Aquiares; and to the projects MESOTERRA and FINNFOR, both directed by CATIE. To DAAD (German Academic Exchange Service), CONICIT (Consejo Nacional para Investigaciones Científicas y Tecnológicas de Costa Rica), and the Schlumberger Foundation Faculty for the Future, for their financial support.\

REFERENCES

Barrera-Bassols, N., J. A. Zinck and E, Van Ranst. (2006) Symbolism, knowledge and management of soil and land resources in indigenous communities: Ethnopedology at global, regional and local scales. *CATENA* 65 (2): 118-137.

Berkes, F. (2009) Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management* 90 (5): 1692-1702.

Chapman, T. G. (1990) Construction of Hydrological Models for Natural Systems Management. *Mathematics and Computers in Simulation* 32 (1-2): 13-37.

Chen, S. E., P. Bhagowalia and Shively, G. 2011. Input Choices in Agriculture: Is There A Gender Bias? *World Development* 39 (4): 561-568.

Costanza, R., R. d'Arge, R. Costanza, R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton and M. van den Belt. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387 (6630): 253-260.

de Groot, R. S., M. A. Wilson, and R.M.J. Boumans. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41 (3): 393-408.

Gómez-Delgado, F., O. Roupsard, G. le Maire, S. Taugourdeau, A. Pérez, M. van Oijen, P. Vaast, B. Rapidel, J. M. Harmand, M. Voltz, J. M. Bonnefond, P. Imbach and R. Moussa. (2011) Modelling the hydrological behaviour of a coffee agroforestry basin in Costa Rica. *Hydrol. Earth Syst. Sci.* 15 (1): 369-392.

Gray, J. (1998) Family farms in the Scottish borders: A practical definition by hill sheep farmers. *Journal of Rural Studies* 14 (3): 341-356.

Grinevskii, S. O., and M. V. Novoselova. (2011) Regularities in the formation of groundwater infiltration recharge. *Water Resources* 38 (2): 175-186.

Jackson, I. G. (1986) Relationships between raindays, mean daily intensity and monthly rainfall in the tropics. *International Journal of Climatology* 6 (2): 117-134.

Jose, S. (2009) Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry Systems* 76 (1): 1-10.

Peel, M. C., B. L. Finlayson, andM.C. Peel. (2007) Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.* 11 (5): 1633-1644.

Philip, J. R. (1957) The theory of infiltration: 1. The infiltration equation and its solution. *Soil Sci* 83 (5): 345-357.

Rapidel, B. 2011. *Ecosystem services from agriculture and agroforestry: measurement and payment*. London; Washington, D.C., Earthscan.

Start, D. and C. Johnson. (2004) *Livelihood Options? The Political Economy of Access, Opportunity and Diversification*. London, Overseas Development Institute**:** 56.

Wu, J., R. Zhang and J.Yang. (1996) Analysis of rainfall-recharge relationships. *Journal of Hydrology* 177 (1-2): 143-160.

Environmental and Economic Sustainability Actions in Two HELP Basins: São Francisco Verdadeiro (Brazil) and Carapá (Paraguay)

RAFAEL HERNANDO DE AGUIAR GONZÁLEZ[1], FRANCISCO PEDRO DOMANICZKY LANIK[1, 2], CÍCERO BLEY JUNIOR[1, 2] & ANA CAROLINA GOSSEN SIANI[1, 2]

1 *International Hydroinformatics Center (CIH), Itaipu Technological Park Foundation (FPTI), Brazil/Paraguay*
rafael@pti.org.br

2 *ITAIPU Binacional, Brazil/Paraguay*

Abstract This article presents a holistic view of a major reservoir located on the border between Brazil and Paraguay. It takes into account two different realities, along with their specific characteristics. It presents an overview of the actions applied in the search for solutions that bring environmental and economic benefits, thus creating a base for regional sustainability. The study was performed in two hydrographic basins: São Francisco Verdadeiro on the Brazilian side, and Carapá on the Paraguayan side. It demonstrates two analysis scenarios that consider the preservation of environmental resources and the water-energy nexus. The objective is to minimize contamination and pollution and maximize the use of resources available within the basin.

Key words Water; energy; environmental conservation; environmental actions; biogas

1 Introduction

The basins São Francisco Verdadeiro (Brazil) and Carapá (Paraguay) are located in a central region of South America. They are both hydrographic units belonging to the hydrological network of the Prata basin, which is considered one of the largest basins in the world, with an area of 3.1 million km, equal to 17% of South America's surface. In this context, the main river of the Prata Basin water system is the Paraná River, which is located in the biggest hydroelectric production plant in the world, ITAIPU Binacional, whose reservoir has an extension of 170 km in diameter and a surface area of 1,350 km. The addressed basins contribute directly to the maintenance of the Itaipu Binacional reservoir; being the most extensive and the most representative drainage areas in the incremental basin of the hydroelectric plant, they have an important influence on the quality of the reservoir.

The productive activities developed in the two basins and their regional characteristics are similar, especially in one characteristic: predominance of small urban areas and a high concentration of agricultural activity. This article presents successful actions that occur in the HELP basins, represented by a variety of programs and projects of entities involved in the search for solutions to common problems arising from agricultural and agro-industrial activities.

The objective of this article is to present two scenarios. The first is the São Francisco Verdadeiro basin, an area influenced and completely disturbed by livestock production, which is considered a potentially polluting activity, with emphasis on the act of converting animal waste into an energy source, starting from biogas. That which was earlier considered to be waste and discarded in the incorrect manner was transformed into an energy production source, establishing a relationship of resource reuse and a new concept in the use of residual waters as an energy source.

The second scenario is the Carapá river basin, considered to be a substantial basin for the production of grains such as soy and corn, with considerable environmental preservation through actions that occur in the region; on the other hand, considering that this is the main impact resulting from activities practiced in the basin, the basin shows fragmented areas of original vegetation.

In order to understand these hydrographic basins, this article reveals specific characteristics of these basins and, primarily, that which is being done in the search for solutions that promote environmental and economic benefits, thereby providing regional sustainability; in so doing, the article presents the two scenarios of implementation and their capacity to be replicated in other similar hydrographic basins.

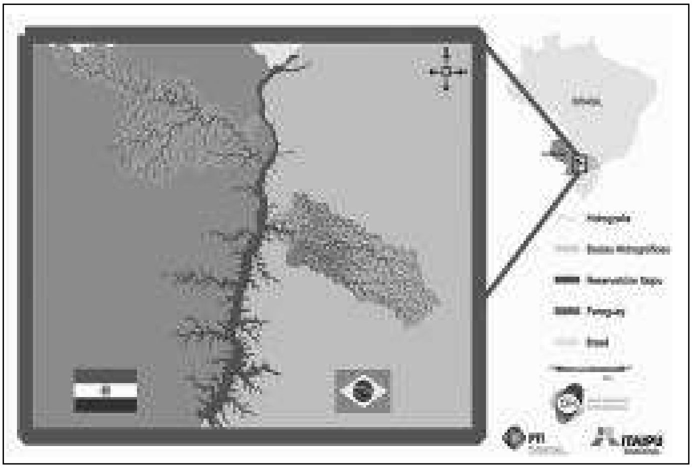


Fig. 1 Locations of the SFV and Carapá hydrographic basins. Source: CIH (2011).

2 HELP Basins

The São Francisco Verdadeiro Hydrographic Basin (Brazil)

The hydrographic basin of the São Francisco Verdadeiro River (SFV) is located in the west of the state of Paraná in southern Brazil, in an area of approximately 2,212 km, with its mouth at the confluence of the Itaipu Binacional Hydroelectric Plant reservoir. The São Francisco Verdadeiro River travels 240 km in its main channel and its hydrographic network runs approximately 3280 km until it reaches the reservoirs, passing through 11 (eleven) municipalities with primarily agricultural economies.

This region is specialized in the conversion of vegetable protein into animal protein, considering its productive chain that goes from soy and corn plantations to the industrialization of pork and poultry, in addition to the intense production of dairy cattle. Because they generate waste that, by means of the hydrological network, can degrade the quality of the river and of the Itaipu reservoir and weaken the environment, these are activities with a high environmental impact. The existing nutrients in the waste of agricultural production reach the rivers, causing an explosion of harmful algae. The water quality is often toxic to the animals that are supplied by it, reaching the stage of eutrophication and swamping in sites where the river flow is lentic.

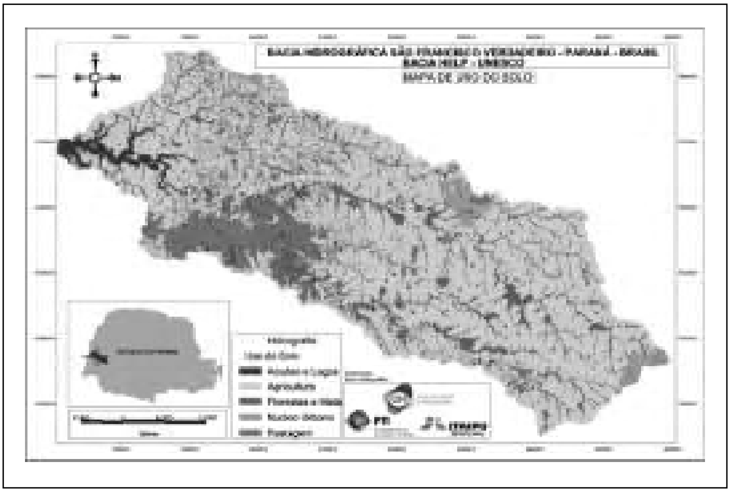


Fig. 2 Soil use in the SFV basin.

The analysis of the use of soil in the basin, using Geographic Information Systems (GIS) and images from the SPOT satellite dated 1990 and 2006, shows the use and the regional evolution regarding the activities employed in the basin, according to Fig. 2.

The data demonstrates the growth of the urban area (from 36 km to 86 km) considering human waste as a potential river pollutant; the most representative increase, however, is concentrated in the grazing areas (from 59 km to 216 km), provoked by intense agricultural production that advances into forested areas (from 614 km to 352 km), decreasing their conservation areas.

In this point it appears that there is a profound and decisive change in the way of addressing and understanding production and how it intensifies effects on the environment. In order to establish the development of a region it is necessary to ensure the availability of energy; on the other hand, it is impossible to imagine a sustainable future without the preservation of the environment and, above all, that of water, the element essential to humanity.

The challenge of establishing the nexus of water and energy, as integrated and directly related elements, treating them in a joint manner in order to present solutions that reconcile this important contradiction, is of extreme importance for the development of this region. The SFV hydrographic basin has an intense production of livestock that generates waste, polluting to the water of the rivers.

On the other hand, this waste, dealt with in the correct way, can be transformed into energy from the conversion and use of biogas as an energy source.

In this context, Fig. 3 shows the "Agro-energy Cooperative for Family Agriculture in Rio Ajuricaba", a small micro-basin belonging to the SFV basin with approximately 40 producers of cattle and hogs connected by a gas pipeline that leads the biogas to a Thermoelectric Plant with the production potential of approximately 1460 kWh/day.

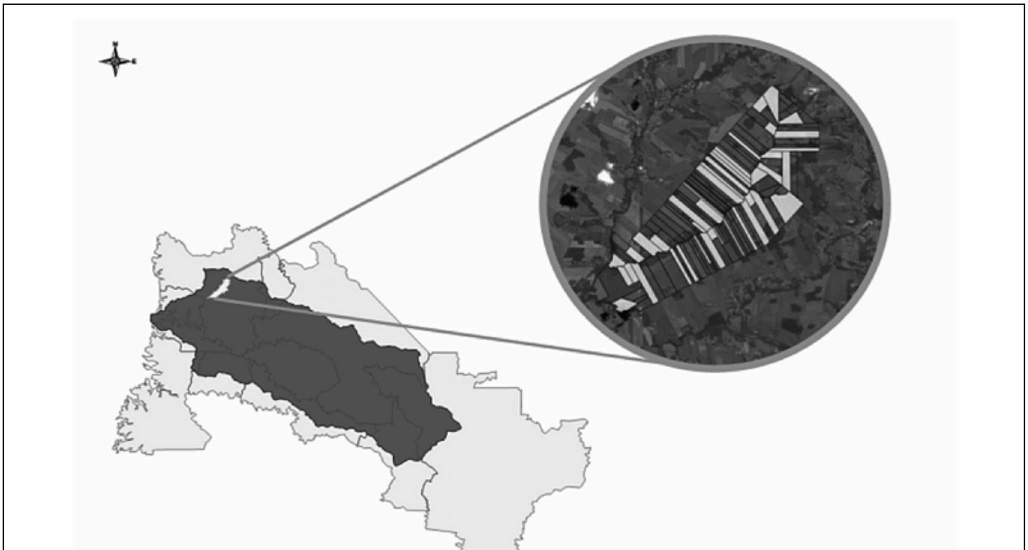


Fig. 3 Agro-energy Cooperative for Family Agriculture in Rio Ajuricaba.
Source: Itaipu Binacional, 2011.

A previous study of the energy production potential of the residual biomass of animal production in the São Francisco Verdadeiro basin is shown in Fig. 4; the quantity of existing animals in the basin can be transformed into biogas and, afterwards, into energy, given the specific factors of conversion utilized by the regulations of the IPPC "Guidelines for National Greenhouse Gas Inventories" (2009).

The data, presented in Fig. 4, demonstrates the quantity of the basin's potential production in kWh/day, estimated to be a total 987,392.46 kWh/day. Therefore, it is clear that this model can be applied as a form of solution to the environmental problems that occur in the basin and, above all, to ensure regional development, considering energy as the main input for development. The use of energy sources that reconcile environmental preservation with the valuation of an economy in the region of this model, by means of the use of animal waste as the raw material for energy

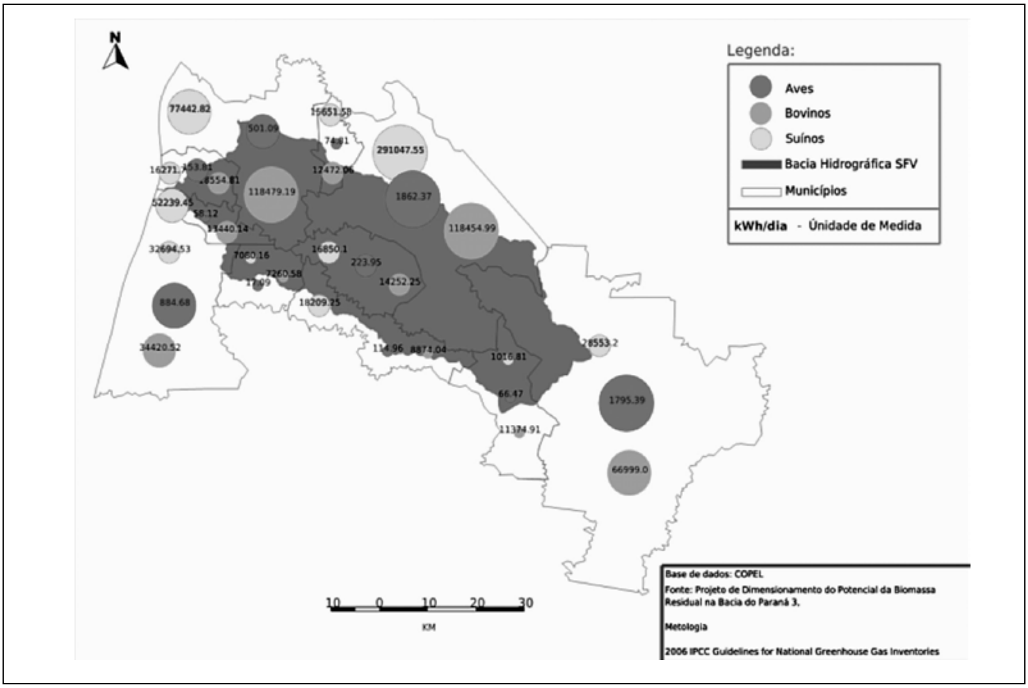


Fig.4 Potential energy production from animal waste.
Source. Itaipu Binacional, 2011

generation, becomes the focus of this study.

The Carapá Basin (Paraguay)

The Carapá river basin is situated in the in the High Paraná basin, located in the Department of Canindeyú, east of the Eastern region of Paraguay, with an area of 287,500 hectares, distributed over 7 towns. It has an average altitude of 337 m, reaching 220 m at its mouth in the Itaipu reservoir (Fig. 1).

The length and width of the basin are: 115 km and 23.4 km, respectively, producing an annual average outflow of 40 m3/s, with a maximum variation of 183 m3/s and a minimum of 11 m3/s, and an annual precipitation of 1700 mm, according to surveys from the last 10 years, up until May of 2011.

In terms of hydric availability, the Carapá River has an average annual outflow of 40 m3/s, offering an estimated 1,260 million m3 of water per year.

In relation to subterranean waters, the basin is situated on top of the Guaraní Aquifer System (SAG), one of the largest subterranean water reservoirs of the world. This group of sandy rocks, with spaces and cracks that are pre-filled with water, has a permanent reserve of 45,000 Km. It is found at a considerable depth, and its exploitation has been relatively minor, with 17 artesian wells serving small regions of less than 5,000 inhabitants. It is approximately 160 meters deep, with an outflow of between 32m3/s to 3m3/ and an average of 13 m3/s, according to the National Environmental Sanitation Service of Paraguay.

The basin population does not surpass 25,000 inhabitants, and the landscape is covered with large agricultural areas. There is a predominance of agricultural activity, with a principal production of grains (soy and corn). There is also a great fragmentation of the native vegetation timber forests, which constitute the last timber resources of the region, with an area of 35,000 hectares, which represents 12 % of the hydrographic basin, causing the loss of the interconnection of habitats and reduction of biodiversity. Fig. 2 shows the transformation of the wooded areas cited and the predominance of intensive agricultural activity on an orthophotomap dated from 1993. The green represents the remaining wooded areas.

The proposed methodology tends towards sustainability, related to the minimization and correction of contamination, and the maximization of the benefits of hydric resources for energy sources. The proposal for following the evolution of the basin consists of establishing a graphic baseline situation of the basin. The different environmental actions and activities are then carried out using a structured form with a collective focus and an ample individual participation that is conscious, and stimulated by the users of the hydric resource in the basin. This proposal considers the permanent use of preventive actions using environmentally friendly technologies, intensive agricultural exploration, and the preservation of wooded fragments, with the respective fomenting of biomass in the interconnection systems between the fragments, causing a stimulated dynamic of the natural trophic chains, and the subsequent preservation of native species, and partial re-composition of the habitat.

Therefore, the proposal articulates the development of activities for the environmental programs of Itaipu Binacional, and the control and monitoring activities that the company performs in the region, looking to systematize them and structure them in a coordinated effort with other governmental institutions within the context of legal actions with basins and microbasins as the law 3239/2007 provides.

This proposal details activities characterizing water use in microbasins and the systemization of information regarding the preservation or protection of the margins of the watercourses, as well as the promotion of agroecological measures. These measures minimize soil and hydric resource erosion and sedimentation, as well as following potable water and its sanitation.

Another critical element of this methodology is the conformation and strengthening of individual and collective participation in basin groups, backed by the wide participation of hydric resource users, promoting legal and preventive measures in the basin. The methodology hopes to achieve the following objectives:

- Rescuing the river and creek beds within the hydrographic basin to mitigate the effects of erosion and sedimentation
- Reducing pollution by agrotoxins with the adequate treatment of production residues
- Regeneration of degraded soils, improving their capacity and the recuperation of timber areas
- Establishing development policies, guaranteeing potable water for the population
- Restoring biological pathways and chains of reproduction, increasing biodiversity
- Utilizing biomass for energy and preservation of the hydrographic basin

- Serving as a regional example of good basin management practices

3 Web Rádio Água (Water Radio Network) - A Communication Model for Projects in the HELP Hydrographic Basins

Web Rádio Água is a project developed by the International Hydroinformatics Center (CIH) that partners with the Renewable Energy Council (Assessoria de Energias Renováveis- ER.GB) of ITAIPU Binacional (IB), Itaipu Technological Park Foundation (FPTI) and the International Hydrological Programme (IHP) at UNESCO. Through teaching and collaborative learning mediation, Web Rádio Água works in different media languages, with an emphasis on audio archives, joining efforts and interactivity foster educational knowledge and promote civil society for the construction of citizenship and the promotion of sustainability in Latin America and the Caribbean. It is hoped that through these efforts of the communications model, the projects interacting in the São Francisco Verdadeiro and Carapá hydrographic basins may use the Web Rádio Água as a means of communication. It will serve as an information and experience exchange for each environment. Using a more inclusive concept, it can be described as an interactive web platform dedicated to communication, developed entirely with free tools, that facilitates the exchange of information and experiences, through the accessing of information about water, technology, energy, and the environment. The project approaches communication aiming towards a common good, through a model in which users have a space to interact, produce, and publicize their own content, creating an exchange of knowledge, a construction of citizenry, and the promotion of sustainability through the participation and collaboration of society in hydrographic basins in question.

4 Final Considerations

This model directs the elaboration and definition of future scenarios in the energy and water fields. It considers the maintenance of ecosystems, with a minimal impact of production activities on the hydrographic basic environment. It treats water as a resource that is necessary for life, and energy as a resource that is necessary for regional development. The hydrographic basin is therefore converted into a productive unit for energy.

REFERENCES

Bley, C. J.; Libânio, J. C.; Galinkin, M.; Oliveira, M. M. (2009)*Agroenergia da Biomassa Residual: perspectivas energéticas, socioeconômicas e ambientais*. Foz do Iguaçu/Brasília: Technopolitik Editora.

ITAIPU Binacional - Programas Cultivando Água Boa/Porã e Plataforma Itaipu de Energias Renováveis.

González, R. H. A. (2008) *Derivação de dados da bacia hidrográfica são francisco verdadeiro - paraná com uso de geoprocessamento*. UDC.

OEA. *Cuenca del río de la Plata; estudio para su planificación y desarrollo*. Washington, D. C.

The Water Journey and Issues of a River Basin with Limited Resources

RUTH GAMBOA[1] & DECLAN HEARNE[2]

1 *University of the Philippines Mindanao, Mintal, Davao City, Philippines*
ruthupmin@yahoo.com

2 *HELP-Davao, DOST Region XI Compound, Bajada, Davao City, Philippines*

Abstract Using the spiral model of IWRM, the water journey of Davao City, southern Philippines, in the last century can be divided into three main turns, namely: supply, sustainability, and governance. The first turn is about drinking water supply. Springs and rainwater at the turn of the 20th century gave way to tap water in the 1970s, when the water district was established. The water district extracts groundwater as built-up areas continue to expand. The second turn started at the end of the century and is about water sustainability incorporating science in planning. Managing water at the ecosystem-level and commissioning technical studies was pioneered in 1998 by an NGO, the People Collaborating for Environmental and Economic Management (PCEEM). The approach of using science was adopted by the city and culminated in the passing of the Watershed Code in 2007. This marks the third turn, which is mainstreaming water governance by officials who must get their electoral mandate every three years. Each major turn has its sub-turns and as water-related disasters become real events in the city, local awareness has mobilized self- and group-help where the local government is highly expected to be a champion across political administrations.

Key words Spiral model; governance; groundwater

5. WATER EDUCATION AND KNOWLEDGE SHARING

Application of the Watershed Sustainability Index to a HELP Watershed in an Arid Zone: The Elqui River Basin, North-Central Chile

ANA ELIZABETH CORTÉS[1], RICARDO OYARZÚN[2,3], NICOLE KRETSCHMER[3], HENRIQUE CHAVES[4] & GUIDO SOTO[1]

1 *Water Center for Arid and Semi-Arid Zones in Latin America and the Caribbean (CAZALAC), La Serena, Chile*
2 *Department of Mining Engineering, Universidad de La Serena, La Serena, Chile*
3 *Arid Zone Advanced Studies Center, Universidad de La Serena, La Serena, Chile*
4 *Department of Forestry Engineering, Universidad de Brasilia, Brasilia, DF, Brazil*

Abstract The Watershed Sustainability Index (WSI), developed to estimate basin sustainability in an integrated manner, with emphasis on water resources management, was applied in the Elqui River Basin over a period of five years (2001-2005). The Elqui watershed is located in the semiarid region of Chile, and has been recently incorporated into the River Basin Network of the UNESCO HELP Program. The result was a WSI value of 0.60 (in the range of 0-1) rating the basin's sustainability as "intermediate". The main watershed strengths were related to the Environment and Policy components. On the other hand, the weakness observed in the watershed was related to the Hydrology indicator, mainly due to water scarcity issues. The determination of the WSI at the Elqui basin demonstrates the value of this method, both as an analytic, quantitative instrument, and as a practical management tool for water authorities, water users, and stakeholders. However, updating regional information is recommended in order to increase the accuracy of the WSI and to incorporate the method to mid- and long-term strategies for the Elqui basin and other neighbouring watersheds.

Key words Hydrology; environment; life; policy; Watershed Sustainability Index; Elqui river basin

1 Introduction

In 2008, the Elqui river basin in Chile was included as a new basin in the HELP Program worldwide watershed network. One of the first initiatives carried out was to assess the sustainability level of the current situation and management practices adopted in the basin, using the WSI approach. The application of the WSI, which is presented in this contribution, was carried out as part of the working tasks of the UNESCO-supported Water Center for Arid and Semi-Arid Zones in Latin America and the Caribbean (CAZALAC). Together with the purpose of obtaining the WSI for the UNESCO-HELP Elqui river basin, the study pointed to perform an analysis of the potentialities and limitations associated to the application of sustainability indicators in general, and the WSI in particular.

2 Methodology

Area of Study

The Elqui river basin is located in North-Central Chile. It extends between 29º27'- 30º34'S and 71º22'-69º52' W, covering an area of 9,700 km^2 (Fig. 1). It includes three sub-watersheds: Turbio River (4,200 km^2), Claro River (1,550 km^2), and Elqui River (3,950 km^2) (Oyarzun, *et al.*, 2006). The whole hydrological system extends between the Andean mountains and the Pacific Ocean over a length of only 150 km. Thus, the watershed presents extreme altitude differences between its headwaters and its discharge point to the sea (i.e., about 5,000 m), which favours the existence of turbulent river flows.

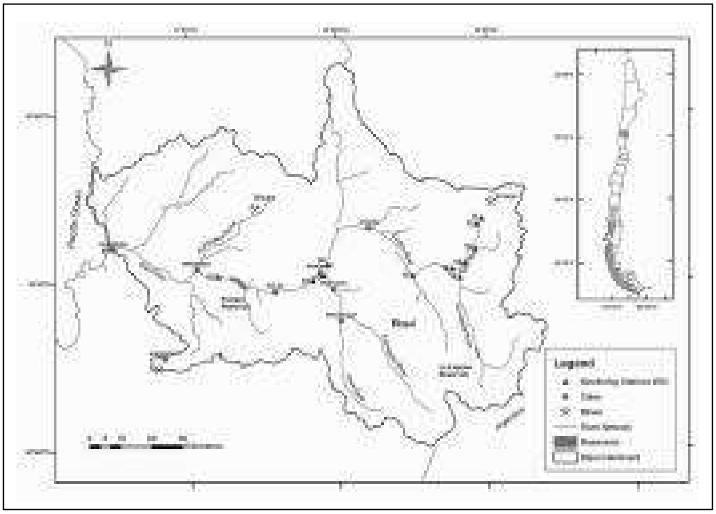


Fig. 1 The Elqui river basin with main tributaries, cities, mining districts and water monitoring stations.

The WSI

The Watershed Sustainability Index (WSI) is described in detail in Chaves and Alipaz (2007) and UNESCO (2008). Thus, to save space, only the key aspects of the index, as well as some modifications performed during the process of its determination for the Elqui river basin, are covered here.

The WSI is an integrated basin indicator, used to estimate the sustainability condition of a given basin, taking into account hydrological, environmental, and socioeconomic aspects (Chaves and Alipaz, 2007; UNESCO 2008):

$$WSI = (H + E + L + P)/4 \qquad (1)$$

where *WSI* (0-1) is the watershed sustainability index; *H* (0 -1) is the hydrology sub-indicator; *E* (0 -1) is the environment sub-indicator; *L* (0-1) is the life (human) sub-indicator; and *P* (0-1) is the policy sub-indicator. All sub-indicators have the same weight, since their relative importance cannot be established a priori (Chaves and Alipaz, 2007).

Each one of the four WSI sub-indicators (H-E-L-P) is determined from information that represents current status of Pressure (i.e., human activities that cause or can provoke problems in the environment; thus, Pressure components describe pollutant emission and natural resources use); State (i.e., situation of different aspects of the environment at a given moment; the State also depends on the natural conditions, the pressures over the system, and the protection actions taken); and Response (Response components relate to the efforts of the society and managers to address environmental problems and reclaim impaired systems). This follows a dynamic model established by the OECD. The advantage of using a Pressure-State-Response approach lies in the fact that it takes into account cause-effect aspects, allowing different stakeholders, managers, and decision makers to notice and understand the interconnections between the parameters (OECD, 2003).

Each one of the quantitative and qualitative components is divided in levels and scores (i.e., 0, 0.25, 0.50, 0.75 and 1; 0 is assigned to the worst condition, whereas 1 represents the best status), allowing the use of simple spreadsheets instead of equations or other complex functions for the purpose of the WSI calculation (Chaves and Alipaz, 2007). The detailed information about the different components, their levels and scores, are defined in Tables 1, 2, and 3.

Table 1 Description of WSI Pressure parameters, levels, and scores (from Chaves and Alipaz, 2007).

Sub-Indicator	Pressure components	Level	Score
Hydrology	_1-variation in the basin per capita water availability in the period studied, relative to the long-term average (m3/person year)	_1<_20%	0.00
		_20%<_1<_10%	0.25
		_10%<_1<0%	0.50
		0<_1<+10%	0.75
	_2-variation in the basin BOD5 in the period studied, relative to the long-term average	_2>20%	0.00
		20%>_2>10%	0.25
		0<_2<10%	0.50
		_10%<_2<0%	0.75
		_2<_10%	1.00
Environment	Basin E.P.I. (rural and urban) in the period studied	EPI>20%	0.00
		20%<EPI>10%	0.25
		10%<EPI<5%	0.50
		5%<EPI<0%	0.75
		EPI<0%	1.00
Life	Variation in the basin per capita HDI-Income in the period studied, relative to the previous period.	_<_20%	0.00
		_20%<_<_10%	0.25
		_10%<_<0%	0.50
		0<_<+10%	0.75
		_>+10%	1.00
Policy	Variation in the basin HDI-Education in the period studied, relative to the previous period	_<_20%	0.00
		_20%<_<_10%	0.25
		_10%<_<0%	0.50
		0<_<+10%	0.75
		_>+10%	1.00

Table 2 Description of WSI State parameters, levels, and scores (from Chaves and Alipaz, 2007).

