“Save the Water” – A China water management game project

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Abstract. Sustainable water resources management is a challenge world-wide. The aquifer system of the North China Plain is a severe example. Population growth, intensification of agriculture, and modified water availability due to climate change have led to over-abstraction of groundwater, with consequences such as soil subsidence, increase of pumping costs and sea water intrusion. Since 2014, researchers of the Institute of Environmental Engineering of the Swiss Federal Institute of Technology (ETH Zurich) and hydrosolutions Ltd. have been working together in a comprehensive project on the threat of groundwater depletion due to the extensive aquifer tapping for farmland irrigation in Guantao, prefecture of Handan, China. Their work focused on creating a monitoring system for groundwater levels and pumped volumes using electricity consumption as a proxy. Also, for understanding better the farmers’ behavior, especially their reactions to different government policies concerning the decrease of groundwater consumption, a very simple version of a simulation game has been created. In order to better represent the complexity of the real situation and to professionalize the game design, the Subject Area in Game Design (ZHdK) joined the team. This contribution addresses the design challenges, solutions and users’ testing results of the last two years of developing the serious games series “Save the Water” for this project, including two board game versions and a digital browser game.

Keywords: Serious Games, Applied Games, Game Design, Groundwater Management, Overpumping, North China Plain.

1 Introduction

In arid and semi-arid regions, reliable agricultural production is only feasible with irrigation. Groundwater as the only water resource, which is available all year round, has become more and more attractive to agricultural water users to guarantee reliable yield in agriculture. Severe over-pumping of aquifers has been common. It is estimated that about one quarter of the 1000 cubic kilometers pumped annually from aquifers worldwide is unsustainable use which causes depletion of aquifers [1].

Aquifers can store water over years and are therefore particularly suited for mitigation of drought periods, which are expected to occur more frequently under climate change. To serve this purpose they must however be allowed to recover in times of above-average rainfall. Only under strict management, aquifers will be able to relieve droughts reliably.

While a release of irrigation water from a surface reservoir is easily controlled, extraction of groundwater can neither be easily monitored nor effectively controlled by local water authorities due to the presence of a large number of wells. The difficulty posed by managing them is the major reason why many aquifers in arid climate regions are over-pumped. New technology shall support tackling the challenge of bringing these aquifers back to a sustainable extraction mode.

In the past 30 years the aquifers in the semi-arid North China plain have been severely over-exploited. In some places water tables dropped at a speed of two meters per year. The natural flow system, in which water is recharged from the mountains and in the plain and discharged towards the sea, has been reversed in both the lower and the shallow aquifer layers due to the formation of deep cones of depression in heavily exploited areas [2].

The over-exploitation is primarily a consequence of the intensification of agriculture to feed a growing population. While the natural precipitation in the North China plain is sufficient to support one grain crop per year under average rainfall conditions, the double cropping of mainly winter wheat and maize can only be sustained by the depletion of groundwater resources.

The vulnerability of China to the impacts of climate change and inter-annual climate variability is high. Together with rapid economic and population growth and urbanization, long-term climatic trends have strained China's water resources to an extent that all major river basins in the North and North-West are suffering from water shortage. The country's water supply and agricultural production is threatened by changing spatial and temporal distribution of precipitation connected with more frequent weather extremes such as prolonged droughts, heat waves and floods. The over-pumping decreases the amount of water stored in the aquifers and thus the ability of aquifers to serve as reservoirs for mitigating climate extremes.

The growing complexity and interdependence of water management processes requires the involvement of multiple stakeholders. Interdisciplinary collaboration is increasingly vital for strategy development and implementation. There is a need for specifically developed tools, which could facilitate or enhance these collaborations between stakeholders.

The solution to groundwater over-pumping requires behavioral change of the irrigating farmers. Therefore, creating and increasing the awareness of rural population regarding to the problem is critical. The playful education via an interesting game seems to be a promising alternative to traditional appeals by posters and similar media [e.g. 3]. By reviewing well-established related research and development (R&D) work on games and game research for water resource management, we identify three main strategies approaching the respective game design: Following the digital approach, we could identify rather simulative or tabular-like [e.g. 4, 5] applications, while other playful approaches such as role-playing games are applied in analogue workshops [e.g. 6] or solely serving as research tool [e.g. 7].

