SYSTEMS THINKING FOR ADVANCING A NEXUS APPROACH TO WATER, SOIL AND WASTE

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Systems Thinking for Advancing a Nexus Approach to Water, Soil and Waste

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So what exactly does 'systems thinking' have to do with the nexus approach to water, soil and waste? It comes down to the fact that nexus problems are usually very complex, and systems thinking can help us work through and understand this complexity. Nexus problems are complex because they deal with many different interactions between the numerous parts of the nexus. They are complex because they try to combine water, soil and waste management in some efficient way. And they are complex because they are concerned with human behaviour as it affects the consumption of resources.

Systems thinking can help us manage this complexity because it gives us a structured way of thinking about the whole system rather than its parts, and about connections rather than just content. Systems thinking comes with a large set of mathematical formalities for looking at systems in a rigorous way, and offers us a considerable toolkit of techniques relevant for studying nexus problems, including systems dynamics, integrated assessment, simulation and modelling, and many more.

Today I'd like to give you some concrete examples of systems techniques and systems concepts that can be beneficial for solving nexus problems.

Mapping the nexus and its linkages

A very valuable and simple way to apply systems thinking to the nexus approach is to use systems techniques to map out a nexus problem. Methods range from simple causal loop diagrams, to more formal systems dynamics diagrams. The great advantage of mapping out the nexus problem is that it helps us visualize the different interlinkages of the problem. We see this in the causal loop diagrams I use later for illustrating nexus issues (Figures 4 through 7). In theory, if we understand the linkages, we can better understand the system and better identify solutions to water, soil and waste problems. But the glitch is that the number of linkages is usually so large that we can't see the forest for the trees, so to speak. Luckily, systems thinking tells us that we don't have to comprehend how all the linkages work, just the smaller number of critical linkages that determine the behaviour of the system;

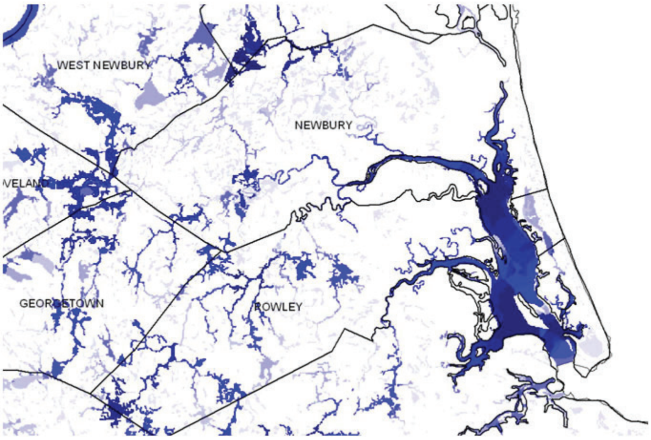


Figure 1: Interconnectedness of aquatic systems in Eastern Massachusetts. (Source: University of Massachusetts at Amherst Critical Linkages Project)

if we understand these we should be able to manage a system. The idea of critical linkages is related to the cybernetics concepts of strong connectedness and sensitivity between different parts of a system. A connection between A and B is 'strong' or 'sensitive' if a change in A causes a big change in B.

Figure 1 uses an example from nature to illustrate this idea. Here we see the rivers, lakes and inlets that make up the aquatic system of the eastern part of the US State of Massachusetts. Dark blue sections of this picture indicate pieces of the system that are 'strongly connected' because of their flow characteristics, as compared to the lighter coloured sections. Because they are tightly connected, if one part of a particular dark section is changed, for example by dumping in pollutants, conditions are bound to change in the other part of this section. Hence, these stretches of the aquatic system are internally strongly connected. So, this map can help water managers to see where and whether their intended changes impact the entire watershed, thus giving them better ways to evaluate different management options. We will see other types of critical linkages in a few moments.

