Agent Oriented Requirement Engineering for Lake Mathematical Modelling: Preliminary Study

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***Abstract*— Agent oriented requirement engineering (AORE) is useful in transforming mathematical models to agent oriented modelling and simulation. The transformation process is based on a requirement elicitation study in which various stakeholders will understand users' requirements through elicitation questions and interviews. The AORE enable the modellers to understand the mathematical model and translate the model into the agent context. With AORE, the computational science students can enjoy the benefits of agent modelling and simulation during their study. This paper presents the work to guide the computational science and mathematical students in agent based simulation. It presents a method to transform the discrete mathematical model into individual based modelling and simulation. Consequently, the method is able to promote the agent technology to a wider audience. We proposed an extended version of AORE that can offer requirements elicitation support in environmental modelling, a computational science (CS) domain of study. The mechanism of AORE within a state of the art agent oriented methodology (AOM) is presented in details through a lake modelling case study in this paper. Also, a demonstration on simulating the case study in agent simulation, NetLogo, and comparison with the origin simulation results of lake model is elaborated to validate the feasibility of AORE.**

***Index Terms*— Agent modelling; Agent simulation; Mathematical model.**

I. INTRODUCTION

Mathematical modelling is one of the major courses taught in Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak (UNIMAS). During the course, the students are taught on various mathematical topics like differential equation, multivariable calculus, linear algebra and so on. The core study of Computer Science (CS) is adopting math in problem solving. Hence, mathematical formulation is the fundamental knowledge of CS, while MATLAB and Maple are among the well know simulation tools among the CS lecturers and students. On the other hand, there is an active research on individual modelling and simulation through agent oriented modelling and simulation.

The intention to learn the agent modelling and simulation seems to be a non-trivial task. There is neither course in this study nor guidelines or methods to shape the mathematical model into agent context. In order to bridge the learning gap on agent modelling and simulation among the CS and mathematical students, we proposed to adopt Agent Oriented Methodology (AOM) in this research. AOM is introduced to model a complex socio-technical system. It adopts the agent paradigm to model and develop the complex system which involve human, hardware, network and software [1][8][9]. The agent paradigm introduces notion of goal, role, organization, domain knowledge, social, norm, interaction, behaviour, motivation. It has been widely adopted in the domain of manufacturing, intelligent system and robotic, games [7]. This paper presents the work to guide the computational science and mathematical students in agent based simulation. It presents a method to transform the discrete mathematical model into individual based modelling and simulation. Our hypothesis is that AOM is able to bridge the learning gaps in the area of agent modelling and simulation among the CS and mathematical students in University. Consequently, the method is able to promote the agent technology to a wider audience.

The adoption of Agent Oriented Requirement Elicitation (AORE) is reported in this paper. The mechanism of AORE is presented in details through a lake modelling case study in this paper. Also, a demonstration on simulating the case study in agent simulation, NetLogo, is elaborated to validate the feasibility of AORE. Indirectly, this further partially validates the usefulness of AOM methodology in complex software system modelling and simulation development.

Works have been done to propose a methodology for computational science development processes [3][4]. In the work of [4], the processes for mathematical modelling are identification of model starting points; formulate the problem; create model solution; verification of develop model. In line with the needs of a systematic way on mathematical modelling, we propose AOM as part of the computational science development process, especially in agent modelling and simulation.

Section two presents the motivation case study on this project. It covers the lake model elaboration in general. This is followed by the elaboration of the proposed AOM for agent oriented mathematical model in Section three. Section four presents the walkthrough example to transform the lake mathematical model into agent context through eHOMER. Then, the modeller can proceed to agent simulation through NetLogo. Section five presents the simulation of the lake model through agent simulation platform, NetLogo together with the simulation results. The paper is concluded in section six.

II. MOTIVATION CASE STUDY

Eutrophication is an ecosystem response, caused by excess of input nutrients (notably phosphorus) comes from mainly agricultural activities and is a widespread and growing problem of lakes, rivers and coastal oceans. The Lake Model [2] is an ecological exploratory model or mathematical model where it is used for studying the connection between social behaviours and ecological dynamics in the area of Lake Eutrophication management. In this model, human and lake are represented as a set of differential equations. The model describes the ecosystem in terms of variable relationships of ecosystem elements. We will describe each of these ecosystem elements below.

