IMPACTS ON CIVIL INFRASTRUCTURE

Climate Change Risks on Roads, Bridges and Urban Drainage

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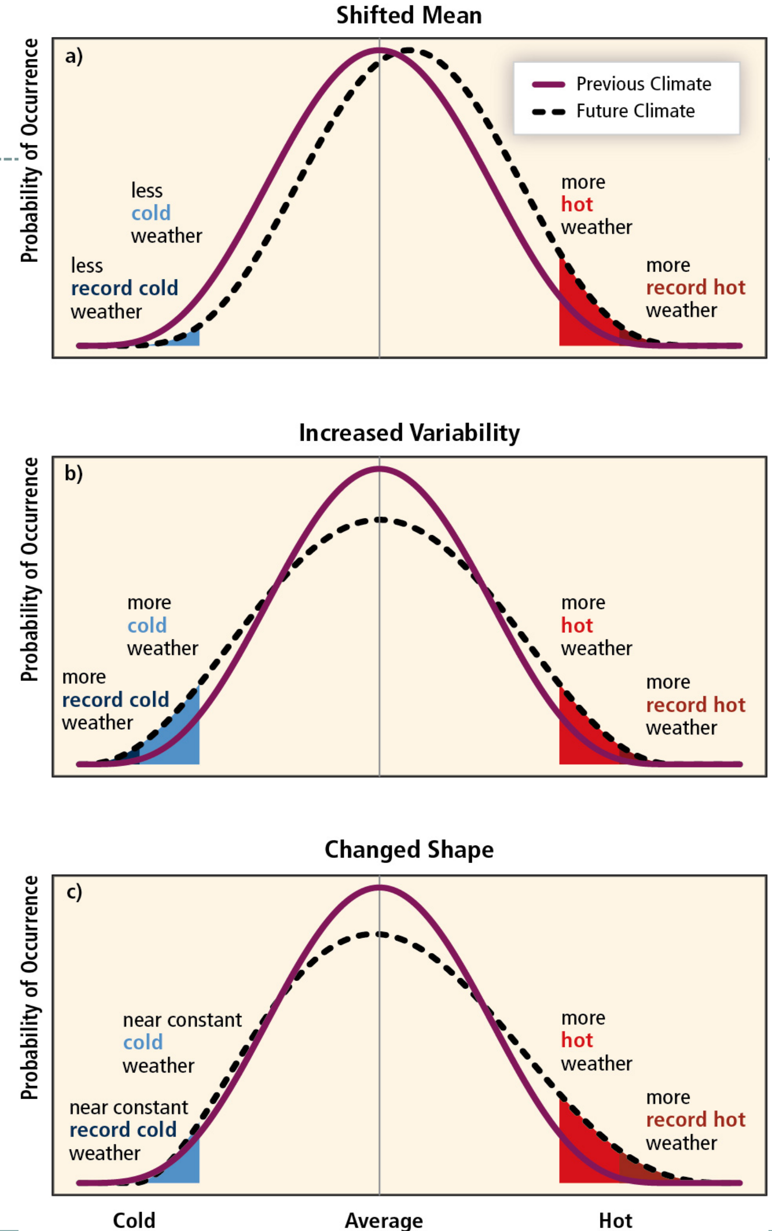
MIT JOINT PROGRAM
SCIENCE POLICY
GLOBAL CHANGE

Why Talk about Infrastructure in a Water Session?

Sector	Sample impacts
Water	• Systems stressed by flooding • Supply risks for water users
Property	• Damage and destruction of property by flood, bushfire • Degradation of foundations • Impaired health and productivity
Electricity	• Damage from flood/fire • Strain/collapse in heatwaves • Impaired health and productivity
Road + Rail	• Flood-induced washouts • Heat induced rail buckling, road cracking • Impaired transportation of people and goods

- **Infrastructure is designed to risk-based standards.**
- **Vulnerable to changes in Extreme Events:**
  - **Temperature,**
  - **Precipitation**
  - **Flooding**

Climate Change is Impacting the Risk of Crossing Design Threshold



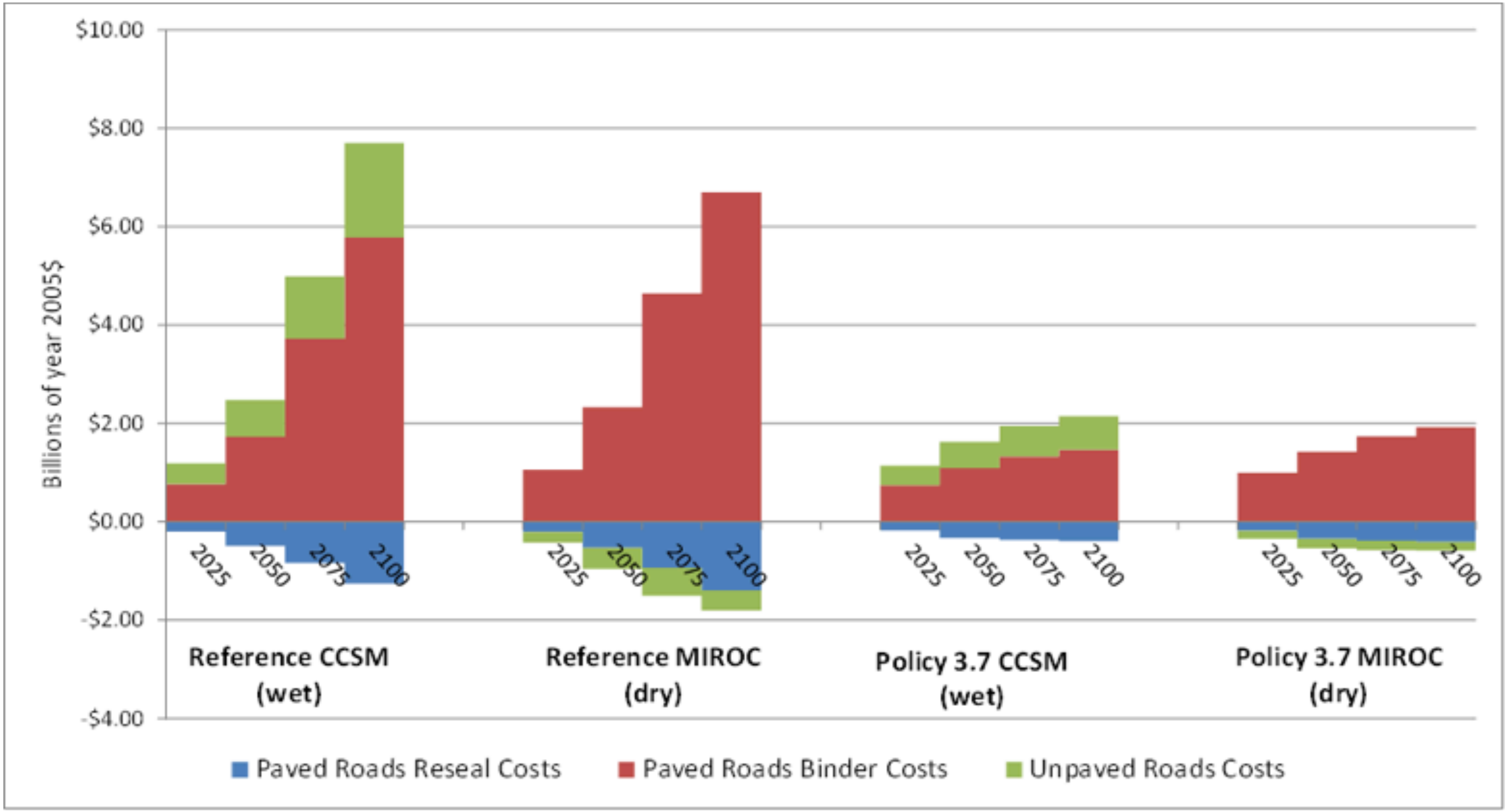
Temperature Impact on Pavement

CLIMATE CHANGE IMPACT ON PAVEMENT

Table 1. Superpave binder performance grades and Costs

Performance Grade	7-day Maximum Pavement Temperature (˚C)	Cost (year 2010$ per lane mile)
PG-46	46	$197,000
PG-52	52	$210,000
PG-58	58	$225,000
PG-64	64	$241,000
PG-70	70	$258,000
PG-76	76	$276,000
PG-82	82	$295,000