However, there are no applications featuring a proper game design including state of the art game mechanics, graphics and narration in the analogue and digital approach although this is the most attractive way to raise awareness, to motivate people to learn about serious topics and ideally change their behavior.
Furthermore, the cultural contexts in existing applications range from India, to Mexico, to USA. So far and to the best of our knowledge, there are no state of the art game design-based applications, which focus on the Chinese water management culture.

To contribute to this topic, we present the R&D project "Save the Water" which is the result of a collaboration between the Institute of Environmental Engineering of the Swiss Federal Institute of Technology (ETH Zurich), the Subject Area in Game Design and the Game Lab of the Zurich University of the Arts (ZHdK), hydrosolutions Ltd., Zurich and the Southwestern University of Finance and Economics, Chengdu, China. The multi-year project is supported by the Swiss Agency for Development and Cooperation, the Ministry of Water Resources in China and the Chinese Academy of Sciences.

Since 2014, researchers of the Institute of Environmental Engineering of the Swiss Federal Institute of Technology (ETH Zurich) and hydrosolutions Ltd. have been working together in a comprehensive project on the threat of groundwater depletion due to excessive farmland irrigation in Guantao County, prefecture of Handan. Their work focused on creating a monitoring system for groundwater levels and pumped volumes using electricity consumption as a proxy [8]. Also, for better understanding the farmers' behavior, especially their reactions to different government policies concerning the decrease of groundwater consumption, Dr. Pan He (now South-West University of Finance and Economics, Chengdu, China) worked with a very simple version of a simulation game analogous to the ones described in [2]. In order to better represent the complexity of the real situation and to professionalize the game design, the Subject Area in Game Design (ZHdK) joined the team. The teams of ETH and hydrosolutions Ltd. (consisting of Swiss and Chinese experts) provided the quantitative hydrological and agronomical framework, having studied and interacted with the groundwater management system on the ground in China for many years. In a joint effort they first developed two versions of a board game in 2017, then, in 2018/19, a digital game [9] to fulfill different tasks in this research project. These tasks include the awareness building of rural population about the risk of groundwater depletion, and the evaluation of farmers' risk attitudes and preferences.

In this paper, we present the interdisciplinary, research-based and iterative design process of a serious game for water management of Chinese farmers.

First, we introduce the "Save the Water" board game and the results of a test we conducted with water management experts and Chinese farmers who played the prototype, and elaborate on how participants' feedback informed the redesign of the board game. In addition, we present the further design of a digital game prototype and provide an outlook on our future R&D work.

2 "Save the Water" – A Water Management Game Project

2.1 The Board Game (Complex Version)

User-centered Design Process. To meet the challenge of developing applied games remotely for a different cultural context [10], an iterative, user-centered design process served best to shape the usability of the game. Starting in early 2017, the board game (Fig. 1) was developed at the Zurich University of the Arts, accompanied by numerous meetings and smaller play testings with ETH staff and ZHdK game design students.

Since the game's purpose was to simulate the cropping practice in Guantao County and to raise the awareness for the growing risk of groundwater depletion, one of the main design foci lies on how the common groundwater resource should be displayed, in order to visualize responsibility and consequences of the player's actions, and to signal a dangerously low stage of the aquifer. Also, it was investigated what the game mechanics would have to look like, so that the game would be fun to play, while still reflecting the scientific facts.

Fig. 1. First board game version.

Game Mechanics. To respond to the basic conflict, which is underlying the serious game, the board game's story puts the participant in the role of a Chinese farmer who struggles with the challenges posed by the need for profitable cropping under the issue of groundwater depletion. Even though there is an instruction manual/rule book, the game is guided by a game master, since the game is developed for a workshop-like setting for farmers, students and water resource managers (administrative cadres).

