LAGOON, AGENTS AND KAVA: A COMPANION MODELLING EXPERIENCE IN THE PACIFIC.

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Multi Agent Systems (MAS) have been developed to study the interaction between societies and the environment. Here we use MAS in conjunction with a Companion Modelling approach to develop a Negotiation Support System for groundwater management in Tarawa (Rep of Kiribati). In agreement with the complex and dynamic nature of the processes under study, the Companion Modelling (ComMod) approach requires a permanent and iterative confrontation between theories and field circumstances. Therefore, it is based on repetitive back and forth steps between the model and the field situation.

The methodology applied in Tarawa relies on three successive stages. First, a Global Targeted Appraisal focus on social group leaders in order to collect different standpoints and their articulated mental models. These collective models are partly validated through Individual Activities Surveys focusing behavioural patterns of individual islanders. Then, these models are merged into a single conceptual one that is further simplified in order to create a role-playing game. This game is played during iterative sessions, generating innovative rules and scenarios. Finally, when the rules become too complex, a computer based version of the game replaces the board version. Stakeholders can explore the possible futures of freshwater management in Tarawa and eventually agree on an equitable collective solution.

Keywords: Water management, Multi-Agent System, Companion Modelling, Pacific, Tarawa

1. INTRODUCTION

Low coral islands are heavily dependent on groundwater for freshwater supplies. The availability, quality, and management of groundwater are central to sustainable development and poverty alleviation in many developing small island nations. Increasing populations, growing per capita demand and restricted land areas limit water availability and generate conflicts (Falkland and Brunel, 1993).

This study is carried out in the Republic of Kiribati, on the low-lying atoll of Tarawa. The water resources are predominantly located in freshwater lenses on the largest islands of the atoll. The water table is typically 0.8 to 1.6m below ground surface. Groundwater is supplemented by rainwater on most of these islands. South Tarawa is the capital and main population centre of the Republic. The water supply for the urban area of South Tarawa is pumped from horizontal infiltration galleries in groundwater protection zones called « water reserves » on Bonriki and Buota islands. These currently supply about 1300 m^3/day, equivalent to about 30L/capita/day of freshwater, representing 60% of the needs of South Tarawa's communities. Rainwater tanks and local private wells supply the rest (White et al., 2002).

The declaration by the Government of water reserves over privately owned land has lead to conflicts, illegal settlements and vandalism of public assets. Beside, the water consumption per capita tends to increase towards western-like standards, threatening the sustainability of the actual exploitation system. Finally, pollution generated by the 45 000 habitants of South Tarawa has already contaminated all the freshwater lenses, with the exception of Buota and Bonriki reserves (White et al., 1999). The Government is now conducting intensive groundwater investigations on the islands of Abatao and Tabiteuea in order to delineate the freshwater lenses and to provide more accurate estimates of the sustainable yields from these islands. Depending on the results of the investigations and community discussions, the groundwater resources could be partly used to supplement the water supplies from Bonriki and Buota to South Tarawa. However, already available information underlines the necessity to take into account the social impact of such implementation, in order to avoid the problems encountered on Bonriki and Buota.

Our project aims at providing the relevant information to the local actors, including institutional and local community representatives in order to facilitate the dialogue and devise together sustainable and equitable water management practices. Multi-Agent Based Simulations (MABS) coupled with a Role-Playing Game have been implemented to fulfil this aim. They provide powerful tools for studying interactions between societies and their environment (Bousquet et al., 2002). They have the potential to greatly reduce conflict over natural resource management and resource allocation. In order to collect, understand and merge viewpoints coming from different stakeholders, the following 5-stage methodology is applied: collecting local and expert knowledge, blending the different viewpoints into a game-based model, playing the game with the different stakeholders, formalizing the different scenarii investigated in computer simulations, exploring the simulated outcomes with the different stakeholders. The first three stages are successively described in this paper.

2. COLLECTIVE KNOWLEDGE

2.1 Theoretical assumptions

We acknowledge the constructivist theory in socio-psychology and believe that the nature of individual representations is socially constructed through people's interactions with their physical and social environment (Descola, 1996). We agree on the fact that these adaptive mental models can be partly elicited through Knowledge Engineering-based techniques and translated into conceptual models (Becu et al., 2003). We assume that social groups carry collective representations of their environment and that these mental models can be partly elicited from wisely selected representatives. We argue that individuals belonging to the same group share the same representation, but their behaviour is driven by personal motivations and tacit knowledge. Thus, they can temporarily dismiss part of the shared representation. Our methodology includes two sets of interview. The first one, called *Global Targeted Appraisal (GTA)*, is focusing on groups' representatives, or *Group Voices*, and its objective is to elicit representations rather then individual behaviours. The second one, *called Individual Activities Survey (IAS)*, is conducted with individual belonging to the same groups.

2.2 Global Targeted Appraisal

Prior to the interviews, a short survey helped selecting relevant spatial and social groups and understanding their hierarchical links in order to identify 30 *Group Voices* belonging to different religious, cultural, administrative, educational or gender groups. They were then interviewed individually at their place through semi-structured interviews in order to highlight their understanding of the main interactions between local people and water resources. The interview was divided into three exercises:

- Exercise 1 was based on photo interpretation and dealt with Tarawa overall features,
- Exercise 2 consisted in a cognitive mapping focusing on the interviewee's home island,
- Exercise 3 consisted in a card game focusing on water cycle and human use.

