Social-Hydrological Risk in the Mexico City Basin

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TEACHING NOTES

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INTRODUCTION

It was 4pm when Georgina heard the bell rung at the end of the alley. She grabbed her rubber boots and climbed over the raised threshold at her front door – her attempt to keep the waters out -- and stepped down into the black, smelly water that was now a few inches deep in the alley. Joining her neighbors in the pouring rain, and admonishing her children to climb up on the kitchen table, she hurried to the end of the alley where the pump was located. Reaching into the drain, now clogged with garbage and silt, with her bare hands, she pulled out the tube to clear the end of the pipe of garbage. Her neighbor, Luz, flipped the switch and the pump started up. Slowly, slowly, they watched the water begin to move down into the sewers. This time they were lucky, the filthy water did not enter any home. Nevertheless, she was thankful that she had raised her stove up on cider blocks after the last time they were flooded. The stove was one of her more valuable possessions.

Meanwhile, in the community of Miravalle, perched on the hill just 600 meters above Georgina's residence, Lupe was dumping buckets of water she was collecting from the downpour into a 50 gallon "tambo." She was grateful that as a result of the storm she was going to have enough water to meet her needs for laundry washing over the next few days. Where she lived, her water supply was intermittent -- she typically received water only twice a week, for a couple hours, in system of water delivery called "tandeo". And the quality of the water was typically horrible: "tamarind" color, and often smelly. While she had limited space and capacity to capture and store the rainwater they received, the extra gallons she managed to collect during the storms would be make a big difference. Unfortunately, such rainfall events were concentrated only in a few months of the year. For the dry season, she was forced to "find" water -- typically buying water from private suppliers who come to the neighborhood with tanks.

In a third floor office in the center of the city, Manuel, the director of the new Resilient Cities initiative for Mexico City, watched the rain with increasing preoccupation. In an hour, he was to meet with his staff to discuss how they were going to address the problem of water scarcity and flooding through the project. Where to start? Who should be involved? He was a bit overwhelmed by the complexity of the problem. He was determined to involve more than the staff of the environment ministry in which his office was located, but getting the other sectors on board and committed was a challenge.

Managing water excess and scarcity is one of the foremost challenges for society this century. These challenges are exemplified in Mexico City, a megalopolis of 22 million and one of the world's largest urban areas. The city was founded in 1325, improbably located in the center of a series of shallow, saline lakes that at that time covered the Valley of Mexico. For over 600 years, catastrophic flooding and access to potable water have challenged the city's residents, motivating extensive investments in hard infrastructure to supply the city with fresh water, or to protect the city from periodic flooding. Perplexingly, the ways in which city managers and residents have responded to the challenge of water in the city have both enabled the city to thrive, while simultaneously creating conditions of pending crisis via subsidence and over-

reliance on fallible infrastructure. With each successive investment, water systems have become less sustainable. Today, all residential and industrial wastewater (only 8% treated) is combined in the same infrastructure as storm water and pumped out of the Basin through the *Gran Canal* and the "Deep Sewage" system (*Drenaje Profundo*). Both systems were designed to operate with the help of gravity, but increasing land subsidence now requires fuel-intensive pumping to drain sewage and flood water. Today half of the city's freshwater is pumped from an overexploited aquifer below the city and the other half via interbasin transfers from adjacent watersheds (Lerma and Cutzmala) at increasingly high economic and ecological costs. Even though much of the population does not have adequate access to potable water or sewerage, very little water is recycled or reused. Over the last century, land speculation, political incentives, and deregulation have forced newcomers and the poor to the urban fringe. Urban settlements, land-cover change, and ecosystem degradation have impacted the southern ecological conservation areas and upland watersheds, creating increasing runoff and exposure to hydrological hazards downslope. Localized flood events impact transportation routes, commercial activity, public health, and property. The chronic nature of the problem raises the specter of increasing vulnerability under a changing climate. Vulnerability in this context is a product of complex socioecological system (SES) dynamics, rather than a simple aggregation of the sensitivity, exposure, and capacity of a city's neighborhoods, businesses, and institutions. In Mexico City, as in many megacities, risks are addressed in fragmented and sectorial ways: one dimension of risk is prioritized over others, tradeoffs among risks are ignored, and adaptations can, over time, exacerbate vulnerability, rather than reduce it.

Introductory Video Links:

PBS News Hour, November 10, 2014 "Mexico City Faces Growing Water Crisis". http://video.pbs.org/video/2365366376/

Altman, L. November 12, 2014. "Water, water, nowhere. Mexico City endures severe shortages." *Nonprofit Quarterly.* http://nonprofitquarterly.org/2014/11/12/water-water-nowhere-mexico-city-endures-severe-shortages/

Baverstock, A. June 2, 2014. "Miserable flooding is a fact of life in Mexico City's impoverished borough. *Vice News.* https://news.vice.com/article/miserable-flooding-is-a-fact-of-life-in-mexico-citys-impoverished-borough

CASE SUMMARY

This case is intended for upper-level undergraduate and graduate students. It is designed to be implemented in approximately 8 sessions, each 2 hours. A shorter version of the case is also possible, and the last section of the Teaching Notes makes suggestions in this regard. While no prior social-ecological theory or conceptual background is needed, the case may be most useful when integrated into a course addressing human-environment interactions, social-ecological concepts (e.g., resilience, adaptation, complexity), or sustainability science more broadly. The case uses the issue of water scarcity and flooding in Mexico City as an entry point into understanding the interaction of biophysical processes, path dependencies in the built environment, conflicting stakeholder perspectives and influences in system dynamics, and tradeoffs in vulnerability interventions. The case is intended to introduce students to some practical skills and approaches for complex system analysis (e.g., system mapping, stakeholder analysis, interviewing, agent based modeling) as well as insights into the complexity of addressing vulnerability and risk in large urban contexts. No prior knowledge on Mexico City or Mexico is needed. Nevertheless, if the case is adopted in a classroom with Spanish-speaking students, there is a significant potential to use the case for a more in-depth and empirically accurate evaluation of risk and vulnerability in the city by encouraging students to look at policy documents and data available online from Mexican agencies and sources.

Social-Hydrological Risk in the Mexico City Basin

TEACHING NOTES

MODULE 1: SES AS COMPLEX SYSTEMS

MODULE 1

The learning goal of Module 1 is to introduce systems thinking and appraisal of as a means of approaching socio-environmental issues. This objective is broken down into 3 classroom sessions, assuming each class period is 2 hours.

- Explore concepts of complex social-ecological systems and their representation in system mapping (Day 1)
- Represent the case study as a complex social-ecological system (Day 2)
- Research variables salient to the case and represent their causal and temporal interactions in Mental Modeler (Day 3)

TOTAL: 3 days [6hr in class; 8hr study load]

Day 1 – System Understanding (2h)

MODULE 1 – SES AS COMPLEX SYSTEMS			
Learning Goal: Introduce systems thinking and appraisal of SES as complex systems as a framework to analyze socio-environmental issues			
	Learning Objectives	**Activities**	**Outcomes and Assessments**
Day 1	A. Identify and explain the criteria that define complex systems B. Reflect on how these concepts can be illustrated in system mapping	A. **Presentation** of a PBS video on the Mexico City Case (MCC) and reading of the introductory case material (15 minutes). B. **Lecture** on complex systems and socioecological systems (SES) (40 minutes). C. **Facilitated discussion** about SES and MCC (20 minutes). D. **Lecture** on tools for system diagramming (10 minutes). E. **Break into groups**: work on identifying variables on MCC (20 minutes). F. **Class discussion** on emergent properties and challenges in identifying variables and interactions (20 minutes). G. **Homework** assignment (5 minutes).	<u>Per group</u>: A. Presentation of a list of variables in the MCC and their potential interactions, discussion on the challenges in representing MCC as a system diagram. B. Diagram: Representation on Mental Modeler of the identified variables and interactions.

PREPARATION (READINGS)

Texts on the Mexico City Case:

- Watts, J. 2015. Mexico City's water crisis – from source to sewer. The Guardian. November 2015. http://www.theguardian.com/cities/2015/nov/12/mexico-city-water-crisis-source-sewer

Video on the Mexico City Case:

- *PBS News Hour,* November 10, 2014 "Mexico City Faces Growing Water Crisis". http://www.pbs.org/newshour/bb/mexico-city-water/

Conceptual articles on SES:

- Zurlini, et al., 2008. Socioecological systems. Elsevier (Book chapter)
- Parrott, et al. 2012. Agents, individuals, and networks: modeling methods to inform natural resource management in regional landscapes. Ecology & Society. 17(3): 32 http://www.ecologyandsociety.org/vol17/iss3/art32/
- Loop Diagrams: http://systemsandus.com/2012/08/15/learn-to-read-clds/

CLASS PLAN

This class will begin with the presentation of the video and reading out-loud of the introductory case material (15 minutes). The instructor then provides a short lecture on social ecological systems, beginning by asking: "How does Mexico City's water situation reflect the dynamics of a social-ecological system?" before entering into a mini-lecture on the definition and attributes of SESs (40 minutes; see Box 1.1 and Module 1 Lecture for suggested slides). The students then enter into a facilitated discussion that relates the concepts revised in class to the material (introductory video(s), text) they have been exposed to on Mexico City Case (MCC) (20 minutes). The instructor then provides another mini-lecture on using tools to analyze and diagram SES such as system-mapping (10 minutes; see Box 1.2). The class then breaks out into subgroups to apply concepts to what they understand about the MCC case, with the effort aimed towards diagraming in MentalModeler (www.mentalmodeler.com) the first model for the MCC (20 minutes). The student´s handouts contain a preliminary list of variables associated with the case study. The students will categorize all of the provided variables (social, biophysical, economic, infrastructural) and diagram the links among them, documenting their hypotheses about why these links exist, and the consequences of these linkages. All groups will incorporate all types of variables in their diagram. The progress on this activity (diagram) will be presented in class the same day (20 minutes). Leave time at the end of the class to explain homework assignment (5 minutes).

