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Grace B. Villamor
Center for Resilient Communities, University of Idaho, gvillamor@uidaho.edu

David L. Griffith
Center for Resilient Communities, University of Idaho, griffith@uidaho.edu

Andrew Kliskey
Center for Resilient Communities, University of Idaho, akliskey@uidaho.edu

Lilian Alessa
Center for Resilient Communities, University of Idaho, alessa@uidaho.edu

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Integrating public/local and scientific knowledge in model development for food-energy-water systems

Grace B. Villamor[a], David L. Griffith[a], Andrew Kliskey[a], and Lilian Alessa[a]
[a] *Center for Resilient Communities, University of Idaho, Moscow, USA*
Emails: gvillamor@uidaho.edu, griffith@uidaho.edu, akliskey@uidaho.edu, alessa@uidaho.edu

Abstract: Conceptual and mental models are useful platforms for communicating and understanding how systems work. However, models or frameworks that are not aligned with the perceptions and understanding of the local stakeholders can propagate model output errors and uncertainties. This paper focuses on two sources of epistemic uncertainty in building food-energy-water systems (FEWS) models: (1) context and framing; and (2) model structure uncertainty. To address these uncertainties, we co-construct the FEWS conceptual model with key stakeholders using the Actor-Resources-Dynamics-Interaction (ARDI) method. The method was adopted to specifically integrate public (and local) knowledge of stakeholders in the Magic Valley region of Southern Idaho into a FEWS model. We first used the ARDI method with scientists and modellers (from various disciplines) working on the system, and then later applied this method with local stakeholders. Afterwards, we compared the results and made necessary adjustments in the conceptual model to align with local stakeholders' understanding of the FEWS. This co-conceptual modelling process with local stakeholders allows for the incorporation of different perspectives and different types knowledge into a system model.

***Keywords**:* ARDI method; co-conceptual model development; stakeholder engagement; uncertainties

1 INTRODUCTION

Food (nutrients), energy and water are interrelated to one another. There is a growing number of studies on understanding the complex relationships of food, energy and water in different landscapes (e.g., water-food-energy nexus) (Endo et al., 2017). Because of their complex relationships, the assessment of trade-offs and synergies are better assessed using integrated modelling approaches (Bazilian et al., 2011; Zhang and Vesselinov, 2017). Several integrated modelling frameworks have been developed in recent years with the capacity to simulate the complex dynamic linkages of target systems (such as Climate, Land, Energy and Water (CLEW) model by Bazilian et al. (2011); the WEF nexus Tool 2.0 by Daher and Mohtar (2015); and the Water Energy and Food security nexus Optimization (WEFO) model by Zhang and Vesselinov (2017)). However, like many integrated environmental modelling approaches, food-energy-water system (FEWS) models face modelling challenges and issues. One of these is the issue of uncertainties. Although there are several definitions of uncertainty, we use the term in the sense of Walker et al. (2003): "*the degree of lack of knowledge about a system or processes or degree of inability to exactly describe its state or behaviour"*. Traditionally, uncertainty assessments are carried out only at the end of a modelling study when models have been calibrated and validated (Refsgaard et al., 2007). However, to better integrate the model results into the broader resource management process, it is important to conduct the uncertainty assessment at the beginning of the modelling process (Refsgaard et al., 2005). Here, we focus on the following two sources of epistemic uncertainties in the FEWS model formulation as characterized by Walker et al. (2003). These two uncertainties are also part of the central nexus modelling challenges identified by Garcia and You (2016):

(1) *Model (structure) uncertainty* is associated with the conceptual model (which includes the variables and their relationships) and how it represents the real system (including its behaviour

and possible future evolution of the system). It arises from a lack of sufficient understanding of the system.

(2) *Context uncertainty* refers to the conditions and circumstances that underlie the choice of the boundaries of the system, and the framing of the issues and formulation of the problems to be addressed within the confines of those boundaries. This includes the uncertainties about the economic, environmental, political, social and technological situation that forms the context for problem being examined.

