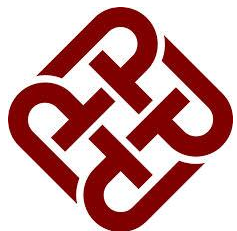


Using mesoscale physical habitat attributes to assess headwater stream water quality

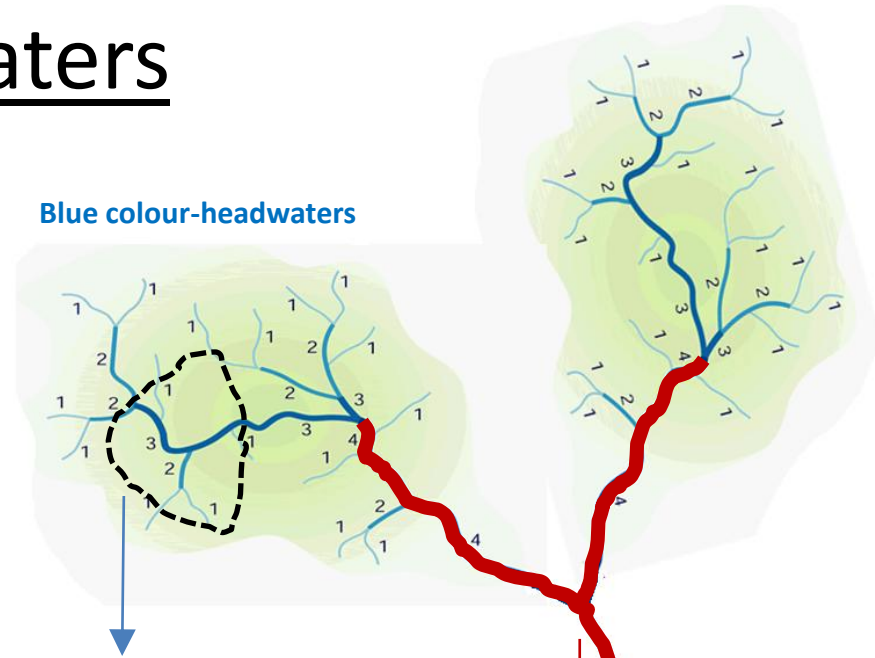
Pattiyage I. A. Gomes and Onyx W.H. Wai



Department of Civil & Environmental Engineering
The Hong Kong Polytechnic University

Headwaters

- Most of the channels consist of headwaters (also known as the lower order streams; order < 3)
- They occupy a large area of the overall catchment and feed into and create large rivers
- Critical roles of headwaters include: flood protection; pollution reduction; provision of habitats for flora and fauna, etc.
- Ecological contributions of headwater streams are disproportionately higher than the well monitored large rivers
- The water quality constituent dynamics in headwater streams is more complex than in the main river
- Furthermore, there is a growing concern of headwater streams because they are subject to frequent human disturbances