ACTIVITIES

A) Presentation of the PBS video on the Mexico City Case (MCC) and reading of the introductory case material (10 minutes).

B) Lecture on complex systems and socioecological systems (SES) (30 minutes).
C) Facilitated discussion about SES and MCC (20 minutes).
D) Lecture on tools for system diagramming (10 minutes).
E) Break into groups: work on mapping MCC SES (30 minutes). See Student Handouts, Module 1, Day 1, Exercise 1 and 2.
F) Class discussion on emergent properties and challenges in diagramming (25 minutes).
G) Homework assignment (5 minutes). See Student Handout Module 1, Day 1 HOMEWORK.

Suggested questions to facilitate discussion about MCC as a Complex SES: *What do we mean by Social-Ecological System? What makes a SES "complex" and dynamic? What aspects of the water situation suggest that an SES framework might be constructive for understanding Mexico City's situation?*

Group discussion leading questions

- How to decide if a variable is actually a variable, or a property of the system resulting from interactions among variables?
- How would you represent interactions, feedbacks, temporal/spatial dynamics?

MATERIALS FOR CLASS

- Students should have access to computers with Internet connection.
- Classroom should have projector and speakers to present video on MCC.

HOMEWORK

Preparation for Day 2 class: Read case articles to create model for Mexico City and fill out associated table (see Student Handout, Module 1, Day 1 HOMEWORK).

CONCEPTS/TOOLS

Concepts: System, complex system, emergent properties, attractors, uncertainty, social-ecological system (SES), elements/variables, interactions, feedbacks
Tools: system mapping.

ADDITIONAL RESOURCES

- Mitchell, M. 2009. Complexity, a guided tour. Oxford University Press.
- Wells, J. 2013. Complexity and Sustainability. Routledge Taylor & Francis Group. New York. 350p.
- Stockholm Resillience Center webpage: http://www.stockholmresilience.org/
- Resillience Alliance: http://www.resalliance.org/
- Complexity resources, including online courses: www.complexityexplorer.org/
- Shumi Bose, 2015. "Meet the architect who wants to return Mexico City to its ancient lakes. *The Guardian* (online, November 13) http://www.theguardian.com/cities/2015/nov/13/alberto-kalach-return-mexico-city-ancient-lakes

Box 1.1 Lecture Notes

Few ecosystems (maybe none) are free of human influence and the socioecological systems (SES) theory comes from the recognition of close interaction between society (human), in terms of social and economic system, and natural system.

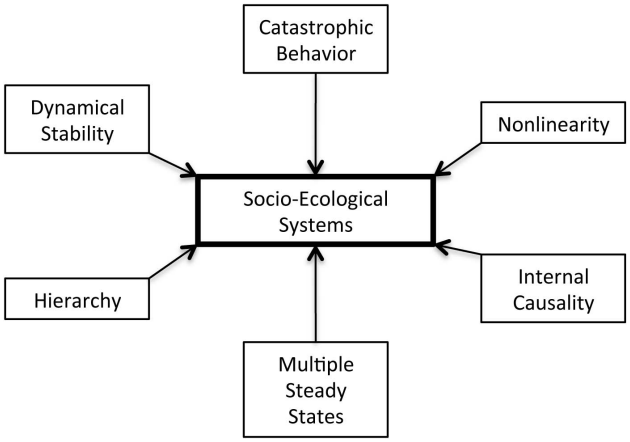
The complexity of a SES is the result of the interaction among a great deal of components that cause new, emergent, and unexpected properties. Thus, an essential goal is to change the perception or aim towards increasingly productive, efficient systems to increasing adaptive systems.

Key properties of SESs as complex systems

Complex systems theory offers a framework to understand the structure and dynamics of both social and ecological systems, a framework more sophisticated than the relevant "traditional" scientific disciplines.

SESs are complex systems because of their emergent properties, generically listed as:

1. *Nonlinearity*. The behavior of the system cannot be understood isolating their components. Or "the whole is more than the sum of their parts".
2. *Hierarchy*. They are hierarchically nested and interactions within the system cannot be understood by focusing only on one hierarchical level (multiple scales of interest).
3. *Internal causality – Self-organization*. There is no identifiable central control.
4. *Dynamic stability*. There are no equilibrium points for the system.
5. *Multiple steady states*. There is not necessarily a unique preferred system state in a given situation, because multiple attractors (or steady states) can be possible in a given situation.
6. *Catastrophic behavior*. It is typical of SESs, sudden, unpredictable behaviors, a great amount of uncertainty.
7. *Chaotic behavior*. Ability to predict the future is limited.



Reference: derived from Zurlini, et al. 2008.

Suggested readings: Zurlini, et al., 2008. Socioecological systems. Elsevier (Book chapter)

Box 1.2 Lecture Notes

SESs models - System mapping (variables, interactions, feedbacks)

What is a model? It refers to a reduced, simplified version of something, a SES for example. A model should capture the "essence" of the system by choosing the components and interactions of the real system that are necessary to gain understanding. In other words, a model is not a replica of the system. Rather, it is one possible representation of it for the purpose of understanding system function, dynamics or behavior.

One way to model a system is to *make a diagram,* or *a system map*. There are two main components of a diagram or system´s map: *variables and interactions*. The variables are things, actors, feelings, connected by links that represent interactions among them. Interactions can indicate causality by drawing links as arrows, and these causalities can be positive or negative depending on the direction of change of the variables given the interaction. As a whole, the group of variables and interactions among them is considered a model or a system map.

From the system map we can investigate system behavior and identify previously unseen interactions that cause specific behaviors. Particularly, it is useful to look for *feedback loops* of interaction within the system. A simple example to illustrate this is to think about population size and the different variables that affect it. In the simplest scenario, the two things that cause a population to change are births and deaths, so we use arrows to represent these causal links. We know that more births lead to a greater population, and fewer births will lead to lower the population, all else equal. We would say this relationship has a positive polarity, the two variables move the same direction. The contrary happens with deaths (figure 1). Now introducing feedback to the model. While more births lead to a greater population, a greater population also leads to more births, therefore a positive causal link from population back to births can be drawn. This link forms a feedback loop, a *reinforcement feedback (more leads to more, less leads to less)*. The contrary occurs with deaths, the more deaths happen, the population size diminishes, leading to future less deaths. This is also a feedback loop, a *balancing feedback loop* (*more leads to less, less leads to more*) (Figure 2).

Feedback loop: a set of relationships where one variable leads to a change in another variable that eventually leads to a change in the original variable.

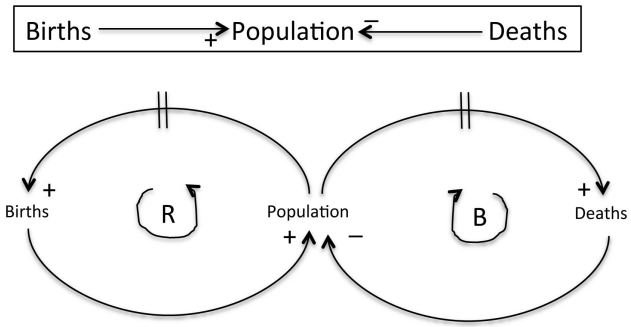


Figure derived from "Systems and Us" (see reference below).

Suggested readings: http://systemsandus.com/2012/08/15/learn-to-read-clds/

Day 2 – Investigating the Study Case using SES framework (2h)

MODULE 1 – SES AS COMPLEX SYSTEMS			
Learning Goal: Understand how concepts of complex systems can be illustrated in system mapping of SES			
	Learning Objectives	**Activities**	**Outcomes and Assessments**
Day 2	A. Illustrate the water challenges in Mexico City in terms of a SES B. Identify and analyze feedbacks in water-related risk in Mexico City	A. Brief **recapitulation on Mexico City case (MCC)** (5 minutes) B. **Breakout group discussion** about variables for the Mexico City case (30 minutes). C. **Plenary discussion about variables**, relationships, outcomes (20 min) D. Breakout **modeling-mapping** of the Mexico City case (30 minutes). E. **Class discussion on their system maps and challenges** in distinguishing variables, drivers and outcomes (25 minutes). F. **Homework** assignment (5 minutes). See Student Handout.	Per group: A. In class draft system model. Individual homework: B. Individual research on a subset of variables (identified by each group for each group member).