Sub-Indicator	State components	Level	Score
Hydrology	Basin per capita water availability (m3/person year), considering both surface and groundwater sources	Wa<1,700	0.00
		1,700<Wa<3,400	0.25
		3,400<Wa<5,100	0.50
		5,100<Wa<6,800	0.75
		Wa>6,800	1.00
	Basin averaged long term BOD5 (mg/l)	BOD>10	0.00
		10<BOD<5	0.25
		5<BOD<3	0.50
		3<BOD<1	0.75
		BOD<1	1.00
Environment	Percent of basin area under natural vegetation (Av)	Av<5	0.00
		5<Av<10	0.25
		10<Av<25	0.50
		25<Av<40	0.75
		Av>40	1.00
Life	Basin HDI (weighed by county population)	HDI<0.5	0.00
		0.5<HDI<0,6	0.25
		0.6<HDI<0.75	0.50
		0.75<HDI<0.9	0.75
		HDI>0.9	1.00
Policy	Basin institutional capacity in IWRM (legal and organizational)	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00

Table 3 Description of WSI Response parameters, levels, and scores (from Chaves and Alipaz, 2007).

Sub-Indicator	State components	Level	Score
Hydrology	Improvement in water-use efficiency in the basin, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
	Improvement in adequate sewage treatment/disposal in the basin, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
Environment	Evolution in basin conservation areas (Protected areas and BMPs) in the basin, in the period studied	_<_10%	0.00
		_10%<_<0%	0.25
		0<_<+10%	0.50
		+10%>_>+20%	0.75
		_>20%	1.00
Life	Evolution in the basin HDI in the basin, in the period studied	_<_10%	0.00
		_10%<_<0%	0.25
		0<_<+10%	0.50
		+10%>_>+20%	0.75
		_>20%	1.00
Policy	Evolution in the basin's WRM expenditures in the basin, in the period studied	_<_10%	0.00
		_10%<_<0%	0.25
		0<_<+10%	0.50
		+10%>_>+20%	0.75
		_>20%	1.00

Data Gathering

The information required to determine the WSI for the Elqui river basin was obtained from several sources, such as available technical reports and public information, as well as through informal interviews with professionals and authorities from both public and private organizations and institutions in the Coquimbo Region. For further details, the reader is referred to Cortés (2010).

WSI Adaptations

With respect to the WSI methodology described in Chaves and Alipaz (2007) some modifications were made in its application to the Elqui basin. These are detailed as follows:

a. Spatial extension of the unit of analysis: Although the original methodology suggests a maximum basin area of 2,500 km^2 for the application of the WSI, and in the case of larger basins their subdivision, the WSI was determined for the Elqui basin as a whole. This was done given the fact that, although there was some information at the municipality level, this administrative subdivision does not necessarily coincide with the sub-basin. Thus, it was decided to aggregate the information at the Province scale given the fact that, at least in the Elqui basin, their boundaries are more coincident between each other.

b. Water quality parameter: Since the WSI methodology allows for the substitution of BOD5, originally considered in Chaves and Alipaz (2007), for other critical water quality parameter, the Electric Conductivity (EC) was chosen instead. Although this parameter does not specifically give us information on the particular ions in the water, it could be of great help detecting possible environmental impacts derived from mining or agriculture in the basin. Thus, the thresholds that were applied are those described in the Chilean water quality regulation, NCh 1333 (INN, 1987), and in the World Health Organization water quality regulation (WHO, 2008). From this, the levels and ranges were defined for the State component (Table 4).

Table 4 Hydrology-quality State parameter, levels and scores considered in this study.

Component	Parameter	Level	Score
Water quality	Long term EC basin average (mmhos/cm)	EC> 2,250	0.0
		2,250> EC > 1,600	0.25
		1,600> EC > 750	0.50
		750> EC > 600	0.75
		600 > EC	1.00

c. Environment-Response component: this element considers the evolution in protected areas, but it was not possible to be determined in the case study, provided that there are no protected areas in the Elqui basin. However, there is a Governmental Program oriented towards the reclamation of degraded and/or eroded soils (*Sistema de Incentivos para la Recuperacion de Suelos Degradados,* SIRSD-*Sustentable*), which was considered as a suitable alternative for the Environmental Response parameter determination.

Validation Workshop with Stakeholders' Participation

After the initial data gathering, systematization and analysis, a socialization and validation workshop of both the WSI methodology and the preliminary results was held with different stakeholders. This activity was especially useful for determining those qualitative aspects the WSI.

3 Results

The WSI is simply the global average of the four (H-E-L-P) sub-indicators. Applying Eq. 1, an overall WSI score of 0.60 was obtained for the Elqui River basin. Table 5 presents the levels, scores and the overall WSI for the Elqui watershed.

Using a similar ranking as the UNDP's HDI (i.e., low for HDI < 0.5, intermediate for HDI between 0.5 and 0.8, and high for HDI > 0.8) (Chaves and Alipaz, 2007), the WSI obtained for the Elqui watershed falls in an intermediate level. Additionally, according to Table 5, the sub-indicator with the lowest score was Hydrology (0.5), whereas the sub-indicators with the highest scores were Environment and Policy (0.67).

In terms of the overall Pressure, State and Response columns, the lowest score was obtained for Pressure (0.53), and the highest for State (0.66). This indicates that although the current basin conditions (State) are moderately good, there are still pressures not related to a specific factor, which threaten the basin's sustainability.

Table 5 Levels and values for the parameters and the Elqui basin WSI.

	Pressure		State		Response		Result
	Level (%)	Score	Level	Score	Level	Score	
Hydrology	-3.37	*0. 5*	2,766	***0.25***	Medium	*0.5*	
	-0.10	0.75	1,525	*0.50*	Medium	*0.5*	
		0.63		0.38		*0.5*	0.50
Environment	7.0	*0.5*	0.72	1.00	0.1%	*0.5*	0.67
Life	-1.3	*0.5*	0.76	0.75	0.52	*0.5*	0.58
Policy	-7.34	*0.5*	Medium	*0.50*	>20%	1.00	0.67
Result		0.53		0.66		0.63	0.60

More specifically, the matrix exhibits in italic font those combinations of subcomponents and parameters considered as "bottlenecks", and in italic and bold font the one (Hydrology State) that represents an "alert". Water users, stakeholders, and decision makers should address these aspects specifically in order to improve the overall watershed sustainability in the mid term. It can be seen that a major "bottleneck" relates to the quantity of water available in the basin. This fact is not surprising for basins in arid or semiarid areas, where there is strong demand for scarce water resources.

4 Conclusions

A Watershed Sustainability Index of 0.6 was obtained for the Elqui river basin for the period 2001-2005, which can be considered as an intermediate sustainability level. The WSI tool is a useful, simple, and adaptable instrument to assess the current state of sustainability of a watershed, and is suitable to support decision-making processes toward integrated and environmentally oriented watershed management. The identification of bottlenecks and alerts becomes a window of opportunity to improve the current situation of the basin, seeking a more efficient coordination between the different institutions related to the management of natural resources.

The WSI is a holistic index, of great potential for environmental management purposes, given the fact that it incorporates social, economic, and environmental factors into the sustainability analysis. Indeed, it can be said that this tool, provided it is applied regularly (e.g., every 5 years), can be a suitable description of the evolution of a basin's condition in terms of its sustainability, helping different stakeholders and water managers in the planning, decision-making and implementation of local strategies for sustainable development. Moreover, it should be used as a reference tool in other basins of the Coquimbo Region, as well as in other parts of the country or in other countries looking for the definition and enforcement of watershed management plans and performance verification mechanisms and indices.

REFERENCES

Chaves, H.M.L. and Alipaz, S. (2007) An integrated indicator based on basin hydrology, environment, life, and policy: The watershed sustainability index. *Water Resources Management* 21: 883-895.

Cortés, A.E. (2010) *Determinación de un índice de sustentabilidad de cuencas (WSI) para la cuenca hidrográfica del rio Elqui* (Cuenca HELP-UNECO). M.Sc. Thesis, Universidad Católica del Norte, Coquimbo, Chile.

(INN) Instituto Nacional de Normalización. (1987) *Norma Chilena Oficial: Requisitos de Calidad de Agua para Diferentes Usos* (NCh133.Of78). Santiago, Chile.

(OECD) Organization for Economic Cooperation and Development. (2003) *OECD Environmental Indicators: Development, Measurement and Use*. Paris, France.

Oyarzun, R., Guevara, S., Oyarzún, J., Lillo, J., Maturana, H. and Higueras, P. (2006) The As-contaminated Elqui river basin: a long lasting perspective (1975-1995) covering the initiation and development of Au-Cu-As mining in the high Andes of northern Chile. *Environmental Geochemistry and Health*. DOI 10.1007/s10653-006-9045-1.

UNESCO. (2008) *Evaluación objetiva de la aplicación y cálculo del Índice de Sostenibilidad de Cuenca en la Cuenca Hidrográfica del Canal de Panamá*. Documentos Técnicos del PHI-LAC, Nº 12.

WHO. (2008) *Guidelines for Drinking Water Quality*. World Health Organization. Available at: http://www.who.int/water_sanitation_health/dwq. Accessed December 22nd 2008.

[1] The Province is an intermediate administrative division in Chile, between the Region and the Municipalities.

Correlation Analysis of Groundwater Evolution and Land Subsidence in the Beijing Plain, China

CHEN BEIBEI[1, 2, 3], GONG HUILI[1, 2, 3], LI XIAOJUAN[1, 2, 3], LEI KUNCHAO[1, 4], LI JIWEI[1, 2, 3] & DANG YANAN[1, 2, 3]

1 *Base of the State Key Laboratory of Urban Environmental Process and Digital Modeling, Capital Normal University, Beijing, China*

2 *Key Laboratory of 3D Information Acquisition and Application, Ministry of Education, Capital Normal University, Beijing, China*

3 *College of Resources, Environment, and Tourism, Capital Normal University, Beijing, China*

4 *Beijing Institute of Hydrogeology and Engineering Geology, Beijing, China*

Abstract Due to the long-term overexploitation of groundwater in Beijing's plain areas, regional groundwater depression funnels have been formed and land subsidence induced. By combining groundwater monitoring networks, GPS monitoring network data, radar satellite SAR data, GIS, and other new technologies, a coupling process model based on dynamic variation of groundwater and deformation response of land subsidence was established in this study, where dynamic variation of groundwater funnels in Beijing areas were analyzed systematically, as well as the land subsidence response process. Studies indicate that the current groundwater funnel areas are mainly distributed in Tianzhu, Shunyi District, and northeast of the Chaoyang District, with an average decline rate of groundwater level of 2.66 m/a, and a maximum decline rate of water level of up to 3.82 m/a in funnel's center. Seasonal and inter-annual differences existed in the response model of land subsidence to groundwater funnel, with uneven spatial and temporal distribution, where the maximum land subsidence rate was about 41.0776 mm/a, and the area with a subsidence rate greater than 30 mm/a was about 1637.29 km^2. It was revealed that a consistency exists between the groundwater funnels and the spatial distribution characteristics of land subsidence, but not entirely. The research results showed that it is more beneficial to reveal the response model of land subsidence to dynamic variation of groundwater by combining conventional technologies with InSAR, GIS, GPS, and other new technologies, providing a new technology for environmental and hydrogeological research, and a scientific basis for regional land subsidence control.

Key words Land subsidence; groundwater depression funnel; overexploitation of groundwater; InSAR; deformation response

1 Introduction

Land subsidence is a non-compensable permanent environmental and resource loss, and a regional geological disaster caused by the failure in geological environment system as well, upon which a series of other environmental disasters can be induced to form disaster chains. The results of many studies indicate that overexploitation of groundwater is the main reason for regional land subsidence (Poland, 1984; Chen, 2000; Xue, 2003). Gelt (1992) believes that long-term and large-scale overexploitation of groundwater is the main cause of land subsidence, resulting in the significant decline of groundwater level, pore water level of aquitards and aquifers, and stress transfer leading to deformation of clay compaction, so as to cause land subsidence. At present, some new progress has been made in numerical model and monitoring technologies of land subsidence. Through research on the relationship between the overexploitation of groundwater and the deformation of aquitards and aquifers caused by aquifer level variations, the laws and development trends of land subsidence were studied and predicted. Based on land subsidence monitoring networks composed of bedrock, stratified, and ground benchmarks, land subsidence monitoring methods were combined with the development of GPS (Global Positioning System) and InSAR technologies, providing new technical methods for land subsidence monitoring and research.

Currently, land subsidence has occurred in 95 cities in China. A series of studies on regional land subsidence monitoring technology and models have been conducted domestically with outstanding practical achievements (Li, *et al*.,2004; Gong, *et al*.,2009), and a more complete monitoring, analysis, and forecasting system has been formed. Beijing is a metropolis with serious water shortage, where the urban per-capita water resource is 248 cubic meters, only equivalent to 1/8 of the national level, and 1/16 of global level. 2/3 of the water supply come from groundwater. The exploitation of groundwater leading to water level decline is a key factor in the formation and development of land subsidence (Jia, *et al*., 2007). Over the years, the groundwater level in Beijing has continued to decline. In the regional subsidence center, the maximum cumulative settlement has reached 1,096 mm, and part of the land surface is still subsiding at an annual rate of 30-60 mm.

2 Method

2.1 Study Area

Beijing is Located between east longitude 115 °25 ‘ - 117 °35’ and north latitude 39 ° 28 ‘ - 41 °05’ (Fig. 1) at the northern part of the North China Plain, which is divided into western mountains, northern mountains and southeastern plains. The seasonal distribution of rainfall is uneven in the study area. Rainfall from June to August is large and concentrated, accounting for 70% of the annual precipitation. From 1999 to 2006, eight consecutive years of drought occurred in Beijing, with little rainfall. The four-year average rainfall was 459.11 mm, equivalent to 84.2% of average annual rainfall in Beijing.

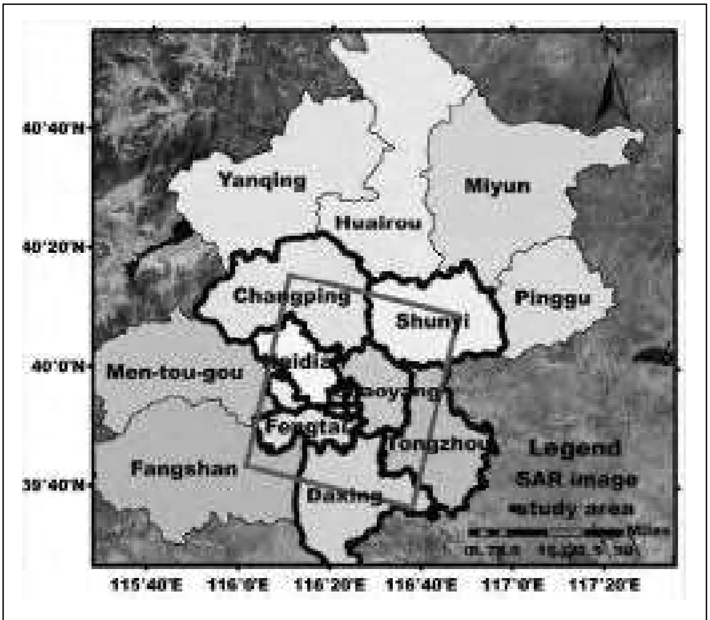


Fig. 1 Location of study area.

2.2 Methodology

Combining routine monitoring, simulation, prediction technologies of groundwater systems, InSAR, GISs and other new technologies, the spatial data field was constructed based on long-term dynamic data of a groundwater observation network. Additional exploration data, GPS monitoring network data, and SAR satellite data were used in this study. Based on the coupling model between dynamic variations of groundwater and deformation response of land subsidence, dynamic variations in Beijing’s groundwater funnels were analyzed systematically, as well as the evolutionary process of land subsidence response (Fig. 2).

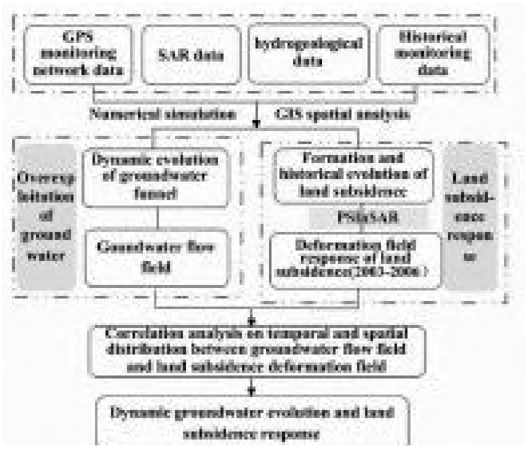


Fig 2 Model framework diagram.

3 Results

3.1 Acquisition of Spatial Information of Land Subsidence Time-Series (2003-2006)

Combined with the transit baseline, archived data, and other factors, the typical time series in the rapid development of Beijing's land subsidence (2003-2006) was obtained, and ASAR and SRTM data were used for interferometric processing with the new PS-InSAR technology (Hooper, A, *et al.*, 2004). Information about land subsidence deformation was acquired for mutual validation and research with historical routine subsidence information, in order to reveal the temporal and spatial development trend of land subsidence in Beijing areas.

According to the analysis on InSAR time-series deformation results, land subsidence in Beijing areas showed such characteristics as seasonal fluctuations (as shown in Fig. 3 - left), where the scopes and amplitudes of land subsidence in autumn and winter were greater than those in spring and summer. For example (as highlighted on Fig. 3 - left), the amplitude and scope of SAR image deformation on Jan 14, 2004 were significantly greater than those on July 7 in the same year. Meanwhile, the research results showed a great difference in the rate of land subsidence in Beijing areas (the positive value in red indicates subsidence in Fig. 3 - right) with a maximum subsidence rate of about 41.0776 mm/a. The subsidence area with a rate greater than 30 mm/a covered 1637.29 km2, and is mainly distributed in the Chaoyang, Shunyi, Changping, and Tongzhou Districts. In addition, InSAR time-series deformation results were relatively consistent with the trend of routine monitoring information on leveling (as highlighted on Fig. 3 - right). InSAR, GIS and other new technologies were used for further revealing the spatial evolutionary trend of land subsidence.

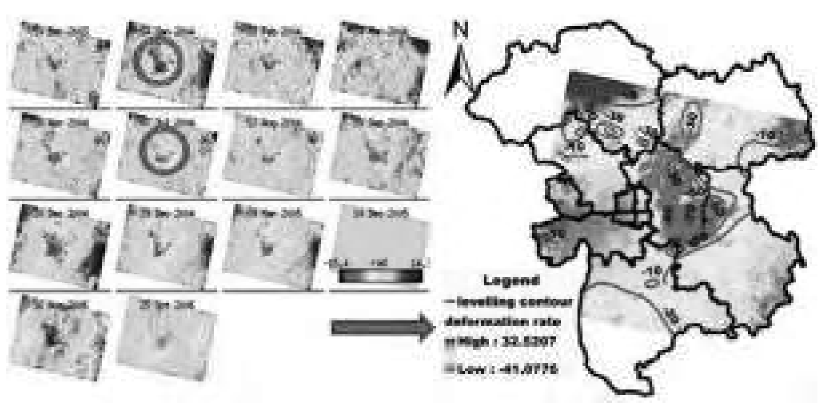


Fig. 3 PS-InSAR land subsidence results in Beijing areas (the left figure shows the deformation value and the right figure shows the deformation rate).

3.2 Correlation Analysis between Land Subsidence and Groundwater

Combined with groundwater level contours (2003-2006) and deformation results extracted by PS-InSAR from 2003 to 2006, the correlation between land subsidence response trends and groundwater flow field was analyzed comprehensively (Fig. 4). It was revealed that serious land subsidence occurred in the areas with greater water depths, mainly in Tianzhu (Shunyi District), the Chaoyang District, and northwestern Tongzhou District, which illustrates good consistency between the variations of groundwater flow field and the response process of land subsidence.

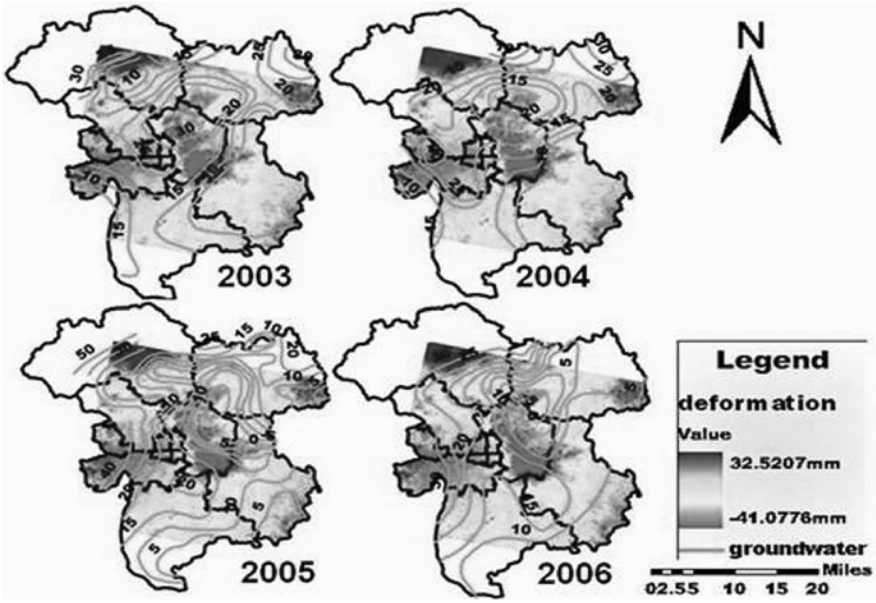


Fig. 4 Groundwater contours and land subsidence.

After a TIN created for groundwater level contours from 2003 to 2006, raster graphics operations were adopted for obtaining dynamic variations of groundwater flow filed in three years (Fig. 5). Moreover, a three-year trend of groundwater level decline was analyzed and combined with the trend of land subsidence for comprehensive spatial analysis. It was also found in the analysis that groundwater funnel location was consistent with the spatial location of land subsidence funnels, but not entirely (Fig. 5). The groundwater depression funnels were mainly distributed in Tianzhu (Shunyi District) and northeast of the Chaoyang District. In recent years, the groundwater level was continued to decline in these areas with a decline average rate of 2.66 m/a, and a maximum decline rate of 3.82 m/a in the funnel center. As viewed from the InSAR time-series land subsidence trend (Fig.4 - right), land subsidence funnels not only occurred to the Tianzhu (Shunyi District) and Chaoyang areas, but also to the Tongzhou District, with a very clear decline trend of subsidence funnel and the maximum subsidence rate found in the study area, of 41.0776 mm/a. It was shown that the groundwater exploitation in the Chaoyang subsidence funnel was reduced in recent years to a certain extent, and the concentrated exploitation areas extend towards northeast suburbs, so that the scope of the Tianzhu-Tongzhou subsidence funnel was expanded continuously.

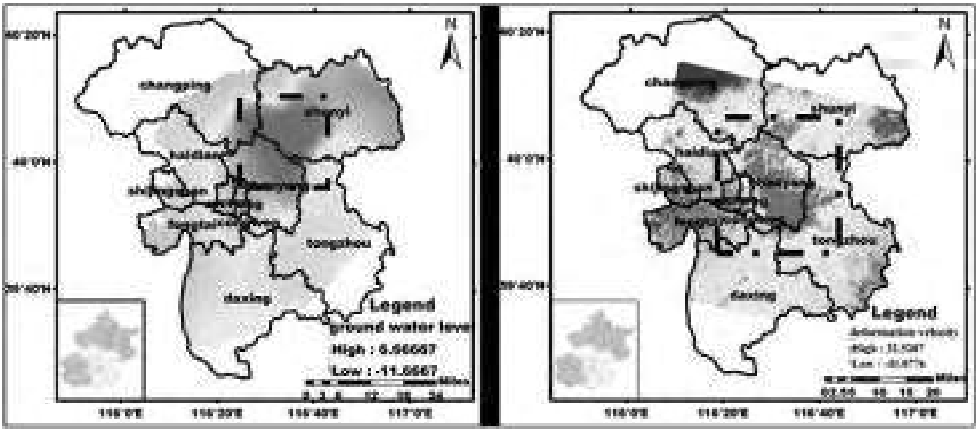


Fig. 5 Groundwater level and land subsidence trend diagrams in the study area (2003-2006).

Affected by regional hydrogeological conditions, thickness of compressible layers, stratum structure, the horizon of groundwater exploitation, and other factors (Jiao and Qiu, 2006; Jia, *et al.*ÅC2007), the groundwater depression funnel can well reflect the regional situation of land subsidence, but it is difficult to describe the spatial distribution

Therefore, compared with the application of numerical simulation technology to land subsidence control (Shi, *et al.*, 2008; Gong, *et al.*, 2000), InSAR technology is more dominant in the acquisition of large-scale and high-precision subsidence information, so as to provide a good data basis for land subsidence control and risk monitoring. Combined with the spatial analysis function of GIS technology (Oh and Lee, 2010), a better understanding was gained on the relationship in temporal and spatial distribution between land subsidence and groundwater level, in order to provide decision support for groundwater exploitation management.

4 Conclusions

By combining groundwater monitoring networks, GPS monitoring network data, radar satellite SAR data, GIS, and other new technologies, the coupling process model based on dynamic variation of groundwater and deformation response of land subsidence was established, so as to reveal the temporal and spatial evolution of groundwater depression funnels in Beijing areas, as well as the spatial response trend of land subsidence a from two-dimensional scale to a three-dimensional scale:

1) Based on routine historical monitoring results in two-dimensional scale and the systematic analysis of the response model of land subsidence to groundwater funnel, emphasis was made on three-dimensional response information of land subsidence deformation fields (2003-2006), acquired by Persistent Scatterers for SAR Interferometry (PSInSAR) technology. The results showed that great seasonal and interannual differences exist in Beijing's land subsidence, with uneven spatial and temporal distribution, and a maximum subsidence rate of about 41.0776 mm/a. The subsidence areas with a rate greater than 30 mm/a cover 1,637.29 km2, and show a trend of eastward movement.

2) From the comparative analysis on InSAR deformation response information of land subsidence with the evolution of interannual groundwater flow field, it was revealed that the groundwater funnel was consistent with the spatial distribution characteristics of land subsidence funnels, but not entirely. It was proven that although the occurrence of land subsidence in Beijing was mainly due to the exploitation of groundwater, the development of areas of subsidence was also correlated to hydrogeological conditions, stratum structures, and so on. It is required to carry out further in depth studies on these issues.

Acknowledgments
We thank Andy Hooper for supporting us regarding technical information about StamPS and data processing. The Research has been funded by the Program of International S&T Cooperation (No. 2010DFA92400), the Non-profit Industry Financial Program of MWR (No. 200901091), and the Natural Science Foundation of Beijing (No. 8101002).

REFERENCES

Beijing Bureau of Geology and Mineral Exploration and Development, Hydrogeology and Engineering Geology Team in Beijing. (2008) *Ground water in Beijing.* Land Press of China.

Chen chongxi. (2000) Thinking on land subsidence caused by groundwater exploitation. *Hydrogeology And Engineering Geology* 1: 45-60.

Gelt J. (1992) Land subsidence, earth fissures, change Arizona's landscape. *Arroyo* 6 (2): 7-15.

Gong Huili, Li Menlou, Hu Xinli. (2000) Management of Groundwater Resources in Zhengzhou City, China. *Water Research* 34 (1): 57-62.

Gong Huili, Zhang Youquan, Li Xiaojuan, *et al.* (2009) The Research of Land subsidence in Beijing Based on Permanent Scatterers interferometric synthetic aperture radar (PS-InSAR) technique. *Progress in Natural Science* 19 (11): 1261-1266.

Hooper. A, Zebker. H, Segall. P, *et al*. (2004) A new method for measuring information on volcanoes and other natural terrains using insar persistent scatterers. *Geophys Re Lett* 31 (23): 5.

Jia Sanman, *et al*. (2007) The Impacts of Land Subsidence on Urban Construction in Beijing. *Geological Hazards* 2 (4): 19-23.

Jia Sanman, Wang Haigang, Zhao Shousheng, *et al*. (2007) A Tentative Study of the Mechanism of Land Subsidence in Beijing. *City Geology* 2 (1): 20-26.

Jiao Qing, Qiu Zehua. (2006) Research Progress of Major Active Faults in Beijing Plain Area. *Institute of Crustal Dynamics, CEA* 18: 72-84.

Li Deren, liao Mingsheng, Wang Yan. (2004) Progress of Permanent Scatterer Interferometry. *Editorial Board of Geomatics and Information Science of Wuhan University* 29 (8): 664-668.

Oh H, and Lee S. (2010) Assessment of land subsidence using GIS and the weights-of-evidence model. *Engineering Geology* 115 (1-2): 36-48.

Poland, J. F., ed. (1984) Guidebook to studies of land subsidence due to ground-water withdrawal [J]: Paris, France, UNESCO *Studies and Reports in Hydrology*, 305 p.

Shi X, Wu J, Ye S, Zhang Y, *et al*. (2008) Regional land subsidence simulation in Su-Xi-Chang area and Shanghai City, China. *Engineering Geology* 100 (1-2): 27-42.

Wang Ping. (2004) Study on Land Subsidence Caused by Overexploiting Groundwater in Beijing. *Site Investigation Science and Technology* 5: 46-49.

Xue Yuqun, Zhang Yun, Ye Shujun, Li Qinfen. (2003) Land subsidence in china and its problems. *Quaternary Sciences* 23 (6): 585-593.

New Information Technologies for Sustainable Water Management A Solution to Cope with Global Changes?

BEATRICE MOSELLO
Graduate Institute of International and Development Studies, Geneva, Switzerland
beatrice.mosello@graduateinstitute.ch

Abstract New information technologies have clearly influenced policy and decision-making strategies in a number of different areas and for all actors at the international, regional, national, and local level. This becomes particularly true with regards to environmental issues, where the capacity to act and adapt in an effective manner depends precisely on the quality and credibility of salient information. Along these lines, we will analyse the ways in which new information technologies today serve decision support systems in the area of integrated river management, thereby merging river ecosystems and hydropower requirements, by combining available scientific tools with local specificities and operational requirements. More specifically, we will consider the case of the Aosta Valley, a typical alpine region where issues linked to the sustainable production and usage of hydropower present difficult, and yet unavoidable, challenges for local decision-makers dealing with water resources. There, the Sustainable Hydropower in Alpine River Ecosystems (SHARE) project has been run for the past three years in order to produce software, online tools, and a set of generally applicable and comparable indicators and monitoring standards to best inform decision-makers on how to effectively manage water resources -also in view of the impacts of prospected climatic changes. Our analysis lead to the conclusion that new technologies can positively inform decision and policy-making over water resources and other environmental-related issues, in such a way as to guarantee their adaptive capacity *vis-à-vis* climatic and socio-economic changes. In addition, they contribute to the formation of partnerships and networks among stakeholders that span across different levels of action, thereby increasing participation and cooperation towards a common goal.