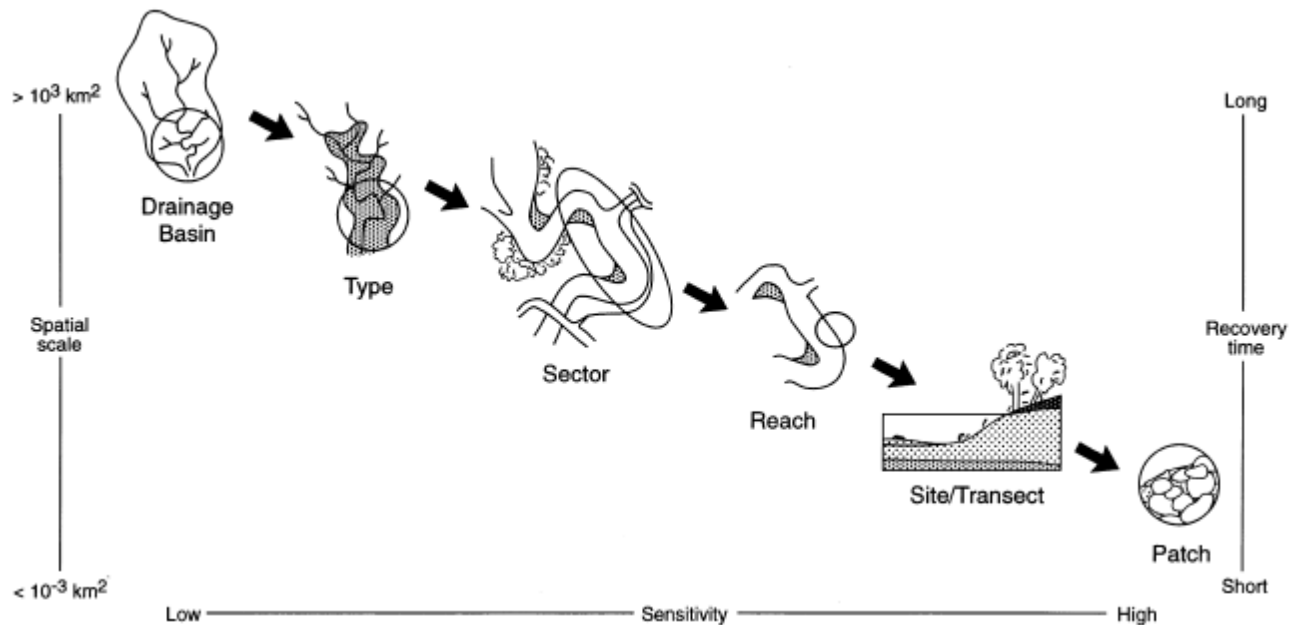


Assessment of water quality in headwaters

- No special differences between headwaters and (large) rivers
- There are many different sampling strategies for water quality monitoring in streams
- Common strategies
 - Sampling at junction points of river branches
 - Sampling targeting specific inputs and locations/parameters of previous studies
 - Dividing the stream into equal lengths (cells; also known as cell-in-series)
- Cell-in-series (CIS)
 - CIS has been extensively used in formulation of mass transport in streams and riverine systems for water quality modeling
 - an ideal probabilistic sampling strategy
 - CIS is more representative in steep, mountainous and shallow streams due to the dominance of advective transport
 - Advantages include, simplicity in formulation and provide better mathematical expression
 - However, the main problem of CIS is the selection of cell size (distance between two sampling locations) - different water quality variables show different trends of spatial variation
- An alternative approach may be using mesoscale physical habitats (MPH)

Mesoscale physical habitats (MPH)

Ecologists prefer a functional classification approach of rivers based on scale (e.g., catchment, type, sector, reach, transects and patches) for evaluating river health (Maddock, 1999). Ecologists express river health in terms of species diversity and abundance.



A functional classification of rivers based on scale (Maddock, 1999)

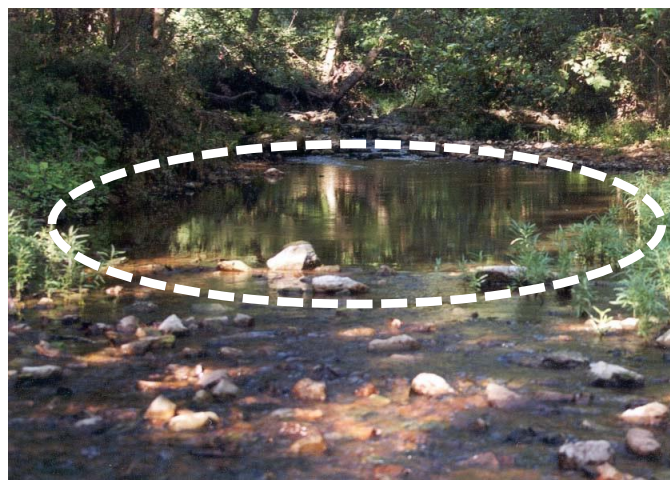
The medium sized (mesoscale) components of river channel habitats are important particularly in headwater streams (Newson and Newson, 2000). e.g. pool, riffles, run, glide, etc.

Mesoscale physical habitats (MPH)

- Definition
 - A universal, spatially explicit definition is lacking because size of a MPH varies with stream size, surrounding geography, etc.
 - Objective definition for meso? (1–10 × channel width, see Moir and Pasternack, 2008)
However, not all MPHs necessarily fall within this range
 - MPH can be best described as an interdependent set of the same physical variables over a discernible landform known as a morphological unit (e.g., scour pool, riffle, and lateral bar) (Moir and Pasternack, 2008)
- Irrespective of a universally acceptable definition, MPHs with their unique hydro-morphological features can be easily identified by visual observation of surface flow (water-air interface) behavior (Newson and Newson, 2000). “MPHs are easily identifiable hydraulic patches in a stream. Further, they will have unique bed sediment profiles”.
- It has been proven by scientists that visual classification of mesoscale habitats is statistically valid referring major hydraulic variables such as Froude number (Padmore et al., 1998)



Flow type: unbroken standing waves;
Associated MPH: Riffle



Flow type: scarcely perceptible flow;
Associated MPH: Pool

Some MPHs are positioned in pairs (e.g. pool-riffle)



Flow type: chute;
Associated MPH: Spill
(if chute flow over individual boulders, then referred as cascade)



