

Article

Supporting Multi-Stakeholder Participation Processes: A Serious Game Application for Watershed Management in Colombia

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Abstract: Multi-stakeholder participation processes in watershed management face challenges due to limited monitoring and baseline data, resulting in a lack of awareness among stakeholders about the current state of the watershed. This knowledge gap often leads to conflicts of interest, wherein the broader impacts of individual decisions are overlooked. To overcome these limitations, this paper explores the design and implementation of a Serious Game (SG) aimed at coproducing a watershed management plan at the basin scale within the specific context of the Campoalegre River basin in Colombia. By providing an interactive platform, the SG facilitates collaboration between local actors, who may be unfamiliar with existing watershed plans, and decision-makers. The goal is to create a participatory space where stakeholders can comprehend the watershed management plan structure and prioritize actions based on various climatic, social, and economic conditions. Following the application of the SG, stakeholders demonstrated an improved understanding of the basin, fostering increased participation, open debate, and the proposal of actions. These outcomes serve as valuable inputs for the implementation of water management planning policies, showcasing the potential of SGs in bridging knowledge gaps, and fostering effective multi-stakeholder engagement.

Keywords: water governance; planning; coproduction; decision-making; collaboration; discussion; dialogue; conflict resolution



Citation: Gonzalez, C.; Moncada, A.; Santos, T.F.; Rincón, W.; Coleoni, C.; Macura, B. Supporting Multi-Stakeholder Participation Processes: A Serious Game Application for Watershed Management in Colombia. *Water* **2024**, *16*, 1581. <https://doi.org/10.3390/w16111581>

Academic Editors: Leszek Kuchar, Mariusz Adynkiewicz-Piragas, Alicja Edyta Krzemińska and Anna Zaręba

Received: 7 May 2024

Revised: 24 May 2024

Accepted: 27 May 2024

Published: 31 May 2024



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1. Introduction

The increasingly widespread recognition of ‘coproduction’, i.e., the participation of non-research stakeholders in the production of knowledge and the global trend towards multi-stakeholder participation (MSP) in watershed management, is heralding a new wave of methods and tools in water governance [1]. This transformation in policy and practice implies an important turning point, in which collaborative, trans-, and interdisciplinary research processes have become crucial to improving water governance. Such processes are needed to address the participatory inequities and marginalization currently prevalent in decision-making around water in Latin America [2].

Watershed management aims to protect the hydrological services, vegetation, and land use provided by the watershed by reducing or avoiding negative downstream or groundwater impacts [3]. To successfully implement watershed management actions, it is necessary to involve a representative array of multiple stakeholders [4], including all communities affected by the decisions [5].

Even when watershed management includes a broad representation of stakeholders in its participation processes, three common key barriers often hinder the stakeholders’ ability to effectively influence the process. (i) Environmental institutions and decision-makers

frequently face knowledge gaps regarding current watershed conditions due to a lack of monitoring and baseline data in sectors such as agriculture, forestry, and mining [6]. Therefore, knowledge sharing among researchers, specialists, and practitioners across various fields within the watershed is crucial. (ii) Conflicts of interest often emerge from an unclear understanding of the watershed and the interconnections between influencing sectors. This lack of clarity leads to the effects of individual actions on other sectors being overlooked, posing a significant challenge to integrating goals across all sectors [7]. (iii) There is a lack of participation spaces where actors can be represented in the watershed planning process and influence the outcome of watershed plans [8]. Additionally, stakeholders are generally unaware of existing planning policies in their region and their importance in water resources management due to their complexity and the lack of communication between stakeholders and decision-makers [9]. To address these barriers, innovative approaches like water diplomacy and participatory tools are essential. Water diplomacy has emerged as a vital component in managing transboundary water resources, emphasizing the political and cooperative dimensions of water governance to foster peace and security. This approach seeks to mitigate conflicts and enhance cooperation across different levels of governance, from local to international scales [10].

Complementing water diplomacy with participatory approaches, Serious Games (SGs) are dynamic tools with multifaceted applications extending beyond the sole aim of knowledge generation [11] and are acknowledged for creating immersive learning environments [12], fostering participant engagement, overcoming communication barriers, and developing mediation and negotiation skills [13–15]. SGs are used to promote dialogue and decision-making about water resources. For example, The River Basin Game addressed a conflict and contributed to fostering cooperation among stakeholders as it encouraged the players to strategize collaboratively and reflect on the consequences of their actions [16]. SGs have proven adaptable across diverse fields, including water policy and management. Catering to audiences with varying experience and knowledge levels, SGs are versatile instruments with wide-reaching potential.

Unlike traditional education-focused approaches, this paper emphasizes the role of SGs as a dynamic tool for water management planning. The SG designed for the Campoalegre River basin in Colombia serves as an interactive platform to navigate the complexities of stakeholder involvement in the development of the water management plans. Incorporating realism and engagement, SGs offer a unique approach to addressing challenges in participatory processes. They serve as more than educational tools; they become instruments for experiential learning, fostering collaboration, and enhancing decision-making in water policy and management.

In the context of participatory focus, this paper explores the innovative use of SGs, examining their potential to break down communication barriers, enhance participant engagement, and address knowledge gaps among stakeholders involved in watershed planning processes.

By assessing the application of SGs in this domain, the paper aims to contribute to a deeper understanding of their role in facilitating effective stakeholder participation within water management. The paper is organized as follows: Section 2 defines the context of the basin participatory process within the larger planning framework in Colombia and the case study. Section 3 presents an overview of the SG concept and its applications in water resources management. Section 4 describes the methodology and design of the SG in the Campoalegre River basin. Section 5 describes the outcomes obtained from the application of the SG. Finally, Section 6 presents conclusions and recommendations for future work.

2. The Case Study: Campoalegre River Basin, Colombia

2.1. The Participatory Framework in Watershed Management at Basin Scale

Integrated Water Resources Management (IWRM) is a general framework for water management, which calls for participation from and collaboration between experts, government authorities, and the community [17]. IWRM intends to make decisions in a watershed

more informed, creative, and rooted in the basin's interdisciplinary knowledge [18]. In Colombia, the federal government adopted a national IWRM policy, known as the National Policy for Integrated Water Resources Management (abbreviated as PNGIRH in Spanish), in 2010. The IWRM policy in Colombia calls for developing planning processes at different scales (national, regional, and local) in a nested system [19] by the application of different planning documents. The Watershed Management Plan at Basin Scale (abbreviated as POMCA in Spanish) is the planning tool and guideline at the watershed hydrological scale, developed by the Colombia Ministry of Environment, through which the coordinated use of soil, water, flora and fauna, and watershed management is planned, with the participation of the population living in the watershed territory, leading to the proper use and management of such resources [20].