Satellite Monitoring of Lake Atitlan in Guatemala

BETZY HERNANDEZ[1], AFRICA FLORES[2], BESSY GARCIA[1], ANTONIO CLEMENTE[1], MIROSLAVA MORÁN[1], EMIL CHERRINGTON[1], MARCELO OYUELA[1], OCTAVIO SMITH[1] & JOSÉ MARIA GUARDIA[1]

1 *Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC), City of Knowledge, Panama*
betzy.hernandez@cathalac.org

2 *Department of Atmospheric Sciences, University of Alabama in Huntsville, USA*

Abstract Intensive use of the Lake Atitlan watershed in Guatemala has led to alarming levels of pollution. In October 2009, a massive bloom of phytoplankton in the lake motivated the Guatemalan Ministry of Environment (MARN, in Spanish) to approach the Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC) seeking technical advice. In response to the MARN's request, and in the context of the Regional Visualization & Monitoring System (SERVIR), a joint effort between CATHALAC, NASA, USAID, and other partners, the ALI, ASTER, and Hyperion sensors were tasked with monitoring the Lake. As a consequence, analyses using satellite imagery obtained by these sensors were developed regularly between October and December 2009, and shared with the MARN (and with the general public via www.servir.net). According to the data, initially, the bloom covered some 617 hectares, equivalent to 5% of the Lake's surface; peak contamination was observed on November 22, when some 38% of the Lake's surface was covered. Following that, the bloom gradually decreased, virtually disappearing by December of that same year. In addition to satellite monitoring of Lake Atitlan itself, analysis of the basin draining to the Lake was also conducted, allowing for identification of areas highly susceptible to erosion by rainfall. Sediment discharge was evident mainly in the Panajachel and Quiscab Rivers. Remote sensing techniques also showed a slight overall decrease of the Lake's surface by 2.92 km^2 during the dry season over a period of twenty-one years, likely due to landslides that occurred during storm events, such as 2005's Hurricane Stan. Support provided by CATHALAC to Guatemala also included training representatives from the MARN and the Lake's management authority in remote sensing techniques for environmental monitoring. The information generated is being utilized in the Lake's rehabilitation, and to keep the general public informed about what is occurring in this significant resource.

Key words Cyanobacteria; chlorophyll; monitoring; remote sensing; satellite; Atitlan; Guatemala

1 Introduction

Lake Atitlan is located in the Department of Solola, west of the Guatemalan capital, Guatemala City. It is located in an ancient volcanic caldera, bound by deep cliffs to the north and east, and by three volcanoes to the southwest. The Lake sits in a 541 km^2 endorheic drainage basin or watershed -meaning it lacks a surface water outlet. Those same endorheic characteristics accentuate the concentration of pollutants, sediments and other eroded materials, which accumulate in the lake. The management of lands within the watershed is therefore critical to the Lake's health.

Lake Atitlan also constitutes an important natural resource for tourism in Guatemala; populations totaling more than 200,000 surround it. For years, human activity within the Lake's basin has been negatively impacting the Lake's functions. Some of the most significant impacts are due to nearby municipalities dumping untreated sewage directly into the Lake.

Intensive agriculture has also led to erosion, sediment transfer, and even decreased water infiltration into underground aquifers (Kogio, 1995). Kogio (1995) also notes that the percent of such infiltration in the Central Plateau has declined due to land use change, since most of the catchment area has been used for agricultural purposes.

Pressures exerted on the lake and its watershed have caused levels of deteriorated water quality, which in turn have come to alarm the Government's Ministry of Environment and Natural Resources (MARN, in Spanish). In late 2009, a massive phytoplankton bloom motivated the MARN to approach the Water Center for the Humid Tropic of Latin America and the Caribbean (CATHALAC), seeking technical support to analyze the pollution problem in the lake and to generate constant satellite monitoring for this strategic Guatemalan resource.

2 Study Objective

To provide technical support to Guatemala's Ministry of Environment and Natural Resources regarding the degree of contamination in Lake Atitlan, via satellite-based monitoring on the Lake's water quality.

3 Methodology

Analysis of the Chlorophyll Level in the Lake

In the context of the Regional Visualization and Monitoring System (SERVIR), and in response to the request from the MARN, CATHALAC initiated the process of satellite-based monitoring of Lake Atitlan in October 2009. This monitoring was facilitated by the constant acquisition of imagery from the Advanced Land Imager (ALI), ASTER, Enhanced Thematic Mapper+ (ETM+), and Hyperion sensors, to study the phytoplankton blooms. This imagery allowed for an analysis of the behavior and progression of pollution in the lake's surface, via remote sensing techniques based primarily on the detection of the chlorophyll being produced by Cyanobacteria during photosynthesis. The ASTER imagery also permitted studying photosynthetic activity via heat emitted by chlorophyll.

While detection of high aquatic chlorophyll concentrations might indicate the presence of algae, bacteria, zooplankton, or fungi, early field work indicated the presence of cyanobacteria specifically. The identification of the specific type of cyanobacteria is the subject of ongoing analysis and field work. During the blooms, CATHALAC's analyses were supplemented by on-the-ground work conducted by the Universidad del Valle de Guatemala and the University of California-Davis (Rejmánková, *et al*., 2011, in press). The joint effort between the three organizations was successful in providing information on the magnitude of the affected area. For Guatemala, this was the first type of analysis that employed satellite imagery to detect pollution in water bodies.

It should be noted that the techniques used to estimate chlorophyll in Lake Atitlan are based on the optical characteristics of this pigment. The measurement of chlorophyll concentration is usually used to estimate the amount of algae in surface waters.

High concentrations of algae can cause low dissolved oxygen levels, which can contribute to the Lake's eutrophication. The presence of chlorophyll in the water changes its normal reflectance as illustrated in Fig. 1. The reflectance of water bodies loaded with algae significantly increases in a different wavelength as opposed to water without algae.

The increase in the amount of chlorophyll is associated with the decrease in the relative amount of energy in the blue part of the electromagnetic spectrum (0.45 to 0.52 μm) and increase in the green part of the spectrum (0.52 to 0.60 μm) (Gitelson, 1992; Han, 1997).

Different indices are used to identify chlorophyll in the water, for example, and according to Jensen (2007), low concentrations of chlorophyll can be identified through the 'simple ratio,' a fraction derived by dividing the near-infrared part of the electromagnetic spectrum by the red part of the spectrum: near-infrared (705 nm) / Red (670 nm).

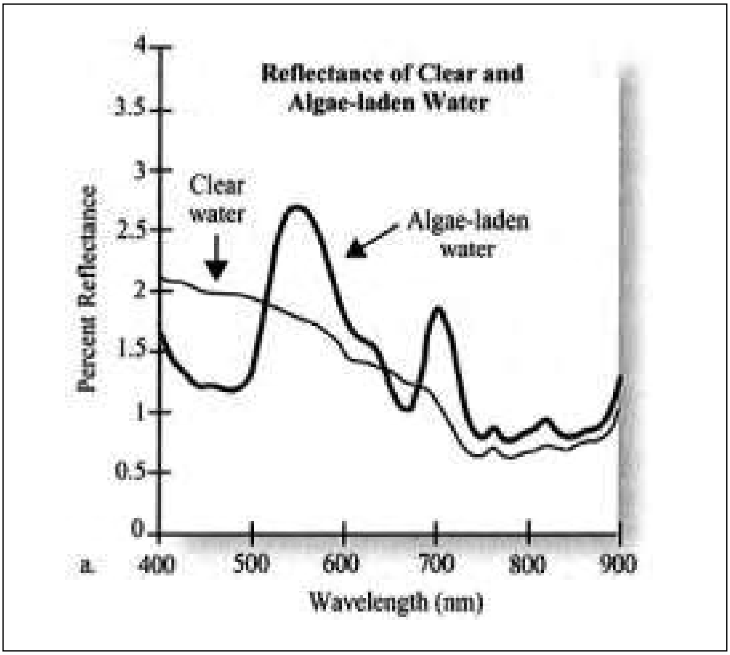


Fig. 1 Percent reflectance of clear and algae-laden water with spectroradiometer based on *in situ* measurements.
Source: Jensen, 2007.

According to the same author (Jensen, 2007) high chlorophyll concentrations show more reflection at 690-700 nm (the red part of the spectrum). Another index used often to identify chlorophyll is the Normalized Difference Vegetation Index (NDVI). The NDVI technique is based on the fact that chlorophyll absorbs energy in the red band or red portion of the spectrum, while the mesophyll structure of the plant shows dispersion in the infrared spectrum (Myneni, *et al*., 1995; Pettorelli, 2005). The formula for NDVI is: NDVI = [NIR-RED] / [NIR + RED], where NIR = near-infrared light; RED = red light. The analyses provided to the MARN were based on the use of NDVI to detect chlorophyll presence, although the rapid nature of the analyses did not allow for field validation.

Estimation of Sediment Concentrations

As in the case of chlorophyll, sediments can be identified through remote sensing. Monitoring of the erosive processes which generates sediments is crucial because the accumulation of sediments in bodies of water contributes to their eutrophication, among other effects. Sediments also bring with them pesticides, phosphorus, nitrogen, and organic compounds. As in the case of chlorophyll, it is difficult to identify quantitative sediment concentrations using only remote sensing, but it is possible to identify their points of discharge and determine the general dispersion of sediment plumes.

According to Jensen (2007), the reflectance characteristic of sediments in water show higher values in the wavelengths of the visible bands. Several studies support the theory for determination of sediments through merely the visible parts of the electromagnetic spectrum that can be studied using satellite imagery. Miller & McKee (2004) for example, noted that the red spectral channel of the Moderate Resolution Imaging Spectroradiometer (MODIS) allowed for a fairly robust linear correlation (R2 = 0.89) with respect to *in situ* measurements of total suspended solids (i.e., sediments).

Analysis of Changes in the Lake Atitlan Watershed

In addition to the analysis of pollution in the Lake, changes in land use in the basin were also analyzed. This analysis was performed using high-resolution imagery from Digital Globe Inc.'s WorldView-2 (WV-2) satellite (2010 imagery was provided courtesy of Digital Globe distributor, GeoSolutions Consulting, Inc.), and was compared with 2006 orthophotos from Guatemala's Ministry of Agriculture, Livestock and Nutrition (MAGA, in Spanish). Using remote sensing techniques, areas with high soil exposure, susceptible to erosion into the lake by surface runoff from rainfall, were also identified.

Determination of the Lake's Extent

Change in the Lake's surface area was assessed through comparison of the 2010 WV-2 imagery with 1989 Landsat imagery. Identification of the extent of the body of water *per se*, through remote sensing, as with the other variables, is based on identifying the spectrum that best represents this type of coverage. Water extent was determined using the imagery's near-infrared spectral channels (~850-900 nm), where the most contrast in reflectance between water and land cover can be identified (Rudorff, 2007). Identifying the extent of the lake was important to evaluate temporal changes in water surface area, and thus, estimate trends.

4 Results

Analysis of the Chlorophyll Level in the Lake

Beginning in late October 2009, proliferation of chlorophyll on the surface of Lake Atitlan was analyzed. Initial analysis of the satellite images indicated that the cyanobacteria blooming covered some 617 hectares, equivalent to 5% of the Lake's surface. By mid-November 2009, the bloom covered approx. 4,410 hectares, some 36% of the Lake's surface, and peak contamination was identified on November 22, 2009, when chlorophyll covered approx. 4,753 hectares, or 38% of the Lake's surface. Subsequently, the proliferation gradually decreased, declining to 0% of the Lake's surface by December of that year. Field tests were able to verify that the blooming had been caused mainly by the cyanobacterium *Lyngbya hieronymusii* (Dix, 2009).

Changes in Land Use and Estimation of Sediments

The comparison of satellite images from the lake's watershed managed to show changes over a 21-year period. Relocation of infrastructure, urban expansion, and the expansion of road networks was visible. Remote sensing techniques allowed for the location of areas with high soil exposure, which during rainy seasons are likely to erode, causing sediment and organic material discharge into the lake. This discharge of sediments was mainly evident in the Panajachel and Quiscab Rivers. Analysis of satellite imagery indicates that the Lake's surface diminished by 2.92 km^2 over that 21-year period. This decrease in lake surface area could be due to the intrusion of soil into the lake by the sediment transfer and deposition from rivers, landslides, or possibly also by processes of eutrophication and variations in lake level. For example, in the north of the Lake Atitlan, landslides caused by 2005's Hurricane Stan are known to have diminished part of the Lake's surface.

Capacity Building and Use of the Information

As part of the work conducted, training was given to personnel from the MARN and Lake Atitlan's management authority, to allow them to use satellite imagery for monitoring not only Lake Atitlan, but also other water bodies across the country, using freely available, periodically acquired imagery, such as Landsat and ASTER imagery, which can be provided at no cost in the context of SERVIR. The Guatemalan government, international cooperation agencies, and the national media in Guatemala have used the information generated by CATHALAC to keep the Guatemalan people informed, as well as to initiate the process of rehabilitating Lake Atitlan.

5 Future Research

As an extension of these initiatives, the MARN and CATHALAC have recently signed an agreement with the purpose of developing applied research, education, and technology transfer activities in areas of interest. Additionally, CATHALAC's specialists are currently working to refine the spectral signature of the cyanobacteria, experimenting with hyperspectral sensors, in order to aid future detection of the blooms.

REFERENCES

Aranoff, S. (2005) *Remote Sensing for GIS Managers*. First Edition. ESRI Press. 487 pp.

Dix, M. (2009) *Estudios Ecológicos: El lago de Atitlán, Antes y Ahora*. Presentation, Universidad del Valle de Guatemala. www.savelakeatitlan.org/images/Dix-New%20lago0ct09.pdf.

Gitelson, A.A., (1992) The peak near 700 nm on radiance spectra of algae and water: relationships of its magnitude and position with chlorophyll concentration, *International Journal of Remote Sensing*, 13:3367-3373.

Han, Luoheng. 1997. Spectral Reflectance with Varying Suspended Sediment Concentrations in Clear and Algae-Laden Waters, *Photogrammetric Engineering & Remote Sensing*, Vol. 63, No. 6, pp 701-705.

Jensen, J.R. (2007) *Remote Sensing of the Environment: An Earth Resource Perspective*. Second Edition. Prentice Hall. 592 pp.

Kogyo Kokusai Co. (1995) *Estudio sobre el desarrollo de las aguas subterráneas en el altiplano central de la República de Guatemala*. JICA. INFOM. 390 pp

Miller, R. L. and McKee, B. A. (2004) Using MODIS Terra 250 m imagery to map concentrations of total suspended matter in coastal waters, *Rem. Sens. Environ.* 93: 259-266.

Myneni, R.B. *et al.* (1995) The interpretation of spectral vegetation indexes, *IEEE Trans. Geosci. Rem. Sens*. 33, 481-486.

Pettorelli, N. *et al*. (2005) Using the satellite-derived NDVI to asses ecological responses to environmental change, *Trends in Ecology and Evolution.* Vol. 20 No. 9 p. 504-510.

Rejmánková, E., Komárek, J., Dix, M., Komárková, J., & Girón, N. (2011) Cyanobacterial blooms in Lake Atitlan, Guatemala, *Limnologica - Ecology and Management of Inland Waters*. doi: 10.1016/j.limno.2010.12.003. In press.

Rudorff, CM., Novo, ELM., Galváo, LS.; and Pereira, FILHO, W. (2007) Derivative analysis of hyperspectral data measured at field and orbital level to characterize the composition of optically complex waters in Amazon, *Acta Amazon.*Vol. 37, no.2, p. 269-280.

Lessons Learned on Integrated Micro Watershed Management in the Tacana Volcano Associated Watersheds (Mexico-Guatemala): The Case of Guatemala

CARLOS ROSAL & OTTONIEL RIVERA
UICN Mesoamérica e Iniciativa Caribe
carlos.rosal@iucn.org

Abstract The Tacana watershed straddles in the border between Mexico and Guatemala, with the Tacana Volcano towering in the middle. The area comprises the watersheds of the Suchiate, Coatan, Cahoacan, and Cosalapa Rivers in Mexico, and the Suchiate catchment in Guatemalan territory. Because of their geomorfology, the basins associated to the Tacana Volcano, on the border between Mexico and Guatemala, very easily concentrate rain water, resulting in massive flows with subsequent landslides and floods in the middle and lower sections of the watershed; producing serious impacts to the local, regional, and national economies. In this region, even though there are large extensions of coffee plantations that are becoming organic, in general, in the upper basin poverty is high, especially on the Guatemalan side; where it has been estimated that 53% of the population survive with less than $2.00 a day. The department of San Marcos is one of poorest in Guatemala. According to the study Livelihoods Areas in Guatemala, (FAO-SESAN, 2009), the municipalities of Tacana, Ixchiguán, San Jose Ojetenám, and Sibinal are located in the area of subsistence agriculture, with high and extreme poverty levels. The highlands of the Suchiate and Coatan watersheds are very vulnerable to the effects of climate change. Hurricane Stan, in 2005, devastated the area, exposing its social, economic, and environmental vulnerability. For over six years, IUCN has accumulated experience in the region on the optimization of benefits provided by freshwater, soils, and ecosystems, participatory diagnosis of climate change effects on livelihoods, implementing water and sanitation measures (with other partners) oriented to reduce heath and gastrointestinal illnesses, and techniques to protect aquifer recharge areas and capacity building. Through a comprehensive and strategic process based on existing governance estructures in Guatemala (Development Councils Act), IUCN has achieved the consolidation of 14 micro watersheds councils with the participation of multiple stakeholders, the establishment of a methodology for implementing micro watersheds management plans, and the establishment (in their early stages) of two participatory water management funds. Also, IUCN has interested the Ministry of Agriculture in applying the new agricultural practices with a focus on the micro watersheds, which will result in a new rural development scheme. This new community planning and management model can be replicated in other micro watersheds.

Key words Micro watersheds; micro watershed councils; water governance; ecosystem approach; climate change adaptation

New Ecosystemic and Complex Pedagogy for Water Sustainability

EMILIO A. MESSINA G.
Environmental Division, Panama Canal Authority (ACP), Panama
emessina@pancanal.com

Abstract This article analyzes the state of the global, regional and national environment and acknowledges an environmental crisis expressed in environmental degradation. It also proposes that this crisis is the result of the mechanistic paradigm of science, whose positivist educational model has been insufficient in changing patterns of production and consumption that degrade natural elements. Due to this insufficiency, it is inferred that the environmental crisis is generated by the absence of an approach to manage knowledge in an integrated way, thus producing ecological illiteracy. Ecological illiteracy is defined as the inability of humans to work within the limits of nature, and the expression of the exhaustion of the empirical-analytical paradigm, which promotes linear conceptions of the world. In contrast, we develop an alternative paradigm from the concepts of environmental complexity and ecosystem philosophy, on which the conceptual basis of an ecosystemic education model and a complex hermeneutic court are designed. This model allows for the advancement of knowledge by identifying that the thoughts and values of the complex ecosystem paradigm cannot address the environmental crisis, as long as they are based on the positivist pedagogical models that are reductionist and fragmented; on the other hand, hermeneutic pedagogy is the platform from which it is possible to implement both the thoughts and values of the complex ecosystem paradigm. This new pedagogy will allow us to address the environmental crisis in which humanity is immersed.

Key words Ecosystemic crisis; ecological illiteracy alternative paradigm complexity

Marked by new situations and problems, the world is torn between complex, integrative approaches and factual, demonstrative, and linear philosophies, stating that all cognitive approaches that emphasize the former are considered mechanistic, and those which place their emphasis on the latter are considered holistic.

The environmental crisis is the product of the lack of, or insufficiency of, environmental management, which has been called *ecological illiteracy.* However, this condition does not occur by itself. It is an expression of the exhaustion of an empirical-analytical paradigm that promotes mechanistic and linear conceptions of the world and, furthermore, claims to be part of the problem and the solution at the same time. This imposition as the dominant paradigm has left other concepts that represent alternative paradigms that have the ability to explain, understand, and promote values beyond pure quantification, measurement and verification, such as the ecosystemic-complex, the historical-hermeneutic, and the critical-social one.

This world view is based on assertive values and individual and expansionist ways of thinking. For this reason, the values and philosophy of alternative paradigms, since they are integrationist, holistic and cooperative forms, are strictly excluded. These values and philosophies have the ability to permeate the vision of human development which is based on concepts of economic growth that glorify unsustainable production and consumption models. Evidence of this appears in the so-called ecological footprint indicator, which identifies a depletion and overexploitation of the planet by 30% above its regenerative capacity. This is an expression of conflicting objectives for sustainable human development that strive to create harmony among economic growth, social equality and environmental sustainability, while impeding the identification of human integrity within the web of interactions that sustain, consciously and unconsciously, the world in which it plays a fundamental role.

From this perspective, we understand that everything essential is hidden behind its appearance, and that only through an interdisciplinary approach can we understand the essence of this, which is not directly perceivable. A bias for the mechanical view of the world exists in this perspective; a bias that separates, isolates, and relegates the latticework of which the multiple dimensions of life are constituted, and is described in the narrative of this work under a concept we call ecosystemic. Thus, we are bounded by the fact that ecosystems contain transforming messages about the duties of human societies, which can teach us exemplary lessons on communication, information sharing, limits, flexibility, adaptation, and organization. All of these lessons fall under the holistic conception of life, which is quite absent in the pedagogy of the modern world and in constitutive values. In this regard, human societies, as well as nature societies, are conceived as parallel worlds not having any interconnection or interaction, as proposed in our ecosystemic perspective. Thus, ecosystems can be considered natural schools that teach us integral and conservationist values, incorporating both quality and cooperation, all of which are absent in human systems. On the contrary, in human societies, we find the antithesis of these natural schools of thought is expressed in a modern rationale that incorporates elements of nature within a perverse logic that objects and exploits it beyond limits, and in addition, uses [nature] as a dumping ground for waste generated by this exploitation process. This view produces an increasing depletion of the earth's bio-capacity, where the form of socially organized work promotes production and consumption patters that require an intensive use of natural elements and, therefore, is unsustainable. This rationalization of nature means that *green* is better represented in paper money than in the ecosystem. In this regard, Worster (2004) argued that:

> "Whoever decided that dollar bills should be green had the right instinct. There is a deep, yet easily ignored, connection between the green money in our pocket and the green earth; this connection even exceeds mere color. The dollar bill needs paper, which is to say that it requires trees. Similarly, all our wealth is derived from nature: the forests, land, water, and soil. It is easy to see that these resources are limited and finite. The same should happen with wealth; yet, it seemingly never is unlimited and can be expanded and multiplied by human ingenuity. Somewhere within the dollar bill there is a warning that what you have in your hand is part of a limited land and must be treated with respect" (p.109).

What Worster denotes is simply the expression of the ecosystemic crisis that produces what we call ecological illiteracy. This classification requires us to promptly address the negative values of productive rationality and consumption patterns that promote individualism and a relationship against, instead of with, nature. When Hardin (1968), wrote *The Tragedy of the Commons*, about the freedom and responsibility of people using goods that belong to all, he defined the main dilemma as a situation in which several individuals, motivated only by personal interest and acting independently but rationally, end up destroying a limited, shared resource, the *common good*. It is as saying: "If I do not do it, someone else will."

In the analysis of the whole, have we forgotten that what we do to the pathway, we do to ourselves? This exacerbated hedonism finds support in an order that is set and accepted by the international community, called paradigm. The paradigm underlying the mechanistic world view is called empirical-analytical. This reference in current and historical context is defined as a school of philosophy that states that the only authentic knowledge is scientific knowledge, and that this knowledge can only come from positive affirmation of theories by way of the scientific method.

The positivist view derived from epistemology that arose in France in the early nineteenth century, with the help of French philosopher Auguste Comte (1838) and Britain's John Stuart Mill, and then extended and developed throughout the rest of Europe in the second half of the century. According to this school of thought, all the philosophical and scientific activities must be carried out only in the context of analysis with facts verified by experience. These positivist and neo-positivist conceptions (see Table 1) are characterized by a quantitative, historical, and fragmented knowledge, thus blurring the vital human process. For an obvious reason, in order for a condition to be called knowledge it must be susceptible to measurement, quantification, and verification; otherwise, it will be excluded and marginalized.

Table 1 Contrasts between positivist and neo-positivist conceptions

POSITIVISM	NEO-POSITIVIST
• Methodological monism • The scientific explanation is unique; there is only one scientific method that corresponds to the deductive physical mathematics method • The fundamental explanation is based on general hypothetical laws • Scientific knowledge should be able to predict, control, and dominate nature • It is the so-called the Natural Sciences Method that is opposed to recognizing social science as a science	• Principle of Verification • Only propositions that can be empirically verified through events that give us experience and logic make sense • The reality analysis will only be scientific if it works with the Logical-Mathematical Theory and empirical verification through experimentation • In science everything must be subjected to direct observation and verification by experiment • Much of the knowledge of social science is not science

Source: Specialized University of the Americas. Ph.D. Notes. Panama, 2008.

The empirical-analytical paradigm and its reductionist pedagogy are in crisis. As one of the paradigms of factual sciences today, we recognize their contributions to welfare and human progress. However, evidence reveals its inability to stop the profound imbalances in natural and social systems. On the other hand, its intention and its hegemony have become part of the problem, also capable of converting an asset into a negative -to call the truth a lie, or to make war to achieve peace. With this we cannot ignore the contribution of science to the idea of human progress, but we can agree that instrumental reason and technology distort and dehumanize, with man being the perpetrator and victim at the same time.

From this distorted idea of progress, under which knowledge can be used in various forms, when referring to the use of atomic energy and the start of the so-called *Ecological Era,* Worster (2004) states that the absurdity of the contributions of the science paradigm are unveiled in this quote:

> "When that first nuclear fission bomb exploded and the color of the sky at dawn abruptly changed from pale blue to reaper white, physicist and project leader Robert Oppenheimer first felt a heightened reverence, which then gave way to a bleak phrase from the Bhagavad-Gita: I have become death" (p.7).

A common misconception is that it is not possible to continue to think within the same paradigm that promotes breakdown, while at the same time, proposing solutions that do not alter the established order. Its assertive, rational, analytical, reductionist, and linear thought, has resulted in values that we have socially accepted through culture, with its consequent expansion in competitive, quantitative, and domination practices. This set of mentioned axioms find an appropriate setting for reproduction within a society of men in patriarchal cultural contexts that favor them, reward them financially, and give them political power.

Thus, the environmental crisis, which is also a crisis of perception and values (Capra, 1998, p. 26), is the result of a reading of the world that moves at a different pace than our reductionist technical-scientific possibilities, and runs under an expansive, intensive, rational, and instrumental vision of life (deep ecology). The latter is understood not hedonically, but rather under a framework that includes everything.

Environmental sustainability requires incorporating new conceptual basis in order to develop a pedagogical model that allows educating for life and not for the mechanical reproduction of the world. It is a commitment to serving the most sublime of human aspirations; it is an approach that serves the Aristotelian religion: to reunite nature and neighbor. Today is a time of change, to see the future through an integrated approach that allows us to ask new questions of novel problems.

That said, we are committed to the transformation of a pedagogy that allows the assertive, expansionist, and linear vision of the world and the life within it. We are committed to strive for an integrated, conservationist, cooperative, associative, and qualitative pedagogy that permits us to reverse the intensity of ecological damage and to ensure the needs of those who walk the world of tomorrow. We are urged to educate ourselves to be free, not only in the certainty suggested by the dominant scientific paradigm, but in the chaos and uncertainty of the integrated whole.

Finally, we observe that complexity points to fully totalizing and worldly holistic considerations, this being the key to the pedagogical model, while hermeneutics offers an educational platform to convey, express, and communicate such complexity. It also provides a look beyond quantitative models, which gives us the ability to place the subject in other positions from its experience and the experience of others, being less restrictive, monolithic, and more textual. The dimensions of the subject: the corporeal, emotional, intellectual, and experiential, coincide with the comprehensive vision of human development and its multiple dimensions that are also addressed in the thematic content of the study (see Fig. 1).

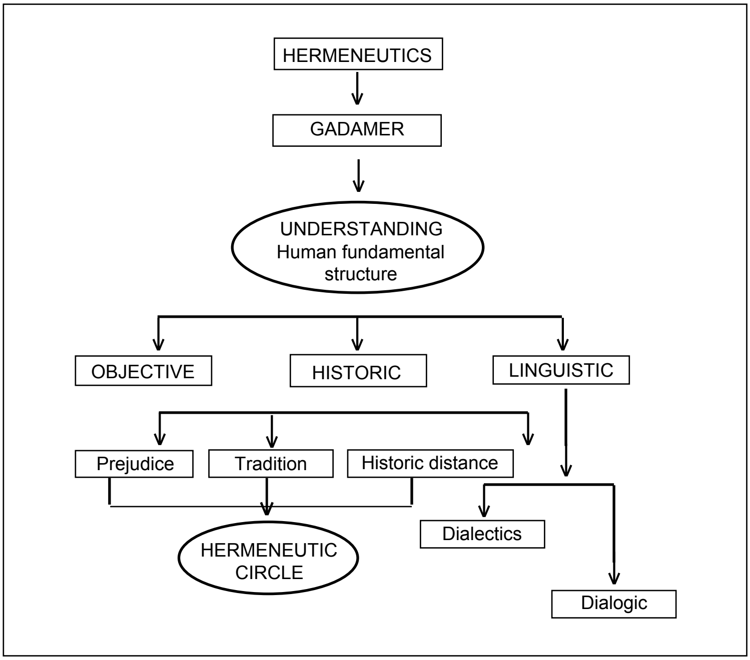


Fig. 1 Hermeneutics Categories.
Source: Prepared by the author (2010) UDELAS.

As stated, we conclude that the environmental crisis is not a natural crisis, but rather, an ecosystemic crisis, and can only be understood as socially and historically determined, i.e., ecosystems today are the result of interactions of the past.

The mechanistic paradigm of science and its pedagogical model are insufficient to limit environmental degradation, ecological footprints, and ecological illiteracy. This paradigm promotes expansionist and intensive axioms or the main driver of unsustainable environmental, ecological footprints and illiteracy. One cannot continue seeking solutions within the same paradigm that produces the consubstantiation problem between pedagogy and science. Alternative models can be built with contributions from ecology, complex thinking, and hermeneutics, which reveal both the instability of the paradigm of science and the ecosystemic principles and relationships in human systems. Due to this contribution we are able to rethink the problem in its complexity and interrelatedness, and thus propose innovative contributions to it, that are synergistic and innovative solutions to complex problems.

The conceptual basis for the design of an ecosystemic pedagogical model and a complex hermeneutical court are the starting points for the transformation required by the global system, the country and the region, and these are the basis for the sustainability of water.