The Lake is presented as:

$$P_{t+1} = (1 - s - h)P_t + I_t + rM_t f(P_t) \quad \text{with } f(P_t) = P_t^q/(m^q + P_t^q) \tag{1}$$

$$M_{t+1} = (1 - b)M_t + sP_t - rM_t f(P_t) \tag{2}$$

Other environmental entity to mediate the flow of phosphorus between human and lake is the soil (the land surrounding the lake). As such, the mathematical model formula for Soil is as follow:

The means of Inputs to lake (I) is the sum of soil erosion and direct inputs from intensive farmers. Hence, the model of I is as follow:

$$S_{t+1} S_t(1 - a_2F_2) - \mathrm{SF} + a_1F_1 \quad \mathrm{SF} = S_tL_2 \exp\left(z_t\sigma - \left(\frac{\sigma^2}{2}\right)\right) \tag{3}$$

$$I_t = L_1F_1 + \mathrm{SF} \tag{4}$$

where L_1 is the phosphorus amount not absorbed by Soil but directly flows into lake as a result of intensive farming.

On the other hand, the Human model are described in the following equations.

$$U_{t,t} = abs(E[R_{t,t-1}] - R_{t,t-1}) \quad \text{and} \quad E[R_{t,t}] = \frac{x_t\alpha_{1t} + (1 - x_t)\alpha_{2t}}{1 + \theta_{1t}E[P]^{\theta 1t}} \tag{5}$$

The most important variable that drives the farmers' cognitive processes is the uncertainty variable. Uncertainty, noted as absolute value only of U, can be quantified as the difference between expected returns, E[R] and the actual returns, R. The final process of human system is for farmers to decide which phosphorus management approach to commit for highest expected returns in future.

III. AOM FOR AGENT ORIENTED MATHEMATICAL MODEL

The AOM consists of four phases [1]. First, AORE is used to understand the user requirement and presented the answer within the agent context. This is followed by agent modelling in which it involves the agent modelling process taken from conceptual domain modelling, and platform independent design modelling. Finally, a platform specific design simulation modelling is conducted to simulate the agent model within a simulation platform like NetLogo.

- *Describe mathematical model in agent concepts through agent oriented requirement elicitation*
- *Real world conceptual domain modelling*
- *Agent simulation world modelling-platform independent modelling layer*
- *Agent simulation world modelling- platform dependent modelling layer*

Figure 1: AOM adoption for conceptualizing agent oriented mathematical model

This section presents the transformation process from mathematical model to agent oriented mathematical model through AOM. Figure 1 shows the transformation process that is adopted from AOM. First, the CS students or modeller need to describe the mathematical model in an agent way through AORE. Then, the modeller will involve in modelling the real world phenomena within the real world domain conceptualization modelling phase. This is followed by agent simulation world -platform independent modelling layer and agent simulation world- platform dependent modelling layer.

