Climate Change Adaptive Design
How to Forgive Design and Ensure Funding?

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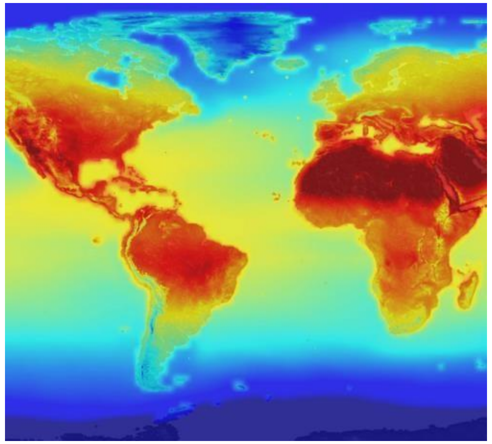
What is Climate Change?

- Abnormal variations to the climate over a significant period of time
- Visible changes in weather pattern
  - Changes to temperature, precipitation, humidity, wind speed and direction etc.
  - Changes in frequency and severity of extreme weather events
    - Flooding, hurricanes, tornadoes, ice storm, flash flood, heat wave, forest fire, polar vortex etc.
- Global warming and GHG (Greenhouse Gas) emissions
- Timeframe ranging
  - Decades to million years



"Everybody talks about the weather but nobody does anything about it." – *Mark Twain*

Local to Global

- IPCC (Intergovernmental Panel on Climate Change)
- ICLEI (International Council for Local Environmental Initiatives)
- Environment and Climate Change Canada
- FCM (Federation of Canadian Municipalities)
- MOECC (Ontario Ministry of Environment and Climate Change)
- Local Government (Municipalities)

Think Globally, Act Locally

ONTARIO RECITATION .588/17

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INFRASTRUCTURE FOR JOBS AND PROSPERITY ACT, 201.5

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STRATEGIC A$SET AGEME POLICIES

Strategic asset management policy

1) Exeiy municipality shall prepai‘e a strategic asset management *policy* thnt includes the following:

1. Any of the municipality's goals, policies or plans that are supported by its asset management plan

i. the actions that may be required to address the ivliiieiabilities that rnas′ be caused by climate chance to the municipality's infiashuctui e assets, in respect of such matteis as,

A. operations, such as increased maintenance schedules,

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ii. the anticipated costs that could arise lrom the vulnerabilities described in subparagraph i.

iii. adaptation opportunities that may be undertaken to manage the vulnerabilities described in subparagraph i,

iv. mitigation approaches to climate change, such as greenhouse uas emission reduction goals and targets, and

v. disaster *planning* and contingency funding.

6. A process to ensure that the municipality's asset management planning is aligned with any of the following financial plans:

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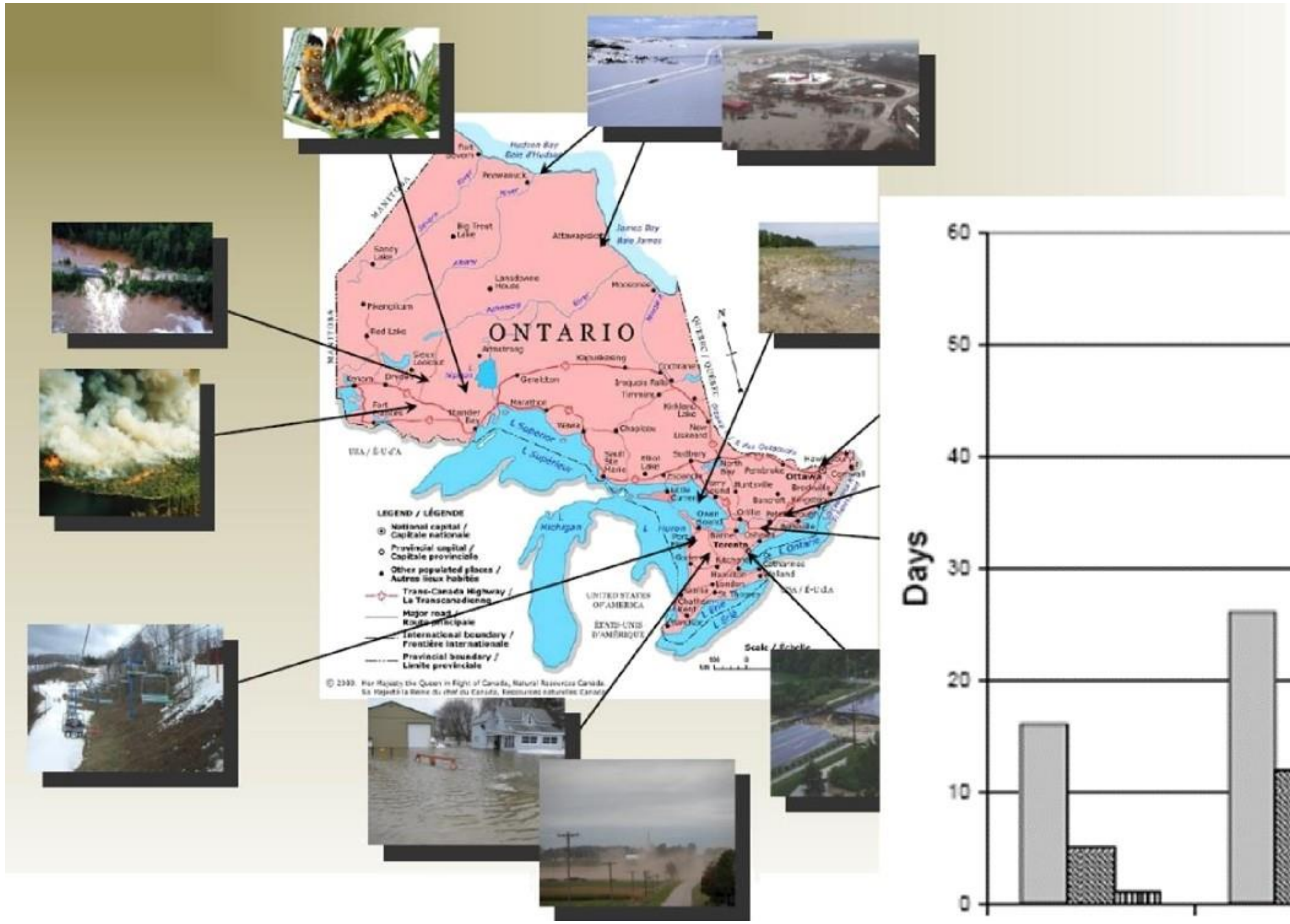