Different methodologies and tools can be applied for uncertainty assessment, and one of these methods is stakeholder involvement in the modelling process (Refsgaard et al. 2007). This paper presents the co-construction of a conceptual model for the FEWS in the Magic Valley region of Southern Idaho. Conceptual modelling is an important step in model process building (Argent et al., 2016; Gupta et al. 2012). Our main aim is to describe the key structure (including agents) of the target system according to two knowledge systems or groups: namely, scientific and public/local knowledge (Villamor et al., 2014). To understand the interactions between food production and consumptive waste streams, including energy reclamation and water use at watershed scales, we adopted the Actor-Resources-Dynamics-Interactions (ARDI) method (Etienne et al., 2011). The ARDI method is part of the companion modelling that has been widely implemented for sustainable resource management (Barreteau et al., 2012; Étienne, 2013). Its main output is a collective conceptual model of involved stakeholders, which is useful in translating to role playing games and computer-based simulation models (such as agent-based model) (Dumrongrojwatthana et al., 2011; Gourmelon et al., 2013; Villamor et al., 2014). For agent-based modellers, the actors are translated to agents, the dynamics and processes to sub-models, and interactions can be used as rule-based decisions.

2 METHOD

2.1 Magic Valley: study area

The Magic Valley region is located in the south-central part of State of Idaho. It consists of eight counties, and Twin Falls is the region's largest city and metropolitan area. Agricultural production and dairy operations are the major economic engine of the region as well as for the economy of the State of Idaho. There are also food processors and aquaculture ventures in the region. All production depends on water from surface or ground water, and the entire region lies in the Eastern Snake Plain Aquifer (ESPA). At the same time, residents in the municipalities are competing for water resources while food and dairy industries discharge wastewater, where it makes its way into surface waters or infiltrates into the groundwater.

2.2 Data collection and analysis

A total of three workshops were conducted between January and March 2018. The first (scientific) group is composed of eight researchers and scientists with various disciplines such as geography, ecology, environmental laws, environmental science, hydrology and economics. This group is responsible for building FEWS models for the Magic Valley as part of a research program to produce integrated modelling for FEWS. The second (local stakeholders) group composed of local dairymen, farmer/water irrigator, food processing representative, a livestock extension agent and a water-rights lawyer. The participants in the second group were identified by a stakeholder advisory group (SAG) established in the beginning of 2017 to guide integrated modelling efforts. Prior to the conceptual modeling workshops, two SAG meetings were conducted in May and November 2017, to define the research problem relating to the FEW systems in the Magic Valley. Building on these two previous meetings, the design for implementing the ARDI method was modified. The key resources were identified – water (i.e., surface and ground) and wastes from agricultural production and dairy operations. Our modelling workshops revolved around identifying key elements in the structure of the FEW system: (1) *actors* who could or should play a role in managing or deciding the use of water (surface and ground) and wastes; (2) *dynamics and processes* that drive changes in the Magic Valley; and (3) *interactions* that link the actors and resources and affect how actors perceive the sub-systems to function (see Etienne et al. (2011) for detailed procedure). For identifying the most important actors and dynamics affecting system change, the participants were asked to rank top three for actors and top five for dynamics. The results were analysed by comparing these key structures according to knowledge groups and assessing whether they share the same conception of the FEW systems in the Magic Valley.