The POMCA's purpose is to balance the social and economic use of natural resources with conserving the ecological functions of the basin [20]. In the POMCA's creation process, the stakeholders elect the members of the Basin Council, which is meant to represent the inhabitants and economic sectors in the watershed. The Basin Council's role is to provide a space for dialogue, listen to proposals, and seek consensus around the management of the watershed [20].

Each Basin Council, with stakeholders such as water authorities, researchers, and government, develops the POMCA in phases, including preparation, diagnosis, prospective and environmental zoning, formulation, execution, and monitoring and evaluation. In the formulation phase, each POMCA defines strategic focus areas, and outlines programs and projects to manage and conserve the watershed. The strategic focus areas define objectives with a set timeline, based on a diagnosis of the current conditions. The programs in the POMCA aim to work towards the objectives through a set of specific projects, often interconnected and coordinated with each other [20]. The programmatic component of the POMCA, an integral part of the formulation phase, is fundamental to achieving the objectives set forth in the POMCA, without neglecting the other strategic lines, programs, or projects and activities that the water authorities or users implement in addition to those established in the POMCA.

The POMCA development process needs to properly consider the interests of all stakeholders to create a fair and equitable watershed plan. Transparent procedures can help build trust between the council members, creating an environment where a wider range of actors would feel comfortable providing feedback [17,18]. To best work towards implementing projects that maintain the provision of goods and ecosystem services of the watershed, the council should promote collective awareness of the economic value of water management and identify self-management and self-financing strategies from the territories. According to the POMCA Guideline developed by the Colombia Ministry of Environment, the POMCA formulation phase should do the following:

- Design participatory spaces to collect feedback from local actors and connect them with technical elements typical of planning methodologies.
- Foster understanding among both decision-makers and stakeholders of the elements of the water management programs that must be included in the POMCA submission.
- Host consultation and dialogue to help modify, adjust, and approve of the POMCA strategic focus areas, programs, and projects.
- Guide the implementation phase of the POMCA by dialogue with the multiple stakeholders and local actors.

During watershed planning, due to competing environmental, social, and economic interests, conflicts that create barriers to water management often arise between stakeholders [21]. Specifically, the root source of the conflicts is often competing and multiple water usage needs, e.g., for consumption, agricultural production, hydropower, recreation, and ecological purposes [22]. In addition, stakeholders often lack knowledge about the overall water availability and quality, making it difficult to define and evaluate management strategies for the basin [23].

In Colombia, particularly in the eco-region of Eje Cafetero, the water supply of the suburban area faces significant challenges due to a lack of planning, land use transformation, and shortcomings in the management of public utility companies [24]. The case study, the Campoalegre River basin, is part of the Eje Cafetero region. Therefore, there is a need for a tool in the planning process that could help stakeholders explore conflicts of interest in a constructive space, exchange knowledge, and coproduce watershed management plans.

2.2. Campoalegre River Basin Background

The Campoalegre River is in the western-central region of Colombia in the eco-region of Eje Cafetero (Figure 1). The basin encompasses an area of about 641 km² and contains seven municipalities, with four municipalities in the department of Risaralda (79% of its area) and three municipalities in the department of Caldas (22% of its area).

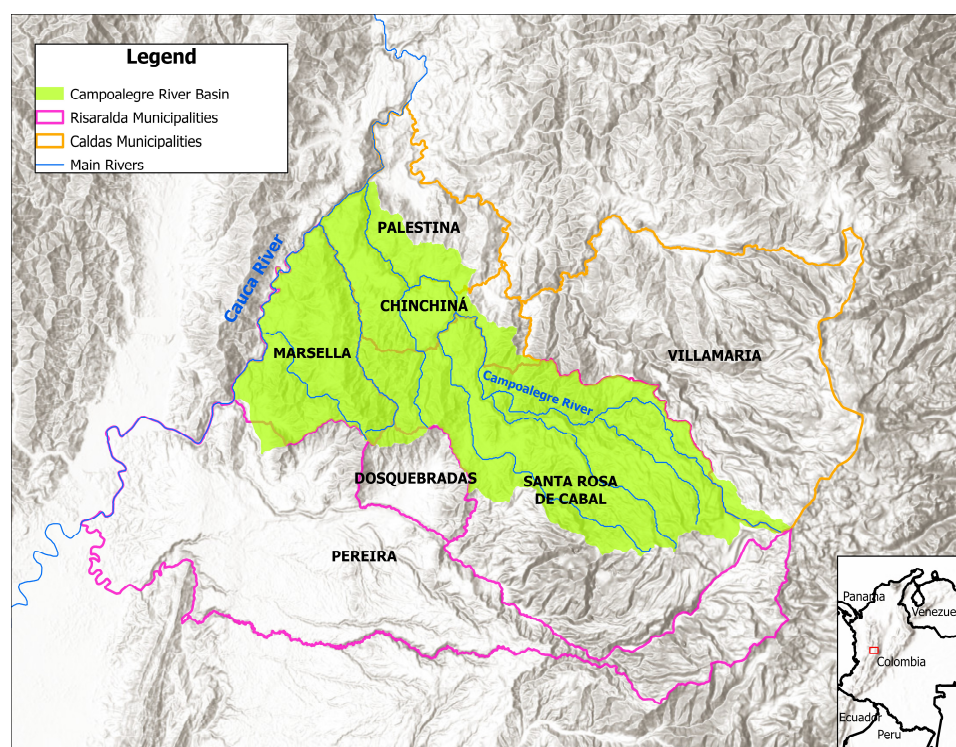


Figure 1. Campoalegre River basin location.

The Campoalegre River basin has a high diversity of climate types, with temperatures ranging between warm, temperate, and cold in the paramo [25]. This climate variability creates high species biodiversity as well as hydrologic variability. The headwaters present good water quality conditions and thermal springs having the potential for geothermal energy development and tourism projects. The basin has high precipitation (1000 to 7000 mm/year) [26], allowing for significant agricultural development. Being in the coffee region of Colombia, coffee production generates the most employment and revenue in the basin. Tourism is the present sector with the greatest promise for growth in employment and economic development for the municipalities of the POMCA [25,27].