For the first exercise, 4 successive groups of photos referring to different aspects of Tarawa's environment and activities were given to the interviewee. For each group, the interviewer gave at first the general topic of discussion and asked the interviewee to describe important elements in the photos related with the topic. In order to structure the discussion and to avoid missing elements, additional prompting questions were available if necessary. The "How?" and "Why?" questions were eventually used to precise the interviewee's view. According to the laddering technique , "How?" provides more in-depth information about the process described, and "Why?" provides more global reasons concerning the process described. The topics to be discussed with the interviewee were: population, landuse and landownership; social and economic activities; climate and environment; water resources and water use; environmental pollution and water quality.

For the second exercise, the interviewee was provided with a sheet of paper and asked to draw successively the location or the spatial distribution of the island's key features. Key features were grouped according to topics largely overlapping the ones described for South Tarawa. The interviewer interacted directly on the map with the interviewee. When one group of key features had been displayed on the map, prompting questions used during the first step were reused in order to cross check information consistency and to outline the island's specificities.

The third exercise focused on the way the interviewee understood and represented water management processes. Water management included natural water cycle along with human activities (consumption, pollution, protection). It was based on a card game between the interviewer and the interviewee. The interviewer had 60 cards in his hands, representing "elements" that seemed important for water management processes. At first, the cards "*Coconut* ", "*Rainfall*" and "*Groundwater*" were dispatched on a board and the interviewee was asked to provide other elements in order to complete the natural water cycle. The interviewee was also asked to draw links between cards (action, relation, impact) and to describe them in a few words. The second set of cards displayed was: "*Household*", "*Pig*" and "*Vegetable Crop*". The topic was about direct water management from local settlers. The last set of cards included "*Government*", "*PUB*" (the local water agency) and "*South Tarawa Residents*". This part focused more on water management at the institutional level.

2.2 Individual Activities Survey

The objectives of this second field survey were to partly validate the models elicited during the *Global Targeted Appraisal* and to quantify some relationships already described by the *Group Voices*. In order to achieve these objectives, 24 persons were selected amongst the 4 islands and submitted to specific individual interviews. This time, the interview relied upon a more structured questionnaire form, focusing on local facts and personal activities and behaviour. Interviews were generally held in the central house or shelter with viewing distance to the well and other domestic facilities. Questions were grouped within five topics, which are very similar to the ones used in the GTA: demography and landownership;

activities and landuse; water resource and water use; improving water-use and sanitation; water reserve.

2.3 Results

2.3.1. Results from the GTA

First exercise

The first exercise of the GTA was meant to establish confidence with the interviewees and to let them browse general topics without focusing immediately on sensitive local issues. Thus, we started from demographic evolution and constraints and ended with global problems of pollution on south Tarawa. From a psychological viewpoint we wanted to confirm the ability of the interviewees to develop dynamic rationales from static material (photos). A second objective was to test our ability to elicit their mental constructs.

Some interviewees made extensive use of the photos during the interview, others focused mainly on one of them to develop their rationale. In several occasions interviewees developed their ideas without referring to the photos at all, in some sort of story telling mode. Pre-selected prompting questions were instrumental in order to keep the discussion alive during most of the interviews. The *Transcript Analysis* technique was adapted and applied to each recorded interview (Newell, 1982, Shadbolt and Milton, 1999). Three lists of elements (words or group of words) were completed: social/institutional elements, spatial/geographical elements, and passive/biological elements. Semantic links between these elements were defined according to the grammatical structure of the transcript.

All interviewees were fully aware of the population increase on South Tarawa and its impact on society and environment. Increased pollution, land pressure and alcoholism linked with unemployment were the main issues described. Monetized activities were mainly linked to Government jobs available on South Tarawa, while subsistence economy, based on fishing and cropping, still prevailed on Abatao and Tabiteuea islands. The overseas sailor contracts constituted the main source of regular private income for many households. In these cases, the husband's absence reinforced the leading role of women in the local monetized sector. Most interviewees had stressed out the fact that climate pattern and weather features had changed over time. But concerns about coastal erosion and sea level rise issues were not yet largely shared in the population. The concepts of soil water infiltration and groundwater recharge were well admitted by a large majority of the interviewees. However, the concept of evaporation was still fairly vague.

Even if the traditional view "*my land/my well/my water*" was still recognized, the scientific-born concept of "*one island/one water*" was widely accepted. The impact of tidal wave and flood/drought on the water lens had often been mentioned and discussed. Illegal taping onto the PUB pipes and illegal settling on the water reserves were issues openly discussed by several interviewees. About pollution, most interviewees mentioned in the first place solid wastes, specially cans and tins. They also acknowledged the impact of pigs on the environment as they were causing bad smells and participating in disease spreading. Only half of the interviewees perceived the direct link with water lens contamination. Human wastes were often not mentioned at all.

Second exercise

The second exercise of the GTA was meant to focus on specific issues related to the interviewee's island. Most of the time, it was mainly an update of the general considerations expressed during the first exercise and the discussion often concentrated on the specific features of the island's society and environment. From a psychological viewpoint, our objective was to confirm the interviewees' ability to represent spatial entities, to manipulate these entities on the map and to describe dynamic processes directly on the map. These were essential elements to validate the use of a *Role-Playing Game* later on.

