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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 Rechna Doab watershed, Pakistan

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ABSTRACT

Over the course of the last twenty years, participatory modeling has increasingly been advocated as an integral component of integrated, adaptive, and collaborative water resources management. However, issues of high cost, time, and expertise are significant hurdles to the widespread adoption of participatory modeling in many developing countries. In this study, a step-wise method to initialize the involvement of key stakeholders in the development of qualitative system dynamics models (*i.e.* causal loop diagrams) is presented. The proposed approach is designed to overcome the challenges of low expertise, time and financial resources that have hampered previous participatory modeling efforts in developing countries. The methodological framework was applied in a case study of soil salinity management in the Rechna Doab region of Pakistan, with a focus on the application of qualitative modeling through stakeholder-built causal loop diagrams to address soil salinity problems in the basin. Individual causal loop diagrams were developed by key stakeholder groups, following which an overall group causal loop diagram of the entire system was built based on the individual causal loop diagrams to form a holistic qualitative model of the whole system. The case study demonstrates the usefulness of the proposed approach, based on using causal loop diagrams in initiating stakeholder involvement in the participatory model building process. In addition, the results point to social-economic aspects of soil salinity that have not been considered by other modeling studies to date.

Key points

- A systems thinking and modeling methodology for the initialization of stakeholder engagement in soil salinity management is proposed.
- An integrated approach to soil salinity management (including environmental, social, economic and technical aspects) is proposed.
- The methodology supports the preparation of an integrated systems perspective through stakeholder-built causal loop diagrams.
- The methodology was tested through a case study of the Rechna Doab watershed in Pakistan.
- The case study results revealed important causes of soil salinity and solution strategies that have not been examined by other modeling studies to date.

1. Introduction

Soil salinity remains a very dynamic and challenging process to manage sustainably in the arid and semi-arid regions of the world. For example, on average, 14%, 20% and 26% of irrigated lands in Iran, India and Pakistan, respectively, are salt-affected (Shahid, 2013). An estimated 6 million hectares (Mha) of irrigated agricultural land in Pakistan, the focus area of this paper, is affected by soil salinity, causing a 62% loss in agricultural incomes (Tanwir et al., 2003). To solve the issue, the Pakistani government initiated a number of

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Salinity Control and Reclamation Projects (SCARPs) in the latter part of the 20th century; however, in 2000, further implementation was discontinued due to poor performance, high costs, and the short operational life of the associated infrastructure (Ghumman et al., 2012). The SCARP projects' demise resulted in weed growth in surface and subsurface drains, causing standing brackish water to accumulate on agricultural land. Such reclamation projects are usually designed based on the advice of local and foreign consultants, who in turn have based their advice on the results of physical modeling studies and site investigations. Some past physically-based soil salinity modeling studies in the area include LEACHM (Aslam and Van Dam, 1998), SALTMOD (Nasir et al., 2003), SWAP (Kuper, 1997; Qureshi et al., 2004; Sarwar et al., 2001) and UNSATCHEM (Condom et al., 1999). These studies, focusing only on the technical field-scale issues associated with soil salinity, recommended solutions without taking into account stakeholders in any meaningful way, or the social-economic aspects of the problem. This may result in the failure of policy decisions as observed in the SCARP case. Stakeholder participation is very important for successful policy decisions (*e.g.* Saadat et al., 2011; Adamowski et al., 2011; Adamowski et al., 2013; Halbe et al., 2014; Medema et al., 2014a, 2014b); in fact, Nutt (2002) showed that 50% of policy decisions usually ‘failed’ because decision-makers did not include the knowledge and interests of key stakeholders.

Stakeholder involvement in environmental management and modeling has received very little attention to date in Pakistan. Small landholdings, the poor economic status of farmers, limited modeling and mathematical skills, and a lack of technical, political, and financial support have hampered the adoption of participatory modeling of soil salinity issues in Pakistan. Researchers have highlighted the need for joint action by governments, NGOs and farmers for salinity control and have advocated for the inclusion of stakeholders in all stages of soil salinity modeling and management (Tanwir et al., 2003). The modeling approach proposed in this paper is directly focused on addressing these types of problems regarding the initialization of stakeholder involvement in developing countries such as Pakistan.

The benefits of applying local, along with expert, knowledge in modeling exercises have been widely demonstrated in various research studies (*e.g.* Campisi et al., 2012; Adamowski et al., 2009; Niazi et al., 2014; Halbe and Adamowski, 2011; Halbe et al., 2013; Langsdale et al., 2006). Meaningfully incorporating stakeholder contributions into the modeling process can help incorporate the ideas and knowledge of local key stakeholders, integrate physical and socio-economic components within a watershed or sub-watershed level, and improve model boundaries and completeness by ensuring that all relevant issues and views are addressed. Stakeholder engagement helps decision-makers take into account local realities, strengths, and constraints when developing appropriate policies and strategies, and can also reduce the level of conflict among stakeholders (Sterman, 2000). Stakeholder participation can also help garner support for the implementation of the most suitable strategies, as the involvement of local stakeholders in the development of these strategies creates a sense of ‘ownership’ and commitment to seeing the strategies successfully implemented (Pahl-Wostl et al., 2007; Straith et al., 2014).

The inclusion of stakeholders in water resources management has been advocated by many agencies in the water resources field (*e.g.* Global Water Partnership, European Union, International Water Management Institute) and frameworks (*e.g.* IWRM, adaptive management) as an integral component of sustainable water resources planning and management. However, to date, many organizations that are in charge of participatory watershed management have experienced significant challenges in finding effective and simple ways to, among other things, engage stakeholders in watershed modeling and management, especially in areas with low levels of expertise and funding, as is the case in many developing countries. Other significant challenges in participatory modeling are lack of stakeholder interest and unstable group composition. Burgin et al. (2013), having conducted a study of stakeholder engagement in water policy in Australia, reported that more than half of the participants attended only one of twelve meetings. In another study, Videira et al. (2009) highlighted the issue of unstable group composition in a participatory river basin management modeling study carried out in Portugal. In addition, it is often difficult to capture individual stakeholder points of views or ‘mental models’ in group meetings since, for instance, some stakeholders might be reluctant to voice their opinions in the presence of government officials or their superiors in the organization.

The innovative modeling approach proposed in this paper, based on causal loop diagrams, (Mendoza and Prabhu, 2006; Sendzimir et al., 2007; Stave, 2002; Videira et al., 2009) directly focused on addressing these types of problems. The proposed approach is based on ‘co-construction’ participatory modeling that allows for the direct involvement of stakeholders with limited technical expertise, even in situations with limited financial and time availability, as is frequently the case in developing countries such as Pakistan. The two main objectives of the research presented in this paper were to: (i) propose a step-wise and simple approach for engaging stakeholders in soil salinity management in developing countries under constraints of limited expertise, as well as financial and time resources, and (ii) explore the application of the proposed approach in Pakistan's Rechna Doab region.

The proposed participatory modeling process can be categorized into four successive stages: (i) problem framing, (ii) stakeholder analysis, (iii) construction of individual causal loop diagrams (CLD), and (iv) construction of an overall group CLD (*i.e.* a CLD that includes all the views of the different stakeholder groups). The first stage describes the process of problem definition, which is crucial in the selection of stakeholders. The second stage involves the categorization of selected key stakeholders according to their roles and attributes. This type of analysis is important in prioritizing stakeholders according to their roles and importance. The third stage discusses the process of representing stakeholder views and ideas in the form of causal loop diagrams (CLDs), while the fourth stage involves the process of merging individual CLDs (mental models) into a final group CLD.

This research is particularly innovative since, to date, no attempt has been made to develop a simple and easily adoptable methodology to initialize stakeholder involvement in the development and use of qualitative causal loop diagram models with the aim of resolving agricultural water management issues (in this case soil salinization), applicable even in situations where stakeholders have minimal expertise, financial resources and time, as is often the case in many developing countries. A description of the proposed stepwise qualitative modeling process is provided in the following section.

2. Methodology

Stakeholder initialization and involvement in model development is a central issue in participatory modeling, and a variety of approaches, methods and guidelines exist to involve stakeholders in participatory modeling. Reed et al. (2009) and Reed (2008) provide a comprehensive review of different stakeholder engagement techniques. Normally, stakeholders are engaged through group meetings or interviews in a pre-defined form. The main problem with group meetings is the poor attendance of stakeholders; for example, not all of the participants might be interested in attending meetings. Stakeholders, particularly in developing countries, tend to have a lower interest in participating in group meetings compared to individual interviews (Burgin et al., 2013; Videira et al., 2009), as in the former case they may not be able to express their views openly due to the presence of 'opposing' groups or superiors in their organization. Another reason for the avoidance of centralized large-group meetings (*i.e.* those that require the traveling of stakeholders to a central meeting place) was that in studies addressing a large watershed area in developing countries, group meetings are usually not possible due to limited resources. As such, in the proposed approach, the facilitator travels to the stakeholders to guide the development of the individual CLDs.

The proposed approach in this study was developed so as to require less time and financial resources as well as mediation skills by omitting large group meetings (except for one large meeting when the overall group CLD is agreed upon). The overall process is illustrated in Fig. 1, consisting of four main stages and seven steps: Stage i: problem definition (step 1); Stage ii: stakeholder analysis (step 2); Stage iii: stakeholder interviews (step 3) with construction of individual CLD models (step 4), which are later digitized using the Vensim software (step 5); Stage iv: construction of an overall group CLD (step 6) and the preparation of simple thematic models from the final merged CLD group model (step 7). The sections below describe each step in detail.