Flow type: free fall;
Associated MPH: waterfall

Rationale of using MPHs for water quality sampling

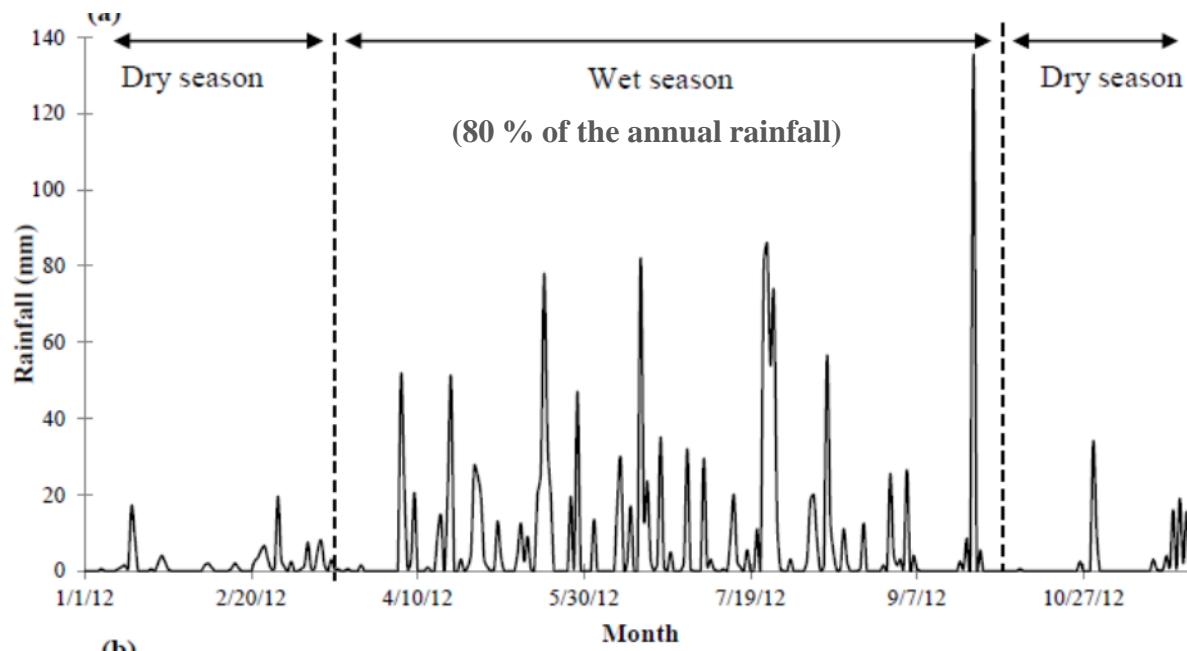
- Roles of MPHs have been long recognized in ecology/biology specially in macroinvertebrate/fisheries studies (mainly pools and riffles)
- In hydraulics and engineering disciplines, emphasis is on the physical (sediment and hydraulic) characterization of MPHs (e.g. this is useful in river rehabilitation designs)
- The fate of contaminants in a stream is influenced by attenuation and assimilation capacities of the system
 - Attenuation: reduction in contaminant concentration due to dilution, mixing and/or dispersion
 - Assimilation: association of contaminants by sediments and plants
- MPHs have unique flow patterns (e.g. riffle turbulent flow) and bed sediment profiles (e.g. pool fine bed sediment with scarcely perceptible flow), and may represent extreme conditions for attenuation and assimilation. Therefore, MPHs have a close link with water quality variation

Study Aims

- To evaluate the applicability of MPHs in headwaters as sampling units for different pollution conditions and flow episodes
- To gain insight of the role of in-stream physical heterogeneity on water quality and its implication on re-naturalization of flood channels

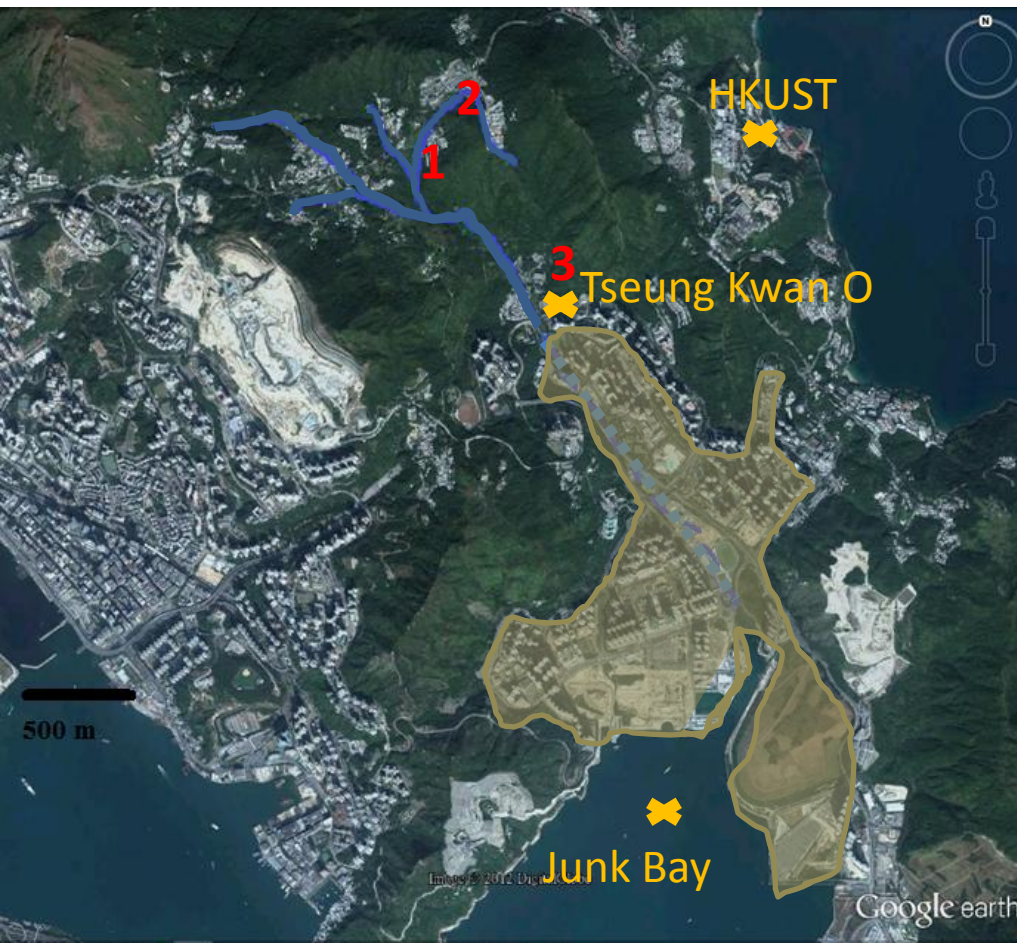
A few facts about Hong Kong streams and rivers and introduction to the study area