2.3. Defining Strategies, Focus Areas, Programs, and Projects in the Watershed Management Plan (POMCA)

The programmatic component of the Campoalegre River basin, developed by the Basin Council, integrates expertise from various stakeholders, including local institutions, communities, economic sectors, smallholders, indigenous groups, and academics. This collaborative effort is a result of an in-depth process involving problem and conflict identification within the region. It addresses crucial topics of interest such as water supply and

quality, biodiversity, risk management, economic development, and governance, which emerged from the thorough analysis of issues affecting the watershed.

Initially, the council collected information in the pre-diagnostic, prospective, and environmental zoning stages to identify the problems and conflicts in the study area [27]. Subsequently, in addressing these issues, all involved actors actively participated in proposing solutions through a series of meetings that comprised two integral parts:

1. Problem and conflict identification, aligning with the diagnosis of the region, recognizing potential conflicts, and analyzing environmental zoning.
2. Proposing actions to respond to the identified problems and conflicts. The actions generated in these meetings form the programmatic component of the POMCA, which comprised the five strategic focus areas, 14 programs, and 25 projects shown below in Table 1.

Table 1. Strategic focus areas, programs, and projects under the Campoalegre POMCA.

Strategic Focus Area	Program	Project
Environmental governance	Environmental education	Education as a tool to build a safe and sustainable territory
	Territorial capacity	Capacity development of the Basin Council
		Strengthening capacities of community aqueducts
		Participatory and collaborative management for the ordination and management of the basin
Environmentally sustainable productive systems	Protection and safeguarding of cultural heritage	Development of community capacities to implement conservation measures, risk management, and adaptation to climatic change
		Financial management for the POMCA's sustainability
		Harmonization of management and planning instruments
Comprehensive disaster risk management and adaptation to climate change	Sustainable agricultural productive systems	Research, education, conservation, protection, and safeguarding of cultural heritage
		Integration of methodological strategies for the strengthening of the sustainability of agricultural production in the influence area of the Rio Campoalegre POMCA
		Sustainable green business strengthening and development
Comprehensive management of biodiversity and water resources and their ecosystem services	Disaster risk knowledge	Development and consolidation of entrepreneurs and business units of the ecotourism and agrotourism sector as green businesses
		Strengthening the level of risk knowledge in the basin
		Preventive measures for risk reduction
Comprehensive management of biodiversity and water resources and their ecosystem services	Disaster risk reduction and adaptation to climate change	Corrective and mitigation measures for risk reduction
		Risk transfer
		Strengthening preparation for emergency response
Comprehensive management of biodiversity and water resources and their ecosystem services	Disaster management	Ecological structure of the basin with recognition in the planning instruments and environmental and territorial management
		Conservation of the watershed's ecological structure
		Implementation of individual domestic wastewater treatment systems (Sistemas de Tratamiento de Aguas Residuales Domésticas STARD) in the rural areas of the basin
Comprehensive management of biodiversity and water resources and their ecosystem services	Consolidation of the ecological structure of the watershed	Evaluation, adjustment, implementation, and monitoring of the master plans of aqueduct and sewer systems (Planes Maestros de Acueducto y Alcantarillado, PMAAs), sanitation and wastewater management plans (Planes de Saneamiento y Manejo de Vertimientos, PSMVs) and the comprehensive solid waste management plans (Planes de Gestión Integral de Residuos Sólidos, PGIRSS)

Table 1. Cont.

Strategic Focus Area	Program	Project
Comprehensive management of biodiversity and water resources and their ecosystem services	Water safety	Formulation and/or updating and implementation of methodological guidelines by sector for the presentation and implementation of programs for the water's efficient use and saving (Programa de Uso Eficiente y Ahorro del Agua, PUEAA)
	Regional environmental observatory for monitoring, follow-up, control, and evaluation	Regional and integral technological platform for monitoring, control, and evaluation
Knowledge management		Identification of the threat, vulnerability and analysis and risk assessment
	Watershed technical studies	Studies for the evaluation of the state of biodiversity and its ecosystem services Studies for the incorporation of environmental sustainability in the productive sector

The intricate interactions and potential positive or negative impacts of these actions across different sectors remain unclear for the stakeholders and actors. That is when the SG can play a crucial role in elucidating these complexities by providing a simulated environment where stakeholders can explore and understand the consequences of their decisions. This tool proves valuable in enhancing comprehension of the interconnectedness of various sectors within the watershed, facilitating more informed and effective decision-making processes.

3. Serious Game

3.1. Serious Game Concept in Conflict Resolution

SGs can accommodate participants with differing knowledge, relations, and cultures by implementing an adaptive and playful approach towards knowledge transfer [28]. The SGs also can contribute to conflict resolution by performing the following functions:

- Integrating information, simulation models, and expert knowledge across different components of water resources and rules, and promoting cooperation in the same decision platform [29].
- Bringing stakeholders and researchers together in a safe space to discuss, learn, and extract the meaning and results of traditional decision-making models (hydrological), thereby helping close the knowledge gap between policy and science [30].
- Communicating complex ideas around competing interests or perspectives, prompting participants to find common goals and understand the larger context among the wider range of actors in the basin [31].
- Supporting strategic decision-making by prompting participants to seek solutions to the complex problems faced by decision-makers (public and private) during watershed planning [32].

3.2. Serious Game Applications in Water Resources

SGs have emerged as effective tools in water resources planning and management, offering immersive experiences to users while addressing critical aspects of sustainable water use and basin management. In this context, several SGs have been developed, each with a unique focus and set of objectives. Table 2 provides a concise overview of some notable SGs in the field.

Table 2. Serious Game applications in water resources management.

