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CO-DESIGN OF AN INTEGRATED OPERATIONAL WATER MANAGEMENT TOOL FOR THE VALLE DEL CAUCA, COLOMBIA

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ABSTRACT

This paper presents the developments of a tool for integrated water management (*Herramienta para el Manejo Integral del Agua – HERMANA*). HERMANA combines; real-time meteorological, hydrological, and water quality data and forecasts; information from an institutional database; surface water and groundwater models; and, drought indicators based on satellite data into a web-based platform. Together, these tools provide the basis to plan for integrated, operational water management. To optimize the usability of these tools, we implemented an intensive co-design framework that consisted of developing a number of use cases in collaboration with the end user, the Corporación Autónoma Regional del Valle del Cauca (CVC). These use cases provide CVC with a step-wise approach to deal with a number of water management issues. Results show the impact that an integrated operational tool can have at a number of levels within the organization by making the water resources information accessible and visible in a tailored way. However, the largest hurdle is not the integration of data systems and models, which is usually technically feasible, but rather the sustainable implementation and integration into the decision-making process of a water management authority's organization. Our co-design approach included numerous interviews and workshops with CVC's staff to better understand the decision-making process within the organization, the requisite data and information, how the data and information are used, and how it can be presented in such a way that it facilitates decision-making processes. Outcomes from these discussions and a roadmap for future implementation are presented.

Keywords: conjunctive water use; surface water-groundwater interactions; operational water management; integrated watershed management; decision support system.

INTRODUCTION

To support a sustainable and equitable management of increasingly pressurised water resources, water authorities need to have access to up-to-date information on the availability, demand and use of these resources. However, up-to-date information on the availability and use of water resources is often scarce in Colombia. Moreover, this information is often dispersed, as it is contained in various reports, databases, private computers, and other locations that are not necessarily accessible to the professionals that need to take daily or periodic decisions.

This is also the case in the Department of the Cauca Valley, where the Corporación Autónoma Regional del Valle del Cauca (CVC) is responsible for the integrated management of water resources. CVC has a number of independent data feeds, models, and tools at their disposal; however, this information is often only available as static data in reports. Decisions are thus taken primarily based on such static (and often outdated) information, rather than on current data that are representative of the actual situation. CVC lacks a way to support water management decisions during periods of water scarcity and surplus, which may lead to poorly informed decision-making. CVC also needs tools to better assess and develop strategies for conjunctive water use, justify decisions made to water users, and improve stakeholder communication.

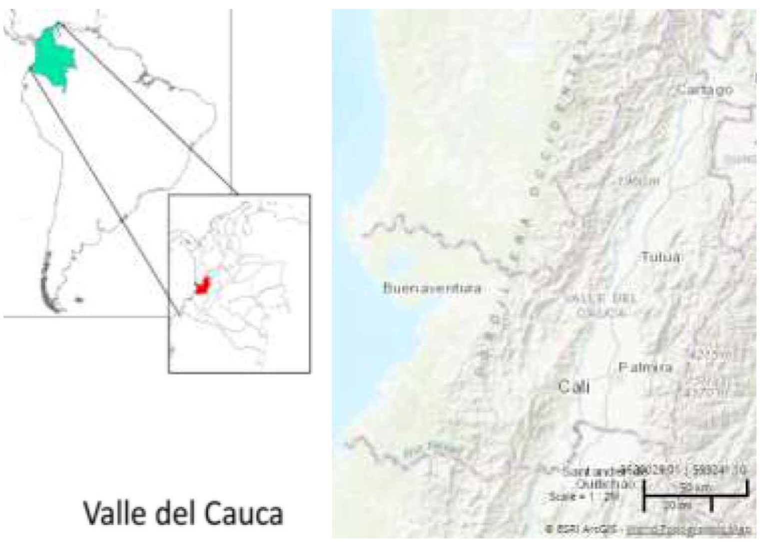

Figure 1. Location of the Valle del Cauca Department, Colombia.

