Hydrology and
Earth System
Sciences

Discussions

Multi-level storylines for participatory sociohydrological modelling — involving marginalized communities in Tz'olöj Ya', Mayan Guatemala

Jessica A. Bou Nassar[1], Julien J. Malard[1], Jan F. Adamowski[1], Marco Ramírez Ramírez[2],
Wietske Medema[1], Héctor Tuy[2]

[1]Dept. Bioresource Engineering, McGill University, 21111 Lakeshore Road, Sainte-Anne-de-Bellevue, QC, H9X 3V9, Canada
[2]IARNA, Universidad Rafael Landívar, Vista Hermosa III, Campus Central, Zona 16, Edificio Q, Oficina Q-101, Ciudad de Guatemala, Guatemala

Correspondence to: Jessica A. Bou Nassar (jessica.bounassar@mail.mcgill.ca)

Abstract. New and unconventional sources of data that enhance our understanding of internal interactions between socio-economic and hydrological processes are central to sociohydrological modelling. Participatory modelling (PM) departs from conventional modelling tools by informing and conceptualizing sociohydrological models through stakeholder engagement. However, the implementation of most PM processes remains biased, particularly in regions where marginalized communities are present. Most 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 minoritized language - in participatory sociohydrological modelling is proposed. The adopted approach employs interdisciplinary storylines to inform and conceptualize system dynamics-based sociohydrological models. 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 minoritized linguistic backgrounds (Kaqchikel, Tz'utujil, and K'iche'), in the PM activity. The proposed approach facilitated the effective participation of marginalized stakeholders. Moreover, it (1) helped develop an understanding of mechanisms governing the eutrophication of the lake, (2) initiated collaborations between Indigenous 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. Additionally, the suggested process helped decrease the impact of power imbalances in water resources management and empower community-based decision-making.

1 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

Hydrology and
Earth System
Sciences

Discussions

45   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).

50   Conventional modelling tools (e.g. physically based models) are often ill-suited for addressing the
     challenges above, since they fail to endogenously incorporate socio-economic processes when addressing
     hydrological problems (Inam et al., 2017a; 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

55   resources management requires transformative interdisciplinary methods, such as participatory sociohydrological
     modelling, 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).
            System dynamics (SD) modelling is a powerful tool for participatory modelling (PM) (Inam et al., 2017a).
     SD models can capture socio-economic processes elicited from stakeholders and can accommodate nonlinearity,

60   multi-causality, and delays. They can also replicate iterative bi-directional feedbacks embedded in sociohydrological
     systems (Prodanovic and Simonovic, 2010). Furthermore, SD models can provide visual aids, and are therefore
     more comprehensible and stakeholder-friendly (Alcamo, 2008). As a result, SD models can accommodate
     stakeholder participation and enhance model development with situated knowledge.
            PM can incorporate stakeholders in decision-making through its departure from conventional model

65   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 minoritized languages) - is challenging. Most 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

70   exclusion of key actors, especially marginalized communities. As such, three issues are raised. First, most PM
     activities require professional skills and expertise, thereby preventing the involvement of less literate stakeholders –
     e.g. Inam et al. (2015) (Maynard and Jacobson, 2017). Second, participatory methods usually overlook group
     dynamics, yielding participatory decisions that reinforce the interests of those in power - e.g. Eker et al. (2018)
     (Cooke and Kothari, 2001). Third, common participatory model-building processes usually fail to recognize

75   integrated participation in multilingual regions, which can further marginalize minoritized 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

80   roles in water resources management. Thus, they can be primary contributors to model-building activities and
     finding well-suited solutions for studied problems (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 business and adopted by
     corresponding actors (Hassanzadeh et al., 2019). Second, marginalized communities are often the most vulnerable to

85   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 well-being (Evans, 2006).
     Third, inclusive participation in policymaking yields 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

90   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.

The primary focus of this research is the development of a participatory method that ensures the inclusion of typically marginalized stakeholders, who are (1) less-literate, (2) relatively powerless, and/or (3) associated with minoritized languages, in sociohydrological modelling. The integration of storylines with SD models 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 listed below:

1. Develop a conceptual framework for building multi-level storylines that can inform the creation of sociohydrological SD models by adjusting the MLP framework.
2. Build a framework for the implementation of the storyline construction process that (1) ensures 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.
3. Evaluate the validity of the process with respect to its ability to (1) incorporate effective participation of marginalized stakeholders, (2) induce collaboration, (3) integrate diverse perspectives, (4) facilitate model-conceptualization, and (5) produce descriptions of relevant sociohydrological phenomena.

A case study was carried out in the Atitlán Basin, Guatemala, which integrated stakeholders from the Indigenous Mayan community into the suggested participatory model-building activity 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 minoritized linguistic backgrounds: Kaqchikel, Tz'utujil, and K'iche'. The study applied the suggested storyline development framework to investigate the relationships that govern the eutrophication problem in Lake Atitlán from a holistic community-based perspective and empower community-based decision-making. The remainder of the paper is structured as follows: Section 2 discusses existing PM methods and presents the argument for using storyline development to ensure the inclusion of marginalized stakeholders in conceptualizing SD models. Section 3 provides background information for the case study. Section 4 introduces the MLP framework, elaborates on the developed conceptual framework for multi-level storyline development, and provides a stepwise approach for implementation. The results of the implementation of the process in the Atitlan Basin are presented in Sect. 5. Section 6 evaluates and discusses the results from the perspective of sociohydrological phenomena, and Sect. 7 concludes the study.

2 Background

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 well-suited for portraying the complexity of sociohydrological processes.

Spatial mapping has also been used for facilitating the inclusion of stakeholders, with little to no literacy, in participatory activities. This approach allows locals 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 ill-suited for the conceptualization of sociohydrological models, 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 – was suggested by Colfer and Dudley (2011) to include less-literate stakeholders in participatory activities. Nevertheless, this genre of activities can only be conducted in group sessions, disregarding the potential effects of unhealthy group dynamics. Stakeholders are 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 fail to elicit 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. Although CLDs have been previously applied in participatory research (Inam et al., 2015, 2017b), their construction requires reading and writing skills. Hence, they are ill-suited for involving less-literate participants in participatory model-building activities.

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 social 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 solving water resources problems where (1) cross-dimensional collaboration across different fields (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 interconnectedness of different dimensions and domains are not only characterized by hydrological systems but by the implementation and institutionalization of generated decisions (Haeffner et al., 2018; Hassanzadeh et al., 2019).

Storytelling can also 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). 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 modelling 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., 2001). Therefore, they are well-suited for helping to inform and conceptualize SD models. New and unconventional data sources that can enhance understanding of and capture sociohydrological phenomena are needed for the development of holistic, participatory SD models that represent complex interactions between hydrological and socio-economic variables (Mount et al., 2016). The highly descriptive and flexible nature of storytelling captures the empirically observed complexity associated with such phenomena (Leong, 2018).

Storylines have been used by many researchers to complement models (Arico et al., 2001; Booth et al., 2016; Trutnevyte et al., 2014). Guhathakurta (2002) stated that storylines underpin models as a means of reconstructing and investigating stories. Also, 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 modelling and resource management has been limited (Arico et al., 2001; 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, those storytelling approaches have been specifically designed to inform conventional models (such as physically based models), and are ill-suited for conceptualizing SD models.

The storyline construction processes used in the above-listed studies start with requiring stakeholders to
190   state the most significant or uncertain drivers that are expected to shape the future trajectory of the modelled
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,
195   depicting the extrema of the driver states: (1) low and high climate change impacts (x-axis) and (2) favourable and
unfavourable 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
modelled variables. However, in SD modelling, prior to considering driving forces, interactions between diverse
200   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 subsistence. Therefore, the problem's triggers are not considered as external
'drivers' imposed on the system but rather internally acting and reacting within the modelled structure (Forrester,
1969).

Additionally, the key mechanism for exploring plausible futures or scenarios using SD models is through
205   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 SD models are characterized by components that are endogenously interacting
within the system. Therefore, the unique nature and structure of SD models require a different storytelling technique
that produces storylines capable of informing and conceptualizing the founding relationships of the model and
210   characterizing future scenarios using internal model variables.