- Most of the HK lotic waters are streams
- Also most of the streams are short (many with no distinctive middle course - with braided channels), small, and steep
- Though steep, Hong Kong streams have flat lands and pools separated by steep bedrock outcrops and boulder reaches throughout the stream course
- Varying hydrological permanence (large number of ephemeral streams (non-perennial sections) occupying over 50% of the total stream network) (Reason: contrasting wet and dry seasons)

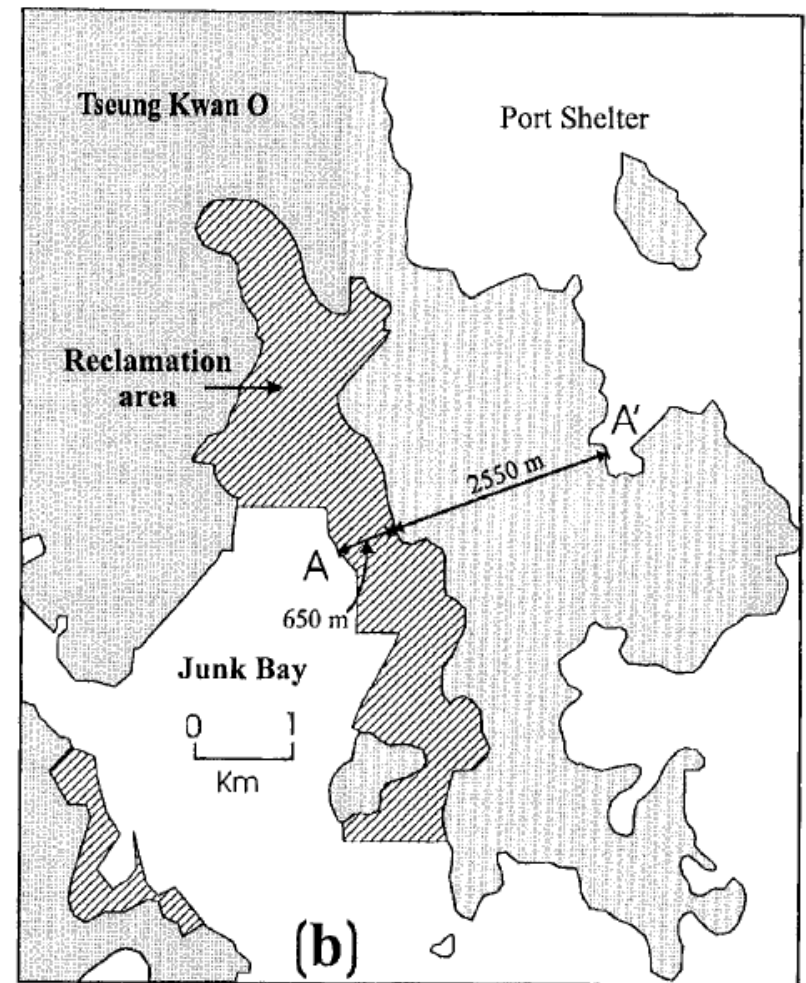
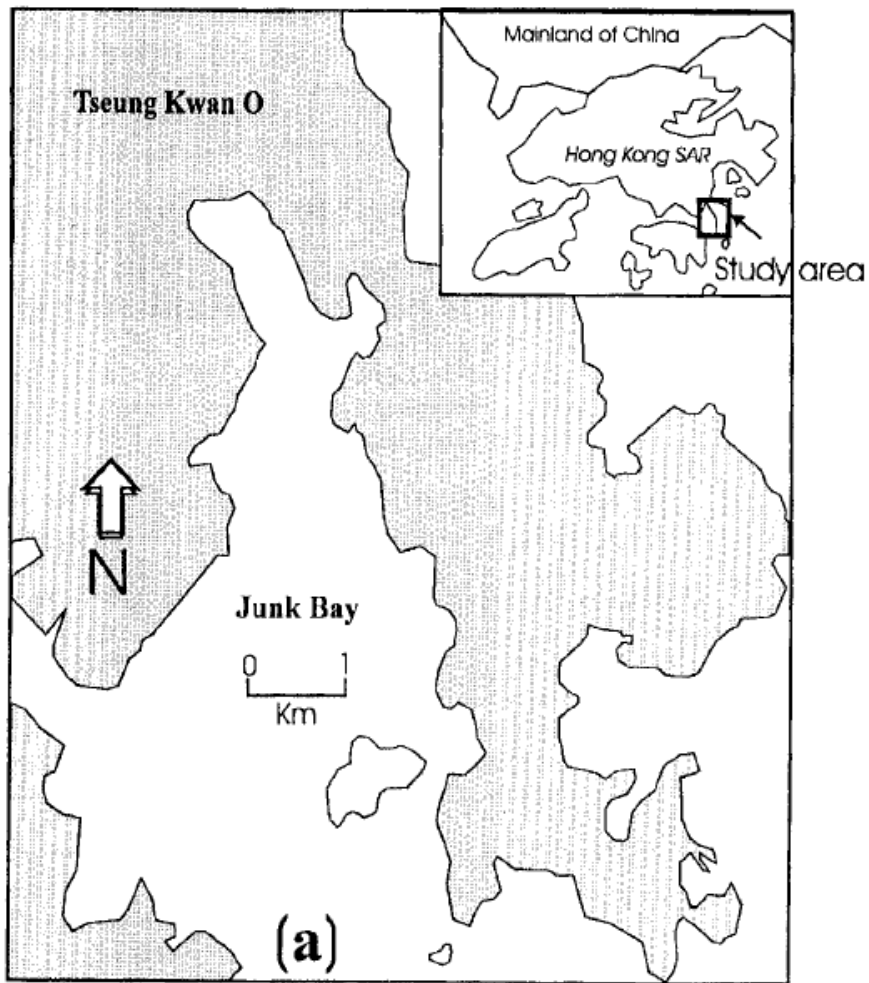


