FLUVIAL HAZARDS AT THE TOP OF THE LAKE

LIVING WITH RIVERS ON THE EDGE

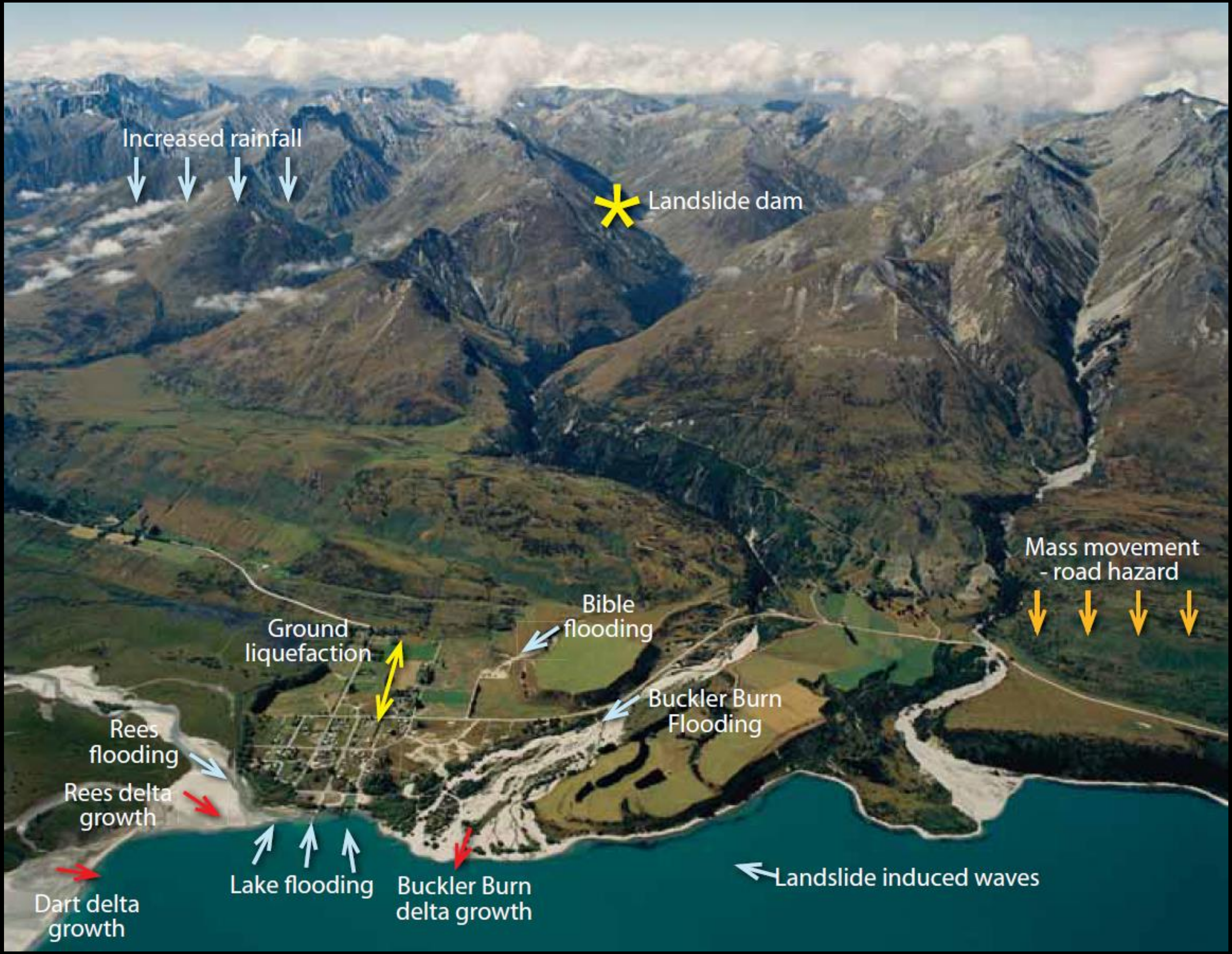
PROFESSOR JAMES BRASINGTON

Waterways Centre for Freshwater Management

THE GLENORCHY HAZARDSCAPE

Complex array of seismic, mass movement and flood hazards

Coupled or '*cascading*' hazards



FLUVIAL HAZARDS

If not the most catastrophic threat … rivers pose the **most frequent hazard** to the lakeside communities

Risks to **life, property and critical infrastructure**

- Direct inundation and swift water hazards
- Entrained debris and sediment
- Bank and stream erosion

Unlike other natural hazards … at Glenorchy we expect **fluvial hazards to increase in frequency and severity in the coming decades**

FEBRUARY 4TH 2020; c/o LUKE HUNTER

FAR FROM EQUILIBRIUM

DRIVER 1: CLIMATE CHANGE

- 0.5-1.5 ^{o}C by 2040; 0.5-3.5 ^{o}C by 2090
- 20-40% increase in winter rainfall and intense storms
- Up to 100% increase in mean annual flood flow

DRIVER 2: RIVER BED AGGRADATION

- Build up of riverine sediment
- Reduces the cross-sectional area
- Reduces the gradient of the river

→ **REDUCED FLOOD CAPACITY**

REES-DART DELTA, DECEMBER 2009

LEGACY IN THE LANDSCAPE

> 20 major glaciations affecting the Southern Alps in the last 2.6 million years

- Carved deep parabolic – (u-shaped) valleys

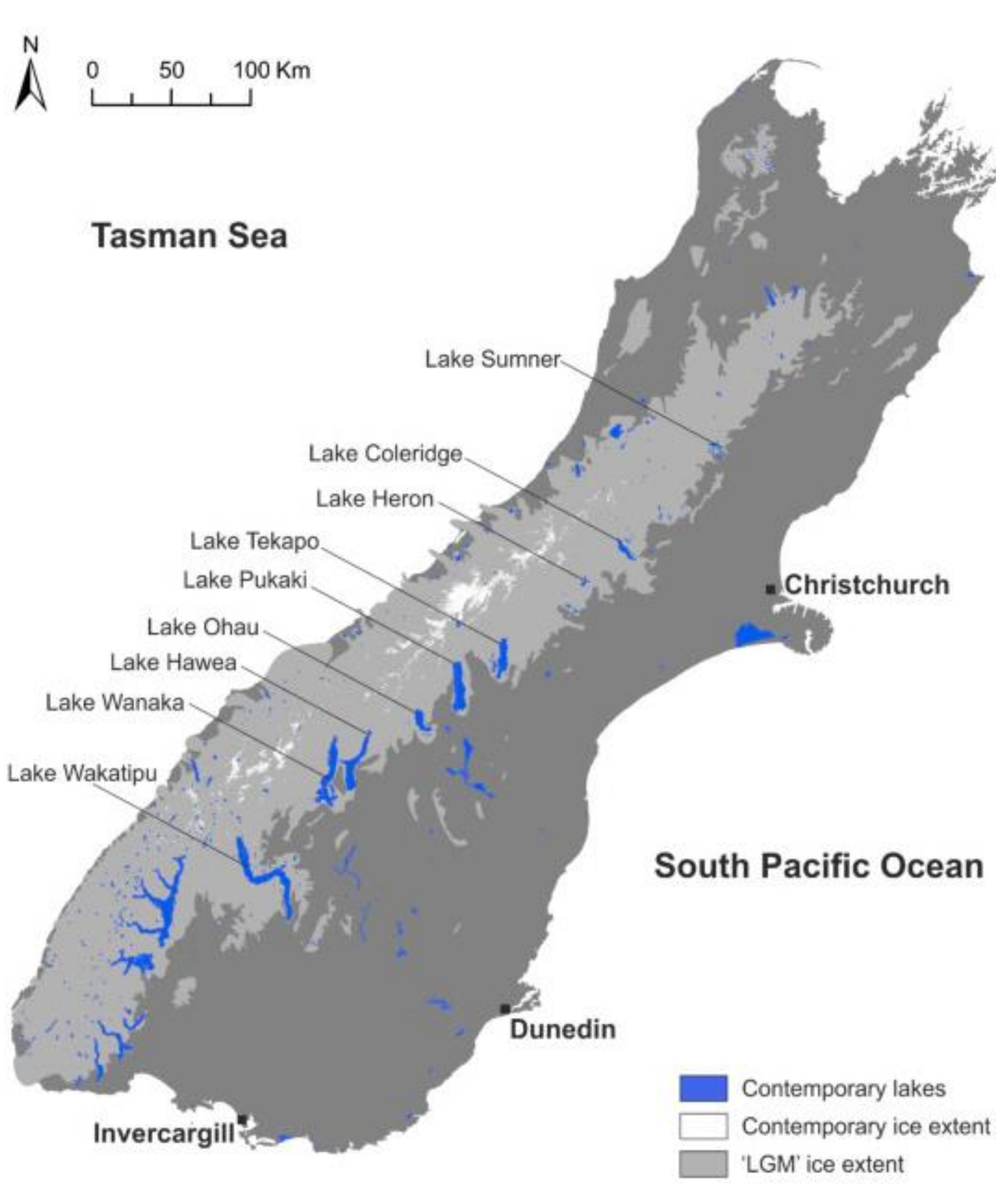
Deglaciation > lake formation *c*. 18,000 ka

- Impounded by large terminal moraines

Lake levels adjusted over time in response to downcutting and re-routing of the outlet

- 360 m > 309 m
- Connecting upstream to Diamond Lake

Cook, Quincey, Brasington 2013; Sutherland et al., 2020



ICE EXTENT AT THE LAST GLACIAL MAXIMUM (28-35 Ka)

LEGACY IN THE LANDSCAPE

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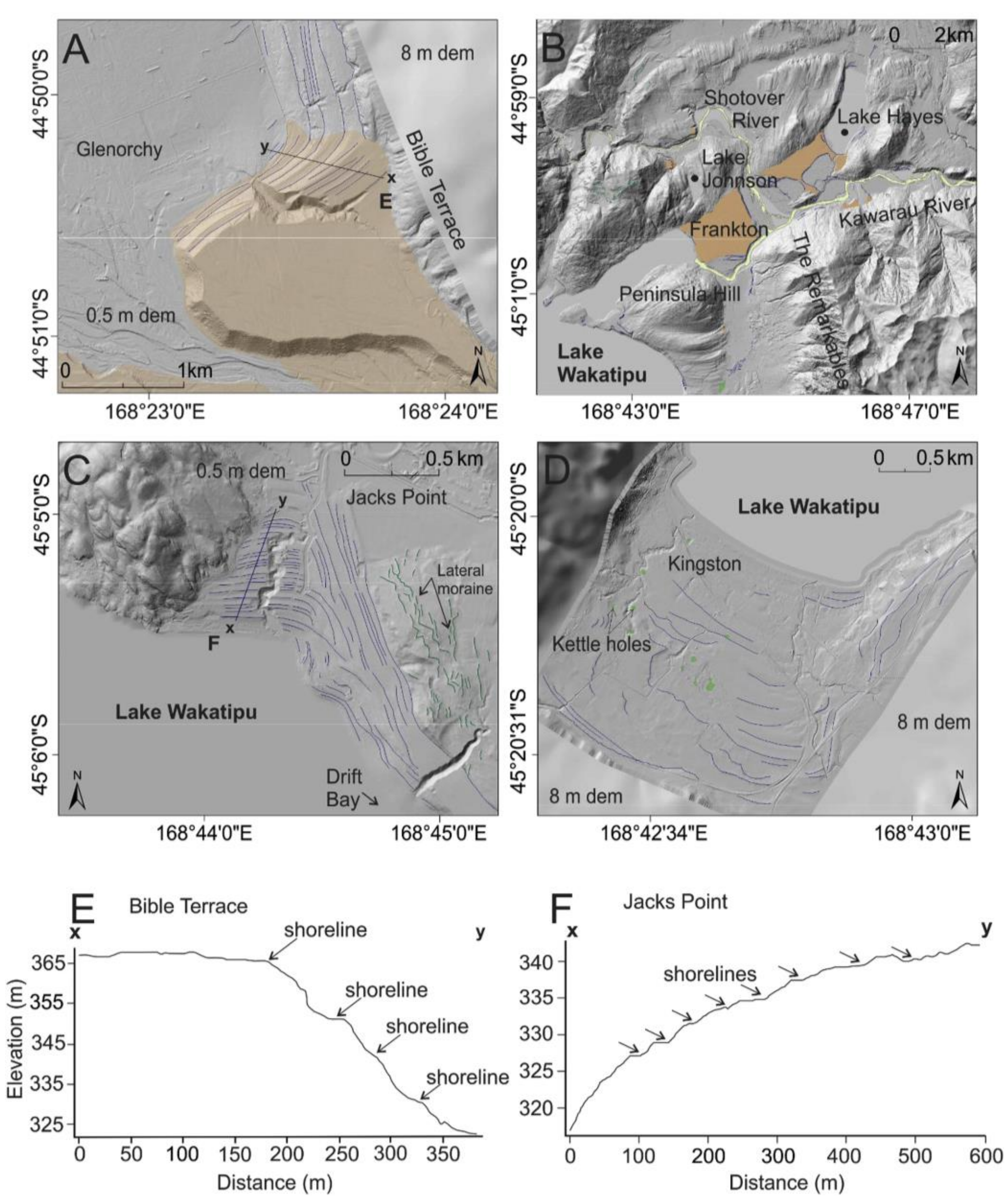

after Sutherland et al., 2020

AGENTS OF EROSION

Globally extreme rates of erosion

- Glacial legacy > oversteepened slopes
- Continuing uplift > 5 mm / year
- Orographic precipitation > 5000 mm / year

Unstable ‘paraglacial’ landscape

- Catchment dominated by active landslides
- Retreating headwater glaciers

‘*Unlimited*’ sediment availability

- More sediment available than the capacity of the rivers to transport it downstream
- *Transport limited* catchment system

TE HORO | SLIP STREAM, MAY 2014

A LIVING LANDSCAPE

Valleys infilled with extensive fluvial sediments

- braided rivers
- boreholes to > 50 m
- Likely 100s m fill

Lower reaches

- As the lake drained progressively to 309 m, Dart and Rees Rivers combined to create a large alluvial delta

ADVANCING delta

- 120 m over last 50 years
- 2-3 m per year

ACTIVE DEBRIS FAN, SLIP STREAM, MAY 2015

A LIVING LANDSCAPE

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REES-DART LOOKING TOWARDS MT ALFRED, MAY 2015