We were impressed with the mapping and drawing abilities demonstrated by all the interviewees (one exception only). Geographical references, symbol choices and drawing capabilities were good enough to allow instant understanding from the interviewer. It is worth mentioning that the mapping exercise helped correcting a general misunderstanding on Tabiteua and Abatao about recent drilling implemented by the Government. A majority of people thought that these bores were the definitive pumping wells. The map helped us to reveal the confusion and to re-establish a clear communication of the facts. A striking outcome from the exercise was the fact that not only the four islands constituted a spatial continuum between South and North Tarawa, they represented as well a temporal bridge between present and past times. Social, environmental and economic evolution on Bonriki was largely replicated on the three other islands. It was specially true about land tenure issues.

Regarding water issues, remembering that we didn't ask the interviewees about *THEIR* own feelings but more generally about local *PEOPLE* thoughts, the situation was contrasted. Where Water Reserves already existed, angry and happy people coexisted. The opposition mainly focused on the level of financial compensations (Land lease), but one has to recognize that this claim was strongly backed by a barely sustainable pressure on land tenure. This pressure had already boosted the land market to unexpected levels. Access to *THEIR* water through the PUB reticulated system was also described as a fair claim. On Abatao and Tabiteua, the fears crystallized around the landownership issues. Beyond the financial bargaining game, traditional livelihood and environmental harmony were genuine arguments. Bonriki and Buota cases were often taken as examples of the way things shouldn't be done.

Third Exercise

The last exercise was directly meant to elicit individual knowledge of water management processes. The card game was designed in order to disaggregate these representations into unit elements and causal links. As mentioned previously, part of the elements was already discussed during the first exercise (in a broader context) and it was interesting to observe whether these elements might reappear during the card game. From a psychological viewpoint, beyond the ability of the interviewees to disaggregate their mental constructs into basic elements, we were interested in verifying their acceptance to play the game by the rule and their capability to justify a given choice. Again, these hints were valuable in the perspective of a Role-Playing Game implementation.

The story was divided into 3 stages of evolution (pristine island, remote settlers and interconnected islands) and cards were distributed at each stage. A first analysis consisted in counting the number of cards and noting the elements cited. Overall, the interviewees took an average of 28 cards out of 60 and most of them were much more comfortable with the second theme. The reference to their daily life obviously helped to build useful analogies, whereas the level of abstraction required with themes 1 and 3 was more challenging. An interesting outcome was the fact that a large majority of people were able to describe an infiltration-like process linking the rainfall input with the groundwater recharge. The freshwater lens itself was seldom perceived as a specific entity but rather an attribute of the soil itself ("*water in the soil*"). The sanitation elements were often skipped from the representation as if they were not part of the water cycle. This was relatively surprising as most of these people were referring, when prompted, to pollution mechanisms during the photo interpretation exercise. Finally, the interaction with South Tarawa was described through engineering elements and links. But the institutional and legal aspects were merely represented through negotiation between landowners and Government ("*Compensation*" card).

Different table breakdowns gave more details about specific socio-cultural sub-groups. First, higher educated people had a better understanding of complex processes (*Evaporation*, *Taxation*) and a better awareness of modern technologies *(Pump*, *Gallery*). This group hardly overlap with a precise age group. If the young/middle age group mentioned "*Evaporation*" more often then their elders, this group was mainly characterized by a strong focus on financial negotiations with the government about the water reserves (*Landowner* and *Compensation* elements). We were also interested in checking whether the Government Expert and Council Member groups would display specific features. So far, the latter didn't show any specificity compared with the overall results. But the first group clearly demonstrated its (partial) belonging to the high education one (*Evaporation* and *Taxation* elements). Beyond this common characteristic, the experts are almost the only ones to mention the pollution and sanitation elements in the water cycle (*Pollution*).

In conclusion, the GTA allowed us to collect first-hand valuable information. This information was used in order to design a bottom-line model of freshwater management on the atoll. This model was used as a template to build a Role-Playing Game, called *AtollGame*. A critical question was whether people shared equivalent representations of the hydro-geological processes. The GTA successfully demonstrated that almost everybody was able to describe an infiltration process leading to the recharge of an island-wide freshwater lens. This was of prime importance in order to step forward into the next phase of the negotiations. Finally, the ability of the interviewees to explicit their mental constructs, to manipulate spatial entities on the map, to break down complex systems into simple elements and to accept to play games by the rule, confirmed the potential of success of a Role-Playing Game during the next phase.

2.3.2. Results from the IAS

As mentioned in the methodology, the IAS was meant to partly validate the models elicited during the Global Targeted Appraisal and to quantify some relationships described during the Global Targeted Appraisal. 24 people, all but 3 landowners, were interviewed.

Family members ranged from 3 to 18 people on Tabiteua and Abatao, and from 3 to 16 on Buota and Bonriki. On an average, each family was composed of 8 members. We considered here the close family living in the same compound and sharing some facilities. Most of the time they included 3 generations from direct descend. The average size of a block of land was 2.5 acres. Most of the time, these blocks were collectively owned by different members of the family (between 2 and 10). The maximum size of a block was approximately 6 acres. Very often, other related families, according to the *extended family* concept, also occupied these blocks. On an average, 3 other families were living on the same block as the interviewee. Actually, this average value hardly expresses the diversity of the cases (between 0 and 10).