The notion of coupling storylines with SD models has been previously suggested (Geum et al., 2014;
Mallampalli et al., 2016; Olabisi et al., 2010). Mallampalli et al. (2016) highlighted the suitability of SD modelling
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
215   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 SD models underpinned by a scenario storyline, containing
relationships that only represented the year 2050. SD 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 SD model
220   simulations from that exact phase of the process. In other words, SD was not used as a tool to explore possible future
states of the modelled system. Its use was restricted to simulating already-built and previously conceptualized future
scenarios.

Although this approach might be useful for providing visions of alternative futures, it is ill-suited for
designing decision-support tools, testing policies and BMPs, and generating policy-based scenarios for water
225   resources management. This method does not make use of one of SD's key advantages: 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
230   leverage points requires a thorough exploration of the modelled system as-is (prior to projecting it) and an
understanding of its components and relationships (which was not achieved in the studies mentioned above). 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 modelling process and not at the initial phase. Hence,
235   this study presents a framework for the construction of interdisciplinary storylines that aim to (1) inform and
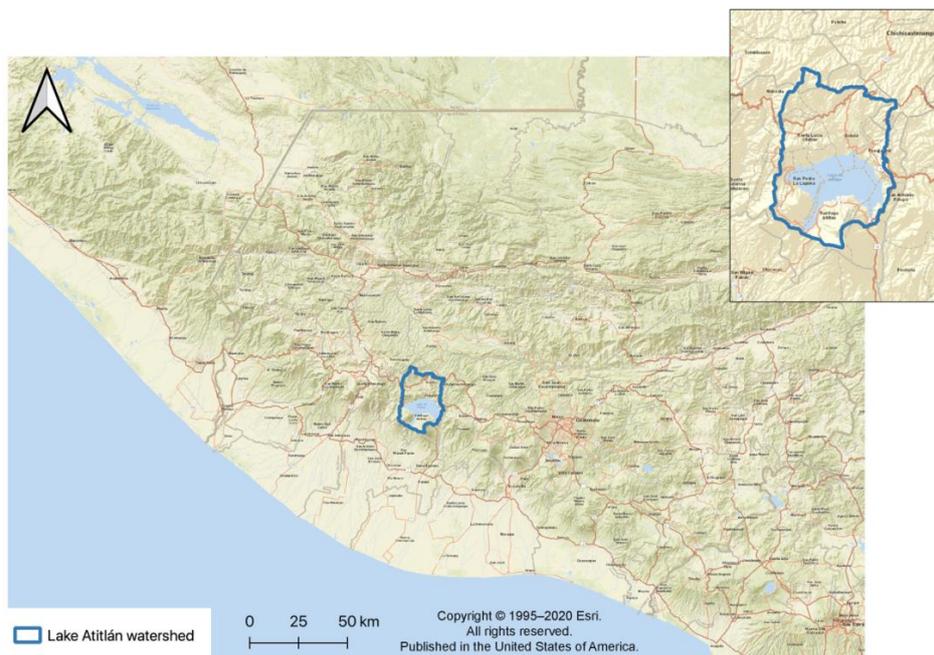conceptualize SD models and (2) make use of leverage points to empower decision-making.

3   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 highland, endorheic lake formed in a collapsed

240   caldera. The lake's surface area is 137 km2, while the Lake Atitlán watershed is 541 km2 (Fig. 1) (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- and nonpoint-sources of nutrient pollution. The most

245   prominent are agricultural runoff, untreated wastewater, and eroded soils (Weisman et al., 2018). For the past 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 massive cyanobacteria bloom covering 40% of its surface in October 2009 (Komárek et al., 2013).

250   The Atitlán Basin encompasses 15 municipalities and approximately 400,000 people. Forests and agricultural areas cover more than 70% of the watershed. Agriculture, aquaculture, and tourism are the dominant economic sectors in the region. 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

255   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 massive, centralized infrastructure to collect

260   wastewater from all the towns encircling the lake and transport it to a treatment plant outside the watershed. The wastewater would then be treated and used by agroindustrial farms for irrigation. 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 destroy the lake's ecosystem and

265   biodiversity. Third, since the basin encompasses multiple seismic faults, some Indigenous communities question the resilience of massive 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 1: Location of the study area in Guatemala. Created in QGIS (https://qgis.org/) using Esri (2009).

4 Methodology

4.1 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 bound 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

7

Hydrology and
Earth System
Sciences
Discussions

Open Access

EGU

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 determining whether associated radical innovations will yield a shift in the dominant regimes (Kemp et al., 2001; Mylan et al., 2019).

295 The MLP framework has not been used for the development of storylines that aim to inform and conceptualize SD models and, therefore, is modified in Sect. 4.2 in this study to accommodate the latter. This study builds on three concepts of the MLP framework: (1) the three levels, (1) 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.

300

4.2 Conceptual Framework: Multi-level Storyline Development

Storylines developed to conceptualize SD models 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 modelled problem– ideally targeting
305 leverage points. The construction of SD models using storytelling is, therefore, underpinned by the integration of storylines developed at three levels: Macro, Meso, and Micro (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
310 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 modelled system, which are essential for initiating the SD model's conceptualization and informing the Meso-level
315 storyline. The Meso-level storyline portrays the modelled 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, and 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 an SD model allows for the exploration of the system's leverage points and weakness zones. Subsequently, this informs the
320 Micro-level storylines, which encompass BMPs or policies and corresponding outcomes within the context of the modelled 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) fortify or dilute dynamics already embedded within it. The emergence and simulation of certain BMPs or policies then depict the starting point of the corresponding policy-
325 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).
330 The components of storylines associated with each level are displayed in Fig. 2. 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.
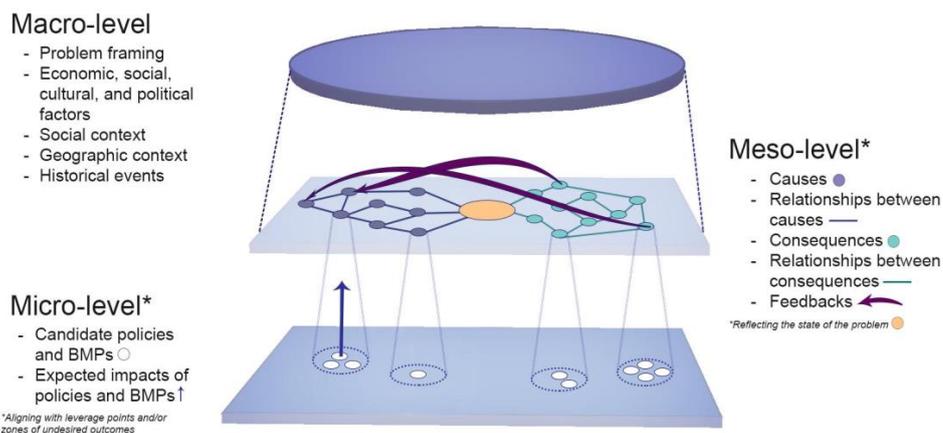
335

Figure 2: Components of storylines at three level: Macro, Meso, and Micro (modified from Geels et al. (2002) to accommodate multi-level level storyline development)

4.3   Implementation of the Process

340   The proposed storyline development process 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 the corresponding region is present in the team.

4.3.1   Stage 1: Macro-level Storylines

345   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 social backgrounds 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 provide language translations between stakeholders. The purpose of the focus group is to:

350   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., 2001)

b.   Contextualize the study system by delineating dominant economic sectors, power imbalances, cultural diversity, and the region's political culture, among others (Mostert, 2018)

355   c.   Set the social and geographic contexts of the model

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. Narratives are recorded in writing. This step aids the guidance team in

360   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.

4.3.2 Stage 2: Developing Meso-level Storylines

1. Performing 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). 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).

