Fluvial Geomorphology & Natural Channels

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Acknowledgements:

- *Graduate students & post docs who have engaged with these issues and cases*
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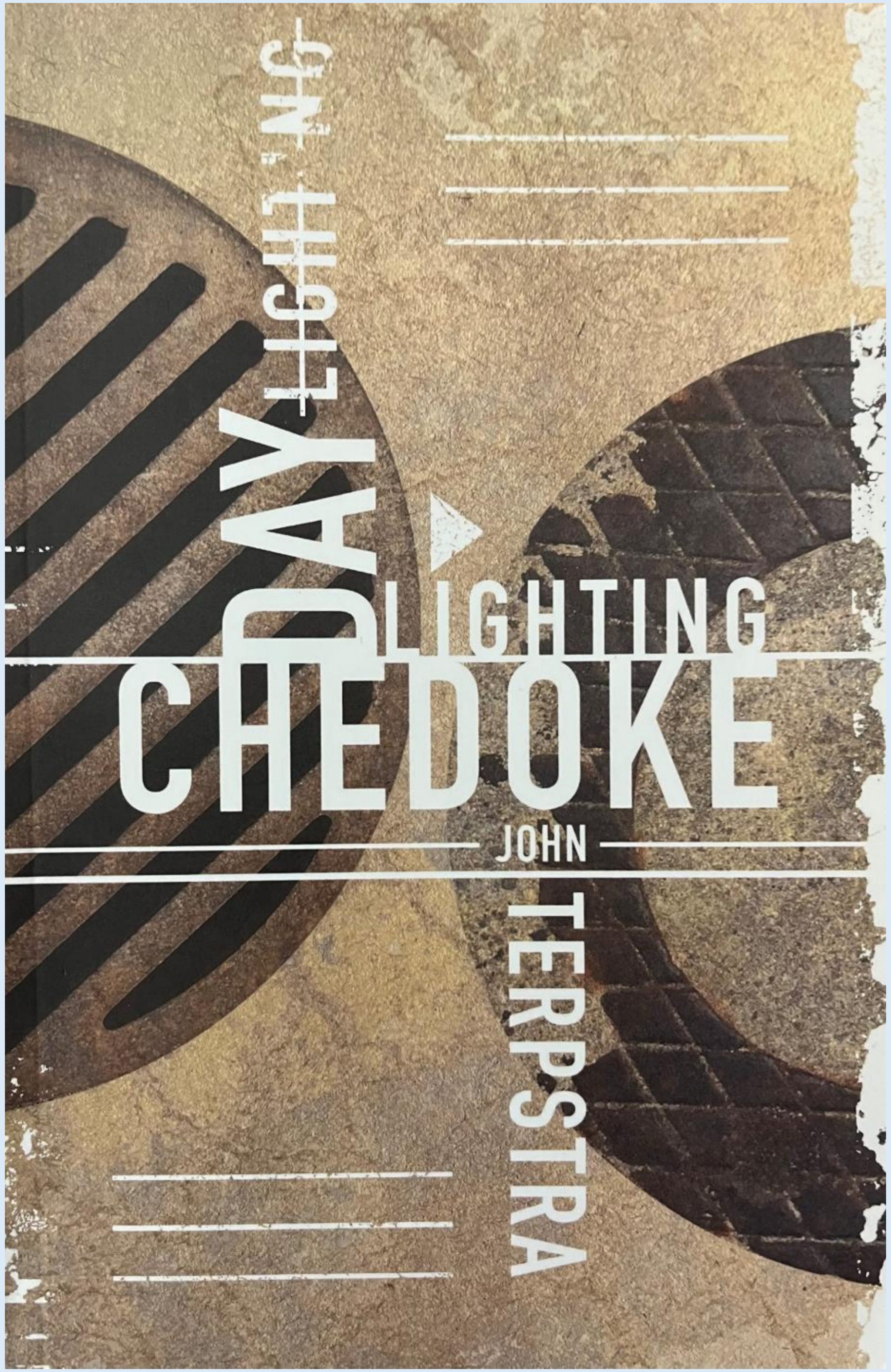
- *Collaborators & colleagues; Joe Desloges, Ray Kostaschuk, Bruce MacVicar, Lief Burge*

NSERC CRSNG

Western

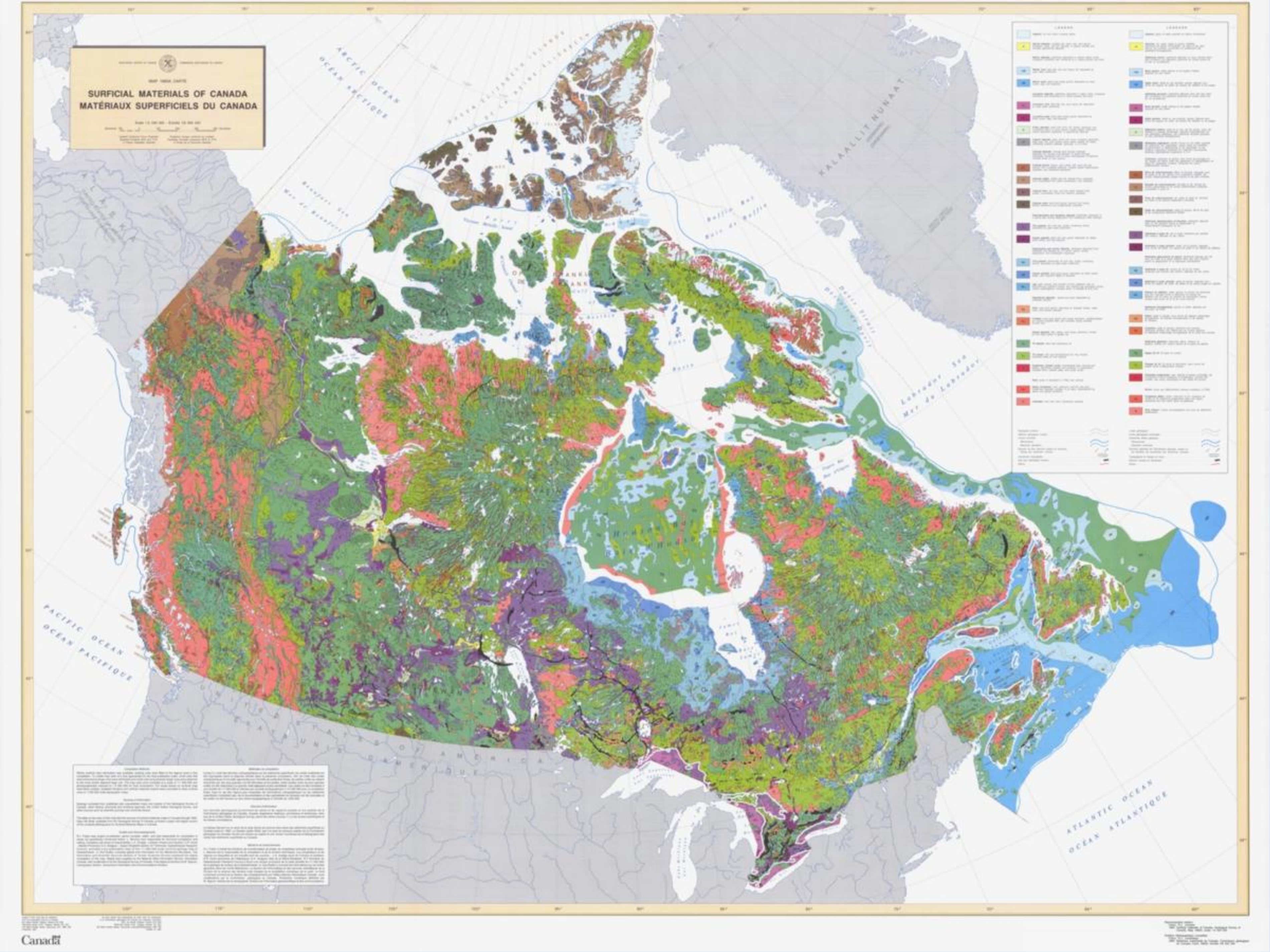
8th Conference on Natural Channel Systems 2026, Hamilton



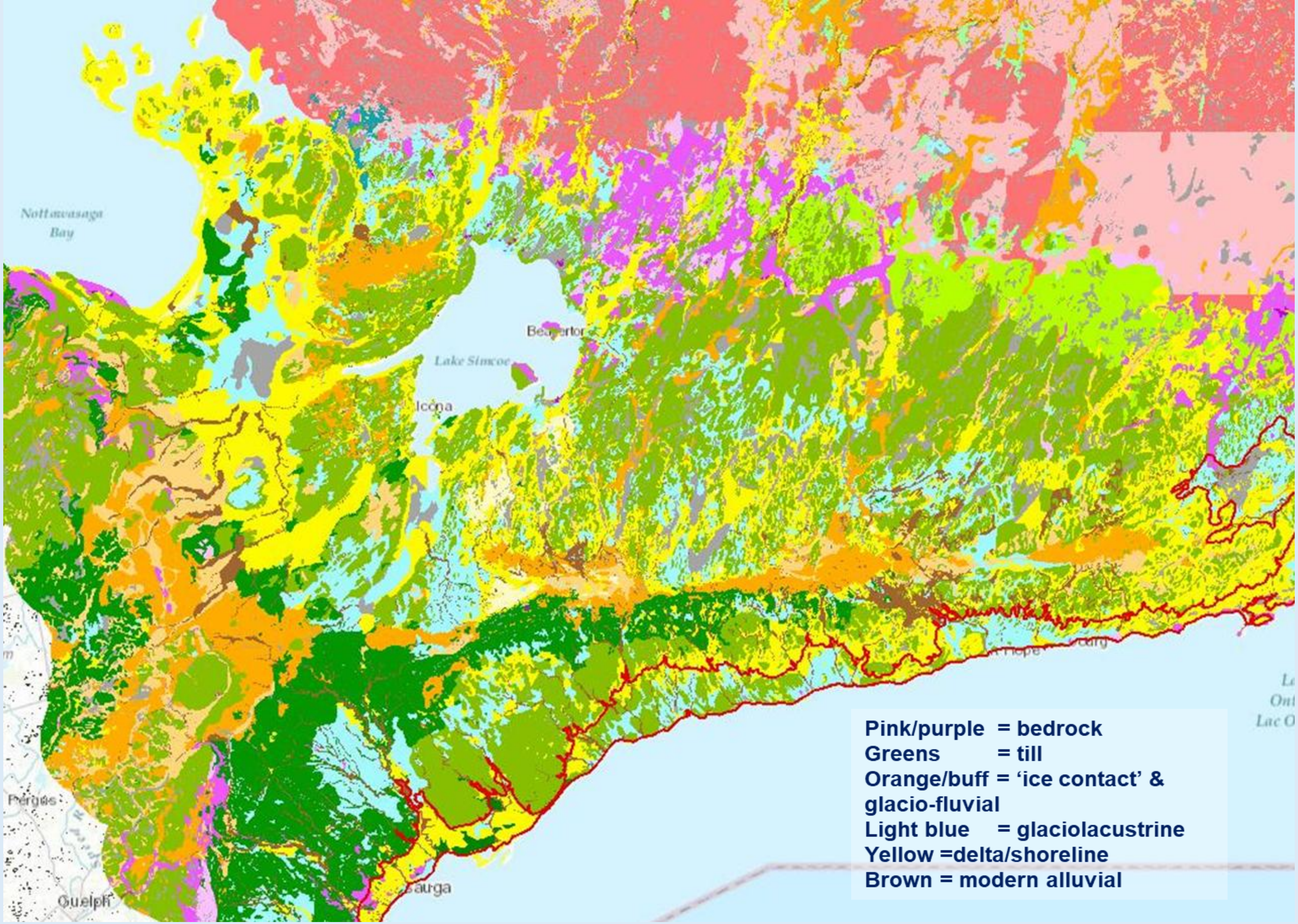
“We choose the landscapes we live in”

The landscape changes when we pursue the stories connected to it.

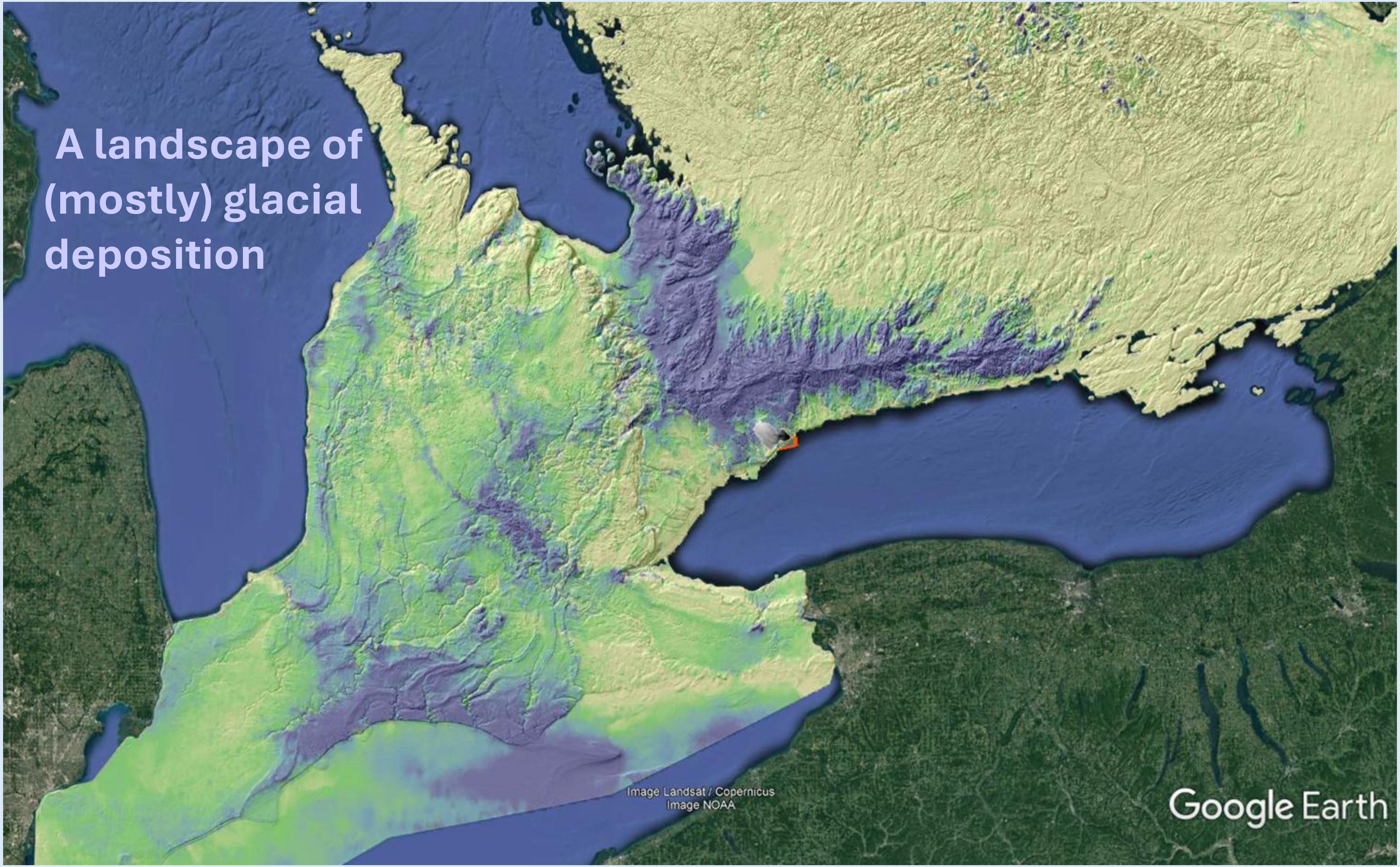
Learn the stories and the landscape looks different. Transformed. Layered. Alive.