In recent years, much more data, information, and many more tools have been made available for water resources management in the Cauca Valley. However, this information and these instruments are not yet incorporated in the decision-making process due to the difficulty to access these quite technical and often poorly integrated systems. To resolve these challenges, a tool for integrated water management (*Herramienta para el Manejo Integral del Agua – HERMANA*) is under development that integrates different types of data, information, models and tools. This includes:

Information from CVC's institutional database, GeoCVC, including over 250 hydroclimatological stations and over 2,500 groundwater monitoring wells;

Real-time meteorological, hydrological, and water quality data and forecasts from FEWS-IDEAM (using Delft-FEWS, see Werner et al., 2013);

Surface water models (HBV, SOBEK), which are included in FEWS-IDEAM; and

Drought indicators based on satellite data from InfoSequía.

HERMANA is a web-based water information tool to support integrated water management. HERMANA displays weather and water data, generates user-defined overviews, forecasts, and warnings tailored to the needs of water authorities and their stakeholders. The HERMANA dashboards are configured via the

HydroNET Water Control Room applications in which different types of data, information, models and hydro-climatological tools are combined in order to support both tactical and strategic decision-making related to water resources in Colombia. At the time of publication, the system is also being expanded to incorporate results from a numerical groundwater flow model, iMOD, which has been incorporated into a Delft-FEWS system, called FEWS-ESCACES. An overview of the data sources and technical components of HERMANA is provided in Figure 2.

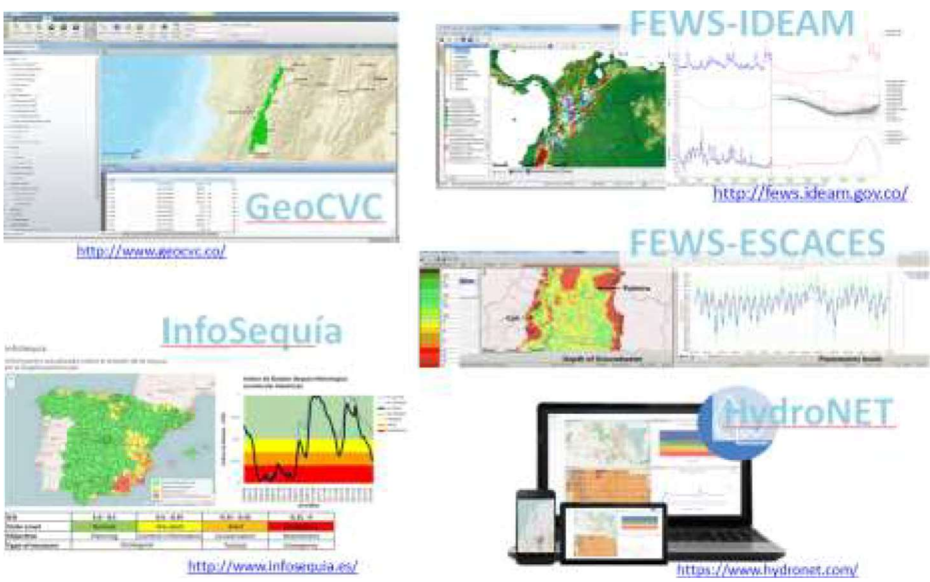

Figure 2. Data sources and technical components of HERMANA.

HERMANA is based on the concepts of similar decision support systems currently in use at Dutch Regional Water Authorities (DRWAs). However, it has been adapted to the needs of CVC, with the possibility and flexibility of implementing it elsewhere in Colombia. With HERMANA, CVC will be able to monitor the real-time status of the hydrological and hydrogeological system and take informed management decisions based on this information. CVC will be able to forecast the impacts of droughts and floods in their area of jurisdiction, and define and test management strategies during periods of water scarcity and surplus. Ultimately, the added value of HERMANA is foreseen to be manifold:

Enhancing water security during dry periods;

Minimizing impacts of extreme events;

Developing and implementing sustainable water use strategies; and

Improving the effectiveness and transparency of management processes by providing access to relevant stakeholders.

METHODS

HERMANA comprises a combination of hard- and software systems (screens, computers, models, data management system, and dashboards). This can be used by CVC to access real-time and static water resources information, allowing them to take operational, tactical and strategic water management decisions and to communicate with stakeholders. The general set up of the HERMANA approach is divided into a number of work packages (WP), each with a distinct activities and outcomes. The interrelation between the WPs is provided in Figure 3. This paper describes the steps taken in WP1 (Identification of decision process and information needs), WP2 (Evaluation of existing data, information and tools), and WP3 (Co-design of HERMANA).