The expression of ecological illiteracy is directly proportional to the crisis of the paradigm: higher illiteracy leads to increased degradation of natural elements. Its tangible empirical context allows us to ask: How much nature is needed to sustain the productivity and efficiency of development models based on economic growth? How much water is needed to sustain current rates of production and consumption? In this sense, a study published in 2010 by researchers from the National Geographic Society promoted some indicators in the context of the submission of water to the productive rationality, and made a warnings about the insufficiency of water by 2050. The indicator called virtual water (Hoekstra, 2002) facilitates the calculation of the water footprint (Aldaya, 2008). From our conceptual approach this reveals that water over-use is also permeated by values that support the idea of "common good", reducing water to just another input in the business chain, whose marginal value is set to a pure market relationship, due to its capacity to generate wealth and prosperity, but not welfare. We find that to produce a kilogram of beef requires 15,947 liters of water; a derived product such as a kilogram of sausage requires 11,535 liters; whereas to produce a kilogram of corn requires 909 liters of water. Considering the above, green markets, without a holistic and integrative axiological conception, represent a threat to water sustainability, if the society continues to think within the paradigm that generates the problem.

The above stated advices society on the need of a new pedagogy that builds on the water axis around which life is sustained. This poses a problem to solve: to construct a new society, through the promotion of natural and human resources, that the existing society squandered five centuries ago; a new society in which we emphasize water as the natural integrating element. We must understand that our greatest assets are our own people, water, and ecosystem biodiversity, which are provided naturally, and that the key area of interaction between these resources consists of watersheds that define the natural structure of a territory. In this sense, a sustainable society must be created by its own citizens. Society must be educated to be democratic and can only be fully educated and democratic if it is equitable. A democratic, educated and fair society can only be sustainable if it is prosperous. Prosperity based on inequality is a sure route to environmental disaster.

Table 2 The new alternative paradigm and integrated management approaches in tackling complex problems.

Problem	Contributions from the alternative paradigm	Integrated Management	Results
Crisis of the paradigm of science that promotes values of modernity of the assertive type and produces ecological illiteracy, which promotes degradation of the elements of nature and environmental unsustainability	**Principles of ecology** Ecological interdependence (networks) The cyclical nature of ecological processes (recycling) Cooperation (partnership rather than competition) Flexibility (networks fluctuating and flexible to changing environmental conditions) Diversity (allows adaptation to changing environmental conditions) **The ecological inter-dependence** ***Economic system***: Relationships with: agriculture, industries, trade, transport, energy, communications, fishing ***Social system:*** Relationships with: education, employment, housing, recreation, community participation, security, trust, freedom, peace, etc. ***Environmental system:*** Relationships with: biodiversity, climate, air, water, natural vegetation, land, seas. ***Hermeneutics:*** Man as a historical and contextual subject	Complexity of the ecosystem approach which supports (i) integrated knowledge management; (ii) integrated management of the territory; (iii) management of production systems and human development, and (iv) integrated management of public policy	Harmonization of the conflicting objectives of sustainable development Control of the driving forces that produce environmental unsustainability Improvement of ecological illiteracy

Source: Messina Emilio. (2011) Doctorate in Education Sciences. UDELAS. Panama, Panama

REFERENCES

Aldaya, Maite. (2008) Water footprint analysis for the Guadiana river basin. *Papeles de Agua Virtual*, No.3. Fundación Marcelino Botín, Universidad Complutense de Madrid (UCM) Departamento de Geodinámica, Spain.

Aguilar V., L.F. (1992) *La hechura de las políticas*, Miguel Ángel Porrúa, Mexico.

Aguilar V., L.F. (1993) *Problemas públicos y agenda de gobierno*, Miguel Ángel Porrúa, Mexico.

ANAM. (2009) *Estrategia Nacional del Ambiente: Gestión ambiental para el desarrollo sostenible 2008-2012.*

ANAM. (2008) *Plan Nacional de Desarrollo Forestal: Modelo de desarrollo sostenible.* Panama.

ANAM. (2009) *Informe del Estado del Ambiente, GEO Panamá.*

ANAM. (2002) *Informe de resultados de la cobertura boscosa y uso del suelo de la República de Panamá, 2003-2008.*

Banco Interamericano de Desarrollo. (2006) *Informe la política de las políticas públicas*. Washington, D.C.

ANAM. (2006) *Indicadores ambientales de la República de Panamá.*

ANAM. (2007) *Política Nacional de Cambio Climático.*

ANAM. (2007) *Política Nacional de Descentralización de la Gestión Ambiental.*

ANAM. (2007) *Política Nacional de Gestión Integral de Residuos no Peligrosos y Peligrosos.*

ANAM. (2007) *Política Nacional de Información Ambiental.*

ANAM. (2007) *Política Nacional de Producción Más Limpia.*

ANAM. (2007) *Política Nacional de Recursos Hídricos.*

ANAM. (2007) *Política Nacional de Supervisión, Control y Fiscalización, Ambiental.*

ANAM-CATHALAC. (2003) *Informe final de resultados de la cobertura boscosa y uso del suelo de la república de Panamá*. Panama.

ANUIES. (1999) *Plan de acción para el desarrollo sustentable en las instituciones de educación superior*. Mexico: Universidad Veracruzana e Instituto tecnológico de Veracruz.

Bernal, Bosco (2001) *Informe Nacional de Desarrollo Humano* (Informe preliminar): Educación y Pobreza. PNUD. Panama. p. 7-9

Capra, Fritjof. *La trama de la vida, una nueva perspectiva de los sistemas vivos*.

Castro Herrera, Guillermo. (2006) A propósito del proyecto de ampliación del Canal de Panamá. El transítsmico contra el tránsito. Published in the weekly bulletin *Peripecias* Nº 2, on July 21st, 2006.

Comisión Económica para América Latina y el Caribe. (2008) *Panamá, Pobreza y Distribución de Ingreso en el periodo 2001 - 2007*. Printed by the United Nations, Chile, August 2008.

Downs, A. (1993) El ciclo de la atención a los problemas sociales, in Aguilar V, L.F., *Problemas públicos y agenda de gobierno*, Miguel Ángel Porrúa, Mexico.

Elizalde, Antonio. (2009) *Reflexiones sobre sustentabilidad, desarrollo y cordura*. Serena (Chile), October 2009.

Gaceta No.22068. (1992) *Ley No. 10. (1992, 1 de julio)*. Asamblea Legislativa. Artículo 1.

Gómez, Desider. (1996) *Desarrollo sustentable amazónico: estudio de las políticas de desarrollo planteadas en el marco del Tratado de Cooperación Amazónica, 1978 y 1972.* Universidad Latinoamericana de Ciencias Sociales, Ecuador.

Hans Gadamer. (2007) *Verdad y Método*. Volume I, page 11. Salamanca.

Hardin, Garret. (1968) The Tragedy of Commons. In: *Science*, v. **162**: 1243-1248.

Hoekstra, A.Y. (editor). (2002) *Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade*, IHE Delft, The Netherlands.

Margalef, Ramón. (1998) *Ecología*, 9ª edición, Omega, Barcelona.

Lahera E. (2004) Política y políticas públicas. Cepal, Chile.

Leff E. (2006) *La Complejidad Ambiental*. Mexico.

Leff, Enrique. (2007) *Globalización, Racionalidad Ambiental y Desarrollo Sustentable.* Nova, Madrid.

Leyton, Fabiola Donoso y colaboradores. (2008) *Éticas Aplicadas y Bioética*. Universidad de Barcelona. Programa de Ética, Política y Racionalidad en la Sociedad Global Ética. Spain.

Lezama, José. (2001) El Medio Ambiente como Construcción Social: Reflexiones sobre la Contaminación del Aire en la Ciudad de México. *Revista Estudios sociológicos*. May-August, 2001/vol. XIX, number 002. Mexico pp.325-338.

PNUMA-ANAM. (2006) *Estrategia Nacional de Biodiversidad, Plan de Acción y Primer Informe sobre el Estado de la Biodiversidad Biológica de Panamá*. Panama.

PNUMA. (2007) *Informe de Síntesis del Grupo Intergubernamental de Expertos sobre el Cambio Climático*. Switzerland.

PNUMA. (1987) *Informe Burtland nuestro futuro común.* UN.

PNUMA. (2010) *Geo Lac 3. Perspectivas del Medio Ambiente: América Latina y el Caribe.*

Reali, Pablo. (2009) Publicación en *Forestal Way*. Uruguay.

Worster, Donald. (2004) Transformaciones de la Tierra. Universidad de Panamá. Colección Agenda del Centenario. Instituto de Estudios Nacionales. Panamá.

Integrated Sustainability Analysis of Six Latin-American HELP Basins

HENRIQUE M. LEITE CHAVES
School of Technology-EFL, Univ. of Brasilia-UnB, Brasilia-DF, Brazil
hchaves@unb.br

Abstract The Watershed Sustainability Index-WSI, a simple and yet robust indicator of basin sustainability, was applied to six Latin American HELP basins, between 1996 and 2007. Basin managers and stakeholders participated in the estimation of the WSI, avoiding eventual biases. The mean WSI for the basins studied was 0.64 out of 1.00, ranging from 0.47 (Antequera basin in Bolivia) to 0.76 (Panama Canal basin, Panama). The WSI's standard deviation was 0.11. Basin sustainability was poorly correlated with watershed socioeconomic condition, but highly correlated with the number of limiting parameters (# of scores ≤ 0.5). In order to improve basin sustainability in the future, managers and stakeholders ought to tackle the causes leading to the limiting parameters. Although the WSI is a screening method to assess basin sustainability, it is a useful tool for achieving sound watershed management, including under future scenarios.

Key words Watershed sustainability; indicators; Latin America; HELP basins

1 Introduction

Aspects that affect basin sustainability include social, economic, and environmental issues. However, they are often treated separately, and not as an integrated, dynamic processes (Viessman, 1990). Additionally, integrated and environmentally sustainable water management requires more than simply carrying out impact assessments. It needs integration of policy formulation, project appraisal, sound water management laws, and institutions, across the breadth and depth of the decision-making process regarding the use of freshwater resources (Smith and Rast, 1998). Furthermore, watershed management becomes effective when the existing "paradigm lock" between science and management is broken (Unesco, 2011).

To incorporate these and other key watershed management issues in one simple and yet robust indicator, Chaves and Alípaz (2007) developed the Watershed Sustainability Index (WSI). The WSI has four indicators which span basin sustainability, evaluating at the same time the basin state, the existing pressures, and the societal responses. The WSI is simply (Chaves and Alípaz, 2007):

$$WSI = (H+E+L+P) / 4 \quad (1)$$

where: WSI (0-1) is the watershed sustainability index; H (0-1) is the hydrologic indicator; E (0-1) is the environment indicator; L (0-1) is the livelihood indicator; and P (0-1) is the policy indicator. Values close to 1.0 indicate high basin sustainability, and vice-versa.

In order to facilitate the estimation of the parameter levels by the users, both the quantitative and qualitative parameters were divided in 5 scale scores (0, 0.25, 0.50, 0.75, and 1.0). This allows for the utilization of spreadsheets instead of equations or other complex functions (Chaves and Alípaz, 2007). The linear and averaging structure in equation 1 is simple and transparent, allowing for error compensation in the indicators and parameters. This is an important issue in model development, but often overlooked by modelers (Chaves and Nearing, 1991).

Since basin management is more effective in watersheds up to 2,500 km^2 (Schueler, 1995), this is the upper limit suggested for the application of the WSI. However, if larger watersheds are to be assessed, they could be divided in sub-basins, and the overall mean can be computed with the individual WSI scores (Chaves and Alípaz, 2007).

Table 1 Indicators and parameters used in the Watershed Sustainability Index.

Indicator	Pressure parameters	State parameters	Response parameters
Hydrology	- Variation in the basin's per capita water availability in the period; - Variation in the basin's BOD5* in the period	- Basin per capita water availability (long term average) - Basin BOD5* (long term average)	**- Improvement in water-use efficiency (5 yrs.); - Improvement in sewage treatment/disposal (5 yrs.)**
Environment	- Basin's EPI (Rural and urban) in the period	- % of basin area with natural vegetation	**- Evolution in basin conservation (% of protected areas, BMPs) in the period**
Livelihood HDI	- Variation in the basin's per capita income in the period	- Basin HDI (weighed by county population)	**- Evolution in the basin's in the period**
Policy	**- Variation in the basin's HDI-Education in the period**	**- Basin's institutional capacity in IWRM**	**- Evolution in the basin's**

* Or another water quality parameter, whichever is the most critical.

WSI values over 0.8 indicate high basin sustainability; values under 0.5 represent low sustainability, and scores between 0.5 and 0.8 represent intermediate sustainability (Chaves and Alípaz, 2007).

The objective of the present paper is to report on the results of the application of the WSI to different Latin-American river basins in the last 15 years, identifying their strengths and weaknesses, and suggesting courses of action to increase their sustainability in the future.

2 Methodology

The Watershed Sustainability Index (Chaves and Alípaz, 2007) has been applied to six Latin-American Unesco/HELP basins, in relatively recent evaluation periods. Whenever possible, the WSI was estimated with the participation of local managers and stakeholders, avoiding eventual biases in its computation. Table 2 lists the basins and the periods analyzed.

Table 2 Watersheds where the WSI was calculated in Latin America.

Watershed	Area (km^2)	Country	Period
São Francisco Verdadeiro	2,200	Brazil	1996-2000
Canal de Panamá	3,000	Panamá	2003-2007
Tacuarembó	16,900	Uruguay	1999-2004
Antequera	226	Bolivia	1997-2001
Elqui	9,826	Chile	2001-2005
Reventazón	3,000	Costa Rica	2001-2005

As seen in Table 2, a wide range of watershed sizes, climates, and socioeconomic conditions were studied. The WSI was applied to each of the six basins, and the overall index, in addition to the parameter combinations which contributed to the decrease of the overall WSI, were estimated.

3 Results

The WSIs for the six studied basins are presented in Tables 3-8 below. The overall WSI is given in the tables' lower right corner, and the limiting parameter combinations, with scores equal to or lower than 0.50, are highlighted.

Table 3 WSI for the S. Francisco Verdadeiro River basin (Brazil).

Indicator	**Pressure**		**State**		**Response**		**Result**
	Level	**Score**	**Level**	**Score**	**Level**	**Score**	
	4.8%	0.75	33,600	1.00	Medium	0.50	
Hydrology	4.6%	0.50	1.3	1.00	Poor	0.25	
		0.63		1.00		0.38	0.67
Environment	11%	0.25	26%	0.75	2%	0.75	0.58
Livelihood	3.4%	0.75	0.81	0.75	5.1%	0.75	0.75
Policy	6.3%	0.75	Poor	0.25	5%	0.75	0.58
Result		0.60		0.70		0.66	**0.65**

Table 4. WSI for the Panama Canal basin (Panama).

Indicator	**Pressure**		**State**		**Response**		**Result**
	Level	**Score**	**Level**	**Score**	**Level**	**Score**	
Hydrology	85%	1.00	32,371	1.00	Good	0.75	
	0%	0.75	0.4	1.00	Good	0.75	
		0.88		1.00		0.75	0.88
Environment	12%	0.25	57.9%	1.00	142.7%	1.00	0.75
Livelihood	1.42%	0.75	0.67	0.50	1.4%	0.50	0.58
Policy	1.45%	0.75	Good	0.75	25%	1.00	0.83
Result		0.66		0.81		0.81	**0.76**

Table 5. WSI for the Tacuarembó River basin (Uruguay).

Indicator	**Pressure**		**State**		**Response**		**Result**
	Level	**Score**	**Level**	**Score**	**Level**	**Score**	
Hydrology	2.5%	0.75	7,000	1.00	Poor	0.25	
	2.0%	0.50	1.5	0.75	Medium	0.50	
		0.63		0.88		0.38	0.63
Environment	15%	0.50	40%	1.00	5%	0.50	0.67
Livelihood	-5%	0.50	0.80	0.75	12%	0.75	0.67
Policy	6%	0.75	Medium	0.50	4%	0.50	0.58
Result		0.60		0.78		0.53	**0.64**

Table 6. WSI for the Antequera River basin (Bolivia).

Indicator	**Pressure**		**State**		**Response**		**Result**
	Level	**Score**	**Level**	**Score**	**Level**	**Score**	
Hydrology	-4.5%	0.50	2,000	0.25	Medium	0.50	
	5.0%	0.50	4.8	0.75	Poor	0.25	
		0.50		0.50		0.38	0.46
Environment	10.5%	0.25	24%	0.50	5%	0.75	0.50
Livelihood	3.5%	0.75	0.52	0.25	4.0%	0.75	0.58
Policy	-4.0%	0.50	Poor	0.25	-10%	0.25	0.33
Result		0.50		0.38		0.53	**0.47**

Table 7. WSI for the Elqui River basin (Chile).

Indicator	Pressure		State		Response		Result
	Level	Score	Level	Score	Level	Score	
Hydrology	-11%	0.25	2,627	0.25	Medium	0.50	
	-40%	1.00	1,3	0.25	Medium	0.50	
		0.63		0.25		0.50	0.46
Environment	7.5%	0.50	20%	0.50	1%	0.50	0.50
Livelihood	4.4%	0.75	0.8	0.75	4.4%	0.50	0.67
Policy	4.4%	0.75	Medium	0.50	20%	1.00	0.75
Result		0.66		0.50		0.63	**0.59**

Table 8. WSI for the Reventazón River basin (Costa Rica).

Indicator	Pressure		State		Response		Result
	Level	Score	Level	Score	Level	Score	
Hydrology	-5%	0.50	7,000	1.00	Excellent	1.00	
	-10%	1.00	2.0	0.75	Medium	0.50	
		0.75		0.88		0.75	0.79
Environment	5.9%	0.50	44%	1.00	18%	0.75	0.75
Livelihood	11%	1.00	0.71	0.50	4%	0.50	0.67
Policy	5%	0.75	Good	0.75	15%	0.75	0.75
Result		0.75		0.78		0.69	**0.74**

A relatively wide range of WSI scores was obtained for the six basins studied, varying from 0.47 (low sustainability) to 0.76 (intermediate sustainability). The mean WSI for the six basins was 0.64, with a standard deviation of 0.11 (Fig. 1).

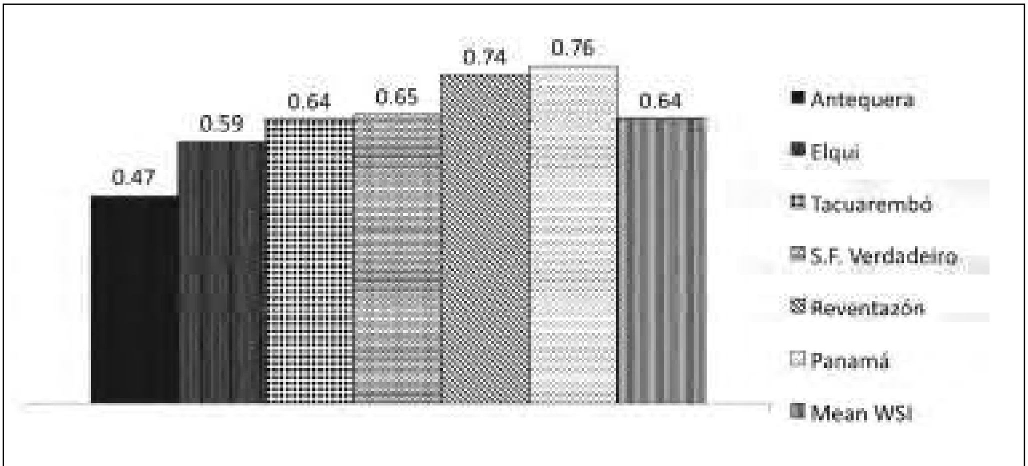


Fig. 1 WSI values for the six basins studied.

The bottlenecks contributing to the reduction of the WSI, shown in the highlighted cells in Tables 3-8, were generally different in the six basins studied. While basins with dryer climates (Antequera and Elqui) had lower scores in hydrology/quantity parameters, humid basins presented higher scores in the same parameters, as expected.

Unlike the Water Poverty Index (Sullivan and Meigh, 2003), there was no significant correlation (r = 0.40) between a basin's HDI and the WSI (Fig. 2), indicating that different parameters to those of socioeconomic nature are required to explain overall basin sustainability.

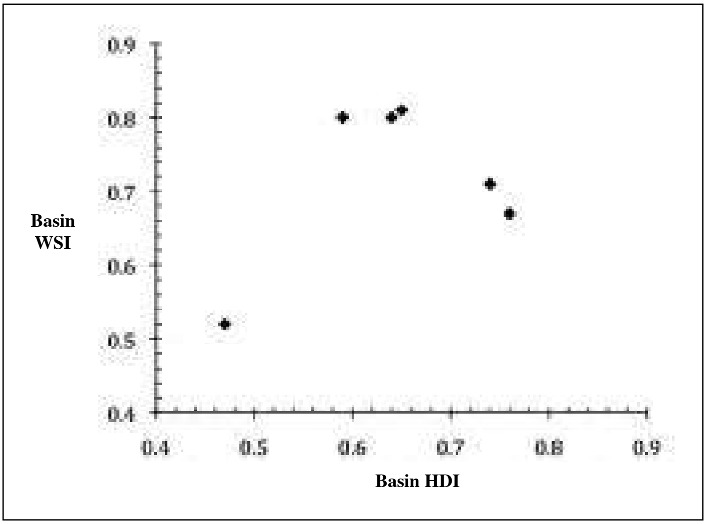


Fig. 2 Correlation between basin HDI and WSI.

4 Strategies for the Future

Overall, basins with a higher number of limiting parameters (scores < 0.50) had lower WSI values (Fig. 3), indicating that to increase basin sustainability one has to tackle the issues which led to the limiting parameters with low scores.

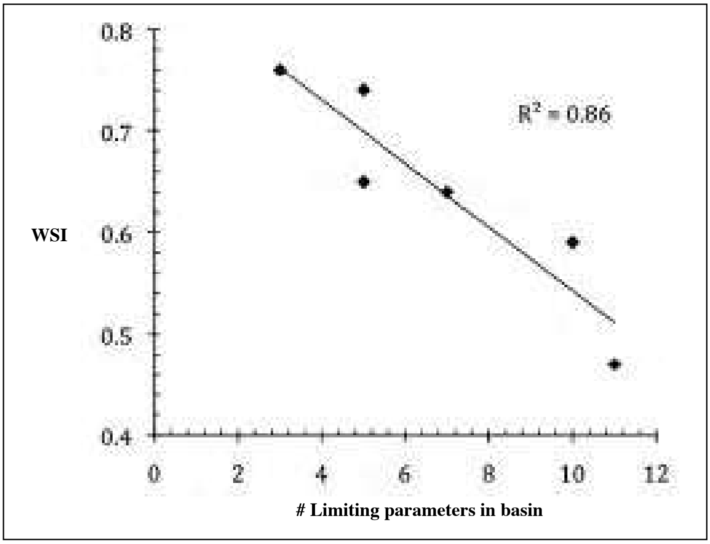


Fig. 3 Relationship between the number of limiting parameters and the basin WSL

Parameter improvement examples include strengthening education, promoting basin economic growth, and the development of efficient water resources management. The WSI allows for the estimation of basin sustainability under different socioeconomic, hydrologic, ecological, and policy scenarios, with the participation of stakeholders and decision-makers.

REFERENCES

Chaves, H.M.L. and Alípaz, S. (2007) An integrated indicator based on basin hydrology, environment, life, and policy: The watershed sustainability index. *Water Resources Management* 21: 883-895.

Chaves, H.L. and Nearing, M.A. (1991) Uncertainty analysis of the WEPP soil erosion model. *Trans. of the ASAE* 34 (6): 2437-2444, St. Joseph.

Schueler, T. (1995) *Site planning for urban stream protection*. Metropolitan Washington Council of Governments, Washington.

Smith, D. and W. Rast. (1998) Environmentally sustainable management and use of internationally shared freshwater resources, in Reimold, R. (ed.): *Watershed management*. McGraw-Hill, NY, p. 277-297.

Sullivan, C.A. and Meigh, J.R. (2003) Considering the Water Poverty Index in the context of poverty alleviation. *Water Policy* 5: 513-528.

UNESCO. (2005) *Hydrology for the Environment, Life and Policy -HELP* (Brochure). Paris, 20 p.

Viessmann, W. (1990) Water management issues for the nineties. *W. Res. Bull.* 26 (6): 886-891.

Research on the Tridimensional Deformation and Evolution Mechanism of Ground Subsidence in a Typical Area in Beijing

GONG HUILI[1,2,3], LI XIAOJUAN[1,2,3], CHEN BEIBEI[1,2,3], LEI KUNCHAO[1,4] & ZHANG YOUQUAN[1,2,3]

1 *Base of the State Key Laboratory of Urban Environmental Process and Digital Modeling, Capital Normal University, Beijing, China*

2 *Key Laboratory of 3D Information Acquisition and Application, Ministry of Education, Capital Normal University, Beijing, China*

3 *College of Resources, Environment, and Tourism, Capital Normal University, Beijing, China*

4 *Beijing Institute of Hydrogeology and Engineering Geology, Beijing, China*

Abstract Research on tridimensional deformation and evolution mechanisms of land subsidence is conducted to address such problems. By combining the different dimensions of the regional water circulation processes at different periods, the tridimensional monitoring network, consisting of the global positioning system, synthetic aperture radar interforemetry (INSAR) techniques, and ground-underground monitoring networks, is integrated and optimized. The latest development in INSAR technology is combined with standard techniques and methods, including leveling measurements, layerwise marks, and groundwater monitoring networks, among others, to improve the accuracy of deformation monitoring and perform a crossover study on disciplines such as remote sensing, mapping, hydrogeology, and so on. Several techniques and methods, such as the geographic information systems spatial analysis, groundwater numerical simulations, and so on, are adopted to perform spatial data mining based on the interaction of ground deformation and the groundwater flow field. The mutual feedback mechanism in the multilayered aquifer system assessment and the tridimensional deformation of the ground surface are disclosed. Further quantitative studies on the contributions of groundwater overexploitation, natural subsidence, and dynamic and static loads to the differential subsidence of the regional ground surface must be conducted to provide a scientific basis for the regulation and control of regional ground subsidence.

Key words Land subsidence; spatial data field; aquifer system; groundwater flow field; load stress field

1 Introduction

A typical subsidence area in Beijing suffers a 60-year history of long-term groundwater overexploitation, resulting in the formation of a regional groundwater depression cone and ground subsidence development (Jia, *et al*., 2007; Gong, *et al*., 2009). These degradations are worsened by the exploitation and utilization of superficial urban space in the city, the static load of reinforced concrete due to urban development and construction, and drastic changes in the dynamic load, among others, resulting from the tridimensional city traffic network. Therefore, a series of problems on regional environmental geology is triggered, and city safety is severely threatened.

Research on the tridimensional deformation and evolution mechanism of ground subsidence is conducted to address the aforementioned problems. By combining the different dimensions of the regional water circulation processes at different periods, the tridimensional monitoring network, consisting of the global positioning system, synthetic aperture radar interforemetry (INSAR) techniques (Ferretti, 2001), and ground-underground monitoring networks, is integrated and optimized. The latest development in INSAR technology is combined with standard techniques and methods, including leveling measurements, layerwise marks, and groundwater monitoring networks, among others, to improve the accuracy of deformation monitoring and perform a crossover studies on disciplines such as remote sensing, mapping, hydrogeology, and so on. Several techniques and methods, such as the geographic information system spatial analysis, groundwater numerical simulations, and so on, are adopted to perform spatial data mining based on the interaction of ground deformation and the groundwater flow field. The mutual feedback mechanism in the multilayered aquifer system evaluation and the tridimensional deformation of the ground surface are disclosed. Further quantitative studies on the contributions of groundwater overexploitation, natural subsidence, and dynamic and static loads to the differential subsidence of the regional ground surface must be conducted to provide a scientific basis for the regulation and control of regional land subsidence.

2 Methodology

Combining routine monitoring, simulation, prediction technologies of groundwater systems, InSAR, GIS, and other new technologies, the spatial data field was constructed based on long-term dynamic data of a groundwater observation network, additional exploration data, GPS monitoring network data, and SAR satellite data in this study.

Based on the coupling model between dynamic variations of groundwater and deformation response of land subsidence, dynamic variations in Beijing's groundwater funnels were analyzed systematically, as well as the evolutionary process of land subsidence response, the mutual feedback mechanism in the multilayered aquifer system evolution and land subsidence response is clarified, and the tridimensional deformation of the regional ground subsidence in Beijing, as well as its evolution mechanism, is disclosed.

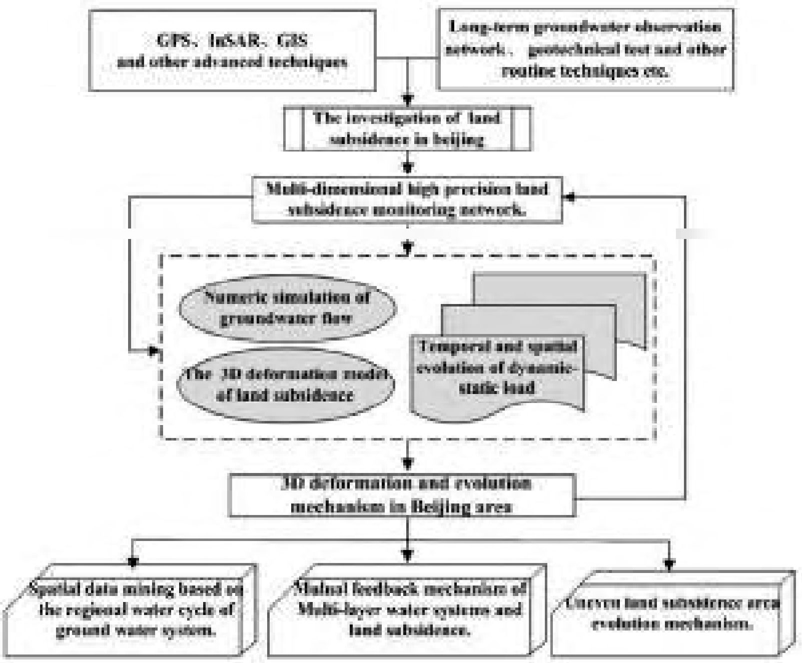


Fig. 1 Comprehensive analysis model for monitoring land subsidence and its mechanism.

3 Results and Analysis

3.1 Acquisition of High-Precision Deformation Information on Land Subsidence in the Beijing Area

An application study on synthetic aperture radar interferometry (INSAR) based on multi-network monitoring is conducted in the current study to obtain information on the high time-spatial resolution ratio on ground deformation of the subsidence area from the millimeter to the centimeter scales. Considering that an effective interferometric result cannot be obtained because of signal delays in the troposphere generated by anisotropies of signal decorrelation and the atmosphere, a new permanent scatterer and StamPS (Hooper, 2007) is used to perform the interferometry. Global positioning system (GPS) monitoring network data, meteorological observation station data, and MERIS data are combined to establish an atmospheric correction model and integrate the established atmospheric delay correction model into the StamPS algorithm to improve the PS algorithm. Thus, the effect of the atmospheric aqueous vapor is reduced, the large regional interferometric accuracy of the PS algorithm is improved, and accumulated information on the ground subsidence between 2003 and 2009 is obtained.