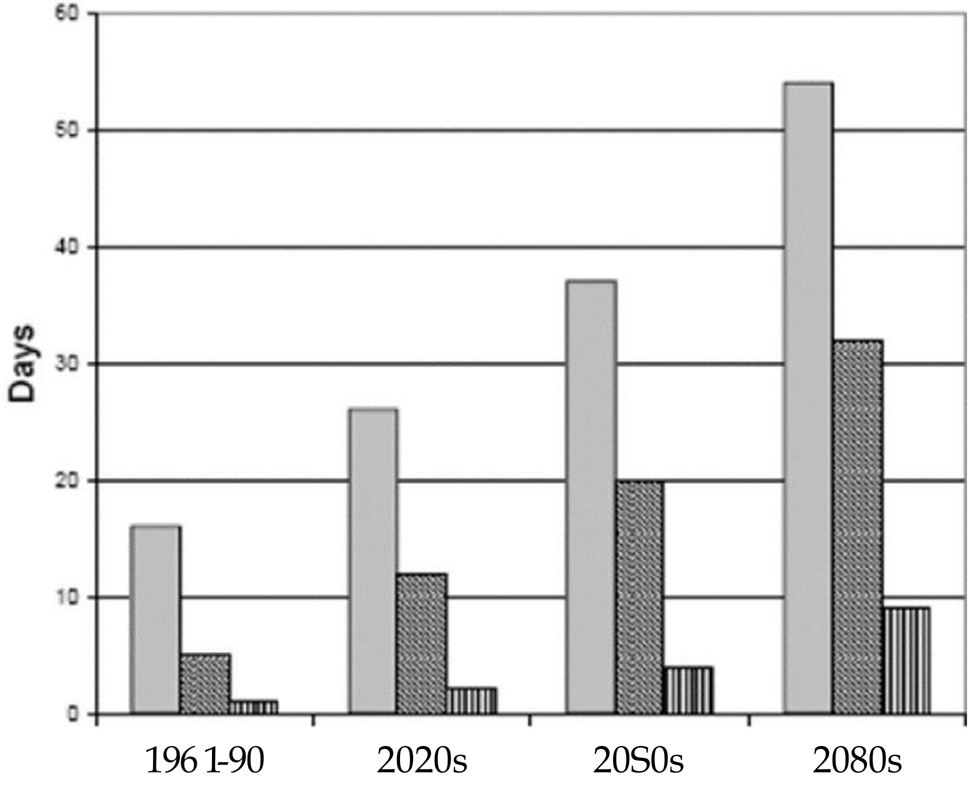

O Days with temperature akove 30 degrees

B Days with temperature akove 32 degrees

B Days with tenaperature above 35 degrees

Extreme Events in GTA

- Toronto Flood (July 8, 2013)
  - Damage $1.2 Billion
  - 300,000 residents without power
- Burlington Flood (August 4, 2014)

[Don Valley Parkway]

[QEW/Guelph Line]

[QEW/Walkers Line]

[Toronto Area]

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Direct Impacts on Transportation O&M

- Traffic incident management
- Road and lane closures
- Reduce or variable speed limit
- Disruption of transit services
- Road and transit diversions
- Signal failure
- Truck restrictions
- Work zone management
  (to accommodate additional lane and road closures)

- Loss of
  - Roadway capacity
  - Communication (due to power outages)
  - Emergency preparedness (timely evacuation)
  - Integrity and service life of infrastructure
  - Economic productivity
- Reduce or no mobility
- Increase of safety risk

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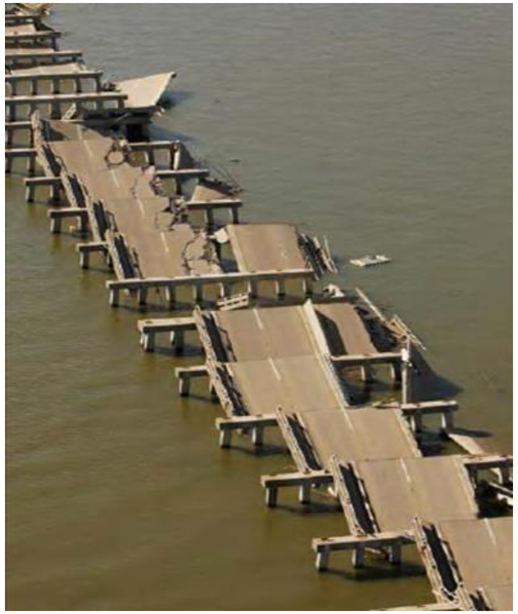
Impacts on Transportation Infrastructure

