The H_2Ours game to explore Water Use, Resources and Sustainability: connecting issues in two landscapes in Indonesia

Lisa Tanika[1], Rika Ratna Sari[2], Arief Lukman Hakim[1], Meine van Noordwijk[2,3], Marielos Peña-Claros[1], Beria Leimona[3], Edi Purwanto[4], Erika N. Speelman[5]

[1]Forest Ecology and Forest Management Group, Wageningen University & Research, 6708 PB Wageningen, The Netherlands
[2]Plant Production Systems, Plant Science, Wageningen University & Research, P.O. Box 430, 6700 AK Wageningen, The Netherlands
[3]World Agroforestry, ICRAF Southeast Asia, Bogor 16001, Indonesia
[4]Tropenbos Indonesia, Bogor, Indonesia
[5]Geo-Information Science and Remote Sensing, Wageningen University & Research, 6708 PB Wageningen, The Netherlands

Correspondence to: Lisa Tanika (lisa.tanika@wur.nl)

Abstract. Restoring hydrological functions affected by economic development trajectories faces social and economic challenges. Given that stakeholders often only have a partial understanding of the functioning socio-hydrological systems, it is expected that knowledge sharing among them will help to be better aware of the consequences of the land use choices and ways to manage water. To facilitate the collective learning a tool is needed that simplifies the social-hydrological system but still accommodates the crucial social and technical aspects. However, data-driven simplification can lead to very site specific models that are difficult to adopt for different conditions. To address these issues, this study aims to develop a highly adaptable serious game based on process-based understanding to make it easily applicable to any situation and to facilitate co-learning among stakeholders regarding complex socio-hydrological problems. We designed a 'serious' game that revolves around a simple water balance and economic accounting, with environmental and financial consequences for the land-users. The game is based on process-based understanding of the system, allowing for both relevant site-specificity and generic replicability. Here, we describe the development of the game and explore its capacity to visualise, discuss and explore Water: Use, Resources and Sustainability ('H_2Ours') issues at landscape level. The H_2Ours game was designed using a combination of the Actors, Resources, Dynamics and Interaction (ARDI) and the Drivers, Pressure, State, Impact, and Responses (DPSIR) frameworks. The design steps for constructing the game led to a generic version, and two localised versions for two different landscapes in Indonesia: a mountain slope to lowland paddy landscape impacting groundwater availability in East Java, and a peatland with drainage-rewetting, oil palm conversion and fire as issues triggering responses in West Kalimantan. Based on evaluation referring to credibility, salience and legitimacy criteria, the H_2Ours game met its purpose as a tool for knowledge transfer, learning and triggering action. We discuss the steps that can lead to re-designing and adaptation of the game to other landscapes and policy-relevant issues.

1 Introduction

A recent call for collective action by the Global Commission on the Economics of Water (Mazzucato et al., 2023) asked for turning the tide, shifting from exploitation, over-use and wastage of freshwater resources to stewardship, wise use and social-hydrological restoration. To achieve this shift, a better understanding is needed on the relation between the social and hydrological systems, and on how this relation varies over time and space (D'Odorico et al., 2019). For example, many locations are experience hydrological problems due to changes in the use of land and water to meet food production, and other domestic and industrial needs (Djuwansyah, 2018). These uses often affect negatively the ability of water systems to retain their hydrological functions, which results in an increase in the water demand (Rosa et al., 2018), leading ultimately to degradation of the water system. Consequently, hydrological restoration aims to re-establish or restore the hydrological functions, and to avoid further hydrological degradation by managing water resources sustainably or eliminating the causal factors (Zhao et al., 2016).

Four interacting knowledge-to-action steps are needed to determine adequate strategies for social-hydrological restoration (Van Noordwijk, 2018). These steps are understanding (technical agenda setting based on social relevance of environmental issues), commitment to goals (social understanding of urgency), operationalization of common but differentiated responsibility (in its social-ecological context) and innovation for better solutions (through monitoring and learning). Consequently, the first step for any restoration planning is developing a shared understanding of how the above- and belowground ecosystem structure and climate generate the hydrological functions and underpin the range of ecosystem services provided (van Noordwijk et al., 2022). Furthermore, the interactions between ecological-technical aspects and socio-economic conditions in a landscape (e.g., land tenure, the existence of regulations and incentive-disincentive mechanisms) make the socio-hydrological systems even more complex. Unfortunately, the lack transfer of knowledge between and within different groups of stakeholders often blocks the commitment, operationalization, and innovation stages of successful restoration (Creed et al., 2018).

Learning leads to gaining new information, knowledge, predictive ability, and ultimately to scenario development and knowledgeable decisions. However, providing information alone is not a catalyst that can trigger the associated knowledge to action chain (Marini et al., 2018). Therefore, 'services' that facilitate active learning and 'experiences' that provide a social context to technical aspects are needed for collective learning beyond knowledge transfer. In the 'learning' literature, there is a consensus that people learn more quickly through experiential learning where they can actively explore, engage with the process and then reflect on what happened during the exploration (Kolb and Kolb, 2005; Fanning and Gaba, 2007; Kolbe et al., 2015). Thus, we need tools that can show how a socio-hydrological system works as a whole and allow people to see and experience the consequences of the decisions made, to strengthen knowledge sharing and to facilitate collective decision-making. Two tools are being increasingly used in this context: hydrological modelling (Guo et al., 2021; Tsai et al., 2021) and serious gaming (Rossano et al., 2017; Feng et al., 2018; Ferguson et al., 2020). Hydrological modelling focuses on converting data to information, knowledge and understanding of technical aspects, and it is used to simulate various land-use change scenarios and quantify the likely consequences of various water management practices (Singh and Kumar, 2017). In contrast, serious gaming focuses on relating knowledge and understanding of social and technical aspects to enhance the credibility of decisions made. It adopts the basic elements of gaming, such as challenges, rewards, experiences, strategies, emotions, to allow stakeholders to safely explore management options (Fleming et al., 2014, 2016).

Although one can see all models as games, and all games as models, these conceptually related tools have developed as separate communities of practice (van Noordwijk et al., 2020). Games are models as they are succinct and often stylised representations of a more complex reality, and models are games as they allow the exploration of alternative strategies. In addition, both approaches require breaking down a complex system into several pieces, which is challenging as not all elements in the real conditions can and should be included in the models and/or games. Several considerations can serve as a guide in the simplification process from reality to model and game simulation (Medema et al., 2019), such as what knowledge we want to share with participants, what we want them to learn, and what changes/responses we expect from them.

Socially interactive games and models that explore larger spatial and temporal horizons have complementary strengths. As reviewed in Villamor et al., (2023), games and models can 1) seek a conceptual triangulation of representing the processes behind complex realties, 2) strive for numerical consistency between games and empirical models, 3) use games in the development of scenario models, or 4) use models in the design of games that trigger players to learn by experiencing manageable complexity. As an example of the letter, Lohmann et al. (2014) designed and tested model-based role plays with Namibian land reform beneficiaries, simulating 10 years of rangeland management. In this paper, we explore the feasibility of transforming a hydrological model into a serious game to provide socio-hydrological dynamics to stakeholders with diverse backgrounds to develop restoration plans.

Simplifying the complexity of the system and highlighting the socio-hydrological issues from a hydrological model into a socio-hydrological game will facilitate knowledge transfer among stakeholders and offer a better decision-making tool (Savic et al., 2016). But such a simplification process can lead to serious games that are very specific to a given local context, making it difficult for the game to be applied to other places. For that reason, the elements and rules in the game should be easily adapted to other locations, or at least there should be guidelines on how the game can be applied elsewhere.

Therefore, the objectives of this study are to develop a serious game that is adaptable to different socio-hydrological contexts and issues, and to clarify how such a game can facilitates knowledge transfer and knowledge sharing regarding water use and water management, and can supports negotiation and coordination among various stakeholders. To achieve our objectives we developed a generic game with two adaptations to two different locations in Indonesia differing largely in hydrological characteristics. First, we developed the H_2Ours game based on the socio-hydrological characteristics of the Rejoso watershed in East Java. Then, we modified the H_2Ours game according to the conditions of the Pawan-Kepulu peatland, West Kalimantan.

We organised the paper by presenting as method the stages of how we prepared, designed, tested, implemented and evaluated the H_2Ours games. The game itself is the primary ‘result’, illustrated by the game dynamics during test settings and early applications with local stakeholders. Feedback by game participants is presented as an evaluation of the current games. We close by discussing the simplification process from reality to game, effectiveness of the game to achieve the goals set, and the lessons learned.

2 Methodology

This study consists of four stages from the diagnosis of the study area to the evaluation of the game (Fig. 1). The different stakeholders involved in each stage are also provided.

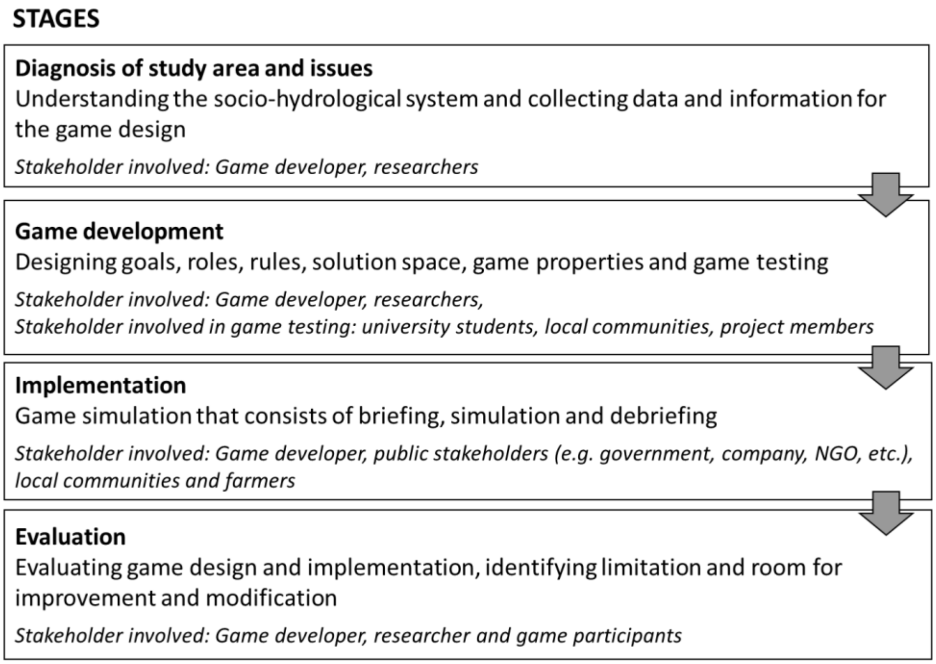

Figure 1: Stages undertaken from the preparation to the evaluation of the H_2Ours game, including stakeholder involvement across the different stages of this study

2.1 Study areas

The two study areas used in this research, namely the Rejoso watershed and the Pawan-Kepulu peatlands (Fig. 2), differ in physical characteristics (hydrological system, land cover, soil type), but they experience similar socio-hydrological problems (lack of coordination and collective action). Rejoso watershed restoration was conducted by the '*Rejoso Kita*' project in which World Agroforestry (ICRAF) was responsible for research and development of conservation and restoration strategies, while Pawan-Kepulu peatland restoration was conducted by Tropenbos Indonesia through the '*Working Landscape*' project and '*Fires*' project. Both areas have environmental problems because of the disruption of the buffering peak flow that contribute to floods due to lack of infiltration, which in turn is key to the supply of groundwater. To restore those hydrological functions, understanding about the relationship between land-use and (surface-ground) water management and water balance at the landscape level is crucial before developing a joint strategy (IPBES, 2018).

