Systems thinking for advancing a nexus approach to water, soil and wastes

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The nexus of water, soil and wastes is made up of innumerable connections, in particular the complex interactions between society and the environment. In this vast space of ideas and institutions, systems thinking can bring better understanding of nexus problems and provide insight into good management strategies.

There is no universally accepted definition of "systems thinking" but most would agree that it involves thinking in terms of a whole system rather than its parts, focusing on linkages rather than components, and observing patterns rather than content. There is also a large tool kit of systems methodologies that can be brought to bear on nexus problems, including integrated assessment modeling, systems dynamics diagrams and models, scenario analysis, and systems engineering.

Systems thinking can help describe the linkages in the nexus through visualization techniques such as systems dynamics diagrams and causal loop diagrams. These diagrams can be used to identify the connections between components in a system, and then to find out which of these connections are the "*critical linkages*" that determine the behavior of a system. Identifying critical linkages can help, among other things, to identify possible policy leverage points.

Tools particularly useful for identifying critical linkages are life cycle models and integrated assessment models. An integrated assessment model[1] was used, for example, to identify the critical linkages between dietary preferences, per capita meat consumption, food demand, cropland and rangeland area, water and other inputs to farm productivity, and finally, the emissions of greenhouse gases related to agricultural land use. The researchers provided evidence through this set of critical linkages that greenhouse gas emissions related to agricultural land use could be significantly reduced by lowering meat preferences. This example illustrates how models can be used to analyze critical linkages in a complex "nexus system", and also how this analysis can generate important policy-relevant insights.

Systems thinking can also help illuminate particular issues on the nexus of water, soil and wastes. One such issue is the impact of the "rebound effect" on improvements in irrigation water use efficiency. The rebound effect occurs when efficiency improvements do not achieve their intended aims because of unexpected cause-and-effects. In the case of irrigation water efficiency, the rebound effect could mean that efficiency actions inadvertently lead to a loss in water availability elsewhere. For example, a case study from the Kansas plains[2] found that shifting to a more water efficient version of pivot irrigation indeed saved water from the farmer's perspective but set into motion a set of actions that ultimately reduced water availability in the whole basin. In this case, farmers took advantage of cost savings from efficiency improvements to shift to more water-intensive crops and/or make more frequent and extensive use of irrigation. This increased the overall irrigation water demand and accelerated depletion of groundwater sources of irrigation water. Authors of the case study suggested that restricting water allowances for irrigation could ultimately counteract the rebound effect by discouraging farmers from expanding their irrigated areas, and this would slow down the depletion of groundwater resources.

From the systems perspective, this and other case studies[3,4] of the rebound effect and irrigation water use efficiency suggest the following:

- The rebound effect can be seen as the failure to reach the systems goal of maximizing services from water and soil, while minimizing waste.
- The rebound effect occurs if critical system linkages are not taken into account especially with regards to human behavior (e.g. farmers responding to cost savings coming from efficiency gains invest in more irrigated crops)
- Solutions can be found by examining the "larger system", including critical linkages. In the case studies, solutions arose when the *whole* water resource was taken into account (groundwater aquifer or entire river basin) rather than just the immediate irrigation water use on farms.

Summing up, although a general systems approach to nexus problems is not yet available, ultimately this approach is likely to have the following elements:

1. Mapping of the nexus system using systems science tools, and using this mapping to clarify whole system goals
2. Using models to quantify system linkages
3. Identifying out of all system linkages the "critical system linkages" and feedbacks that determine systems behavior
4. Using insights about critical system linkages to identify policy options that achieve the goals of the whole system

Building on these initial ideas, systems thinking can illuminate problems and help identify solutions on the nexus of water, soil, and wastes.

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[1] Stehfest, E. et al. 2009. Climate benefits of changing diet. *Climatic Change*. 95:83–102. DOI 10.1007/s10584-008-9534

[2] Pfeiffer, L.; Lin, C. 2014. Does efficient irrigation technology lead to reduced groundwater extraction?: Empirical evidence. *Journal of Environmental Economics and Management*, 67 (2), 189-208.

[3] Dumont, A. et al. 2013. Is the rebound effect or Jevons paradox a useful concept for better management of water resources? Insights from the irrigation modernization process in Spain. *Aquatic Procedia*.1:4-76.

[4] Warda, F; Pulido-Velazquez, M. 2008. Water conservation in irrigation can increase water use. *PNAS* 105(47): 18215–18220