2. Conducting individual semi-structured interviews with stakeholders: The guidance team prepare focal questions to direct the construction of the Meso-level storylines and carry 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 freely rather than restrict them (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 SD 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., 2001). 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.3) 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: (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 3: The single-driving force method

3. 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. 4). The sign corresponding to each link indicates the type of relationship between the two variables: (+) indicates a direct relationship, while (-) implies an indirect one. Two types of feedback loops exist: balancing and reinforcing (refer to Inam et al., 2015). The semi-structured interview (elaborated in the previous step) is designed to elicit narratives containing

405   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. 5).
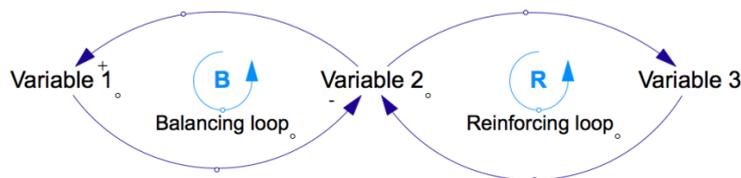

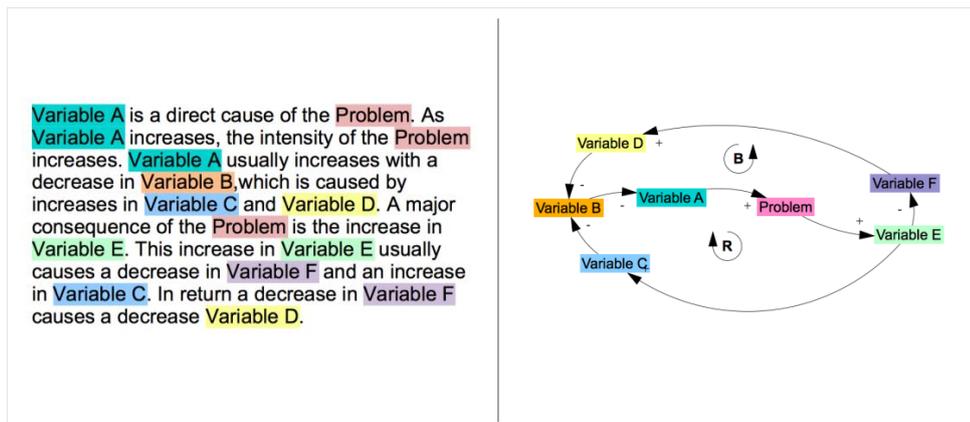**Figure 4: CLD: variables, causal links, and feedback loops**

410

Figure 5: A simplified version of a storyline and its concomitant CLD

4. Each individual CLD is joined, forming an overall merged CLD - as per Inam et al. (2015).

415   5. The merged CLD is (1) checked for inconsistencies and/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. 5).

6. 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.

420   7. 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., 2001), 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.6, is recommended (Alcamo, 2008).
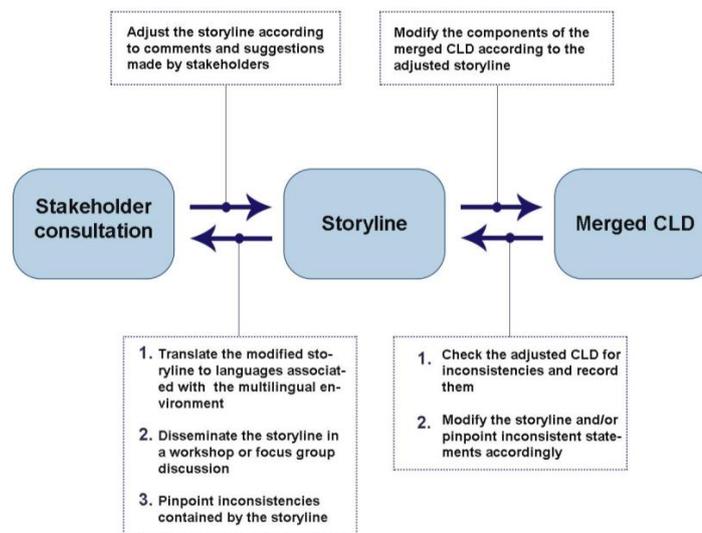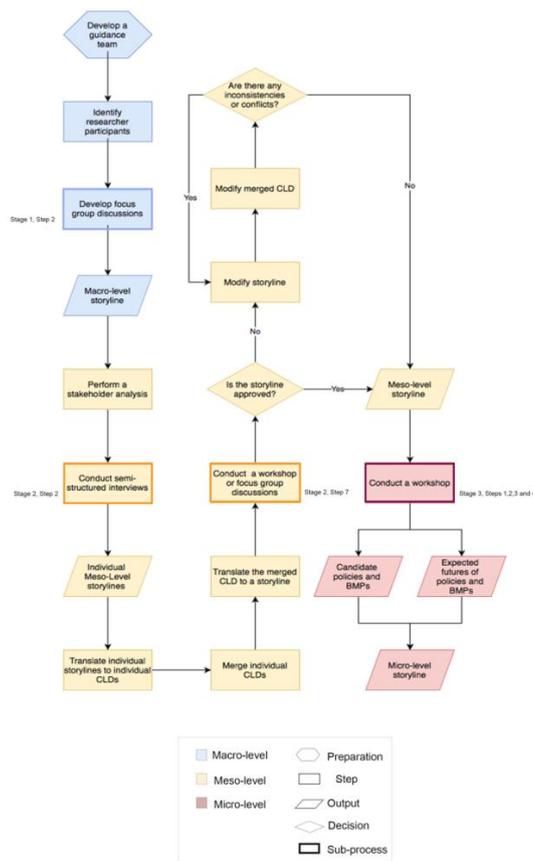
425

Figure 6: Iterative process between stakeholder consultation, storyline development, and CLD construction

8. 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 are not capable of understanding 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.

9. 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 concomitant CLD represent the business as usual scenario, containing causes and consequences of the problem as-is without the implementation of policies or BMPs.

4.3.3 Stage 3: Developing Micro-level Storylines

1. In a collective workshop, stakeholders are (1) addressed by 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 and/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 and/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 and/or BMP in the context of the modelled 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 and discussed until an agreement on suitable solutions is reached. This paper does not cover the implementation of this step.

Hydrology and
Earth System
Sciences
Discussions
Open Access

EGU

455

Figure 7: Multi-level storyline development process

5   Results

460   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 1 displays the demographics of the Atitlán watershed's general population
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 of the activity. All activities were carried out
in relevant languages.

465

470

Hydrology and
Earth System
Sciences
Discussions

Open Access
EGU

Table 1: Demographics of project participants

Demographics	Participatory Modelling (%)	General Population of the Study Site (%)
Women	24.1	52
Men	75.9	48
Indigenous	62.1	96
Hispanic	37.9	3
Indigenous language	58.6	81
Spanish language	41.4	18
Literate	86.2	70
Illiterate	13.8	30

475

5.1 Macro-level Storylines

The guidance team met with researchers from local and national, Indigenous and non-Indigenous, academic and governmental institutions, conducting research projects in the area. Focus groups were held with researcher participants. All interviewed parties confirmed that the lake eutrophication and associated water quality problems

480 were a concern to the Atitlán watershed. 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 surrounding activities and received significant national and international media coverage.

Participants highlighted the dominance of three types of economic activities in the area: (1) agriculture, aquaculture, and tourism. They also delineated the presence of two types of authorities: Indigenous and non-

485 Indigenous. For example, in Tz'olöj Ya' there are two municipalities, an Indigenous municipality and an official one. Nevertheless, the Indigenous municipality is not officially recognized by the Guatemalan government. 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

490 policies. Therefore, different stakeholder groups have attempted to implement various remedies to improve the lake's water quality. However, their efforts had 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

495 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, and Indigenous stakeholders have Kaqchikel, Tz'utujil, or

500 K'iche' first languages. Many Indigenous stakeholders 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. making up to 96% of the population in the province of Tz'olöj Ya').

Researcher participants also highlighted some historical events that influenced the problem and associated

505 reactions. For example, residents had first witnessed cyanobacterial blooms in the lake in 2008 and more extensive ones in 2009. These blooms induced residents' environmental awareness of the lake's unhealthy trophic state,

510 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) was proposed to solve the lake's eutrophication problem, triggering tensions between various communities opposing or supporting the project.

From the Macro-level storylines elicited from primary researcher participants, the authors concluded that the model should address 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,

515 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

520 them in the process. Finally, the consideration of stakeholders from both official governmental institutions and local Indigenous authorities was deemed important.

5.2 Meso-level Storylines

525 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 municipalities in the Atitlán watershed, local Indigenous authorities, relevant governmental institutions (the lake's authorities, environmental institutions, and agricultural institutions), farmers' associations, fishermen's associations, academic institutions, non-governmental organizations, community-based organizations, and owners of tourism businesses. To construct the Meso-level storylines, stakeholders were

530 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).

5.2.1 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,

535 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 stakeholders 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

540 the dominance of inorganic agricultural practices in the area to the need for farmers to maximize profit and governmental subsidies on inorganic fertilizers, among others.