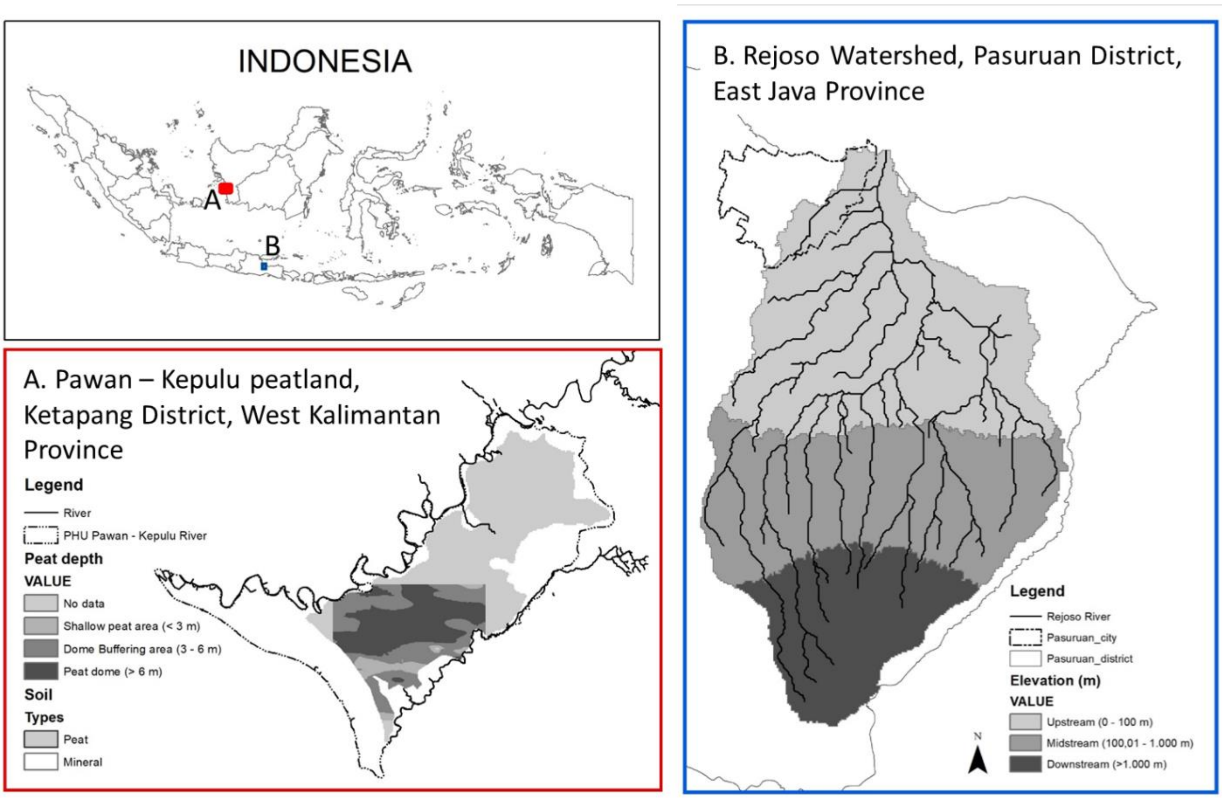

Figure 2: The two study areas of this study: A. Rejoso Wateshed that consists of upstream (elevation >1000 m above sea level (masl.)), midstream (elevation 100–1000 masl.) and downstream (elevation < 100 masl.), and B. Pawan-Kepulu peatland that consists of peat dome (peat depth > 6 m), peat buffering dome (peat depth 3–6 m) and shallow peat (peat depth <3 m).

The Rejoso Watershed (1600 km^2) is in the Pasuruan district, East Java Province, Indonesia. Based on the elevation and hydrological system, we can divide the Rejoso watershed into three areas: downstream (<100 masl. (meter above sea level), midstream (100-1000 masl.) and upstream (>1000 masl.). This watershed is a national priority because the Umbulan spring is used, through a recent pipeline, to supply water to 1.1 million people in the surrounding metropolitan area. Land conversion from agroforestry to intensive agriculture in the recharge areas (>700 masl. upstream and midstream area) and massive groundwater extraction using artesian wells in the downstream area for rice field were thought to cause the reduced average discharge of the Umbulan spring, from 5 m^3/s (1980s) to 3.5 m^3/s (2020) (Leimona et al., 2018; Amaruzaman et al., 2018; Toulier, 2019; Khasanah et al., 2021). As the declining spring discharge is disrupting the water supply for drinking water, agriculture and industries, stakeholders in the Rejoso Watershed need to develop strategies to restore the hydrological function of their watershed through land-use management in the recharge area and groundwater utilization in the downstream to maintain the continuity of water supply in the Umbulan spring (Khasanah et al. 2021).

The Pawan-Kepulu peatland is a peat area between the Pawan and Kepulu Rivers, functioning as a unified hydrological system. This peatland is in the Ketapang district, West Kalimantan Province, Indonesia (Fig. 2A). Based on the peat depth, we divided the Pawan-Kepulu peatland into relatively shallow peat area (peat depth <3 m), buffering the dome area (peat depth 3–6 m) and dome (peat depth >6 m). In the 2000s, local communities and oil palm companies started to build canals for artificial drainage to facilitate timber extraction and for facilitating the management of oil palm and other forms of agriculture (Carlson et al., 2012). However, during the dry season, the canals cause a decrease in the groundwater level so that the peatland becomes drier and more vulnerable to fire. Land fires are detrimental to both the local area and at the global level with the haze and carbon emissions (Widayati et al., 2021). Therefore, there is interest to restore the hydrological function of peatlands to prevent or reduce land fires (Murdiarso et al., 2021).

2.2 Diagnosis of the study areas and issues

For systems diagnosis and developing the H_2Ours game, the minimum required information composed of: hydrological information (to define boundaries of the hydrological system, hydrological problems and efforts that should be done to overcome the causes and impacts of the problems, rainfall, potential evapotranspiration), land cover information (typology, main locally relevant types, recent land cover change and life-cycle profitability estimates), and socio-economic information (village conditions, socio-economic issues, alternative livelihood options, institutional conditions). These information were collected using the Rapid Hydrological Appraisal (RHA) approach, which has been used and tested in a number of Southeast Asian countries (van Noordwijk et al., 2013; Jeanes et al., 2006)(van Noordwijk et al., 2013; Jeanes et al., 2006). In this approach, the information were grouped based on local ecological knowledge (LEK), public ecological knowledge (PEK) and modeller/scientist ecological knowledge (MEK). Mapping these different knowledge systems showed overlap, gaps and contrasts that provided starting points for further exploration.

To make it easier to describe the interactions between components in a socio-hydrological system, we structured the socio-hydrological condition of the study area based on the Dynamic, Pressure, State, Impacts and Responses (DPSIR) and Actors, Resources, Dynamic and Interaction (ARDI) frameworks. The DPSIR framework is widely used to carry out hydrological assessments because of its superiority in connecting various components in a socio-hydrological system (Sun et al., 2016; Lu et al., 2022). We used DPSIR to trace the causes of problems, including interactions and relationships between social and hydrological components and to further explore various responses to socio-hydrological problems (Sun et al., 2016). The ARDI framework is widely used in companion modelling approaches to guide system diagnosis as a first step in designing serious games (Etienne et al., 2011). We used ARDI framework to identify main stakeholders involved in water management, main resources, main processes that affect changes in resources, and interaction between stakeholders and resources (Villamor et al., 2019).

2.3 Game development

In this step, we transformed the information from the DPSIR and ARDI analyses into components needed in the game design: goals, roles, rules, and solution space (Fig. 1).

2.3.1 Scope and objective

The first stage in designing a serious game is to determine the scope and objective of the game (Silva, 2020; Mitgutsch and Alvarado, 2012). The scope of the game refers to the problem or issues to be addressed. The objective of the game refers to what kind of knowledge, new insight or impacts are expected to be obtained by players after participating in the game. We determined the scope and the objective of the game based on the socio-hydrological problem defined in the previous stage (Sect. 2.2).

2.3.2 Roles

According to the ARDI framework (Sect. 2.2), we defined the roles based on the main stakeholders involved in water management in each study area. Related to these roles, we designed goals that players must achieve during each simulation based on discussions and interviews with the related stakeholders according to their actual goal.

2.3.3 Rules

According to the ARDI and DPSIR frameworks (Sect. 2.2), we transformed the interaction between actors and resources as the rules of the H_2Ours game. To show the dynamics of change in resources and the impact of human decisions, the game rules consist of a set of values attached to each decisions type of land-use and water infrastructure that describes both the economic and the water balance component. The economic component consists of the production costs/capital required to manage a certain land-use type and the income derived from that land-use. The water balance component consists of surface flow and infiltration of each land-use type and water infrastructures. The values used as rules for the economic component referred to research findings by ICRAF and Tropenbos Indonesia (Sec. 2.1). For the water balance component, the Rejoso data were obtained from the hydrological modelling and field measurement (Leimona et al., 2018; Suprayogo et al., 2020), while the Pawan-Kepulu data was based on field measurement (Tanika et. al, manuscript in prep.). Several local communities then validated the values through a process of discussion and game testing (Sect. 2.3.6). We simplified the values for each land-use type as a ratio between land-uses to make the quantification process easier during the simulation process. A simple guideline for developing or modifying rules can be seen in the Appendix A.

There are two conditions that are used to mark the position of the participants towards their goals in the game, namely economic and environmental conditions. We derived the economic conditions based on a simple profit calculation equation, where profit is revenue minus all financial expenses (taxes, cost, incidental cost, etc.). The underlying economic analysis applied a life-cycle perspective to the various land-use systems, annualizing discounted future cost and benefit flows. At the sub-landscape level (e.g., upstream, dome), total profit is the difference between total revenue and total production costs. While the environmental indicators were derived based on a simple water balance model implemented in the Generic River Flow (GenRiver) model (https://www.worldagroforestry.org/output/genriver-generic-river-model-river-flow) (Van Noordwijk et al., 2017). Consequently, the relationship between the two conditions allowed us to describe the socio-hydrological system of each study area.

2.3.4 Game solution space analysis

The purpose of game solution space is to define the outcomes of all possible choices made by players in the game (Speelman et al., 2014). The solution space of the H_2Ours game was explored based on the average of economic and environmental outcomes obtained from 3, 10, 30, 100, 300 and 1000 games with random choice. One random-choice game consisted of 10 rounds in which climate conditions and land-use decisions made by players were completely random. The random-choice of land-use and climate condition were generated in R, then simulated using Excel spreadsheet as an imitation of the real H_2Ours game to calculate the economic and environmental conditions. In addition, we assessed the probability of outcomes within the solution space under random decision-making as a point of reference for the actual game implementation.

2.3.5 Game properties

The purpose of game development is to bring the game design into a real form that players can play or touch such as a game board, various required tokens, and other attributes that support the simulation of the game. Because we expected the decisions made by the participants during the game simulation represented their actual decisions, we developed the game as close to the reality as possible. The game board, the game's land-use options, and water simulation miniature are the key elements of recognition for players. Therefore, we adapted these elements to the conditions of each study area.

2.3.6 Game testing

The purpose of game testing is to assess the game's playability and dynamics. We tested the game in two ways: checking all the quantification systems using an Excel spreadsheet and the complexity through role playing testing. In the role-playing testing, we tested the game several times with different participants: members of the project, undergraduate students and non-targeted farmer groups. During the role-playing testing with project members, we checked the suitability and the game elements with the reality; with the students, we calibrated and validated the rules and feedback system in the game; and finally with the farmer groups, we checked if the rules of the game were sufficiently clear.

2.4 Game implementation

In this study, we executed ten game sessions which a total of 93 people participating, with five sessions in each of the study areas. All game sessions in Rejoso watershed were held in October 2021, while in Pawan-Kepulu peatland were held in August 2022. In each study area, a first one game session was organised with members of a multi-stakeholder forum consisting of representative of governments, NGOs, private sectors, and universities to get ideas on regulations and programs that would be offered to farmer communities, and four game session were organised with farmer groups to explore the implementation of the regulations and programs resulting from the game session with the multi-stakeholder forum.

For each game session, we invited in total of 9-12 representatives of farmer groups from upstream, midstream and downstream village in Rejoso watershed, and 12-16 representatives of four villages in the Pawan-Kepulu peatland. In the invitation, we let the group determine who would attend the simulation, provided that the group representatives were willing to hold discussions and exchange information with participants from other villages. For the four sessions with farmer groups, we grouped participants according to different criteria to get a variety of decisions. For the Rejoso watershed, we conducted two sessions with participants who had experience with a recent Payment for Ecosystem Services (PES) program (Leimona et al., 2018) and two sessions with participants from neighbouring villages where the PES program was not active. For the Pawan-Kepulu peatland, we conducted a game session with members of the village forest management unit, a session with members of an active farmer field school, and two sessions with people who are not members of village forest management unit and farmer field school. Game sessions took place in a central location in each of the landscapes to allow easy access for all participants. During the game session, the participants were asked we asked to play the game with the role of a farmers from their location within the landscape.

Each game session required half a day of implementation (briefing, simulation and debriefing), excluding game preparation and participant surveys for further research. We started the session with a briefing of around 10–15 minutes to help participants connect with the game by introducing the environment, setting goals, and clarifying the roles and rules of the game (Rudolph et al., 2014). At the end of playing the game, we did a debriefing of around 30–40 minutes to allow participants to reflect on what they experienced and learned during the game(Crookall, 2023; Kim and Yoo, 2020). To maintain consistency of the H_2Ours for different game sessions, we used the game session guideline provided in Appendix B.