There are two goals for each player, a common and an individual goal. The collective goal of all players is not to deplete the aquifer, while the individual goal of each player is to have more points/money than the other players at the end of the 4 rounds (e.g. cropping years). Therefore, the game is over and everyone loses the moment the aquifer is depleted by any one player. If the groundwater stays above the red line, the player who earns the largest amount of points/money wins.

The game material (see also Fig. 2) consists of the central groundwater pool and a circle which shows nine different agricultural phases of the farmer within a year: Weather forecast, seeding/buying, actual weather conditions, irrigation, harvest, upkeep, council meeting, events and entering into a new year. The game is made for 4 players, each having a character card, a land card (one at the beginning, several during the game course), water chips and coins. In the game, the players in turn can take actions phase by phase over the year: Based on the initial weather forecast (phase 1), they decide in phase 2 whether to rent more land, what kind of crop seeds (single/double crop or vegetables) or extensions to buy – extensions being a large water pump, water tank or insurance, which are shown on the character card. When in phase 3 the actual weather/rain conditions are clear, the groundwater pool card is "recharged" with blue tokens which represent water units (as the groundwater declines, the color of those water tokens changes from blue to yellow, then orange and, at the end, red). In the fourth phase (irrigation), the players take those water units and place them on their field cards, the amount of units depending on their choice of crops (single cropping of maize, double cropping of winter wheat and summer maize, or vegetables). For example, double cropping needs more water than single cropping; in deficit irrigation mode one less water drop is given. Water saving equipment can save another drop; the greenhouse vegetables need more water than grain fields, but can be (depending on the market price) much more profitable.

During each "pumping" phase, the player rolls two 3-sided dice to determine possible negative pumping effects (when still in the blue phase, less negative events happen than when the groundwater pool is low). Such negative effects impact all players, reflecting the common pool property of the groundwater resource; they can be "illegal pumping" (as a consequence, one additional water unit has to be removed from the pool), or occurrence of "salt water" (as a consequence, the harvest of each player gets reduced by one silver coin for every field he/she owns) or further negative consequences.

In phase 5, harvest, every player earns coins depending on the crop and the water units applied in irrigation. In phase 6, upkeep, every player pays his/her upkeep. The total upkeep cost is calculated by adding up the upkeep costs of all fields and all extensions.

In phase 7, the "council meeting" is held. Together the players discuss the last and the coming year. They can talk about a common strategy (e.g. concerning which crops to buy) or decide upon a water pumping policy: The players can choose one of the predefined policies or create a custom one for the next year; but all players need to agree on a policy unanimously to put it into force.

In phase 8 (events), in turn every player draws a card and reads it in private. If the bottom of the card indicates an instant effect, the card is played immediately. Otherwise the player can keep the card covered and can play it whenever he/she decides to. Such events can be positive (e.g. grants or state subsidies), or negative, such as agricultural pests, social taxes, unexpected draughts etc. Then, in the last phase, the game master advances the game to the next year.