A LIVING LANDSCAPE

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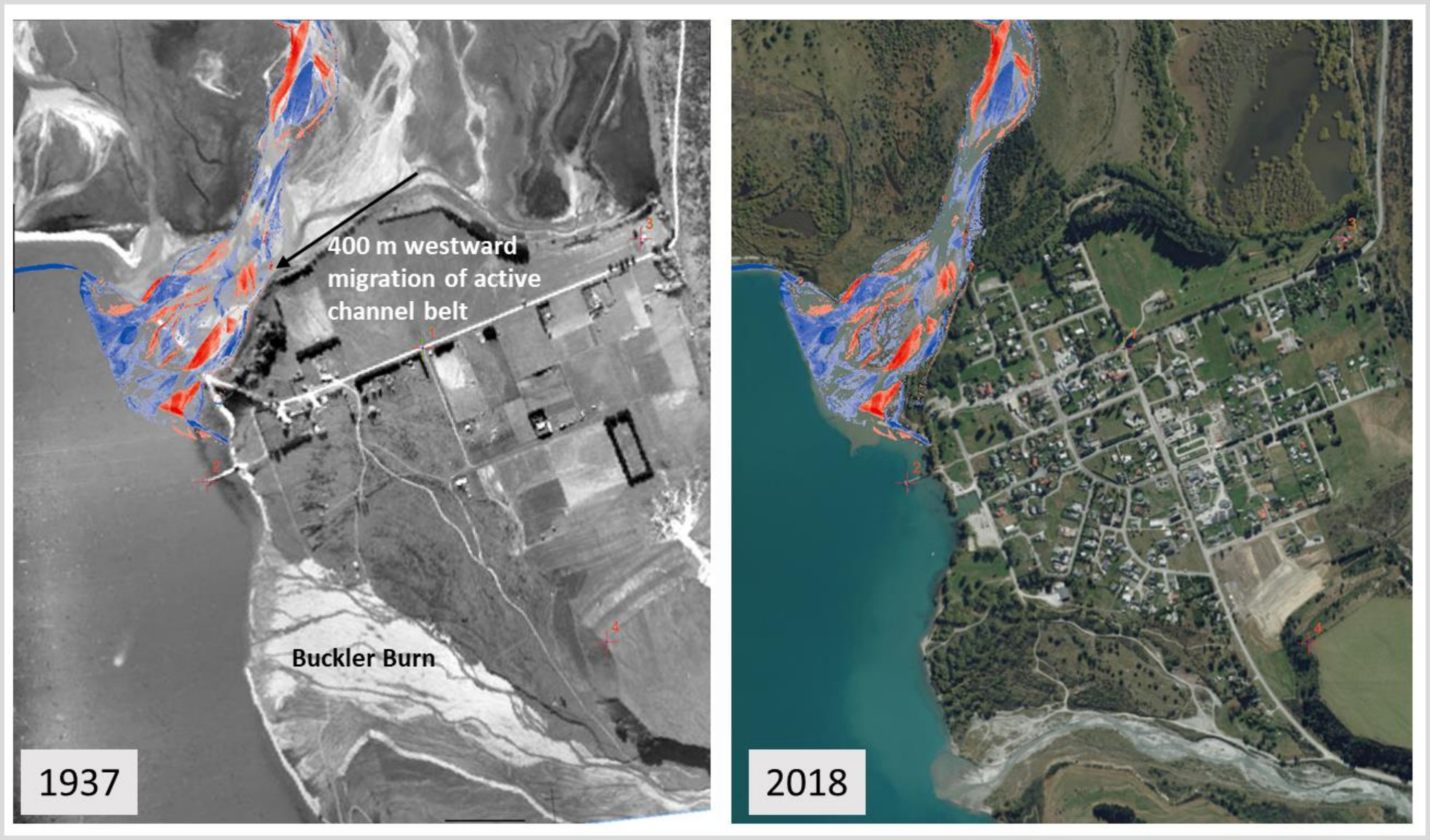
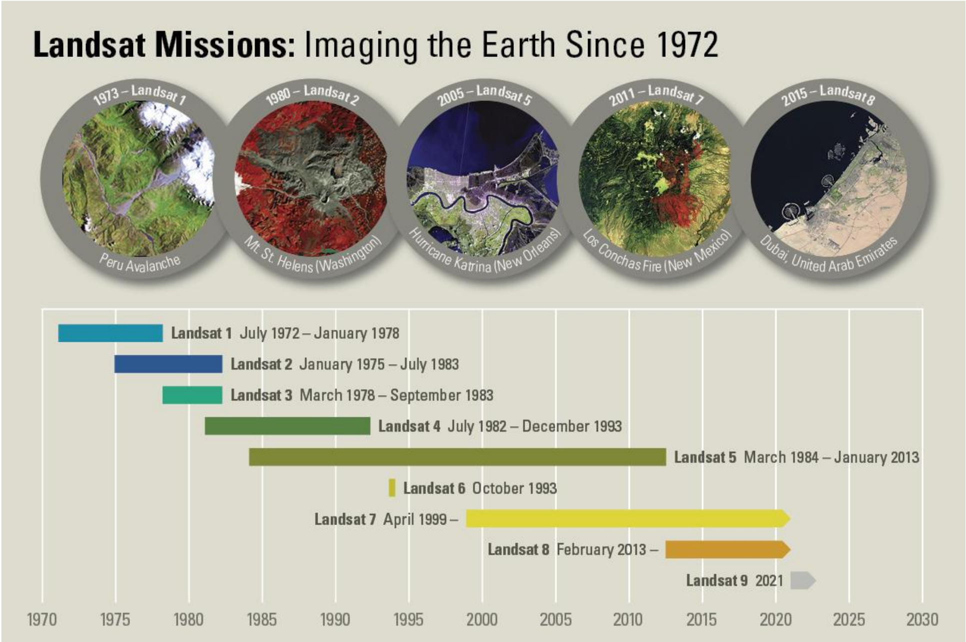
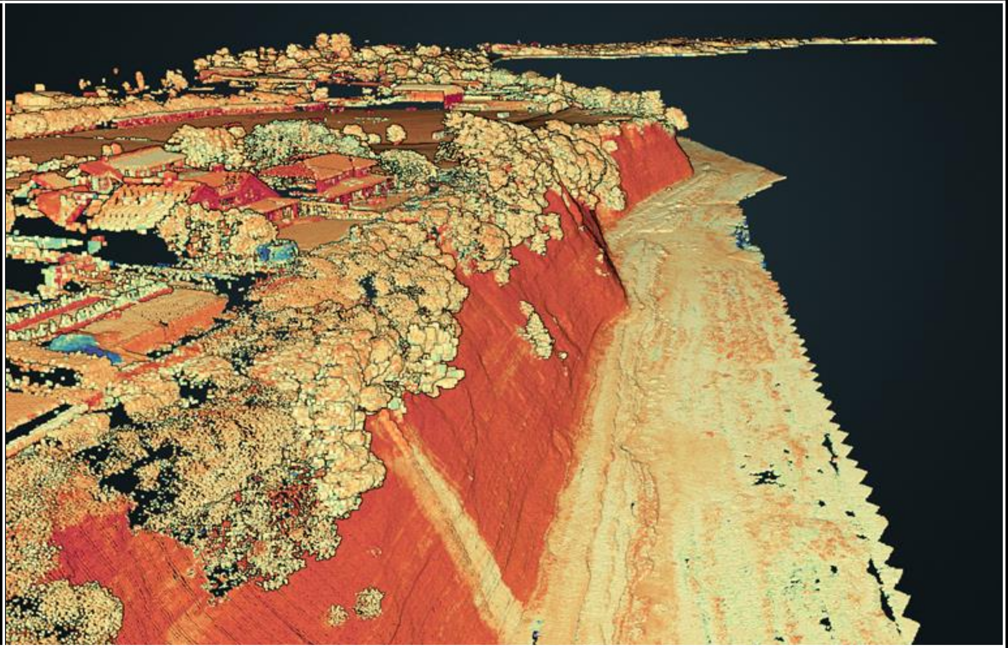


SHINING NEW LIGHT ON RIVERSCAPES: BEAM ME UP SCOTTY …





EARTH OBSERVING SYSTEMS AND SATELLITES

- Metric aerial photography since 1940s
- LANDSAT since 1973
- Archives of environmental change

NEXT GENERATION SPACE TECHNOLOGIES

- 30-80 cm imagery
- Stereo-Imaging
- Precision mapping

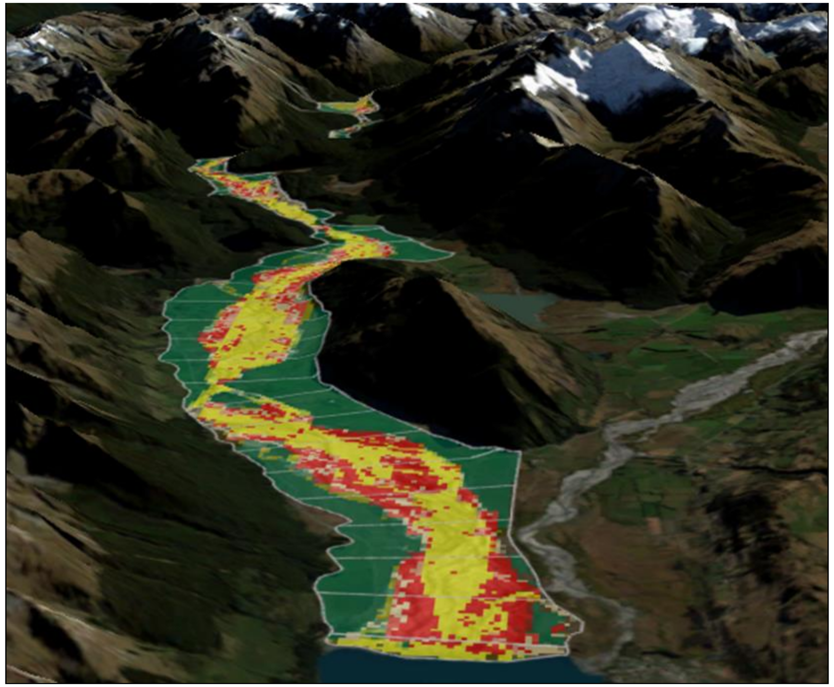
MOVING BEYOND MAPS > CAPTURING HIGHER DIMENSIONS

- 3D laser scanning
- 00-000s of 3D observations per metre
- Quantify landscape change

NEW PERSPECTIVES ON OLD QUESTIONS

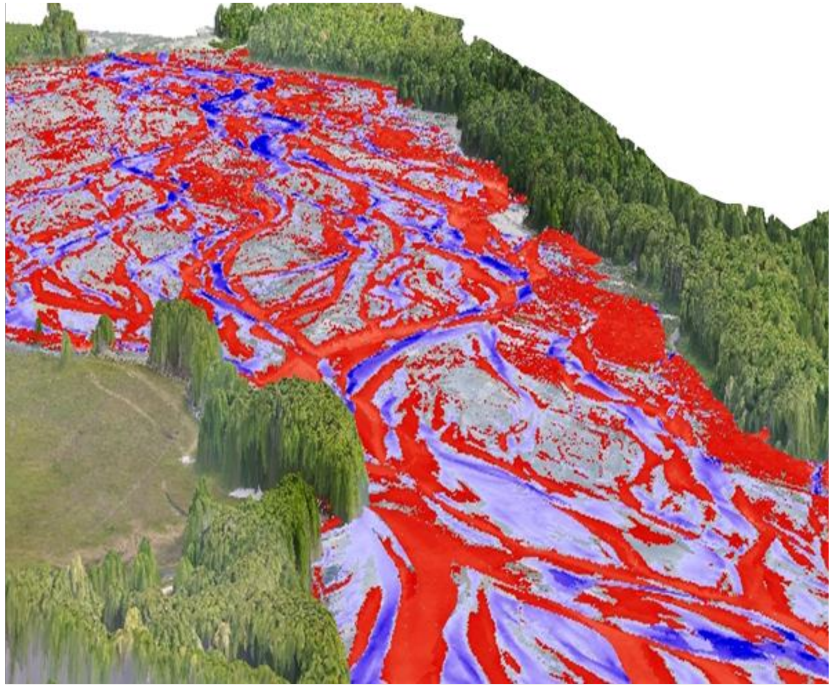
SEDIMENT DELIVERY

How much sediment is generated by erosional processes and supplied to the rivers?



RESTLESS RIVERS

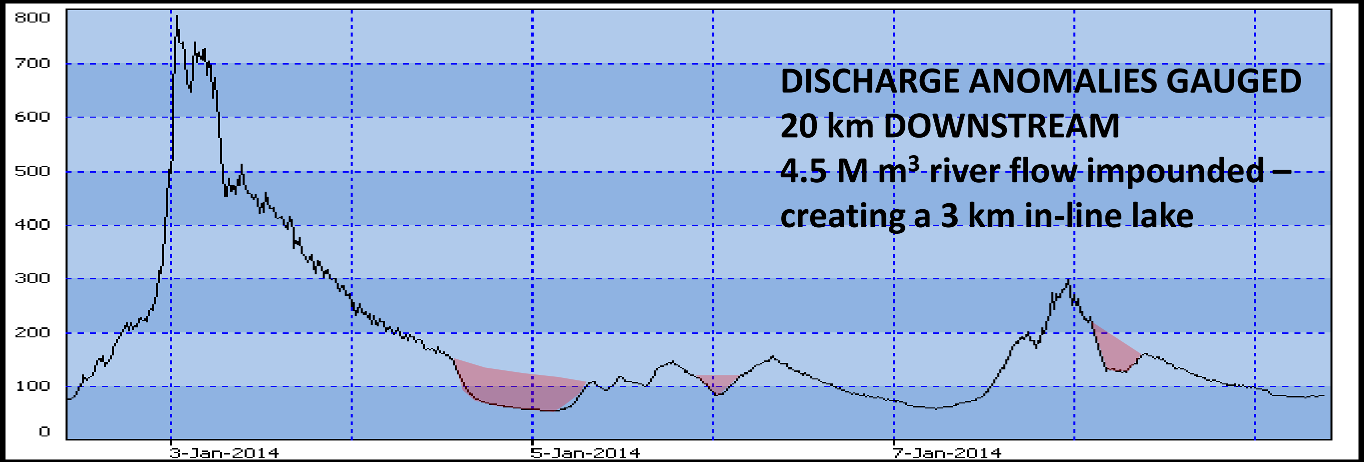
Where does the sediment go and how to the rivers respond over centennial timescales?



PROCESSES MECHANISMS

What controls the rate of sediment transfer through rivers and how do they adjust to floods?

1. TE HORO | SLIP STREAM LANDSLIDE



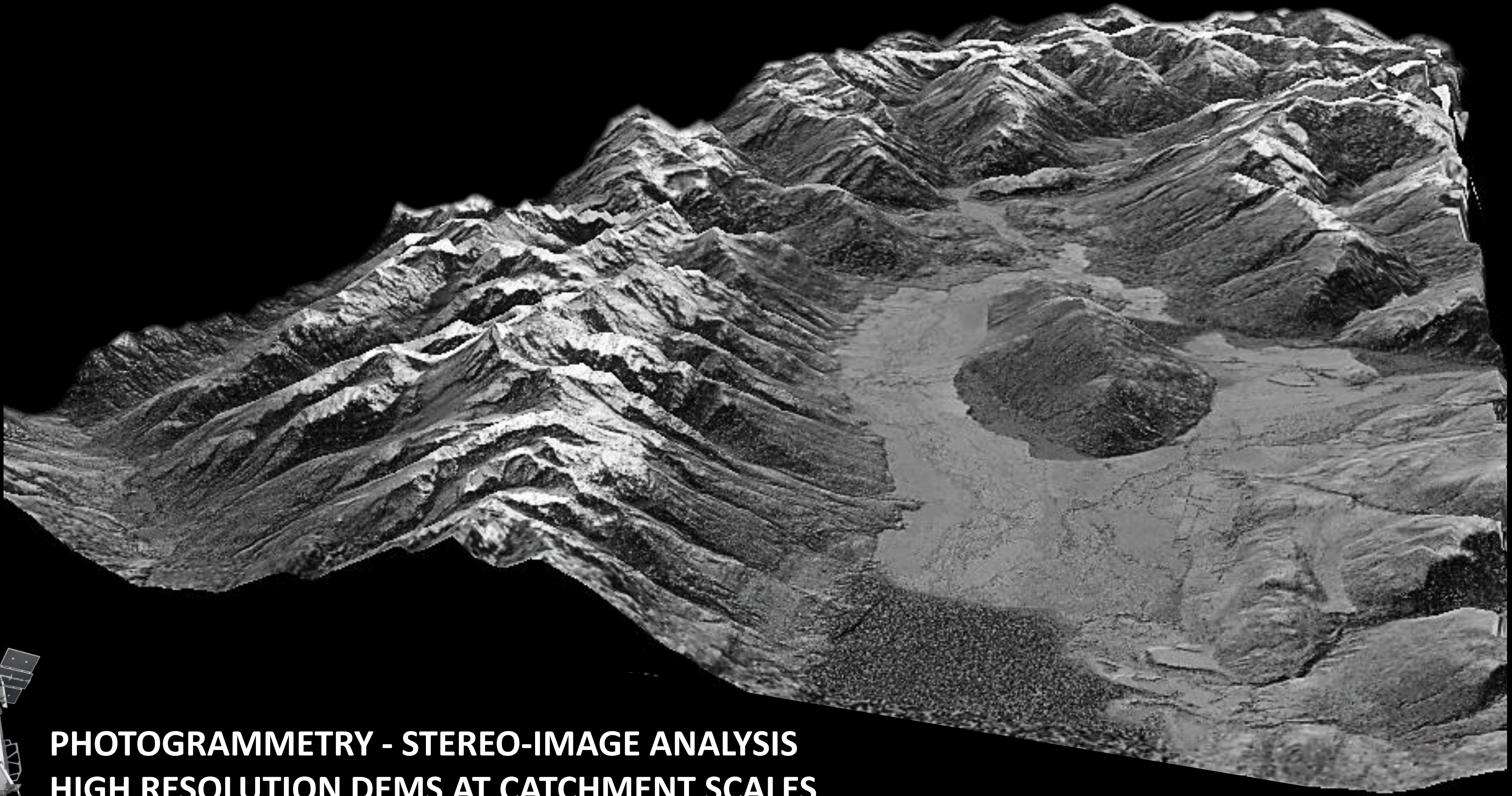
5^{TH} JANUARY 2014 LANDSLIDE AND DEBRIS FLOWS IMPOUNDED RIVER TO CREATE A NEW INLINE LAKE