2.5 Game evaluation

The aim of the evaluation stage is to assess the game session process and the game in achieving its objective. The game session process was evaluated based on game performances criteria in the form of rules that can be understood, fun and playability over time. While evaluating the game in fulfilling its objectives is more complicated than evaluating the game session process. Ideally, the evaluation of the game in achieving its objective can be evaluated after several simulations at various levels of simulation, and should be conducted before, during and after the game sessions (Oprins et al., 2015). With these conditions, the evaluation of the game can only be done after the game designer has done a lot of game trials and these trials requires numerous resources (in terms of funding, participants and time). To overcome this problem, several studies have proposed an assessment through an input-output process, which can integrate the assessments obtained during development process and after the game session (Bedwell et al., 2012). We followed the latter approach and carried out the evaluation based on several criteria that refer to credibility, salience, and legitimacy (Table C1 in Appendix C), using some criteria developed by Belcher et al. (2016). From the game development perspective, credibility refers to whether a game is built based on scientifically reliable knowledge, including the data and methods used to build the game. Salience refers to how far the game can show the relevance of goals, rules and finding to the actual situation. Finally, legitimacy refers to how the participant can accept the game by relating the game simulation to their actual situations (Cash et al. 2002).

From the long list of criteria (Belcher et al., 2016), we chose four credibility criteria, five salience criteria and two legitimacy criteria which we considered to be the most relevant for evaluating the H2Ours game. Each of these criteria were measured during the game design process and after the game implementation. We included those criteria during the game design using the ARDI and DPSIR frameworks to diagnose issues in the study area (Section 2.2). A rapid evaluations were conducted after the game session to assess the game session process and the game in achieving its objective. We converted those game performace criteria and creadibility, salience and legitimay criteria into Likert used questions and asked all game participants to fill in the survey. In the Likert survey, we used five-point scales (strongly disagree, disagree, neutral, agree, and strongly agree) on six statements to ask participants about their feeling during the game, their understanding of the rules of the game, the length of the game simulation, new knowledge that they got from the game, and implementation the game to their reality.

3 Results

We organized the results side by side between Rejoso watershed version and Pawan-Kepulu peatland to make it easier to see the similarities and differences even though the Pawan-Kepulu peatland version of the H_2Ours game was developed after the Rejoso watershed version.

3.1 Diagnosis of the study areas and issues

Based on the results from the DPSIR and ARDI analyses, we found that the Rejoso Watershed and the Pawan-Kepulu peatland have similarities in the socio-hydrology context (Table 1). Expectations on better economic conditions led local communities to changes in land cover, and excessive extraction of water resources (groundwater) caused disruption of the water balance. This disruption resulted in local communities and multi-stakeholder forum experience various hydrological problems, such as water shortages (or decreasing the groundwater level) and flooding. However, these two sites are also different regarding their hydrological contexts, such as hydrological boundaries, topography, and water management, and interactions among stakeholders and landscape (Fig. 3, Fig. D1). Two proposed solutions (responses) were identified by ICRAF and Tropenbos Indonesia based on their research findings to restore hydrological functions in watersheds and peatlands, namely better land use management and (ground) water management (Table 1; component 7-Response).

Table 1. Framing problem definition for the Rejoso Watershed and Pawan-Kepulu Peatland, Indonesia. Problem definition was done the using Driver, Pressure, State, Impact and Response (DPSIR) and Actor, Resource, Dynamic and Interaction (ARDI) frameworks, based on ICRAF and Tropenbos research findings

	COMPONENTS	REJOSO WATERSHED	PAWAN-KEPULU PEATLAND
1	Hydrological boundary/ landscape	Watershed (and/or groundwater catchment)	Peatland hydrological unit
2	Zone partition	(1) Upstream: elevation >1000 meter above sea level (masl.)	(1) Dome: peat depth > 6 m (2) Buffering area: peat depth 3-6 m

		(2) Midstream: elevation 100-1000 masl. (3) Downstream: elevation <100 masl.	(3) Shallow peat area: peat depth <3 m
3	**D**river	To get a better household income and livelihood	
4	**P**ressure	(1) Land-use conversion into non-tree-based system in the recharge area (upstream and midstream) (2) Massive artesian well construction for paddy field (downstream area)	(1) Land-use conversion into oil palm (dome and buffering area) (2) Massive canal construction to drain peatland water
5	**S**tate	(1) Increasing runoff and reducing infiltration (upstream and midstream) (2) Increasing groundwater uptake (downstream)	Increasing water outflow from peatland and decreasing peatland water level. This condition makes peatland become drier during the dry season
6	**I**mpact	(1) Decreasing groundwater supply in the Umbulan spring (2) Floods (during rainy season)	(1) Peat fires (during the dry season) (2) Floods (during the rainy season)
7	**R**esponse	(1) Land-use/cover management (2) Better groundwater management through artesian well management	(1) Land-use/cover management (2) Better groundwater level through canal blocking management/ distribution
8	**A**ctors	Multi-stakeholder forum and farmers/local communities	
9	**R**esources	(1) Money (2) Water balance (especially groundwater and surface water)	(1) Money (2) Water balance (especially groundwater and surface water)
10	**D**ynamic	(1) Land-use/cover change (2) Water management (artesian well management)	(1) Land-use/cover change (2) Water management (canal blocking management)
11	**I**nteraction	Fig. 3	Fig. D1

The interaction between stakeholders and the landscape is represented by the type of decisions regarding their landscape taken by the multi-stakeholder forum and local communities. Local communities (farmer from upstream, midstream, and downstream village in Rejoso Watershed and farmers from neighbouring villages: Village 1-Village 4 in Pawan-Kepulu peatland) have the authority to make decisions regarding their land which consists of land-use types and water management types (artesian wells in Rejoso watershed and canal blocking in Pawan-Kepulu peatland). Multi-stakeholder forums have authority over regulations and programs applied to local communities to achieve their goals. Multi-stakeholder forum can refer to their existing or potential regulation and program.

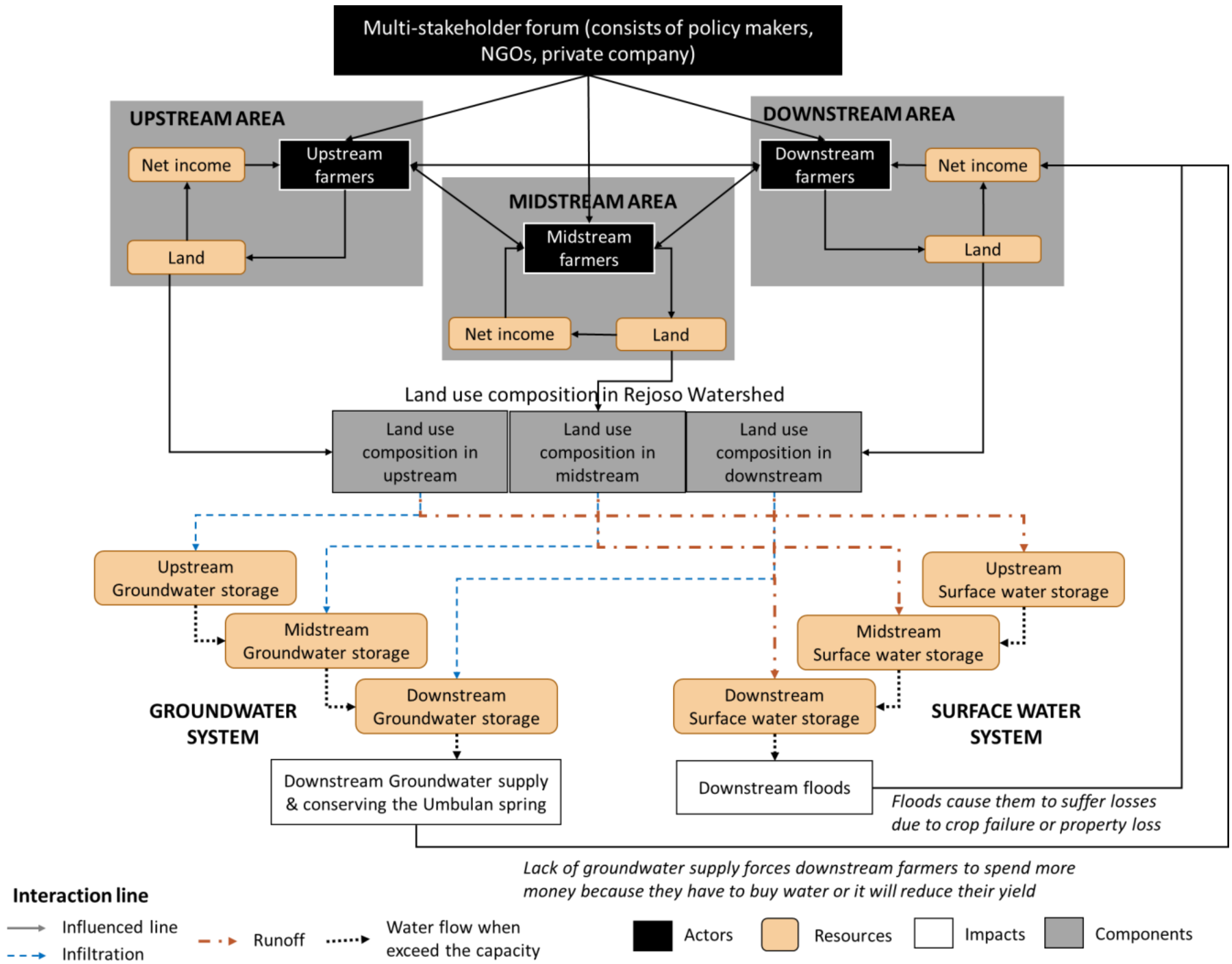

Figure 3: Socio-hydrological model for the Rejoso watershed, defined using the ARDI framework. Interactions among actors and between actors to landscape influence land-use composition. The land composition affects the hydrological and economic situation, which influences back to the interactions. A similar socio-hydrological model with some adjustments for Pawan-Kepulu peatland was also developed (Appendix D).

3.2 Game development: H₂Ours game

3.2.1 Scope and objective of the game

As a serious game, the H₂Ours game has the objective of becoming a tool to help sharing knowledge and building collaboration between stakeholders to restore hydrological functions in a landscape. Based on Table 1, we determined the goal for H₂Ours game simulation in those two study areas are for knowledge sharing and facilitating collaboration, specifically for groundwater water restoration and flood prevention. However, the H₂Ours game in Rejoso watershed addressed the supply and utilization of deep groundwater, while in Pawan-Kepulu peatland it addressed peatland's groundwater as an indicator of the wettability of peatlands and its vulnerability to land fires.

3.2.2 Roles

Based on the stakeholder identification survey in Rejoso Watershed and Pawan-Kepulu peatland, we defined two key roles for this game, namely a multi-stakeholder forum and local (or farmer) communities. The goal of the multi-stakeholder forum is to prevent natural disasters meaning water scarcity and floods in Rejoso watershed, and fires and floods in Pawan-Kepulu peatland. In the Rejoso watershed, local communities can be grouped into people who live in the upstream village, midstream village and downstream village based on the village elevation. Meanwhile in Pawan-Kepulu peatland, local communities can be grouped into four groups of people living in four neighbouring villages (Village 1 – Village 4). Local communities represent landowners. Their goal is to fulfil their household needs (food and taxes). The H_2Ours game brings the various interests of these actors together and shows how they make their decisions regarding the management of land and water resources to meet their economic and environmental expectations.

3.2.3 Rules

At the start of the game, players (i.e. multi-stakeholder forum or local communities) received a limited amount of play money. Community members were asked to manage their land to meet their household needs by arranging the land-use type combination and water management in their area with the play money provided, while multi-stakeholder forum was asked to run programs or to help reduce the local community's financial problems. Once players decided on how they would manage their land or community programs, the economic and environmental rules linked to those land-use decisions were applied (Table 2). These rules then defined the dynamics of the economic and environmental conditions (Table 2, and Table D1 and D2 for the Pawan-Kepulu peatland).

When during the rainy season the total of surface water in the downstream area of Rejoso watershed and in the shallow peat of Pawan-Kepulu peatland exceeds its capacity (>800 ml), it caused flooding. When the groundwater exceeds its capacity (>700 ml), the excess water flows to the Umbulan springs in Rejoso watershed and to sea in Pawan-Kepulu peatland. But, when the groundwater was less than <200 ml, it caused water shortages for agriculture in the Rejoso Watershed and made peat soil dry which triggered fires in Pawan-Kepulu peatland. These environmental impacts decreased the overall community income. As the consequence of this situation, the players might not have enough money to manage their land, buy food or pay taxes in the next round of the game. The multi-stakeholder forums with their limited budget could then choose to help them by providing financial help or making regulations/programs to prevent these environmental problems. Through this gameplay, we aimed to stimulate players to collaborate to achieve their goals.