- Increase in heat waves
  - Damage road surfaces and rails
- Increase in arctic temperature
  - Melting of permafrost, winter road collapse and impacts on steel and timber structures
- Rising sea levels
  - Submerge subways, roads, bridges and ports
- Increase intense rain fall
  - Flooding and wash away roads and bridges
- Increases in hurricanes and cyclones
  - Destroy signals, poles and power failure

[Rail Buckle, US DOT]



[Hurricane Damage Hwy 90, Volpe NTSC]

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Wastewater Infrastructure

EXAMPLES OF WEATHERING PROCESSES LIKELY AFFECTED BY THE CHANGING CLIMATE	INFRASTRUCTURE IMPACTS
Permafrost degradation	• New containment structures in continuous permafrost zone may need to be built • Potential rupture of drinking water and sewage fines. sewage storage tanks • Potential seepage from sewage storage • Failure of frozen-core dams on tailing ponds due to thawing and differential settlement
Hotter, drier summers and heat waves	• Ir›creuseJ Jemur ‹J for wuter ‹delivery z r J cullectiur systerTS
Increase in rainfall	• Stormwater infrastructure more frequently exceeded • Require increased capacity on wastewater treatment facilities • Urban drainage systems could fail, causing problems such as sewer backups and basement flooding
Increased trequency cf storm surges and high«r tiJ«s	• Implications for large urhan drainage systems • Potential impact en the strength in wastewater systems • Sinking of land surfaces • R‹›ildinps, tank age. housed process eq« ipment affected fry flooditsg • Overtaxing of drainage facilities • Pipeline ruptures

Climate Change Cost Impacts

- Averting climate change may cost $700B per year
  - Costs on renewable power, low-carbon transport and energy efficiency to meet UN's goal to cap temperature rises - World Economic Forum
- Extreme weather events alone will cost Canadians an average $5B/year by 2020 and upwards of $43B/year by 2050 (TD Bank)
- Alberta Flood (2013) - $6B
- Toronto Flood (2013) – $1.2B
- Burlington Flood (2014) - $90M +
- Fort McMurray Wildfire (2016) - $9.9B

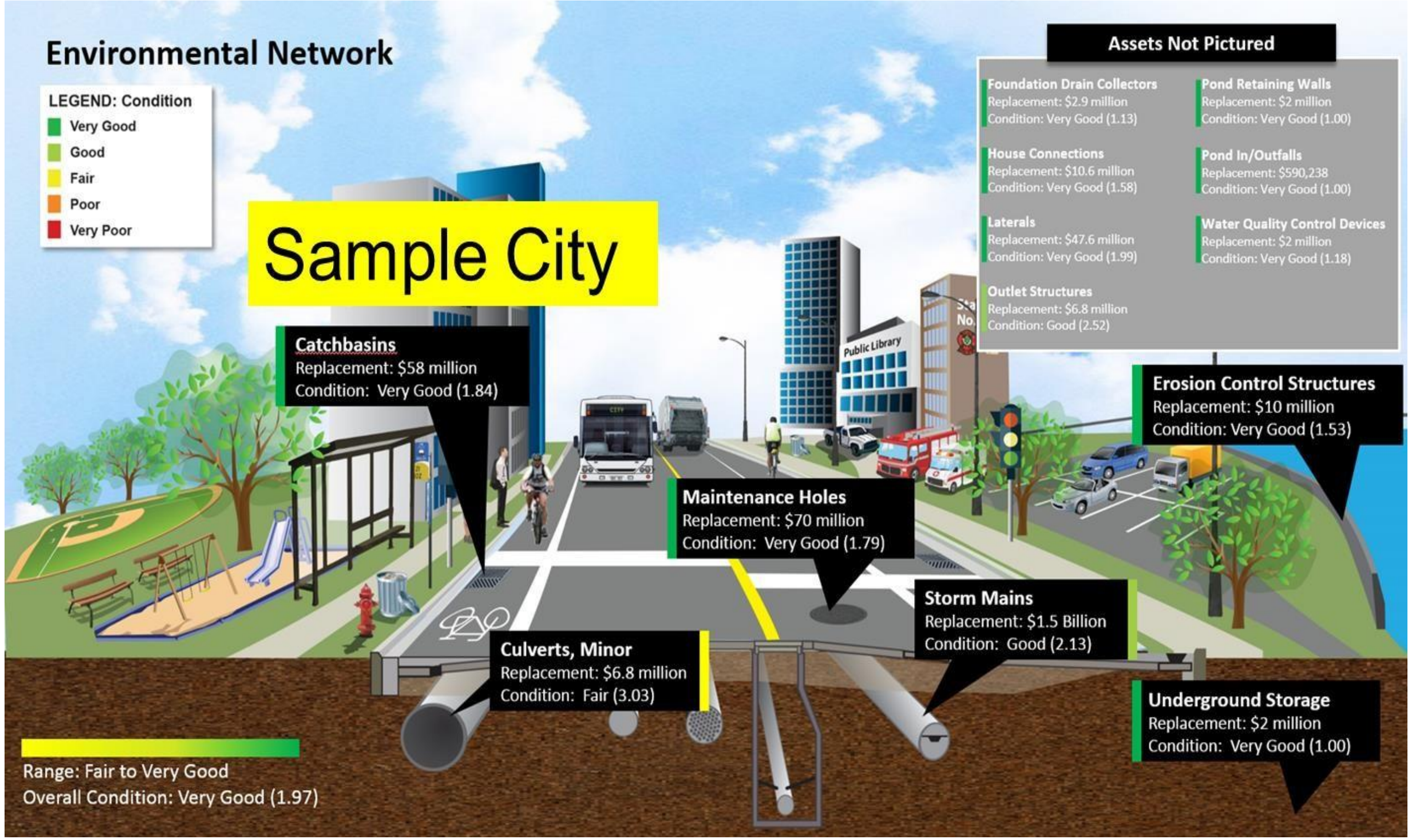
Why Engineers Need to Involve?

