The inclusion of marginalized communities in stakeholder engagement for managing human-water systems: The case of Maya Peoples in the Lake Atitlán Basin

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Abstract

The study of human-water systems requires unconventional sources of data that enhance our understanding of interactions between socio-economic and biophysical components. Stakeholder engagement can (1) facilitate the conceptualization of human-water systems through participatory modelling (PM) and (2) lead to the identification of socially acceptable and environmentally desirable solutions in water resources management. However, the implementation of many stakeholder engagement activities remains biased, often treating communities as homogeneous units and failing to perceive the different needs and capabilities within a society. This might lead to the exclusion of key actors, particularly stakeholders associated with marginalized communities.

A participatory model-building framework (PMBF) that facilitates the incorporation of marginalized stakeholders – associated with low literacy levels, who are relatively powerless, and/or associated with marginalized languages – is proposed. The method aims to (1) conceptualize systems models using multi-level storylines and (2) inform solutions and best management practices (BMPs). It is underpinned by the Multi-level Perspective (MLP) framework (Geels, 2002). A case study was carried out in the Lake Atitlán Basin (LAB), Guatemala, to understand (1) the relationships governing the lake's eutrophication problem and (2) solutions and barriers to their implementation. The PM process incorporated participants from the Mayan community, having diverse literacy levels and emerging from three linguistic backgrounds (Kaqchikel, Tz'utujil, and K'iche').

The suggested method facilitated the effective involvement of marginalized stakeholders. Additionally, it (1) helped develop an understanding of mechanisms causing the problem, (2) facilitated dialogue between indigenous and non-indigenous communities, (3) elicited solutions targeting the system's leverage points, and (4) helped identify caveats and barriers of some proposed solutions. The process produced three submodules: agriculture, wastewater and tourism, and environmental awareness. Each submodule represented socioculturally-specific relationships governing nutrient discharge mechanisms. The identification of such relationships

aids in the development of well-targeted policies and BMPs. Moreover, the process allowed the delineation of implications on policymaking from stakeholders' elaborations on solutions and barriers. Policy implications covered inclusive stakeholder engagement, sustainable agricultural practices, wastewater treatment planning, and environmental education.

Résumé

L'étude des systèmes hydriques humains nécessite le recours à des sources de données non conventionnelles qui permettent de comprendre les interactions entre les composantes socio-économiques et biophysiques. L'engagement des parties prenantes peut (1) faciliter la conceptualisation des systèmes d'eau humain par la modélisation participative (MP) et (2) conduire à l'identification de solutions socialement acceptables et écologiquement souhaitables dans la gestion des ressources en eau. Cependant, la mise en œuvre de nombreuses activités d'engagement des parties prenantes reste biaisée, traitant souvent les communautés comme des unités homogènes et ne percevant pas les différents besoins et capacités au sein d'une société. Cela peut conduire à l'exclusion d'acteurs clés, en particulier des parties prenantes associées aux communautés marginalisées.

Un cadre participatif de construction de modèles qui facilite l'intégration des acteurs marginalisés - associés à de faibles niveaux d'alphabétisation, qui sont relativement impuissants, et/ou associés à des langues marginalisées - est proposé.La méthode vise à (1) conceptualiser des modèles de systèmes en utilisant des scénarios à plusieurs niveaux et (2) à informer les solutions et les meilleures pratiques de gestion. Elle est étayée par le cadre de la perspective multi-niveaux (Geels, 2002). Une étude de cas a été réalisée dans le bassin du lac Atitlán au Guatemala, afin de comprendre (1) les relations régissant le problème d'eutrophisation du lac et (2) les solutions et les obstacles à leur mise en œuvre. Le processus de MP a intégré des participants de la communauté maya, ayant des niveaux d'alphabétisation divers et issus de trois milieux linguistiques (Kaqchikel, Tz'utujil, et K'iche').

La méthode proposée a facilité la participation effective des parties prenantes marginalisées. En outre, elle (1) a permis de mieux comprendre les mécanismes qui sont à l'origine du problème, (2) a facilité le dialogue entre les communautés autochtones et non autochtones, (3) a suscité des solutions ciblant les points de levier du système, et (4) a aidé à identifier les réserves et les obstacles de certaines solutions proposées. Le processus a produit trois sous-modules: l'agriculture, les eaux usées et le tourisme, et la sensibilisation à l'environnement. Chaque sous-

module représentait les relations socioculturelles spécifiques régissant les mécanismes de rejet des nutriments. L'identification de ces relations aide au développement de politiques bien ciblées et de meilleures pratiques de gestion. En outre, le processus a permis de délimiter les implications sur l'élaboration des politiques à partir des élaborations des parties prenantes sur les solutions et les obstacles. Les implications politiques ont porté sur l'engagement inclusif des parties prenantes, les pratiques agricoles durables, la planification du traitement des eaux usées et l'éducation à l'environnement.

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Format of Thesis

A manuscript-based MSc. thesis must include:

a) A detailed table of contents
b) An abstract in English and French
c) An introduction the describes the purpose and objectives of the research
d) A literature review (in addition to that included in the manuscript(s))
e) The text of one or more manuscripts
f) A final conclusion and summary

1. As manuscripts for publication are frequently very concise documents, where appropriate, additional material must be provided (e.g.,in appendices) in sufficient detail to allow a clear and precise judgment to be made of the importance and originality of the research reported in the thesis.

2. In general, when co-authored papers are included in a thesis the candidate must have made a substantial contribution to all papers included in the thesis. In addition, the candidate is required to make an explicit statement in the thesis as to who contributed to such work and to what extent. This statement should appear in a single section entitled "Contributions of Authors" as a preface to the thesis. The supervisor must attest to the accuracy of this statement at the doctoral oral defense. Since the task of the examiners is made more difficult in these cases, it is in the candidate's interest to clearly specify the responsibilities of all the authors of the “co-authored papers”.

Contributions of Authors

Chapter 3 of this thesis has been published in the Hydrological and Earth System Sciences (HESS). Chapter 4 will be submitted to a peer-reviewed journal. Both chapters were presented at several conferences. The author of this thesis prepared both manuscripts, designed the stakeholder engagement process, conducted field work, and analyzed the results using systems thinking and qualitative methods in Grounded Theory. Prof. Adamowski was the thesis supervisor and provided advice throughout the process.

Dr. Julien Malard at the Department of Bioresource Engineering, McGill conducted field work and provided feedback on the first and second manuscript. Marco Ramírez, researcher at Instituto de Agricultura, Recursos Naturales y Ambiente (IARNA), Guatemala made significant contributions to the field work. Dr. Héctor Tuy, researcher at Instituto de Agricultura, Recursos Naturales y Ambiente (IARNA) provided advice and feedback on the field work. Dr. Wiestke Medema, researcher at the Depatmenr of Bioresource Engineering, McGill, participated in the review of the first manuscript. Emma Anderson, MSc. candidate at the Department of the Bioresource Engineering, McGill, edited the second manuscript and contributed to its review process. Mohammadreza Alizadeh participated in the review process of the second manuscript.

List of publications and scientific presentations

A. Thesis components that have been published or to be submitted for publication in peer-review journals:

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Bou Nassar, J., Malard, J., Adamowski, J., Ramírez Ramírez, M., Tuy, H.: The use of interdisciplinary storylines to ensure the inclusiveness of marginalized stakeholders in participatory sociohydrological modelling: A case study in Tz'olöj Ya', Mayan Guatemala, EGU General Assembly 2020, Online, May 4–8 2020, EGU2020-11178, https://doi.org/10.5194/egusphere-egu2020-11178. (Oral presentation)

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Julien Malard, **Jessica Bou Nassar**, Jan Adamowski, Marco Ramírez Ramírez, Héctor Tuy. Storytelling and participatory system dynamics modelling for water resources management in

Lake Atitlán of Tz'olöj Ya' in Mayan Guatemala. EGU General Assembly 2020, Online, May 4–8 2020, EGU2020-11483, https://doi.org/10.5194/egusphere-egu2020-11483. (Oral presentation)

Marco Ramírez, **Jessica Bou Nassar**, Julien Malard, Héctor Tuy Yax, Jan Franklin Adamowski. Proposition d'une méthodologie inclusive de toutes les connaissances pour le développement de modèles hydrologiques : étude de case du lac Atitlán. *87^e Conrès de l'ACFAS 2019*, Gatineau, Québec, Canada. (Oral presentation)

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List of Abbreviations

PM	Participatory modelling
PMBF	Participatory model-building framework
BMP	Best management practices
MLP	Multi-level Perspective
LAB	Lake Atitlán Basin
CLD	Causal loop diagram
FCM	Fuzzy cognitive map
SAS	Story and Simulation
WWT	Wastewater treatment
WWTP	Wastewater treatment plant

Chapter 1: Introduction

Water resources management addresses complex problems, underpinned by intercalations between biophysical and socio-economic components. Conventional modelling tools, such as physical-based models, may be ill-suited for investigating such problems (Malard et al., 2017), as they often exclude dynamic interactions between environmental and socio-economic processes or consider socio-economic variables as exogenous factors (Inam et al., 2017). Moreover, conventional models may reinforce expert-oriented and externally imposed research, and disregard community participation, which could lead to lack of stakeholder trust in the models and decisions based on them (Cooke & Kothari, 2001). Water resources management requires transformative, interdisciplinary methods, such as participatory modelling (PM) of human-water systems, capable of addressing these challenges.

1.1. What are the barriers to inclusive PM?

Participatory modelling has triggered changes in typical model building, packaging, and disseminating processes, to better accommodate participation of stakeholders from diverse sectors (Voinov et al., 2016). However, many PM processes are not yet cognizant of diversity and differentiation within a society, and tend to treat communities as homogeneous units having similar needs, capabilities, and interests (Guijt & Shah, 1998). In light of this, three main barriers to inclusive PM have been identified. First, many PM activities may require reading, writing, or professional expertise and would fail to effectively engage stakeholders with low literacy (Maynard & Jacobson, 2017). Second, participatory methods might not consider the mitigation of unhealthy power dynamics, which might yield decisions that are labelled ‘participatory’ but are, in fact, reinforcing the interests of those already in power (Cooke & Kothari, 2001). Third, conventional PM processes might not accommodate multilingual participation, which would reinforce the marginalization of those speaking underrepresented languages.

Even if marginalized stakeholders choose to engage in the PM process, failing to characterize and address relevant barriers effectively prevents their full participation. In other words, in some cases, marginalized stakeholders could be figuratively rather than effectively participating, which results in the 'illusion of inclusion' (Few et al., 2007). If stakeholders are not effectively participating due to barriers such as low literacy, lack of expertise, unhealthy power dynamics, or language barriers, they are likely to be underrepresented in the PM results, conclusions, and final decisions (Mease et al., 2018; Sutton, 2006; Turner & Weninger, 2005).

1.2. Why is inclusion important?

The inclusion of marginalized communities is crucial for sustainable water resources management for several reasons. First, inclusive stakeholder engagement is necessary to capture a holistic perspective of the problem and inform culturally relevant solutions that can be implemented across stakeholder groups (Mease et al., 2018). Second, marginalized communities play important roles in water resources management, and can make significant contributions to PM results (Colfer and Dudley, 2011). For example, many marginalized stakeholders are heavily involved in agriculture and aquaculture and can inform practical solutions that could be promoted and adopted by businesses (Hassanzadeh et al., 2019). Third, socially and economically marginalized stakeholders are often the most vulnerable to environmental change (Butler & Adamowski, 2015; Ford et al., 2020). These communities should have the right to be involved in decisions that impact their livelihoods and be represented in participatory decision-making schemes (Kiker et al., 2005). Fourth, inclusive participation results in sustainable management. While politicians and corporations are often interested in short-term benefits, communities, including marginalized ones, tend to focus on long-term solutions and conservation for future generations (Colfer, 2005).

1.3. Research objectives

The main focus of this thesis is the implementation of a participatory method that facilitates the inclusion of marginalized stakeholders, who are: (1) less literate, (2) relatively powerless, and/or (3) associated with marginalized languages, in the context of human-water systems. A case study of Mayan communities was conducted in the Lake Atitlán Basin (LAB), Guatemala and included: (1) relatively powerless stakeholders, (2) individuals associated with different literacy ranges, and (3) participants associated with three different marginalized languages: Kaqchikel, Tz'utujil, and K'iche'.

The goal of the study was to investigate the eutrophication problem in Lake Atitlán from a holistic perspective and empower community-based decision-making.
The specific objectives of this thesis are:

1. Develop a conceptual PM framework that: (1) is inclusive by design and (2) can inform and conceptualize human-water systems.
2. Suggest a framework for the implementation of the inclusive PM process that: (1) facilitates the participation of less literate stakeholders, (2) reduces unhealthy power dynamics, and (3) accommodates a multilingual context.
3. Implement the inclusive process in LAB to understand the causes and consequences of eutrophication in LAB and identify solutions and barriers to their implementation.
4. Evaluate the validity of the process with respect to its ability to: (1) incorporate effective participation of marginalized stakeholders, (2) induce a dialogue, (3) integrate diverse perspectives, (4) facilitate model-conceptualization, (5) produce descriptions of relevant human-water feedbacks, (6) extract solutions and barriers to their implementation.

1.4. Contributions

This research is innovative in two main ways:

1. It develops and implements a PM process that is explicitly inclusive by design. To the author's knowledge, the inclusion of participants who are less-literate, relatively powerless, and associated with marginalized languages, from developing the conceptual framework of a PM through to its implementation, has not previously been done in studies of water resources management.
2. The process is based on the integration of storylines with causal loops diagrams (CLDs) and a Multi-level perspective (MLP) framework developed by Geels (2002). Although the

PM framework is built on CLDs, storytelling, and the MLP framework, it integrates the three approaches uniquely.

There are two main contributions to practical knowledge:

1. A holistic understanding of the diverse dimensions of the eutrophication problem in LAB and a comprehensive list of policy implications.
2. Insights into the challenges of inclusive stakeholder engagement, derived during the implementation of the PM activity. These lessons could inform future improvements of inclusive stakeholder engagement processes.

1.5. Thesis outline

Chapter 2 reviews literature related to different participatory methods and focuses on storyline development in the contexts of linear and systems modelling. The first manuscript (Chapter 3) presents a method that integrates MLP with storylines and CLDs and a stepwise process for the implementation the method. The results of the activity were analyzed using systems thinking. The second manuscript (Chapter 4) analyzes the results of the activity using qualitative methods in Grounded Theory, highlighting outputs that have not been addressed in Chapter 3. Chapter 5 outlines the conclusions and summary, and Chapter 6 discusses the contributions of the thesis, the limitations of the research, and recommendations for future work.

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Chapter 2: Literature review

2.1. Participatory methods for data Collection and model conceptualization

The use of participatory modelling in recent years has resulted in the development of a broad range of participatory methods for different stages of the modelling process such as scoping, goal-setting, data and knowledge acquisition, model conceptualization, model formulation and quantification, and presentation and dissemination of results (Voinov et al., 2018; Voinov & Bousquet, 2010). The research objectives of this study require effective participation in the participatory model-building process, allowing stakeholders to provide model concepts, processes, and interactions between corresponding processes, among other forms of model inputs. Specifically, there is a need for methods to (1) elicit data and knowledge from stakeholders and (2) allow participants to effectively contribute to model conceptualization. The study requires an approach compatible with participatory activities that:

1. Ensure the inclusion of typically marginalized illiterate participants, and therefore require neither reading nor writing skills (Cooke & Kothari, 2001; Maru et al., 2009).
2. Are practical and applicable in multilingual contexts (Mondada, 2012).
3. Allow and encourage high-level stakeholder engagement (Reed, 2008).
4. Can be conducted in group sessions allowing discussions between participants of different perspectives when necessary (Evans, 2006).
5. Can be conducted in one-on-one sessions in order to avoid unhealthy power dynamics (Halbe et al., 2015).
6. Guide participants rather than restrict and constrain them (Butler & Adamowski, 2015).
7. Provide a detailed portrayal of model inputs in order to ensure effective inclusion of ideas elicited from stakeholders.
8. Deliver information and knowledge for model inputs in a non-ambiguous manner (e.g.,not prone to misinterpretation) (Dorasamy, 2017).

A systematic review that examines the participatory approaches encompassed by the literature with particular attention to the two specific components mentioned above, of the participatory model-building process required in this study, ((1) data and knowledge acquisition and (2) model conceptualization) is presented below and summarized in tables 1 and 2. Each approach is described, followed by a corresponding justification as to why or why not it was adopted in this study.

2.1.1. Fuzzy cognitive mapping

Fuzzy cognitive maps (FCMs), first developed by (Kosko, 1986), are made up of nodes (also known as concepts) and causal links between nodes. Each link is associated with (1) a fuzzy weight, ranging from 0 to 1, indicating the strength of the corresponding causal relationship, and (2) a sign, either positive or negative, indicating whether the relationship is direct or indirect, respectively (Jetter & Kok, 2014). Although FCMs have been successfully applied in participatory modelling research (Raffaele Giordano et al., 2017; Özesmi & Özesmi, 2004), their construction requires participants to have reading and writing skills, therefore excluding participants with a low level of literacy. Moreover, FCMs are only semi-quantitative (Kok, 2009), and since the aim of this study is to portray quantitative results of plausible futures, the qualitative results produced by FCMs would present only a limited understanding of future developments. This reduces the model's potential in confidently supporting decision-making (Ernst et al., 2018; Trutnevyte et al., 2014) and the FCM method is therefore ill-suited for this research.

2.1.2. Rich Pictures

The Rich Pictures approach uses pictures and symbols in an unstructured way to capture flows of information, communication, and human activity (Berg & Pooley, 2013). The method aims to accommodate participatory activities in culturally diverse, less-literate, and multilingual communities, and has been used in participatory research (Berg & Pooley, 2013; Colfer & Dudley, 2011; Voinov et al., 2018). However, the use of symbolism and pictures yields ambiguity and can be misinterpreted (Lewis, 1992). Hence, the method is ill-suited for portraying the complexity of, and details contained by, socio-environmental processes.

2.1.3. Questionnaires

Questionnaires consist of a set of written or printed questions, developed for the purpose of a specific survey or study. Questionnaires have been used by many authors in participatory research (Beall et al., 2011; Hussien et al., 2017; Voinov et al., 2016). Nevertheless, questionnaires are not compatible with the methods required for this study. Questionnaires are not designed to be conducted in groups, and thus do not encourage interactions between participants. Moreover, they tend to restrict the ideas and thoughts of participants. Questionnaires also do not allow for an iteration of interactions between researchers and participants, and therefore only induce low-level stakeholder engagement in the model-building-process.

2.1.4. Games

Participatory research has recently incorporated games for elicitation of data and knowledge from stakeholders. Role playing games, for example, allow participants to stand in different positions and trigger their reactions to studied issues. These provide researchers with patterns of decisions typically taken by diverse agents regarding the investigated issue (Guyot & Honiden, 2006; Shelton et al., 2018). These games, however, cannot be carried out in individual sessions and are not practical in multilingual contexts. The method is therefore not appropriate for this research study.

Fishbowl is a game that ensures inclusiveness of illiterate participants within the data elicitation activity. In this game, experts are seated in a curved space, at which they speak for a couple of minutes about the studied issue. Afterwards, an empty seat is placed in the open-curved space, facing the group of experts. Anyone in the audience can take the seat and speak or question the experts for one minute (Colfer and Dudley,2011).

Line on the Floor is a game typically used when opinions of participants are needed. Participants having a certain opinion are asked to stand on one side of the line while others having a different opinion are requested to stand on the other side (Colfer and

Dudley,2011). Neither method takes unhealthy power dynamics, typically encountered in activities carried out in marginalized communities, into consideration. Moreover, they allow brief engagement of participants in the model-building activity and fail to elicit detailed portrayal of requested knowledge. Therefore, Fishbowl and Line on the Floor are not appropriate for this study.

2.1.5. Causal loop diagrams (CLDs)

A CLD contains variables connected by links indicating causal relationships. The connectors are either positive or negative implying direct or inverse correlations between linked variables, respectively. Within these diagrams, closed loops have either a reinforcing or balancing nature, and aid in understanding the dynamics of the represented structure. CLDs include multicausality, delays, and non-linearity, and can be converted into stocks and flows for quantification. Also, they are compatible with systems models. Stakeholder-created CLDs have been previously applied in participatory research (Inam et al., 2015, 2017; Perrone et al., 2020). However, their development often requires reading and writing skills; less-literate participants might perceive them as complex and might not be comfortable constructing or understanding them. Therefore, stakeholder-created CLDs are ill-suited for involving less-literate participants in a participatory model-building activity. In some studies, CLDs were processed by researchers from interviews or focus groups, ex-post (Enteshari et al., 2020; R. Giordano et al., 2020; Pham et al., 2020; Santoro et al., 2019). This method might increase researcher influence on the model, thereby producing ambiguous statements prone to misinterpretation (Kim & Andersen, 2012).

2.1.6. Storytelling

Storytelling involves the development of storylines in the form of narrative texts and has been used in many participatory studies (Guhathakurta, 2002; Moezzi et al., 2017). Since the method requires neither reading nor writing skills, it is compatible with the involvement of less literate stakeholders in participatory activities. Storylines can be developed in individual sessions, which are suitable for participatory activities in marginalized communities where unhealthy power dynamics exist. Storytelling can also be carried out in group sessions, which are necessary when discussions between participants of different perspectives are required. Moreover, the method encourages high-level stakeholder engagement since elicited storylines not only provide researchers with knowledge and information but also aid in conceptualizing the model. Additionally, storytelling allows the portrayal of the studied issue in detail and with reduced ambiguity.

According to Table 2 and the above-mentioned elaboration, storytelling is a participatory method appropriate for this study. In addition to meeting all the criteria listed in Table 1, storylines are compatible with systems modelling (used in this study) since they incorporate nonlinearities, multi-causality, and delays. Nevertheless, the storytelling approach has its limitations. First, a storyline is neither transparent nor reproducible, making it difficult for:(1) stakeholders to validate and trust the model and (2) future researchers to reconstruct the storylines (Alcamo et al., 2008). Second, the quantification of storylines is not always feasible since many narratives encompass abstract assumptions that cannot be incorporated by models (Kok, 2009). However, integrating storytelling with a participatory method such as a CLD, which compensates for its aforementioned weaknesses, is promising (Ernst et al., 2018). First, translating storylines into CLDs makes storylines reproducible and more transparent, since CLDs provide visual aids that can depict variables encompassed by the original storyline as well as connections between those variables (Alcamo, 2008). Second, the method facilitates the quantification process, by which storylines are translated into CLDs and subsequently into stocks and flows. Finally, the CLD construction process can be initiated with storytelling, which enables the incorporation of stakeholders with low levels of literacy in model-building activities. The method used in this study therefore aims to use storytelling to generate storylines that are could be coupled with CLDs.

Table 1. Method selection criteria.

Code	Statement
S1	The method is compatible with participatory model-building activities including illiterate stakeholders.
S2	The method is compatible with participatory model-building activities in a multilingual context.
S3	The method allows high-level stakeholder engagement.
S4	The method can be carried out as a group activity.
S5	The method is appropriate for one-on-one sessions.
S6	The method does not restrict or constrain participants.
S7	The method allows the elicitation of detailed inputs from stakeholders.
S8	The method allows the elicitation of inputs that are neither abstract nor prone to misinterpretation.

Table 2. Assessment of participatory methods for data collection and model conceptualization.

