An aerial photograph of a city, likely Phoenix, Arizona, showing a dense urban landscape with various buildings, roads, and green spaces. The image is overlaid with a dark, semi-transparent rectangular box that contains white text. The sky is filled with soft, white clouds, and the overall lighting is bright, suggesting a clear day.

Infrastructure Risk and Resilience in an Era of Uncertainty and Non-Stationarity

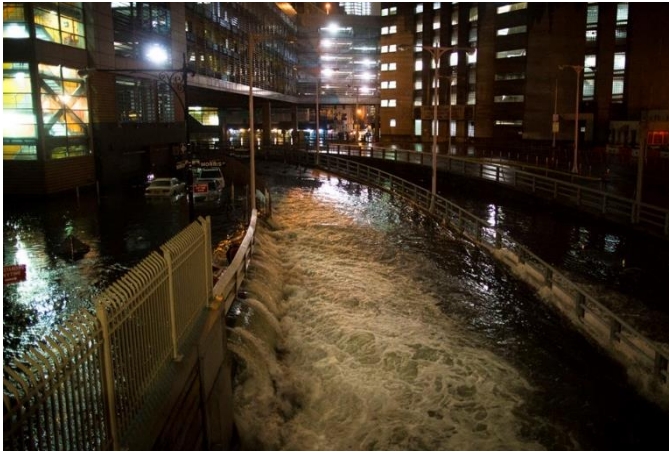
**Symposium on Sustainable Infrastructure
April 5, 2019**

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Collaborators: Mikhail V. Chester, Daniel A. Eisenberg, David M. Iwaniec, Benjamin L. Ruddell, Cliff I. Davidson, Rae Zimmerman, Thaddeus R. Miller, Heejun Chang, Christopher Hoehne, Andrew Fraser, Erica Gilrein, Thomaz Carvalhaes, Brad Allenby, and B. Shane Underwood

Motivation

Hurricane Sandy, 2012



I-10 Flood in Phoenix, 2014



I-10 Washout in California, 2015



2017 Hurricane Season



Tidal Flooding Miami Beach, Ongoing



2018 CA Wildfires



Direct and Indirect Pathways of Disruption

Flint Water Crisis, 2014 -



Supply
Water

Capacity

DIRECT

Recurring Flooding in Houston



Loss of

City, 2012

(Markolf et al., 2019)