A few stakeholders cited inorganic soaps and detergents from women 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

545 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 correlated different land-use variables (such as agricultural, forest, and urban areas) to nutrient concentration levels in Lake Atitlán (figures 8 and 9). For example, some stakeholders stated that an increase in population leads to an increase in

550 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.

5.2.2 Consequences

555 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

560 illnesses that would decrease workers' productivity, leading to the reduction of agricultural labour and cultivated areas, consequently. Others highlighted the effects of loss of fish species due to high concentrations of nutrients, consequently affecting fishermen's income. 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.

565 ### 5.2.3 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. 8) and tourism (Fig. 9) economic sectors and (2) one module representing the mechanisms governing environmental awareness in the region (Fig. 10).

570 Feedback links between (1) farmer's income and education (B1, Fig. 8), (2) poverty and education (R5, Fig. 9), and (3) tourism business revenues and potential investments in WWT plants (WWTPs) (R6, Fig. 9) indicate that the relationship between nutrient enrichment in Lake Atitlán and economic prosperity is represented by a reinforcing feedback loop (Fig. 11 (a)). In other words, some stakeholders stated that economic prosperity (1) increases the education rate, which ultimately decreases population and, subsequently, nutrient enrichment in Lake

575 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 2).

On the contrary, relationships between (1) farmer's income and potential investments in improving irrigation efficiency (R1, Fig. 8), (2) farmer's income and potential investments in cultivated areas (R2, Fig. 8), and (3) the number of tourists and the amount of discharged wastewater (B4 and B5, Fig. 9) portray feedbacks between

580 nutrient enrichment in Lake Atitlán and economic prosperity in the form of a balancing loop (Fig. 11 (b)). 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. 8, R7 in Fig. 9), which are presently

585 unsustainable, then economic prosperity exacerbates nutrient enrichment in Lake Atitlán. This balancing relationship between economic prosperity and nutrient enrichment was strictly the contribution of Indigenous stakeholders (Table 2).

Conversely, stakeholders linked the dominance of cyanobacteria with environmental awareness. Balancing loops representing this relationship (displayed in Fig. 10), were strictly elicited from members of the civil society

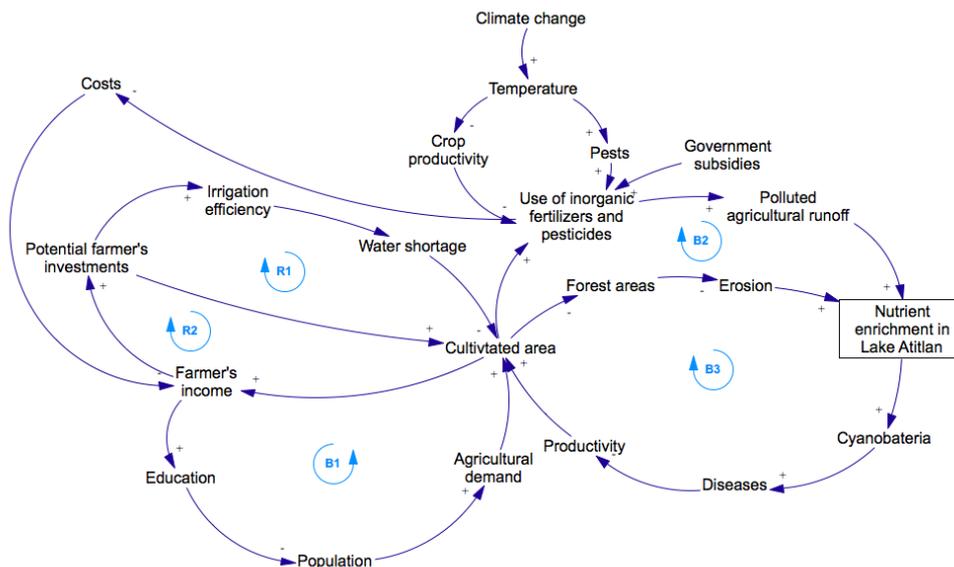590 (NGOs and community-based organizations with indigenous and non-indigenous members) (Table 2).

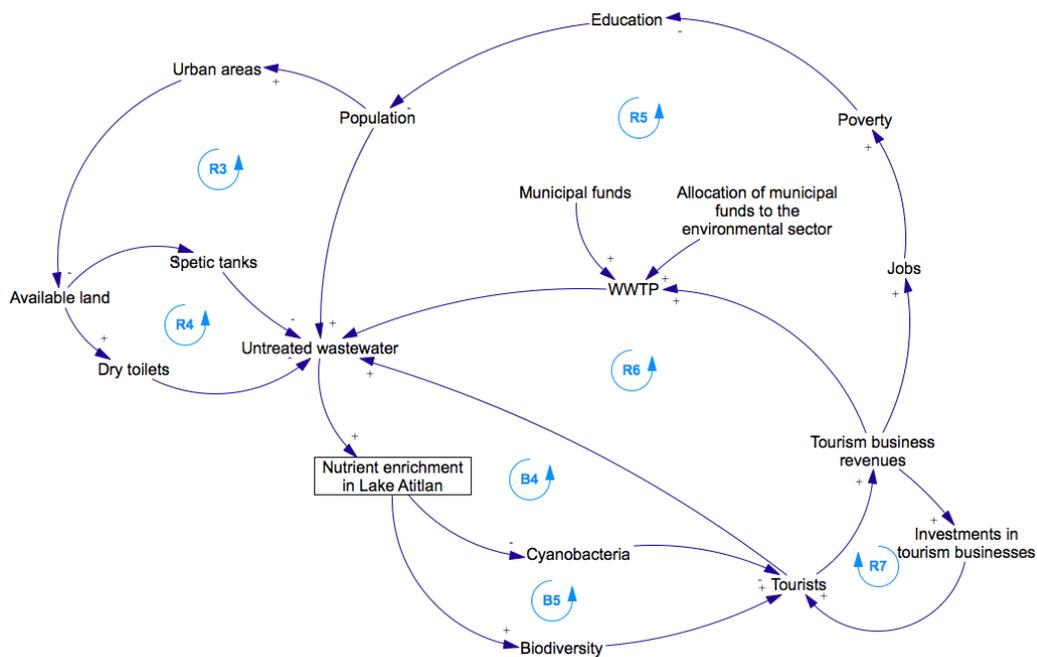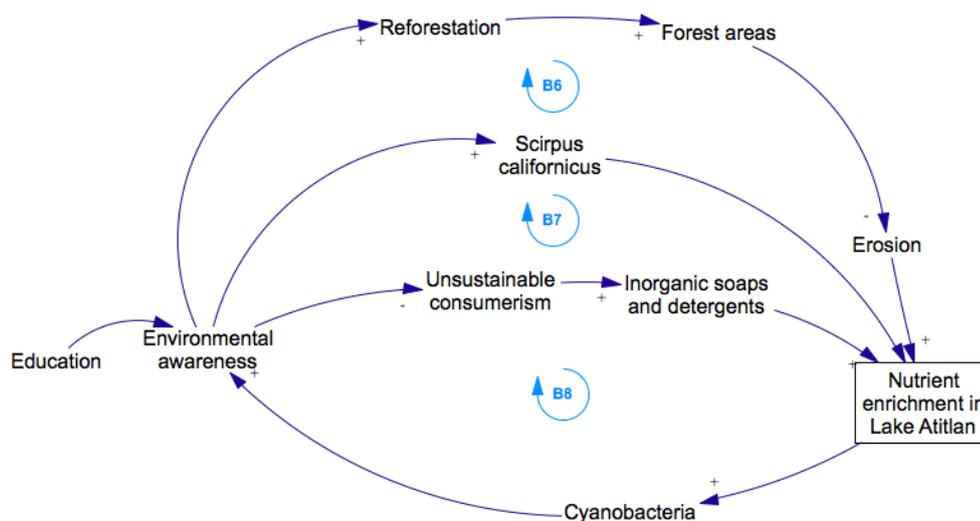**Figure 8: Agriculture submodule**