In terms of employment, there was a huge difference between Tabiteua/Abatao where only one interviewee relied on a regular job and Buota/Bonriki where nearly 75% of the families were enjoying at least one regular income. On an average, they generated a $425 of monthly income. Subsistence economy was based on fishing (fish, shellfish), local product manufacturing (thatching, string) or local food marketing (coconut, papaya, toddy). On an average they generated a mere $140/week, but it was pretty hazardous to translate this figure into a monthly income as most of these activities are very irregular and subject to fund-raising initiatives for example. A special attention was given to vegetable cropping activities. They mainly concerned Abatao (100% of interviewees) and Bonriki (50% of interviewees). In their case, the average subsistence income jumped towards $250/week with a more regular pattern controlled by market niches (schools, hospital, restaurants).

In terms of water use, each interviewee, except one, had access to a personal well. But alternative sources of water delineated again a large difference between Tabiteua/Abatao (only one person collecting rainwater into drums) and Buota/Bonriki where the collect was more diversified (38% use drums, 19% use PUB water, and 11% use rainwater tanks). On an average, families used 460 l of water daily. Given an average family size of 8 people, the consequent 58 l/person/day represented a rather high estimate of the usual figures quoted in the literature (between 30 and 50 l/person/day). One has to remember that most of the interviewees didn't face any problem of water availability, and that most of them enjoyed very good water quality. Hence, a free access resource didn't limit the consumption. Furthermore, most interviewees confessed that everyone in the family, including children, was getting water from the well on an instant demand basis (90% of cases). Consumption from families regularly watering their vegetable plots jumped to an average 100 l/person/day.

Nearly 95% of the interviewees considered their water as safe and didn't recall any health incident linked with water quality. Nobody on Tabiteua/Abatao considered that their island faced pollution problems, whereas 45% on Buota/Bonriki complained about an increasing threat. It was an interesting statement as:

- 95% recognized that grey waters were just thrown away around the house.
- 25% recognized that they were discarding solid wastes on the beach
- 30% recognized that they were discarding solid wastes in the bush (pit, hole)

Only few interviewees mentioned watering the garden with grey waters or composting the domestic wastes. Nevertheless, 29% admitted to regularly burn solid wastes.

Regarding the Water Reserve issues, questions were slightly different for Tabiteua /Abatao (forecasted) and Buota/Bonriki (implemented). 44% of the interviewees on Buota/Bonriki remembered that the Government provided information about the pumping, 31% were not present at that time and only 25% denied receiving any information. Nevertheless, nearly 50% were not satisfied with the implementation by the Government, 19% had no comment and only 31% were satisfied with the implementation. In order to agree on the actual pumping, 31% mentioned higher financial compensation, 19% access to PUB water and facilities, 19% requested the recognition of their rights. 44% emitted strong doubts about Government's ability to manage properly the water pumping and distribution, whereas 25% felt pretty confident about it and 31% had no opinion. On Tabiteua/Abatao the situation was clearer as we were discussing an on-going process. 100% of the interviewees recognized that the Government informed them beforehand, but 63% disagreed with the implementation as they felt forced into it. While 50% of the interviewees would like to enter financial negotiations with the Government, 38% remained strongly opposed to any move towards a water reserve on their island. This opposition was not blindfolded as a mere 50% had no opinion about the Government's ability to conduct a proper implementation and the remaining 50% equally divided into pros and cons.

In conclusion, we would like to underline the fact that the IAS confirmed the fact that sanitation issues were largely disconnected from the water management consideration for most of the interviewees. Hence, we confirmed that the gap in the mental constructs elicited during the GTA largely overlapped with the behavioural models displayed during the IAS.

3. ATOLLGAME: THE MODEL

3.1 Elements of design

As previously stated, the agent-based model and the corresponding role-playing game were designed accordingly to the different viewpoints, converging or conflicting, recorded during the interviews. Freshwater lenses were perceived as global and undivided resources on each island. But few interviewees described the "lens" entity and its properties. Hence, we decided to implement a very simple reservoir-like entity in the model. Water infiltration into the soil is acknowledged, through different descriptions, by a majority of interviewees. Water uptake by vegetation and evapotranspiration processes were far less perceived. Hence we decided to use a very simple water balance model linking the groundwater with the atmosphere. Seasonality of the climate was differently perceived. Hence, we decided to create a quasi-random rainfall allocation rule. Sea level rise and global change influences were kept as exploring scenarios. Daily water use was generally described in equivalent terms. But only few interviewees linked solid wastes and grey waters production to the infiltration process. Hence, we decided to focus mainly on daily water demand and to let the sanitation issues arise from the playing sessions later on.

Landowners, traditional or new buyers, are the essential actors in the negotiations with the government. Hence, it was decided that each active agent in the model or player in the game had to become a local landowner. The connection between land tenure issues and water management was an essential element. It drives the land use restrictions and land leases discussions. Hence, it was decided to design the model around land and water allocation conflicting rules. The population increase, mainly through immigration, was perceived as a threat in terms of water consumption, pollution generation and pressure on the land. Hence it was decided to submit the agents/players to increasing numbers of new settlers on their land. Financial issues linked with water management mainly dealt with land leases, equipment investment and, seldom, with water pricing. Hence, it was decided to allocate different types of income to the agents/players in order to activate these mechanisms.

3.2 The virtual landscape

AtollGame was created with VisualWorks©, using the CORMAS platform developed by Bousquet et al. (1998). AtollGame includes:

- Spatial active entities: *AtollCell*
- Social entities: *Household* and *AgentPUB*
- Spatial passive entities: *Landuse*, *Wateruse* and *WaterBalance*.