PREPARATION (READINGS)

Sources of information for SES Mexico City case

- Carrera-Hernández, J. 2006. Interim Report IR-06-022 Mexico City´s Water Management: In search of sustainability. http://webarchive.iiasa.ac.at/Admin/PUB/Documents/IR-06-022.pdf
- Tortajada, C. & Castelán, E. 2003. Water Management for a Megacity: Mexico City Metropolitan Area. AMBIO: A Journal of the Human Environment 32(2): 124-129. http://www.bioone.org/doi/abs/10.1579/0044-7447-32.2.124
- Izazola, H. 2009. Water and Sustainability in Mexico City. In: *Water and Development* Vol-II (e-book) ed., Catherine Marquetteayloan. UNESCO (www.eolss.net).
- Watts, J. 2015. Mexico City's water crisis – from source to sewer. The Guardian. November 2015. http://www.theguardian.com/cities/2015/nov/12/mexico-city-water-crisis-source-sewer

CLASS PLAN

This class will begin with a brief recapitulation by the instructor on Mexico City case to re-orient the students to the case (5-10 minutes). The class will then break into groups to discuss questions (see below, and student handout) designed to help students identify the problem(s), causes, actors, and processes of interest and concern (30 minutes). The students will reconvene for 20 minutes to report back on what they had identified and how their understanding has

changed from Day 1. They then return to their breakout groups to improve their systems diagram in MentalModeler (www.mentalmodeler.com) of the Mexico City case, making sure that they are capturing full diversity of biophysical, economic, social and cultural processes in their models and are thinking through types of feedback relationships among variables (30 minutes). Briefly, allow subgroups to present their progress and challenges to class regarding distinguishing variables, variable relationships and outcomes (10 minutes). Leave time at the end of the class to explain the homework assignment and allow the students to organize their group to accomplish the task assigned (20 minutes). The result of this activity has to be turned in the next class accompanied by a narrative.

ACTIVITIES

A. Brief recapitulation on MCC (5 minutes)
B. Breakout group discussion about variables for the Mexico City case (30 minutes).
C. Plenary discussion about variables, relationships, outcomes (20 min)
D. Breakout modeling-mapping of the Mexico City case (30 minutes).
   Make sure that students are capturing full diversity of biophysical, economic, social and infrastructural components
E. Class discussion on their system maps and challenges in distinguishing variables, drivers and outcomes (10 minutes).
   Have students think about how actors and the interests and agendas of actors are or are not represented in the model.
F. Homework assignment (20 minutes).

Group discussion leading questions About Variables for the MCC: *What is or are the problems identified in the Mexico City case? / What are causing the problems? / How are the differential causal factors related to other causal factors? / Are there feedbacks between the social, biophysical, economic and infrastructural processes? / What evidence is there of emergent properties? / Who are the actors? How are the causes and the actors related?*

MATERIALS FOR CLASS

- Students should have access to computers with Internet connection.

HOMEWORK (See Student Handout, Module 1, Day 2 HOMEWORK)

- Jigsaw: In each group, the students agree how to divide up the variables represented in their model for further research. The idea is that each student in each group will be responsible for a subset of interacting variables. They will independently research these variables and their relationships, seeking additional information, data, etc. that provides insight into the selected variable, its definition, its measurement, its trends and impacts on other variables in Mexico City. They will fill out a more detailed table on these variables as their homework assignment (see Student Handout, Module 1, Day 2). It is important that as a group, the students are covering a full diversity of variables (social, infrastructural,

economic, biophysical).

- Turn in: Accompanying the table the students fill out (see student handout), each student will turn in a short essay answering the following questions (note: narrative should include all variables and be clear on their relationship with the full system, use the table to complete the required information and guide the narrative):
    - Are the variables increasing, decreasing, rapidly or slowly changing?
    - Are the variables changing linearly or not? Why?
    - What is known or uncertain about the variables?
    - In which ways does the variable(s) directly affect others in the system?
    - Are there variables that are missing from the system model (master model)?

CONCEPTS/TOOLS

Concepts: Variables, drivers, outcomes, interactions, feedbacks.
Tools: Systems mapping (mental models)

ADDITIONAL RESOURCES

- WWF: "Big cities, big water, big challenges. Water in an Urbanizing World". http://www.wwf.se/source.php/1390895/Big%20Cities_Big%20Water_Big%20Challenges_2011.pdf

Day 3 – Investigating the Case Study using SES framework, and creating the master model (2h)

MODULE 1 – SES AS COMPLEX SYSTEMS			
Learning Goal: Use the SES framework to create the master model for the Study Case			
	Learning Objectives	**Activities**	**Outcomes and Assessments**
Day 3	A. Explore different forms of system interactions in the context of the Mexico City case. B. Evaluate implications of connections, time and spatial scale for the system variables in terms of system outcomes in the face of interventions. C. Create master model for the Mexico City case.	A. **Groups meetings** for presentations of the individual research on variables (40 min). B. Class reconvenes, **each group presents 3 slides** emphasizing feedbacks, dynamics, and uncertainties. C. **Class discussion** and feedbacks on the groups models (60 min). D. **Break out into groups** to discuss how to incorporate comments on their master model (10 min) **E. Homework** (10 min). Final summative assessment via Master Model of MCC.	Per group: Master model of MCC and narrative. This outcome will be graded as final summative assessment for this module.

PREPARATION (READINGS)

Recommended:
Stafford Smith, M. et al. 2010. "Rethinking adaptation for a 4 ° world." *Philosophical Transactions of the Royal Society of London, Series A: Physical Sciences and Engineering.* 369: 196-216.

CLASS PLAN

This class will begin with the different groups meeting to share their individual research on variables. Each individual shares what she/he has learned about the variables she/he was responsible for. In groups, they work to revise their systems diagrams (40 minutes). Then the entire class reconvenes, with each group having prepared a systems diagram to share with the class and 3 slides highlighting where the key feedbacks between social and biophysical dynamics are in the system, what are the biggest uncertainties about the dynamics, and on what time frames key outcomes (emergent properties) are evident. Leading questions for class discussion should focus on capturing the sense of dynamics, cross-scalar processes and uncertainties and how this impacts management of risk and water in the city (60 minutes).

Then, the groups get 10-15 minutes at the end of the session to discuss among themselves how they are going to incorporate the comments of the class into their final product. Students have to complete their models and model narratives as a collaborative homework assignment (see Student Handout Module 1, Day 3 for instructions). Finally, the teacher spends 10 minutes explaining the rubric for the final homework (see Rubric below).

ACTIVITIES

A. Groups meetings for presentations of the individual research on variables (40 min).
B. Class reconvenes, each group presents 3 slides emphasizing feedbacks, dynamics, and uncertainties.
C. Class discussion and feedbacks on the groups' models (60 min).
   Leading questions for discussion: *How do uncertainties in the interaction of variables impact management of risk or decision making? How do differences in scale (spatially and temporally) for interacting variables affect perception of the consequences of actions? How does the nature of the variable pose different challenges for management? / Does the variable change fast or slowly? / How far (spatially) do the impacts of a variable reach? / How do uncertainties in the interaction of variables impact management of risk or decision making? How do differences in scale (spatially and temporally) for interacting variables affect perception of the consequences of actions?*
D. Break out into groups to discuss how to incorporate comments on their master model (10 min).
   - Reflect on uncertainty, spatial and temporal effects of variables and their interactions.
   - Complete integrative table on all variables (see below)
   - Reflect on the challenges that spatial and temporal behavior of the variables and their interactions pose to management strategies or interventions.
   - Outline narrative
E. Homework (10 min). Final summative assessment via Master Model of MCC.

HOMEWORK

(see Student Handout, Module 1, Day 3) As a final summative assessment, each group will turn in the following:

1) Master Model (causal loop diagram) of Mexico City's water challenges, represented as a social-ecological system
2) Table of variables (composite table from Day 2's homework incorporating contributions of all group members)
3) Narrative (2000 words): Using the Master Model and accompanying table as your sources, present and justify a strategy for intervening in the system to address what you have decided is one of the more critical aspects of the social-ecological interactions in the system. Describe how your strategy addresses the dynamics of the system and the

challenges posed by differential time and spatial scales of problem causes and outcomes.

GRADING RUBRIC (group members will all receive the same grade for this assignment)

Project Component	Unsatisfactory	Satisfactory	Exemplary
Master Model	*Limited evidence of understanding of feedbacks and causal relationships. Model presents superficial understanding of case study dynamics.*	*Model represents some key feedback relationships and captures most of the key dynamics presented in the readings.*	*Model represents clear and comprehensive understanding of complexity of system dynamics*
Variable table	*Little evidence of research beyond materials presented in class. Poor understanding of variable definitions, dynamics and relations.*	---	*Evidence of extensive research providing solid justifications for variable descriptions and insights into variable dynamics.*
Narrative	*Superficial analysis touching on only a few aspects of the system, providing limited justification for proposed interventions.*	---	*Proposed interventions follows from analysis of system variables and demonstrates clear understanding of implications of variable dynamics for management*

CONCEPTS/TOOLS

Concepts: Master model, interactions, feedbacks, cross-scales, dynamics.
Tools: Mental Modeler (scenarios tool).

ADDITIONAL RESOURCES

To reflect on vulnerability and risk management of SES considering feedbacks, cross-scales and dynamic behavior of interacting variables.