595

Figure 9: Tourism submodule

600

Figure 10: Environmental awareness submodule

605

Table 2: Highlights of unique contributions from diverse stakeholder groups

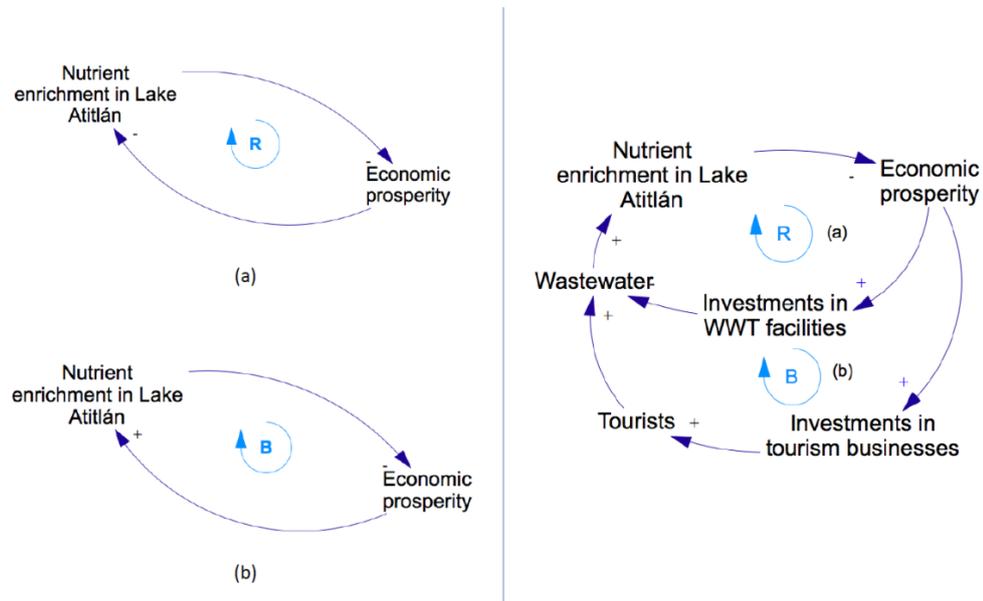| Contribution	Reference	Contributors
'WWTP' variable	R6 in Fig. 9	Mix of Indigenous and non-Indigenous stakeholders
'Dry latrines' and 'Septic tanks variables	R4 and R3 in Fig. 9	Indigenous stakeholders
Reinforcing feedbacks between nutrient enrichment in Lake Atitlán and economic prosperity (Fig. 11 (a))	B1 in Fig.8; R5 and R6 in Fig.9	Mix of Indigenous and non-Indigenous stakeholders
Balancing feedbacks between nutrient enrichment in Lake Atitlán and economic prosperity (Fig. 11 (b))	R2 and R1 in Fig.8, B4 and B5 in Fig.9	Indigenous stakeholders
Balancing feedbacks between nutrient enrichment in Lake Atitlán and environmental awareness	B6, B7, and B8 in Fig. M	Civil society
Positive correlation between crop productivity and the use of inorganic fertilizers	Excluded (refer to Sect. 5.2.4)	Decision-makers
Negative correlation between crop productivity and the use of inorganic fertilizers	Fig.8	Agriculturists/ farmers

18

Figure 11: The relationship between nutrient enrichment in Lake Atitlán and economic prosperity (reinforcing loop (a) and balancing loop (b))

5.2.4   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 agriculturalists 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 2). 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. 8, the relationship between crop productivity and organic farming is considered negative (Table 2).

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/or 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'el. 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. 9).

5.3 Micro-level Storylines

635   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), 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 definitely decrease nutrient concentrations in Lake Atitlán. Those who were

640 against it stated 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

645 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 encompassed by the watershed). The opposition also cited public safety concerns since the area is bounded by faults.

         Different stakeholder groups suggested different policies and BMPs targeting various leverage points (e.g.

650 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

655 outcomes with actual results. They specified the significance of setting the variable 'Farmer's income' (Fig. 8) as an evaluation metric for relevant policies and BMPs, to ensure their cooperation. Fishermen associations suggested imposing regulations for sustainable fishing practices and planting and preserving Scirpus californicus. They also emphasized that fishermen's income should be an evaluation index for potential policies to ensure the collaboration of fishermen and the aquaculture industry. Finally, members of the civil society highlighted the importance of forest

660 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.

665 ## 6 Discussion

6.1 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 minoritized languages), (2) fosters cooperation, (3) integrates different

670 perspectives of the problem, (4) facilitates model-conceptualization, and (5) yields a nuanced understanding of sociohydrological relationships governing the investigated problem. The suggested methodology was able to incorporate participants of low literacy levels, which would not have been achieved using CLDs alone since they require reading and writing skills. 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

675 reassured the confidentiality of their identities. This process succeeded in reducing unhealthy power dynamics and provided leeway for the participation of key stakeholders who usually exclude themselves from such activities due to power issues.

Hydrology and
Earth System
Sciences
Discussions
Open Access
EGU

680

Moreover, the variety of relevant languages spoken by the guidance team and stakeholders' freedom to convey information in their preferred language allowed 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. Numerous Indigenous stakeholders 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

685

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, leading to successful collaboration.

690

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 modelling process made exclusively by Indigenous stakeholders and displayed in Table 2. Moreover, in many cases, similar to the demonstrated case study (e.g. Hassanzadeh et al., 2019; Izurieta et al., 2011), marginalized stakeholders are

695

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 SD 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

700

within that scope. Meanwhile, the extraction of the Meso-level storylines helped develop a proper understanding of the relationships (causes, consequences, and feedbacks) governing the problem. Once the Meso-level was described, leverage points in the modelled 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 best management practices and policies by targeting the leverage points and undesired outcomes

705

mentioned above.

6.2   Sociohydrological Phenomena

Eliciting storylines from stakeholders helped detect sociohydrological phenomena, even more so than CLDs. During the construction of CLDs, participants are restricted by variables and causal links between them.

710

Storylines provided leeway 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. Two sociohydrological phenomena (Di Baldassarre et al., 2019) were detected and discussed in this exercise: the Rebound Effect (Dumont et al., 2013) and the Pendulum Swing (Van Emmerik et al., 2014). This shows how storytelling is aligned with sociohydrology; it facilitated the capture of abstract concepts

715

encompassed by sociohydrological phenomena that could not have been identified using conventional model-building methods or data sources.

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

720

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

Hydrology and
Earth System
Sciences
Discussions
Open Access
EGU

725   reallocated by farmers to cultivate more crops and irrigate larger areas (Fig. 8). The latter has been confirmed by earlier discussions with farmers, who claimed to favour profit maximization. The information elicited by the proposed methodology allowed for the consideration of expected farmers' behaviours and navigation of commonly made assumptions that contradict them. This is important for robust decision-making in water resource management, since ignoring behaviors when creating solutions can lead to unintended socioeconomic feedbacks that lessen or

730   reverse the intended impact. In other words, acknowledging relevant sociocultural behaviours 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 a sociohydrological phenomenon described as the change of priorities from immediate economic prosperity to environmental protection or vice versa

735   (Di Baldassarre et al., 2019). This phenomenon was delineated by several stakeholders and represented in two different balancing loops (B6 and B7 in Fig. 10). 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 sociohydrological 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

740   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 fishermen 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

745   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

750   degradation and economic growth. Mechanisms that create reinforcing feedbacks (e.g. R6 in Fig. 9) and balancing feedbacks (e.g. B5 in Fig. 9) 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

755   (i.e. WWTPs). This indicates that the applied method was capable of organically capturing the archetypal debate concept through diverse socioculturally explicit perspectives. This is crucial for (1) modelling sociohydrological systems, where different governing sociocultural mechanisms require more nuanced versions of generalized relationships and (2) developing well-targeted recommendations in sociohydrology. For example, in this case study, including a contextualized version of the relationship between economic prosperity and nutrient enrichment of the

760   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.

765   **7**   **Conclusion**

       The proposed participatory model-building framework addresses the challenges of tailoring PM activities in sociohydrology to accommodate diversity within societies and ensure the inclusion of marginalized stakeholders (i.e. less literate, comparatively powerless, and/or associated with minoritized languages). To date, most PM processes' implementation remains biased as they often view communities as homogeneous units and do not

770   consider different capabilities, needs, and interests within diverse communities.

The authors suggest that storyline development is capable of ensuring inclusiveness in participatory SD modelling. However, since the literature on PM in environmental and resource management contexts primarily provides participatory storyline development methodologies that (1) are either 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,

775 the authors propose a conceptual framework for developing storylines that aim to conceptualize and inform SD models while making use of the systems' leverage points. 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 ensuring the inclusion of marginalized stakeholders.

