Dam Resilience Research Programme (DRRP)

Understanding the whole-life performance of our dams in a seismic setting

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Outline

1. Introduction/context
2. Criticality of embankments in New Zealand
3. NZ-specific challenges to embankment resiliency
4. Research: geotechnical vulnerabilities
5. NZ embankment resilience

1 – Introduction/Context

Performance deficiency Photo: BCHydro

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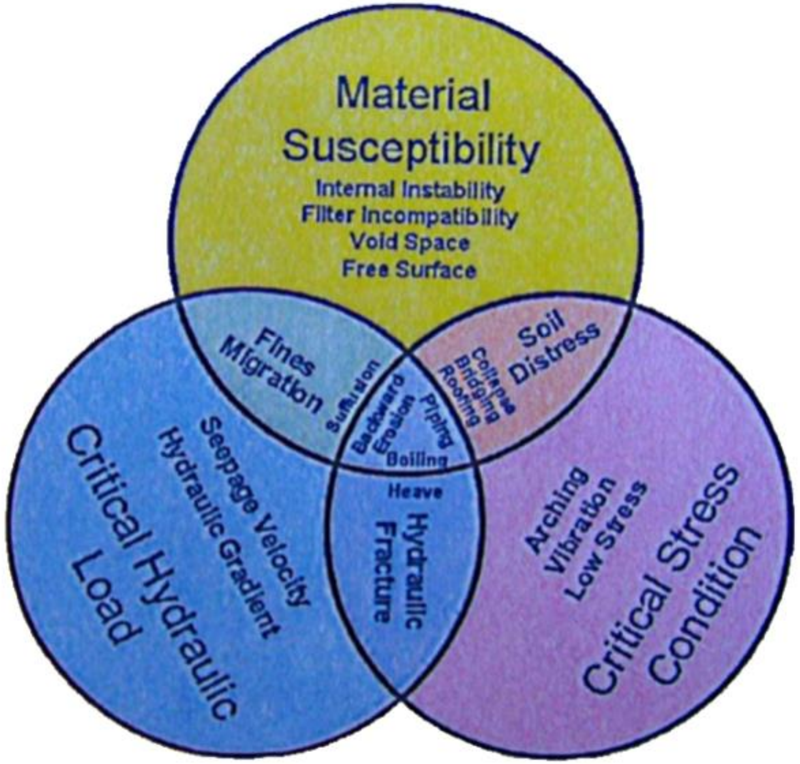
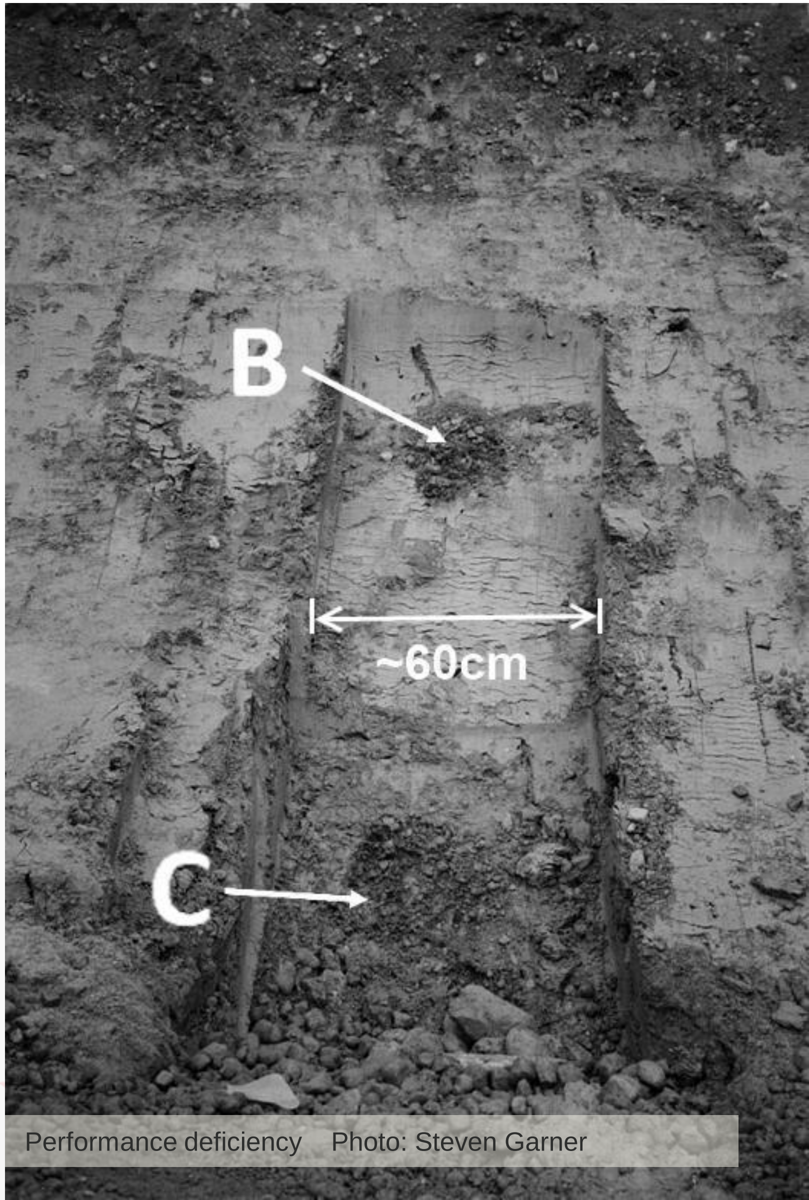


Figure 2.1: Controlling factors and internal erosion mechanisms (Garner and Fannin, 2010).

Performance deficiency Photo: Steven Garner



Performance deficiency Photo: Steven Garner

Dam Resilience Research Programme

International research groups

(Internal instability, scale modelling)

UC University of Canterbury · The University of Auckland

Laboratories, faculty, staffing, students, projects

- Geology
  (project collaborations)
- Geography
  (project collaborations)