- Chelleri L, Waters JJ, Olazabal M, Minucci G (2015) Resilience trade-offs: addressing multiple scales and temporal aspects of urban resilience. Environ Urban 0:1–18. doi: 10.1177/0956247814550780
- Scheffer M, Carpenter S, Foley J a, et al (2001) Catastrophic shifts in ecosystems. Nature 413:591–596. doi: 10.1038/35098000
- Kinzig AP, Ryan P, Etienne M, et al (2006) Resilience and regime shifts: Assessing cascading effects. Ecol Soc. doi: Artn 20

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TEACHING NOTES

MODULE 2: HUMAN AGENCY IN SES

MODULE 2

The learning goal of Module 2 is to understand and explain the role of human agency and power in the SES. This goal is broken down into 3 classroom sessions, assuming each class period is 2 hours. The learning objectives for each day are as follows:

- Identify the stakeholders in the MC case and analyze their interests and influence; Diagnose mechanisms of stakeholder agency in the SES (Day 1).
- Understand what is a mental model; Learn basic interviewing skills for eliciting mental models; Practice eliciting mental models from qualitative data (interviews); Design basic research hypotheses to evaluate SES dynamics (Day 2).
- Analyze qualitative data to elicit mental models; Compare mental models of stakeholders in Mexico City; Explain differences in mental models, and the implications for interventions in system dynamics (Day 3).

TOTAL: 3 days (6hr in class; Study load: 3hr]

Day 1 – Stakeholders: influence and interest (2h)

MODULE 2 - HUMAN AGENCY IN SES			
Learning Goal: Understand and explain the role of human agency and power in the SES			
	Learning Objectives	**Activities**	**Outcomes and Assessment**
Day 1	A. Identify the stakeholders in the MC case and analyze their interests and influence B. Diagnose mechanisms of stakeholder agency in the SES	A. **Plenary**: Brainstorm on what are stakeholders and their categories. B. **Break into groups**: Stakeholders' interest vs influence in the system C. **Plenary**: Brainstorm on ways that stakeholders influence a system and on their interest vs influence in the system D. **Break into groups***:* Fill out Interest and Influence matrix for the Mexico City stakeholders. E. **Presentation**: 1-2 groups present matrix. Brainstorm on mechanisms of influence, scale and spatial scope of influence.	<u>Per group</u>: A. Table: List of key stakeholders in Mexico City case, hypothesized interest, influence and mechanisms of influence. B. Diagram: Influence and interest Matrix, Accompanied by 1-3 sentence explanation of placement of actor in matrix.

PREPARATION (READINGS)

- Students come to class having reviewed the articles on Mexico City case (MCC) and on stakeholders and created a preliminary list of stakeholders from readings.

MCC assigned readings:

- Tortajada, C. & Castelán, E. 2003. Water Management for a Megacity: Mexico City Metropolitan Area. AMBIO: A Journal of the Human Environment 32(2): 124-129. http://www.bioone.org/doi/abs/10.1579/0044-7447-32.2.124;
- Carrera-Hernández, J. 2006. Interim. Report IR-06-022 Mexico City´s Water Management: In search of sustainability. http://webarchive.iiasa.ac.at/Admin/PUB/Documents/IR-06-022.pdf)

SH assigned readings:

- Stakeholder analysis: a review (Brugha and Varvasoszky, 2000) http://www.sihealthpolicy.org/wp-content/uploads/2013/06/stakeholder_analysis.pdf
- Using stakeholder analysis to increase the effectiveness and relevance of water resources systems modelling (Hermans, 2001) http://hydrologie.org/redbooks/a268/iahs_268_0183.pdf
- Stakeholder Analysis (World Bank) http://www1.worldbank.org/publicsector/anticorrupt/PoliticalEconomy/stakeholderanalysis.htm

CLASS PLAN

The class will begin by brainstorming on what stakeholders are. The teacher will facilitate an open brainstorming and discussion (in plenary) with the following starting guiding questions: *What is a stakeholder/actor? Why (what evidence)? Who are the stakeholders in MCC SES? What stakeholders' categories do we have?* (see Box 2.1 for categories examples). The answers should be written down on a board. Class OUTPUT: Stakeholders general definition(s) and main stakeholders' categories. (~ 20 min). Next, the following activity is to break into groups and answer the following questions in cards or paper: *What are their interests, views, objectives? How important are they? How are they affected? How do they affect / influence the case study? How should stakeholders participate or contribute? In what ways do they influence a system? What is their interest vs influence in the system?* (~ 15 min). The class in brought back to a second plenary brainstorm where the teacher facilitates the answering of the questions (*In what ways do they influence a system? What is their interest vs influence in the system?)* by writing down a summarized version on the board (~ 7 min). After that, the teacher will give a short and introductory presentation (~ 7 min, 3-4 slides) on what is a stakeholder analysis and how is it used (See Box 2.1 for examples of tools for stakeholder analysis -1. Stakeholders' matrix, and 2. Interest and influence matrix). The opening question for this presentation can be: *Which methods and tools do you know to analyze stakeholders in a system?* The following activity is to break into groups again and fill out a Interest and influence matrix for the Mexico

City stakeholders: fill out matrix with explanation with hypotheses related to interest and influence [guiding questions: *What influence do they have? What are their mechanisms of influence? What are the consequences of their influence, for whom?]* (~ 20 min). Select one group to present matrix. Students comment on how stakeholders have been categorized, what stakeholders might be missing, having students justify where they have placed actors on matrix and why, and what does this say about what we think are key mechanisms of influence. Facilitator notes criteria that are affecting how students are placing actors in diagram.

ACTIVITIES

A. Plenary: Brainstorm on what are stakeholders? *Why (what evidence)?* And which stakeholders' categories do we have?
B. Break into groups*: What are their interests and objectives? How important are they? How are they affected? How do they affect / influence the MCC case study? How should stakeholders participate or contribute? In what ways do they influence a system? What is their interest vs influence in the system?*
C. Plenary: Brainstorm- *In what ways do they influence a system? What is their interest vs influence in the system?*
D. Break into groups*:* Fill out Interest and Influence matrix for the Mexico City stakeholders, with hypothesis on: *What influence do they have? What are their mechanisms of influence? What are the consequences of their influence, for whom?*
E. Presentation: 1-2 groups present matrix. Brainstorm on mechanisms of influence, scale and spatial scope of influence.

MATERIALS FOR CLASS

- Flipchart paper for developing matrices.

OUTPUTS

Per group:

- Table: List of key stakeholders in Mexico City case, hypothesized interest, influence and mechanisms of influence.
- Diagram: Influence and Interest matrix. Accompanied by 1-3 sentence explanation of placement of actor in matrix.

HOMEWORK

- Groups revise their matrix if necessary or desired before handing in to teacher.
- IN CLASS: one-minute essay answering the question, "What is the difference between influence and interest?"

FURTHER READINGS

- Knowledge co-creation portal Multi-stakeholder partnerships, Centre for Development Innovation, Wageningen University and Research Centre (http://www.mspguide.org/about-portal)

- Stakeholder identification http://www.mspguide.org/tool/stakeholder-identification
- Stakeholder Analysis: Importance/Influence Matrix http://www.mspguide.org/tool/stakeholder-analysis-importanceinfluence-matrix
- Tools for Development. A handbook for those engaged in development activity (Version 15.1, March 2003) http://webarchive.nationalarchives.gov.uk/+/http:/www.dfid.gov.uk/Documents/publications/toolsfordevelopment.pdf
- Power: a practical guide for facilitating social change (Hunjan and Pettit, 2011) http://www.carnegieuktrust.org.uk/getattachment/f4cd28e9-8518-4d7b-9c9b-119e555d79df/Power---A-Practical-Guide-for-Facilitating-Social-.aspx
- Integrated water resources management plans. Training Manual and Operational Guide. International Network for Capacity Building in Integrated Water Resources Management (Cap-Net), Global Water Partnership (GWP), United Nations Development Program (UNDP). March 2005 http://www.sswm.info/sites/default/files/reference_attachments/CapNet%202005%20Integrated%20Water%20Resource%20Management%20Plans.pdf

BOX 2.1 Lecture Notes on Stakeholders

Stakeholder "An agency, organization, group or individual who has a (direct or indirect) interest in the intervention or project, and/or who affects or is affected (positively or negatively) by the implementation and outcome of it".

Categories of stakeholders:

- Primary stakeholders:
  - Those who are ultimately affected/benefit from the intervention.
  - Project beneficiaries, poor and marginalized groups.
- Secondary stakeholders:
  - Government agencies, NGOs, research institutions, etc.
  - They participate in the project because they have a stake / interest in or can contribute to it.
- External- or other- stakeholders: People, groups and/or institutions that are not formally involved in specific project activities but can have an impact on or be affected by a project.

Stakeholder analysis: An approach for understanding a system by identifying the key actors - or stakeholders - in the system and assessing their respective interest and influence in that system; It involves a range of tools for the identification and description of stakeholders on the basis of their attributes, interrelationships, conflicts and interests related to a given initiative or resource.

Objectives of a stakeholder analysis:

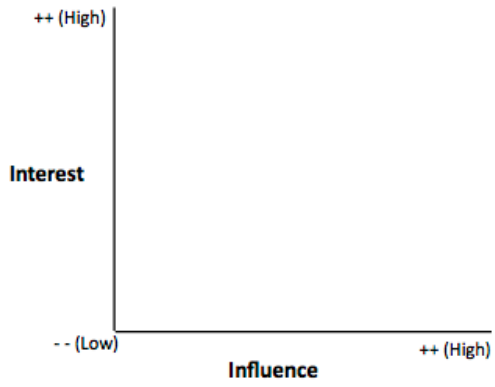
- To identify and define characteristics of -people, groups or institutions- who might be affected by an intervention or can affect its outcome
- To identify local institutions and processes upon which to build
- To provide a foundation and strategy for participation: mobilization of key stakeholders
- To make a start with understanding needs and interests of the key stakeholders

- Understand the relation between stakeholders and potential conflicts
- Assess the capacity of different stakeholders to participate and influence a system

Influence and interest:

- 'Influence' is the power a stakeholder has to facilitate or impede the achievement of an activity's objectives; it represents the power which stakeholders have to control what decisions are made; and the extent to which the stakeholder is able to persuade others into making decisions and following a certain course on action.
- The 'interest' that groups or individuals may have in the system should be also considered *[Guiding questions to assess the interests of different stakeholders include: What are the stakeholder expectations? What benefits are likely to result from a project or policy for the stakeholder? What resources might the stakeholder be able and willing to mobilize? What stakeholder interests conflict with a certain project or policy?].* Important to realize when assessing the interests of the different stakeholders is that some stakeholders may have hidden, multiple or contradictory aims and interests. The various organizations and interest groups that need to be engaged in a strategy process each have their own interests that they will seek to promote and defend. They can become involved in the process in different ways and contribute at different levels: for example, to identify and find solutions to problems, to build a vision and goals for the future, and to debate policy options and possible actions.