(Tseung Kwan O observatory)

Study area : Tseng Lan Shue Stream



- *Headwater – mountainous stream*
- *Steep-short*
- *Only perennial sections are shown*



Sea
 Land
 Reclaimed land

Coastlines at Tseung Kwan O, Hong Kong, China (a) in 1977 and (b) in 1998. (Source: Jiao et al., 2001)



Source of a tributary: a r...



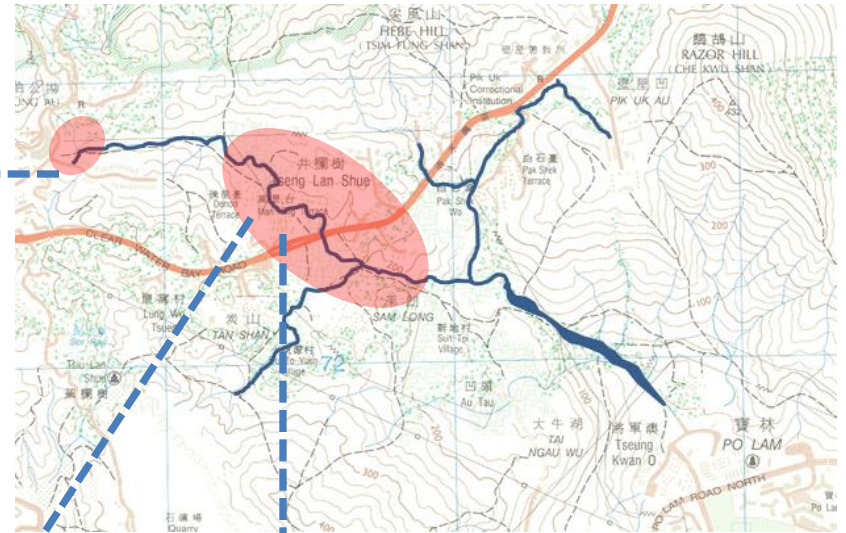
The stream has many typical pristine features: morphologically as well as in terms of flora and fauna



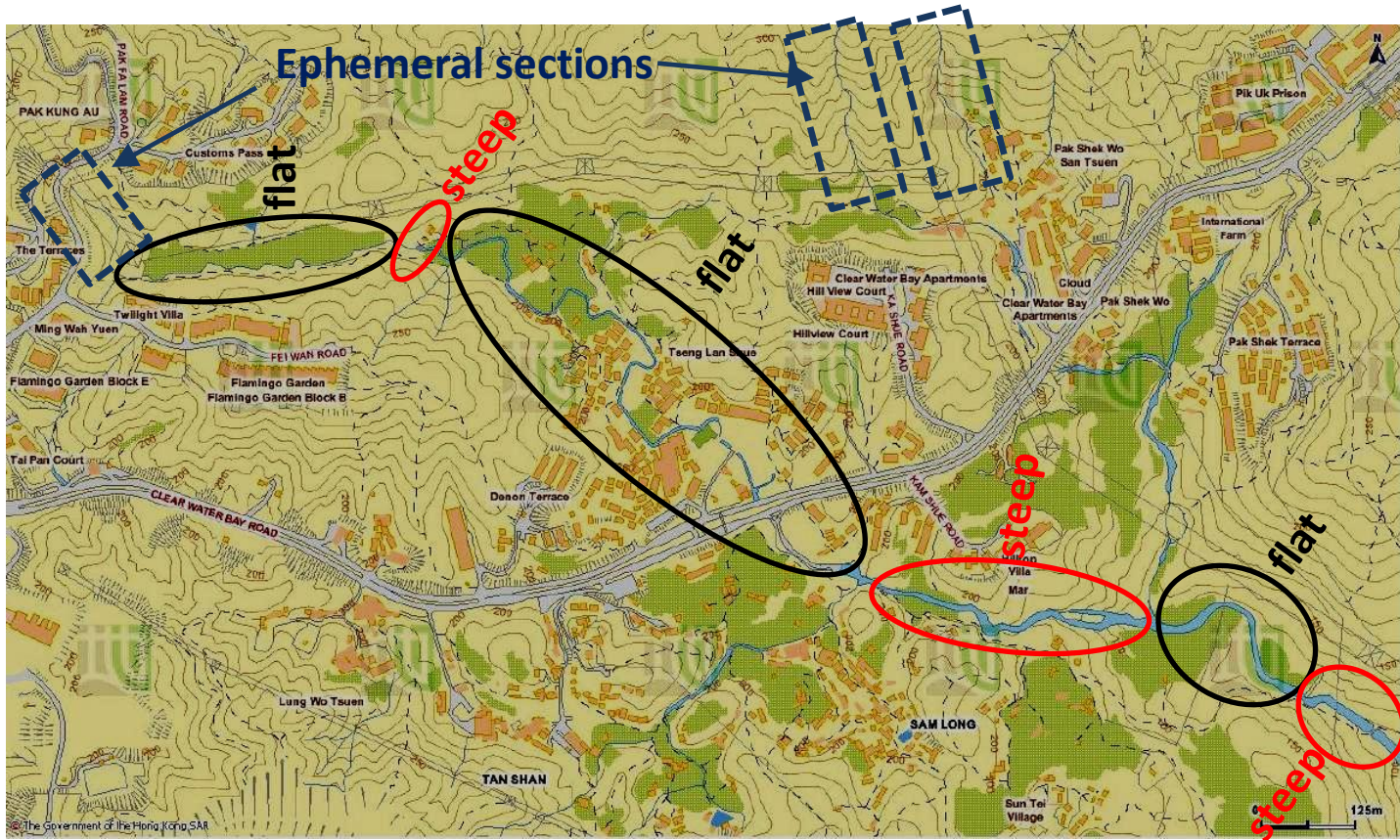
Mayflies, grazers, predators, etc.