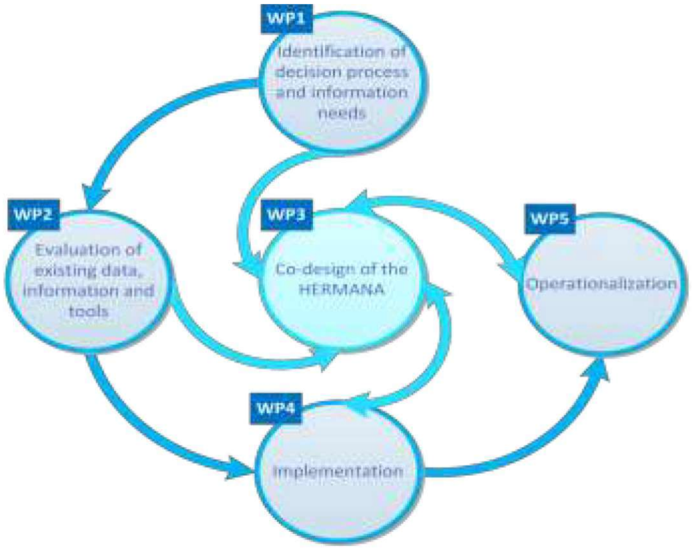

Figure 3. General set up of the HERMANA approach.

Step 1: Exploration and identification

The functional requirements of the system were developed through a number of workshops with the future users, identifying to a large extent the data and information needs and decision-making processes that HERMANA is intended to support. Governance aspects that are relevant to the management of water resources in the Cauca Valley were also analyzed during this identification process, including the different levels of HERMANA users within CVC and the information and level of detail that each of these users need. During this initial identification process, various work forms and methods were applied, such as:

Interviews with key persons within CVC, stakeholders and key partners to identify their operational information needs and the possibilities for CVC to improve their communication with stakeholders;

Workshops to specify information needs following the rugby ball methodology (Figure 4) and function-issue matrix (see Table 1);

Interactive sessions (role play calamity on the Cauca River) and plenary discussions;

Presentations on a variety of topics, including information needs, CVC's monitoring network, mandates and roles of Regional Water Authorities (RWAs) and Water Management Information Centres in the Netherlands, FEWS-IDEAM, FEWS-ESCACES, InfoSequía, dashboard mock-ups, HydroNET, and stakeholder participation for the development of groundwater policies;

Questionnaires on (i) the decision-making process (steps, nature, sources of information); (ii) information needs (related to the function-issue matrix); and (iii) indicators/parameters (visualization of HERMANA);

Field visits; and

Review of policy documents.

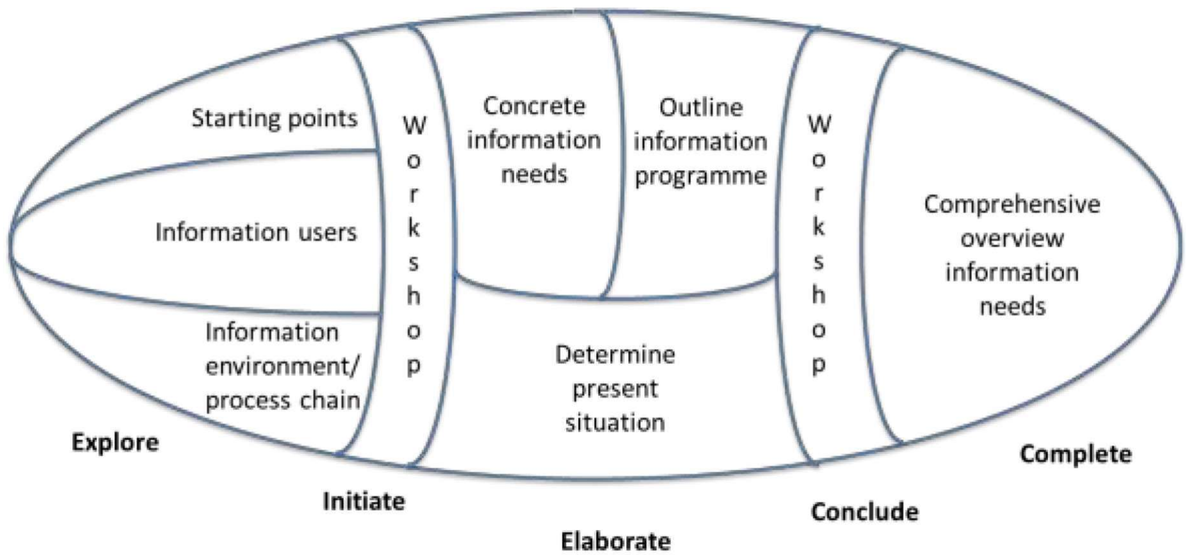

Figure 4. 'Rugby ball methodology': steps to specify information needs (Timmerman & Mulder, 1999).

