CR Service Levels, Network Level Resilience Modelling, Adaptation Pathways & ADB Green Roads Toolkit

Dr Ian Greenwood

Greenwood Associates Infrastructure Consultants

CR Service Levels

Is this Resilient?

- <u>Auckland Motorway, New Zealand</u>

- Carries circa 200,000vpd
- Combination of king tide and storm surge
- 3 lanes + busway impacted for a couple of hours
- Processes in place to monitor predicted tide levels
- Advanced warning in media and signage
- Traffic management plan enacted
- Maintenance crew ready to sweep road as water recedes
- Not a big issue = emergency mitigated

How About Now?

- Same motorway, another km along the road
- Friday night of a long weekend
- Unpredicted very heavy rainfall
- NZTA communications team went home

- The difference between an inconvenience and a disaster is often as simple as communication!

Source: NZTA

Source: NZ Herald

Resilience is Not ‘Always Available’

- Resilience is not the same as ‘always being available’

- Oxford Dictionaries

noun

1. the capacity to withstand or to recover quickly from difficulties; toughness.
2. the ability of a substance or object to spring back into shape; elasticity.

- A CR transport system is not one that is available 100% of the time, but is one that withstands an agreed magnitude of event without being compromised, and that can readily recover from a larger magnitude event.

Climate Resilience Service Levels

- We typically have:
  - Road condition measures (IRI, rutting, potholes etc)
  - Road safety measures (iRAP, fatal+serious etc)
  - Traffic congestion levels (HCM A to D)
  - Geometric standards (lane and shoulder width, horizontal and vertical curvature)

- But very uncommon to have resilience-based service levels
  - What size event should the road remain open? And how long can it be closed for?

- **Without clearly defined service levels, by default every road is already CR – just maybe not to the level that communities are happy with.**

What Do CR Service Levels Look Like

- Definition of a size of climatic event
- How the asset should respond under that event

Road Class	Impassability Time for Flood Events: Return Period			
	5 Year	10 Year	50 Year	100 Year
Trunk Road	Nil	Nil	< 2 hours	<12 hours
Regional Road	Nil	<6 hours	<24 hours	<2 days
District Urban Road	Nil	<6 hours	<24 hours	<2 days
District Rural Road	<2 hours	<12 hours	< 2 days	<5 days
Community Road	<12 hours	<2 days	<5 days	<7 days
Farm Access	< 24 hours	<5 days	<10 days	<10 days