PHYSICAL

Atlanta Snowstorm, 2014

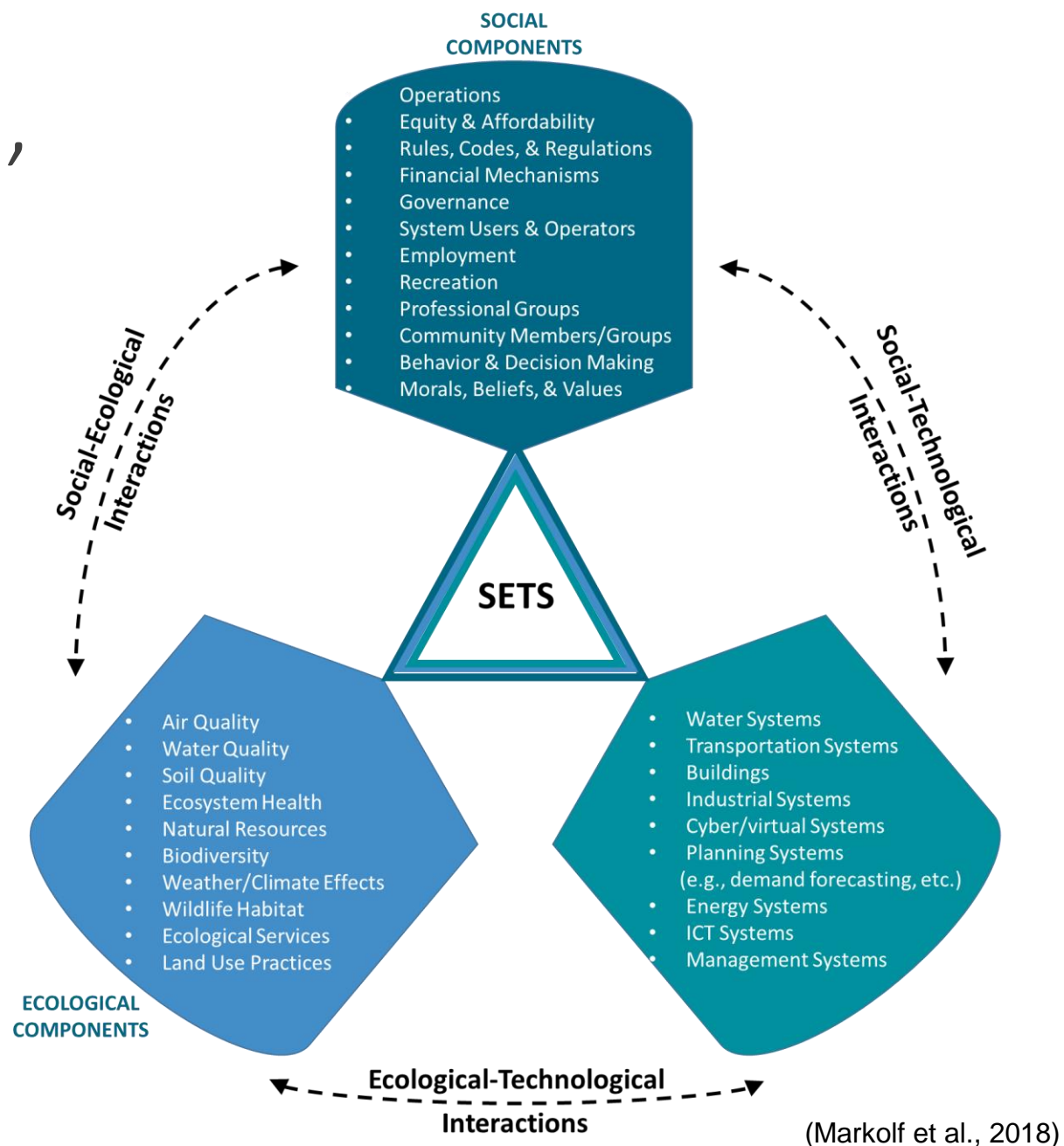


INDIRECT

NON-PHYSICAL

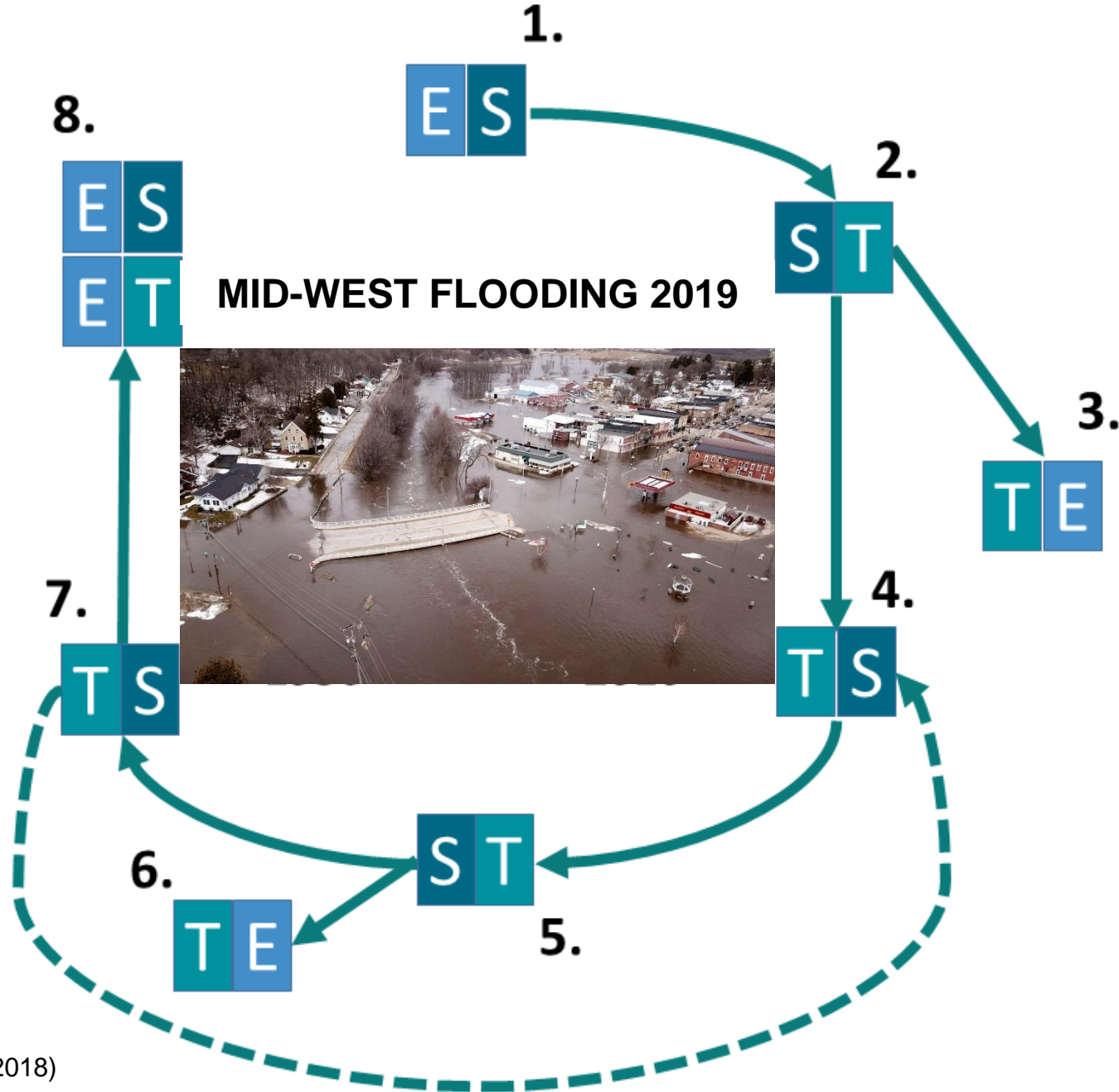
SETS as a lens for identifying 'lock-in' and analyzing 'logical' interdependencies