3 RESULTS AND DISCUSSION

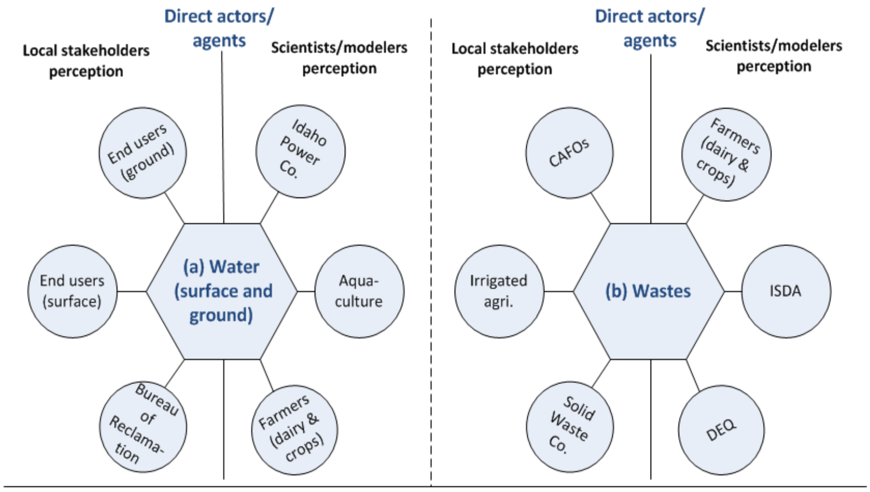
3.1 Actors

Figure 1 depicts the key actors in the Magic Valley who have direct roles in deciding the use of water and agricultural wastes. Differences were evident between the two knowledge groups:

I. *Local stakeholders (water*): end users of water were classified according to water sources, which were seen as the two top ranked direct actors. The end users consisted of property owners with pumps such as dairies and surface water users such as crop farmers, food processors and municipalities. Particular attention was given to those local stakeholders that are using ground water due to the problem of aquifer recharge. The Bureau of Reclamation ranked the third most important actor, due to control of surface water storage and release through managing impoundments.

II. *Scientists/modellers (water)*: Idaho Power Co. was ranked as the most important, followed by aquaculture and farmers. They classified actors according to use, e.g., grouped together dairy and crop production as one key actor as farmers (both surface and ground water for food), whereas aquaculture (surface water for food) and Idaho Power Co. (surface water used for generating electricity) were considered distinct by how they were using water (rather than by how much water they were using).

III. *Difference/adjustment of understanding (water)*: As clarified by the local stakeholders, the water source is divided (surface vs. ground) but use is mixed. For example, a county on the south side of the Snake River might solely use surface water, whereas food processors/industries north of the river are using both surface and ground water. The local stakeholders underscored the important role of the Bureau of Reclamation, which manages the reservoirs to store water and release water through contracts with canal and power companies (i.e., Idaho Power) for irrigation use, electricity production and flood control. Although the irrigators and canal companies monitor the amount of water in reservoirs, the Bureau has the authority to regulate the water flows and implement policy. In this way of conceptualizing the FEWS, power companies, canal companies, the Idaho water board, state legislature and the public were identified as indirect actors.



CAFOs = Concentrated Animal Feeding Operations; ISDA = Idaho State Department of Agriculture; DEQ = Idaho Department of Environmental Quality

Figure 1 Actors who play the major role in managing and deciding the use of water (a) and wastes from agriculture and dairy production (b).

Regarding wastes, the following are the main differences identified:

I. *Local stakeholders (wastes)*: classified separately the concentrated animal feeding operations (CAFOs) from irrigated agriculture as two different actors, which seen as the two top ranked direct actors. The Southern Idaho Solid waste company (SISW) ranked the third most important actor for waste management. The SISW is a regional solid waste district that offers recycling and waste diversion programs.

II. *Scientists/modelers (wastes)*: like water resources, they aggregated dairy and crop production as one actor and perceived as the most important actor. ISDA and DEQ ranked top two and three actors, respectively.

III. *Difference/adjustment of understanding (wastes)*: The local stakeholders pointed out the difference between CAFOs and irrigation agriculture, aside from the volume and concentration of waste they generated, the two actors should be separated due to the regulations (i.e., CAFOs are highly regulated as compared to irrigation agriculture). The ISDA and DEQ, which were seen by the scientists/modelers group as important direct actors, are viewed by the local stakeholders as indirect actors. In addition, the local stakeholders underscored the role of SISW particularly on disposing and recycling animal carcasses and biosolids, which the scientists/modelers group was not aware of.