SURFICIAL MATERIALS OF CANADA
MATÉRIAUX SUPERFICIELS DU CANADA
ARCTIC OCEAN
OCÉAN ARCTIQUE
KALAALLIT NUNAAT
Baffin Bay
Baie de Baffin
Labrador Sea
Mer du Labrador
PACIFIC OCEAN
OCÉAN PACIFIQUE
ATLANTIC OCEAN
OCÉAN ATLANTIQUE
Canada

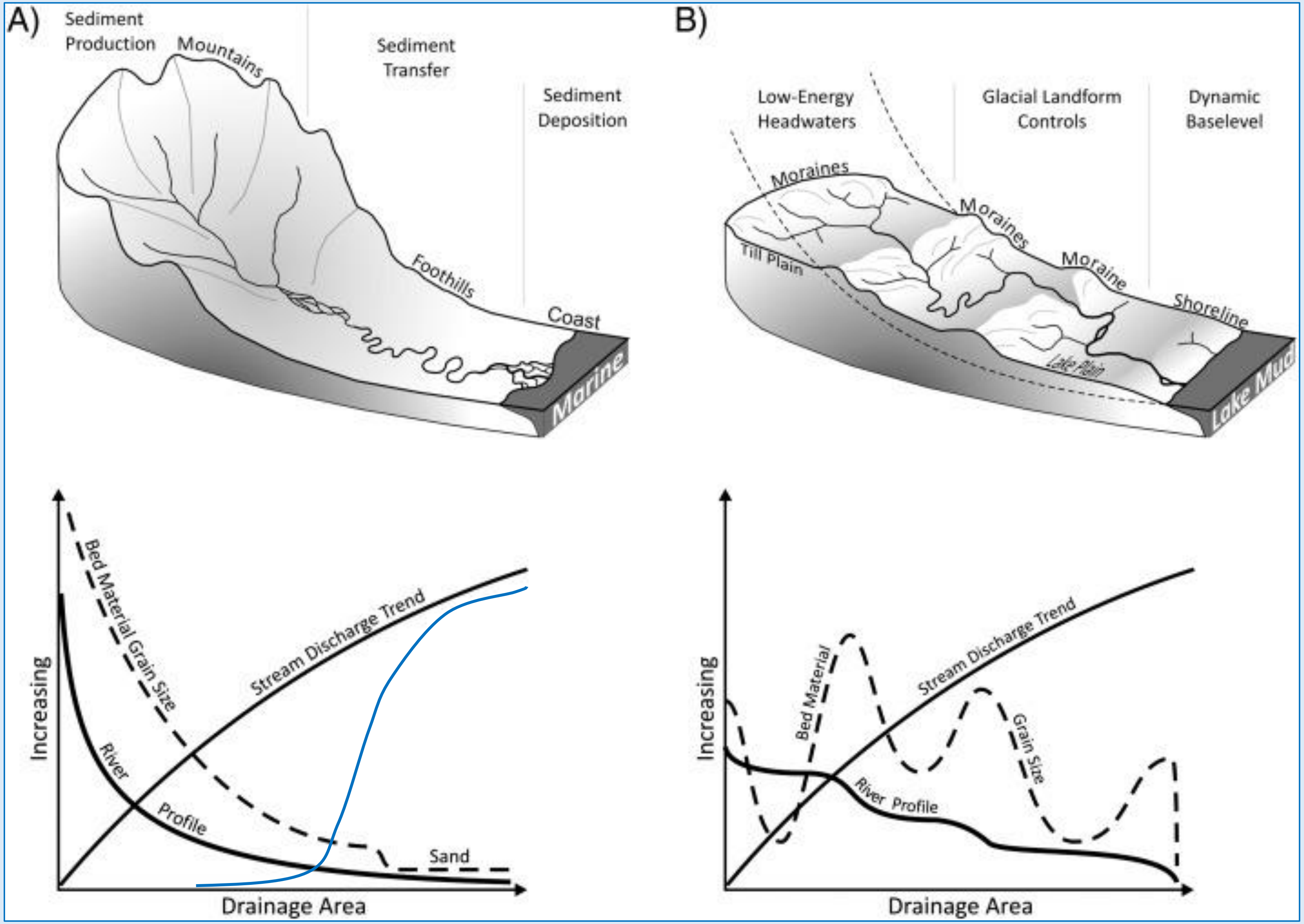
Local variation in source material for rivers



A landscape of (mostly) glacial deposition



Watershed and fluvial landscapes, channel types, sediment sources & spatial patterns different from 'textbook'



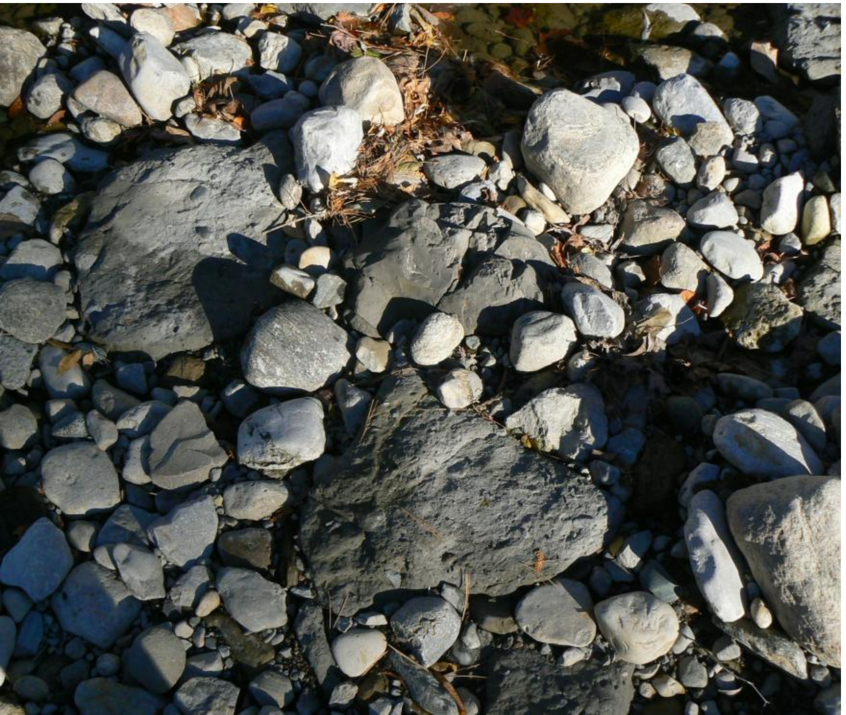
https://www.sciencedirect.com/science/article/abs/pii/S0380133015001847 Phillips and Desloges 2015

Semi-alluvial channels

[see also Ashmore & Church, GSC Bulletin 555, The Impact of Climate Change on Fluvial Processes in Canada]

- Incised into non-alluvial material
- Non-alluvial material is readily eroded by existing flows – not abrasion-dominated
- Direct sources of bed material are a mix of alluvium and non-alluvial.
- Non-alluvial material may directly yield gravel, cobbles, boulders etc.
- Transient (often very thin) alluvial cover on bed
- Bars and planform may be similar to fully alluvial channels but local and short-term scour restricted
- Channel dimensions adjustable (similar regime dimensions as alluvial (?) – but slope may not be equilibrium
- May be incised and confined

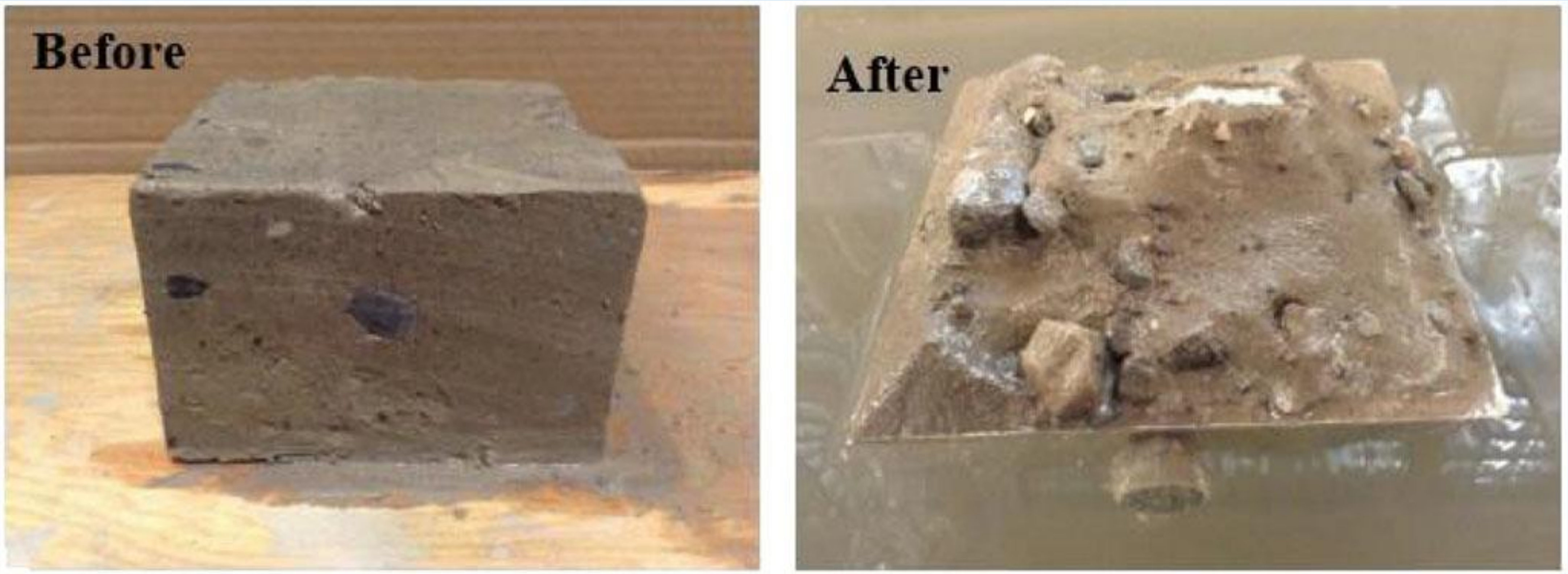


- Cohesive glacial sediments may be highly erodible – different from most bedrock substrate
- Flume experiments (Leila Pike & Susan Gaskin)
- (previous in situ jet testing, Imran Khan)

- Critical stress for erosion 1-5 Pa

  [For medium gravel critical stress approx. 30-50 Pa]



- What are conditions for formation of cover?
- Is stable partial cover possible?
- What are morphological and supply controls?
- What is effect of bedload supply on transport rate?
- What happens to channel morphology when cover forms?
- Is ‘runaway de-alluviation’ possible?

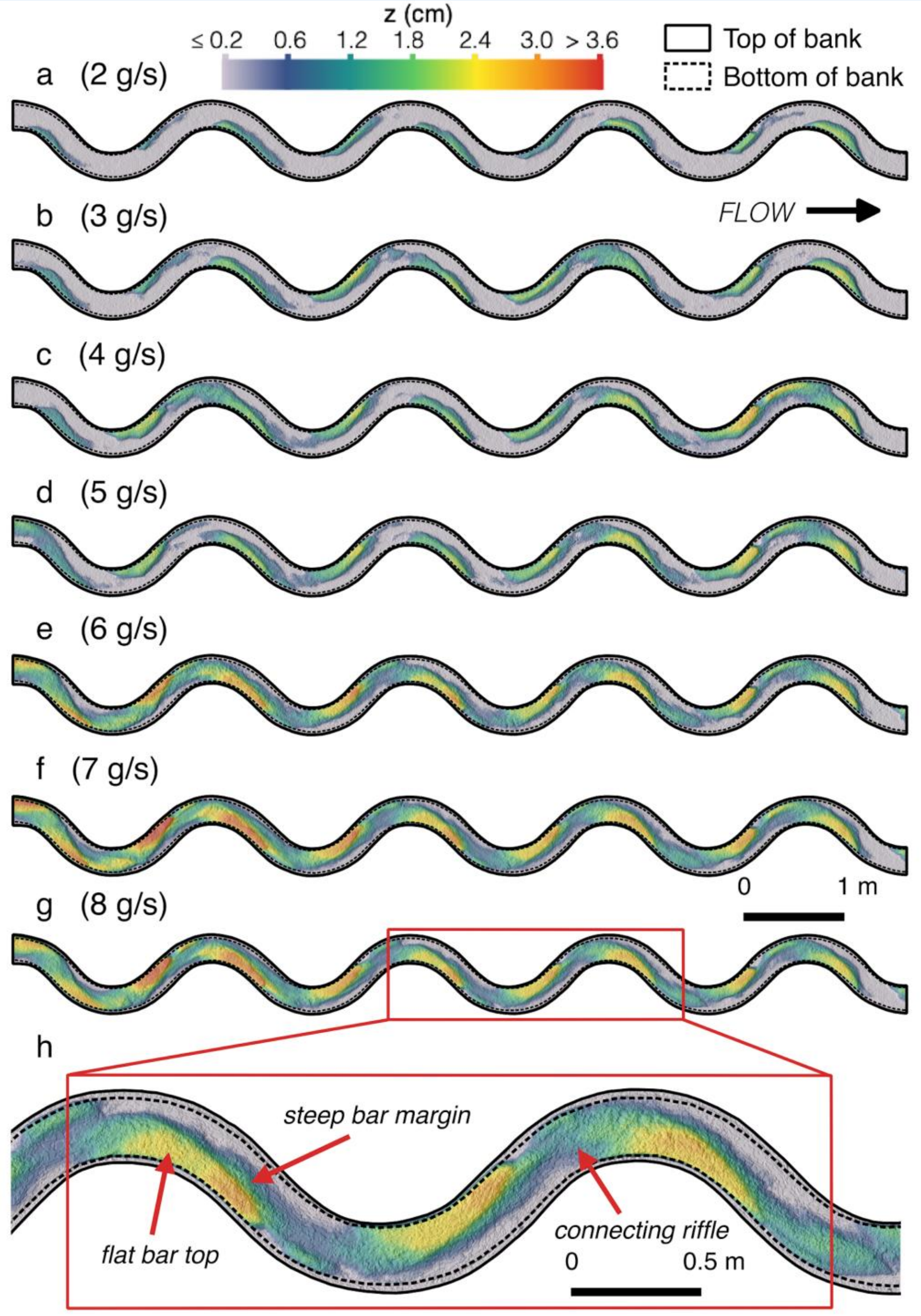
An approach to channel design & ‘nature-based’ functioning

Flume experiments and some field observations:
Sinuous planform with fixed bed, ‘equilibrium’ experiments at progressively high sediment feed rate, bed cover, bed morphology and bedload output

Tatiana Hyrtsak, Matilde Welber, Elli Papangelakis, Sarah Pierce, Bruce MacVicar, Danielle Barr

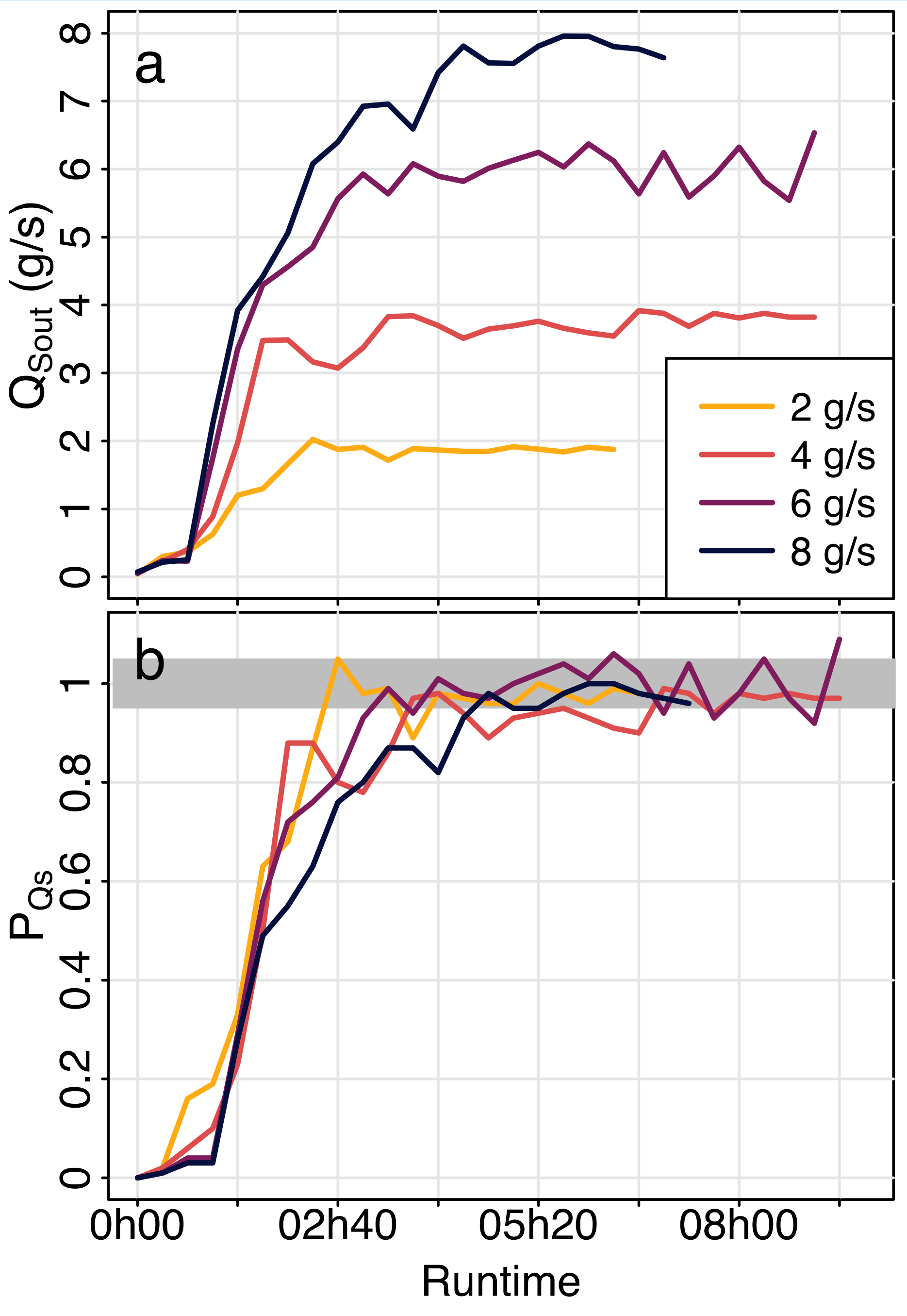
Supply, cover formation (& loss) & morphology