Table 2. Economic and environmental impacts as the rules of the H_2Ours game in the Rejoso Watershed. The variation of environmental components resulting from different land-use options in the upstream and midstream depends on the ability of the land-use options to infiltrate water, while the variation of environmental components downstream depends on the use of water based on farmers' perceptions. The rules of H_2Ours game in the Pawan-Kepulu peatland are in the Appendix D. (AF= agroforestry).

Land-use	Production cost (unit money)	Income/year (unit money)		Environment impacts during wet year (ml)			Environment impacts during dry year (ml)		
		Wet year	Dry year	Runoff	Infiltration	Water use	Runoff	Infiltration	Water use
UPSTREAM AND MISTREAM									
All crop	12	25	13	40	0	0	0	0	5
Mixed AF low density	9	17	9	30	10	0	0	0	5
Mixed AF moderate density	6	9	6	20	20	0	0	0	0
Mixed AF high density	3	6	4	10	30	0	0	0	0
All trees	1	0	0	0	40	0	0	0	0
DOWNSTREAM									
Paddy	12	12	25	0	0	10	0	0	15
Maize	9	15	18	0	0	5	0	0	10
Orange	7	11	15	0	0	0	0	0	5
Cucumber	9	15	13	0	0	2.5	0	0	7.5
Banana	5	10	10	0	0	0	0	0	0

In addition, the economic and environmental conditions are also influenced by the yearly weather (wet year of dry year). In each round, participants decided on land-use without knowing whether the next round would be a ‘dry’ or ‘wet’ year (and rounds did not simply alternate).

3.2.4 Game solution space analysis

As reference for the player-based game runs, in 300 game runs with a random decision making process, the groundwater distribution varied depending on the location, while the distribution of surface water in the upstream and midstream is almost the same, and in the downstream is wider (Fig. 4A and Fig. 4B). Upstream and midstream had almost the same frequency distribution of surface water flows while runoff from the upstream and midstream areas was dominated by wet years, which then may potentially cause flooding downstream in the same year. Contributions of groundwater from upstream and midstream also responded to wet years, but groundwater utilization by downstream occurs mostly during the dry years. Therefore, the frequency distribution of groundwater contributions were wider than those for surface water.

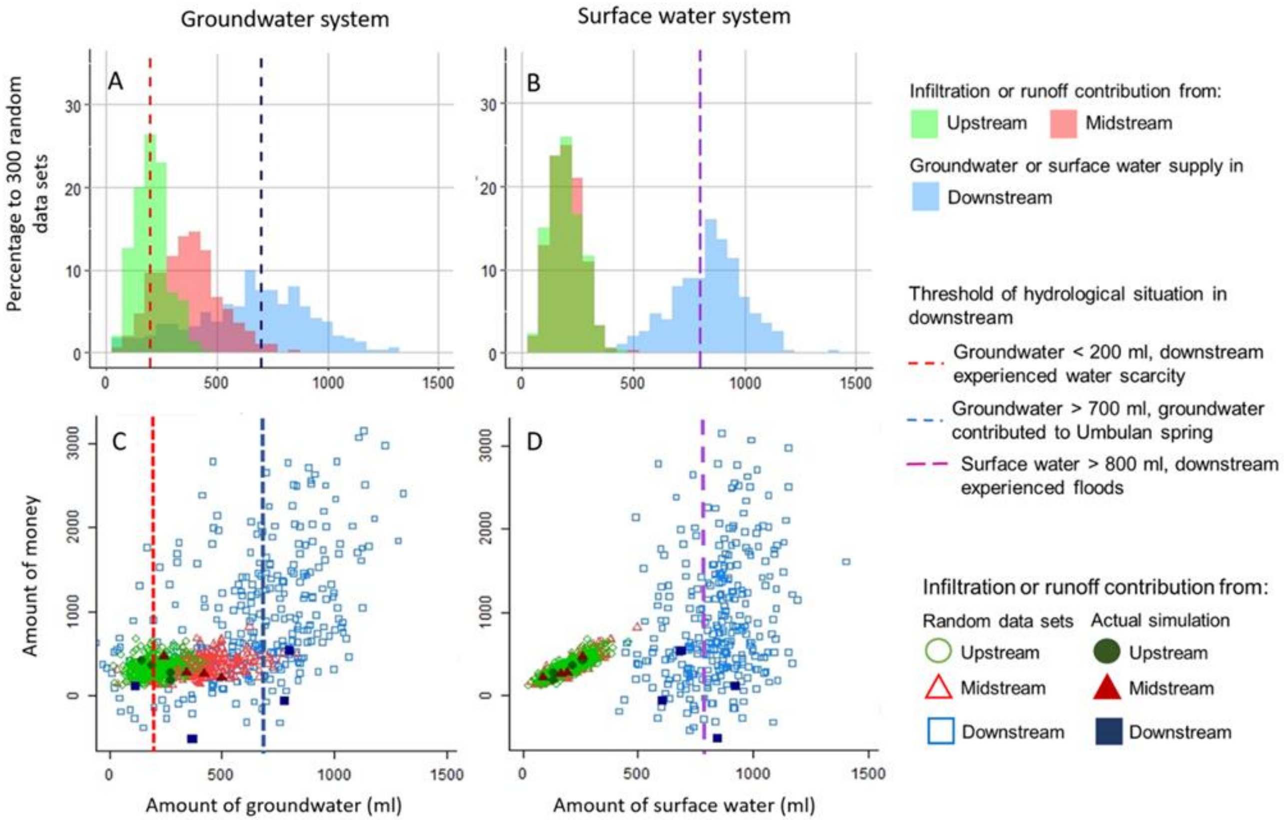

Figure 4: Simulation of hydrological and economic situation in H_2Ours game using random value (N = 300) and game actual simulation (obs.) results (N = 4) for the Rejoso watershed. A. Distribution of infiltration contribution from upstream and midstream and groundwater supply in downstream based on simulation with the random value; B. Distribution of runoff contribution from upstream and midstream and surface water accumulation downstream based on simulation with the random value; C. Groundwater situation and economic situation based on random value simulation and actual simulation; D. Runoff situation and economic situation based on random value simulation and actual simulation. Appendix E provides a further analysis of the solution space

Related to the economic outcomes (Fig. 4C and Fig. 4D), efforts to increase infiltration in the upstream and midstream have not contributed much to increasing the income of the community. However, the efforts of farmers in the upstream and midstream areas to improve their economic conditions resulted in increased runoff, which causes flooding in the downstream areas. Therefore, for the downstream area, the relationship between environmental and economic conditions varies because of the influence from upstream and midstream conditions.

The presence of relationship values between humans and nature and humans and other humans (relational values) influences decision making regarding natural resource management (van Noordwijk et al., 2023, 2020). Therefore, the decisions made by players during the game are influenced by various factors (e.g. interactions between players, game settings, level of player ecological knowledge, etc.) (Rodela and Speelman, 2023), whereas random decision making is used to build solution space. For example, when the upstream and midstream groups decided to maintain and improve their economic conditions, they caused a reduction in groundwater supply and increase flooding for downstream area, which caused the downstream group to pay for the losses it experiences. Apart from that, during the game session the facilitator also provided PES scenarios (Appendix B, Game Play number 9: repeat step 6 for the rest of the rounds with additional scenarios such as providing payment for ecosystem services). This scenario offers downstream groups to contribute a certain amount of money to maintain more trees in the upstream and midstream. Therefore, the downstream player groups always spend more money than the mid- and upstream player groups either as a loss due to the environmental consequences (floods or water scarcity) or due to their efforts to prevent negative impacts by joining the PES program.

3.2.5 Game properties

To make the game engaging, we prepared game materials such as a game board to represent the landscape, land-use tiles according to the existing and future land use types, play money token, and water infrastructures token (Fig. 5). We also created, water balance miniatures (Fig. 6) to demonstrate how surface water flows and leads to floods and water infiltration increases ground water supply. Each round after calculating the economic condition and environmental conditions based on Table 3, we asked players to pay production costs, taxes, etc. and get income, incentives, etc. using play money. The water balance was shown via a miniature with real water according to the produced surface water and groundwater.

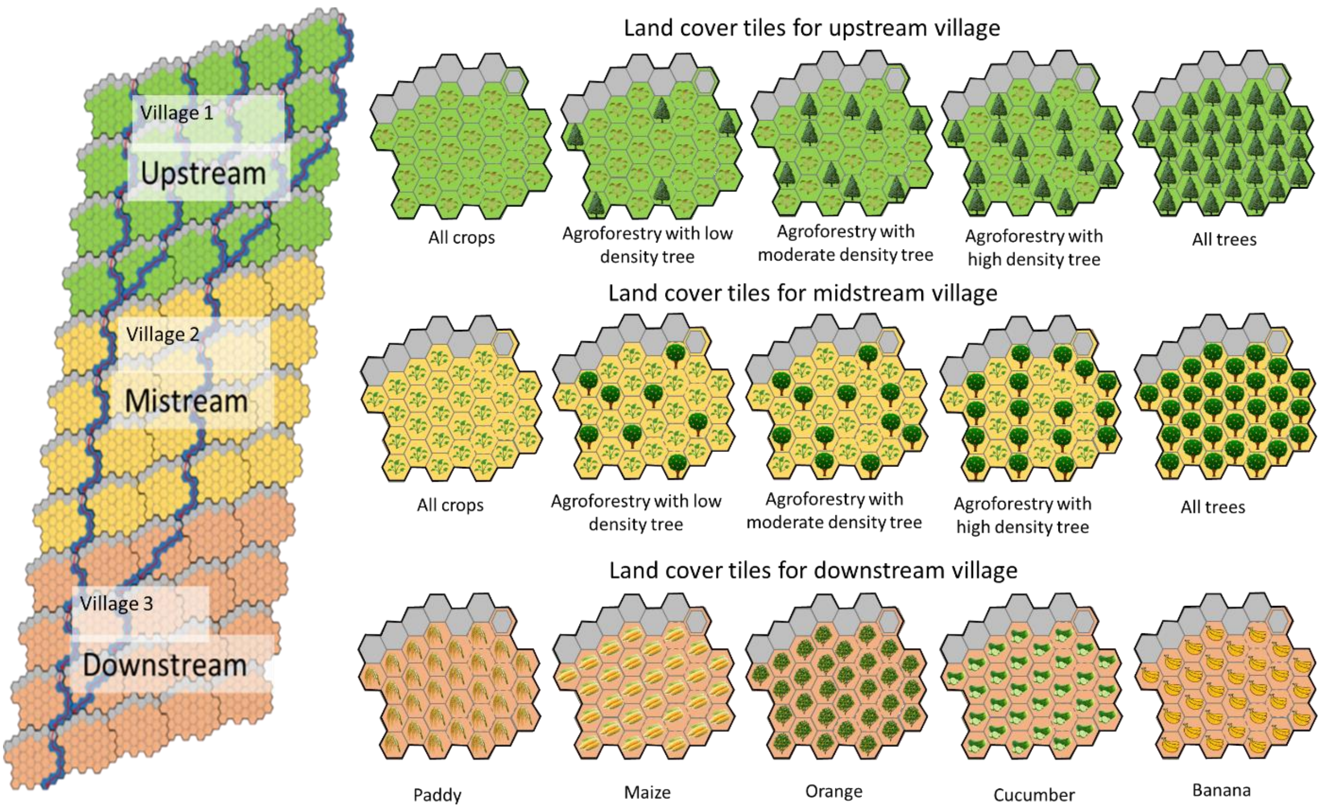

Figure 5: Game board and land use/cover tiles of the H_2Ours game in Rejoso Watershed. The land cover options in the upstream and midstream area varies based on their ability to infiltrate water, while in the downstream area varies based on farmer's perception on water utilization. See appendix D for the game materials for the Pawan-Kepulu peatland.

Figure 6: Simple water balance model of H_2Ours game in Rejoso watershed to show the dynamics of changes in hydrological conditions because of land-use change and water utilization. See appendix D for the simple water balance model for the Pawan-Kepulu peatland

3.2.6 Game testing

From the results of checking the game calculation in excel, we adjusted the values used in the rules to ensure that these values are sensitive enough to changes in strategy by players, i.e., the initial money given to players, as well as the initial water for groundwater and surface water. The role-playing testing with project members allowed us to validate the game scenarios that would be applied in the game implementation; with the university students, we adjusted the flow of the game, the number of rounds to 8-10 rounds, and the length of simulation time to two hours; and with the local communities (non-targeted participants), we checked the terminology used during the simulation.

3.3 Game implementation

The game session with the H_2Ours game takes approximately two hours (excluding briefing and debriefing). For the Rejoso watershed version, the two hours of game session consisted of 10 rounds with 6-12 players divided into 3 groups (or 2-4 people per group) acting as local communities: upstream, midstream, and downstream. The Pawan-Kepulu peatland version, the two hours game session consisted of 8 rounds with 8-16 players divided into 4 groups, and players are asked to select their village name as first step of creating ownership. In both versions, an additional group of players consisting of 2-4 people can act as public stakeholders (government, companies, NGOs) and interact with the villages.

During the game session, players acting as a farmer/local community tried to improve their household income and livelihood, at least to a level that would allow them to manage their household for the next year. The results of the game implementation showed that there was a trade-off between economic and environmental conditions, and among the upstream, midstream and downstream groups (Fig. 4, below). In the Rejoso watershed, the efforts of the upstream and midstream communities to improve their economic situation by increasing crop area brought a negative environmental impact as flooding and water scarcity for downstream communities. The efforts of upstream and midstream communities to reduce these problems resulted in a reduction of their economic outcomes. This situation led to negotiation among those communities. In contrast, the negotiation process in the Pawan-Kepulu peatland was related to the canal blocking construction among villages and between villages with the multi-stakeholder forum. To achieve a closed hydrological system to maintain the wetness of the peatland, the construction of canal blocking must be carried out collectively by all villages according to the location suggested by the multi-stakeholder forum. The construction of canal blocking reduced the income of farmers/local communities due to decreased yield or increased harvesting costs. Furthermore, the multi-stakeholder forum also persuaded the community by giving them some compensation to protect the peat dome area by maintaining more trees.

During the debriefing of the sessions, the participants in Rejoso watershed and Pawan-Kepulu peatland mentioned that the game showed that any decision at the plot level impacted hydrological function at the landscape level. They also mentioned that if they had not met their economic needs, the economic conditions became their priority. They also indicated that they would accept any regulation or program from other stakeholders if their income is not reduced significantly. But, if that happened, they hoped for compensation. From the multi-stakeholder forum's perspective, they said that it would be easier if the village knew what they wanted in advance, so that the programs and assistances would be able to match their needs. In addition, regulations should also be complemented by supporting schemes, such as compensation or incentive schemes, not just regulations issued by the government. Further analysis to these different perspectives will be presented in follow-up manuscripts (Tanika et al, in prep).

3.4 Game evaluation

After playing the game, the participants of both study areas were asked to fill a survey to assess the credibility, salience and legitimacy (Table 3). For the credibility of the game, based on the average of Rejoso watershed and Pawan-Kepulu peatland, the survey shows that 87% of the participants indicated that they understood well and very well the rules of the game, while 78% of participants indicated to know the purpose of the game. For the salience and legitimacy of the game, the survey show that 92% of participants gained new understanding and 87% said that they could apply the knowledge that they took away from the game to their real life. Besides the credibility, salience and legitimacy criteria, we also asked the participants about their opinion regarding the game session process. From the survey, 87% of the participants enjoyed the simulation and 79% of them feel that the length of simulation time was fair.

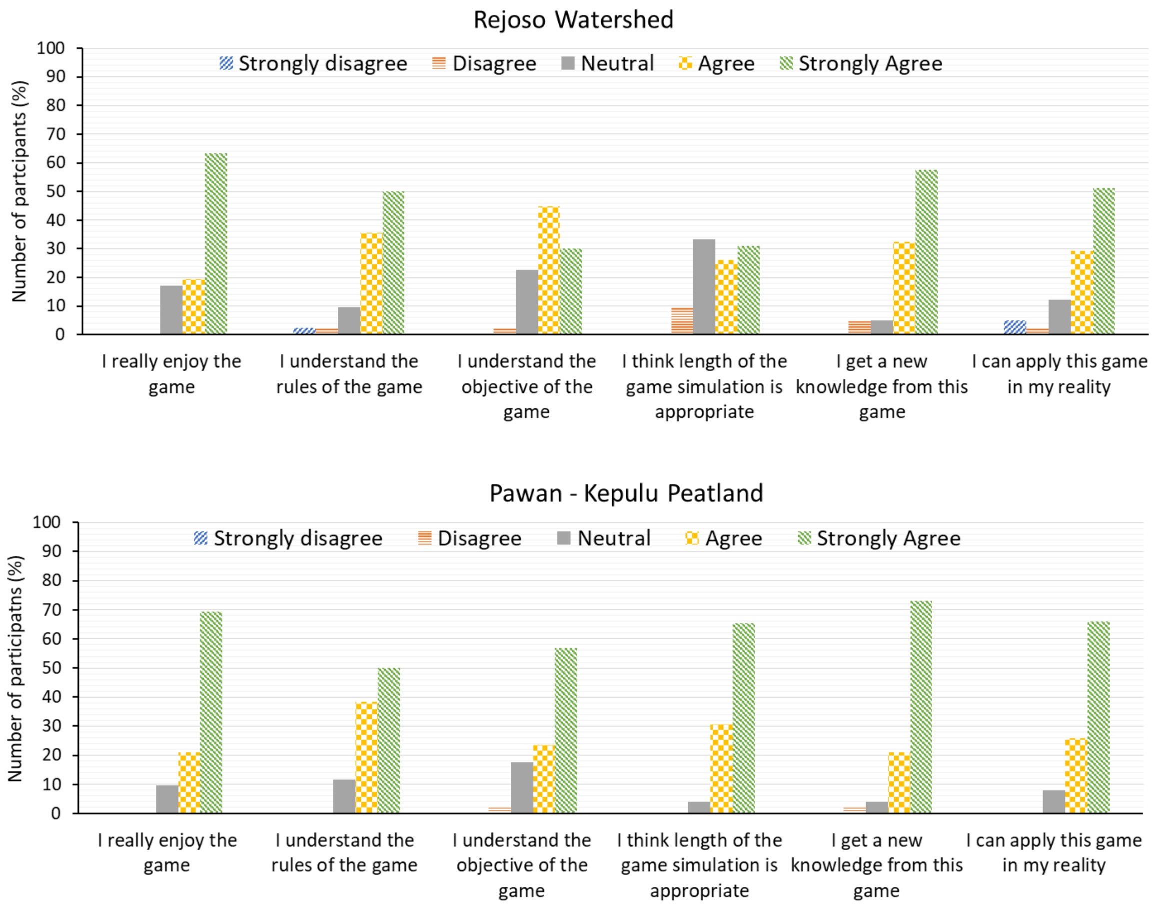

Figure 7: Game evaluation from the participants in the Rejoso watershed (N = 41 people) Watershed and Pawan-Kepulu peatland (N= 52 people)

4 Discussion

To meet the first objective of this paper to develop an adaptable serious game that can represent the socio-hydrological system, we show the generic version of the H_2Ours game as the result of the development and modification process in two different landscapes in Indonesia (Sect. 4.1). Then, to assess whether H_2Ours games can facilitate the knowledge transfer and knowledge sharing regarding water use and management and supports negotiation and coordination among various stakeholders as the second objective, we evaluated H_2Ours game based on input-output assessment according to evaluation criteria (Sect. 4.2).

4.1 The adaptable of H_2Ours game allows simplifying the complexity of the socio-hydrological systems

The complexity of a system is closely related to the number of interdependent information and interactions between elements in the system (Vidal and Marle, 2008; Rumeser and Emsley, 2019). Models and games simplify this complexity by reducing the amount of information and interactions, only showing the relevant information through the holistic perspective (Strait and Dawson, 2006; Rumeser and Emsley, 2019). In the H_2Ours game, we used the DPSIR and ARDI frameworks to identify the interconnections of the components of the complex socio-hydrological system of the Rejoso watershed (Table 1, column 3). Then we modified that version of the H_2Ours game based on the socio-hydrological condition of the Pawan-Kepulu peatland and added it to column 4 in Table 1. Therefore, these well-established frameworks act as the generic version of the H_2Ours game, which can easily be modified according to other socio-hydrological realities.

The two study sites experience more complex socio-hydrological problems than represented in the H_2Ours game. In our game, the water quantity issues were represented in line with national priority issues in that location, which resulted in groundwater scarcity and floods for Rejoso, (Fig. 3) and fire and floods for Pawan-Kepulu peatland (Fig. D1). In reality, the Rejoso watershed also experience other hydrological problems, such as erosion and landslides in the upstream areas, water quality degradation due to high amount of chemical fertilizer (Amaruzaman et al., 2018; Leimona et al., 2018), while the Pawan-Kepulu peatland also experience land degradation and water contamination because of mining in the upper area of peatland (Widayati et al., 2021). The complexity in a socio-hydrological system is formed due to many relationships and inter-connection of the various components (aggregate complexity), therefore self-organization through gradual learning is the key to a better transformation (Manson, 2001). If all the real life problems would have been included at once in the game, the risk of confusing people, especially those without a technical educational background (Gomes et al., 2018), which would preclude their understanding of the causes and effects of the problem. Therefore, by unravelling each individual problem and showing its causes and associated-impact, players were able to expand their understanding gradually. We believe that the generic game H_2Ours creates the opportunity to explore different problems, allowing the players to gain a deeper understanding and start building connections among various problems. In this way, it is possible to create opportunities to build overall socio-hydrological understanding in the future.

By comparing the H_2Ours game in the two study areas, we found that there were game elements that remained the same while others had to be adjusted to the local situation. Game elements related to the interaction among humans or between humans and the environment (relational value) are similar in the two study areas (e.g. land-use management to maximize profits, effort scenarios to restore hydrological functions, the need for coordination and negotiation among stakeholders). As such these elements maintained the same between the locations (Driver and Pressure in Table 1). However, the environmental response to the drivers and pressure requires technical adjustments (State and Impact in Table 1) to local conditions (e.g., hydrological boundaries, land-use types and composition, water infrastructures, hydrological systems). Therefore, our generic H_2Ours game (defined using the components of Table 1) showed to be easy to adapt to other problems or other locations. In addition, it is expected to overcome the complexity of a system as we can choose what the most important and most influential socio-hydrological problems that want to be addressed.

4.2 Game evaluation and lesson learned

During the game design, we evaluated the H_2Ours game using the input-output assessment process (Bedwell et al., 2012). Here, credibility, salience and legitimacy were assessed throughout the different stages of H_2Ours game development (Fig. 1). During the game development of the Rejoso watershed, we accommodated the credibility of H_2Ours game by relaying on the biophysical and hydrological research, including hydrological modelling through the GenRiver model (Suprayogo et al., 2020; Leimona et al., 2018), while in the Pawan-Kepulu peatland based on the biophysical measurement and hydrological modelling (Tanika et. al, manuscript in prep.). For the salience and legitimacy, we relied on results of participatory research done involving various stakeholders in Rejoso watershed and Pawan-Kepulu peatland (Widayati et al., 2021; Amaruzaman et al., 2018; Leimona et al., 2018). By considering the criteria of credibility, salience and legitimacy since the data and information collection, it was easier for the H_2Ours game to fulfil these criteria during the evaluation after the simulation.

As hydrological problems are usually complex and fundamental, any potential solution requires ample time for integrated planning, and all relevant stakeholders to understand the dynamics of the system at large scale (Medema et al., 2019). The H_2Ours game tries to present simple representation of the landscape so that it makes it easier for players to be aware of the conditions of neighbouring players and to gain system level perspective of socio-hydrological issues. Improving player knowledge by looking at socio-hydrological problems in a broader context encourages responsible behaviour towards the environment which is directly proportional to commitment (Keles et al., 2023). The evaluation of the game after the simulation (Fig. 7) indicated that most of the participants gained new knowledge from the game which they could apply in real life. Transparency of the rules of H_2Ours game allowed players to see the interdependent connections between elements in the complex socio-hydrological system more clearly and made it easier for players to explore various possibilities and to gain lessons from the reflection results (Kolbe et al., 2015; Kolb and Kolb, 2005; Fanning and Gaba, 2007). During the game session, after the players began to understand how the H_2Ours game works, the players started to initiate communication in the form of negotiations or coordination between groups or with external parties such as multi-stakeholder forum. This is in accordance with the four interacting knowledge to action steps in restoration strategies, which commitment begins after the mutual understanding have been made (Van Noordwijk, 2018). One of the advantages of a serious game is that participants interact directly with the environment and get feedback as quickly as possible so that they can immediately analyse and correct inappropriate strategies (Bartolome et al., 2011; Feng et al., 2018). Moreover, during the H_2Ours simulation, players were also faced with the game situation that resemble actual situation, so they are indirectly encouraged to find possible solutions together as two last parts of restoration strategies related to operationalization and innovation.

There are several lessons learned from the H_2Ours game development and simulation process in this study. First, setting up the game material with attributes of the local context helped participants to build emotions during the simulation. Second, to maintain participant commitments on restoration after the game simulation, it is important to show that their collaborative and collective actions really work in achieving their goals in the end of the game simulation. Third, based on the evaluation and debriefing results, even if they stated they can apply the ideal collaborative actions that were explored in the game session, in real life, the enabling conditions needed to support this still required to be build (e.g. regulation, integrated planning strategies, etc.). As the game is a simplification of the real-life system, forms of collaborative action can be discussed directly by the players. In real life, the parties that are needed for successful collaboration may not easily meet each other to discuss issues openly. Therefore, it is necessary to create a condition where stakeholders can meet and explore collaboration options to jointly address issues and achieve goals. Without such encounters, the commitment that referred to in the four knowledge-to-action chains cannot be attained.

In this research, we invited participants from upstream, midstream, and downstream to play from the perspective from their location in the landscape. We expect that this impacted how the game was played. We intend to explore the impacts of role switching by asking farmers to play the role of a farmer in another location in the landscape.

5 Conclusion

The generic version of the H_2Ours game allows for the exploration of the complexity of a socio-hydrological system. The game can be easily modified according to different needs and conditions. The complexity of the socio-hydrological system can be applied separately and/or simultaneously depending on the knowledge level of the intended participants. With an adaptable game as the one developed, the game designer can adjust the level of complexity included in the game, and even include an advanced simulation that combines all possible problems and interactions found in a socio-hydrological system.

The H_2Ours game can facilitate transfer and share knowledge, and triggers collaborative actions by simplifying in time and space. The H_2Ours game save the time because the transparency of the rules allows players to see that the restoration target is something that can be achieved in the future with a clearer perspective by exploring various strategies and scenarios during the game sessions. Space simplification allows players to see the entire landscape and the relationship between components that influence each other. In addition, they can also inventory the various enabling conditions needed to make the strategies in the game can be implemented in real terms (e.g. need of for multi-stakeholder collaboration, restoration masterplan).

Appendix A. H_2Ours rule development

One of the challenges in developing or modifying the H_2Ours game is providing values for the economic and environmental impact components for each type of land-use. Here is a simple guidance to modifying the H_2Ours game rules:

1. Determine the types of land-use in the landscape. If the land-use types are varied enough, take the 4-6 most dominant land covers, including the new land-use types that might be intervened.
2. For each type of land-use, determined the amount of the economic value (production costs and income) and environmental value (runoff, infiltration, water use/utilization). The value used as a rule does not have to be the actual value. You can only use the ratio value between land-use types after setting up the maximum and minimum value. A simple method to

collect this information is by conducting survey to several farmers and ask them to rank or make score the land-use type based on their economic and environmental impacts (Fig. A1).

3. Determine infrastructures that will be used in games that might affect economic and environmental conditions (e.g. artesian wells for irrigation, canal blocking, water storage, etc.).
4. Determine how each of these infrastructures affects economic and environmental conditions (e.g. artesian wells: construction cost, threat, amount of groundwater extraction, etc.). You can conduct a survey to collect that information, then normalize the value following the economic and environmental value.
5. During the game testing, evaluate those values with the participant whether it is reasonable and represents their actual condition

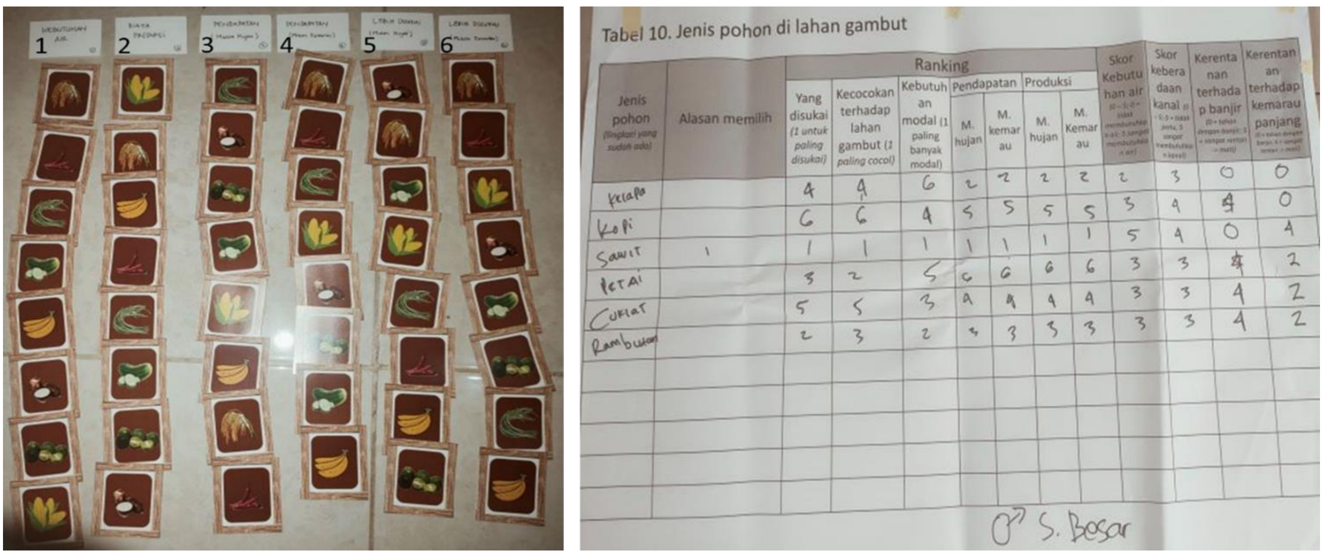

Figure A1. Left: an example of the results of sorting the types of land-use in Rejoso watershed by one of the local farmers, respectively: 1. Water use, 2. production cost, 3. income during wet season, 4. income during dry season, 5. preferences during wet season and 6. preferences during dry season. For the water balance component, we derived from hydrological model parameterization. Right: example results of scoring of land-use type during focus group discussion with some farmers in the Pawan-Kepulu peatland to collect information about preferences, suitable to peat soil, production cost, income during wet and dry season, yield during wet and dry season, water use, and dependence on the present of canal, vulnerability rate to floods, and vulnerability rate to drought.

Appendix B. Guideline for facilitating H_2Ours game

Overview	Simulation of the impact of land-use/cover change and water management on hydrological situation (water balance)

Objective	Knowledge sharing and decision making to support collaborative and collective actions among stakeholders
Benefits	1. Players can explore many scenarios of land-use/cover and water management and see its impact to their hydrological situation 2. Players can feel the trade-off between economic and environment and explore the solutions 3. Players can learn about negotiation and collaboration
Duration	2 hours (or around 8 – 10 rounds)
Number of players	6 – 16 players
Material	1. Board of the game 2. Land-use tokens 3. Money tokens 4. Mini water balance simulation model 5. Water infrastructure token (optional)

Game play

1. Welcoming all the players and give a general introduction about the workshop and game/simulation
2. Selecting 2-3 people from players to act as public stakeholders whose role is responsible for the management of the whole watershed or peatlands by providing regulations or programs to prevent various environmental problems (optional)
3. Grouping the remaining the players into 3 groups (for watershed version) or 4 groups (for peatland version) to represent the farmers from different villages. During the game simulation, their goals are to live happily by fulfilling their needs.
4. Briefing players by giving explanations/definitions about the terminology that is often used in the game and building connection between the game properties with their actual situation so the decision made by the players can be very close to their reality.
5. Introducing co-facilitator for each group who help calculation of economic resources (optional)
6. Giving initial money to players (300 – 450 per group) and initial groundwater and surface water into the water balance simulation model
7. Starting round by asking player to decide their land-use system, then calculation of the economic and environmental impact based on the (random) weather situation in that round
8. Repeat step 6 for round 2 and 3 as the warming up
9. Repeat step 6 for the rest of the rounds with additional scenarios, such as announcing regulation by government, providing payment for ecosystem program, etc. You can develop the scenarios based on the stakeholder perceptions of what they should do to restore the hydrological function through discussion or interview.
10. Debriefing session, by asking the player their strategies to achieve their goal and their feeling during the game simulation

Appendix C. Criteria of Credibility, Salience and Legitimacy

In this study, we refer to the criteria of credibility, salience and legitimacy by Belcher et al. (Belcher et al., 2016) in the development and evaluation process of the H_2Ours game. Table C1 shows the criteria that we consider most relevant to represent the objective of the H_2Ours game to facilitate the transfer and sharing knowledge to support negotiation and collaboration among stakeholders. To use these criteria, we adjusted the definition of each criterion from the original definition (column 3) to a definition that meets the objectives of H_2Ours (Column 4). Then, how we include each criterion in the development and evaluation process of the H_2Ours game is shown in columns 5 and 6.

Table C1: Criteria used to measure the credibility, salience and legitimacy of the H_2Ours game (adapted from Belcher et al. (2016). The criteria included were used to assess effectiveness in sharing understanding and encouraging collaboration for H_2Ours game development and simulation.

No	Criteria	Original definition according to (Belcher et al., 2016)	Adjustment of to meet the objective of H_2Ours game	How to include the criteria during the game design	Evaluation after game implementation
CREDIBILITY					
1	Clear problem definition	The research problem is clearly defined, researchable, grounded In the academic literature and relevant to the context	The issues handled in the H2Ours game are relevant to the actual situation	In diagnosis of the study area and issues using ARDI and DPSIR (Sect. 2.2)	Likert question: the possibility to apply the knowledge from the game in the reality
2	Clear objective	Research objectives are clearly stated	The objective of the H2Ours game is clearly stated	In scope and objective (Sect. 2.3.1)	Likert question: understanding the objective of the game
3	Appropriate methods	Methods are fit to purpose and well-suited to answering the research questions and achieving the objectives.	Methods used are scientifically proven	The data and method used scientifically proven with some publications	There was no evaluation for this criterion after the game because we used

				(Sect. 2.1 and Sect. 2.2)	scientifically proven method
4	Clearly presented argument	The movement from analysis through interpretation to conclusions is transparently and logically described. Sufficient evidence is provided to clearly demonstrate the relationship between evidence and conclusions	The rules, dynamics, and interactions in the H_2Ours game built based on logical interpretation supported by scientific data and methods	Component interaction analysis based on ARDI and DPSIR (Sect. 2.2 and Sec. 2.3)	Likert question: Understanding the rules of the game
SALIENCE/RELEVANCE					
5	Socially relevant research problem	Research problem is relevant to the problem context	The problems/issues raised in the H_2Ours game are in accordance with the issues/problems in actual conditions	The information used based on participatory approach (referring some publication in Sect. 2.1)	Likert question: The possibility to apply the knowledge from the game in the reality
6	Engagement with problem context	Researchers demonstrate appropriate breadth and depth of understanding of and sufficient interaction with the problem context	The H_2Ours game is built by demonstrating the interaction of various elements (physical and social, interaction between	Problem analysis based on DPSIR (Sect. 2.2)	Likert question: The possibility to apply the knowledge from the game in the reality

			stakeholders) that are shown in actual conditions.		
7	Explicit theory of change	The research explicitly identifies its main intended outcomes and how they are intended/expected to be realized and to contribute to longer-term outcomes and/or impacts	H_2Ours game was built explicitly to facilitate knowledge sharing and knowledge transfer to trigger collaborative action among various stakeholder	Set the purpose of the game in the game development proses (Sect. 2.3.1)	Likert question: Gaining new knowledge from the game simulation
8	Relevant research objective and design	The research objectives and design are relevant, timely, and appropriate to the problem context, including attention to stakeholder needs and values	The objectives and design of the H_2Ours game are relevant to the problem context, including considering what the stakeholder needs and values	Based on ARDI and DPSIR analysis (Sect. 2.2 and 2.3)	Likert survey: 1. understanding the objective of the game 2. the possibility to apply the knowledge from the game in the reality
9	Appropriated project implementation	Research execution is suitable to the problem context and the socially relevant research objectives	The solutions in the H_2Ours game is generated based on activities that can be implemented in the actual condition	The solutions based on the multidisciplinary research (Sect. 2.1)	Likert question: the possibility to apply the knowledge from the game in the reality
	LEGITIMACY				

10	Effective collaboration	Appropriate processes are in the place to ensure effective collaboration (e.g. clear and explicit roles and responsibility agreed upon, transparent and appropriate decision-making structures)	The H_2Ours game shows transparency of rules, responsibilities, decision-making between game participants, so the players can build collaboration between them	Simple game rules based on actual condition to facilitate participant game understanding (Sect. 2.3)	Using before and after survey using q-methodology to identify the change in stakeholder perception
11	Genuine and explicit inclusion	Inclusion of diverse actors in the research process is clearly defined. Representation of actors' perspectives, values, and unique contexts is ensured through adequate planning, explicit agreements, Communal reflection, and reflexivity.	Involvement of various stakeholders during the process of H_2Ours game preparation, design, implementation, and evaluation to accommodate various perspectives, knowledge, values, interests of stakeholders	Involvement of various stakeholders in this study (Fig. 1)	Likert survey: the possibility to apply the knowledge from the game in the reality

Appendix D. H_2Ours game for peatland version (case study Pawan-Kepulu peatland)

Based on some references, focus ground discussion and interview with various stakeholders in Pawan-Kepulu peatland, we found that this area experiences land and forest fires during the dry year (season) and flood during the wet year (season). Land cover conversion from forest to oil palm plantation and crop season has led massive canal construction to get better production. This situation makes this landscape drier during the dry year and vulnerable to fires.

The hydrological boundary of peatland is a Peatland Hydrological Unit (PHU) as an area between two rivers. Usually in this landscape, there is a peat dome (the deepest peat area), an area surrounding the peart dome (i.e. buffering dome area) and an area with shallow peat. Villages are spread over the peat dome and the buffer zone with villages having different proportions of peat dome and buffer zone areas. However, for simplification, peat depth (including that of the peat domes) was distributed evenly between villages (Figure D1). However, for future game adaptations, the peat depth distributions in each village can be adjusted on the game board.

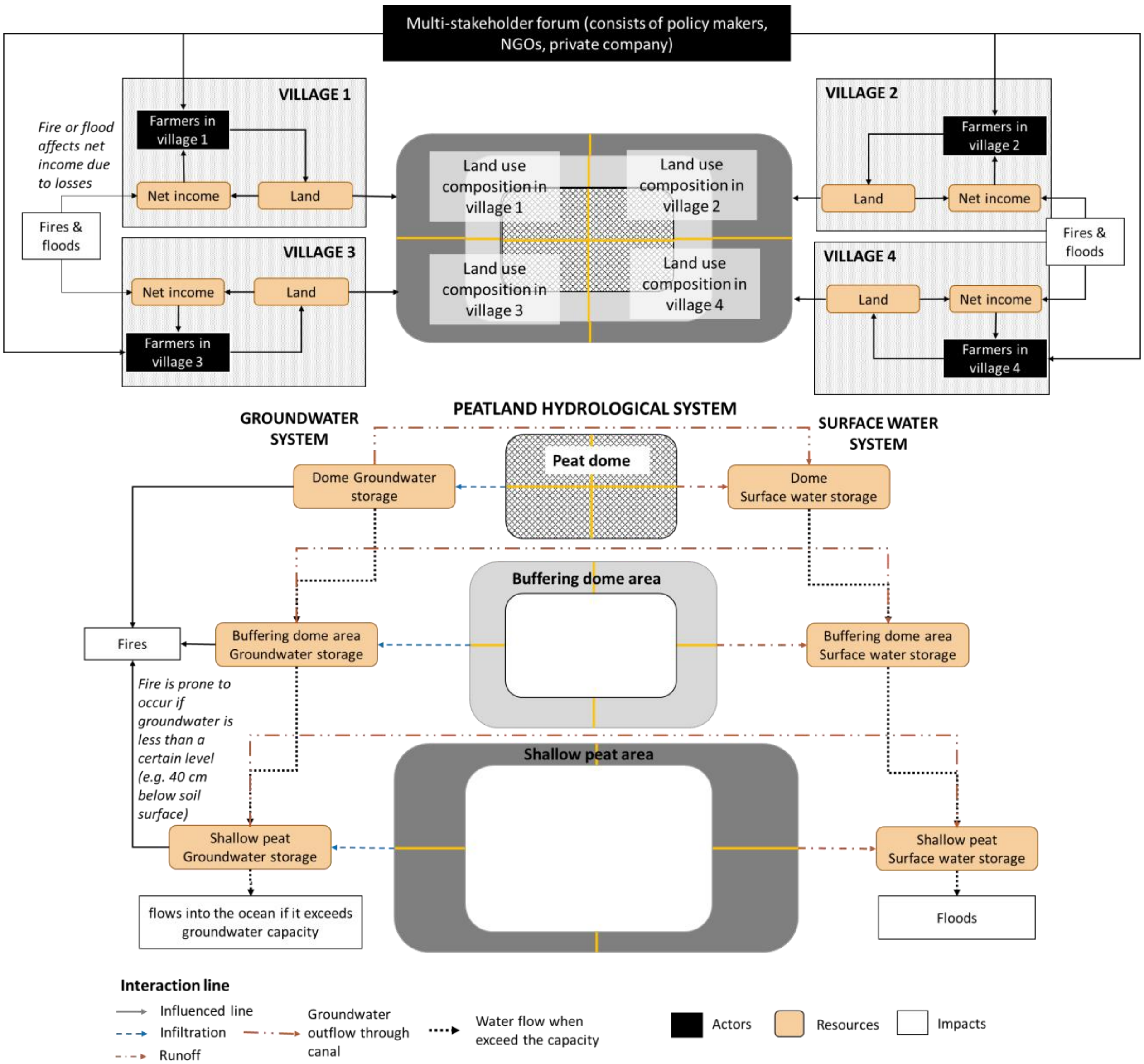

Figure D1. Socio-hydrological model defined using the ARDI framework that was used to design the H_2Ours game for Pawan-Kepulu peatland. Interaction among actors and between actors to landscape influence land-use composition which affect the hydrological and economic situation, then its influences back to interaction.

Rules of game

Based on measurement data, focus group discussion with local farmers and some references, we design the rules of the H_2Ours game for peatland version by combining six land-use options (all trees, all oil palm, oil palm + trees, oil palm + crop, all crop, and shrub/burned area) and three canal density options (without canal, low- and high-density canal) (Table D1 and D2).

Table D1. Economic impacts in Pawan-Kepulu peatland version, the production cost in dome area +2/plot and in the buffering dome area +1/plot

Land-use options	Canal density options	Production cost/year in the shallow peat area (unit: money)	Income/year (unit: money)	
			Wet Year	Dry year
All tree	Without	1	0	3
	Low	1	0	3
	High	1	0	3
All Oil palm	Without	6	6	9
	Low	9	9	17
	High	12	17	25
Oil palm + trees	Without	3	4	6
	Low	4	6	9
	High	6	9	17
Oil palm + seasonal crop	Without	5	4	8
	Low	7	7	15
	High	10	12	20
Crop	Without	4	3	7
	Low	5	5	13
	High	8	7	15
Shrub	Without	0	0	0
	Low	0	0	0
	High	0	0	0

Table D2. Environmental impacts in Pawan-Kepulu peatland version, we assumed during the dry year there is no runoff or infiltration (a = dome area, b = buffering dome area, c = shallow peat area, x = runoff (unit: ml), y = infiltration (unit: ml) and z = groundwater out flow through canal (unit: ml))

	Dry year	Wet Year

Land-use	Canal density	a	b	c	a			b			c		
			z		x	y	z	x	y	z	x	y	z
All tree	Without	0	0	0	0	20	0	2.5	17.5	0	5	15	0
	Low	7.5	5	2.5	2.5	17.5	10	5	15	7.5	7.5	12.5	5
	High	15	10	5	5	15	20	7.5	12.5	15	10	10	10
All Oil palm	Without	0	0	0	10	7.5	0	12.5	5	0	15	5	0
	Low	7.5	5	2.5	12.5	5	10	15	2.5	7.5	17.5	2.5	5
	High	15	10	5	15	2.5	20	17.5	1	15	17.5	1	10
Oil palm + trees	Without	0	0	0	5	15	0	7.5	12.5	0	10	10	0
	Low	7.5	5	2.5	7.5	12.5	10	10	10	7.5	12.5	7.5	5
	High	15	10	5	10	10	20	12.5	7.5	15	15	5	10
Oil palm + seasonal crop	Without	0	0	0	15	2.5	0	17.5	1	0	17.5	1	0
	Low	7.5	5	2.5	17.5	1	10	19	1	7.5	19	1	5
	High	15	10	5	17.5	1	20	19	1	15	19	1	10
Crop	Without	0	0	0	19	1	0	19	1	0	19	1	0
	Low	7.5	5	2.5	19	1	10	19	1	7.5	19	1	5
	High	15	10	5	19	1	20	19	1	15	19	1	10
Shrub	Without	0	0	0	20	0	0	20	0	0	20	0	0
	Low	7.5	5	2.5	20	0	10	20	0	7.5	20	0	5
	High	15	10	5	20	0	20	20	0	15	20	0	10

Game Properties

The component of the H_2Ours game for peatland version is similar with watershed version with modification in the board as the landscape and the land-use options (Fig. D2). The board is designed in such a way that it resembles a PHU with a dome in the middle, a buffering area around the dome and shallow peat on the outside. In the real simulation, we can add river and road to help player have a connection with their real situation.

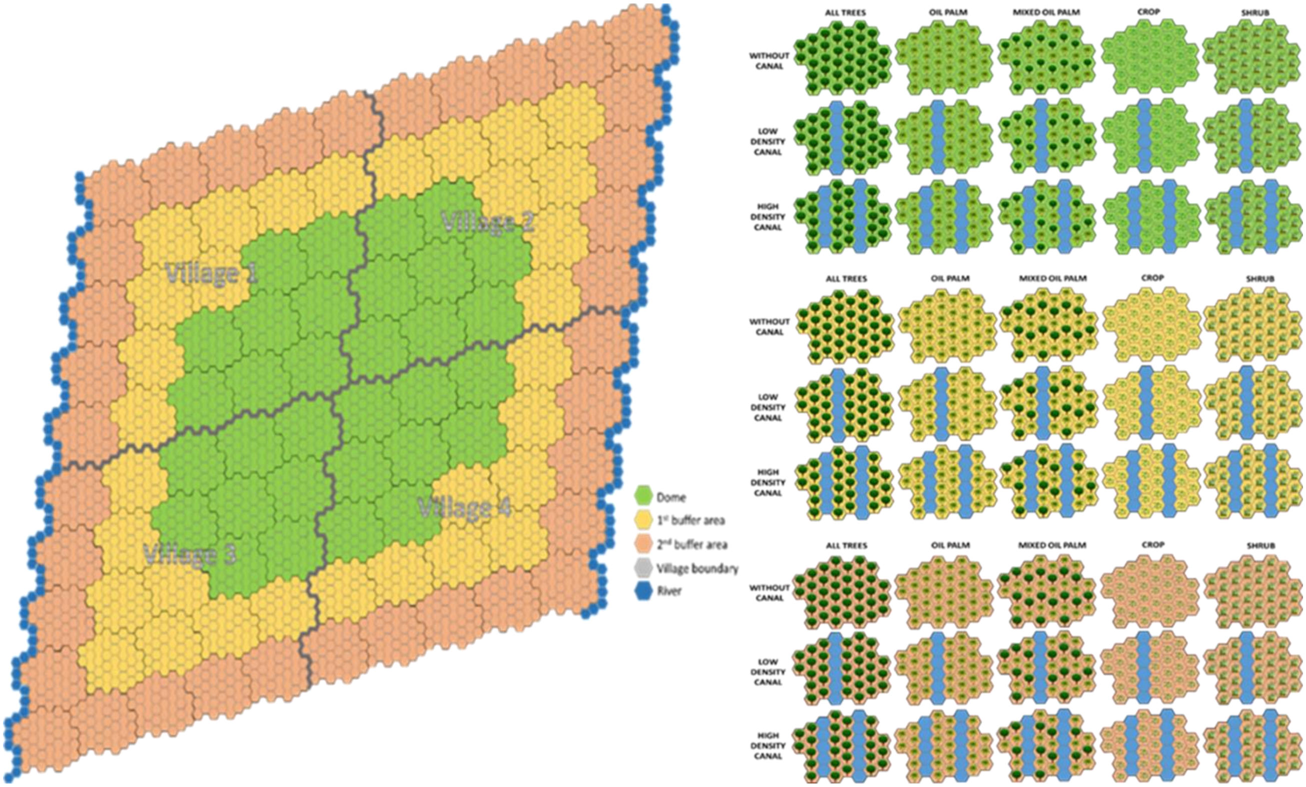

Figure D2. Board of H_2Ours game for peatland version that consist of dome area, buffering dome area and shallow peat area (left); and land-use option (all trees, all oil palm, oilpalm+trees, all crop and shrub) with various canal density (without canal low canal density and high canal density) for Pawan-Kepulu peatland area (right)

Similar with the Rejoso watershed, the H_2Ours game for peatlands also has the same water balance miniature (Fig. D3). This water balance model follows the hydrological system in Fig. D1. In the groundwater system, each tank has a fire vulnerable threshold. This threshold represents 40 cm below soil surface in its actual condition as stipulated by government regulations. If the groundwater in each zone is below this limit, then the area has the potential for fires which causes harm to the local community.

Figure D3. Simple water balance model of H_2Ours game in Pawan-Kepulu peatland to show the dynamics of changes in hydrological conditions as a result of the changes in land-use and canal density. The red line in each tank in the groundwater system represent the fire vulnerable threshold.

In addition to the H_2Ours game for the peatland version, there is a peat infrastructure token in the form of canal blocking and fire fighters (Fig. D4). In the reality, the canal blocking blocks the canal to reduce/stop the groundwater outflow. In this game simulation the canal blocking changes the land-use from high to low density canal or from low to without canal. The firefighter helps to prevent plot from fires during the dry year/season. However, providing canal blockings and firefighters cost some money.

Figure D4. Additional token as canal blocking (left) and firefighters (right) for H_2Ours game

Appendix E. Solution space of H_2Ours game in Rejoso watershed

The rules of the game determine the possible outcomes or ‘solution space’, within which the specific choices made by game participants are located. If all choices would be random (equal probability of all choices available), without response to the outcomes so far, a substantial variation in outcomes is possible. The primary outcomes of interest are the surface water flows (rainfall not used as canopy interception evaporation or infiltration into the soil), and the groundwater flows (water infiltrating and not used for subsequent evapotranspiration), all depending on both land cover and rainfall.

A first question in defining this solution space is the number of random series that need to be evaluated to accurately estimate the frequency distributions of outcomes in various response parameters. We present data for 3, 10, 30, 100, 300 and 1000 iterations (Fig. E1 – E4) (each including 10 rounds and three zones, thus 30 land-use choices and 10 weather conditions (dry or wet)). The actual game simulation was only done 4 times; therefore, the closest solution space is with 3 or 10 random values, which is have not sufficiently representative the distribution. Based on Fig. E1 and E2, the solution space distribution pattern starts to appear in 30 random data sets. Therefore, to see the actual distribution of the farmer's decision making, at least we need 30 game simulations. Figure E3 and E4 show the relationship between economic conditions (money) and environment (groundwater and surface water) in the downstream area is more scatter compared to upstream and midstream. However, related to groundwater supply in downstream (Fig. E3), the more groundwater supply, and the higher the economic benefits obtained. On the contrary, the more runoff obtained from upstream and midstream (Fig. E4), it will decrease their economic benefits.

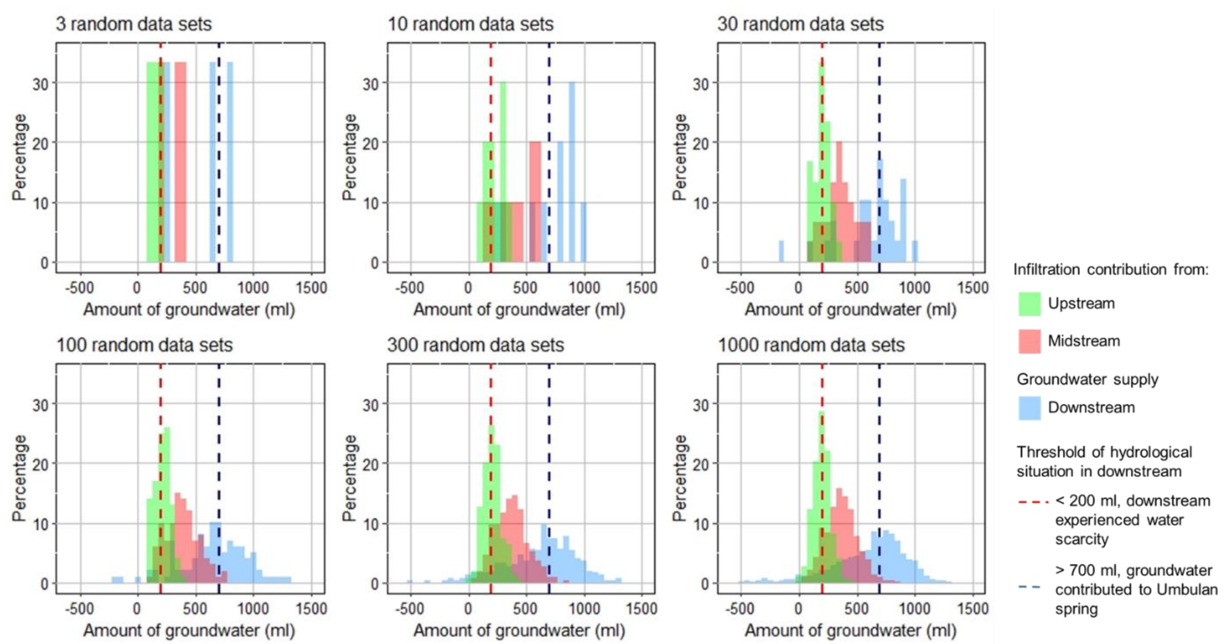

Figure E1. Distribution of infiltration contribution from upstream and midstream and groundwater supply in downstream based on simulation with the random value

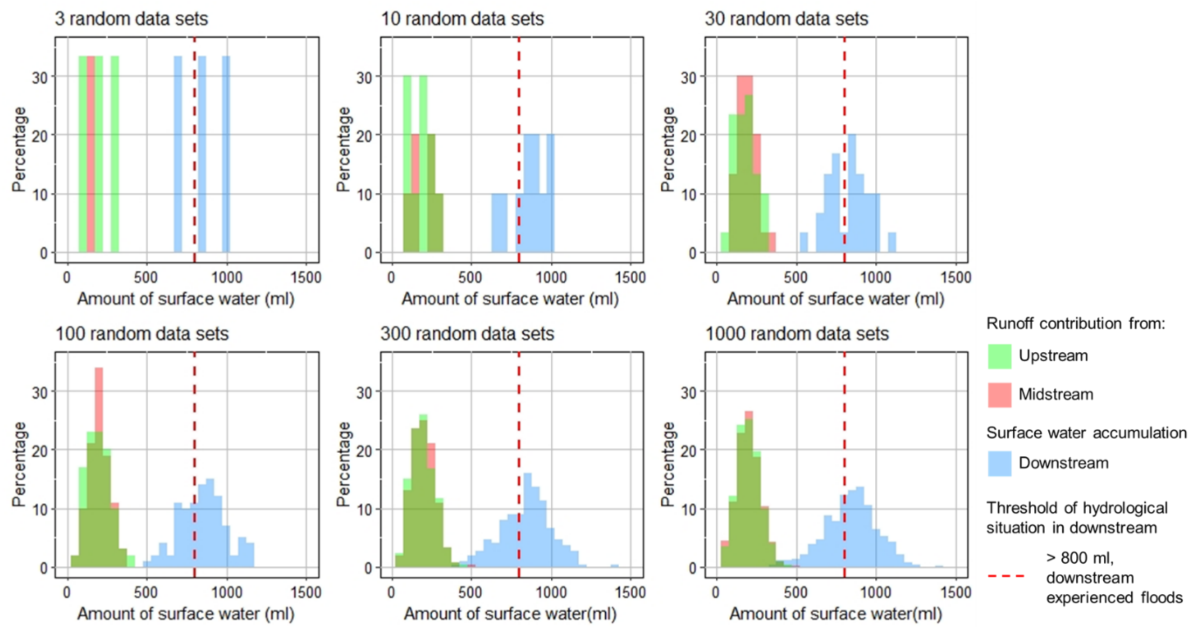

Figure E2. Distribution of runoff contribution from upstream and midstream and surface water accumulation in downstream based on simulation with the random value

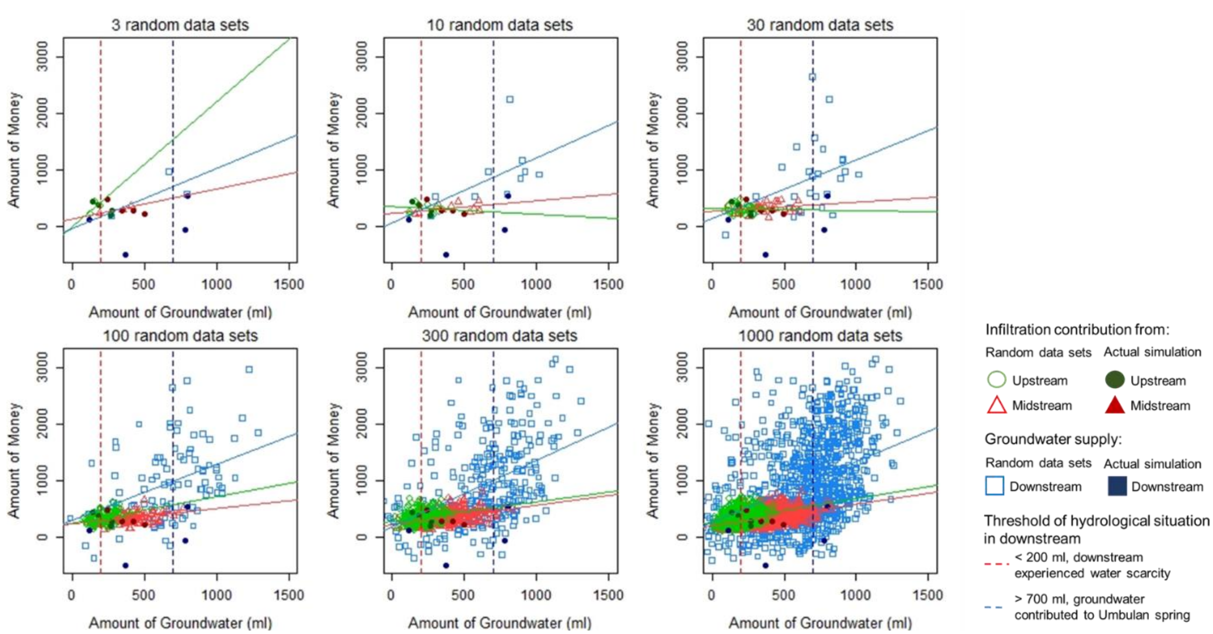

Figure E3. Groundwater and economic conditions based on random value simulation and actual simulation

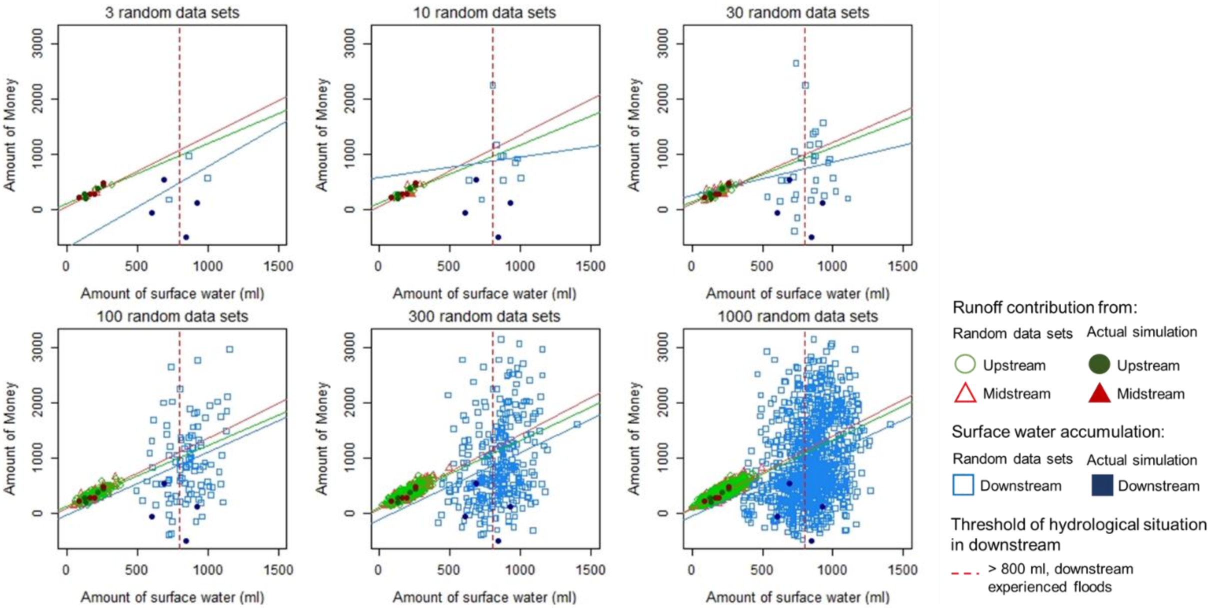

Figure E4. Runoff and economic conditions based on random value simulation and actual simulation

Data availability

All raw data can be provided by the corresponding authors upon request

Competing interests

The authors declare that they have no conflict of interest.

Author contribution:

LT, RRS and ALH designed the research project, LT, RRS and ENS designed the game, LT performed the game simulation and game analysed, LT, MvN, MPC and ENS wrote the manuscript, EP and BL gave input on the performance of game simulation in each case study area.

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