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**Innovative and Sustainable Groundwater Management in the Mediterranean**

**D4.2 Report on the Participatory Systems Mapping and the Conceptual Model**

**VERSION 1.0**

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Executive Summary

The overall objective of the InTheMED project is to implement innovative and sustainable management tools and remediation strategies for MED aquifers (inland and coastal) in order to mitigate anthropogenic and climate-change threats by creating new long-lasting spaces of social learning among different interdependent stakeholders, NGOs, and scientific researchers in five field case studies, located at the two shores of the MED basin, namely in Spain, Greece, Portugal, Tunisia, and Turkey.

InTheMED will develop an inclusive process that will establish an ensemble of innovative assessment and management tools and methodologies including a high-resolution monitoring approach, smart modelling, a socio-economic assessment, web-based decision support systems (DSS) and new configurations for governance to establish efficient and sustainable integrated groundwater management in the MED considering both the quantitative and qualitative aspects.

The objective of Deliverable 4.2 is to document the creation of learning spaces in Konya, Turkey, spanning the two field campaigns in March and July 2021 and the two modeling workshops in September 2021 and February 2022. To fulfill this objective, this report introduces the challenges in groundwater governance in general and in particular in Konya, the problems diagnosed in the field campaigns that lay the foundations of the participatory modeling process, the research design and preliminary outcomes as anecdotal evidence of learning and conceptual maps, or seed models that are in development process to simulate the future pathways towards sustainable use of groundwater resources.

1. Introduction

This is the documentation of D4.2 of the “Innovative and Sustainable Groundwater Management in the Mediterranean” Grant Agreement Number 1923 project.

* 1. Groundwater Sustainability as a Complex Dynamic Problem

 Ensuring groundwater sustainability is difficult due to both the shared traits of all common pool resources and the characteristic qualities of groundwater itself. As for all common pool resources, the hardship of preventing access is an indirect incentive for free riding, which precludes the collective action necessary to sustain the resource in the long run (Dietz et al., 2002; Schlager, 2007). Even if certain individuals or groups were successfully denied their access to the resource, the coordination problems between a limited number of users are still likely to result in the overexploitation of groundwater (Dietz et al., 2002). Individuals have a high propensity to avoid precautions that require a certain amount of time and financial costs, because their altruistic behavior may easily be leveraged by free riders. As a result, users of the resource are likely to ‘race to harvest’ the resource (Dietz et al., 2002). In other words, even if a certain group of users renounced their short-term benefits for the greater good (sustainable use of the resource), their efforts will be rendered useless unless most of the users cooperate. Those who try to do good will suffer the consequences of excess extraction even though they had no part in it. The prioritization of individual short-term benefits over the long-term social benefits results in the “tragedy of the commons” (Hardin, 1968). To prevent the tragedy, allowing for communication between the relevant stakeholders, creating an environment of trust, and building decision mechanisms that provide coordinated action and prevent probable cooperation problems are of prime importance (Dietz et al., 2002).

Groundwater cannot be approached independently from other system components to which it is connected. Rural or urban land use, agriculture, industry, surface water, wetlands, and several other ecosystems are examples of groundwater related systems (Villholth & Conti, 2018). The high level of interconnectedness inevitably increases the complexity and uncertainty within such systems, through rich nonlinear feedback. Therefore, groundwater issues are not only about the groundwater resource itself. Decisions on the withdrawal or use of groundwater are related to other relevant system components and may possibly have unforeseen consequences on agricultural land systems, groundwater and surface water connection, or biodiversity (Re, 2015; Saito et al., 2021). Furthermore, time lag in responses to any intervention in such interconnected systems makes it harder to comprehend system structure and estimate behavior (Saito et al., 2021).

In addition, groundwater has many characteristic traits that separates it from other natural resources and those must not be overlooked when discussing groundwater sustainability. First, hydrological systems are dispersed in wide areas, and are compositely constructed; therefore, there usually is a mismatch between the administrative boundaries and the hydrological system boundaries (Theesfeld, 2010). This mismatch complicates the sustainable use of groundwater resources, and in some cases may result in conflicts between different administrative units. The wide dispersion of the resource also leads to considerable time lags between any human intervention to the resource and its impact on groundwater and other systems that they are connected to. Some interventions are likely to be irreversible and unpredictable (such as saltwater intrusion or sink-hole formation), but the over extraction might not be noticed before the resource loses its renewability (Dietz et al., 2002; Theesfeld, 2010). The short-sightedness in that sense, should be a primal concern when dealing with groundwater-related issues. Therefore, both the temporal and the spatial dynamics of groundwater should be addressed correctly to secure groundwater resources. Systemic delays, accumulations, and unforeseen feedback pose significant threats to groundwater sustainability.

Second, groundwater is an “invisible” resource (Saito et al., 2021, p. 8). Even with today’s technology, identifying the physical boundaries of groundwater and assessing its depletion is not particularly easy as aquifer hydrogeology is heterogeneous. The invisibility of the resource makes it difficult to determine the recharge rate, discharge points, and flow of groundwater in between aquifers. It is impossible for local users to know the aquifer capacities, boundaries, and the impact their extraction will have on the basin level, without the help of experts such as engineers or hydrogeologists (Schlager, 2007).

The availability of continuous data is crucial in groundwater governance and sustainability. Today, unfortunately, many regions in the world lack sufficient empirical data, therefore aquifer characterization is inadequate. Decision-making is mostly based on estimations derived from outdated and sparse data (Schlager, 2007). The required information covers not only the hydrological / hydrogeological data such as aquifer structure, storage capacity, groundwater levels, and water budgets, but also the groundwater extraction and use data (Schlager, 2007). Therefore, complete, and correct information about infrastructure (such as number of wells, their depth, well capacities etc.) is necessary. However, obtaining such detailed information is costly and, in most cases, unlikely.

Identifying the relevant stakeholders and the social boundaries is as difficult as identifying the physical boundaries of groundwater (Theesfeld, 2010).  The social boundaries are dynamic; therefore, the governance process and the institutional structure should be adaptive to social, environmental, political, and economic changes. The number and variety of stakeholders for groundwater use is high, leading to information asymmetries and inevitable conflicts of interest, further decreasing the probability of cooperation (Dietz et al., 2002). The information asymmetries could occur involuntarily, for example between central and local governing bodies, or voluntarily, when certain stakeholder groups knowingly misdirect others to gain advantage over the resource (Theesfeld, 2010).

All that said, groundwater sustainability is an interdisciplinary topic that interests hydrology and hydrogeology, economy, political science, and other social sciences; like all social-economic-environmental issues. Therefore, groundwater sustainability should be framed as a highly dynamic and complex problem that relates to many different scales temporally, spatially, and institutionally.

* 1. Konya, Turkey as the Case Study

Konya Closed Basin (KCB) has been on both local and national agenda, with its water scarcity and groundwater stress. The area has semi-arid climate conditions with annual precipitation of 300-350 mm, which is nearly half of the average yearly precipitation in Turkey (740 mm). For the last 30 years, the basin has experienced significant change in climate. The annual precipitation has decreased 10-25 mm and is anticipated to further decrease by 20-30%, along with a potential of 7°C increase in average temperatures (WWF, 2014).

Groundwater use in the basin began in the 1960s; given that the basin holds 17% of groundwater sources and only 2% of the surface water sources of the country, groundwater dependency rapidly increased, as the surface water had constantly fallen short of demand (WWF, 2014). Annual available surface water (1.93 billion m3) and groundwater (2.45 billion m3) are lower than the average surface water use (2.0-2.5 billion m3) and groundwater use (4.0-4.5 billion m3), resulting in annually 50% water budget exceedance (WWF, 2014).

The crop pattern had an important role in shaping the rural development, industry, welfare and most importantly the water consumption levels in the KCB. Since the 1960s, the government has incentivized production of sugar beets. In the following years fruits, potato, corn and trefoil production has increased in the basin. Maize and sunflower production has been supported via financial schemes since the 2000s (Figure 1). All these crops have higher water demand, compared to grains (wheat and barley) which were the dominant crop of the basin and did not require irrigation (WWF, 2014). With the change in crop patterns, the water demand consequently increased in the basin, resulting in significant groundwater level reduction.