Finding critical linkages

So why is it useful to identify critical linkages? First of all, it helps us prioritize the parts of the nexus to be studied – instead of studying the whole nexus problem, we could focus on the parts with critical linkages. Secondly, we could use these critical linkages to build a model that could then be used to better understand how water, soil and waste problems interact. And thirdly, these critical linkages sometimes show where the policy leverage points are located and could be used for identifying management options.

How would we find critical linkages, assuming we want to find them? One way is to sit down with stakeholders and experts familiar with a nexus problem and ask them to describe what they think are the critical linkages. We could also draw a systems dynamics map of the nexus problem and then build and use a systems dynamics model based on this map. Still another way is to use one of the many different kinds of models that are already available and that already include many different linkages, some of which are critical for a particular set of conditions and some of which are not.

One type of model that can be used are life cycle assessment models, which are particularly appropriate if the problem of

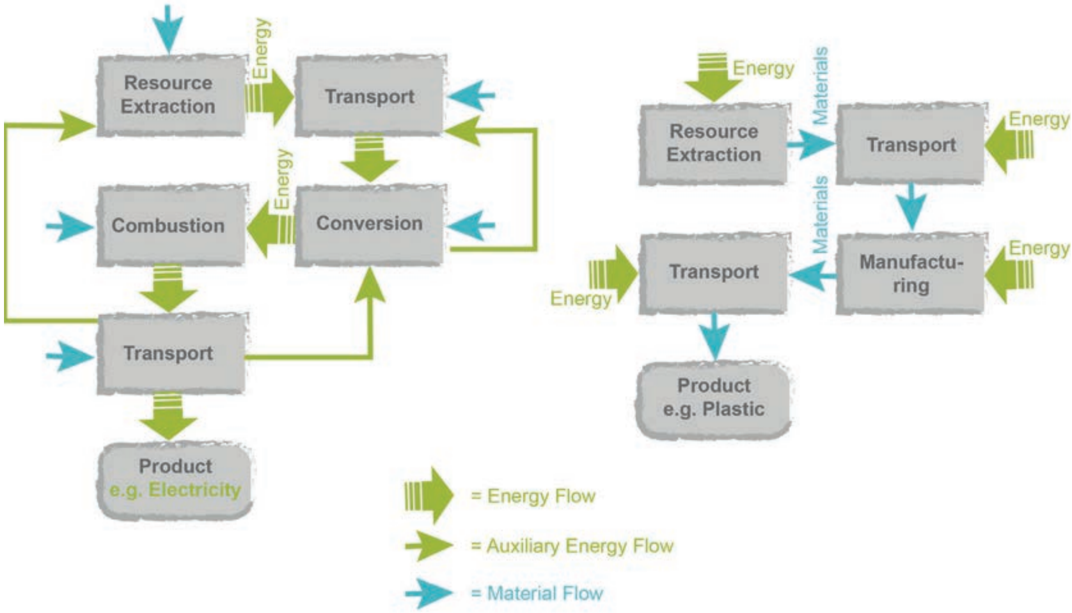


Figure 2: Sketch of topics covered by life cycle analysis models. (Source: Uwe Fritsche from IINAS and Lothar Rausch from Öko-Institut as ETC/ACC Consortium partners; Design: UNU-FLORES/Claudia Matthias)

interest has to do with the environmental and resource impacts of entire supply chains. This type of model is used to examine the impacts of entire industries or the entire life cycle of a product (Figure 2).

Another type of model that can be used is an integrated assessment model. This type of model was originally developed to deal with regional acidification and global climate change issues. Now there are many such integrated assessment models around and they usually cover a wide range of water, soil and waste issues (Figure 3). Such models are particularly useful for analysing the spatial and temporal aspects of interconnected systems.