The proposed framework was tested in the Atitlan Basin, Guatemala and aimed to incorporate marginalized
780 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 minoritized 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 needed collaboration for the successful implementation of solutions. Moreover, the method provided stakeholders
785 with leeway for narrating more nuanced versions of relationships between variables, allowing the extraction of contextualized sociohydrological phenomena.

The suggested conceptual framework facilitated the translation of storylines into relationships that form the conceptual basis of the SD 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,
790 therefore, could help decision-makers develop well-targeted recommendations in water resources management. Author

8   Author Contributions

JBN developed the methods, carried out field work, performed the analysis, and wrote the paper. JM and MRR conducted field work. JA, JM, HT, and WM supervised the research. The authors declare no conflicts of
795 interest.

9   Acknowledgements

800 ## References

Alcamo, J.: Chapter Six The SAS Approach: Combining Qualitative and Quantitative Knowledge in Environmental Scenarios, Dev. Integr. Environ. Assess., 2, 123–150, doi:10.1016/S1574-101X(08)00406-7, 2008.

Alcott, B.: Jevons' paradox, Ecol. Econ., 54(1), 9–21, doi:10.1016/j.ecolecon.2005.03.020, 2005.
805 Arico, S., Bridgewater, P., El-beltagy, A., Harms, E., Program, S., Hepworth, R., Leitner, K., Oteng-yeboah, A., Ramos, M. A. and Watson, R. T.: The Millenium Ecosystem Assessment., 2001.

Arnell, N. W., Livermore, M. J. L., Kovats, S., Levy, P. E., Nicholls, R., Parry, M. L. and Gaffin, S. R.: Climate and socio-economic scenarios for global-scale climate change impacts assessments: Characterising the SRES storylines, Glob. Environ. Chang., doi:10.1016/j.gloenvcha.2003.10.004, 2004.
810 Ayrton, R.: The micro-dynamics of power and performance in focus groups: an example from discussions on national identity with the South Sudanese diaspora in the UK, Quant. Res., 1–17, doi:10.1177/1468794118757102, 2018.

Di Baldassarre, G., Martinez, F., Kalantari, Z. and Viglione, A.: Drought and flood in the Anthropocene: Feedback mechanisms in reservoir operation, Earth Syst. Dyn., 8(1), 225–233, doi:10.5194/esd-8-225-2017, 2017.
815 Di Baldassarre, G., Sivapalan, M., Rusca, M. and Cudennec, C.: Socio-hydrology : Scientific Challenges in Addressing a Societal Grand Challenge., 2019.

Berg, T. and Pooley, R.: Rich Pictures: Collaborative Communication Through Icons, Syst. Pract. Action Res.,

26(4), 361–376, doi:10.1007/s11213-012-9238-8, 2013.

820 Bohensky, E. L. and Maru, Y.: Synthesis, part of a Special Feature on Integrating Indigenous Ecological Knowledge and Science in Natural Resource Management: Perspectives from Australia Indigenous Knowledge, Science, and Resilience: What Have We Learned from a Decade of International, , 16(4), 1–19, doi:10.5751/ES-04342-160406, 2011.

Booth, E. G., Qiu, J., Carpenter, S. R., Schatz, J., Chen, X., Kucharik, C. J., Loheide, S. P., Motew, M. M., Seifert, J. M. and Turner, M. G.: From qualitative to quantitative environmental scenarios: Translating storylines into

825 biophysical modeling inputs at the watershed scale, Environ. Model. Softw., doi:10.1016/j.envsoft.2016.08.008, 2016.

van Bruggen, A., Nikolic, I. and Kwakkel, J.: Modeling with stakeholders for transformative change, Sustain., 11(3), 1–21, doi:10.3390/su11030825, 2019.

Burgin, S., Webb, T. and Rae, D.: Stakeholder engagement in water policy: Lessons from peri-urban irrigation,

830 Land use policy, 31, 650–659, doi:10.1016/j.landusepol.2012.09.010, 2013.

Butler, C. and Adamowski, J.: Empowering marginalized communities in water resources management: Addressing inequitable practices in Participatory Model Building, J. Environ. Manage., 153, 153–162, doi:10.1016/j.jenvman.2015.02.010, 2015.

Calvert, S.: Managing Stakeholders, in The Commercial Project Manager, edited by J. R. Turner, pp. 214–222,

835 McGrawHill, Maidenhead., 1995.

Carpenter, S. R., Booth, E. G., Gillon, S., Kucharik, C. J., Loheide, S., Mase, A. S., Motew, M., Qiu, J., Rissman, A. R., Seifert, J., Soylu, E., Turner, M. and Wardropper, C. B.: Plausible futures of a social-ecological system: Yahara watershed, Wisconsin, USA, Ecol. Soc., 20(2), doi:10.5751/ES-07433-200210, 2015.

Cobb, A. N. and Thompson, J. L.: Climate change scenario planning: A model for the integration of science and

840 management in environmental decision-making, Environ. Model. Softw., 38(April 2009), 296–305, doi:10.1016/j.envsoft.2012.06.012, 2012.

Colfer, C. J. P.: The complex forest : communities, uncertainty, and adaptive collaborative management, Resources for the Future., 2005.

Colfer, C. J. P. and Dudley, R. G.: Strengthening Links Between Anthropologists and System Dynamicists :

845 Participatory Group Modeling & Natural Resources, Int. Conf. Syst. Dyn. Soc., 2011(June), 2011.

Convertino, M., Foran, C. M., Keisler, J. M., Scarlett, L., Loschiavo, A., Kiker, G. A. and Linkov, I.: Enhanced adaptive management: Integrating decision analysis, scenario analysis and environmental modeling for the everglades, Sci. Rep., 3, 37–39, doi:10.1038/srep02922, 2013.

Cooke, B. and Kothari, U.: Participation: the new tyranny?, Zed Books., 2001.

850 Daniell, K. A., Coombes, P. J. and White, I.: Politics of innovation in multi-level water governance systems, J. Hydrol., 519(PC), 2415–2435, doi:10.1016/j.jhydrol.2014.08.058, 2014.

Delmotte, S., Couderc, V., Mouret, J. C., Lopez-Ridaura, S., Barbier, J. M. and Hossard, L.: From stakeholders narratives to modelling plausible future agricultural systems. Integrated assessment of scenarios for Camargue, Southern France, Eur. J. Agron., 82, 292–307, doi:10.1016/j.eja.2016.09.009, 2017.

855 Dumont, A., Mayor, B. and López-Gunn, E.: Is the Rebound Effect or Jevons Paradox a Useful Concept for better Management of Water Resources? Insights from the Irrigation Modernisation Process in Spain, Aquat. Procedia, 1, 64–76, doi:10.1016/j.aqpro.2013.07.006, 2013.

Eker, S., Zimmermann, N., Carnohan, S. and Davies, M.: Participatory system dynamics modelling for housing, energy and wellbeing interactions, Build. Res. Inf., 46(7), 738–754, doi:10.1080/09613218.2017.1362919, 2018.

860 Elsawah, S., Guillaume, J. H. A., Filatova, T., Rook, J. and Jakeman, A. J.: A methodology for eliciting, representing, and analysing stakeholder knowledge for decision making on complex socio-ecological systems: From cognitive maps to agent-based models, J. Environ. Manage., 151, doi:10.1016/j.jenvman.2014.11.028, 2015.

Van Emmerik, T. H. M., Li, Z., Sivapalan, M., Pande, S., Kandasamy, J., Savenije, H. H. G., Chanan, A. and Vigneswaran, S.: Socio-hydrologic modeling to understand and mediate the competition for water between

865 agriculture development and environmental health: Murrumbidgee River basin, Australia, Hydrol. Earth Syst. Sci., 18(10), 4239–4259, doi:10.5194/hess-18-4239-2014, 2014.

Evans, K.: Field guide to the future : four ways for communities to think ahead., 2006.

Ferráns, L., Caucci, S., Cifuentes, J., Avellán, T., Dornack, C. and Hettiarachchi, H.: Wastewater management in the basin of lake Atitlán: a background study, Dresden., 2018.

870 Figueiredo, P. and Perkins, P. E.: Women and water management in times of climate change:participatory and inclusive processes, J. Clean. Prod., 60, 188–194, doi:10.1016/j.jclepro.2012.02.025, 2013.