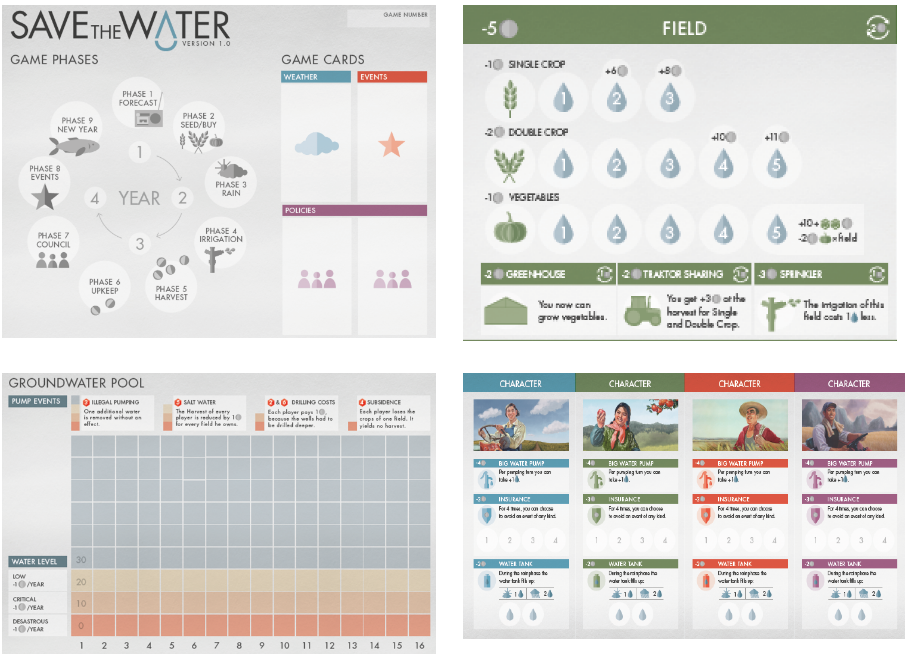

Fig. 2. Game material: the nine game phases for the game overview (top left), a player's field card (top right), the common groundwater pool (bottom left) and the four character cards (bottom right).

3 User Testing

To gain insights regarding the overall game experience, the cooperative playability and the mediation effect of the underlying message of the board game, we conducted several play testings with the first "Save the Water" prototype. The testings took place in Guantao, China (Fig. 3).

3.1 Questionnaire Evaluation

Procedure. First, we playtested the original board game with N=12 Chinese experts (m=7, w=5), aged 27 to 51 years (M=37.1; SD=7.57) from the field of water management (engineers or managers). Participants played the game in 3 groups of 4 players each and were instructed about the general rules and game mechanics by a game master, who joined and moderated the game session. After the game session, participants were asked to complete a short survey with questions about their exact professional background, individual gaming preferences, overall game experience, most and least favorite experience with the board game, game functionality and understandability, their individual goal (single versus multiplayer) and the perceived meaningfulness of the game. Some questions were ranked with a 5-point Likert scale, while others allowed for shorthand descriptions and keywords.

Fig. 3. Play testings with Chinese water management experts (left) and farmers (right).

Results. We found that most of the experts enjoyed playing the game a lot. Regarding game complexity, most testers reported that the game was not too complex at all (M=3.42; SD=0.90). The majority of participants understood the gameplay after the first round (first game "year"). Most participants wanted to play the game again (M=3.60; SD=0.72) although play duration was rather experienced as too long (M=3.3; SD=0.65). Most testers felt that they enjoyed playing rather in a cooperative way (serving the group goal), while only some reported that they preferred playing rather competitively (for their individual goal) (M=3.50; SD=0.80).

When asked what they liked the most about the tested board game, participants reported different things: The most frequently mentioned favorite experiences were group dynamics among the players during the play session (e.g. "discussion about crop choice and how to use water" or „the group decides that every field can be irrigate by two units of water only"), followed by specific game mechanics (e.g. "the decrease of the bad events as the groundwater level increases") and specific in-game events (e.g. "groundwater drawdown").

When asked what they liked least about the game, participants mentioned some game rule-related problems (e.g. "it is not clear at which stage the player should buy the field extension" or "it is not clear if the player can still buy the land after the real weather is revealed") or play strategy-related topics (e.g. "The play strategy doesn't change too much with respect to the changing water depth.").

Furthermore, we asked participants to choose a statement which was applicable for their experienced meaningfulness of the game. The majority found the statement "This game could stimulate reflections and discussion about the topic of water use." Some participants further remarked "This game could stimulate a group process / the way we discuss this topic with our colleagues."

Finally, participants could make additional comments and provide further feedback. Among other things, participants recommended to implement rewards for the winner, serious punishments for causing a critical water level in the game, as well as mechanics like other facilities to increase the water availability, free planting, fruit trees and water transfer from other places.