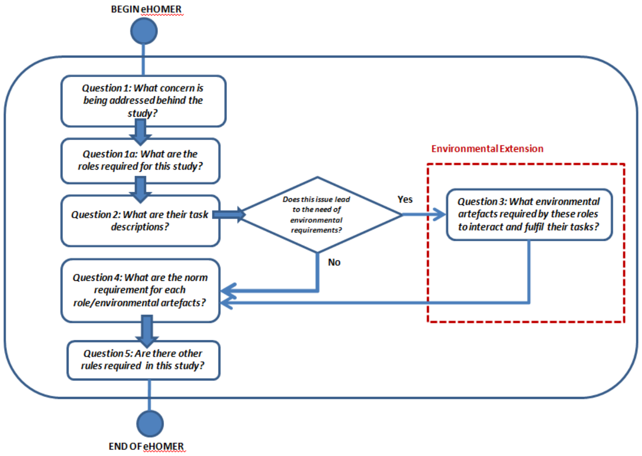


Figure 2: The process flow on the eHomer for scientific domain

We extend the Human Oriented Method for Eliciting Requirements (HOMER) in order to transform the mathematical model into agent context for later phase. HOMER is designed as the requirement elicitation method in AOM [1]. HOMER is an elicitation approach that is explicitly agent oriented. HOMER uses organization as its guiding metaphor for eliciting requirements where requirements are gathered by looking at the organizational metaphor in the problem area in terms of who will be tasked to solve (or partially solve) their problem. They are gathered in a way it is easily understood by clients/stakeholders regardless of their technical background. For example, "Who will be hired to handle this problem and what are the aspects of the problem will this person solve?" Through this metaphor, a problem pattern can be formed easily. A problem pattern is formed by first, asking which position required to solve this problem; then scope further by discovering more about the job description/rules this position have – asking "What is the purpose of this position? "What are the tasks need to be handled? "What knowledge and resource required for this person to handle his/her task? "Who does this person rely on to fulfil this job?" From the elicited answer, the discovered requirement can be easily translate into the goal model and role model, domain model from conceptual domain modelling phase to platform independent design phase and platform specific phase [5].

Figure 2 shows the extended HOMER (eHOMER) to elicit the mathematical model and turn into agent modelling and simulation project for later phases. In this case, the interviewee will use those questions to understand the mathematical model together with the domain expert. The outcome of the elicitation is the agent oriented requirement specification.

In general, elicitation process begins when interviewees (i.e. domain experts) are asked "What concern is being addressed behind the study?" as expressed in Question 1. The purpose of such question is to allow them to reveal their own problem. Next, we need to define the entity that will play certain role that constitutes this problem statement as stated in Question 1a. Once Question1a is answered, the elicitation of the role is taken to understand the "behavioural description" through Question 2. Question 3 elicits the knowledge about the environmental properties that supports the living roles. Environmental artefacts are represented as rocks, lake, river, land patch and so on. The environmental artefact can directly influence the social subsystem in environmental system. For example, farmer's fertilization practices directly affects natural resources is an example of interaction between social and natural subsystems. Environmental (i.e. lake) may deal with changes caused by the natural phenomena and it will influence the decision making of farmers. Question 3 is optional as some CS studies may not consider environmental aspects in their models. Therefore, between Question 2 and Question 3, we must ask this important question to our interviewee "Does this issue lead to the need of environmental requirements?" If the answer is yes, the interviewee will proceed to Question 3. Otherwise, the interviewee will proceed to Question 4 to elicit norm requirements. The norm requirement will govern the roles/environmental artefacts' tasks. Finally, Question 5 elicit the "rules that concerns about system or problem boundary". For example, "No other artefacts except soil, mud and water should be implemented for Lake Model study" or "size of lake area must not exceed 20 acres" or "carrying capacity must not exceed 10,000 units".

From the agent oriented requirement specification that is produced in the elicitation phase, we can proceed to agent modelling. In this case, the modeller can proceed to real world domain conceptual modelling and agent simulation world modelling. Due to the space limit, we will not present the elicitation phase and NetLogo simulation in details in this paper.

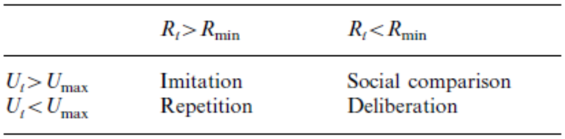
The model configuration in this study is based on the following steps. At Step a, we must define agent types, behaviours and rules based on our elicited requirements. Afterwards, in Step b, these agent specifications should be implemented as programming constructs for NetLogo simulation. For example, conceptualize agent as NetLogo "turtle", behaviour as "procedure", knowledge as "local/global variables". Once model is fully "written" in NetLogo, we must specify its parameter values in order to run simulation. At Step c, simulation should be configured according to the input agreed by experts or domain experts for experiment design. At Step d, simulation must be able to answer its objectives and questions. This cycle can be reiterated as many times until stakeholders are satisfied. At Step e, iterated prototypes will become the final product upon decision maker's approval.