Source: Jasper Cook

Network Level Resilience Modelling

Credit to E. Koks (Vrije Universiteit Amsterdam) for these slides

Transport risk analysis -> a multi-layered approach

Hazard Database

Hazard footprint

Asset-Level Exposure & Vulnerability

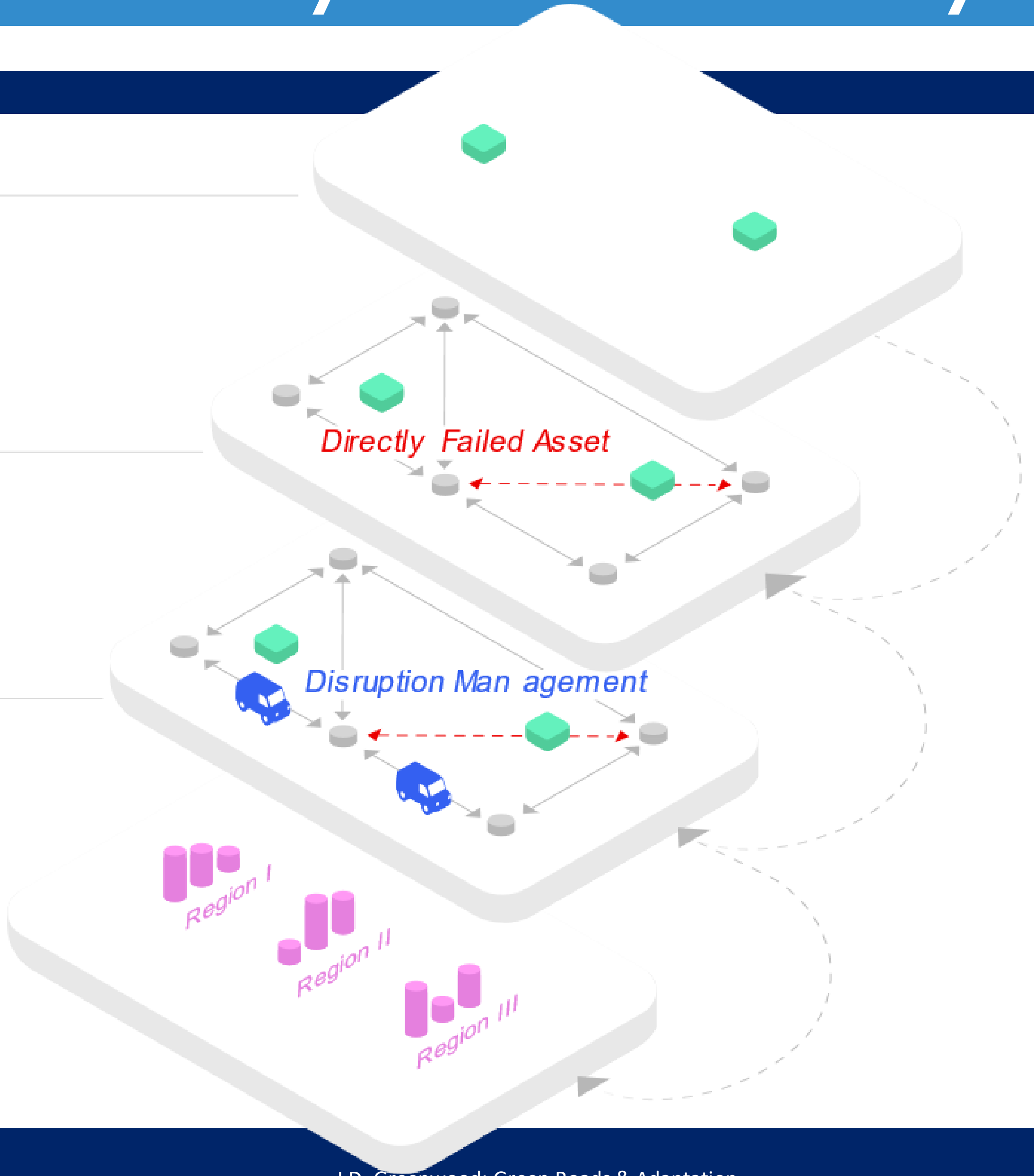
Origin/Destination

Network Failure & Service Disruptions

Infrastructure Services

System-level Risks

Regional loss metrics



Adaptation Appraisal

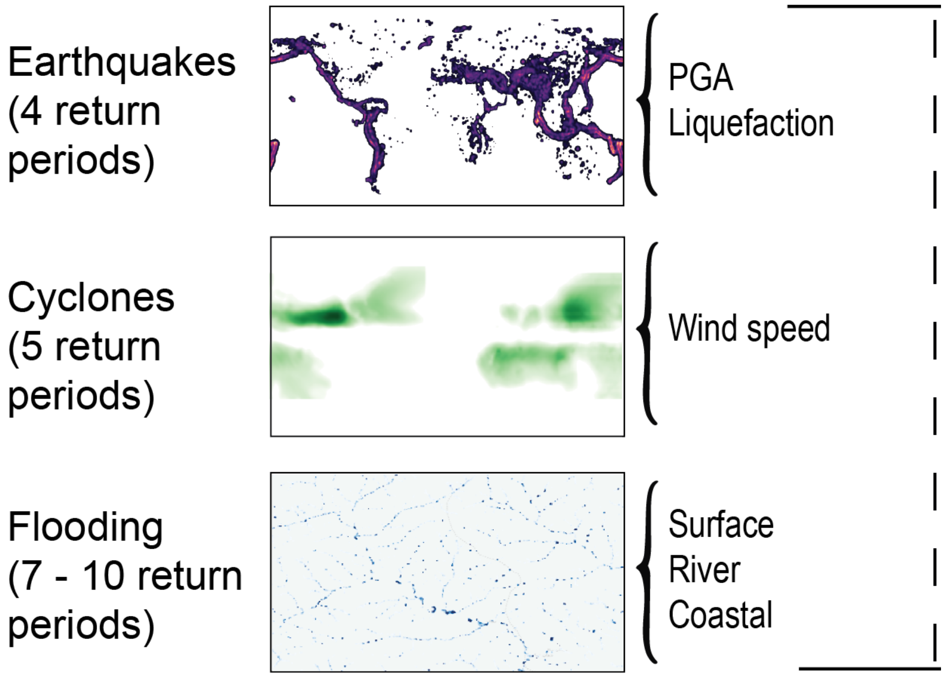
- Asset-level strategies
- System-level strategies
- Network-level strategies

Avoided Losses | Adaptation Costs

Investment decisions

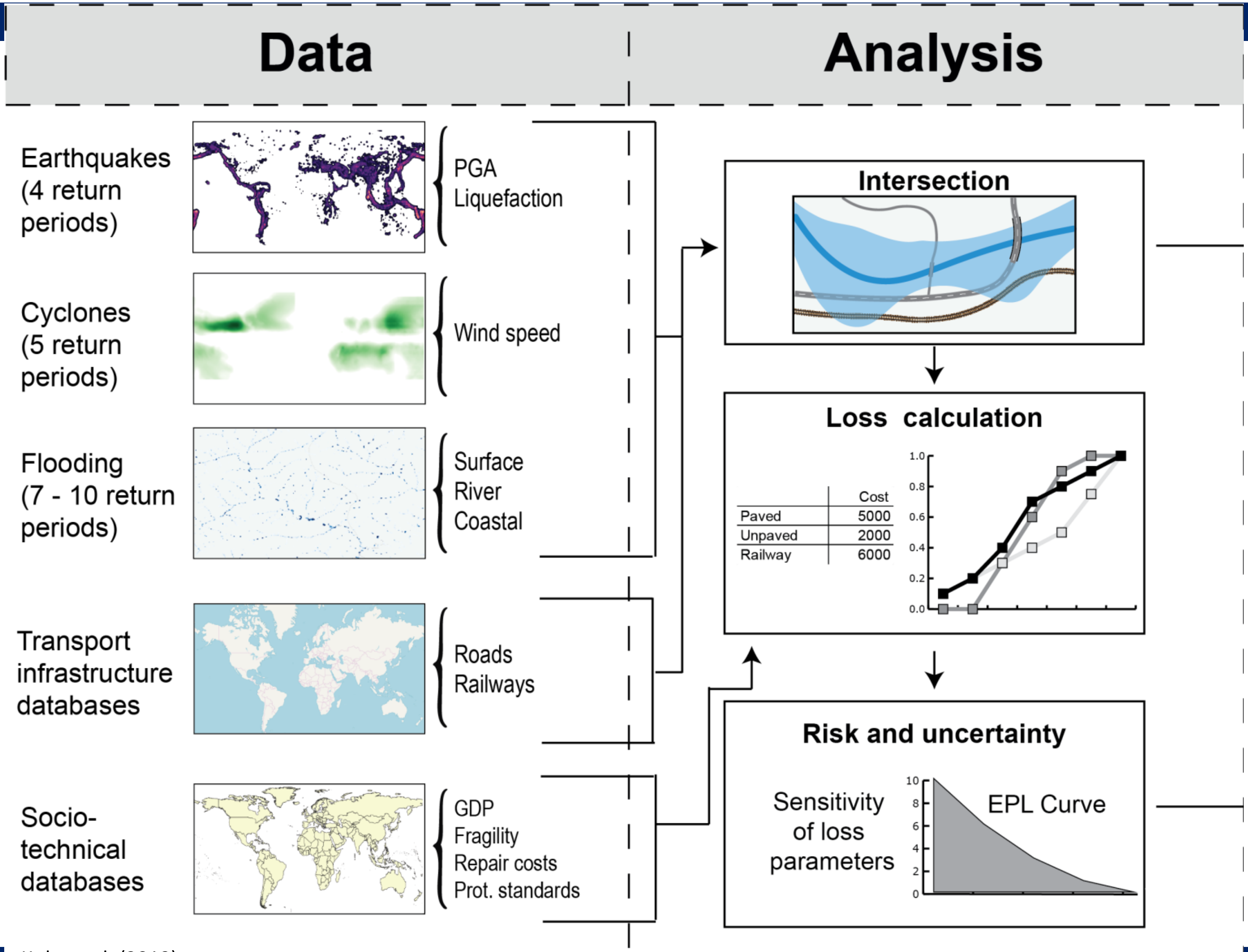
Transport risk analysis -> hazard database

- An analysis of the consequences starts with (spatial) data on various natural disasters, weather extremes, and climate change.
- While some data can be obtained from the public domain, local or tailored information is sometimes required

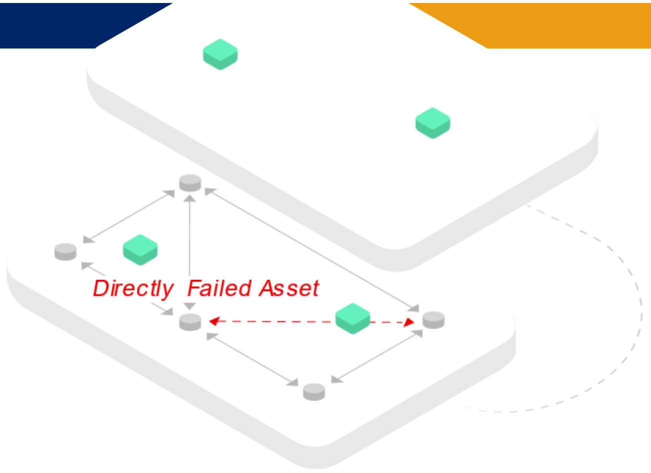


Koks et al. (2019)

Transport risk analysis -> asset-level impacts



Koks et al. (2019)