Foran, T., Ward, J., Kemp-Benedict, E. J. and Smajgl, A.: Developing detailed foresight narratives: A participatory technique from the Mekong region, Ecol. Soc., 18(4), doi:10.5751/ES-05796-180406, 2013.

Forrester, J. W.: Urban Dynamics, M.I.T. Press., 1969.

875 Forrester, J. W.: Counterintuitive behavior of social systems, Theory Decis., doi:10.1007/BF00148991, 1971.

Foxon, T. J., Hammond, G. P. and Pearson, P. J. G.: Developing transition pathways for a low carbon electricity system in the UK, Technol. Forecast. Soc. Change, 77(8), 1203–1213, doi:10.1016/j.techfore.2010.04.002, 2010.

Foxon, T. J., Pearson, P., Arapostathis, S., Carlsson-Hyslop, A. and Thornton, J.: Branching points for transition pathways: How actors respond to stresses and challenges, Energy Policy, 52, 146–158,
880 doi:dx.doi.org/10.1016/j.enpol.2012.04.030, 2013.

Freeman, R.: Strategic Management: A Stakeholder Approach, Cambridge University Press, Cambridge., 2010.

Funtowicz, S. O. and Ravetz, J. R.: Science for the post-normal age, Futures, doi:10.1016/0016-3287(93)90022-L, 1993.

Geels, F. and Kemp, R.: "Transities vanuit sociotechnisch perspectief." Report for the Dutch Ministry of
885 Environment, Univ. Twente, Maastricht MERIT, 63, 2000.

Geels, F. W.: Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study, Res. Policy, 31(8–9), 1257–1274, doi:10.1016/S0048-7333(02)00062-8, 2002.

Geum, Y., Lee, S. and Park, Y.: Combining technology roadmap and system dynamics simulation to support scenario-planning: A case of car-sharing service, Comput. Ind. Eng., 71(1), 37–49, doi:10.1016/j.cie.2014.02.007,
890 2014.

Guhathakurta, S.: Urban Modeling as Storytelling: Using Simulation Models as a Narrative, Environ. Plan. B Plan. Des., 29(6), 895–911, doi:10.1068/b12857, 2002.

Guijt, I. and Shah, M. K.: The myth of community : gender issues in participatory development, Intermediate Technology Publications., 1998.

895 Gunda, T., Turner, B. L. and Tidwell, V. C.: The Influential Role of Sociocultural Feedbacks on Community-Managed Irrigation System Behaviors During Times of Water Stress, Water Resour. Res., 54(4), 2697–2714, doi:10.1002/2017WR021223, 2018.

Haeffner, M., Jackson-Smith, D. and Flint, C. G.: Social Position Influencing the Water Perception Gap Between Local Leaders and Constituents in a Socio-Hydrological System, Water Resour. Res., 54(2), 663–679,
900 doi:10.1002/2017WR021456, 2018.

Hassanzadeh, E., Strickert, G., Morales-Marin, L., Noble, B., Baulch, H., Shupena-Soulodre, E. and Lindenschmidt, K. E.: A framework for engaging stakeholders in water quality modeling and management: Application to the Qu'Appelle River Basin, Canada, J. Environ. Manage., 231(August 2018), 1117–1126, doi:10.1016/j.jenvman.2018.11.016, 2019.

905 Hazeleger, W., Van Den Hurk, B. J. J. M., Min, E., Van Oldenborgh, G. J., Petersen, A. C., Stainforth, D. A., Vasileiadou, E. and Smith, L. A.: Tales of future weather, Nat. Clim. Chang., 5(2), 107–113, doi:10.1038/nclimate2450, 2015.

Inam, A., Adamowski, J., Halbe, J. and Prasher, S.: Using causal loop diagrams for the initialization of stakeholder engagement in soil salinity management in agricultural watersheds in developing countries: A case study in the
910 Rechna Doab watershed, Pakistan, J. Environ. Manage., 152, 251–267, doi:10.1016/j.jenvman.2015.01.052, 2015.

Inam, A., Adamowski, J., Prasher, S., Halbe, J., Malard, J. and Albano, R.: Coupling of a distributed stakeholder-built system dynamics socio-economic model with SAHYSMOD for sustainable soil salinity management – Part 1: Model development, J. Hydrol., 551, 596–618, doi:10.1016/j.jhydrol.2017.03.039, 2017a.

Inam, A., Adamowski, J., Prasher, S., Halbe, J., Malard, J. and Albano, R.: Coupling of a distributed stakeholder-
915 built system dynamics socio-economic model with SAHYSMOD for sustainable soil salinity management – Part 1: Model development, J. Hydrol., 551, 596–618, doi:10.1016/j.jhydrol.2017.03.039, 2017b.

Izurieta, A., Sithole, B., Stacey, N., Hunter-Xenie, H., Campbell, B., Donohoe, P., Brown, J. and Wilson, L.: Developing indicators for monitoring and evaluating joint management effectiveness in protected areas in the northern territory, Australia, Ecol. Soc., 16(3), 22, doi:10.5751/ES-04274-160309, 2011.

920 Kemp, R., Rip, A. and Schot, J.: Constructing Transition Paths Through the Management of Niches, in Path Dependence and Creation, edited by R. Garud and P. Karnoe, pp. 269–299, Lawrence Erlbaum, Mahwa (N.J.) and London., 2001.

Komárek, J., Zapomělová, E., Šmarda, J., Kopecký, J., Rejmánková, E., Woodhouse, J., Neilan, B. A. and Komárková, J.: Polyphasic evaluation of Limnoraphis robusta, a water-bloom forming cyanobacterium from Lake
925 Atitlán, Guatemala, with a description of Limnoraphis gen. nov, Fottea, 13(1), 39–52, doi:10.5507/fot.2013.004, 2013.

Komárková, J., Dix, M., Komárek, J., Girón, N. and Rejmánková, E.: Cyanobacterial blooms in Lake Atitlan, Guatemala, Limnologica, 41(4), 296–302, doi:10.1016/j.limno.2010.12.003, 2011.

Leong, C.: The Role of Narratives in Sociohydrological Models of Flood Behaviors, Water Resour. Res., 54(4),

Hydrology and
Earth System
Sciences
Discussions

Open Access

EGU

930   3100–3121, doi:10.1002/2017WR022036, 2018.

Liu, D., Tian, F., Lin, M. and Sivapalan, M.: A conceptual socio-hydrological model of the co-evolution of humans and water: Case study of the Tarim River basin, western China, Hydrol. Earth Syst. Sci., 19(2), 1035–1054, doi:10.5194/hess-19-1035-2015, 2015.

Malard, J. J., Inam, A., Hassanzadeh, E., Adamowski, J., Tuy, H. A. and Melgar-Quiñonez, H.: Development of a
935   software tool for rapid, reproducible, and stakeholder-friendly dynamic coupling of system dynamics and physically-based models, Environ. Model. Softw., 96, 410–420, doi:10.1016/j.envsoft.2017.06.053, 2017.

Mallampalli, V. R., Mavrommati, G., Thompson, J., Duveneck, M., Meyer, S., Ligmann-Zielinska, A., Druschke, C. G., Hychka, K., Kenney, M. A., Kok, K. and Borsuk, M. E.: Methods for translating narrative scenarios into quantitative assessments of land use change, Environ. Model. Softw., doi:10.1016/j.envsoft.2016.04.011, 2016.

940   Martins, R., Cherni, J. A. and Videira, N.: 2MBio , a novel tool to encourage creative participatory conceptual design of bioenergy systems e The case of wood fuel energy systems in south Mozambique, J. Clean. Prod., 172, 3890–3906, doi:10.1016/j.jclepro.2017.05.062, 2018.

Maynard, L. and Jacobson, S. K.: Human Dimensions of Wildlife Stakeholder Participation in Wildlife Management : Adapting the Nominal Group Technique in Developing Countries for Participants with Low Literacy
945   Stakeholder Participation in Wildlife Management : Adapting the Nominal Group T, Hum. Dimens. Wildl., 22(1), 71–82, doi:10.1080/10871209.2016.1225139, 2017.

Meadows, D.: Leverage Points: Places to Intervene in a System, , 1–12, doi:10.1080/02604020600912897, 1999.

Mitchell, R. K., Agle, B. R. and Wood, D. J.: Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts, Acad. Manag. Rev., 22(4), 853–886,
950   doi:10.5465/AMR.1997.9711022105, 1997.