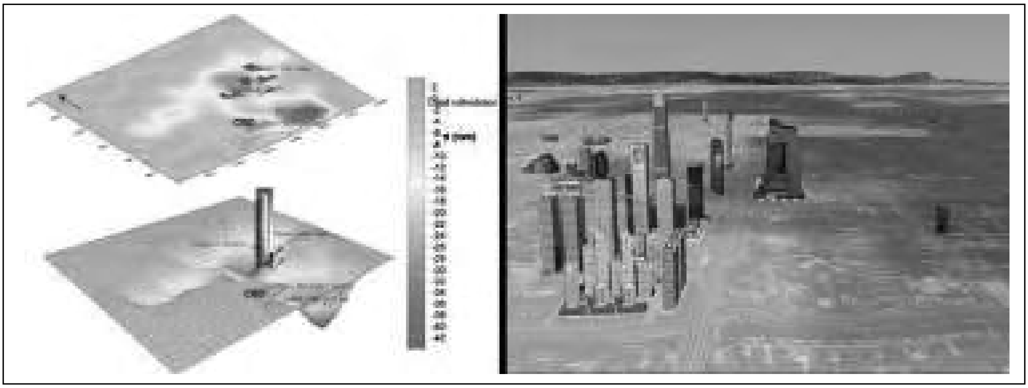


Fig. 2 High-precision deformation information on ground subsidence in the Beijing area.

3.2 Research on the Formation Mechanism of Ground Subsidence in the Beijing Area

The spatial parameters are identified and the spatial boundary is optimized based on tridimensional information extraction and monitoring of the regional land subsidence. Different techniques and methods, such as interferometry, groundwater numerical simulation (Gong, *et al*., 2000), geographic information system (GIS) spatial analysis, and so on, are adopted to analyze the spatial evolution characteristics of the groundwater flow field based on the regional water circulation process.

A system-wide study based on ground deformation, groundwater flow, and stress fields is conducted by combining measures such as physical geographic exploration, pumping test, geological trial trench, and so on. InSAR is combined with the GIS spatial analysis technique to extract tridimensional deformation information and perform tridimensional numerical simulations of the regional groundwater flow field and land subsidence. In addition, this integration analyzes the response characteristics of the groundwater flow field evolution and ground subsidence under the function of the comprehensive dynamic power, and discloses the tridimensional evolution mechanisms in regional differential ground subsidence.

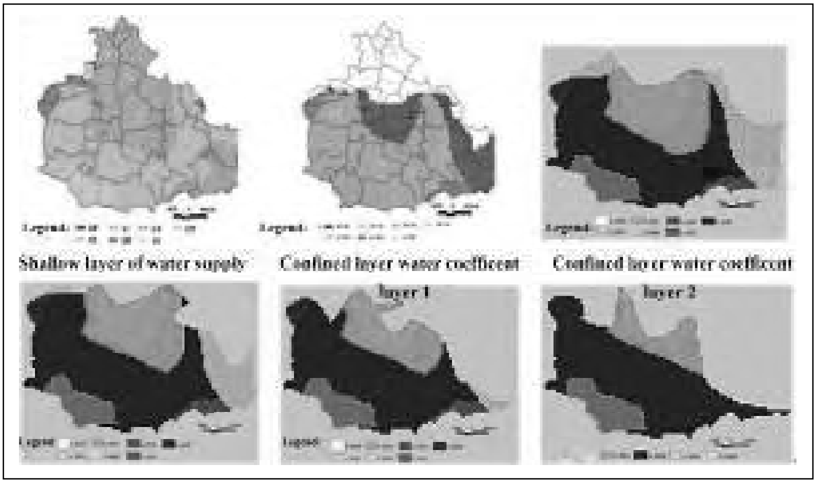


Fig.3 Identification and estimation of regional seepage field parameters.

A comprehensive interdisciplinary crossover study on remote sensing, mapping, hydrogeology, and engineering geology, among others, is conducted to address several comprehensive factors, such as long-term overexploitation of the ground water in Beijing, exploitation and utilization of the near-surface space in the city, increasing dynamic and static loads, and so on, as well as to clarify the overall mutual feedback mechanism in the multilayered aquifer system and land subsidence.

4 Conclusion

The latest in high-technology observation, long-term existing groundwater observation networks, leveling networks, and so on, are combined with standard techniques and methods used to analyze land subsidence to address the problems of long-term groundwater overexploitation in Beijing (Beijing Bureau of Geology and Mineral Exploration and Development, 2008), exploitation and utilization of the near-surface space in the city, increasing dynamic and static loads, and induced environmental and geological problems such as regional differential subsidence and multilayered aquifer system changes, among others, to improve the accuracy in tridimensional deformation monitoring and disclose the deformation mechanism of ground subsidence.

The InSAR technique and the coherent point set selection method based on the integration of the amplitude variation characteristic and the phase space coherence characteristic are adopted in the present paper to obtain a coherent point density and reduce the effect of decoherence. The combined technique is also used to guarantee the accuracy and reliability of the large, single-framework regional deformation monitoring results and obtain high-precision monitoring information on ground subsidence.

By starting the interdisciplinary crossover study on remote sensing, mapping, hydrogeology, and so on, combined with regional water circulation processes of different dimensions and at different periods, the mutual feedback mechanism in the multilayered aquifer system evolution and land subsidence response is clarified, and the tridimensional deformation of the regional ground subsidence in Beijing, as well as its evolution mechanism, is disclosed.

Therefore, the different contributions of groundwater overexploitation, natural subsidence, and dynamic and static loads to the regional ground subsidence are quantified, the spatial data mining of the groundwater system based on the regional water circulation process is investigated, and the response characteristics of the groundwater flow field evolution, as well as ground subsidence, is clarified.

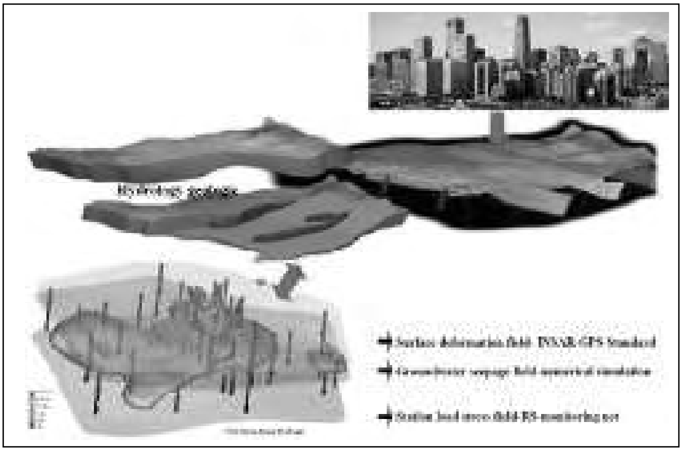


Fig. 4 Mutual feedback mechanism in the multilayered aquifer system and ground subsidence.

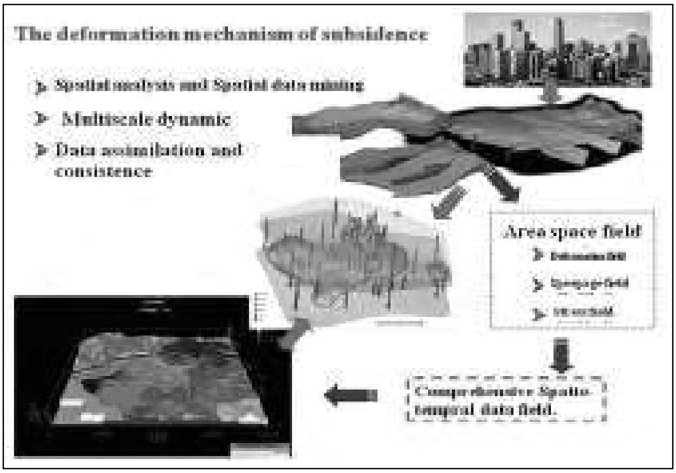


Fig. 5 Formation mechanism of ground subsidence based on the spacial data field.

Acknowledgments

The Research has been funded by the Program of International S&T Cooperation (No. 2010DFA92400), the Non-profit Industry Financial Program of MWR (No. 200901091), and the Natural Science Foundation of Beijing (No. 8101002).

REFERENCES

Gong Huili, Zhang Youquan, Li Xiaojuan, *et al*. (2009) The Research of Land subsidence in Beijing Based on Permanent Scatterers interferometric synthetic aperture radar (PS-InSAR) technique. *Progress in Natural Science* 19 (11): 1261-1266.

Jia Sanman, *et al.* (2007) The Impacts of Ground Subsidence on Urban Construction in Beijing. *Geological Hazards* 2 (4): 19-23.

Ferretti, C. Prati, F. Rocca. (2001) Permanent Scatters Insar Interferometry [J]. *IEEE Transactions on Geoscience and Remote Sensing* 39 (1): 8-20.

Hooper. A, Zebker. H, Segall. P, *et al*. (2004) A new method for measuring information on volcanoes and other natural terrains using insar persistent scatterers. Geophys. Re. Lett. 31 (23): 5.

Gong Huili, Li Menlou, Hu Xinli. (2000) Management of Groundwater Resources in Zhengzhou City, China. *Water Research* 34 (1): 57-62.

Beijing Bureau of Geology and Mineral Exploration and Development, Hydrogeology and Engineering Geology Team in Beijing. (2008) *Ground water in Beijing*. Land Press of China.

Hydrological Modeling with the Automatic Calibration Model (PEST) in the Guishui River, China

JING ZHANG, LINRUI SONG & HUILI GONG
College of Resources, Environment, and Tourism, Capital Normal University, Haidian District, Beijing, China
maggie2008zj@yahoo.com

Abstract The Hydrological Simulation Program-FORTRAN (HSPF) was used to simulate the stream flow of the Guishui River, located in Northwest Beijing, China. In the application, aside from the PWATER module for water discharge, an irrigation module was also developed to calculate shallow groundwater for agriculture irrigation. In the study, a hydrologic model was established using HSPF to simulate stream discharge and the state of water in the Guanting Reservoir, with the purpose of providing powerful support for future water reservoir management. Three gauging stations were used for model calibration. The set of hydrological parameters was aided by the automatic calibration model (PEST). The results showed that parameters calibrated using PEST were reasonable and fair, and indicate that water resource reduction caused by land use change will bring about serious water shortages for agricultural irrigation.

A Simplified Index for Watershed Management (IsGC) in Cuban Basins

JORGE MARIO GARCÍA FERNÁNDEZ, VIVIANA CASTRO ENJAMIO & JOAQUÍN B. GUTIÉRREZ DÍAZ
National Institute of Hydraulic Resources, Cuba
jorgem@hidro.cu

Abstract Cuba started its experience in the National Watershed Council in 1997, and has continuously and systematically moved forward in 11 work programs related to the country's natural, economic, and social resources. The output of this work is the Simplified Index of Watershed Management (IsGC), an assessment tool of economic, social and environmental events that take place each year in a basin. The index is calculated both for present-day and for historical periods, using information from selected and simplified sustainability indicators. In order to calculate the IsGC, 5 stages must be followed, beginning with the methodological selection of 6 basic assessment indicators, which are discussed in Watershed Council meetings related to water, soil, and forest resources. Each indicator is given a relative weight depending on its importance and priority on each basin, it is provided by expert criteria and the use of group dynamics applying a deductive type additive model, which proposes a classification that directly reflects the degree of intervention in each basin and its evolution. The highest values of the IsGC, those closest to 100, indicate high intervention, and the lowest values, those closest to zero, indicate low intervention in the basin.

Key words Index; management; assessment; intervention; basin; Cuba

1 Reference Context

According to several sources of international literature, a *watershed* is "the territorial space drawn by the dividing line of the waters that make up a hydrological system that flows to a main river, lake, sea or coastal area. It is a three-dimensional environment that integrates components and interactions of both superficial and underground waters, and it is an area where the natural resources and infrastructure, the latter created for economic and social development, are located, generating in return favorable and unfavorable impacts to the human well-being and the environment" (CARE, 2005).

Analogous with the definition of environmental administration included in Environmental Law 81 (ANPP - Cuba 1997), we define water basin administration as "a group of instruments and mechanisms of different nature and reach applied in a coherent and harmonic way in the basin in order to achieve its sustainable development."

The simplified Index of Watershed Management (IsGC in Spanish) is a tool for assessing economic and social intervention in a basin, as constituents of its integrated management for sustainable development. It is offered both currently and historically through indicators and selected information about its sustainability, which is simplified and added.

The IsGC is an algorithm that expresses a measure of the basin's state, taking selected indicators as a starting point. It is a relatively simplified expression of the complex interaction between different factors, its possible success will depend on the quality of the available information.

2 Methodological Stages in the Development of the IsGC

A deductive index was chosen considering its relatively simple and reliable development. The fundamental stages for its development are:

a. Selection of indicators
b. Definition of the relative weighs or importance of each selected indicator (i)
c. Obtaining values for each selected indicator in a scale of 0 to 100 (p)
d. Selection of the simplified model (algorithm)
e. Classification of the state of management in the basin using the IsGC's value

2.1 Selection of the Indicators

The universe of indicators is identified inside the 11 subprograms established in the National, Territorial and Specific Watershed Councils of Cuba. The selection is made according to their importance, their capability to be assessed, and their direct and indirect impact in the quality of life of the population:

- Percent of improved soil surface relative to the total agricultural surface of the basin (a)
- Percent of surface covered with forests relative to the total area of the basin (b)
- Percent of pollutant load disposal relative to the total generated (c)
- Percent of the population with access to drinking water relative to the total population (d)
- Percent of the population with access to sanitation relative to the total population (e)
- Percent of water used in the basin relative to the total available water resources (f)

2.2 Definition of the Relative Weights or Importance of each Selected Indicator (i)

Starting from the approach that each water basin has its own characteristics, this methodological stage is aimed at defining the relative weight of each indicator according to its importance in the basin. They are obtained through the consent of a group of experts. The Delphi Method was selected among the techniques to be applied. Fig. 1 shows the steps in this second stage of work.

Through the application of a questionnaire to the experts, the 6 selected indicators are scored from 0, being not very important, to 4, being very important. The experts work in teams that carry out statistical analyses to provide a weighted value for each indicator. The sum of the relative weight of the 6 indicators equals 1.

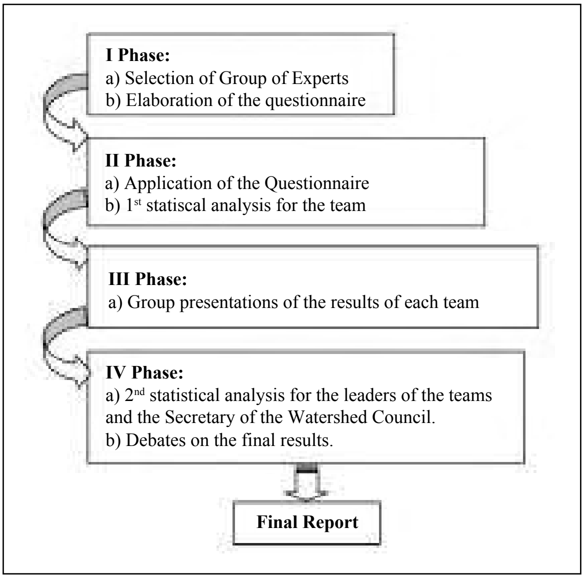


Fig. 1 Second methodological stage for the calculation of the IsGC. Source: Developed by the authors.

3 Scale Values of each Indicator Selected on a Scale of 0 to 100 (p)

This is the third stage for the calculation of the IsGC, and it consists in granting to each one of the 6 selected indicators a value of quality and establishing for each one a determined range regarding the indicator.

Table 1 Examples for soil and forest indicators.

Indicator: Improved Soil Surface		**Indicator: Surface covered with forests**	
Scale of the indicator	**Quality value**	**Scale of the indicator**	**Quality value**
Smaller than 0.7%	15	Smaller than 50%	15
Between 0.7 and 1.4%	30	Between 50.1 and 65%	25
Between 1.41 and 2.1%	45	Between 65.1 and 80%	50
Between 2.11 and 2.8%	60	Between 80.1 and 90%	75
Between 2.81 and 3.5%	80	Larger than 90.1%	100
Larger than 3.5 %	100		

4 Selection of the Simplified Model (Algorithm)

This algorithm is an additive model of deductive type that is frequently mentioned in international literature for the elaboration of different indices, due to its simplicity and effectiveness. The model is in agreement with the evaluated objectives of the management activities through interventions applied to the case. The mathematical formulation of the IsGC is the following:

$$IsGC = \sum_{1}^{6} (i.p)$$

where i is the quality value of the indicator and p is the relative weight.

5 Classification of the Watershed's Management according to the Values of the Simplified Index (IsGC)

The proposed classification aims to reflect the level of intervention and management actions in each basin, as well the evolution of these actions over time. The values of the IsGC closest to 100 indicate a high level of intervention in the basin; the values closest to zero are at the inferior limit and clearly indicate a very low level of intervention. Values among 50-60 indicate a medium level of intervention.

When interpreting these results, it should be taken into consideration that only tangible indicators of actions that have positively contributed to improve, conserve, or maintain the natural resources of the basin were selected. However, the environmental services that ensure the quality of life of the inhabitants should also be taken into account.

The IsGC started being implemented in 2010, using information from basins of national interest. The results are shown in Table 2. Fig. 2 shows the behavior of the IsGC during the period 2006 - 2010 in these basins of national interest. Following its release, the IsGC began to be applied in some basins of provincial interest.

Table 2 Results of the IsGC. Period 2006 - 2010 (Unit of measure: %).

Basins of National Interest	2006	2007	2008	2009	2010
Cuyaguateje	53.29	63.29	70.8	61.63	54.96
Ariguanabo	70.79	69.96	61.62	67.46	61.63
Almendares- Vento	66.63	63.29	59.13	74.97	70.8
Ciénaga de Zapata*					64.96
Hanabanilla	73.28	77.45	81.62	85.79	85.79
Zaza	64.95	64.95	73.29	78.29	64.95
Cauto	57.46	59.96	68.28	70.53	68.29
Mayarí		44.12	57.46	59.96	59.96
Toa	72.45	75.78	71.63	79.95	74.12
Guantánamo- Guaso	61.62	67.45	66.62	78.28	72.45

Source: CNCH Annual Reports
*The Ciénaga de Zapata basin began its activity in 2010.

Comments and Precisions

- Percent of wat
- Basins that score 75.1 or higher are considered to have a high level of management intervention. The only basin occupying this category is the Hanabanilla basin, and very close to this value is the Toa basin. The rest of the basins (see Table 2), are among the 35.1 and 75.0 scores, and are considered to have a moderate level of management. Basins with scores under 35.0 are considered to have a poor level of intervention
- The IsGC responds to the variations in behavior of the selected indicators, i.e., a basin could score high with regards to one indicator, but low with regards to another. This occurrence is observed in basins with increasing pollution loads due to an increase in pig livestock and other factors that require urgent waste water treatment by the Council, as they involve living organisms. Some examples of these basins are the Cuyaguateje, the Ariguanabo, the Almendares - the Vento and the Guantánamo - and the Guaso basins.

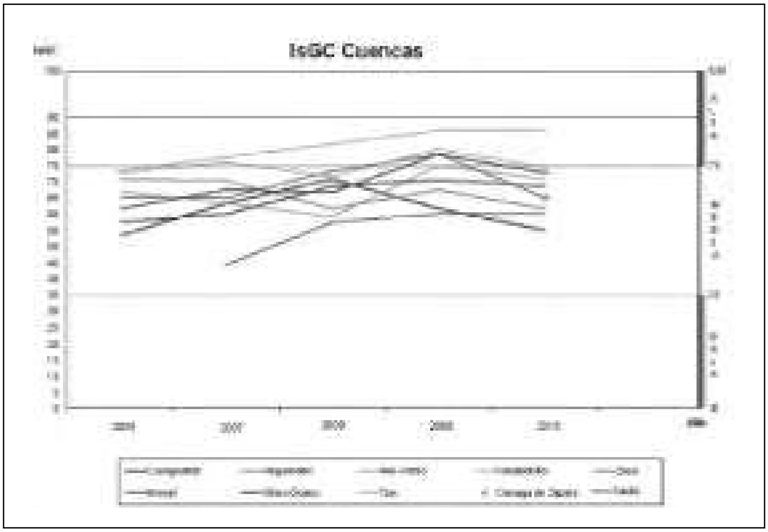


Fig. 2 IsGC Results, 2006 - 2010.

- The indicator of forest cover maintains a sustained increment during the whole period of analysis in all basins, considering the growth of approximately 0.3% according to the Index of Current Forests (IBA) in the last few years. The most noticeable basins with high forest cover are the basins of Toa (97.9%), Hanabanilla (94.4%) and Guantánamo - Guaso (94.2%). The lowest level of forest cover was found to be the Ariguanabo basin (60.6%)
- The Zaza basin maintains a very low Index of Potential Forest (IBP), of only 8.1%. Currently, its environmental order is planned to be studied, a priority being the identification of new areas that can be dedicated to forestry. In a similar way, the indicator of improved soil surface barely reaches 10%

6 Conclusions

The calculation of the IsGC to evaluate the behavior of the management interventions in the basins of both national and provincial interest will constitute an instrument for decision-making at different levels by the Council. With the classification of the indicators and the calculation of the index, priority actions for a basin's management can be identified.

This new tool for management assessment in Cuban watersheds will improve the Watershed Council's activities, which began in 1997, and confirms the maturity that the organization has reached since then.

REFERENCES

Astigarraga, E. *Método de Delphi***.** Universidad de Deusto, San Sebastián.

Battelle Memorial Institute. (1973) *Planning, design and operation of comprehensive water quality monitoring systems.* Report WHO, PHO.

Chaves, Henrique M.L., Alipaz, Susana. (2007) An integrated Indicator for Basin Hydrology, Environment, Life, and Policy: The Watershed Sustainability Index. *Water Resources Manag*. 21: 883-895.

De las Cuevas, R, (2007). *Evaluación de la calidad de las aguas de la cuenca Cochino-Bermejo mediante Índices Generales de Calidad de Aguas (ICA)*. M.Sc. thesis. INRH.

García, J. M., Gutiérrez. J. (1982) Un índice regional de calidad de agua para acuíferos cársicos. *Memorias del Coloquio Internacional sobre Hidrología Cársica en la Región del Caribe.* UNESCO-PHI-Instituto de Hidroeconomía. Editora Palacio de las Convenciones., p. 567-588.

García, J. M., Gutiérrez J. (1992) Índices de calidad del agua: Resumen de las experiencias cubanas. *Memorias del XXIII Congreso AIDIS*. Tomo I. Parte I. 1. Calidad y Protección de Recursos Hidráulicos. 1.1. Calidad del agua de las fuentes, pág. 104-117. Editora Palacio de las Convenciones. La Habana. Cuba.

García J. M., Gutiérrez J., Beato, O. (1983) Un índice para evaluar la calidad de las aguas superficiales. *Revista Voluntad Hidráulica* 62, p. 47-52.García, J.M. (1988) *El control de la contaminación de las aguas: Monitoreo y estudios intensivos*. Doctorate in Technical Sciences thesis.

Gutiérrez J., González, A. (1974) *Un índice de Contaminación de las Aguas Subterráneas*. Grupo Hidráulico Nacional. DAP. Mimeographed pamphlet.

Mattingley-Scott, Mark. *Estructuración de un proceso de comunicación de grupo para ocuparse de un problema complejo. Descripción del Método Delphi de T.J. Gordon, Olaf Helmer y Norman Dalkey*.

Ministerio de Medio Ambiente y Recursos Naturales El Salvador. (2005) *Manual de Manejo de Cuencas*. CARE, UE. 153 pages.

Morales, M. (2008) *Diseño de un Índice de Calidad de Agua para el manejo y gestión de los ríos de Ciudad de La Habana*. ISPJAE. M.Sc. thesis.

UNEP, SOPAC. (2005) The Environmental Vulnerability Index EVI. Available at www.sopac.org/evi

Yale and Columbia University. (2005) Environmental Sustainability Index ESI. Available at www.yale.edu/esi.

Flood Mitigation Using an Integrated Now-Casting Model for the Langat River Basin, Malaysia

MOHD EKHWAN TORIMAN[1], MAZLIN MOKHTAR[2] & RAHMAH ELFITHRI[2]

1 *School of Development and Environmental Studies (FSSK), Universiti Kebangsaan Malaysia*
ikhwan@ukm.my

2 *Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia*

1 Introduction

The basic cause of flooding in Malaysia is the incidence of heavy monsoon rainfall and the resulting large concentration of run-off, which exceeds river systems' capacity (Mohd Barzani, *et al.*, 2011; Mohd Ekhwan, 2009). Rapid urbanization within river catchments in recent years has also served to compound the problem with higher run-off and deteriorate driver capacity, which have resulted in increased flood frequency and magnitude (Mohd Ekhwan, 2010; Yusri, 2007).

In reality, floods are one of the most common hazards in Malaysia, particularly in the Langat River Basin. Located in a tropical area, the basin receives heavy rain with an average of 2000 mm to 3500 mm a year. The climate is influenced by two monsoons, the North-East monsoon occurs from November to March, and the South-West Monsoon from May to September. The first one carries heavy rain to the east coast of the Peninsula. With an increased trend in land development, more and more areas are becoming sensitive to short duration-high intensity rainfall, which leads to flooding.

Among flood mitigation methods, various flood forecasting and warning systems based on advanced hydraulic models have been applied, but they have proved inadequate to predict impending floods. Thus, they have had limited effect in reducing costs and damage to life and property due to flooding. Moreover, the practical limitations of rain gauges for measuring mean rainfall over large, and sometimes-inaccessible, areas are becoming apparent. Hydrologists and planners are thus increasingly turning to apply more accurate and faster ways to deliver flood information to the public, so that they can be alert and prepare for evacuation.

Before 1980, Malaysia's Drainage and Irrigation Department (DID) did not have any facility for anticipating floods, except from emergency weather reports and forecasts. They typically found themselves reacting to information phoned in by people who had either experienced damage or who had noticed that flooding was occurring. In the year 1988, a pilot project, a GIS display of flood risk maps, was used for the upper Klang River Basin (including the capital city of Kuala Lumpur). The study resulted in the preparation of flood risk maps which show the extent of flooding due to various discharges and rainfall intensity-duration-return periods. These maps provided useful reference to town planners and land owners in the planning of future developments in the flood prone areas of the Klang Valley (Hiew, 1996).

The information, however was limited, and could only be accessed through DID's documents and websites. The people, particularly those living near rivers, do not have any clue of when they need to prepare prior and during water floods. Therefore, the need of real time images of rainfall induced flash floods, and of where the rain is and has fallen, etc. are extremely important in flood now-casting models. These models include information coming from up-river dams, indicating river flows, in near real time.

Vulnerable people, particularly living near rivers, have now got the potential to receive some warning about impending floods. Also there is the knowledge that the DID, in collaboration with the private sector and the university, are working towards flood now-casting in their areas in a proactive rather than reactive way. With the current flood forecasting capability developed by

DID, 6 to 12 hour warnings of impending floods allow the public to evacuate. This is a far cry from December 1993 and 1998, when most areas along the Sg Jelok at Kajang were submerged due to flash floods, resulting in serious economic consequences (Mohd Ekhwan, 2000).

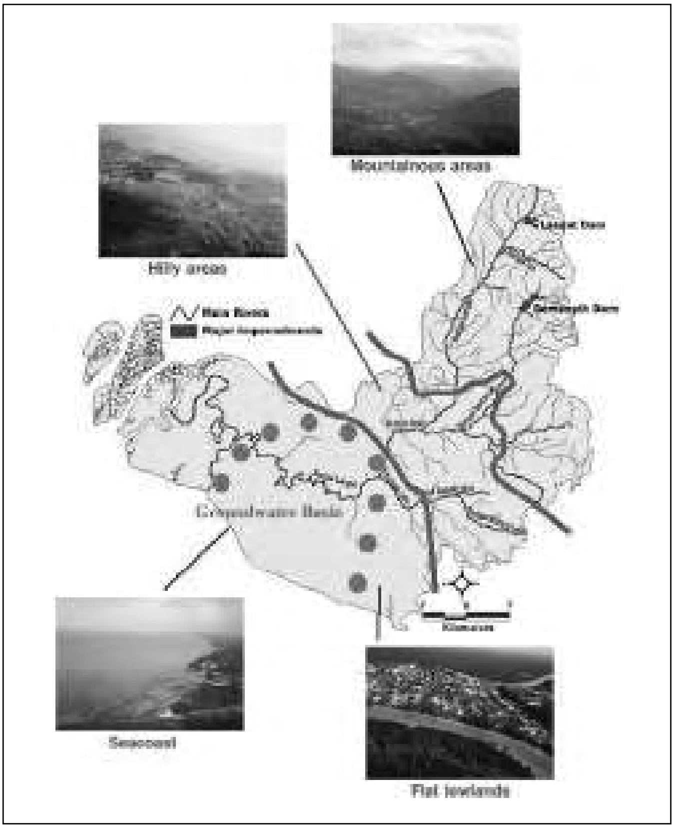


Fig. 1 Ground water and major river network in the Langat River Basin.

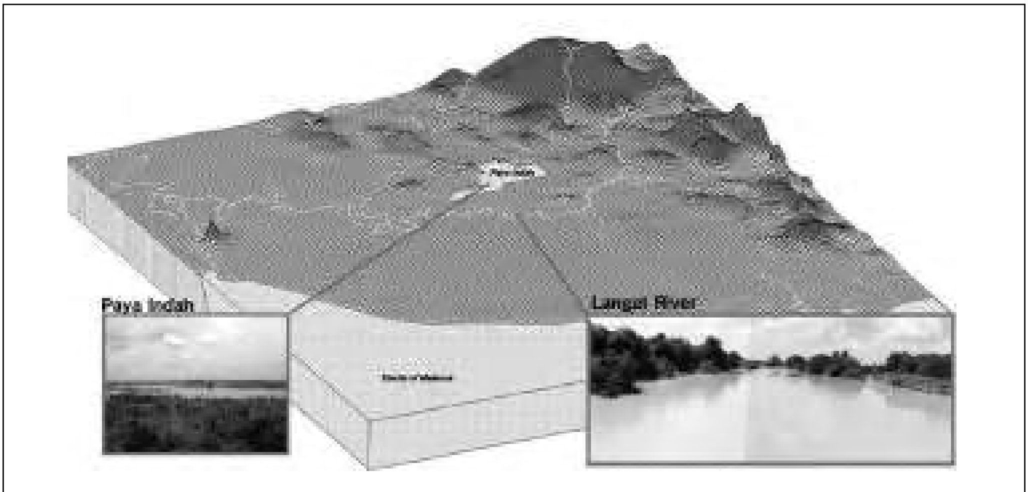


Fig. 2 Topography of the Langat River Basin.