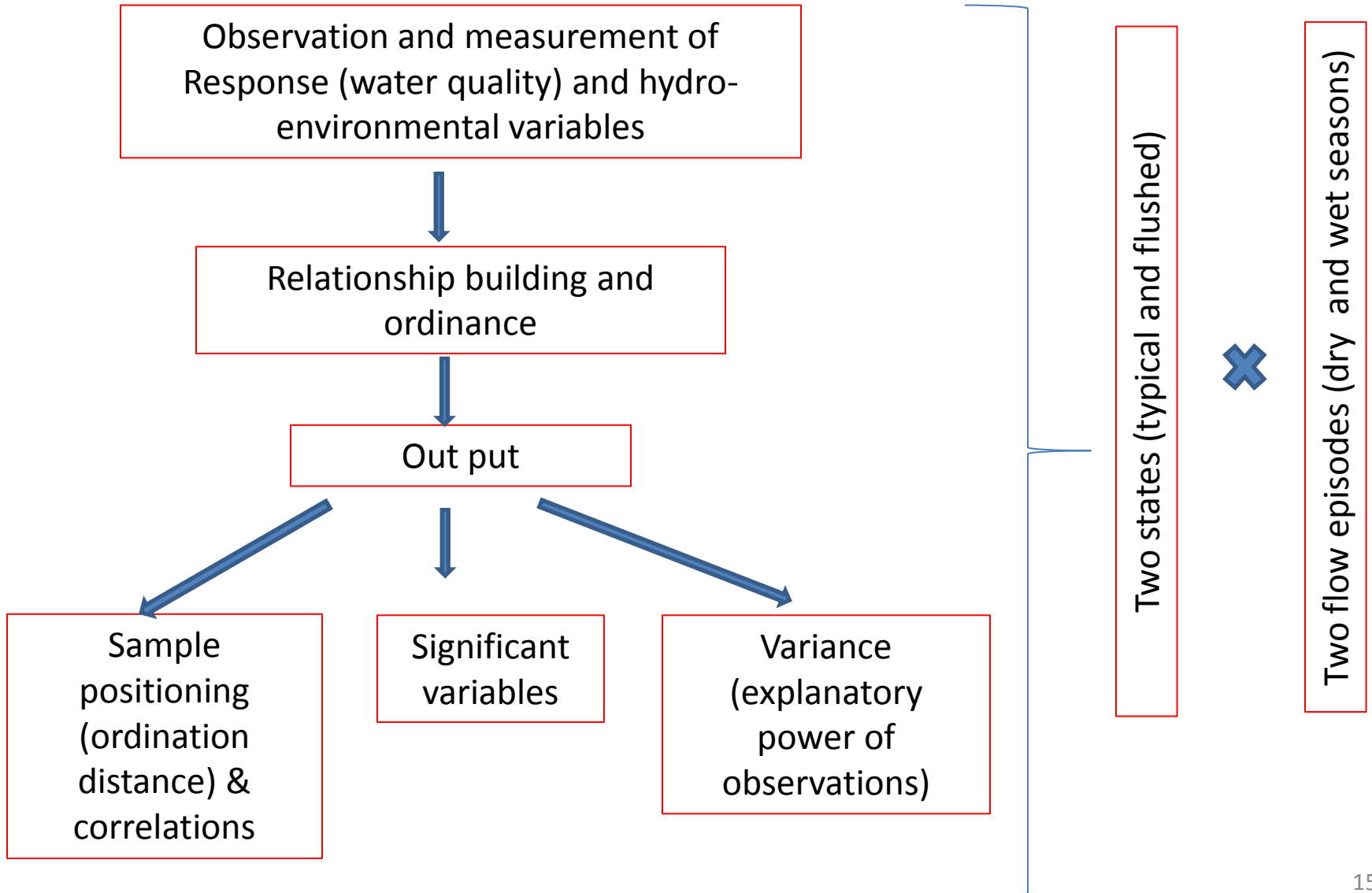
Observations for regulation and pollution