EXAMPLE of an Influence and Interest Matrix:



Source: Knowledge co-creation portal Multi-stakeholder partnerships, Centre for Development Innovation, Wageningen University and Research Centre (http://www.mspguide.org/about-portal)

DAY 2 - Mental models (2hr)

MODULE 2 - HUMAN AGENCY IN SES			
Learning Goals: Understand and explain the role of human agency and power in the SES			
	Learning Objectives	**Activities**	**Outcomes and Assessment**
Day 2	A. Understand what is a mental model B. Learn basic interviewing skills for eliciting mental models C. Practice eliciting mental models from qualitative data (interviews) D. Design basic research hypotheses to evaluate SES dynamics	A. **Plenary**: Instructor facilitated discussion on mental model (definitions, attributes utility in SES). B. **Break into groups**: Each group will develop questions to elicit the mental model of their peers on flood risk. C. **Plenary**: Groups share their questions with the class and class discusses effectiveness of questions in eliciting mental models. D. **Break into groups**: Students conduct interviews within their groups. E. **Exchange between groups**: Students share the diagrammed mental models captured in the interview with another group. F. **Plenary discussion**: Discuss what was learned in the exercise about interviewing, about mental model elicitation, and about differences in mental models.	<u>Per group</u>: A. Interview protocol B. Interviewee's mental model <u>As a class</u>: C. List of hypotheses on how stakeholders' mental models may differ in Mexico City

PREPARATION (READINGS)

Students will come to class having read the assigned articles and having had thought about the following questions: What is a mental model? How can understanding mental models provide insights into SES interactions? How can interviews aid in eliciting mental models?

Assigned readings:

- Jones, N. A., H. Ross, T. Lynam, P. Perez, and A. Leitch. 2011. Mental models: an interdisciplinary synthesis of theory and methods. *Ecology and Society* **16**(1): 46. [online] URL: http://www.ecologyandsociety.org/vol16/iss1/art46/

- Cone, J. and K. Winters 2011. Mental Models Interviewing for More-Effective Communication. In Mental Models Interviewing for More-Effective Communication, ed. Oregon Sea Grant. Oregon State University: Oregon State University.

CLASS PLAN

The class will begin with a facilitated (~ 20 min) on what is a "mental model", the dynamics of mental models, the relationship of mental models to the "real world" and why they are significant in SES research and analysis. See Box 2.2 below for ideas on the organization of this discussion. The class will then break into groups of 3 students (~ 20 min). Ask each group to come up with no more than 4 questions that would help in eliciting a mental model of **flood risk** held by one of their peers. Remind them that mental model interviewing demands minimal intervention on the part of the interviewer. Possible lines of questioning might be:

- "What do you associate with the idea of flooding in Mexico City?"
- "What comes to mind when you think of how flooding occurs?"
- "To what extent do you think this is a significant issue?"

Return to plenary (~ 20 min). Call on a few groups to share their questions with the class as a whole; discuss the extent to which the questions might or might not guide answers in a particular direction and whether or not the questions are likely to elicit the model held by the interviewee. Allow students to modify questions if they like. Discuss how a mental model could be captured and represented on paper, for example by listening for key concepts/factors/variables and how the interviewee associates these variables (represented by arrows linking concepts via direction of influence). Return to groups of three: One student will be the interviewer, one the interviewee, and one the note-taker/diagrammer. Students conduct interviews to elicit the mental model of their peers of flood risk. The diagrammer captures the interview on paper (~ 30 min). Following interviews, groups exchange mental model diagrams they have captured with one other group. They look at the output of the other group and compare the concepts/ factors represented and the relationships among factors. Ask them to consider: What is different? What is the same? Why might these differences exist? What emerged as variables common to both models? Are their cause-effect relationships that are also common? How might position/responsibility of the actor, disciplinary knowledge, personal experience etc. affect what was elicited? How might the models of the students different from residents and water managers immersed in the Mexico City context? The groups return to a plenary for conclusions (~ 10 min). The instructor leads a discussion on what students learned about mental models and what informs them and how they are elicited. Have students share hypotheses about how they think their own models might differ from actors in Mexico City. How might these differences influence the dynamics of the flood/scarcity problem in Mexico City?

Finish the class with a quick feedback exercise (collected by instructor as feedback into learning objectives):

- Define mental model in your own words.

- In 1 -3 sentences, describe factors that might lead to different mental models about a problem.

ACTIVITIES

A. Plenary: Instructor facilitated discussion on mental model (definitions, attributes utility in SES). See Box 2.2 below.
B. Break into groups: Each group will develop ~ 4 questions to elicit the mental model of their peers on flood risk.
C. Plenary: Groups share their questions with the class and class discusses effectiveness of questions in eliciting mental models. Instructor leads discussion on how to represent mental models in diagrams.
D. Break into groups: Students conduct interviews within their groups; one student interviews, one is interviewee, one is note taker/diagrammer.
E. Exchange between groups: Students share the diagrammed mental models captured in the interview with another group. They compare mental models in terms of variables represented, relationships among variables, complexity/ simplicity, emphasis of models.
F. Plenary discussion: Discuss what was learned in the exercise about interviewing, about mental model elicitation, and about differences in mental models. Students hypothesize on how stakeholder mental models in Mexico City may be different than their own, and why.

MATERIALS FOR CLASS

- Pieces of blank paper for diagraming mental models of interviews.
- At least one student in each group should bring a computer to write interview questions OR paper on which to write down questions for interviews.

OUTPUTS

- List of interview questions.
- Mental models of interviewees.

HOMEWORK

Each student is assigned one interview transcript of an actor in Mexico City (see Student handouts, Interview transcripts). These transcripts are based on real interviews (conducted by or commissioned by the case study authors); the content of the interview has been modified to ensure that identities are masked completely. Each interview is identified only by a generic descriptor: Public sector disaster manager, Urban resident, Urban planner.
On their own time, the student will read the interview transcript and record each core concept mentioned by the interviewee as part of their vision of the water problem in Mexico City as a variable in Mental Modeler (http://www.mentalmodeler.com). They then illustrate the relationships among the variables as described by the interviewee by arrows. The student can test the validity of the arrow according to the interviewee's description of the relationship by "reading" the relationship, for example, between variable A and variable B as "Variable A *influences* variable B" (or a change in variable A *causes a change* in variable B).

They save their version of the mental model on their computers and will bring these to class.

Box 2.2 Lecture Notes on Mental Models to Guide Instructor-Led Discussion

- Jones and colleagues (2011:3) define a mental model as "a cognitive structure" comprised of "representations of objects, their relationships and dynamics as well as the attributes or characteristics of these and the person's valence (cognitive and emotional) to the objects, relationships and dynamics."
    - What is meant by a "cognitive structure". How do cognitive structure come to be? What informs them?
        - E.g., personal experience, perception, cultural context, formal knowledge.
- Do they change over time?
    - Yes: In response to experience, learning (individually, and with others in social contexts), through reasoning.
- How "accurate" or "realistic" are mental models? Is it important that they are accurate?
    - Mental models are always incomplete, partial, representations of reality. They are inherently subjective. This doesn't mean they are necessarily "wrong" or "right". Typically, we believe our own mental models to be "true." But understanding differences in mental models can help illuminate why actors have different understandings of system interactions, why they behave differently in relation to system dynamics, and how they propose different solutions to problems they confront.
- Why are we interested in mental models in SES analysis?
    - Mental models inform individual and organizational action and behavior in relation to risk.
    - Actions and behaviors in turn modify SES system dynamics.
    - Differences in experience and understanding result in differences in ideas about solutions: this can lead to conflict.
- Return to the scenarios of Georgina, Lupe and Manuel (Introduction to the course) and their experiences with flooding and water scarcity. While we don't know what their mental models are, ask the class how you might expect their mental models to differ, and why?
    - The class would be expected to come up with ideas such as their experience with the risk is different, their access to knowledge and information is different, abundance and scarcity of water has different impacts for them, their scale/scope of understanding of the problem is different, their ability to intervene in the problem (their *agency*) is different.