Participatory Methods	Overview	Phase(s) of modelling	S1	S2	S3	S4	S5	S6	S7	S8	Literature
Fuzzy cognitive mapping	Cognitive maps consisting of concepts and causal links that are associated with fuzzy weights	• Data collection • Model conceptualization									(Jetter & Kok, 2014; Mallampalli et al., 2016; Özesmi & Özesmi, 2004)
Causal loop diagrams - stakeholder created	Diagrams consisting of variables connected by causal links with polarity implying natures of relationships, built by participants	• Data collection • Model conceptualization									(Inam et al., 2015; Perrone et al., 2020; Sohns et al., 2020)

Causal loop diagrams - translated by researchers ex-post	Diagrams consisting of variables connected by causal links with polarity implying natures of relationships, extracted from interviews and processed by researchers ex-post	• Data collection • Model conceptualization									(Enteshari et al., 2020; R. Giordano et al., 2020; Pham et al., 2020)
Rich Pictures	Diagrams consisting of images and texts that represent participants' ideas	• Data collection • Model conceptualization									(Berg & Pooley, 2013; Lewis, 1992)
Spatial mapping	Map productions undertaken by locals to depict information and knowledge	• Data collection									(Mccall & Dunn, 2012; Rambaldi et al., 2007; Reilly et al., 2018)
Questionnaires	Studies conducted to gather data by polling sample populations	• Data collection									(Beall et al., 2011; Hussien et al., 2017; Voinov et al., 2016)
Narratives, storylines, and scenarios	Internally consistent and coherent descriptions of certain states	• Data collection • Model conceptualization									(Alcamo & Ribeiro, 2001; Booth et al., 2016; Trutnevyte et al., 2014)
Games											
Role playing	A game that is based on the creation and use of a virtual world to collect information and explore a certain situation	• Data collection									(Guyot & Honiden, 2006; Shelton et al., 2018)

Fish bowl	A game that allows assigned participants brief 3 to 5 minute expressions of respective views on modeled subjects	• Data collection									(Evans, 2006)
Line on the floor	A game by which a line on the floor represents a boundary between two categories with different opinions	• Data collection									(Evans, 2006)

- Disagree
- Agree conditionally
- Agree

2.2. Conventional participatory scenario-building and storyline development

Scenario analysis is defined as the evaluation of plausible futures by considering alternative trajectories yielding plausible states of investigated issues. Timpe & Scheepers (2003) conceptualized conventional scenarios using the Scenario Funnel displayed in Fig. 1. The funnel represents the increasing uncertainty of future events over time. The paths contained within the funnel show the multiplicity of possible future states of a certain system and the possibility of non-linear development trends. The existence of different scenario trajectories, corresponding to one state, usually depends on allowing different drivers of change, trends, and levels of uncertainty to impact different scenario paths. Hence, the conceptualization of conventional scenarios assumes that scenario trajectories start at one point in time (the dot intersecting the vertical axis in Fig. 1) and are driven forward, in different directions, due to influences of diverse driving forces, trends, or uncertainties, unfolding various plausible futures.

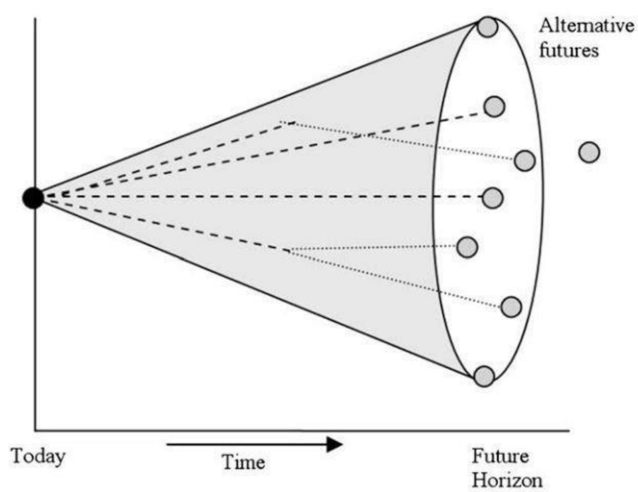

Figure 1. Conceptual Scenario Funnel (Mahmoud et al., 2009; Timpe & Scheepers, 2003).

2.2.1. Two-dimensional scenario-matrix approach

The 2D scenario-matrix approach – also known as the minimal approach – has been widely used to initiate construction of scenarios that are affected by various drivers, trends, and levels of uncertainty and are underpinned by the Scenario Funnel (Amer et al., 2013; Arico et al., 2001; Delmotte et al., 2017; Evans, 2006). In order to frame scenarios, the 2D scenario-matrix approach suggests the selection of two critical uncertain drivers of change, considered most important to the study. Afterwards, a matrix depicting the two different extremes of each driver is constructed. In each of the four quadrants of the matrix, a scenario is developed.

For example, Arnell et al. (2004) constructed a 2D scenario matrix (Fig. 2) using two drivers: governance and development. The matrix is therefore bounded by two extremes of governance, which are global and local, and two extremes of development, which are economic and environmental. In scenario A1 (Fig. 2), global governance and economic development are assumed. A1 is therefore bounded by these two assumptions about the selected drivers of change (governance and development), representing a future that is governed by economic development and global governance. The 2D scenario-matrix method has been implemented in various fields such as socio-ecology (Arico et al., 2001), agriculture (Delmotte et al., 2017), and others (Arnell et al., 2004; Priess et al., 2018).

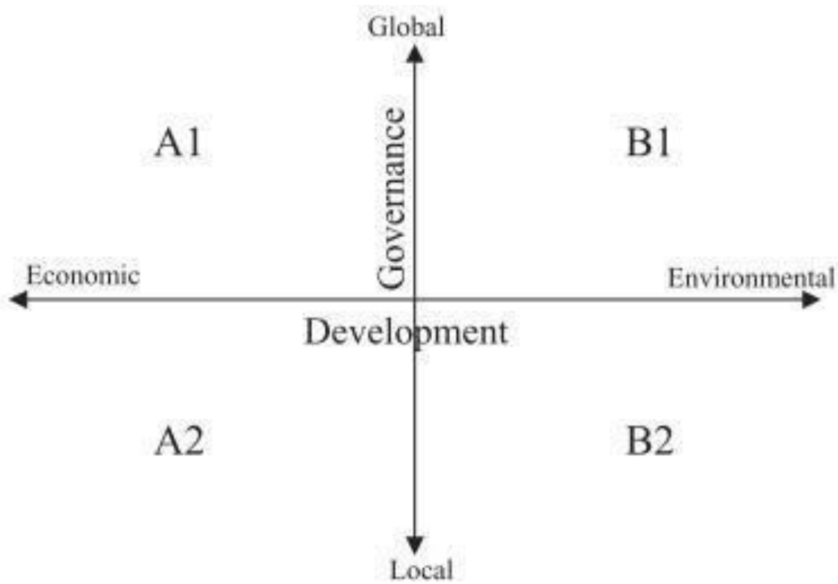

Figure 2. 2D scenario-matrix (Arnell et al., 2004).

Arico et al. (2001) constructed the Millennium Assessment socio-ecological scenarios to explore different societal transitions and policies associated with ecosystem services. In their study, the authors used the 2D scenario-matrix approach. They extracted the two most significant uncertain drivers of change from stakeholders: (1) the type of transition and (2) the applied governance approach. Therefore, the scenario-matrix in Arico et al. (2001) was bounded by two kinds of transitions: globalized and regionalized; and two different governance approaches: reactive and proactive. The authors used the Story and Simulation (SAS) approach to build the scenarios. In the first phase of the SAS scenario-planning process, data and knowledge were acquired by interviewing scenario end-users and conducting literature reviews to identify focal questions, key uncertainties, and cross-cutting assumptions associated with the scenarios. The second phase, in which storylines were developed and quantified, covered three components of the model-building process: model conceptualization, quantification, and formulation. First, preliminary storylines were drafted by two teams of experts, using each corner of the scenario matrix as a starting point for each of the four scenarios, and employing knowledge elicited from end-users and the literature review. Storylines were underpinned by a conceptual framework that classified six types of interactions: (1) impacts of ecosystem services on human wellbeing, (2) impacts of direct drivers of change (such as land-use change, climate change, or introduction of species) on ecosystem services, (3) impacts of direct drivers of change on human wellbeing, (4) impacts of indirect drivers of change (such as economic and demographic changes) on direct drivers of change, (5) impacts of indirect drivers of change on human-wellbeing, and (6) impacts of human-well-being on indirect drivers of change. The quantification process was then instigated and, simultaneously, preliminary storylines were revised in a workshop with end-users, yielding improved storylines. After scenario elements had been quantified, storylines were again revised in a workshop. The quantification process was done by soft-linking storylines to models. Finally, model inputs elicited from storylines were reviewed and corresponding models were run again. The authors highlighted the importance of iterations between quantification and adjustment of storylines.

Delmotte et al. (2017) elicited narratives from stakeholders to investigate potential innovative agricultural systems that incorporated environmental and economic sustainability while providing local and global food security in the Camargue, Southern France. The authors followed a four-step process, holding four workshops in total. In the first step, drivers of change were identified and ranked by stakeholders, and the two most prominent drivers were selected: (1) climate change and (2) economic conditions for rice cultivation. Then, a two-dimensional scenario matrix was built, depicting the polar opposites of states of drivers: (1) low and high climate change impacts and (2) favourable and unfavourable economic conditions for rice cultivation. In the second step, the scenario matrix was used to instigate four plausible storylines from each of its four quadrants. The storylines included all the initially elicited drivers of change, which were arranged using the criteria of Alcamo & Ribeiro (2001): realism, consistency, contrast, and creativity. Thirdly, adaptation strategies, within the context of each storyline, were delineated. For example, for the scenario defined by high climate change impact and unfavourable economic conditions, the development of innovative cropping systems was suggested as an adaptation strategy. In the fourth step, inputs from storylines were assigned to a bio-economic model for quantification, generating scenarios. Hence, the climate change driver was translated into: (1) changes in availability of agricultural land due to expected changes in soil salinity yielded by alterations in evapotranspiration rates, (2) constraints on crops, and (3) changes in crop yield. The driver corresponding to economic conditions prompted the simulation of: (1) different kinds and levels of subsidies, (2) changes in the prices of resources such as water and energy, and (3) different crop prices.

2.2.2. Other methods for conventional conceptualization of participatory scenarios

Many scenario-analysis studies did not use the 2D scenario-matrix approach although they underpinned scenario conceptualization methods with the Scenario Funnel (Fig. 1). They focused on drivers of change that were influencing scenario trajectories as they proceeded forward in time, exogenously interacting with scenario components. Numerous methods, other than the 2D scenario-matrix approach, were used by researchers to frame scenarios using drivers of change. For example, some studies constructed scenarios governed by more than two drivers and others considered more than two trends for a certain driver (among many other ways drivers of change were used to frame scenarios).

Carpenter et al. (2015) developed participatory scenarios to investigate plausible futures of ecosystem services in the Yahara Watershed, Wisconsin, USA, by constructing participatory storylines and coupling them with biophysical models. Researchers first determined the scenario-analysis goals and then initiated story development and model simulation processes simultaneously. The storyline development process was conducted by integrating global scenarios literature with stakeholders' perspectives. Four workshops were held by which (1) storylines regarding different regimes and outcomes in the Yahara Watershed were extracted from stakeholders and (2) significant drivers of change impacting ecosystem services were selected: climate and land use/cover. Four storylines were constructed, corresponding to four different regimes: (1) business as usual, (2) accelerated development in technology, (3) strong governmental interventions, and (4) changes towards sustainability. Subsequently, quantitative time-series corresponding to both drivers, climate and land use and cover, were developed for each storyline. The quantitative time-series were then used as biophysical model inputs, in order to quantify changes in ecosystem services according to each of the storylines. As a result, quantitative scenarios that showed reactions of ecosystem services to shifting drivers (climate and land use and cover) upon various regimes in Yahara Watershed were developed. Carpenter et al. (2015) started the scenario-building process by formulating storylines, and then used assumptions from the constructed storylines to quantify significant drivers, which were then used as inputs to biophysical models to quantify changes in ecosystem services in each storyline. In other words, the authors exogenously investigated the effects of the primary driver, which was the dominant regime, on ecosystem services in the watershed. Therefore, the conceptualization of scenarios in this study was likened to that underpinning the 2D scenario-matrix approach, by which scenario trajectories are exogenously influenced by drivers of change and bounded by certain assumptions corresponding to certain drivers.

Foran et al. (2013) developed a participatory technique for the generation of qualitative scenarios. The participatory activity included two workshops and was carried out in a seven-step process: (1) preliminary identification of issues, social and geographical contexts, and time frame by organizers; (2) construction of a historical timeline with stakeholders, delineating forces that had impacted the studied issue in the past; (3a) participatory creation of an initial scenario framework by identifying drivers of change and critical uncertainties; (3b) classification of identified driving forces on a two-dimensional array with the vertical and horizontal axes delineating perceived importance and uncertainty, respectively; (3c) use of the aforementioned two-dimensional array as a structure underpinning scenarios to be established; (4) creation of a specific scenario framework by allowing stakeholders to select subsets of uncertain drivers from the initial scenario framework and construct trajectories linking start and desired end points, while considering interactions between driving forces; (5) generating first-order narratives by converting abstract and dynamic forces depicted in the specific scenario framework to a chronological, coherent, and consistent storyline; (6) identification of desired and undesired events in storylines by stakeholders; and (7) revision of narratives and incorporation of important events from other narratives to ensure consistency. The authors portrayed an elaborated procedure for qualitative scenario construction that focused on framing scenarios with drivers of change, which directed scenarios forward in different paths and yielded different outcomes or plausible futures.

Techniques for the elicitation of storylines and conceptualization of scenarios – generated by the aforementioned studies and other similar ones (Arico et al., 2001; Arnell et al., 2004; Booth et al., 2016; Carpenter et al., 2015; Delmotte et al., 2017; Evans, 2006; Foran et al., 2013) – are compatible with conventional quantification methods yielded by soft-linking storylines with one or multiple models. However, they are not fully equipped for quantifying storylines and generating scenarios using systems modelling – modelling a certain state, issue, or problem in the form of a system containing dynamically interacting components – for several reasons. First, conventional scenario-building processes (such as those encompassed by previously-elaborated studies) usually require framing scenarios with selected drivers of change, and consider these frames as initiators for the storyline development process. Hence, the conceptualization of conventional scenarios assumes that scenario trajectories start at one point in time and are driven forward in different directions due to influences of diverse driving forces, generating various plausible futures(Fig. 1).

While drivers, trends, and uncertainties are inevitably contained by storylines elicited from stakeholders to form conventional scenarios, causal iterative interactions that yielded the initial state - the starting point intersecting the vertical axis in Fig. 1 – are not encompassed by extracted narratives (or at least not by techniques in previously mentioned studies). However, in complex systems mimicked by systems modelling, prior to considering driving forces and projecting forward in time, interactions between diverse direct and indirect causes that yielded the initial state being investigated, are present. In other words, the problem as-is is created by eliciting the interacting relationships deemed essential to the subsistence of the problem. Therefore, the problem's triggers are not considered to be externally imposed on the system but rather act and react within the modelled structure (Forrester, 1976). Second, conventional scenario conceptualization methods bound scenarios with assumptions derived from the selection of certain drivers and their trends. These methods do not provide sufficient boundaries needed for scenarios generated from systems models. In systems models, system boundaries are crucial. They are established as a part of the model's structure and a legitimate representation of system boundaries should be embedded within the methods used for conceptualization of scenarios derived from systems models. This would facilitate the storyline development process by initially limiting the scope of the storyline by the system's boundaries. Third, as mentioned previously, conventional scenarios are generally based on drivers that interact exogenously with other model variables encompassed by scenario trajectories. However, the key point in generating scenarios using systems models is adding a component (or more) to the system or adjusting a certain trend of a component already encompassed by the system. In both cases, unlike conventional scenarios, scenarios derived from systems models are characterized by components that are set to endogenously interact within the system and its structure. Therefore, conventional scenario conceptualization along with associated storyline development techniques are ill-equipped for the generation of scenarios in the context of systems modelling.

2.2.3. Integration of storytelling and systems modelling

The formulation of a systems model is underpinned by the construction of CLDs (Beall et al., 2011; Díaz, 2015; Inam et al., 2015; Mavrommati et al., 2014). In CLDs, variables embedded within the system are connected by links indicating causality. The connectors are either positive or negative implying direct or inverse relationships between linked variables, respectively. Within these diagrams, closed loops may be reinforcing or balancing. In a reinforcing loop, the impact of variation of any variable circulates through the loop, reaching that same variable and reinforcing its initial deviation. In a balancing loop, the impact of the variation of a variable circulates and returns to the initially altered variable with a deviation opposite to the initial one. CLDs are used for conceptualizing a systems model and are transformed into stocks and flows for quantification. Most studies incorporating systems models, including participatory systems modelling (Inam et al., 2015; Schmitt et al., 2017), initiate model development with the production of CLDs. Little importance has been given to the instigation of systems modelling using the development of narratives for purposes of data and knowledge acquisition and model conceptualization.

Storylines can consider nonlinearities, multi-causality, and complex causal links (Arico et al., 2001). Therefore, they are well-suited for describing complex systems and being used as sources of input for systems modelling. Guhathakurta (2002) acknowledged that models are underpinned by storylines, and function as means of reconstructing and investigating stories. The author developed a simple systems model to examine the past and plausible futures of communities living in a southern Arizona watershed and succeeded in translating different simulations of the model into narrative scenarios. Guhathakurta (2002) did not use storylines to develop the systems model, but rather used the model to tell stories. In this way, the author portrayed the compatibility of storytelling with systems modelling.

Mallampalli et al. (2016) evaluated narrative translation methods in the land use and land cover literature. The authors considered systems modelling as an approach suitable for transforming qualitative narratives into quantified scenarios by either direct or indirect translation. The direct translation method involved stakeholders and experts working jointly to (1) identify relevant relationships among concepts, producing CLDs, and (2) explore plausible scenarios. The indirect translation method required the elicitation of storylines from stakeholders, which were subsequently transformed into CLDs by researchers. The CLDs were then digitized and quantified using systems modelling, yielding scenarios. The authors did not elaborate on storyline development methods. However, if storylines are not explicitly designed to translate to CLDs, the indirect translation method ex-post poses two main concerns: (1) it might increase the susceptibility of the model to researcher influence and (2) it might increase the likelihood that storylines are misinterpreted (Kim & Andersen, 2012).

Geum et al. (2014) used an integrated method consisting of a technology roadmap and systems modelling, to aid in scenario planning. Taking a car-sharing service in Korea as a case-study, the authors first constructed qualitative scenarios (optimistic, pessimistic, and neutral). Then, from these scenarios, they derived technology roadmaps – strategic frameworks to realize constructed scenarios, linking external businesses and internal strategies. Finally, they used systems modelling to convert the roadmap to an operational viewpoint. Although this study involved storylines and systems modelling; its methodology might not be suitable for modelling complex systems. The authors did not use systems thinking to conceptualize the system (Forrester, 1976), but rather used systems modelling to quantify already developed scenario roadmaps.In other words, the three qualitative scenarios, (optimistic, pessimistic, and neutral) that were translated into three system dynamics models, were already conceptualized: systems modelling was used for quantification and evaluation, rather than for aiding the conceptualization of qualitative scenarios through systems thinking.

A framework that explicitly elaborates the formulation of storylines that serve as a conceptual ground and source of input to systems models is lacking. There is a need for a methodology that aims to construct storylines that are tailored to translate into CLDs and serve as inputs to systems models. Creating storylines that provide inputs to aid in developing a systems model of a studied complex system allows the simulation of the business-as-usual scenario. The business-as-usual simulation delineates points of leverage and undesired outcomes. Successively, one way to restructure or reconfigure the system can be conducted by selecting and simulating one or a combination of new system components, yielding different scenarios (e.g.,policy-based scenarios). The simulation of policies, for example, might alter the dynamics of the issue or problem embodied by the system, producing a new scenario with each new state of dynamics. Therefore, an all-inclusive framework, delineating not only the development of storylines that structure the modeled system but that also elicits new components (such as valid policies) and corresponding possible futures, is needed to construct scenarios from the integration of storylines and systems models of defined problems or states.

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Connecting text to Chapter 3

This chapter presents a framework that explicitly elaborates the formulation of storylines that serve as a conceptual ground and source of input to systems models. The methodology aims to construct storylines that are tailored to translate into CLDs and serve as inputs to systems models. The suggested approach accommodates a multilingual environment and facilitates the inclusion of less-literate and/ or relatively powerless stakeholders in participatory modelling.

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Chapter 3: Multi-level storylines for participatory modeling – involving marginalized communities in Tz'olöj Ya', Mayan Guatemala

3.1. Abstract

Unconventional sources of data that enhance our understanding of internal interactions between socio- economic and hydrological processes are central to modeling human–water systems. Participatory modeling (PM) departs from conventional modeling tools by informing and conceptualizing human–water systems through stakeholder engagement. However, the implementation of many PM processes remains biased, particularly in regions where marginalized communities are present. Many PM processes are not cognizant of differentiation and diversity within a society and tend to treat communities as homogeneous units with similar capabilities, needs, and interests. This undifferentiation leads to the exclusion of key actors, many of whom are associated with marginalized communities. In this study, a participatory model-building framework (PMBF), aiming to ensure the inclusiveness of marginalized stakeholders – who (1) have low literacy, (2) are comparatively powerless, and/or (3) are associated with a marginalized language – in participatory modeling, is proposed. The adopted approach employs interdisciplinary storylines to inform and conceptualize human–water systems. The suggested method is underpinned by the multi- level perspective (MLP) framework, which was developed by Geels et al. (2002) to conceptualize socio-technical transitions and modified in this study to accommodate the development of interdisciplinary storylines. A case study was conducted in Atitlán Basin, Guatemala, to understand the relationships that govern the lake's cultural eutrophication problem. This research integrated key stakeholders from the Indigenous Mayan community, associated with diverse literacy ranges, and emerging from three different marginalized linguistic backgrounds (Kaqchikel, Tz'utujil, and K'iche'), in the PM activity. The proposed approach facilitated the participation of marginalized stakeholders. Moreover, it (1) helped develop an understanding of mechanisms governing the eutrophication of the lake, (2) initiated a dialogue between Indigenous Peoples and non-Indigenous stakeholders, and (3) extracted potential solutions targeting the system's leverage points. The participatory model-building activity generated three submodules: (1)

agriculture, (2) tourism, and (3) environmental awareness. Each submodule contained socioculturally specific mechanisms associated with nutrient discharge to Lake Atitlán. The delineation of such nuanced relationships helps develop well-targeted policies and best management practices (BMPs). Additionally, the suggested process helped decrease the impact of power imbalances in water resources management and empowered community- based decision-making.

3.2. Introduction

Cultural eutrophication and associated algal blooms have become prevalent in freshwater ecosystems worldwide (Smith and Schindler, 2009). Anthropogenic activities (e.g., agricultural, industrial, and residential) have exacerbated the trophic states of lakes by increasing the associated discharge of point-source and nonpoint-source limiting nutrients (Schindler, 1974). Such water quality problems are challenging to solve as they are characterized by the complex interactions between biophysical and socio-economic dimensions (van Bruggen et al., 2019; Gunda et al., 2018). Deterioration of lake ecosystems due to cultural eutrophication is especially magnified in developing countries, where governing bodies tend to be more tolerant of practices contributing to aquatic nutrient enrichment (Nixon, 1995; Withers and Haygarth, 2007). To address problematic human–water interactions in developing countries, the bottom-up development of management practices and policies with stakeholders is crucial (Perrone et al., 2020).

Conventional modeling tools (e.g., physically based models) are often ill suited for addressing the challenges mentioned above, since they fail to endogenously incorporate socio-economic processes when addressing hydrological problems (Inam et al., 2017; Malard et al., 2017). They are also complex, lack transparency, and are often incompatible with participatory methods. Consequently, they reinforce expert-oriented and externally imposed opinions, which tend to lack situated knowledge (Cooke and Kothari, 2001; Inam et al., 2015). As such, water resources management requires transformative interdisciplinary methods, such as participatory modeling of human–water systems, to better capture local realities and improve understanding of the socio-economic factors impacting water-related problems (van Bruggen et al., 2019; Inam et al., 2015).

Systems thinking is a powerful tool for participatory modeling (PM) (Inam et al., 2017). Systems thinking can capture socio-economic processes elicited from stakeholders and can accommodate nonlinearity and multi-causality. It can also delineate iterative bi-directional feedbacks embedded in human–water systems (Prodanovic and Simonovic, 2010). The identification of such feedbacks is important to better inform and conceptualize human–water systems. Furthermore, systems thinking can be accompanied by visual aids, generating more comprehensible and stakeholder-friendly models (Alcamo, 2008). As a result, systems thinking can accommodate stakeholder participation and enhance model development with situated knowledge.