Serious Game	Developer	Scope of Application	Main Objectives	Geographic Focus
Aqua Republica	DHI: Danish Hydraulic Institute, 2016 [33]	Water resources planning and management	Understand river basin concepts and visualize the consequence of their decisions	Fictional basin
Shariva (Shared River)	Douven et al., 2014 [34]	Transboundary cooperation, flood management	Build capacity in transboundary cooperation addressing flood management and mitigation	Mekong River Commission
Irrigania	Seibert and Vis, 2012 [35]	Water use education	Represent water conflicts among farmers to educate students	Not specified. Fictional villages
SimBasin	Craven et al., 2017 [36]	Water resources planning and decision support	Bring stakeholders together and illustrate the uncertainties, relationships, and feedback in the basin, acting as an accessible introduction to modelling and decision support for non-experts	Magdalena–Cauca macrobasin in Colombia

These SGs serve diverse purposes, providing interactive learning experiences that range from educating students about water conflicts among farmers in Irrigania to fostering awareness of transboundary cooperation in Shariva. Aqua Republica addresses global conflicts through sustainable water management in a fictional basin, while SimBasin engages stakeholders in the decision-making processes of the Magdalena–Cauca macrobasin in Colombia. Each game caters to specific needs within water resources planning and management.

Moreover, these SGs play a crucial role in capacity-building among basin stakeholders. Aqua Republica helps decision-makers and communities understand river basin concepts, promoting sustainable water management [33]. Shariva focuses on transboundary cooperation and flood management, offering a real case study related to the Mekong River Commission [34]. Irrigania aids students and educators in building capacity by simulating water conflicts among farmers [35]. SimBasin acts as a comprehensive tool to engage stakeholders in decision-making processes, allowing exploration of uncertainties and relationships in the basin [36].

SGs provide participants with a unique perspective on water, offering insights into surface versus groundwater value, the consideration of water as a good versus a right, and nexus connections. They effectively represent the basin in planning processes, aiding participants in understanding the current situation and anticipating future impacts on the watershed [37]. This understanding is crucial for developing effective watershed plans, as it enhances communication skills, fosters an understanding of underlying conflicts in the basin, and enriches participation processes [38].

Based on these applications, the implementation of a SG in participation processes and water policies, like the POMCA, is developed within a shared vision planning framework. It recognizes the roles played by players with different spatial influences and their often-contradictory decisions and interests (e.g., protection of biodiversity, maximization of economic benefits, improvement of water quality). This SG allowed stakeholders to understand the projects and actions in the POMCA and their possible impacts, using fictional situations or challenges to guide users in choosing actions to address specific challenges.

4. Serious Game Development and Application: Watershed Management Plan at Campoalegre River Basin—Colombia

4.1. POMCA Campoalegre Serious Game Design

The POMCA Campoalegre Serious Game was developed to support the POMCA formulation phase described in Section 2.1 for the Campoalegre River basin. The Campoalegre SG was applied in two online workshops in June 2021 (an online setting was used due to the COVID-19 pandemic). The game brought together stakeholders belonging to different productive sectors in the basin, e.g., the coffee federation, water supply companies, smallholders' associations, NGOs, academics, environmental authorities, and municipal and government entities in charge of planning processes.

The game was developed by code in R (v 4.1.0) and using a web interface platform with the Shiny package. It may be accessed online via https://latinoamericasei.shinyapps.io/Juego_Serio_POMCA_Campoalegre/ (accessed on 1 August 2021). This Serious Game had four main objectives:

1. Communicate complex ideas and concepts such as resource allocation models and connect stakeholders with practical, easy-to-understand tools.
2. Allow stakeholders to get familiar with the guidelines and actions of the POMCA.
3. Generate a participation space where stakeholders can explore alternative actions within the POMCA and their effects across the watershed related under different climatological, economic, and social scenarios.
4. Open a free space for discussion and debate between decision-makers and stakeholders regarding the alternative POMCA actions during the game. It collects feedback from stakeholders about the POMCA actions so that watershed planning and decisions are well informed by considering different voices.

The SG was applied in the POMCA process because of its potential to raise awareness in a practical and straightforward way about the social, technical, and economic factors related to the management of complex water systems by bringing together multiple actors (state, users, and civil society) in a single space while using a conflict resolution approach. The SG may allow the POMCA formulation to be developed in a shared vision planning framework, recognizing the roles of the players (basin councilors and stakeholders such as representatives of local authorities, the community, the hydroelectric sector, aqueducts, smallholders, indigenous communities) with different spatial influences of their often-contradictory decisions and interests.

4.1.1. Identified Problems and Conflicts in the Case Study, and Their Interrelations

To develop the Campoalegre SG, information and expert knowledge were used to identify and group problems and conflicts in the Campoalegre River basin into 11 components including risk, water supply and quality, biodiversity, productive sectors, and governance (Table 3).

Conversations between the experts in the region revealed significant interrelations among the identified problems and conflicts within the basin. For instance, the availability of water for human consumption directly impacts water quality, as both aspects are intrinsically linked to the physical, chemical, and biological characteristics of water bodies. Moreover, the state of conservation of natural landcover influences the risk of flash floods and fire threats, underscoring the intricate relationship between ecosystem health and natural disaster susceptibility. By identifying systemic problems and understanding their interrelations, stakeholders gained a more comprehensive understanding of the multi-faceted challenges facing the Campoalegre River basin. This awareness fosters holistic decision-making, wherein actions are evaluated not only for their direct impact but also for their potential to mitigate broader systemic issues. The recognition of these interrelations directly influenced the design of the Serious Game, guiding the selection and formulation of action packages to address the interconnected problems and conflicts. By incorporating this understanding into the gameplay mechanics, a dynamic environment was created where stakeholders can explore the complexities of water resources management and strate-

gize collaboratively to achieve sustainable outcomes. This approach not only enhances the realism and relevance of the Serious Game but also empowers stakeholders to make informed decisions that consider the broader implications of their actions on watershed health and resilience.

Table 3. Description of the components applied in the Campoalegre Serious Game.