GRI

External linkages

Ministry for the Environment

Ministry of Business, Innovation & Employment

New Zealand Society on Large Dams

- Councils
- UBC (Vancouver)
- Sheffield (UK)
- Others via ICOLD EWG

Peter Amos

DAMWATCH

genesis

meridian

Mercury

Trust power

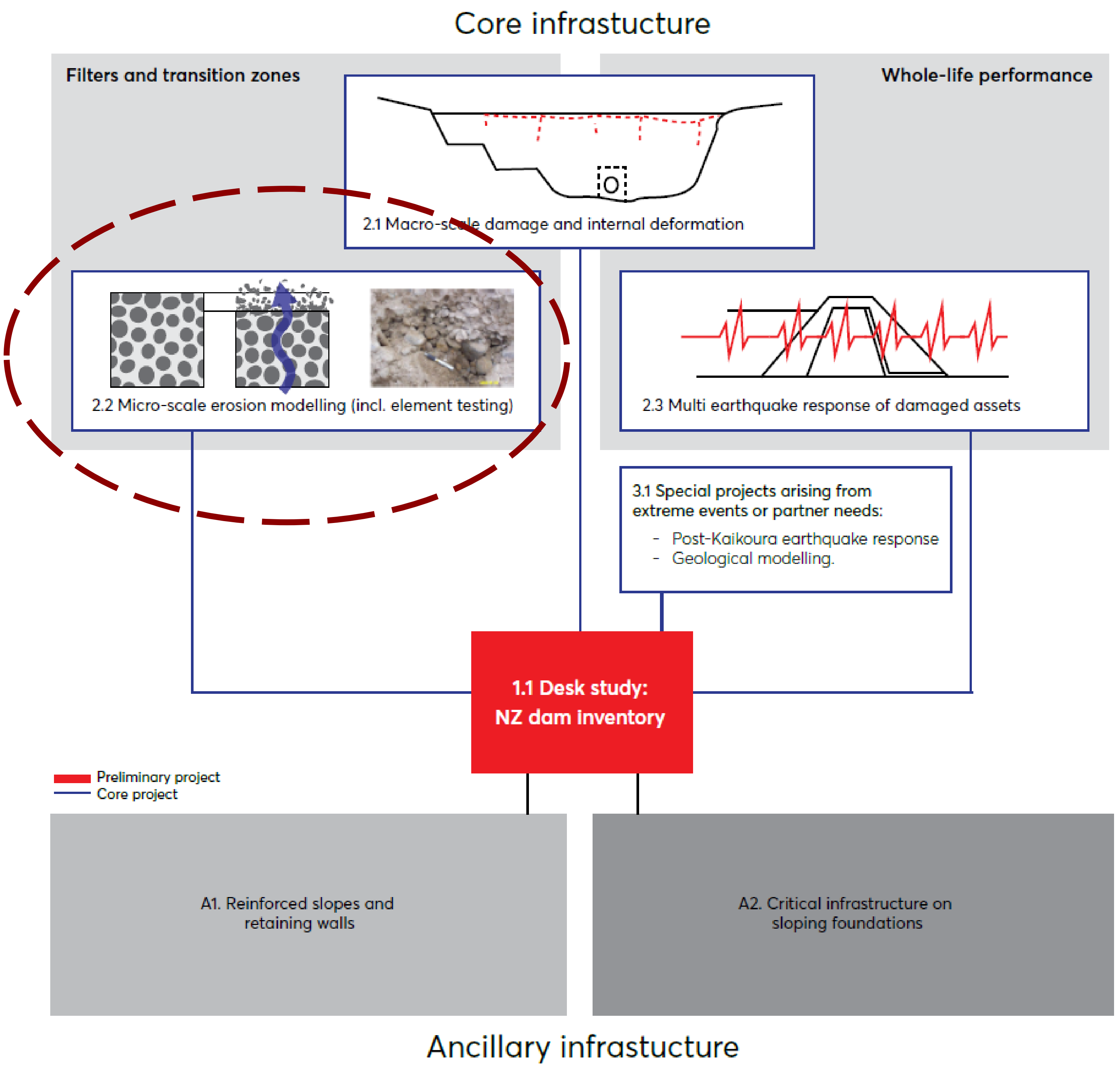
Programme Steering Committee

Stopbanks/levees

Resilience to Nature's Challenges – Kia manawaroa – Ngā Ākina o Te Ao Tūroa – National Science Challenges

The University of Auckland – Te Whare Wānanga o Tāmaki Makaurau – New Zealand

+ Regional councils, Unitary Authorities


Core infrastructure
Filters and transition zones
Whole-life performance
2.1 Macro-scale damage and internal deformation
2.2 Micro-scale erosion modelling (incl. element testing)
2.3 Multi earthquake response of damaged assets
3.1 Special projects arising from extreme events or partner needs:
- Post-Kaikoura earthquake response
- Geological modelling.
1.1 Desk study: NZ dam inventory
Preliminary project
Core project
A1. Reinforced slopes and retaining walls
A2. Critical infrastructure on sloping foundations
Ancillary infrastructure

NZID/NZIS: Verification of research focus

1. **Material susceptibility**
   - Age, geology
   - Location, construction dates (design standards)
2. **Hydraulic loading**
   - Reservoir depth
   - Embankment height, geometry
3. **Stress conditions**
   - Overburden, compaction conditions, geometry
   - Embankment height
4. **Criticality/priority structures**
   - Potential Impact Classification, height, reservoir size, function, location