PM can incorporate stakeholders in decision-making through its departure from conventional model-building, packaging, and dissemination processes (Voinov et al., 2016). However, the implementation of such processes – particularly in regions with marginalized communities (i.e., less literate, comparatively powerless, or associated with marginalized languages) – is challenging. Many PM processes do not focus on diversity and differentiation within a society and tend to treat communities as homogeneous units with similar needs, capabilities, and interests (Bohensky and Maru, 2011; Guijt and Shah, 1998). Undifferentiated treatment in PM can lead to the exclusion of key actors, especially marginalized communities. As such, three issues are raised. First, many PM activities require professional skills and expertise, thereby preventing the involvement of less literate stakeholders (Inam et al., 2015; Maynard and Jacobson,

2017). Second, many participatory methods usually overlook group dynamics, yielding participatory decisions that reinforce the interests of those in power (Cooke and Kothari, 2001; Eker et al., 2018). Third, participatory model-building processes might fail to recognize integrated participation in multilingual regions, which can further marginalize Indigenous languages (e.g., Hassanzadeh et al., 2019).

One of the broad aims of many participatory approaches is to increase the involvement of socially and economically marginalized communities in making decisions that impact them and are impacted by them (Guijt and Shah, 1998; Izurieta et al., 2011). This is necessary for several reasons. First, marginalized stakeholders play vital roles in water resources management. Thus, they can be primary contributors to model-building activities and finding appropriate solutions for the problems being explored (Colfer and Dudley, 2011; Figueiredo and Perkins, 2013). For example, many marginalized communities are involved in agriculture and aquaculture and have sufficient experience to determine the practices that could be successfully integrated into everyday practices and adopted by corresponding actors (Hassanzadeh et al., 2019). Second, marginalized communities are often the most vulnerable to environmental change, such as water quality degradation of freshwater ecosystems. Therefore, these communities should have the right to participate in decisions that affect their environment, lives, and wellbeing (Evans, 2006). Third, inclusive participation in policymaking can facilitate sustainable management. While politicians and businesses are often interested in short-term benefits, communities tend to focus on long-term solutions that ensure the availability of water resources for future generations (Colfer, 2005). Finally, earlier research established that interactions between different participants with diverse backgrounds and perspectives are crucial in participatory processes, increasing creativity and producing new insights (Funtowicz and Ravetz, 1993; Martins et al., 2018; Webler, 1995). Therefore, to align the objectives of PM with the concerns outlined above, approaches that ensure the inclusion of marginalized stakeholders in such processes are needed.

Some participatory methods supporting the inclusion of marginalized stakeholders in PM and data collection processes have been suggested. For example, the “Rich Pictures” approach uses pictures and symbols in an unstructured way to capture flows of information, communication, and human activity (Berg and Pooley, 2013). The method aims to accommodate participatory activities in culturally diverse, less literate, and multilingual communities (Berg and Pooley, 2013; Colfer and Dudley, 2011; Voinov et al., 2018). However, the use of symbolism and pictures yields ambiguity and can be misinterpreted (Lewis, 1992). Therefore, this method is not necessarily well-suited for portraying the complexity of human–water interactions.

Spatial mapping has also been used for facilitating the inclusion of stakeholders, with little to no literacy, in participatory activities. This approach allows local stakeholders to (1) generate maps depicting information and knowledge – the where and how – associated with a problem and (2) reveal their perceptions of that problem. Participatory spatial mapping has been useful for triggering discussions between stakeholders but is not suitable for exploring future scenarios. Although the method has been successfully applied in the data collection process of participatory research (Rambaldi et al., 2007; Reilly et al., 2018), it is not well-suited for the conceptualization of human–water systems, as they encompass complex interactions between spatially and temporally distant components and non-spatial variables (Di Baldassarre et al., 2017; Forrester, 1969).

Additionally, facilitation techniques, such as "Fish Bowl" – an activity that allows each participant a brief period to express views on the investigated issue – or "Line on the Floor" – an activity where a line on the floor represents a boundary between two categories of stakeholders with different opinions, were suggested by Colfer and Dudley (2011) to include less literate stakeholders in participatory activities. This genre of activities can only be conducted in group sessions, and there is the problem of the potential effects of unhealthy group dynamics. Stakeholders are often more likely to engage in individual rather than group sessions and communicate openly when alone (Burgin et al., 2013; Videira et al., 2009). Moreover, these methods could have challenges in eliciting the detailed stakeholder perceptions that are required by PM processes.

Another approach, stakeholder created causal loop diagrams (CLDs), contain variables connected by links indicating causal relationships. Causal loop diagrams have been previously applied in water resources management (e.g., Hassanzadeh et al., 2019; Stave, 2003) In many cases, their construction required reading and writing skills (e.g., Inam et al., 2015, 2017; Perrone et al., 2020) or technical skills (e.g., Mavrommati et al., 2014; Tidwell et al., 2004). This can pose challenges when involving less literate stakeholders in participatory model-building activities. In some studies, causal loop diagrams were extracted from interviews or focus group discussions and processed by researchers, ex post (e.g., Enteshari et al., 2020; Giordano et al., 2020; Pham et al., 2020; Santoro et al., 2019). There are two challenges related to this: (1) it increases the risk of researchers' influences on the model, and (2) it might yield ambiguous statements that are prone to misinterpretation (Kim and Andersen, 2012). Both are especially critical in the context of marginalized communities, where perspectives of less powerful stakeholders often tend to be lost or disregarded (Butler and Adamowski, 2015; Cooke and Kothari, 2001).

The primary focus of this research is the implementation of a participatory method that facilitates the inclusion of traditionally marginalized stakeholders, who are (1) less literate, (2) relatively powerless, and/or (3) associated with marginalized languages, in modeling human–water systems. The method suggests an extension to CLD building to facilitate inclusion. The integration of storylines with causal loop

diagrams through the multi-level perspective (MLP) framework is proposed to enhance the involvement of marginalized stakeholders in PM processes. The MLP framework was initially developed by Geels (2002) to conceptualize socio- technical transitions and explains developments in and interactions between three levels: landscape, regime, and niche (elaborated in subsequent sections). The framework was adjusted in this study to accommodate the interdisciplinary development of storylines. The objectives of the study are to

1. propose a conceptual framework for building multi- level storylines that (1) is inclusive by design and (2) can inform and conceptualize human–water systems, by adjusting the MLP framework;
2. suggest a framework for the implementation of the storyline construction process that (1) facilitates the participation of less literate stakeholders, (2) reduces unhealthy power dynamics, (3) accommodates a multilingual context, and (4) makes use of the system's leverage points to select best management practices (BMPs) and policies; and
3. evaluate the validity of the process with respect to its ability to (1) incorporate effective participation of marginalized stakeholders, (2) induce a dialogue, (3) integrate diverse

perspectives, (4) facilitate model- conceptualization, and (5) produce descriptions of relevant human–water feedbacks.

A case study was carried out in the Atitlán Basin, Guatemala, which integrated stakeholders from the Indigenous Mayan community into the proposed participatory model-building process to fulfill the third objective. This case study was selected since it incorporates relatively powerless stakeholders, associated with diverse literacy ranges, and belonging to three different marginalized linguistic backgrounds: Kaqchikel, Tz'utujil, and K'iche'. The study applied the proposed storyline development framework to investigate the relationships that govern the eutrophication problem in Lake Atitlán from a holistic community-based perspective and to empower community-based decision-making. The remainder of the paper is structured as follows. Section 3.3 discusses the conceptual framework for multi-level storyline development. Section 3.4 provides background information for the case study. Section 3.5 provides a stepwise approach for implementation of the multi-level storyline development framework. The results of the implementation of the process in the Atitlán Basin are presented in Sect. 3.6. Section 3.7 evaluates the results and discusses them from the perspective of human– water feedbacks, and Sect. 3.8 concludes the study.

3.3. Conceptual framework

In this section, the building blocks of the method – storytelling and the MLP framework – are discussed. An argument for using storyline development to facilitate the inclusion of marginalized stakeholders in conceptualizing human–water systems is presented. Finally, the conceptual framework for the development of multi-level storylines is elaborated.

3.3.1. Storytelling

Storytelling techniques are a way to visualize and describe conditions using oral or textual narration, to provide information and insight (Hazeleger et al., 2015; Moezzi et al., 2017; Zscheischler et al., 2018). This method helps people from different domains and professional and sociocultural backgrounds better understand different perspectives since it provides leeway for elaboration and does not restrict the communicator with a technical approach. The storytelling approach is suggested for helping to solve water resources problems where (1) cross-dimensional collaboration across different fields and entities (e.g., agriculture, government, and academia) is necessary to ensure a holistic understanding of the problem, policy outcomes, and potential risks (Thaler and Levin-Keitel, 2016; Treuer et al., 2017), and (2) the inter- connectedness of different domains transcends hydrological systems and involves the implementation of generated decisions (Haeffner et al., 2018; Hassanzadeh et al., 2019).

Storytelling can also help accommodate the participation of marginalized stakeholders. Since storylines are usually communicated verbally, the process requires neither reading nor writing skills and, therefore, is compatible with the involvement of less literate stakeholders in participatory activities (Colfer and Dudley, 2011). The method allows participants to use anecdotes and metaphors to describe their observations. This is useful in the context of less literate stakeholders or non-modelers who might not be able to explicitly portray their observations in a technical manner. Also, it can be carried out either in individual sessions – to reduce unhealthy power dynamics (Butler and Adamowski, 2015) – or in group sessions – which is necessary when discussions between participants of different perspectives are required (van Bruggen et al., 2019; Evans, 2006). Storytelling allows for the portrayal of the studied issue in detail and with reduced ambiguity since it encourages participants to elaborate on their descriptions of conditions. The elicited storylines provide researchers with knowledge and information while also aiding in model conceptualization, characterization of future scenarios, and evaluation of modeling results (Alcamo, 2008; Trutnevyte et al., 2014). Due to the flexibility of the storytelling process, storylines can also consider nonlinearities, multi-causality, and complex causal links (Arico et al., 2005). Therefore, they are well-suited for helping to inform and conceptualize systems models. Data sources that can enhance understanding of and capture human–water feedbacks are needed for the development of holistic, participatory models that represent complex interactions between hydrological and socio-economic variables (Mount et al., 2016). The highly descriptive and flexible nature of storytelling helps capture the empirically observed complexity associated with such phenomena (Leong, 2018).

Storylines have been used by many researchers to complement models (Arico et al., 2005; Booth et al., 2016; Trutnevyte et al., 2014). Guhathakurta (2002) stated that storylines underpin models as a means of reconstructing and investigating stories. In addition, Trutnevyte et al. (2014) stated that the iteration between storylines and model results could correct over or underestimations depicted by either. Nevertheless, the incorporation of participatory storytelling techniques in environmental modeling and resource management has been limited (Arico et al., 2005; Carpenter et al., 2015; Cobb and Thompson, 2012; Delmotte et al., 2017; Treuer et al., 2017). Methods guiding participatory storytelling have focused on conducting interviews with stakeholders, carrying out collective workshops, developing appropriate focal questions, and iterating between model results and stakeholders (Arnell et al., 2004; Booth et al., 2016; Cobb and Thompson, 2012; Foran et al., 2013). However, these storytelling approaches have been specifically designed to inform conventional models (such as physically based models) and are not necessarily well-suited for systems modeling.

The storyline construction processes used in the above- listed studies start with requiring stakeholders to state the most significant or uncertain drivers that are expected to shape the future trajectory of the modeled problem. Hence, those techniques usually frame the resulting models with selected drivers of change, which are the initiators for the storyline development process. For example, Delmotte et al. (2017) held a workshop in which drivers of change were identified and ranked by stakeholders, and the two most prominent drivers were selected: (1) climate change and (2) economic conditions for rice cultivation. Then, a two-dimensional matrix was built, depicting the extrema of the driver states: (1) low and high climate change impacts (x axis) and (2) favorable and unfavorable economic conditions for rice cultivation (y axis). This matrix was then used to instigate four plausible storylines from each of its quadrants. This concept is dominant in storyline construction processes and is convenient for informing physically based models, in which driving forces are only interacting exogenously with other modeled variables. However, in systems thinking and modeling approaches, prior to considering driving forces, interactions between diverse components that cause and reinforce the problem are required. In other words, the problem, as is, is created by eliciting the relationships essential to its continuance. Therefore, the problem’s triggers are not considered external “drivers” imposed on the system but rather internally acting and reacting within the modeled structure (Forrester, 1969).

Additionally, the key mechanism for exploring plausible futures or scenarios using systems thinking is through adding a component (or more) to the system, adjusting a certain trend of a component (or more) of the system, or both. Unlike conventional scenarios produced by physically based models, which are shaped by external drivers of change, scenarios derived from systems thinking are characterized by components that are endogenously interacting within the system. Therefore, the unique nature and structure of systems models require a different storytelling technique that produces storylines capable of informing and conceptualizing the founding relationships of the model and characterizing future scenarios using internal model variables.

The notion of coupling storylines with systems thinking has been previously suggested (Geum et al., 2014; Mallampalli et al., 2016; Olabisi et al., 2010). Mallampalli et al. (2016) highlighted the suitability of systems modeling for quantifying narratives but did not elaborate on associated storyline construction methods. Olabisi et al. (2010) developed different socio-ecological scenario storylines with stakeholders; each storyline described a plausible future corresponding to the year 2050 in Minnesota, driven by certain elements (e.g., natural, social, political) and associated trends. The authors then constructed several systems models underpinned by a scenario storyline, containing relationships that only represented the year 2050. The model results were only used to evaluate the consistency of scenario storylines. The storyline construction process used by Olabisi et al. (2010) (and elsewhere; Geum et al., 2014) was initiated by identifying driving forces and outcomes of alternative futures, excluding systems thinking from that phase of the process. In other words, systems thinking was not used as a tool to explore possible future states of the modeled system; systems modeling was used to simulate pre-built and previously conceptualized future scenarios.

Although this approach is useful for providing visions of alternative futures, it is not necessarily well-suited for designing decision-support tools, testing policies and BMPs, and generating policy-based scenarios for water resources management. This method does not make use of one of the key advantages of systems thinking: the ability to expose leverage points. A leverage point is a position in a system where a minimal shift generates a major change in the system's functioning (Meadows, 1999). The majority of leverage points cannot be identified intuitively. Even if a leverage point is delineated intuitively, it is often misused, leading to unintended system behavior. In other words, relationships governing leverage points are counterintuitive (Forrester, 1971). Therefore, the identification of leverage points requires a thorough exploration of the modeled system as is (prior to projecting it) and an understanding of its components and relationships. In return, the detection of leverage points aids decision-making by highlighting where a policy or BMP could be assigned to yield a transformative change in the system's state. In this context, BMP or policy-based scenarios should be suggested and generated in the later phases of the modeling process and not at the initial phase. Hence, this study presents a framework for the construction of interdisciplinary storylines that aim to (1) inform and conceptualize models using systems thinking and (2) make use of leverage points to empower decision-making.

3.3.2. Multi-level perspective (MLP) framework

The MLP framework (discussed in detail elsewhere: Geels and Kemp, 2000; Geels, 2002; Kemp et al., 2001) was developed for the analysis and description of socio-technical transitions (Timpe and Scheepers, 2003). This framework has been widely adopted for depicting transitions in the electricity sector (Foxon et al., 2010, 2013; Moallemi et al., 2017; Moallemi and Malekpour, 2018). The framework has also been used to describe transitions in water governance (e.g., Daniell et al., 2014; Orr et al., 2016; Xu et al., 2016).

The MLP framework was established to explain the development of technology from interactions occurring within and between different levels: landscape, regime, and niche. The landscape represents the "Macro-level", which contains external factors that bind and contextualize transition trajectories. It involves a set of heterogeneous factors (e.g., social structure and political coalitions) and defines the environment for developments and corresponding interactions. The regime delineates the "Meso-level", reflecting the stability of existing developments in technology. It outlines the rules that restrain activities within communities, setting the environment for the occurrence of socio-technical transitions. The niche depicts the "Micro-level", accounting for the radical innovations which are not yet part of the dominant regime (Geels, 2002). The relationship between the three concepts is a nested hierarchy, implying that landscapes contain regimes and regimes contain niches. Therefore, niches emerge within the context of the prevailing regimes and corresponding landscapes, according to associated rules and capacities. The prevalent regimes and landscapes strongly influence the emergence of niches. This highlights the significance of the alignment of developments at the three levels, by which existing arrangements play a significant role in shaping innovations at the niche level and in determining whether associated radical innovations will yield a shift in the dominant regimes (Kemp et al., 2001; Mylan et al., 2019).

The MLP framework has not been used, in the context of systems thinking, for the development of storylines that aim to inform and conceptualize models and, therefore, is modified in Sect. 3.3.3 in this study to accommodate the latter. This study builds on three concepts of the MLP framework: (1) the three levels, (2) the nested hierarchy of levels, and (3) the recognition that existing arrangements play a central role in shaping future developments of the system. In this paper, the three levels are referred to as Macro-level, Meso-level, and Micro-level, instead of landscape, regime, and niche, respectively.

3.3.3. Integrated approach: multi-level storylines

Storylines developed to conceptualize a systems model should inform (1) the boundaries of the system representing the problem, (2) the components and interactions that make up the system (contained within the boundaries), and (3) the desired BMPs and policies within the context of the modeled problem – ideally targeting leverage points. The construction of conceptual models using storytelling is, therefore, underpinned by the integration of storylines developed at three levels: Macro-level, Meso-level, and Micro-level (Geels, 2002). The relationship between the three levels is depicted as a nested hierarchy. Meso-level storylines are within the scope of Macro-level storylines and informed by them, and Micro- level storylines are within the scope of Meso-level storylines and informed by them. Understanding and structuring the constituents of the storylines from stakeholders at each level is required to facilitate storytelling and model conceptualization processes.

The Macro-level storyline sets the gradient for all plausible present and future outcomes produced by the model. It contains historical influences, social and geographical contexts, the problem definition, and the assigned time horizon (Convertino et al., 2013; Inam et al., 2015). Hence, it provides the boundaries and scale of the modeled system, which are essential for initiating the model's conceptualization and informing the Meso-level storyline. The Meso-level storyline portrays the modeled problem's state, which is yielded by dynamic interactions between the components of the problem, contained by system boundaries. It is made up of the causes and consequences of the problem, as well as the relationships and feedbacks between them. The storyline is designed to depict the problem and the corresponding state as is. Translating the Macro-level and Meso-level storylines into a CLD allows for the exploration of some of the system's leverage points. Subsequently, this informs the Micro-level storylines, which encompass BMPs or policies and corresponding outcomes within the context of the modeled problem. For effective policy selection, candidate policies (policies that are deemed suitable by several stakeholders) contained by the Micro-level storylines should target leverage points and undesired outcomes. Policies can either (1) restructure or reconfigure the system or (2) strengthen or weaken dynamics already embedded within it. The emergence and simulation of certain BMPs or policies then depict the starting point of the corresponding policy-based scenario. However, the changes induced by and the outcomes of the simulated BMPs or policies are underpinned by, and occur, within an existing system. Therefore, the exploration of the dominant system's arrangements that shape and influence plausible future developments is crucial prior to constructing Micro-level storylines. Hence, having a holistic view of the system allows for the establishment of policies and BMPs that target long-term transformation of the system's problematic state, rather than short-term remedies (Forrester, 1969). The components of storylines associated with each level are displayed in Fig. 3. The figure shows that policies contained by Micro-level storylines should be aligned with depicted leverage points or undesired outcomes. It also displays multiple policy options for a single selected point.

Multi-level storylines can be used in parallel with CLD building to facilitate more inclusive stakeholder participation. Storylines provide an opportunity for stakeholders to describe their observations, using, for instance, anecdotes and metaphors. This is particularly useful in the presence of less literate or non-expert stakeholders who might not be comfortable with the technical aspects of CLD building and might not explicitly place their observations in the context of variables and links. Additionally, disseminating and communicating results in the form of storylines is more suitable for an audience of non-modelers, especially in the context of marginalized communities that include stakeholders who might not be comfortable with deciphering CLDs. Moreover, the method is explicitly and systemically designed to dynamically translate from storylines to CLDs and vice versa, which makes (1) stakeholders' statements less prone to misinterpretation and (2) the process less susceptible to researchers' influences, compared to other CLD-building processes that require ex post extraction of CLDs from interviews or focus group discussions (Giordano et al., 2020; Pham et al., 2020). This facilitates the conservation of stakeholders' views.

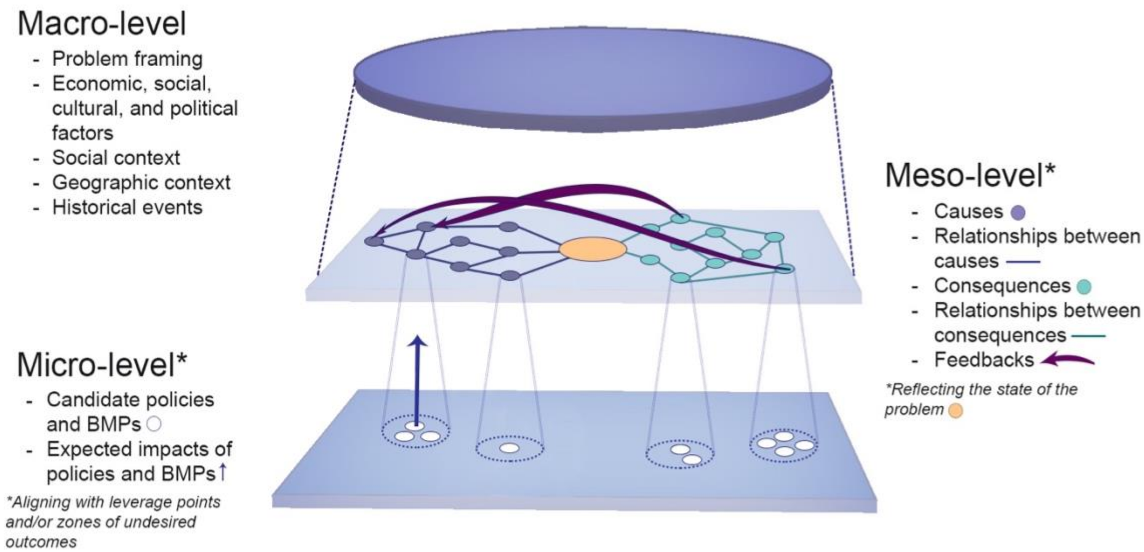

Figure 3. Components of storylines at three levels: Macro-level, Meso-level, and Micro-level (modified from Geels et al. (2002) to accommodate multi-level storyline development).

3.4. Case study

Lake Atitlán is the deepest lake in Central America, with an average depth of 220 m and a maximum depth of 341 m. Located in the southwestern region of Guatemala, it is a high- land, endorheic lake formed in a collapsed caldera. The lake's surface area is 137 km^2, while the Lake Atitlán watershed is 541 km^2 (Fig. 4) (Ferráns et al., 2018; Newhall, 1987). Lake Atitlán is a warm monomictic lake that experiences two main seasons: (1) dry from November to April and (2) wet from May to October (Weiss, 1971). More than 50 % of the watershed consists of steep slopes (Komárek et al., 2013).

The Atitlán Basin contains numerous point sources and nonpoint sources of nutrient pollution. The most prominent are agricultural runoff, untreated wastewater, and eroded soils (Weisman et al., 2018). For the past several decades, increased development of the area, coupled with poor environmental management practices and policies, has yielded a surge in nutrient loading to the lake. This ongoing process of cultural eutrophication has recently shifted the lake's state from oligotrophic to mesotrophic (Komárková et al., 2011). Lake Atitlán experienced a very large cyanobacteria bloom covering 40 % of its surface in October 2009 (Komárek et al., 2013).

The Atitlán Basin encompasses 15 municipalities and approximately 300000 people (INE, 2018). Forests and agricultural areas cover more than 70% of the watershed (Komárková et al., 2011). Agriculture, aquaculture, and tourism are the dominant economic sectors in the region (Ferráns et al., 2018). The Atitlán Basin is home to three Mayan communities: Kaqchikel, Tz'utujil, and K'iche'. The marginalization of these communities is magnified at institutional levels (national and local) and in education systems, where associated Indigenous languages are seldom acknowledged. These Indigenous communities are dependent upon the lake and value it economically, socially, and spiritually. The cyanobacterial blooms in 2009 hindered drinking, fishing, and leisure activities, which are crucial for the lives of Indigenous communities in the vicinity of Lake Atitlán.