IV. TRANSFORMING LAKE MATHEMATICAL MODEL INTO AGENT CONTEXT THROUGH EHOMER

Use SI as primary units. English units may be used as secondary units (in parentheses). For example, write "15 Gb/cm^2 (100 Gb/in^2)." An exception is when English units are used as identifiers in trade, such as "3½-in disk drive." Avoid combining SI and CGS units, such as current in amperes and magnetic field. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity in an equation. Table 1 shows partially elicited answer or specification upon the elicitation process through eHOMER. Due to the space limit, we only present the specification for a human actor, farmer. It capture how a farmer look like and behave in eutrophication management. Question 1a, modeller needs to discover this "Farmer" role further by requesting role attributes with greater details. Question 2 below presented the elicited Farmer's purpose/goal, tasks, task constraint, interaction protocol, resource requirement, knowledge items and adaptive knowledge, ranging from general information to mathematical representations. There are two environmental entities that represent natural subsystem in Lake Model: Soil and Lake. In eHOMER perspective, these elements can be identified as environmental "artefacts". Similar to our elicitation approach in Table 1 below, we have enquired ecological requirements by using Question 3 to elicit "task description" in these "artefacts". Finally, we concluded our elicitation by answering the remainder questions in eHOMER, Question 4 and 5, to elicit "code of behaviour" in farmer, soil and lake and their environment "boundary rule".

Table 1
Partially elicited answer or specification upon the elicitation process through eHOMER

1	*What concern is being addressed behind the study?*	Solve the problem of understanding Lake Eutrophication in ecosystem management
a)	*If you were to solve the problem of understanding Eutrophication, which entities do you require?*	farmer

<table>
<tr><th colspan="2"><i>2. For each entity, we need to collect a “task description”:</i></th></tr>
<tr><td>a)</td><td>At higher level, the purpose of farmer is to allow the observation of the impact of agricultural practices towards environment – the farmer’s management of phosphorus usage for fertilization.
As an observed role, the farmer’s sole purpose is to make money. The farmer gains income by managing a farm (produces crops, maintains/sustains crops and sells crops). To sustain/maintain crops, the farmer has to perform phosphorus fertilization to sustain crops and increase crop yields.</td></tr>
<tr><td>b)</td><td><u>Tasks</u>
<i>Manage farm</i>
Sub tasks for “<u>Manage farm</u>”
• Choose intensive/conservative phosphorus management initially
• Move around*
• Supply phosphorus to water and soil
• Remove phosphorus from soil
• [etc.]
<u>Task constraints/restrictions</u>
i. “<i>Add phosphorus to water and soil</i>” when “<u>adopt intensive phosphorus management</u>”
ii. “<i>Remove phosphorus from soil</i>” when “<u>adopt conservative phosphorus management</u>”
iii. Farmer can only have ONE phosphorus management at a time – cannot become intensive and conservative at the same time.
<i>iv.</i> Use R equation from [Lake Model paper] as calculation formula for “Generate income” task – <i>see Formulas section below</i>
v. Constraint to trigger Adapt – must require the measuring of degree of farmer’s uncertainty (U) and satisfaction of return (<i>comparing actual returns against targeted returns</i>) as inputs for adaptation. Uncertainty is quantified as difference between <i>expected returns</i> and the <i>actual returns</i> of the decision made in previous year – <i>see Formulas section below</i>
vi. Constraint to trigger Adapt – there are several types of decision making methods at disposal. Switch of these skills MUST based upon level of uncertainty and satisfaction of returns. For example, deliberate when uncertainty and level of returns are low. <i>Figure 1</i> below lists the conditional statements of various decision making methods.
vii. Constraint to trigger Adapt – must occur either through self initiation (<i>Deliberate</i>) or by interacting with others (<i>Social Comparison</i> and <i>Imitation</i>). Cannot adapt through self initiation and interaction simultaneously.
viii. Constraint to trigger Adapt – ONLY one decision can be made per year.
ix. Repeat same phosphorus management strategy if not going to deliberate and socially compare or imitating others (<i>see Repetition in Figure 1</i>)
<u>Formulas</u>
<i>Actual returns (R)</i>
$U_{i,t} = abs(E[R_{i,t-1}] - R_{i,t-1})$
<i>Uncertainty(U)</i>
$U_{i,t} = abs(E[R_{i,t-1}] - R_{i,t-1})$
<i>Expected returns (E[R])</i>
$E[R_{i,t}] = \frac{x_t \alpha_{1t} + (1 - x_t)\alpha_{2t}}{1 + \theta_{1t} E[P]^{\theta 1t}}$