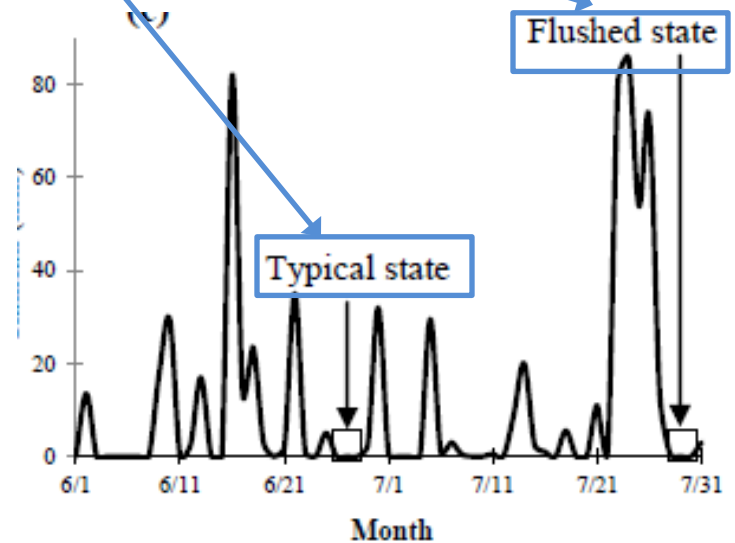
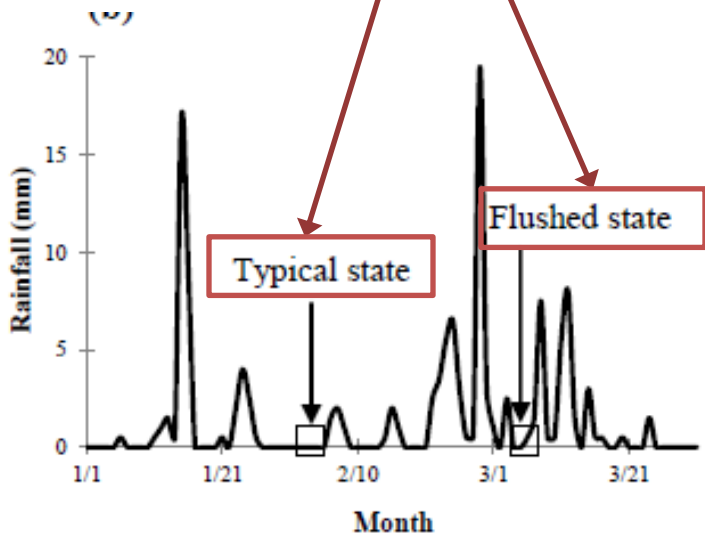
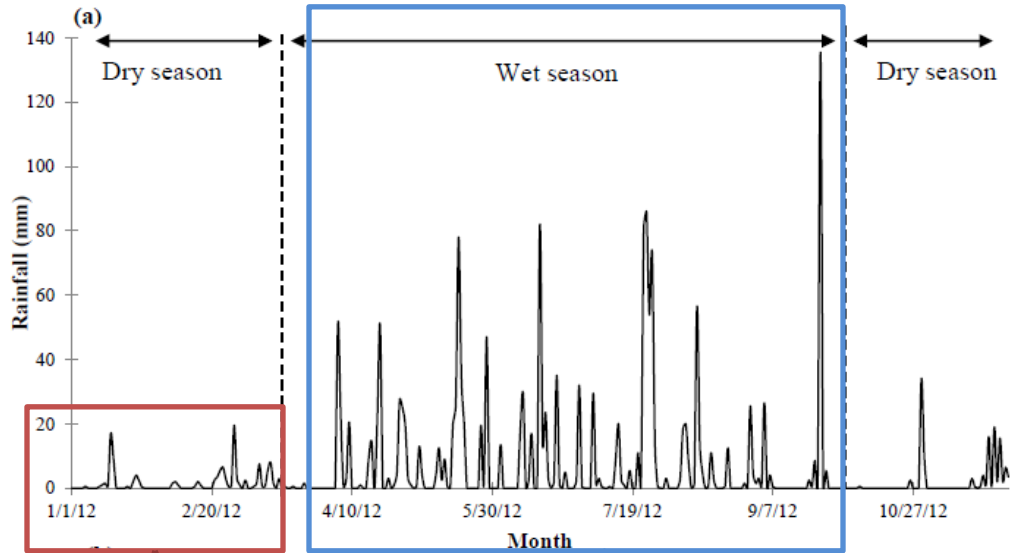
Channel profile