- Complex 3D morphology controlled by both sediment supply rate **and** planform geometry
- Increased supply gives more cover & decreased supply causes cover loss
- Cover location tied to bend morphology
- Bar-riffle morphology formed with large topographic variation – coarse riffles, fine bar tails
- Flat bar tops with steep bar margins at high sediment supply rates
- Exposed bed even at highest supply rate



Bedload Transport

- Bedload reaches input-output balance at all supply rates
- Transport rate increases with sediment supply rate ⇒ bedload transport rate (capacity) is mediated by the cover state
- Bedload not simply a function of discharge (shear stress) – supply-limited and dependent on morphology
- Helpful to understanding dynamics of cover in semi-alluvial channels and to effects of changes in supply, channel engineering and design



Urbanization & fluvial transformations

Fluvial geomorphology – many years of studies of effects of urbanization on rivers

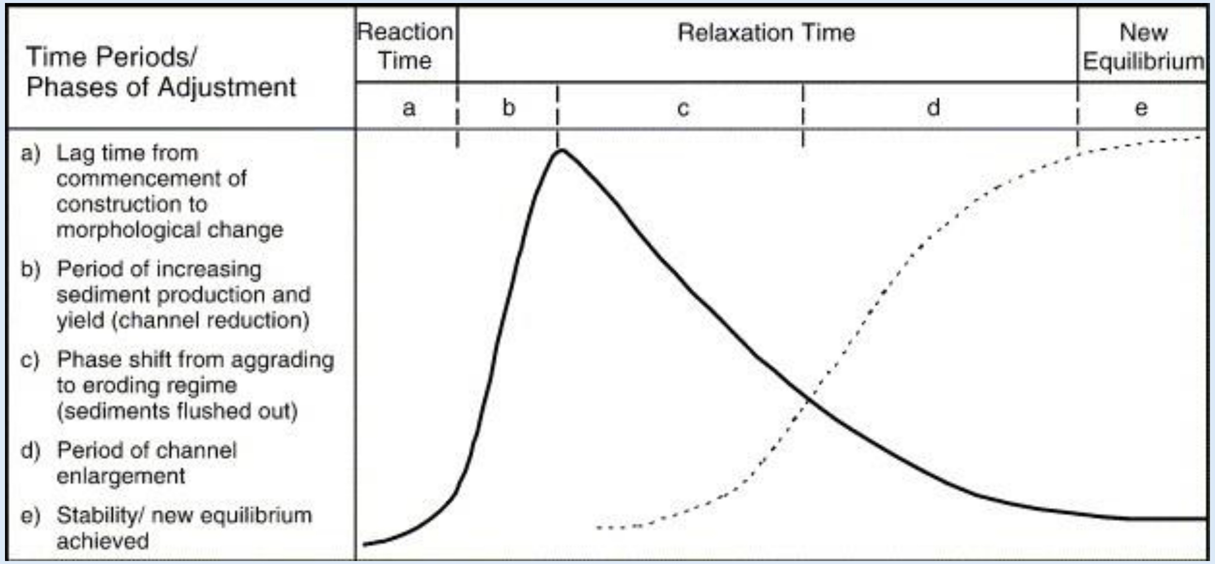
Usually very small watersheds, single before-after or side-by-side cases

Seen as ‘one-off’ impact short-term response - quasi-experiment on fluvial adjustment

Few with known discharge change

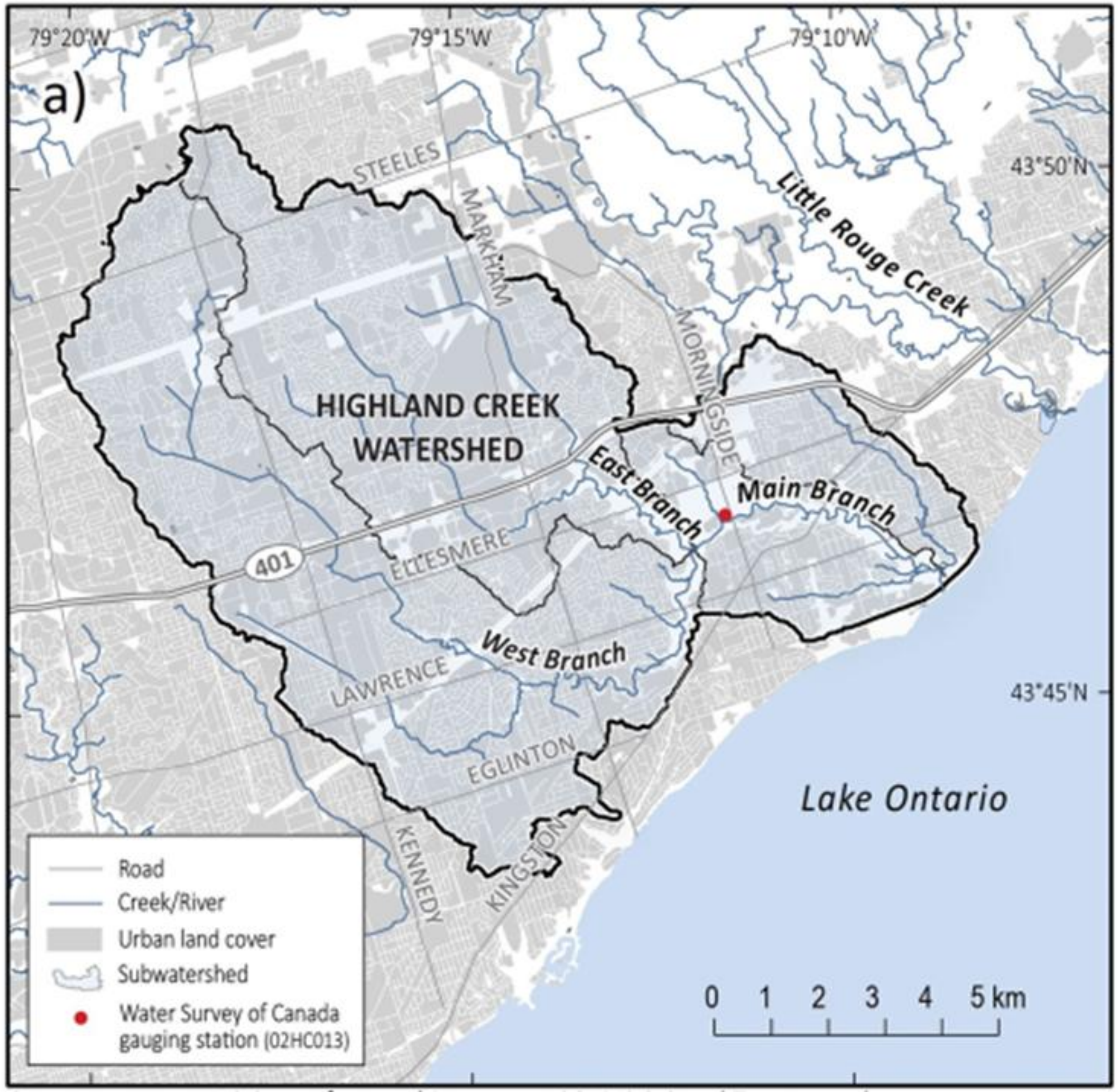
Limited data but common effect is channel enlargement (expected from hydraulic geometry principles), channel pattern change, incision, etc

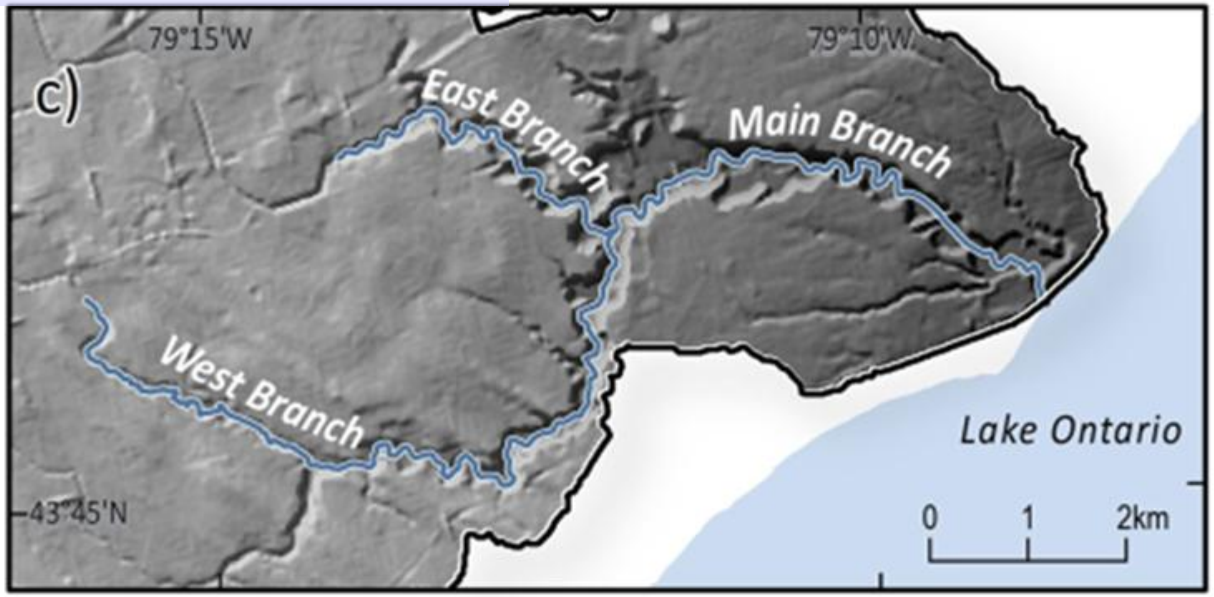
What do we learn from much longer trajectory and richer data base?



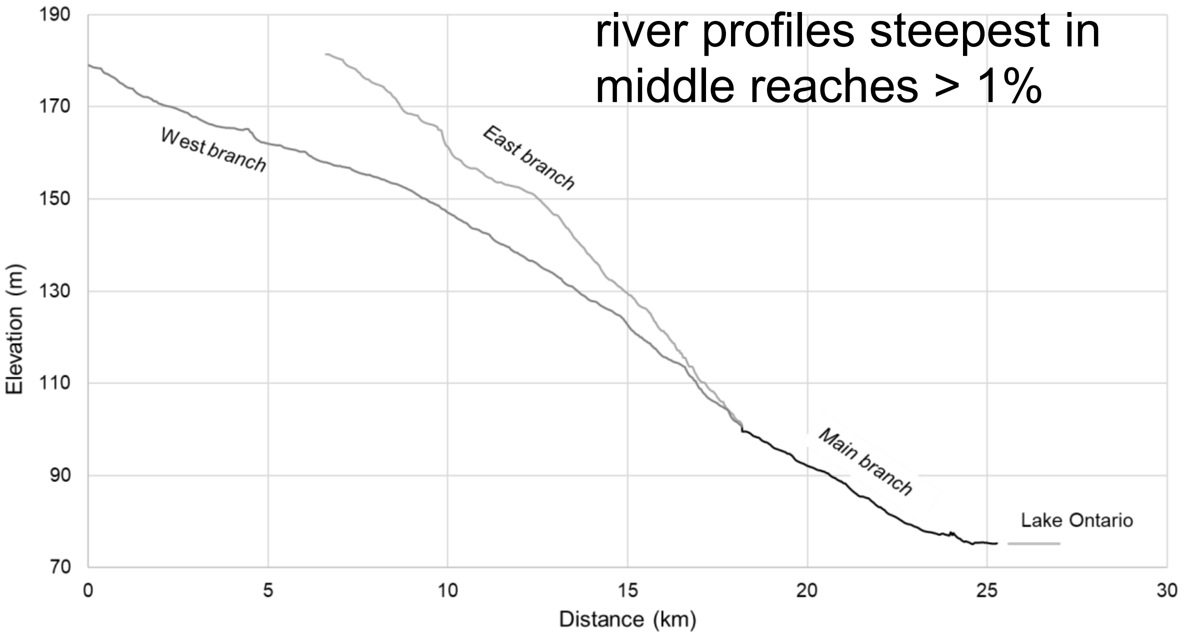
From Chin, 1996

Stories of Highland Creek & Natural Channels





river profiles steepest in middle reaches > 1%

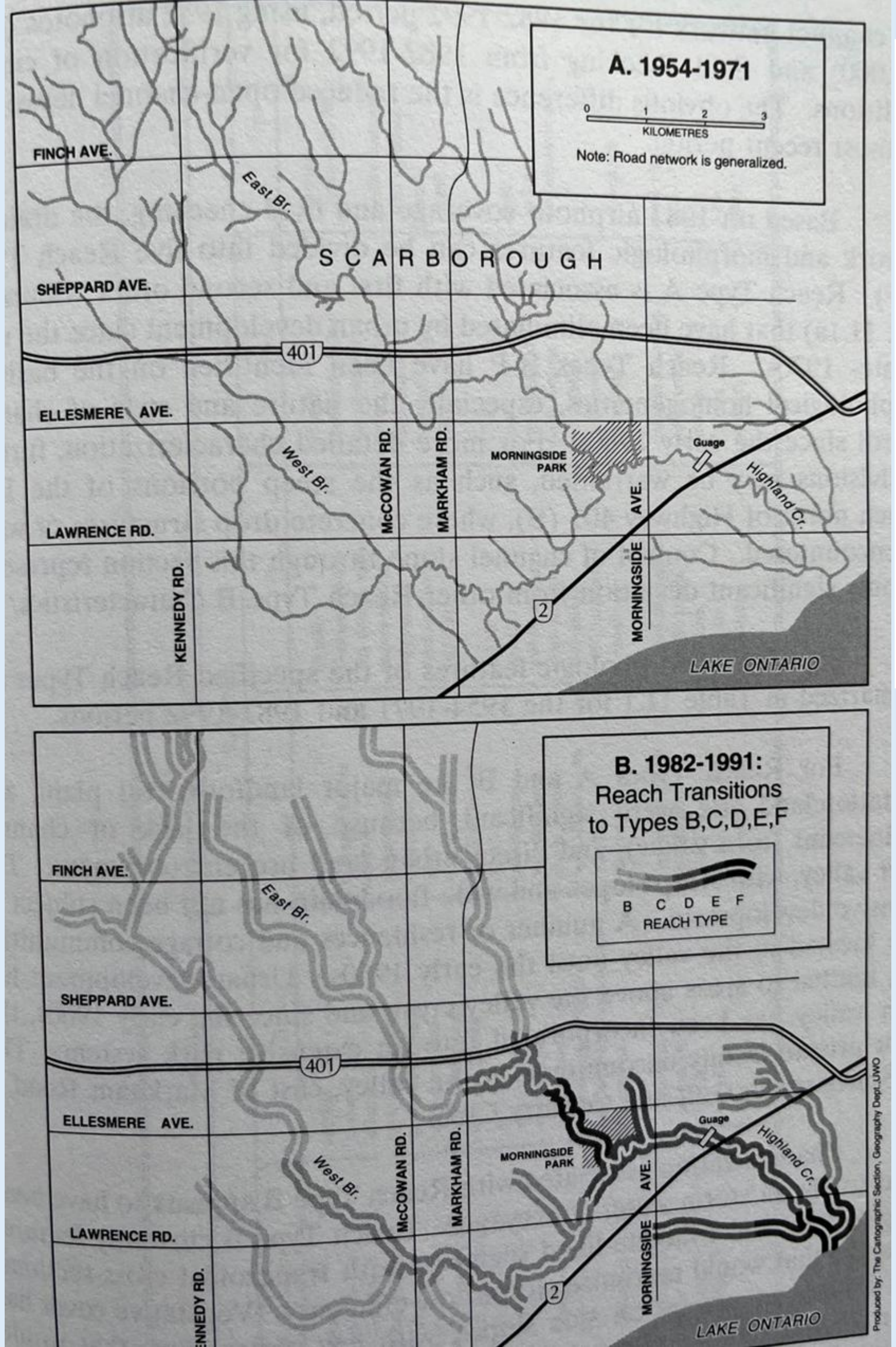


Ashmore et al., 2023 John McDonald, Mariane Vocal-Ferencevic, Victoria Barlow
+ lots of support from consultants, TRCA, City of Toronto