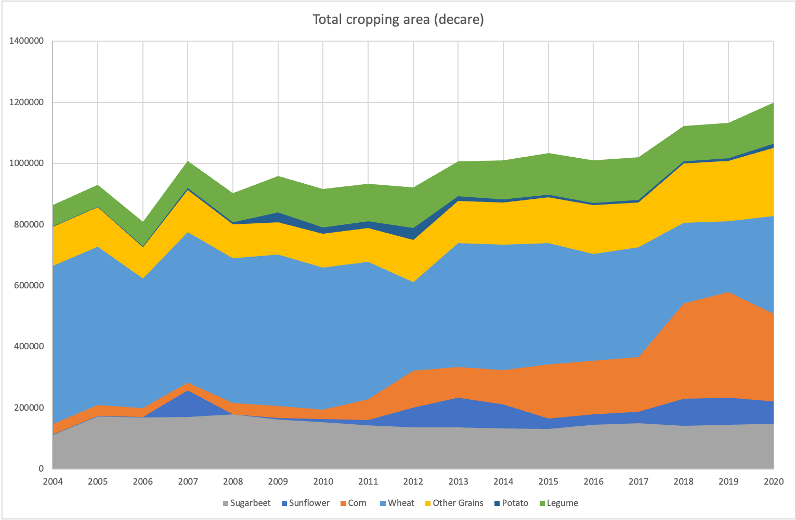
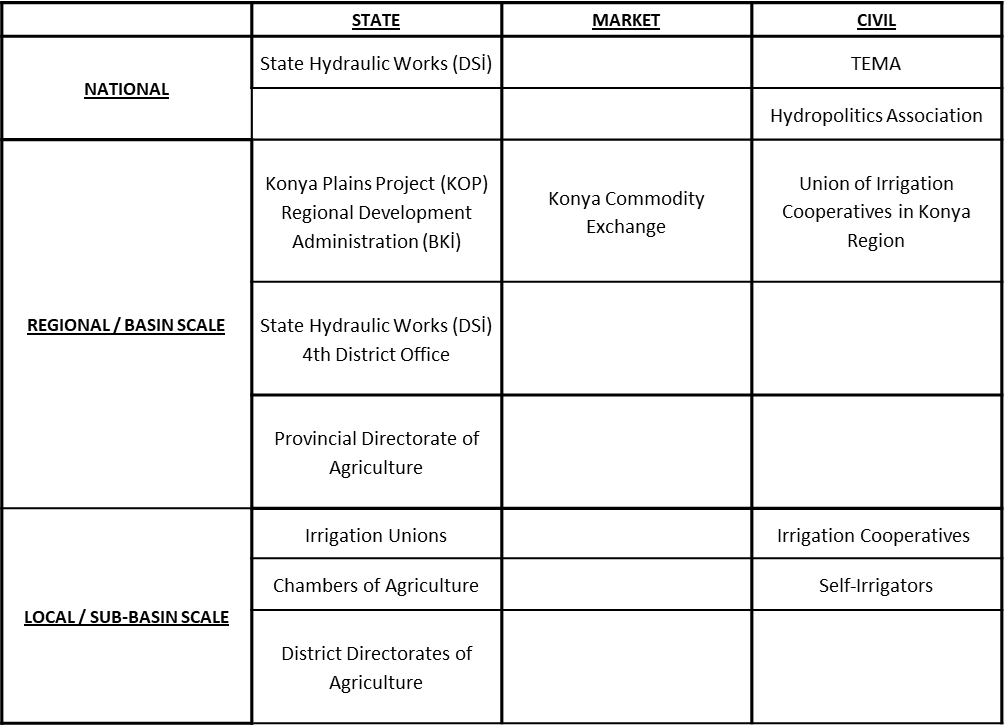


Figure : Temporal change in crop pattern in Çumra, Konya

For analyzing the challenges and improving the management conditions in a basin pressured by water scarcity, it is essential to determine and understand the actors who have authority and stakes on water development and use and the hierarchical relationships and information flows amongst them. Because irrigation has the overwhelming share in groundwater consumption, we focus on actors in the agricultural sector and related to agricultural water consumption. At the national level, State Hydraulic Works (DSI) is the main authority in water governance and the sole institution which can enforce development and consumption of both surface and groundwaters.

Table : Stakeholders in Konya Closed Basin



At the basin scale, Konya Plains Project Regional Development Administration (KOP BKI) facilitates regional economic development and social welfare growth. In the agricultural sector, it focuses on irrigation development and water efficiency improvements. At the local scale, irrigation unions and irrigation cooperatives are operational in agricultural water resources management. Irrigation unions operate both surface and groundwaters whereas irrigation cooperatives operate only the groundwaters under their space of jurisdiction. There are 15 irrigation unions in the Konya Closed Basin, now directed by trustmen appointed by DSI. Irrigation unions are responsible for the operation and maintenance of irrigation facilities in return for collected shares and fines from their members. Unions also run educational campaigns to increase higher production volumes. Irrigation cooperatives are responsible for land development, and educational campaigns on increasing irrigation efficiency, and providing financial loans to its shareholders for irrigation facilities and operation. There are 322 irrigation cooperatives in Konya province.

Konya Closed Basin encompasses more than 5 million hectares (7% of the country) and 7 cities. For this study, we chose to focus on a district of the basin (Çumra, Konya) that has relatively high water availability and has been a prominent region in irrigated agriculture since the 1960s. The region hosts some of the oldest irrigation cooperatives in the country and has a rich tradition of agricultural production.

1. Problem and Purpose

It is evident that the groundwater in4 Konya-Çumra is over-extracted, i.e., the extractions are above recharge rates and the piezometric levels are declining. Moreover, it is possible to foresee that if the current patterns in agricultural consumption rates, crop and technology choices, moreover the water governance schemes prevail, water consumption will be restrained only with its natural limits, manifested as drying wells and unbearably high investment and consumption costs. There is sufficient evidence indicating that the wells are already drying, and water provision costs are increasing. On the other hand, compared to setting voluntary limits to water consumption under a form of social contract, the foreseen involuntary limits induced by groundwater depletion will be costly since the farm systems will already be locked in with machinery, equipment and other contracts tuned in irrigated agriculture. Therefore, the stakeholders in Konya-Çumra are faced with the dilemma of either anchoring on present production rates and pursuing current water consumption or significantly reducing consumption through a combination of measures including land reduction, crop and technology change which would predictably reduce production rates, however, sustain a reasonable stream of profits in the future. Moreover, groundwater depletion and advocated supply side solutions such as inter basin water transfers result in multiple problems including water quality, environmental injustice and habitat and wildlife losses.

In Konya-Çumra, reduction in agricultural water consumption is an imperative for the good of agricultural communities in the future and for the environment. However, although almost all the stakeholders involved in our analysis are aware that the resource is over-extracted, there is not a firm, well defined and commonly shared understanding on what exactly is the problem and its drivers, who are the responsible parties and what are the feasible, socially acceptable high leverage interventions that can alleviate the problem. With that regard, we argue that groundwater sustainability in Konya-Çumra is a “wicked problem” because of its complex interconnected characteristics, with multiple stakeholders with different perceptions and goals involved in decision making, sometimes with conflicting interests for the management of an inadequately observed, insufficiently characterized, commonly appropriated depletable natural resource. In particular, the wickedness of the problem on the ground stems from the observations emphasizing that:

* The groundwater volume, safe extraction limits and overall extraction are not adequately known and convincingly disseminated, building a barrier against science-based approaches to groundwater management.
* Both the institutional and individual stakeholders suffer from “blaming the others” syndrome and cannot assess the systems wide consequences of their own actions on the making of the problem.
* As a corollary of the above, there are disagreements on the drivers of groundwater depletion. Water regulating institutions, as expressed by their officials, blame short term political interests of the elected, for relaxing the monitoring and control over water consumption and farmers for their inappropriate water use. Farmers tend to blame the government for high agricultural input prices which are difficult to compensate for without seeking high yields and revenues and also blame the consumers and markets for pressuring themselves for high production rates.
* The public institutions for water and agricultural governance operate with limited information feedback and data sharing amongst themselves and sometimes with conflicting goals on overlapping activities of interest.
* The irrigation unions and cooperatives are not productively functioning to serve their purposes, for managing the quotas and equitable water sharing. Beyond unions and cooperatives, except avantgarde emerging organizations, there is lack of communication, learning and cooperation between individual irrigators.

The complexity depicted above, comprising the overstressed groundwater system with multiple stakeholders with different goals and interests often with insufficient knowledge and limited information sharing creates a rather pessimistic collective understanding of the situation on the ground, expressed as “nothing can be done before the resource is depleted all the way down” or “unless there is sufficient inter basin water transfer”. On the contrary, reflected as an optimistic but fatalistic view, expressed as “the protector’s grace will be with us next year, if not this year”. So as to approach and articulate this wicked problem characterized above, then to reverse the doomy narrative dominating the collective mindset through a science-based inquiry and to move forward towards sustainable governance and management of groundwater resources in the region, we aim at creating learning spaces or living labs to enhance learning amongst a large stakeholder base through scientific inquiry and experimentation. As we do this, our methodology is system dynamics, community-based approaches and group model building as described in the next section.