Two 80 acres virtual islands were created, each one on a 25x45 regular spatial grid with hexagonal cells. Each unit cell corresponds to a 490 m² land area. We decided to work on environments representing virtual islands in order to prevent stakeholders from feeling personally tackled. Island 1 corresponds to scarcely populated island (50 families) where the government is already pumping freshwater. Island 2 corresponds to an overcrowded island

(200 families), already polluted and depending upon a freshwater adduction pipe for drinking water. Each hexagonal cell provides isotropy properties used to model freshwater lenses by generating isopiezometric circles. Each cell holds one *Landuse* passive entity, which type can be tree, crop or bare soil and one *WaterBalance* passive entity. The modelling time step corresponds to a 10 days period and the simulations are limited to 1 year.

Several modelling viewpoints were created, directly accessible during the simulations, in order to represent key features of the system. The *Landuse viewpoint* visualizes the eventual changes between the three land use types. The *LensDepth viewpoint* allows following the depth evolution of the Lens during the simulations. The *WellWater viewpoint* represents the water salinity evolution, varying between fresh, brackish and salty.

3.2 The water balance and hydro-geological models

The recharge of the freshwater lenses is directly controlled by the infiltration rate through the unsaturated soil layers. The water balance is simulated within AtollGame using a slightly modified version of the mass-conservation driven model proposed by Falkland (1992) for South Tarawa. This three-reservoirs-based model, called WATBAL, uses rainfall and potential evapotranspiration (PET) as input data. Runoff is not taken into account because of the very high permeability of the coral sand soils. The first reservoir intercepts the rainfall at the vegetation level. The second reservoir corresponds to the soil water storage and the water entering the third reservoir corresponds to the recharge of the freshwater lens. Recharge of the lens may occur only after plants have satisfied their water requirements. Tree crops (mainly coconut trees in our case) are able to extract water directly from the lens. This model was adapted to AtollGame by bringing down the hydrological calculations at the level of each Cell through its *WaterBalance* and *Landuse* entities. Each instance of these two classes can operate its specific part of the water balance. Hence, AtollGame takes the spatial heterogeneity of the processes and their time dependence into account.

The shape and the depth of the freshwater lenses are calculated according to the model proposed by Volker et al. (1985). This model predicts the depth of the freshwater lens and the thickness of the transition zone from the recharge and uptake values, according to the maximum length of the lens. Two strong assumptions limit the use of this simple 2D-model: (1) the recharge is constant and (2) the lens is in a steady-state condition. Hence, the model is often used for long-term predictions based on ten years averaged data. This vertical, 2D representation had to be adapted to the AtollGame distributed grid (Perez et al., 2003). Hence, some Cells have been selected and designated as lens centres or Nuggets. Using the isotropy property of the grid, each Nugget is surrounded by concentric circles of isopiezometric Cells. The orthogonal distance between the lagoon and ocean shores, crossing the Nugget gives the value of the radius (L). The distance between two Nuggets may be smaller then their respective radius; in this case, a common Cell is given the deepest value calculated at each time step. The global shape of the lens corresponds to overlapping bowls.

The hydrological model, using outputs from the water balance's one, provides an update of the cell's attribute "depth" at each time step. This attribute is then used to specify the water quality of the lens by updating the cell's attribute "*wellWaterQuality*" according to a simple rule: if the depth is lower than 1.6m, the water is considered as salty, if the depth is higher than 3.1m the water is said to be fresh and in between the water is declared as brackish.

3.3 The social entities

Two classes of social entities were defined. On Island 1, 50 *Household* agents have been creating. They all represent a family but only 11 are *landowners*, the rest are *relatives*. On Island 2, there are 200 *Household* agents, 42 of whom are *landowners*. The initial locations of the households are saved in the environment. The main attributes of each *Household* are: the size, the drinking and domestic water requirements, a list of *Wateruse* equipment and a consumption satisfaction index. Theoretical demands are set up to estimated levels of 20L/day/person for drinking water on Island 1 and 40 L/day/person on Island 2. For both islands, the domestic water consumption has been fixed at 40 L/d/person. Households are all provided with a well, some are given a rainwater tank and some, only on Island 2, have a connection to the water pipe. The decision process dealing with water consumption follows a simple rule: households satisfy their drinking water needs from their rainwater or PUB connection, if any, and supply their domestic water demand with their well. If they only have a well, they use it for both purposes, taking the risk to drink brackish or salty water according to their well water quality. The water availability is updated at each time step according to the type of equipment (direct rainfall, groundwater or PUB pipes). Groundwater extraction from individual wells is limited by a maximum depletion rate in the vicinity of the well. One process accounts for population growth through the introduction of new relatives at the beginning of each time step.

The *AgentPUB* class contains only one instance representing the Public Authority Board, in charge of the water distribution among the population. At this stage of the model, social interactions focus only on the competition for water between households and the management decisions from PUB. The *AgentPUB* is characterized by the volume of water pumped from Island 1 and given to Island 2. The pumping rate is initialized at 150 m^3/time step. The distribution among the different households on Island 2 is driven by their ranking distance along the main pipe. The *AgentPUB* can modify its pumping rate according to the average recharge rates.