The Kevin Bellamy Story

The Geomorphic Character and Quality of Highland Creek, 1994

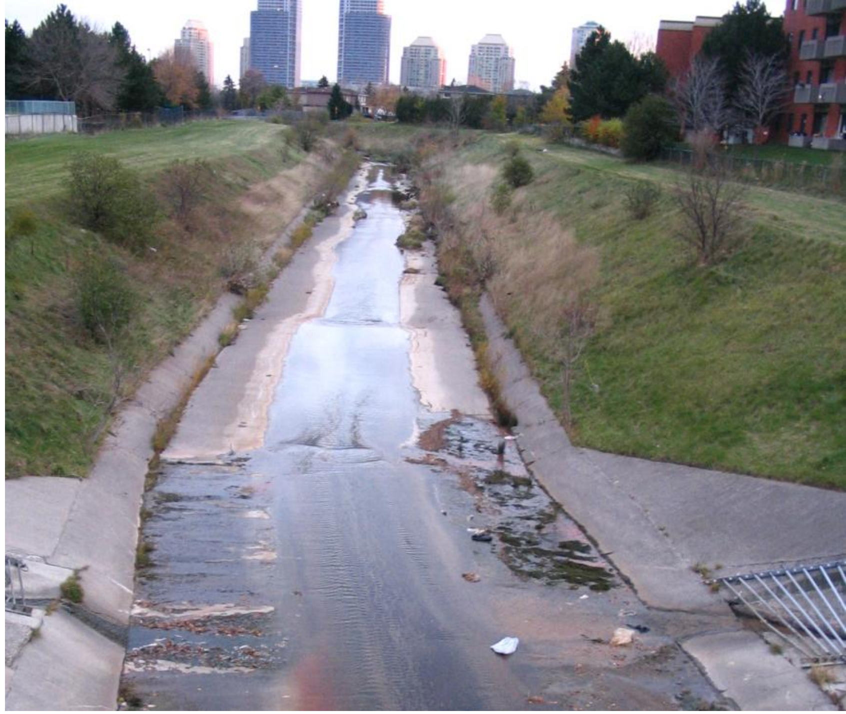
Highland Creek east branch, 1990 photo by K. Bellamy



Reach type	Major characteristics
Type A&B	concrete trapezoid, weirs
Type C	Single sinuous, gabions, armour stone, rectangular section, some and-gravel bed
Type D	Single sinuous, large rip-rap, trapezoidal section , sand-cobble over cohesive glacial sediment, concrete, rock weirs,
Type E	Single to braided, partly unconfined, sand-gravel alluvium over cohesive glacial sediment, local armour stone & rock weir
Type F	Single-anastamosed, sand-silt, rip-rap & natural river mouth

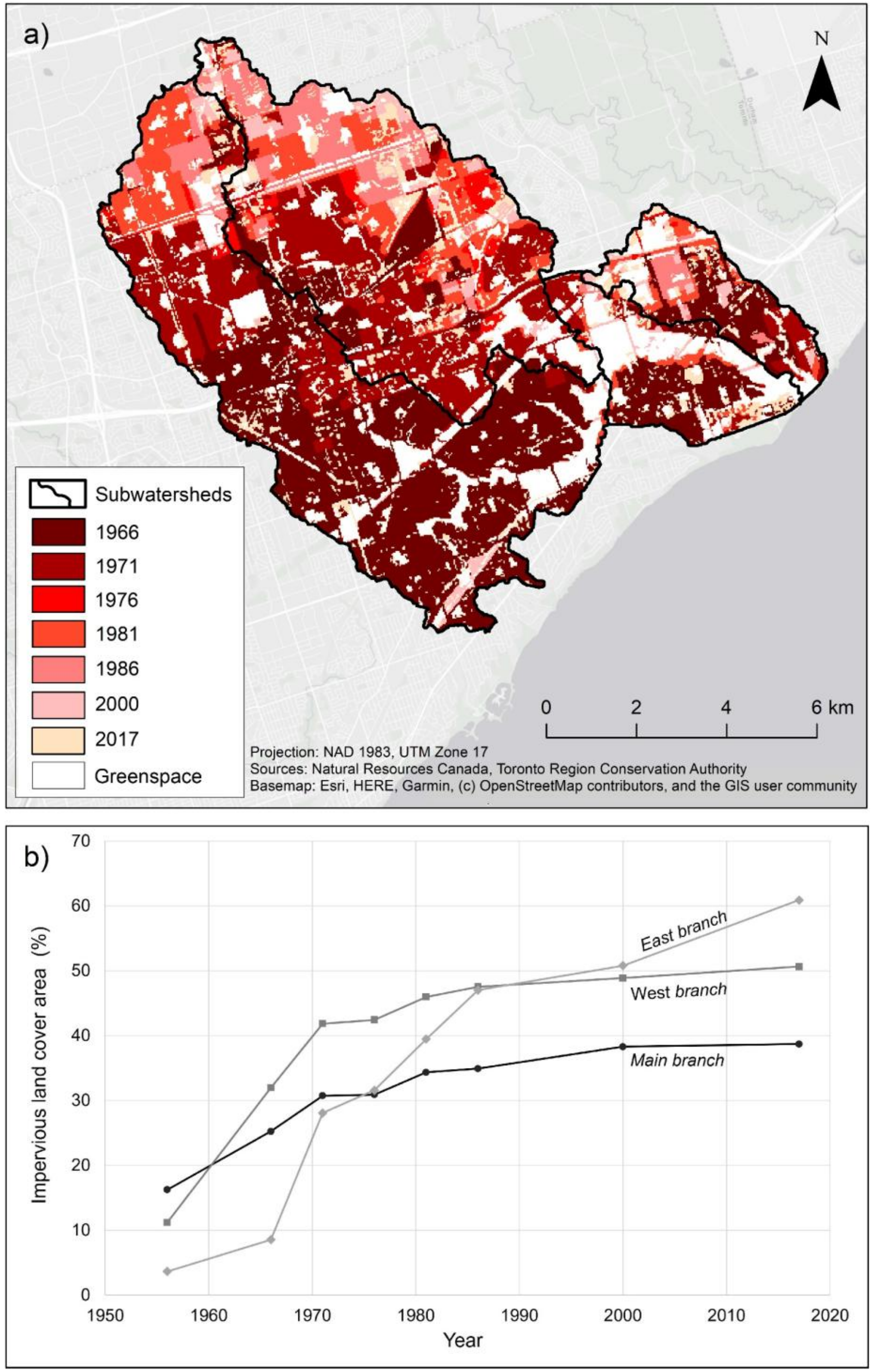
- Gabion revetments, channelization etc. on west branch 1965-1970
- Major damage in 1976 flood reaches types C & D
- Incision - grade control. Bank protection, rip rap…
- Some reaches had no resemblance to original channel
- East branch close to natural - thin alluvium over cohesive clay and rock weirs over sanitary sewer crossings
- Limited sediment supply, exposed clay – risk of 'de-alluviation'

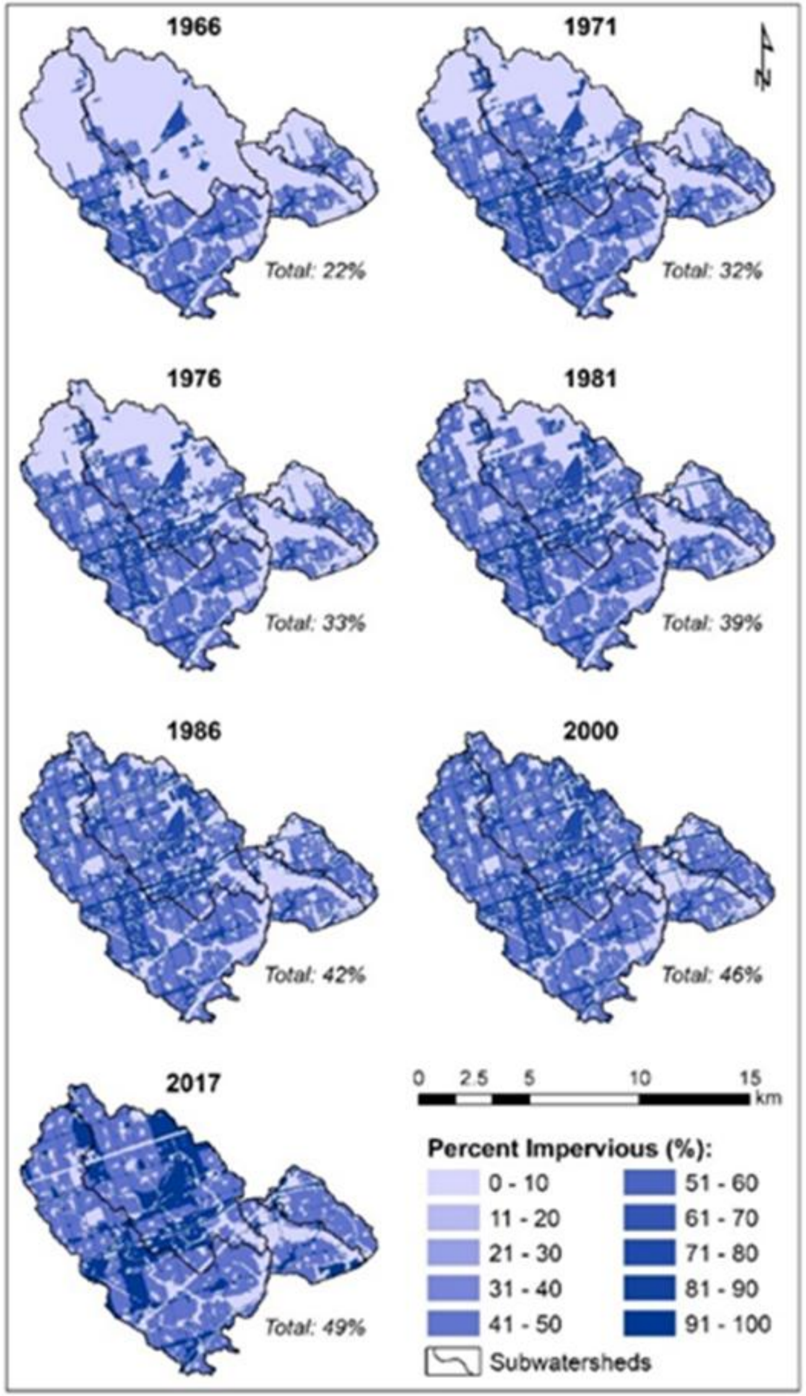





Progressive urbanization – SW-NE “up” the watershed over several decades

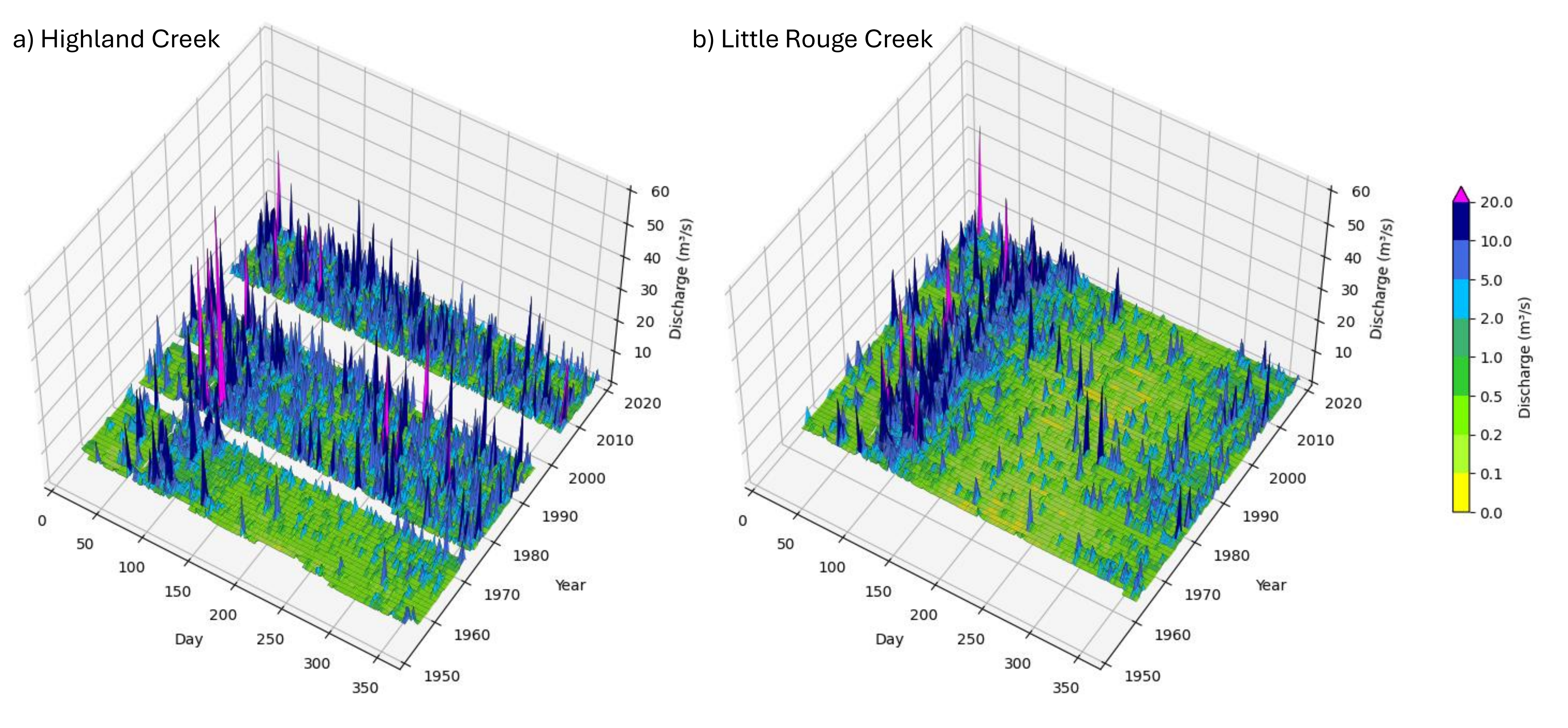
Almost 100% urban (except greenspace = river valley) & 40-60% impervious area by c. 2000