1. Methodology
   1. System Dynamics

Human mind is not well-suited to grasp the existing non-linearity of the complex systems that we live in (Vennix & Forrester, 1999). The most straightforward solutions which seem obvious to us as humans, usually incite the problem in the long run - be it social, corporate, or environmental. The term *mental model* is used to distinguish between the actual mechanisms of a system and how these are perceived by individuals. This implies that individuals might have different understandings of how a system operates. Often mental models are astoundingly wrong, because real life systems consist of dynamic feedback mechanisms but usually the delays, accumulations, and circularity in said mechanisms are underestimated by our mental models (Hovmand et al., 2012).  In other words, our ability to find and implement solutions to problems is parallel to our understanding of the system; thus, failure to manage (a company/country, a situation, or a crisis) is due to our lack of understanding of the complexity of the system at hand. Scholars of system dynamics make use of models as design objects, as a response to the insufficiency of our mental models, so the model serves as a learning environment about the behavior of a system (Hovmand et al., 2012). Sterman (2014) argues that simulation is the only effective way for humans to learn about complex systems.

The goal of the system dynamics approach is to understand the source of a problematic dynamic behavior or trend within the system, discover the structure that generates such behavior, find and test leverage points in the system to end or reverse the undesired trend (Stave, 2010). Models built with this approach focus on the behavior of key variables over time and the feedback structure that creates the observed behavior, based on the defined problem and purpose of the model. Appropriate stock and flow structures are built to identify and capture proper feedback loops, and the relationship between variables are mathematically formulated (Andersen et al., 2007). Stocks are variables that accumulate or dissipate over time, and flows are the rate of change in stock variables. Figure 2 visualizes a stock-flow example to help readers better understand the concept.

oda içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure : The barrel analogy: Water in a barrel is a stock variable that accumulates or dissipates in time; extraction is an outflow and percolation through precipitation is an inflow

* 1. Group Model Building

Involving stakeholders into system dynamics studies for simulation is customary. However, prominent scholars in the field of system dynamics developed a new approach termed as Group Model Building (GMB) in 1980s to discover the potential leverage that stakeholder involvement adds to the models, which indicated a deeper level of stakeholder engagement, by involving them directly in the model building process (Hovmand, 2014). Andersen et al. (2007) argue that system dynamics methodology was developed as a response to corporate policy problems, therefore, stakeholder engagement in model construction is inherently aimed by the approach. Interested readers are referred to Vennix and Andersen (1999) which summarizes the process that led to the development of the GMB approach in more detail.

GMB, by definition, is not a prescriptive methodology to be strictly followed; but is the collection of techniques to construct system dynamics models for decision making, with the involvement of those who have a stake in the outcome of the decision (Andersen et al., 2007; Hovmand et al., 2012). Below, we briefly explain each of the four main components of a GMB process: the participants, the scripts, the team, and the boundary objects.

Participants

Personality, background, and number of participants alter the output of the GMB sessions. Purpose of the study is essential in participant selection. With too few participants, group dynamics might be lost, whereas with too many participants, the quality of interactions might decrease and a risk of domination of the conversation by a few salient characters arises (Hovmand, 2014).

Team and Roles

Conducting a group model building workshop requires high cognitive capacity and several skills. Since people that hold all the necessary skills are quite rare (Sterling et al., 2019), researchers ordinarily conduct these sessions in teams. Many researchers like Hovmand (2014) highlight the significance of teamwork for the success of the process and identify basic roles within the team, based on the essential job descriptions. In the relevant literature, 5 main roles are identified for a GMB process, namely: facilitator (elicitor), reflector (modeler), process coach, recorder, and gatekeeper (Hovmand et al., 2012). All five roles do not necessarily need to be fulfilled by five different people; based on the intensity of the session, one can take up two or more roles. However, usually the facilitator and the reflector do not undertake any other roles.

The facilitator leads the group discussion (Hovmand et al., 2012). Facilitation has more to do with the process than the content. In other words, the facilitator is not there to teach, but to guide the procedure (Vennix & Forrester, 1999). Vennix and Forrester (1999) differentiate the attributes and skills required for effective facilitation. Briefly, the facilitator should have knowledge about system dynamics and modeling skills, so that they ask the right questions to lead the conversation. They should also have process structuring, conflict handling, and communication skills. During the GMB meeting, the facilitator should adopt a helping, positive attitude, should be neutral to the content of the discussion, and nurture a healthy conversation.

The modeler follows the conversation carefully and translates the discussion into the model language. They keep track of how the formal model is emerging and provide model-based insights to the whole group. Obviously, the modeler should have knowledge and experience in system dynamics and modeling.

The process coach prepares the day plan, observes the process carefully, and alters the program if necessary. Since the responsibility of the process coach is mainly pre-meeting, one of people with an active role may undertake this role as well.

The recorder, as befits the name, is responsible for recording the process by taking notes, photos, or videos. Lastly, the gatekeeper is a member of the stakeholder group, responsible for bridging between the modeling team and the rest of the stakeholders.

Scripts

Scripts are mainly patterns of facilitation. They consist of activities to foster cognitive processes for knowledge elicitation. A collection of scripts emerged over time and research teams can follow those to design and facilitate their own GMB sessions (Hovmand et al., 2012). Often the output of one script is used as an input for a subsequent script. With a strong line up of the scripts, participants feel that the effort they put into the various sessions of the workshop is used efficiently. Otherwise, they might get discouraged and disconnected from the process (Felipe Luna-Reyes et al., 2006; Hovmand, 2014; Richardson & Andersen, 2010).

Hovmand et al. (2012) draw an analogy between formal models and scripts: scripts help modeling teams organize and visualize an otherwise potentially messy discussion environment, as formal models are helpful tools in understanding and visualizing complex systems.

GMB sessions usually have a very limited time. Therefore, making the best of available time to create a fruitful discussion environment that generates useful information and insights for the modeling team is of priority (Hovmand et al., 2012). Scripts provide a framework for GMB sessions so that sessions are more likely to proceed smoothly in an organized manner.

The group tasks in scripts fall into one of the four categories (Hovmand et al., 2012): divergent, convergent, evaluative, and presentation. It should be noted that the main scripts are mostly either convergent or divergent. Divergent activities provide an array of different ideas and views; they elicit different mental models of the stakeholders. Contrarily, in convergent activities, the various ideas put forward are clustered and categorized. The variety in mental models of the stakeholders lead to a situation of ‘multiple realities’ (Vennix & Forrester, 1999), thus the need for convergent activities.

Additionally, documentation of scripts is important for it serves as case practices, helps spread GMB practices overall, increases transparency of GMB sessions and helps novice researchers in replicating or designing effective GMB sessions (Hovmand et al., 2012). Documentation increases replication of similar sessions, to better evaluate the efficiency. Also, scripts can be altered and adapted to the specific necessities of the stakeholder group. For more detailed information on scripts, interested readers are referred to Scriptapedia, an online handbook of scripts, and Group Model-Building ‘Scripts’ as a Collaborative Planning Tool by Hovmand et al.

Boundary Objects

Visual metaphors (for example, stock flow diagrams, causal loop diagrams, output graphs) are useful tools to facilitate transdisciplinary knowledge sharing. In GMB studies, system dynamicists refer to those as “boundary objects”. An accepted definition for boundary objects is as follows: “A tangible representation of dependencies across disciplinary, organizational, social, or cultural lines that all participants can modify. It can effectively advance shared understanding when participants can transform the representation to show more clearly their understanding of the dependencies among them and the implications for each participant’s resources, operations, and goals” (Black & Andersen, 2012, discussed in Hovmand, 2014, p. 22).

System dynamics models built in GMB workshops have a dual identity. That is, the facilitating team and the participants view the model as both a “microworld” and a “boundary object” (Andersen et al., 2007). The microworld view relates to the idea that the model is a realistic representation of the system at hand, and an arena to try various policies to see how they would function in real life. On the other hand, in the boundary object view, the model is considered as a social construct. It provides useful insights about the social dynamics and creates a platform to discuss differences within the community (Andersen et al., 2007; Luna-Reyes et al., 2006).

Benefits of GMB

Knowledge acquisition by way of eliciting mental models is a challenge in many disciplines of science (Pahl-Wostl, 2008). Through a facilitated GMB study, researchers can elicit assumptions, ideas, knowledge, and system-related mental models of the stakeholders. When those are vocalized, an opportunity to start discussions and negotiations arise. As the diversity within the stakeholder group increases, so does the richness of knowledge and the cumulative understanding of the links between various components of the system at hand. Thus, proposed strategies to govern the system improve (Richardson & Andersen, 2010; Sterling et al., 2019). A more diverse stakeholder group also implies an increased democratic participation (Hovmand et al., 2012).