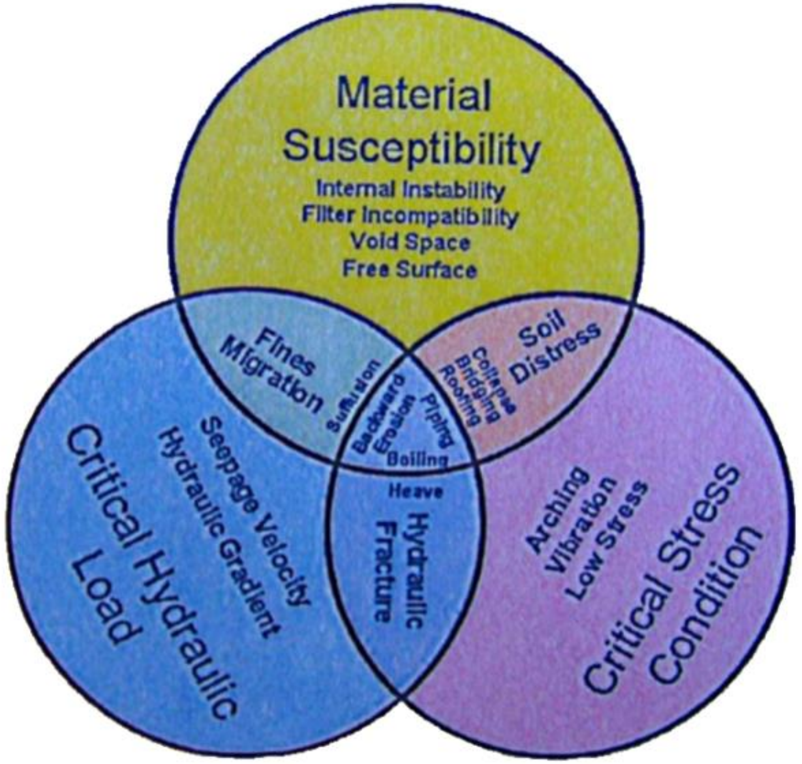
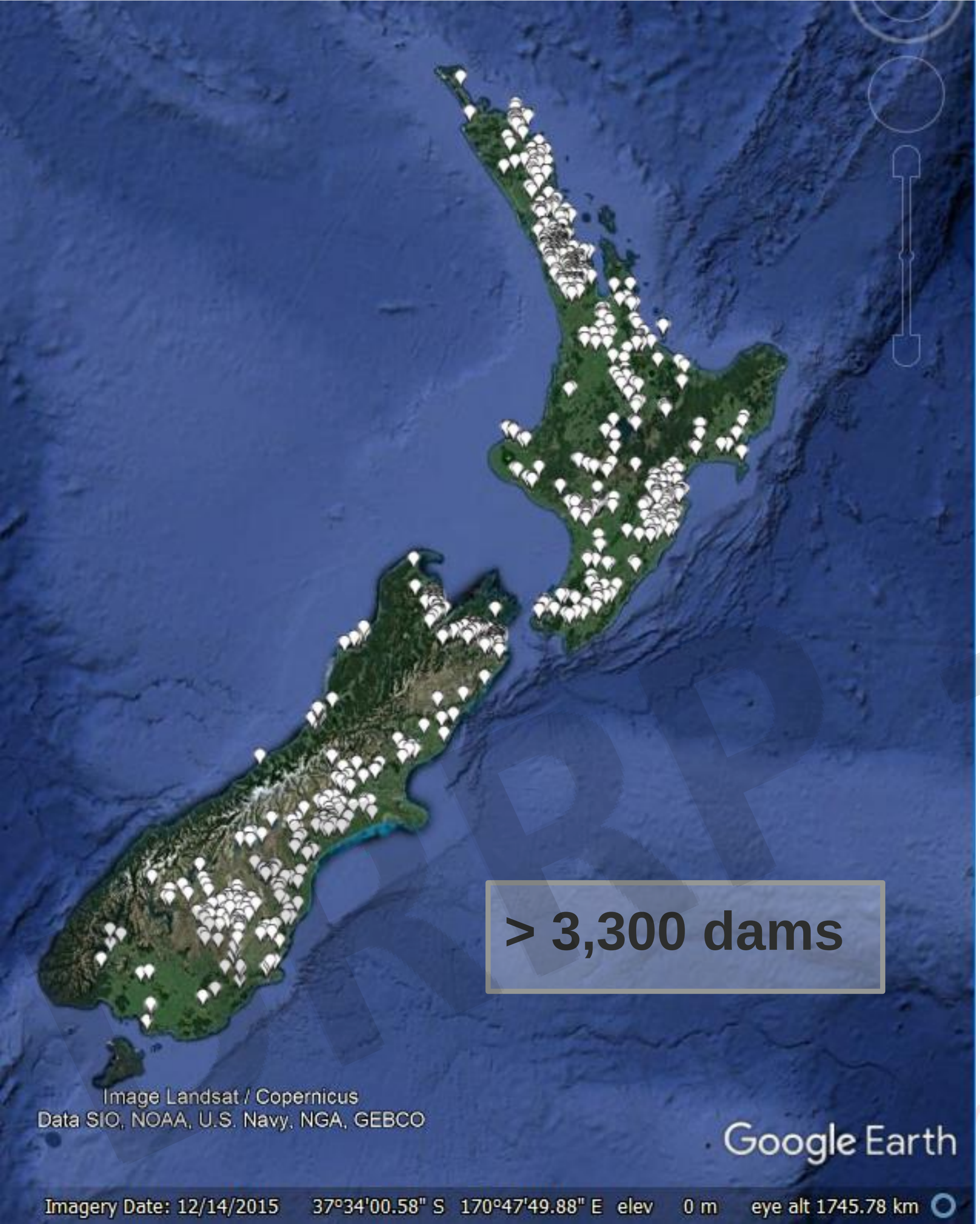
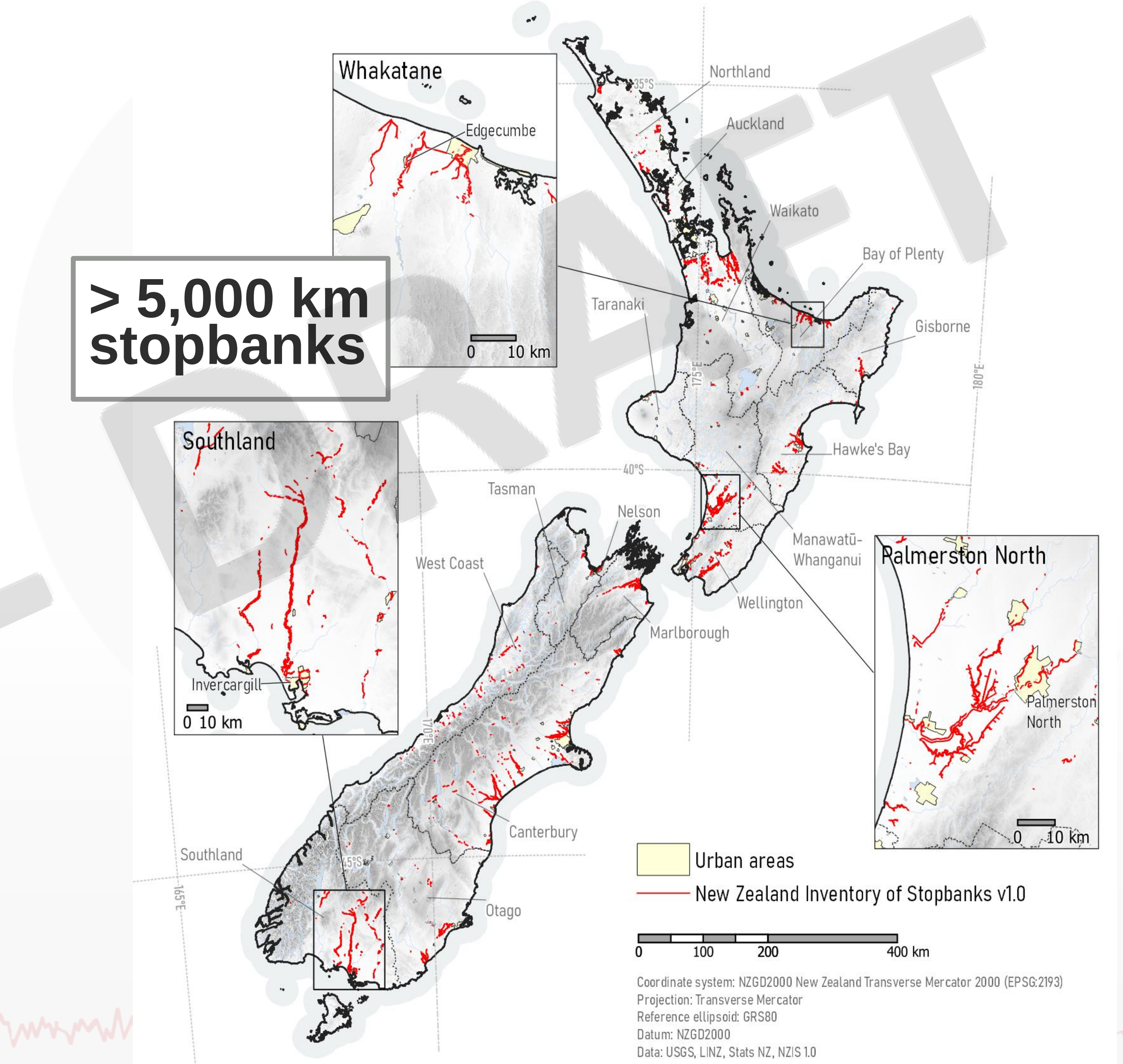


Figure 2.1: Controlling factors and internal erosion mechanisms (Garner and Fannin, 2010).