PEAK Q > 800 m^3 s^{-1}

INITIAL ASSESSMENT 1-2 M m^2 SEDIMENT

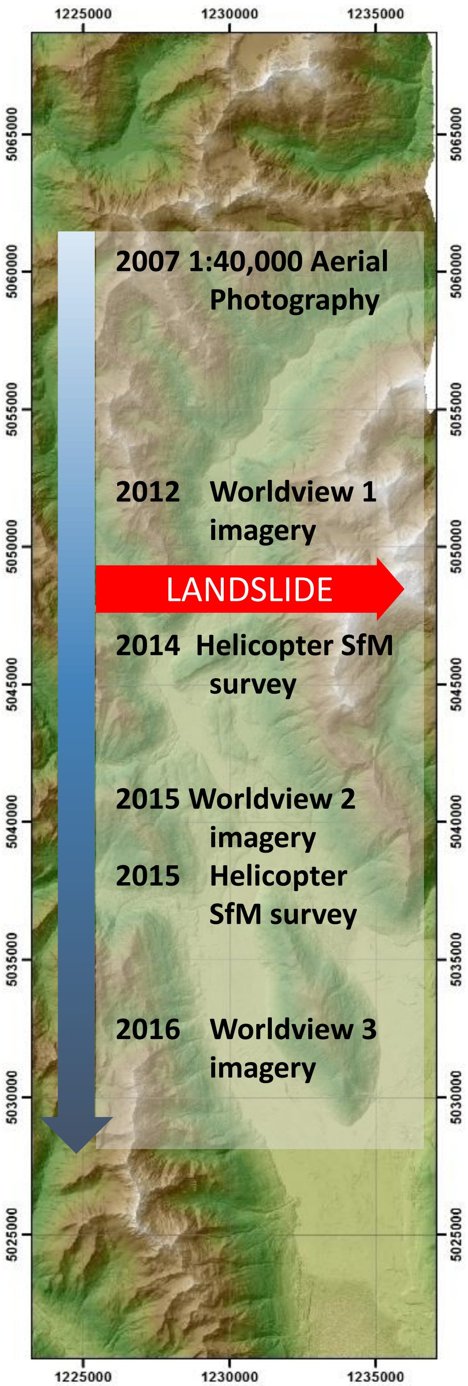
4.5 M M^3 LAKE BUT NO IMMEDIATE DAM BREAK THREAT

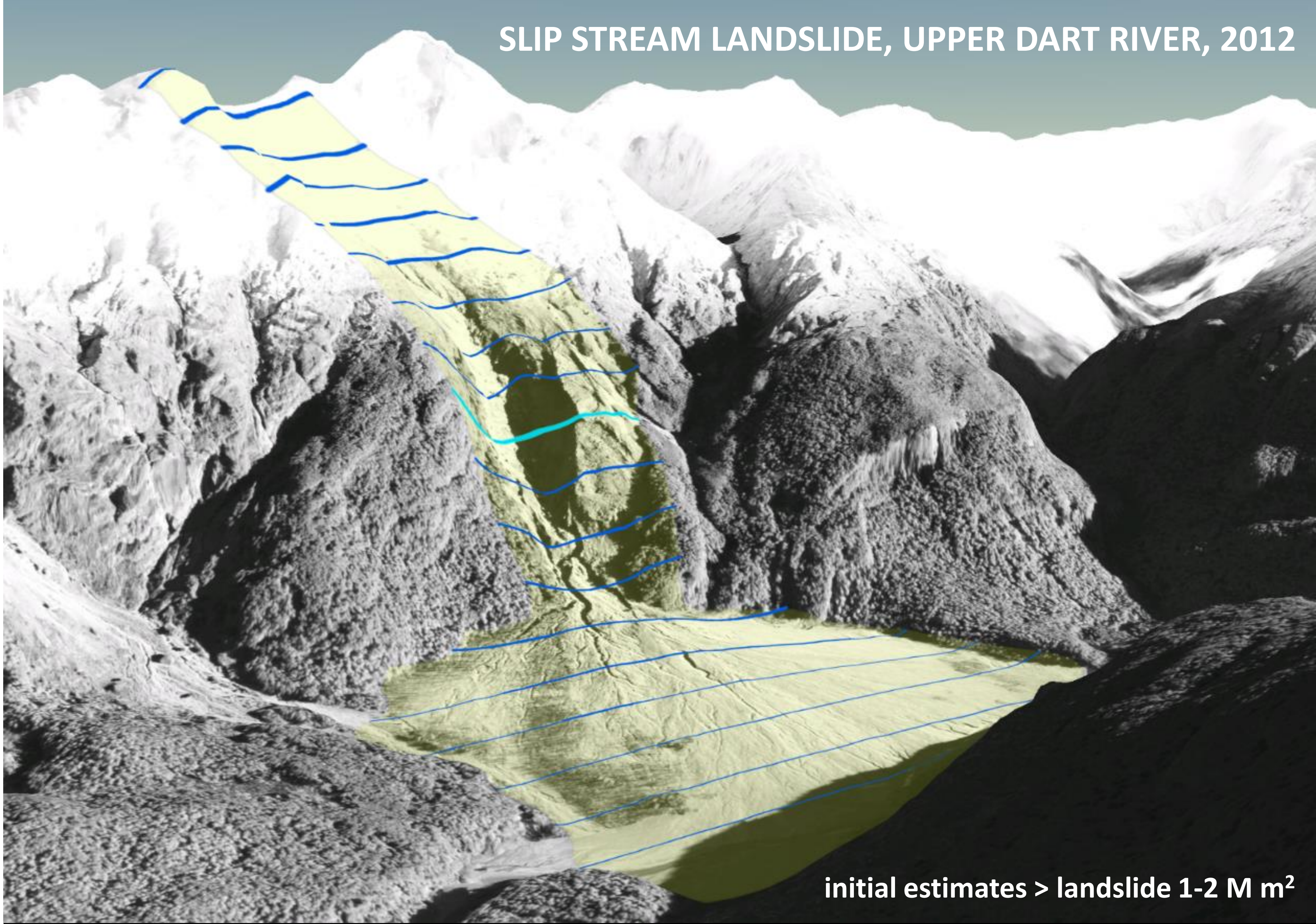
QUANTIFYING SEDIMENT DELIVERY PROCESSES

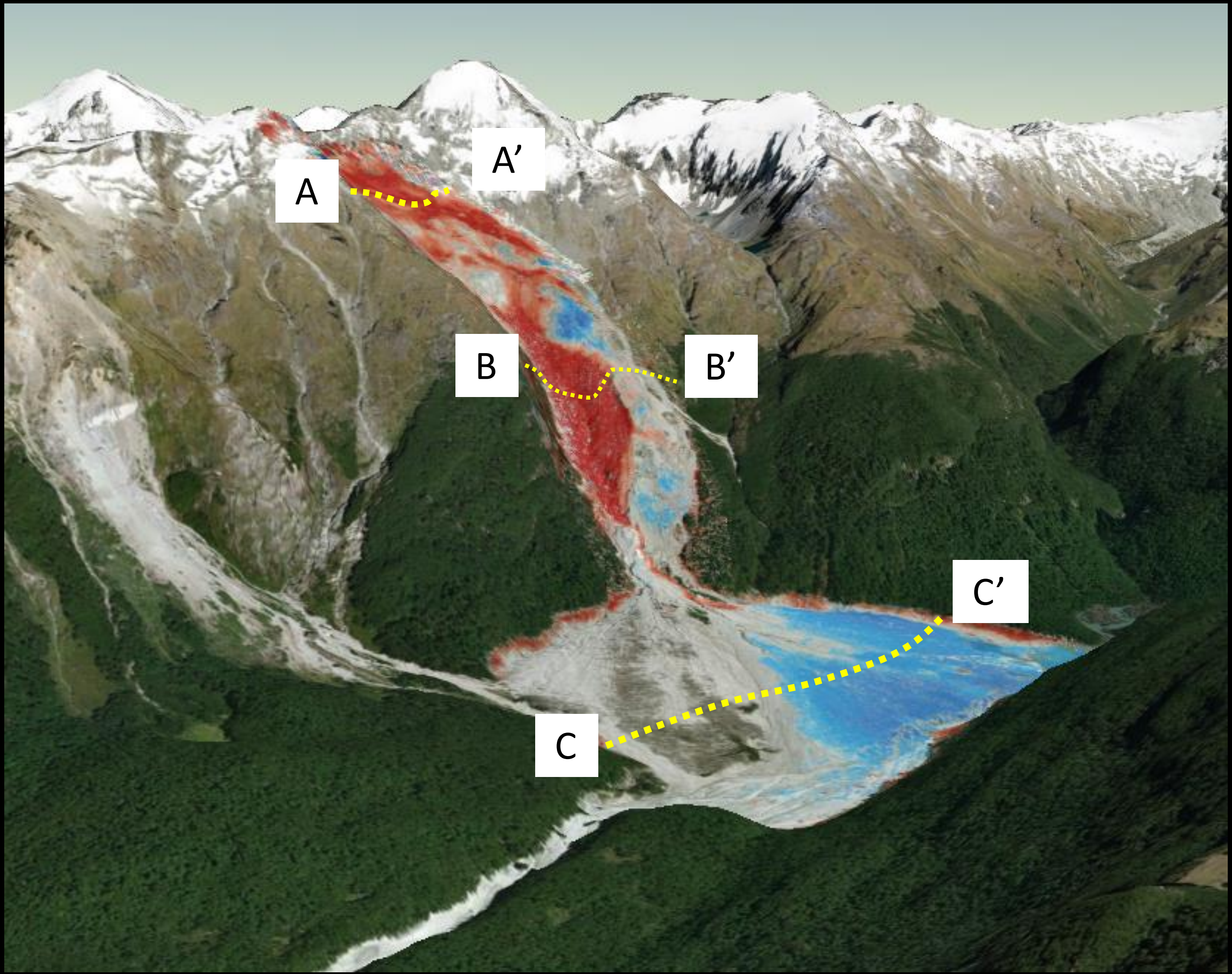


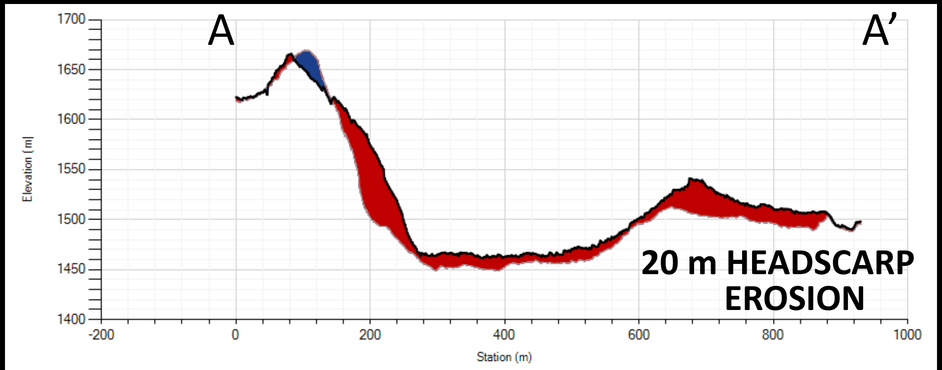
PHOTOGRAMMETRY - STEREO-IMAGE ANALYSIS
HIGH RESOLUTION DEMS AT CATCHMENT SCALES

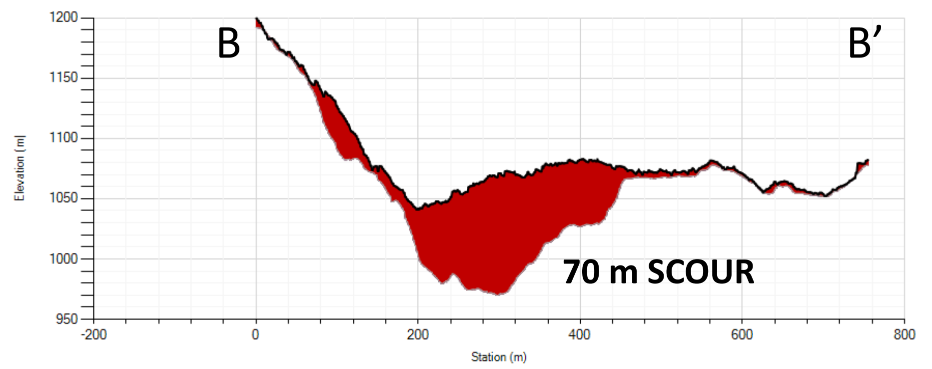
SLIP STREAM LANDSLIDE, UPPER DART RIVER, 2012