USA ROAD ADAPTATION COSTS

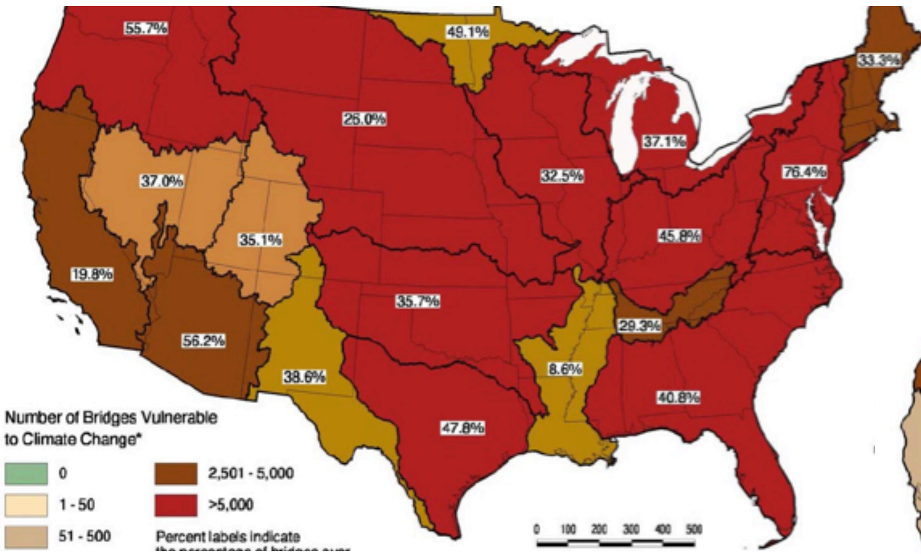


BRIDGES

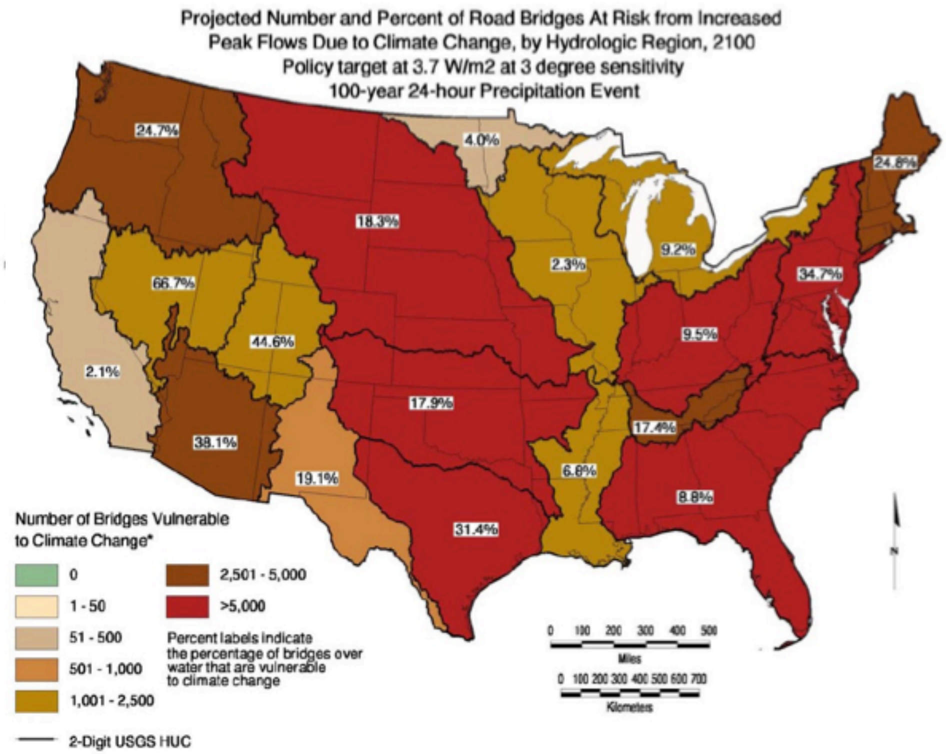

BRIDGE WASHED-OUT
PARKER
Arizona
California
QUARTZSITE
62
95
10
111
86
78
95
RIGHT NOW
I-10 BRIDGE WASHED OUT IN CALIFORNIA
ALTERNATE ROUTES BETWEEN PHOENIX & LOS ANGELES
ABC15 ARIZONA
abc 15
ARIZONA
11:05 90°