DAY 3 - Mental models (2hr)

MODULE - Human agency in SES			
Learning Goal: Understand and explain the role of human agency and power in the SES			
	Learning Objectives	**Activities**	**Outcomes and Assessment**
Day 3	A. Analyze qualitative data to elicit mental models B. Compare mental models of stakeholders in Mexico City C. Explain differences in mental models, and the implications for interventions in system dynamics	A. **Break into groups**: Comparison of interpretations of interview transcripts. *What is the stakeholder's primary concern? What factors influence this concern? What does sort of interventions might the stakeholder advocate for, given their mental model?* B. **Plenary:** Facilitated discussion on relationship of mental models to stakeholder analysis from Day 1 of module. Students reflect collectively on what it might mean for the system's dynamics if a stakeholder with a specific mental model has a strong influence/importance in the system vs. one with relatively little influence/importance. C. **Break into groups:** Trace implications of stakeholders' mental models on system using the Master Model created in Module 1. *What part of the system's dynamics is most likely to concern the stakeholder? What variables is the stakeholder most likely to have influence over? If greater power were given to this stakeholder, what might be the consequences for the system?* D. **Plenary: Concluding** discussion/ Debriefing. *What insights did they gain from their discussion? How might the mental models of a specific group of stakeholders affect system dynamics? How might mental models change?*	<u>Per group</u>: • Description of mental model of stakeholder interviewed (from transcript analysis) • Master model with "pathways" traced reflecting variables potentially influenced by stakeholder

PREPARATION (see Homework for Module 2, Day 2 (in preparation for Day 3)

Each student is assigned one interview transcript of an actor in Mexico City (Student handouts, Homework in preparation for Module 2, Day 3: Interview Transcripts). These transcripts are based on real interviews; the content of the interview has been modified to ensure that identities are masked completely. Each interview is identified only by a generic descriptor: Public sector disaster manager, Urban resident, and Urban planner.

On their own time, the student will read the interview transcript and record each core concept mentioned by the interviewee as part of their vision of the water problem in Mexico City as a variable in Mental Modeler. They then illustrate the relationships among the variables as described by the interviewee by arrows. The students can test the validity of the arrow according to the interviewee's description of the relationship by "reading" the relationship, for example, between variable A and variable B as "Variable A *influences* variable B" (or a change in variable A *causes a change* in variable B).

They save their version of the mental model on their computers and will bring these to class.

CLASS PLAN

The class will begin by breaking the class into groups according to which stakeholder interview transcript they have read and analyzed independently at home. Students will discuss their analysis and interpretation of the interview transcript following guiding questions provided by the instructor (~ 15 min). They will then reconvene in plenary to participate in a discussion lead by the instructor on how their stakeholder's mental models, as elicited in the interview, differ or are the same. They situate their stakeholder in the stakeholder analysis they completed on Day 1 of the module in terms of influence and interest in the system (~ 20-30 min). The students return to small groups (of 3 or 4), this time with at least one representative of each type of stakeholder in each group. Using the Master Model of the system they prepared in Module 1, they explore the implication of each stakeholder's mental model on the system, given the stakeholder's influence/interest and how the stakeholder prioritizes issues and causal relationships in the system. Using different color pens, they will trace the likely influence of the actors' actions in the system, either through intentional or unintentional intervention (~30 min). They conclude in a plenary discussion summarizing what they learned about the possible influence of mental models on system dynamics, and the relationship of mental models to the relative power of different actors in system change (~20 min). They are assigned a Summative Assignment synthesizing all three modules as homework.

MATERIALS FOR CLASS

- "Master Model" prepared by class participants at end of Module 1 (copies for all students in course).
- Stakeholder matrix prepared in Module 2, Day 1.

OUTPUTS

- Description of mental model of stakeholder interviewed (from transcript analysis).
- Master model with "pathways" traced reflecting variables potentially influenced by stakeholder.

HOMEWORK (SUMMATIVE ASSESSMENT, MODULE 2)

Using the accumulated material of the modules, students will propose an intervention that would most likely to be associated with each stakeholder's mental model and influence. For example, a student might suggest “reforesting the watershed” as an intervention associated with a peri-urban natural resource user, or “increasing the infrastructural drainage capacity” for a water manager. They would then describe how that intervention affects the dynamics of the SES, drawing from their understanding of the stakeholder’s individual mental model, the master model, the stakeholder analysis and the background materials provided for case study. The final product will be approximately 2-3 pages of text, plus a copy of the master model tracing the influence of the different actors. Students should be instructed to draw explicitly on the interview data, the stakeholder analysis and the background material as part of their analysis.

GRADING RUBRIC

	Poorly executed	Proficient	Excellent
Analytical Content	Text demonstrates poor understanding of theory and concepts associated with mental models. Hypotheses of influence of actor over system is poorly substantiated with background materials, stakeholder analysis and/or interview data.	Text demonstrates adequate understanding of concepts, although lacking depth and analytical insight. While further support and justification for analysis of stakeholders’ influence could have been provided, the analysis demonstrates adequate understanding.	Text demonstrates mastery of concepts and theory presented on mental models, stakeholder analysis and SES dynamics. The propositions concerning stakeholder influence in the system are well-supported by the background material, stakeholder analyses and interview analysis.
Organization/ Completeness	The text is poorly written and organized; lacking synthetic vision. References to background material are not appropriately cited.	--	The text is well-written, clearly organized and demonstrating a capacity for comparison and synthesis as appropriate in the introductory and conclusion statements.

Social-Hydrological Risk in the Mexico City Basin

TEACHING NOTES

MODULE 3: VULNERABILITY, RISK AND RESILIENCE

Module 3.

TOTAL: 3 days [6 hr in class; 4 hr Study time]

The learning goal of Module 3 is to understand the causes, manifestations and interaction of differential social, ecological and infrastructural vulnerability in SES. This objective is broken down into 3 classroom sessions, assuming each class period is 2 hours.

- Explain how specific SES interactions create vulnerability in the system (Day 1)
- Create hypotheses concerning how vulnerability of one part of system affects other ele ments in system and across scales (Day 2)
- Explore how vulnerability to water scarcity and flooding are interrelated and emergent via a simple agent based model (Day 3)

Day 1. How specific SES interactions create vulnerability in the system (2hr)

MODULE 3 - VULNERABILITY, RISK AND RESILIENCE			
Learning Goal: Understand the causes, manifestations and interaction of differential social, ecological and infrastructural vulnerability in the SES.			
	Learning Objectives	**Activities**	**Outcomes and Assessment**
Day 1	Explain how specific SES interactions creat e vulnerability in the system	E. **Plenary**: Facilitated discussion about vulnerability (theoretically) and applied to Mexico City F. **Break into groups**: master model analysis G. **Plenary**: Concluding discussion/Debriefing.	<u>As a class:</u> • Vulnerability, Exposure, Sensitivity table for Mexico City <u>Per group:</u> • Insights on master model and vulnerability patterns

PREPARATION

Homework prior to class: Student will read conceptual frameworks and theory about vulnerability in addition to an article on Mexico City (see Student Handout, Preparation for Module 3, Day 1). They will annotate the Mexico City article based on what they learned in conceptual readings, and bring these notes and questions to the discussion.

CLASS PLAN

This class will begin with a lecture from the professor that traces the history of vulnerability science (see Supplemental materials: Module 3 Vulnerability Lecture slides; ~15 min) to lead into facilitated discussion that draws on the theoretical concepts in the readings (Box 3.1) (30 minutes). This leads to a plenary brainstorm to list out on a chalkboard or flipchart who in Mexico City is specifically vulnerable to what, and why (15 mins). Class break of 10 minutes suggested here.

The second hour of class break students into small groups to discuss relationships among variables that reinforce vulnerability. This requires either projecting or printing off copies students' master models for reference. Students will return to their master model. Instruct students to evaluate the variables represented in terms of vulnerability drivers and outcomes. They will answer a series of questions in the Student Handout (see Module 3, Day 1, In Class Activity 1 and 2).

For example, if the students' master models have a relationship between "groundwater pumping" and "subsidence" and "flooding" and "public health", as well as "groundwater pumping" and "water demand", the students might consider how intervening in water demand might affect vulnerability to flooding.

This small group break out should last ~30 minutes. Students return to plenary and take turns presenting major insights to the class (~15 minutes). It will be helpful to have the master models in mental modeler to display on the screen while students present their insights. Leave time at the end of class to explain the homework assignment (~5 mins).

ACTIVITIES

A. Plenary: Facilitated discussion about vulnerability (theoretically) and applied to Mexico City (45 mins for Lecture + Discussion)
B. Break into groups: master model analysis (30 mins)
C. Plenary: Concluding discussion/Debriefing. *What insights did they gain from their discussion? How might the mental models of a specific group of stakeholders affect system dynamics? Under what circumstances might the mental models held by an actor or group of actors change?* (15 mins)

MATERIALS FOR CLASS

- Lecture slides and notes to discuss vulnerability (see Supplemental Material)
- Handouts for group brainstorm activity and small group questions to reanalyze master

models (Student Handouts, In class Activities).

- Print off copies of each master model from module 1 for the small group master model discussion.

OUTPUTS

As a class:

- Table: List of key vulnerable groups with associated exposure and capacity/sensitivity variables

In small groups:

- Presentation: New questions and reflections on master model

HOMEWORK

- See preparation for Module 3, Day 2 in Student Handouts

Box 3.1 : Leading Questions for Facilitated Discussion about Vulnerability

- What do we mean by vulnerability?
- How might vulnerability of two households, *exposed* to the same threat (a flood event, for example) be different?
- Why would this be the case (i.e., differences in sensitivity to the event due to the demographic or socioeconomic attributes of the population; or differences in capacities, due to social standing, financial resources, capacity to influence system dynamics)
- What causes vulnerability? Are drivers of vulnerability always *external* (e.g., an "act of God") to a system? Or could they be internal (endogenous)? Can you think of examples? How do exogenous and endogenous factors interact to create conditions of vulnerability?
- How does vulnerability differ when we talk about people, systems, or biophysical elements in system?
- Do we mean the same thing when we say "this is a vulnerable household" as when we say "this is a vulnerable city" or "this is a vulnerable watershed"? How might the vulnerabilities of these different system elements be related?
- How might ideas about what vulnerability is or means differ among different stakeholders in the system? Why might this be the case?