By bringing different knowledge systems together, GMB strives for reducing the gap between scientific and local communities. Re (2015) refers to this issue as “demystifying science and scientists”. This is particularly important not only because the stakeholders (most especially, non-expert stakeholders) usually refuse to cooperate with the researchers when they do not trust the science or the scientists, but also because local and scientific knowledge systems are complementary to each other. GMB approach helps to combine formal analysis and empirical data with subjective knowledge and perceived dynamics of the system (Pahl-Wostl, 2008). Without clearly identifying the local dynamics of coupled systems and how they are perceived by relevant stakeholders, the models will be inadequate in estimating the future behavior of the systems to develop well-informed policies. Moreover, the flow of information in GMB is reciprocal. While researchers gain insights about the perceived dynamics of the coupled system from the stakeholders (Scholz et al., 2014), they also share their empirical data with the stakeholders and help them to create robust decisions (Re, 2015).

The benefits of including stakeholders into earlier phases of the modeling process is often overlooked (Hovmand, 2014). Stakeholders possibly feel more empowered when their inputs (ideas, information, assumptions) are included in the resulting conceptual model and it creates a sense of ownership of the model among participants, especially for non-experts (Richardson & Andersen, 2010; Sterling et al., 2019). In that sense, GMB separates from other participatory approaches. However, not only should the end model (i.e., formal model) be based on the conceptual model built in the workshop with the stakeholders, but the formal model should also resemble the conceptual model visually, to keep the stakeholders’ trust.

Allowing stakeholders to experiment with different scenarios in their own model is another beneficial feature of GMB. A scenario is a reasonable pathway to the future. Through simulation models, scenarios help us to cope with the uncertainties that the future holds. Participation of a diverse stakeholder group enriches the scenarios, capturing a wide range of uncertainties during the decision-making process (Pahl-Wostl, 2008).

Moreover, use of scenarios in GMB contributes to achieving compliance with the shared decisions, after experimenting with other possible choices of action and familiarizing stakeholders with the outcomes (Pahl-Wostl, 2008).

With increasing complexity and high uncertainty around us, attention to social learning is growing, especially in environmental governance disciplines. Social learning is a goal for polycentric governance, thus a pro-argument for participatory modeling approaches (Pahl-Wostl, 2008). Even in cases where stakeholders cannot reach consensus on the subject, the GMB process initiates a constructive dialogue by increasing awareness of divergent opinions, and fosters social learning (Scholz et al., 2014). Scenario development in GMB contributes to social learning as well, and it is useful not only for making policies, but also implementing them (Scholz et al., 2014).

In addition, a growing “modeling as learning” community advocates GMB because they see modeling as an intrinsic part of governance. Also, the stakeholders are to benefit from the model the most, so they should own it by introducing impalpable aspects of the dynamics into the model (Pahl-Wostl, 2008).

Potential Risks in GMB

GMB does not ensure a smooth process. In complex social-economic-environmental problems, the conflicts between stakeholders are often rooted and strong. If the stakeholders fail to reach consensus with the guidance from the facilitator, one of the three following scenarios is likely to happen (Black, 2013):

1. The version of the model that is supported by a stronger group within the stakeholders is accepted because the others comply with it,

2. Each group conceptualizes different models, excluding one another from the process,

3. The end model covers all the ideas vocalized by the stakeholders and loses selectivity in identifying key variables and main dynamic relationships.

Hovmand (2014) argues that when a GMB process fails, the reason is almost always the failure of conflict resolution and reaching a consensus in the model building phase. However, the skills and relevant experiences of the modeling team also play a key role in the process (Sterling et al., 2019). Modelers should minimize their own bias, be receptive and be able to transform the discussions in the workshop into a proper conceptual model. In many cases, facilitation skills determine the level of stakeholder engagement.

Additionally, the social and political context deeply varies regionally (Scholz et al., 2014). Cultural differences within different stakeholder groups should be considered. Some cultures may not be open to knowledge sharing, or the motives of the stakeholders might differ from one group to another. The potential mismatch between expectations of the researchers from the process and anticipation of stakeholders is another reason why a GMB process might fail (Sterling et al., 2019).

1. Research Design

Our efforts to create a long-lasting learning space for sustainable groundwater management, augmented with system dynamics and group model building methodology consists of several steps, including desktop literature review, field campaigns and three workshops, among which two of them are already conducted. Table 2 below illustrates the flow of conducted, and impending activities. In this deliverable, we focus on the process and the outcomes of the first and second modeling workshops.

Table : Research design and flow of activities

|  |  |  |  |
| --- | --- | --- | --- |
| **Activity** | **Date** | **Purpose** | **Verification and synthesis** |
| Desktop literature review | Fall 2020 | Identify sustainable groundwater management challenges, actors, and potential participants | D4.1 The Social-Economic System  Characterization, Stakeholder Mapping and Water Governance for Selected Case Studies |
| First field campaign | Spring 2021 | Approach institutional stakeholders for data and knowledge acquisition | D4.1 |
| Second field campaign | Summer 2021 | Approach individual stakeholders for data and knowledge acquisition | D4.1 |
| First modeling workshop | Fall 2021 | Building a living lab with key informants and forerunners, building consensus around the problem and suggested interventions | M4.1 First Living Lab Guiding Problem Identification and System Characterization |
| Second modeling workshop | Winter 2022 | Slicing the problem into manageable units, conceptual modeling, and seed model development | M4.2 Second Living Lab Scrutinizing and Refining the Conceptual Model |
| Third field campaign | Fall 2022 | Validating and testing the simulation model with the forerunners |  |
| Third modeling workshop | Winter 2023 | Model based analysis of suggested interventions with simulations in a workshop and larger conference setting |  |

* 1. First Modeling Workshop, Fall 2021

The purpose of the first workshop was to build a living lab with the key informants and forerunners identified during the field works, build trust between the research team and the participants and to build consensus around the manifestations of the problem and suggested interventions. 26 people from 14 institutions participated in a one-day event in Konya city center. Benefiting from the best practice published in Scriptapedia and Andersen and Richardson (1997) the workshop started with a presentation activity, followed by divergent and convergent activities.

The team assumed the role of facilitator, three co-facilitators, two modelers, recorder, and the process coach. During the presentation activity, modeling, models, and their use via simulations were introduced through a live example synchronized between the black board illustration and onscreen computer modeling.

The second activity was divergent and was built on the “graphs over time” script of the Scriptapedia, where the participants in breakout groups of six, first warmed up to discuss the problems that they face due to water scarcity and then with the help of co-facilitators, identified as many problems as they can sketch over behavior time graphs to describe its historical development. These outputs were presented by group representatives and discussed on board during a follow up plenary, while the facilitator elicited variables out of the narratives verbally expressed by the presenters.

The third activity followed the second with the same breakout groups, this time with projections to the future along business as usual and desired pathways. Along with the desired pathways, the groups also identified suggested interventions that they think would take them towards the desired pathways. During a follow up plenary, group outputs were presented and discussed in parallel with variable elicitation.

The fourth activity was a presentation by the facilitator on conceptual mapping, illustrating how one can build conceptual maps around the key variables of interest thinking through their immediate causes and effects and seeking circular casualties through which the effects become causes of themselves.

The fifth activity was convergent to exercise on the possible causal maps which can explain the emergence of the problems and depict the nodes for the interventions identified during the previous activities. For this purpose, the breakout groups worked with co-facilitators and presented their works during a follow up plenary.

The workshop adjourned with a short closing session highlighting the desire and wishes for building a long-lasting partnership that would take us through further stages of this learning experience.

The fundamental outcomes in the form of visual objects of this workshop is depicted in Figures 3 and 4.

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Figure : Exemplary outputs from 3rd session (The black/blue lines represent the anticipation for business-as-usual scenario and the green lines represent desired states subject to solution suggestions)

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Açıklama otomatik olarak oluşturuldu

Figure : Exemplary conceptual maps from the 4th session

* 1. Towards Second Modeling Workshop

On the way towards the second modeling workshop, the research team published and disseminated a short report on the fundamental outcomes of the first workshop among the participants. This report synthesized the identified problems and outlined suggested interventions as depicted in Figures 3 and 4 above. Several other tasks were undertaken: Firstly, the modeling team did several iterations to identify the sectors and the boundary of the model that is going to be targeted. Figure 5 shows an in-progress conceptual model, representing the complete model boundaries. These include the hydrologic dynamics of groundwater, changes in crop pattern and irrigation technologies, the financial aspects of agricultural production and investments, agricultural production (yield), and factor consumption that accompany production.

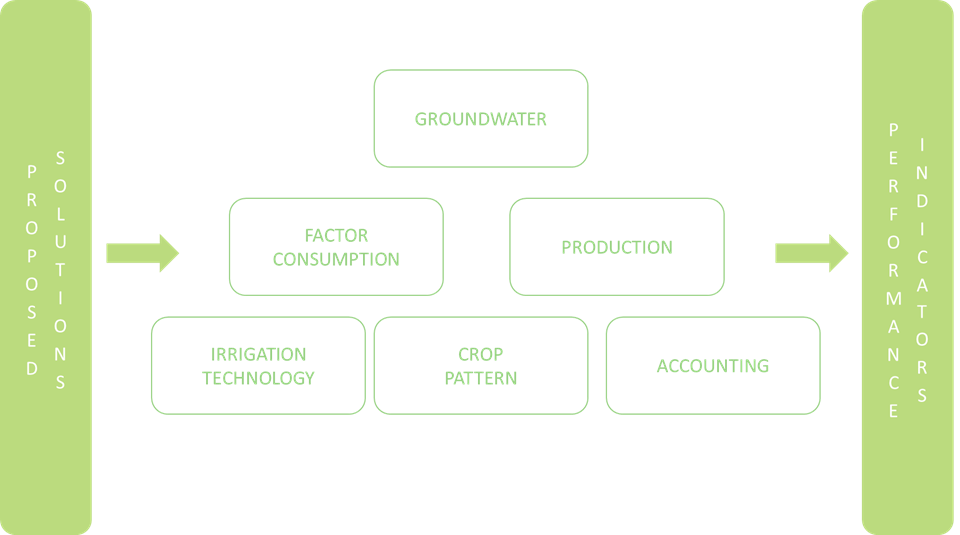


Figure : Complete concept model

Secondly, the qualitative behavior over time depicted in Figure 3 was verified with hard data. For this, we identified key variables of interest in the concept model depicted in Figure 5, various data needs that are going to be used for model behavior validation and searched the databases. Thirdly, observing that the concept model is too large to focus on during the second workshop, we sliced the problem and the model into manageable units as depicted in Table 3 below. The rows of the table further aggregates and reduces the dynamic problems identified during the first workshop. Accordingly, groundwater levels, number of wells, yields, acreage of water intensive crops and modern irrigation technologies are key variables of interest. The columns slice the problem into reduced units which can be worked out individually. Accordingly, Model I can focus on the interactions between groundwater levels, wells, and yields while Model II substitutes the yields with crop choices and Model III substitutes crop choices with technology choices.

Table : Planned modeling activities for the second living lab

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Açıklama otomatik olarak oluşturuldu

* 1. Second Modeling Workshop, Winter 2022

The purpose of the second workshop was to build conceptual maps and seed models that would help us understand why and how the identified problems were created and what the expected system response would be if the interventions suggested during the previous phases of this study were implemented. 20 participants from 10 organizations participated in the workshop. The research team assumed their roles in the previous workshop. The one-day event consisted of presentation and convergent activities and benefited from the Scriptapedia scripts entitled “concept model” and “ratio exercise”. The workshop started with two presentation activities, first one presenting the key findings of the first workshop, including the reference modes and suggested interventions, and the second one for building an agreement on the selected problem slice depicted in Table 3 and a starting stock-flow model template that is going to be used to develop the seed model. Other visual objects, such as water accumulation and drainage in an irrigation tank, and multiple groundwater irrigators on a parcel with a single crop helped to build an understanding on the selected problem and the model template (Figures 2 and 6).

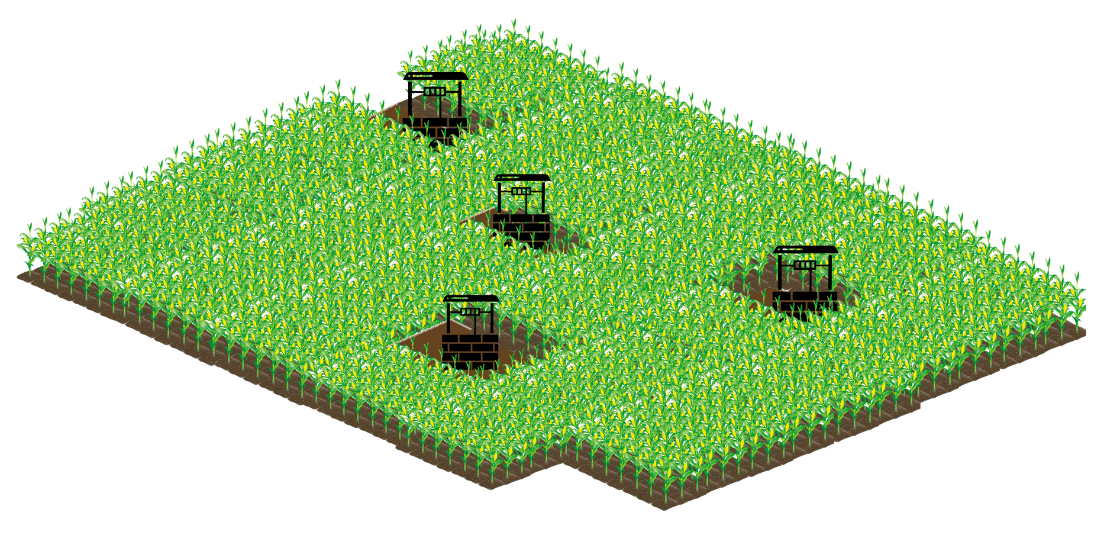


Figure : The visual representation of the model template

Third activity was developed on the model template with variable elicitation and the ratio exercises to pursue causal mapping. To facilitate this process, the plenary facilitator typically asked questions such as "What drives the seasonal water extraction capacity?"; "What drives the seasonal irrigation water demand in a particular season?"; "What happens if there is a gap between water demand and water supply in a particular season?". Observing that the activity was rather overwhelming for the participants, the workshop adjourned early afternoon, after building a seed model addressing the first problem slice. The seed model and its exemplary simulation by the modeling team is described in the next section.

One surprising observation during the third activity, while trying to build an agreement on the stating stock-flow template was that the participants found it difficult to understand the supply side of the groundwater system (the capacity) versus the demand side and their relative magnitudes (the ratio) deriving other variables in the system, possibly the adjustment for water extraction and irrigation quantities. One participant found it counterintuitive to talk about the “supply capacity” driven by the natural and anthropogenic assets (of the groundwater mass and the wells as a proxy for irrigation infrastructure) and said, “I never looked at the problem that way”.

* 1. Further Work

The seed model described in the next section will further be developed and integrated with the second and third model slices and a reliable water budget calculated by hydrogeological modeling. The model will structurally and behaviorally be validated and communicated with the participants individually to enhance its acceptance and practical use by the community. Last, the model will serve as the basis of a simulation driven model analysis workshop open to a larger community including the first two workshop participants.

1. Seed Model and Simulation

Among those three, we started working on the first prominent issue in the second workshop, and the resultant model was briefly introduced in M4.2. In this section, we build on that introduction; we discover the first seed model in more detail, discuss first numerical simulation results, and highlight the limitations of the seed model along with planned developments to that model. Figure 7 shows the conceptual model of the developed seed model that focuses on the dynamics of groundwater, wells, and product yield. In this model, changes in groundwater table affect the well closing and well digging (thus number of actively working wells), well depth, and well capacity (well capacity being defined as the maximum amount of water that can be extracted from an average well in one irrigation season). Well capacity is also affected by the power of the pumps being used for extraction and well density (explained later). Groundwater consumption is determined by how much farmers wish to consume and how much they can extract with the infrastructure at hand. Lastly, groundwater consumption impacts the obtained yield.

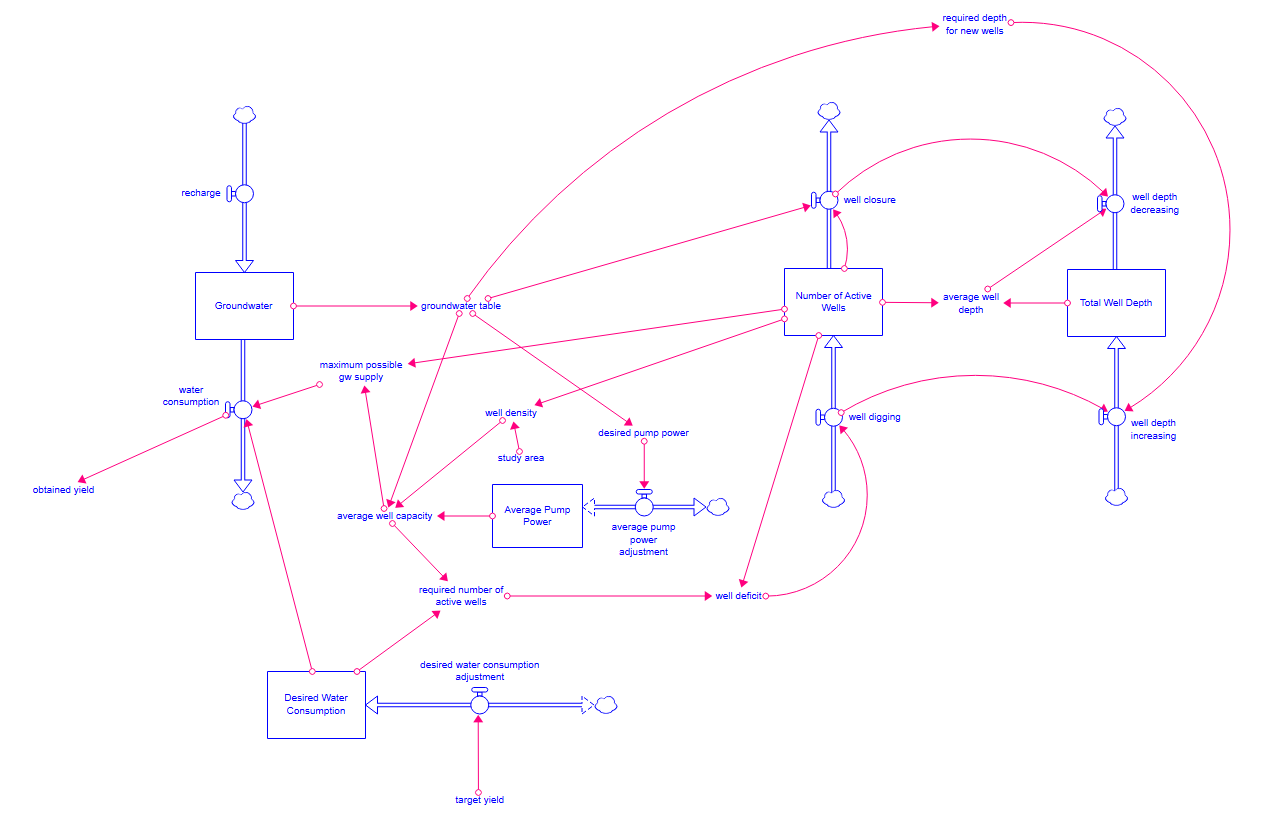


Figure : The conceptual seed model

* 1. Seed Model Overview

The model runs on a yearly basis, from 2000 to 2050. Figure 8 shows the seed model, as built on Stella Architect. It focuses on groundwater, well, and yield dynamics, as mentioned above.

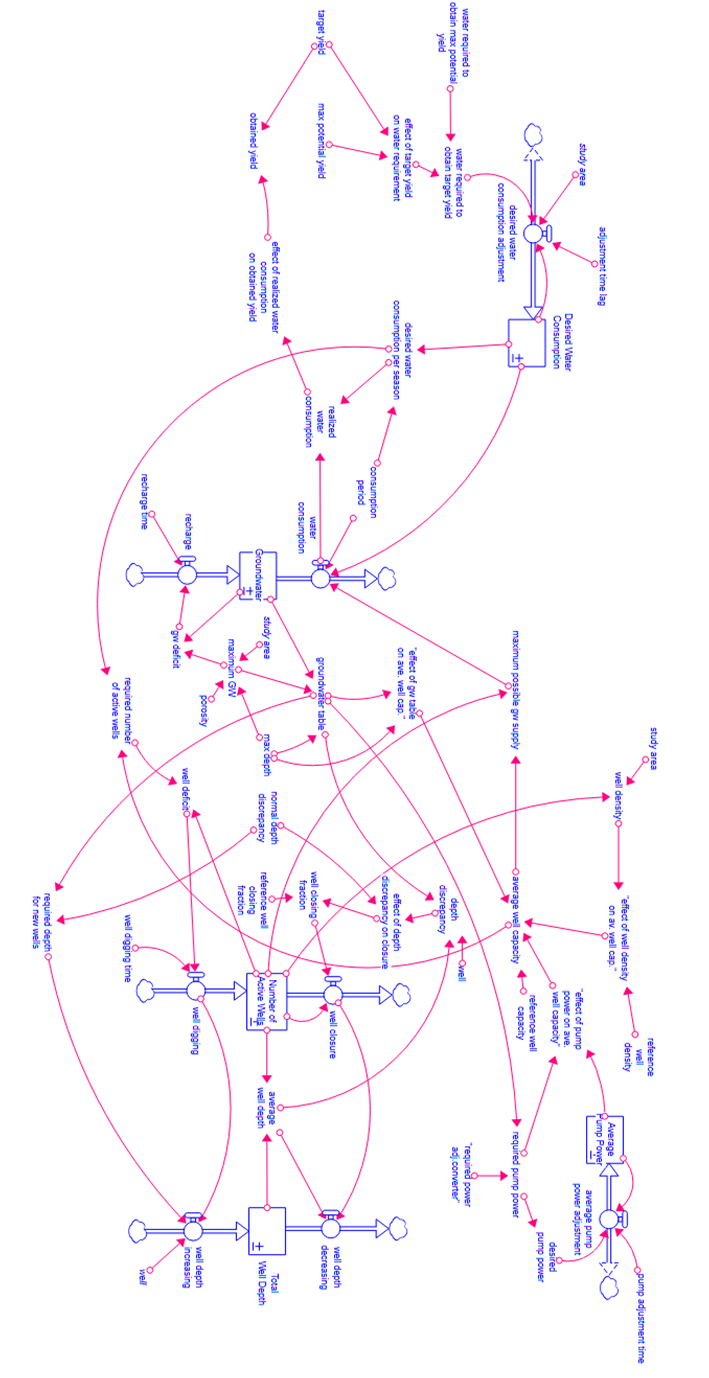


Figure : Seed model

Main Feedback Loops

Figures 9 – 12 show the feedback loops within the model and are briefly explained below.

Figure 9 shows the pump power loop. If the groundwater table drops, farmers will require more power to extract water from a deeper level. Therefore, the desired pump power will increase, and in time farmers will invest in more powerful pumps. With a certain amount of delay, the average pump power will increase, thus the average well capacity will also increase. The maximum possible groundwater supply will be higher due to the increased well capacity, and farmers will be able to use more water, decreasing the groundwater table further. This is a reinforcing loop because the change in groundwater table is fortified when the loop operates.

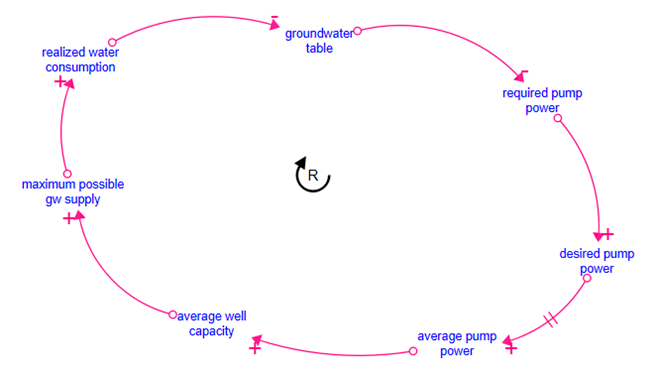


Figure : The pump power loop

Figure 10 shows two loops, one balancing and one reinforcing. If number of active wells increase, the maximum possible groundwater supply increases. Therefore, farmers can use more water. Higher realized water consumption leads to a decrease in groundwater table. Depth discrepancy is defined as the difference between groundwater table and average well depth. Therefore, drops in groundwater table decrease the depth discrepancy, and decrease in average well depth increases it. When we look at the balancing loop, we see that the drop in groundwater table caused by increased water consumption, decreases the depth discrepancy, therefore well closure is higher. At the end of the loop, we see that the initial increase in the number of active wells is balanced. On the other hand, when we look at the reinforcing loop, we see that drop in groundwater table also leads to a decrease in average well depth, because farmers dig deeper wells as the groundwater table falls. Therefore, the depth discrepancy increases, lowering the rate of well closure.

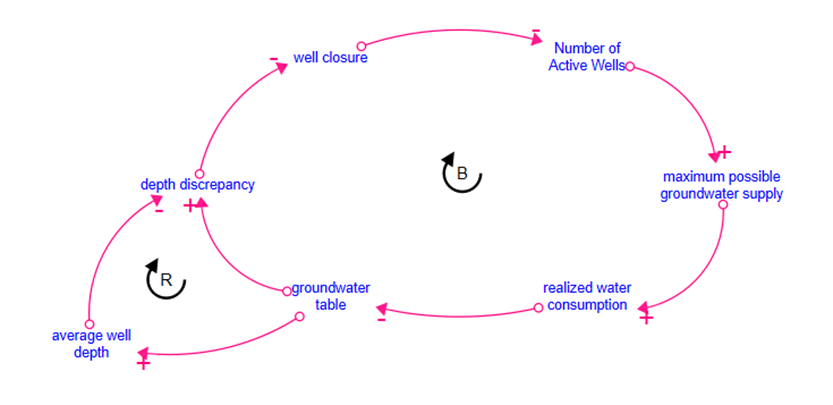


Figure : Well closure loops

The well digging loop in Figure 11 is a balancing one. Required number of active wells is determined by how much water farmers wish to consume in a season (desired water consumption) and average well capacity. Well deficit is the difference between the required number of active wells and the actual number of active wells. If well deficit increases, well digging rate becomes higher, therefore farmers have more active wells, decreasing the well deficit after all.

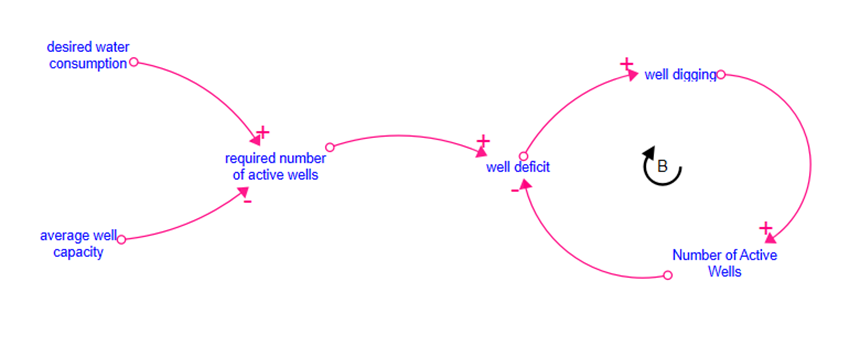


Figure : Well digging loop

Figure 12 shows the reinforcing well density loop. Well density is defined as the number of active wells per unit area. Since the study area is fixed, higher number of active wells means higher well density. However, as well density increases, the average well capacity decreases. As explained above, the required number of wells is determined by the average well capacity and desired water consumption. Thus, if the average well capacity decreases, the required number of active wells increases, boosting the well digging rate. We end up with an even higher number of wells.

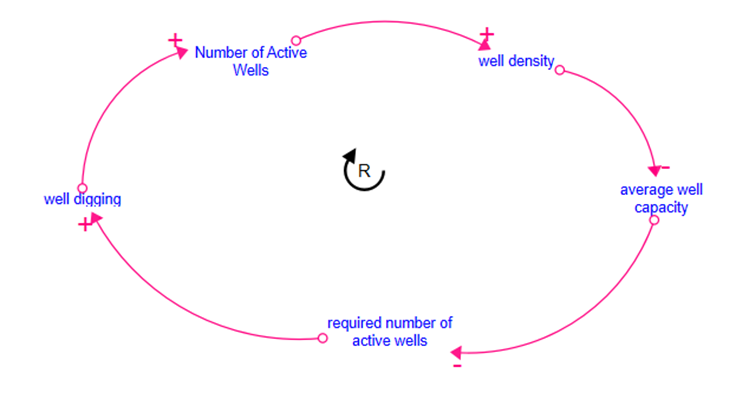


Figure : Well density loop

Main Equations

The main equations of the seed model are as follows:

Equations I, II and III relate to groundwater usage. The groundwater stock accumulates through recharge and dissipates through water consumption.

Water consumption is calculated as a minimum of how much water farmers wish to consume to obtain their target yield, and how much they can consume given the infrastructure at hand. Therefore, the desired water consumption per season is determined mainly by the target yield, and the maximum possible groundwater supply is defined as a multiplication of the number of active wells and average well capacity. Well capacity is, as mentioned above, defined as the maximum amount of water that can be extracted from a well in an irrigation season. Average well capacity is impacted by the well density (number of wells per unit area), the power of the pump being used for extraction, and groundwater table.

The recharge is added to the model symbolically; the actual recharge rate is undetermined but known to be very low. Therefore, we added a very high recharge time to represent the slow inflow in the model.

Equations IV, V, and VI relate to the number of active wells. The stock accumulates by well digging and dissipates through well closure.

Well digging is triggered by well deficit, which is defined as the difference between the required number of wells (to supply the desired water consumption per season) and the existing number of wells. Well digging time is the delay between the decision and the action of digging new wells.

Well closure is a multiplication of the number of active wells and the well closing fraction. The fraction is impacted by the difference between the groundwater table and average well depth. If depth discrepancy is high, meaning that the wells are at a deeper level compared to the groundwater table, well closing fraction is low and vice versa.

The total well depth stock does not relate much to the reality; we are obviously interested in the average well depth or depth of individual wells and not the sum of them; however, it is a modeling choice we made for easier implementation and calculation of the average well depth. That being said, the stock accumulates by well depth increasing and dissipates by well depth decreasing. As groundwater table drops, new wells need to be deeper. Thus, well depth increasing is calculated as a multiplication of well digging and required depth for new wells. On the other hand, we remove closed wells from the number of active wells stock (Equation IV), thus we also remove them from the total well depth stock through well depth decreasing, which is calculated as a multiplication of well closure and average well depth.

With this structure, we obtain average well depth by basically dividing the total well depth over the number of active wells.

Farmers can increase their yield with extra irrigation up to a certain level. Therefore, the target yield determines the desired water consumption. The desired water consumption is expected to reach the water required to obtain target yield in the study area, with the adjustment time lag as seen in equations X and XI.

1. ,

Average pump power changes through the adjustment flow. It is formulated as the difference between desired and average (existing) pump power over pump adjustment time. The pump adjustment time represents the delay between decision and action of investing in new pumps. Therefore, the average pump power is expected to converge to the desired pump power in time.

The desired pump power changes correlatively with groundwater table because one would require more power to extract water from deeper levels.

* 1. Simulation

The result of the base run is as follows:

Figure 13 shows the behavior of the groundwater table, average well depth, required depth for new wells, and total well depth. When compared to Figure 14, which presents the observed average groundwater table in Çumra, the general trend of decreasing groundwater table in the model outputs is considered adequate. The factors that may have caused the leap between years 2010-2015 in Figure 14 (change in crop pattern or irrigation efficiency, change in precipitation regime, change in governance structures etc.) is not included in the seed model, therefore the difference in groundwater table behavior in Figure 13 is plausible.

The model assumes that the required depth for new wells is 50 meters below the groundwater table, and we see in Figure 13 that the average well depth remains between groundwater table and required depth; as groundwater table decreases, wells with low depth are closed, and new wells are dug deeper. Therefore, average well depth behaves as the groundwater table does.

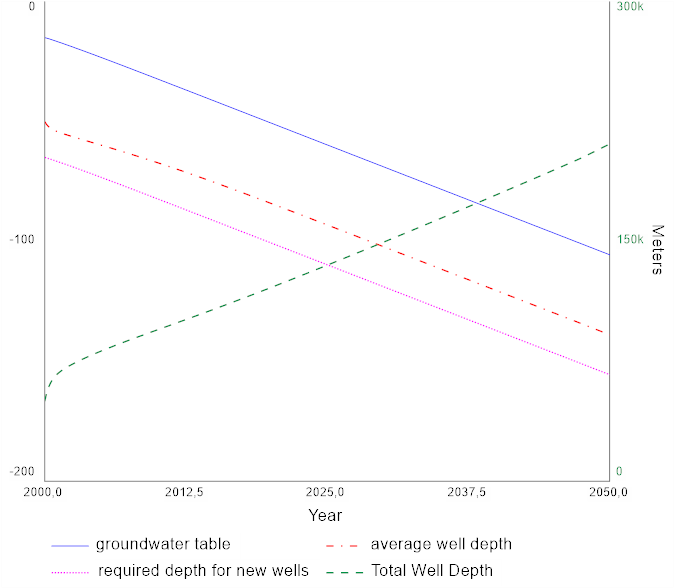


Figure : Groundwater table, average well depth, required depth for new wells, and total well depth

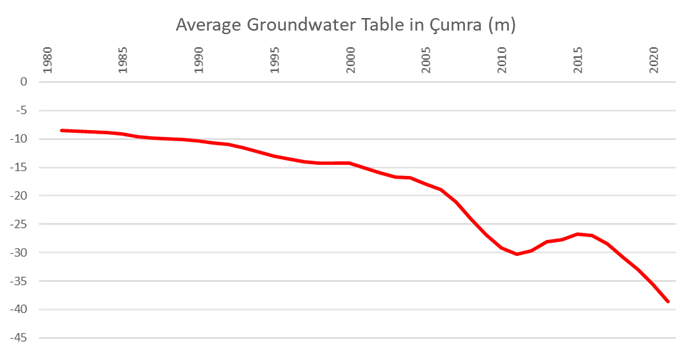


Figure : Observed average groundwater table in Çumra

Over the years, we observe an increase in the number of active wells in the model. Even though we know that there is in fact an increasing trend in that variable, empirical data of the number of wells in the region over time is absent; therefore, we cannot know for sure if the model can capture the increase sufficiently. However, intuitively we can claim that the actual increase in well numbers is much higher than in Figure 15, because the change in crop pattern in Çumra from grains to green plants has increased the irrigation water demand considerably and this dynamic is not included in the seed model.

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Figure : Number of active wells, required number of active wells, and well deficit variables

The target yield is provided as a constant parameter in the seed model. In Figure 16, we see that the obtained yield converges quickly to a level very close to the target yield, implying that the farmers’ water consumption is almost as high as (but not equal to) the desired water consumption per season (as seen in Figure 17).

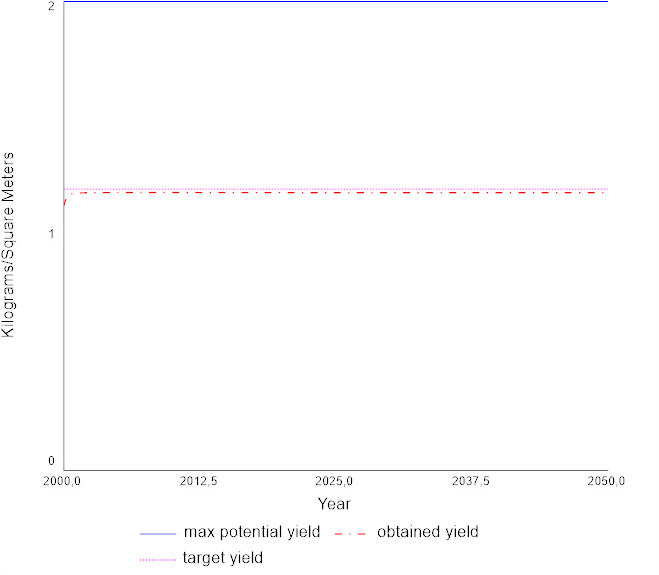


Figure : Maximum potential yield, target yield, and obtained yield

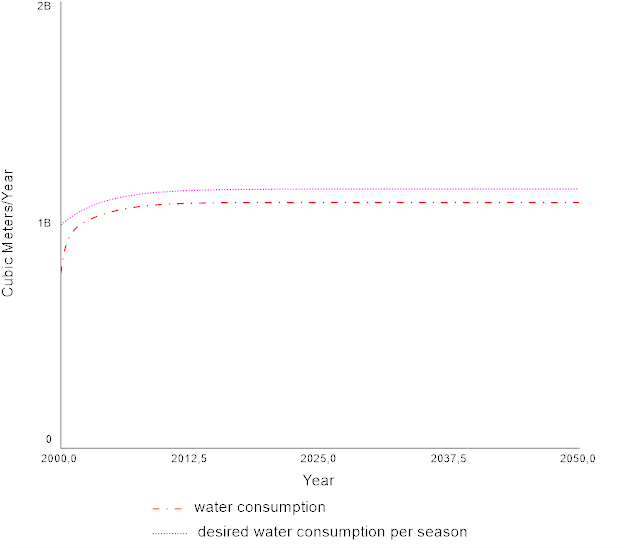


Figure : Water consumption flow and desired water consumption per season

Figure 18 shows the average and desired pump power variables. We observe that initially the average pump power is equal to the desired pump power. However, as the desired pump power increases due to the decrease in the groundwater table, the average pump power follows a similar trend but lags due to the pump adjustment time.

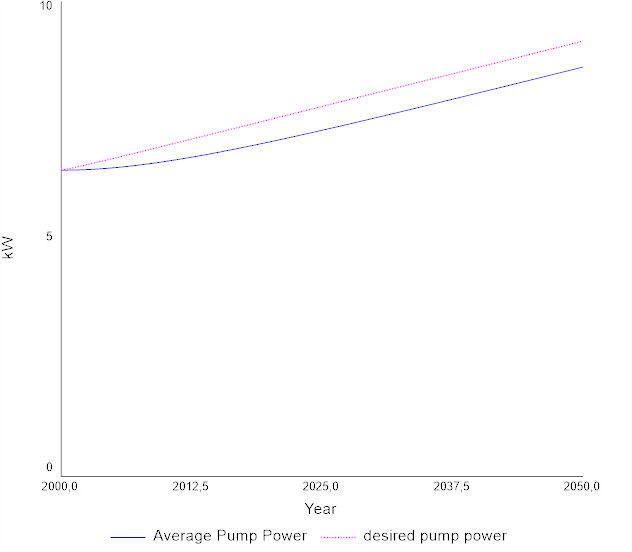


Figure : Average and desired pump power

* 1. Limitations of the Seed Model

The seed model introduced above, besides being an adequate representation of the groundwater, wells, and yield issues, has many limitations. To start with, this model does not consider crop selection or irrigation technology decision dynamics, both of which had been identified as core issues in the living labs. This model assumes a single crop, farmers decide on the level of irrigation based on the target yield, and how much water they use determines the obtained yield in this model. However, the target yield is constant, which is another limitation of the model. Identification of the target yield, in fact, should be considered a goal setting dynamic. Therefore, the potential changes in the target yield must be endogenized in the model.

Thirdly, the groundwater related part of the model needs to be developed further; the lack of information and data on the groundwater dynamics makes it very difficult to validate the structure of the model. In system dynamics approach, the structure is as important as the behavior, because the goal is to generate the observed behavior by implementing the correct system structure. The recharge structure in the model is simply incorrect; it was pointed out earlier that the recharge rate was added symbolically. Input from the hydrogeological model is expected to further develop this model.

Lastly, the model does not incorporate financial aspects of agriculture. For example, the drops in groundwater table significantly affect the cost of irrigation because more energy is required to extract groundwater from deeper levels. After a certain level, irrigation with groundwater may become infeasible. Similarly, the investment decisions (for instance in wells or machinery) and factor consumption costs of agricultural production (other than water, such as fertilizer or pesticides) are also absent from the model.

1. Concluding Remarks

We frame the issue of groundwater sustainability in Konya-Çumra as a ‘wicked’ problem, because it is a highly complex and dynamic problem that concerns a diverse set of stakeholders with different perceptions of the subject and varying, sometimes conflicting, interests over the resource.

The content of this deliverable bridges the way we frame the groundwater issues in Çumra and the methodological approach we adopt; the interconnectedness, and the dynamic nature of the problem requires a holistic, systemic perspective that endogenizes all relevant drivers of change. Moreover, the diversity of stakeholders, their divergent perceptions regarding groundwater sustainability and current situation, and their conflicting interests that serve at cross-purposes make cooperation among stakeholders difficult, if not impossible. Especially in the absence of a healthy communication environment that fosters mutual trust and understanding and helps build social capital, coordination and cooperation becomes even more unlikely.

Participatory system dynamics (SD) methodologies, specifically group model building (GMB), are suitable when studying such problems. The endogenous view SD provides is valuable when studying such complex issues. The added value of stakeholder participation in SD, especially in the model building phase (as in GMB) is manifold: Local stakeholders and the modeling team have two distinct, yet valuable knowledge systems. The scientific perspective the modeling team brings to the table and the field information local stakeholders have, are complementary to one another. With appropriate facilitation, GMB can destroy the invisible walls between stakeholders, converge varying perceptions, help build consensus on the very definition of the problem, and promote mutual understanding. Additionally, including stakeholders in the earlier phases of the modeling process also increases model ownership within stakeholders, therefore, high leverage policies are adopted by more stakeholders, more easily.

Accordingly, in the first living lab session in September 2021, our purpose was to build trust between the participants and the research team, and to build consensus on the prominent issues that relate to groundwater sustainability in Konya-Çumra. The second living lab session in February 2022 aimed at developing conceptual maps and seed models to help us understand why the identified problematic trends emerged and how the system would respond to the proposed solutions were to be imposed.

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