Step 2: Detailed questionnaire and elaboration

Following the initial identification of information needs, a more detailed questionnaire about the decision-making process, necessary tools and other functional requirements of HERMANA was developed. This was based on the seven common steps for effective decision making:

Identify the decision;
Gather relevant information;
Identify the alternatives;
Weigh the evidence;
Choose between the alternatives;
Take action; and
Review the decision(s) and their consequences/impacts.

Step 3: Definition of use cases and conceptual design

Based on the results of the questionnaires and input from CVC as described above, an initial conceptual design was created. Use cases were developed to work through the decision-making process on a step-by-step basis, linking data collection, presentation, and the development of dashboards. These use cases cover many of the ways in which HERMANA can be applied for operational water resources management in the Cauca Valley, providing insight into the additional value of the system. The use cases have been translated into flow charts (an example is provided in Figure 6) and are used as a reference throughout the development of the system in order to:

Test HERMANA and check whether the system suits the identified user needs;
Develop a user manual for HERMANA;
Observe (evaluate and elaborate on) the operational decision-making processes; and
Develop capacity and train users.

RESULTS

Step 1: Exploration and identification

The initial results of the rugby ball methodology identified the most important data and information needs relevant for the development of HERMANA. Overall, the data needs could be characterized in four main categories:

Hydro-climatological data and information;
Groundwater and aquifer data and information;

Surface water and river system data and information; and
General and institutional data and information.
Step 2: Detailed questionnaire and elaboration

The next step resulted in a function-issue matrix that identified the most important functions of the water system in the Cauca Valley and the critical water-related issues in the region. The participants from CVC identified agriculture, drinking water production, environmental sustainability and water security (related to flooding) as the most important functions. Droughts, floods and surface water and groundwater quality were considered to be the most important issues. The complete function-issue matrix is provided in Table 1.

Table 1. Function-issue matrix for water resources management in the Cauca Valley.

Issues	Functions: Hydro-power	Agricul-ture	Human consump-tion	Domestic use	Industry	Livestock	Environ-ment	Recrea-tion	Landscape	Cooling	Water security (flooding)	Dilution (river)
Extreme events (downpour, heat wave)	X	X	XX					XX				
Overexploi-tation		XX	X	XX	X	X	XX					
Floods		XX	X					X		X	X	X
Sediment transport	X	X	XX		X		X					
Droughts	XX	XX	XX	XX	X	XX	XX	X	X	X		XX
Landslides		X	XX				X					
Surface water pollution		X	XX			X	XX	X				XX
Groundwater pollution		X	XX	XX	X	X	X					
Water scarcity (supply-demand imbalance)		XX	XX			X	XX	XX	X			X
Fires		X	X			X	X	X	X			
Changes in land use / cover	X	XX	X				X	X				

The highlighted combinations of functions and issues were assigned as higher priority for the development of the system, and were used to define:
Problems and obstacles;
Solutions, measures, and action perspectives; and
The information required to implement and evaluate the effectiveness of solutions, measures and action perspectives.

Step 3: Definition of use cases and conceptual design
The results of the function-issue matrix were used to define the use cases for HERMANA since they represent the most relevant cases for which CVC needs to take decisions. They also guided the process of the conceptual design of the system (Figure 5). The majority of the data required to meet the information needs for each of the use cases is available within CVC. However, in order to develop HERMANA, many additional connections were required. It should be noted that with this approach, the data is retrieved on-

demand directly from the connected data sources for display in the configured dashboard. The data itself is not made persistent within the HydroNET system and stays in its original location without being copied or stored elsewhere. Once the identified data sources were connected in HydroNET, dashboards were tailored to CVC's needs, providing warnings, forecasts and overviews of their water system. This added-value information is directly available so that well-informed, transparent and accountable decisions can be taken and replicated when needed.