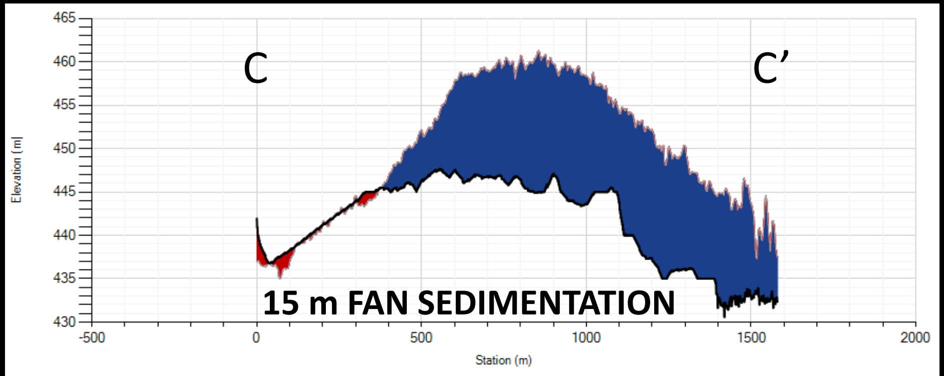






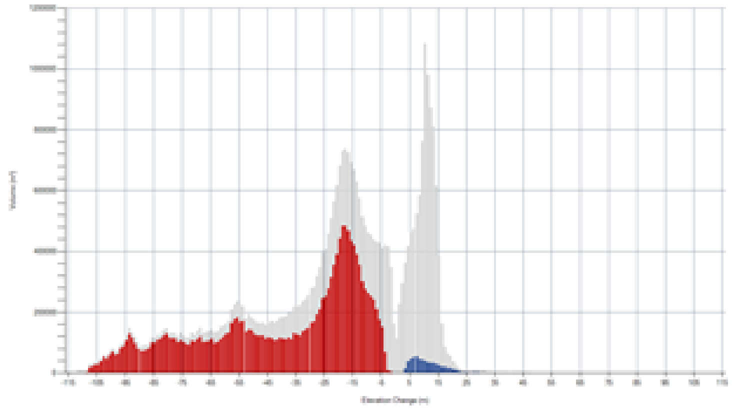




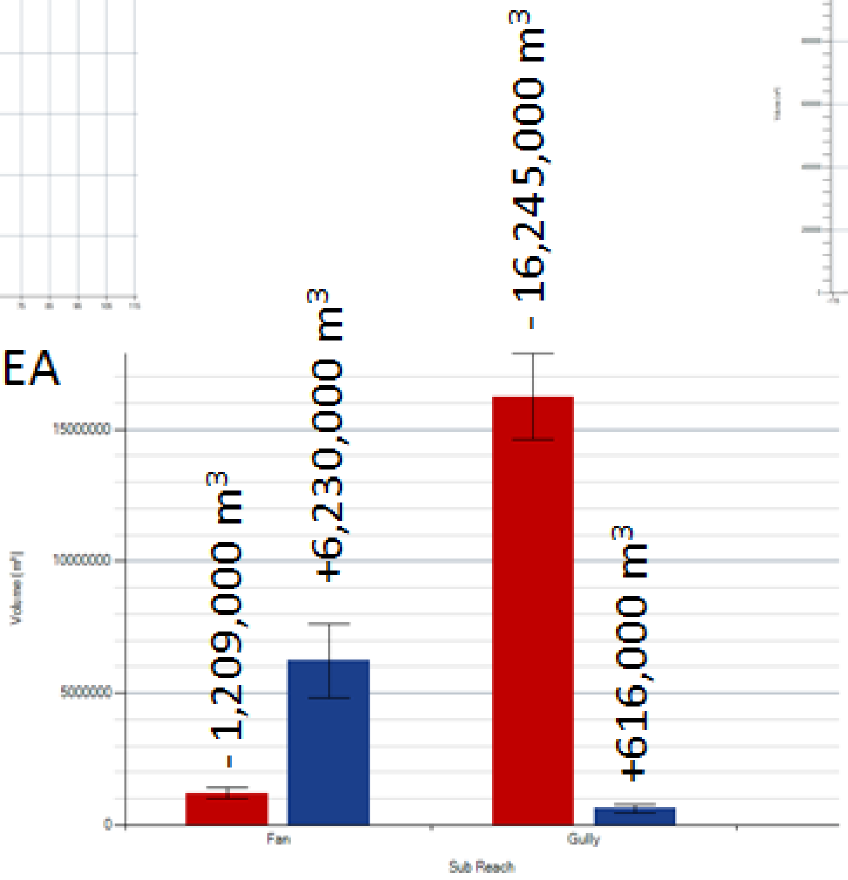


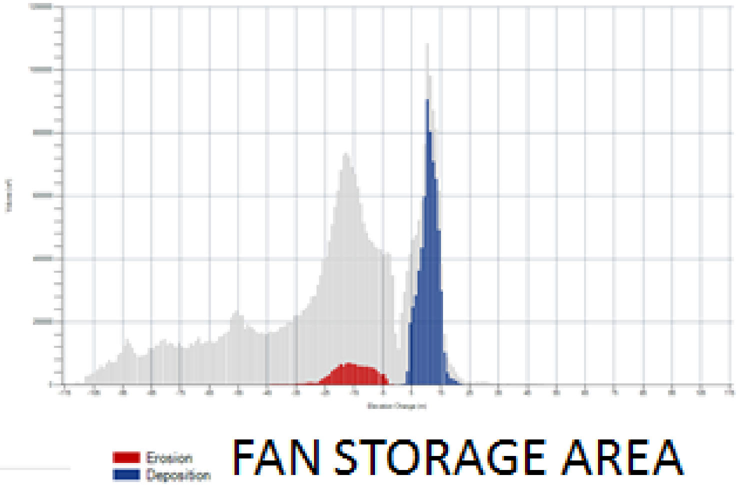
TOPOGRAPHIC CHANGE ANALYSIS: 2015-2012

QUANTIFYING SEDIMENT BUDGET



LANDSLIDE SOURCE AREA





FAN STORAGE AREA

INITIAL ESTIMATE ~1-2 M m^3

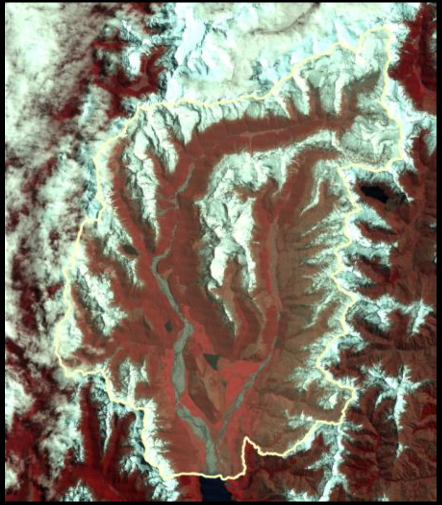
ANNUAL COARSE SEDIMENT LOAD TO WAKATIPU JUST 300,000 m^3

PRODUCTION – FAN STORAGE = SEDIMENT SUPPLY TO RIVER

17,454,000 – 6,846,000 = 10,608,000 m^3

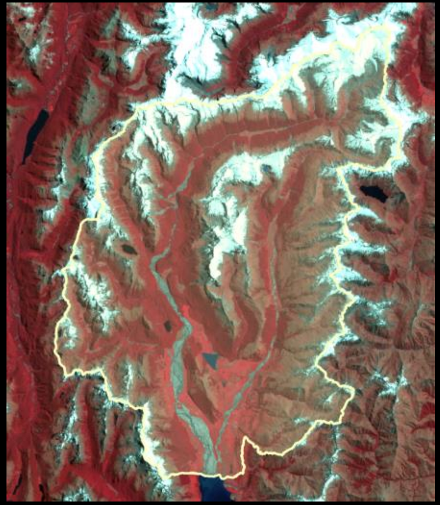
2. AN ARCHIVE OF LANDSCAPE CHANGE


1973


1988


1989


1990


2001


2004

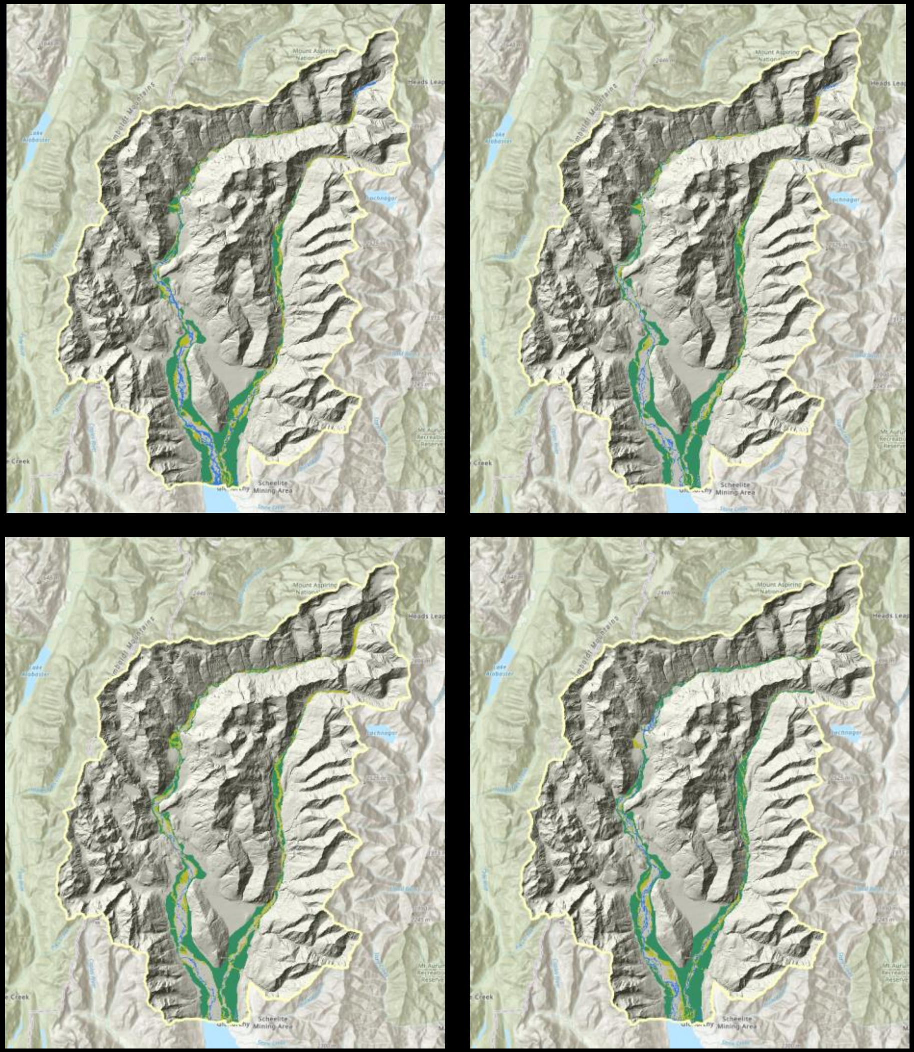

2005


2010


2019

MAPPING THE RIVER CORRIDOR

1973 1990



2001 2019

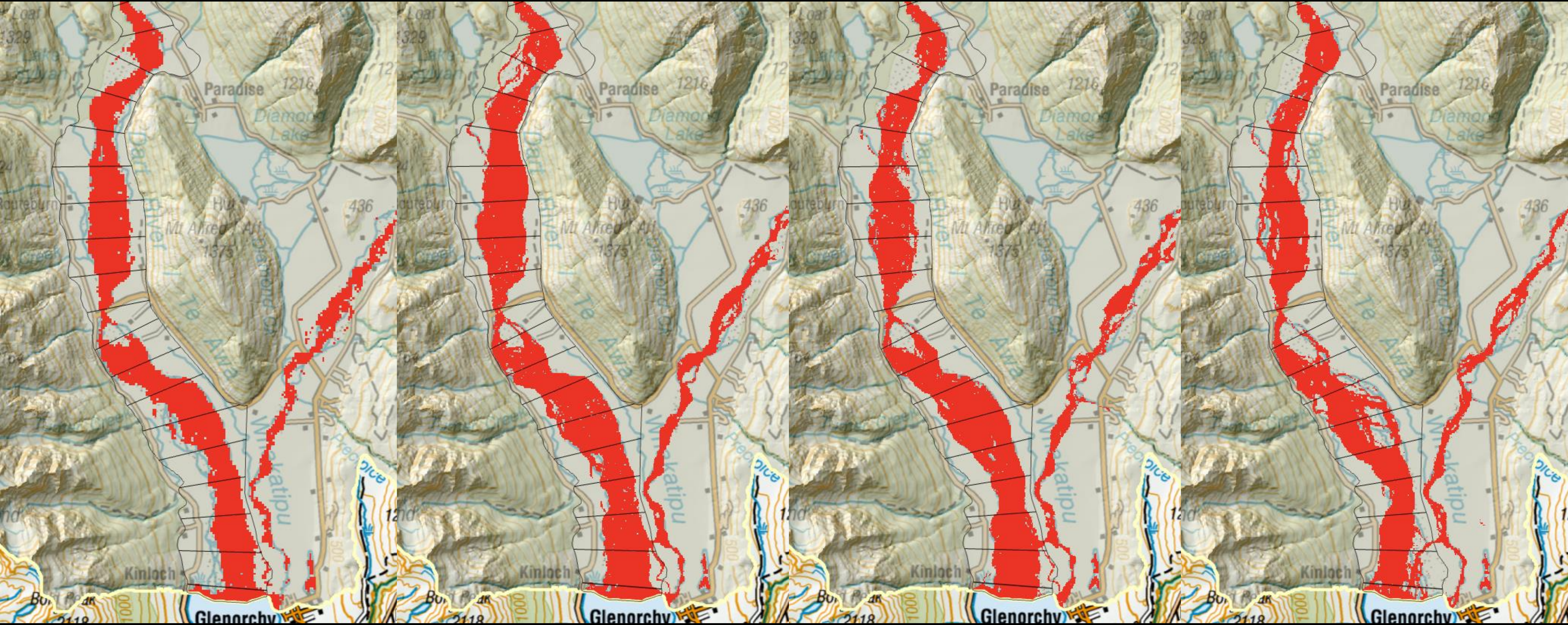
Machine Learning > classifying landcover

Visible and near infrared spectral response provides basis for landcover classification

WETTED CHANNEL
ACTIVE GRAVEL
PARTIALLY VEG
STABLE

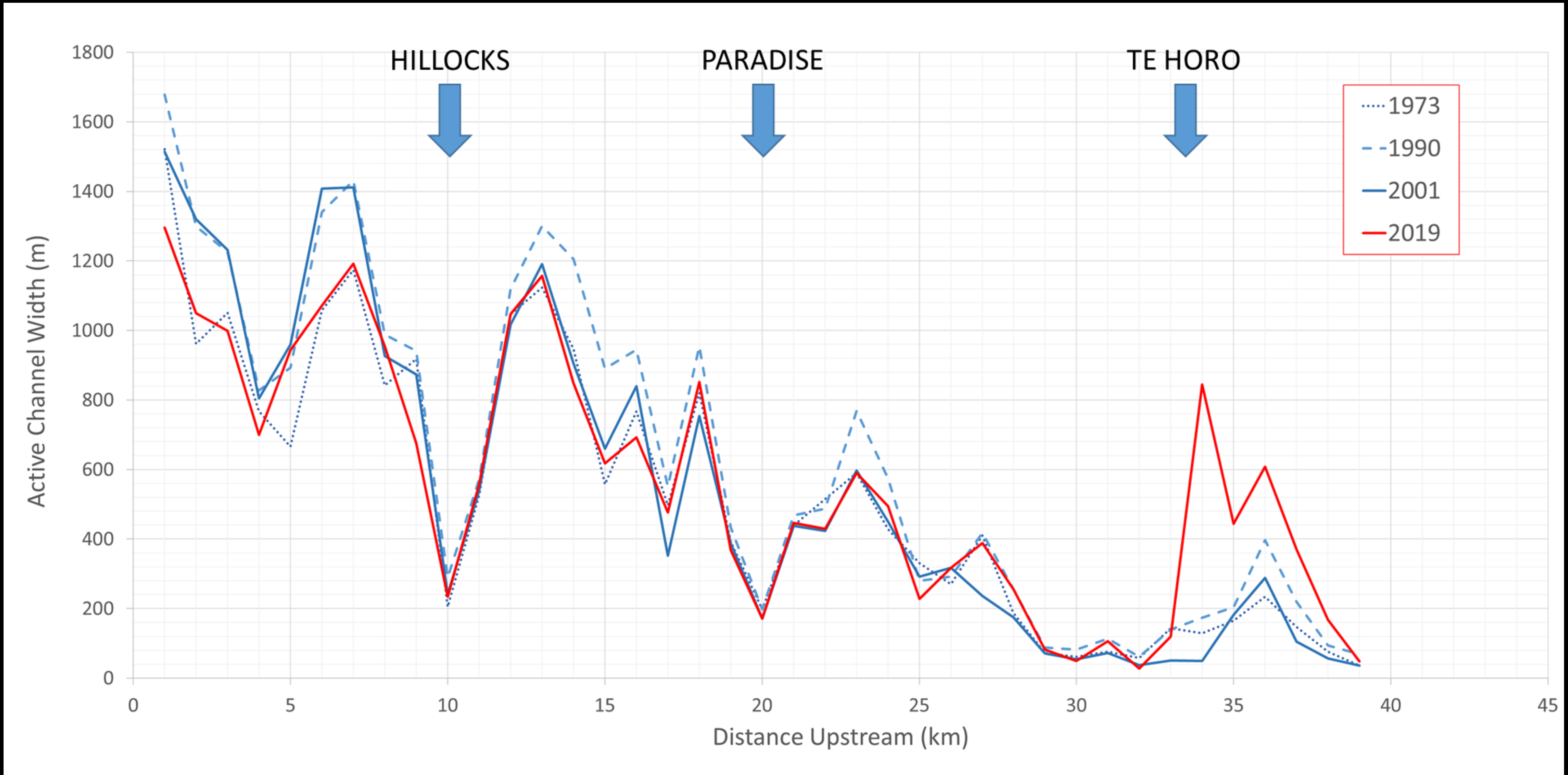
Wetted Areas Exposed Gravel	Active channel bed
Partially Vegetated	Disturbed/Stablizing channel bed
Stable	‘Inactive’ valley floor