2 – Embankments in Aotearoa

NZ Inventory of Dams (NZID), NZ Inventory of Stopbanks (NZIS)

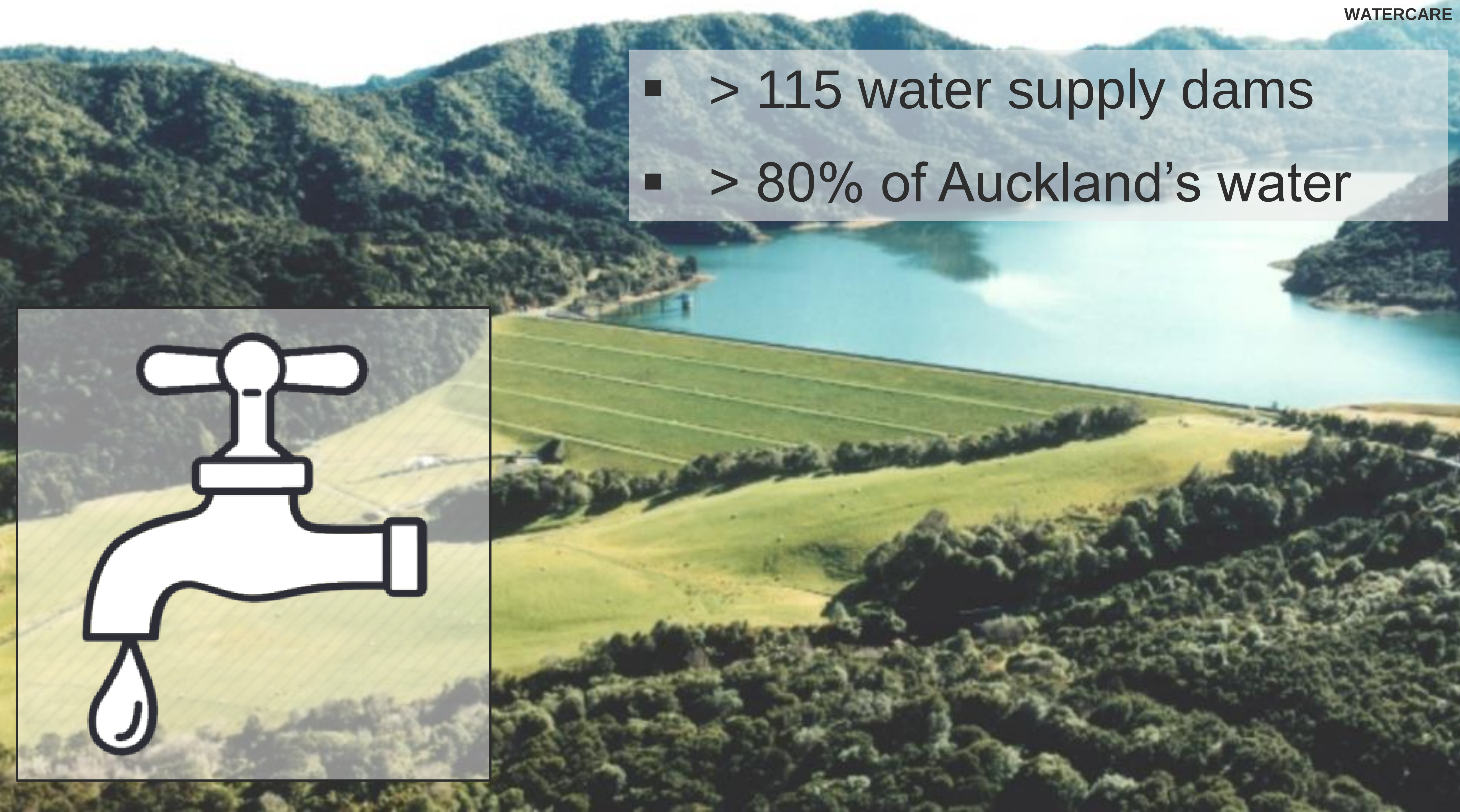




Crawford-Flett, Blake, Pascoal, Wilson, Wotherspoon (forthcoming) *A standardised inventory for New Zealand's stopbank (levee) network and its application for natural hazard exposure assessments*

- > 125 hydroelectric dams
- 55-60% of electricity

- > 115 water supply dams
- > 80% of Auckland’s water

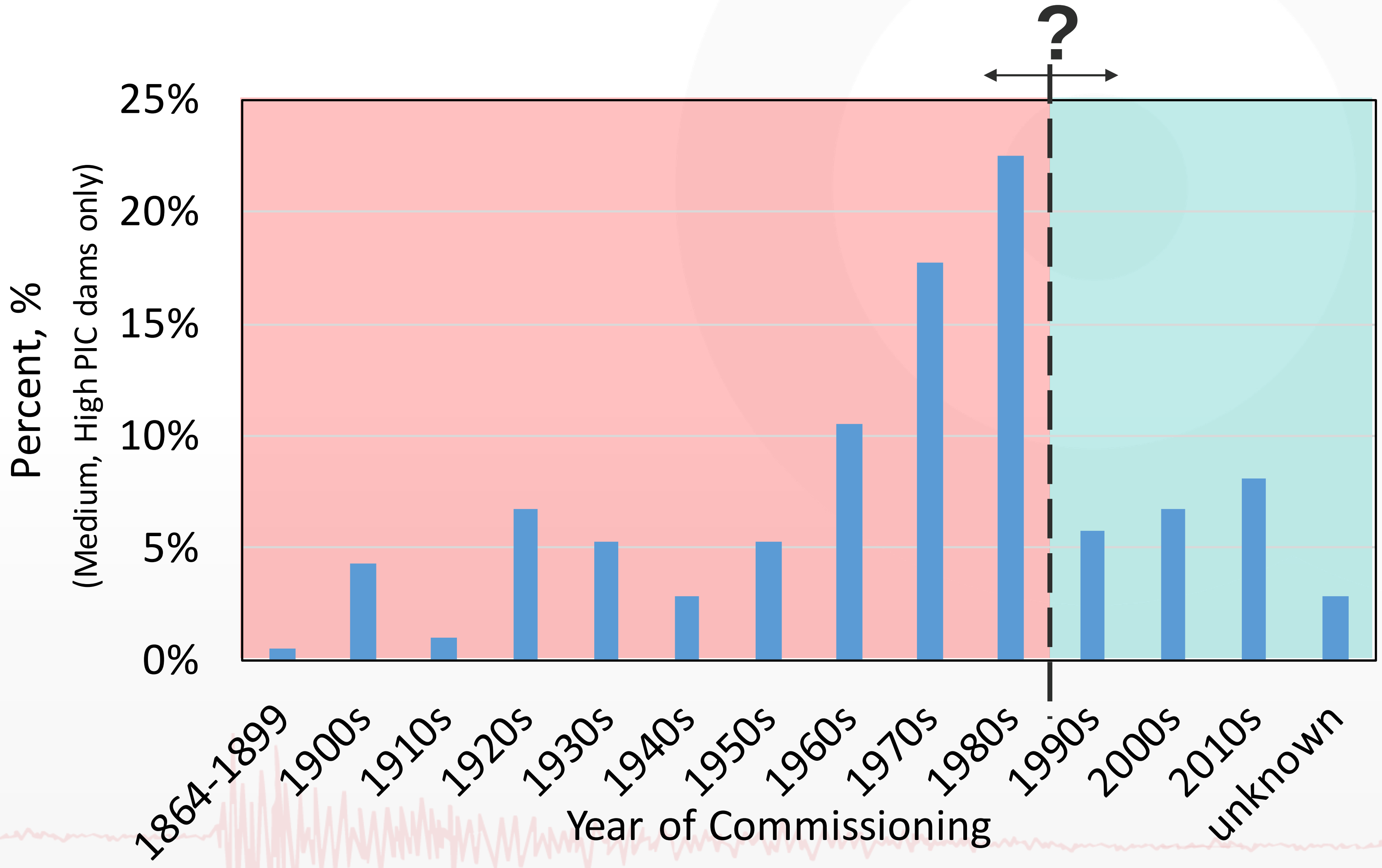


- > 1300 agricultural/pastural dams
- Veges, fruit, meat, milk, wine…

- > 600 - 1000 flood protection dams
- > 500 dams protecting urban Auckland

…Plus an additional > 5,000 km + stopbanks/levees

Our dams are (typically) 'old'