3.2 Dynamics and processes

The following are the main dynamics and processes creating change in the Magic Valley in relation to water and wastes according to local stakeholders and scientists/modellers group. Figure 2 and 3 illustrate the main dynamics or processes.

I. *Local stakeholders (water):* Snowpack, precipitation and recharge in the biophysical category, which ranked as the most important dynamics/processes, followed by technological category including things such as water storage, infrastructure and management. Cost of electricity was seen as an indirect but powerful driver of local processes (by affecting cost of pumping ground water).

II. *Scientists/modellers (water):* Aquifer level (biophysical) and water rights (policy) were tied for most important, followed by type and price of crops or commodities. Hydrological cycle and population growth ranked as fourth and fifth most important, respectively.

III. *Difference/ adjustment of understanding (water):* It is expected that scientists/ modellers highlighted the biophysical processes, which were also noted by local stakeholders. However, local stakeholders emphasized that snowpack and precipitation determine the water availability for the whole Magic Valley, whereas scientists/ modellers emphasized aquifer level. Both groups identify population growth as important social dynamics; whereas, the cost of electricity was viewed by local stakeholders as one of the most important drivers of change.

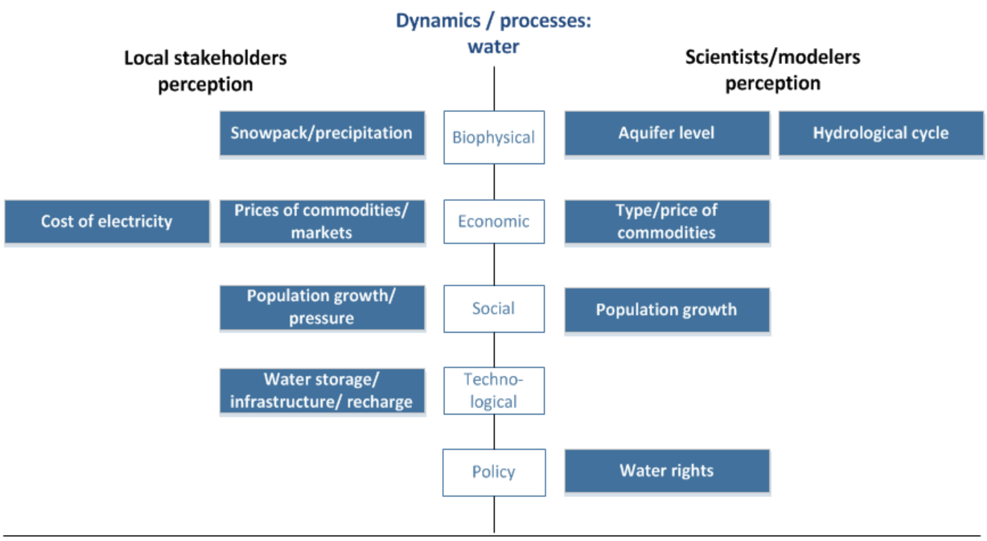


Figure 2 Key dynamics and processes creating changes in relation to water resource in Magic Valley

For wastes, the following are the main dynamics and processes identified:

I. *Local stakeholders (wastes)*: The cost of treatment and disposal and cost of transportation ranked the first and second most important dynamics affecting the system.

II. *Scientists/modellers (wastes)*: The five dynamics depicted in Figure 3 were determined to share the same level of importance.

III. *Difference/adjustment of understanding (waste):* The local stakeholders identified socio-economic dynamics as the major processes affecting study area. Eliciting the local stakeholders' perception on the costs of transportation and electricity helped the scientists/modellers to understand why bio-digester plants are not being utilized in the region as a solution to convert manure to bioenergy. The main reasons are: 1) the landfill fees are low; 2) land is available to dump the wastes (e.g., manure); and 3) electricity from hydropower is very cheap.