Using models for nexus problems

Figure 4 gives an example of how an integrated assessment model can provide a useful analysis of a Water-Soil-Waste Nexus problem (although the authors did not use that terminology) and help identify critical linkages. In this case, the IMAGE 2 integrated assessment model was applied to questions about the relationship between food production and the emissions of greenhouse gases (Stehfest et al. 2009). The typical way of studying this relationship is to examine how population and economic growth affect food demand, how that demand determines the amount of cropland and rangeland used in the world and finally how changes in agricultural land affect the release of greenhouse gas emissions. In this case, the authors broadened the boundaries of the system to include the influence of dietary preferences

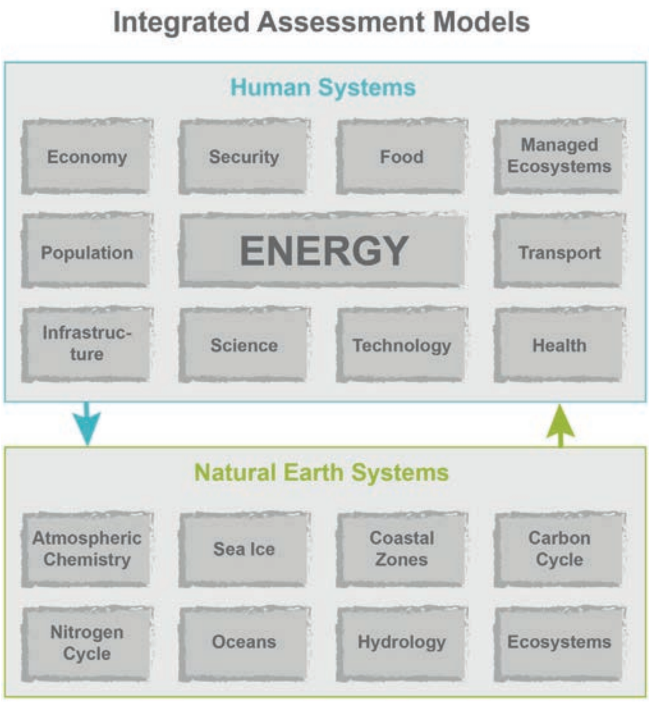


Figure 3: Sketch of topics covered by integrated assessment models. (Source: Integrated Assessment Modeling Consortium; Design: UNU-FLORES/Claudia Matthias)

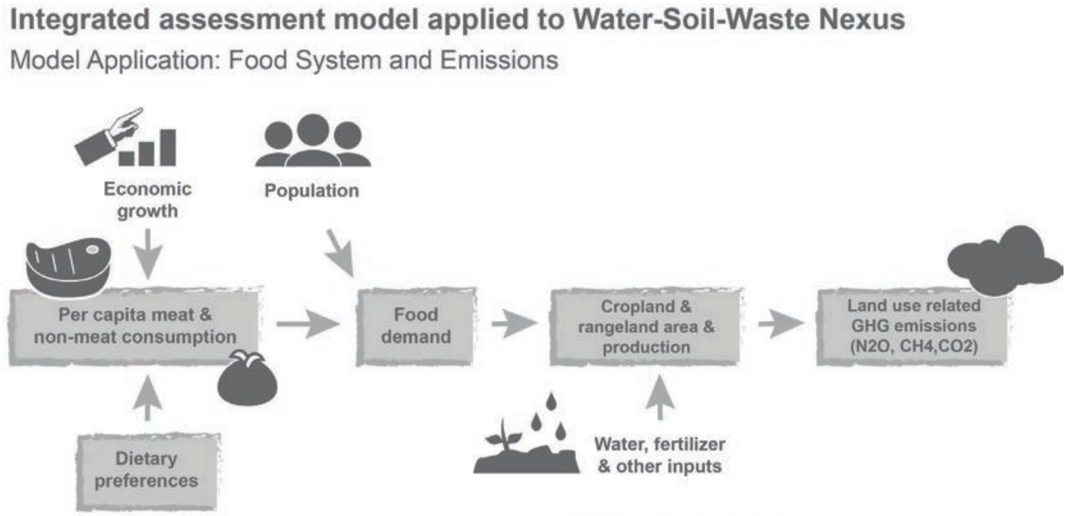
on per capita consumption of meat and non-meat products. The model has equations that relate changes in per capita consumption to the amount of cropland and rangeland, which in turn influences the release of greenhouse gas emissions (Figure 4).