<table><tr><th></th><th>$R_t > R_{\min}$</th><th>$R_t < R_{\min}$</th></tr><tr><td>$U_t > U_{\max}$</td><td>Imitation</td><td>Social comparison</td></tr><tr><td>$U_t < U_{\max}$</td><td>Repetition</td><td>Deliberation</td></tr></table>
Figure 3: The classification of decision making skills with U_{max} and R_{min} as threshold values and U and R as observed variables. Diagram adopted from [Janssen, 2001].</td></tr>
<tr><td>c)</td><td>Other farmers</td></tr>
<tr><td>d)</td><td>Other farmers</td></tr>
<tr><td>e)</td><td>Phosphorus (for fertilization)
Returns (to trigger Adapt)</td></tr>
<tr><td>f)</td><td>When farmer performs “Generate income”, the level of returns may <i>change over time</i>. This is due to due to environment factors which can directly impact the level of returns: random weather influence and quality of lake water. The change in level of returns directly affects the level of uncertainty and returns satisfaction.
As a result, the farmer needs to trigger “Adapt”. Based on the conditional statements in Figure 1 for choosing decision making methods in <i>Task Constraints/Restrictions</i> section shown in <i>2 (b)</i> above, the farmer “<i>Deliberates</i>” his/her own decision, which results in shifting from one phosphorus practice to the other with the goal on maximizing profit in future.
[etc.]</td></tr>
<tr><td>g)</td><td>Before interacting with other farmers, the farmer must perform “generate income” first. Same as the process in 2(g) above, level of returns changes over time, affecting level of uncertainty and returns satisfaction, resulting in trigger of “Adapt”. [etc.]</td></tr>
<tr><td>h)</td><td>The farmer can become a “<u>beacon”</u> for other farmers to “adapt” and follow the same process as in 2(h).
This farmer can influence others by inspiring others to “compare socially” (i.e. when this farmer go intensive, other uncertain farmers with same ability and returns level will follow his/her direction).</td></tr>
</table>

Once farmer requirements are completely elicited, we move on to next section, Question 3 – is environmental properties required in this model? As the title says, section for environmental elicitation is MANDATORY for this model development. In [2], there are two environmental entities that represent natural subsystem in Lake Model: Soil and Lake. Finally, we need to collect description of codes of behaviour for Farmer role, Soil and Lake entities. We will conclude our elicitation by filling in eHOMER’s Question 4 and Question 5 with the following information.

4. We need to collect description of codes of behavior for all/each entity.	
a)	Farmer, Lake and Soil cannot assume other roles but themselves only. Farmer must stay on Soil at all times. No Farmer can enter the Lake.
b)	For f**armers** • Must not leave the environment at all times. • Population size of farmers must remain the same at all times. • Must not become intensive and conservative at the same time. For Soil and Lake • There can be only ONE Lake and ONE Soil exists at any given time. • Soil and Lake must not change their tasks at all times
c)	***Part 1 (Farmer), Part 2 (Soil) and Part 3 (Lake)*** below describes the chain of tasks performed by each entity. **<u>PART 1: Farmer</u>** For **Farmer**, the sequence of tasks are in the following: **Step 1.** Initially, select **one of phosphorus management** for fertilization (only in the beginning). **Step 2.** Manipulate environment, i. If flagged as *intensive farmer*, **Supply phosphorus to water and soil**, ii. Otherwise, **remove phosphorus from soil** when choosing conservative approach. **Step 3. Calculate returns/income** to generate **Actual returns**. **Step 4.** Compare **Actual returns** with target returns (**minimum returns**). **Step 5**. Calculate **uncertainty**. **Step 6.** Based on results from **Step 4 and 5**, check suitable decision making skill (see Figure 1 conditional table in Q2b). **Step 7.** If satisfied with returns and not uncertain, go back to **Step 2.** Otherwise, do **Step 8.**

Step 8. Trigger **Adapt** – switch phosphorus management approach either by

- Self – Deliberation, or…

Interaction – Social Comparison or Imitation
Repeat **Step 2** to start the cycle again.