3.2 Participatory Observation and Expert Interviews

Procedure. Secondly, we tested the game with N= 24 Chinese farmers (age 40-60 years, m=12, w=12). Other than with the water management experts, feedback of the farmers has not been received by means of written questionnaires, since many of the farmers have a low formal education level. Therefore, play testing results were obtained by observation during the play sessions and by discussions/questions after the games, guided by the team members (ETH/ZHdK/hydrosolutions). Those play testings also took place in April 2017 in Guantao.

Results. It turned out, that for the target group of the Chinese farmers, the game was too complex, and it took too long to play. The rules were too complicated, there was too much text and there were too many features for the farmers to understand the game in a reasonable time, even less for them to feel motivated to discuss water management strategies. It proved to be valuable and necessary to have a Chinese speaking game master or facilitator who introduced the game and explained the rules properly. Nevertheless, there was a strong demand for a redesign of the board game.

3.3 Redesign: Complex and simple board game versions

Redesign. To meet the observations and results from play testings, the game designers and researchers developed an additional simple version of the complex board game (Fig. 4): In the biggest change, the character cards were abandoned completely, therefore eliminating special add-ons such as extensions, insurances etc. This way, there was less text, and about half of the possibilities to make decisions disappeared, cutting the game time in half to one hour. The main game mechanic of the agricultural phase loop played for four years remained. Also three of the original five policy cards were kept in order to stimulate discussions among the players, covering the topics of rationing, water rights and regulation.

Fig. 4. Simplified board game version after redesign process

Fig. 5. New character cards for complex board game version after redesign process

Overall – by means of oral feedback from discussions with water management experts, students and farmers alike – there was a preference of a different visual style (Fig. 5), as far as the character cards of the complex card game were concerned. The original "socialist-realism" art style of the character cards was changed into a more photorealistic style.

4 The Digital Game

Aim. After the board game design and redesign phases, the development of the digital water management game started in 2018. In the second (and current) main project phase the development of the digital adaptation of "Save the Water" was and is taking place [11]. The aim of the digital version is to collect data about the farmers' decision making more conveniently – the on-site board game sessions/workshops served their purpose well with respect to stimulating discussion and communicating the community background of the groundwater issue. But also, it proved to be an expensive and elaborate method, which consequently should be supplemented by a browser game as different research tool. Since smart phones are widely spread among the targeted players (farmers, agricultural students), the digital game version can reach them more broadly than a workshop-mediated game experience. Also, as will explained below, through the administrative panel, the game variables (cost and income per crop, points needed for level upgrade etc.) can be adjusted, and quantitative data on player behavior data can be gathered in a digital form.

Game Mechanics. Basically, the browser-based simulation game [12] shares a similarity in game mechanics with the board game, since it is also based on the intra-annual agricultural phases. The goal for the player is to keep and expand his farm during as many years as possible, and accumulate as much money as possible while preventing the depletion of the groundwater.

In contrast to the board games, the digital game is a single player game, due to technical reasons (much easier to program), but also because in this way more people can be reached for playing asynchronously and more statistics can be gathered in the online survey at the end, while the board game always needs four players to play simultaneously and be interviewed on-site. In the single player digital version, it was consequently harder to convey awareness to the factor that the groundwater resource is a common good with shared responsibility. Features to communicate this have been developed, e.g. system messages (Fig. 6) or narrative comments in the game (where the player hears about other farmers who have irrigated very responsibly or, to the contrary, have over-used water quota, see Fig. 7). Also, a global leaderboard is being implemented, for the players to compare their game results world-wide with others and get a multiplayer or community feeling in an alternative way.

In addition, there is an enhanced policy layer being implemented. The digital game already has an administration panel, where the game master can choose parameters for a certain game session (number of game years, crop prices, weather tendencies etc.). Now the game master can also attach a specific policy to a game session, such as restraints (e.g. only single cropping allowed), rewards or punishments for over-using the resource. The tracking of the reactions of the players in response to certain policies and the resulting behavioral data should, at some point, inform the water administration officials in formulating effective policies (subventions, restrictions) in real life.