REES-DART ACTIVE CHANNEL BELT



1973 **1990** **2001** **2019**

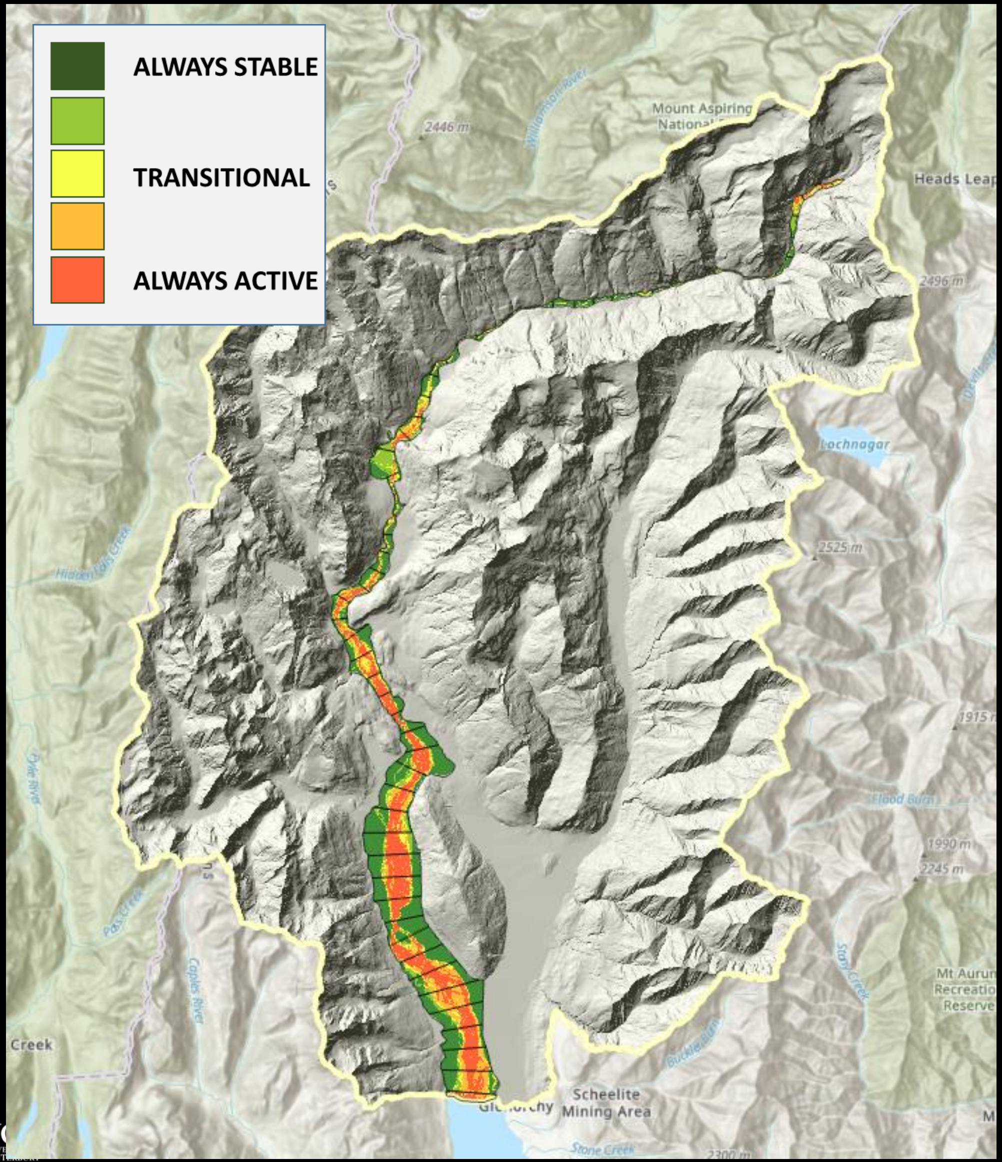
REES-DART ACTIVE CHANNEL BELT



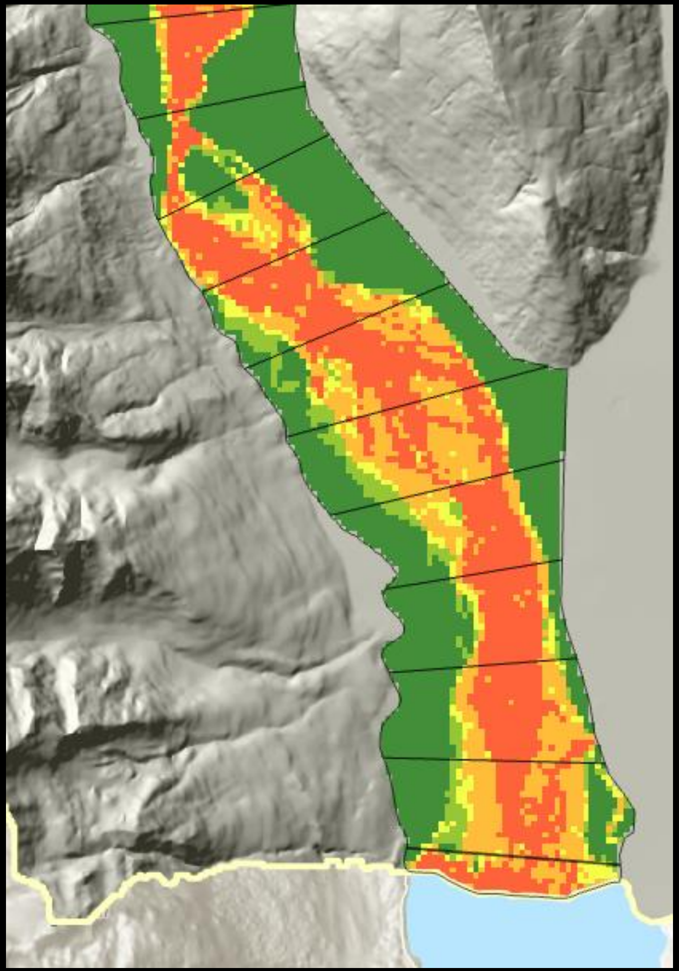
1) Long-term migration of lower reach/delta from TL to TR

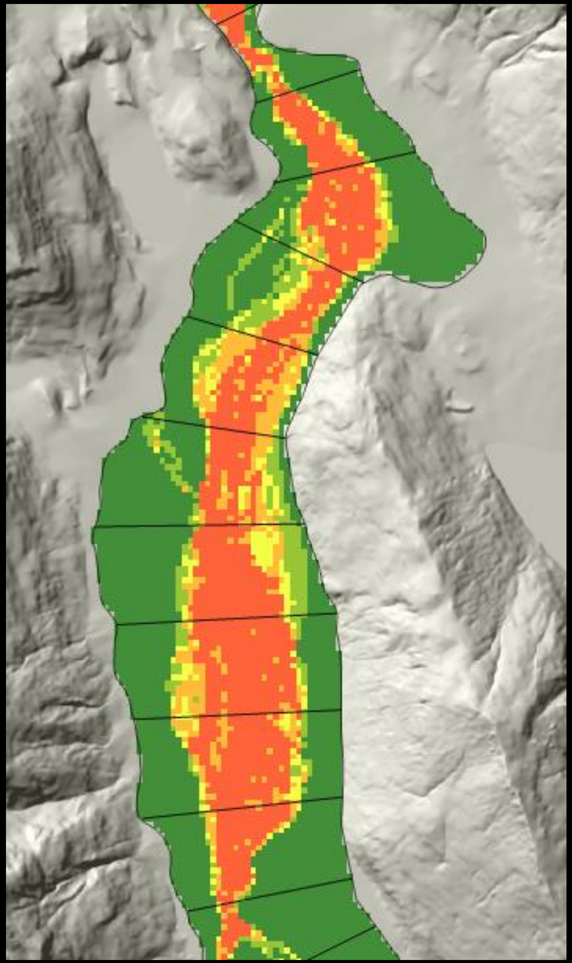
2) Expansion followed by contraction of active river corridor

WHERE IS THE RIVER??!



Probability models > land-use zoning

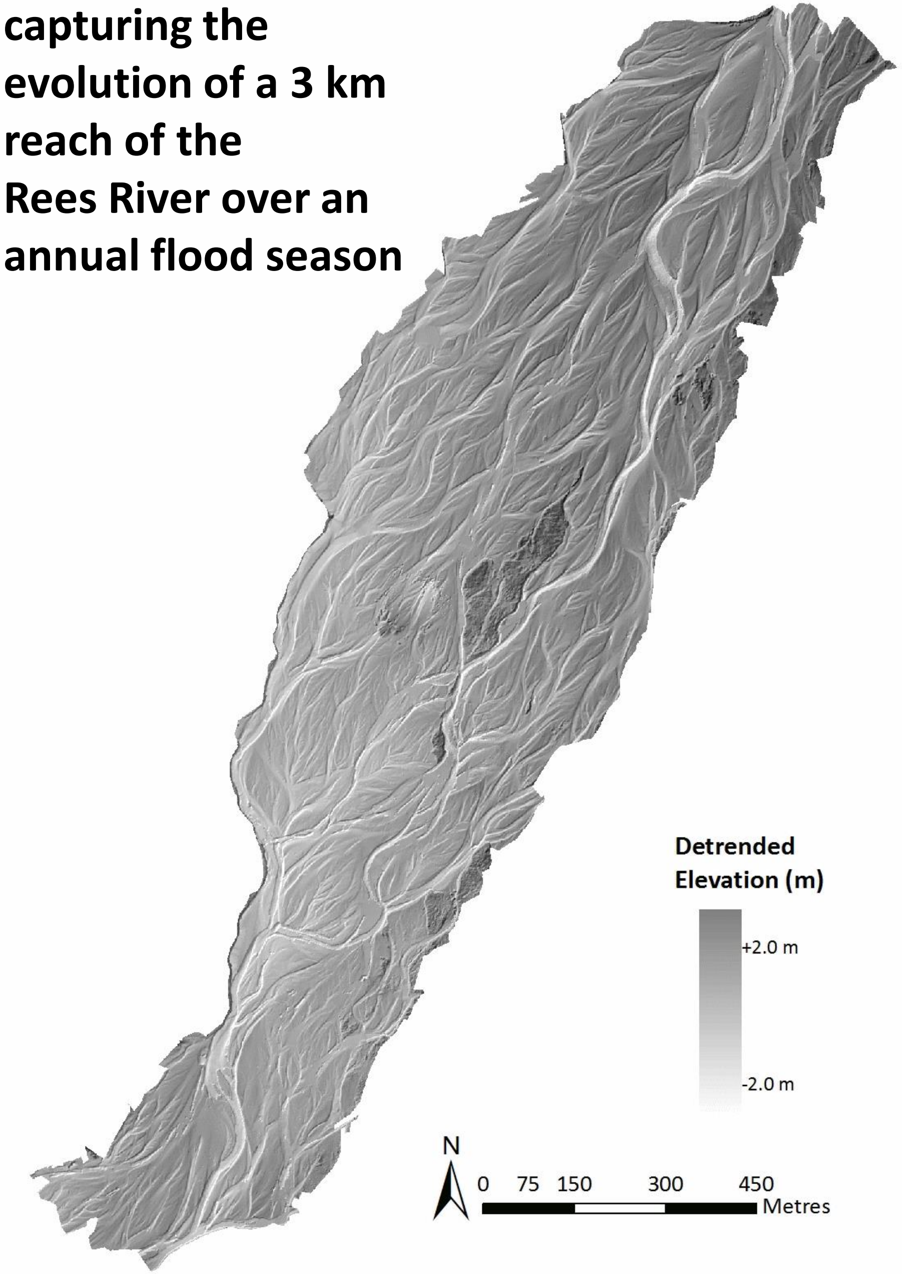


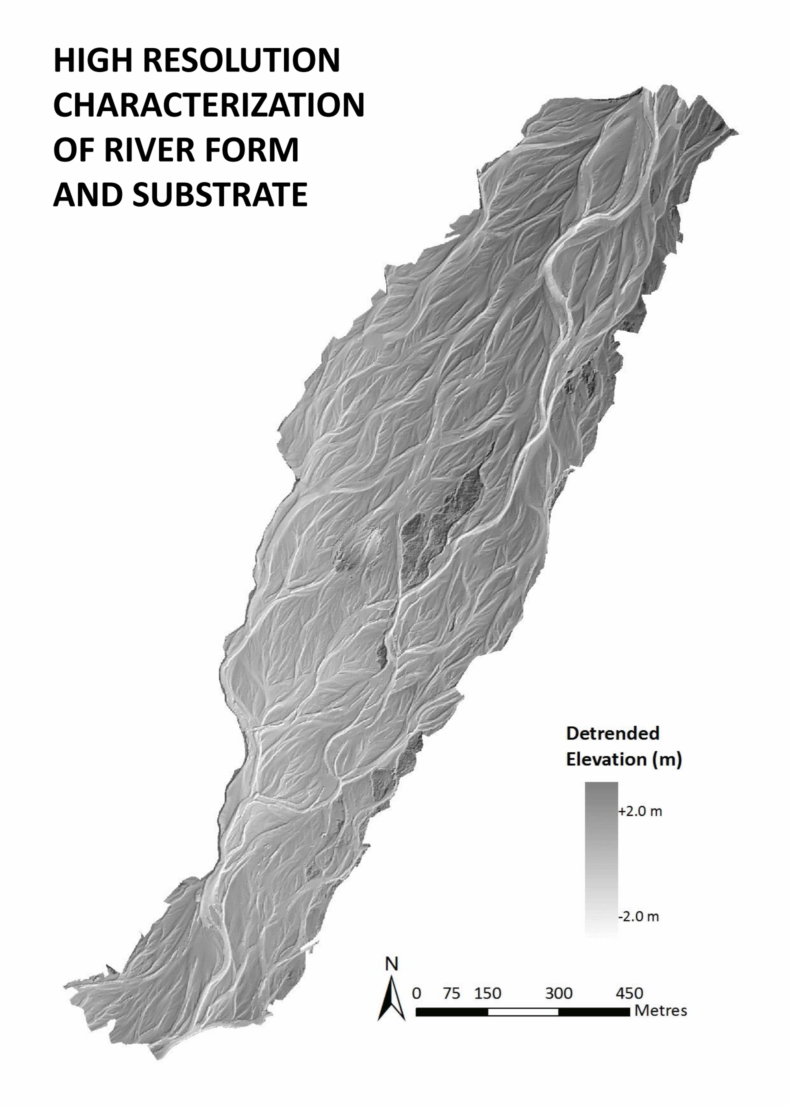


3. DRIVERS OF RIVER ADJUSTMENT

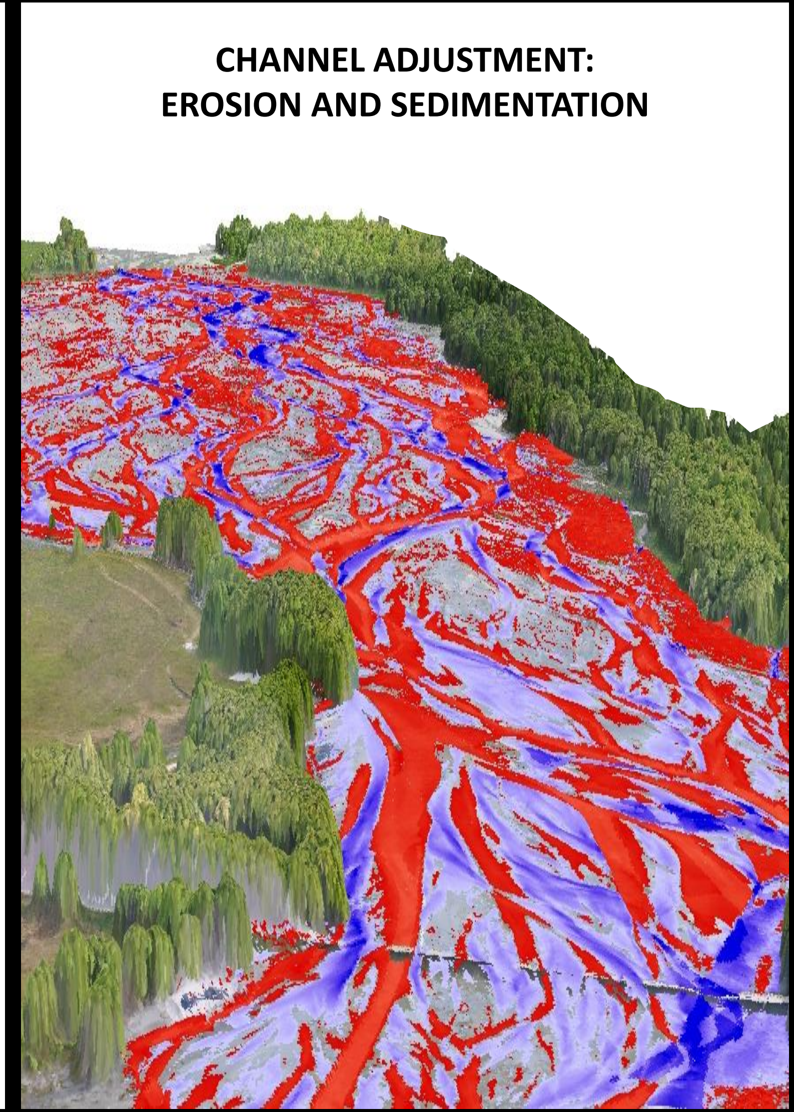
AMPHIBIOUS MOBILE TLS: REESCAN PROJECT 2009-2011