- Impacts on Public Safety
  - Disruptions in everyday life
  - Physical injury
  - Loss of life
  - Health impact
  - Temporary evacuation and relocation
- Impacts on Public Interests
  - Mobility
  - Business disruption and loss of employment
  - Damage and destruction to infrastructure
  - High costs of repairs and replacement
  - Environmental impact (long-term)

Physical Infrastructure Systems

- Characteristics:
  - Interdependency
    - Direct
    - Indirect
    - Sub-system
  - Connectivity
    - Internal
    - External

[Modern Urban Infrastructure Network]



Vulnerable Infrastructure and Assessments

- Infrastructure in our life-line
  - Highways, bridges and overpasses
  - Train stations, bus terminals and subway facilities
  - Airports
  - Legislative buildings
  - Water supply and purification plants
  - Business centre's
  - Pipelines
  - Ports
  - Public places and arenas
  - Shopping plazas
  - Auditorium, art galleries and museums
  - Iconic monuments and structures

- Characterization of the infrastructure
- Determination of critical aspects
- Assessment of likelihood (qualitative probability)
- Evaluation of existing countermeasures
- Development of a prioritized plan for risk mitigation

CRITICAL ASSET	CRITICAL ASSET FACTOR														TOTAL SCORE (x)
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
Asset 1															
Asset 2															
Asset 3															
Asset 4															
Asset 5															
Asset n															

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Vulnerability Assessment

- Vulnerable
  - Total Load > Total Capacity
- Resilient
  - Total Load < Total Capacity
- Adaptation is necessary if vulnerable

Vulnerability

Infrastructure Component	Total Load	Total Capacity	Vulnerability
	(mm/24 hr)	(mm/24 hr)	
	L_T	C_T	$V_R = \frac{L_T}{C_T}$
Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	101	88	1.15
Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	153	121	1.26
Catch Basins (Storm Sewers) & Extreme Rainfall	139	117	1.19

[PIEVC – Public Infrastructure Engineering Vulnerability Committee]

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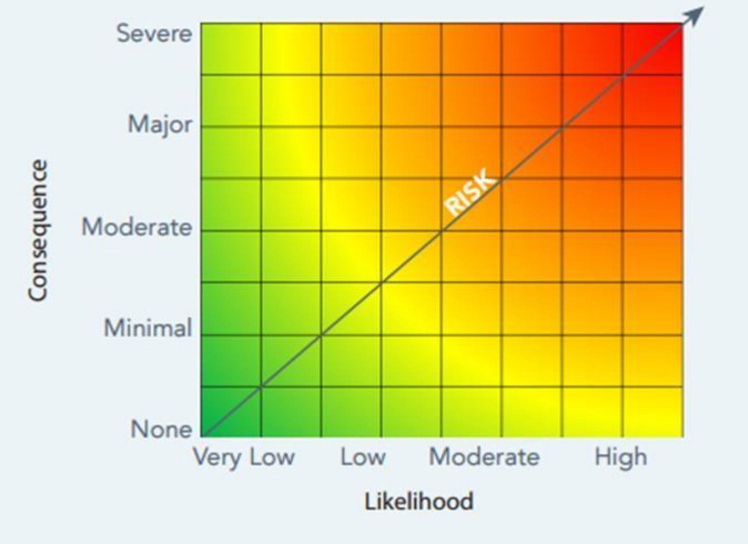
Risk Assessment

- Risk = Probability of a negative event (Likelihood) x Severity of the event (Consequence)
- Risk Thresholds

Risk Rating Matrix

Likelihood Level	Level of Risk	Consequence Level: Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
	Almost Certain (5)	Medium (5)	Medium (10)	High (15)	Extreme (20)	Extreme (25)
	Likely (4)	Low (4)	Medium (8)	High (12)	High (16)	Extreme (20)
	Possible (3)	Low (3)	Medium (6)	Medium (9)	High (12)	High (15)
	Unlikely (2)	Low (2)	Low (4)	Medium (6)	Medium (8)	Medium (10)
	Rare (1)	Not Significant (1)	Low (2)	Low (3)	Low (4)	Medium (5)



Threshold	Response
Low Risk	1 No immediate action necessary
Medium Risk	2 Action may be required 3 Engineering analysis may be required
High Risk	4 Immediate action required

Key Questions to Consider Climate Change Adaptation for Infrastructure Design

- What climate change trends are projected for the region?
- Which projects/assets be exposed to those impacts?
- Is the infrastructure sensitive to the climate change impacts? to what degree?
- What are the risk thresholds (low, medium, or high)?
- What adaptation strategies might be appropriate for reducing the risk?
- What factors are important in selecting appropriate strategies?
- What approaches should be used to evaluate, select and implement the adaptation strategies?

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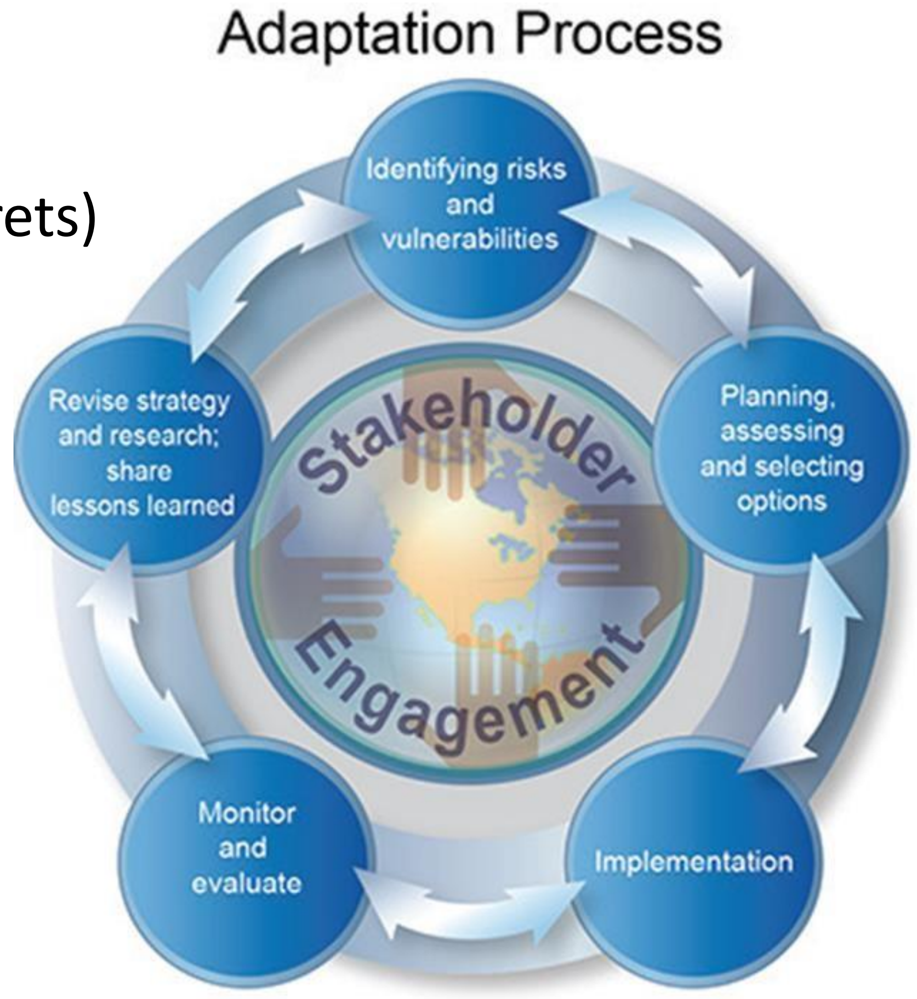
Adaptation to Climate Change

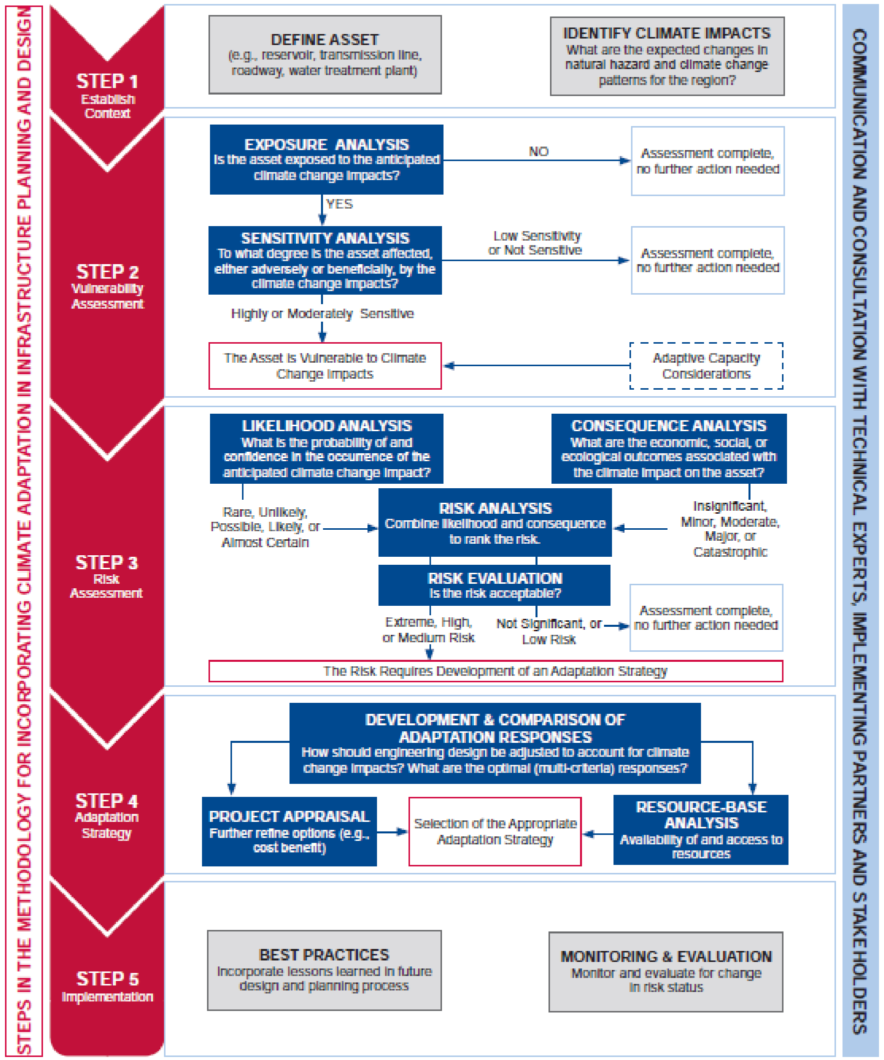
- Adaptation Options
  - Short-term (No regrets)
  - Medium-term (Low-regrets)
  - Long-term (Win-win)
- Adaptation Process
  - National Climate Assessment (NCA)



5 STEP PROCESS	
1	Establishing the Context
2	Vulnerability Assessment
3	Risk Assessment
4	Development of Adaptation Strategies
5	Implementation

Climate Change Adaptive Design

- Establishing the Design Parameters
  - Define assets
  - Identify climate impacts
- Vulnerability Assessment
  - Exposure analysis
  - Sensitivity analysis
- Risk Assessment
  - Likelihood analysis
  - Consequence analysis
  - Action measures
- Develop Adaptation Strategy
  - Comparative adaptive responses
  - Project prioritization
- Implementation
  - Best practices
  - Monitoring and evaluation



Climate Drivers and Design Implications

- Heat waves
- Precipitation/Flood
- Storm serge/tidal wave
- Sea level rise
- Strong winds
- Drought
- Wild fire

Climate Change Drivers	***Impacts***	***Design Considerations***
Temperature Change (Number of days +30°C and -20°C)	**Wider temperature variation** **Freeze-thaw cycle** **Permafrost**	**Cracking** **Joints** **Material properties** **Expansion/Contraction**
Excessive Precipitations (>75 mm/24 hrs.)	**High water levels** **Drainage capacity and flow** **Flooding** **High moisture in soils**	**Foundation design** **Elevations** **Flow capacity/Hydraulics** **IDF curves**
Windstorms (EF Scale: >EF2)	**Stronger speeds** **Change of directions** **Vibrations and turbulences**	**Wind gust factors** **Direction of wind** **Suspended structures** **Stronger materials**

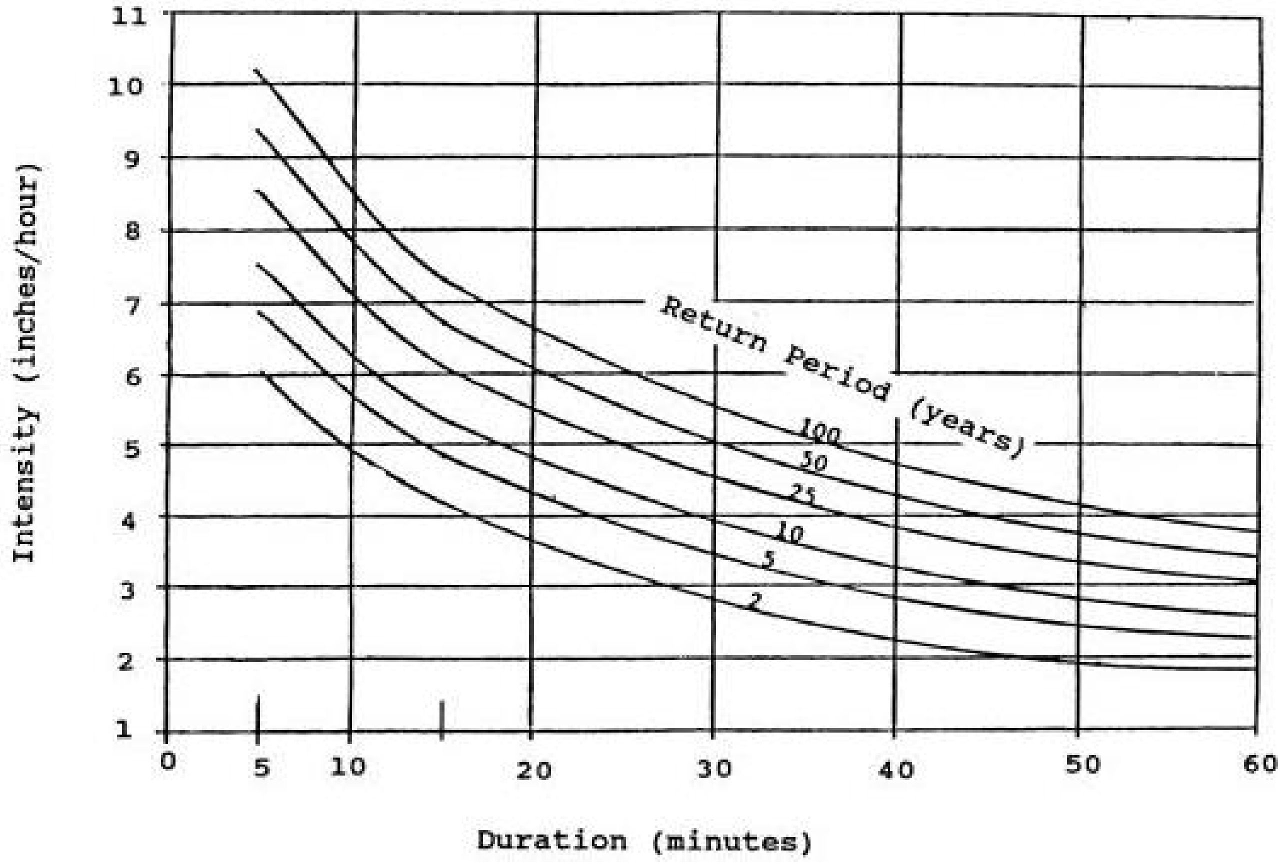
Challenges for Engineering Practices

- Access to climatic data is not easy
  - Not readily available
- Lack of regional and local climate models
  - A majority of current climate science is performed at the global scale
  - Practioners/Engineers need more localized models to effectively design infrastructure
- Current engineering practice utilizes historic data to design infrastructure
  - Incorporating future climate trends into infrastructure design and adopt low-regret, adaptive measures
  - Climate parameters are uncertain
- Code and design standards development are slow process and depends on experimental verifications
  - Climate parameters are unpredictable due to wide variations
  - Lacking in level of confidence
- Climate drivers are uncontrolled
- Assumptions may be vague
- Climate impacts are a function of current and future climate variability, location, asset design life, function, and condition
- Climate variability or increased frequency of extreme events may mean that infrastructure is no longer optimally designed for even short-term events
- Benefits of adaptations are not readily evident
- Lacking procurement and HR policies
- Communications between scientists, engineers, planners, politicians and stakeholders are very difficult

Good News: CSA is initiated a project to updating CHBDC to reflect Climate Change Adaptation and Extreme Weather Events for the CHBDC 2024 Edition.

IDF (Intensity-Duration-Frequency) Curves

- Consistency in Standards
- Challenges to use IDF information
  - Difficulties in understanding the theoretical basis
  - Uncertainties in selecting IDF information
  - Techniques used to develop IDF
  - Effects of seasonality, climate cycles and climate change



Rainfall Intensity = Total amount of rain (depth) / Duration [mm per hour (mm/h)]
Heavy/Intense Rain = When the Rainfall Intensity is > 7.6 mm (0.30 in) per hour

Canadian Codes and Other Standards

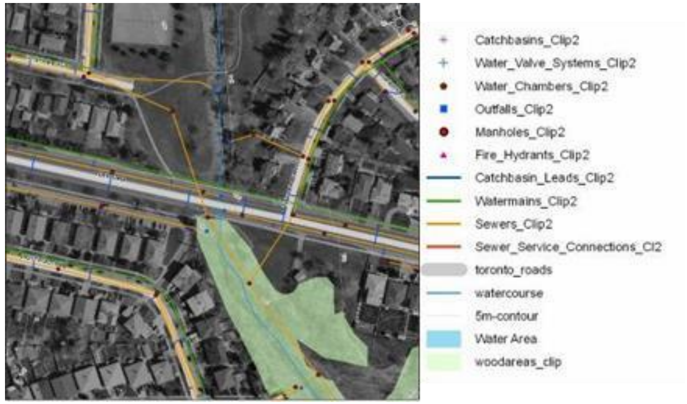
- Bridges - CHBDC
  - Section 2: Durability
  - Section 3: Loads
  - Section 6: Foundations
  - Section 7: Buried structures
  - Section 11: Joints and Bearings
- Buildings
  - NBCC
  - Ontario Building Code
  - BC Building Code
  - CAN/CSAS501-14
  - CSA Plus 4011
- Roads
  - TAC
  - MTO
- Railways
  - GO/Metrolinx
  - AREMA
- Dams
- Coastal Infrastructure
- Water and Wastewater
  - MOE
  - LID
  - Drinking Water
  - Source Water Protection
  - Wastewater Effluent Regulations
- International Standards
  - AASHTO, TRB, FHWA, CalTran
  - British Standards
  - Eurocode
  - Australia/New Zealand
  - ISO Standards
    - ISO 9000 – Quality Management
    - ISO 14000 – Environmental Management
    - ISO 14090 – Adaptation to Climate Change (New)
    - ISO 31000 – Risk Management
    - ISO 55000 – Asset Management

Case Study - Toronto

- City of Toronto (2011) Climate Change Vulnerability Assessment for Culverts
- Culvert management system review
- Risk and vulnerability assessment
  - Load and capacity analysis
- PIEVC protocol

Climate Parameters

High Temperature	High Intensity, Short Duration Rainfall	Hurricane/Tropical Storm
Low Temperature	Heavy Winter Rain	High Wind/Downburst
Heat Wave	Freezing Rain	Tornado
Cold Wave	Ice Storm	Drought/Dry Periods
Diurnal Temp. Variability	Snow Storm/Blizzard	Heavy Fog
Sustained High Temp. in winter	Snow (Frequency)	
Freeze/Thaw	Snow Accumulation	
Heavy Rain	Lightning	
Heavy 5 day Rain	Hailstorm	



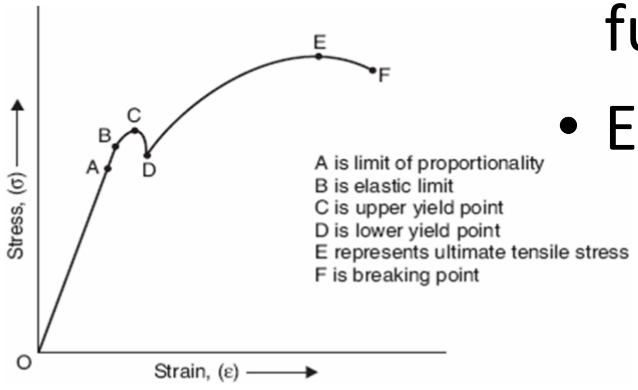
[Culvert Profile]

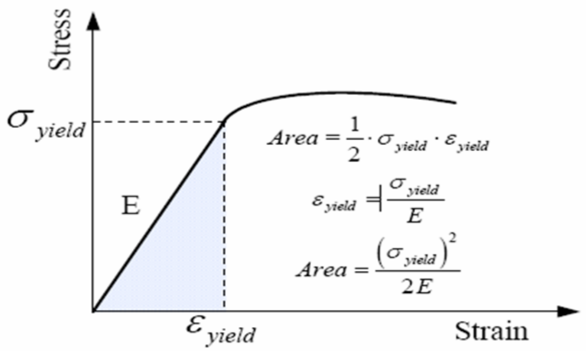
[City of Toronto Culvert Locations]

Resilience in Engineering and Environment

- A non-dimensional material property
- **Resilience** is the ratio of it's yield strength to elastic modulus
- A highly resilient material can withstand greater deflections and generates higher forces

- Design parameters
  - tolerance, safety, integrity and durability
- Structural control
- Structural monitoring





- Ability to comeback or regain functionality
- Emergency services
  - Manage the consequences
  - System is resilient, if: (1) appropriate response (2) adequate resources (3) speedy recovery (4) mitigate hazard and (5) quantify intangible impacts
- Ecology and environment
  - Amount of disorder can withstand
  - The return time to a stable condition

Green Infrastructure and Enhancing Resilience

- Natural infrastructure
- Low carbon infrastructure
  - Less GHG emissions
- No adverse impacts on natural eco systems
- Low impact development
  - These practices include rain gardens, vegetated swales, roofs gardens and porous pavements
  - Such as forests, stream buffers and wetlands, and reducing the size of paved surfaces
- Less waste
  - 3R (Reduce, Re-use and Recycle)

- Design robust and intelligent systems
- Develop a strategic asset management plan
  - Reduce backlog
  - Consider infrastructure funding as investment
    - Maintain state-of-good repair
  - Infrastructure funding optimization
- Innovative tools and techniques
  - NDT, trenchless, accelerated and rapid construction etc.
  - Implement structural health monitoring
- Knowledge transfer
  - User’s vs. Owner’s perspectives
  - Awareness, responsibilities, education, sharing and caring

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Innovations and Thoughts

- Pavement Materials
  - Algae, tire chips and refurbished
  - Chemical multicomponent deicer
    - No winter maintenance over 20 years!
- Carbon Negative Cement
  - Cement made of magnesium silicate instead of calcium carbonate
  - Low-energy uses and absorbs CO_2
- Ultra High Performance Concrete
- Self Healing Concrete
  - Microcapsule sodium silicate
  - Protective coating
  - Sunlight-induced

- Wastewater
  - Recycle and Reuse
  - H_2S to H_2
- FRP Reinforcement
  - Higher strength and less weight
  - Corrosion free
  - Steel free decks
- Fit for Purpose Solutions
  - Smart Manholes
    - Sensor in cover monitor water levels
    - Stop backups before happen
    - Cleaning costs reduced to 90%+

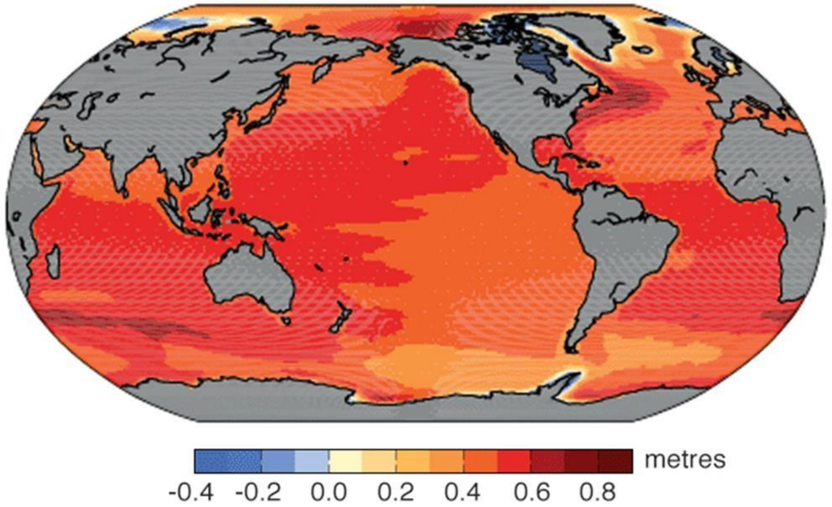
[GFRP Reinforcement in Bridge]

Funding Mechanisms

- Federal Funding
  - The Low Carbon Economy Fund
  - Green Infrastructure Fund
  - Public Transit Infrastructure Fund
  - Clean Technology Programs
  - Climate Action Fund
  - Carbon Pollution Pricing Proceeds Programming
  - Environmental funding
- Provincial Funding
  - Climate Change Partnership
  - Green Ontario Fund

Transit a tive esi n

Thank You



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