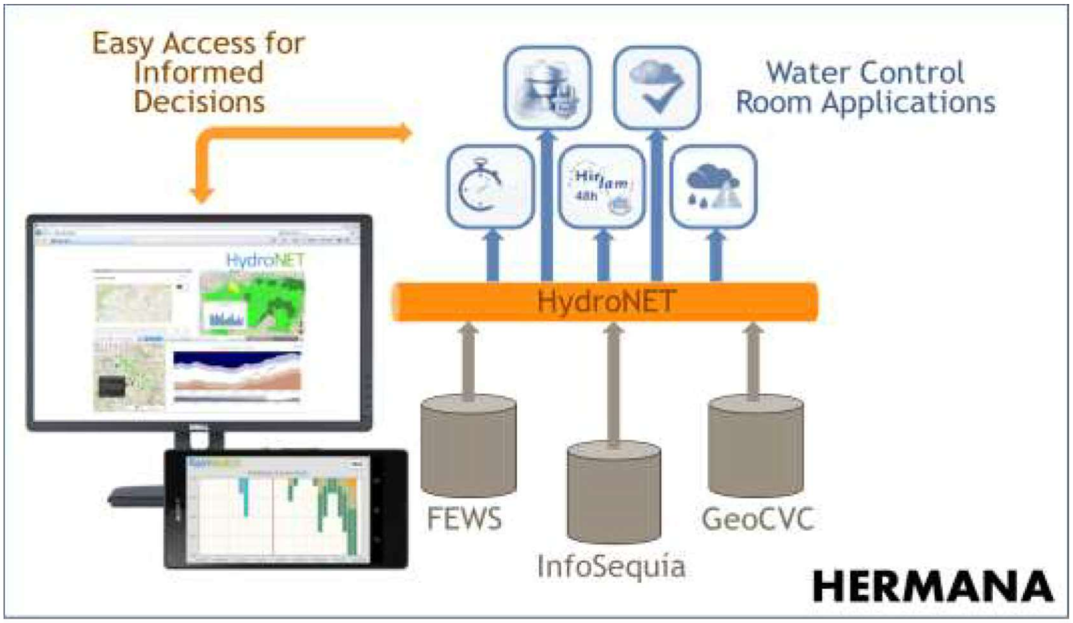

Figure 5. Conceptual design of HERMANA.

Based on the main issues identified by users during the information needs workshops, four initial use cases were developed: drinking water supply for the City of Cali, floods, droughts, and groundwater quality. Each of these use cases first has a situation/problem statement followed by a detailed description of how to approach the seven common steps for effective decision making. The flow charts created indicate which system should be accessed at each step in this process (GeoCVC, FEWS-IDEAM or HydroNET) and which action or decision is required from various users at those given steps (field personnel, professionals, and directors from CVC).

For example, the drinking water supply use case has the following problem statement: water quality at Navarro (water quality monitoring station upstream of the drinking water intake point for the City of Cali) is decreasing, and more water is needed at Puerto Mallarino (drinking water intake point for the City of Cali) to ensure sufficient supply for the city. Water levels in the Salvajina reservoir (upstream) are very low. It is an El Niño year, which means that recovery of the levels in the reservoir is very slow. This use case was based on an actual event that took place in October 2015. The locations of Puerto Mallarino, Navarro and Salvajina Dam are provided in Figure 6.