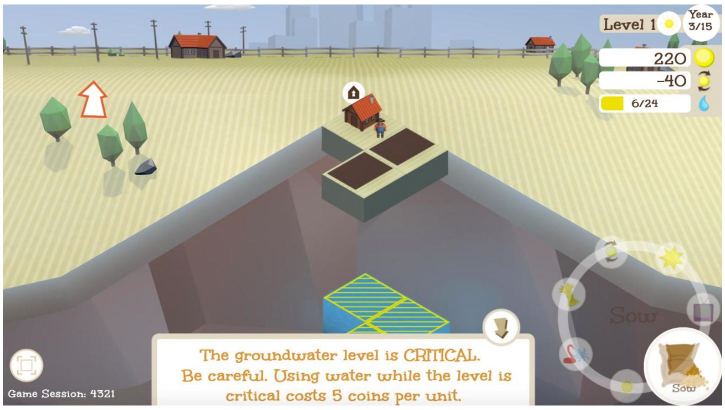

Fig. 6. In-game system message in the digital game

Fig. 7. Simulation of community feeling in the digital game

5 Discussion

The main goals of the “Save the Water” game project are to raise awareness for sustainable groundwater use, and to test management policies and the according behavioral attributes of the Chinese farmers in Guantao County. It should sensitize the farmers for the threat of groundwater depletion, spread and gather knowledge, and start a discourse. These are challenging tasks, since groundwater is per se invisible, and as long as water can be pumped to irrigate fields, the danger of depletion is not explicit (it can be understood only indirectly, when farmers have to deepen wells to reach the groundwater table). Furthermore, the games should also function as a research tool for ongoing ecological and socio-economic research, and yield, especially for the digital game, data about decision-making in response to various water use and cropping policies. The dual path of analogue and digital serious games applied in the same R&D project is a unique strategy for groundwater projects; and its design documentation and analysis was the main focus of this contribution.

By the iterative design process and by developing heterogenous analogue and digital games, the “Save the Water”-game series is working well towards those aims, which has been shown through the questionnaires, the participatory observations and informal discussions with the participants. Especially the board game instigates discussions about irrigation and cropping strategies. Dynamics unfold when players are torn between individual economic goals (to make money) and the collective ecological goal (to use water sustainably for irrigation).

The digital game is more casual; there the awareness-transfer cannot be observed directly, even though this game version is closer to reality than the board game: While crops prices and water units, weather consequences and other parameters have to be simple integer numbers in the board game to allow convenient payments with tokens and simple addition in-game by the players themselves, the overall data can be much more detailed in the digital game. Its scientific strength therefore lies in the data mining possibility: In the next part of the research project, analysts will be able to see when exactly players change their behavior, e.g. switch from double to single cropping, or when they start using sprinklers etc.. The data interpretation of the current digital game shall yield further results so that the serious games will hopefully further support the scientific, multi-year project of the Institute of Environmental Engineering of the Swiss Federal Institute of Technology and hydrosolutions.

6 Outlook

What will happen with these serious games in the future? For the digital game, there will continuously be a public online version with stable parameters [8]. Parallel to that, the administration panel allows different game masters to customize game sessions, e.g. for specific groups or class rooms, and is accessible only per link (which allows the mapping of the retrieved data onto the respective game adjustment, with own parameters and policies). Target groups for this will be farmers, agronomy students and water management experts alike.

The simplified board game shall be used for workshops for farmers conducted by Chinese agricultural college graduates. As village officers, they can hopefully use the game during their field work with farmers, and spread the message about sustainable groundwater use.

The complex board game is being custom-produced in a limited number, in order to serve as communication and promotion tool for the ETH project partners. For both the simplified and the complex board game version PDF-files are available for the public containing all game materials.

In March 2019, in collaboration with a team from Beijing University a farmers' survey will be conducted. In this survey, traditional questionnaires will be used in combination with the digital game to collect farmers' responses to different groundwater policies.

In addition, the results from the digital game play will be analyzed for extracting the behavioral rules of farmers, which will be used to develop an agent based model in a coupled human-nature system for understanding the development of the groundwater system in Guantao taking into account the farmers' decision-making process.

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