This paper describes how the flood now-casting system, which assists agencies, planners, and the public, has been put in place in Langat River Basin. The main objective is to develop real time flood information that can be delivered to the public using a simple mobile website that can be accessed from mobile phones with GPRS or 3G services.

The InfoBanjir website (http://infobanjir.water.gov.my), was designed to serve the requirements of DID personnel in Malaysia, as well as local agencies, private companies, and international stakeholders. Now, with more internet users, as well as more mobile phones in the Langat River Basin, the InfoBanjir waebsite will be able to meet the demands of the public. As reported by the DID's website, the InfoBanjir website receives up to 34,000 hits per day, especially during the flooding seasons.

2 Study Area

The Langat river basin catchment area is about 1,815 km2. The main river course length is about 141 km, mostly situated around 40 km east of Kuala Lumpur. The average annual rainfall is approximately 2,400 mm, ranging from 1,800 to 3,000 mm. The highest rainfall occurs in the months of April and November, with a mean of 280 mm. The lowest rainfall occurs in the month of June, with a mean of 115 mm. Figures 1 and 2 illustrate the physical features of the Langat River Basin.

Drainage density (D) is the ratio of the total channel length accumulated for all orders within the catchment area (Horton, 1945). Based on Strahler's (1957) texture classification, the drainage density of the Langat Basin can be said to be that of low density. The bifurcation ratio was defined by Horton (1945) as the ratio of the number of streams of one order to the number of streams of the next highest order (n + 1). In the Langat River catchment, the average value of the bifurcation ratio is 4.93. Taking Peninsular Malaysian examples from Sabry (1997) at the Tekala River (5.1), Koh (1978) at the Lui River (3.75), and Mykura (1989) at the Klang River (5.9), the mean bifurcation ratio at most of the catchment areas in the Peninsula is approximately 5.

The Langat Basin is an important water catchment area, providing raw water supply and other amenities to approximately 1.2 million people. Important conurbations served include towns such as Cheras, Kajang, Bangi, the Government Centre of Putrajaya, and others. There are two reservoirs (Semenyih and Hulu Langat), and 8 water treatment plants (4 of which operate 24 hours), which provide clean water to the users after undergoing treatment.

3 Methodology

Now-casting refers to time and place specific forecasts (30, 60 minute) that are heavily based on observations. Operational methods for flash flood warnings in now-casting do not even involve a forecast, but rely on monitoring rainfall accumulation from rain gauges. Flash floods occur when particular meteorological events are combined with certain hydrological conditions. Several approaches to now-cast flash floods are being developed. However, predictions of the magnitude and timing of flash flood events is a major challenge. Flash floods are often cited as being caused by storm rainfall and the link between high intensity rainfall and antecedent rainfall prior to storm events. The rainfall intensity-duration pattern of each storm during, or immediately after, which flash floods have occurred, can be analyzed, and a series of points representing a range of rainfall durations (x) and associated intensities (y) can be plotted. Further events may be similarly analyzed and, if the same durations are used, a series of vertical data columns can be achieved, each one representing events associated with different rainfall intensities for a given duration.

The lower boundary of these data points represents the threshold for rainfall-induced flash flood. An additional element to this approach can be to undertake the same type of analysis for storm events that do not trigger flash floods. This allows the threshold to be defined from below as well as from above, lending an additional degree of certainty to the process.
Some of the innovations detailed here include:

- Employment of GIS to capture real-time rainfall over sub-catchments as input to the rainfall/ runoff model by integrating the optimal spatial rain fields
- Derivation of a short term rain field now-casting method to advect possible future rain fields in real time, in order to anticipate where it will rain up to an hour ahead (Fig. 3).

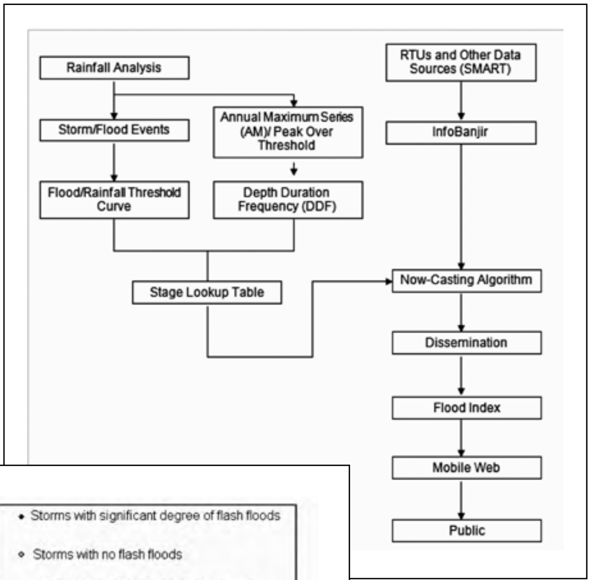


Fig. 3 Schematic diagram of the flood now-casting approach.

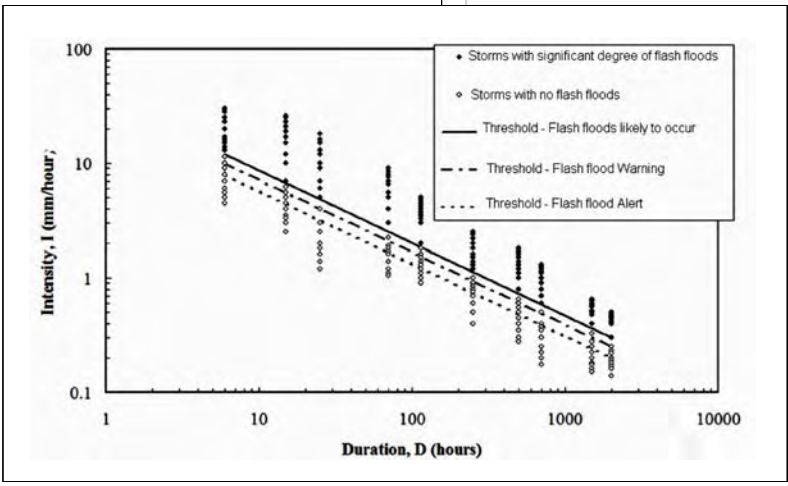


Fig. 4 Flash flood threshold levels.

4 Results and Discussion

Fig. 4 illustrates the development of a purely hypothetical rainfall-threshold-curve following the described methodology. It should be noted that, while the approach is sound, it is difficult to justify the expenditure of resources to analyse 'non-events'. The hypothetical rainfall data in Fig. 4 was utilized to develop three (also hypothetical) threshold levels:

- A threshold level above which flash flood might be expected to occur
- A threshold level at which a warning is issued and action taken -set at a lower level to give adequate time for effective notification and action
- A still lower threshold level at which instruments are checked and key personnel alerted to the possibility of the development of conditions likely to lead to a flash flood -a precursor to the issue of a flash flood warning

It is important to note that threshold levels developed in this manner are in no way final. Quantification of rainfall in order to determine conveyance is an important part of now-casting. Rainfall quantification is generally done using isopluvial maps and Depth-Duration-Frequency (DDF) curves. The Rainfall-Threshold curves and the Depth-Duration-Frequency curves can be used to determine the risk that the capacity of the structures in the area may be exceeded. In this methodology, the DDF curve will be used to quantify the rainfall magnitude for the area alongside the Jalan Sg Chua, one of the most vulnerable areas related to flash flood in the Langat River Basin. The DDF curve will be used in combination with the rate of rise (m/hr) technique for the stage estimation through a look up table that contains stage information from historical events collected by the Sg Langat telemetry station in Kajang (Fig. 5).

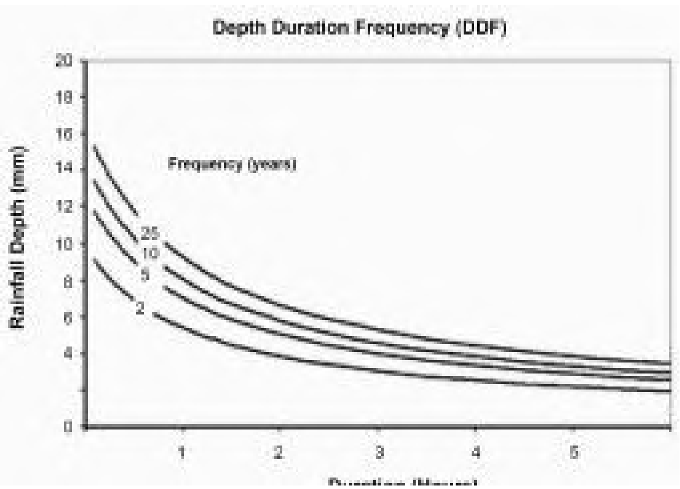


Fig. 5 DDF measured at Sg Langat at Kajang.

Once the Rainfall-Threshold curve, DDF and the stage lookup table have been established, an algorithm will be programmed into the InfoBanjir system to compute and assess the flood risk. The risk will provide warnings to areas adjacent to Jalan Sg. Chua. These warnings will be shown in InfoBanjir, the Mobile Web, and as SMS alarms to the pre-determined SMS users. Sample messages are as follows:

- *Message 1*: "*Heavy Rainfall! Rising river at Jalan Sg. Chua and surrounding areas - JPS Malaysia 20/02/2011 - 15:30*"
- *Message 2*: "*Minor flooding and river rising at Jalan Sg Chua and surrounding areas, exercise caution - JPS Malaysia 20/02/2011 - 16:30*"

The proposed Mobile Website that can be accessed from mobile phones with GPRS or 3G service will display the flood indices in a user-friendly and easily understood fashion. Fig. 6 shows an example of a mobile webpage.

Fig. 6 Mobile Web example.

5 Conclusion

The application of real-time hydrological information is not the solution to all the problems mentioned above, but it may mitigate flood problems and in this way reduce the economical losses and health problems the public faces from urban flooding. Also, information generated by a real-time hydrological information system will be applied, by using also historical data for design and maintenance analyses, to achieve a better functionality of the urban hydrological system. Making hydrological information publicly available over the internet and mobile phones is at present a feasible task, which makes data collection more valuable and the work of hydrologists more highly appreciated by the public. In this project, the essential back bone for forecasting rain and urban flooding is established, and it can easily be extended to achieve more accurate forecasts, e.g., by adding on-line rain gauges to the system or by changing the sampling time for the rain gauges to a shorter period. In addition, the hydrological information can be applied in conjunction with real-time hydrological and urban drainage models, providing decision support and warning systems to deal with urban flooding and flash floods. The authors believe that, in the future, hydrological information systems like the one described in this paper will be part of the infrastructure in any major city around the world.

Acknowledgements

A special thank goes to the Centre for Research & Instrumentation Management (CRIM), Universiti Kebangsaan Malaysia, for providing us with the Research Funding (UKM-AP-PLW-05-2010). Our grateful thanks also go to Drainage and Irrigation Malaysia (DID) for their general support.

REFERENCES

Hiew Kim Loi. (1996) *Flood mitigation and flood risk management in Malaysia*. Paper presented in the International workshop on floodplain risk management. Kuala Lumpur. 205-216.

Ho, K. H., Ghazali, A. H., and Chong, S. F. (2002) *Calibration and Evaluation of Modified Tank Model (Flood Forecasting Model) for Kelantan River Basin, Malaysia.* Proceeding of the Water Engineering Conference Malaysia 2002. July 23-24. University Putra Malaysia http://eng.upm.edu.my/wec2002/sessions/watergeo.htm. Accessed Aug 15, 2003.

Mohd Ekhwan Toriman, A. Jalil Hassan, M. Barzani Gazim, Mazlin Mokhtar, S.A. Sharifah Mastura, Othman Jaafar, Othman Karim & Nor Azlina Abdul Aziz. (2009) Integration of 1-d Hydrodynamic Model and GIS Approach in Flood Management Study in Malaysia. *Research Journal of Earth Sciences* 1 (1): 22-27.

Mohd Ekhwan Toriman, Othman A. Karim, Mazlin Mokhtar, Muhammad Barzani Gazim & Md. Pauzi Abdullah. (2010) Use of InfoWork RS in modeling the impact of urbanisation on sediment yield in Cameron Highlands, Malaysia. *Nature and Science.* 8 (2): 67-73.

Mohd. Ekhwan Toriman (2000) Banjir sebagai bencana: Isu, cabaran dan pengurusannya di Malaysia dalam Jamaluddin Md. Jahi. (eds). *Pengurusan persekitaran di Malaysia.* Pusat Pengajian Siswazah, UKM. Bangi press. 127-147.

Muhammad Barzani Gasim, Salmijah Surif, Sahibin Abd. Rahim, Ainon Hamzah, Md. Pauzi Abdullah, Mohd Ekhwan Toriman, Mazlin Mokhtar, Wannor Azmin &Sulaiman & Mohd Ismail Yaziz. (2011) Development and Land-Use Change in the Semenyih River Basin and Their Impact, Selangor, Malaysia. Research Note, *The Arab World Geographer / Le Géographe du monde arab* 14 (2): 205-214.

Yusri, Othman A. Karim, Khairul Nizam Abdul Maulud & Mohd Ekhwan Toriman. (2007) Geographical Information System Application for Estimating Land Use Changes of Pekanbaru City. *Jurnal Dinamika Pertanian.* Vol. XXIII. Bil. 3. 157-164.

Watershed Sustainability Index (WSI) for the Reventazón River Basin in Cartago, Costa Rica, 2000-2005 Period

NICK CATANO[1], MARK MARCHAND[1], SIMONE STALEY[1], YAO WANG[1] GUILLERMO FLORES M.[2] & GUSTAVO CALVO[3]

1 *School of Engineering, Worcester Polytechnic Institute (WPI), USA*

2 *Committee for the Demarcation and Management of the Reventazón River Upper Basin (COMCURE), Cartago, Costa Rica*
gflores@racsa.co.cr

3 *Environmental Management Center, RIOCAT-UEN Production, ICE, Cartago, Costa Rica*

Abstract The Committee for the Demarcation and Management of the Upper Reventazón River Basin (COMCURE), in Cartago, Costa Rica, with the support of CONAPHI-Costa Rica, joined the HELP Basins of UNESCO's International Hydrological Program (IHP-LAC) in 2009. Following this addition, COMCURE estimated its Watershed Sustainability Index (WSI), dividing the watershed into three regions: high, mid and low, based on their altitude and environmental aspects. The applied methodology was developed by Chaves and Alipaz; it integrates Hydrology (H), Environment (E), Life (L), and Policy (P) aspects in a three parameter framework: Pressure, State, and Response. The final indices obtained for each region are similar (0.74, 0.73, and 0.74) for the high, mid, and low region, respectively. The lowest relative score for the basin was 0.50, which corresponds to the Life indicator, and it reveals that the existing living conditions throughout the basin are relatively unsatisfactory. The upper region performed well on all indicators. The middle region needs to improve the environmental pressure parameter, since it is suffering from the effects of agricultural and human activities. Several strategies are recommended to solve these problems: incorporation of additional wastewater and sewage treatment plants, and the development of additional projects for sustainable agriculture in the region. The lower region has problems with the hydrological quantitative pressure setting parameter, which points to the possibility that, in the future, waterr availability in the region should be increased.

Key words Index; Sustainability; Basin; Hydrology; Environment; Life; Policy

1 Introduction

The Reventazón River Watershed is located in the central area of Costa Rica's Atlantic Coast. It includes an area of 2,950 km^2, which is equivalent to 5.20% of the national territory, and is 125 km in length. It encompasses territories of the Cartago and Limón Provinces. Its population of 550,000 is concentrated mostly in the upper and middle parts of the basin. It is third in size among all the country's rivers, and plays an important role in the country's economy, as it provides 38% of the country's hydroelectric power, 25% of the drinking water in San José, 85 % of the vegetable production (potatoes and onions), 33% of the livestock, and 50% of the national cement production, not taking into account the contributions from the lower parts of the basin.

The balance of natural resources in the basin is threatened by degradation processes such as erosion and sediment transport, over-application of chemical fertilizers and pesticides, poor waste disposal on farms, lack of treatment systems for urban wastewater, poor urban waste disposal, deforestation, and soil overuse by poor agricultural practices (tillage of soils for horticulture). These processes are associated with high rainfall, steep slopes, and fragile soils, mainly of volcanic origin, which produce high runoff, landslides, sediment transport, and a long history of flooding at critical sites along the basin. Regarding water pollution, the basin is second nationwide, with 11% of the total pollution estimated in the country.

Following these situations, and given the basin's economic and environmental importance, Law No. 8023 was adopted in the year 2000, creating the Committee for the Demarcation and Management of the Upper Reventazón River Basin (COMCURE) as a pilot experience in watershed management, with projections to other watersheds in the country. The implementation of the Management Plan started a process of effective sustainable development on the basin.

COMCURE, with the support of CONAPHI-Costa Rica, joined the HELP Basins of UNESCO's International Hydrological Program (IHP-LAC) in 2009. Shortly after this affiliation, COMCURE estimated the Watershed Sustainability Index (WSI) for the basin, in order to confirm the health status of the different regions, and thus detect the critical problems experienced on each one. To achieve this, COMCURE commissioned a team of students from the Worcester Polytechnic Institute's School of Engineering (USA), which calculated the WSI for each of the basin's three regions.

2 Methodology

The applied methodology for determining the Watershed Sustainability Index (WSI) was developed by Chaves and Alipaz (2007). This index takes into account cause-effect relationships and integrates Hydrology (H), Environment (E), Life (L), and Policy (P) aspects in a three parameter framework: Pressure, State, and Response. Each indicator is given equal weight.

2.1 Quantitative Analysis

Population figures from Costa Rica's National Institute of Statistics and Census, classified by counties and districts for the 2000-2005 period, were used. Data from the Human Development Index (HDI) and its sub-indices (HDI-Income and HDI-Education) were taken from the Cantonal Human Development Atlas of Costa Rica (2007). Water Availability (WA) and BOD5 data were found in reports from Costa Rica's Electricity Institution (ICE in Spanish), which was sourced from various control stations distributed throughout the basin, from 2000 to 2008.

2.2 Population Composition

To obtain more reliable parameters for the HDI and its sub-indices, they were weighted based on population on each district and region (see Fig. 1). The boundaries that separate the three regions were defined by political boundaries, so that each county is considered uniquely as part of one of the three regions.

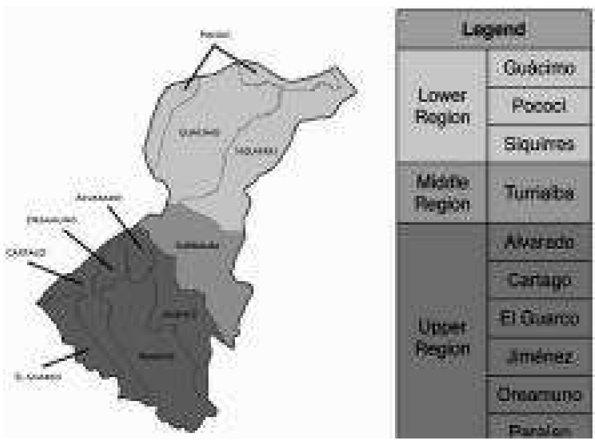


Fig. 1 The Reventazón River Basin divided into its high, middle and lower regions, based on altitude and political divisions.

2.3 Pixel computation on protected area maps

Protected area maps of the entire basin for 2000 and 2005 were used, obtained from the Protected Wildlife Areas Document. To obtain numerical values from the maps, we superimposed the maps with Fig. 1. Then, using Adobe Photoshop Creative Suite 4, a pixel count was made for each protected area in each region, and another pixel count for the entire region, to calculate the actual percentage of protected areas in the region.

3 Results

The results are presented separately for the high, middle and lower regions of the Reventazón River basin. The compiled and systematized information was divided according to each indicator, namely: Hydrology, Environment, Life, and Policy.

3.1 Hydrology (H) Indicator

The Hydrology indicator covers all water aspects in the Basin. We present results for the two sub-indicators: water quality and quantity.

3.1.1 Water Quantity

Table 1 summarizes the average Water Availability per capita per year for the three regions, on a long-term (1954-2005) and short-term (2000-2005) period. The reference population is the entire population for the three regions in 2005.

Table 1 Average Water Availability (WA) data ($m^3/_s$) from the hydrologic measurement stations in the three regions on the Reventazon River Basin.

			Long-Term (1954-2005)		Short-Term (2000-2005)	
Region	**Population (2005)**	**Control Stations**	**Water flow rate (m^3/s)**	**Regional W_A (m^3/s/person*year)**	**Water flow rate (m^3/s)**	**Regional W_A (m^3/s/person*year)**
High	311,436	La Troya	9.39	15,136	11.40	19,801
		Palomo	37.29		41.85	
		Angostura	102.80		142.30	
Middle	49,854	Guayabo	111.24	58,140	115.00	60,105
Low	85,789	Pascua	149.75	132,427	162.50	120,094
		Hamburgo	210.50		164.20	

Table 2 shows the Pressure parameter scores (Percentage variation in Water Availability in long and short terms), which are 1.00 for the upper region, 0.75 for the middle region, and 0.50 for the lower region. The State parameter was based on Water Availability in the long run. All three regions exceeded the 6,800 m^3/year/person recommended standard, and therefore a score of 1.00 was assigned to all three regions. For the Response parameter, not enough quantitative information on water use efficiency was obtained, for which substitute values of 1.00 were used, taken from the preliminary study (Hydrology Group, 2009). The average results of the WSI indicate that the upper region obtained a 1.00 score, the middle region obtained a 0.92 score, and finally, the lower region obtained a 0.83 score.

Table 2 Calculated and substitute values of water quantity in the three regions on the Reventazón River Basin.

HYDROLOGY QUANTITATIVE RESULTS							
Region	**Pressure**		**State**		**Response**		**WSI Average Score**
	Value	**Score**	**Value**	**Score**	**Value**	**Score**	
High	34.1%	1.00	15136	1.00	Excellent	1.00	1.00
Middle	4.3%	0.75	58140	1.00	Excellent	1.00	0.92
Low	-6.5%	0.50	132427	1.00	Excellent	1.00	0.83
Total							0.92

3.1.2 *Water Quality*

Having only Biochemical Oxygen Demand (BOD5) data between 2000 and 2005, instead of using the short-term average variation with respect to the long-term average, we used the BOD5 variation in 2005 with respect to 2000, to calculate the Pressure parameter. The result of this calculation was applied equally to all the three regions in the basin. The BOD5 is 1.87 mg/l for 2000, and 1.42 mg/l for 2005, for which the 2 variance is -24.3%, resulting in a score of 1.00. The State parameter used BOD5 figures for the year 2000, and it was applied equally to all three regions. As established, the 1.87 mg/l value gave a 0.75 score. As for the Response parameter, a score of 0.50 was determined for the watershed's improvement level, in terms of treatment and sewage disposal (Hydrology Group, 2009). The WSI final average for all regions was 0.75. Table 3 shows these Hydrology qualitative results.

Table 3 Calculated and substitute values of water quality in the three regions on the Reventazón River Basin.

HYDROLOGY QUALITATIVE RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
High	24.3%	1.00	1.87	0.75	Regular	0.50	0.75
Middle					Regular	0.50	0.75
Low					Regular	0.50	0.75
Total							0.75

3.2 *Environmental (E) Indicator*

As indicated in Table 4, for the Pressure parameter, the high and low regions scored 0.75 for having very good IPA values. The middle region obtained a score of 0.50. For the State indicator, the upper and lower region have about 28% of their area covered by natural vegetation, and thus obtained a score of 0.75; the middle region excelled, with over 40% of its area covered by natural vegetation, obtaining a score of 1.00. For the Response parameter, which assesses the evolution of the environmental parameters, the percentage variation in protected lands between 2000 and 2005 is 18.9% for the high region, for a score of 0.75. The other two regions obtained a 1.00 score. The WSI final averages show that the middle and lower regions scored highest (0.83), while the upper region had a slightly lower value of 0.75.

Table 4 Calculated values for the Environmental indicator, in the three regions on the Reventazón River Basin.

ENVIRONMENT RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
High	2.81	0.75	29.73%	0.75	18.9%	0.75	0.75
Middle	9.63	0.50	59.17%	1.00	20.8%	1.00	0.83
Low	4.76	0.75	27.28%	0.75	35.8%	1.00	0.83
Total							0.81

3.3 Life (L) Indicator

Table 5 shows that the upper and middle regions scored 0.50 on the Pressure indicator, while the lower region received a score of 0.75. For the State parameter, the middle and lower regions received a score of 0.50, and the high region received a score of 0.75. As for the Response parameter, which is the percentage change in overall HDI, the three regions scored relatively poorly: 0.50. Final WSI average scores for the upper and middle region were 0.58, while the lowest score corresponded to the middle region: 0.50.

Table 5 Calculated values for the Life indicator, in the three regions on the Reventazón River Basin.

LIFE RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
High	-0.6	0.50	0.77	0.75	3.77	0.50	0.58
Middle	-2.3	0.50	0.67	0.50	3.88	0.50	0.50
Low	5.9	0.75	0.63	0.50	9.24	0.50	0.58
Total							0.56

3.4 Policy (P) Indicator

The Pressure parameter in Table 6 shows that all regions obtained equally good scores: 0.75 for each one. Results for the Policy State parameter are based on surveys carried out regarding the legal and institutional frameworks. As we could not obtain sufficient information for the Response parameter, substitute values were used to calculate mean scores. For the State and Response scores, 0.75 values were assigned, which yielded final mean scores of 0.75 for each region (Policy Group, 2009).

Table 6 Calculated and substitute values for the Policy indicator in the three regions on the Reventazón River Basin.

POLICE RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
High	4.25	0.75	Good	0.75	N/A	0.75	0.75
Middle	4.27	0.75	Good	0.75	N/A	0.75	0.75
Low	6.70	0.75	Good	0.75	N/A	0.75	0.75
Total							0.75

3.5 Overall Watershed Sustainability Index (WSI)

Table 7 shows the parameter average scores and mean scores for each region and for the entire basin. It can be observed that all final averages of each region are similar (0.74, 0.73 and 0.74 for the high, mid, and low region respectively). Among all indicators, the lowest relative score for the basin was 0.50, which went to the Life indicator. The upper region performed well in all remaining indicators, while the middle region needs to improve on the Environmental Pressure parameter, and the lower region has a problem with the Hydrological Quantitative Pressure parameter.

Table 7 Compendium of regional results for the Reventazón River Basin, according to the WSI indicators and parameters.

Region	Indicator	Pressure Score	State Score	Response Score	Indicator Score		REGION FINAL SCORE
High	Water Quantity	1.00	1.00	1.00	1.00	0.88	0.74
	Water Quality	1.00	0.75	0.50	0.75		
	Environment	0.75	0.75	0.75	0.75		
	Life	0.50	0.75	0.50	0.58		
	Policy	0.75	0.75	0.75	0.75		
	AVERAGE SCORE	0.80	0.80	0.70			
Middle	Water Quantity	0.75	1.00	1.00	0.92	0.83	0.73
	Water Quality	1.00	0.75	0.50	0.75		
	Environment	0.50	0.75	1.00	0.83		
	Life	0.50	0.50	0.50	0.50		
	Policy	0.75	0.75	0.75	0.75		
	AVERAGE SCORE	0.70	0.80	0.75			
Low	Water Quantity	0.50	1.00	1.00	0.83	0.79	0.74
	Water Quality	1.00	0.75	0.50	0.75		
	Environment	0.75	0.75	1.00	0.83		
	Life	0.75	0.50	0.50	0.58		
	Policy	0.75	0.75	0.75	0.75		
	AVERAGE SCORE	0.75	0.75	0.75			
PARAMETERS TOTAL SCORE		0.75	0.78	0.73			

4 Conclusions

The WSI results point to problems on each region. The generally low scores on the Life indicator show relatively unfulfilled living conditions on the entire basin. The low Response parameter on Hydrological Quality indicates the need for the improvement of treatment plants and proper wastewater disposal in the watershed. Results for the Pressure parameter in the Quantitative Hydrology indicator indicate the possibility of future increases in water availability in the lower region. Scores for the Environmental Pressure parameter mean that the middle region suffers from the impacts of agricultural and human activities.

Through COMCURE, the Reventazón River Basin should promote projects to improve its sustainability. The moment is critical to start making unprecedented efforts to restore the watershed, since the WSI results point not only to the major problem areas, but also to those which do not show signs of future improvement, unless intervention measures are taken.

5 Recommendations

- Add treatment and disposal systems for sewage and wastewater in urban and rural areas, in order to reduce pollution from sewage, soap, and agrochemicals.
- Continue COMCURE's work with local farmers, through sustainable agriculture projects in the basin area.
- Add solid waste collection systems and improve its treatment technologies. It is also desirable to train the basin's inhabitants on proper management and recycling practices.

REFERENCES

Arce, Rafael. (2004) *Resumen Diagnóstico Cuenca Reventazón*. Consultoría del Dr. Rafael Arce para Proyecto Redes Comunitarias para la Gestión del Riesgo, Costa Rica: www.cne.go.cr/CEDO-Riesgo/docs/2655/2655.pdf.

Atlas Cantonal de Costa Rica. *Guías de Costa Rica*: www.mapasdecostarica.info/atlascantonal/atlas_cantonal.htm.

Chaves, H., y Alipaz, S. (2007) An Integrated Indicator Based on Basin Hydrology, Environment, Life, and Policy: The Basin Sustainabilty Index. *Water Resource Management* , 21, 883-895.

Chaves, H. (2009) *Desarrollo y Validación del Índice de Sostenibilidad de Cuencas (ISC) para la Cuenca Hidrográfica del Canal de Panamá*. Autoridad del Canal de Panamá. Informe Técnico No. 269731.

Chaves, H. (2009) *Índice de Sostenibilidad de Cuencas en América Latina*. http://helpforum.ning.com/forum/topics/watershed-sustainability-index.

Instituto Costarricense de Electricidad (ICE). (2009) *Copia de Caudales Río Reventazón-1*.

Grupo de Hidrología. (2009) *ISC Hydrology Results Presentation*. Cartago, Costa Rica: COMCURE.

Grupo de Políticas. (2009) *ISC Policy Results Presentation*. Cartago, Costa Rica: COMCURE. HELP 2009. Tomado en 2009 de UNESCO: http://portal.unesco.org.

Hezri, A., y Dovers, R. (2006) Sustainability indicators, policy and governance: issue for ecological economics. *Ecological Economics*, 60, 86-99.

Iglesias, A. (2003) *Integrated System for the Treatment y Recycling of Wastewater in Latin America: Reality and Potential*. IDRC.

Information about Reventazón-Parismina. (2007) Taken from the October 2009 issue of *Hydrology for the Environment, Life and Policy*: http://helpforum.ning.com/page/information-about-1.

Instituto Nacional de Estadística y Censos. (2005) *C01 Población estimada cerrada según provincia, cantón y distrito 1999 - 2005*. Tomado en octubre de 2009 de www.inec.go.cr/.