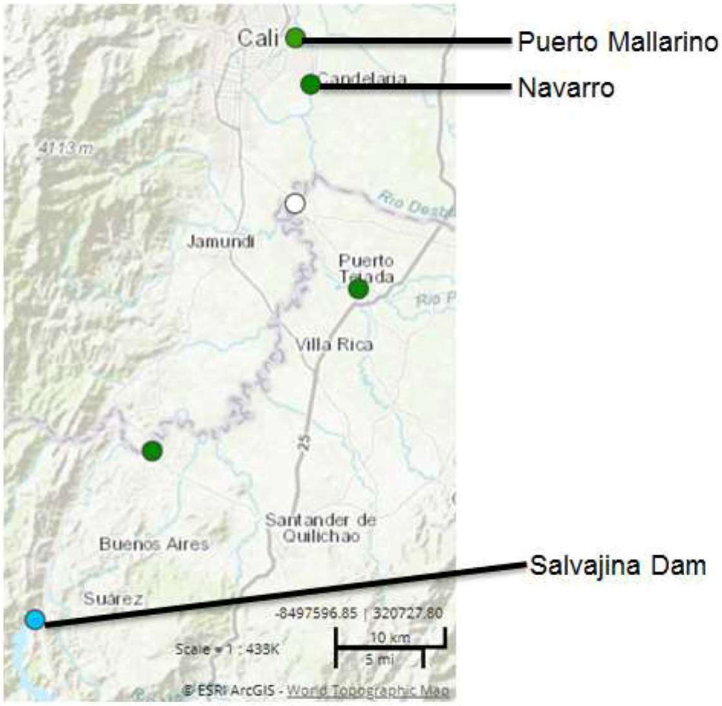

Figure 6. Locations of Puerto Mallarino, Navarro and Salvajina Dam.

The decision-making process for this use case is as follows:

Identify the decision: CVC needs to take a decision to guarantee the availability (quantity & quality) of water at the Puerto Mallarino intake point. Human water consumption is a priority;

Gather relevant information: flow at Puerto Mallarino and other upstream locations, water quality parameters at Navarro and other upstream locations, water level in Salvajina reservoir, discharge from Salvajina Dam, precipitation (recent and forecasted) per station and aggregated per sub-basin, groundwater levels, and groundwater abstractions;

Identify the alternatives: do nothing, release more water from Salvajina Dam, restrict other surface water and groundwater uses, or use emergency groundwater extraction wells;

Weigh the evidence: evaluate the impacts and risks of each alternative, and the indicator(s) that can be used to weigh these objectively (and reproducibly);

Choose between the alternatives: CVC's Technical Committee prepares an evaluation of the alternatives based on the indicators identified during the step above. A technical report with recommendations is sent to the Technical Directorate. The Technical Director presents the report to CVC's Director General, who decides on the appropriate measure(s) to take;

Take action: the General Directorate publishes an administrative resolution and communicates with the relevant actors, such as the operator of Salvajina Dam. CVC prepares a press release for all stakeholders and the general public justifying their position; and,

Review the decision(s) and their consequences/impacts: CVC regularly reviews the alternatives and reevaluates them based on their impacts and respective indicators.

The flow chart for this use case is provided in Figure 7.