In 2018, government authorities endorsed a proposed project (referred to as the "Mega-collector") to enhance the lake's water quality. The project involves building large, centralized infrastructure to collect wastewater from all the towns encircling the lake and transporting it to a treatment plant outside the watershed. The wastewater would then be treated and used by agro-industrial farms for irrigation. According to discussions with stakeholders, some Indigenous communities have raised objections for several reasons. First, they are concerned with the reallocation of the watershed's water resources due to associated implications on the basin's water shortage problem and the inequitable distribution of benefits. Second, they emphasize that such a large-scale project would have very negative impacts on the lake's ecosystem and biodiversity. Third, since the basin encompasses multiple seismic faults, some Indigenous communities question the resilience of large infrastructure in an earthquake-prone zone. Fourth, they highlight that the project would not solve the eutrophication problem definitively since it disregards other contributing factors such as agricultural runoff and soil erosion.

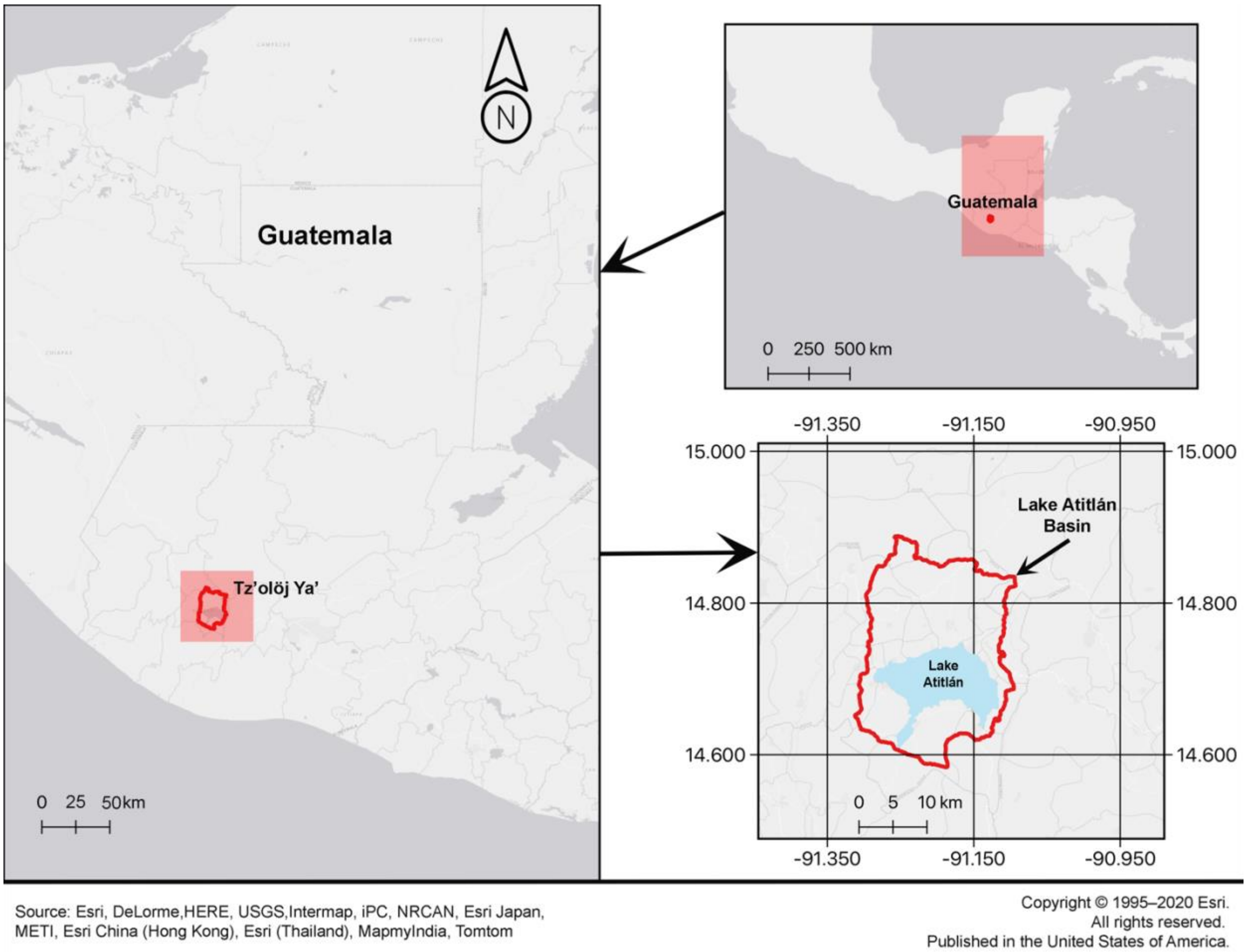

Figure 4. Location of the study area in Guatemala. Created in QGIS software using Esri (2009).

3.5. Methodology

The proposed storyline development process (Fig. 9) takes PM activities in multilingual contexts into account. Therefore, prior to initiating the process, a multilingual guidance team is developed. The team consists of experts and organizers. At least one person with a good command of each language included in the project and knowledge of the corresponding region was present in the team.

3.5.1. Stage 1: the Macro-level storylines

1. *Identifying researcher participants.* Researcher participants (stakeholders from local institutions researching in the study area) are selected to construct Macro- level storylines. It is important to select researcher participants from different professional

and sociocultural backgrounds and who identify as belonging to marginalized groups, to construct a holistic view of the problem.

2. *Developing a focus group with primary stakeholders.* A focus group is created where the guidance team provides language translations between stakeholders. The purpose of the focus group is to
    a. frame the problem: the problem should not be defined too narrowly as it will take its definite shape after subsequent interviews with the complete group of participating stakeholders (Arico et al., 2005);
    b. contextualize the study system by delineating dominant economic sectors, power imbalances, cultural diversity, and the region's political culture, among others (Mostert, 2018);
    c. set the social and geographic contexts of the model; and
    d. outline historical events that have influenced the problem (Foran et al., 2013).

Stakeholders share information in narrative form. The guidance team leads the discussion to obtain the information required to build the model's Macro-level storylines. However, they refrain from restraining participants' ideas or opinions. They also ensure that marginalized communities are discussed. Narratives are recorded in writing. This step aids the guidance team in enhancing situated knowledge and recognizing their positionality in the model-building process while also providing the context for the Meso-level and Micro-level storylines.

3.5.2. Stage 2: developing Meso-level storylines

1. When performing a stakeholder analysis, the Macro- level storyline informs the stakeholder analysis process. The primary stakeholders selected in Stage 1, along with members of the guidance team, brainstorm to identify other relevant stakeholders (Calvert, 1995; Vos and Achterkamp, 2006). The guidance team explicitly delineates stakeholders representing the different dimensions (economic, social, cultural, and political) mentioned in the Macro-level storyline. The team actively seeks individuals and organizations that are associated with marginalized communities.
2. Stakeholders participating in the model-building process are then grouped according to their roles (i.e., decision-makers, users, implementers, and experts) and attributes (i.e.,

power, urgency, interest, and legitimacy) and selected to ensure that at least one person representing each role and attribute is included (Freeman, 2010; Inam et al., 2015; Mitchell et al., 1997).

3. To conduct individual semi-structured interviews with stakeholders, the guidance team prepares focal questions to direct the construction of the Meso-level storylines and carries out individual semi-structured interviews with all participants. Interviews are conducted individually to minimize the influence of power dynamics on the model-building process (Ayrton, 2018; Butler and Adamowski, 2015; Colfer and Dudley, 2011; Inam et al., 2015). Semi-structured interviews are used since they allow interviewees to speak more freely (Ayrton, 2018; Elsawah et al., 2015; Voinov et al., 2018). Since some stakeholders might not be comfortable with their narratives being recorded, interviewers only take notes of the interview (Elsawah et al., 2015; Strauss and Corbin, 1990). Also, participants are asked to use linguistic statements that reflect qualitative knowledge (e.g., when X increases, Y decreases) to extract storylines that are meant to conceptualize systems models (Alcamo, 2008). The role of the interviewer is to extract phrases containing indicators that can be estimated. When an interviewee states an ambiguous concept, the interviewer asks the interviewee to explain more until a tangible relationship between definite variables is identified. The steps of the interview process are elaborated below.
    a. A focal question is formulated by the guidance team to elicit direct and indirect causes of the problem (Arico et al., 2005). For example, what are the underlying causes of the investigated problem? Stakeholders are asked to respond to the focal question in a set of coherent statements, building storylines.
    b. The single-driving-force method (Fig. 5) is used as a starting point to elicit direct and indirect consequences yielded by the problem. As per the field guide established by Evans (2006), narratives can be elicited using the single-driving-force technique by asking questions such as the following. (1) What happens if the problem is reinforced? (2) What happens if the problem is diminished? (3) What happens next? (4) What are the consequences of that? The chain of

questions derived from the single- driving-force method is prolonged to elicit feedback effects of consequences on pre-stated causes.

Figure 5. The single-driving-force method.

4. Each of the extracted narratives is translated into an individual CLD by the guidance team. A CLD is made up of variables and causal links between them (Fig. 6). The sign corresponding to each link indicates the type of relationship between the two variables: "+" indicates a positive causal relationship (i.e., when the causative variable increases, the effect increases and when it decreases, the effect decreases), while "−" implies a negative causal relationship (i.e., when the causative variable increases, the effect decreases and when it increases, the effect decreases). Two types of feedback loops exist: balancing (Fig. 6a) and reinforcing (Fig. 6b) (refer to Inam et al., 2015). The semi-structured interview (elaborated in the previous step) is designed to elicit narratives containing identifiable causes, consequences, and feedbacks. Therefore, this step requires the guidance team to delineate the extracted causes, consequences, and feedbacks, and arrange them in CLD format (Fig. 7). The guidance team strives to ensure that all views are conserved and included in each individual CLD.
5. Ensuring the conservation of all identified relationships, each individual CLD is joined, forming an overall merged CLD as per Inam et al. (2015).
6. The merged CLD is (1) checked for inconsistencies or conflicts and (2) transformed into a storyline by listing the causes, consequences, and feedbacks contained by the CLD in a coherent and comprehensive narrative (Fig. 7).
7. The modified storyline is translated into the languages considered in the model-building activity to make it more accessible to all stakeholders, including marginalized ones.

8. A collective workshop or focus group discussion is held in which (1) the storyline is re-examined with stakeholders and compared with their expectations (Arico et al., 2005), and (2) associated inconsistencies and points of conflict (previously identified in Stage 2, step 5) are discussed with them. The storyline is then modified accordingly. The execution of multiple iterations between stakeholder consultations, storylines, and CLDs, as displayed in Fig. 8, is recommended (Alcamo, 2008).
9. There are two outcomes to this stage: (1) a merged storyline to disseminate the results to marginalized stakeholders (specifically those with low literacy levels who might not be comfortable with the technicalities of CLDs) and (2) a merged CLD which is primarily used by the guidance team and associated researchers to visually identify feedback loops and facilitate the development of stocks and flows in later stages of the project.
10. The system's leverage points (e.g., balancing and reinforcing loops) and zones of undesired outcomes are identified after a merged storyline and corresponding CLD are agreed upon. It is important to note that this storyline and corresponding CLD represent the business-as-usual scenario, containing causes and consequences of the problem as is without the implementation of policies or BMPs.

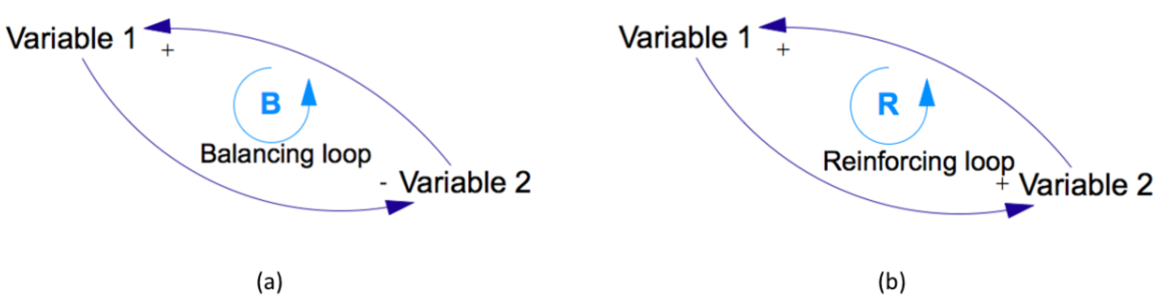

Figure 6. CLD: variables, causal links, and feedback loops.

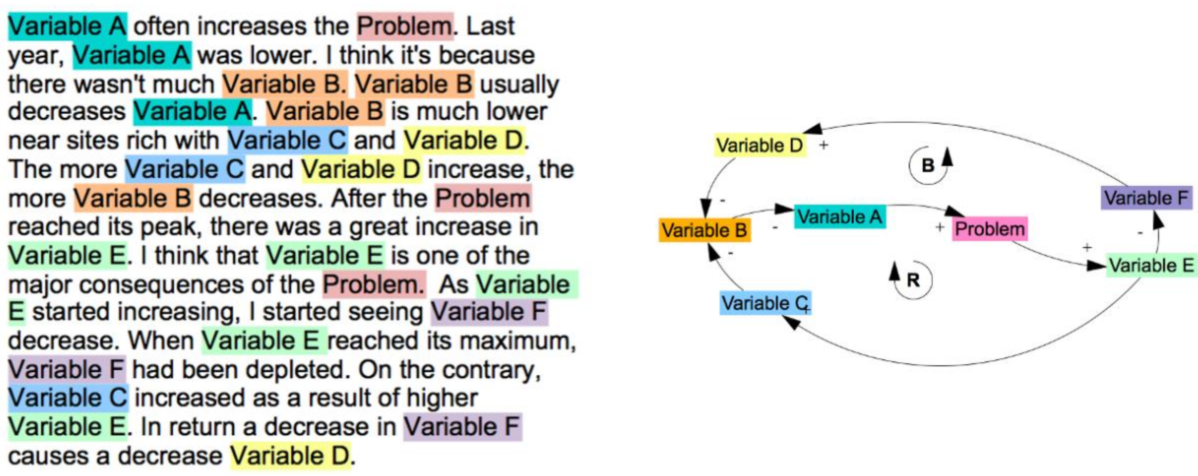

Figure 7. A simplified version of a storyline and its corresponding CLD.

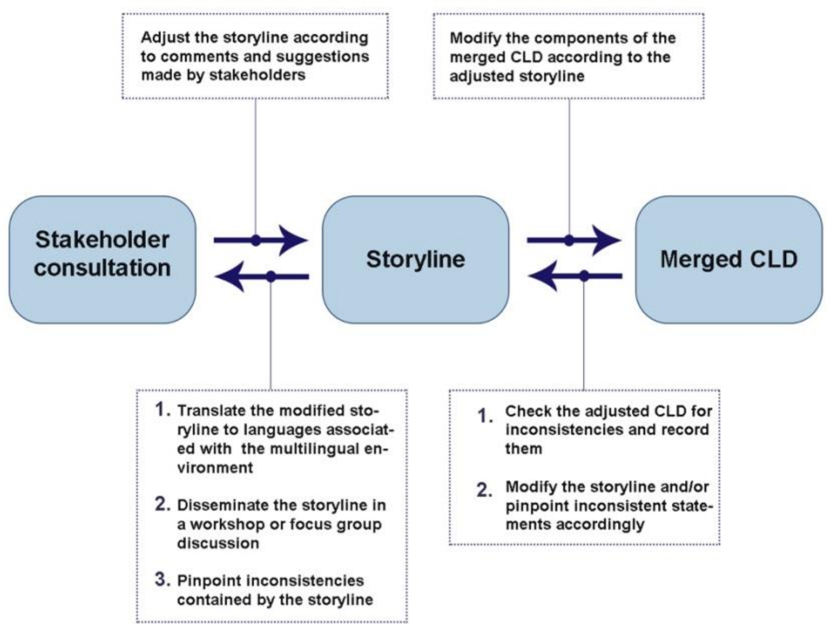

Figure 8. Iterative process between stakeholder consultation, storyline development, and CLD construction.

3.5.3. Stage 3: developing Micro-level storylines

1. In a collective workshop, stakeholders are (1) addressed in the languages they speak and understand and (2) grouped according to their preference towards receiving the results in CLD or spoken narrative form.

2. Leverage points, such as balancing and reinforcing loops, and zones of undesired outcomes are outlined to stakeholders, highlighting targets for BMP and policy applications. Candidate policies that are capable of influencing highlighted targets (i.e., leverage points or undesired outcomes) are elicited from stakeholders.
3. Members of the guidance team ask relevant questions to understand how the suggested policy or BMP either (1) reconfigures or restructures the system or (2) weakens or reinforces aspects of it. The first part of each Micro-level storyline is comprised of the description of each suggested policy or BMP and how it can be integrated into the system.
4. Participants are asked to describe how the implementation of suggested policies or BMPs changes the system's dominant state. In other words, they are asked to describe the future of the suggested policy or BMP in the context of the modeled problem. Elicited predictions, regarding each suggested policy or BMP, make up the second part of each corresponding Micro-level storyline.
5. These policies and BMPs are then simulated in a quantitative version of the model. The results are subsequently presented to stakeholders by members of the guidance team, in the form of a comprehensive narrative, to accommodate non-modelers and less literate stakeholders. These results are discussed until an agreement on suitable solutions is reached. This paper does not cover the implementation of this step.

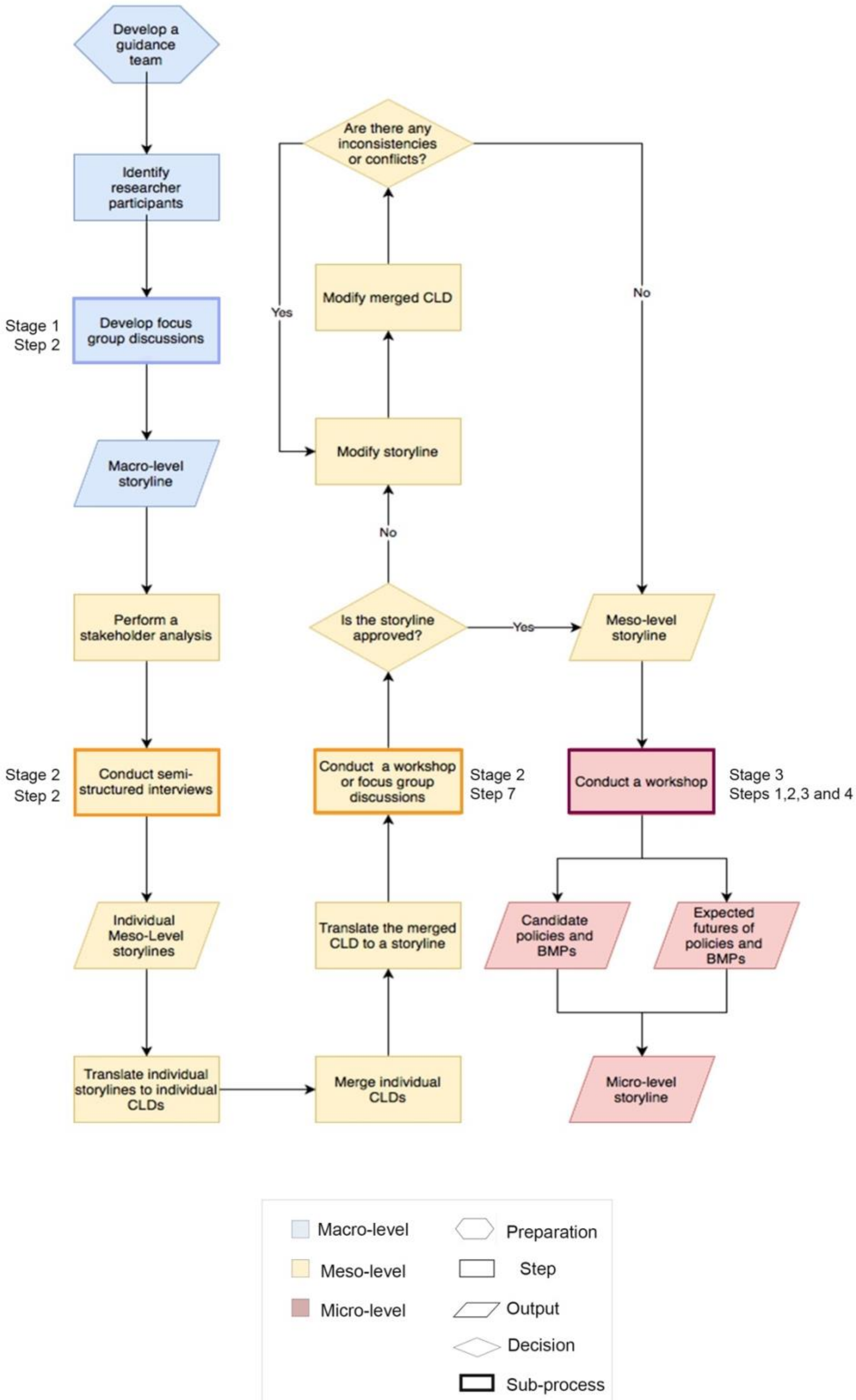

Figure 9. Multi-level storyline development process.

3.6. Results

The Lake Atitlán case study examines the proposed framework's ability to engage stakeholders from the marginalized Mayan community in a participatory model-building activity to investigate the mechanisms governing cultural eutrophication in the area. Table 3 displays the demographics of the Atitlán watershed's general population (INE, 2018) and stakeholders who participated in the case study. A guidance team of three individuals with Kaqchikel, Tz'utujil, K'iche', and Spanish language skills was established before initiating the activity. All activities were carried out in relevant languages. Members of the guidance team were aware that the activity presented a learning opportunity to them as well and remained cognizant of their positionality in the research setting. The priority of the guidance team was to create a space that allowed stakeholders to communicate their perspectives, needs, and concerns. This section provides an elaboration of extracted Macro-level, Meso-level, and Micro-level storylines. The authors highlighted three submodules (Figs. 10– 12), which are part of one conceptual model. The full model can be found in the Supplement.

Table 3. Demographics of project participants.

Demographics	Participatory modeling (%)	General population of Tz'olöj Ya' (%)
Women	24.1	52
Men	75.9	48
Indigenous	62.1	96
Kaqchikel	44.4	39
Tz'utujil	44.4	16
K'iche'	11.2	44
Hispanic	37.9	3
Indigenous language	58.6	81
Spanish language	41.4	18
Literate	86.2	70
Illiterate	13.8	30

3.6.1. Macro-level storylines

The guidance team met with researchers from local and national, Indigenous and non-Indigenous, and academic and governmental institutions conducting research projects in the area. Researcher participants included individuals who identify as belonging to marginalized groups. Focus groups were held with researcher participants. When asked about an overarching problem in the Atitlán watershed, all parties mentioned the lake's eutrophication and associated water quality problems. The eutrophication of Lake Atitlán has been a pressing environmental problem for more than a decade. Researchers' interest in Lake Atitlán has increased since a major episode of cyanobacterial blooms covered 40 % of the lake's surface in October 2009. This event impacted the activities in the area and received significant national and international media coverage. Moreover, the endorsement of the Mega-collector by the government in 2018 reinforced the community's interest in the problem. All research participants have been working on projects associated with the lake's pollution.

Participants highlighted the dominance of three types of economic activities in the area: agriculture, aquaculture, and tourism. They also delineated the presence of two types of authorities: Indigenous and non-Indigenous. For example, in Tz'olöj Ya' there are two municipalities, an Indigenous municipality and an official one. Nevertheless, the Indigenous municipality is not recognized by the Guatemalan government as the main authority but rather as auxiliary. In some towns, such as Pan Ajache'l and Tz'ikinajay, local Indigenous authorities called "Cofradías" have power over local decision-making. However, a governmental institution remains the official authority for managing the Atitlán Basin. The area lacks a unified platform for decision-making, which restricts the proper implementation of BMPs and policies. Therefore, different stakeholder groups have attempted to implement various remedies to improve the lake's water quality. However, their efforts have never been joined, failing to significantly impact the state of the lake. The contrasting perspectives of different stakeholders and the complex political culture of the area have been prominent barriers to the coordinated discussion and implementation of sustainable solutions. Most researcher participants agreed that the eutrophication problem stems from the lack of unified attempts to restrict nutrient discharge into the lake. Furthermore, they emphasized that the success of bottom-up management strategies or policies that aim at controlling nutrient enrichment requires the collaboration of stakeholders with diverse views, backgrounds, roles, and capabilities, many of whom belong to Mayan communities.

The Atitlán watershed encompasses diverse communities with distinct cultural backgrounds. Non-Indigenous stakeholders are primarily Spanish-speaking persons, and Indigenous Peoples have Kaqchikel, Tz’utujil, or K’iche’ first languages. Many Indigenous persons do not communicate well in Spanish and are more comfortable using their native languages. However, Indigenous languages in the region often face discrimination. This is reflected in educational systems, where these languages are not usually acknowledged, even in areas where Indigenous communities are predominant (e.g., 96 % of the population of the department of Tz’olöj Ya’ is Indigenous).

Researcher participants also highlighted some historical events that influenced the problem and associated reactions. For example, residents had first witnessed cyanobacterial blooms in the lake in 2008 and more extensive ones in 2009. These blooms increased residents’ environmental awareness of the lake’s unhealthy trophic state, triggering bottom-up stakeholder-led actions. Also, some stakeholders mentioned that two hurricanes, Agatha in 2005 and Stan in 2010, had caused damage to the lake’s ecosystem. Finally, in 2017, the Mega-collector project (elaborated on in Sect. 3.4) was proposed to solve the lake’s eutrophication problem, triggering tensions between various communities opposing or supporting the project.

Macro-level storylines showed how primary researcher participants chose to model the eutrophication problem of Lake Atitlán. The geographical scope of the model was limited to the Atitlán Basin, and stakeholders from Indigenous and Hispanic origins were considered. Three major economic sectors and concomitant stakeholders were also considered for the model-building activity: agriculture, aquaculture, and tourism. Although Mayan communities make up the majority of the area, most of the past participatory activities in the basin have been in Spanish. From the background information given by participants on power imbalances in the area, and to address relevant power dynamics, the official languages of the model-building project (including internal communication between the guidance team and researcher participants) were chosen to be Mayan languages. However, the Spanish language was still used to address the Hispanic community and include them in the process. Finally, the consideration of stakeholders from both official governmental institutions and local Indigenous authorities was deemed important.

3.6.2. Meso-level storylines

The guidance team used information encompassed by Macro-level storylines about involved authorities, communities, and economic sectors in the area to identify relevant stakeholders. The initial list of stakeholders included Indigenous and non-Indigenous municipal authorities in the Atitlán watershed, local Indigenous authorities (i.e., Cofradías), relevant governmental institutions (the lake's authorities, environmental institutions, and agricultural institutions), farmers' associations, fishers' associations, academic institutions, non-governmental organizations, community-based organizations, and owners of tourism businesses. To construct the Meso-level storylines, stakeholders were first informed of the problem and its background using the Macro-level storyline and then interviewed to elicit causes and consequences underpinning the problem (following the structure of a CLD construction process).

3.6.2.1. Causes

Members of the guidance team initiated each interview with the following focal question. What are the causes of the nutrient enrichment problem in Lake Atitlán? The majority of the interviewees listed soil erosion, inorganic agriculture, and untreated wastewater discharge as primary causes for nutrient enrichment. They attributed soil erosion to deforestation and the latter to urbanization, expansion of agricultural land, and forest fires. Most Indigenous participants stated that the lack of septic tanks and dry toilets exacerbated wastewater discharge. However, a mix of Indigenous and non-Indigenous participants attributed the latter to the lack of wastewater treatment (WWT) facilities, combined with an increase in population (Table 2). Many stakeholders also connected the dominance of inorganic agricultural practices in the area to the need for farmers to maximize profit and governmental subsidies on inorganic fertilizers, among other causes.

A few stakeholders cited inorganic soaps and detergents from people washing their laundry in the lake as a contributor to nutrient enrichment. Some participants linked the loss of native fish species, due to overfishing and invasive fish, to increases in nutrient concentration. Education and environmental awareness were also correlated to multiple variables each. For example, some stakeholders mentioned that an increase in the education level yields a decrease in population but an increase in environmental awareness. Subsequently, an increase in environmental awareness would lead to a decrease in the use of inorganic soaps and detergents. Moreover, participants connected different land-use variables (such as agricultural, forest, and urban areas) to nutrient concentration levels in Lake Atitlán (Figs. 10 and 11). For example, some stakeholders stated that an increase in population leads to an increase in urban areas, consequently yielding a decrease in available land per household for the installment of septic tanks or dry toilets. As mentioned earlier, this increases quantities of discharged wastewater and, consequently, nutrient concentrations in Lake Atitlán.

3.6.2.2. Consequences

In the second part of the semi-structured interviews, the guidance team used the single-driving-force method to elicit the consequences of the nutrient enrichment problem. Participants were asked the following questions. (1) What happens if nutrient concentrations in the lake increase? (2) What happens if they decrease? All participants listed cyanobacterial blooms and the loss of biodiversity as direct consequences of nutrient enrichment of Lake Atitlán. Some stakeholders correlated cyanobacterial blooms to a decrease in tourism, resulting in less revenue for many businesses in the watershed. Other stakeholders mentioned that cyanobacteria would cause illnesses that would decrease workers' productivity, leading to the reduction of agricultural labor and cultivated areas. Others highlighted the effects of loss of fish species due to high concentrations of nutrients, consequently affecting the income of people involved in fishing. As mentioned by participants, the aforementioned indicates that an increase in nutrient enrichment leads to decreased economic prosperity in tourism, agriculture, and aquaculture. Some participants stated that high concentrations of nutrients render the lake's freshwater undrinkable, potentially leading to illnesses and loss of productivity in the area, in addition to increased use of plastic bottles.

3.6.2.3. Feedback loops

The narration of consequences by stakeholders allowed for the identification of feedback effects. The most important feedback loops are contained by (1) two modules representing the local agriculture (Fig. 10) and tourism (Fig. 11) economic sectors and (2) one module representing the mechanisms governing environmental awareness in the region (Fig. 12).

Some feedback loops were described by stakeholders in terms of generalized relationships between nutrient enrichment and economic prosperity (Fig. 13). Feedback links between (1) farmer's income and education (B1, Fig. 10), (2) poverty and education (R5, Fig. 11), and (3) tourism business revenues and potential investments in wastewater treatment plants (WWTPs) (R6, Fig. 11) indicate that the relationship between nutrient enrichment in Lake Atitlán and economic prosperity is represented by a reinforcing feedback loop (Fig. 13a). In other words, some stakeholders stated that economic prosperity (1) increases the education rate, which ultimately decreases population and, subsequently, nutrient enrichment in Lake Atitlán, and (2) increases potential investments in WWTPs, reducing nutrient discharge into the lake. Those feedback effects were elicited from a mix of Indigenous and non-Indigenous stakeholders (Table 4).

On the contrary, relationships between (1) farmer's income and potential investments in improving irrigation efficiency (R1, Fig. 10), (2) farmer's income and potential investments in cultivated areas (R2, Fig. 10), and (3) the number of tourists and the amount of discharged wastewater (B4 and B5, Fig. 11) portray feedbacks between nutrient enrichment in Lake Atitlán and economic prosperity in the form of a balancing loop (Fig. 13b). Namely, some participants implied that economic activities generated by agriculture and tourism yielding economic prosperity (which is perceived by other stakeholders to provide the resources for education and technological investment for environmental improvement) are the primary causes of the nutrient enrichment problem. Since economic prosperity reinforces economic activities (R1 and R2 in Fig. 10, R7 in Fig. 11), which are presently unsustainable, economic prosperity therefore exacerbates nutrient enrichment in Lake Atitlán. This balancing relationship between economic prosperity and nutrient enrichment was strictly obtained from the contribution of Indigenous participants (Table 4).

Conversely, stakeholders linked the dominance of cyanobacteria with environmental awareness. Balancing loops representing this relationship (displayed in Fig. 12), were strictly elicited from members of civil society (NGOs and community-based organizations with Indigenous and non-Indigenous members) (Table 4).

3.6.2.4. Points of conflict

Multiple points of conflict were detected and discussed with relevant participants (selected according to their relevance to the case-specific conflicts) to find solutions. For example, while farmers stated that a decrease in crop productivity and an increase in pests would drive farmers to use more inorganic fertilizers and pesticides, decision-makers suggested that they would make farmers shift to organic agricultural practices, seeking long-term benefits (Table 4). Members of the guidance team met with farmers to discuss this paradox and found that the actual barrier for the adoption of organic agricultural practices is economic. The majority of farmers in the area preferred rapid and short-term monetary benefits over the long-term advantages of organic agriculture. Therefore, as presented in Fig. 10, the relationship between crop productivity and the use of inorganic fertilizers is considered negative (Table 4).

Another point of misunderstanding was the relationship between income and investments in WWT facilities. Some participants stated that increased revenue from tourism, agriculture, and aquaculture leads to increases in potential investments in WWT facilities. Nevertheless, others emphasized the importance of distinguishing different sources of income and the relevance of these sources to the sectors responsible for investing in WWT facilities. They also highlighted that a significant barrier to the development and maintenance of

WWT plants is the distribution of public funds. Regardless of the public sector's monetary capacity, an insufficient amount of funds is typically allocated to environmental management services, such as WWT facilities. After investigating these claims with employees in the tourism sector, an increase in tourism was considered to increase the tourism business owners' capacity to invest in on-site WWT systems. This has already been done in multiple hostels in towns around Lake Atitlán, such as Pan Ajache'l. Also, subnational governments (the official municipalities) are considered responsible for the construction of central WWTPs in towns contained by the watershed. Subnational governments corresponding to towns in the watershed receive the majority of their income from subsidies and grants. Therefore, an increase in subsidies and grants, coupled with increased allocation of funds to environmental services, is expected to increase the development of WWT facilities (Fig. 11).

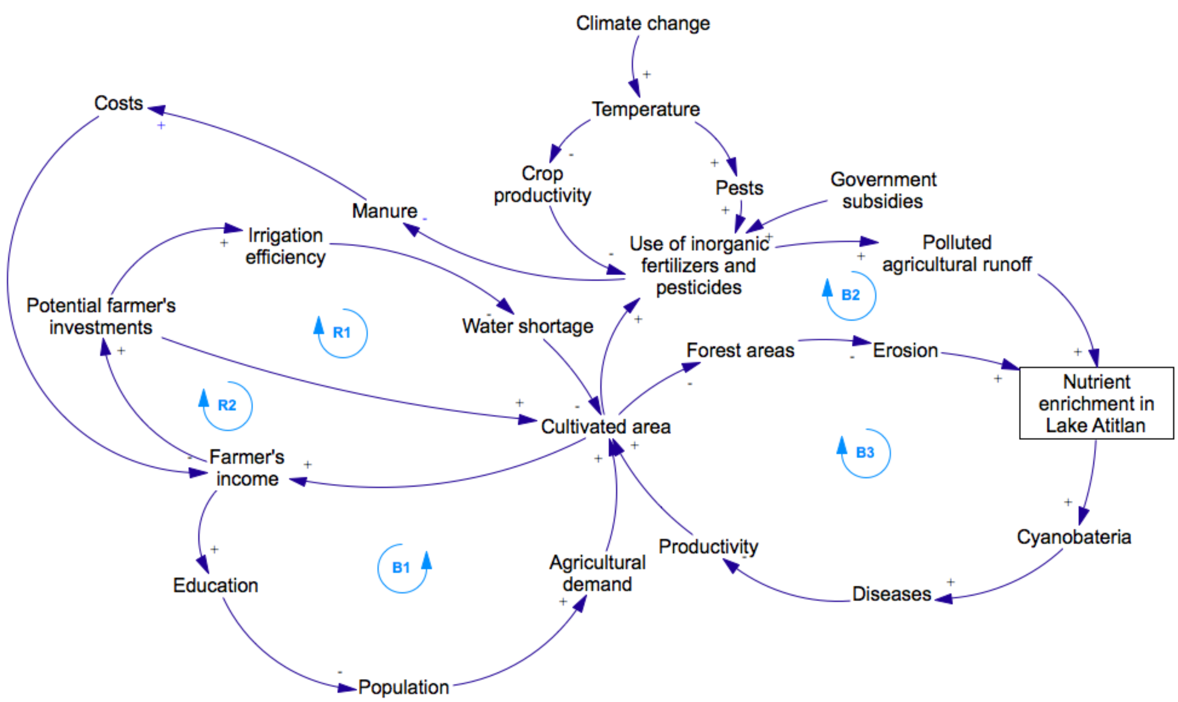

Figure 10. Agriculture submodule.

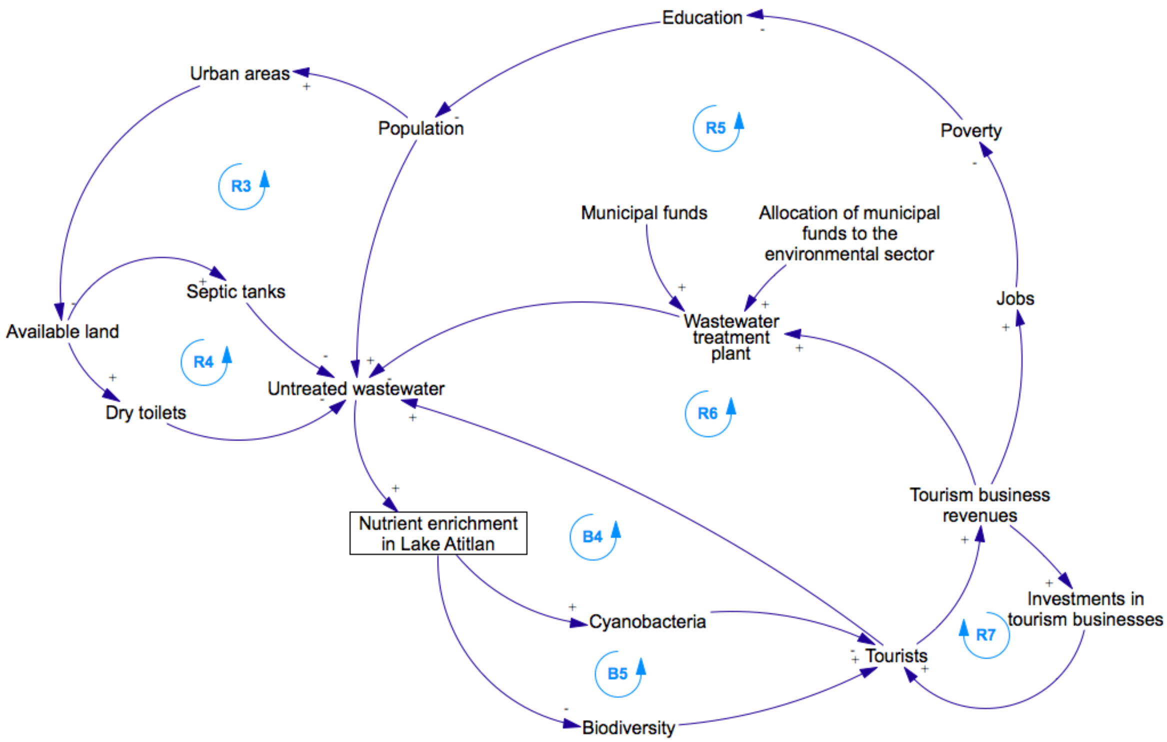

Figure 11. Tourism submodule.

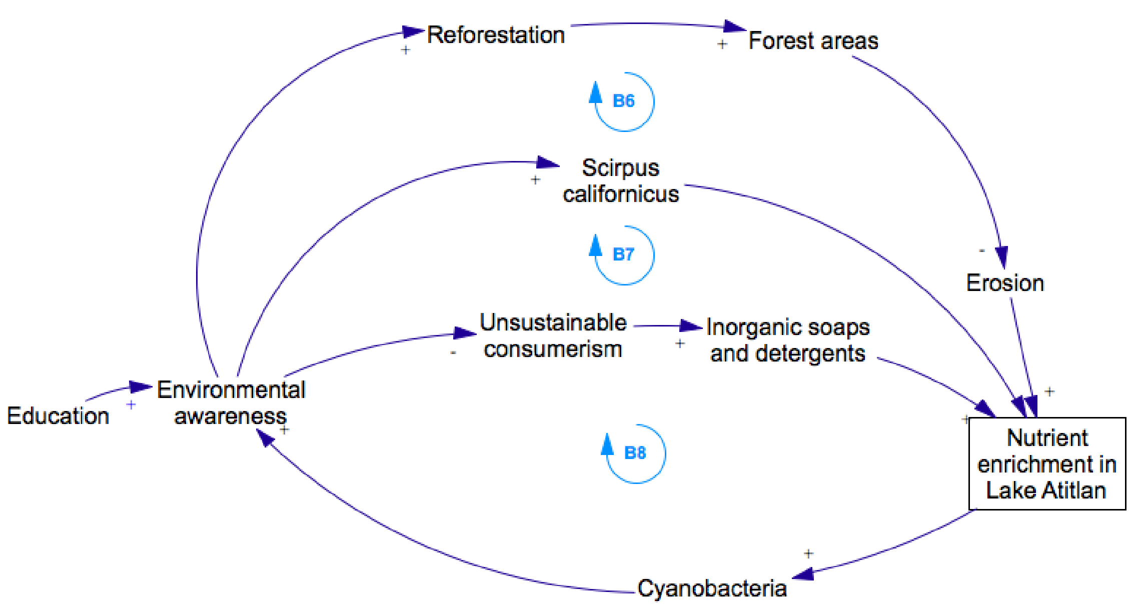

Figure 12. Environmental awareness submodule.

Table 4. Highlights of unique contributions from diverse stakeholder groups.

Contribution	Reference	Contributors
'WWTP' variable	R6 in Fig. 11	Mix of Indigenous and non-Indigenous participants
'Dry latrines' and 'Septic tanks' variables	R3 and R4 in Fig. 11	Indigenous participants
Feedbacks contributing to the reinforcing loop between nutrient enrichment in Lake Atitlán and economic prosperity (Fig. 11 (a))	B1 in Fig. 10; R5 and R6 in Fig. 11	Mix of Indigenous and non-Indigenous participants
Feedbacks contributing to the balancing loop between nutrient enrichment in Lake Atitlán and economic prosperity (Fig. 11 (b))	R1 and R2 in Fig. 10, B4 and B5 in Fig. 11	Indigenous participants
Balancing feedbacks between nutrient enrichment in Lake Atitlán and environmental awareness	B6, B7, and B8 in Fig. 12	Civil society
Positive relationship between crop productivity and the use of inorganic fertilizers	Excluded	Decision-makers
Negative relationship between crop productivity and the use of inorganic fertilizers	Fig. 10	Agriculturists or farmers

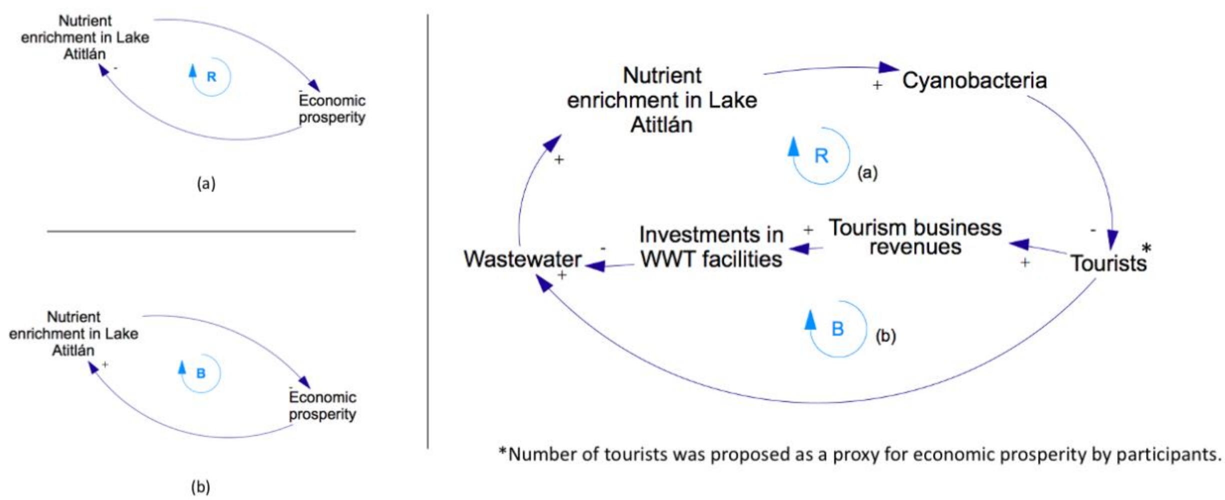

Figure 13. The relationship between nutrient enrichment in Lake Atitlán and economic prosperity – reinforcing loop (a) and balancing loop (b). The two loops on the left represent generalized relationships of the two loops on the right, mentioned and agreed upon by participants. The two contradicting views underpinning the two generalized relationships (loops (a) and (b) on the left) were elicited by different stakeholder groups. The delineation of both relationships shows that all potentially valid points can be represented explicitly in the model, which reinforces the point of inclusivity. Quantification would show which of the two loops dominates the model's behavior.

3.6.3. Micro-level storylines

A collective workshop was held to construct the Micro-level storylines. At first, the candidate solution, known as the Mega-collector project (discussed in Sect. 3.4), was the center of the policy discussion. There was a clear divide between stakeholders who supported or opposed the project. Stakeholders who advocated for the Mega-collector stated that wastewater discharge into the lake is the primary cause of eutrophication. Therefore, implementing the project would definitively decrease nutrient concentrations in Lake Atitlán. Those who were against the project stated that it (1) does not target major mechanisms contributing to the nutrient enrichment problem, such as agricultural runoff and erosion and (2) eliminates dilution (which is essential for decreasing nutrient concentration) by diverting treated wastewater from the watershed. Moreover, one stakeholder highlighted that more than 60 % of wastewater in the area is not discharged through a drainage system, meaning that the project would only target about 40 % of produced wastewater. Some stakeholders, therefore, stated that the Mega-collector project would not be as effective in improving the lake's trophic state. Moreover, they emphasized that exporting water resources outside the watershed would exacerbate the water shortage problem. They also expected that the large-scale project would pose a threat to the lake's biodiversity (which is crucial to residents and businesses in the watershed). The opposition also cited public safety concerns since the area is bounded by seismic faults.

Different stakeholder groups suggested different policies and BMPs targeting various leverage points (e.g., reinforcing and balancing loops). Decision-makers reiterated the importance of developing WWTPs. While some suggested a centralized WWTP (resembling the Mega-collector project), others recommended a decentralized WWT system. Farmers focused on the importance of organic agriculture to reduce the discharge of polluted agricultural runoff into Lake Atitlán. They highlighted the importance of (1) economic incentives to align sustainable agricultural practices with farmers' goals of profit maximization and (2) good governance to align expected outcomes with actual results. They specified the significance of setting the variable "Farmer's income" (Fig. 10) as an evaluation metric for relevant policies and BMPs, to ensure their cooperation. Fishers' associations suggested imposing regulations for sustainable fishing practices and planting and preserving *Scirpus californicus*. They also emphasized that fishers' income should be an evaluation index for potential policies to ensure the collaboration of fishers and the aquaculture industry. Finally, members of the civil society highlighted the importance of forest preservation and reforestation initiatives to prevent eroded soils from entering the lake. When asked about the future of the policies and BMPs they recommended, stakeholders stated that they do not expect each policy or BMP to have a significant impact alone. However, they expect the collaboration between different sectors and the collective implementation of the mentioned policies and BMPs to decrease nutrient concentrations in Lake Atitlán.

3.7. Discussion

3.7.1. Evaluation

The purpose of this study was to show how integrating the multi-level storytelling technique into participatory model- building processes (1) facilitates the inclusion of marginalized stakeholders (less literate, relatively powerless, and associated with marginalized languages), (2) initiates a dialogue, (3) integrates different perspectives of the problem, (4) facilitates model conceptualization, and (5) yields a nuanced understanding of human–water feedbacks governing the investigated problem. The suggested methodology was able to incorporate participants of low literacy levels, which might not have been achieved using other methods. Participants who cannot read or write were able to convey information comfortably. Also, stakeholders were at ease during individual interviews, especially when the guidance team assured them of the confidentiality of their identities. This process succeeded in reducing unhealthy power dynamics and provided an opportunity for the participation of key stakeholders who usually exclude themselves from such activities due to power issues.

Moreover, the variety of relevant languages spoken by the guidance team and stakeholders' freedom to convey information in their preferred language allowed for the participation of numerous primary stakeholders whose first language was not Spanish (the language used in similar activities in the past). Additionally, Indigenous communities considered the use of Indigenous languages as official languages of the project to have greater implications (e.g., it increased their trust in the activity). Numerous Indigenous participants cited this as the primary reason for their participation. Indigenous communities had lost confidence in such processes, as they had witnessed the “tyrannical potential” of participatory activities (Cooke and Kothari, 2001) since previous participatory approaches in the area did not effectively incorporate them. Therefore, instead of effectively integrating Indigenous communities in decision-making, previously conducted participatory processes often reinforced illegitimate and unjust decisions while claiming them as “participatory”. The use of Indigenous languages by members of the guidance team and in documents, visual presentations, and workshops was key to gaining the trust of Indigenous communities. This trust triggered the willingness of some Indigenous participants to start a dialogue and communicate with other stakeholder groups. Carried out in a culturally relevant way, the participatory process allowed Indigenous communities and Hispanic stakeholders to discuss and share solutions during workshops.

The authors suggest that inclusiveness endorses equitable community-based decision-making. They also emphasize that fostering the inputs of marginalized stakeholders and inducing collaboration through inclusion is important for implementing successful solutions. This is evident by the significant contributions to the modeling process made exclusively by Indigenous participants. Exclusive contributions by different stakeholder groups, representing their unique perspectives, are displayed in Table 4. All these contributions were conserved and included in the conceptual model. Moreover, in many cases, similar to the demonstrated case study (e.g., Hassanzadeh et al., 2019; Izurieta et al., 2011), marginalized stakeholders are central to both the persistence and remediation of the examined environmental problem. Therefore, ensuring their inclusion in participatory model- building activities is crucial.

The construction of multi-level storylines also proved to be compatible with CLD development (which is important for conceptualizing systems models). Elicitation of the Macro- level storyline guided and informed the subsequent stages of the process and helped define the scope of the model and the variables and policy scenarios within that scope. Meanwhile, the extraction of the Meso-level storylines helped develop an appropriate understanding of the relationships (causes, consequences, and feedbacks) governing the problem. Once the Meso-level was described, leverage points in the modeled system were explored by identifying critical balancing and reinforcing loops before considering BMPs and policy scenarios. Finally, the elicitation of Micro-level storylines aided in identifying potential BMPs and policies by targeting the leverage points and undesired outcomes mentioned above.

Quantification is needed to assess the impacts of suggested solutions. Nevertheless, some insights can be identified from the qualitative modeling exercise. For example, wastewater treatment, which was discussed by stakeholders, could play an important role in decreasing the discharge of untreated wastewater produced by residents and tourists (R6 in Fig. 11).

However, about 60 % of wastewater in the area is not discharged through a drainage system (Romero, 2013). Therefore, contrary to what some stakeholders suggested, the proposed plan would not present an optimum solution unless coupled with other projects such as drainage system planning and dry toilets. On another note, aiming to reduce the consumption of inorganic fertilizers by supporting organic agriculture (as mentioned by participants in Sect. 3.6.3) could potentially decrease the contribution of agricultural activities to nutrient enrichment (Fig. 10). In this light, subsidies on inorganic fertilizers present an interesting leverage point in the system. Re-examining subsidies and reallocating financial resources to incentivize organic agriculture might play a role in increasing the efficiency of fertilizer application and, consequently, decrease nutrient enrichment in the lake. Finally, the goal of the system is a potent leverage point (Fischer and Riechers, 2019; Meadows, 1999). In this case, rethinking the goal, which focuses on decreasing nutrient enrichment, might be useful. This was not explicitly mentioned by stakeholders as a solution but rather implicitly through discussions about the Mega-collector. The Mega-collector project was opposed by many stakeholders partially since they anticipate that, while addressing the lake’s water quality problems, it could also lead to other problems (e.g., water shortage, economic disparities and loss of biodiversity). Therefore, shifting the goal of the system to focus on an environmental component that could offer a more holistic view of the system’s wellbeing, such as biodiversity, might be useful.

On another note, this study has three main limitations. First, it is difficult to assess the inclusiveness of the process. For example, the authors considered unique contributions of different stakeholder groups to indicate inclusiveness; however, this might simply be an indicator of the complexity of the problem (Rowe and Frewer, 2004). Second, the process included individual sessions to reduce the impact of unhealthy power dynamics and encourage the effective involvement of less powerful participants (Inam et al., 2015). However, group sessions (e.g., workshops and focus groups) were needed to initiate a dialogue between different stakeholder groups (Evans, 2006). The guidance team tried to detect unhealthy power dynamics and designed the agendas of these group sessions to explicitly encourage the participation of less powerful stakeholders. However, the extent to which unhealthy power relations impacted the effectiveness of participation was unknown. Finally, a feedback loop between crop productivity and use of inorganic fertilizers (Fig. 10) might exist. However, the mechanisms and nature of this loop have not been further explored due to time constraints.

3.7.2. Human-water feedbacks

Eliciting storylines from stakeholders helped detect human– water feedbacks, even more so than CLDs. When participants construct CLDs themselves, they are restricted by variables and causal links between them. Storylines allowed for narrating more nuanced versions of connections between variables. This prevented participants from making reductionist assumptions (typically resulting from the restrictive nature of CLDs) and allowed for relevant discussions. Dynamics of human–water feedbacks discussed by stakeholders were aligned with those mentioned in the literature: the “Rebound Effect” (Dumont et al., 2013) and the “Pendulum Swing” (Van Emmerik et al., 2014). This shows how storytelling is compatible with human–water systems; it facilitated the capture of abstract concepts encompassed by human–water feedbacks that might not have been identified using other model-building methods or data sources. The identification of relationships that have been observed or pointed out by previous studies is valuable to the advancement of the study of human–water systems.

The Rebound Effect describes the appearance of unintended outcomes resulting from the implementation of technocratic solutions that fail to consider sociocultural factors (Di

Baldassarre et al., 2019). More specifically, it states that the application of technologies to increase efficiency in resource use often increases resource consumption (Alcott, 2005; York and McGee, 2016). An example of the Rebound Effect, known as the irrigation paradox (Dumont et al., 2013), was highlighted by stakeholders. Numerous participants questioned the assumption that an increase in farmers' technological investments in irrigation efficiency would definitively reduce agricultural runoff. While water shortage is a dominant problem in the region's agricultural sector, most participants agreed that increased irrigation efficiency would lead to the expansion of cultivated land. The saved water would thus be reallocated by farmers to cultivate more crops and irrigate larger areas (Fig. 10). The latter has been confirmed by earlier discussions with farmers, who claimed to favor profit maximization. The information elicited by the proposed methodology allowed for the consideration of expected farmers' behaviors and navigation of commonly made assumptions that contradict them. This is important for robust decision-making in water resources management, since ignoring behaviors when creating solutions can lead to unintended socio-economic feedbacks that lessen or reverse the intended impact. In other words, acknowledging relevant sociocultural behaviors using unconventional methods, such as storytelling, might help ensure that the actual outcomes of corresponding solutions are consistent with predicted ones.

The Pendulum Swing (Van Emmerik et al., 2014; Liu et al., 2015) is described as the change of priorities from immediate economic prosperity to environmental protection or vice versa (Di Baldassarre et al., 2019). This phenomenon was delineated by several stakeholders and represented in two different balancing loops (B6 and B7 in Fig. 12). Central to the representation of this phenomenon was the concept of environmental awareness, which was mentioned by many stakeholders in this study and highlighted in previous models (e.g., Van Emmerik et al., 2014). For example, stakeholders stated that the major cyanobacterial blooms in 2009 increased environmental awareness in the area. Prior to the blooms, practices encouraged the expansion of agricultural areas through deforestation. However, after the symptoms of the lake's degradation appeared, extensive reforestation campaigns were initiated by the government to prevent soil erosion. Therefore, the cyanobacterial blooms caused a shift to prioritizing forest over agricultural areas. The cyanobacteria bloom also spurred fisher-led campaigns for the restoration and protection of *Scirpus californicus* along the lake's borders, which had been overexploited for craft production and destroyed by hurricanes Stan (2005) and Agatha (2010). Through these examples, it can be seen that storylines can complement datasets and quantification processes. Elicited explanations, such as expected changes in forest areas, could enable robust projections of data trends, explain fluctuations in data trends, and facilitate the conceptualization and projection of relationships contained by the model.

The generated model also reflects a more general conflict over the relationship between environmental degradation and economic growth. Mechanisms that create reinforcing feedbacks (e.g., R6 in Fig. 11) and balancing feedbacks (e.g., B5 in Fig. 11) between factors indicative of economic growth (e.g., revenue and investments) and the lake's trophic state were elicited from stakeholders. As mentioned earlier, for example, while some stakeholders suggested that tourism activities yielded mechanisms exacerbating the lake's trophic state, others highlighted the need for revenues generated by such activities to invest in technological facilities to improve the lake's water quality (i.e., WWTPs). This indicates that the applied method was capable of organically capturing the archetypal debate, surrounding the relationship between environmental degradation and economic growth, through diverse socioculturally explicit perspectives. This is crucial for (1) modeling human–water systems, where different governing sociocultural mechanisms require more nuanced versions of generalized relationships and (2) developing well-targeted recommendations in water resources management. For example, in this case study, including a contextualized version of the relationship between economic prosperity and nutrient enrichment of the lake allows the development of relevant recommendations that aim to (1) intensify the impact of the reinforcing loop (e.g., optimize the allocation of resources generated by economic prosperity to reduce nutrient enrichment in the lake) and (2) abate the impact of the balancing loop (e.g., ensure that economic prosperity is driven by environmentally sustainable economic practices that have no or minimal adverse effects on Lake Atitlán) by targeting the socioculturally specific mechanisms that govern each.

3.8. Conclusion

The proposed participatory model-building framework helps to address the challenges of tailoring PM activities in water resources management to accommodate diversity within societies and facilitate the inclusion of marginalized stakeholders (i.e., less literate, comparatively powerless, or associated with marginalized languages). In general, the implementation of many PM processes remains biased as they often view communities as homogeneous units and do not consider different capabilities, needs, and interests within diverse communities.

The authors suggest that storyline development is capable of facilitating inclusiveness in participatory modeling. However, since the literature on PM in environmental and resource management contexts primarily provides participatory storyline development methodologies that are either (1) compatible with the development of linear models or (2) do not expose the leverage points of the system prior to selecting and testing relevant solutions, the authors propose a conceptual framework for developing storylines that aim to conceptualize and inform systems models while making use of the leverage points of the systems. The proposed framework is underpinned by the MLP framework, adjusted to accommodate the conceptualization of multi-level storylines. The authors then offer a stepwise approach for implementing the process while helping to facilitate the inclusion of marginalized stakeholders.

The proposed framework was tested in the Atitlán Basin, Guatemala, and aimed to incorporate marginalized Mayan communities in the PM process. The applied method was able to (1) incorporate stakeholders who are less literate, relatively powerless, and associated with a marginalized language in the PM process and (2) integrate different perspectives of diverse community members. Results showed that not only is inclusiveness important to endorse equitable decision-making, but it also (1) fosters key inputs from marginalized stakeholders and (2) induces the needed dialogue for the successful implementation of solutions. Moreover, the method provided stakeholders with an opportunity for narrating more nuanced versions of relationships between variables, allowing the extraction of contextualized human– water feedbacks.

The suggested conceptual framework facilitated the translation of storylines into relationships that form the conceptual basis of the systems model. As a next step, the conceptual model can be transformed into stocks and flows and quantified. The quantified model would be inherently underpinned by socioculturally specific relationships and, therefore, could help decision-makers develop well-targeted recommendations in water resources management.

3.9. Supplement

The supplement related to this article is available online at: https://doi.org/10.5194/hess-25-1283-2021-supplement.

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Connecting text to Chapter 4

In this chapter, the results of the stakeholder activity were analyzed using qualitative approaches based on the Grounded Theory. The paper focuses on solutions to the eutrophication problem in Lake Atitlan and barriers to their implementation. It also outlines challenges to inclusive stakeholder engagement that can inform future research.

This chapter will be submitted to a journal. The author of the thesis was responsible for conducting field work, performing the analysis, and writing the paper. Dr. Julien Malard and Marco Ramirez contributed to the field work. Emma Anderson edited the paper. Dr. Adamowski, Dr. Julien Malard, and Mohammadreza Alizadeh supervised the project. The list of references cited in this paper is presented at the end of the chapter.

Chapter 4: Placing inclusion at the center of stakeholder engagement: nutrient management with the Mayan Indigenous community in Lake Atitlán Basin

4.1. Abstract

Cultural eutrophication, due to the anthropogenic discharge of nutrients, is a challenge facing water bodies globally. This is a multifaceted problem underpinned by interactions between human and water systems. Stakeholder engagement can be a powerful tool for (1) developing an understanding of mechanisms that underpin cultural eutrophication and (2) informing environmentally and socially acceptable solutions. However, many stakeholder engagement activities do not characterize and address the barriers that prevent the inclusion of marginalized stakeholder groups, leading to the exclusion of key actors. In this research, an inclusive stakeholder engagement process was conducted with Mayan Indigenous Peoples in the Lake Atitlán Basin, Guatemala, which has experienced severe cultural eutrophication for more than a decade. The process, which included interviews, focus group discussions, and workshops, aimed to facilitate the inclusion of marginalized stakeholders - less-literate, relatively powerless, and associated with marginalized languages. The results were analyzed using qualitative methods in Grounded Theory (e.g. open coding). The study generated policy implications focusing on four components: inclusive stakeholder engagement, sustainable agriculture, wastewater treatment planning, and education. Additionally, challenges of inclusive stakeholder engagement were identified to inform future research.

4.2. Introduction

Cultural eutrophication, defined as excessive plant growth in surface waters due to anthropogenic nutrient pollution, poses a major challenge to aquatic ecosystems (Smith and Schindler 2009). Since the 1950s, increases in population, food production, fertilizer applications, and animal and human waste discharge have drastically increased the mobilization of nutrients (Howarth et al. 2005, Beusen et al. 2016). The transport of nutrients to water bodies is then facilitated by land use change, such as the expansion of agricultural land and deforestation (Seitzinger et al. 2010, Beusen et al. 2016). Eutrophication can lead to oxygen depletion, production of toxins, fish kills, and a decrease in aquatic species diversity (Diaz and Rosenberg 2008). Moreover, it incurs significant costs for many economic sectors, complicates the treatment of drinking water, and damages the aesthetics of water bodies (Pretty et al. 2003, Smith and Schindler 2009).

Cultural eutrophication is a complex, multifaceted problem involving interactions between socio-economic and biophysical components (Smil 2000). However, the formulation of environmentally and socially acceptable solutions to such problems is often restricted by the disconnect between evidence-based recommendations, decision-makers, and actors responsible for implementing solutions locally (Blake et al. 2000, Tippett et al. 2007). Therefore, stakeholder engagement is crucial for developing a holistic understanding of the problem, delineating the socio-culturally specific mechanisms that underpin it, and informing local decisions (Inam et al. 2015, Perrone et al. 2020).

Stakeholder engagement should be inclusive, incorporating a diversity of perspectives to capture knowledge and culturally-relevant solutions that can be adopted and promoted by actors (Mease et al. 2018, Hassanzadeh et al. 2019). In particular, effective environmental decision-making requires the involvement of the communities that are impacted by an environmental problem (Kiker et al. 2005, Evans et al. 2006). Marginalized communities are often the most vulnerable to environmental degradation (Butler and Adamowski 2015). For example, Indigenous Peoples rely on natural resources for their economic, social, cultural, and spiritual wellbeing and can be heavily impacted by degradation or loss of ecosystem services (Ford et al. 2020). Yet, such communities are usually underrepresented in participatory decision-making schemes (Mease et al. 2018).

Three broad issues that might contribute to the lack of representation are highlighted. First, marginalized communities might not be considered in the stakeholder analysis, excluding them in subsequent engagement (Reed et al. 2009, Sharpe et al. 2021). Second, they might choose not to get involved. Studies have suggested numerous reasons why stakeholders choose not to participate, including time and resources (Reilly and Adamowski 2017), low perception of risks (McComas 2001), and lack of relatively strong opinions (Johnson et al. 1993) - among others. The reasons tend to be case specific (Sutton 2006). For example, in the context of marginalized communities, having witnessed the 'tyrannical potential' of participation in previous stakeholder engagement activities might be a key reason why some underrepresented groups choose not to get involved (Guijt and Shah 1998, Cooke and Kothari 2001, Saporito 2016). Third, if marginalized groups choose to participate, they might not be well-accommodated during the process. In other words, barriers to their effective participation might not be characterized and taken into account (Bohensky and Maru 2011, Holifield and Williams 2019, Bou Nassar et al. 2021). When stakeholders are not actively participating due to certain barriers (e.g. language barriers, power dynamics, and lack of expertise in participatory processes), they are more likely to be underrepresented in final decisions (Turner and Weninger 2005, Sutton 2006, Mease et al. 2018). This study does not address (1) but touches on (2) and focuses on (3).

Numerous stakeholder engagement activities in environmental management have involved or attempted to involve typically underrepresented groups (Inam et al. 2015, Mzembe 2016, Benham and Hussey 2018, Mease et al. 2018). Kepore and Imbun (2011) and Ulrich et al. (2016) engaged Indigenous Peoples in Canada and Papua New Guinea, respectively; however, both studies mentioned that they were not able to gain more holistic views of the Indigenous Peoples' perspectives due to challenges they did not elaborate on. Tonmoy et al. (2020) mentioned that Indigenous communities were not highly represented in their surveys or workshops without specifying the reasons that had led to the lack of representation. They then carried out individual interviews to fill the gaps. Hence, the approach to the inclusion of marginalized stakeholders was reactive rather than proactive. Inam et al. (2015) incorporated smallholding farmers in a stakeholder engagement process that required reading and writing. Although the approach might have excluded less literate participants, barriers to fuller participation were not mentioned. Hassanzadeh et al. (2019) carried out a participatory activity in a multilingual region without mentioning language barriers or how they were addressed. For example, if marginalized languages were not accommodated, the effective participation of stakeholders associated with them could be hindered. Similarly, many other studies involving stakeholder engagement in environmental management did not explicitly characterize and address the barriers that prevent researchers from effectively engaging marginalized groups (Reilly et al. 2018, Boiral et al. 2020).

In light of this, the authors suggest that barriers to inclusive participation in environmental decision-making be proactively identified. This would play a role in enhancing the effectiveness of engagement and helping contribute to real inclusion rather than the 'illusion of inclusion' (Few et al. 2007). Therefore, the primary focus of this research is the application of an inclusive stakeholder engagement process, incorporating Mayan Indigenous communities in Lake Atitlán Basin (LAB) to investigate anthropogenic nutrient enrichment. The objectives of the study are to:

1. Apply an inclusive stakeholder engagement framework in LAB which proactively identifies and addresses barriers to effective participation of marginalized groups.
2. Understand the causes and consequences of anthropogenic nutrient enrichment in LAB and identify solutions and barriers to their implementation.
3. Delineate implications for policy-making in the context of anthropogenic nutrient discharge in LAB.
4. Identify the challenges of inclusive stakeholder engagement faced by this research to inform future research.

In a previous study, Bou Nassar et al. (2021) (1) presented and discussed the results of the stakeholder engagement process using systems thinking, (2) focused on conceptual modeling (primarily targeting an audience of modelers), and (3) elaborated the causes and consequences of the eutrophication problem. The current study uses methods in Grounded Theory (Viirman 2015) to analyze the results for a broader, multidisciplinary audience and provides three main additional contributions: (1) it provides a deeper focus on solutions, (2) it introduces stakeholders' perspectives on barriers to proposed solutions and integrates both, barriers and solutions, to produce implications for policy-making, and (3) it draws on lessons learned from the process to discuss broader implications on challenges of inclusive stakeholder engagement. The remainder of the paper is structured as follows: First, the study site is presented. Then, the stakeholder engagement framework is provided. Following that, the findings of the stakeholder engagement process are presented. Lastly, the process is evaluated, the findings are discussed from the perspective of policy-making, and challenges of inclusive stakeholder engagement are highlighted.

4.3. Study area

Formed in a collapsed caldera, Lake Atitlán is the deepest lake in Central America (Fig. 14). It witnessed a massive cyanobacteria bloom, covering 40% of its surface area, in October 2009 (Komárek et al. 2013). Today, almost 11 years later, the lake is still experiencing ongoing human-induced eutrophication. Lake Atitlán is endorheic and is located in the southwestern region of Guatemala with an average depth of 220 m, a maximum depth of 341 m, and a surface area of 137 km^2 (Newhall 1987). The watershed is 541 km^2 and experiences two main seasons: dry and wet (Weiss 1971). Steep slopes make up more than 50% of LAB (Komárek et al. 2013).

Lake Atitlán Basin contains 15 municipalities and has a population of almost 300,000 (INE 2018). More than 70% of its terrestrial area is covered with forests and cultivated land. Increased economic activity in agriculture and tourism, coupled with a lack of environmental regulations and policies, has increased point and nonpoint source nutrient pollution and eutrophication of the lake. The lake's trophic state has recently begun shifting from oligotrophic to mesotrophic (Rejmánková et al. 2011).

There is a lack of water quality data in LAB (Rejmánková et al. 2011). Moreover, there is no consensus in the literature on the lake's limiting nutrient(s). Rejmánková et al. (2011) and Komárek et al. (2013) mentioned that an increased phosphorus discharge into the lake caused the blooms. Corman et al. (2015) stated that phosphorus and iron were the limiting nutrients of eutrophication. Weisman et al. (2018) indicated that a colimitation of inorganic phosphorus, inorganic nitrogen, and organic carbon might exist.

The basin is home to three Indigenous communities (Kaqchikel, Tz'utujil, and K'iche') and Hispanic residents. Indigenous communities depend on the lake for economic, social, spiritual, and cultural purposes and have witnessed a history of marginalization in Guatemala. This marginalization is perpetuated by the educational system, which often does not incorporate Mayan languages, and at the governmental level, which considers Indigenous municipalities as auxiliary.

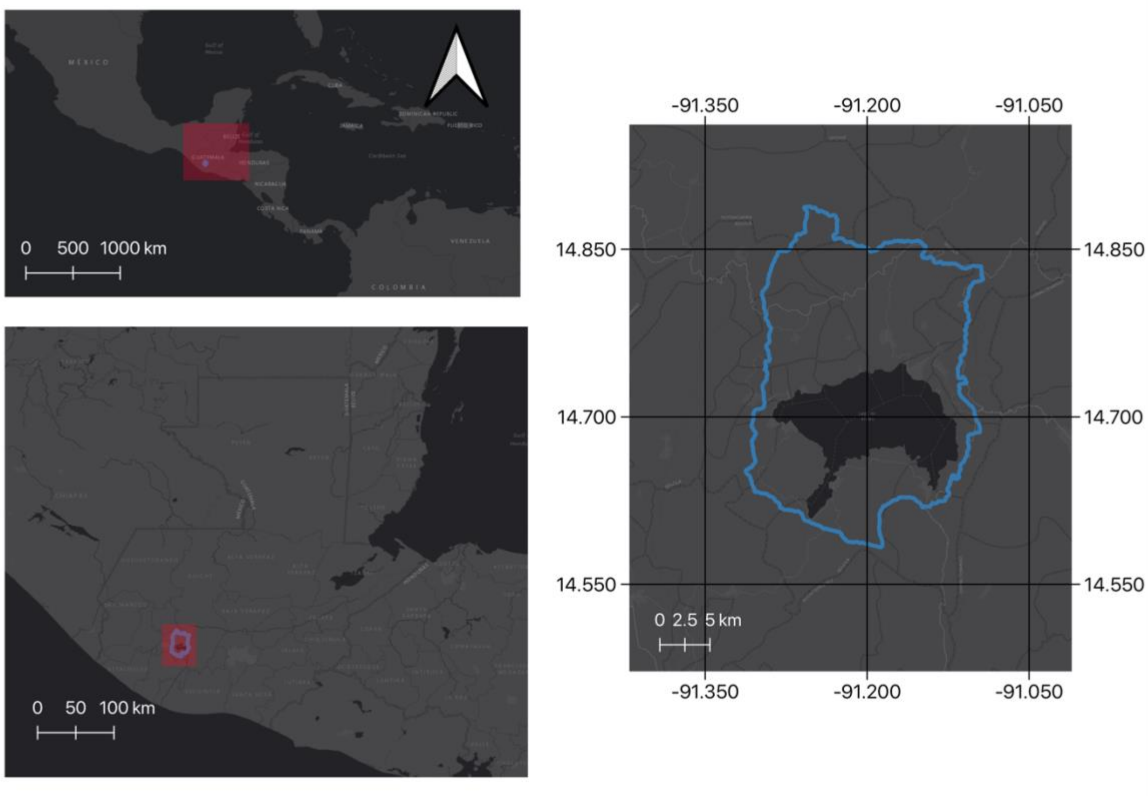

Figure 14. Location of the Lake Atitlán Basin. Created in QGIS software using Esri (2009).

4.4. Stakeholder Engagement Framework

Investigating the issue of anthropogenic nutrient discharge in LAB is complex and requires methods that (1) integrate the perspectives of diverse stakeholders and (2) bridge the gap between science, economic sectors, governance bodies, and society (Ulrich et al. 2016). To conserve the views of marginalized stakeholders and reduce barriers to their participation, the authors propose the use of a stakeholder engagement framework, developed by Bou Nassar et al. (2021), that is inclusive by design, elaborated in this section.

4.4.1. Inclusion by design

The authors reviewed the demographics of the LAB population prior to designing a stakeholder engagement framework (Bou Nassar et al. 2021). They investigated first languages, ethnicities, and literacy using data provided by Instituto Nacional de Estadistica (INE) (2018) to characterize the barriers to the effective participation of marginalized groups. The study area includes stakeholders who are less literate, relatively powerless, and/or associated with marginalized languages (Table 5). The stakeholder engagement approach was tailored to explicitly accommodate the effective participation of the aforementioned groups (Bou Nassar et al. 2021). The inclusive process entailed three main features:

- **Storytelling** - The authors selected storytelling to facilitate the participation of less literate individuals (Bou Nassar et al. 2021). Oral storytelling is a way to describe conditions and provide insights using oral narration (Hazeleger et al. 2015, Moezzi et al. 2017, Zscheischler et al. 2018). It does not require participants to have reading or writing skills. Since the method does not limit the communicator with a technical approach, it encourages the participation of stakeholders who might not be comfortable with more restrictive approaches, such as mental mapping (Colfer and Dudley 2011). It also provides communicators with the opportunity to share anecdotes and metaphors that help them explain their observations and viewpoints.
- **Individual sessions** - The views of relatively powerless stakeholders are often overshadowed by more powerful and vocal stakeholders (Turner and Weninger 2005, Evans et al. 2006, Ayrton 2018). The authors attempted to reduce unhealthy power dynamics by having the process carried out in individual sessions when needed (Butler

and Adamowski 2015, Inam et al. 2015, Ayrton 2018). This facilitated the effective participation of relatively powerless stakeholders who might not have effectively contributed to group discussions.

- **Multilingualism** - There is a need to be cognizant of language barriers in multilingual environments to prevent the further marginalization of underrepresented languages and associated groups (Mondada 2012, Mease et al. 2018). The empowerment of dominant yet marginalized native languages of Indigenous residents (Kaqchikel, Tz'utujil, and K'iche') was facilitated by making Indigenous languages the official languages of the activity. Every stage of the process was multilingual, accommodating Kaqchikel, Tz'utujil, K'iche', and Spanish speakers. Members of the guidance team, who carried out the field research, used these Mayan languages for internal and external communication (Bou Nassar et al. 2021).

4.4.2. Problem framing

The cyanobacterial blooms in October and November of 2009 prompted coverage by national and international media and were perceived as a serious environmental problem (Harvey 2012). Many researchers became interested in studying the lake and finding solutions to its eutrophication problem (Rejmánková et al. 2011, Komárek et al. 2013, Ferráns et al. 2018, Weisman et al. 2018). In the first step of this research, a focus group was developed with researcher participants (i.e. stakeholders from local institutions conducting research in LAB) to (1) discuss the overarching environmental problem in LAB and (2) contextualize the participatory activity by defining social, economic, political, and cultural aspects of the study site. Researcher participants included Indigenous and non-Indigenous members (Bou Nassar et al. 2021).

4.4.3. Stakeholder analysis

The guidance team, along with researcher participants, used brainstorming to identify relevant stakeholders (Calvert 1995, Vos and Achterkamp 2006). The process involved highlighting stakeholders pertinent to the social, economic, political, and cultural aspects of LAB, which were defined at the Problem Framing stage (Bou Nassar et al. 2021). The guidance team actively sought Indigenous groups who are usually underrepresented in decision-making schemes in the area. Afterwards, identified stakeholders were categorized according to their roles (i.e. decision-makers, users, implementers, and experts) and attributes (i.e. power, urgency, interest, and legitimacy). Participants were selected to ensure that all roles and attributes were represented (Mitchell et al. 1997, Freeman 2010, Inam et al. 2015, Bou Nassar et al. 2021). Stakeholders were contacted by the guidance team via phone or email, or in person. Participants included farmers, fishers, decision-makers (working in governmental institutions and Indigenous and non-Indigenous municipalities), individuals associated with the civil society (i.e. NGOs and community-based organizations), and academics (Bou Nassar et al. 2021). The guidance team tried to reach out to owners of tourism businesses, but they were non-responsive. The demographics of the participants are shown in Table 5.

Table 5. Demographics of the project participants (Bou Nassar et al., 2021).

Demographics	**Stakeholder engagement activity (%)**	**General Population of Tz'olöj Ya' (%)**
Women	24.1	52
Men	75.9	48
Indigenous	62.1	96
Kaqchikel	44.4	39
Tz'utujil	44.4	16
K'iche'	11.2	44
Hispanic	37.9	3
Indigenous language	58.6	81
Spanish language	41.4	18
Literate	86.2	70
Illiterate	13.8	30

4.4.4. Semi-structured interviews

The guidance team carried out 14 interviews with 19 interviewees. Semi-structured interviews were used since they allow interviewers to guide the interviewees rather than restrict them (Elsawah et al. 2015, Ayrton 2018, Voinov et al. 2018, Bou Nassar et al. 2021). Interviews were not recorded since this might have made some stakeholders uncomfortable (Strauss and Corbin 1990, Elsawah et al. 2015). Instead, interviewers took written notes of each interview (Bou Nassar et al. 2021). Interviews were normally carried out in individual sessions to allow stakeholders who might feel restrained in the presence of other community members to communicate openly and participate effectively. However, three stakeholders asked to conduct the activity with one or more partner(s). Participants were asked to answer questions in narrative form, using storytelling (Hazeleger et al. 2015, Moezzi et al. 2017, Bou Nassar et al. 2021). They were not restricted with a technical approach but rather provided with leeway to share anecdotes and metaphors to elaborate their viewpoints. Stakeholders who were comfortable doing so constructed causal loop diagrams as they were being interviewed. The aim of the causal loop diagrams was to assist in systems thinking which is outside the scope of this study but covered in Bou Nassar et al. (2021). The language of each interview was decided by the interviewee. The purpose of the interview was to: (1) understand the causes and consequences of nutrient enrichment in LAB, (2) identify potential solutions, and (3) delineate barriers to the implementation of solutions. The interviews were analyzed using methods in Grounded Theory, which consists of methods to identify themes from textual data and produce meaningful concepts. Open coding (Berg 2007) was used to identify, label, and categorize concepts that were articulated during the interviews (Taylor et al. 2016). Open coding was performed using NVivo (released March 2020).

4.4.5. Workshops

The guidance team used snowball sampling, a technique (Vogt 2005) by which existing participants refer the guidance team to new key stakeholders to reach out to additional stakeholders who might contribute to the activity (Bou Nassar et al. 2021). New participants were invited to participate in collective workshops (and individual interviews) that accommodated four languages (Kaqchikel, Tz'utujil, K'iche', and Spanish). Combined, twentytwo stakeholders attended two collective workshops. The purpose of the workshops was to discuss potential policies and best management practices. While the interviews extracted solutions from stakeholders, the collective activities initiated a dialogue about solutions, which were underpinned by the information and suggestions elicited from the interviews (Bou Nassar et al. 2021). Specifically, in the workshops, solutions were discussed in more depth, exposing potential pitfalls and advantages.

The guidance team was cognizant of the presence of power dynamics at workshops and designed the agendas to explicitly incorporate topics associated with marginalized stakeholder groups. Facilitators also encouraged marginalized stakeholders to participate, express their viewpoints, and lead discussions. The main workshop discourse was carried out in Kaqchikel. The guidance team used chuchotage (also known as whisper interpretation) to accommodate participants who speak other languages. Chuchotage is a form of simultaneous interpretation where the interpreter remains beside a small target group and whispers a translation of what is being said (Hamid 2020). The workshops started with a description of the synthesized results of the interviews. The guidance team used storytelling to disseminate the results. Afterwards, participants were asked to suggest and discuss best management practices (BMPs) and policies that they thought would decrease nutrient input in LAB and help control eutrophication. This initiated multiple debates and discussions between different stakeholder groups.

A survey questionnaire was developed and distributed at the end of the two workshops to evaluate the participation of stakeholders in workshops. The target of the survey was to investigate whether or not stakeholders effectively participated in workshops. Broadly, the ability of participants to understand, express, and feel satisfied and comfortable (Bickerstaff and Walker 2001, Carr and Halvorsen 2001, Rowe and Frewer 2004) were used as indicators for effective participation in workshops. This was to ensure that participants, and especially marginalized stakeholders, were not figuratively but rather explicitly part of the collective sessions. Questions were read out loud to ensure that participants with low literacy were able to participate. Additionally, participants responded on a ‘Mood-o-meter,’ a diagram resembling that in Fig. 15, which does not require reading or writing skills (Evans et al. 2006). The questionnaires were anonymous.

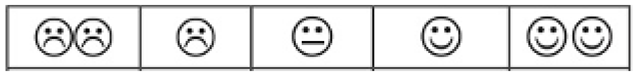

Figure 15. 'Mood-o-meter' extracted from Evans et al. (2006).

4.5. Findings

4.5.1. Focus group discussion

During the focus group discussion, researcher participants stated that the overarching environmental problem in LAB was human-induced eutrophication. This was primarily attributed to the mismanagement of nutrient discharge in the area. Researcher participants informed the guidance team about the background of the study site (Bou Nassar et al. 2021):

- Economic: There are three dominant economic sectors in LAB: tourism, agriculture, and aquaculture (Bou Nassar et al. 2021).
- Social and cultural: LAB contains multiple communities with different cultural backgrounds. There are Kaqchikel, Tz'utujil, and K'iche' Mayan Indigenous communities, in addition to Hispanic communities (Bou Nassar et al. 2021). Hispanic residents are typically Spanish-speaking, and Indigenous residents usually speak Kaqchikel, Tz'utujil, or K'iche' (as a native tongue). Many Indigenous stakeholders also speak Spanish. Mayan languages in the area are marginalized and discriminated against. For example, although the area is mostly inhabited by Indigenous communities (96% of the population), educational programs are in Spanish. The LAB population has a high percentage of illiterate inhabitants (30%). Indigenous communities in the area heavily depend on the lake for their economic, cultural, spiritual, and social wellbeing (Bou Nassar et al. 2021).
- Political: The area contains two types of authorities, Indigenous and non-Indigenous. Non-Indigenous municipalities are considered by the government as the main official authorities (Bou Nassar et al. 2021). Indigenous municipalities have only been recognized by the government as auxiliary and, therefore, remain underrepresented. Local Indigenous authorities, known as Cofradias, impact local decision-making in some

towns in LAB. Nevertheless, the main authority governing the lake is a governmental institution called Autoridad para el Manejo Sustentable de la Cuenca del Lago de Atitlán y su Entorno (AMSCLAE). LAB lacks a unanimous decision-making platform (Bou Nassar et al. 2021). This hinders the implementation of decisions and policies aimed at solving the lake's water quality problem. Efforts to address problems in the lake have mostly been community-based, bottom-up actions triggered by visible signs of environmental degradation, such as cyanobacterial blooms and damage caused by hurricanes (Agatha in 2005 and Stan in 2010). Groups and authorities have not been working complementarily and collectively on solutions. LAB, therefore, lacks (1) a sustainable plan to address the lake's eutrophication problem and (2) a governance body that is representative of stakeholders' different interests and perspectives.

4.5.2. Semi-structured interviews

Several themes were identified from the semi-structured interviews and grouped under causes (direct and indirect), consequences (direct and indirect), solutions, and barriers displayed in Fig. 16. The syntheses of major findings derived from semi-structured interviews are listed below.

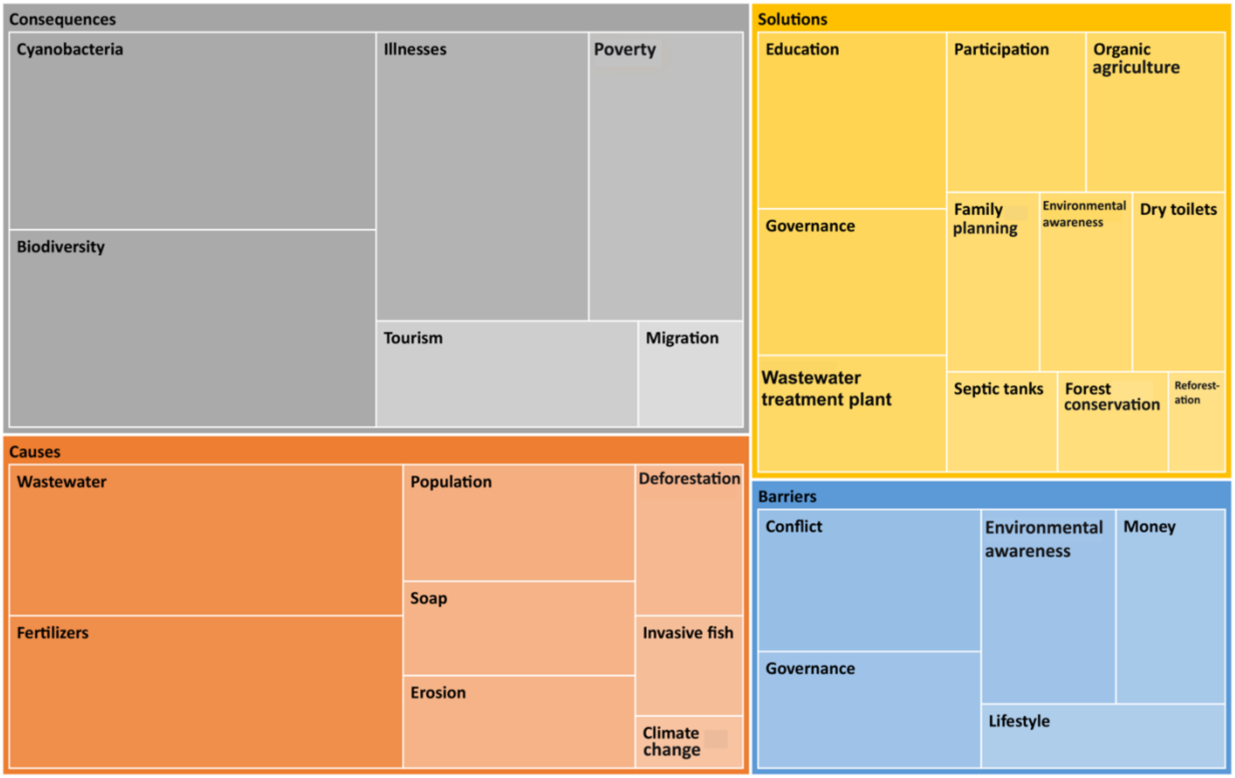

Figure 16. The most identified themes from the semi-structured interviews. The size of each rectangle is proportionate to the number of stakeholders who mentioned the corresponding theme. The figure was made using NVivo (released in March 2020).

4.5.2.1. Causes

The primary causes of eutrophication in the lake, addressed by all (Indigenous and non-Indigenous) participating stakeholders, were untreated wastewater discharge and inorganic fertilizer use (Table 6). Many stakeholders highlighted the absence of proper drainage systems in LAB. Wastewater is either discharged to the lake or to the soils, streams, or rivers, which drain into the lake. Population increase in LAB, including incoming tourists, is a driver for the increase in untreated wastewater discharge.

The majority of stakeholders also highlighted the use of inorganic fertilizers for agriculture. Some stakeholders attributed that to decreasing crop productivity as a result of climate change. Others mentioned that subsidies offered by the government removed financial restrictions, which allowed farmers to use more fertilizers in pursuit of profit maximization, which decreased the application efficiency. The notion of profit maximization and the increase in agricultural demand (due to an increasing population) are also leading farmers to cultivate more land, which increases total fertilizer consumption. Some stakeholders cited erosion as the primary means for transporting heavily fertilized soils into the lake. Erosion is triggered by a loss of forests either by felling, forest fires, or expansion of agricultural lands.

A few stakeholders mentioned that the use of inorganic soaps and detergents for washing laundry on the shores of the lake also increased nutrient enrichment. Some Indigenous stakeholders in agriculture and aquaculture stated that the introduction of invasive fish species to the lake exacerbated the eutrophication problem.

4.5.2.2. Consequences

Loss of biodiversity increased the risk of cyanobacterial blooms, and a rise in illnesses were the consequences mentioned by all stakeholder groups (Table 6). Since the lake is central to the area's tourism, some stakeholders mentioned that loss of biodiversity and spread of cyanobacterial blooms would make it less appealing to tourists, consequently decreasing tourism in the area, impeding the region's economic growth, increasing unemployment, and resulting in migration and poverty.

4.5.2.3. Solutions

The need for wastewater treatment plants was stated by many stakeholders. Notably, only Indigenous stakeholders highlighted the installation of septic tanks and dry toilets as a solution to the discharge of untreated wastewater (Table 6).

Some stakeholders pointed out the need for organic agricultural practices. One called for going further and incorporating permaculture to decrease the conspicuous consumption of inorganic fertilizers. A few stakeholders mentioned the need for forest conservation and reforestation initiatives to decrease the land's susceptibility to erosion.

Many participants highlighted the importance of good governance. Some suggested that regulations should be implemented, while others mentioned the need for constant monitoring and evaluation schemes. A few stakeholders suggested that the participation of different communities in decision-making is crucial to finding well-suited solutions and ensuring the collaborative implementation of policies and BMPs. Many participants mentioned the need for education in two different forms:

1. Environmental education: Incorporating environmental education into school curriculums and holding relevant educational campaigns to improve environmental awareness at the community level.
2. Capacity building for farmers: Training farmers and strengthening their knowledge about organic agriculture, permaculture, and soil conservation.

4.5.2.4. Barriers

Stakeholders from Indigenous and non-Indigenous groups across the majority of sectors mentioned that the conflict between different stakeholder groups is a major barrier to the implementation of solutions (Table 6). Some Indigenous stakeholders stated that the lake's authorities have not consulted them about potential solutions or involved them in decision-making schemes that affect the lake (and consequently, their livelihoods). The lack of dialogue between Indigenous and governmental authorities has impeded the effective implementation of solutions.

Many stakeholders brought up the theme 'Governance' in the context of barriers rather than solutions. These stakeholders associated governance with the current political structure in the area and linked governing institutions with the perpetuation of systemic marginalization. Others highlighted the lack of a unified governing platform to solve the aforementioned conflict and start an open dialogue for the implementation of solutions. These stakeholders often expressed a loss of confidence in the potential of the governing system to make significant changes.

Others identified a lack of environmental awareness at the individual and community levels as impeding the urgency of implementing solutions. Some stakeholders mentioned that the lack of financial resources and/or failure to allocate funds to environmental services are major barriers to the development of wastewater treatment plants, the expansion of education initiatives, and capacity training for farmers. Finally, Indigenous stakeholders uniquely stated that the modern lifestyle (Table 6) - reflected by the deviation from Indigenous habits, rise in consumption, use of inorganic soaps and detergents, and use of inorganic fertilizers - is a major barrier to resolving this and other environmental problems.

Table 6. Contributions of different stakeholder groups. The symbol 'x' indicates that the corresponding stakeholder group mentioned the corresponding theme.

Themes		**Non-Indigenous**	**Indigenous**	**Sector**				
				Governance	**Academia**	**Civil Society**	**Agriculture**	**Aquaculture**
Biodiversity	Consequences	x	x	x	x	x	x	x
Conflict	Barriers	x	x	x	x	x		x
Cyanobacteria	Consequences	x	x	x	x	x	x	x
Dry toilets	Solutions		x	x	x		x	
Environmental Awareness	Solutions and Barriers	x	x	x	x	x	x	x
Fertilizers	Causes	x	x	x	x	x	x	x
Illnesses	Consequences	x	x	x	x	x	x	x
Invasive Fish	Causes		x				x	x
Lifestyle	Barriers		x	x			x	x
Septic Tanks	Solutions		x	x				
Wastewater	Causes	x	x	x	x	x	x	x

4.5.3. Workshops

4.5.3.1. Solutions

Although the aim of the guidance team was to collectively discuss potential solutions with stakeholder groups, the workshop discussion gravitated towards a debate about the Mega-collector project. The Mega-collector is a large-scale wastewater collection system that was proposed as a solution for the eutrophication problem and endorsed by the government in 2018. The project would include a subaquatic pipe network to collect wastewater from the towns encircling the lake and convey it to a wastewater treatment plant (WWTP) located outside LAB. The treated water would then be used for the irrigation of agroindustrial farms on the southern coast of Guatemala. The project includes plans for biogas generation and nutrient recuperation (Hinds et al. 2015). Arguments of proponents and opponents, as mentioned during the workshop, are listed as follows.

Proponents argued that (1) wastewater is the main contributor to nutrient enrichment in Lake Atitlán, (2) discharging the effluent of WWTPs into the lake would further contribute to its eutrophication, and (3) the benefit to cost ratio of the project is lower than other alternatives. Opponents argued that (1) there is insufficient consideration of the negative impacts of the project's inter-basin water transfer. The allocation of LAB's water resources to agroindustrial lands outside the watershed might exacerbate the basin's water shortage problems. Also, the reallocation implies that the benefits of the project are not meant to serve LAB's Indigenous communities. Using treated wastewater within LAB to provide direct benefits for its communities would be a better alternative. Additionally, (2) a large-scale, subaquatic construction project around the lake would have negative consequences on its ecosystem, causing terrestrial and aquatic biodiversity loss, (3) the basin is an earthquake-prone zone (situated on multiple seismic faults) which makes the risk of structural collapse high, and (3) the megastructure compromises the resilience of the community, especially since LAB is not equipped with a governance body that is capable of reacting to malfunctions or failures of the subaquatic sewage system (e.g. LAB authorities lack a crisis emergency council to mitigate accidental spills). (4) While the proponents state that wastewater is the biggest contributor to nutrient enrichment of the lake, no attempt has been made to quantify the contribution of agricultural practices to the eutrophication problem. Therefore, the Mega-collector project might not solve LAB's water quality problem. Moreover, (5) almost 60% of untreated wastewater in LAB is not discharged through an appropriate drainage system. Thus, the project targets only 40% of total discharged wastewater, which might not be sufficient to solve the problem. (This has been mentioned by stakeholders and estimated by Romero (2013). However, other studies, such as Ferráns et al. (2018) and AMSCLAE (2018), have provided a different estimate: about 45% of wastewater is not discharged through an appropriate drainage system.)

Alternatively, a variety of solutions were suggested by stakeholders in the workshops. Although some solutions mentioned in interviews were reiterated, Table 7 only shows stakeholders' feedback on previously proposed solutions. This highlights the added value of dialogue between different stakeholder groups. Two suggestions were mentioned in the workshops but not during the interviews: (1) family planning to address the impact of an increasing population on nutrient discharge and (2) the implementation of a sustainable fishing policy to protect the lake's fish species

Table 7. Highlights of the workshop discussions about solutions proposed during the interviews.

Suggested solutions from the interviews	Comments on proposed solutions
Wastewater treatment plants	- Some stakeholders suggested a decentralized wastewater treatment system that considers the rehabilitation of existing WWTPs in the area as an alternative to building a large, centralized WWTP (like the Mega-collector). - It is important to consider developing an extensive drainage system to optimize the amount of wastewater that is treated.
Septic tanks	- The water table in LAB is shallow in some areas of the basin (Hernández et al. 2013). Therefore, caution should be taken in the installation and maintenance of septic tanks to prevent groundwater contamination. †
Organic agriculture	- Farmers' concerns usually revolve around profit maximization. Therefore, accompanying the

	promotion of organic agriculture with economic incentives is important for the adoption of relevant practices. - Government subsidies on inorganic fertilizers have been provided to support food security (which is an issue in Guatemala). Food security must be taken into account when re-assessing traditional agricultural practices.

† *Sites with shallow water tables are unsuitable for septic tanks since they pose a risk to the functioning of the system and on groundwater quality (Harris et al., 1996).*

4.5.3.2. Feedback survey

The results of the workshops' survey questionnaires are displayed in Figure 17. Most stakeholders (1) were comfortable with the methods used, (2) expressed their views freely, (3) understood the disseminated information, (4) would participate in a similar activity, and (5) recommend the implemented stakeholder engagement approach. However, the results show that not all stakeholders were able to participate effectively in the process. For example, about 30% of stakeholders felt neutral about the methods used. Additionally, one out of 22 participants did not feel comfortable at all with the methods. Additionally, one participant was not able to express their views freely.

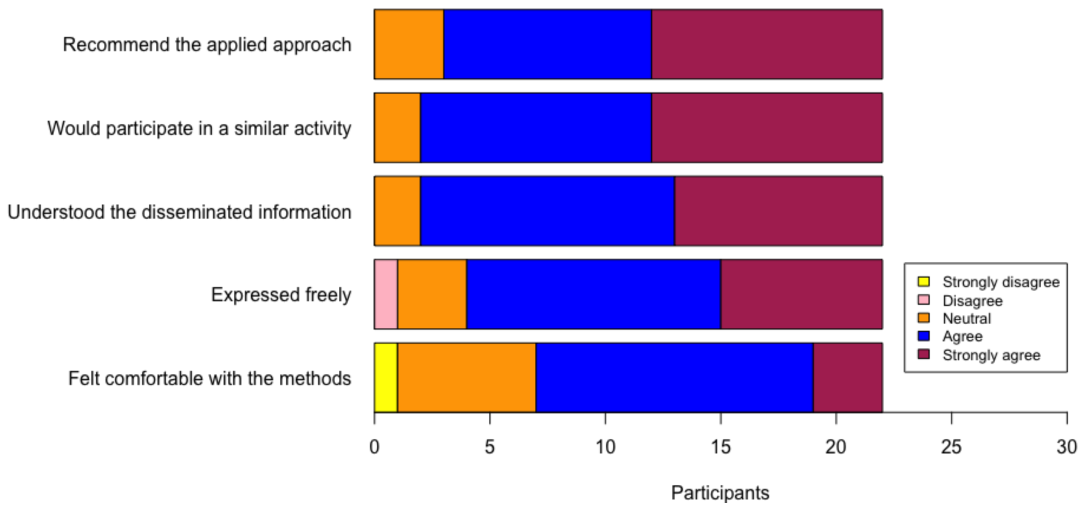

Figure 17. Survey results.

4.6. Discussion

The inclusive stakeholder engagement process has three primary forms of added value. The first form is reflected by the participation of marginalized stakeholders. As shown in Table 5, the activity was attended by Indigenous and less-literate participants. The inclusion of marginalized stakeholders is integral to solving the nutrient enrichment problem in LAB. The second form is reflected by the unique contributions of different stakeholder groups (Table 6). Exclusive contributions of different stakeholders represent the diverse dimensions of the problem, which aid in the development of effective, well-targeted, and sustainable solutions (Colfer 2005). The third is represented by the dialogue between participants associated with different groups. Dialogue is key to solving multifaceted environmental problems (Sandker et al. 2010).

The execution of the activity had three main limitations. First, the exact representation of the wider public was not achieved (Table 5). While marginalized stakeholders stated that previous participatory processes in the area did not often effectively incorporate them, data regarding past participation is lacking. Therefore, there is no baseline for explicitly judging whether the process shows an improvement or decline in representativeness. Second, some participants were not comfortable with the methods used in the workshop (Fig. 17). This might be attributed to methods used for simultaneous interpretation. The first workshop had one whisper interpreter for seven Spanish-speaking participants, which caused some inconvenience. Third, the presence of power dynamics in the collective workshops might have led one of the participants not to express their viewpoints freely (Fig. 17). More attention should be given to the empowerment of less vocal participants in group sessions. In the remainder of this section, the authors discuss the implications of the engagement process on policy-making regarding anthropogenic nutrient discharge in LAB. They then discuss the broader implications of the activity on challenges to inclusive stakeholder engagement.

4.6.1. Policy implications

Policy implications associated with nutrient management in LAB, as derived from the results of this research, touch on four overarching themes: stakeholder engagement, agricultural practices, wastewater management, and education.

Stakeholder engagement - Stakeholder engagement in the formulation, implementation, and evaluation of decisions and policies is significant for the success of solutions (Leal Filho and Brandli 2016). The main barriers to solutions in LAB, as mentioned by participants, were (1) ongoing conflicts underpinned by the exclusion of Indigenous communities (which make up to 96% of the population) in decision-making processes, (2) the lack of a unified platform that represents the perspectives of the diverse sectors and communities, and (3) the perpetuation of marginalization of some stakeholder groups. To overcome these barriers, decision-makers in the area need to employ a high level engagement process which empowers the community and allows it to actively participate in making decisions that impact it. Additionally, this engagement process should incorporate inclusive methods that are cognizant of the diversity of the communities and history of marginalization in LAB. High level and long-term engagement are necessary for overcoming barriers of stakeholder engagement like mistrust or lack of confidence in the process (Voinov and Bousquet 2010). Making an organizational commitment to an inclusive stakeholder engagement process can facilitate both high level and long-term engagement. Therefore, institutionalizing such a process could be a step for governing bodies towards the successful implementation of solutions in LAB (Franklin 2020).

Agriculture - To promote food security, a national policy was put in place by the Guatemalan government aiming to subsidize inorganic fertilizers. This policy has significantly increased consumption and might have decreased the efficiency of fertilizer allocation. In this research, the abandonment or adoption of subsidies on fertilizers cannot be addressed since the authors acknowledge the existence of trade-offs between food security and farmers' economic wellbeing on one hand and the consumption of inorganic fertilizers on the other. In this light, policies regarding fertilizer management would benefit from interdisciplinary discussions that address food security, the lake's degradation, and farmers' economic wellbeing. The increased consumption of inorganic fertilizers can be addressed by developing economic incentives that encourage organic agricultural practices. These incentives need to make the profitability of organic agriculture competitive with that of inorganic agriculture. It is important to couple incentives with capacity development for farmers about organic agriculture. These programs can also include nutrient bookkeeping and fertilizer management programs (to enable farmers to track and manage their consumption better) (Forsberg 1998) and soil conservation training to avoid nutrient loss.

Wastewater - Wastewater treatment is crucial for reducing nutrient enrichment in LAB. However, it is important to base the project planning framework for wastewater treatment on the needs and priorities of communities residing in LAB. The construction of new WWTPs requires careful consideration of the impacts on valued biological and physical systems since biodiversity is a unanimous concern among all stakeholder groups. In this case, a detailed environmental impact assessment is required to foresee adverse effects and risks. There is a need for a holistic evaluation of impacts to avoid burden-shifting from one environmental component to another. An example of burden-shifting was highlighted by some stakeholders who described how the Mega-collector might create a water shortage problem while attempting to solve the water quality problem. Therefore, there is a need to avoid the reallocation of water resources from LAB to another area. Additionally, considering the existing landscape of wastewater systems in the area is crucial. For example, many households in LAB lack proper drainage systems. Addressing this problem might be integral to optimizing WWT in LAB. Finally, the rehabilitation of existing WWTPs in the area is an important consideration.

Education - An increased focus on environmental education and Indigenous Knowledge in school curricula is suggested to advance environmental awareness in the community. Additionally, the expansion of the outreach of environmental education initiatives could be considered by NGOs and governmental institutions.

Policies that prevent the transportation and delivery of nutrients to the lake, such as reforestation initiatives, are needed in addition to policies that aim to reduce nutrient discharge in LAB. However, they are not elaborated on here since the scope of this study is restricted to anthropogenic nutrient discharge.

4.6.2. Challenges of inclusive stakeholder engagement

1. **There are tradeoffs between power dynamics and dialogue.**

Although power dynamics can be reduced by conducting individual sessions with participants (Inam et al. 2015), group sessions are needed to initiate a dialogue between different stakeholder groups (Evans et al. 2006). Therefore, a key challenge remains in balancing the need for individual sessions and group discussions. Assessing the trade-offs between power dynamics and dialogue is difficult. When is a dialogue benefiting the activity? When is it being dominated by certain stakeholder groups and reinforcing the 'tyrannical potential' of participatory activities? Detecting unhealthy power dynamics and thoughtfully structuring interactions between participants in group discussions are critical tasks for the guidance team (Pankowski 1984, Johnson-Bailey and Cervero 2002). Therefore, a major challenge is ensuring equal opportunity of participation within group sessions (e.g. workshops and focus groups).

2. **Evaluating the effectiveness of the process is a difficult task.**

There is no universal definition of the term ‘effective participation’ (Rowe and Frewer 2004). The various definitions of effectiveness can be categorized under two broad concepts: fairness and efficiency (Renn et al. 1995, Rowe and Frewer 2005). Moreover, there are no standardized criteria for measuring effectiveness (Rowe and Frewer 2000, Shirk et al. 2012). For example, an appropriate evaluation criterion for this study would be inclusiveness, which reflects the authors’ definition of 'effective participation' (Blahna and Yonts-Shepard 1989, Carr and Halvorsen 2001). Additionally, it is difficult to select appropriate indices. For example, the authors consider the multiplicity of unique perspectives (Table 6) as an indicator of inclusive and effective participation (Gundry and Heberlein 1984) (i.e. an indication that views were expressed, conserved, and not overshadowed (Bickerstaff and Walker 2001). However, many different perspectives might simply indicate the complexity of the problem (Rowe and Frewer 2004). Finally, stakeholder engagement is a long process, and its impacts might appear months or years after implementation. The assessment of an activity’s outcomes in a timely manner might not be possible. Nevertheless, the quality of the implemented process may be representative of the expected quality of outcomes (Rowe and Frewer 2004). However, there is no explicit definition of what a ‘quality process’ entails.

3. **Building trust with communities that have experienced the ‘tyrannical potential’ of participation takes time and active effort.**

Previous stakeholder engagement approaches in LAB did not effectively incorporate Indigenous communities. Participants stated that this had generated decisions that were called ‘participatory’ but were, in fact. reinforcing the interests of the most powerful. Likewise, many communities have witnessed the ‘tyrannical potential’ of participatory processes (Cooke and Kothari 2001), and as a result, have lost trust in such activities (Fig. 18). Therefore, the inclusion of communities that are usually poorly engaged is a major challenge (Ulrich et al. 2016, Boiral et al. 2020) and requires time and effort. How can trust be established between researchers and such communities? How can researchers build and sustain meaningful relationships with these communities?

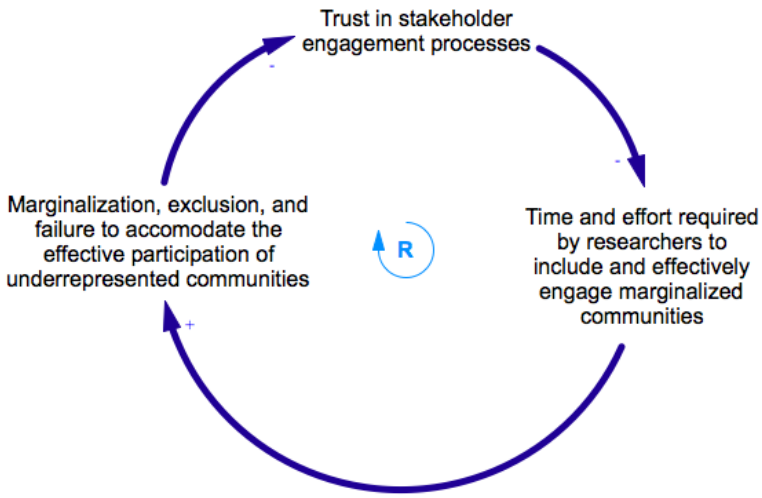

Figure 18. The vicious cycle of marginalization in stakeholder engagement: the exclusion or ineffective participation of marginalized groups leads to a loss of trust in stakeholder engagement processes (Cooke & Kothari, 2001). Without trust, new engagement processes require additional time and effort from researchers to ensure the inclusion and effective participation of these communities. Increased time and effort requirements increase the difficulty of including and accommodating marginalized stakeholders, decreasing the likelihood of effective engagement by researchers.

Language is important for effective communication with stakeholders (Mease et al. 2018). In the case of this activity, the guidance team learned and used Mayan languages for external and internal communications, documents, presentations, and workshops which led to greater implications and helped build meaningful relationships. Some participants perceived this as an effort researchers were making to connect with the community and, as a result, became more confident with the process. Nevertheless, at times, researchers acquiring the language might be time-consuming or unfeasible.

Additionally, ensuring the transparency of the process is crucial (Daniell et al. 2014). Why is the activity being conducted? What does the activity entail? What are the expected outcomes? What will the output be used for? Who are researchers working for? To whom are they affiliated? Researchers might have to provide answers to all these questions to build trust with the community. Maintaining open communication by developing formal and informal channels of communication can help increase transparency and build trust. In this case study, the guidance team developed formal channels of communication through feedback surveys and scheduled phone calls, emails, or visits (depending on each stakeholder's preference). Additionally, they lived with the community, shared its lifestyle, and interacted with community members on a daily basis. This created informal channels of communication which (1) helped maintain open communication and transparency and (2) was key to building meaningful relationships between researchers and stakeholders. Hence, this study shows that ensuring transparency requires active measures and constant effort to foster an open exchange of information at every step of the process.

Finally, building and sustaining relationships with stakeholders requires long-term engagement (Akhmouch and Clavreul 2016). Long-term participatory activities help develop trust and confidence in the process and overcome barriers towards stakeholder participation (Cotton and Mahroos-Alsaiari 2015). Institutionalizing the process can facilitate the long-term continuation of stakeholder engagement (Halbe et al. 2018). However, there might be systemic barriers to institutionalization. For example, the lack of a unified decision-making platform in LAB poses a challenge to institutionalization.

4. **The inclusive dissemination of complex information to diverse participants requires expertise in science communication.**

As highlighted in this paper, stakeholder engagement activities might involve participants with low literacy, in addition to non-experts. Science communication plays a significant role in bridging the gap between researchers and marginalized communities. However, many researchers have not received training on how to communicate with the general public, including illiterate stakeholders (Powell and Colin 2008). Additionally, different forms of science communication emerge depending on the context of the activity (Bucchi 2008). Therefore, there is no standard approach for science communication (Trench 2008, Suldovsky et al. 2017). In this study, the authors communicated complex scientific findings using storytelling, which is culturally relevant to Indigenous stakeholders. However, maintaining the intricacies of scientific findings while ensuring stakeholders' understanding was challenging to the guidance team.

Enhanced science communication training and tailored dissemination plans are crucial considerations for more inclusive stakeholder engagement processes.

4.7. Conclusion

The conducted stakeholder engagement process facilitates the inclusion of marginalized stakeholders in investigating environmental problems and informing local decisions. The process is inclusive by design and is based on characterizing and addressing barriers to the inclusion of marginalized stakeholders. The process focuses on facilitating the participation of less-literate and relatively powerless individuals in a multilingual context and included individual interviews, one focus group discussion, two workshops, and a survey. The proposed process was implemented in the LAB, Guatemala, to provide a better understanding of the mechanisms underpinning the anthropogenic eutrophication of the lake and delineate potential solutions that can be promoted and adopted by relevant actors. The results of the stakeholder engagement activity were analyzed using qualitative methods in Grounded Theory.

As discussed by stakeholders, the anthropogenic emission of nutrients in the LAB is mainly attributed to the discharge of untreated wastewater and the use of inorganic fertilizers. Concerns expressed by participants revolve around biodiversity loss, cyanobacterial blooms, illnesses, and a decrease in tourism. Four policy implications are delineated to solve the issue: the need for (1) high-level stakeholder engagement and the empowerment of community-based decision-making by authorities, (2) wastewater treatment planning that takes into consideration the needs, priorities, and concerns of stakeholders, (3) sustainable agriculture that remains profitable to farmers, and (4) environmental education that incorporates Indigenous perspectives.

The authors suggest that further research on inclusive stakeholder engagement in informing environmental problems could focus on four components: (1) tools and methods to further reduce the impacts of power dynamics in group settings, (2) methods for measuring and evaluating the effectiveness and inclusiveness of stakeholder engagement exercises, (3) approaches to build trust with marginalized communities, and (4) science communication in the context of less-literate and non-expert stakeholders.

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Chapter 5: Summary and Conclusions

The main objective of this research was to develop a PM method that facilitated the inclusion of marginalized stakeholders, who were: (1) less literate, (2) relatively powerless, and/or (3) associated with marginalized languages, in modelling and informing a human-water system. To demonstrate the usefulness of the method, the participatory process was implemented with Mayan communities in LAB, Guatemala. The case study included stakeholders who were: (1) relatively powerless, (2) associated with different literacy ranges, and (3) associated with three different marginalized languages: Kaqchikel, Tz'utujil, and K'iche'.

The development of an inclusive PM framework was primarily motivated by the barriers of many conventional PM processes to the inclusion of less literate and relatively powerless stakeholders in a multilingual context. Briefly, many PM methods (1) require reading, writing, or advanced expertise, (2) do not explicitly consider unhealthy power dynamics, or (3) do not accommodate a multilingual context. To address those shortcomings, the process in this study was: (1) underpinned by storylines to facilitate the inclusion of less-literate participants, (2) included individual interviews to mitigate unhealthy power dynamics, and (3) was multilingual at every phase. The secondary motivation for the development of the PM framework was the focus of many conventional storyline development methods on linear modelling. The suggested storyline development method was explicitly designed to inform and conceptualize systems models. In the following subsections, summaries and conclusions of this research are given.

5.1. Evaluation of the framework

The inclusive stakeholder engagement process facilitated the following:

1. **Inclusion of marginalized stakeholders**: the activity was attended by stakeholders who were less literate, relatively powerless, and associated with marginalized languages. Participants who could not read or write were able to convey information comfortably, something that might not have been achieved using other methods. Moreover, stakeholders were comfortable expressing their points of view during individual interviews, especially when assured of anonymity. This approach helped reduce

unhealthy power dynamics and facilitated the participation of key stakeholders who did not usually get involved due to power issues. Finally, the guidance team's accommodation of the multiple languages spoken in the basin provided participants with the freedom to convey information in their preferred languages. This allowed the participation of stakeholders associated with marginalized languages who were not comfortable expressing themselves in Spanish (the language typically used in similar activities in the area). The inclusion of marginalized stakeholders was integral to understanding and solving the nutrient enrichment problem in LAB.

2. **Integration of unique perspectives**: The process facilitated the extraction of the unique contributions of various stakeholder groups. Unique contributions of different stakeholders represented the diverse dimensions of the problem, which helped to develop effective, well-targeted, and sustainable solutions. These contributions were not only extracted but also conserved and included in the conceptual model.

3. **Initiation of a dialogue**: The activity allowed the initiation of dialogue between different stakeholder groups. The dialogue generated constructive feedback to proposed solutions and highlighted barriers to their implementation. This is key to the development of practical policies and BMPs.
4. **Model conceptualization**: The extraction of multi-level storylines from stakeholders was compatible with CLDs, which serve as the qualitative base of systems models. Macro-level storylines, elicited through focus group discussions with research participants, defined the scope and context of the model. Meso-level storylines, elicited through individual interviews, developed an understanding of the mechanisms governing the problem. Micro-level storylines delineated potential solutions targeting the system's leverage points. Further analysis of proposed solutions and barriers offered a more holistic understanding in terms of practicality and implementation, which could generate a more robust simulation of policy-based scenarios.
5. **Identification of human-water feedbacks**: Since the applied methods allowed a nuanced and non-restrictive narration of human-water interactions, they helped extract

human-water feedbacks that have previously been delineated in the literature. The identification of such feedback is important for the advancement of the study of human-water systems. Human-water relationships delineated in this study were the “Rebound Effect” and the “Pendulum Swing”.

5.2. The eutrophication problem in LAB

The results of this study showed that the direct contributors to nutrient enrichment in Lake Atitlan were the discharge of untreated wastewater, the increased use of inorganic fertilizers on surrounding farmland, and soil erosion. These mechanisms have led to the degradation of Lake Atitlan and increased its susceptibility to harmful algae blooms. As a result, negative effects including reduced tourism activities, lower economic growth, and poor public health have increased. Some stakeholders mentioned that economic growth decreased nutrient pollution in Lake Atitlan because it increased the capacity for investment in environmental services such as wastewater treatment plants and environmental education. However, some Indigenous stakeholders stated that increased economic growth had led to an increase in lake nutrient enrichment since the activities driving this growth, were not environmentally sustainable. The identification of both relationships was important to provide holistic and well-targeted recommendations that aimed to: (1) ensure that sufficient funds are allocated to environmental services in the area and (2) achieve economic growth through sustainable activities that have minimal to zero adverse effects on the lake.

An unexpected observation that was extracted from the modeling activity was the positive causal relationship between irrigation efficiency and nutrient enrichment. Efficient irrigation decreases water shortages (which is a problem in LAB) and could lead to the allocation of water for the cultivation of more land. In the context of LAB, expanded land cultivation led to a rise in the total use of fertilizers, which increased lake nutrient pollution. On another note, a reinforcing balance occurred between nutrient enrichment and environmental awareness. Some stakeholders mentioned that when the symptoms of the lake’s degradation were most evident (e.g., cyanobacterial blooms), environmental awareness increased and efforts to limit nutrient enrichment also increased, which might result in a reduction in nutrient pollution. Multiple solutions and barriers were suggested by stakeholders, revolving around four main themes: inclusive stakeholder engagement, wastewater treatment planning, sustainable agriculture, and education. Barriers to the implementation of solutions mainly stemmed from the lack of: (1) dialogue between stakeholder groups, (2) a unified decision-making platform, (3) environmental awareness, and (4) allocation of funds to environmental services.

Chapter 6: Contributions to knowledge, limitations, and recommendations for further research

6.1. Contributions to knowledge

This research was innovative since it developed and implemented a PM activity that was designed to be inclusive. From developing the conceptual framework of the PM process through to its implementation, stakeholders who were less literate, relatively powerless, and associated with marginalized languages were a focus of this study. To the author's knowledge, such an approach has not been carried out in previous studies of water resources management. Additionally, this thesis provided an innovative methodological contribution. The process was based on the combination of storylines with CLDs and the MLP framework in a unique way. This research also provided two main contributions to practical knowledge. First, it delineated a holistic understanding of the eutrophication problem in LAB that was not restricted to biophysical components but rather integrated social, economic, and cultural aspects. Second, it delineated challenges to inclusive stakeholder engagement that could be relevant to similar future activities in diverse contexts.

6.2. Limitations

This study had four main limitations:

1. The exact representation of the population in LAB was not achieved in the conducted stakeholder engagement process. Marginalized stakeholders stated that they were not often effectively included in participatory activities in the past. However, data associated with past participation were lacking and there was no baseline for judging whether or not the process used in this study improved representation of a broad range of stakeholders.
2. Inclusiveness of the activity was not evaluated using an explicit process. There is, in fact, no standardized process for evaluating the inclusiveness of an activity. Moreover, selecting the right indices for evaluation is critical. For example, unique contributions of

diverse stakeholder groups were considered an indicator of inclusiveness in this study although these might only be an indicator of the complexity of the problem.

3. During the first workshop, one whisper interpreter was assigned to seven Spanish-speaking participants. This resulted in some participants feeling uncomfortable during the process and might have limited their participation and understanding of the activity.
4. Although the process included individual sessions to reduce the impacts of unhealthy power dynamics, conducting group sessions was necessary to initiate dialogue between participants. Power issues might have prevented some participants from expressing their views freely during workshops.

6.3. Recommendations for further research

This thesis concludes with two main recommendations for further research:

1. Quantification is needed to assess the impacts of suggested solutions. The construction of a quantified system dynamics model coupled with a physical-based model, aiming to integrate socio-economic components with hydrological processes is suggested.
2. The development of an explicit process for the evaluation of the stakeholder engagement activity is suggested. Such an evaluation process would help assess the inclusiveness of the process and highlight areas that need improvement to achieve a fuller participation of marginalized stakeholders.