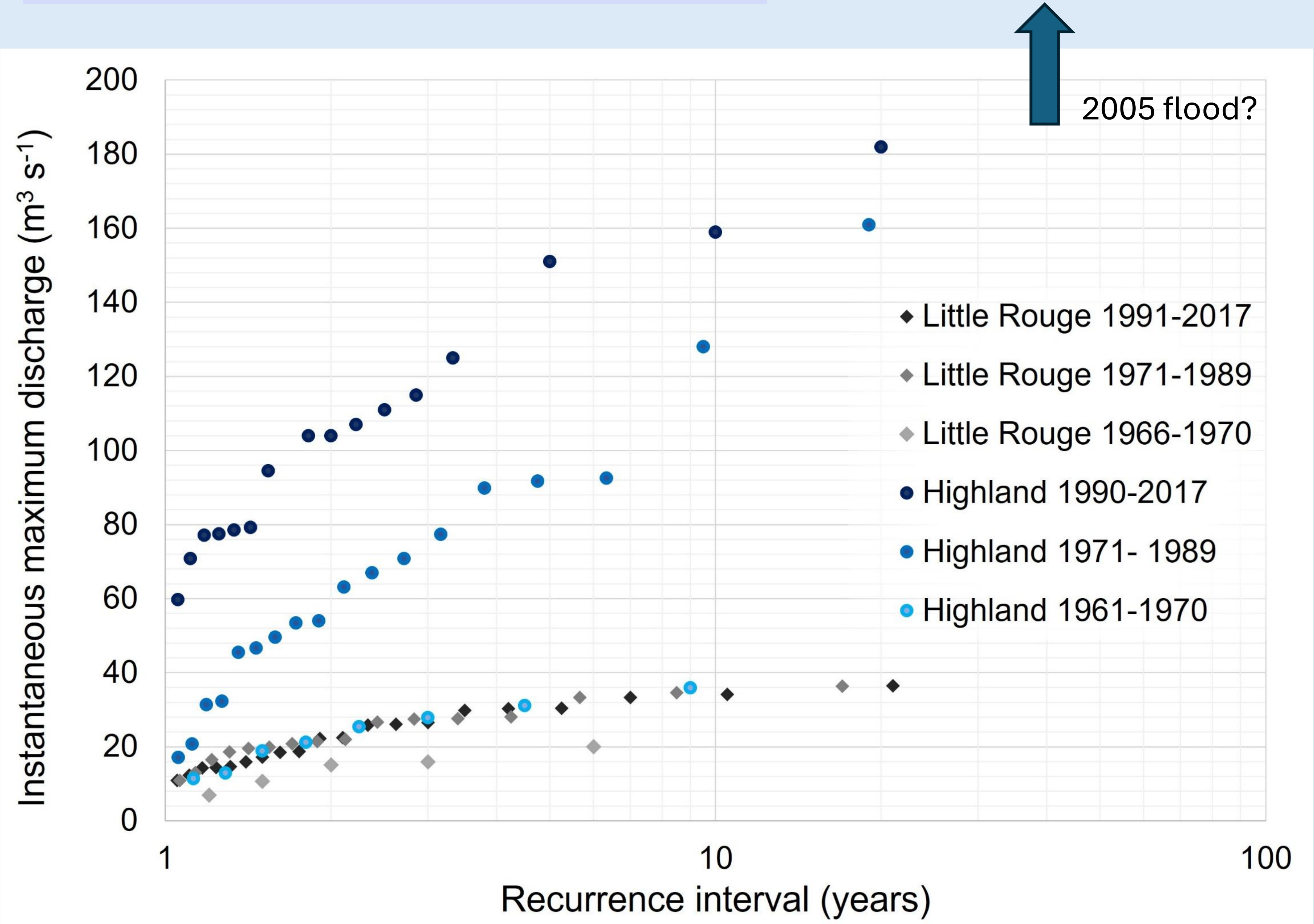


Victoria Barlow

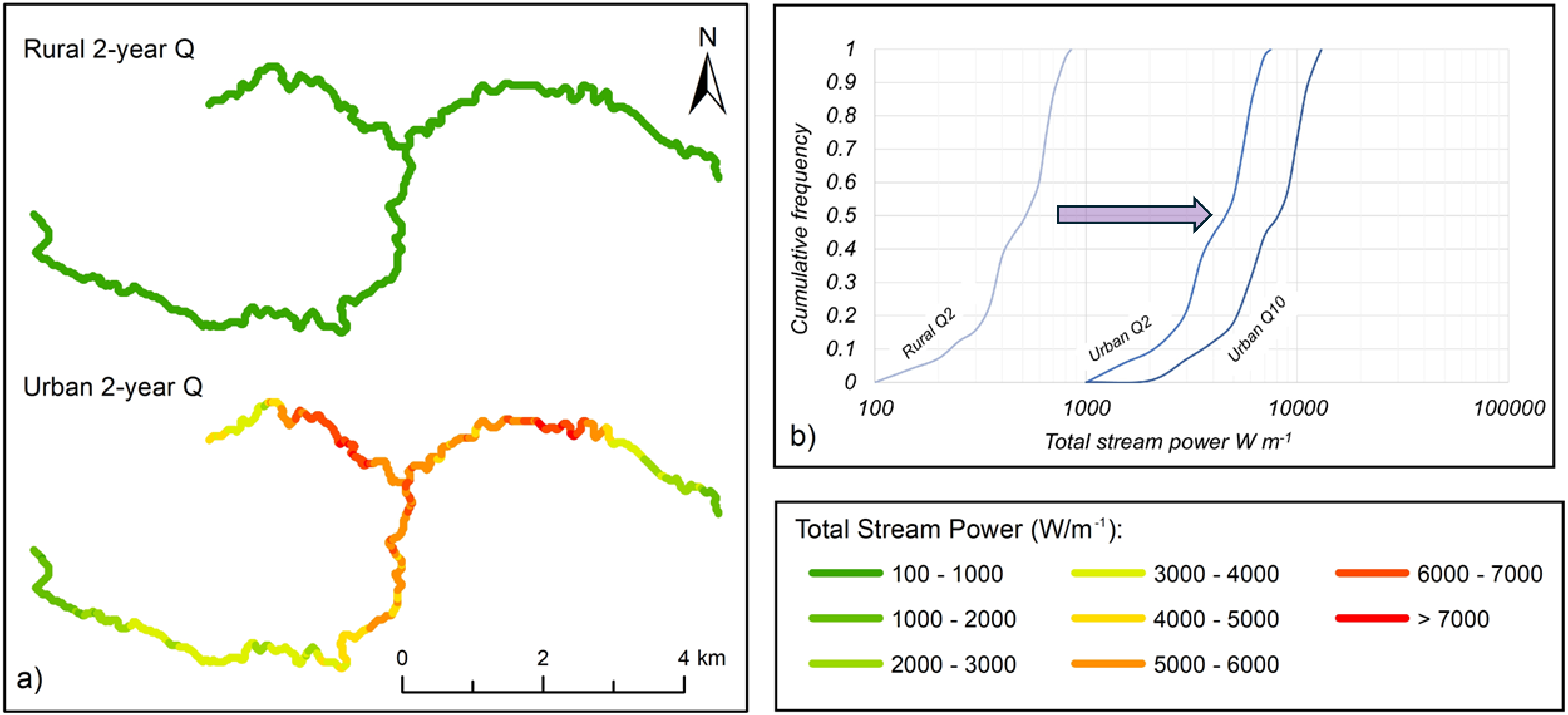
Major discharge changes beginning c.1970 – flashy floods, loss of seasonal flow pattern



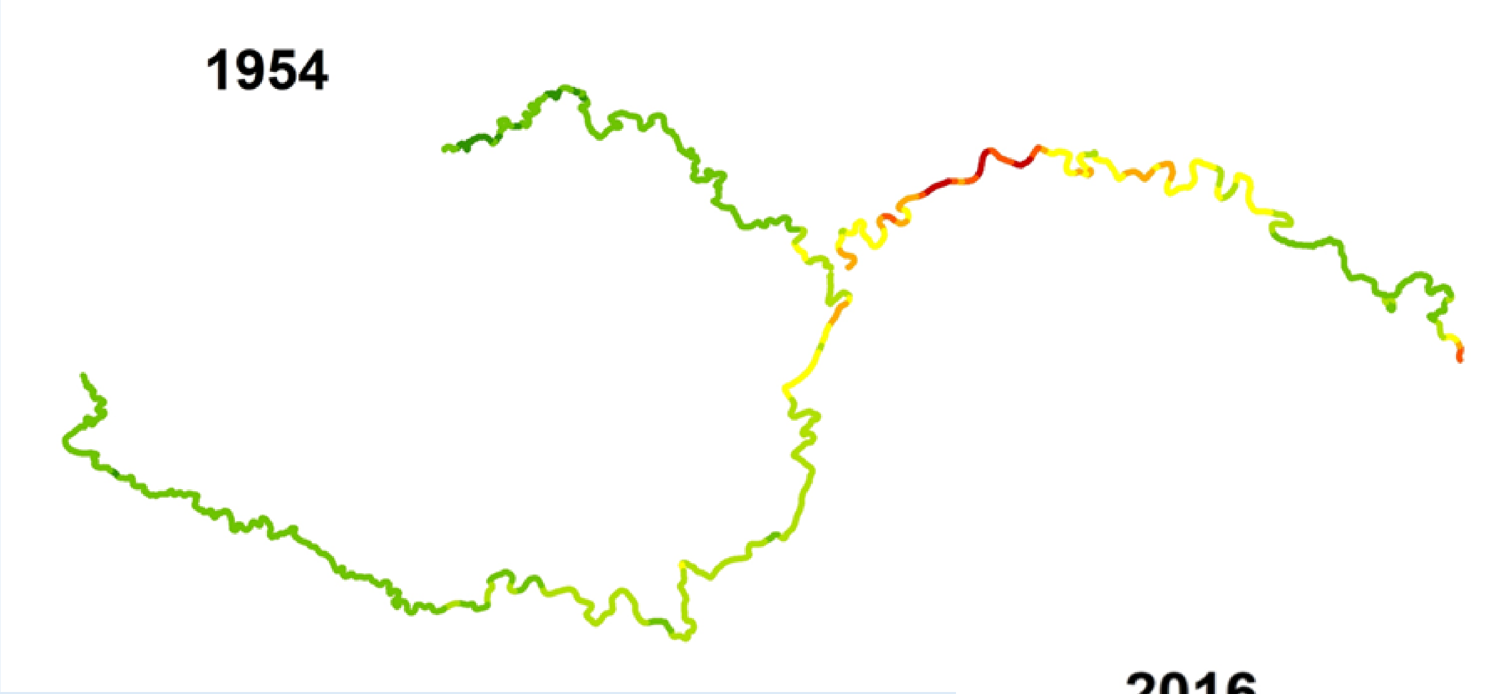
Peak flood flows increase > 4x

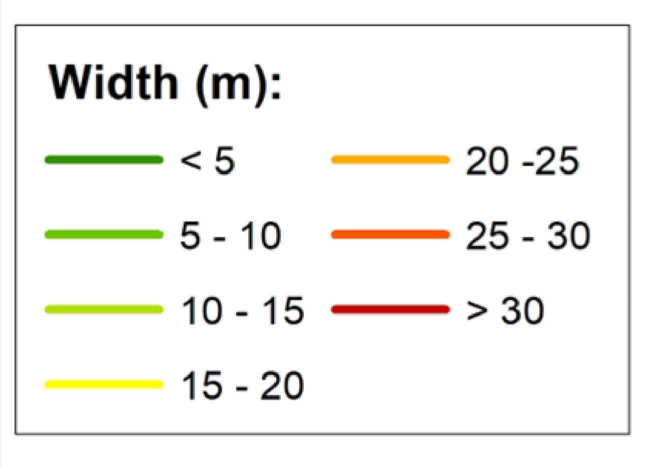


Huge (up to x10) increases in total stream power from discharge increases (higher with channel straightening/steepening)

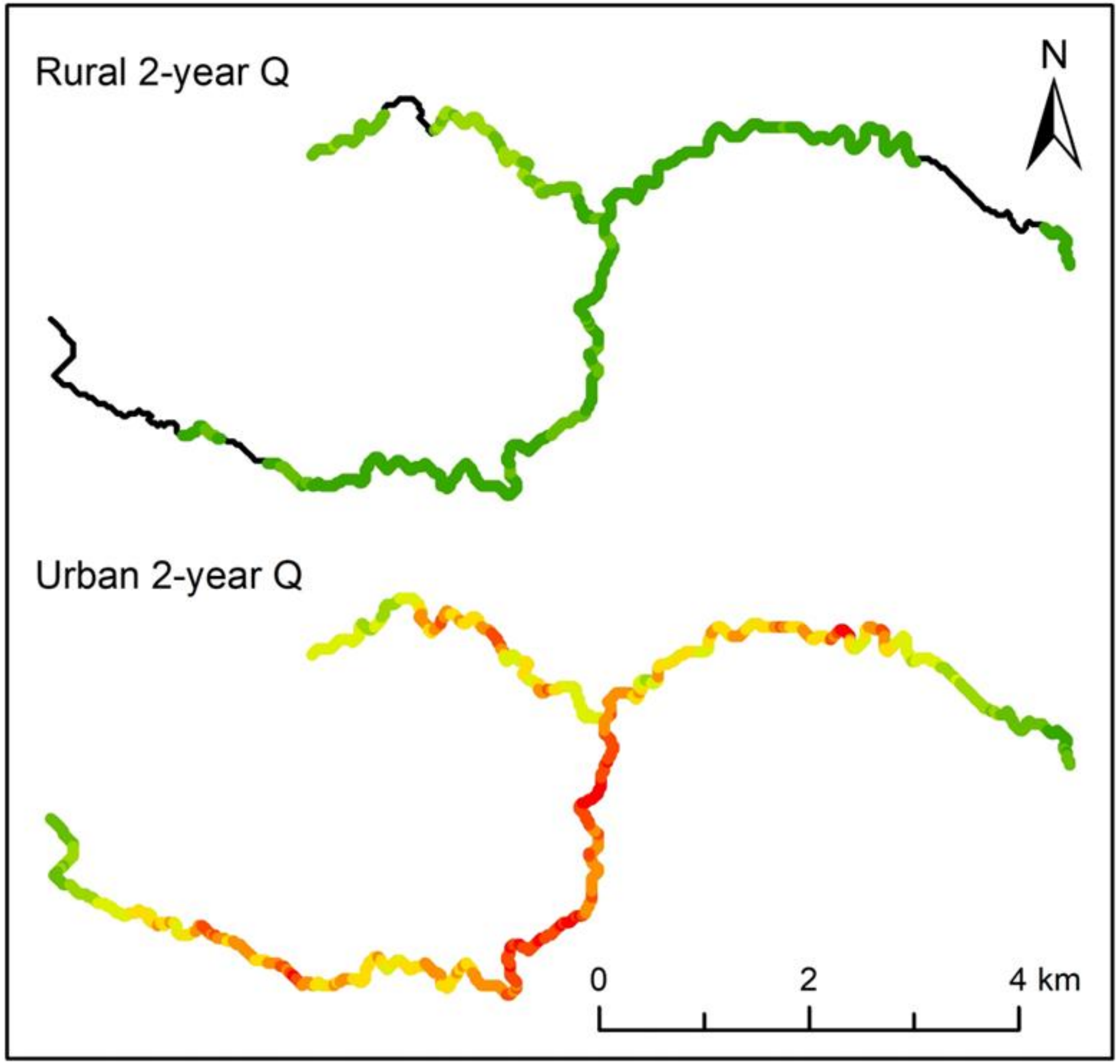


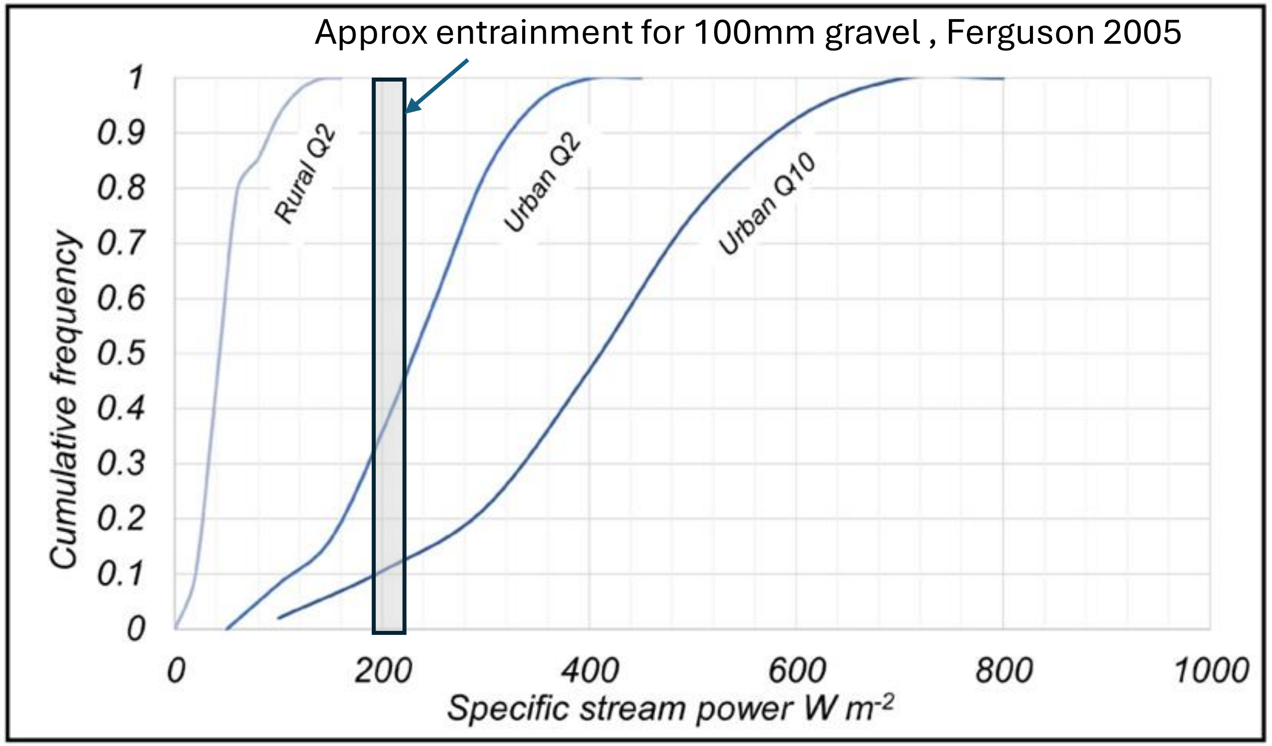
Increased power → increased width (but > on East Branch.....)

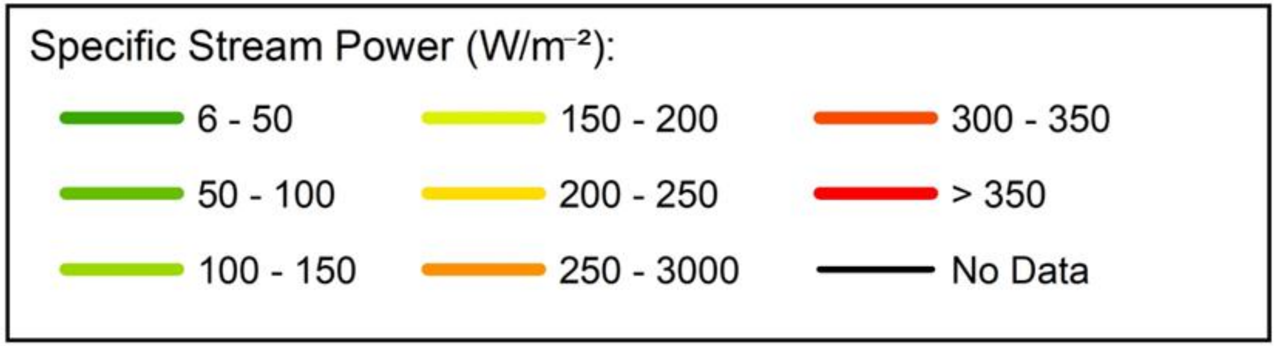




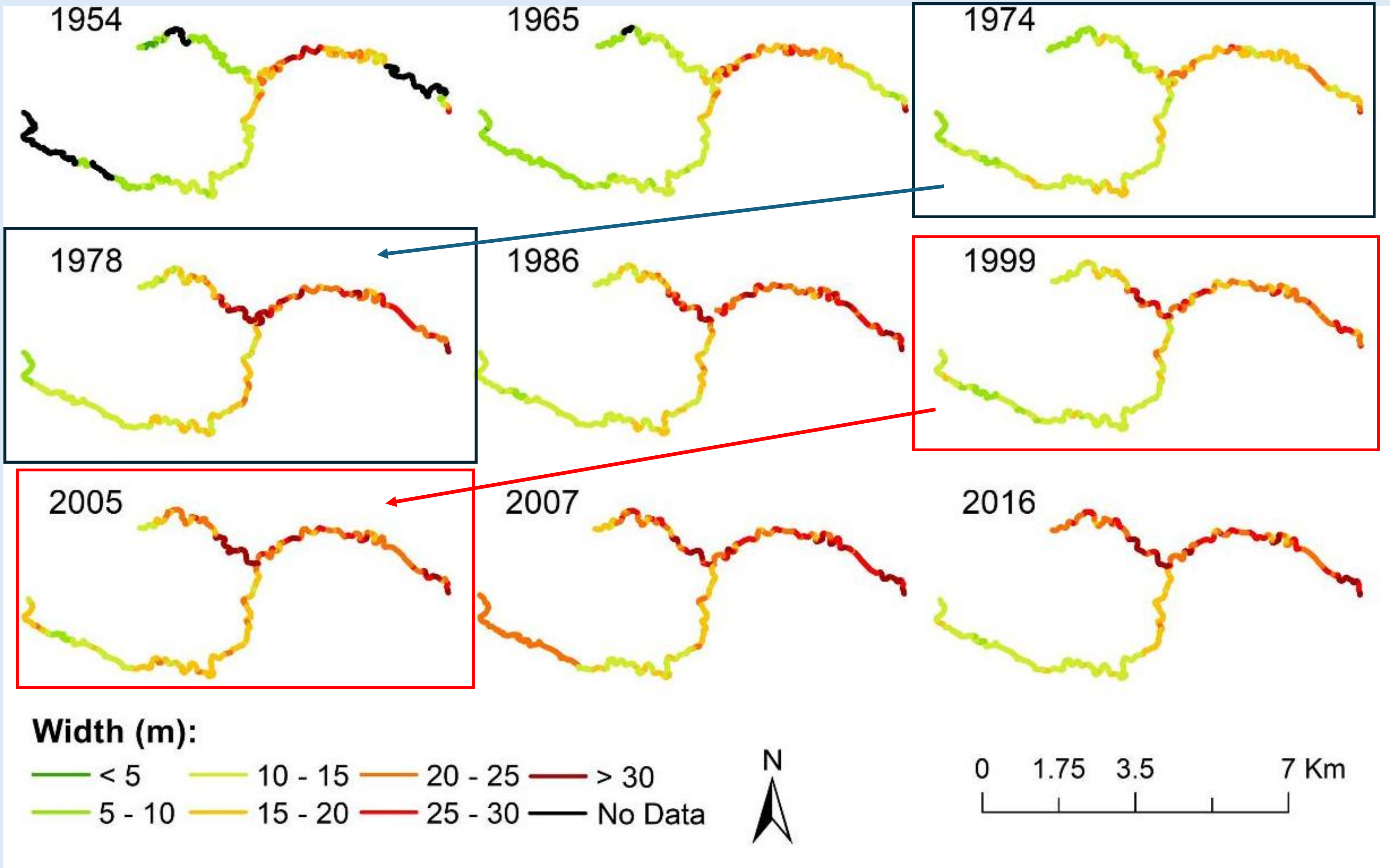
Specific stream power also increased – greater on west branch because increased total power but limited width increase (> bed erosion & incision potential)



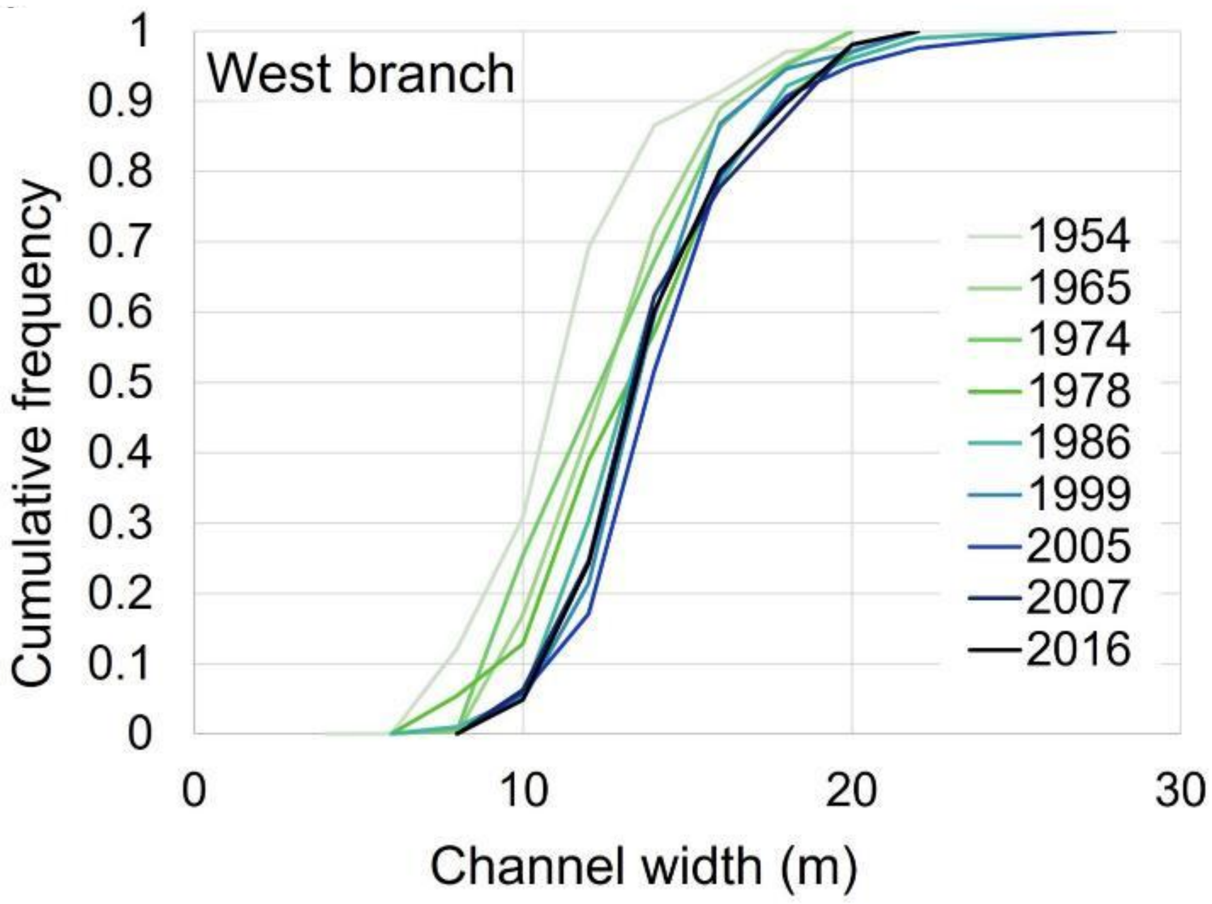


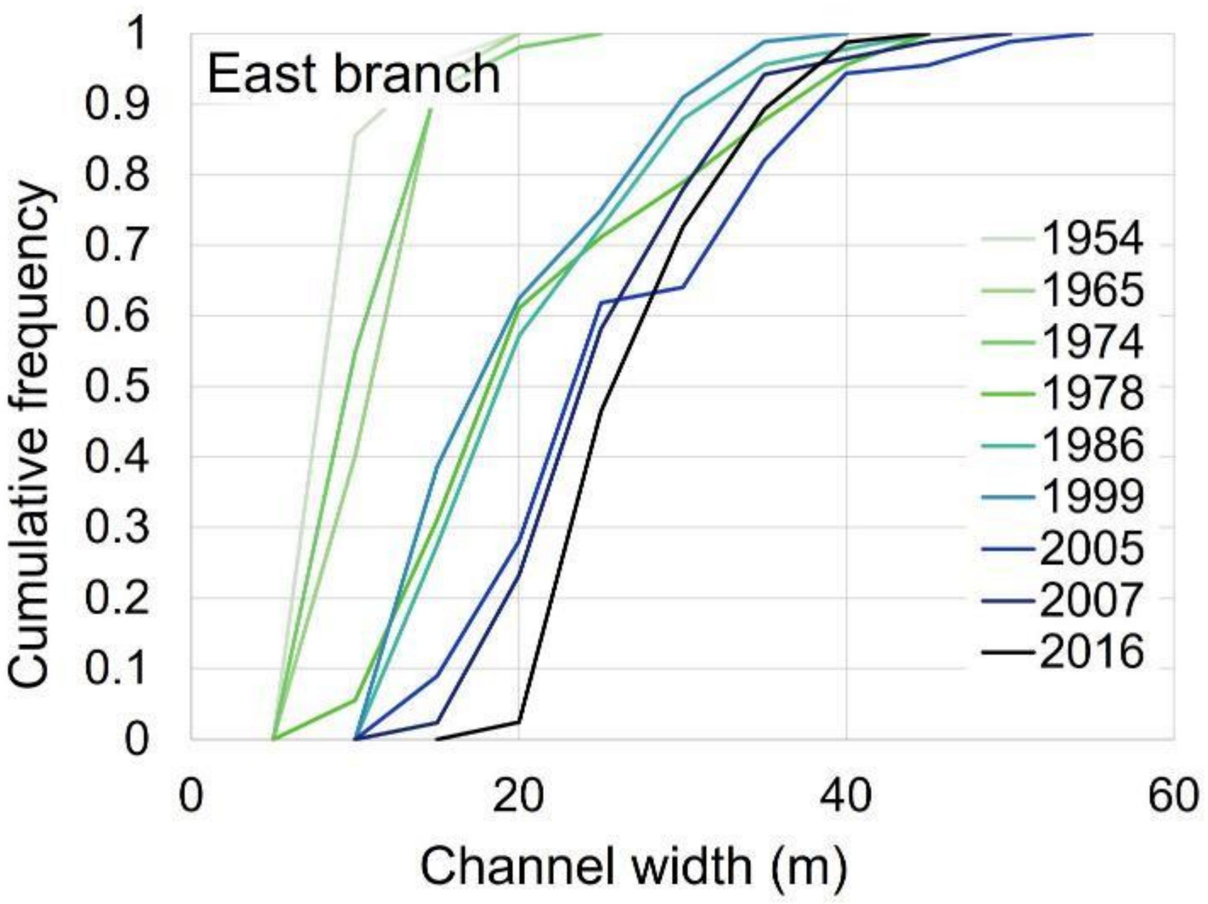


- Progressive transformation of river channel as urban area expanded
- Large floods in **1976, 2005** cause most of the change

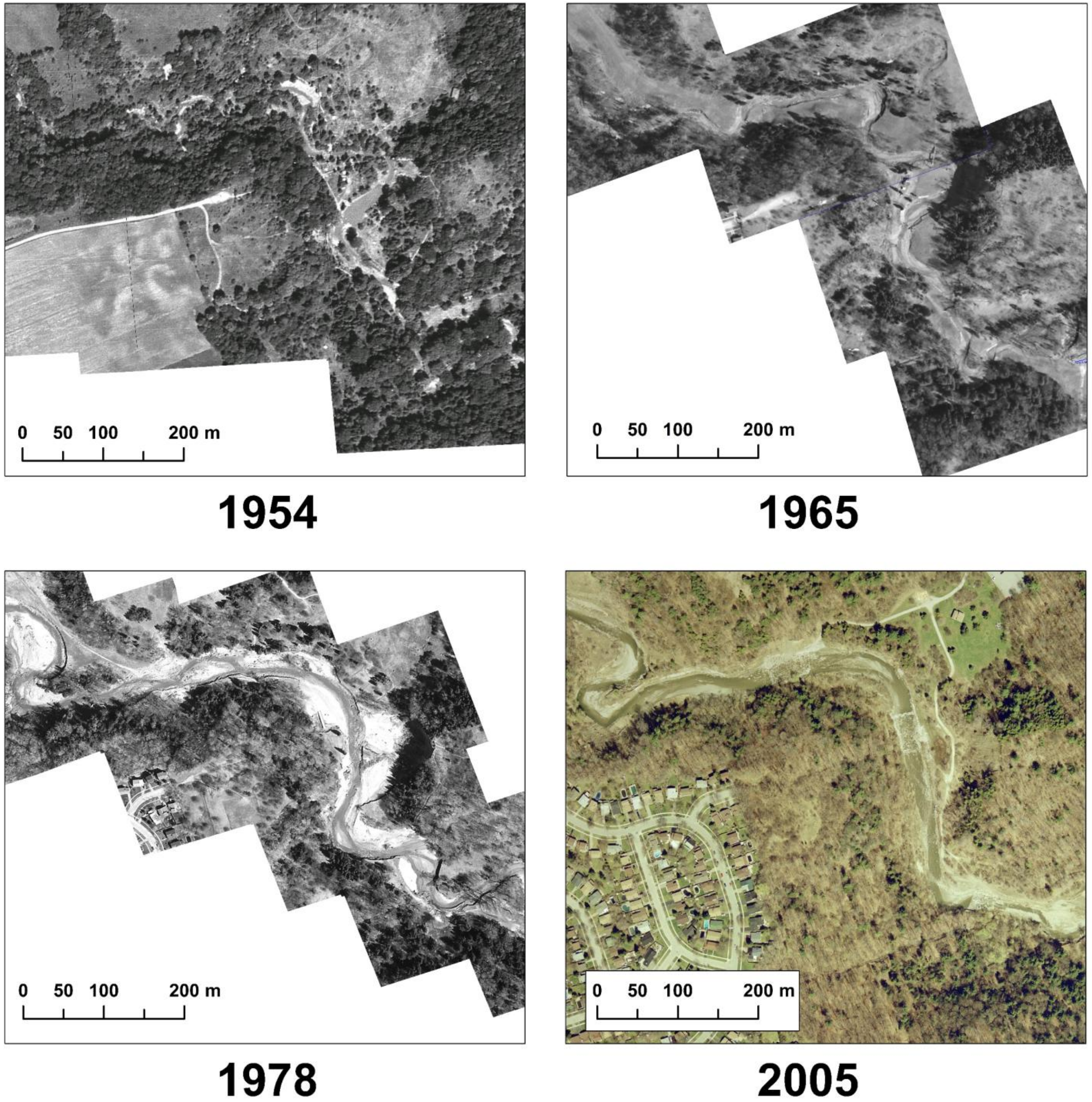


- Progressive one-way widening over 60 yrs with episodic change from major flood events
- 1976 – first flood after beginning of urbanization of east branch
- West branch response earlier but constrained by 1960s/70s engineering



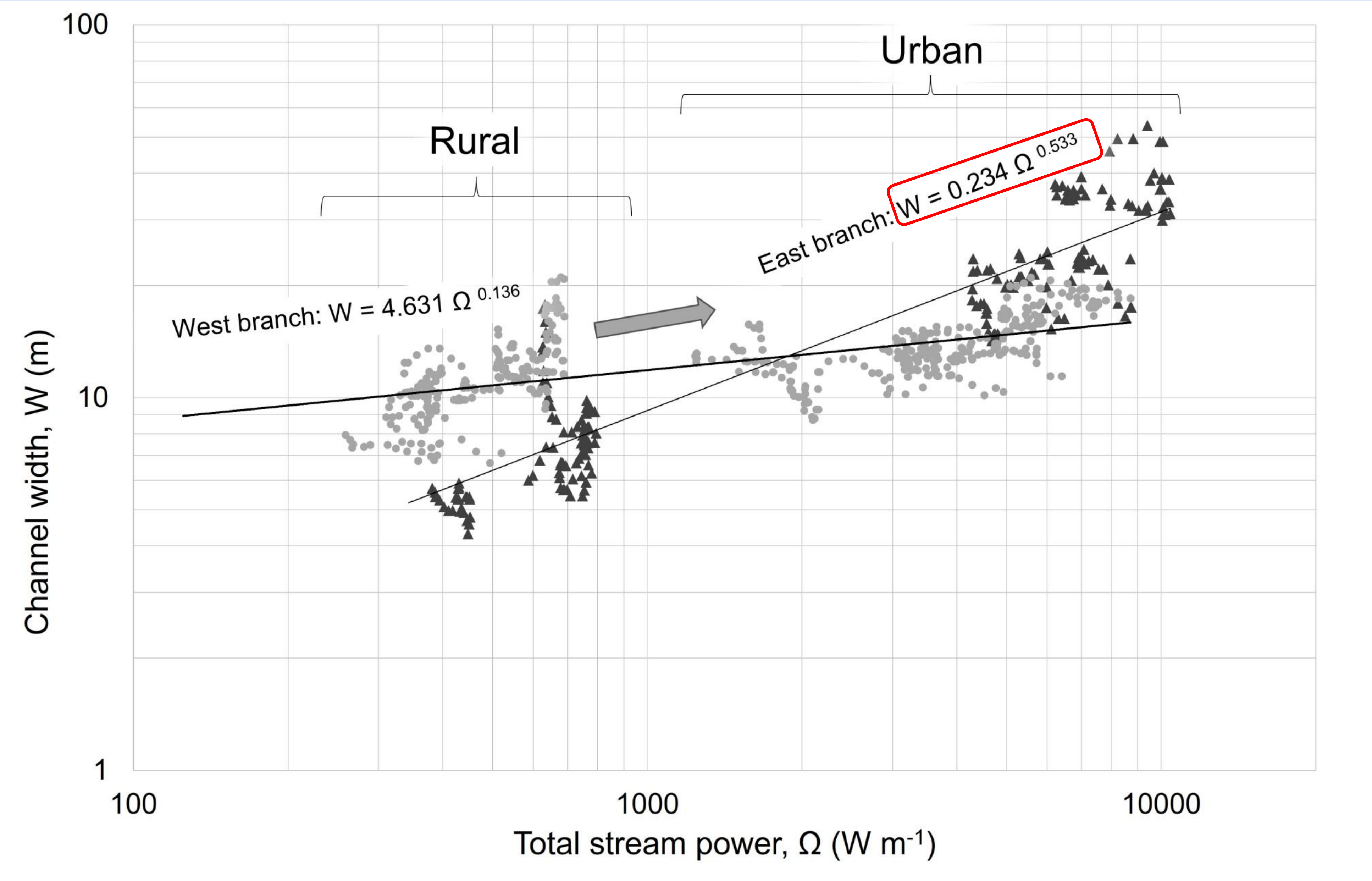


Morphological change lower East Branch (Bellamy reach type E)