Challenges to Understanding Embankment Resiliency

NZ-specific challenges for assessment of particle migration mechanisms

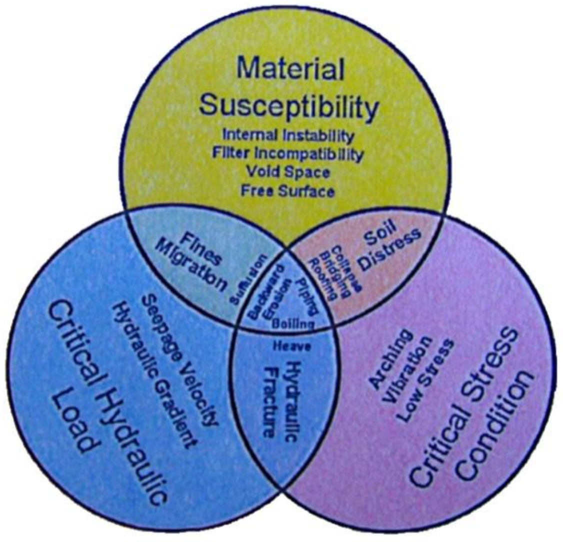
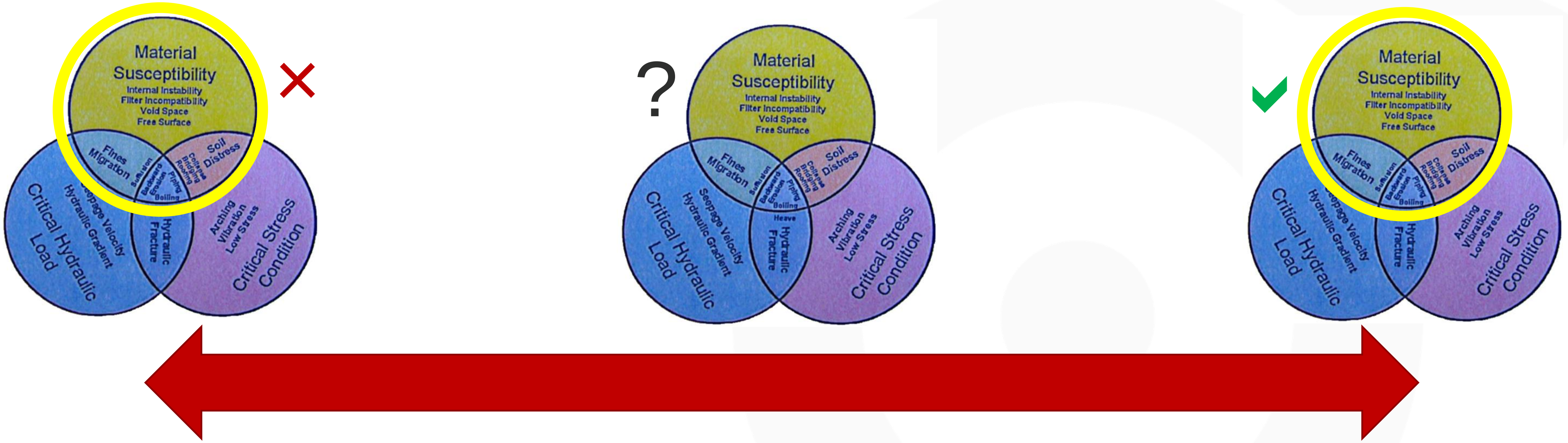


Figure 2.1: Controlling factors and internal erosion mechanisms (Garner and Fannin, 2010).

1. **Material susceptibility**
   - Highly-variable geology
   - Many very widely-graded soils (particularly core, filter zones)
   - Do published methods apply to volcanically-derived soils?
2. **Stress conditions**
   - State-of-practice criteria for particle migration do not address seismic conditions.
   - Earthquake-aftershock sequencing, and cumulative impacts of seismic loading (whole-life performance).

- **ALSO:** De-centralised stewardship/knowledge in both dam and stopbank space since 1980s

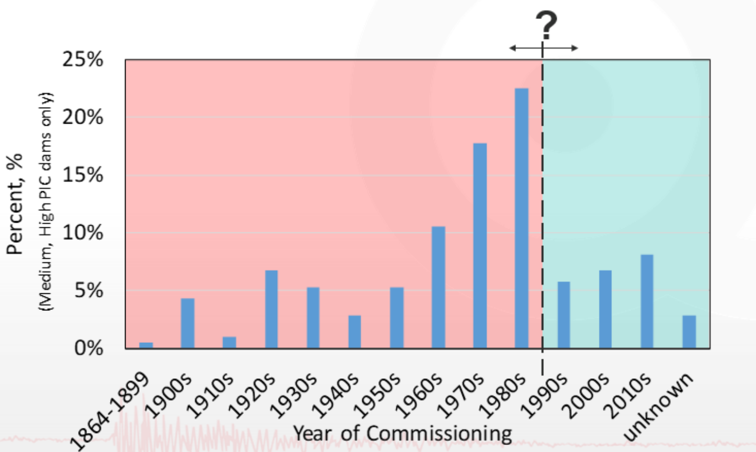


Continuing Erosion

"Common sense"?

Some (?) Erosion

Dams that do not meet modern design criteria?