An important aspect of vulnerability is individual and group perceptions about system interactions, which contribute to different mental models. These are informed by direct experience, information available to an actor, as well as the actor's scope of influence and interaction in a system (e.g., the difference between the perception of a local resident about his/her neighborhood, vs. a city manager who has information and responsibilities for an entire city).

Group Brainstorm Example Table (to summarize our understanding of vulnerability in Mexico City)

Vulnerable group	**Biophysical Exposure**	**Social Condition (Sensitivities, Capacities)**

Day 2. How vulnerability of one part of system affects other elements in system and across scales (2hr)

MODULE 3 - VULNERABILITY, RISK AND RESILIENCE			
Learning Goal: Understand the causes, manifestations and interaction of differential social, ecological and infrastructural vulnerability in SES.			
	Learning Objectives	**Activities**	**Outcomes**
Day 2	Create hypotheses concerning how vulnerability of one part of system affects other elements in system and across scales	A. **Plenary**: how is vulnerability be understood at different scales? B. Small group stakeholder analysis C. **Plenary**: Concluding discussion/Debriefing. How changes in stakeholder influence might affect the vulnerability and risk transfer hypothesis identified.	Per group: Table of stakeholder analysis and consequences of intervention

PREPARATION

Homework prior to class: Student will read one article on the hidden costs of adaptation and another on vulnerability at different scale in Norway (See Student Handout, Module 3, Day 2 Preparation). They take the concepts and analyze how vulnerability changes across scales and according to influence of different actors for Mexico City.

CLASS PLAN

This class should build on the last, which took stock of the "current" vulnerability in the system. Now, students will think through how vulnerability may change -- shifting across time and space in Mexico City -- due to the "adaptation" decisions and interventions of different actors. The beginning of class should review what students learned about vulnerability in the last class (10 min), which should lead into a discussion of the readings about how to assess vulnerability at different scales. The O'Brien article discusses the difference between vulnerability and resilience, which could be interesting discussion given that vulnerability typically refers to particular system elements and resilience attempts to capture the dynamics of interacting elements in a larger system (this could be augmented with other readings, e.g. Turner et al. 2010). Discussion should take ~30 minutes (see Box 3.2). Student needs to be clear on how one

might (theoretically) assess tradeoffs and risk transfers at the end of this discussion -- e.g. how to identify a relationship between adaption and vulnerability or risk transfer, develop a hypothesis to test this, and think through what science/data/modeling is required to test the hypothesis. Take a short break (10 min).

The second half of class students will break into small groups, each group assigned to represent a stakeholder group in Mexico City (corresponding to stakeholders assessed in Module 2). The groups will work together to propose potential interventions that would reasonably correspond to the needs, interests and priorities of the stakeholder. The groups will hypothesize the potential unintended consequences in the system of their stakeholders' interventions. Each small group will fill out a small table (See Student Handout) to organize their conversations before they come back together to share and discuss (30 min) (See Box 3.2 below). The discussion should note the different influences of each stakeholder in their current position- and consider what might happen if influence would decrease or increase among actors in Mexico City (30 mins- Box 3.3). The teacher can walk through an example of how an intervention by an actor could cause a "risk transfer" (see Box 3.4 for potential examples). It may be helpful to return to Box 3.4 when discussing the final assignment. This leaves ~10 mins to explain how to download Netlogo- and where to download the ABM for day 3.

ACTIVITIES

A. Plenary: how is vulnerability understood at different scales?
B. Small group stakeholder analysis
C. Plenary: Concluding discussion/Debriefing. How might changes in stakeholder influence affect the vulnerability and risk transfer hypothesis identified?

MATERIALS FOR CLASS

- Lecture slides and notes to review vulnerability
- Review list of stakeholders student produced in Module 2
- Handouts for actor/influence with stakeholder analysis

OUTPUTS

In small groups:

- Table on stakeholder intervention and potential consequences.

HOMEWORK

Download Netlogo (Complete Netlogo tutorial 1 online). See link and instructions in Student Handout, Module 3, Day 3 (preparation).

Box 3.2. Discussion on resilience and cross-scale vulnerability

What is vulnerable in Mexico City? (Make a list of system attributes that are vulnerable)

How does this vulnerability affect the dynamics of the city as a whole?

For example, does the vulnerability of a particular neighborhood to chronic flooding affect the vulnerability of the city? Under what conditions might the vulnerability of one element, area, or aspect of the city create conditions of vulnerability at higher/broader scales of analysis?

Does the vulnerability of the city as a whole have the same implications for all elements within the city? Why or why not?

How might interventions in one part of the system to address vulnerability to specific threats effect other parts of the system? What unintentional vulnerabilities are created? Can such unintentional vulnerabilities also be created by interventions at a particular *scale* of analysis? (E.g., interventions implemented in very specific and local contexts (e.g., local rainwater harvesting) vs. interventions intentionally designed to affect broader city dynamics (e.g., a city-wide policy))

Are there thresholds or conditions at which local processes (vulnerabilities, or responses to them) scale up to affect processes at larger scales? What might these thresholds be? (e.g., frequencies of extreme events? Proportion of population involved in implementing a "local" action? The influence of a particular actor, or the point of intervention in the system?

Box 3.3 Stakeholder Analysis and Consequences of Intervention

Stakeholder Analysis:
Divide students into stakeholder groups: 1. Delegation leaders 2. Community members 3. SEDUVI (Ministry of Housing) 4. Mexico City water authority (SACMEX) 5. Federal water authority (Conagua)

This stakeholder has capacity to implement interventions. Hypotheses: What types of vulnerability are addressed by intervention, what new vulnerabilities are created, what vulnerabilities might be transferred to other populations, parts of system, other places in city, or future states of system? How certain are you that this might happen? What evidence would you use to support or claim or test this hypothesis?

EXAMPLE
ACTOR: City water authorities
INFLUENCE: Controls infrastructure development and water allocation to each delegation.

PROBLEM	**Intervention**	**Adaptation/Mitigation**	**New Vulnerability**	**Evidence to test the relationship**

Stakeholder and Influence Discussion
What unintended consequences might occur when trying to solve one water issue Mexico City? How would you test this (what evidence would you need to gather to support your hypothesis?
Discuss different stakeholders influence and capacity may define vulnerability. What if influences of actors in the system change?

Optional/More advanced
Do you see a difference in how a risk transfer happens over space, across systems, or over time? Which one would be the most difficult to monitor or predict? See Box 4 for some examples of how a proposed intervention may mitigate risk in one part of Mexico City's water system at the expense of causing a new problem elsewhere.

Box 3.4. Examples of Risk/Vulnerability Transfers in Mexico City
Student may have identified these already, but the teacher may use some of these as an example to spur discussion about intervention, or to give students ideas to write about for the policy brief for day 3.
Part of the issue with the Basin of Mexico's water dynamics in its current (very deep) basin of attraction is the fundamental nature of its "wicked" problem. There are no solutions/panaceas- there are only transfers and tradeoffs. Increasing robustness at one scale by solving part of the problem may increase vulnerability elsewhere. Most of these are not considered or not governed. A few examples- most of which have some study, data, or empirical evidence that could be used to document these relationships.

1. Decreasing flooding in Mexico City, increases floods in the state of Hidalgo, which receives Mexico's waste water
Problem: Capacity of drainage network
Solution: Build a new tunnel to increase the ability to evacuate water from the city by 100%
Transfer: Flood vulnerability transfers spatially from D.F to Hidalgo. (this is governed somewhat by the National Water Commission that is trying to build flood infrastructure to prevent flooding in Hidalgo).

2. Increase water supply in one section of the city, increases subsidence in the Valley as a whole and thus risk of flooding
Problem: Lack of water supply and pressure in some neighborhoods
Solution: continue to pump water from the basin's aquifer
Transfer: Water supply vulnerability decreases and transfers to the cost of subsidence, which must now be covered by the public sector. Over the longer term, subsidence increases risk of flooding.

3. Increase water supply through inter-basin transfers
Problem: Lack of water supply and pressure in some parts of the city
Solution: bring water to the city from other basins
Transfer: Water supply vulnerability decreases in Mexico City but may affect water supply and environmental flows in another basin

4. Solve the housing crisis by increasing # of houses units through densification or expansion
Problem: Need for urban expansion due to growing population. Densification is more expensive.
Solution: Either increase densification, or let city expand onto conservation land or farmland
Transfer: Housing problem decreases in Mexico City but new risks are transferred to the lower parts of the city as flood risk increases with urbanization on watershed, and/or subsidence increases due to increase in water supply needs.