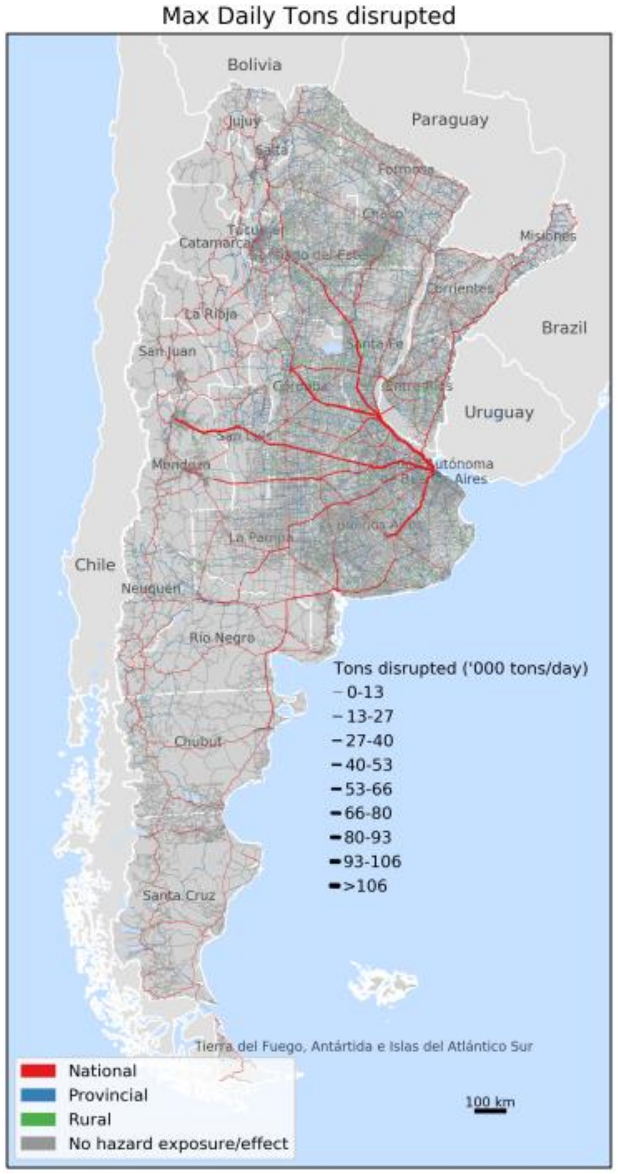


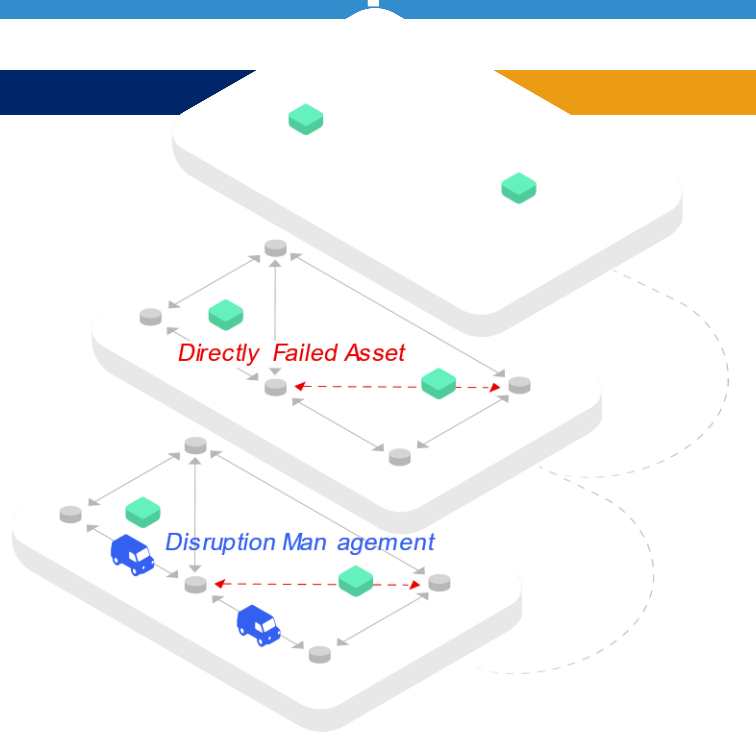
Transport risk analysis -> network-level disruptions

Estimating and disrupting services by combining:

- network information (e.g. topology characteristics)
- the assets that are potentially vulnerable (hotspot analysis)
- information about network usage (capacity and usage)

- This allows for a better estimation of the real consequences (and costs) of disruptions. And helps prioritize investments.





Transport risk analysis -> network interdependencies

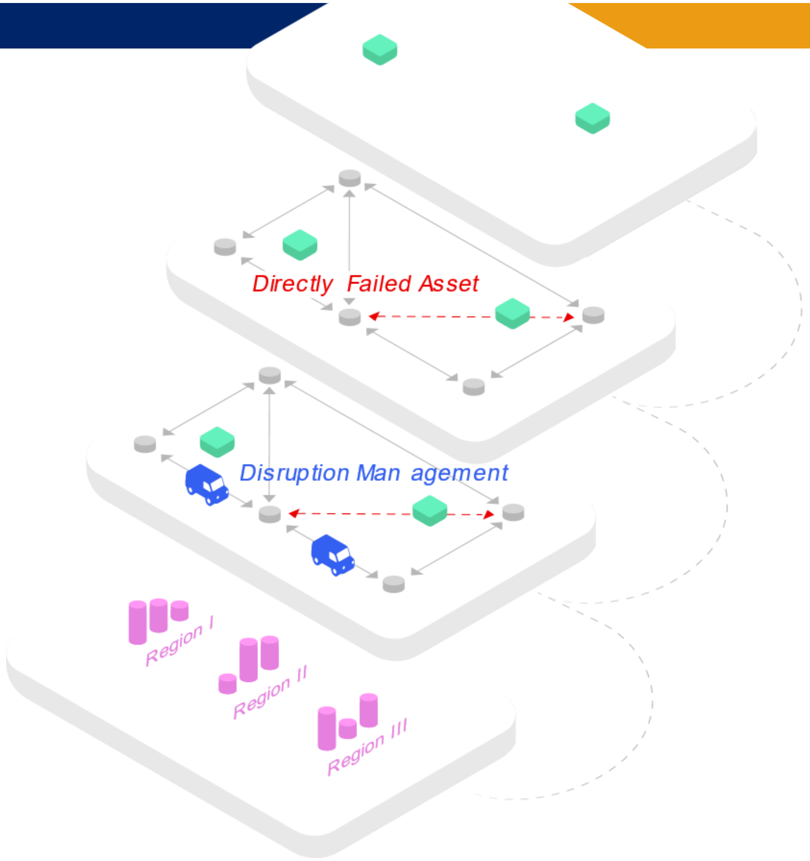
- Identifying (inter)dependencies between infrastructure networks

- Transportation hubs are most likely dependent on power infrastructure, causing various cascading effects:
  - A substation is flooded/hit by an earthquake, but the transport hub is not → still no functioning transport hub
  - They might be affected at the same time, but the substation is taking longer to recover/was more severely affected → still no functioning transport hub.

- Dependencies between infrastructure assets are hard to model, so assumption on dependencies and usage are often being made (e.g., each transport hub is dependent on the nearest power substation)

Transport risk analysis -> macroeconomic impacts

- Translating service disruptions into macroeconomic impacts.
- Several metrics will be estimated to do so:
  - **Total macroeconomic loss** – the sum of the direct and indirect losses in US$ per day, due to the losses of commodity flows that arise from individual links whose failure causes trip isolations, where the only available route option along the origin-destination (OD) route becomes physically inaccessible
  - **Freight redistribution cost** – the total difference between the post-disruption and pre-disruption cost estimates of all OD flows rerouted due to link failure. The freight redistribution costs should be assigned to the transport link whose failure causes those redistributions.
  - **Total economic impact** – the overall economic criticality of the network links is the sum of their macroeconomic losses and the freight redistribution costs incurred due to failures.