0.25 m DEMs capturing the evolution of a 3 km reach of the Rees River over an annual flood season

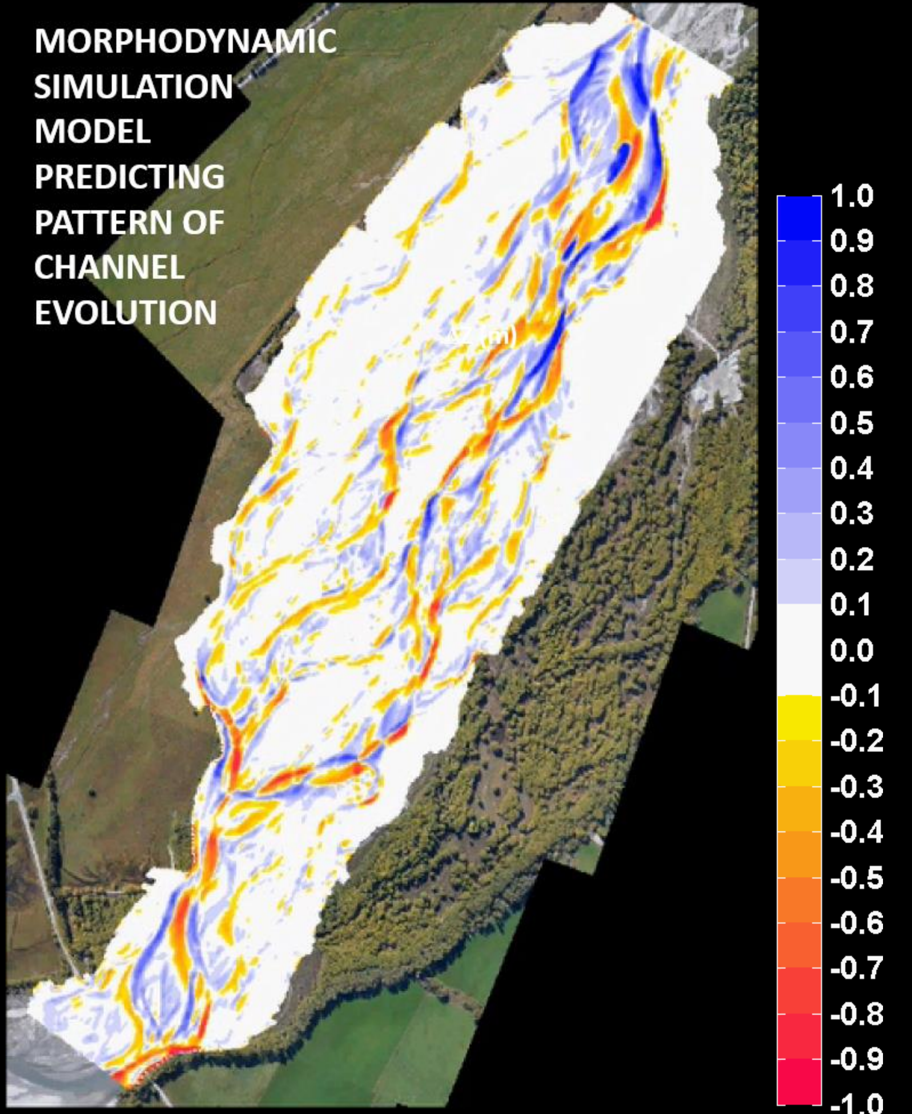




CHARACTER
(FORM AND STRUCTURE)

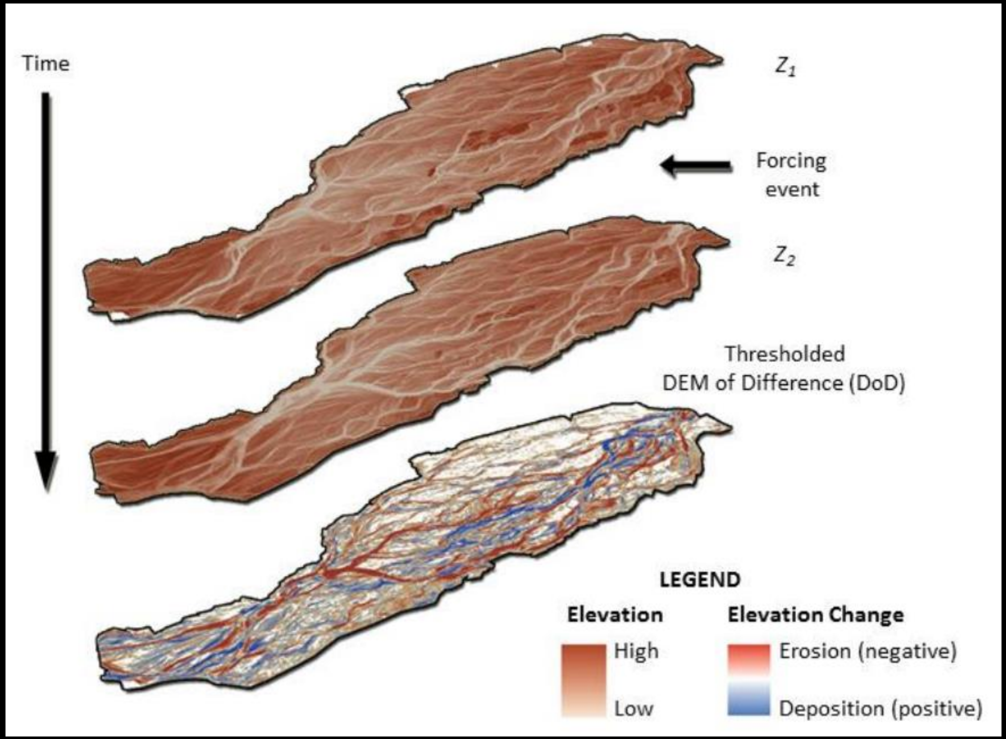


CHANGE
(MOBILITY AND TRAJECTORY)



PROCESSES
(DRIVERS, FORCES & RATES)

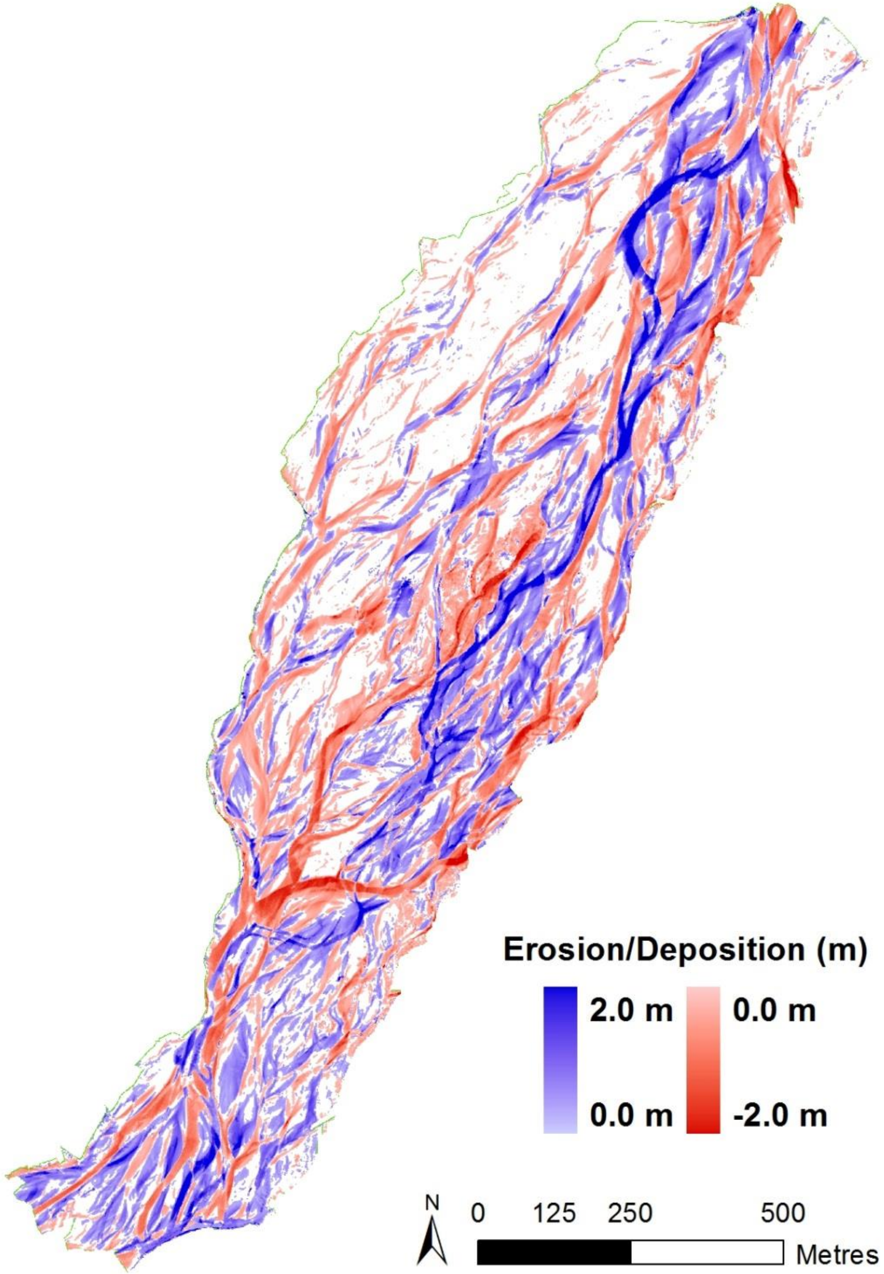
3. DRIVERS OF RIVER ADJUSTMENT



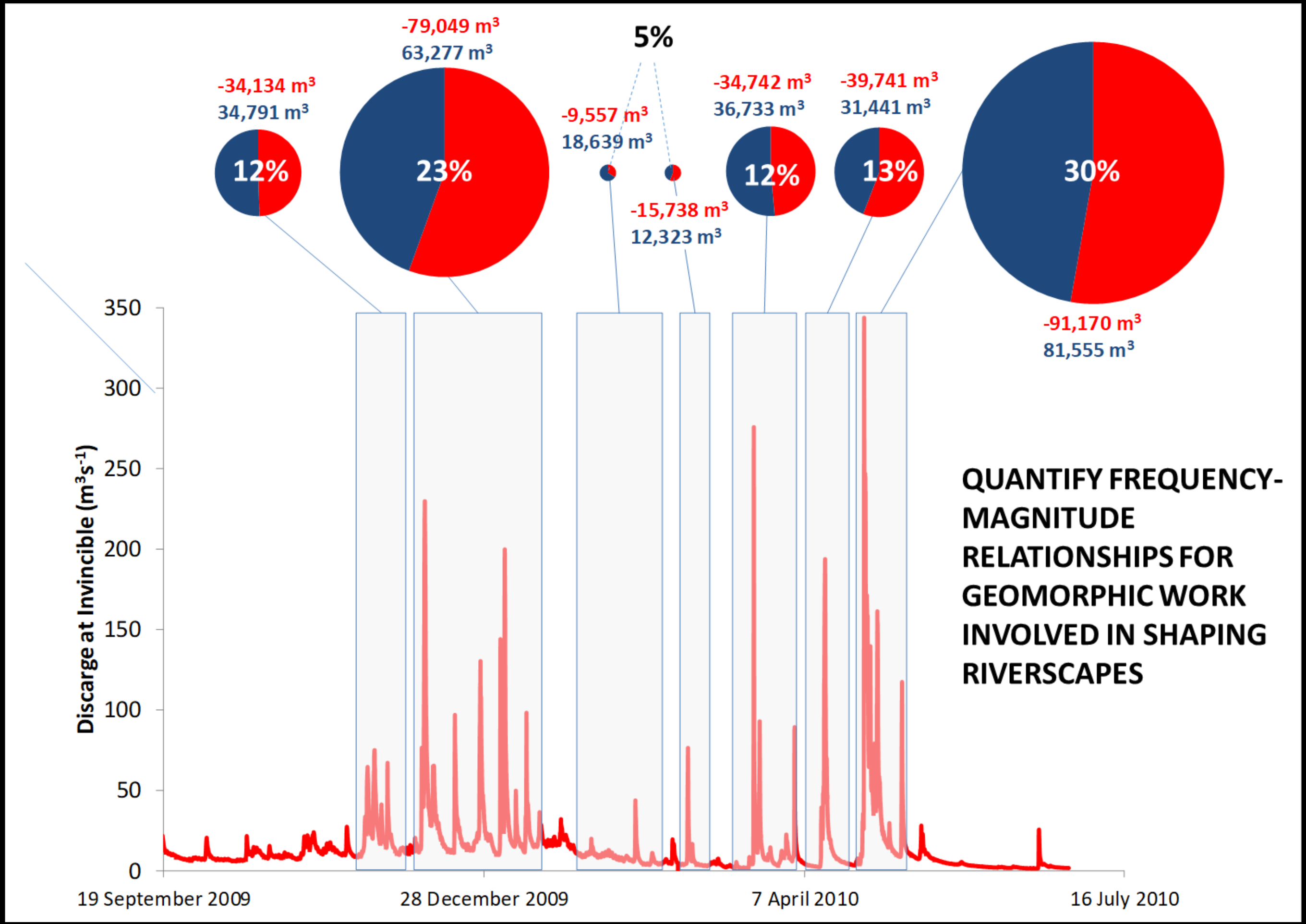
	80% C.I.
Ve (m^3)	124,442
Vd (m^3)	82,463
ΔZ (m)	-0.036
$\overline{d_e}$ (m)	-0.395
$\overline{d_d}$ (m)	0.328

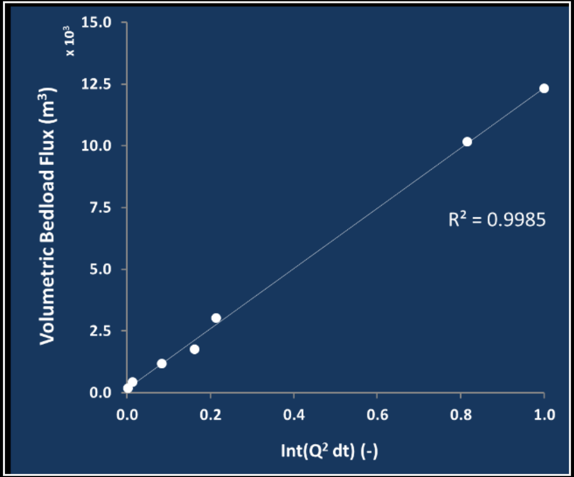
71% reach experienced scour
72% reach experienced fill

50% reach repeated scour and fill cycles
78% of the river bed mobilized/disturbed during a single year



CONTROLS ON SEDIMENT TRANSPORT





Rate of sediment transport increases predictability with the intensity of the driving flood