No Erosion

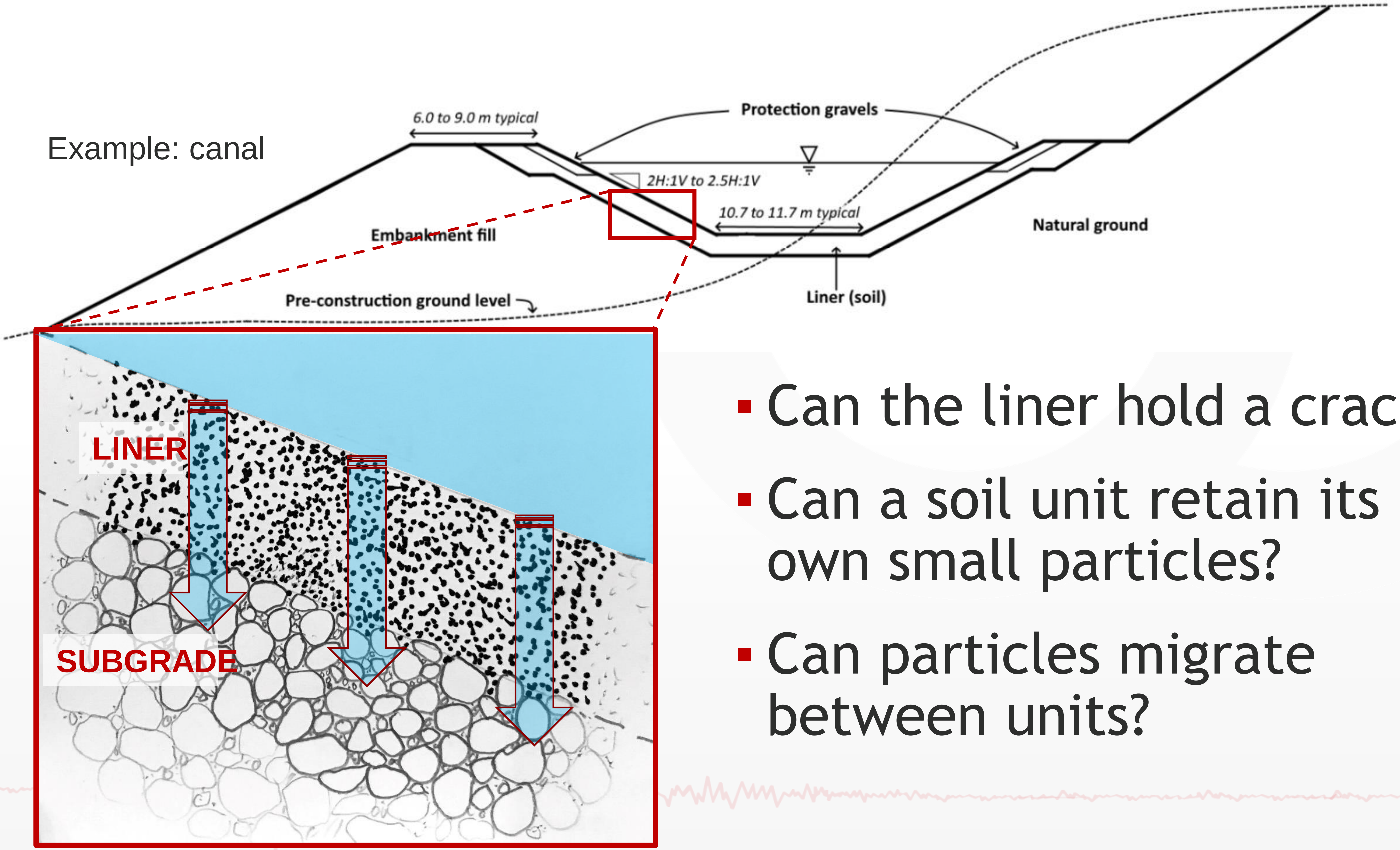
Modern design criteria (post 1990)

Research: Geotechnical vulnerabilities

- **Crack-holding potential:** can the earthfill sustain a crack?
- **Internal stability:** can a soil unit retain its own small particles?
- **Filter compatibility:** can soil particles migrate between fill zones?

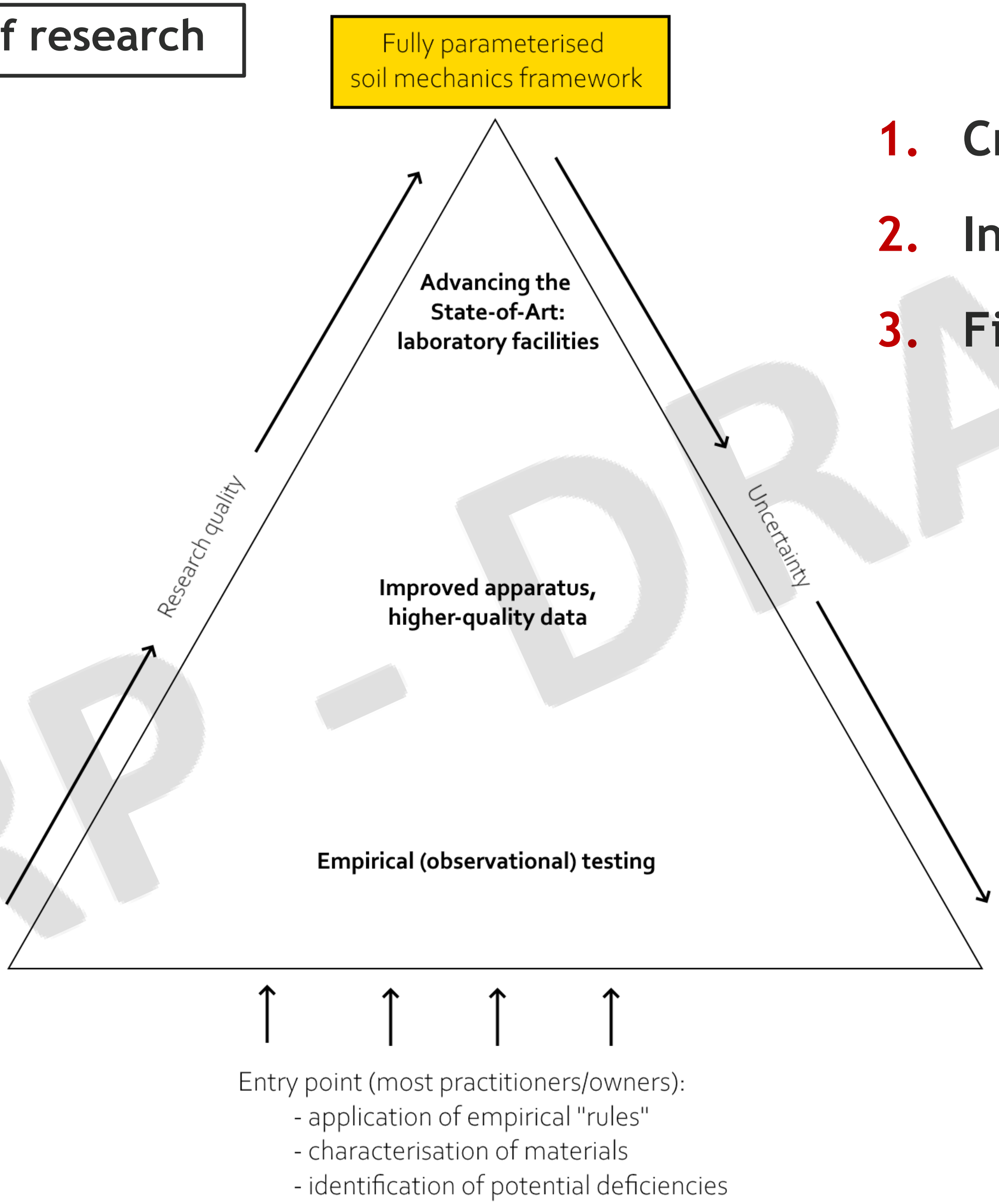
No standardised testing procedures exist

Example: canal



- Can the liner hold a crack?
- Can a soil unit retain its own small particles?
- Can particles migrate between units?

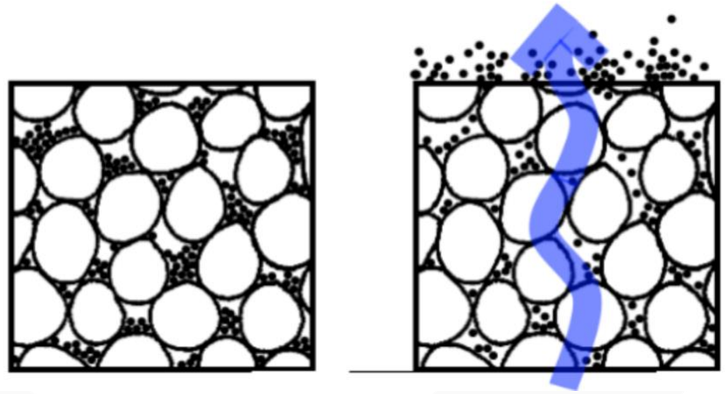
Non-standardised tests: path of research



1. **Crack-holding potential**
2. **Internal stability**
3. **Filter compatibility**

What does this look like? Observational testing:

- Stopbank/riverbed/dam fill/foundation... etc...