Component	Description
Water quality for human consumption	Availability of water resources in terms of quality for human consumption.
Water resources quality	Physical, chemical, and biological characteristics of the water bodies in the basin.
Availability of water for human consumption	Availability of water resources in terms of quantity for human consumption.
State of conservation of natural landcover	Status of natural landcover in the sub-basins that favors the conservation of biodiversity and ecosystem services.
Ecological structure planning and land management instruments	The territorial entities and the environmental authority include in the land management instruments the strategic areas and ecosystems of the basin that should be conserved or restored.
Governance	The technical, administrative, and political capacity of the environmental authorities and territorial entities for water and natural resources management in the basin. The institutional arrangements and the supporting regulatory framework help to fulfill this purpose. The agreements between institutional and social organizations that contribute to water and natural resources management.
Risk—hazard of flash floods	The risk of flash flood danger to lives or property.
Risk—fire threat	The risk from plant cover fires, which can occur due to combustibility conditions of plant covers, temperatures, or lack of rain. High and medium threat levels are considered.
Risk—threat of mass movement	Risk is considered in terms of a threat from mass movements, such as landslides.
Agricultural sector	Agricultural and livestock production systems that improve the production process and generate positive environmental impacts.
Tourism sector	Productive activity that consists of enjoying the natural attributes of the environment and that is carried out in an environmentally responsible manner.

4.1.2. Action Evaluations

The strategic focus areas, programs, and projects defined by the council for the Campoalegre River basin, presented in Section 2.3 (Table 1), address the components associated with the problems and conflicts in the region. However, this information may be challenging for the stakeholders and actors in the region to comprehend. Therefore, it is crucial that they can understand the solutions proposed by the council through clear and easy-to-understand actions. For this Serious Game, the solutions from the council were grouped into actions that correspond to a subject, which, in turn, addresses the strategic focus areas, programs, and projects. The actions and subjects of the Serious Game are presented in Table 4.

To help conduct such an analysis of the effects of the proposed actions in each subject, an evaluation system in the SG was developed, defined by “Sustainability Points” (SPs). The SPs are a standardized measure of the predicted effects by component of each strategy in each sub-basin area. For example, an action that involves wastewater treatment systems in a sub-basin will significantly increase SPs in that sub-basin and downstream, particularly in the water quality component. However, sub-basins not connected to where the treatment system is implemented or components like the risk of flash floods would not be affected in terms of SPs for these actions.

Table 4. Campoalegre Serious Game actions for each subject.

Subject	Action
Sanitation	Do nothing related to sanitation Implement sanitation and wastewater management plans Implement individual domestic wastewater treatment systems Cleaner production
Risk mitigation measures	Do nothing related to risk mitigation measures Riverbanks management Stability, erosion control, and water management Fire preparedness
Environmentally sustainable production systems	Do nothing related to environmentally sustainable production systems Implementation of agroforestry, organic, and conservation agriculture Implementation of sustainable livestock Implementation of polycultures
Comprehensive management of biodiversity and ecosystem services	Do nothing related to comprehensive management of biodiversity and ecosystem services Conservation and restoration of strategic areas and ecosystems Ecological structure of the basin in land use and environmental planning instruments
Safe and sustainable use of water	Do nothing related to safe and sustainable use of water Sectoral programs for the water efficient use and saving
Sustainable tourism systems with a strengthened superstructure	Do nothing related to sustainable tourism systems with strengthened superstructure Strengthened sustainable value networks
Environmental governance in the basin	Do nothing related to environmental governance in the basin Environmental education Strengthening of community aqueducts Capacity-building of the River Basin Council Strengthening of institutional capacities Real and effective environmental participation to influence decision-making in the basin

Because the game explores results related to components across a wide range of sectors, not all actions can be modelled in one software component. To evaluate the predicted effects of the actions across the components of each sector, the games use the Leopold multi-criteria evaluation matrix [39,40]. This is a multi-criteria evaluation matrix used in environmental impact assessment, and it aims to systematically assess and evaluate the potential impacts of various land use alternatives on the environment. The matrix consists of rows representing different environmental factors or criteria (such as water quality, air quality, biodiversity, etc.) and columns representing different land use activities or alternatives. Each cell in the matrix contains a qualitative or quantitative score (SPs for this Serious Game) representing the impact of a specific land use alternative on a particular environmental factor.

According to the combination of actions taken, the SPs could increase or decrease depending on the predicted conditions of the sub-basin. The starting conditions of the basin, called the baseline scenario, and predicted effects of the actions were defined by the experts based on their knowledge of the Campoalegre River basin, insight from existing models, and a literature review.

4.1.3. Visualization of Results

For the Serious Game results to effectively support resources management and allocation decision-making, the information presented must be concrete, reliable, and updated, and possess scientific integrity. The visualization of results is crucial, and color choices play

a significant role, as Western cultures associate green and blue with positive results and red with negative results [41].

The results of the Campoalegre Serious Game are visualized in Figure 2, demonstrating changes in Sustainability Points (SPs) following the selection of action packages. Three types of visualization were employed:

- Maps (Figure 2a): Sub-basins were colored according to changes in SPs as the average of all components, but individual components could also be displayed;
- Bar charts (Figure 2b): These depicted the SPs' changes in each sub-basin across each component. Each color represents a subbasin;
- Heatmaps (Figure 2c): These illustrated changes in SPs in each sub-basin across each component. Red colors show decrease, and blue an increase of SPs.

Points obtained according to the selected action package.