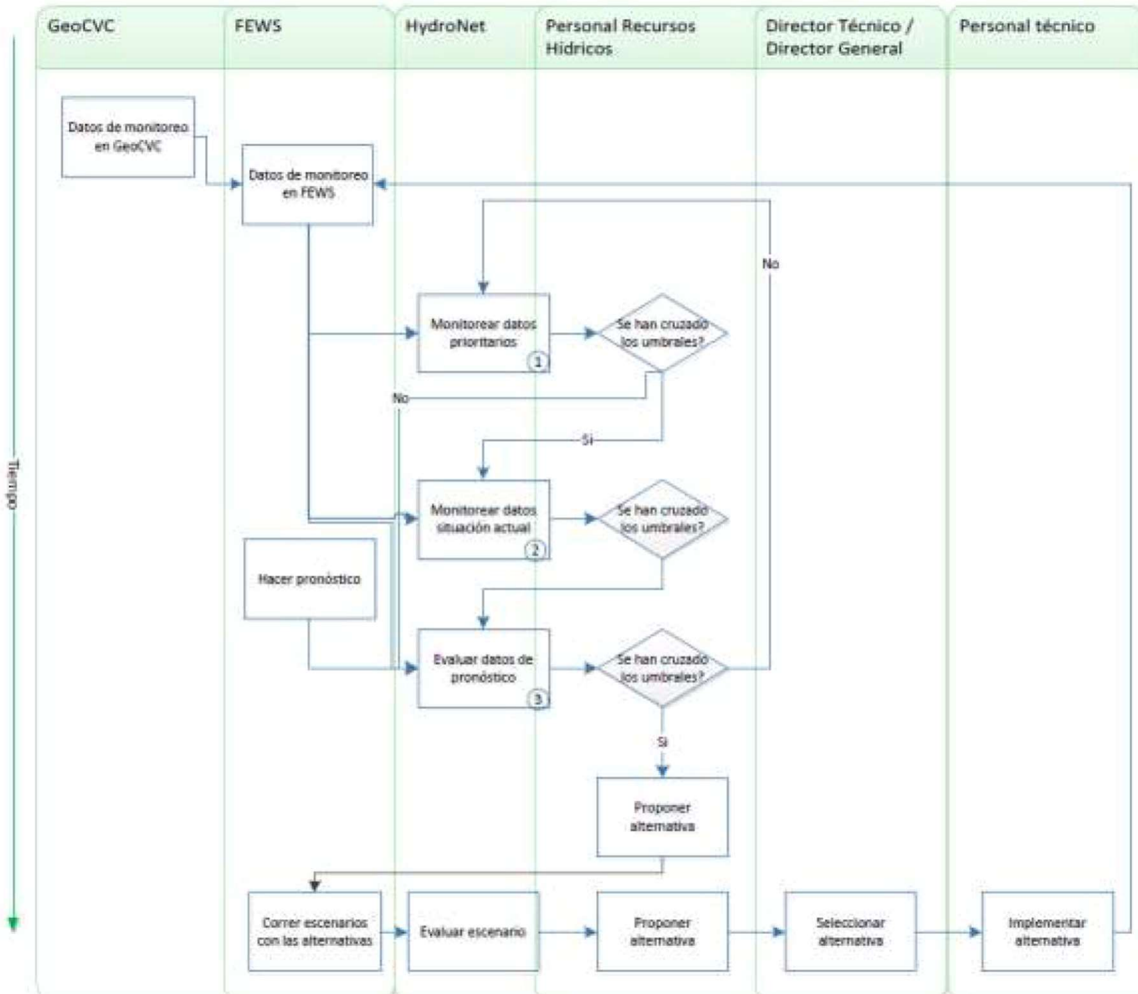

Figure 7. Flow chart for the drinking water supply use case for the City of Cali.

For each of the use cases, at least three dashboards have been created: the first showing priority data (monitored on a regular basis), the second showing additional data with the current situation (monitored periodically or when the thresholds for priority data have been exceeded), and the last showing forecasted data (monitored periodically or when the thresholds for priority data have been exceeded). A sample dashboard showing both priority data (water level at Puerto Mallarino and Dissolved Oxygen at Navarro) and data that gives a broader overview of the current situation (average precipitation per sub-catchment for the past month and water level in Salvajina reservoir) for the drinking water supply use case is provided in Figure 8.