4. ATOLLGAME: THE ROLE-PLAYING GAME

4.1. Conceptual framework

A Role-Playing Game (RPG) has been designed as a medium of communication based on the existing conceptual model. It is meant for opening or developing the communication between stakeholders. In a well-designed RPG, players are aware of the issues at stake but allow themselves to express their views and behave accordingly to their beliefs. Another fundamental characteristic is the ability of the RPG to generate collective scenarios that will explore new management avenues. In order to achieve these tasks, the RPG must:

- *Represent* simplified features and processes encountered in the reality. In particular, biophysical processes, social interactions and spatial descriptions should be understood and accepted by all players as plausible assumptions.

- *Secure*, at every stage of the game, the neutrality of the selected rules and of the Game-Master decisions. This “fair game” is instrumental in helping players to build self-confidence and to advocate their viewpoints.

- *Create* opportunities for players to comment, modify and improve the rules. Indeed, the game is intentionally designed with a rudimentary set of rules that needs improvement.

Thus, players come progressively from playing against each other to a situation where they appropriate the game collectively.

Finally, when players have realized the collective benefit of the game, they tend to explore more complex situations and to implement many more rules. Most of the time, the increasing complexity tends to bring together the artificial game and the real environment. What is at stake with this approach is to give the local stakeholders the capacity to build their future together. Instead of asking foreign expertise to provide an hypothetical best solution, this expertise is used to help local people adopting an equitable management of the resource. Of course, manipulation, lobbying, struggle for power are inherently part of the process, but in an armless and controlled environment.

4.2. The game

The set of the game is composed of two maps identical to the environments of the model displayed on separated tables. Both maps represent a virtual island with households and relatives. 8 players are allocated on each island to numbered locations and asked to sit by their plots. On the first map, a string delimits the reserve boundaries and adhesive and coins are used to represent the pumps and galleries. On the second map, the main pipe is delineated by a stripe of adhesive. Players take the role of householder. They will attempt to find enough water for their family during the game. Additionally, they should attempt to minimize their costs. At the beginning of the game, each player randomly draws a card that defines his/her personal profile in the game and on the basis of which he/she behaves throughout the session. Players' profile includes job, number of members in his household, water needs and equipments. All materials used during the game are bilingual: English and I-Kiribati.

The players

On Island 1, amongst the 8 players, 1 is a public servant, 3 are seamen and 4 have no job. On Island 2 the distribution is slightly different: 3 public servants, 3 seamen and 2 have no job. All of them are landowners living on their land. They earn virtual money from their jobs (2 to 6 tokens) in the form of matches . The relatives living or arriving on their land at the beginning of each round can cost them money (-2 or -1 tokens) or provide some additional income (0 to 2 tokens).

The duration

Four rounds (each equivalent to a 3-month season) are to be played. The first round corresponds to a good rainy season (550 mm), the second one to a very bad season (190 mm), the third and fourth rounds only replicate the data from the first round. On Island 1, the pumping rate from the government is steady and corresponds to a 150 m3/day. On Island 2, the government is providing the local residents 150 m3/day through the pipe.

The objective

The individual objective of the players is to minimize the number of angry or sick people in their house. People may become ANGRY because they didn't have enough water to drink during the round. People may become SICK if they drank unhealthy water during the round. Unhealthy water means that the water is polluted or salty. POLLUTION depends on the number of people living on the island and contaminating the freshwater lens. SALTY

WATER depends on the recharge rate of the fresh water lens and the location of the people on the island. Rainfall and pumping rate affect the level of recharge. Rainwater or water from the adduction pipe are safe to drink.

In order to provide drinking water to their family, players are given BUCKETS at the beginning of the game. One bucket can store 20 litres each day. One person is supposed to need 20 litres of drinking water each day. The initial number of buckets is lower then the family's needs, by 2 or 3 buckets. In order to provide enough water to their family, the players have to BUY equipment that will increase their storing capacity, counted in equivalent-buckets. A manual PUMP costs 2 tokens and provides 2 more buckets of storing capacity. A RAINWATER TANK costs 3 tokens and provides 5 more buckets of storing capacity. A PUB TANK costs 3 tokens and provides 5 more buckets of storing capacity. Normally, the rainwater tank and the PUB tank automatically refill at the end of each round. But, if the rainfall during the round was not sufficient, the rainwater tanks remain empty. The same happens with the PUB tanks if the adduction pipe cannot provide enough water during the round.

Players can decide to farm vegetable gardens in order to increase their income. Each CROP card costs 1 token and needs 4 extra buckets of water for irrigation at each round. The profit from the crop depends on the climate. If the round was rainy, then the crop provides 2 extra tokens to the player. If the round was dry, the crop failed and there is no extra income.

4.3. The rounds

First session:

- First round: relatives are already on the player's land. Good rainy season. Players have to invest on equipment in order to provide enough drinking water to their family. Some may notice that their well is located on a brackish or salty area.
- Second round: relatives are randomly coming on the player's land. They influence income. Players may invest more on water equipment or decide to try to crop. The bad rainy conditions influence the quality of the freshwater lens. All the crops fail and the Rainwater tanks are empty for the next round.
- Third round: relatives are randomly coming on the player's land. They influence income. Players have to overcome the reduction in storing capacity due to the empty rainwater tanks. It is a good rainy season, the freshwater lens quality improves and the crops are successful.
- Fourth round: relatives are randomly coming on the player's land. They influence income. One player is given the opportunity (CHANCE card) to leave his place on Island 2 and to relocate on Island 1 if he can make a deal with another player on that island. One player on island 1 is given the opportunity (CHANCE card) to sell part of his land to a new settler, he can accept or not. The other players continue to supervise their water needs.