Day 3. Explore emergent vulnerability in an Agent-Based Model (2hr)

MODULE 3 - VULNERABILITY, RISK AND RESILIENCE			
Learning Goal: Understand the causes, manifestations and interaction of differential social, ecological and infrastructural vulnerability in SES.			
	Learning Objectives	**Activities**	**Outcomes**
Day 3	Explore how vulnerability to water scarcity and flooding are interrelated and impacted by interventions via a simple agent based model	A. **Lecture**, intro to ABM B. Individual, partner, or group **exploration** of ABM C. **Plenary**: discussion/Debriefing. How did different interventions affect the system according to the ABM? How could the model be extended to text new hypotheses?	A. In pairs or groups: learn how to run and record observations form an ABM B. As a class: Insights on how decisions impact vulnerability, and how hypotheses can be formed and tested in an ABM. C. Final Summative Assessment assigned

PREPARATION

Homework prior to class: Student will download Netlogo and complete one tutorial. They will also read about the model they will use in class (The ODD), and one conceptual article that describes and defines Agent Based Modeling.

CLASS PLAN

This class will focus on one method that can be used to test hypothesis in emergent vulnerability and risk transfers: Agent-based Modeling. The class will begin with an introduction to what agent based modeling is, and how it could be applied to understand cross scale vulnerability (30 mins, see Box 3.5). It is optional to have student open Netlogo and play with a model at the end of this lecture to get a feel for what NetLogo is and does BEFORE launching

into the example ABM for the case. Note that this could add an additional 10-20 minutes! We suggest the Schelling Model (segregation, indications on slide 26).

The second and longest portion of the class focuses on students using an example model built for this case by Beth Tellman (Risk Transfer Model, Mexico, by Beth Tellman, as part of the NSF MEGADAPT project; see acknowledgement on Case Study title page) with free Netlogo software. Students will use the model to systematically explore how different interventions influences the number of people exposed to water scarcity and /or flooding (60 min). Start by discussing what the model is and does from the ODD and slides 38-40). Walking through the flow chart on page 40 is helpful. The ABM author (Beth Tellman- btellman@asu.edu) is available to Skype in for a class discussion if desired!

This can be done in partners, in groups, or students can do it alone. There are 7 possible interventions in the ABM, with each taking about 40 minutes to run. We recommend having each student or student group pick ONE intervention to run for a specified time set by the teacher- could be between 10-30 minutes- (see Student Handouts, Module 3, Day 3, for instructions). Each student should run a different "intervention". Note that students should all try to stop their model at the sample number of ticks. We found it useful to have students report their results on slide 42 to compare. In about 10 minutes, most models will only be able to run through 600 ticks. Make sure students understand how to read data from the plots of the Netlogo model so they can record results before you have them start simulations.

The teacher should be available in case students have questions about the model from reading the ODD (Overview, design concepts, and details) for their homework. While the model is running, students will discuss and fill out worksheets. If there are time constraints, have them concentrate on just a few outputs (e.g. infrastructure) rather than all of them. Ask the students: What do you think might happen with each intervention? (see Box 3.5).

Students should record notes on how different interventions affects the system, and what they observe. While they are waiting for model runs to finish, they will be given a white paper that analyzes all 7 results of the government interventions. They will read and discuss p 7-17 together, and fill out a series of questions on the student handout. The discussion (20 min) after model runs are complete should use insights gained in working with the model to begin brainstorming about policy intervention for the summative assessment. Leave 10 minutes at the end of class to discuss the final summative assessment.

ACTIVITIES

A. Lecture, intro to ABM (slides 1-35)

B. Individual, partner, or group exploration of ABM with worksheet (use slides 38-42)
C. Plenary: discussion/Debriefing. *How did different intervention affect the system according to the ABM?* (use slides 42-52)

MATERIALS FOR CLASS

- Lecture notes to introduce ABM (see ABMrisktransferlecture.ppt)
- Running copy of model to show students how it works (go to https://www.openabm.org/model/4907/version/1/view)
- White paper on model results and ODD description of the model (https://www.openabm.org/model/4907/version/1/view download risktransferresults.pdf and risktransferODDv1.pdf
- Final assignment to discuss at end of class

HOMEWORK

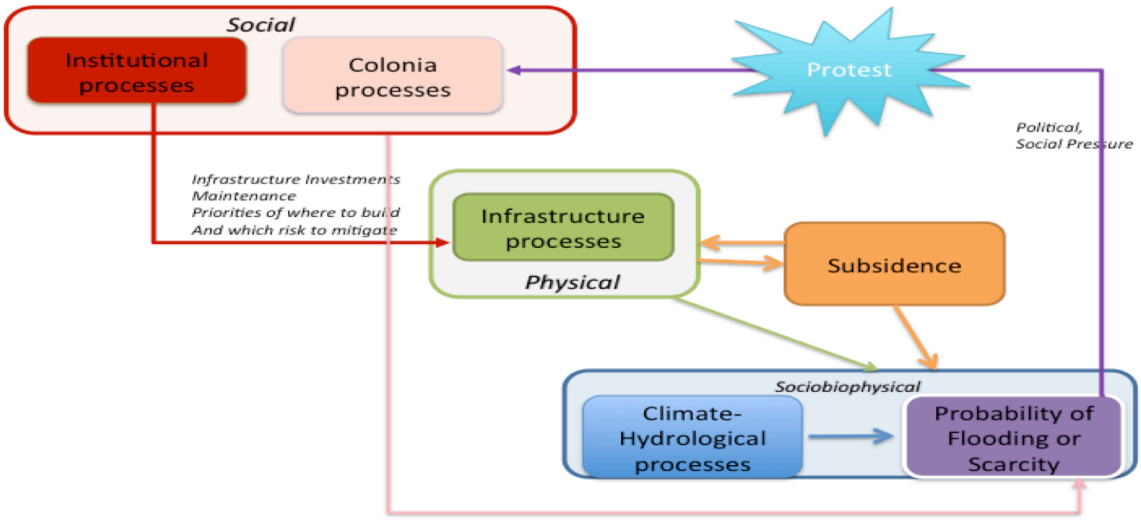
- Students will write a policy brief as a final summative assessment of not only this module but of the entire case. See Student Handout for the Summative Assignment and associated Rubric.

Box 3.5 Agent based model discussion

The ABM (below) contains a small number of biophysical variables, precipitation and subsidence that represent conditions of Mexico City. The model simulates connections between government intervention, *colonias*/neighborhoods, and the biophysical system. This model shows in in particular how water demands influence the groundwater dynamics from water extraction that influences both subsidence and flooding.

Which of the parts of system (according to master model or can refer back to student's group models) are well represented in the ABM (below)? Which are over simplified?

Do you agree with the author's conclusions on page 16/17 of the model analysis? Did the ABM answer the questions hypothesized on page 3? What hypotheses do you have about Mexico City you think an ABM could help answer? What data and new submodels might be required to answer that question?



APPENDIX

Suggestions for adapting the case to a shorter time frame (6 days).

For students who have already had significant exposure to the concepts and ideas of complex adaptive systems, resilience thinking, or social-ecological system frameworks, the case could be accelerated. One possible structure would be the following:

Revised Module 1: 2 days

Revised Day 1: Have the students prepare for the first class by reading the articles included in preparation for Day 2 (i.e., Carrera-Hernández 2006; Tortajada and Castelán 2003; or Izazola 2009). Follow the instructions for Module 1, Day 1, but eliminate the mini lectures on social-ecological systems and system diagramming (assuming this knowledge already exists). Facilitate a discussion, following the presentation of the videos and introductory vignettes, about how Mexico City's water issue is exemplary of a complex social-ecological system and "wicked" problem. Emphasize *feedbacks (positive and negative)* and how feedbacks relate to maintaining or disrupting system states. Break the students into groups to list variables and to position these variables in Mental Modeler. Assign the "jigsaw" homework (Student Handout, Module 1, Day 2) as homework for Day 1.

Revised Day 2: Students meet in groups to discuss their research findings and to revise their "master models" as described in the class plan for Day 3. Assign summative assignment as homework for Day 2, emphasizing the need to explain and consider cross-scale (temporal and spatial) dynamics and the implication for decision-making.

Revised Module 2: 2 days

Revised Day 1: As described in Module 2, Day 1.

Revised Day 2: Request that students prepare for the day by reading Jones et al and Cone and Winters, as describe in the Teaching Notes, as well as one of the three interview transcripts (included in the Student Handouts as homework for Day 2). Run facilitated discussion/lecture on mental models and their elicitation, as described (20 min). Skip the process of designing interview questions and practice interviewing. Break into groups of two, organized by which interview transcripts a student has read. Have the student groups diagram the mental model of the interviewee based on the transcript (~ 20-30 min). Conduct plenary discussion on differences in the mental models and how the actors might be situated in a stakeholder matrix (as described in Day 3). Reserve time to explain the summative assessment described at the end of Day 3. Provide an concrete example of "tracing" the influence of an actor in one of the students' existing master models to facilitate the homework process.

Revised Module 3: 2 days

Revised Day 1: Conduct as described, however on the basis that students have had some introduction to vulnerability, include the readings from Day 2. Include in the introductory statements and discussion on vulnerability the idea that vulnerability and interventions to address vulnerability could imply tradeoffs across scale and space (20 min). Spend 30 minutes in break out groups diagnosing the drivers of vulnerability for different system actors/elements as described in Day 1. Reconvene, and request that students now undertake the exercise described in Day 2 (Stakeholder analysis and consequences of interventions) (30 minutes). Reconvene for 30 minutes of discussion of cross-scale consequences and tradeoffs in vulnerability interventions in a complex system, and how the position (influence) of actors in the system may affect such tradeoffs.

Revised Day 2: Conduct as described for Day 3.