But is the linkage between meat consumption, land use, and greenhouse gas emissions a critical linkage? In this study, the authors found that a 'Healthy Diet' scenario with low meat consumption resulted in much lower greenhouse gas emissions – one third lower – than a reference case. So the conclusion we can draw is that this linkage is indeed critical, at least under the conditions they examined. More importantly, I think this example shows how existing models can be used to identify critical linkages in the Water-Soil-Waste Nexus. In this case, an integrated assessment model was used, but it is easy to imagine that in other cases a life cycle analysis model might be more useful. The point is, the nexus approach is likely to require the help from a wide variety of different kinds of models. In some cases it might also make sense to combine different models or modelling approaches. All this makes it particularly urgent for UNU-FLORES to go forward with its evaluation and cataloguing of useful computer models for nexus studies.

Rebound effect in a systems setting

Now I'd like to make a bridge between the idea of critical linkages and other ideas from systems thinking and look at how this set of ideas can influence how we manage the nexus.

To make this bridge, I would like to use some examples from the topic of 'resource efficiency', which I know is of particular interest here at UNU-FLORES and in the nexus discussion in general. And I would like to drill down to a particularly interesting aspect of this topic, namely, the so-called *rebound effect*. In simple terms, the rebound effect refers to processes that hinder the achievement of targets for improving resource efficiency. This effect has already been studied for several years in the field of energy. As an example, our research colleagues tell us that the rebound effect is around 10 to 30 percent in the United States,



2050 Land use emissions

Scenario	Gt C eq / year
2050 Reference	3.3
2050 Healthy diet	2.1

Figure 4: Example of an integrated assessment model applied to a water-soil-waste nexus problem. Author's interpretation of results in Stehfest et al. 2009. (Design: UNU-FLORES/Claudia Matthias)

when fuel efficiency of autos is improved. That means that after purchasing autos with higher fuel efficiency, auto drivers tend to drive about 10 to 30 percent more kilometres than previously. When you have finally gotten rid of your gas-guzzling car and have bought a nice, compact, energy efficient car, and then say 'Hey, we're saving a lot of money on fuel, so let's take a few more trips to the countryside' you become part of the rebound effect.

The issue of the rebound effect is now slowly making its way into an arena very relevant to the Water-Soil-Waste Nexus – the issue of irrigation water efficiency. Here the question is whether improving the efficiency of water use for irrigation really achieves its intended goals. From the systems perspective, the intended goals go beyond improving some particular irrigation equipment; they extend to goals for reducing water scarcity in an entire river basin or groundwater catchment. To make this point, I will describe a series of case studies from the literature; one from the Rio Grande in Mexico and the United States, one from the Ebro river basin in Spain, and one having to do with the groundwater aquifer in Kansas in the United States. All of these come to amazingly similar conclusions.

A common thread of these case studies is that their authors all wanted to find out whether government-subsidized improvements in irrigation efficiency led to a decrease in water scarcity. In the case of the Rio Grande (Warda and Pulido-Velazquez 2008), a switch was made from surface irrigation to drip irrigation, moving from perhaps a 50 percent field efficiency to potentially 90 percent or