John McDonald

East branch widening in line with expected rate of increase in relation to stream power changes – semi-alluvial response similar to fully alluvial channel. But not West branch



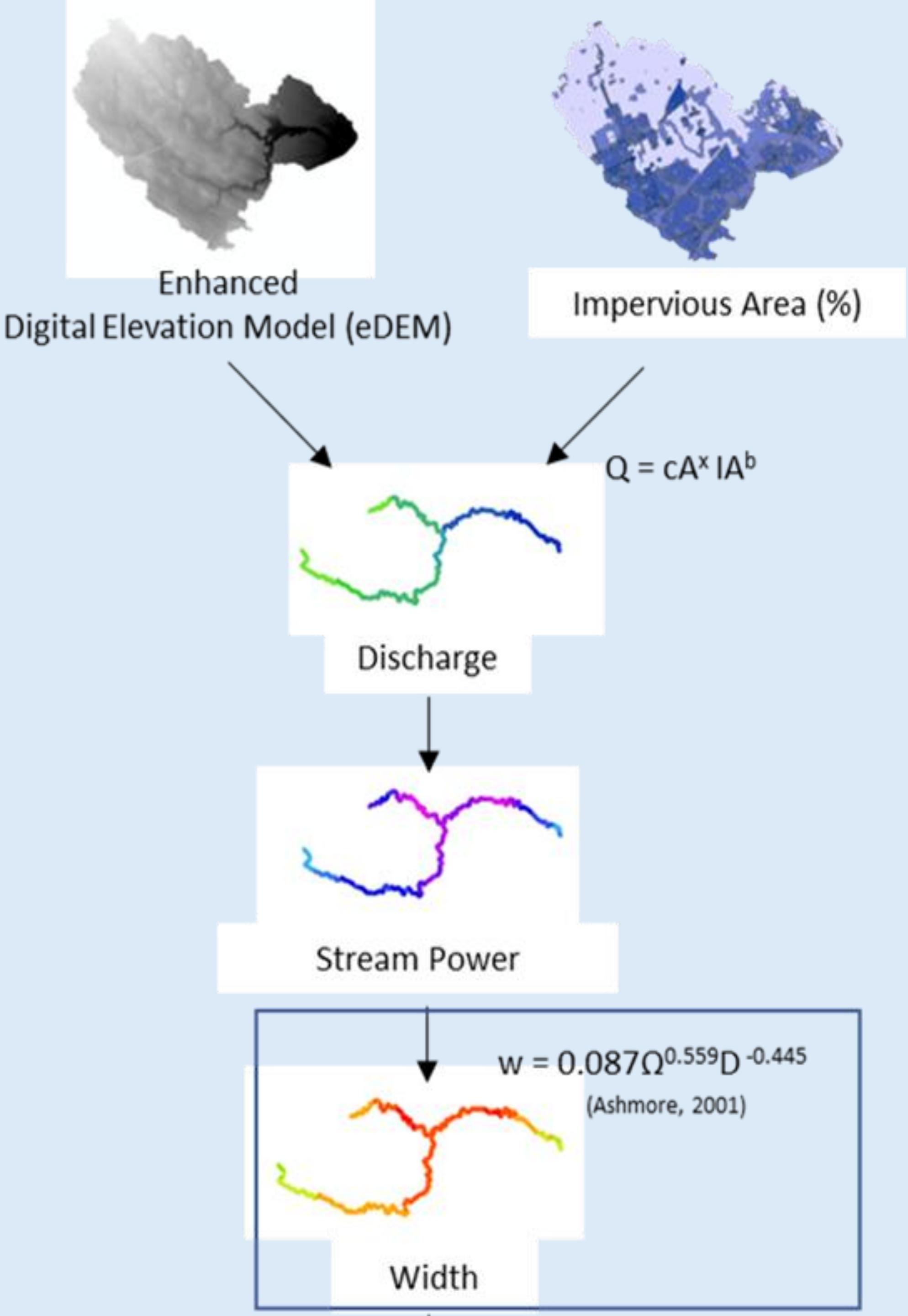
Prediction of width change ?

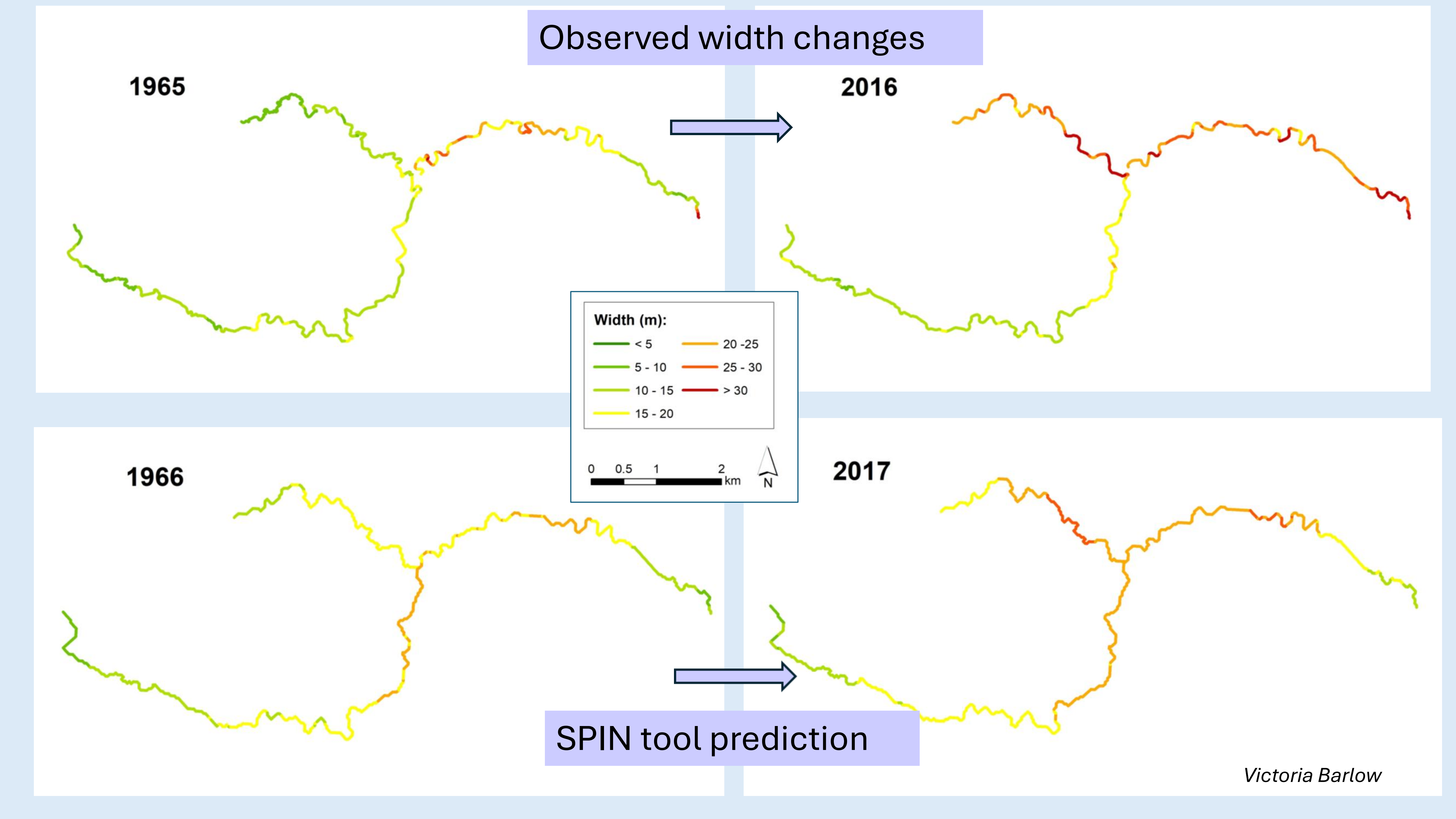
SPIN (Stream Power Index for Networks) with added regime width equation

Possible to pre(post)dict width change from historical land cover information and compare to 'actual' changes (and all land cover stages over time)

Could anticipating changes have reduced interventions and allowed 'natural' adjustment?

Kimisha Ghunowa, Bruce MacVicar, Victoria Barlow





Observed width changes
1965
2016
Width (m):
< 5
5 - 10
10 - 15
15 - 20
20 -25
25 - 30
> 30
0
0.5
1
2
km
N
1966
2017
SPIN tool prediction
Victoria Barlow

A story of intervention – of what channel should/could be and of changing perception, understanding and purposes

Initial channelization on west branch in 1960s

Erosion concerns prior to 1976 flood – then first major 'remedial' work on selected sites after 1976 flood and in early 1980s

Recognition of importance of natural valley character

Regrading banks (2:1) + rip-rap and armour rock

Also rock weirs (sanitary sewers)and drop structures

- 1 -

I PURPOSE OF PROJECT

The purpose of this project is to enable The Metropolitan Toronto and Region Conservation Authority to continue to carry out channel improvements on the East Branch of the Highland Creek and further to extend remedial works to the West Branch between Lawrence Avenue and the Scarborough Golf Course. The project covers a three year period from 1984-1986.

The goal of the Authority through this project is to minimize the hazards of erosion to life and property on the Highland Creek Watershed in the Municipality of Metropolitan Toronto and is a continuation of the work initially undertaken in the "Projects for Channel Improvements on the East Branch of Highland Creek 1982 and 1983".

To achieve its goal the Authority has defined the following objectives:

(a) to implement a program of site specific remedial works based on a priority ranking of sites as defined and outlined in the 'Preliminary Engineering Study on Erosion Control, East Branch - Highland Creek';

(b) to recognize the importance of the natural valley character in the design of remedial works wherever feasible.

(i) Regrading of affected bank to a minimum 2:1 slope;

(ii) Placement of a 400 mm thick well graded granular base (or and equivalent filter cloth);

(iii) Placement of an average 450-550 mm layer of rip rap protection;

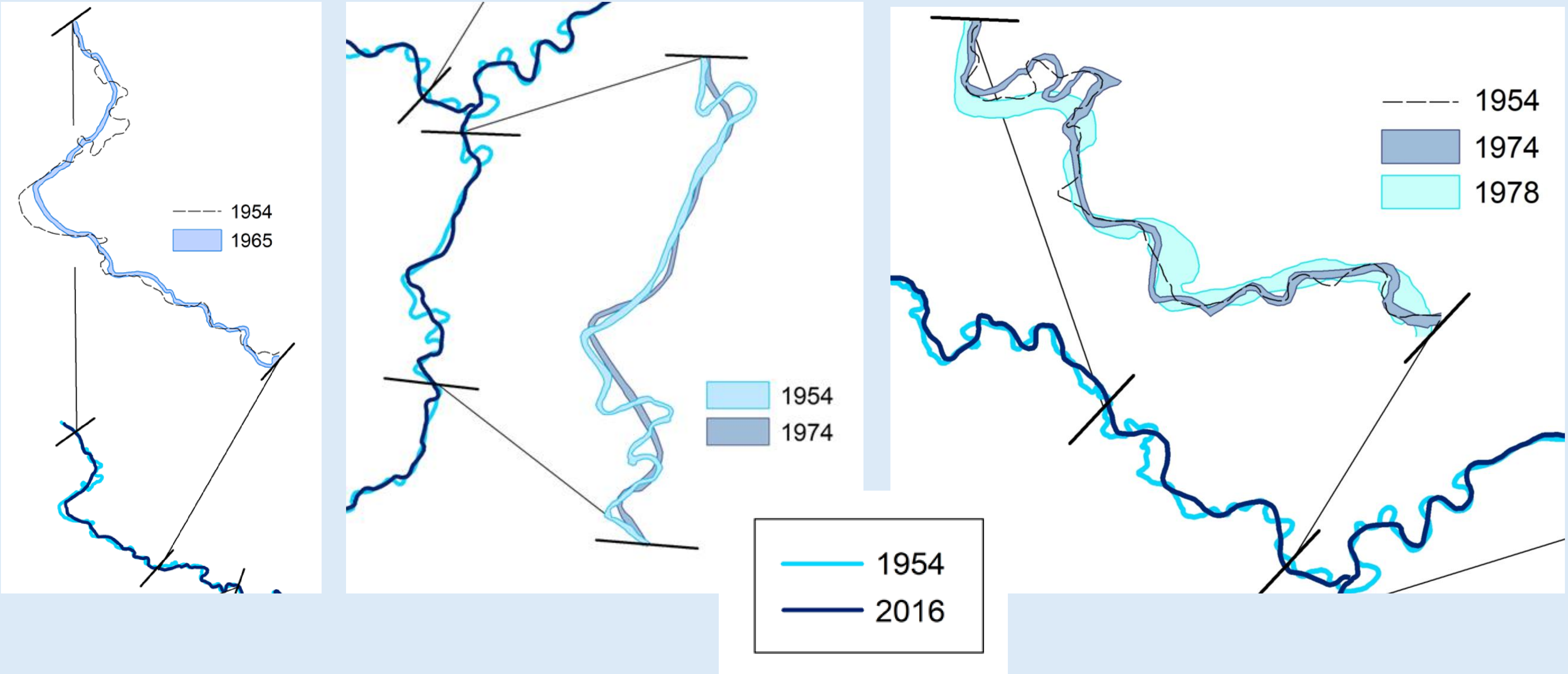
(iv) Placement of rip rap protection to a minimum height of two metres above the existing invert. This would provide complete toe protection for the annual runoff event.

(v) Extend rip rap protection upstream to where the existing channel is stable. If the rip rap cannot be tied into a stable section, a rock cut-off wall should be constructed.

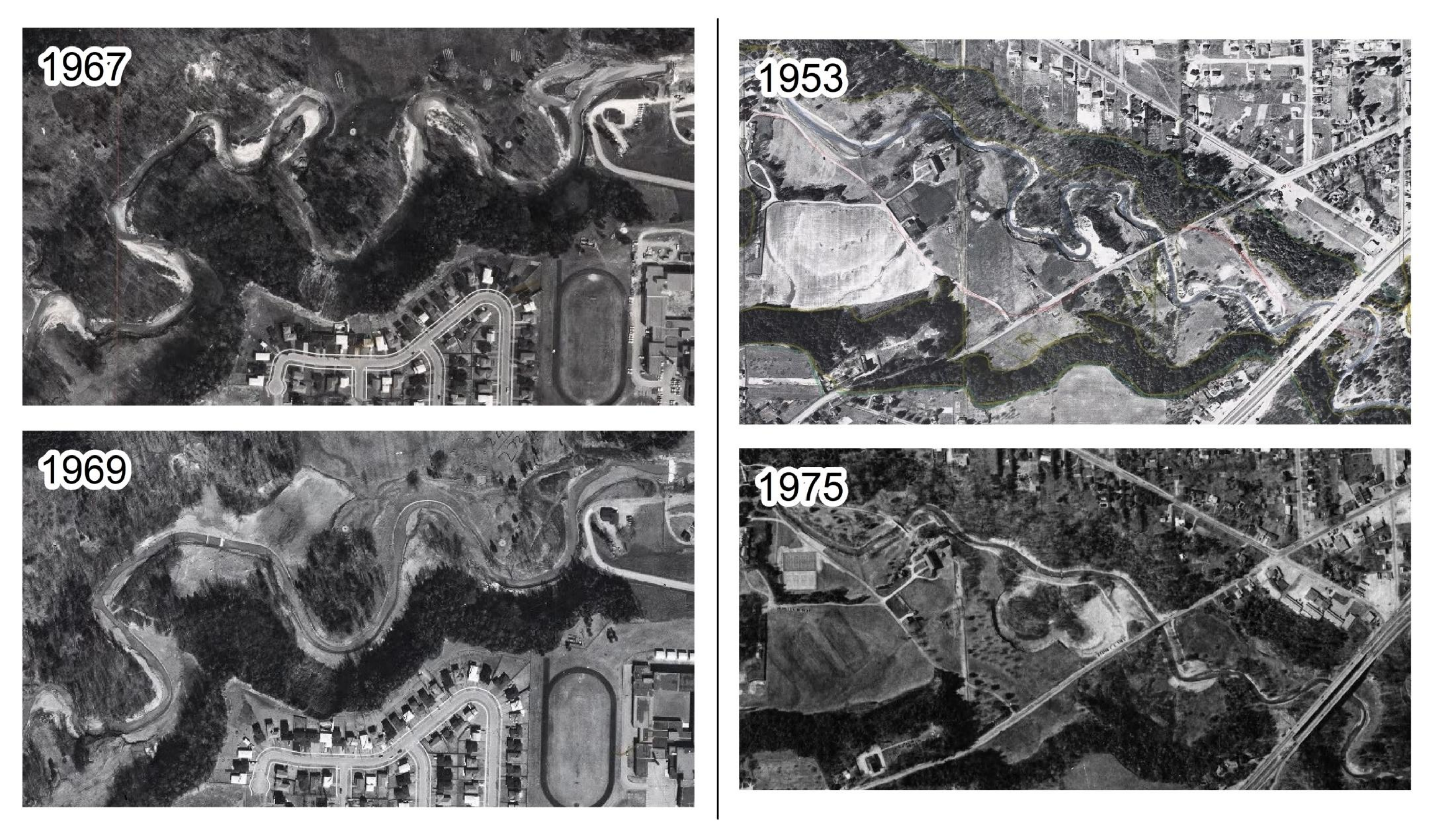
Extensive channel pattern change – channel engineering and 'natural' flood effects

West Branch
Channelization 1960s & 70s

East Branch
Channel pattern shift to low-sinuosity 1976 flood

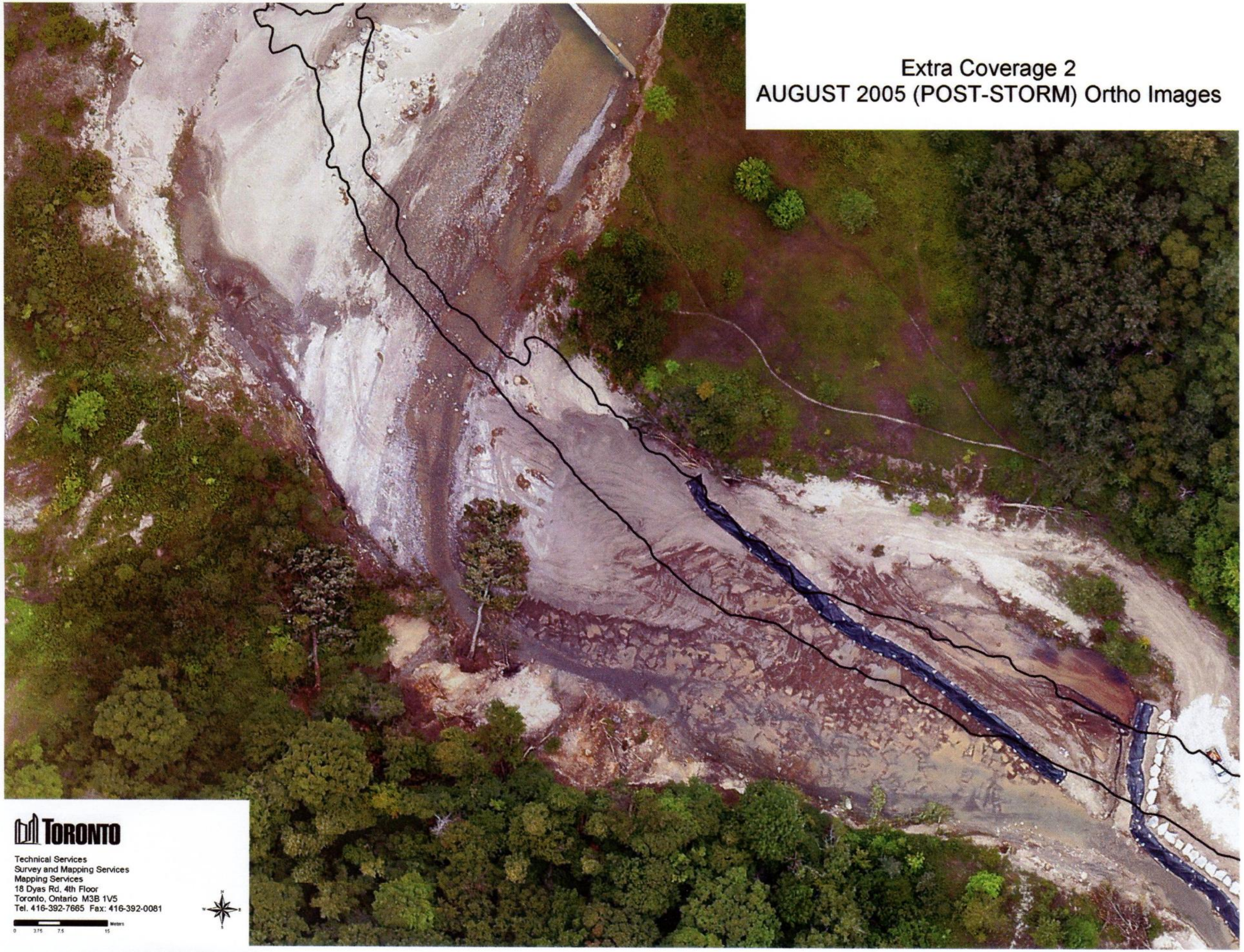


Almost continuous process of various interventions gradually transforming channel morphology and **limiting geomorphic functioning** – driven by (changing) views of the river function and relations



2005 Flood

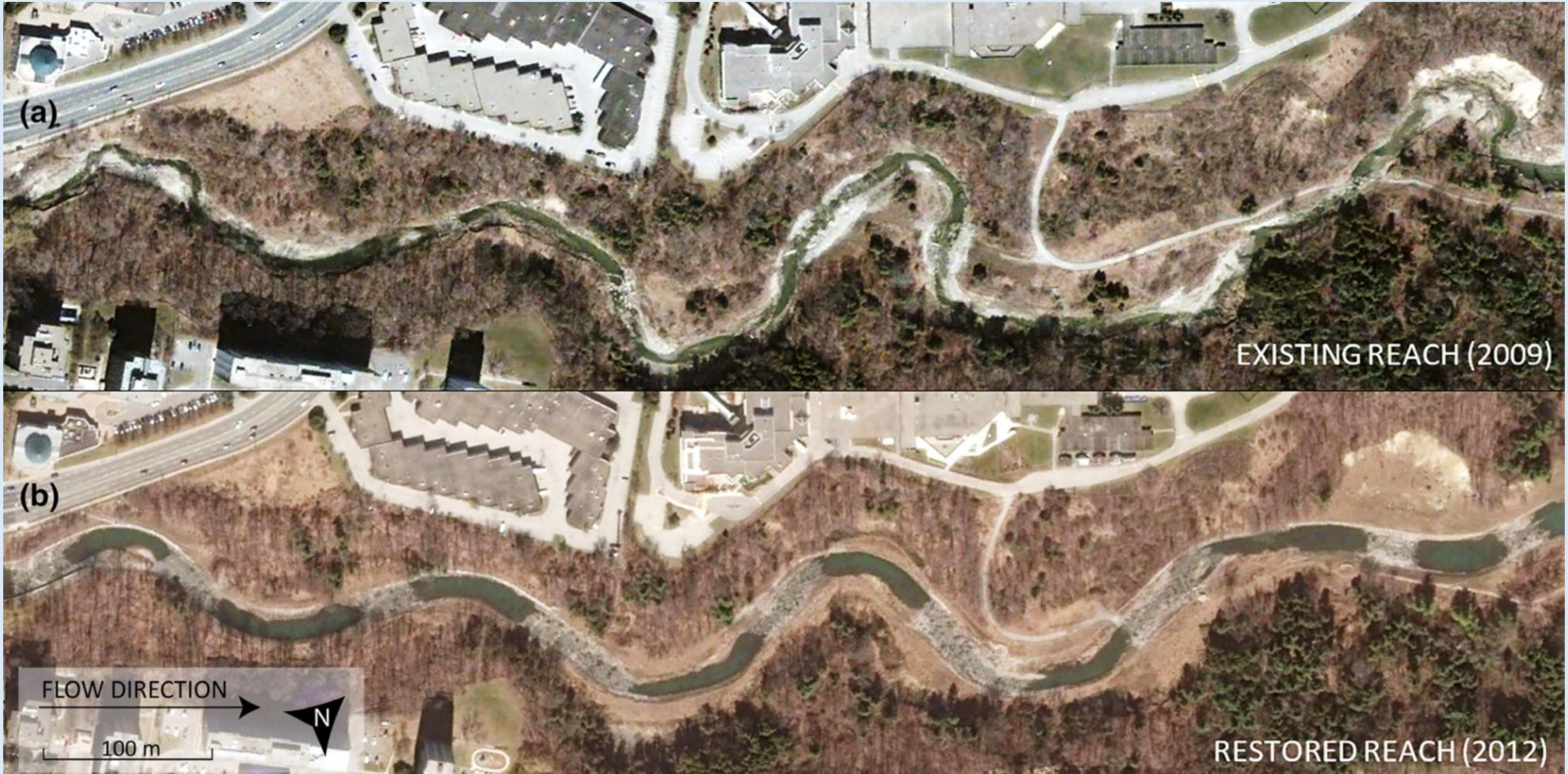
East branch – extensive widening, channel migration, local de-alluviation, bend cutoff and infrastructure damage




2005
Pre-flood


2005 after flood

Intervention after 2005 flood quite different from 1976/77
Channel re-design, transformation - new approaches & thinking about the river



Complex intersection and evolution of events, policy, ideas, and epistemic and institutional power

1954 Hurricane Hazel: Major flood damage in several rivers – triggers institutional rethinking of risk and river transformation

1950s and 60s Major urban expansion & increased peak flows – widespread river "improvement" + also 'damage' from widening & incision with increased costs. Un-engineered channels free to adapt but still threaten infrastructure

1990s beginning of river re-naturalization (Natural Channels Initiative) – influenced by geomorphic restoration generally & geomorphic research & practice

2003 Geomorphic Master Plans + ecological goals

2005 – Large flood, major damage, opportunity to implement master planning and more-natural design solutions

1946: Ontario Conservation Authorities Act

1957 (Post-Hazel) Merger of 4 CAs into single MTRCA (now TRCA)

1958 Plan for Flood Control and Water Conservation (not all implemented) – **excluded development from valley lands** also beginning of land acquisition

1960s (and 1950s) commodification of large land tracts for private developers- affects style, rapidity & density of development

1980s adoption of new watershed-ecosystem planning principles (Royal Commission on Toronto Waterfront 1988) & **1994** City of Toronto & MTRCA Taskforce - Stream Corridor Management Program – shift to natural channels, ecosystem conservation, environment & community use

2003 Wet Weather Flow Study (City of Toronto) & Geomorphic Master Plans

2005 Ontario Greenbelt Act

[2017 Urban River Valley designation within Greenbelt]

- **Thinking inside the channel - Designed Adaptation** – massive increases in fluvial energy require designs that produce **novel rivers** - geomorphic design with infrastructure constraints

- Increased epistemic power of particular approaches produces particular types of river that rethink and reimagine function of, and relations to, the river and become embedded in the riverscape: **re-storying the river** (Eric Higgs) to create evolving **expert landscapes**

- Particular events (floods aren't just hydro-geomorphic events) produce major channel change but also provide opportunity and impetus for re-thinking and re-configuring according to particular kinds of knowledge and power. (1976 vs 2005)

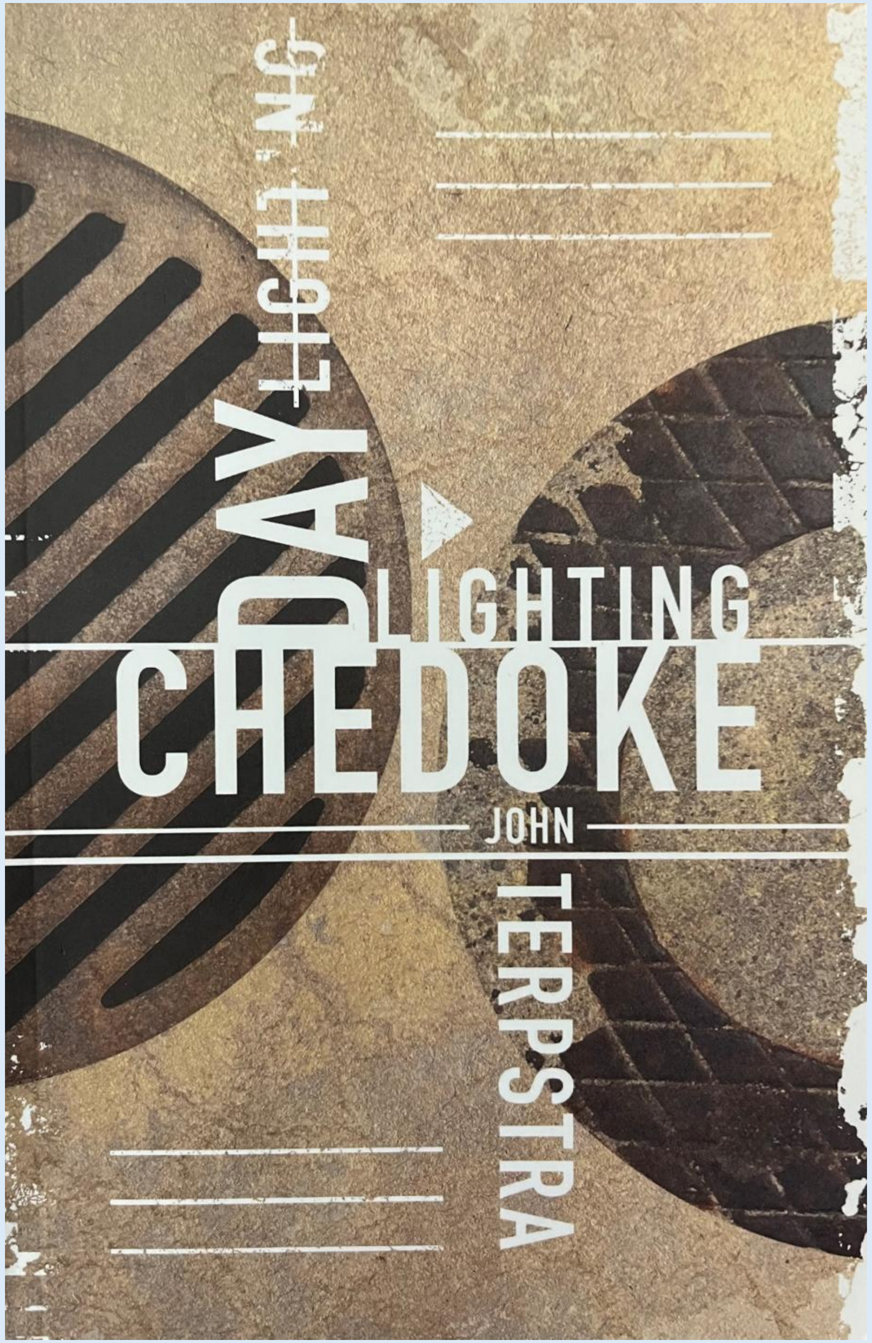
- Path dependency – past decisions may foreclose on some possible pathways and futures

- Urbanization of rivers is a story of socio-fluvial transformation - continual, ongoing process – urbanization does not have well-defined end point – it's part of the life of the riverscape (no vestige of a beginning, no prospect of an end)

We know little about geomorphology of Highland Creek prior to 1950s

Human occupation of Highland Creek extends over 1000s of years. The area of the watershed is the ancestral land and waters of the Mississauga and Chippewa. The lands were surrendered, and some indigenous rights extinguished, by the Williams Treaties of 1923 to claim land for development. The Governments of Canada and Ontario restored rights, formally apologised, and paid compensation, in 2018. Highland Creek is a colonial watershed

What other paths & stories were possible for Highland and other streams and rivers?



We choose the landscapes we live in

The landscape changes when we pursue the stories connected to it.

Learn the stories and the landscape looks different. Transformed. Layered. Alive.

Forget or ignore the stories, neglect to enter or hold up your side of the conversation and all you are left with is what is in front of your eyes

The futures of rivers depend on it


Thanks!