Instituto Nacional de Estadística y Censos. (2005) *Extensión en has de las áreas silvestres protegidas según categoría*. Tomado en octubre de 2009 de www.inec.go.cr/.

Ness, B., Urbel-Piirsalu, E, Anderberg, S., y Olsson, L. (2007) Categorizing tools for sustainability assessment. *Ecological Economics*, 60, 498-508.

Parris, T., y Kates, R. (2003) Characterizing and measuring sustainable development. *Annual Environmental Resources*, 28, 13.11-31.28.

Programa de las Naciones Unidas para el Desarrollo - Costa Rica (PNUD-COSTA RICA), Universidad de Costa Rica - Escuela de Estadística (UCR). (2007) *Atlas del Desarrollo Humano Cantonal de Costa Rica 2007*. San José, C.R.: PNUD.

PNUD - *Informes sobre el Desarrollo Humano*. http://hdr.undp.org/en/statistics/data.

The Watershed Sustainability Index in the Limarí River Basin, Chile

NICOLE KRETSCHMER[1], ANJA WENDT[2], RICARDO OYARZUN[1,3] & HENRIQUE CHAVES[4]

1 *Centro de Estudios Avanzados en Zonas Áridas, Universidad de La Serena, La Serena, Chile* nicole.kretschmer@ceaza.cl

2 *Technische Universität Dresden, Fakultät Forst-, Geo-, Hydrowissenschaften, Fachrichtung Wasserwesen, Dresden, Germany*

3 *Departamento Ingeniería de Minas, Universidad de La Serena, La Serena, Chile*

4 *Faculdade de Tecnologia - EFL, Universidade de Brasília, Brasilia-DF, Brazil*

Abstract This paper summarizes the results of applying the Watershed Sustainability Index (WSI) in the Limarí Basin (13,356 km^2), located in the semi-arid North of Chile. The purpose of the WSI is to assess the sustainability of a basin, looking at hydrological as well as social, environmental, livelihood, and policy issues. Since the Index uses a Pressure-State-Response function, a long term period as well as a recent study period were considered here. The period studied was 2000-2009. The Limarí basin was divided into 5 sub-basins ranging between 1,000 and 4,300 km^2, which almost coincide with the administrative boundaries of the municipalities in the Limarí province. The overall WSI for the Limarí Basin was 0.63 (out of 1.0), which corresponds to an intermediate level of sustainability. Looking at the sub-basins, the worst result was 0.51 (lower limit of the intermediate level). The bottlenecks responsible for lowering the WSI in the basin were the hydrology and livelihood indicators, and management actions shall be centered in them to improve the basin's overall sustainability.

Key words Sustainability Index; Limarí; decision support; hydrology; environment; life; policy

1 Introduction

Even though integrated water management has been widely discussed in Chile since the late 90s, no integrative and systematic approach has been implemented yet. Recently, a more elaborated proposal from the environmental agency (formerly CONAMA, currently the Environmental Ministry, EM) has been submitted to promote and implement integrated water management on a catchment scale (Conama, 2007), but until now, no more than a general framework exists. Furthermore, the EM has developed a framework for Secondary Surface Water Quality Regulations (Conama, 2004), which is now again under development and assessment.

In the end of 2008, the region of Coquimbo initiated a new approach for a platform of discussion about water issues: The regional water round table. Through three regional workshops with high stakeholder participation, an agreement with clear objectives on what this "water entity" should address was formulated. Also here an integrated approach was the concern.

Decision makers have to define priority areas based on the development of the area. Thus, the calculation and analysis of an index about sustainable management is essential. Since the Limarí Basin is the main agricultural production region in North-Central Chile, it is relevant to provide its stakeholders, as well as decision makers, with new information obtained from all the data gathered in different areas.

2 Water Sustainability Index

The Watershed Sustainability Index (WSI) is an integrated indicator based on a basin's hydrology (H), environment (E), life (L) and water policy issues (P), and responses (Chaves, 2007). In the past these aspects were often treated separately and not integrated. In general, integrated indices are used for survey and planning purposes (Chaves, 2007). Thus the WSI was developed to propose an index which pays attention to all important issues influencing watershed sustainability.

In addition to that, the WSI also responds to the dynamic of the development process between these indicators, using a pressure-state-response function.

Table 1 Indicators and parameters of the WSI (adapted from Chaves, 2007).

Indicators	***Pressure***	***State***	***Response***
Hydrology	Variation in the basin's per capita water availability in the period analyzed, relative to the long-term average	Basin per capita water availability (long term average)	Improvement in water-use efficiency in the period analyzed
	Variation in the basin BOD_5[1] in the period analyzed	Basin BOD_5 (long term average)	Improvement in sewage treatment/disposal in the period analyzed
Environment	Basin's EPI[2] (Rural and urban) in the period analyzed	Percent of basin area with natural vegetation	Evolution in basin conservation (percent of protected areas, BMP_s[3]) in the period analyzed
Life	Variation in the basin per capita income in the period analyzed	Basin HDI[4] (weighted by county population)	Evolution in the basin HDI in the period analyzed
Policy	Variation in the basin HDI-Education in the period analyzed	Basin institutional capacity in Integrated Water Resources Management (IWRM)	Evolution in the basin's IWRM expenditures in the period analyzed

Each parameter receives a score (0; 0.25; 0.50; 0.75 or 1).
[1]*Biological Oxygen Demand,* [2]*Environmental Pressure Index,* [3]*Best Management Practices,* [4]*Human Development Index*

Finally all indicators are considered with the same weight when calculating the WSI by the following function:

$$WSI\ (0\text{-}1) = (H + E + L + P) / 4 \qquad (1)$$

The obtained WSI score can be divided accordingly into the following three groups that categorize the basin's sustainability: low (WSI < 0.5), intermediate (0.5 ≤ WSI ≤ 0.8), or high (0.8 < WSI).

3 Application to the Limarí Basin

The province of Limarí is located in the semi-arid North-Central of Chile (31° S). Here the normal average annual rainfall does not exceed 120 mm whereas potential evapotranspiration exceeds 1000 mm. Additionally the region has to cope with strong inter- and intra-annual variations of water availability. Nevertheless, the main activity in the basin (13,356 km²) is irrigated agriculture, which is possible through a regulated and coordinated hydrological and management system. It is physically composed by three reservoirs, storing together 1000 MCM, and the associated channel network. An important part of the irrigated area dedicates its production to pomiculture for exportation; just a small part is used for annual crops; the cultivated area below the channel network adds up to 65,000 ha (Kretschmer, *et al.*, 2008).

Because the basin management at the local and regional level is more effective in watersheds up to 2500 km² (Chavez, 2007), this is the upper limit suggested for the application of WSI.

In the Limarí Basin also the climatic, economical, and environmental conditions vary extremely between the mountainous areas in the east and the coastal areas in the west. Furthermore, the political boundaries are very similar to the main sub-catchments. Therefore, it was decided to divide the Limarí Basin according to the communes into the following five sub-catchments: Ovalle: 3558 km², Río Hurtado: 2180 km², Monte Patria: 4335 km², Combarbalá: 2283 km², and Punitaqui: 1001 km. (Fig.1).

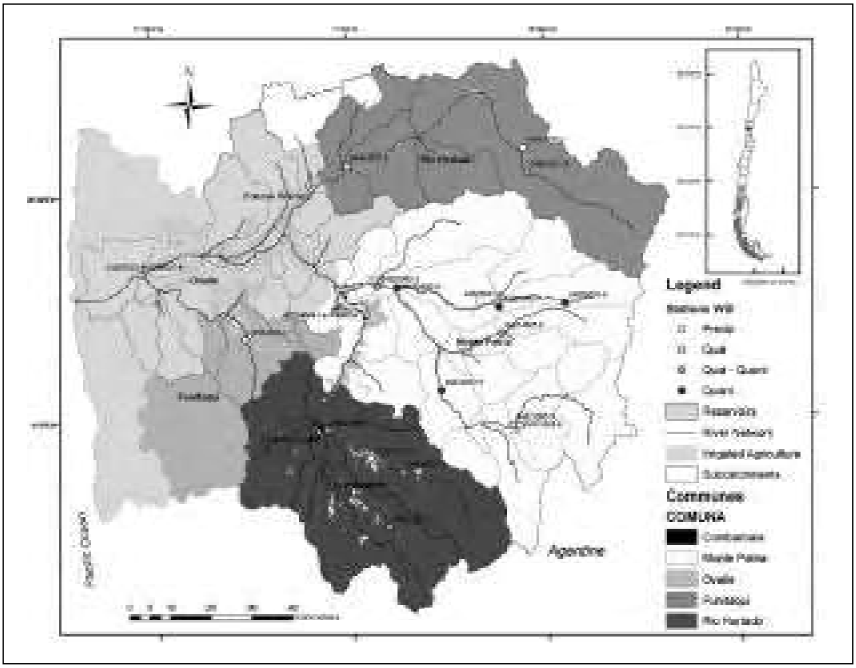


Fig. 1 The Limarí basin with its sub-basins, 5 different communes and monitoring stations.

Even though two municipalities are bigger than their sub-catchments (Ovalle and Punitaqui) due to the nature of data gathering regarding livelihood and policy information, we used the administrative boundaries for these Indicators.

Chaves & Alipaz (2007) suggest considering a 5-year study period because the HDI (Human Development Index) and other census data are published every five years in general. In Chile however, most data gathering has a 10-year interval, (e.g., agricultural census, population census).

Furthermore, the area of the Limarí Basin is located in a semiarid climate which in some years is strongly influenced by effects of "El Niño" or "La Niña". So that the final decision was made to analyze a 10-year period, from 2000 to 2009, to get a better average of the data assessed, including water scarce and water rich years, and it coincides almost with the two last agricultural censuses (1997, 2007).

For the calculation of the pressure parameter one has to look at the change between the long-term average and the actual study period. Long-term average depends on the availability of the data, which varies between 1960 - 2009, depending on the kind of data looked at. The shortest period of long-term data was given for the water quality data. If data were available, the period between 1972-2009 was used.

4 Hydrology Indicator and Final Results

As an example, the calculation of the WSI Score by the Hydrology indicator is shown in more detail. The hydrology indicator consists of two sets of parameters: one relative to water quantity and the other to water quality. The resulting hydrology WSI is simply the average of the basin's quantity and quality parameters. The pressure parameter concerning water quantity refers to variation of the per-capita water availability per year (in m3) in the period studied, in relation to the long-term average, calculated with the equation below.

$$\Delta avail.Q = \frac{Q2 - Q1}{Q1} * 100 \qquad (2)$$

where: $\Delta avail.Q$ = variation in the basin's per capita water availability in the period, relative to the longterm average (%); $Q2$ = average of the basin's per capita water availability in the period studied (2000-2009); and $Q1$ = average of the basin's per capita water availability in the historic period (1972-2009).

Table 2 Description of water quantity pressure levels and WSI score.

Level	WSI score
$\Delta avail.\ Q < -20\%$	0,00
$-20\% \leq \Delta avail.Q < -10\%$	0,25
$-10\% \leq \Delta avail.Q < 0\%$	0,50
$0\% \leq \Delta avail.\ Q < +10\%$	0,75
$+10\% \leq \Delta avail.Q$	1,00

The calculation of the Hydrology parameters was done with the data of the different monitoring stations which were selected for this study, shown in Fig.1, as well looking at the reservoir management, since the sub-basins were considered separately. Without having the possibility to go into detail, the results shown in Table 3 were obtained using surface water data and groundwater information (Source: DGA and Information of River Authorities) as well as population data (INE: National Statistical Institute).

Table 3 WSI of the Hydrology indicator per sub-basins (Scores and final WSI).

Sub-Basin	Pressure Quantity/Quality	State Quantity/Quality	Response Quantity/Quality	WSI result
Combarbala	0.00 / 0.50	1.00 / 1.00	0.25 / 1.00	0.63
Rio Hurtado	0.75 / 0.75	1.00 / 1.00	1.00 / 1.00	0.92
Monte Patria	0.50 / 0.75	1.00 / 1.00	0.75 / 0.25	0.71
Ovalle	0.25 / 0.50	0.25 / 0.50	0.75 / 1.00	0.54
Punitaqui	0.25 / 0.50	0.25 / 0.50	0.25 / 0.25	0.38

Response of the Quantity Pressure has been evaluated analyzing the water management of the different sub-basins by their corresponding river/channel and reservoir authorities, and looking at the development of irrigation techniques and the corresponding irrigated areas, analyzing the agricultural census of 1997 and 2007. In Table 3 it can be clearly seen how different the results are in the different basins.

Looking at the water quality part of the Indicators, the WSI refers normally to the BOD5 as a quality parameter to consider, assuming that in the main parts in the world this parameter is available. Unfortunately it is not considered in the monitoring program of the water authority -DGA (Dirección General de Aguas)-, so based on a previous study, EC (Electric Conductivity) was chosen to be the parameter to consider in the whole basin. This needed a new adaption on the WSI scores, which have been altered due to Chile's secondary water quality standard. The response score was assessed looking at investments in sewage treatment plants (source: SISS) and in canalization (source: FNDR).

In the same way, looking at the corresponding parameters for Environment, Life, and Policy, the WSI scores were adapted from Chaves & Alipaz, 2007. To analyze the policy response we looked at data of the National Irrigation Commission (CNR), which subsidizes investments in irrigation techniques; the National Fund for Regional Development (FNDR), which funds installations for potable water, and the Sectoral Fund of the MOP (Ministry for public constructions), which also supports installations for potable water, mainly in rural areas. As we calculated the scores and parameters for the whole Limarí Basin it was possible to estimate the overall WSI as well. Table 4 shows the results of the WSI.

Table 4 Final WSI per sub-basin and for the entire basin.

Sub-Basin Indicator	WSI Combarbala	WSI Rio Hurtado	WSI Monte Partia	WSI Ovalle	WSI Punitaqui	WSI Limarí Basin
Hydrology	0.63	0.92	0.71	0.54	*0.38*	*0.54*
Environment	0.83	0.83	0.75	0.67	0.75	0.74
Life	0.67	0.58	*0.42*	*0.50*	*0.33*	*0.58*
Policy	0.67	0.67	*0.50*	0.59	0.58	0.67
Results	***0.7***	***0.75***	***0.59***	***0.57***	***0.51***	***0.64***

For calculating the overall WSI for the Limarí Basin out of the sub-basin WSIs, we used as a weighting factor the surface area of each sub-basin, like it was done previously for the calculation of the WSI for the Panama Canal basin (UNESCO, 2008).

$$\text{WSI (weigted by areas)} = \frac{\sum[\text{WSI(sub-basin)*Area (sub-basin)}]}{\text{Area (total)}}$$

As an overall result we obtained a *Limarí Basin WSI of 0.63*, which slightly differs from the result shown in Table 4, due to rounding. In terms of basin sustainability, this represents intermediate sustainability.

5 Discussion

For an extensive discussion, the intermediate results of the Pressure/State/Response scores, are of high importance, especially for decision makers to see where the bottlenecks are. Looking at the single indicators of the WSI one can see that the bottlenecks are overall the Hydrology indicator and the Life indicator, which are on the lower edge of intermediate sustainability, just above 0.5. Going into sub-basin/municipality details, it is obvious that the calculation of smaller spatial units is very valuable. Indeed, here we get WSI scores for Punitaqui for Hydrology and Life which correspond to *low sustainability.* The highest score represents the sub-basin of Rio Hurtado, mainly due to the very high WSI in the Hydrology indicator, which is the only one in high sustainability. This is due to a different climate, better management, as well as fewer inhabitants (2.65% of the total basin population). But here also the Life indicator gets a low score. The bottlenecks are quite different looking at the Pressure, State and Response variables of the different sub-basins. The response variable is best in the Hurtado and Combarbala basin (both upstream basins) and worst in Punitaqui and Monte Patria; pressure is highest in Ovalle and Punitaqui. This shows that pressure and response do not match as probably needed.

6 Conclusion

The WSI makes it possible to look in detail at 5 different areas in an integrated way, which is important for sustainable development and shows clearly where action is mostly needed. Improvement is still needed in the distribution of information. Due the new transparency law in Chile, now all public institutions are obliged to provide their information, but working with them made it again clear that inside the institutions data/information management needs often to be improved, specially regarding historical information.

REFERENCES

Chaves, H.; Alipaz, S. (2007) An Integrated Indicator Based on Basin Hydrology, Environment, Life, and Policy: The Watershed Sustainability Index, *Water Resources Management* 21: 883-895.

Kretschmer N., Corso S., Alvarez P. (2008) *Water allocation strategies and their implications - A Drought in the Limarí Watershed, Chile*; Conference proceeding: The International Water Resource Association XIIIth World Water Congress in Montpellier, France, September 2008.

UNESCO. (2008) *Evaluación Preliminar de la Aplicación y Cálculo del Índice de Sostenibilidad de Cuenca en la Cuenca Hidrográfica del Canal de Panamá*, Documento Técnico del PHI-LAC N° 12.

Evolution of Environmental Education for the Conservation of Water Resources in the Panama Canal Watershed

ROLANDO CHECA CAMPOS
Watershed Management Section, Panamá Canal Authority, Panamá
rcheca@pancanal.com

Abstract This paper presents the progress of environmental education experiences in formal, non-formal, and informal settings, relating to natural resource conservation, specifically in the Panama Canal Watershed, beginning in the year 2000. The historical context of the progress of environmental education in this region is related to the transfer of the Canal, which was previously managed by the U.S. agency known as the Panama Canal Commission, to Panama in 1999, now under the responsibility of the Panama Canal Authority. The Panama Canal Authority (ACP), in conjunction with the Ministry of Education (MEDUCA), the National Environmental Authority (ANAM) and the United States Agency for International Development (USAID), have strengthened the progress of environmental education via the Watershed Guardians (unique to Panama), which has become a flagship program in this important region.

Key words Environmental education; water resources; educational community; watershed; Panama Canal Authority; Watershed Guardians

1 Introduction

There is no doubt that the history of the Panama Canal is rich in technical documents, photo and film evidence, as well as oral and written testimonies from many workers and witnesses to the monumental task. Thus, we can infer the evolution of conservation actions during and after completion of the project, as well as through its operation after its inauguration in 1914.

In this sense, it is important to note that among the relevant actions that gave Americans construction advantages in this project, which started in 1904, was the focus on environmental sanitation, implemented in the cities of Panama and Colon, as well as in villages and work sites adjacent to the Canal, in order to combat mosquitoes and thus, eradicate yellow fever and other diseases transmitted by such.

Activities were aimed at environmental health issues through cleanups, guidance, and talks provided to both the working population and the general community. Other environmental elements were incorporated by waves of researchers who worked on various scientific research projects in sites near the Canal.

Environmental education emerged in response to the environmental crisis, and should be understood as a learning process that facilitates the comprehension of environmental realities and the socio-historical process that led to its current decline. It aspires to each individual possessing an adequate awareness of the dependence and belonging to his/her surroundings, and feeling responsible for his/her individual use and maintenance, thus becoming capable of making decisions in this area (Alea, 2005).

It was not until 1972 when the environmental education concept acquired its international patent, as a result of the Stockholm Declaration. While an environmental education boom ensued in developed countries, Latin America was applying it at a slower pace, due to the influence of multiple factors, including: the underdevelopment of most countries in the region, their educational systems, the regional economy, and the fragmented view of human, social, and environmental issues, among other elements.

Specifically regarding environmental education in the Panama Canal area, it is important to note four key aspects in this historical progress:

- The Panama Canal Authority emerged as a state institution responsible for the administration of the waterway, through Title XIV of the Constitution of the Republic of Panama.
- Environmental education in Panama was legally strengthened via Law Number 10 of June 1992, which adopted environmental education as a national strategy to conserve and develop natural resources and preserve the environment.
- The enactment of Law Number 44 of August 1999, which approved the boundaries of the Canal Watershed, and was then repealed in 2006. This included a part of the Coclé province territory, as well as other lands in the province of Colon, which were considered to have "water potential" for the Canal; and
- The significance of the environmental education concept has been developed, as a result of meetings and international discussions, to the extent that various authors have began to give the concept greater consideration.

Based on these facts, and after seeking an approach for the use and implementation of an environmental education concept in Canal operations or activities, the practice formally began in the year 2001. However, it is important to mention that in 1997, under the administration of the Panama Canal Commission, a team worked with populations close to the riparian areas of the Canal to prevent the theft of navigation signaling equipment (solar panels, batteries, cables, etc.). Environmental education resources to increase awareness were employed in this initiative, and eventually an interagency team that offered information and guidelines for environmental protection was formed. In other words, the activities that gave rise to the current management arose in a context with objectives other than environmental education.

In 2000, the Environmental Management Division was formally launched as a key operating unit to ensure compliance with constitutional responsibilities of the Panama Canal Authority (ACP), such as administration, maintenance, use, and conservation of water resources in the Canal Watershed.

Beginning in 2001, the ACP's Watershed Management and Institutional Coordination Division, whose duties were designed to reinvigorate relations with the Ministry of Education (MEDUCA), the National Environmental Authority (ANAM), and other institutional and non-governmental organizations, began to facilitate workshops and short seminars to school teachers within the Watershed. Further emphasis was placed on the production of educational resources and information, intramural activities, and the construction of an environmental education model that could articulate institutional actors.

In 2002, the ACP strengthened its staff and consolidated strategies with MEDUCA and ANAM to establish an adequate platform to share knowledge, experiences, and joint actions, and initiate the construction of an environmental education model for the Canal Watershed. As a result, in March of that year, a Memorandum of Understanding was signed between the ACP, ANAM, MEDUCA and USAID, for the development of an environmental education program called "The Watershed Guardians."

Overall, the program's aim is to promote, together with multiple stakeholders, an environmental culture that fosters sustainable development, and to train human capital in educational communities for efficient and effective participation in the conservation the Canal Watershed's water resources.

From 2003 to 2010, a vision was projected at the strengthening and mainstreaming of school management and inter-agency and multi-cultural participation, in such a manner that takes into account the values, ideas, beliefs, knowledge, attitudes, and behaviors of inhabitants of the Canal

Watershed, under an ecosystems perspective focused on commitment to act against social and environmental risks that threaten the region.

During this period, emphasis was placed on knowledge management that was focused on training teachers and the Watershed Guardians administrators by conducting capacity building activities in the form of workshops (up to 40 hours), high-level courses (more than 120 hours), college degrees (more than 200 hours), educational and scientific field trips, field workshops, etc.

The themes follow logical sequences, as well as relevant design, in harmony with the content of current educational programs that take into account local realities, needs, and interests.

The following relevant themes will continue to be the program's focus:

- Importance of the Canal Watershed
- Project management and environmental leadership
- Strategies for strengthening the Watershed Guardians Program
- Training on the correct use of handling agrochemicals
- A Sustainable Development and Environmental Education degree program
- Strategies for managing solid waste at the community level
- Integrated management of water resources and environmental education
- Incorporating climate change issues in environmental education
- Using protected areas as an environmental education teaching tool

In 2010, an effort was made to create alliances with other institutional stakeholders, to jointly develop and launch a Watershed Academy, to provide a space to share knowledge and a platform for the virtual capacity building and training of teachers.

The development of educational resources (posters, manuals, guides, games, etc.) has been a strength of the ACP's personnel, which, from an institutional and inter-institutional perspective, has positioned it as a critical resource for providing information and activities to students and teachers of 153 schools within the Canal Watershed, as well as other peripheral area buffer zones.

Projection of environmental education in the Canal Watershed, from its scope and levels of functional complexity and application within the institutional reality and in the region, constitutes a part strategic management initiatives for achieving awareness and participation of community leaders (teachers, students, administrators, parents, parent-teacher associations, community organizations, etc.) for the analysis, discussion, and resolution of socio-economic problems and, therefore, provides opportunities to increase knowledge and experience in order to implement sustainable development management strategies and actions.

Other means of substantial conceptual and practical development of strategic management of environmental education in the Canal Watershed have occurred via the development project, "Our Canal and Your Watershed" (NUCA, acronym in Spanish), through which entrepreneurship and basic environmental economic courses are provided to fourth-grade students. Similarly, the environmental mission is reinforced through exploring the following issues: analysis of water quality using basic equipment, solid waste management in schools, risk management associated with floods in schools adjacent to the lake and dam sites, reforestation and school nursery projects, and more recently, school cooperatives.

The Watershed Guardians' Network of Environmental Educators started in 2010. Their mission is to ensure the development of the program from the perspective of professionals in the field, by implementing active research, publications, conferences, and other related events to provide advice on the design of environmental education curriculums generated for the program.

Fig. 1 Environmental Fair.
Source: Environmental Education, ACP.

Participation in the Watershed Guardians program has been achieved through the development of environmental seminars and meetings, which take place in individual schools, then in school districts, and so on, until they become inter-regional events. These events include environmental contests (poetry, drawing, storytelling, successful school experiences, etc.), meetings (events in which representatives from each school program can participate), and workshops and seminars (for teachers and members of local committees, with specific topics that serve as an opportunity for sharing knowledge and the joint organization of community environmental endeavors).

The institutional approach aims to develop activities that enable ACP staff to interact in the process of creating awareness, as well as changing attitudes and behaviors towards sustainable livelihoods. This is conducted through capacity building and the implementation of sound environmental practices at work sites, and by promoting a general understanding of the importance of water resources that drive the Panama Canal. It is also interesting to mention institutional education campaigns via the 3R's (Reduce, Reuse, Recycle) and staff training on environmental issues.

Community and institutional participation in environmental fairs and events has facilitated the transfer of knowledge and information processes, the services and products that the ACP provides to the national community, as well as the positive results of the Canal Watershed's environmental management.

2 Theoretical Framework

In general, the principles which underpin this initiative are:

a. Historical research
b. Environmental education in the educational community and within the institutional framework
c. The objectives of environmental education

First of all, historical research can explain how to reconstruct the past as objectively and accurately as possible, by systematically collecting, evaluating, verifying and summarizing evidence to obtain valid conclusions.

Secondly, environmental education and revitalization within the context of the community can help us understand it as a dynamic and participatory process that facilitates and promotes awareness of a more friendly and sustainable human-nature interaction, from local to global perspectives and back. In addition, the educational community is a group of people who influence and are affected by an educational setting, and who are responsible for promoting activities that facilitate the improvement of the quality of education.

On the other hand, institutional concepts, such as how to involve human beings of a particular society or group in seeking the common good for that group, seek to normalize behavior in a group of individuals.

Finally, the objectives of environmental education, according to the Belgrado Charter (October 1975) are:

- *Awareness.* Helping individuals and social groups acquire greater sensitivity and awareness of the environment and its problems.
- *Knowledge*. Helping individuals and social groups acquire a basic understanding of the environment as a whole, related problems, and the presence and role of humanity in it..
- *Attitudes*. Helping individuals and social groups acquire social values and a deep interest in the environment.
- *Skills.* Helping individuals and social groups acquire the skills to solve environmental problems.
- *Capacity assessment*. Helping individuals and social groups evaluate measures and environmental education programs in terms of ecological, political, social, aesthetic, and educational aspects.
- *Participation.* Helping people and social groups develop their sense of responsibility and be aware of the urgent need to pay attention to environmental issues, and to ensure appropriate action.

3 Objectives

The initiative's overall objectives are:

a. To provide a space for research and systemize the historical progress of environmental education in the Canal Watershed, to serve as a reference and comparative framework when sizing up and evaluating the efforts, investments, processes, services and products from the ACP, that are performed on this topic.
b. To establish integrated connections into the ACP's framework, on order to facilitate the transformation and continuous improvement of environmental education management in the Canal Watershed.

4 General Achievements

- Strengthening inter-institutional development and a strong tendency toward the structuring of a model of environmental education in the Canal Watershed for a responsible environmental behavior.
- Active participation and commitment of the educational community with successful experiences in environmental education.
- Proposals and development of projects and environmental activities that positively affect the educational community.

- Teachers with specific training in environmental education, participating in academic activities at the regional and national levels.
- Development of inter-zonal activities and interregional integration to strengthen the Watershed Guardians program.
- Building a sense of belonging and strengthening environmental culture to achieve attitude and behavior changes.
- Establishing a trend toward implementation of strategies for improving the quality of life of community members and members of the institution.

REFERENCES

ACP, ANAM, MEDUCA y USAID. (2002) *Memorando de Entendimiento: Para el desarrollo del Programa de Educación Ambiental "Guardianes de la Cuenca"*. Panamá.

Alea, A. (2005) Breve historia de la educación ambiental: del conservacionismo hacia el desarrollo sostenible. *Revista Futuros* 12, Vol. 3.

Constitución de la República de Panamá.

Gaceta Oficial. (1992) *Ley N°10, de junio de 1992, por la cual se adopta la educación ambiental como una estrategia nacional para conservar y desarrollar los recursos naturales y preservar el ambiente*. Panamá.

Gaceta Oficial. (1999) *Ley 44, de agosto de 1999, por la cual se aprobaron los límites de la Cuenca Hidrográfica del Canal*. Panamá.

Seminario Internacional de Educación Ambiental. (1975) *La Carta de Belgrado*.

New Learning Foundations for Building Water Knowledge Bridges

SUSANA NETO[1] & JEFF CAMKIN[2]
1 *Technical University of Lisbon, Portugal*
susana.neto@netcabo.pt
2 *Centre of Excellence for Ecohydrology, University of Western Australia, Australia*

Abstract Five regional meetings promoted by UNESCO in 2009 (North-America, Europe, Asia, Australia, and Africa) addressed the growing need for transdisciplinary approaches, holistic vision, incorporation of non-formal knowledge and views, effective participation, and bottom-up action for identification of problems and solutions. There is, however, a general context of tension and competition between specialisations within different disciplines, and without specialisation it is difficult to obtain formal and academic recognition, either at the Undergraduate, Masters, or Ph.D. level. The 2010 Capacity Building Workshop on Water Education in Paris identified the need to build tertiary or vocational level programs that include participants with different backgrounds, in order to facilitate cooperation and exchange of views. The integrated approach should enable communication between specialists addressing specific problems and other experts and practitioners, providing new skills and knowledge competence -a new 'water practitioner' profile. This paper presents insights into experiences of new learning methodologies being applied as part of the Erasmus Mundus M.Sc. in Ecohydrology, in collaboration with the UNESCO International Centre for Coastal Ecohydrology and the UNESCO-IHP HELP network. Two courses have been delivered to date, the first one on Global Water Issues and IWRM in 2010, and the second one on Global Ecohydrology in Action in 2011. The courses utilised the HELP network to bring together experts with practical experience, and in applied and academic research. Drawing on their experiences and those of their colleagues, guest presenters, and course leaders, the participants reflected on their practical IWRM challenges and reconsider their options from a range of new perspectives. Participants are encouraged to think 'outside the water box' and focus on the role of IWRM in delivering a broader set of society's policy objectives.