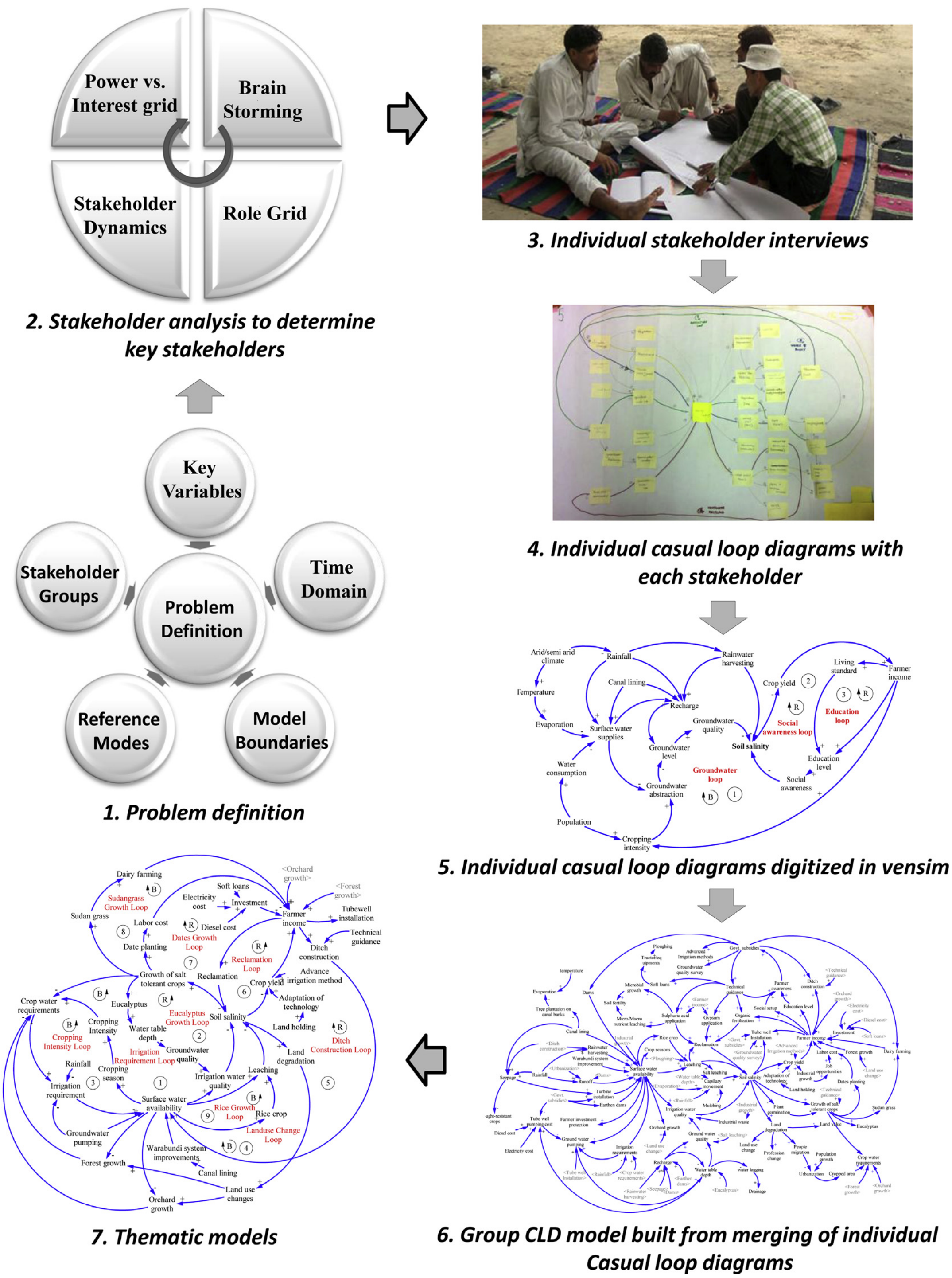

Fig. 1. Qualitative CLD modeling process (main steps of the proposed approach).

2.1. Problem definition

Proper problem definition is important for the *stakeholder analysis* and *causal loop diagram* modeling phases of systems thinking and modeling. It is carried out by a facilitator (*e.g.* the first author of the case study explored in this paper) at the onset of the modeling process through initial discussions with local stakeholders regarding potential problems (*e.g.*, the particular focus in this study was on soil salinity) that need to be addressed in a particular region, followed by a thorough literature review and analysis of the problem. While initially designed to cover a broad spectrum and thereby be inclusive of a wide range of stakeholders, the 'narrowing down' of the problem definition remains an iterative process achieved during subsequent, more focused, stakeholder engagement (described in the steps below). The success of the whole modeling process depends on a clear articulation of the problem that is to be studied and addressed via the proposed approach. While a clear articulation of the problem is particularly helpful in defining the purpose of the model, its boundaries and time domain, it also affects the selection of stakeholders in the modeling process. Care is taken to link the problem definition step to stakeholders' needs, capabilities and skills to maintain their motivation and commitment (Sterman, 2000). The five main stages in problem definition are: (i) selection of the problem theme and key variables, (ii) selection of the time horizon, (iii) definition of model boundaries, and (iv) development of reference modes (*i.e.* a graphical representation of change in the problem over time) to represent the dynamic behavior of the problem and (v) identification of stakeholder groups. Reference modes can be helpful in detecting the variables most indicative of the evolution of the situation (Videira et al., 2009). The problem definition is an iterative process; after stakeholder analysis (see below), the problem definition can be modified (and even completely changed if the key stakeholders think that this is necessary).

2.2. Stakeholder analysis

Once the general problem to be addressed is selected, it is necessary to identify which key stakeholders should be involved in the modeling process. Stakeholder analysis is the process of selecting and categorizing the stakeholders on the basis of their role, interest, power, legitimacy, and urgency. Stakeholder analysis aims to evaluate and understand the stakeholders' relevance to a project or policy (Mitchell et al., 1997). Bryson provides a comprehensive review of different stakeholder analysis techniques. In the current study, a widely tested framework, developed and applied by Elias et al. (2002) in different case studies, is used. This framework combines the widely used stakeholder analysis technique developed by Freeman (2010) and that of Mitchell et al. (1997), rendering the resulting framework more complete, inclusive and versatile than other approaches. The framework consists of four major steps: (i) a listing of stakeholders, including marginal ones, achieved through brainstorming; (ii) their categorization on the basis of their roles; (iii) their prioritization according to their attributes; and (iv) their selection on the basis of their power and interest.

The brainstorming process can be supported by secondary sources (*e.g.* academic literature, reports and the knowledge of facilitators). One effective approach, as suggested by Brugha and Varvasovszky (2000), is to start with a group of stakeholders predefined through a literature survey or local knowledge and to ask them to identify other stakeholders. Brainstorming is, by nature, a divergent process and involves even apparently marginal stakeholders. This stage is iterative in nature and the preliminary list, created in the first step, can be amended during the interview stage of stakeholders upon identification of other individuals or groups. After the list is finalized, details about their roles and group associations can be established.

The list of stakeholders is further categorized according to stakeholder roles. In the current study, the European Commission (2003) criterion is followed to identify four major categories of stakeholder roles with respect to resource issues: decision makers, users, implementers and experts. Assigning different roles to stakeholders is helpful in finding gaps in the first brainstorming step and in looking for omitted relevant parties.

The participation of stakeholders can change over time. New stakeholders may join and old ones may leave the system over the time span of the modeling process. Stakeholder interest may also change over time due to changes in the system state or in strategic issues, and this must be taken into account in the process. In the current study, a comprehensive methodology of stakeholder dynamics developed by Mitchell et al. (1997), which classifies stakeholders on the bases of three relationship attributes (power, legitimacy and urgency), is followed. During the process, stakeholders' attributes may evolve over time, thereby increasing or decreasing their importance according to whether they have acquired or lost one or more attributes. Finally, a power *vs.* interest grid (Crosby and Bryson, 2005) is used to complement the approach of Mitchell et al. (1997).

The final composition of the stakeholders should involve representation of all roles (*i.e.* decision makers, users, implementers and experts), as well as stakeholders who are related to at least one of the attributes of power, legitimacy, urgency, and interest.

2.3. Stakeholder interviews with construction of individual causal loop diagrams

After the completion of stakeholder analysis, potential stakeholders were contacted, and individual interviews were conducted to build causal loop diagrams which record their views on the problem being explored. Causal loop diagrams (CLD) are an excellent way of capturing the views and ideas of stakeholders within a model structure (see Fig. 2). CLDs have been successfully used in water resources planning, policy analysis, sustainable development and natural resource management (Dai et al., 2012; Prodanovic and Simonovic, 2007; Sendzimir et al., 2007).

CLDs are powerful tools for the qualitative analysis of systems. They aid in depicting a system's structure and also mark time delays that are often responsible for difficulties in controlling inherent dynamics. In these diagrams, elements of the system are connected by arrows that link cause and effect variables together to form causal chains. A positive link indicates parallel behavior of variables: in the case of an increase in the causative variable, the effect variable also increases, while a decrease in the causative variable implies a decrease in the affected variable. Alternatively, a negative link indicates an inverse linkage between the variables. Closed circles or loops are important in understanding CLDs. They may be either reinforcing or balancing loops. A reinforcing loop is a cycle in which the effect of a variation in any variable propagates through the loop and returns to the variable reinforcing the initial deviation while a balancing loop is the cycle in which the effect of a variation in any variable propagates through the loop and returns to the variable a deviation opposite to the initial one.

Interviews with each stakeholder were conducted in order to help each stakeholder build their own CLDs. The four steps described by Vennix (1996) were followed to develop the CLDs. Readers are encouraged to read the details of the four-step process followed by referring to Vennix (1996). A stakeholder (*e.g.* a local farmer) is first presented with the purpose, objective and method of drawing a causal loop diagram through a simple example. Colored sticky notes and large plain paper sheets are provided to