Second session:

Players resume the game where they left it the day before.

- First round: the game master introduces one COLLECTIVE EVENT card on each island. On island 1, the card mentions the fact that the government has decided to get rid of all the settlers and crops located on the reserve. Players have to relocate their relatives and they loose the crops removed. On island 2, the card mentions the fact that the government has decided to raise a connection fee from each dwelling connected to the pipe (1 token each round). Then, the game continues like before.

- Second round: the game master introduces one new COLLECTIVE EVENT card on island 2. The card mentions the fact that, due to financial issues, the government cannot maintain properly the adduction pipe. The consequence is that the discharge in the pipe falls to 75 m3/day. Then, the game continues like before.
- Third round: the game master introduces one new COLLECTIVE EVENT card on island 1. The card mentions the fact that, due to water shortage on island 2, the government has decided to increase the pumping rate from 150 m3/day to 250 m3/day. Then, the game continues like before.

4.4. Outcomes from the RPG

At first, it was encouraging to see that representatives from the different islands displayed different viewpoints about the Water Reserves. Hence, the group meetings organized in the villages prior the workshop allowed for a really open debate. On the institutional side, the position of the different officers attending the workshop demonstrated a clear commitment to the project. All the participants showed the same level of motivation either to express their views on the issue or to genuinely try to understand other viewpoints. Participants also accepted to follow the rules proposed by the project team, especially the necessity to look at the problem from a broader perspective.

During the first rounds, the players quickly handled the game and entered into interpersonal discussions and comparisons. The atmosphere was good and the game seemed playful enough to maintain the participants' interest alive. One table grouped 8 players simulating water management on a scarcely populated island (Island 1) where the (virtual) Government was already pumping water. The other table grouped 8 players simulating water management on an overcrowded and polluted island (Island 2), depending on the water pumped from the first island. Interaction between the two tables started when one player from the second island was given the opportunity to move to the other one. The bargaining process that was generated from this new situation illustrated the actual tensions existing, in the reality, around the land tenure market. The connection between water management and land allocation issues was clearly demonstrated by the players' behaviour.

The second day, the introduction of a Water Management Agency and the selection of its (virtual) Director created a little tension among the participants. But, after a while, the players accepted the new situation as a gaming scenario and started to interact with the newly created institution. On island 1, the decision to remove crops and settlers from the (virtual) Water Reserve immediately generated vivid discussions among players. On Island 2, the recovery of service fees from the players connected to the Agency's water pipe had the same effect. At this stage, players started to mix arguments based on the game with other ones coming directly from the reality. On Island 1, players entered direct negotiations with the (virtual) Director of the Water Management Agency. On Island 2, discussions opposed players willing or not to pay the fee.

Finally, the project team introduced the fact that the Water Management Agency was no longer able to maintain the reticulated system due to a poor recovery of the service fees. It had for immediate consequence a sharp decrease of the water quantity offered on Island 2. Then, players from both tables were asked to list solutions to improve the situation on their island. When the two lists were completed, the project team and the participants built a flowchart of financial, technical and social solutions, taking into account issues from both islands (figure 1).

The Role-Playing Game had successfully reached its goal in terms of communication and scenario building. The whole process could have been taken further in terms equitable water management, unfortunately, some participants drove back discussions into endless arguing around financial aspects only. It was collectively decided to stop the process at this stage and wait for the project team to come back with an improved version of the computer model, including the different scenarios created by the participants.

5. DISCUSSION AND PERSPECTIVES

The flowchart (figure 1) was created from the contributions of all the participants and openly discussed among them. Obviously, the actual situation is largely unsustainable either from a financial or social viewpoint:

- The Government relies on the Land Leases (top part of the flowchart) in order to secure social acceptance of the Water Reserves. The land market already pushes land prices to levels that can't be matched by Government Leases. Beside, other technical solutions (Desalination plants, improved distribution) are not yet directly linked with the water exploitation issues on the islands.
- Some local residents claim that the environmental risks created by the pumping in the Water Reserves should be compensated as well. These Damages (bottom part of the flowchart) should be given to all the permanent residents of the island, beside the Land Leases granted to the concerned landowners. But fewer claims were made for negotiated and regulated use of the Water Reserves, weakening somehow the environmental risk claim.

It seems that the flowchart above provides a set of inter-dependent solutions that should be explored in order to gradually unlock the present situation. Whether we look at already existing or forecasted Water Reserves, the following guidelines are highly relevant:

- The financial solutions should be mitigated with technical solutions including regulated access to the Water Reserves or Participatory Management of the pumping.
- The water exploitation issues should be more strongly linked with the water distribution ones, and eventually with the sanitation ones (keeping in mind that the later are generally disconnected from the others by most people).
- Exploring the middle part of the flowchart will enable more 'consensual' stakeholders to participate in negotiations that are presently dominated by more extremist views.
- Management issues on the existing Water Reserves (Bonriki and Buota) and implementation issues on the forecasted ones (Abatao and Tabiteuea) are inherently interrelated. On one side, creating new Water Reserves without confronting the actual problems on the existing ones is not viable. On the other side, the introduction of new actors in the debate helps reducing the actual bipolar confrontation between landowners and the Government on the existing Water Reserves.