Bridges Vulnerable to Changes in 100 year-24 hours storm

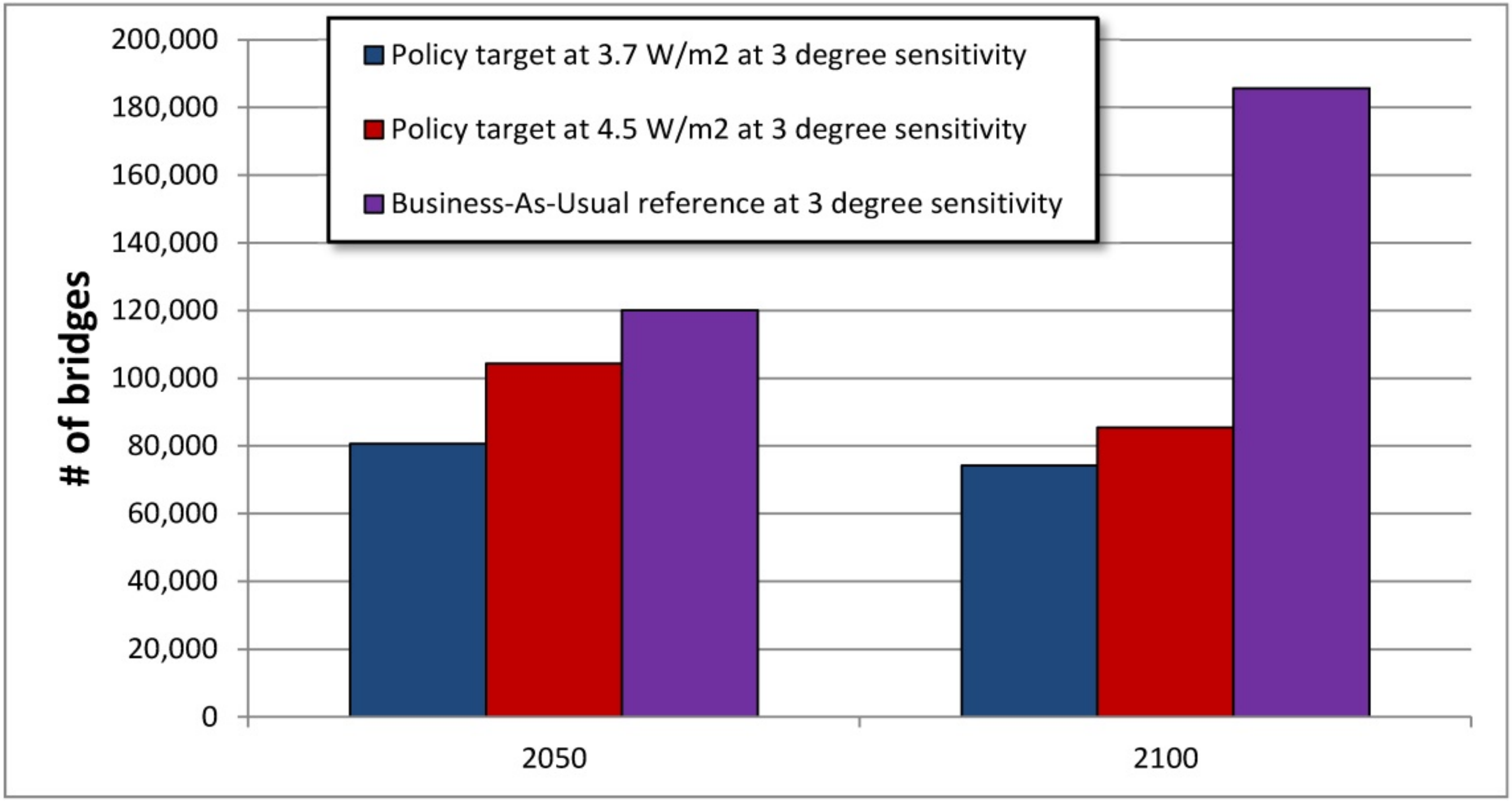
BAU



RCP- 3.7



Bridges Vulnerable to Changes in 100 year-24 hours storm



Urban Drainage Impacts

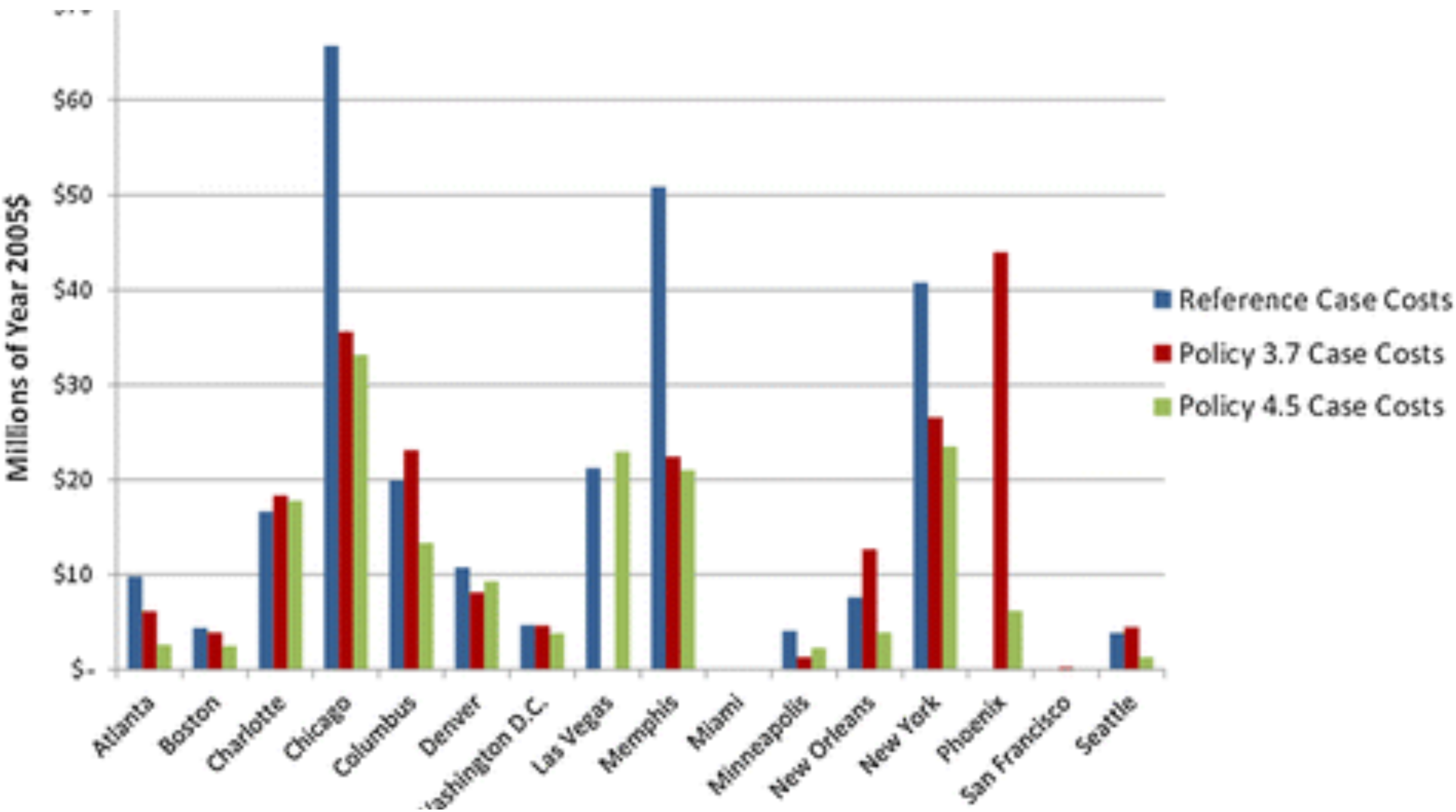
TABLE 1. CITIES INCLUDED IN URBAN DRAINAGE ANALYSIS

CITY	LAND AREA (SQUARE MILES)
Atlanta, GA	132
Boston, MA	48
Charlotte, NC	242
Chicago, IL	227
Columbus, OH	210
Denver, CO	153
Houston, TX	579
Las Vegas, NV	113
Los Angeles, CA	469
Memphis, TN	279
Miami, FL	36
Minneapolis, MN	55
New Orleans, LA	181
New York, NY	303
Oklahoma City, OK	607
Phoenix, AZ	475
San Francisco, CA	47
Seattle, WA	84
Washington, D.C.	61

Flood in Oklahoma City, Oklahoma, May 23, 2015
(Photo by Jim Beckel / The Oklahoman)

Memorial Drive Flooded in Houston, TX, May 26, 2015
(Photos by Cody Duty / Houston Chronicle)

Annualized urban drainage adaptation costs by city and scenario in 2050 (millions 2005$)



USA[1] ECONOMIC IMPACTS

Table 1 Summary of cumulative undiscounted and discounted (3 %) economic impacts through 2100 for reference and policy scenarios based on IGSM-CAM climate projections and 3.0 °C climate sensitivity (billions of 2005$) Undiscounted

Infrastructure sector		Impacts			Avoided costs		Notes
		Reference	Policy 3.7	Policy 4.5	Policy 3.7	Policy 4.5	
Coastal	Undiscounted	$451	$383	$394	$68	$57	Most avoided costs incurred after 2050, excludes storm surge
	Discounted (3 %)	$116	$110	$111	$6	$5	
Roads	Undiscounted	$376	$134	$163	$241	$213	Includes effects to paved and unpaved roads
	Discounted (3 %)	$80	$36	$45	$44	$34	
Bridges	Undiscounted	$356	$237	$279	$120	$77	Most avoided costs incurred before 2050
	Discounted (3 %)	$160	$126	$137	$33	$23	
Urban Drainage	Undiscounted	$79	$44	$51	$34	$28	Based on generic modeling in 19 US cities
	Discounted (3 %)	$20	$12	$14	$8	$7	
TOTAL (undiscounted)					$463	$375	
TOTAL (discounted 3 %)					$92	$69	

Mitigation policies show potential to reduce impacts in the infrastructure sector – a more aggressive mitigation policy RCP 3.7 reduces impacts by 25 to 35 %, and a less aggressive policy RCP 4.5 reduces impacts by 19 to 30 %.

[1] The contiguous lower 48 states

THE WORLD BANK
IBRD • IDA

IEc
INDUSTRIAL ECONOMICS, INCORPORATED

United Nations
Economic Commission for Africa

Enhancing the Climate Resilience of African Infrastructure

ROAD NETWORK

afd AGENCE FRANÇAISE DE DÉVELOPPEMENT

BANK-NETHERLANDS BNPP PARTNERSHIP PROGRAM

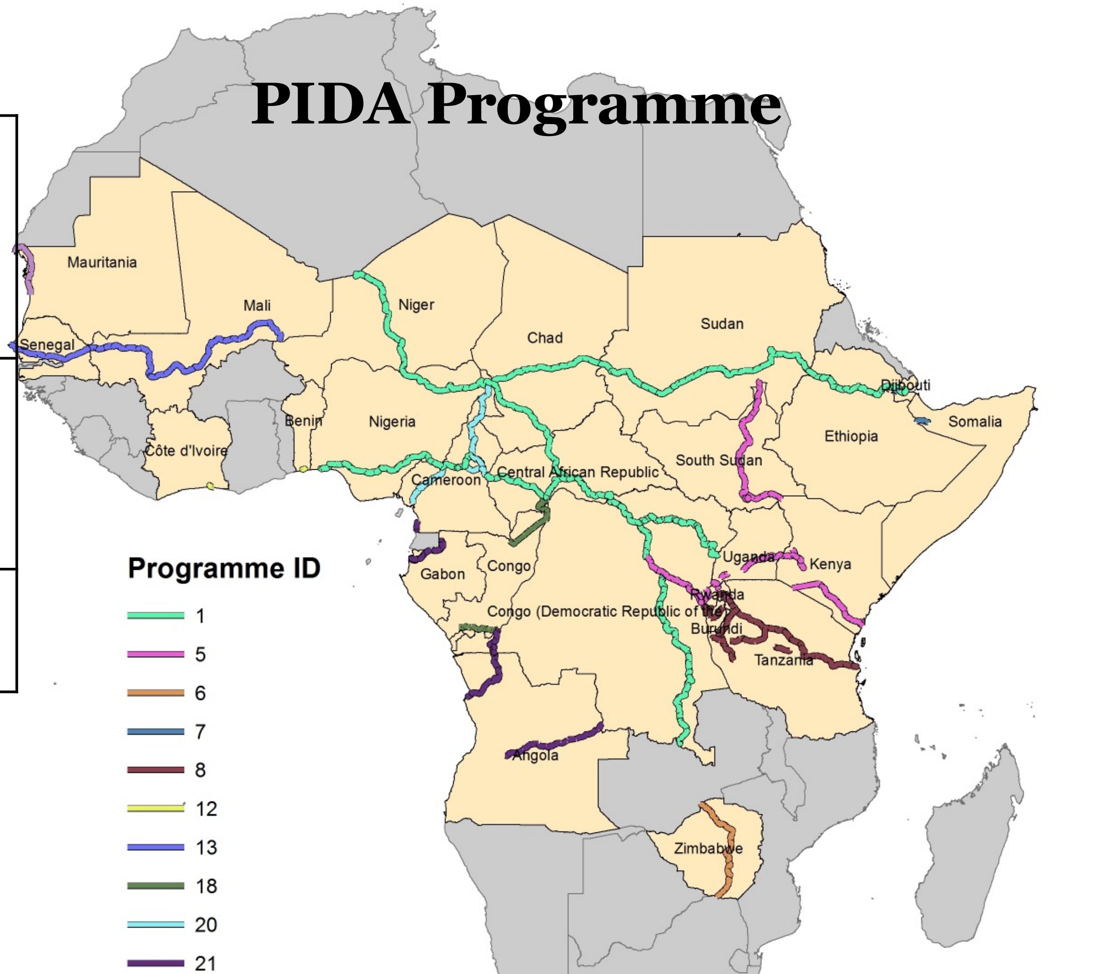
NDF Nordic Development Fund

kfw BANKENGRUPPE

UKaid from the British people

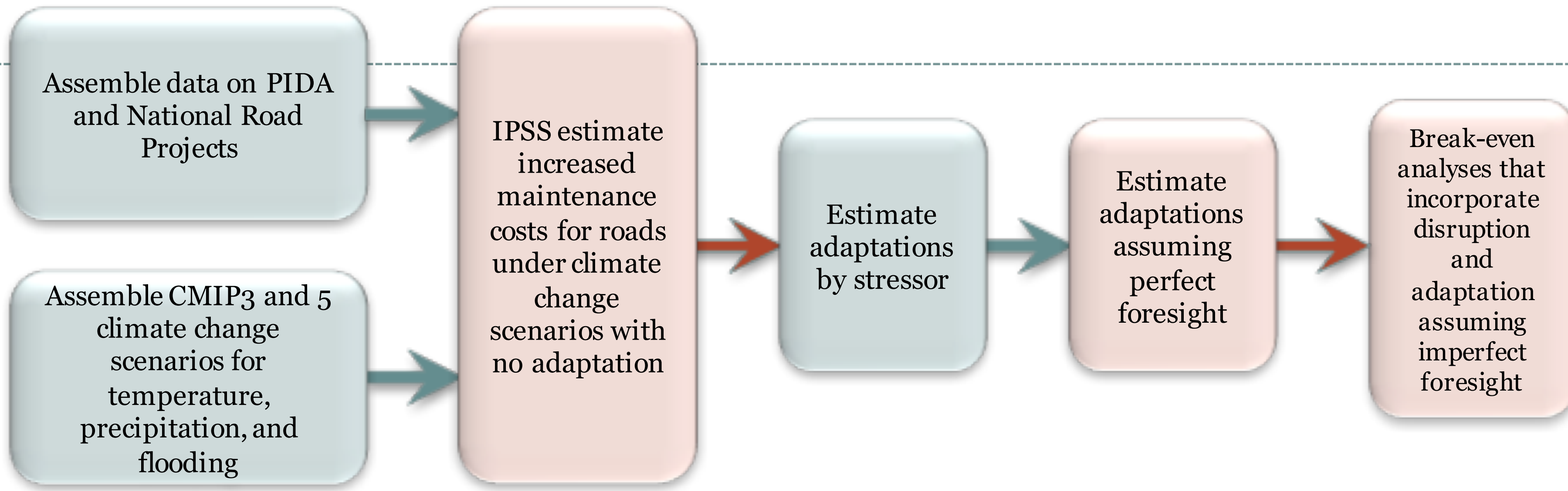
Scope of analysis

Roads in SSA analyzed Million KM	2.4
Country National Investment Plans	49
# of PIDA Programs	11



1. Estimate the **impacts** of climate change on the performance of PIDA and national (country) road investments over a range of climate scenarios
2. Develop and test a **framework** for the planning and design of **adaptation** road investments over a range of climate scenarios
3. Enhance the "**investment readiness**" of African countries to use climate finance to increase climate resilience of road infrastructure

Methodology



- Historical climate sequences: Princeton University gridded data, 0.5 degree resolution, 1948 to 2008 period
- Future climate projections (daily output, 0.5 degree resolution 2001 to 2050):
  - BCSD downscaling method
    - IPCC AR4: 22 GCMs, A2, B1, A1B (56 futures)
    - IPCC AR5: 11 GCMs, 4.5 & 8.5 RCP scenarios (39 futures)

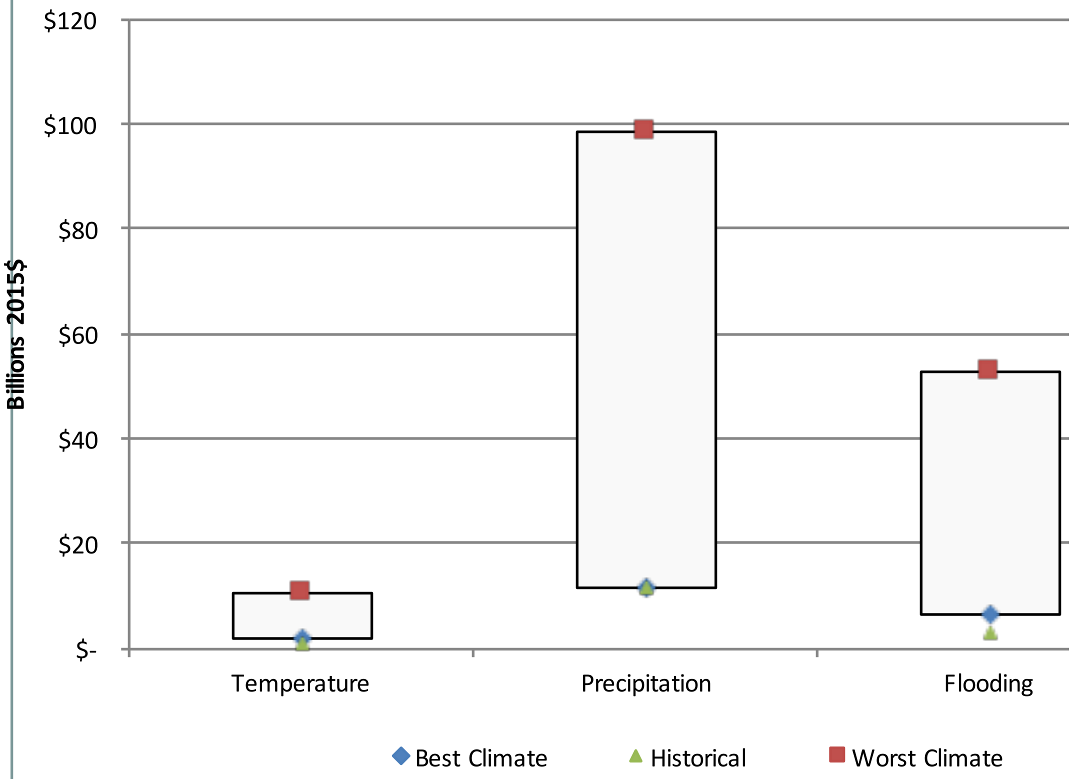
Engineering Impact Analysis

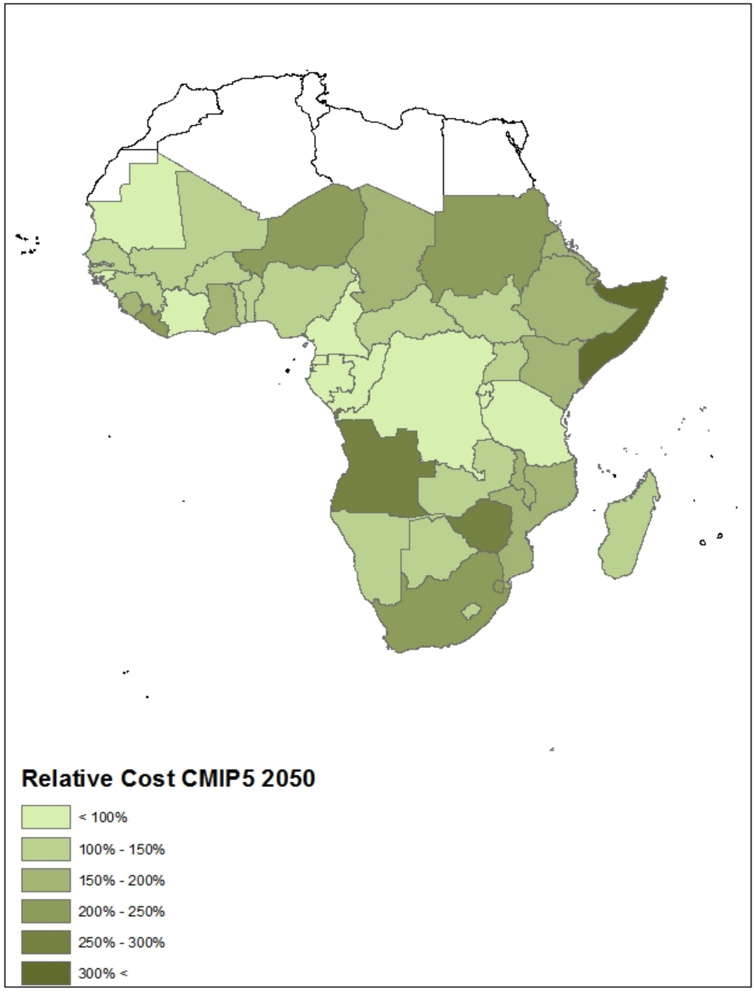
- Temperature
  - Paved Roads – Temperature exceeding pavement thresholds
- Precipitation
  - Paved Roads – Maximum Monthly Precipitation exceeds threshold
- Flooding
  - Damage incurred by floods with return periods exceeding design threshold
- Looking at Maintenance Impacts on a Yearly Basis
  - Assume Maintenance is completed in that year
  - No other adaptations are put in place for vulnerability assessment

Percentage Increase in Road Maintenance Cost from CC Relative to Historic

Reactive response costs for the PIDA+ network, 2015-50

(Present value, 6% discount rate)





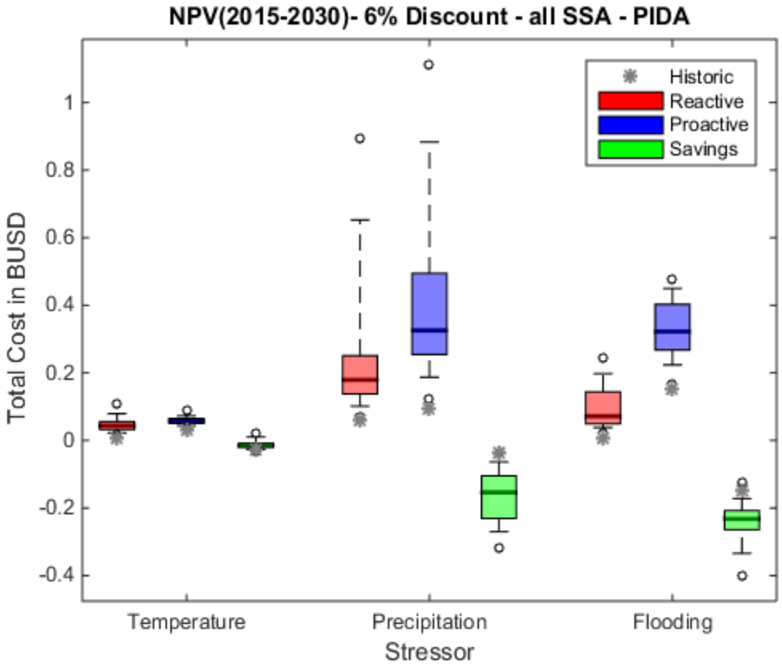
Adaptation Options

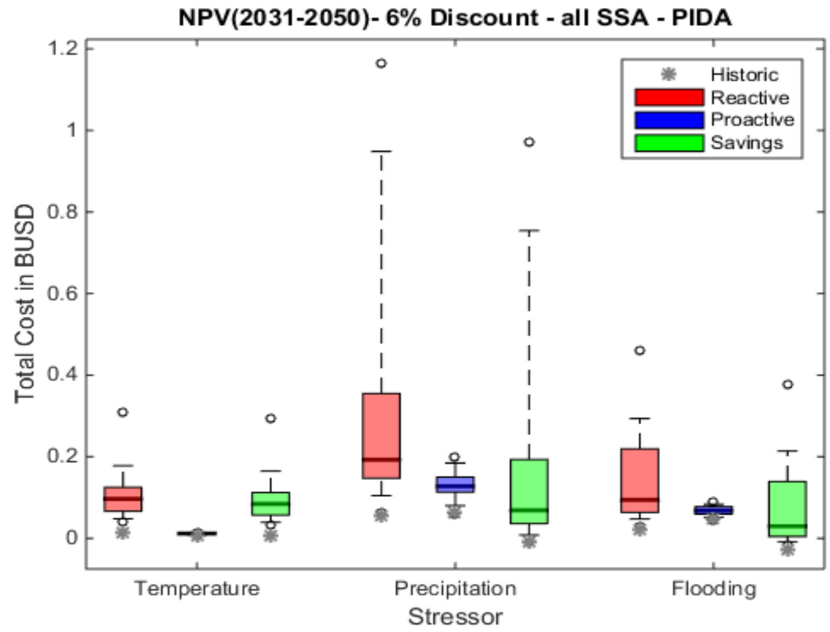
- Temperature
  - Dense seals to reduce binder aging
  - Bitumen binders with higher softening points
- Precipitation
  - Wider paved shoulders
  - Increased base thickness or quality
- Flooding
  - Increased culvert size

Adaptation Costs

Stressor	Adaptation	Adaptation Relative Cost Factor (Primary Roads)	Adaptation Relative Cost Factor (Secondary Roads)
Temperature	Construct Dense Seals	1.02	1.02
Temperature	Modify Base Binders (higher softening point)	1.02	1.02
Precipitation	Increase Base Strength	1.23	1.11
Precipitation	Add Wider Paved Shoulders	1.16	1.34
Flooding	Enhance Culverts and Drainage	1.17	1.08
Flooding (bridges)	Divert water from bridge base (minor) Strengthen bridge piers and abutments (major)	Varies by bridge size and flood severity	

The financial case for adaptation varies by time period



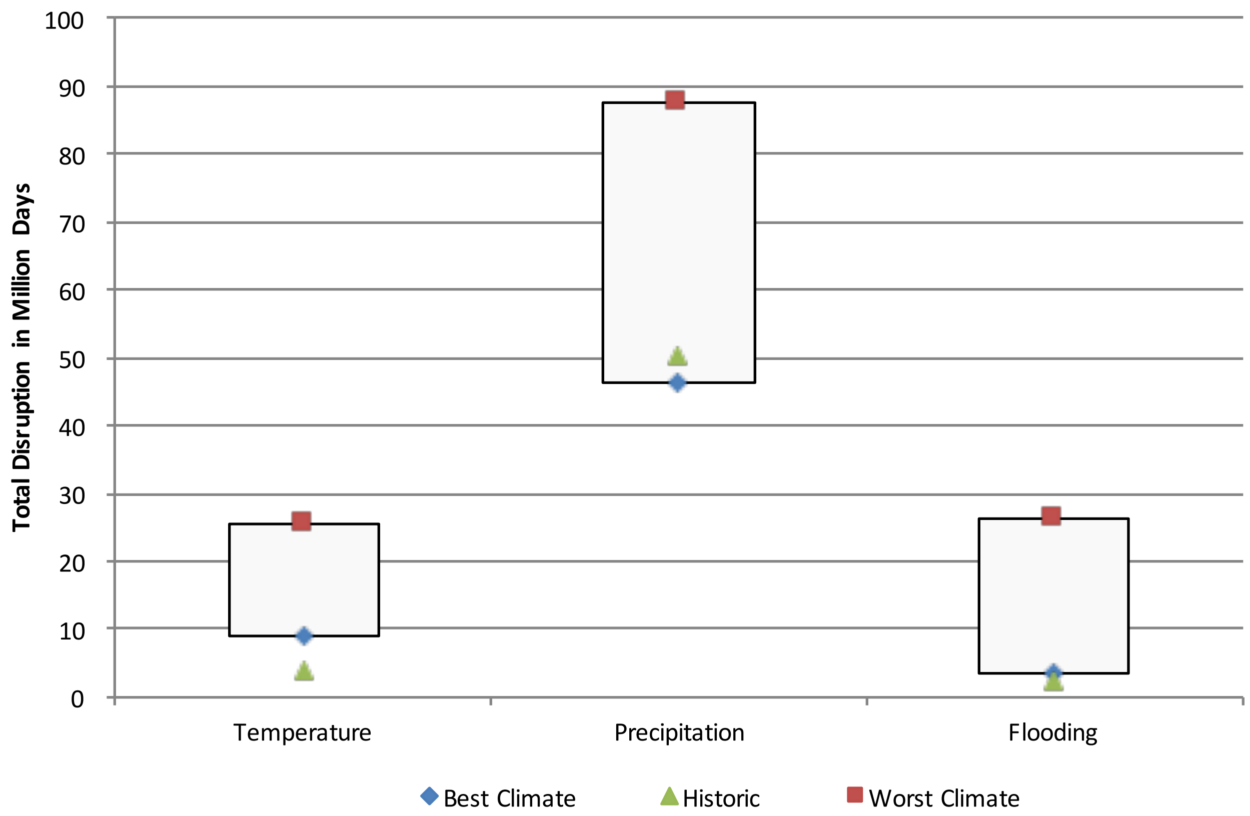


Share of road network for which adaptation generates net life-time savings

Plan type	Road type	2015-2030			2031-2050		
		Flooding	Precipitation	Temperature	Flooding	Precipitation	Temperature
PIDA	Paved	40%	0%	0%	44%	43%	65%
PIDA+	Paved	0%	0%	0%	0%	1%	20%
	Unpaved	2%	2%		2%	2%	

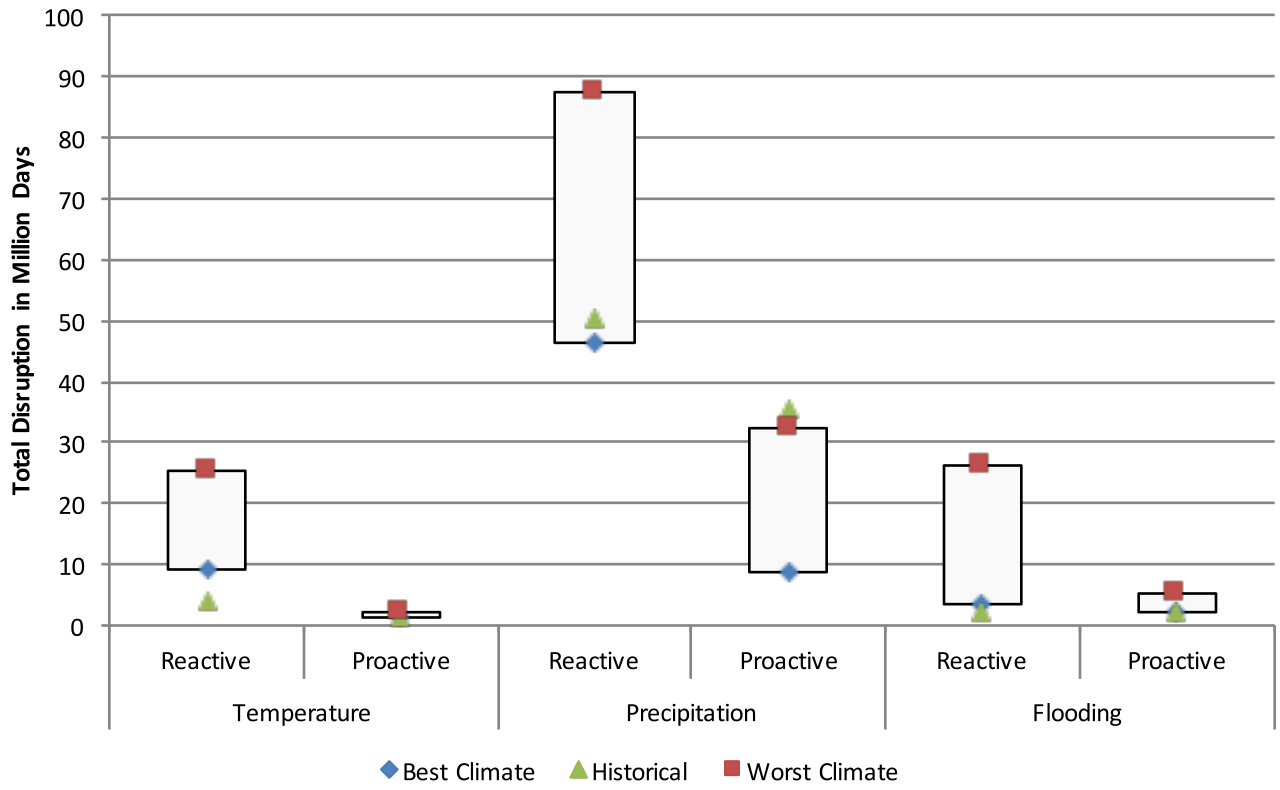
Climate change will also cause disruptions to road networks

Cumulative Disruption for the PIDA+ network With Reactive Response to Climate Change, 2015-50 (million days)



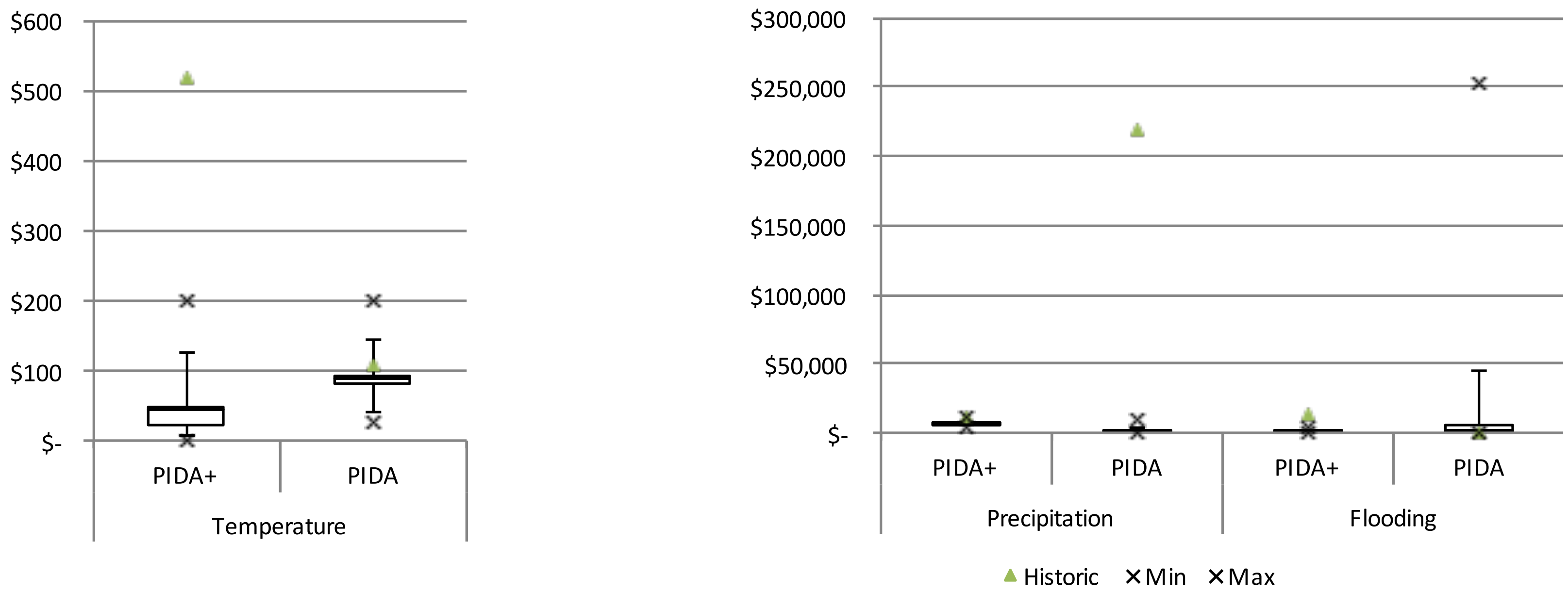
Adaptation has large impact reducing disruption…

Cumulative Disruption for the PIDA+ network, 2015-50 (million days)

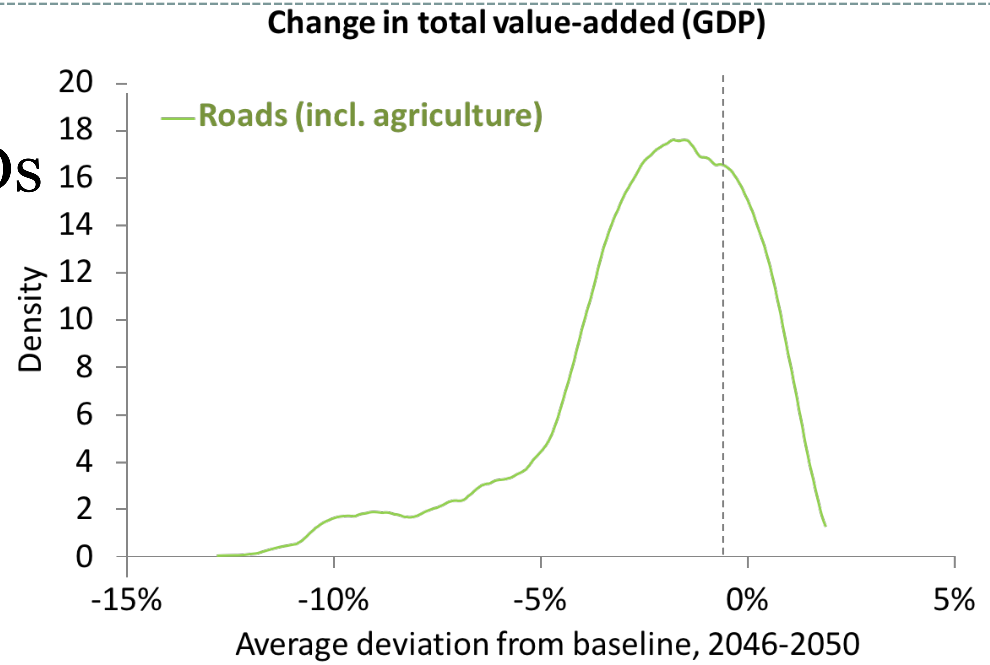


Considering disruption benefits AND financial costs, case for adaptation often strengthens

Distribution of Breakeven Values across Climate Scenarios, Sub-Saharan Africa for PIDA and PIDA+ Roads, for Three Climate Stressors



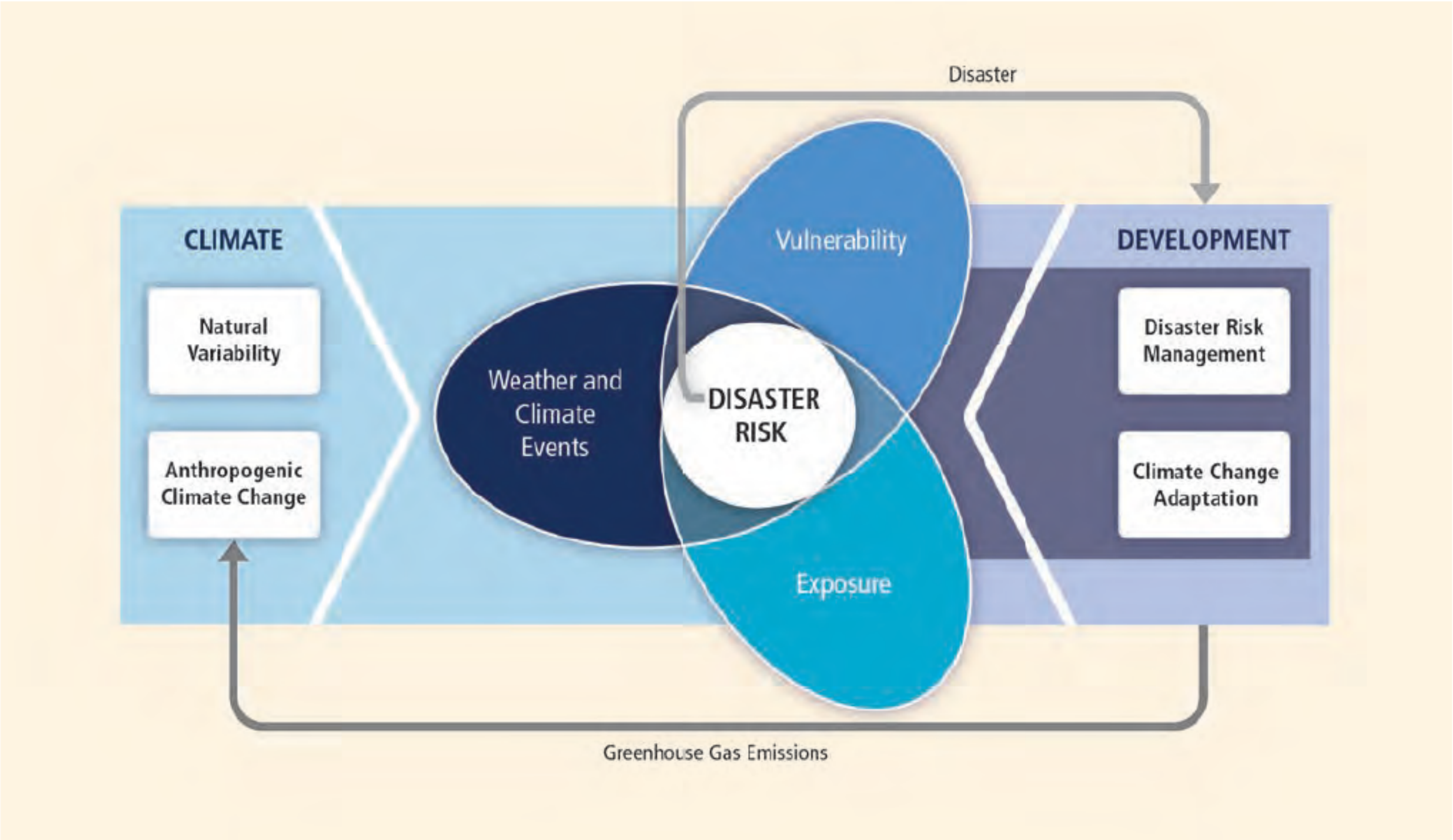
Additional reasons to adapt: economy-wide effects of road traffic disruptions



- Mozambique
- CGE w/ MIT JP 400 HFDs
- Expected Annual Impacts
- $~2.5 bil/year 2010-2050
- ~ -5% of 2010 GDP
  - Source: Arndt and Thurlow, 2015.
  - UNU-WIDER Working Paper.

- South Africa
- CGE w/ MIT JP 400 HFDs
  - Expected Costs are 0.8% of GDP (range of 0.1 to 2.6%) by 2050
  - Current GDP $366 Billion
  - Total loss w/ 5% discount rate $16 B (range: $1.5 to 55 B)
  - Source: Cullis et al., 2015. UNU-WIDER Working Paper

What does this mean for Development and Investment



Key Insights

- Ignoring climate change is most likely not an option
  - A reactive response can lead to a doubling of maintenance costs
  - Higher costs for certain countries/ climate futures
- There is a significant case for adaptation
  - Generally justified for temperature
    - Costs are relatively low
    - Benefits quite likely since temperature will continue to rise
  - Less clear on precipitation and flooding
- The case is likely to be even stronger if benefits other than reduced maintenance costs are included (e.g., disruption)
- Results are sensitive to discount rates – use of a 6% rate consistent with new WB guidance will diminish attractiveness of proactive alternative (which has higher upfront capital costs)

Thank You

QUESTIONS?