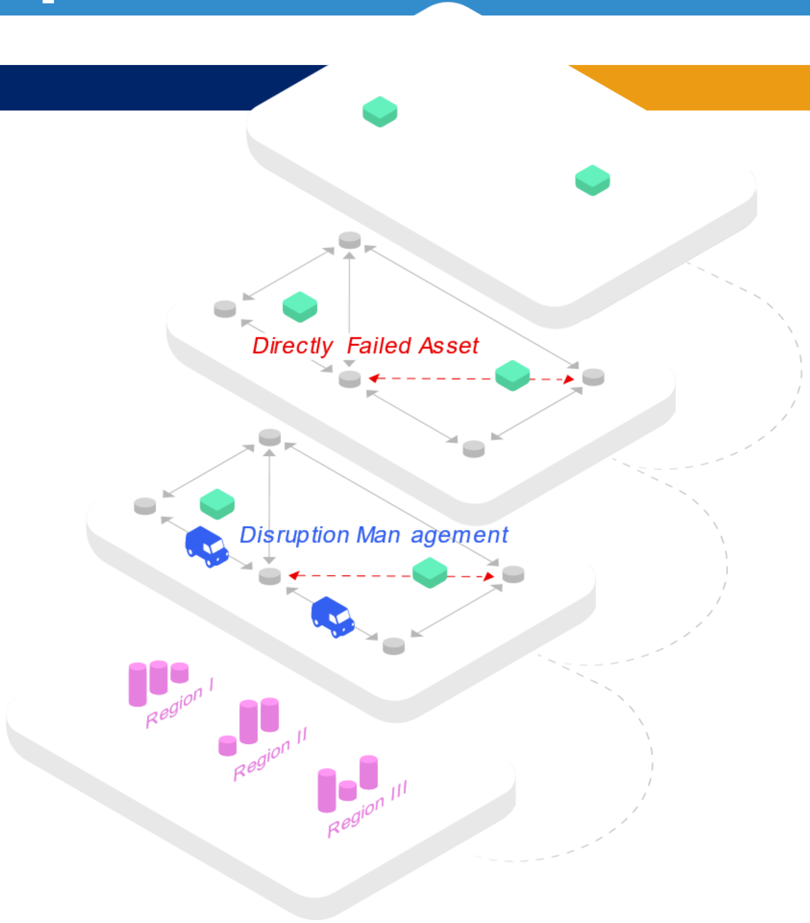
Transport risk analysis -> social impacts

- Translating service disruptions into societal impacts.

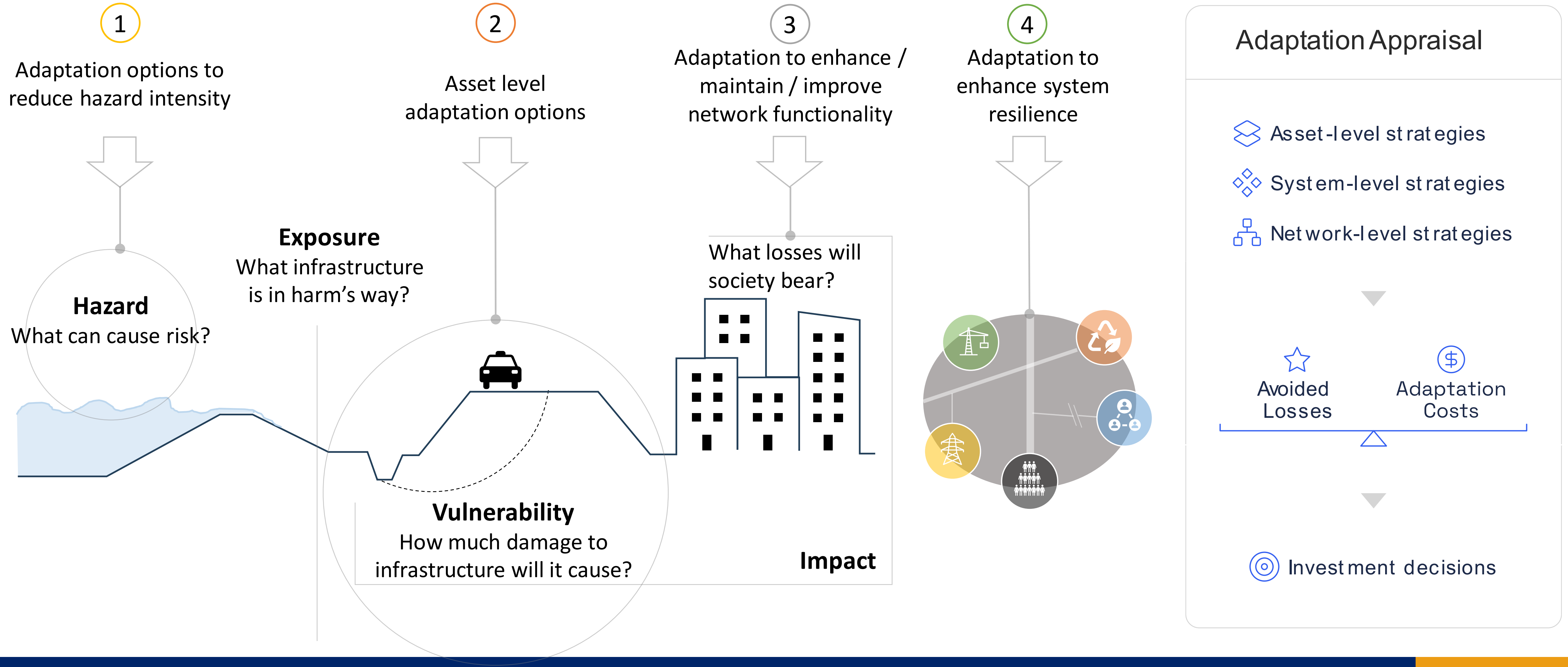
- Whereas the monetary impacts can be helpful to decide where to invest, they do not always provide the full picture.

- Accessibility to local communities may be low in direct financial costs but may have large social welfare costs.

- As such, we will also consider other non-monetary metrics, such as accessibility to hospitals, and number of people affected by closure of road segments.