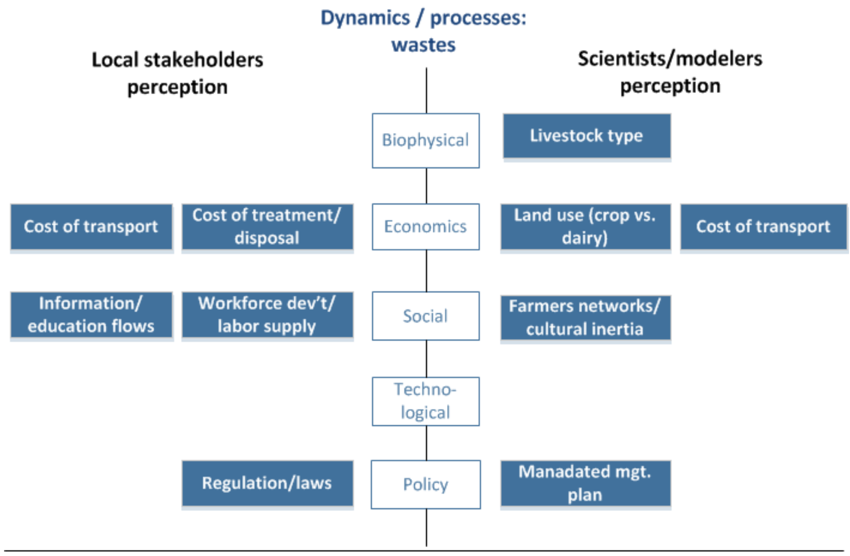


Figure 3 Key dynamics and processes creating changes in relation to wastes in Magic Valley

3.3 FEWS conceptual model

Conceptual models and frameworks are useful platforms for communicating and understanding how the target systems work, which serve as a basis for model simulation. Figure 4 presents the conceptual model developed by scientists and modelers *before* the stakeholders' involvement, whereas Figure 5 presents the conceptual model *after* the stakeholders' involvement.

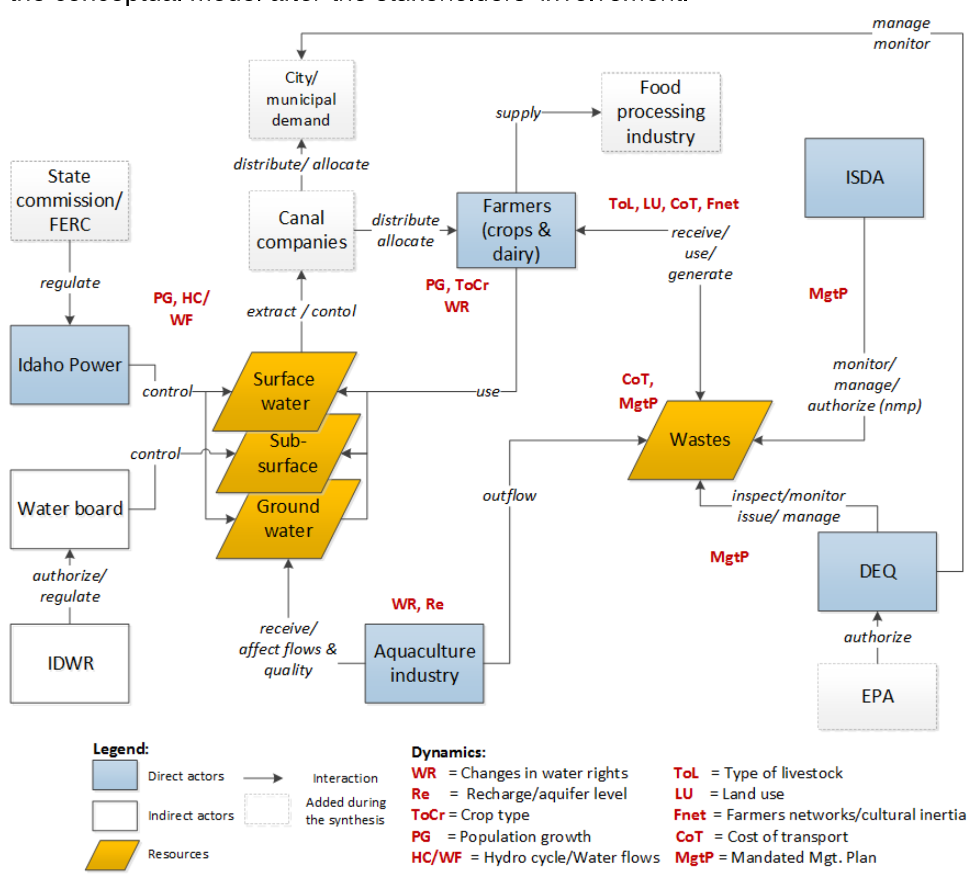


Figure 4 Conceptual model of FEWS in Magic Valley *before* stakeholders' involvement

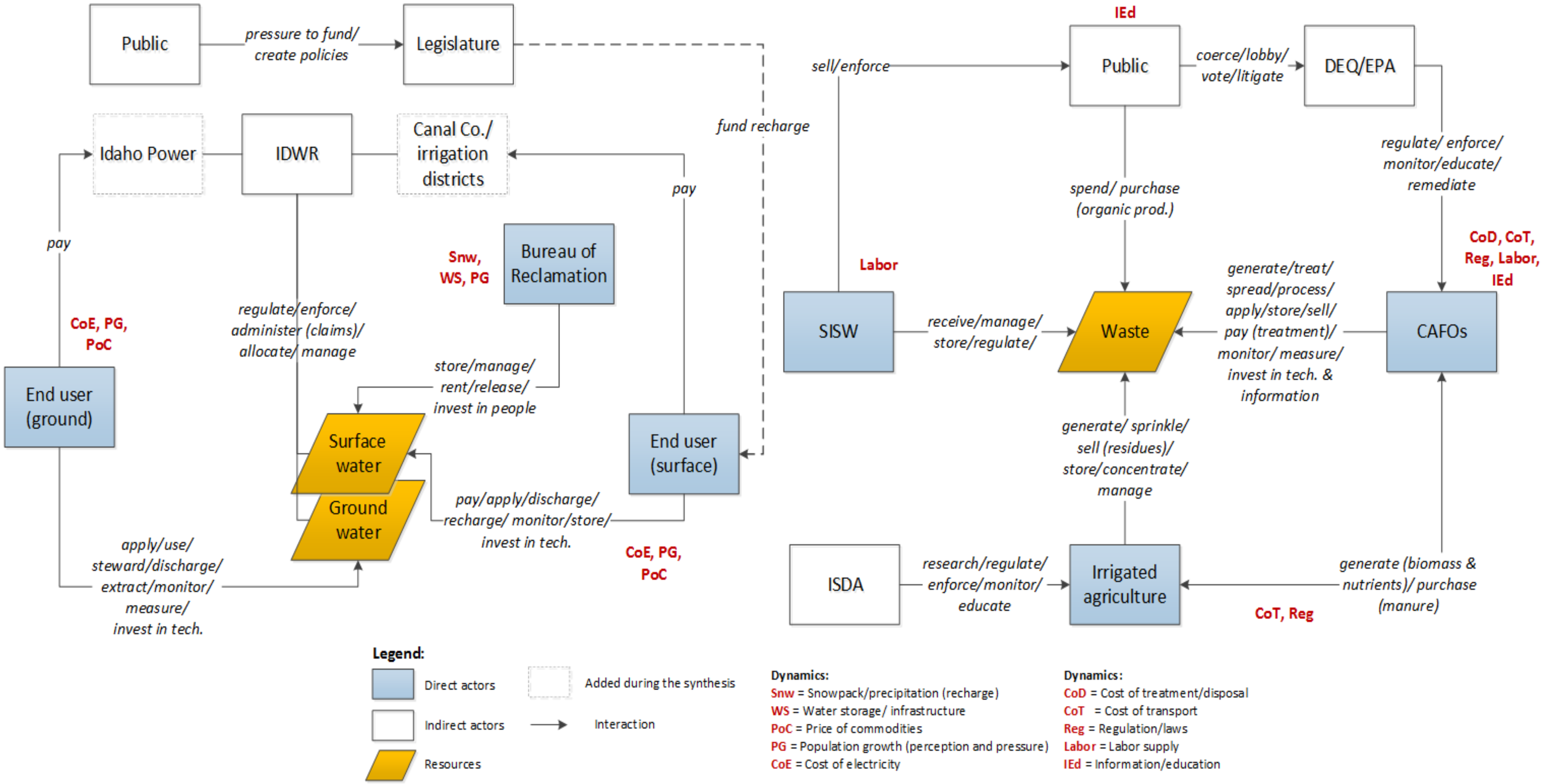


Figure 5 Conceptual model of FEWS in Magic Valley *after* stakeholders' involvement (Note: IDWR = Idaho Dept. of Water Resources; SISW = Southern Idaho Solid Waste; DEQ/EPA = Dept. of Environmental/Quality/Environmental Protection; and ISDA = International Swaps and Derivatives Association)

In Figure 4, the scientists and modelers were confident they were able to identify the various links and feedbacks based on integrating their knowledge from different domains (e.g., ecological, hydrological and socio-economic aspects of water and waste). Developing process and agent-based models from this conceptualization and generating outputs may provide understanding of the FEWS nexus, but it may cast doubts on the validity of model outputs due to uncertainty in framing and understanding the target system. For one thing, it includes actors that are viewed by the local stakeholders as only indirectly influencing the system, and the conceptualization misses out on the most important interactions (i.e., it is an over-simplification).

Figure 5 presents the conceptual model *after* the local stakeholders' involvement. It synthesizes the adjusted understanding of key actors (Figure 1) and dynamics and processes (Figure 2 and 3) through the interactions. Those interactions (*italicized actions and verbs*) provide a richer understanding of links and feedbacks as well as potential interventions for dealing with FEWS trade-offs. For example, if CAFOs and irrigated agriculture are aggregated as by the scientists/modelers group, the loop between the two actors through biomass wastes utilization is ignored. Further, the local stakeholders agreed that having two conceptual models (one for water and one for waste) was important because of the specific actors and dynamics associated with each resource.

The conceptual model in Figure 5 may reflect a more realistic, local view of the FEW systems in the Magic Valley. The co-constructing conceptual or mental model with local stakeholders addresses the two uncertainties mentioned above by:

- Utilising non-scientific and local knowledge and observations to identify the structure and elements (including the boundaries/frames) of the target system, as well as the socio-economic and biophysical contexts, which may affect FEWS behaviour;
- Providing a graphical representation (or visualization) of the target systems and its functions, where the stakeholders can see the various links (or interactions) and feedback loops; and
- Clarifying ambiguous and misinterpretation of terms through stakeholder input.

Moreover, the co-conceptual modelling process improves the understanding of involved parties as it allows for a pluralism of perspectives and incorporation of different types of knowledge into the model. It also helps in establishing trust and confidence with the stakeholders by involving them in the modelling processes. These results support the findings by Argent et al. (2016), Beven et al. (2017), Hamilton et al. (2015) and Voinov and Bousquet (2010) that involving stakeholders in the modelling process opens up the underlying assumptions, limitations and capabilities of the target models.

4 CONCLUSIONS AND RECOMMENDATIONS

Using the ARDI process to build conceptual FEWS models led to different outputs from researcher-driven and stakeholder-driven understanding of the system. Ultimately, rather than saying that one model is "better" than the other, models must be run and output must be verified and validated. However, stakeholder input at this stage already leads to perceptions and processes that are very likely strongly influential on the functioning of the FEW systems in the Magic Valley. While the research team was focused on biophysical and mechanistic processes, the stakeholders identified political and economic processes as being major drivers of decision making.

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