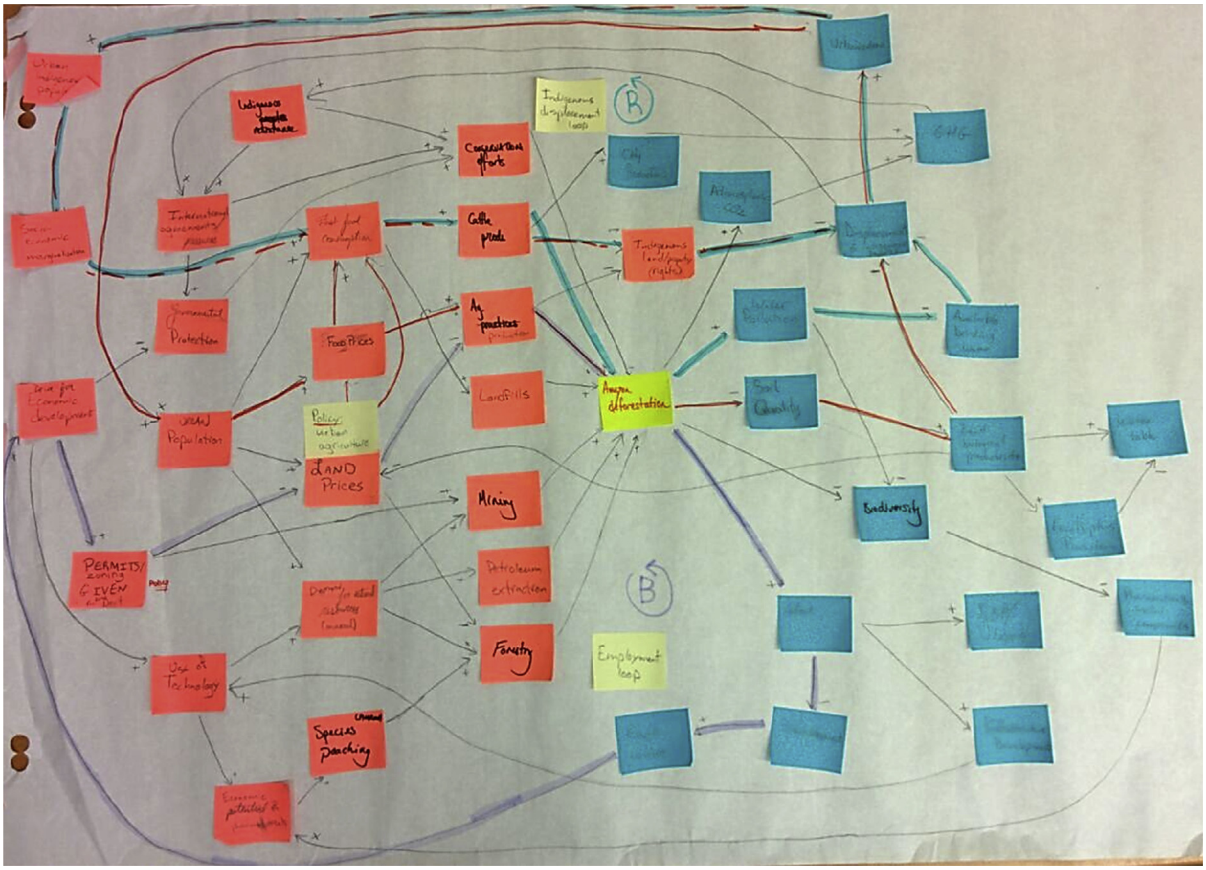

Fig. 2. Causal loop diagram developed during a stakeholder interview. Note: fluorescent yellow sticky note = problem variable; pink sticky notes = causes of problem; blue sticky notes = consequences of problem; light yellow sticky notes = policies/strategies to address problem. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the stakeholder to create their mental model. First, the stakeholder affixes the problem variable in the middle of the sheet; then, the stakeholder is asked to add causes (direct or first-order causes first, and indirect or second-order causes second, and so on) on the left side of the problem variable, using sticky notes. In the next step, causes are joined through causal links, and polarities and directional arrows are added (in pencil). Direct and indirect consequences (or first-order and second-order consequences, etc.) are then added on the right side of problem variable. Similarly, causal links with polarities are defined between the consequences. Finally, causes and consequences are joined through feedback loops. Fig. 2 shows the initial causal loop diagram of an individual stakeholder (a local farmer in this case) from an actual group model building exercise conducted by the authors.

The following types of questions are asked during the interview to help each stakeholder in developing their individual causal loop diagram:

1. How has the problem developed over time?
2. What are the main direct and indirect causes of the problem's development, including link polarities?
3. What are the consequences of the problem?
4. What are main feedback processes?
5. What kind of short-term policies do you think can be adopted to solve this problem?
6. What kind of long-term polices can be adopted to solve this problem?
7. What are the main hurdles in the success of these policies?

Based on the information received from the stakeholders, the time horizon and the boundaries of the problem definition are refined. In addition, the list of potential stakeholders developed during the stakeholder analysis step is discussed with the stakeholder-interviewee to identify any missing stakeholder groups or individuals.

Depending on the availability of a particular stakeholder, one of three interview options is adopted. When time is limited (*e.g.* 15 min), the interview is recorded and later translated into a CLD by the facilitator. The causal loop diagram is sent to the interviewee afterward for them to approve whether the diagram represents his or her point of view. Where the interviewee's availability is slightly longer (*e.g.* 30 min), a preliminary diagram (based on literature and other stakeholder interviews) is prepared and stakeholders are asked to correct the diagram or to append further causes and consequences to it. If a stakeholder has enough time (*e.g.* greater than one hour), the modeling exercise is started from scratch. During the interviews, stakeholders express their views regarding the problem, its causes, its consequences, feedback loops and possible strategies and policies to address the problem, using causal loop diagrams. All policy options are included in the diagram as policy variables. Important loops are numbered and labeled on the basis of their reinforcing or balancing behavior. Furthermore, for the purpose of quick reference, the loops are named according to the process they represent (*e.g.* groundwater loop, social awareness loop, etc.). After each stakeholder interview process is complete (*i.e.* after a stakeholder has built their CLD), a widely accepted tool for system dynamics modeling studies, Vensim DSS, is used by the facilitator to translate all the paper CLD models into a computer modeling environment.

2.4. Construction of an overall group CLD

Following the development of each of the individual stakeholder CLD models, a preliminary group CLD model is built by the facilitator by analyzing, comparing, and merging all individual casual loop diagrams. The initial group CLD is later discussed in detail in a follow-up stakeholder group meeting (which can last from several hours to a full day) to finalize the overall group CLD. The merged model is aimed at representing the different views and mental models/maps of all the different stakeholders regarding the problem, its causes, its consequences, feedback loops and possible strategies and policies to address the problem along with their preferred strategies (*e.g.*, in this case study, strategies to address soil salinity in the basin). This allows for the highlighting of the perspectives of different stakeholders and for developing an overall mental map of the system.

When choosing which individual stakeholder's model to start to build upon when developing the overall group model, the most comprehensive model is generally used, and variables from the other stakeholders' models are then added. Fig. 3 explains the merging process by taking the example of two stakeholder-built models (denoted as “Model I” and “Model II”). The process begins with the most comprehensive model, and continues until all the complementary, redundant and controversial elements have been addressed in the overall CLD. The whole merging process can be divided into six categories (Fig. 3):

(i) If there is good agreement between two stakeholder-built models (Column 1), *i.e.*, both agreed that variable ‘A’ has the same influence on variable ‘B’, then in the merged model variable ‘A’ is causally linked with variable ‘B’.
(ii) If the first stakeholder thinks process ‘A’ will affect process ‘B,’ while the second stakeholder thinks the opposite (Column 2), then both links are incorporated in the merged diagram, but tagged with an exclamation sign as a controversy.
(iii) If the first stakeholder thinks consequence variables ‘B’ and ‘C’ of variable ‘A’ are causally linked, whereas the second stakeholder believes them to be conditionally independent, then the opinion of the first stakeholder is included in the merged model, but tagged with a question mark as a controversy of type II (Column 3).
(iv) If the first stakeholder believes variable ‘A’ affects both ‘B ‘ and ‘C,’ whereas the second stakeholder believes ‘A’ to only affect ‘B,’ but not ‘C’, then this type of controversy is incorporated by tagging the causal link between ‘A’ and ‘C’ with a question mark as a controversy of type III (Column 4).
(v) If the first stakeholder (or stakeholder group) believes variable ‘A’ influences ‘B’, and the second group thinks it may affect ‘C’ also, then the mental modes of both stakeholder groups are incorporated in the merged CLD by adding an additional causal link to variable ‘A’ (Column 5).
(vi) In the case of redundant elements, such as when mental models “I” and “II” represent the same causal link between variable ‘A’ and ‘C’, but with different levels of detailedness, the opinion of the first stakeholder group with more detail is included in the merged model (Column 6).

The resulting final merged CLD model includes the diverging perspectives of stakeholders. The merged group causal loop diagram is helpful in describing the qualitative behavior of the system through its different reinforcing and balancing loops. This type of qualitative analysis cannot be used to infer quantitative behavior but serves a number of useful purposes, including detecting the system's critical issues, identifying knowledge gaps for further research, increasing stakeholders' understanding of a complex ecological and socio-economic system, finding conflicts of interest, and facilitating decisions regarding long-term policy analysis. Merging individual models from a number of stakeholders may increase model details to the point where sub-models on different aspects can be identified. Hence, it is advisable to split the merged group CLD model into different thematic models (*e.g.* industrial growth, agricultural management) on the basis of environmental, social and physical aspects. It should be noted that the thematic models are all linked to form the overall group CLD. The practical application of the proposed approach is discussed in the following section through a case study completed by the authors in Pakistan's Rechna Doab region.

3. Description of the study area

The approach developed for the initiation of stakeholder engagement via CLDs was tested in a case study undertaken in Pakistan's irrigated region of Rechna Doab. The study site is in the Rechna ‘doab’ (land between two rivers) region, located in the downstream portion of the Ravi and Chenab rivers' inter-fluvial basin (*i.e.* just above the intersection of the two rivers) in Pakistan. Covering roughly 732.50 km^2, the basin is situated within the Haveli canal command. Potentially cultivatable land, presently unexploited due to high soil salinity levels, makes up 30% of the area. Despite significant expenditures on fertilizer inputs, the Haveli subdivision is plagued with much lower returns than neighboring subdivisions (Rehman et al., 1997b). The mean area of the region's landholdings is 3.85 ha (Kiani, 2008). The area is situated in the agro-climatic zones of the Punjab, where rice-wheat [*Oryza sativa* L. – *Triticum æstivum* L.] and cotton-sugarcane-cotton [*Gossypium hirsutum* L. – *Saccharum officinarum* L.] rotations are common. Cotton ginning and sugar production are the main industries of the area. The study area portion of the Rechna Doab basin is shown in Fig. 4.

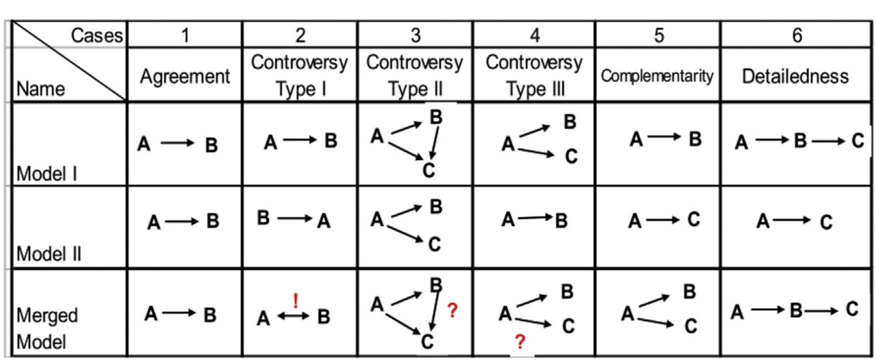

Fig. 3. Marking different perceptions in a merged causal loop diagram.

Due to the scarcity of the surface water supply, 75% of farmers use groundwater of marginal quality for irrigating their crops (Rehman et al., 1997). Groundwater depth varies from 3 to 6 m, with groundwater electrolyte concentrations exceeding 1500 ppm in the middle portion of the basin (IWASRI, 2005). While the use of marginal-quality groundwater creates the problem of secondary salinization in the area, this area could potentially be reclaimed by good management practices and better policies. According to estimates, 26.2% of Pakistan's total irrigated area is salt-affected, but nearly 70% of the salt-affected area is only moderately saline and can potentially be reclaimed (Kazmi et al., 2012).

The Haveli internal command area of the Rechna Doab basin in Pakistan was selected for the case study based on the fact that:

1. It lies on the downstream side of a canal command operating under arid climatic conditions. While soil salinity problems exist under the conditions characteristic of this particular region, the principles and policies developed in this case study can be applied to other areas in Pakistan and elsewhere, where similar conditions prevail.
2. It is bounded by two rivers, providing good hydrological/boundary conditions for the modeling exercise.
3. It is a region that has a large amount of field-recorded data. Various organizations (*e.g.* WAPDA, Irrigation Department and Soil Survey of Pakistan) have actively been monitoring water table depths, water quality and soil salinity since the early 1960s. In addition, a number of previous research studies have been conducted in the area (IWASRI, 2005; Jehangir and Ali, 1997; REC, 1978; Rehman et al., 1997; SMO, 1987; WAPDA, 1978). All of this archival research and data can be used for stakeholder analysis, as well as in developing a reference mode for the system dynamics modeling study.
4. Farmer organizations and NGOs are active in this area, which facilitates their participation in the qualitative modeling exercise.

4. Results

The case study research in the Rechna Doab Basin, Pakistan was conducted to examine the problem of secondary salinization with stakeholders on a sub-watershed scale. The overall process took five months to complete. Overall, it was found that the proposed approach was very cost-effective and required little technical expertise and time from stakeholders, making the approach very useful in a developing country context. All interviewees were able to understand and apply the method after a short introduction of 30 min. This training was sufficient for the participating stakeholders to make their own CLD models. The applications of the different stages of the proposed approach are described in detail in the following sections.

4.1. Stage 1. Problem definition

Based on a detailed literature review conducted by the authors, in addition to expert and stakeholder consultation, the significant increase in soil salinity in the study area was determined to be a critical problem that needed to be addressed via stakeholder engagement. To meet the challenges of waterlogging, the Pakistani government encourages the installation of tube wells. Government subsidies have incited farmers to increase cropping intensities, using the installation of a large number of private tube wells to supply sufficient groundwater. In the last three decades, a 470% increase in tube well growth over Punjab, Pakistan was observed. These tube wells presently supply more than 50% of farm irrigation water (Qureshi et al., 2004) in Punjab. This large increase in tube wells has resulted in both declining groundwater tables (Fig. 5) and deteriorating groundwater quality; the groundwater quality in the middle portion of the study watershed is hazardous, with electrolyte concentrations exceeding 1500 ppm (IWASRI, 2005). Farmers have continued the practice of using marginal-quality groundwater, which results in problems of secondary salinization. Surveys undertaken in the 1970s by the Water and Power Development Authority (WAPDA), and the Soil Reconnaissance Survey of Pakistan,

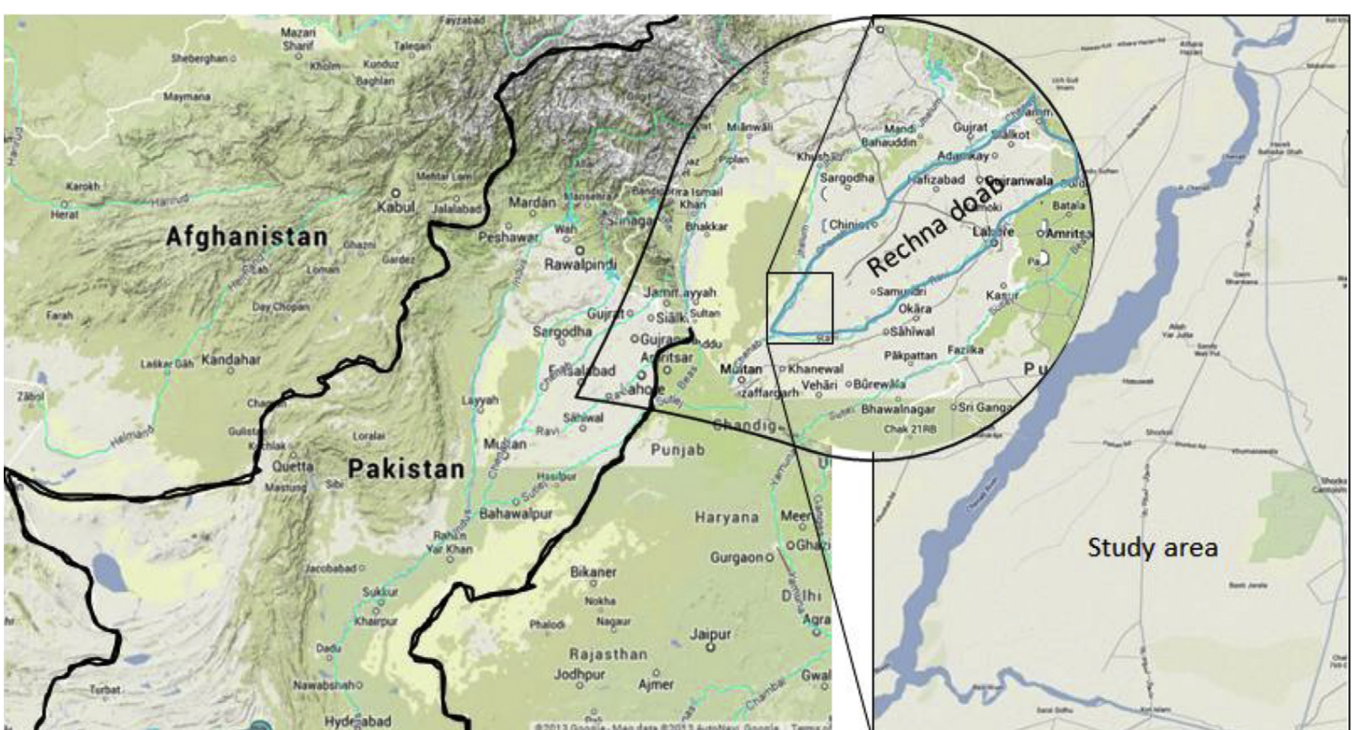

Fig. 4. Study area in the Rechna Doab basin, Pakistan.

confirmed the imminent threat of salinization arising from the use of poor quality groundwater. Fig. 5 shows the change in soil salinity over a period of two decades; the classification is on the basis of USDA criteria [EC < 4 dS/m (non-saline), EC = 4–8 dS/m (slightly saline), EC = 8–16 dS/m (moderately saline), EC > 16 dS/m (strongly saline)] (Richards, 1954). The lessons learned from the failure of SCARPs have highlighted the fact that surface salinity is a highly dynamic process (Metternicht and Zinck, 2003) that is closely tied to human interventions.

During the interview phase of the modeling study (individual CLD development with each stakeholder), the soil problem variable preliminarily considered (*i.e.* soil salinity) was confirmed by stakeholders to be the area's critical problem (see Section 4.3).

4.2. Stage 2. Stakeholder analysis

Following the problem definition stage, a list of stakeholders was created through a brainstorming process (including ‘marginal’ stakeholders at this point). The literature review and expert opinion showed the WAPDA and the Provincial Irrigation Department to be two important stakeholders. The WAPDA is mainly involved in the control of irrigation water releases from dams, whereas its subdivisions, the International Water Logging and Salinity Research Institute (IWASRI) and the Soil Monitoring Organization (SMO), implement, respectively (i) soil salinity control projects, and (ii) monitoring of groundwater levels, along with the qualitative and quantitative evolution of groundwater salinity status.

The Provincial Irrigation Department, together with the local water board, the farmers' organization, and the water user's association, are responsible for the provision of irrigation supplies at farm outlets, and were included in the initial list of stakeholders. The Department of Agricultural Engineering in the Department of Agriculture was found to be another important stakeholder with its sub-departments of well drilling, water management and farm machinery. Other important stakeholders were the Soil Salinity Research Institute, Land Reclamation Department, watershed research organizations, local farmers, industry, tourism, agribusiness, local governments and consultants.

In the next step, based on the framework developed by the European Commission (2003), stakeholders were categorized as experts, decision-makers, implementers, or users in order to assess missing links (see Appendix A). At this stage, sorted stakeholders were contacted and requested to give their suggestions about any missing and possible future stakeholders. The majority of

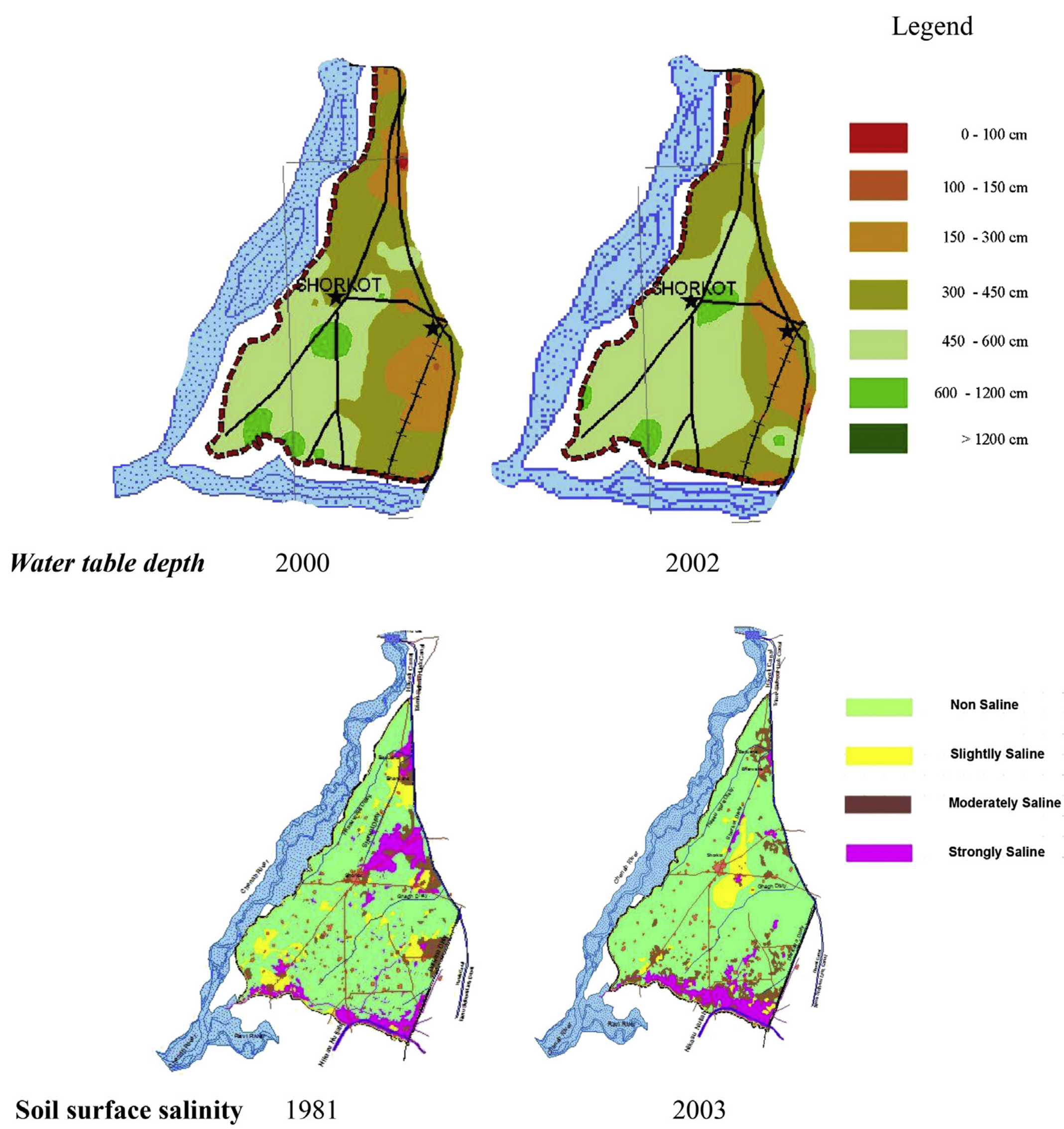

Fig. 5. Change in water table depth and soil salinity in the study area over time (IWASRI, 2005).

stakeholders contacted were satisfied with the list, but suggested adding non-governmental organizations (NGOs) locally involved in carrying out rural support programs for farmer awareness and social welfare. As part of a UN grant, one NGO was initiating a project of land rehabilitation (a Bio Saline project), by providing gypsum to local farmers at a subsidized rate. The majority of stakeholders suggested excluding the tourism industry from the list as it was not a significant stakeholder/player in the area. As such, the tourism industry was excluded, and an NGO was added to the preliminary stakeholder list.

The assessment of stakeholder dynamics was carried out by using the approach developed by Mitchell et al. (1997). In the case study, stakeholder dynamics revealed the possibility of a future participation by the industrial sector. The industrial representative showed the least interest in the study, because this sector grows its crops on its own farms on fertile land. However, in the future the industrial sector may also fall victim to the continued deterioration of groundwater quality and non-availability of surface water. Another sector which may be affected in the future is the domestic sector. The final outcome of the stakeholder typology analysis is illustrated in Appendix B.

In addition, a power *vs.* interest grid approach developed by Crosby and Bryson (2005) was completed to prioritize stakeholders (see Appendix C). The WAPDA, the Ministry of Agriculture and Livestock, Farmer Organizations, the Water Management Department and area water boards were considered to be the most powerful parties with respect to the management of soil salinity in the case study area.

Finally, on the basis of the stakeholder roles, their dynamics, the power *vs*. interest diagram, and stakeholder recommendations, the WAPDA (its sub-departments IWASRI and the Soil Monitoring Organization), the Irrigation Department, Farmers' Organizations (FOs), local farmers, the Water Management Department, industries, NGOs (Bio Saline project), the Agriculture Department, the Land Reclamation Department, and the Soil Salinity Research Institute were included in the individual CLD modeling process.

4.3. Stage 3. Stakeholder interviews and individual causal loop diagram preparation

After the selection of potential stakeholders (described in Section 4.2), these stakeholders were contacted for interviews to develop the individual CLDs. After a 30-min introduction to the process of building causal loop diagrams (CLDs) through an example model, the stakeholders became comfortable with the exercise and built their own CLD models. The first author acted as the facilitator for the development of CLD models. This involved meeting the different stakeholders in different parts of the study area over the course of 8 weeks. The stakeholders showed confidence in the modeling exercise and were satisfied with their causal loop diagrams and how they fully represented their mental maps in the form of causal links.

Individual CLD modeling with each stakeholder began with the problem variable. When stakeholders in the study area were initially asked to point out the main problem to which they attributed their lands' low production, the majority pointed to soil salinity, while others coupled soil salinity with low availability of irrigation water, or inequitable distribution of canal water. All stakeholders held the view that the problem could be solved if good quality water became available in sufficient quantities. The next step involved adding direct and indirect causes of soil salinity in the area, for which different stakeholders were seen to express different perspectives. The primary cause of soil salinity was generally cited as tube well irrigation with marginal-quality groundwater, though in some locations a saline parent material due to the weathering of different rocks (which are rich in salt content) was also closely associated with the problem. Some stakeholders pointed out the historical operations of SCARP tube wells in the area as the major cause. They believed that inadequate drainage capacity had disturbed the salt balance in the area. This opinion was not shared by some other stakeholders, who argued that during the monsoon season their land became flooded with excess water and all these salts should have already been leached out. They considered the continued use of marginal-quality tube water as the major cause of unproductive lands. Some stakeholders pointed to the disposal of sugar mill wastes on productive lands as a major cause, but others considered it a source of fertilization. This aspect needs further investigation, but given the small area affected by this waste, it was not considered a significant variable in this particular study.

The next stage in the CLD building process was the addition of the different consequences of soil salinity. Different direct and indirect consequences were added until stakeholders were satisfied with the model. The added consequences represented what the stakeholders considered important in terms of social, economic and environmental issues. The flexibility of the system dynamics modeling approach allowed for the inclusion of different kinds of variables, which is one of the main strengths of this approach. Major consequences included decreases in crop yield, land degradation, and growth of salt tolerant-crops. In the final stage the developed model structure was analyzed for any feedback relationships between the causes and consequences.

Fig. 6 provides a simplified example of two different policies (*i.e.* investing subsidies in tube well installation or in canal lining) with the basic steps that were used by the stakeholders to develop the individual causal loop diagrams in this study. In this example, soil salinity is first marked as the problem variable. Capillary movement and the water table depth are marked as direct and indirect causes, followed by the addition of government subsidies, tube well installation, canal lining and groundwater pumping as direct and indirect consequences. Linking groundwater pumping with water table depth represents the feedback loop between the causes and consequences. Two different polices for controlling water table depths are represented by reinforcing and balancing loops. In the first case (*i.e.* the balancing feedback loop – the 'groundwater pumping loop' – indicated in red in the Fig. 6), the main focus is on investing government subsidies in tube well installation, which in turn reinforces the effect of groundwater pumping, thereby increasing water table depth from the soil surface. This highlights the policy adopted by the government in the SCRAP V project, when the main cause of soil salinity was due to shallow water table conditions. An alternative government policy is represented by the reinforing 'canal lining loop'. With this policy, the government invests in subsidizing canal lining. This discourages groundwater pumping due to improved canal supplies, and thus improves water table depth with an increase in capillary movement.

Each stakeholder prepared their causal loop diagram independently. During the entire process the facilitator helped with procedural issues only, remaining neutral in order to avoid any sort of influences or biases. Once their views (in the form of causes, consequences, feedback loops, etc.) were expressed in the causal loop diagram, stakeholders were asked by the facilitator: "What kind of policies do you think would be effective in the mitigation of the soil salinity problem?" All research institute and departmental personnel praised government policies regarding canal lining, stating that considerable quantities of water which would no longer be lost to seepage could be effectively used in downstream regions to reclaim irrigated land. On the other hand, farmers strongly criticized the government policy of canal lining in the area, as they believed that this lining, instead of improving surface water supplies, reduced groundwater seepage, thereby causing further deterioration in groundwater quality. Others thought that removal of trees from canal

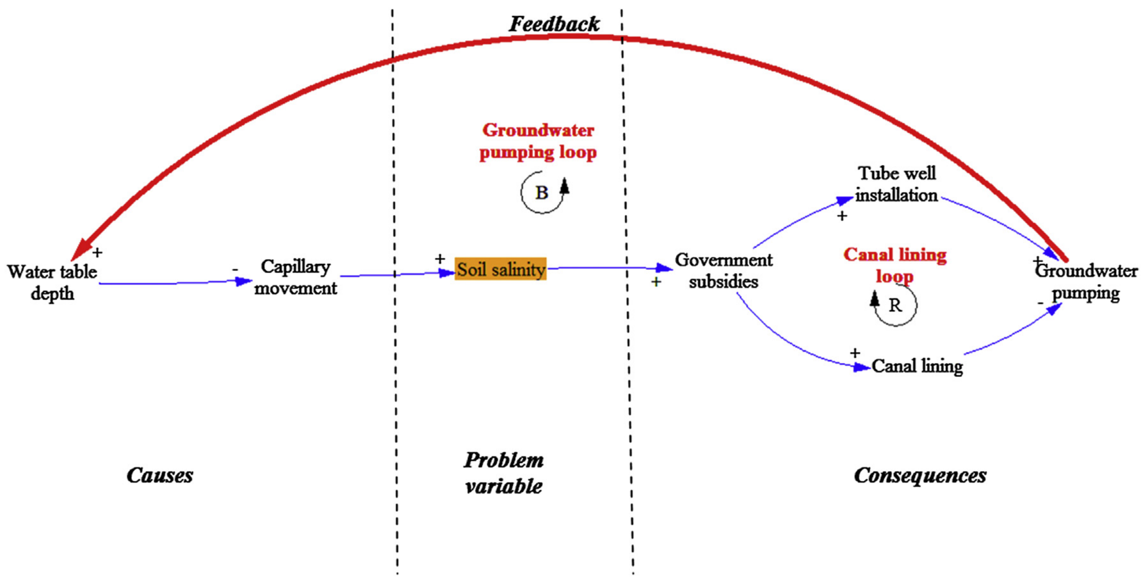

Fig. 6. Casual loop diagram drawing procedure with balancing and reinforcing loops.

banks for lining purposes would increase surface water evaporation losses and that no additional water would reach downstream users. As this situation required further analysis through modeling exercises, both options were included in the merged model diagram. Based on stakeholder recommendations, canal lining is marked as a policy variable. Assessing canal-lining policies through quantified model simulation constitutes one of the next stages of this research, which will be addressed in a future paper.

All stakeholders found Sudan grass [*Sorghum* × *drummondi* (Steud.) Millsp. and Chase] to be the most viable crop option for saline lands. As a salt-tolerant plant, Sudan grass not only removes salts from the soil root zone but can also be used as feed on dairy farms in the area. Some stakeholders highlighted the need for technical support and soft loans from the government for rainwater harvesting. They felt that in the flooding season there is more than enough water to be used if it was stored for future use. They believed that with government support in the form of soft loans they could construct earthen ponds and use flood\rainwater to reclaim their lands. Recharge wells and installation of turbines on canal banks were identified as short-term policies, while construction of large-capacity dams was considered a viable long-term policy for soil salinity control.

4.3.1. Causal loop diagram merging

Following the individual CLD modeling process, individual CLDs were merged by the first author who played the role of facilitator during the individual CLD-building exercises. Merging (see Section 2.4) gives rise to a holistic view of the complete system, as is illustrated in Appendix D, where an example of the merging of two stakeholder-built models is portrayed. The merging process began with the most comprehensive model, with additional variables being incorporated until the views of all stakeholders were taken into account. All controversies and conflicting ideas were indicated in the merged diagram (for future discussions with all stakeholders present together). As part of the finalization of the merging process, stakeholders attended one follow-up meeting, where wide-ranging discussions sought out their opinions on the merged CLD, controversies, etc. This process also allowed for the sharing of one group's ideas with those of the others.

The preliminary merged diagram (*i.e.* the overall CLD) (see Fig. 7) was presented to stakeholders to elicit their opinion regarding the overall model (and process). After some minor changes, all stakeholders indicated their satisfaction with the modeling process and the overall group CLD model. They were surprised about the transparency of the process and very enthusiastic as to how well they were able to depict the aspects of a complex system in a clear, simple and understandable way. Others liked the way different controversies were highlighted, and how discussions aimed at solving these controversies were structured around a CLD model that they had built and therefore understood. According to one group it was “a wonderful way of consensus-building which should be applied to other issues in the environmental field, for social learning and in seeing the bigger picture in the face of a given problem.”

4.3.2. Thematic model development

The next step (completed by the facilitator) was to divide the large merged CLD into different thematic sub-models addressing agricultural, social, environmental, and economic components of the overall system. This kind of division helps in evaluating the details of different aspects in isolation from other factors, and also simplifies the model structure for future quantification purposes (*e.g.* the agricultural sub-model deals with agricultural process variables only, with similar units, whereas the sub-models of the social system deal with the change in education levels, migration, and industrialization parameters with entirely different techniques of quantification and units). It should be noted that the thematic models are all still connected through common variables. The various environmental sub-models (*e.g.* irrigation and groundwater quality, wastewater production) represent the change in environmental conditions due to soil salinity, while economic sub-models deal with government preferences in terms of government subsidies for canal lining and advanced irrigation techniques.

As an example, Fig. 8 shows the inclusion of sub-processes in thematic models. For example, for the agriculture thematic model, farmer income, groundwater, water availability, reclamation and land use/crop rotation processes were included (Appendix E). Amongst the four thematic models, the agriculture model is selected for discussion purposes as it covers an important physical process that governs the dynamics of the local soil salinity process in the Rechna Doab, Pakistan.

4.4. Qualitative analysis of agriculture thematic model

The agriculture thematic model consists of 9 major loops (Fig. 9)

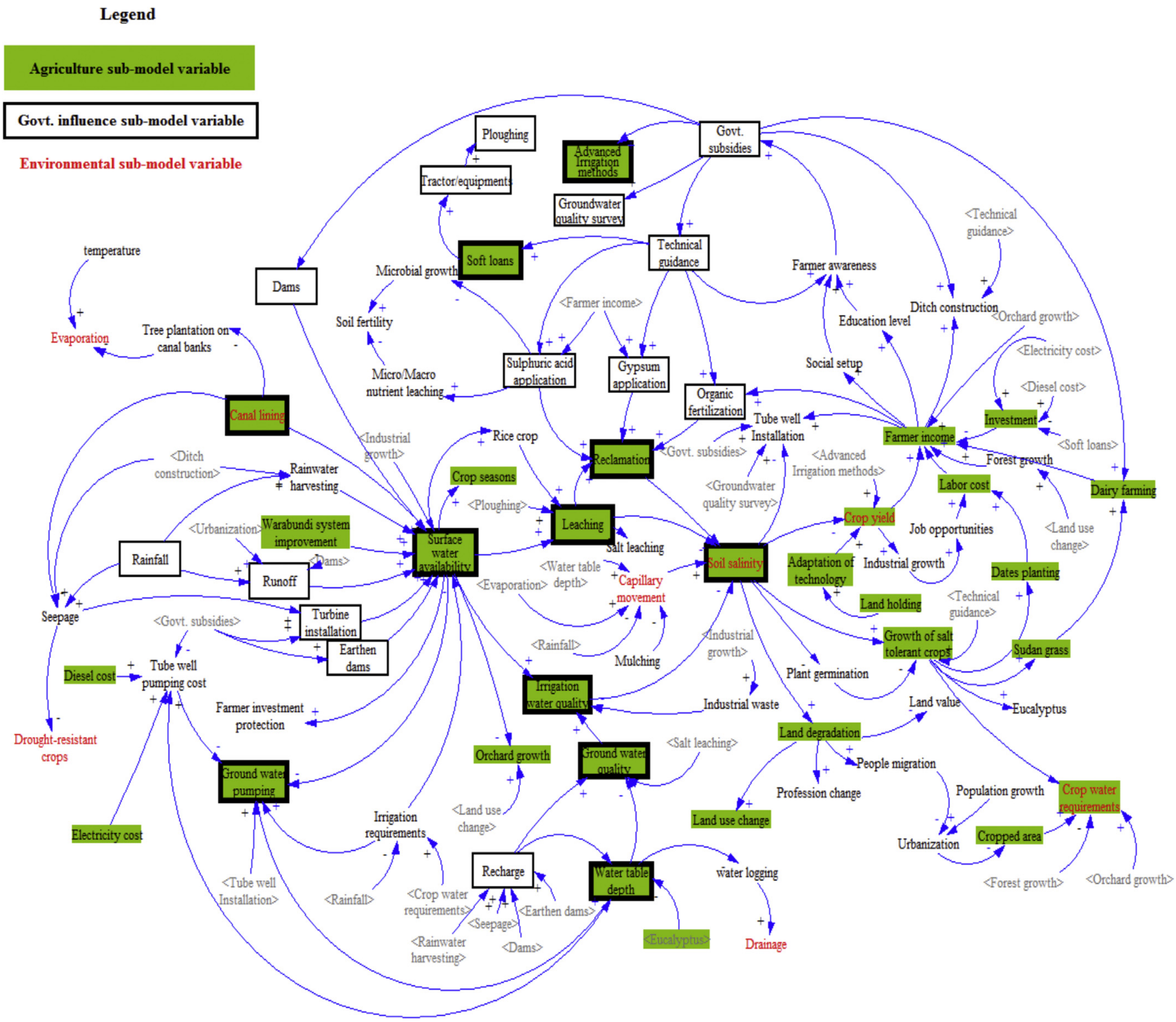

Fig. 7. Final merged causal loop diagram of all eleven CLDs from the different stakeholders.

covering five sub-processes of crop yield, groundwater, water availability, reclamation and land use (Fig. 8). Loop 1 (Irrigation requirement loop) shows the balancing effect of soil salinity on irrigation water requirements. An increase in soil salinity promotes the growth of salt-tolerant crops, which causes a reduction in crop water requirements, thereby increasing surface water supplies by reducing irrigation water requirements. The additional available water, in addition to improving irrigation water quality, leaches down excessive salts, thus reducing soil salinity. On the other hand, an increase in surface water availability increases cropping seasons and cropping intensity, thereby leaving no water for soil reclamation (Fig. 9, loop 3, cropping intensity loop).

This type of behavior represents competition between two types of crop, *i.e.*, a salt tolerant crop and agronomic crops. The system's real behavior can be represented by the interplay of these two loops, the dominance of one loop over the other controlling surface water availability. Shortage of surface water supplies can degrade fertile land and lead to a change in land use (Fig. 9, loop 4, land use change loop). Soil salinity and land use is incorporated with time delay functions, whereas changes in land values are not considered due to their wide variation and the role of real estate therein. On degraded lands, farmers can adopt the option of forest or orchard growth, and by so doing can cause a significant positive effect on farmer income.

This increase in income through crop yield or orchard production can help farmers construct earthen ditches for rainwater harvesting and flood control (Fig. 9, loop 5, ditch construction loop). Rainwater harvesting and a flood storage strategy would yield benefits in terms of assured surface water availability, reduced groundwater pumping, and improved recharge. Another option for increasing surface water availability is canal lining (see Fig. 9, where surface water availability is represented as a function of canal lining and ditch construction in the agriculture thematic model, as seen from the causal links). Increased surface water supply can promote the growth of rice crops (Fig. 9, loop 9, rice growth loop), thereby improving soil leaching efficiency.

Farmers suggested growing Sudan grass on highly saline land, a practice that could be used to promote the development of a local dairy farming industry (Fig. 9, loop 8, Sudan grass growth loop), which could increase farmer incomes. Some stakeholders opposed the idea of Sudan grass and posed the question of whether it is feasible to

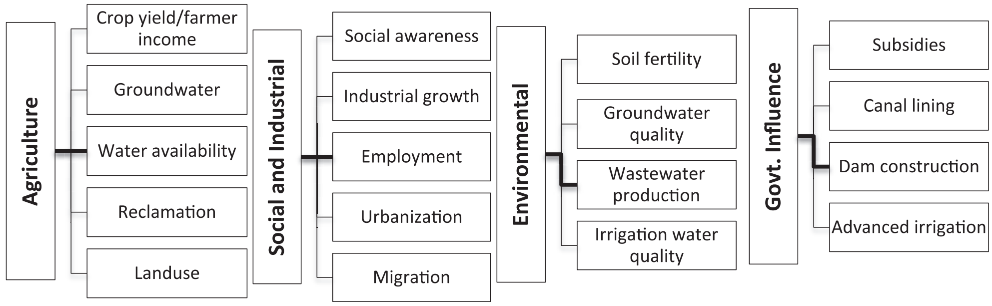

Fig. 8. Merged thematic models with their sub-modeling processes.

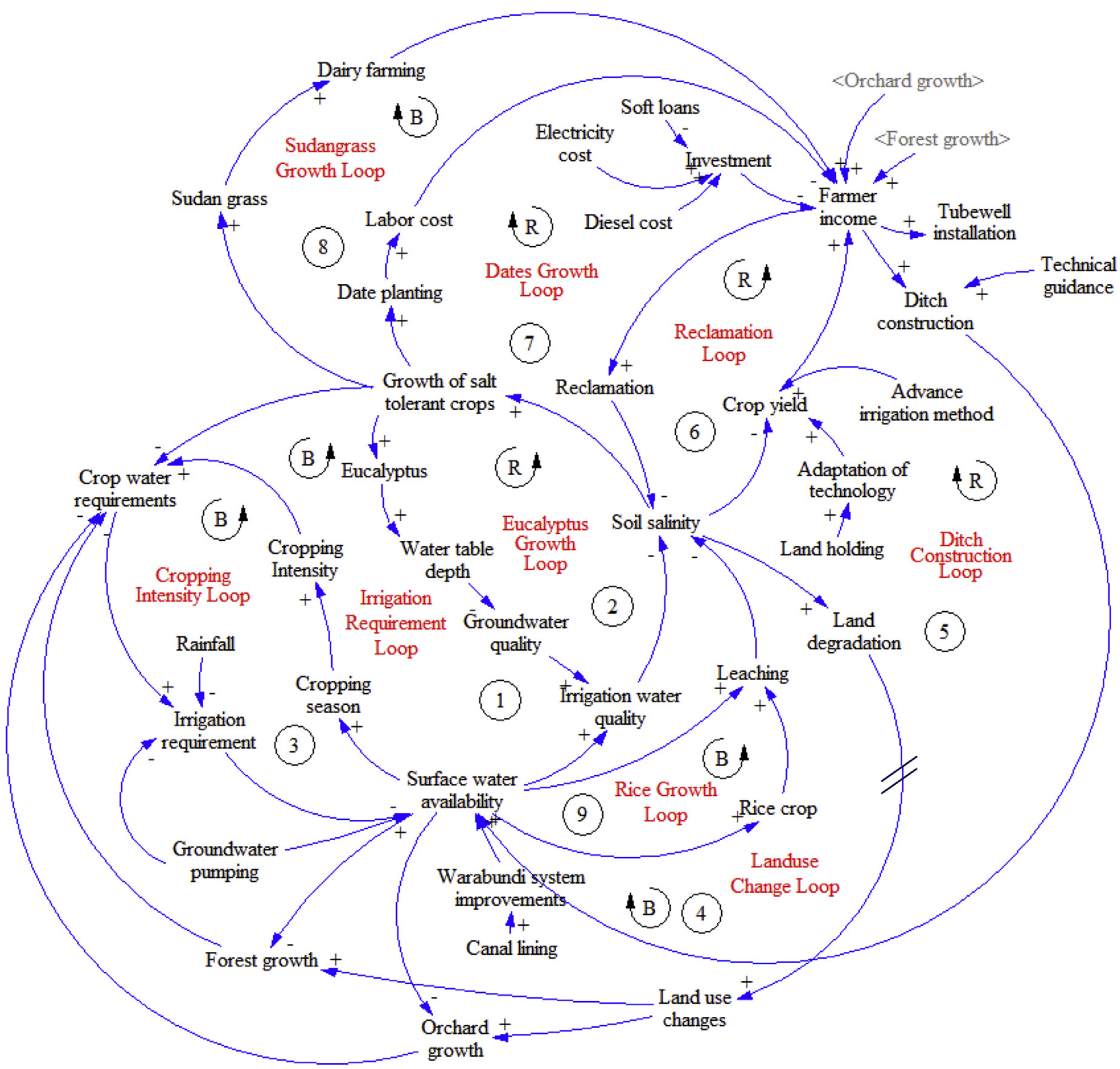

Fig. 9. Digitized merged agriculture thematic model in the Vensim software environment.

convert agricultural land to dairy farming. Both options were included in the model (Fig. 9, loop 8, Sudan grass growth loop, and loop 6, reclamation loop). In a future study, the comparison of the costs and benefits of these approaches would be useful to analyze in detail.

An area that needs particular attention is the promotion of awareness through technical guidance. Some stakeholders are of the view that if enough resources are made available for an awareness campaign, farmers can be led to adopt technological measures (*e.g.* advanced irrigation methods), which would be helpful in improving crop yields (Fig. 9, loop 5, ditch construction loop). Other stakeholders highlighted small landholdings as a major hurdle for the adoption of advanced technologies. They also highlighted the need for technical guidance for reclamation techniques, for rainwater harvesting methods, and in receiving government subsidies. The government needs to implement initiatives in capacity building and social awareness as well as measures to transfer more power to stakeholders to achieve an improvement in their societal behaviors and roles. The complete comprehensive qualitative model contains three more thematic models addressing the environmental, governmental influence, and social and industrial aspects of the system, but due to space limitations only the agriculture thematic model was discussed in detail in this paper.

5. Discussion

This paper covers the first phase of a long-term study in which the authors are involved; the first phase (described in this paper) involves developing a qualitative system dynamics modeling approach to help initialize the involvement of key stakeholders in both the development and use of a model to address a specific issue in a watershed (in this case soil salinity in the Rechna Doab in Pakistan). Past studies have highlighted the significant increase in salinity in the study area over the last few decades (Khan et al., 2008; Qureshi et al., 2004; Rehman et al., 1997). Recent mega-projects (*e.g.* the "SCARP V" and "Bio Saline project") have also identified soil salinity as the most critical issue in the study area. Nearly all research studies in the area have concluded that the problem of secondary salinization can be solved by adopting good management practices through strong stakeholder participation (for example through the development of a holistic model (Khan et al., 2009; Kuper, 1997)), but no initiative has been undertaken to date. The current study is the first of its kind in the project area to involve the active participation of stakeholders. The main purpose of this paper was to describe this relatively simple and cost-effective approach (based on CLDs) to initialize stakeholder participation in the exploration of important water resources issues in agricultural watersheds in developing countries. However, dynamic behavior cannot be inferred from qualitative modeling alone (Richardson, 1996). In the future (*i.e.* in the second phase of this study), the qualitative group CLD model that was developed in this study will be quantified. The purpose of this study was to demonstrate the usefulness of using causal loop diagrams to involve key stakeholders in the initial stages of model development, to facilitate stakeholder discussions, and to develop an integrated perspective on complex issues in agricultural water management.

A frequent comment of stakeholders that participated in the study was that they found the CLD modeling exercise to be very useful for creating awareness and understanding the interaction between different system components. They were very satisfied with the CLD diagrams that they built, and they appreciated the transparency of the process. The participating stakeholders highlighted the need of adapting this approach for increasing social awareness, group learning, and consensus between stakeholders for other problems in their watershed. The modeling framework used in this research is based on a cost and time-effective approach, which makes it more easily adoptable in developing countries. It is also easily understood by non-modeling professionals and provides support for ongoing dialogue processes.

The model developed in this study for soil salinity management is based on an approach with broad boundaries and diverse socio-economic and physical variables, developed with the involvement of stakeholders. It is therefore quite different from the other available physical (e.g SaltMod, SWAP, DRAINMOD-S, Hydrus) and system dynamics salinity (Giordano et al., 2010; Khan and McLucas, 2006; Saysel and Barlas, 2001) models. For example, Saysel and Barlas (2001) used the integration of four physical processes for the dynamic simulation of salt accumulation without consideration of the effects of soil salinity changes on land use, farmer income and industrial growth in the region. In another study, Khan and McLucas (2006) used a real data set for developing reference modes for system dynamics model development. This study was conducted in Australia and only the effect of tree removal on soil salinity changes was investigated. Giordano et al. (2010) also developed a soil salinity monitoring system through system dynamics modeling. However, none of the above studies attempted to include stakeholder perspectives and socio-economic issues in the modeling process. For example, components that were included in the model developed as part of this study, such as land use change, government subsidies and stakeholder awareness, have not been investigated in the past in any soil salinity system dynamics model.

There is a strong need for a modeling tool, such as the one developed in this study, that facilitates, through modeling, the understanding of the dynamics of the soil salinity process from both environmental as well as socio-economic perspectives. The stakeholder-built causal loop models built in this study will be the basis for a quantitative system dynamics simulation model in a future second phase of this study. Such a model will be capable of simulating the socio-economic and environmental aspects of soil salinity in an integrated way (along with feedbacks). Due to their integrated nature, system dynamics models are very useful for analyzing the issue of soil salinity at a broader level. Thus, the joint consideration (and dynamic coupling) of more detailed, physically based models and group built system dynamics models will be an important future research topic. Informal and formal coupling approaches are needed to use disciplinary and interdisciplinary knowledge and will be investigated in the second phase of this research.

6. Conclusions

This paper proposed a step-wise process for the initialization of stakeholder engagement in agricultural watershed management through qualitative causal loop model building under the constraints of limited time, expertise, and financial resources. This study is the first of its kind aimed at an integrated analysis of the issue of soil salinity on a sub-watershed scale with the active participation of stakeholders through causal loop diagrams. The results of the case study indicate that causal loop diagrams are an effective and simple method to initialize stakeholder involvement in the development of qualitative models aimed at addressing complex issues such as soil salinity management. The merged group CLD model developed in this study covered important aspects from land use changes to socio-economic conditions in Rechna Doab, Pakistan. The causal loop diagram provides an excellent platform for group model building that allows key stakeholders from different organizations and groups to share their views and learn from each other while developing a more thorough and holistic understanding of the particular system that they are exploring.