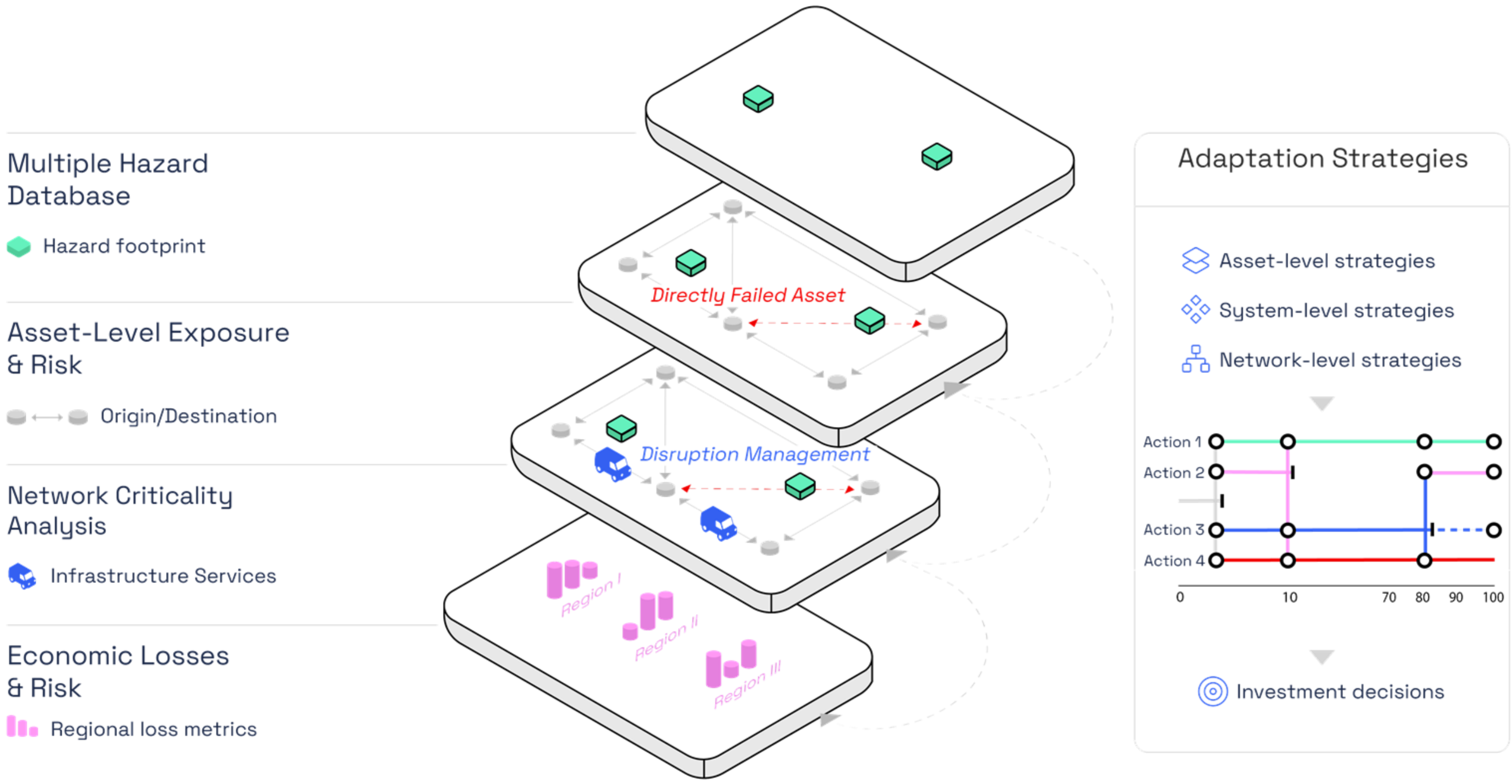
INTEGRATING CLIMATE RESILIENCE



Adaptation Pathways
(or how to meet your CR Service Levels)

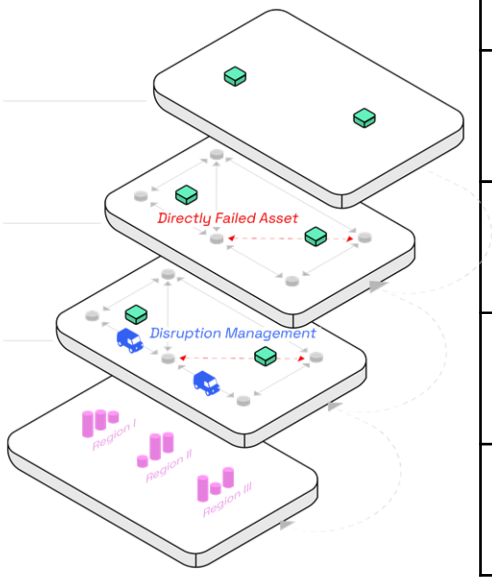
Credit to T. Henning (University of Auckland) and E. Koks (Vrije Universiteit Amsterdam) for a number of the remaining slides

A multi-layered approach: how to tackle adaptation?



miraca

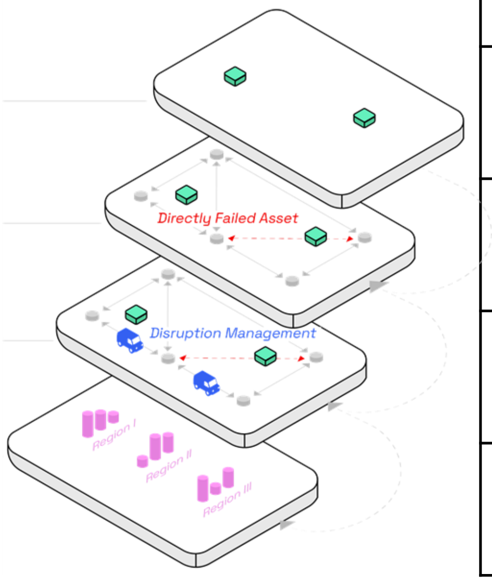
Climate adaptation to infrastructure is multi-tiered (i)



Level	Hazard	Vulnerability	Exposure (CI)	Capacity	Supply/Demand	Recovery
Hazard-level	Intensity Footprint					
Asset-level		Vulnerability function	Geometry (location)			Recovery needs
Network-level			Connections (Network topology)	Edge (link) capacity		
System-level					Node supply/demand	Recovery capacity

miraca Peregrina et al. (in progress)

Climate adaptation to infrastructure is multi-tiered (ii)



Level	Hazard	Vulnerability	Exposure (CI)	Capacity	Supply/Demand	Recovery
Hazard-level	Building dikes and floodwalls					
Asset-level		Elevating railways and embankments				Additional reconstruction crews
Network-level			Building new connections	Increasing freight capacity		
System-level					Increasing inventories	Recovery funds

miraca Peregrina et al. (in progress)

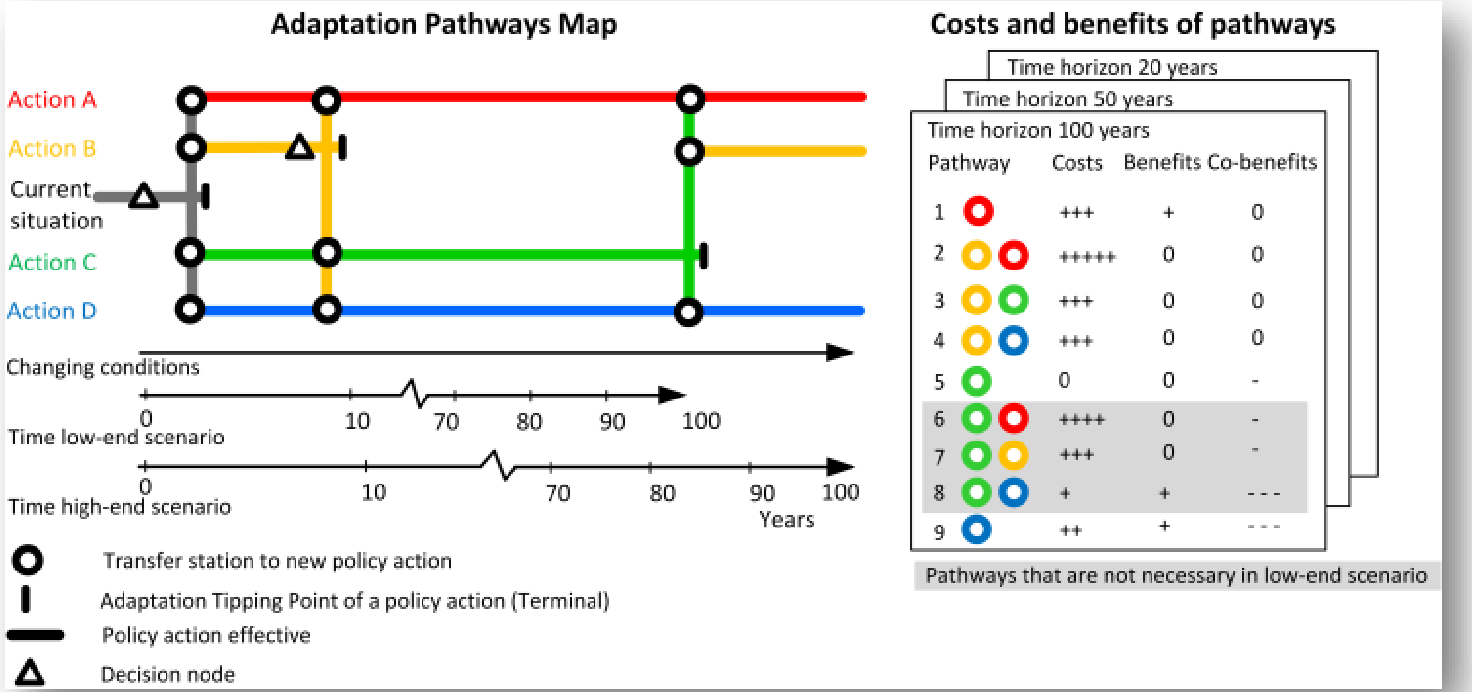
Examples of asset-level adaptation for different hazard types

Flooding	Elevating ways (columns, arches, etc)	Improving stream connectivity (culverts, bridges, overflow channels)
Drought	Building water locks	Soil moisture management (landslip prevention)
Heat waves	Higher temperature specifications	Continuous welded rail
Wildfires	Creating firebreaks	
Windstorms	Wind-tolerant construction	
Landslides	strengthening subgrade/foundations for predicted permanent ground displacement	
Earthquakes	Earthquake-resistant design	

miraca Peregrina et al. (in progress)

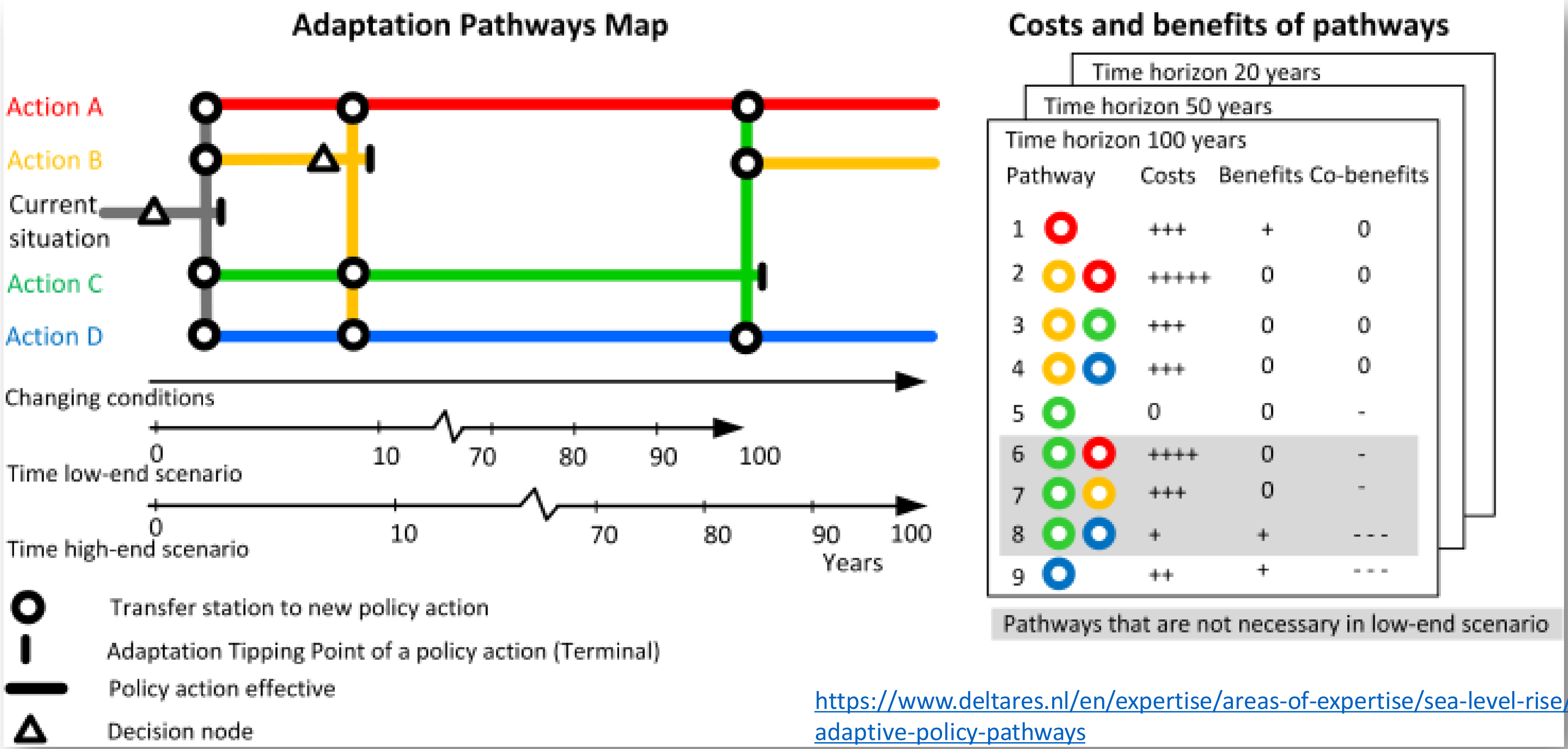
Adaptation Pathways

- Adaptation pathways can be a valuable tool for mapping out various adaptation strategies and comparing them.
- For instance, they assist in finding a balance between incremental adaptation and transformative adaptation.
- While incremental adaptation is often cheaper in the short term, transformative adaptation may be necessary to become climate-resilient to more extreme changes.



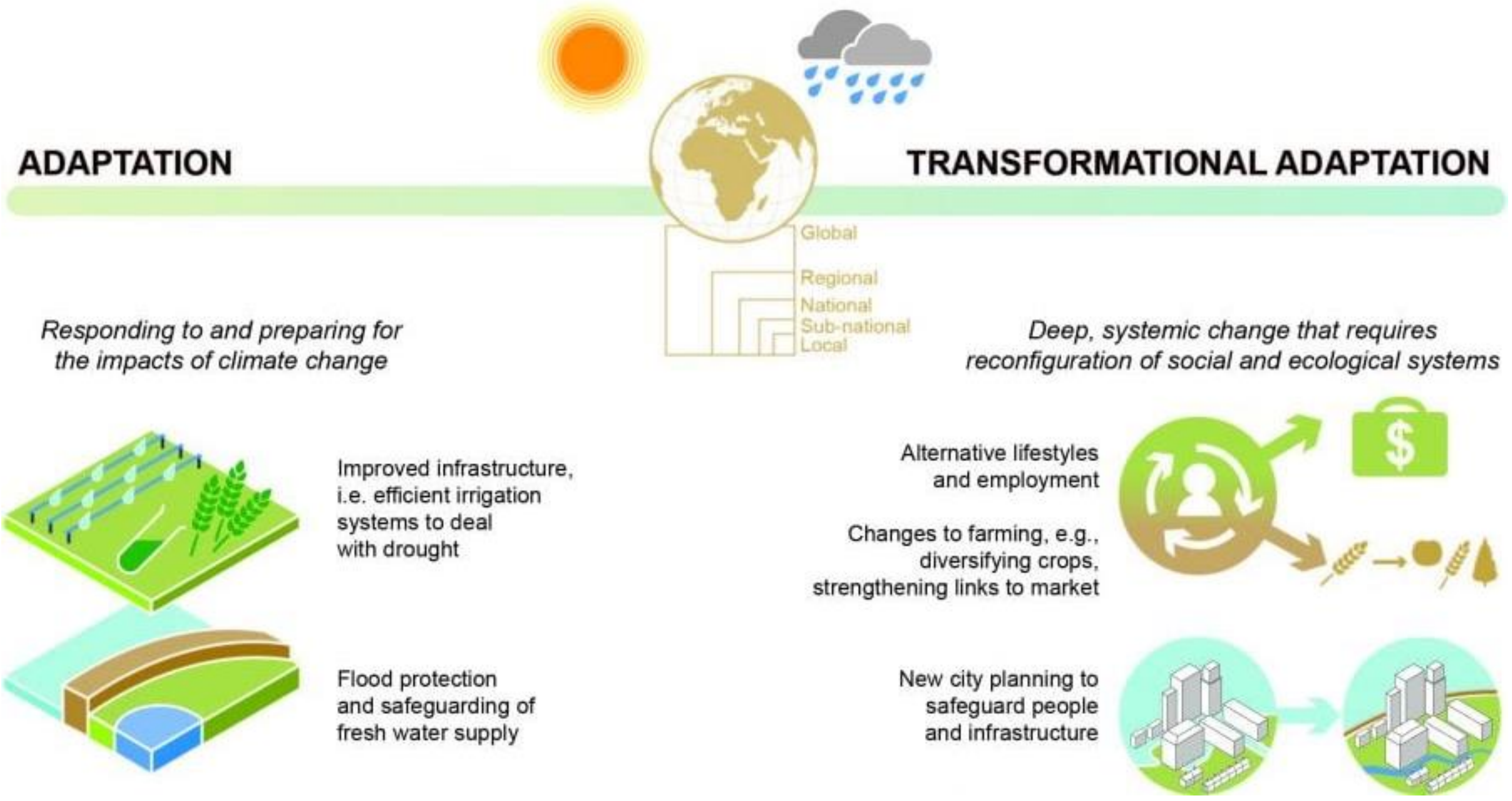
https://www.deltares.nl/en/expertise/areas-of-expertise/sea-level-rise/dynamic-adaptive-policy-pathways

Adaptation Pathways



https://www.deltares.nl/en/expertise/areas-of-expertise/sea-level-rise/dynamic-adaptive-policy-pathways

Transformational versus incremental adaptation



The cost of multi-hazard adaptation requires a collaborative effort to model:

- Still many unknowns in the interactions between adaptation strategies between different natural hazards -> potential for synergies but also risks for maladaptation

- The costs of adaptation is difficult to assess, and even more so in such a multi-tiered context: who gets the benefits, and who will pay?

- A community effort is required to get this going!

Financial Decision Making for Improved Resilience

Delay Investment or Manage Risk Differently

01 **Avoid** - Extreme Risks where investment will not make a difference

02 **Transfer risk** for low risk reduction return on investment (e.g. insurance)

03 **Delay** significant investment that that is not required now (e.g. bridge relocation)

04 **Accept Risk** for majority of the network having low probability or consequences

No Regret Investment

01 **Harden and protect** critical Infrastructure components

02 **Harden and protect** projects having a high risk reduction return for investment

03 **Improve emergency** and response protocols and resources

04 Post-disaster **Build-Back-Better/ Different**

Green Roads Toolkit

Project jointly delivered by

What Are Green Roads?

- Expansion beyond the traditional focus on connectivity, safety and affordability.

- Nine ‘Green Road’ themes:
  - decarbonization
  - climate resilience
  - water and land management
  - reducing pollution
  - improving quality of life
  - preserving biodiversity
  - disaster preparedness
  - sourcing sustainable materials
  - fostering inclusive growth

What Does The Toolkit Do?

- Generates a list of good green roads practice for each theme based on user defined criteria

- Each practice describes:
  - Details of the practice
  - Examples/ illustrations/photos
  - Costs/benefits
  - Enabling arrangements
  - References

- Intent is to prompt new ideas to be picked up in new design projects, or to mitigate issues that may arise from time to time on existing roads

Where do the practices come from?

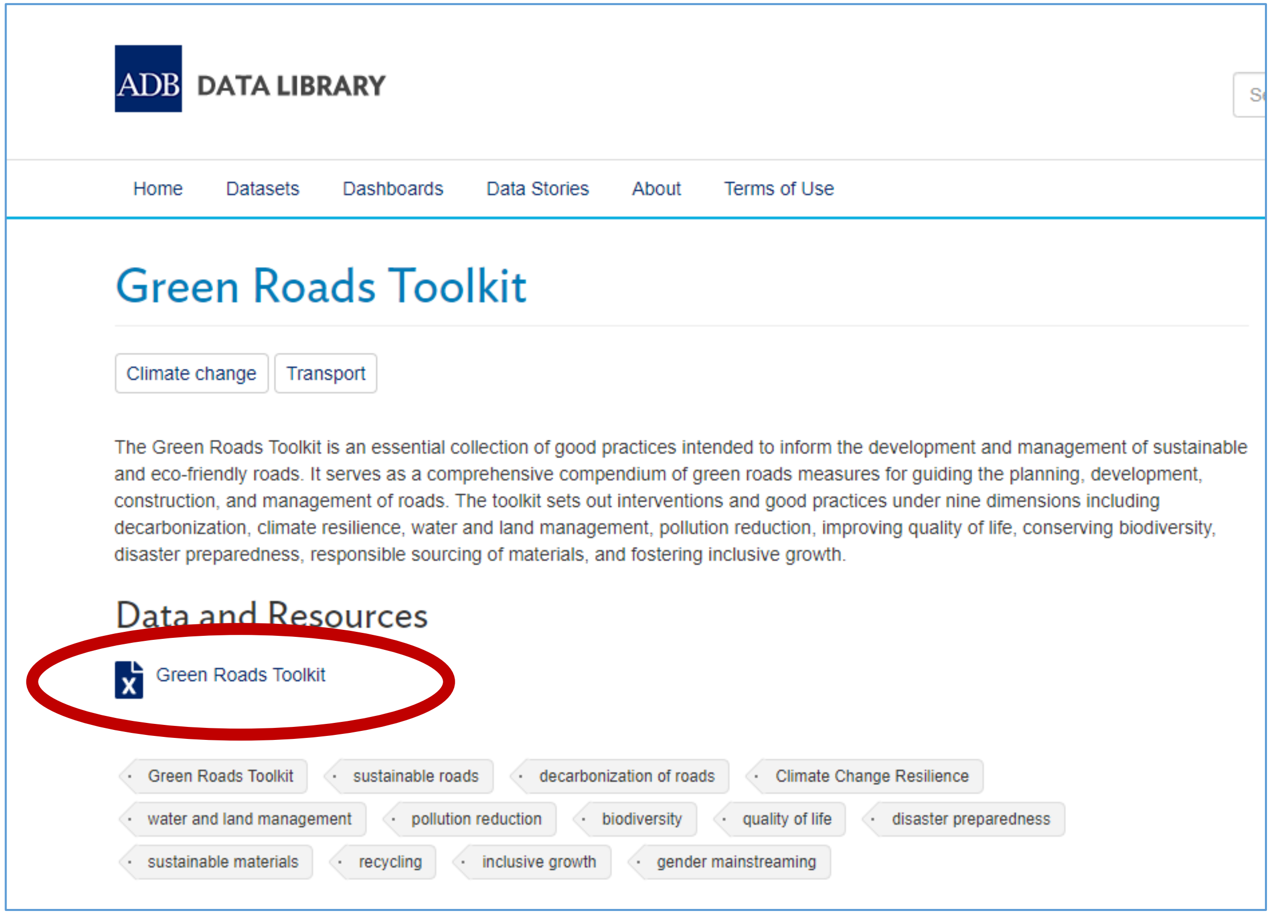
- An extensive (150) and growing collection of best practices
- Open call for good practices and community of practice
- Various practical documentations and project experiences worldwide
- Expert judgement and experiences
- <u>It is a living thing: we welcome new inputs</u>

How To Get It

- https://data.adb.org/dataset/green-roads-toolkit

- Currently an MS Excel tool
- 90MB file

- Plan to move it to an online tool



How It Looks and Works

Project Level Application

Step 1: Select Green Road Theme(s) and project characteristics (Note: Clear all checkboxes in both Step 1 and 2 before making selections)

1 CO2	2 Res	3 W&L	4 Pol	5 QoL	6 Bio	7 Dis	8 Mat
☐	☐	☐	☐	☐	☐	☐	☐

Geography and Climate	Mountainous ☐	Flat ☐	Arid ☐
Standard of road	Low-Volume/rural ☐	Paved highways ☐	Expressed ☐
Road project stage	Planning ☐	Design ☐	Construction/I ☐
Degree of impact	Incremental ☐	Progressive ☐	

Green Road Practices found 145

GR objectives served: ● Core contributions ○ Secondary

Green Road Theme	Intervention Area	No.	Practice Name	1 C02	2 Res	3 W&L	4 Pol	5 QoL	6 Bio	7 Dis	8 Mat
. Decarbonization	1.1. Road Network Planning and Road Transport Management	1.1.1	Traffic management to limit peak hour congestion	●			○				
. Decarbonization	1.1. Road Network Planning and Road Transport Management	1.1.2	Optimize traffic signal timing	●			○	○			
. Decarbonization	1.1. Road Network Planning and Road Transport Management	1.1.3	Low Emission Zones (LEZ)	●			○	○			
. Decarbonization	1.1. Road Network Planning and Road Transport Management	1.1.4	Encourage mass transit (buses and trains)	●			○	○			
. Decarbonization	1.1. Road Network Planning and Road Transport Management	1.1.5	Facilitate the use of fuel-efficient vehicles	●							
. Decarbonization	1.1. Road Network Planning and Road Transport Management	1.1.6	Implement anti-idling ordinances	●			○				
. Decarbonization	1.1. Road Network Planning and Road Transport Management	1.1.7	Introduce electric vehicles (EVs)	●			○				

< > ... Project level | 1.1.1 | 1.1.2 | 1.1.3 | 1.1.4 | 1.1.5 | 1.1.6 | 1.1.7 | 1.1.8 | 1.1.9 | 1.2.1 | 1.2.2 | 1.2.3 | 1.2.4 | 1.2.5 | 1.3.1 | 1.3.2 | 1.3.3

2.6.1	Promoting Nature-based Solutions for roads
Description	Nature-based Solutions (NBS) can be defined as project solutions that are motivated and supported by nature and that may also offer environmental, economic, and social benefits, while increasing resilience. Nature-based solutions include both green and natural infrastructure. Nature-based solutions such as restoring wetlands, controlling drainage with bioswales, lining roads with planted trees in cities, and using cover crops to control erosion near roads can cost-effectively make transportation infrastructure more resilient to the impacts of climate change. Also, they could provide over a third of the mitigation needed to achieve the 2030 targets of the Paris Agreement. Agencies have begun integrating nature-based solutions into their work, but they are not yet utilized to their full potential. Nature-based solutions are fundamental to many of the “green roads” practices identified in this toolkit. Nature based solutions can be very cost effective, enhance local employment, be environmentally friendly and aesthetic, and have long-term value to infrastructure. They rely on natural vegetation and natural systems to help mitigate the impacts of climate change. A common thread among NBS techniques is that they provide a greater value than single-purpose traditional infrastructure to yield community and ecosystem benefits and enhance the resilience of the site.
Area of applicability	(see table below)

Geography and Climate	Mountainous	Flat	Arid	Tropical	Pacific Islands
	x	x	x	x	x
Standard of road	Low-Volume/rural	Paved highways		Expressed highways	Urban roads
	x	x		x	x
Road project stage	Planning	Design	Construction/Implementation		Maintenance
	x	x	x		
Degree of impact	Incremental	Progressive		Transformative	
		x			

Green Road objectives served	1 CO_2	2 Res	3 W&L	4 Pol	5 QoL	6 Bio	7 Dis	8 Mat	9 Inc	10 Con	11 Saf	12 Aff
		●	○		○	○						

Details of the good practice, incl. examples

Nature based solutions (NBS) involve a wide range of nature-related techniques that are both cost-effective and improve climate-related resilience in general and for infrastructure such as roads in particular. It is an integration of engineering with nature! These NBS solutions include but are not limited to:

- Using soil bioengineering such as vegetated structures and live stakes to stabilize roadway cut and fill slopes;
- Restoring floodplains and waterways near roads to prevent local flooding;
- Constructing bioswales and rain gardens in urban settings to prevent local street and area flooding;
- Constructing streets and paths in conjunction with detention or water retention ponds and wetlands areas adjacent to the infrastructure;
- Use of green roofs in urban area buildings to augment local green spaces;
- Planting trees along roads and streets;
- Using permeable pavers and grassy parking areas to enhance groundwater infiltration and reduce runoff;
- Acquiring land in flood-prone areas to allow floods to spread out and flow slowly, minimizing damage to local infrastructure;
- Selecting and managing trees and plant ecosystems that are not vulnerable to fires;
- Restoring sand dunes and mangroves in coastal areas to prevent coastal flooding;
- Avoiding building “ring roads” around coastal islands that often destroy natural coastal vegetation; and
- Installing culverts such as “stream simulation” designs that replicate natural stream channel characteristics through the culvert.

Photos/Graphics

SOIL BIOENGINEERING MEASURES INCLUDING LIVE VEGETATED STRUCTURES AND LIVE STAKES

ROADSIDE VEGETATION AS A BUFFER ALONG STREAMS AND NURSERIES FOR NATIVE VEGETATION IN A ROAD PROJECT

GREEN ROOFS AND BIOSWALES OR RAIN GARDENS ALONG URBAN STREETS

Enabling factors

Improved Design Standards	x	Public Awareness and Education:	x
Modified Tendering Procedures	x	Collaborative Partnerships	x
Policy Development		Roadmaps for Green Roads	x
Environmental Standards	x	Supply systems: available Resources and Materials	x
Regulatory Frameworks		Application of New Technologies	x
Improved Planning Systems		Connection with other programs	x

Costs/benefits

Many nature-based solutions are relatively inexpensive because they involve use of natural vegetation. Also, hazard mitigation using NBS can provide many economic, social and environmental benefits beyond the benefits from traditional flood mitigation projects.

Some components of nature-based solutions may have higher upfront costs (e.g., design for nature-based features, increased permitting coordination, higher contingency). However, nature-based solutions are often preferred alternatives for the cost-savings that are typically seen when compared with solely gray (traditional) infrastructure-based solutions over the long-term.

Challenges to implementation of NBS include building sustainable solutions; getting community involvement in projects; developing technical guidance and standards or regulations for use; and education needed to teach basic concepts of nature-based projects.

Remarks/further reading or viewing

Gray, D.; Sotir, R. 1996. Biotechnical and soil bioengineering slope stabilization-A practical guide for erosion control. New York, NY: A Wiley-Interscience Publication, John Wiley and Sons, Inc. 378 p. (ISBN 0-471-04978-6).

Howell, J. 1999. Roadside Bio-engineering Reference Manual. Department of Roads. His Majesty’s Government of Nepal. Kathmandu. 218p.

B. Webb; S. Douglass; B. Dix:; S. Asam. 2018.White Paper: Nature-Based Solutions for Coastal Highway Resilience. FHWA-HEP-18-037.
Federal Highway Administration, ICF, and South Coast Engineers,
Washington, DC 20006

Environmental Protection Agency.2023. Different Shades of Green. Green Infrastructure Research at the U.S. Environmental Protection Agency Brochure.
https://www.epa.gov/green-infrastructure

Steinfeld, D.; Riley, S.; Wilkinson, K.; Landis, T.; and Riley, L. 2007. Roadside Revegetation: An Integrated Approach to Establishing Native Plants. FHWA-WFL/TD-07-005, Federal Highway Administration, Vancouver, WA. and Umatilla National Forest, Pendleton, Or. 424p.

The Nature Conservancy. 2023. Promoting nature-based
hazard mitigation through FEMA mitigation grants. Joint publication from TNC and AECOM.

Matthews, J; DelaCruz, E. 2022. Integrating Nature-Based Solutions for Climate Change Adaptation and Disaster Risk Management: A Practitioner’s Guide. Asian Development Bank, Manila, Philippines.
https://www.adb.org/publications/nature-based-solutions-climate-change-adaptation-disaster-risk-management

Thank you

Dr Ian Greenwood
ADB Consultant &
Greenwood Associates Infrastructure Consultants
igreenwood.consultant@adb.org
ian@gaic.nz