Moallemi, E. A. and Malekpour, S.: A participatory exploratory modelling approach for long-term planning in energy transitions, Energy Res. Soc. Sci., 35(October 2017), 205–216, doi:10.1016/j.erss.2017.10.022, 2018.

Moallemi, E. A., de Haan, F. J., Webb, J. M., George, B. A. and Aye, L.: Transition dynamics in state-influenced niche empowerments: Experiences from India's electricity sector, Technol. Forecast. Soc. Change, 116, 129–141,
955   doi:10.1016/j.techfore.2016.10.067, 2017.

Moezzi, M., Janda, K. B. and Rotmann, S.: Using stories, narratives, and storytelling in energy and climate change research, Energy Res. Soc. Sci., 31(May), 1–10, doi:10.1016/j.erss.2017.06.034, 2017.

Mostert, E.: An alternative approach for socio-hydrology: Case study research, Hydrol. Earth Syst. Sci., 22(1), 317–329, doi:10.5194/hess-22-317-2018, 2018.

960   Mount, N. J., Maier, H. R., Toth, E., Elshorbagy, A., Solomatine, D., Chang, F. J. and Abrahart, R. J.: Data-driven modelling approaches for socio-hydrology: Opportunities and challenges within the Panta Rhei Science Plan, Hydrol. Sci. J., 61(7), 1192–1208, doi:10.1080/02626667.2016.1159683, 2016.

Mylan, J., Morris, C., Beech, E. and Geels, F. W.: Rage against the regime: Niche-regime interactions in the societal embedding of plant-based milk, Environ. Innov. Soc. Transitions, 31(January 2018), 233–247,
965   doi:10.1016/j.eist.2018.11.001, 2019.

Newhall, C. G.: Geology of the Lake Atitlán Region, Western Guatemala, J. Volcanol. Geotherm. Res., 33(1–3), 23–55, doi:10.1016/0377-0273(87)90053-9, 1987.

Nixon, S. W.: Coastal marine eutrophication: A definition, social causes, and future concerns, Ophelia, 41(1), 199–219, doi:10.1080/00785236.1995.10422044, 1995.

970   Olabisi, L. K. S., Kapuscinski, A. R., Johnson, K. A., Reich, P. B., Stenquist, B. and Draeger, K. J.: Using scenario visioning and participatory system dynamics modeling to investigate the future: Lessons from Minnesota 2050, Sustainability, 2(8), 2686–2706, doi:10.3390/su2082686, 2010.

Orr, C. J., Adamowski, J. F., Medema, W. and Milot, N.: A multi-level perspective on the legitimacy of collaborative water governance in Québec, Can. Water Resour. J., 41(3), 353–371,
975   doi:10.1080/07011784.2015.1110502, 2016.

Perrone, A., Inam, A., Albano, R., Adamowski, J. and Sole, A.: A participatory system dynamics modeling approach to facilitate collaborative flood risk management: A case study in the Bradano River (Italy), J. Hydrol., 580(November 2019), doi:10.1016/j.jhydrol.2019.124354, 2020.

Prodanovic, P. and Simonovic, S. P.: An operational model for support of integrated watershed management, Water
980   Resour. Manag., 24(6), 1161–1194, doi:10.1007/s11269-009-9490-6, 2010.

Rambaldi, G., Muchemi, J., Crawhall, N. and Monaci, L.: Through the eyes of hunter-gatherers: Participatory 3D modelling among Ogiek indigenous peoples in Kenya, Inf. Dev., 23(2–3), 113–128, doi:10.1177/0266666907078592, 2007.

Reilly, K., Adamowski, J. and John, K.: Participatory mapping of ecosystem services to understand stakeholders'
985   perceptions of the future of the Mactaquac Dam, Canada, Ecosyst. Serv., 30, 107–123,

doi:10.1016/j.ecoser.2018.01.002, 2018.

Schindler, D. W.: Eutrophication and recovery in experimental lakes: Implications for lake management, Science (80-.)., 184(4139), 897–899, doi:10.1126/science.184.4139.897, 1974.

Smith, V. H. and Schindler, D. W.: Eutrophication science: where do we go from here?, Trends Ecol. Evol., 24(4), 201–207, doi:10.1016/j.tree.2008.11.009, 2009.

Strauss, A. and Corbin, J.: Basics of Qualitative Research., 1990.

Thaler, T. and Levin-Keitel, M.: Multi-level stakeholder engagement in flood risk management-A question of roles and power: Lessons from England, Environ. Sci. Policy, 55, 292–301, doi:10.1016/j.envsci.2015.04.007, 2016.

Timpe, C. and Scheepers, M. J. J.: Policy and Regulatory Roadmaps for the Integration of Distributed, Ecn-C--04-012, (December), 2003.

Treuer, G., Koebele, E., Deslatte, A., Ernst, K., Garcia, M. and Manago, K.: A narrative method for analyzing transitions in urban water management: The case of the Miami-Dade Water and Sewer Department, Water Resour. Res., doi:10.1002/2016WR019658, 2017.

Trutnevyte, E., Barton, J., O'Grady, Á., Ogunkunle, D., Pudjianto, D. and Robertson, E.: Linking a storyline with multiple models: A cross-scale study of the UK power system transition, Technol. Forecast. Soc. Change, 89, 26–42, doi:10.1016/j.techfore.2014.08.018, 2014.

Videira, N., Antunes, P. and Santos, R.: Scoping river basin management issues with participatory modelling: The Baixo Guadiana experience, Ecol. Econ., 68(4), 965–978, doi:10.1016/j.ecolecon.2008.11.008, 2009.

Voinov, A., Kolagani, N., McCall, M. K., Glynn, P. D., Kragt, M. E., Ostermann, F. O., Pierce, S. A. and Ramu, P.: Modelling with stakeholders - Next generation, Environ. Model. Softw., 77, 196–220, doi:10.1016/j.envsoft.2015.11.016, 2016.

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., Prell, C., Zellner, M., Paolisso, M., Jordan, R., Sterling, E., Schmitt Olabisi, L., Giabbanelli, P. J., Sun, Z., Le Page, C., Elsawah, S., BenDor, T. K., Hubacek, K., Laursen, B. K., Jetter, A., Basco-Carrera, L., Singer, A., Young, L., Brunacini, J. and Smajgl, A.: Tools and methods in participatory modeling: Selecting the right tool for the job, Environ. Model. Softw., 109(August), 232–255, doi:10.1016/j.envsoft.2018.08.028, 2018.

Vos, J. F. J. and Achterkamp, M. C.: Stakeholder identification in innovation projects: Going beyond classification, Eur. J. Innov. Manag., 9(2), 161–178, doi:10.1108/14601060610663550, 2006.

Webler, T.: "Right" Discorse in Citizen Participation: An Evaluative Yardstick, Fairness Competence Citiz. Particip. Eval. Model. Environ. Discourse, doi:10.1177/00953990022019588, 1995.

Weisman, A., Chandra, S., Rejmánková, E. and Carlson, E.: Effects of Nutrient Limitations and Watershed Inputs on Community Respiration in a Deep, Tropical Lake: Comparison of Pelagic and Littoral Habitats, Water Resour. Res., 54(8), 5213–5224, doi:10.1029/2017WR021981, 2018.

Weiss, C. M.: Water Quality Investigations in Guatemala, E.S.E. publication., 1971.

Withers, P. J. A. and Haygarth, P. M.: Agriculture, phosphorus and eutrophication: A European perspective, Soil Use Manag., 23(SUPPL. 1), 1–4, doi:10.1111/j.1475-2743.2007.00116.x, 2007.

Xu, G., Xu, X., Tang, W., Liu, W., Shi, J., Liu, M. and Wang, K.: Fighting against water crisis in China-A glimpse of water regime shift at county level, Environ. Sci. Policy, 61(2016), 33–41, doi:10.1016/j.envsci.2016.03.021, 2016.

York, R. and McGee, J. A.: Understanding the Jevons paradox, Environ. Sociol., 2(1), 77–87, doi:10.1080/23251042.2015.1106060, 2016.

Zscheischler, J., Westra, S., Van Den Hurk, B. J. J. M., Seneviratne, S. I., Ward, P. J., Pitman, A., Aghakouchak, A., Bresch, D. N., Leonard, M., Wahl, T. and Zhang, X.: Future climate risk from compound events, Nat. Clim. Chang., 8(6), 469–477, doi:10.1038/s41558-018-0156-3, 2018.