Sediment is essentially is unlimited

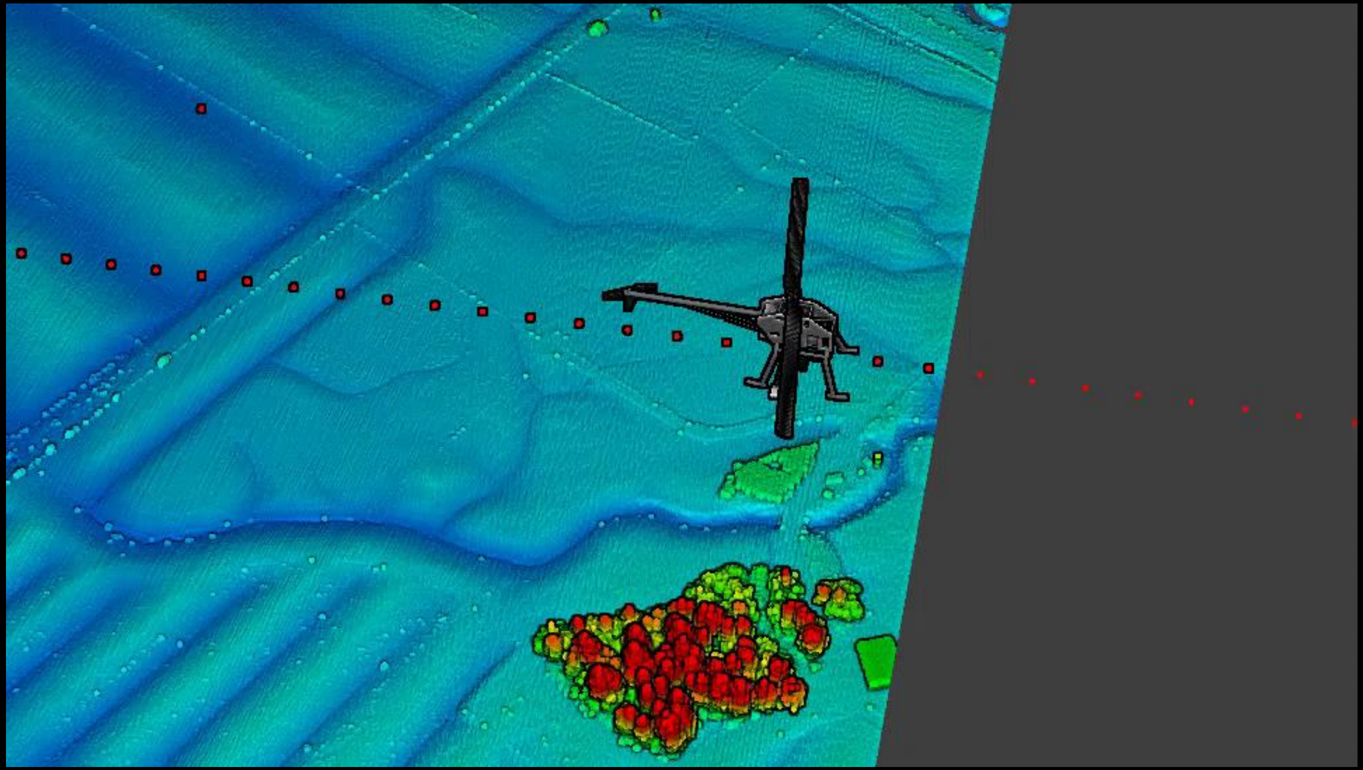
Rate of transport is directly proportional to the power of floods

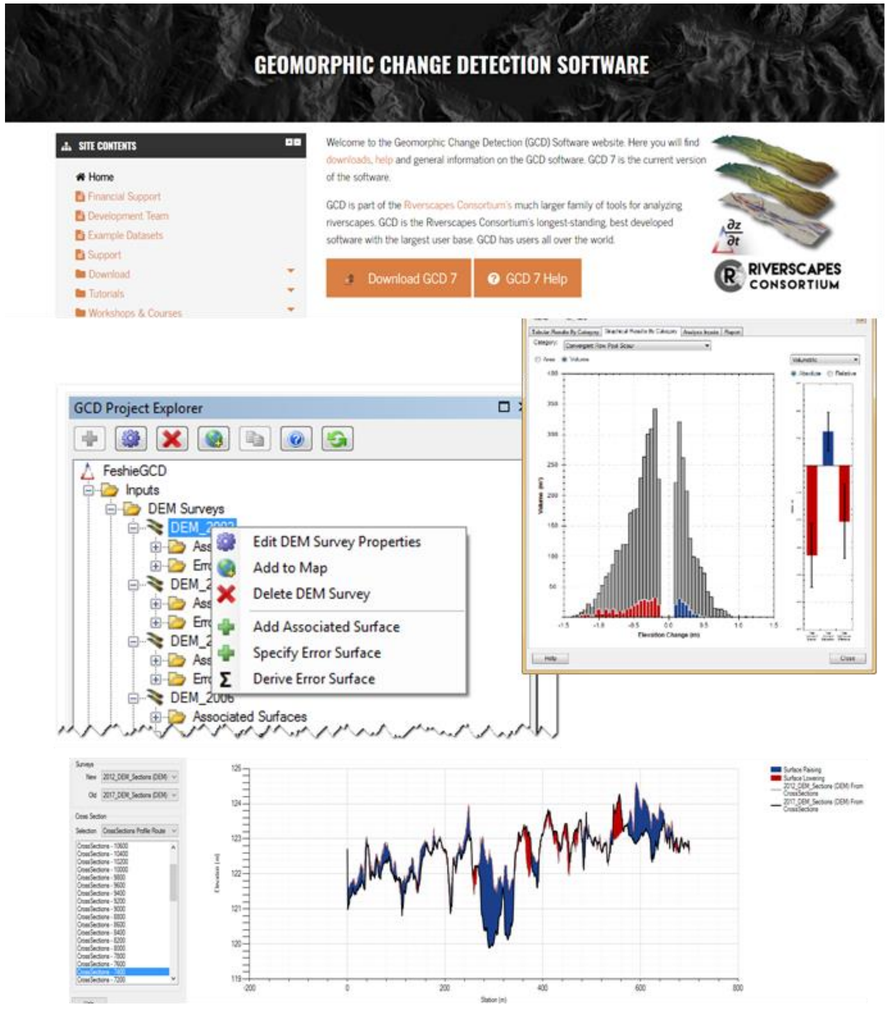
> Increases in flood frequency will lead to a direct increase in the rate of sediment transport

WHAT HAVE WE LEARNED?

1. SEDIMENT SUPPLY (IS HIGH AND) MAY BE DOMINATED BY EXTREME EVENTS
   - Should expect variability over time, which will affect rates of downstream channel stability
2. MAKE SPACE FOR RIVERS – TREAT THE VALLEY FLOOR AND RIVER AS A CONTINUUM
   - Should expect the active river corridor to expand/contract/migrate over decadal timescales
3. SEDIMENT TRANSFER IS 'TRANSPORT LIMITED'
   - Should expect increases in storm frequency and severity to directly impact sediment transfer through the river system

SUPPORTING NEW TECHNOLOGIES TO INFORM MANAGEMENT





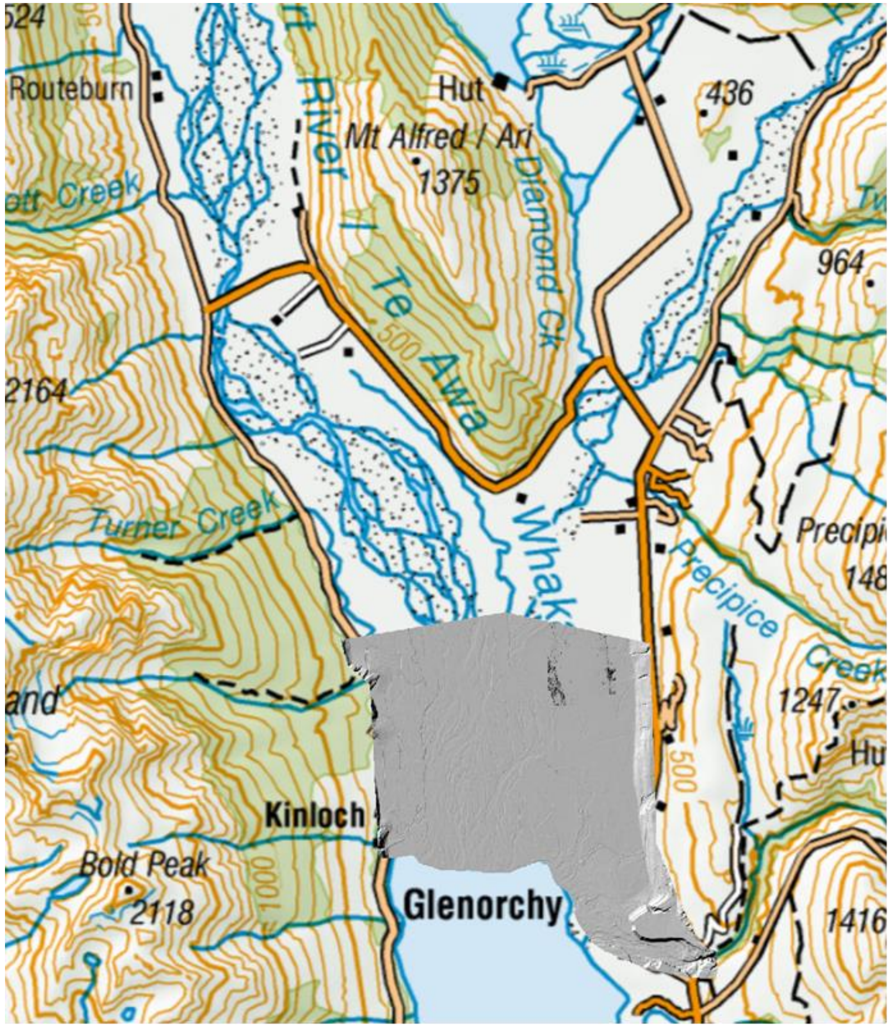
gcd.riverscapes.xyz

AIRBORNE LIDAR SURVEYS
HIGH RESOLUTION 3D MODELS
OF RIVER MORPHOLOGY

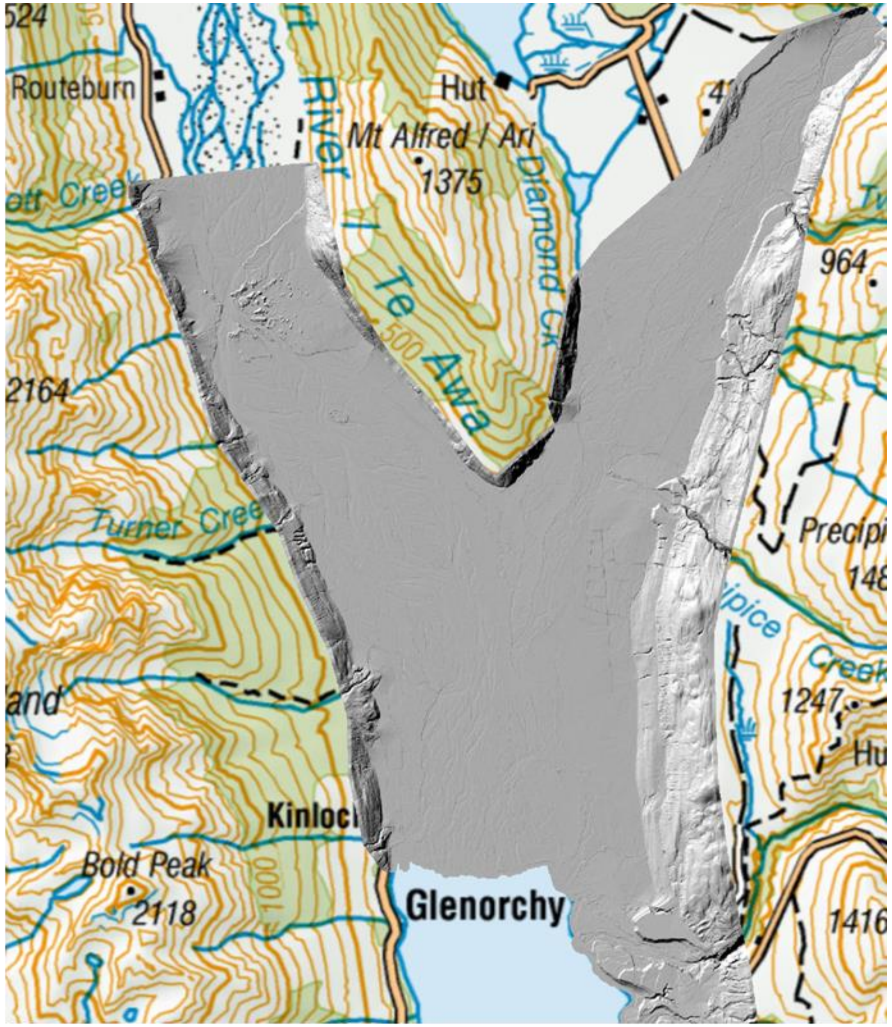
→

GCD ANALYSIS
SOFTWARE

SUPPORTING NEW TECHNOLOGIES TO INFORM MANAGEMENT



2/3 OCTOBER 2011

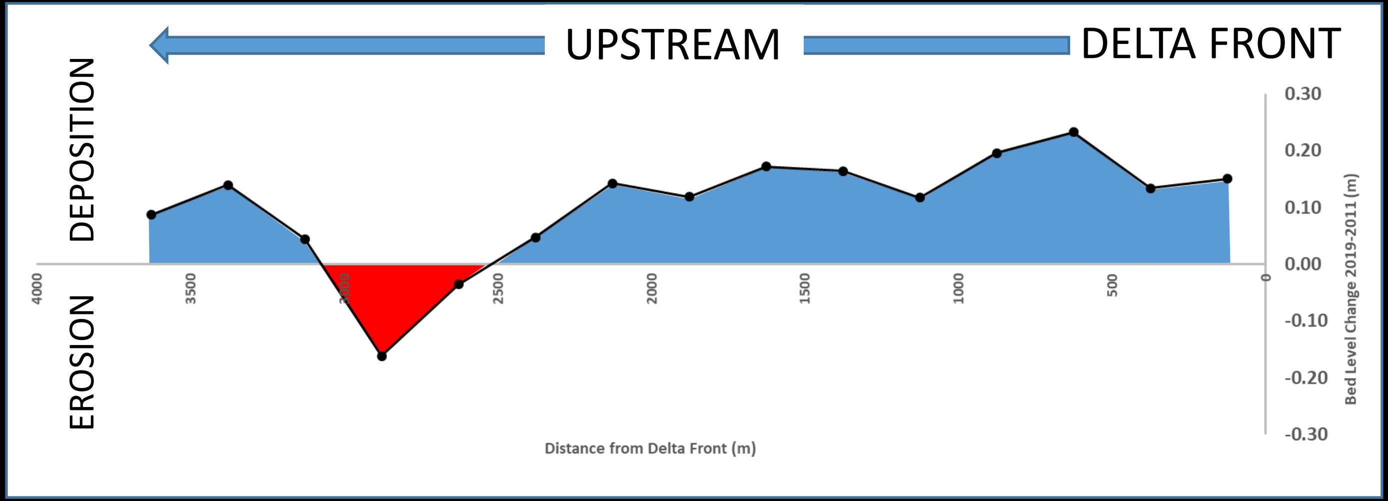


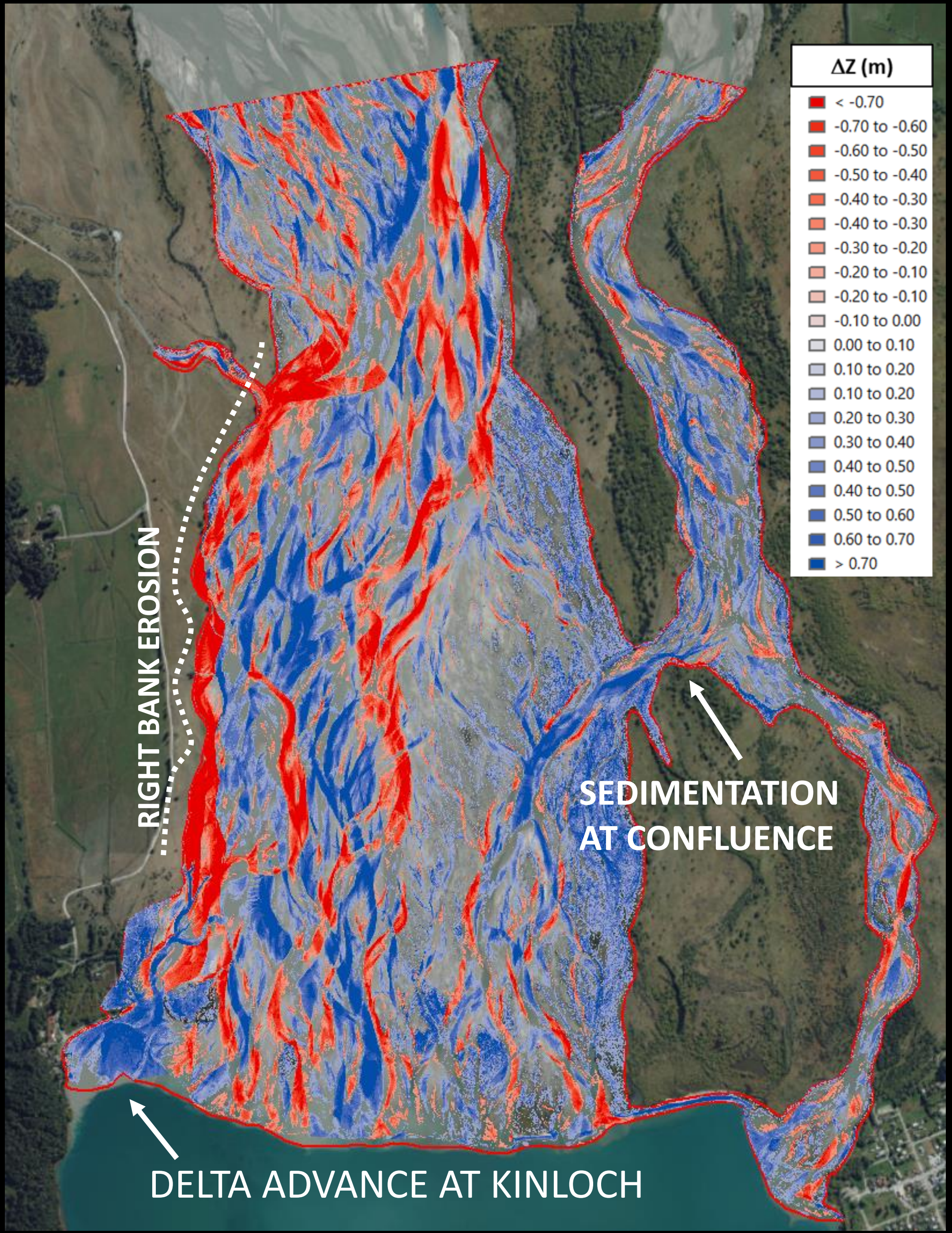
25 JUNE 2019

BED LEVEL CHANGE 2019 - 2011

Difference lidar elevation models surveyed in 2019 and 2011

Erosion (bed lowering) = reds
Sedimentation (bed raising) = blues





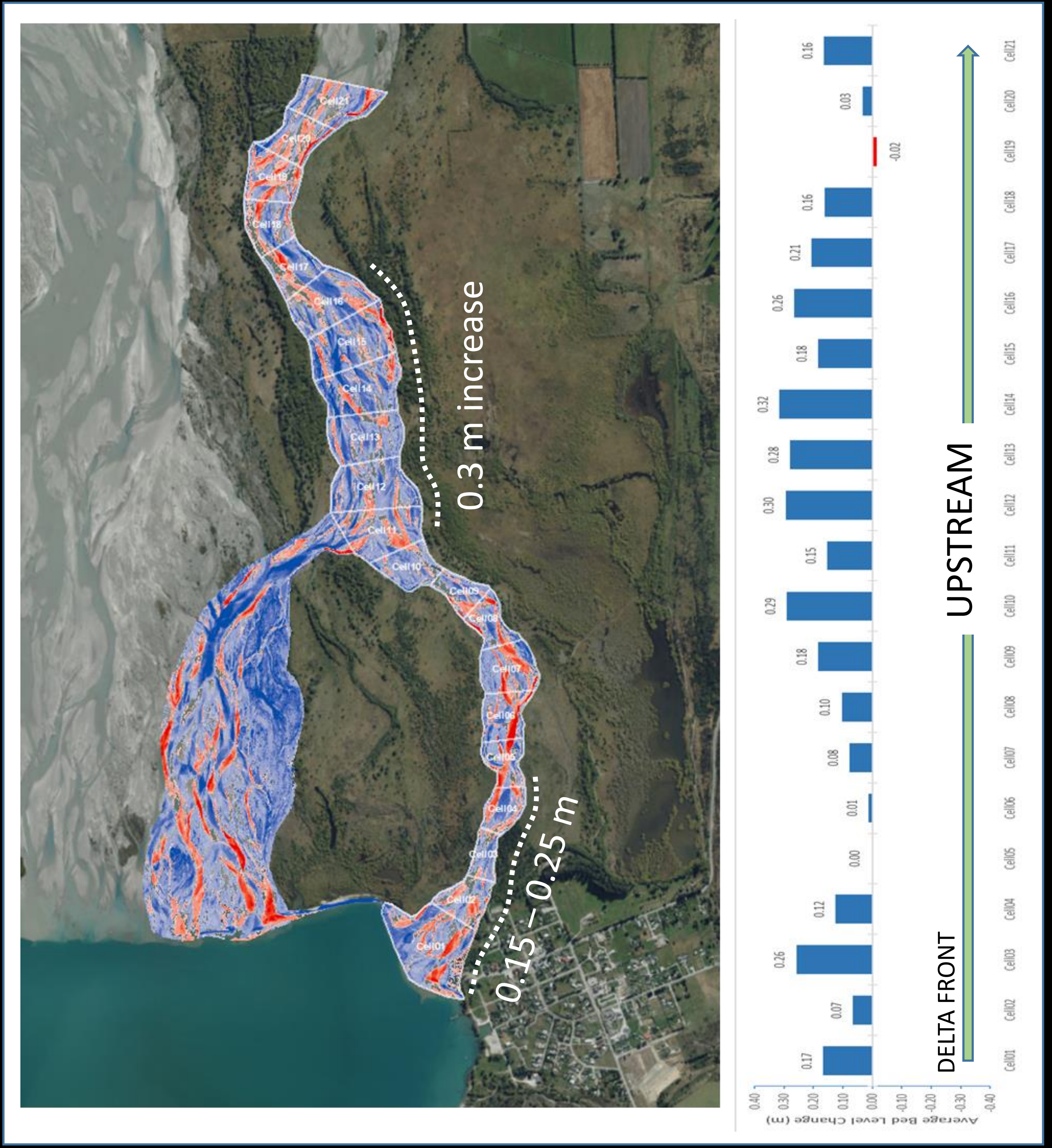
LOWER REES RIVER

Bed level change averaged over 250 m sections (cells)

Significant and extensive sedimentation throughout lower 5 km

- **0.2 – 0.32 m increase in `mean bed level in just 8 years**
- **> 1.25 – 2 m increase over 50 years**

SIGNIFICANT LOSS OF FLOOD CAPACITY



UC UNIVERSITY OF CANTERBURY

JUNE 2020

Significant loss of 'freeboard' evident along reaches of the lower Rees River

INCREASING FLUVIAL HAZARD?

1. **RIPARIAN EROSION**

Increasing bed level > higher rates of anabranch migration

Increased lateral migration of channel belt

> KINLOCH ROAD

INCREASING FLUVIAL HAZARD?

2. LOSS OF SERVICE OF EXISTING STOPBANK PROTECTION

Elevated bed level > higher flood stage

Increased pressure on outer bends

Increased hydrostatic pressure

> Pipe formation under earthen stopbank

> Catastrophic breach

INCREASING FLUVIAL HAZARD?

3. **BACKWATER FLOODING ALONG LAGOON CREEK > OVERTOPPING OF STOPBANK**

Bed aggradation > reduced cross-sectional area and reduced channel gradient

Reduces Rees mainstem flood capacity > blocks and then reverses flow along floodplain channels (Lagoon Creek)

Overtopping of stopbank at low points

BACKWATER FLOODING

INCREASING FLUVIAL HAZARD?

4. **ELEVATED RISK OF SEVERE OUTBREAK FLOODING**

Loss of freeboard upstream

Rerouting of flood flows along steeper path across the floodplain > avulsion

Catastrophic – erosional – flooding with the potential to overwhelm stopbanks

Swift water flooding through township

WAIHO RIVER, MARCH 2019

INCREASING FLUVIAL HAZARD?

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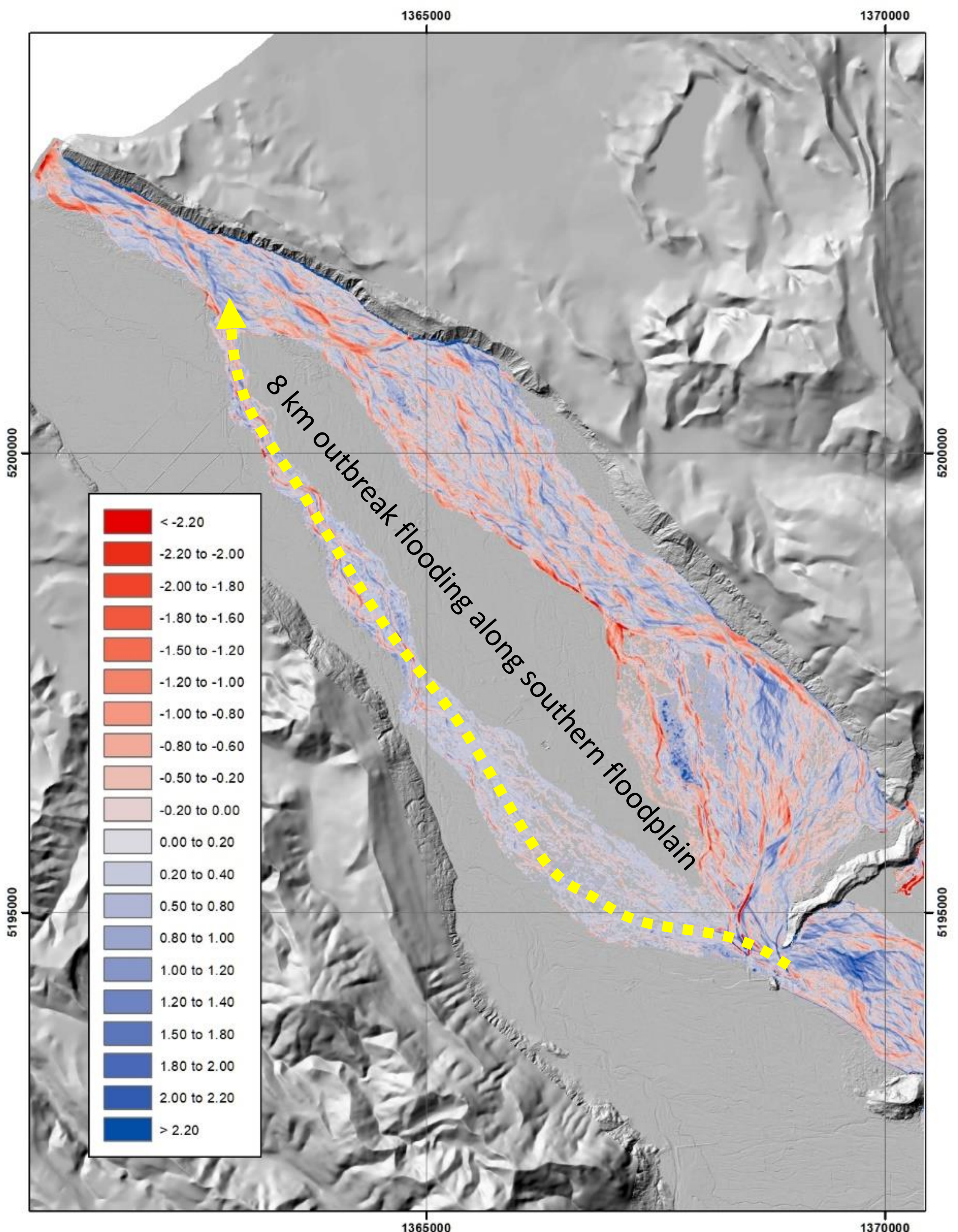

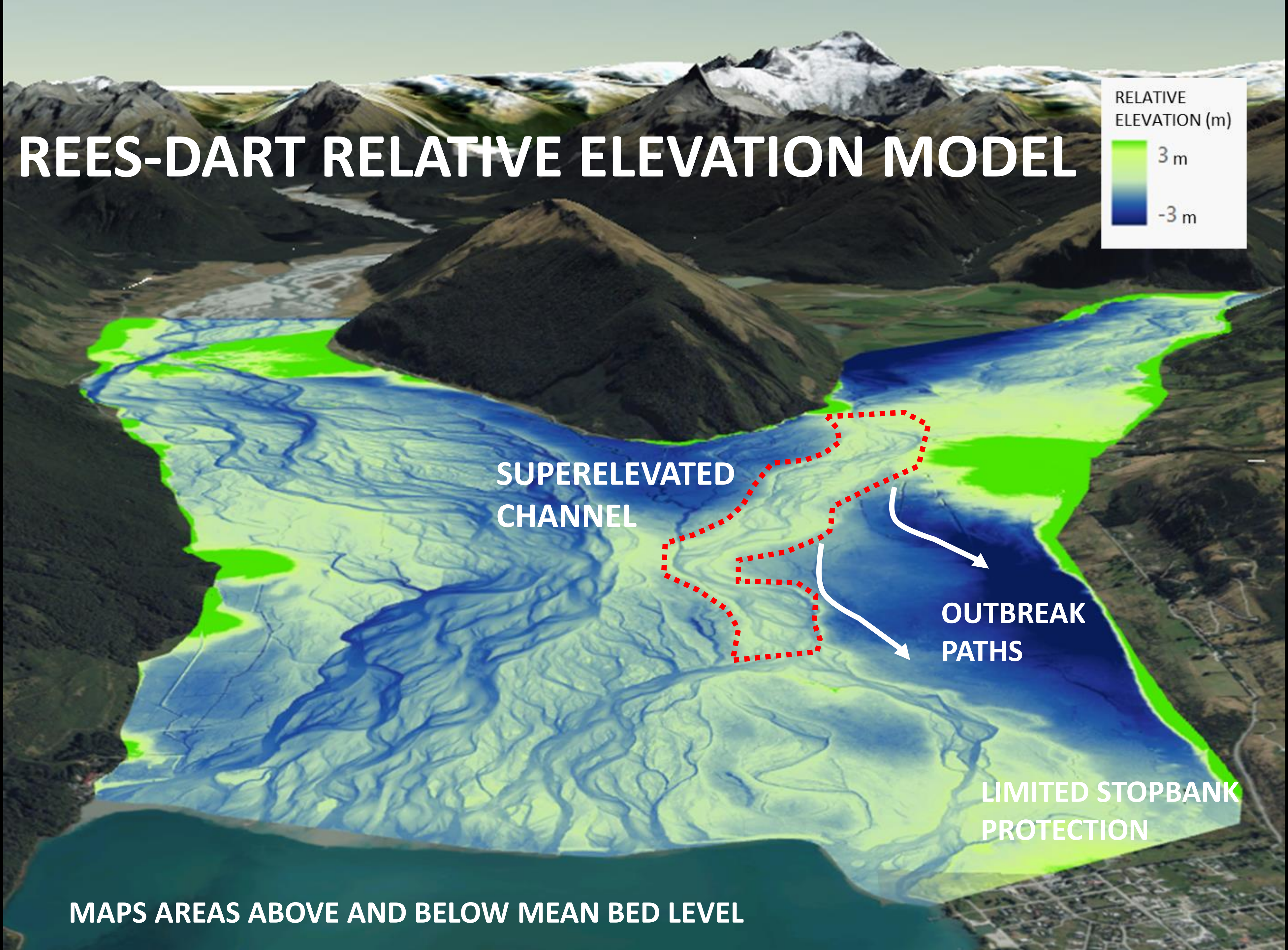
REES-DART RELATIVE ELEVATION MODEL
RELATIVE ELEVATION (m)
3 m
-3 m
SUPERELEVATED CHANNEL
OUTBREAK PATHS
LIMITED STOPBANK PROTECTION
MAPS AREAS ABOVE AND BELOW MEAN BED LEVEL

CONCLUSIONS

Fluvial hazards pose significant and increasing challenge for the local community into the future

Hazard set to increase due to both climate change and long-term geomorphic evolution

Some hazards that will become increasingly hard to mitigate