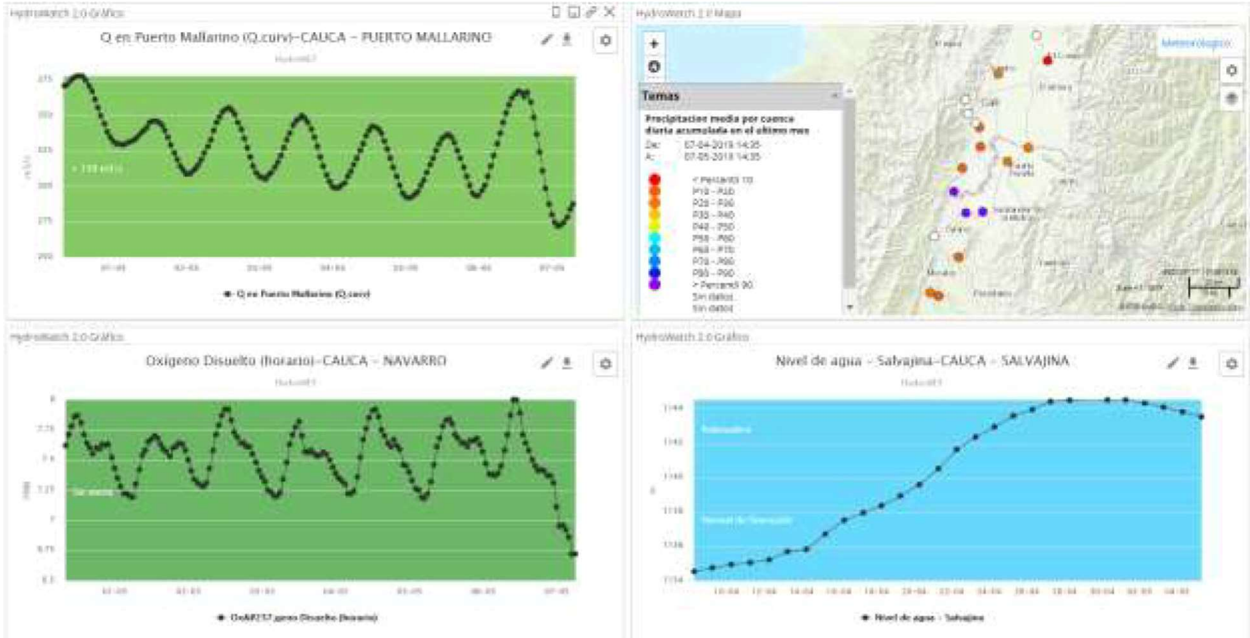

Figure 8. Sample dashboard as displayed in the HydroNET application showing priority data (left) and some of the current conditions (right) for the drinking water supply use case for the City of Cali.

DISCUSSION

A three-layer model of water governance (Figure 9) has been developed by the Water Governance Centre (Willems, 2013) and is often used to characterize governance aspects of water resource management organizations. In the Cauca Valley, HERMANA has the potential to play a substantial role in all three layers of this model. However, in practice, the working and decision-making processes and commitment of staff and stakeholders involved ultimately determines the success of water governance, not the technical tools and instruments. How HERMANA fulfils its potential will need to be reviewed over time.

Figure 9. Three-layer model of water governance (Willems, 2013).

From the water governance content point of view, HERMANA is valuable in terms of turning data into decision support information for operational water resources management and policy preparations. The combination of various indicators and parameters together with general water system information presented in the form of tailored graphs and maps with varying spatial aggregations has thus far proven to be especially beneficial. In the future, it may also improve the day-to-day communication between staff members and external stakeholders. For example, meetings with CVC staff members have indicated the need for planning tools (staff availability, maintenance, logistics, etc.). Dashboards could be created to indicate which stations are or are not transmitting data or which stations have not been recently maintained, providing a quick snapshot of CVC's entire management area. In this way, HERMANA could increase the planning efficiency and reduce the staff time involved in preparing and updating planning schedules.

Despite the fact that much more data, information, and tools have been made available for water resources management in the Cauca Valley in recent years, it has been difficult to incorporate these into the decision-making process. An exception is the implementation and use of Delft-FEWS, which has enabled CVC to make forecasts and management strategies for the operation of the Salvajina reservoir upstream of their area of jurisdiction. HERMANA is linking this information together and combining various other data sources; this has the potential to make a large impact institutionally, but only time will tell if the system truly becomes engrained institutionally in CVC's work process. In the future, HERMANA can be extended to include the calculation of indicators that are currently used by CVC but not regularly updated (e.g. water supply and demand indicators, which are updated roughly every 10 years).

Finally, HERMANA has the potential to play an important role regarding water governance relations and communications, both internally and externally. Internal communication and notifications should be improved as more of CVC's staff is trained to use the system to access and assess dynamic and up-to-date data and information. Externally, HERMANA could also enhance stakeholder communication. Informing partners, stakeholders and the general public, as is done currently through daily bulletins, could be automated and customized with local or regional information depending on a specific situation. For example, CVC currently produces maps showing precipitation information for the last 24 hours and publishes these maps on their website. However, this information is produced only once a day, and is produced manually. It does not get updated on weekends or holidays. Dynamic maps or graphs can be produced within HydroNET and embedded on their website instead, allowing users to pan/zoom into to specific areas of interest (in the case of maps) or focus on a certain period of time (in the case of graphs).

CONCLUSIONS

The co-design of HERMANA together with CVC has shown promising results. CVC has a solid data and information base to cover the main needs that have been identified. Four use cases have been developed and implemented or are currently under implementation into the system. However, these are not the only cases that HERMANA can be applied to. As CVC adopts the use of the system, additional use cases will be developed and can potentially be implemented so that the system continues to grow. Thresholds that are important to the decision-making process are also expected to continue to change as indicators become more refined for each parameter and use case.

The combination of the tools presented here has the potential to be applied elsewhere and to promote trans-sectoral cooperation (e.g. stakeholders in the water industry, authorities, private parties). Enabling the visibility and use of data from different data sources and owners via live links provides information and knowledge available in a standardized and reliable manner. This being said, appropriate local and regional considerations and interests must be taken into account and sufficient time must be available to truly adapt the tools to the water manager's needs.

ACKNOWLEDGEMENTS

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