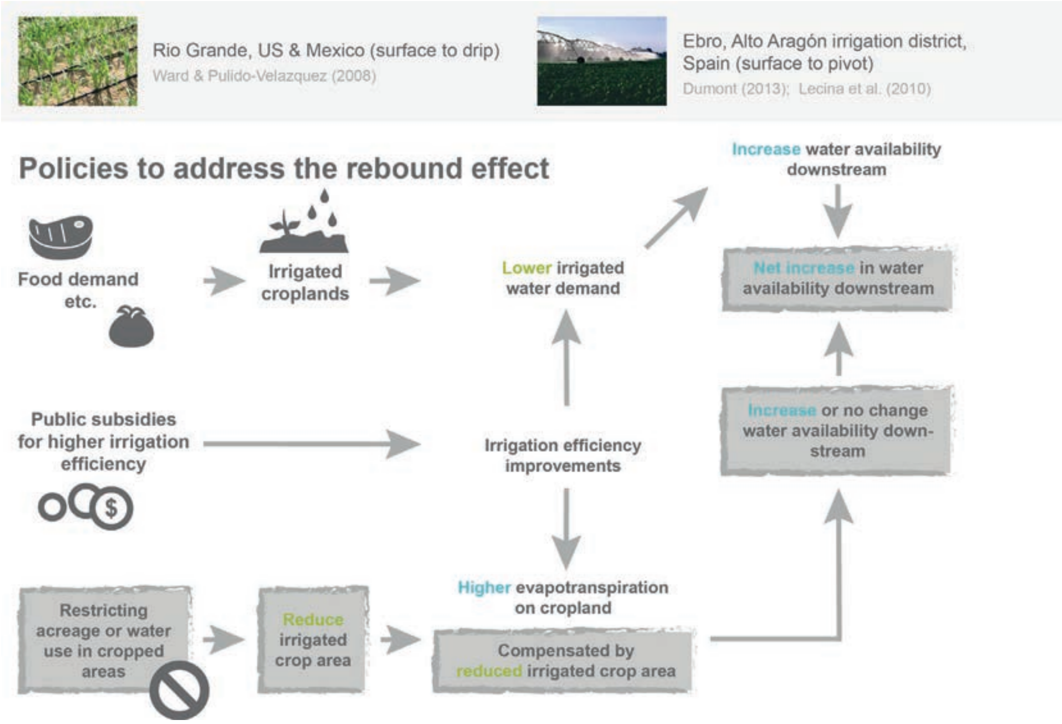


Figure 5: A simple causal loop diagram illustrating the effect of subsidies in stimulating the rebound effect relative to improving irrigation water efficiency. Also depicted are policies to neutralize the rebound effect. Author's interpretation of case studies on the Rio Grande (Warda and Pulido-Velazquez 2008) and Ebro rivers (Dumont et al. 2013). (Design: UNU-FLORES/Claudia Matthias)

higher field efficiencies. In the case of the Ebro (Dumont et al. 2013), farmers shifted from surface irrigation of around 50 percent efficiency to pivot irrigation with perhaps a field efficiency of 75 or 80 percent[1]. In these case studies, the authors found that subsidies did in fact lower the use of water for irrigation. For the Rio Grande, under the highest level of subsidies, irrigation water demand dropped about 10 percent relative to the baseline. But there's a catch to these results. Although less water was wasted on the field, more water was transpired by plants to the atmosphere leaving less for downstream users. Also, in some cases, farmers began to irrigate a greater area of cropland. These changes reduced the amount of water recharging aquifers and flowing downstream. In the case of the Rio Grande, efficiency improvements saved 10 percent of the water needed to irrigate crops but also decreased return flows to downstream users by about 50 percent. Authors of both of these studies concluded that the subsidies actually did not alleviate water scarcity at all.

How can we respond to this rebound effect? Well, the authors of these case studies suggest that the main way of responding would be to take a whole-basin approach.

[1] The field efficiency estimates in this and in the previous sentence are averages from the literature, not from the cited case studies.

This would mean basin-wide restrictions on either the acreage of irrigated crops or the total use of water for irrigation. Presumably this would lead to a reduction in irrigated area and, therefore, the higher transpiration rates of plants would be compensated by the reduced irrigated area (Figure 5). More water would become available downstream of the irrigated fields and water savings would be achieved on the whole basin scale rather than just in particular irrigated fields.

The Kansas case study focused on a situation in which irrigation projects were contributing to the depletion of the regional aquifer (Pfeiffer and Lin 2014). In some parts of Kansas, the water table has dropped by more than 40 meters since the 1970s. Responding to this situation, governments subsidized the shift from one kind of pivot irrigation to a more efficient kind. As a result the farmers realized: 'Now I have more water for the same investment, and a lower marginal cost, so I can use more water'. And that is exactly what they did. Some shifted to more water intensive crops, such as soybeans, and ended up irrigating more frequently. Some began irrigating fields that were too marginal to irrigate earlier. This whole set of actions led to an increase in groundwater withdrawals and an even greater depletion of the regional aquifer (Figure 6).

The authors of this case study came to a conclusion similar to the other authors – solutions to the rebound effect could be found by taking a basin-wide approach rather than focusing on improving efficiency in individual fields. In this case, the authors thought the rebound effect could be dealt with by restricting the water allowances of farmers by either narrowing their water rights or imposing taxes on water. These actions would, in principle, discourage the farmers' shift to water intensive crops or more frequent use of irrigation. This, in turn, would dampen the demand for irrigation water, and decrease withdrawals from the aquifer and its further depletion (Figure 7).

Lessons from systems thinking for the nexus approach

So, what are the lessons to be learned?

First of all, viewed from a systems standpoint, the rebound effect can be seen as a failure to achieve a whole systems goal. The aim of subsidies to irrigators was not just to improve the efficiency on individual fields but to reduce water scarcity in the river basin or aquifer catchment. In this sense, the whole systems goal was reducing basin-wide scarcity.

Secondly, the rebound effect comes from omitting or neglecting critical linkages in the system, especially those linkages that have to do with human behaviour, such as the reaction of farmers to a cheaper marginal cost of water.

Thirdly, these case studies show that solutions become available if we look at the larger system rather than focusing on its smaller parts. We saw that solutions arose when the basin-scale goals were taken into account, rather than just the immediate aims of improving irrigation efficiency on farms.

To sum up, in the course of this keynote address, I was only able to touch on a few of the aspects of systems thinking that can be particularly useful when dealing with the