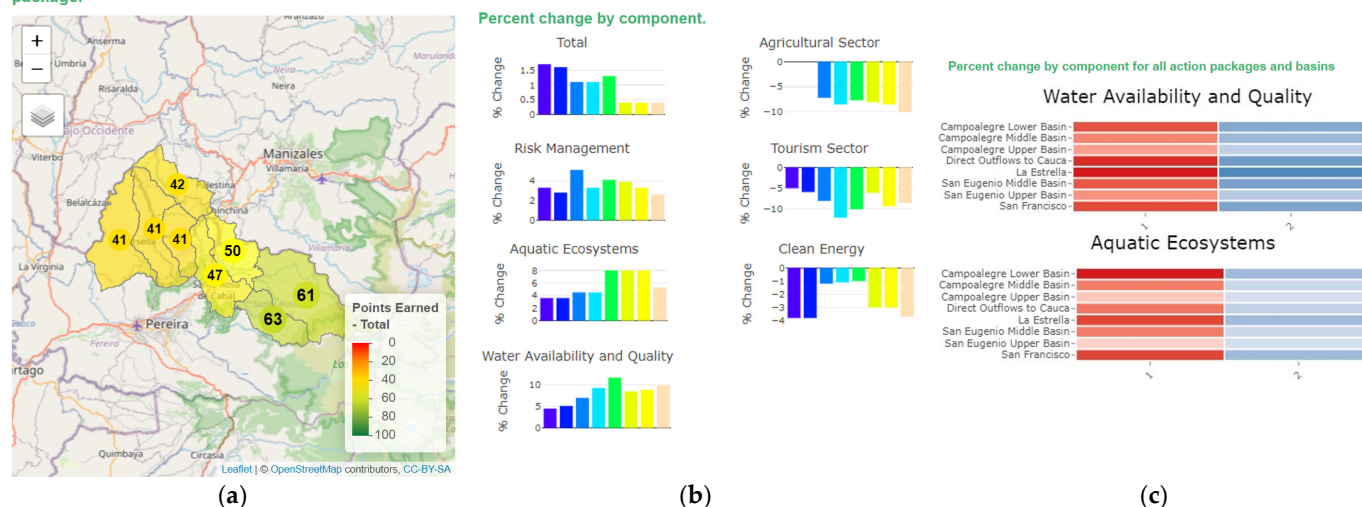


Figure 2. Serious Game results visualization: (a) maps; (b) bar charts; (c) heatmaps.

4.2. Serious Games Rules and Application

The POMCA Campoalegre Serious Game is played according to the following steps as described below:

1. Instructor describes the methodology of the workshop and how the Serious Game will be played;
2. Players are divided into random groups, get familiar with the Serious Game interface, and start to play;
3. Players assign weights to each performance component (see Table 3);
4. Players discuss selection of action packages according to a described challenge;
5. Players describe in a textbox of the game why they choose the selected action package to respond to the challenge and press play;
6. Players visualize results across maps and graphs available in the software to check how their action package resolves proposed challenges;
7. Players discuss the results of the game;
8. Feedback is gathered about the game with all groups reunited.

The online workshop began by introducing Serious Games generally and their importance for participatory planning in natural resources management. Then, we presented background on the baseline scenario, about the Campoalegre River basin, the performance components, the POMCA actions included in the game, and how the results will be shown. To begin playing the game, the stakeholders were divided into playing groups. The moderator (affiliated with the researchers, environmental authorities, or decision-makers) of each group led the players through the game, following the instructions detailed above. After the formal gaming process, the players were called to discuss the game performance

and debate the programmatic structure and actions included in the POMCA. Figure 3 summarizes the methodology applied during the Serious Game workshop.

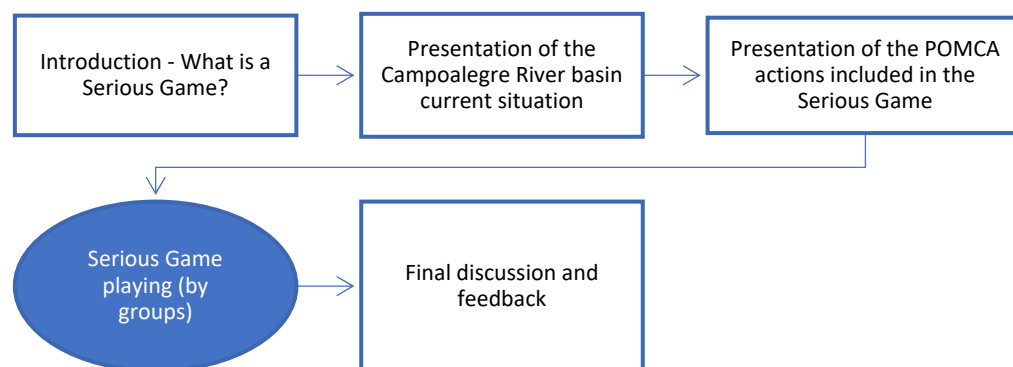


Figure 3. Workshop methodology.

Figure 4 shows graphically the SG application from steps 3 to 6. In the third step of the game, players assign a weight, from 0 to 100, to each of the performance components (Table 3) based on their perceptions of the importance of each component. Before continuing, each group of players must discuss and reach a consensus on weights for each component. The weights are then used to generate the results and will be important when making the actions later in the game. The weights of the components cannot be changed during the game.

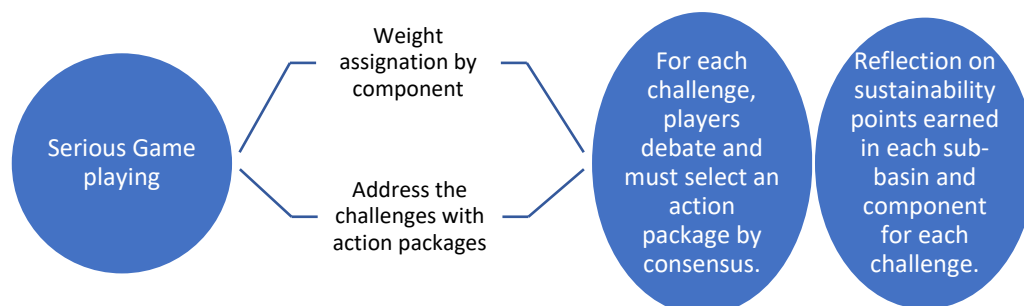


Figure 4. Serious Game application.

Once the weights are assigned to each component (totaling 100%), the players must take actions that respond to the challenges in the basin, described below in this section. The players in each group must reach consensus and choose one or several options per subject. Collectively, the selected actions are called action packages. The available actions per subject are presented on Table 4.

The proposed challenges present hypothetical situations that may occur in the watershed. These situations are related to the climate, economic situation of the region, agricultural crops, governance, use of water resources, quality, and other aspects. The four challenges proposed were the following:

1. There is a rainy season with multiple emergencies due to flash floods and landslides in the region.
2. There is an economic boom in the tourism and agricultural sectors without adequate monitoring and control. This situation has negatively impacted natural resources due to lack of treatment and inadequate pollutant disposal. The agricultural frontier has expanded, increasing fragmentation and loss of biodiversity and ecosystem services. Projects that comply with current environmental regulations are supported.
3. A dry season with high temperatures that caused multiple fires and water shortages has just ended. The quality of most of the alternative sources was not suitable for

consumption because the wastewater was discharged directly without treatment. A lack of response from public and private actors has shown institutional weaknesses. There is a consensus on the need for rational management of resources and to implement water treatment systems. It is proposed to adjust the land and environmental management policies and there is high interest in restoration and conservation actions.

4. The average weather season has no shortage events, floods, mass removal events, or fires. This has favored tourism and the implementation of agricultural projects. Partnerships between the public and private sectors have been strengthened.