PART 2: SOIL

The sequence of Soil tasks are in the following
Step 1: **receive phosphorus waste input** from intensive farmers, then store inside soil. This will increase phosphorus concentration in Soil.
Step 2: **remove soil phosphorus** via conservative farming. This will reduce phosphorus concentration in Soil.
Step 3: **transport phosphorus** to lake when soil erosion occur. During this step, phosphorus concentration in Soil reduces.
Step 4: **Calculate Soil phosphorus level**
Repeat Step 1 to start the cycle again.

PART 3: LAKE

The sequence of Lake tasks are in the following
Step 1: Get phosphorus inputs from intensive farmer and soil erosion.
Step 2: Manipulate phosphorus

- Sedimentation
- Recycle
- Bury
- Flush

Step 3: Calculate water phosphorus level
Repeat Step 1 to start the cycle again.

Role connections

- Farmer Step 2 is linked to Soil Step 1 and 2
- Farmer Step 2 is linked to Lake Step 1
- Farmer Step 3 is linked to Lake Step 3

The following are model assumptions in [Lake Model]:

- *Each cycle takes one year to complete, i.e. farmer adapts once a year.*
- *The model assumes that Lake, Soil and Farmer perform tasks in parallel.*

5. What other rules must be observed in this environment?
Must not include other environmental entities or living entities in this environment.

V. AGENT ORIENTED LAKE MODEL FOR SIMULATION IN NETLOGO

In this section, we present how mathematical elements from human and lake differential equations that are transformed into the agent oriented elicitation requirement as can be mapped directly to NetLogo programming constructs.

Table 2
Simplify NetLogo based lake model

A. Agent classes declaration

```
//...
```

B. Setting behaviour flow (in "run" button of NetLogo)

```
to run
    ask intensive_farmer[
         add_phosphorus_to_lakeandsoil
         generate_returns
         make_decision]
    ask conservative_farmer[
        remove_phosphorus_from_soil
         generate_returns
         make_decision  ]
    ask Lake  [
        process_phosphorus ]
  end
end  ;; end of "run" procedure
```

Table 3
NetLogo parameter: Setting value of R_{min} and U_{max} to low values

Variables	Values
Initial number of Intensive Farmer (F1)	0
Initial number of Intensive Farmer (F2)	20
z	0.5
R_{min}	5
U_{max}	0.5
Initial phosphorus concentration in soil (S)	26
Initial phosphorus concentration in mud (M)	16
Initial phosphorus concentration in water (P)	0.2
Time steps (as years)	100 years

NetLogo [6] is a multi-agent simulation platform for simulation complex phenomena. Table 2 shows part of the NetLogo based lake model. In brief, the requirements from section 4 can be directly mapped to NetLogo programming constructs. Farmer and Lake Agents (Question 1 and Question 3) are assigned as NetLogo turtle breed – breed [farmer] and breed [lake]; Agent behaviours and rules (Question 2, Question 3, Question 4 and Question 5) are assigned as procedures for turtle; Variables (Question 2 and 3) can be assigned as local variable for specific breed type (i.e. recycling rate and sedimentation rate for Lake Agent; knowledge and physical ability for Farmer agent) or shared knowledge (global variable) such as phosphorus level in water, P, to be used by both Lake (to calculate phosphorus concentration in water) and Farmer agents (calculate returns based on quality of water); The equations (from task constraints in Question 2 and 3) are implemented as formula within NetLogo procedures – i.e. the formula to "calculate phosphorus concentration in water" in process phosphorus procedure by Lake agent, based on [2] P equation. Same goes for M, S and R for mud, soil and farmers respectively.