Non-standardized empirical/observational tests:

Limited range of soils

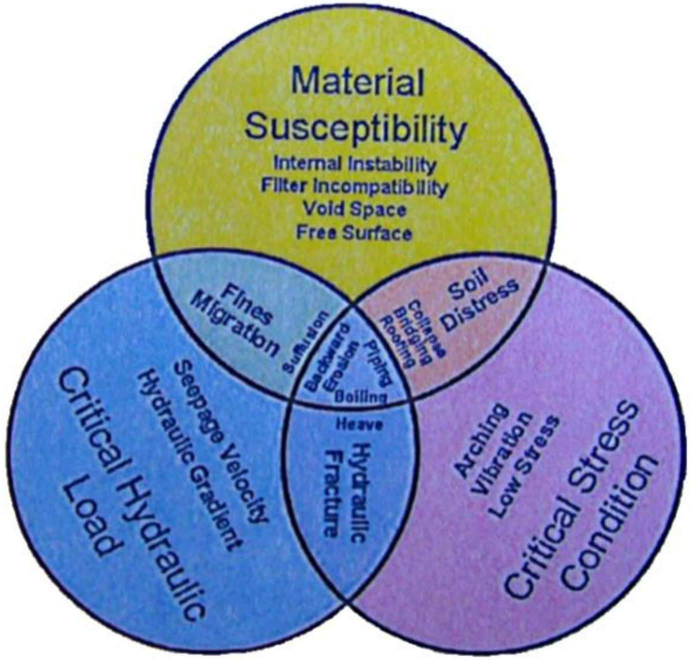


Figure 2.1: Controlling factors and internal erosion mechanisms (Garner and Fannin, 2010).

Basic seepage (downward flow)
× Poorly quantified/controlled

× Stress states unknown

Pointy end: Dynamic Triaxial Permeameter (TXP)

- Designed to accommodate wide range of NZ dam soils

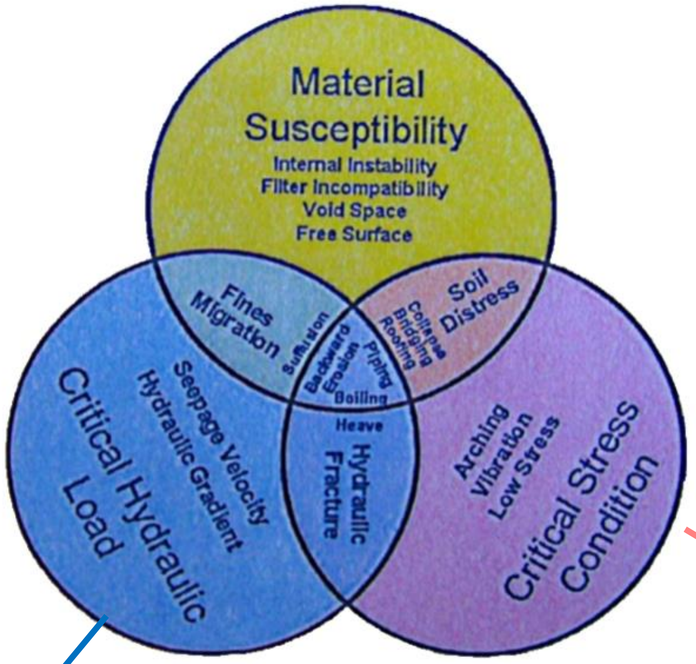
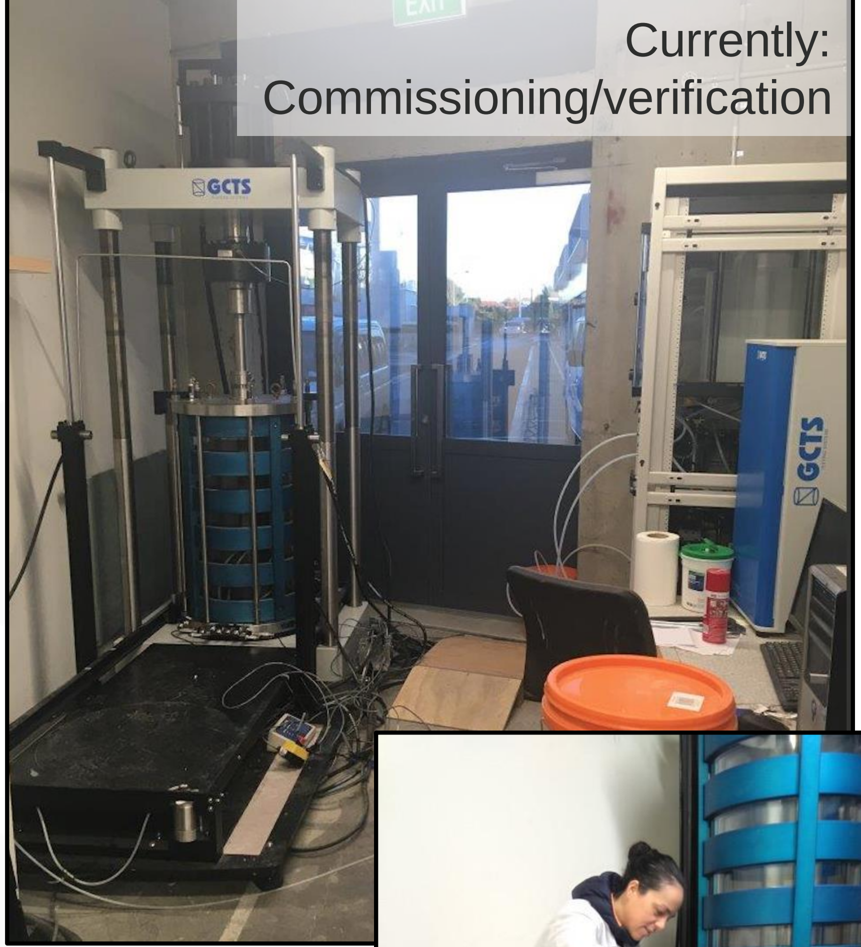


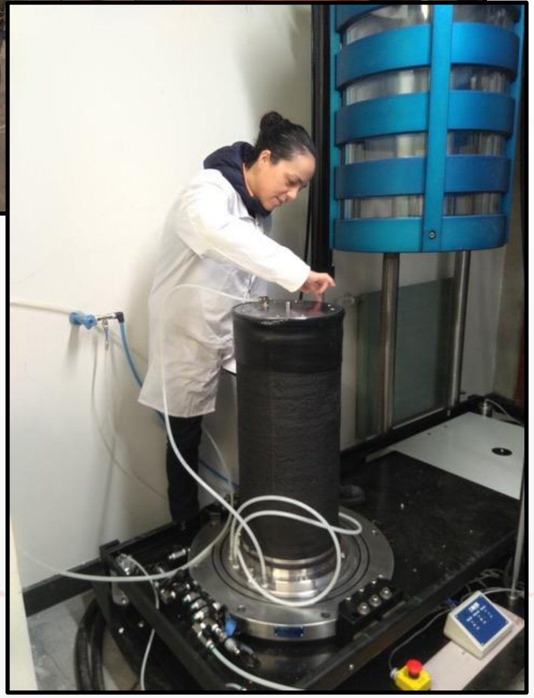
Figure 2.1: Controlling factors and internal erosion mechanisms (G