After the group has selected the action packages for each challenge, they must describe reasoning for their proposed actions. The model then calculates the obtained Sustainability Points (SPs) according to the selected action package. The platform then presents the results in maps, graphs, and heatmaps to compare the SPs under the baseline scenario defined by the expert's knowledge and the proposed action packages. If the SPs of the simulation are higher than the current situation, then the results suggest the proposed actions would improve the watershed conditions. Otherwise, if the SPs are lower, then the action package is predicted to create watershed conditions worse than in the baseline scenario.

Once the Campoalegre Serious Game concludes, participants engage in a crucial phase of reflection and discussion. Players convene to deliberate on the impacts of their chosen action packages across each predefined component. The goal is to collectively assess whether the implemented actions have enhanced Sustainability Points (SPs) within the basin.

This post-game discussion serves as a vital forum for stakeholders to analyze the repercussions of their decisions on various facets of water resources management. Participants explore how their actions have influenced components such as water quality, biodiversity, governance, and other critical parameters. The focus is not only on individual success but on understanding the systemic effects of the chosen strategies.

Moreover, the discussion allows stakeholders to identify synergies or potential conflicts arising from the diverse set of actions taken by different groups. This collaborative reflection aids in developing a comprehensive understanding of the interplay between actions and their overarching impact on the watershed.

In addition to evaluating the immediate SP outcomes, participants dig into the broader implications for the Campoalegre River basin. They consider the potential long-term effects, sustainability of implemented measures, and any unforeseen consequences that may arise in future scenarios. The feedback generated during this post-game deliberation is invaluable for refining strategies, learning from collective experiences, and informing the ongoing process of watershed management planning.

According to the main criteria of SGs in the water resources sector defined by Savic et al., 2016 [37], the following is a summary of the Campoalegre Serious Game:

- **Application area:** The game is applied around the implementation of the actions proposed in the Campoalegre POMCA formulation;
- **Number and type of players:** This is a group game (maximum 10 people for each group) with representatives from different sectors that have influence in the watershed and are involved in the action definition process for the POMCA. The players are already familiar with the basin. The players must discuss and select the best actions to address the local challenges. Each session may have multiple groups to accommodate more participants;
- **User interface:** We designed the game in the R—Shiny interface, which contains information in tabs about the following:
 - a. The programmatic content of the POMCA (strategic focus areas, programs, and projects);
 - b. An introduction to the Serious Game, describing the definition and importance;
 - c. The current context of each POMCA action, including a description of the action, related limitations, opportunities, and conflicts, and predicted 20-year effects;
 - d. Game instructions;

- e. The game platform—participants play the Serious Game by interacting with this tab;
 - f. Questions answered by the participants following the game, used to analyze the results.
- **Simulation model used:** Leopold multi-criteria evaluation matrix;
 - **Performance feedback:** During the game, there is a moderator within each group. In our application, each moderator was affiliated with the researchers, environmental authorities, or decision-makers. The task of the moderators is to encourage MSP and to collect ideas and valuable information from the discussions that can support the construction of the POMCA. Additionally, at the end of the game, the participants are sent a Google Forms survey about the game performance;
 - **Progress monitoring:** The game can be played multiple times, and the R platform saves the actions chosen and the results for each simulation. The same action package is not allowed to be selected twice, thus warning the group of players to change their decisions. The results are displayed through maps, bar charts and heatmaps indicating the increase or decrease in Sustainability Points per sector component and microbasin;
 - **Game portability:** The game is played online with any device with internet access. An offline option is also possible on a computer by installing the R Studio software v 1.4.1717.

5. Serious Game Outcomes

The Campoalegre Serious Game played a crucial role in uniting stakeholders and actors within the river basin to collaboratively design the programmatic content of the POMCA, addressing critical issues in a participatory manner. The outcomes gleaned from discussions post-game underscored the significant contributions of the Serious Game. It facilitated a nuanced understanding of the POMCA's programmatic structure, explaining the direct relevance of its strategic focus areas, programs, and projects to the challenges and actions faced by decision-makers. In parallel, the Serious Game seamlessly complemented existing strategies of the POMCA, providing an innovative space for generating proposals that leveraged current strengths and charted a promising future for the basin.

The participatory decision-making exercise within the Serious Game was particularly lauded by participants for offering insights into the integration and interconnection of different POMCA areas. The workshop's pertinence, innovation, and the intuitiveness afforded by visual graphics and maps were highlighted. Participants expressed that similar Serious Game applications could prove beneficial in other environmental education contexts, fostering participatory spaces in territory-building processes.

Acknowledging the complexity of the POMCA formulation and the need to consider multiple uncertainties, players recommended the Serious Game as a supportive tool in planning processes, aiding in the construction of resilient plans across various uncertainties. One notable observation was the transformation of stakeholder perspectives regarding their interests within specific areas of the watershed. Initially, actors tended to prioritize actions focused solely on their respective zones. However, through the gameplay experience, they recognized both the positive and negative impacts at the basin level, leading to increased openness to forming alliances and implementing actions beyond their specific interests.

Moreover, this Serious Game, due to its incorporation of expert knowledge, allowed for the inclusion of qualitative strategies in a quantitative manner. Strategies such as tourism and governance, which are typically qualitative in nature, were quantified within the game framework, providing a more comprehensive and data-driven approach to decision-making.

Players' recommendations emphasized holistic perspectives, urging continuous recognition of the basin's baseline scenario and the importance of maintaining a strategic focus even during emergencies. They stressed the need for ideal articulation among multidisciplinary sectors facing challenges, emphasizing consensus-building among players with diverse roles. Economic limitations and necessary alliances for strategy implementation were recognized as crucial considerations. The Serious Game was identified as a valuable

tool for understanding actor roles and the impact of components on various aspects of the basin. Lastly, decision-making was underscored to be information-driven, emphasizing the importance of open and shared information in the process. The synthesis of player conclusions and recommendations reflects the nuanced benefits and practical considerations derived from the Serious Game application in the Campoalegre River basin.