Lock-in – Constraints on infrastructure today as a result of past decisions and actions – even in light of new operating conditions or alternatives



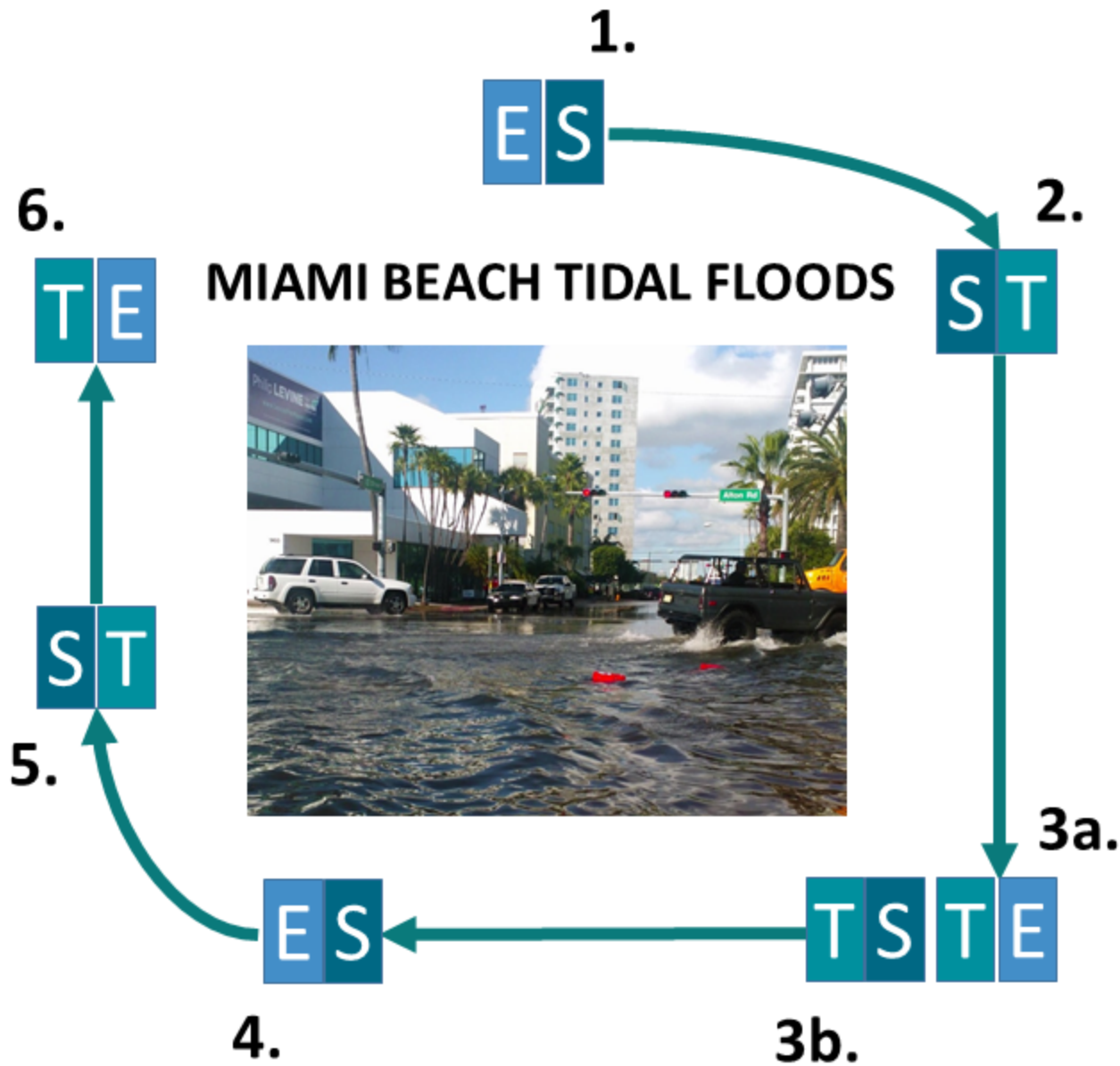
(Markolf et al., 2018)

	PHYSICAL	
<u>Direct Physical</u>	<u>Indirect Physical</u>	
		INDIRECT
<u>Direct Non-Physical</u>	<u>Indirect Non-Physical</u>	
		NON-PHYSICAL



1. Unpredictability/variation in river leads to desire to intervene/"control"
2. Dams, levees, locks, etc. are installed to create more "control"/predictability
3. Dams, levees, locks, etc. lead to altered ecosystems
4. Dams, levees, locks, etc. lead to increased perception/assumption of "control"/predictability
5. Increased perception of "control" leads to more growth/development coupled with increased fortification
6. Additional development further alters ecosystems
7. Re-fortification leads to increased perception of "control"
8. Ecosystem variation & tendency to return to 'steady state' results in potential major disruption

(Markolf et al., 2018)



1. Sea level rise contributes to more frequent and troublesome tidal flooding
2. Concerns over King Tide flooding lead to elevation of certain roadways and installation of pumping stations
3. A) Untreated water from pumping stations has negative effects on water quality in Biscayne Bay
B) Elevated roadways contribute to increased flooding at commercial properties during precipitation events
4. Importance of Biscayne Bay to tourism/local economy leads to concerns over water quality
5. Social importance of clean water in Biscayne Bay leads to retrofitting of pumping stations with water filtration systems
6. Installation of water treatment systems helps address water quality concerns

(Markolf et al., 2018)

Evolving Direct and Indirect Pathways of Disruption

DIRECT



PHYSICAL



curtailed due to water temp/availability

INDIRECT

rd
w is

Washington Post
Emergency Dies in Darkness

our rainstorm in two
years engulfed Ellicott City. Here's how it happened.

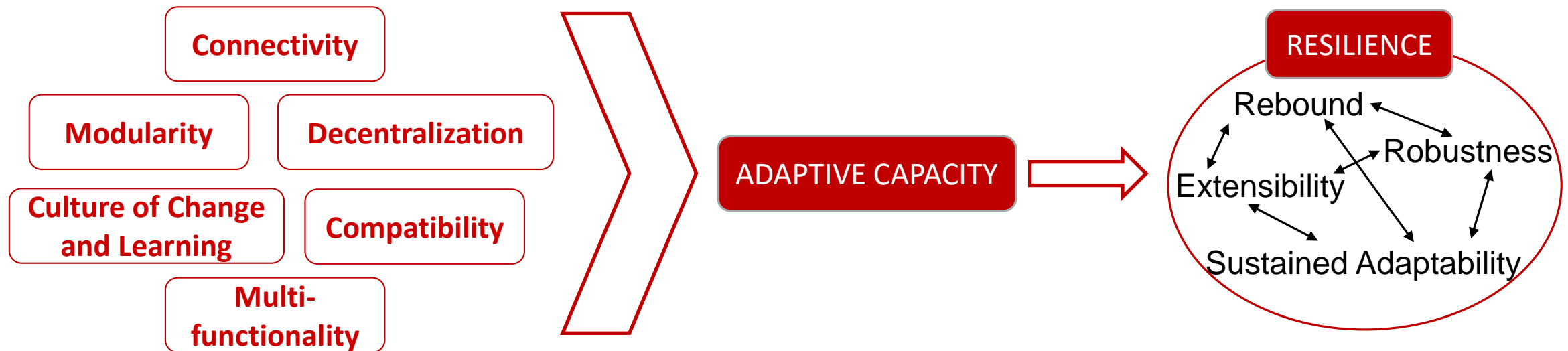
gnaling

NON-PHYSICAL

(Markolf et al., 2019)

Conclusions

- Protecting one infrastructure sector without considering its interactions with other systems can result in unaddressed vulnerabilities
 - Moving forward, indirect and non-physical pathways also warrant consideration/analysis
- How we traditionally protect infrastructure may be insufficient for the future
 - Issues like climate non-stationarity, complex & interconnected systems, and human behavior & decision making can limit the effectiveness of robustness



(Bernardes & Hanna, 2009; Richards, 1996; Chester & Allenby, 2017; Woods, 2015; Seager et al., 2017)

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