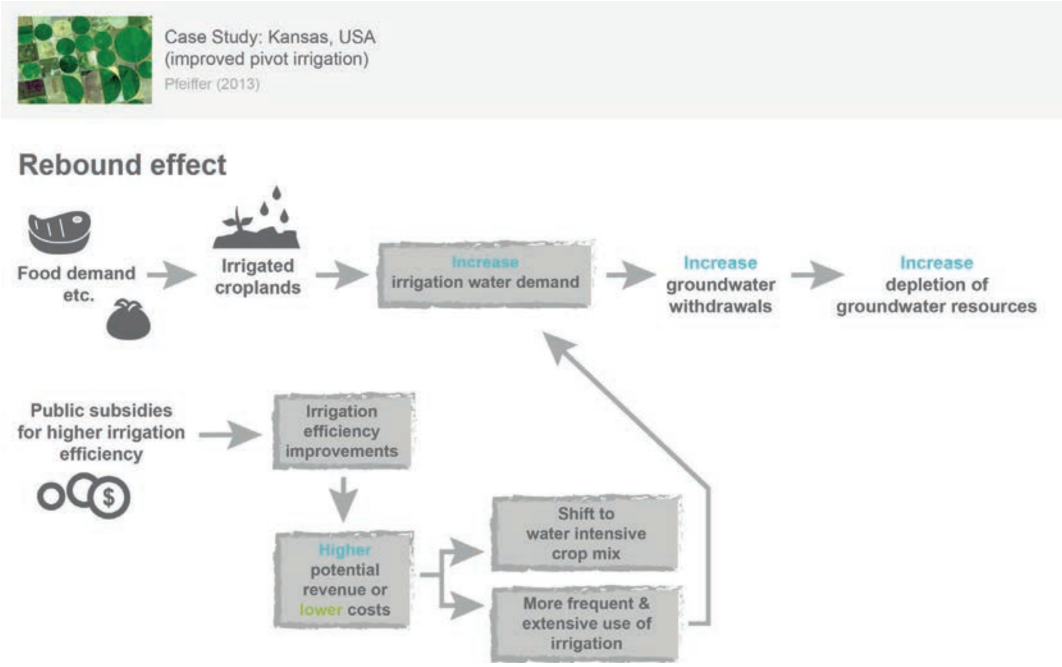


Figure 6: A causal loop diagram illustrating the rebound effect relative to improving irrigation water efficiency. Author's interpretation of a Kansas case study (Pfeiffer and Lin 2014). (Design: UNU-FLORES/Claudia Matthias)

tough interconnected challenges of water, soil and waste management. Nevertheless, let me list some of the key items that I think should be part of a basic systems approach to nexus problems:

- *Mapping the nexus system* – Systems techniques can be used to map the nexus system and articulate its linkages. Through a mapping exercise we can also clarify the goals of the nexus system.

- *Quantifying the linkages* – Models can be used to quantify the linkages in the system. These could be models already available, or a combination of existing models, or in some cases, new models fit to purpose.

- *Identifying critical linkages* – Models or scenario analysis can be used to identify the 'critical' linkages in the system that determine the system's behaviour.

- *Identifying policy options* – Knowledge about critical system linkages can then be used to identify the key leverage points where policies can work best.

In closing, I think you will agree with me that the nexus of water, soil and waste problems is indeed complicated territory. But I think systems thinking gives us the tools we need to navigate through this territory and find solutions that work.

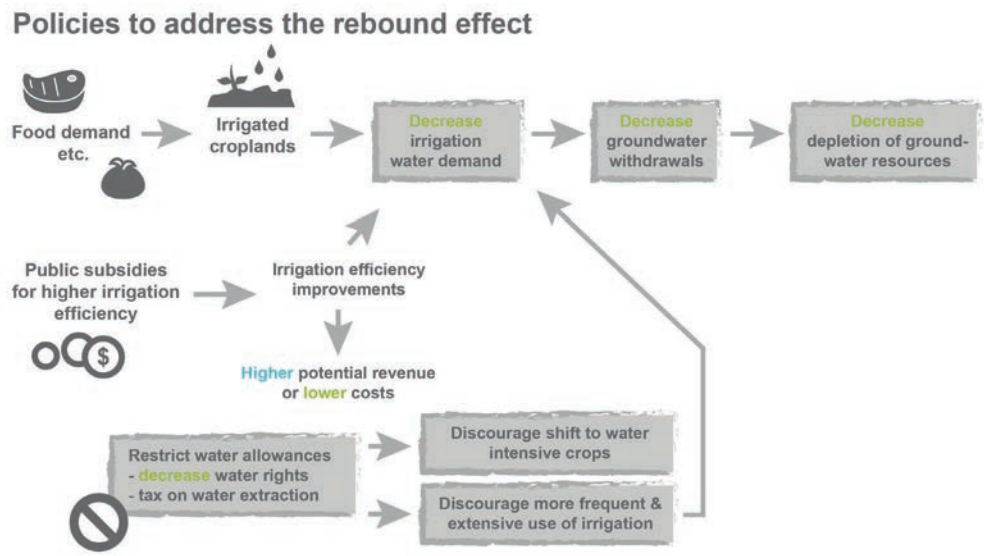


Figure 7: A causal loop diagram illustrating policies to counteract the rebound effect relative to improving irrigation water efficiency. Author's interpretation of a Kansas case study (Pfeiffer and Lin 2014). (Design: UNU-FLORES/Claudia Matthias)

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A PDF and full-length video of this lecture are available on the UNU-FLORES website: **flores**.unu.edu

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