5.1. Comments about the Serious Game Performance

Following the workshop, participants provided valuable insights through open-ended responses, shedding light on their perceptions of the Serious Game and its utility. Notable comments include the following:

- One participant highlighted, “The game is relevant; the workshop is novel, and the graphics help to understand the impact of the actions in the watershed more effectively”;
- Emphasizing the importance of community engagement, another participant noted, “It is crucial to present the game with different communities, as it provides spaces for participation in territorial construction processes”;
- Recognizing the complexity of the planning exercise, a participant stated, “It is a complex exercise that must consider multiple uncertainties. These tools support planning processes and build plans that can be resilient to different scenarios”;
- Addressing the multifaceted challenges within the game, a participant mentioned, “The challenges involved multiple components at a time, and a consensus within the players must be reached. The game helps to understand how the components of POMCA play a key role”;
- Acknowledging the interactive and informative aspects, another participant expressed, “Interesting dynamics, knowledge of territory, plans, and actions recognizing productive sectors, generating easy communication with different sectors”.

These reflections provide valuable qualitative feedback on the relevance, community engagement potential, complexity, and interactive dynamics of the Serious Game. They collectively underscore the diverse benefits and insights gained by participants during the gaming experience.

5.2. Limitations, Critical Reflections, and Potential for Upscaling

The Serious Game (SG) developed for the Campoalegre River basin demonstrates significant potential for enhancing stakeholder engagement and fostering collaboration in watershed management. However, its application has some limitations.

One key limitation is the reduction in complexity inherent in the game design. While the SG effectively increases collaboration between stakeholders who might not normally interact, it is not intended to collect detailed data about the river basin. Instead, its strength lies in facilitating communication and interactions among participants.

Accessibility and inclusion present another set of challenges. The requirement for a computer to play the game limits its usability in low-resource environments and among participants without technical expertise. Additionally, the game can be played both online and offline, but each mode has its trade-offs. Online play can provide accessibility to some participants, but limit others that have a lack of technical knowledge or issues with internet access. Offline play, on the other hand, requires logistical considerations such as a location that is easily accessible for participants and a pleasant space that motivates participants to attend and participate.

User engagement is another critical aspect to consider. Although the number of participants is unlimited, practical experience indicates that the game yields better outcomes with a maximum of ten players. Larger groups can complicate meaningful interaction and lengthen the gameplay, diluting the effectiveness of the exercise.

Furthermore, participants need specific knowledge about the basin, including its physical, legal, and socio-economic characteristics, to fully engage with the game.

Cultural and contextual sensitivity is also crucial. The power dynamics between stakeholders and cultural influences can significantly impact the outcomes of the game.

The SG must be adaptable to different cultural contexts and sensitive to local power structures to ensure that all voices are heard and valued during the gameplay, for example, considering whether online or offline play guarantees a more inclusive approach, or similar.

Finally, the SG described in this paper was developed using expert knowledge rather than a model simulation. Therefore, replicating and implementing the game in different contexts requires collaboration with local experts to tailor the game to the specific watershed and stakeholder dynamics. This customization is essential to ensure the game's relevance and effectiveness. Additionally, if a simulated model representing certain characteristics of the watershed is available, it can be included in the game to demonstrate results associated with the model. This integration would enhance the realism of the game and provide stakeholders with more concrete insights into the potential outcomes of their decisions.

6. Conclusions

Serious Games are emerging as a highly valuable and adaptable tool for facilitating participation processes in water resources management, suitable for diverse scales and management contexts. Their engaging nature transforms what might be perceived as traditional resource allocation models into interactive, dynamic spaces for discussion and coproduction. Through Serious Games, participants, representing various sectors and localities, engage in lively discussions, gaining insights into the complexities of decision-making and resources management. The interactive dynamics of Serious Games provide a unique platform for conflict resolution. Participants, often with conflicting goals and decisions, collaboratively navigate through scenarios, fostering understanding and compromise. This participatory approach contributes not only to conflict resolution but also to capacity-building. Participants acquire a comprehensive understanding of the intricate interplay between socio-technical factors crucial for managing complex water systems.

In the specific case study detailed in this paper, the application of the Campoalegre Serious Game within the POMCA formulation process for the Campoalegre River basin in Colombia yielded positive feedback from participants. The game proved instrumental in stimulating communication and conflict resolution among stakeholders with diverse backgrounds and knowledge bases. The interactive elements and capacity-building aspects of the Serious Game facilitated mutual learning, enabling stakeholders to share insights and propose solutions across a spectrum of interests and perspectives. An additional strength of the Campoalegre Serious Game was its incorporation of real strategies from the POMCA, offering participants a tangible understanding of the programmatic structure. This not only enhanced their appreciation for the complexity of the POMCA but also encouraged constructive dialogue, leading to suggestions for new projects and potential modifications.

Future work should delve into assessing the costs and time associated with implementing POMCA actions within the game framework. This consideration will introduce realistic constraints, enabling stakeholders to make informed decisions while accounting for budgetary and time restrictions. By addressing these practical aspects, future iterations of Serious Games can enhance their effectiveness as tools for collaborative decision-making in water resources management.

Author Contributions: T.F.S., funding acquisition; A.M., W.R. and T.F.S., project coordinators; C.G. led authorship of this paper, with invaluable contributions from A.M., B.M., T.F.S. and C.C.; A.M., T.F.S., W.R. and C.G. conceived and designed the methodology, data collection, and analysis; A.M. and C.G. designed the Serious Game platform; B.M. and C.C. supported writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Corporación Autónoma de Caldas (Corpocaldas) under “Convenio 161 de 2020” and by the Swedish International Development Cooperation Agency (SIDA) through the “Water Beyond Boundaries” Initiative of Stockholm Environment Institute (SEI).

Data Availability Statement: The Serious Game can be found online at https://latinoamericasei.shinyapps.io/Juego_Serio_POMCA_Campoalegre/ and has been accessible since 1 August 2021.

Acknowledgments: We would like to thank all our colleagues who were part of the Campoalegre River POMCA Formulation project: Wilford Rincón, Luisa Cardona, Javier Ariza, Carlos Ospina, Dora Suarez, Ricardo Moncada, Myriam Salazar. We thank the members of the Campoalegre River Basin Council, who allowed our intervention and provided valuable support in each part of the participatory process. We would also like to thank the Autonomous Corporations of Risaralda and Caldas, CARDER, and Corpocaldas for believing in the proposed methodology and betting on innovation in this participatory process.

Conflicts of Interest: The authors declare no conflicts of interest.

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