During the qualitative CLD modeling process in the case study explored in this research project, stakeholders proposed various policies with special reference to economic, social, environmental and technical measures. All stakeholders were in agreement that the soil salinity problem in Rechna Doab is due to an inequitable distribution of surface water supply, which forces farmers to use marginal-quality groundwater to irrigate their crops. Farmer organizations indicated their concern with the government policy of canal lining, and recommended further studies to investigate whether canal lining increased surface water supply or deteriorated groundwater quality through reduced seepage. All stakeholders highlighted the need for an awareness campaign dealing with rainwater harvesting and technological adaptation at the farm level. All stakeholders in the case study were satisfied with the model they had developed, and highlighted the need of adopting this approach for other environmental issues in order to build a better understanding of complex environmental problems, as well as to increase social awareness, group learning, and consensus between stakeholders.

Evaluating the consequences of different stakeholder-recommended polices is a key challenge, which must be tested through a fully quantified system dynamics model (*i.e.* a fully quantified group-built causal loop diagram). This is the next phase of this research project. The future quantified form of the model will be capable of supporting decision-making in soil salinity management, considering stakeholder perceptions as well as social, environmental and economic aspects of the problem.

Acknowledgments

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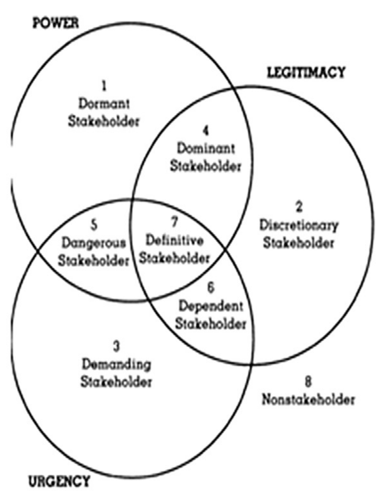
Appendix A. Preliminary list of stakeholders with their respective roles

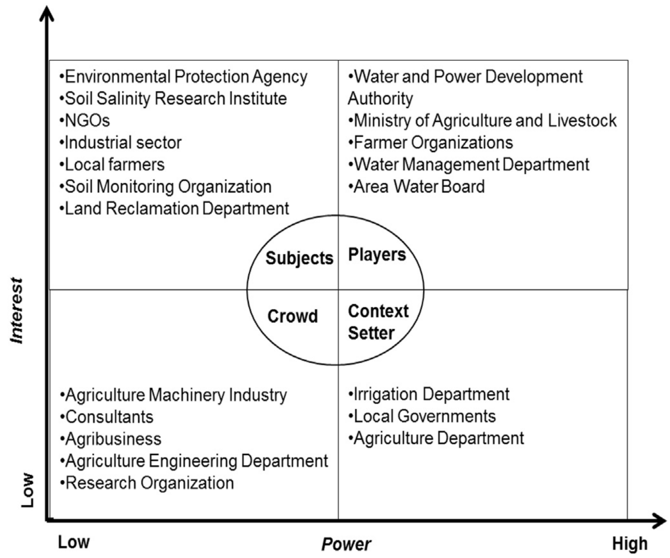
Experts • International Water Logging and Salinity Research Institute (IWASRI) • Land Reclamation Department • Soil Salinity Research Institute • Research Organizations • Consultants • Agriculture Department.	Decision Makers • Water and Power Development Authority (WAPDA) • Punjab Irrigation Department • Ministry of Agriculture and Livestock • Local Governments • Area Water Boards
Implementers • Agriculture Engineering Department • Water Management Department • Water and Power Development Authority (WAPDA) • Environmental Protection Agency • NGO • Area Water Boards	Users • Agricultural Machinery Industry • Industrial Sector • Farmer Organizations • Local Farmers • Agriculture Businesses • Domestic consumers

Appendix B. Stakeholder typology with attributes

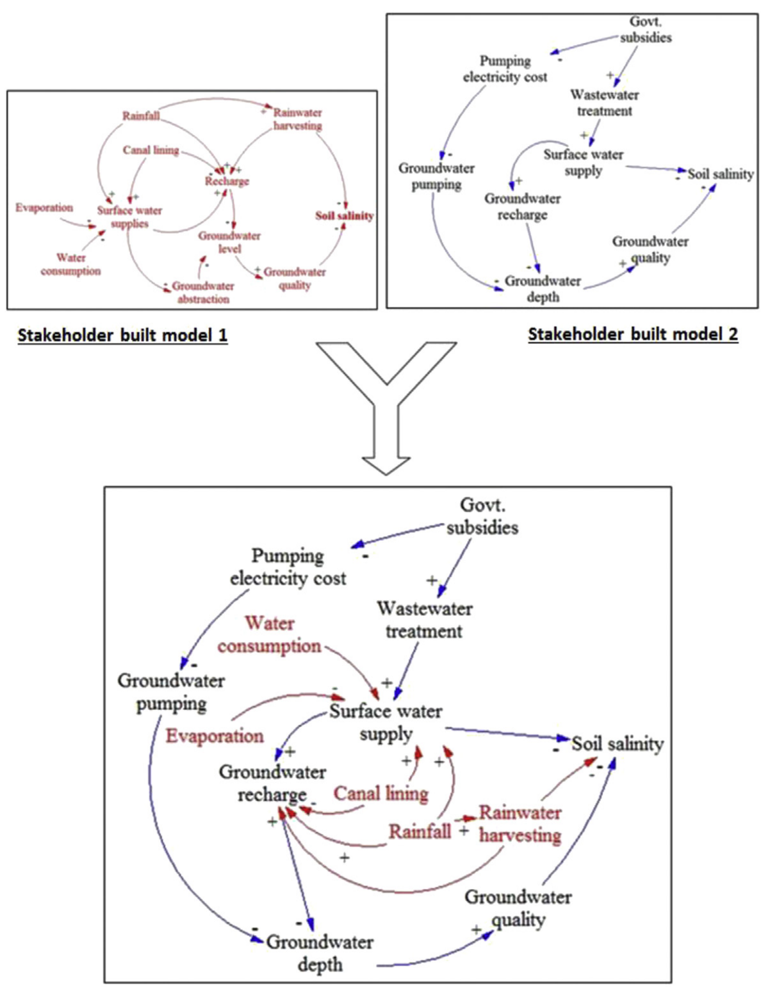
1. **Dormant stakeholders**
2. **Discretionary stakeholders**
   Provincial Agriculture Engineering Department
   Punjab Agriculture Department
   Punjab Soil Testing Laboratory
   Directorate of Land Reclamation (Sub department of Punjab Irrigation Department)
   Research Groups (i.e., International Irrigation Management Institute, International Water Logging and Salinity Research Institute)
   Consultants
   Non-Governmental Organization
3. **Demanding stakeholder**
4. **Dominant stakeholder**
   Local Government
   Irrigation Department
   Industry
5. **Dangerous stakeholder**
6. **Dependent stakeholder**
   Local farmers
   Agribusiness
   Domestic consumers
   Agricultural machinery industry
7. **Definitive stakeholder**
   Water and Power Development Authority
   Farmer Organizations
   Ministry of Agriculture and Livestock
   Soil Salinity Research Institute
   Water Management Department
   Area Water Board



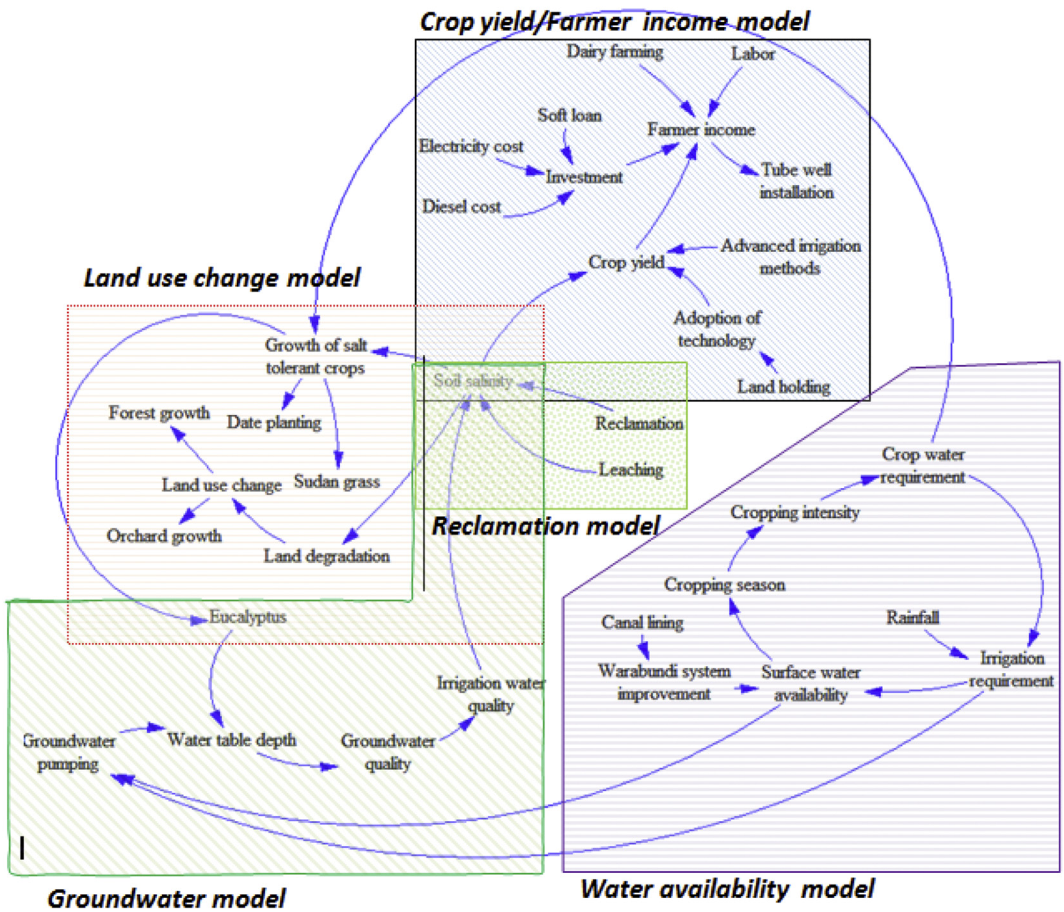
Appendix C. Power *vs.* interest grid of stakeholders



Appendix D. Example of the merging procedure for two individual causal loop diagram models



Appendix E. Merging of five modeling sub-systems in the agriculture thematic model



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