Key words IWRM; learning methodologies; transdisciplinary approach; HELP network

1 Introduction

Growing global water challenges are well documented (UNWWAP, 2009; FAO, 2011). Demographics and increasing consumption resulting from rising per capita incomes are the most important drivers or pressure on water (UNWWAP, 2009). According to the UN, population dynamics such as growth, gender and age distribution, and migration create pressures on freshwater resources through increased demand and pollution. Further, landscape changes associated with population dynamics such as migration and urbanization can create additional pressures on local water resources and increase the need for water services (*Ibid*). The anticipated impacts of climate change pose additional stress on food production systems already under pressure to satisfy the food needs of a rapidly growing and progressively wealthier world (FAO, 2011). As agriculture develops and land and water use intensifies, the impact of agriculture on natural eco-systems becomes even more apparent. This impact damages the integrity of those ecosystems, undermining the food-producing systems that they support. According to the FAO (2011), effective adaptation to the impacts of climate change on water and agriculture will require a sound understanding and integration of agronomic science with water management and hydrology, together with due regard for the resulting environmental interactions and trade-offs.

As pressure on the world's water resources has increased, it has translated into new and increasingly interconnected challenges. In response, water management has also changed over time, with the introduction of new disciplines, new techniques, a new language, and new thinking.

Ecology, economics, and other social sciences have all progressively added to the historic hydrology and engineering base. The evolution and verification of new problems has led to the need to adopt "imported" terms from other sciences (Neto, 2010). This has often led to the use of concepts that were originally defined for a determined purpose in a specific disciplinary context being commonly used with a diverse scope in other disciplinary areas. According to Neto (2010) "this has given rise to a certain conceptual confusion and the construction of a mixed terminology that was not always duly referenced. For example, the concern to bring the efficiency angle into the management of water resources so as to contemplate economic costs led to various terms originating from economics being added to the 'hydrology' vocabulary. An illustration of this is the generally unsuitable and out of context application of the term 'supply' and 'demand' of water, or the 'water market', restricting the assertion to a service provision and interpreting water as a mere 'commodity', subject to natural monopoly". More recently, sociology, anthropology, and social psychology have also become part of solution to the challenges of water management. This has required re-thinking some of the previously integrated terms and encouraged a more rigorous definition of the concepts used by different specialists (*Ibid*).

There has been a shift from seeking solutions within individual scientific disciplines to multidisciplinarity, interdisciplinary solutions and, more recently and increasingly, transdisciplinary thinking and approaches -i.e., to seeking solutions in the interstitial spaces between scientific disciplines. Bammer (2005) describes the important differences in these approaches. Multidisciplinarity does not require researchers to leave their disciplines; it tackles issues by getting researchers in a range of disciplines to use their traditional theories and methods to present an understanding and then attempts to integrate these different understandings. In an interdisciplinary approach, researchers from small clusters of neighbouring disciplines, such as physics, mathematics, and chemistry, or sociology and anthropology, look beyond their own discipline and work together to find areas of overlap likely to yield new understanding. A transdisciplinary approach aims to develop a new common conceptual framework that provides a new level of coherence for the different disciplines. According to Bammer (2005), "researchers must collaborate and integrate across traditional boundaries. They must bring together academic disciplines and become more involved in the implementation of research in policy, product, and action".

There has also been a shift towards the globalisation of both problems and solutions. As problems become increasingly connected, they are also increasingly globalised. Recognition of this globalisation of water problems has triggered awareness of the opportunity to draw ideas and possible solutions from a world of practical experiences in both similar and different contexts. "Researchers, funders, and research end-users are increasingly appreciating that new research skills must be developed if human societies are to be more effective in tackling the complex problems that confront us, and in sustaining the sort of world we wish to live in" (Bammer, 2005). Recent experiences have increased awareness of the risks and consequences of water use decisions. Communities now expect developments to not only have acceptable environmental impacts, but also deliver social and economic benefits. Furthermore, non-government organisations and individuals are better trained, connected, and equipped to monitor decisions. Together, these trends are increasing pressure on decision-makers and dealing with complexity and uncertainty emerges as a shared need and responsibility for government, developers, and the community, so that good decisions can continue to be made (Camkin, *et al*., 2008). In response to this pressure, there is rapid growth in the development of on-line technology that utilises new approaches to learning and supports communities of practice in the resolution of complex problems (*Ibid*).

Five regional meetings promoted by UNESCO in 2009 (North-America, Europe, Asia, Australia, and Africa) addressed the growing need for transdisciplinary approaches, holistic vision, incorporation of non-formal knowledge and views, effective participation, and bottom-up action for identification of problems and solutions. There is, however, a general context of tension and competition between specialisations within different disciplines, and without specialisation it is difficult to obtain formal and academic recognition, either at the Undergraduate, Masters, or Ph.D. level. The 2010 Capacity Building Workshop on Water Education in Paris identified the need to build tertiary or vocational level programs that include participants with different backgrounds, in order to facilitate cooperation and exchange of views. The integrated approach should enable communication between specialists addressing specific problems and other experts and practitioners, providing new skills and knowledge competences -a new 'water practitioner' profile.

A key question is whether any ongoing tension between the need for transdisciplinary thinking and the disciplinary focus of traditional science, and the inclusion of non-scientific knowledge, is being sufficiently addressed to create the freedom and flexibility needed to tackle the increasingly interrelated and complex water challenges the world is facing. The UNESCO-IHP HELP program, including its network of 91 river basins in 67 countries, and more than 2,000 individual lawyers and policy makers, industry and community stakeholders, together with scientists of many different disciplines, provides an outstanding source of experiences, ideas, and potential solutions to water challenges. The UNESCO-IHP Ecohydrology programme also includes a suite of demonstration sites where sustainable, innovative, and transdisciplinary water management practices based on Ecohydrology principles are being implemented, providing yet another important source.

But what more needs to be done? The remainder of this paper presents insights into experiences of new co-learning methodologies being applied as part of the Erasmus Mundus Master Course (EMMC) in Ecohydrology, in collaboration with the UNESCO International Centre for Coastal Ecohydrology (UNESCO-ICCE) and the HELP and Ecohydrology networks. We will describe our approach, feedback from the courses, what we learnt as course coordinators, and some suggestions for the future of HELP and the Ecohydrology Demonstration Sites Programmes.

2 Discussion

The EMMC in Ecohydrology is delivered through a consortium of the UNESCO Institute for Water Education (Netherlands), the University of Lodz (Poland), the Christian Albrecht University of Kiel (Germany), the National University of La Plata (Argentina), and the University of Algarve (Portugal). Several other research institutions and UNESCO Centres from Europe, Latin America, Asia, and Australia are associated with the course, contributing with advanced study courses and promoting student exchange. The EMMC is delivered over 18 months through four modules (thematic areas):

a. Understanding functions, processes and threats in aquatic ecosystems
b. Toolbox for applying Ecohydrology: environmental impact modelling
c. Development of personal skills and research project implementation
d. Integration and specialisation in management or engineering of aquatic ecosystems

The authors of this paper were invited to develop new short courses as part of the M.Sc. curricula to be delivered at the University of Algarve in Faro, Portugal. Two courses were subsequently developed and delivered: Global Water Issues and Integrated Water Resource Management (IWRM), in December 2010; and Global Ecohydrology in Action, in August 2011.

Global Water Issues and IWRM Short Course

The Global Water Issues and IWRM short course was delivered over six days at the beginning of Semester 1 of the EMMC in Ecohydrology, as an elective subject within Module 2: Toolbox for Applying Ecohydrology. There were 11 student participants from 11 different countries: Bangladesh, Bosnia, China, Ethiopia, Germany, India, Poland, Portugal, Tanzania, Turkey, and the United States. Participants had a wide range of experiences and a variety of backgrounds, including hydrology, geography, biology, ecology, fisheries science, environmental science, aquaculture, meteorology, and oceanography. They were introduced, through presentations and discussions with the course coordinators, to the range of current global water issues, the history and intent of key international agreements relating to water, and the core principles of IWRM. In recognition that each of the participants already had important skills and experience, and that collectively the breadth of backgrounds and nationalities brought a wealth of learning opportunity, the participants were engaged in a co-learning dialogue with the course coordinators and their course colleagues over six days. Through semi-structured exercises, including IWRM role playing, participants expressed their own experiences and accessed those of their course colleagues and coordinators. They were encouraged to continually think 'outside the water box' and to focus on the role of IWRM in delivering a broader set of policy objectives. Participants were asked to reflect on the practical IWRM challenges they have been involved with and to consider their options from a range of new perspectives. At the end of the course, each participant gave a brief 'IWRM in Practice' presentation and submitted a final 'Implementing IWRM in Practice' essay on a chosen experience, demonstrating how they might do things differently taking into account what they learned through the course.

Global Ecohydrology in Action Short Course

The Global Ecohydrology in Action short course was delivered over three days at the end of Semester 2 of the EMMC in Ecohydrology as a core subject within the EMMC Summer School. It was designed to help balance the theoretical components of the EMMC with access to real life experiences. There were nine student participants from eight different countries: Bangladesh, China, Ethiopia, India, Kazakhstan, Poland, Tanzania and Uganda. Participants were introduced to several practical examples of Ecohydrology in Action, drawn primarily from UNESCO HELP and Ecohydrology Demonstration Site programs. On the first day, the UNESCO Global Coordinator for HELP and Ecohydrology programs gave an online welcome to the participants, and each day they received online presentations from leading scientists, policy-makers, and industry or community stakeholders involved with a HELP Basin or Ecohydrology Demonstration Site. From their offices in New Zealand, Malaysia, Philippines, and Belgium, the guest presenters gave an overview of the HELP Basin or Demonstration Site and described the practical role that Ecohydrology is playing in their management. Presenters were encouraged to add a personal touch through their own experiences and views. Participants and presenters were in visual and audio contact, and the students had opportunities to ask questions or seek clarification during the presentations, and to discuss issues directly with the presenters during the online tutorial session that followed. Reflecting on what they had heard, participants were asked to identify the challenges faced, the management objectives, and the ways in which Ecohydrology was contributing to meeting the management objectives, as well as to share their thoughts on whether the use of Ecohydrology principles has made a substantial difference. On the final day, each participant gave a brief presentation describing what they learned about Ecohydrology from the Ecohydrology in Action examples and the EMMC.

At the completion of both courses, participants were asked to provide feedback to the EMMC course convenors. At the end of the Global Ecohydrology in Action course, participants interviewed each other on video, at their own initiative, to record their thoughts. These video recordings demonstrate that participants appreciated the course methodology. The participants obviously connected with the guest presenters and were able to recognize the relationship between the practical challenges being faced in the HELP Basins and Ecohydrology Demonstration Sites, and the theory they learned during other EMMC subjects.

The EMMC Coordinator summarised feedback from participants of the two short courses: "The courses were very interesting. They covered a broad range of issues dealing with water resources, and participants realized the crucial importance of considering the human dimensions in the management of water resources. They realized that without engaging society, both from the perspective of the driver for the changes, but also as receiver of the changes, it is not possible to find and establish sustainable solutions for water resources globally. The methodology of promoting dialogue with stakeholders and society that was taught was considered very useful by participants, and it provided good results in enabling profitable dialogue with all the actors involved in the complex management of water resources" (L. Chicharo, 2011, pers. comm., 25 August).

3 Conclusions

In these two courses we attempted to develop a new co-learning methodology aiming at a transdisciplinary approach, which is built from the different backgrounds of each student, their own experiences and expertise, and their expectations. Through the presenters and coordinators, participants not only benefited from new information and experiences, but accessed personal professional networks that are based less on any disciplinary framework and more on a shared vision for IWRM. The participants were invited by several of the guest presenters to contribute their experiences and ideas towards solving existing challenges within the HELP Basins and Ecohydrology Demonstration Sites, further representing a fundamental shift from accessing a professional networks and knowledge to becoming part of the network and knowledge base itself.

Critical to this methodology was also the commitment of individuals within the HELP network. The clearly evident emotional involvement and generosity of the guest presenters -they gave more than just their abundant knowledge- was a catalytic factor that helped participants make the connection between the individual subjects they had studied through the EMMC and the real problems they will have to solve in practice. This commitment and generosity, delivered in relation to real problems through subjects that consolidate the learning from the more technical subjects in the ERMC, was a powerful combination.

Besides different disciplinary backgrounds and countries, there were also very different socio-political contexts represented by participants from developing and developed countries. Actively encouraging the participants to put their stories on the table enabled all participants to view water problems from the widest range of perspectives, providing a significant learning opportunity.

The experiences of the EMMC Global Water Issues and IWRM, and Global Ecohydrology in Action short courses suggest that a substantial opportunity exists for the HELP community to actively and cost effectively contribute to meeting the needs identified at the 2010 Capacity Building Workshop on Water Education in Paris: tertiary and vocational level courses that include participants with different backgrounds in order to facilitate cooperation and exchange of views. Through courses such as these, the HELP community can support both immediate and longer term communication between specialists addressing specific problems, other experts and practitioners, and emerging water professionals, providing new skills and knowledge competences, and helping to develop a new 'water practitioner' profile.

Acknowledgements
We acknowledge the generosity and commitment of all the guest presenters to the EMMC Global Water Issues and IWRM, and Global Ecohydrology in Action courses: Prof. Shahbaz Khan, Prof. Mazlin Mokhtar, Dr. Rahmah Elfithri, Dr. Nora van Cauwenbergh, Dr. Andrew Fenemor, and Declan Hearne. We also acknowledge all the course participants who actively and enthusiastically contributed their experiences for the benefit of all. Technical support from the University of Algarve to ensure that the online presentations ran smoothly was critical and is gratefully acknowledged.

REFERENCES

Bammer, G. (2005) Integration and Implementation Sciences: building a new specialization. *Ecology and Society* 10 (2): 6. [online] URL: www.ecologyandsociety.org/vol10/iss2/art6/.

Camkin, J.K., Bristow, K.L., Petheram, C., Paydar, Z., Cook, F.J. & J. Story. (2008) Designs for the future: The role of sustainable irrigation in northern Australia. In: *Sustainable Irrigation: Management Technologies and Policies II*. Villacampa Estve, Y., Brebbia, C.A. and D. Prats Rico (Eds). WIT Press, pp. 293-302.

FAO. (2011) *Climate change, water and food security*. FAO Water Report 36. Hugh Turral, Jacob Burke and Jean-Marc Faurès. 200 pp

Neto, Susana. (2010) W*ater, Territory and Planning. Contemporary Challenges: towards a Territorial Integration of Water Management.* Ph.D. Thesis. September 2010.

UNWWAP. (2009) *The United Nations World Water Development Report 3: Water in a Changing World*. Paris: UNESCO and London: Earthscan.

Knowledge Management in the Water Sector

SUNETRA LALA[1], NITYA JACOB[1] & SMITA SIVAKUMAR[2]

1 *Water Community of Solution Exchange, United Nations Children's Fund (UNICEF) India*
sunetra.lala@one.un.org

2 *Carollo Engineers, California, USA*

Abstract The Water Community of Solution Exchange (WCSE), India is a Value Network that connects the local communities and administrations for the design and implementation of societal water projects. This paper portrays the WCSE in the perspective of, what the authors label, a Web 2.0 based Value Network dedicated to societal Water projects (W2W). It distills the WCSE's experiences into a W2W management viewpoint by integrating the two distinguishing features of W2W and Web 2.0. Depiction and analysis of a case study on a water initiative facilitated through the WCSE addresses a water project dimensions as distinct from general project management axioms. Synthesis of Value Network theory and personal insights of the WCSE's officials leads into the Web 2.0 dimension. In conclusion, it presents an abstracted management framework annotating the process elements that sustain and nourish the growth of a W2W.

Key words Knowledge networks; value network; water projects; Web 2.0; W2W

1 Introduction

Solution Exchange (SE) is a Value Network that harnesses the Web 2.0 platform and the internet to address development tasks in India. The United Nations Country Team in India established SE as a moderated electronic (e-) forum in early 2005. The forum consists of multiple Communities of Practice (COP), with each community focusing on one of the MDG. The Water Community of Solution Exchange, India (WCSE) is a COP dedicated to achieving MDG #7 - 'Ensure environmental sustainability'. It focuses on providing all rural and urban habitations with drinking water and sanitary facilities. This moderated e-forum connects with local communities and administrations for the design and implementation of ingenious solutions to water problems.

The paper captures the WCSE's experiential learning into a replicable management framework for use anywhere. There are two basic dimensions to reckon with. First, societal water projects are unique because they address the access rights to a scarce resource, and beneficiaries invariably subsist at the fringes of society. Therefore, conventional project management axioms will have to be seasoned to succeed against the odds of societal inequalities. Secondly, an e-Value Network has its own technology challenges, and if managed properly, it can yield geometrically higher benefits.

2 Theoretical Introduction to Value Networks

In the early 1930's, Dr. Jacob Levi Moreno, a self-published psychologist, introduced the 'sociogram', -a cluster of individual points, or 'nodes', connected by straight lines- the first formal attempt to map out the relationships within a group of people. Professor J. A. Barnes of the London School of Economics, in a paper entitled "Class and Committees in a Norwegian Island Parish" (1954) coined the term 'Social Network' as a "a set of points, some of which are joined by lines" to form a "total network" of relations. In the current context, a Social Network is a structure comprising individuals or organizations called 'nodes', which are linked by relationships around a common theme. Etienne C. Wenger, an educational theorist and practitioner, states that COPs are formed by people involved in a process of collective learning in a shared domain of human endeavour. The COP members share a concern or a passion for something they do and learn how to do it better as they interact regularly (2006).

Therefore, we can conclude that a COP is essentially self-governed, supported by a core team of facilitators/moderators. The facilitator/moderator provides the platform or infrastructure for discussions/communications and ensures focus by keeping discussions on track. When the core team establishes the links between the nodes by setting the theme, focus, and agenda around subject matter, knowledge, and expertise, such networks evolve into Knowledge Networks.

Knowledge Networks that go beyond the mere exchange and enhancement of knowledge to provide significant and specified economic value are called Value Networks (Fig. 1). Value Networks are defined as "any web of relationships that generates both tangible and intangible value through complex dynamic exchanges between two or more individuals, groups, or organizations." Any organization or group of organizations engaged in both tangible and intangible exchanges can be viewed as a Value Network, whether private industry, government, or public sector (Allee, 2002).

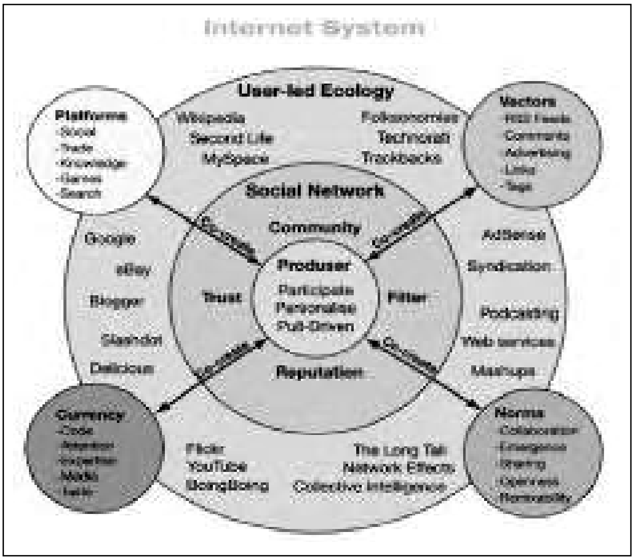


Fig. 1 A Value Network Map.
Source: Smart Services CRC Pty Ltd.

The progression from Knowledge to a Value Network requires concerted and long-term efforts by a core team of facilitators or moderators. In the beginning, all networks strive to achieve critical mass to serve their basic intent -generating and sharing knowledge. In the second stage, there is a steady stream of content, discussions, and knowledge products, and the acquisition of fresh members. In the third stage, networks start focusing on selected themes for discussions and collaboration, identifying champions to take these forward and building strategic linkages with other institutions and networks. In the next stage of evolution, members seek out others with common interests to develop collaborative projects, build on each other's knowledge to further their development goals and influence government projects and policy. At this point, it is possible that institutions or individuals from other networks also join the activities. It is in this evolution process that Web 2.0 technology plays such a vital part.

In Web 1.0, the application service provider dominates where content is generated and distributed from a node. Web 2.0 refers to applications that use the web as a platform to harness the distributive collective intelligence of its users.

3 Water Community of Solution Exchange

The Community works through UNICEF and its nodal ministry, the Ministry of Drinking Water and Sanitation. It has over 3,700 members, who belong to various organizations including NGOs, universities, research institutes, consulting firms, and government water boards. About 8% of the WCSE is from other countries.

Non Government Organizations (NGOs) and the UN system have many decades of development experience in India. Thus, the WCSE started off with the twin advantages of a known pedigree and a wealth of stored information on development projects.

The WCSE seeks to supplement academic research with experiential information or tacit knowledge gleaned through discussions with practitioners, based on their work. This involves identifying members with expertise in a given area, contacting them for their input, editing (where needed) the comments, consolidating them into archival form, and feeding them back to the network.

There are three primary facets to WCSE. The moderated e-discussions are theme-based, aimed at expansion of subject matter knowledge and the facilitation of water projects. The moderator abstracts a 'consolidated reply' from these discussions and archives it in the Knowledge Repository. Some members walk the extra mile and form an action group or field team. The project details, metrics, and lessons learned are also archived in the Knowledge Repository and shared with the WCSE (Fig. 2).

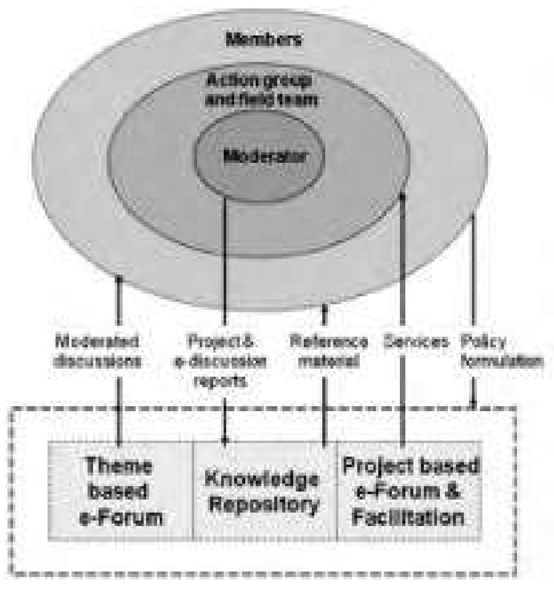


Fig. 2 Facets of WCSE.

The WCSE has at its core a two-member resource team. This team, along with a resource group comprising thought leaders and senior practitioners, establishes the criteria for the issues that will be tackled by the group, convenes action groups as necessary to take on projects, and also evaluates performance.

Some of the issues that have been successfully addressed by the forum are eco-restoration of streams and rivers, fluoride contamination of drinking water, available solid and liquid waste management technology options, combating salt-water ingress in coastal areas, and agricultural water management techniques.

Since its inception in 2005, the WCSE has responded to over 170 queries. Some of the discussion threads have evolved into projects in which the WCSE has not only provided a solution set but has also participated during the solution implementation phase.

It is important to note that water initiatives by the WCSE are different from the regular project management framework in that they strictly aim to be pilot projects. The mandate of WCSE is not full life cycle project implementation, but facilitation that extends to networking, knowledge extraction from focused e-discussions, linking up different sets of participants (the government, experts, NGOs, academia, and the private sector), and launching successful pilot projects.

Moderated e-discussions take place to share knowledge and achieve a specific goal, or facilitate its achievement. The forum acts as a powerful 'pull' factor for people to participate actively (as opposed to being passive information recipients) in the discussions and events of the WCSE. The discussions are also good examples of the utility and power of collaborative knowledge building.

The key functions of the WCSE are informing policies and programs, facilitating water projects up to proof of concept and pilot project phase, promoting individual and institutional learning, building networks of practitioners, and furthering existing domain knowledge.

4 Case Study: The Mazhapolima Well Recharge Project in Kerala, India

Kerala is a coastal state in South India where about 71% of homes depend on household wells for drinking water. Despite an annual average rainfall of 3,000 mm (the national average is 1,000 mm), most of it over a 3-4 month monsoon season, 70% of these wells go dry the rest of the year, resulting in severe water shortages (Census of India, 2001).

Being a member of the WCSE, the District Collector (DC), a State Government appointed head of administration in the Thrissur political district, was aware of its potential for knowledge mobilization and finding collaborative solutions to water issues. Inspired by various e-discussions in the WCSE, the DC drew up a project outline in May 2008 to use rainwater harvesting for recharging household wells in order to augment dry season water availability. The project aimed at recharging the household wells using rainwater collected from rooftop rainwater harvesting (RWH) structures. The district has about 450,000 open wells, accounting for replacement investment value of about of Rs. 18 billion (USD 350 million). By recharging the wells, the project hoped to make use of the existing assets to store water and enhance groundwater reserves.

In August 2008, the DC approached WCSE with his project outline and, in consultation with the moderator, floated a carefully drafted query eliciting inputs on simple technology options, social marketing tools, and innovative financing options from WCSE members. In a period of 3 weeks, 43 responses were generated by the WCSE. The resource team structured the responses into a solution set consisting of national remote sensing maps (to guide choice of suitable locations with high recharge potential), technology options, together with cost information for rooftop RWH structures, and referrals to NGOs that provide training for villagers in the design and construction of RWH structures. The need for an education campaign, consisting of street plays and door-to-door action specifically aimed at educating women on concepts such as groundwater recharge and aquifers, was highlighted.

The DC incorporated the solution inputs and developed Mazhapolima, a participatory well recharge project. Mazhapolima was highlighted at the WCSE's Annual Forum in 2008, and Arghyam, a NGO and a partner of WCSE, offered to support the project with a grant for research and advocacy. A core team, representing the Government of Kerala, the WCSE, and Arghyam, was constituted to run the project under the DC's guidance for its overall monitoring and evaluation.

The project was piloted through a selected Panchayat Raj Institution (PRI; local government unit) of 600 households (Fig. 3). Based on subsequent learning, the process elements were refined and the project was extended to the rest of the district. In the period from May 2008 to April 2010, about 5,770 wells in 37 PRIs had been recharged with rainwater collected using rooftop RWH structures, at an average cost of Rs. 3,000 (USD 60) per well.

Fig. 3 Local labor involvement during construction.

This project intervention has resulted in the reduction of the average time taken by villagers to collect water during the dry months from 1.5 hours to a few minutes a day. Women in India, as in most parts of the developing world, spend a lot of time collecting drinking water. With water available at home, they save time and energy and invest it in earning additional income, educating their children, or leisure.

In July 2009, the WCSE held a Regional Forum highlighting Mazhapolima. The senior government officials at the Forum realized the potential for scaling it up across the State and decided to take it forward.

The Mazhapolima well recharge project shows how a series of interventions by the WCSE paralleled the development, implementation, and evolution of a traditional water security program. Studies had been made on the potential of rainwater harvesting, but Kerala had no experience in the practice, given its (once) abundance of water. There was nothing to string together the concept of rainwater harvesting for well recharge, solution design, and implementation paid for by the people themselves. There was also no way of knowing if the solution was workable until experts assessed it, or got the results to the government for scaling up. The WCSE's role went beyond passive information sharing, as happens on most e-networks. It actively sought input on rainwater harvesting, social mobilization techniques, and financing options, which were used to design and initiate the project. It brought in an external agency for technical inputs and assessment, and based on this assessment, the state government decided to expand Mazhapolima to a water security program across Kerala.

Collaborative knowledge building is a non-linear process and often, the final outcome is hard to measure. In the Mazhapolima case, even though it has become a template for water security projects, the final outcome will rest on the long-term measurement of improved water availability and the resulting betterment of people's quality of life.

5 Conclusion

The Mazhapolima case study shows how a Value Network's work in the cyber space can go hand-in-hand with a project in the physical space. It established a method to determine causal linkages.

The following are suggested steps for managing value networks with the WCSE:

- *Clear problem statements from members*: the members have to understand how the network works and make a clear problem statement. In interacting with the WCSE they must take the discussion towards the ends they want to serve. The moderating team supports these efforts by directing the discussions to members who can make meaningful contributions in different stages of the project cycle.
- *Knowledge sharing*: the primary purpose of the network is to share knowledge. It is easy to "degenerate" into a forum for airing views and advice. This is where effective moderation comes in. By carefully selecting members and channeling their responses, the moderating team keeps members' contributions inside the "knowledge" field, and filters out views and advice that may be irrelevant. This also raises the bar for the quality of the discussion and makes the output more valuable to members.
- *Taking an active role*: while it is attractive to use a term such as "facilitating" to describe the WCSE's role as an impartial platform, the moderating team has to play an active leadership role in selecting discussion topics and discussants. In doing so, it can make value judgments to seek a diversity of opinions and thus bring out as many facets of a topic as possible.
- *Replacement cost*: as the Mazhapolima case study shows, the WCSE acted as a real-time virtual conference, providing inputs to the physical project from its network. This brings down the cost of physical project sustainability. Thus, value networks have a high replacement cost.

In management of virtual projects, a Sloan School Paper titled "How to Manage Virtual Teams" (Siebdrat, 2009) points to a high degree of task-related processes as a primary key to successful management. We encourage the W2Ws to maintain focus on projects and guard against being led into becoming a mere forum for academic debates and discussions.

REFERENCES

Allee, V. (2002) *A Value Network Approach to Modeling and Measuring Intangibles*, presented at Transparent Enterprise, Madrid.

Asian Development Bank. (2000) *Project Performance Audit Report on the Sorsogon Integrated Area Development Project in the Republic of the Philippines, Manila.*

Asian Development Bank. (2004) *Operations Evaluation Department, Effectiveness of Participatory Approaches: Do the New Approaches Offer an Effective Solution to the Conventional Problems in Rural Development Projects?* Report No. SST: REG 2005-01.

Boyd, D. (2006) *G/localization: When Global Information and Local Interaction Collide*, presented at O'Reilly Emerging Technology Conference, San Diego, California.

Census of India. (2001).

Department of Drinking Water Supply, Ministry of Rural Development, Government of India.

Schauer, B. (2005) *Experience Attributes: Crucial DNA of Web 2.0*. www.adaptivepath.com.

Siebdrat, F., Hoegl, M., Ernst, H. (2009) *How to Manage Virtual Teams,* MIT Sloan Management Review.

United Nations Development Program. (2006) *Human Development Report, Beyond Scarcity: Power, Poverty and the Global Water Crisis.*

Wenger, E. (2006) *Communities of Practice A Brief Introduction.* www.ewenger.com/theory.

Acknowledgement

The Second International Symposium on Building Knowledge Bridges for a Sustainable Water Future was possible thanks to the collaboration of:

UNESCO
United Nations
Educational, Scientific and
Cultural Organization

International
Hydrological
Programme

HELP
Hydrology for the Environment, Life and Policy

ecohydrology
programme

CANAL DE PANAMÁ