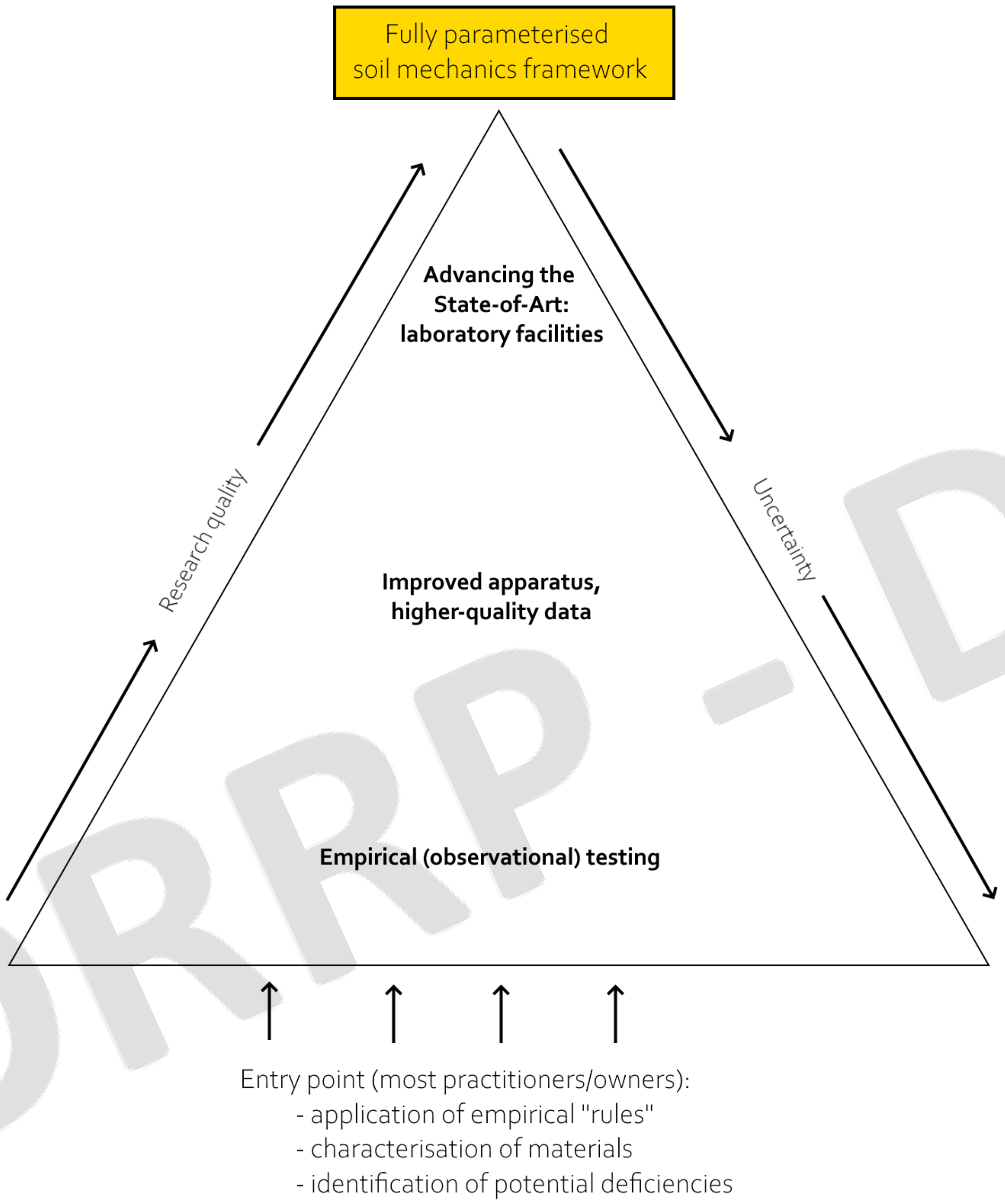
- Seepage capability/control (downward flow),
- Capacity for particle migration

- Triaxial stress control/quantification
- Static and dynamic stress states

Currently: Commissioning/verification







1. Crack-holding potential
2. Internal stability
3. Filter compatibility

Findings to date: outdated concepts (?)

INITIATION →	CONTINUATION →	PROGRESSION →	BREACH/FAILURE
Concentrated leak forms and erosion initiates along walls of crack	Continuation of erosion	Enlargement of concentrated leak	Breach mechanism forms

INITIATION	CONTINUATION OR FILTRATION	PROGRESSION	BREACH
Concentrated leak forms, erosion initiates along walls of crack	Continuation of erosion or Arrest of erosion by filtration	Enlargement of concentrated leak	Breach mechanism forms

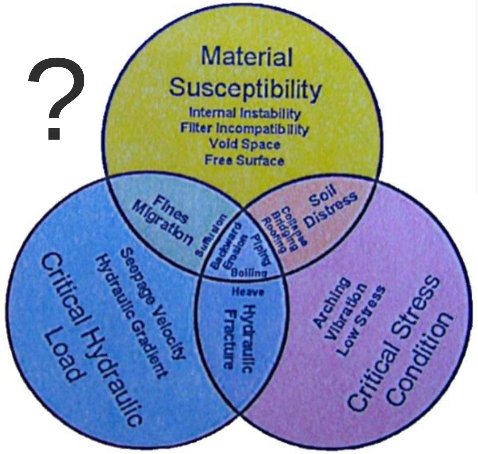
Bridle, 2014

FOUR PHASES OF INTERNAL EROSION IN THE EMBANKMENT INITIATED BY EROSION IN A CONCENTRATED LEAK

Findings to date: meta-stability

Observations and information from Tekapo Canal were assessed to better understand the active internal erosion behaviour. Stable and unstable cyclic behaviour has been denoted as “meta-stable” internal erosion behaviour… **Understanding of the meta-stable internal erosion behaviour is prerequisite to assess dam safety conditions**, risks of failure, and possible mitigation requirements… (Benson, 2011)

… in the case of dams with filters coarser than no-erosion filters, **the filtering action often leads to a meta-stable condition or partial seal such that erosion can re-occur as new pathways break out** into the adjoining ‘unsealed’ portions of the core-filter interface. (Foster, Ronnqvist, Fell, 2018)



Continuing Erosion

"Common sense"?

Some (?) Erosion

Dams that do not meet modern design criteria?

understanding "META-STABILITY"

No Erosion

Modern design criteria (post 1990)

NZ embankment resilience

Understanding Aotearoa embankments

Understanding the state-of-the-nation for dams and stopbanks

- National inventories and collective industry structure (dams project, council SIG) following decentralisation of flood control and hydropower assets across 1980-1990s
- National priorities and key knowledge gaps

Understanding aging assets that don’t meet modern geotechnical design criteria

- Crack-holding properties? Internal stability? Filter compatibility?
- Lab testing – observational -> increasing sophistication/quantification -> State of Art
- Other characterisation (standard) geotechnical tests
- Align further with wider infrastructure, hazard, and climate change research groups

Research outputs

- Enhance local capabilities (international collaboration)
- Specific research to address gaps in knowledge
- **Science-based decision support tools for industry**

Grateful thanks to our partners

Meridian.

Trust power.

genesis

Mercury

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND