The H₂Ours game to explore Water Use, Resources and Sustainability: connecting issues in two landscapes in Indonesia

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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 ~~of~~ 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 ~~enhance their understanding of the socio-hydrological system and the consequences of land-use choices. A tool that simplifies the social-hydrological system but still accommodate the crucial part of the social and technical aspects is needed to facilitate the collective learning~~. However, ~~a~~ data-driven simplification can process has a risk that ~~leads~~ to very site specific models that are ~~and~~ difficult to adopt for different conditions. To address the~~o~~se issues, this study aims to develop a highly adaptable serious game based on process-based understanding to make it easily applicable to any ~~applied to any~~ situation and to facilitate co-learning ~~in order 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, ~~and balancing between~~allowing for both relevant site-specificity and generic replicability. ~~of the game design.~~ Here, we describe the development of the game and explore its capacity to visualise, discuss and explore Water: Use, Resources and Sustainability ('H₂Ours') issues at landscape level~~scale~~. The ~~game design for the~~ H₂Ours game was designed using a~~based on 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 H₂Ours game met ~~can meet~~ its purpose as a tool for knowledge transfer, learning and triggering action. We discuss the ~~provide clear~~ steps that can lead to re-designing and ~~in designing and adapting~~adaptation of the game to ~~the game to~~

another area, which will facilitate the wider application and adaptation of the basic game design 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).

Learning leads to gaining new information, knowledge, predictive ability, and ultimately to scenario development and knowledgeable decisionsinformation, knowledge, predictive ability, and ultimately to scenario development and knowledgeable decisions. However, providing datainformation 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 orand 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).

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.~~Although games and models have the potential to be combined, there are few studies where this has been done explicitly (Villamor et al. 2023, manuscript under review).~~ As an example of the letter, (Lohmann et al., (2014) 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 ~~in~~ develop restoration plans.

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.

STAGES

Diagnosis of study area and issues
Understanding the socio-hydrological system and collecting data and information for the game design
Stakeholder involved: Game developer, researchers

Game development
Designing goals, roles, rules, solution space, game properties and game testing
Stakeholder involved: Game developer, researchers,
Stakeholder involved in game testing: university students, local communities, project members

Implementation
Game simulation that consists of briefing, simulation and debriefing
Stakeholder involved: Game developer, public stakeholders (e.g. government, company, NGO, etc.), local communities and farmers

Evaluation
Evaluating game design and implementation, identifying limitation and room for improvement and modification
Stakeholder involved: Game developer, researcher and game participants

Figure 1: Stages undertaken from the preparation to the evaluation of the H$_2$Ours 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 ~~W~~watershed and the Pawan-Kepulu ~~p~~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) ~~had responsibility~~was responsible for research and development of conservation and restoration strategies, while Pawan-Kepulu peatland restoration ~~is~~was conducted by Tropenbos Indonesia through the '*Working* project and '*Fires*' project. Both areas have environmental problems because of the disruption of the ~~hydrological functions~~ 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).
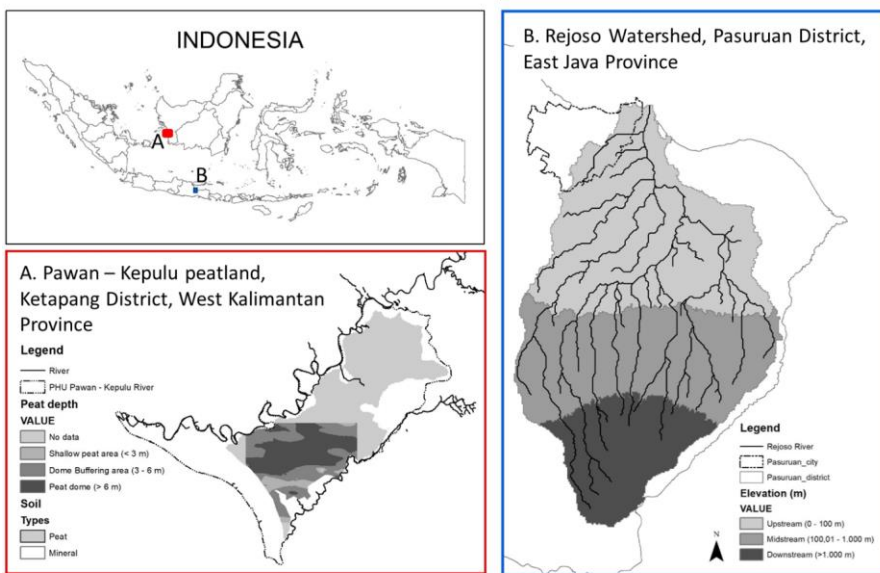
Figure 2: The two study areas of this study: A. Rejoso Wateshed that consists of upstream (elevation >~~-~~1000 m above sea level midstream (elevation 100–1000 masl.) and downstream (elevation < 100 masl.), and B. Pawan-Kepulu peatland that consists of peat dome (peat depth > 6 m), peat buffering dome (peat depth 3–6 m) and shallow peat (peat depth ~~1-3~~<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 (~~0<~~—100 masl. (meter above sea level),

midstream (100–-1000 masl.) and upstream (>-1000 masl.). This watershed is a national priority because the Umbulan spring 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 (~~2017~~2020) (Leimona et al., 2018; Amaruzaman et al., 2018; Toulier, 2019; Khasanah et al., 2021) ~~(Toulier, 2019; Khasanah et al., 2021; Amaruzaman et al., 2018; Leimona et al., 2018)~~. 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).

2.2 Diagnosis of the study areas and issues

For systems diagnosis and developing the H$_2$Ours 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 ~~is a ff~~ramework ~~that~~ 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 ~~modeling~~modelling approaches to guide system diagnosis as a first step in designing serious games ~~design 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). ~~These frameworks became the basis for designing the H₂Ours~~
130 ~~game in two contrasting study areas in Indonesia.~~

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

135 The first stage in designing a serious game is to determine the scope~~topic~~ 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~~is~~ expected to be obtained by players after participating in the game. We determined the ~~topic~~scope and the objective of the game based on the socio-hydrological problem defined in the previous stage ~~diagnostic of study and issues~~ (Sect. 2.2).

140 **2.3.2 Roles**

According to the ARDI ~~results~~framework (Sect. 2.2), we defined the roles ~~in this game~~ 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.~~ in the reality.~~

2.3.3 Rules

145 According to the ARDI and DPSIR frameworks (Sect. 2.2), we transformed ~~actors and resources i~~the interaction between actors and resources as the rules of the H₂Ours game. To show the dynamics of changes in resources and the impact of human decisions, the game rules,~~ the 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 150 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 (~~section ~~Sec. 2.1). For the water balance component, the Rejoso~~'s~~ data were obtained from the hydrological modelling and field measurement (Leimona et al., 2018; Suprayogo et al., 2020), while the Pawan-Kepulu~~'s~~ 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 155 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 ~~B~~A.

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. The solution space of the game was explored based on the average of economic and environmental conditions 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 are completely random. 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 asto the reality as possiblepossible to the reality. The game board, the game's land-use options, and water simulation miniature are the key From all the game properties, the board game, land-use options, and water simulation model are the most crucial elements of recognition for players. game properties that must be available. Therefore, we adjustedadapted these elements to the it according to the conditions of each study area.

2.3.6 Game testing

The purpose of game testing is to confirmassess the game's playability and dynamics. some elements in the game and to test the game before being used for the actual simulation. 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 categories of participants:, namely 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 elementscomponents 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 ~~with different participant groups with a total of 93 participants. The ten game sessions consisted of five sessions at each study areas. The five game sessions consisted of a session with a multi-stakeholder forum to get ideas on regulations and programs that would be offered to local communities/farmers, and~~ four game session were organised with farmer groups to explore the implementation of the regulations and programs resulting from the game session ~~simulation~~ with the multi-stakeholder forum.

~~In~~For each game session, we invited in total of ~~with farmer groups in Rejoso watershed, we invited a total~~ 9-12 representatives of farmer groups from upstream, midstream and downstream village in Rejoso watershed, and 12-16 ~~to a meeting hall where all participants could still reach it. While in each simulation in Pawan-Kepulu peatland, we invited 12-16 representatives~~representatives of ~~of farmer group from~~ four villages in the Pawan-Kepulu peatland. In the invitation, we let 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. ~~in that landscape.~~ During the game were asked we asked ~~the invited farmers to behave as farmers in line with the position of their village in the landscape.~~to play

2.5 Game evaluation

The aim of the evaluation stage is to assess the game session process and the game in achieving ~~the~~its objective. The game 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, ~~of the game. Ideally, t~~the evaluation~~assessment~~ of the game in achieving its objective can be evaluated after several simulation, and should be conducted before, during and after the game ~~simulation~~sessions (Oprins et al., 2015). With these the evaluation of the game can only be done after the game designer has done a lot of game trials and these trials ~~it~~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 ~~from the designing and~~ after the ~~simulation~~game session (Bedwell et al., 2012). We followed the latter approach and carried out the evaluation based

220 criteria that refer to credibility, salience, and legitimacy (Table C1 in Appendix C), using some criteria developed ~~We followed~~ 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).

225 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
230 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.

235 **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$_2$Ours game was developed after the Rejoso watershed version.

3.1 Diagnosis of the study areas and issues

240 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 ~~2~~1). Expectations on better economic conditions led local communities to ~~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
245 hydrological contexts, such as hydrological boundaries, topography, and water management, and interactions among stakeholders and landscape (Fig. 3, Fig. D1~~Appendix C~~). 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~~cover~~ management and (ground) water management (Table ~~2~~1; component 7-Response).

Table 12. 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

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	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.) (2) Midstream: elevation 100-1000 masl. (1) Downstream: elevation <100 masl.Upstream: elevation > 1000 meter above sea level (masl) (2) Midstream: elevation 100 – 1000 masl (3) Downstream: elevation <100 masl	(1) Dome: peat depth > 6 m (2) Buffering area: peat depth 3-6 m (1) Shallow peat area: peat depth <3 m Dome: peat depth > 6 m (2) Buffering area: peat depth 3 – 6 m (3) Shallow peat area: peat depth <3 m
3	**D**river	To get a better household income and livelihoodTo 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) (1) Massive artesian well construction for paddy field (downstream area)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) (1) Massive canal construction to drain peatland water 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) (1) Increasing groundwater uptake (downstream)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 seasonIncreasing water outflow from peatland → decreasing peatland water level → peatland become drier, particularly during the dry season
6	**I**mpact	(1) Decreasing groundwater supply in the Umbulan spring (1) Floods (during rainy season)Decreasing groundwater supply in the Umbulan spring (2) Floods (during rainy season)	(1) Peat fires (during the dry season) (1) Floods (during the rainy season)Peat fires (during the dry season) (2) Floods (during the rainy season)
7	**R**esponse	(1) Land-use/cover management (1) Better groundwater management through artesian well	(1) Land-use/cover management (1) Better groundwater level through canal blocking management/

8	**A**ctors	Multi-stakeholder forum and farmers/local communities~~Multi-stakeholder forum and farmers/local communities~~	
		management~~Land-use/cover management~~	distribution~~Land-use/cover management~~
9	**R**esources	(1) Money ~~(1)~~ Water balance (especially groundwater and surface water)~~Money~~ (2) ~~Water balance (especially groundwater and surface water)~~	(1) Money ~~(1)~~ Water balance (especially groundwater and surface water)~~Money~~ (2) ~~Water balance (especially groundwater and surface water)~~
10	**D**ynamic	(1) Land-use/cover change ~~(1)~~ Water management (artesian well management)~~Land-use/cover change~~ (2) ~~Water management (artesian well management)~~	(1) Land-use/cover change ~~(1)~~ Water management (canal blocking management)~~Land-use/cover change~~ (2) ~~Water management (canal blocking management)~~
11	**I**nteraction	Fig. 3~~Fig. 3~~	Fig. D1~~Fig. C1~~

255 The interaction between stakeholders and the landscape is represented by the type of decisions 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.

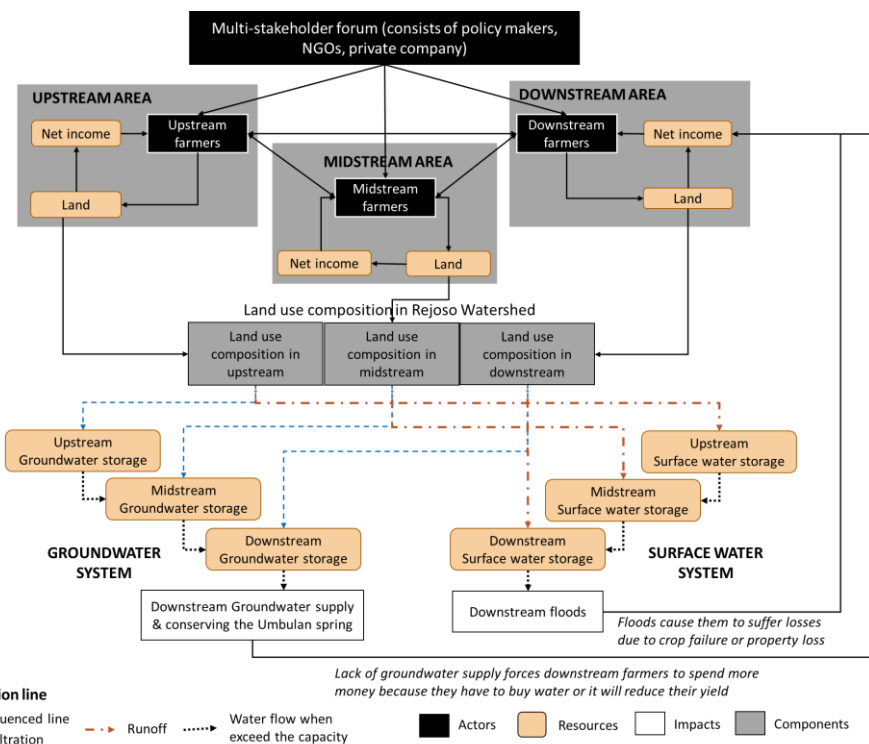



Figure 3: Socio-hydrological model for the Rejoso watershed, defined using the ARDI framework. Interactions among actors and between actors to landscape influence land-use composition. The land composition affects the hydrological and economic situation, which influences back to the interactions. A similar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

3.2 Game development: H$_2$Ours game

3.2.1 Scope and objective of the game

270   As a serious game, the H$_2$Ours 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 ~~2~~1, we determined the goal for H$_2$Ours 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 and a multi-stakeholder forum. The goal of 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 local communities represent land owners and 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. At the start of the game, players received a limited amount of money. Community members were asked to manage their land with the money provided, while we asked multi-stakeholder forums to run programs or to help reduce the local community's economic 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 3). These rules then defined the dynamics of the economic and environmental conditions (Table 3, and for the Pawan-Kepulu peatland in Appendix C). When

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 expected to stimulate promote allplayers to actors to work together and collaborate to achieve their goals.

Table 32. Economic and environmental impacts as the rules of the H$_2$Ours 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$_2$Ours game in the Pawan-Kepulu peatland are in the Appendix CD. (AF= agroforestry).

Land-use	Production Ccost (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. ~~Based on 300 random decision making, the groundwater distribution varies 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 have almost the same distribution of surface water because the runoff produced in the upstream and midstream only occurs during wet years, which then may potentially cause flooding downstream in the same year. Different form surface water, the contribution~~

situation and economic situation based on random value simulation and actual simulation; D. Runoff situation and economic

340 Related to the economic ~~conditions~~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 ~~middle~~ midstream conditions.

345 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

350 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

355 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, ~~more interesting and stimulate engagement,~~ we prepared ~~some~~ game materials such as a game board to represent the landscape, land-use tiles according to the existing and future land ~~cover~~use types, play -money token,

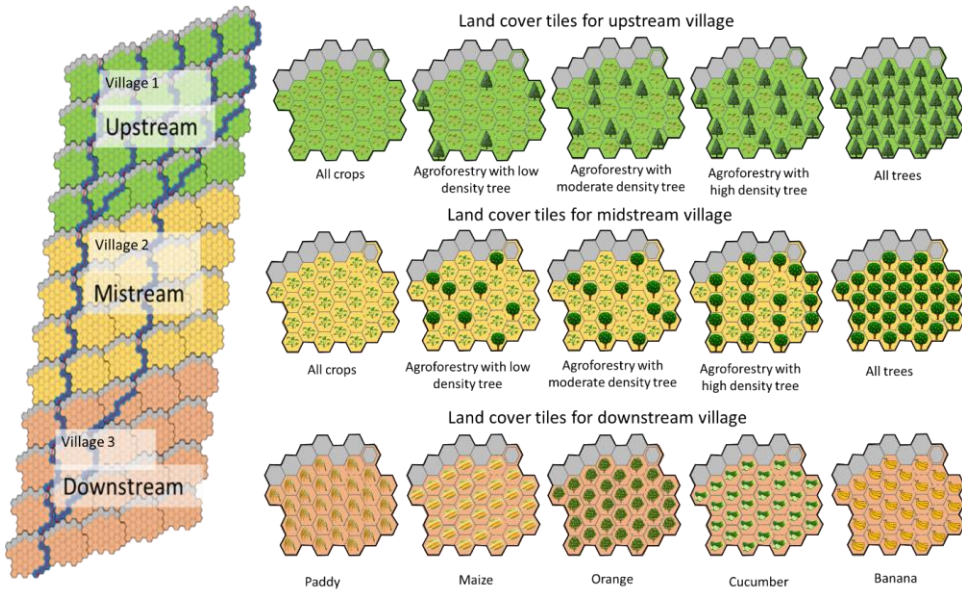
360 and water infrastructures token (Fig. 5). We also created, water balance miniatures (Fig. 6) to demonstrate ~~the water flow and availability of the surface water and the groundwater.~~ how surface water flows and leads to floods and water infiltration increases ground water supply. Each round after 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.

365

Figure 5: Game board and land use/cover tiles of the H₂Ours 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 DC for the game materials for the Pawan-Kepulu peatland.

370

Figure 6: Simple water balance model of H₂Ours 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 Simple water balance model of H₂Ours game in Rejoso watershed to show the dynamics of changes in hydrological

375 **3.2.6 Game testing**

From the results of checking the ~~quantification system~~ game in~~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

380 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$_2$Ours 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

385 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 th~~e game session~~e simulation, players acting as a farmer/local community tried to improve their household income and

390 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

395 resulted in a reduction of their economic ~~conditions~~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

400 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 session~~s~~, the participants in Rejoso watershed and Pawan-Kepulu peatland mentioned that the game showed that any decision at the plot level impacted ~~had an effect on the~~ hydrological function at the landscape level. They also mentioned that if they had not met their economic needs, ~~as long as they had not met their economic needs,~~ the

405 economic conditions became their priority. They also indicated that they would accept any regulation or program from other stakeholders if ~~as long as their~~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
410 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
415 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.~~this simulation in their real life.~~ Besides the credibility, salience and legitimacy criteria, we also asked the participants about their opinion regarding the ~~simulation~~game session process. From the survey, 87% of the the simulation and 79% of them feel that the length of simulation time was fair.

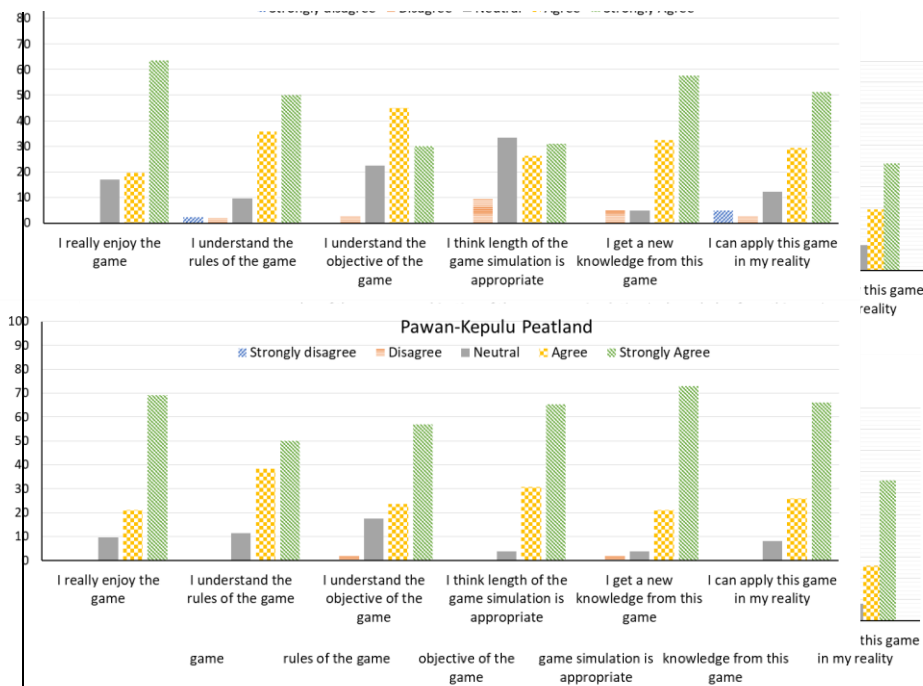



Figure 7: Game evaluation from the participants in the Rejoso watershed (N = 41 people) Watershed and Pawan-Kepulu peatland (N= 52 people)

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 H₂Ours game as the result of the development and modification process in two different landscapes in Indonesia (Sect. 4.1). Then, to assess whether H₂Ours 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 H₂Ours game based on input-output assessment according to evaluation criteria (Sect. 4.2).

4.1 The adaptable of H₂Ours 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 ~~view~~perspective (Strait and Dawson, 2006; Rumeser and Emsley, 2019). In the H₂Ours 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 ~~2~~1, column
435 3). Then we modified that version of the H₂Ours game based on the socio-hydrological condition of the ~~to the~~ Pawan-Kepulu peatland ~~and by changing~~added it to column 4 ~~the components~~ in Table ~~2~~1. ~~based on the socio-hydrological condition of the peatland.~~ Therefore, these well-established frameworks ~~(~~act as the generic version of the H₂Ours game, which can easily be modified according to other socio-hydrological realities.

440

4.2 Game evaluation and lesson learned

During the game design, we evaluated the H₂Ours game using the input-output assessment process (Bedwell et al., 2012). Here, credibility, salience~~salience~~ and legitimacy ~~(Table 1)~~ were assessed throughout the different stages of H₂Ours game development (Fig. 1). During the game development of the Rejoso watershed, we accommodated the credibility of H₂Ours
445 game by relaying on the biophysical and hydrological research, including hydrological ~~modeling~~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) ~~(Amaruzaman et al., 2018; Leimona et al., 2018;~~
450 ~~Widayati et al., 2021)~~. By ~~taking~~considering ~~into account~~ the criteria of credibility, salience and legitimacy since the data and information collection, it was easier for the H₂Ours game to fulfil these criteria during the evaluation after the simulation.

As hydrological problems are usually ~~quite~~ complex and fundamental, any potential ~~their~~ solution requires ~~quite~~ample ~~a long~~ time for integrated planning, and all relevant ~~which requires all~~ stakeholders to understand the dynamics of the system at large scale ~~to have the bigger picture~~ (Medema et al., 2019). The H₂Ours game tries to present simple representation of the landscape
455 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 H₂Ours game allowed players to see the interdependent connections
460 between elements in the complex socio-hydrological system more clearly~~The evaluation of the game after the simulation (Fig.~~
~~possibilities and to gain lessons from the reflection results. This situation made it easier for players to explore various~~
During the game session, ~~simulation,~~ after the players began to understand how the H₂Ours game works, the players started to 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 ~~analyze~~analyse and correct inappropriate strategies (Bartolome et al., 2011; Feng et al., 2018). Moreover, during the H$_2$Ours 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.

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. ~~it still needs to build the enabling condition that support it (e.g. regulation, integrated planning strategies, etc.). Therefore, the commitment, as referred in the four knowledge to action chains, still cannot be carried out directly because still needs external factors that are beyond their control.~~

5 Conclusion

The generic version of the H$_2$Ours 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$_2$Ours game can facilitate transfer and share knowledge, and triggers collaborative actions by simplifying in time and space. The H$_2$Ours 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$_2$Ours rule development

One of the challenges in developing or modifying the H$_2$Ours 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$_2$Ours 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.

515

~~The H₂Ours game is a generic game that solves the complexity of a socio-hydrological system and allows modifications 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~~

520 ~~combines all possible problems and interactions found in a socio-hydrological system.~~

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
525   whole watershed or peatlands by providing regulations or programs to prevent various environmental problems (~~opsional~~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.
530 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
535   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 B. H₂Ours rule development

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 H₂Ours game. Table C1 shows the criteria that we consider most relevant to represent the objective of the H₂Ours 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 H₂Ours (Column 4). Then, how we include each criterion in the development and evaluation process of the H₂Ours game is shown in columns 5 and 6.

Table C1: Criteria used to measure the credibility, salience and legitimacy of the H₂Ours game (adapted from Belcher et al. (2016). The criteria included were used to assess effectiveness in sharing understanding and encouraging collaboration for H₂Ours game development and simulation.

No	Criteria	Original definition according to (Belcher et al., 2016)	Adjustment of to meet the objective of H₂Ours 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 (Sect. 2.1 and Sect. 2.2)	There was no evaluation for this criterion after the game because we used 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	The information used based on participatory approach (referring some	Likert question: The possibility to apply the knowledge from the game in the reality

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			issues/problems in actual conditions	publication in Sect. 2.1)	
6	Engagement with problem context	Researchers demonstrate appropriate breadth and depth of understanding of and sufficient interaction with the problem context	The H$_2$Ours game is built by demonstrating the interaction of various elements (physical and social, interaction between stakeholders) that are shown in actual conditions.	Problem analysis based on DPSIR (Sect. 2.2)	Likert question: The possibility to apply the knowledge from the game in the reality
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$_2$Ours 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$_2$Ours game are relevant to the problem context, including considering what	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

			the stakeholder needs and values		
9	Appropria ted project implemen tation	Research execution is suitable to the problem context and the socially relevant research objectives	The solutions in the H$_2$Ours game is generated based on activities that can be implemented in the actual condition	The solutions based on the multidisciplinar y research (Sect. 2.1)	Likert question: the possibility to apply the knowledge from the game in the reality

LEGITIMACY

10	Effective collaborat ion	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$_2$Ours 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	Involvement of various stakeholders during the process of H$_2$Ours game preparation, design, implementation, and evaluation to accommodate various	Involvement of various stakeholders in this study (Fig. 1)	Likert survey: the possibility to apply the knowledge from the game in the reality

reflection, and reflexivity.	perspectives, knowledge, values, interests of stakeholders

555

Appendix ~~C~~D. H$_2$Ours 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.

560   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

565   evenly between villages (Figure D1). However, for future game adaptations, the peat depth distributions in each village can be adjusted on the game board~~Based on the 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.~~

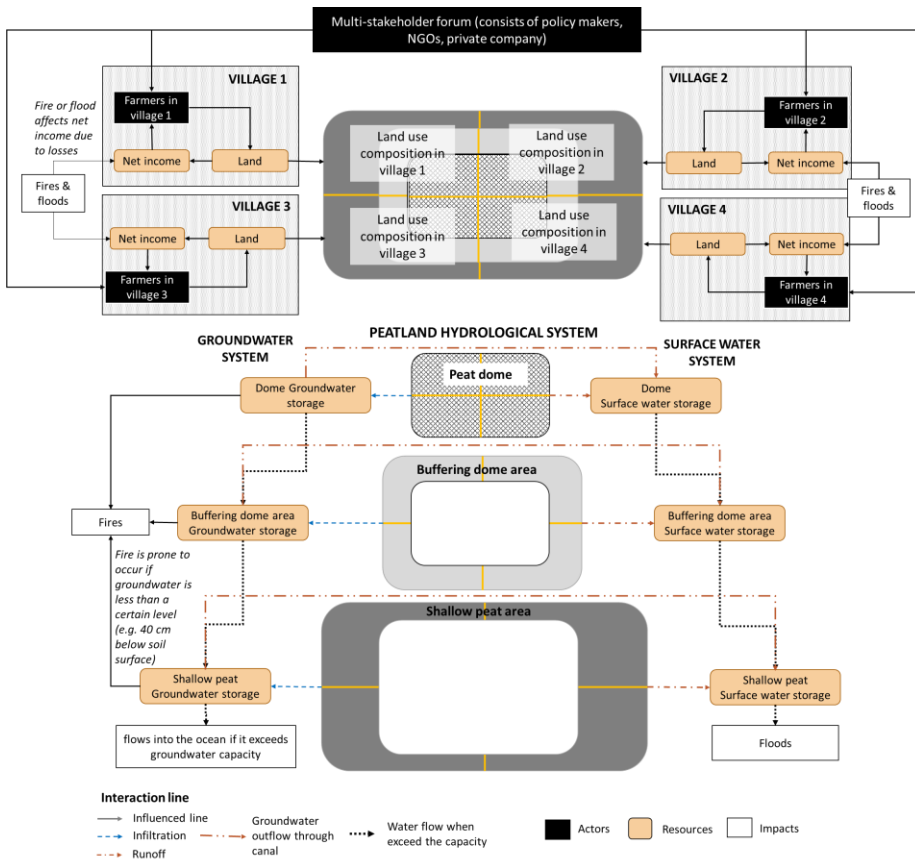



Figure ~~C~~D1. ~~Socio-hydrological model defined using the ARDI framework that was used to design the H₂Ours game for Pawan-Kepulu peatland. Interaction among actors and between actors to landscape influence land-use composition which affect the hydrological and economic situation, then its influences back to interaction~~Socio-hydrological model defined using the ARDI framework that was used to design the H₂Ours 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 H₂Ours game for peatland version by combining six land-use options (all trees, all oil palm, oil palm + trees, oil palm + crop, all crop,

580 and shrub/burned area) and three canal density options (without canal, low-~~density canal~~ and high-density canal) (Table ~~C~~D1 and ~~C~~D2).

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

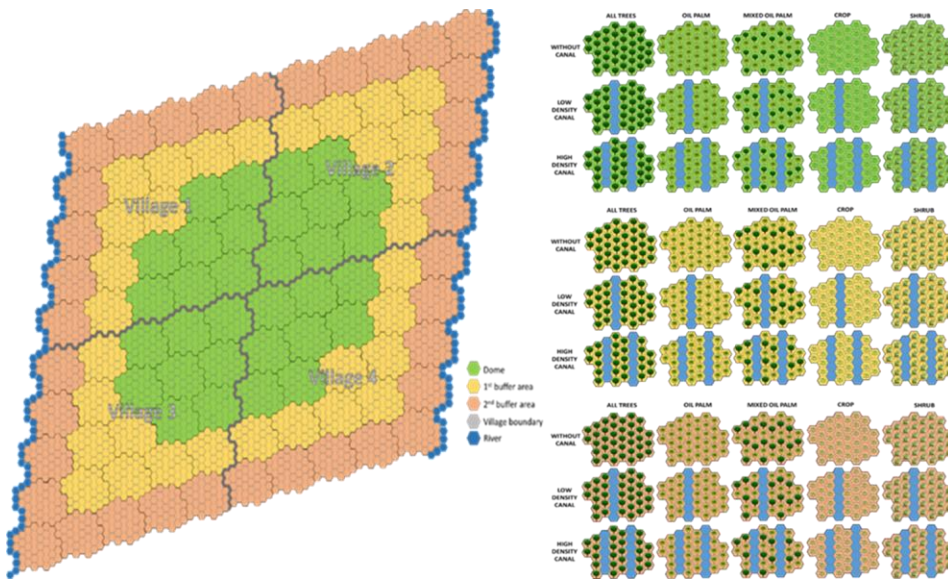
Land-use options	Canal density options	Production cost/year in the shallow peat area (unit: money)	Income/year (unit: money)	
			Wet Year	Dry year
All tree	Without	1	0	3
	Low	1	0	3
	High	1	0	3
All Oil palm	Without	6	6	9
	Low	9	9	17
	High	12	17	25
Oil palm + trees	Without	3	4	6
	Low	4	6	9
	High	6	9	17
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

585 **Table D~~C~~2. 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))**

Land-use	Canal density	Dry year			Wet Year								
		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

590 The component of the H$_2$Ours game for peatland version is similar with watershed version with modification in the board as the landscape and the land-use options (Fig. D~~C~~2). 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.

595 **Figure D̶C2. Board of H₂Ours 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 H₂Ours game for peatlands also has the same water balance ~~model~~miniature (Fig. C̶D3). water balance model follows the hydrological system in Fig. D̶C1. In the groundwater system, each tank has a fire vulnerable
600 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 D~~C~~3. Simple water balance model of H₂Ours 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 H₂Ours game for the peatland version, there is a peat infrastructure token in the form of canal blocking and fire fighters (Fig. D~~C~~4). 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 D~~C~~4. Additional token as canal blocking (left) and firefighters (right) for H₂Ours game

Appendix E~~D~~. Solution space of H₂Ours 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
620   and not used for subsequent evapotranspiration), all depending on both land cover and rainfall.

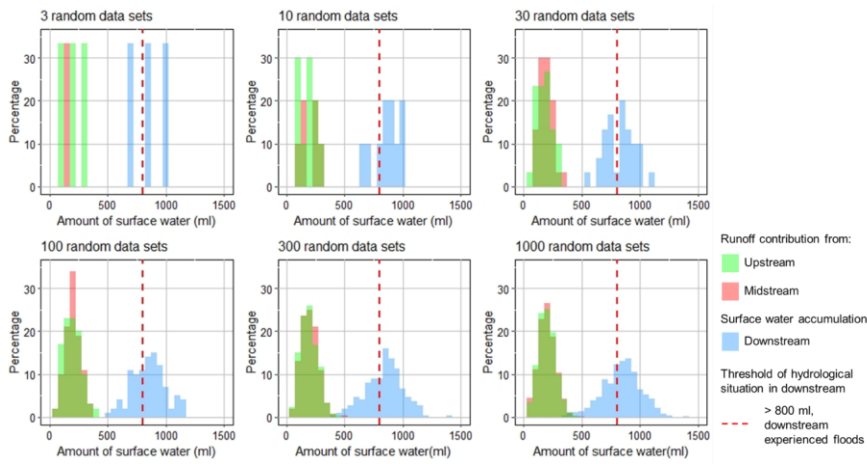
A first question in defining this solution space is the number of random series that need to be evaluated to accurately estimate the frequency distributions of outcomes in various response parameters. We present data for 3, 10, 30, 100, 300 and 1000 iterations (Fig. E1 – E4) (each including 10 rounds 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,

625   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

630   obtained. On the contrary, the more runoff obtained from upstream and midstream (Fig. E4), it will decrease their economic benefits.

~~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~~

635   ~~(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.~~

Figure E~D~1. Distribution of infiltration contribution from upstream and midstream and groundwater supply in downstream based on simulation with the random value

640   **Figure E̶D̶2. Distribution of runoff contribution from upstream and midstream and surface water accumulation in downstream on simulation with the random value**

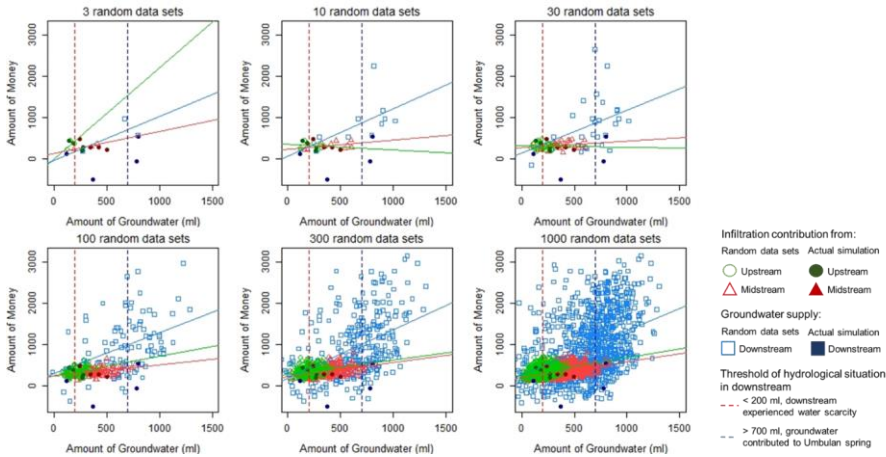
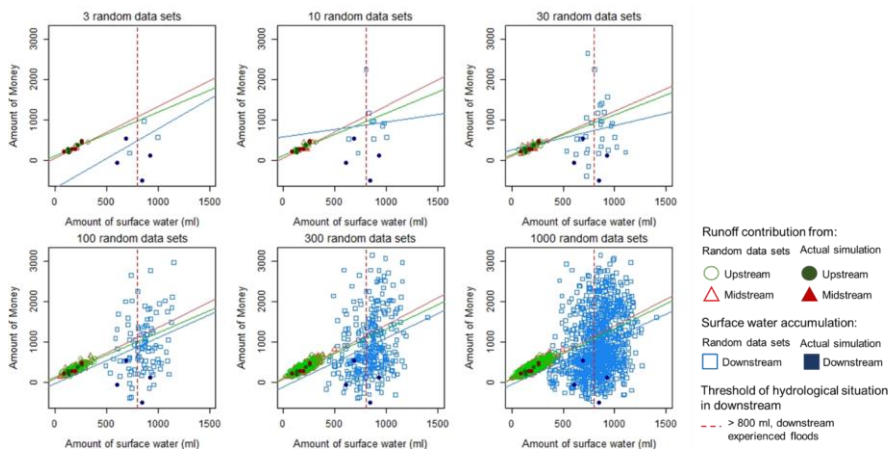



Figure E̶D̶3. Groundwater ~~situation~~ and economic ~~situation~~conditions based on random value simulation and actual simulation

645 **Figure ~~ED~~4. Runoff ~~situation~~ and economic conditions~~situation~~ 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.

650 **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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