An experiment is conducted to simulate the lake model in NetLogo. The simulation configurations are shown in Table 3. We assign NetLogo parameter in table 3 in order to investigate the model behaviour upon using low returns target, Rmin (minimum returns) and tolerance level Umax values (maximum uncertainty. Initially, all farmers use phosphorus conservatively. Figure 4 displays NetLogo simulation output for phosphorus inputs, concentration of phosphorus in soil, water and mud and overall farmer's returns in 100 years upon setting Rmin and Umax to low values.

Based on the results from Figure 4, farmers will remain adopting conservative approach due to low target in returns and low maximum uncertainty tolerance, leading to farmer imitating others who all practiced conservative approach.

Figure 4 shows the reduction of phosphorus inputs to zero due to absence of intensive phosphorus users. As a consequence, the concentration in water also decreases at the same rate and the concentration in mud declines fast due to permanent burial. Concentration in soil decreases due to all farmers selecting conservative approach. Economically, farmer returns will remain stable at quite high level.

Despite our version did not produce plots with identical pattern as the original, our version does correspond to the same narrative in [2]. Looking at mud and soil perspective; decline of phosphorus concentration is plotted as curve in NetLogo whereas results in [2] revealed this as straight line. Nonetheless, the slopes in both models' plots appeared to be in the same direction (have negative slopes), showing that both experiments do elicit the same behaviour – When majority chooses conservative, the level of phosphorus inputs to mud and soil decreases significantly.

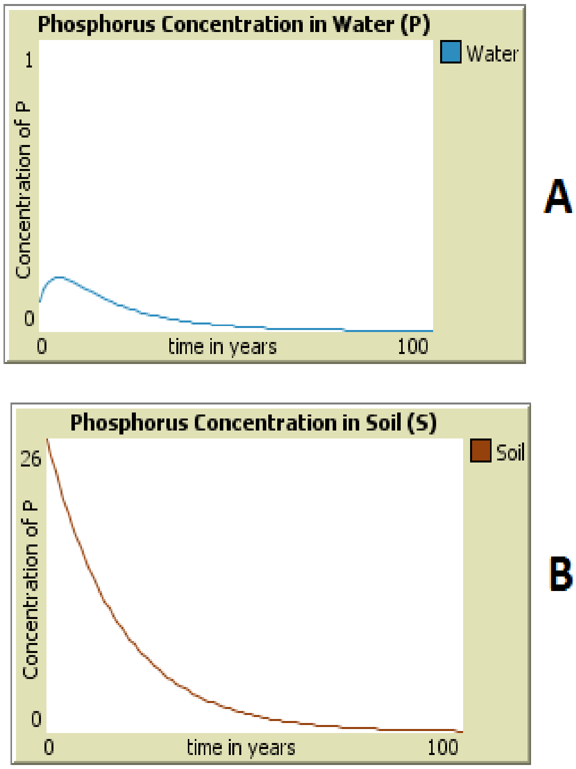


Figure 4: The level of phosphorus inputs, phosphorus concentrations in soil (S), water (P) and mud (M) and overall farmers' returns in NetLogo in 100 years (*Rmin = 5, Umax= 0.5, z = 0.5*)

VI. CONCLUSION

We present the adoption of AORE for transforming the mathematical model into agent context. Then, the modeller can proceed to agent modelling and simulation. Through series of eHOMER questions, we can describe the system in agent oriented perspective by identifying elements in their mathematical models that correspond to specific agent oriented characteristics (role, task, constraints and rule of behaviour) attached in each question. From there, the modeller can proceed to agent modelling and agent simulation. From the case study, we demonstrate that working on agent modelling and simulation is not a trivial task. By following the systematic steps that are described in the experiment, the modeller is able to transform the mathematical model into agent modelling and simulation. Indeed the model that is produced in our approach is able to derive a “similar” pattern during the simulation. Much work is needed to complete the AOM adoption for agent oriented computational science modelling and simulation. Also, empirical study will conduct to validate the AOM as a methodology for learning agent modelling and simulation among computational science and mathematical students.

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