As far as discussions in some villages are characterized by contrasted positions, it was highly recommended that the next steps involve a sequential process for interactions. First, experts from the relevant Government Agencies should be confronted with the new computer version of the game. The final version will include most of the options present in the exisiting flowchart. But the project team needs more information from the local experts in order to provide realistic figures, especially in the financial sector. When most of the options are implemented local experts will select anticipation scenarios to be explored with the local communities. Then, these scenarios should be presented in the different villages through collective meetings where people may have the opportunity to interact with the computer simulations. Evaluation of the Government criteria and scenarios may lead to the creation of newly modified ones. Local experts will study these modified versions again. This back and forth process has to be applied several times in order to narrow the range of options. At last, the Government experts and the island's representatives should meet again to assess the remaining options and hopefully agree on an equitable management scenario.

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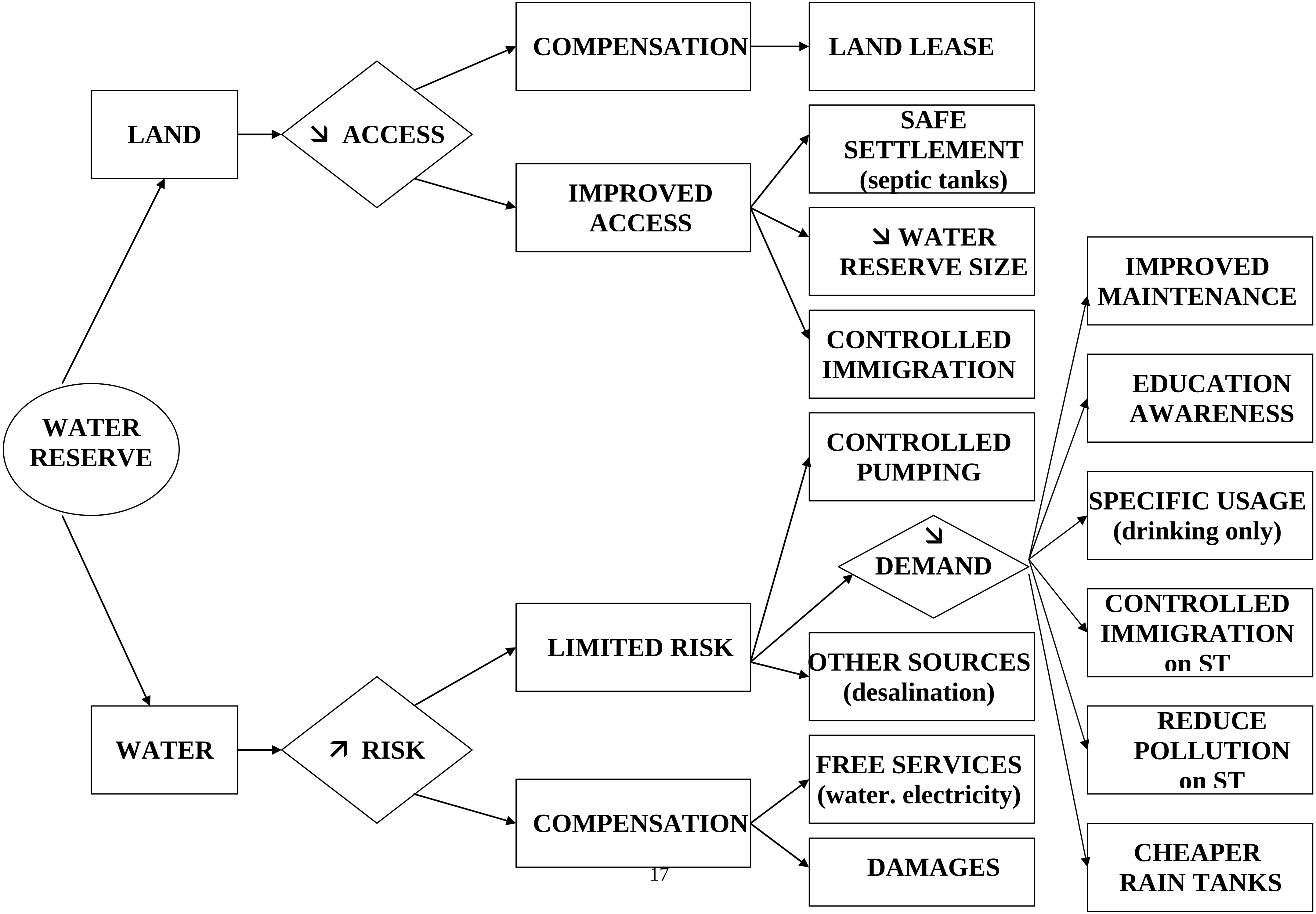
WATER RESERVE
LAND
↘ ACCESS
COMPENSATION
LAND LEASE
IMPROVED ACCESS
SAFE SETTLEMENT (septic tanks)
↘ WATER RESERVE SIZE
CONTROLLED IMMIGRATION
CONTROLLED PUMPING
↘ DEMAND
IMPROVED MAINTENANCE
EDUCATION AWARENESS
SPECIFIC USAGE (drinking only)
CONTROLLED IMMIGRATION on ST
REDUCE POLLUTION on ST
CHEAPER RAIN TANKS
WATER
↗ RISK
LIMITED RISK
OTHER SOURCES (desalination)
COMPENSATION
FREE SERVICES (water. electricity)
DAMAGES