Outline of methodology



Sampling schedule



Response and hydro-environmental variables of the study

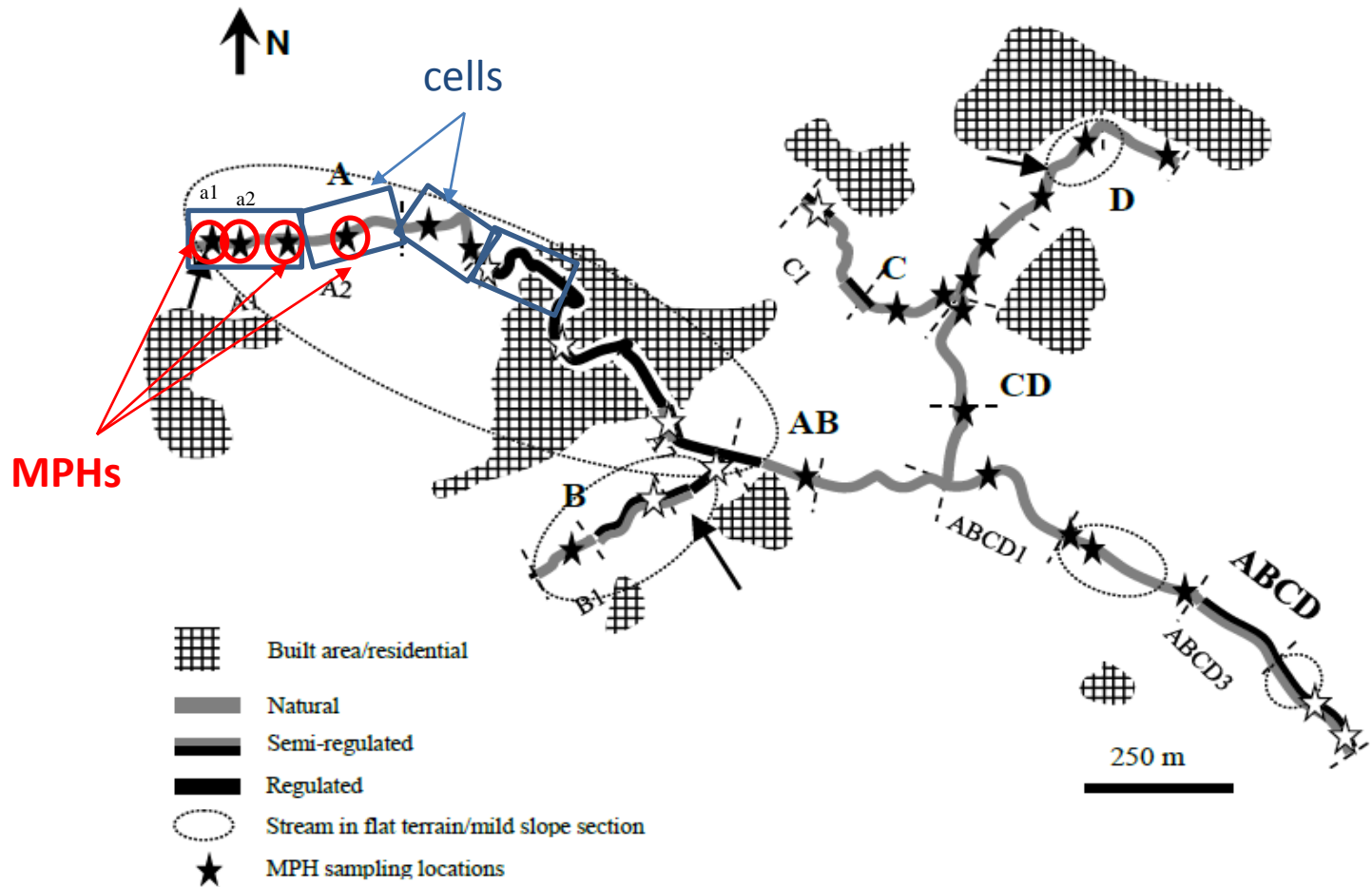
Hydro-environmental variables	Response variables
Velocity (V)	Chlorophyll-a (CHL)
Standard deviation of velocity (SDV)	Total nitrogen (TN)
Relative standard deviation of velocity, (i.e. SDV/V) (dV/V)	Soluble reactive phosphorous (SRP)
Water depth (D) and its associates: SD, dD/D	Dissolved oxygen (DO)
Wetted width (W) and its associates: SDW, dW/W	Turbidity (TUR)
Slope (SLP)	pH
Median particle size (D50)	
Weight of particles less than 1 mm of the top 1 cm layer (P1)	
Number of meso-scale habitats per sampling segment (NM)	

For some response variables composite sampling has been carried out

Response and hydro-environmental variables of the study

Hydro-environmental variables	Response variables
Velocity	Chlorophyll-a
Standard deviation of velocity	Total nitrogen
Relative standard deviation of velocity (Standard deviation of velocity/average velocity)	Nitrate
Water (wetted) depth	Nitrite
Standard deviation of depth	Ammoniacal nitrogen
Relative standard deviation of depth	Phosphorous- soluble reactive
Wetted width	Dissolved oxygen
Standard deviation of width	Turbidity
Relative standard deviation of width	Conductivity
Slope	
d_{50}	
Weight of particles less than 1 mm of the top 1cm layer (PSMALL)	
Discharge (flow rate)	
Number of meso-scale habitats per sampling segment (NM)	

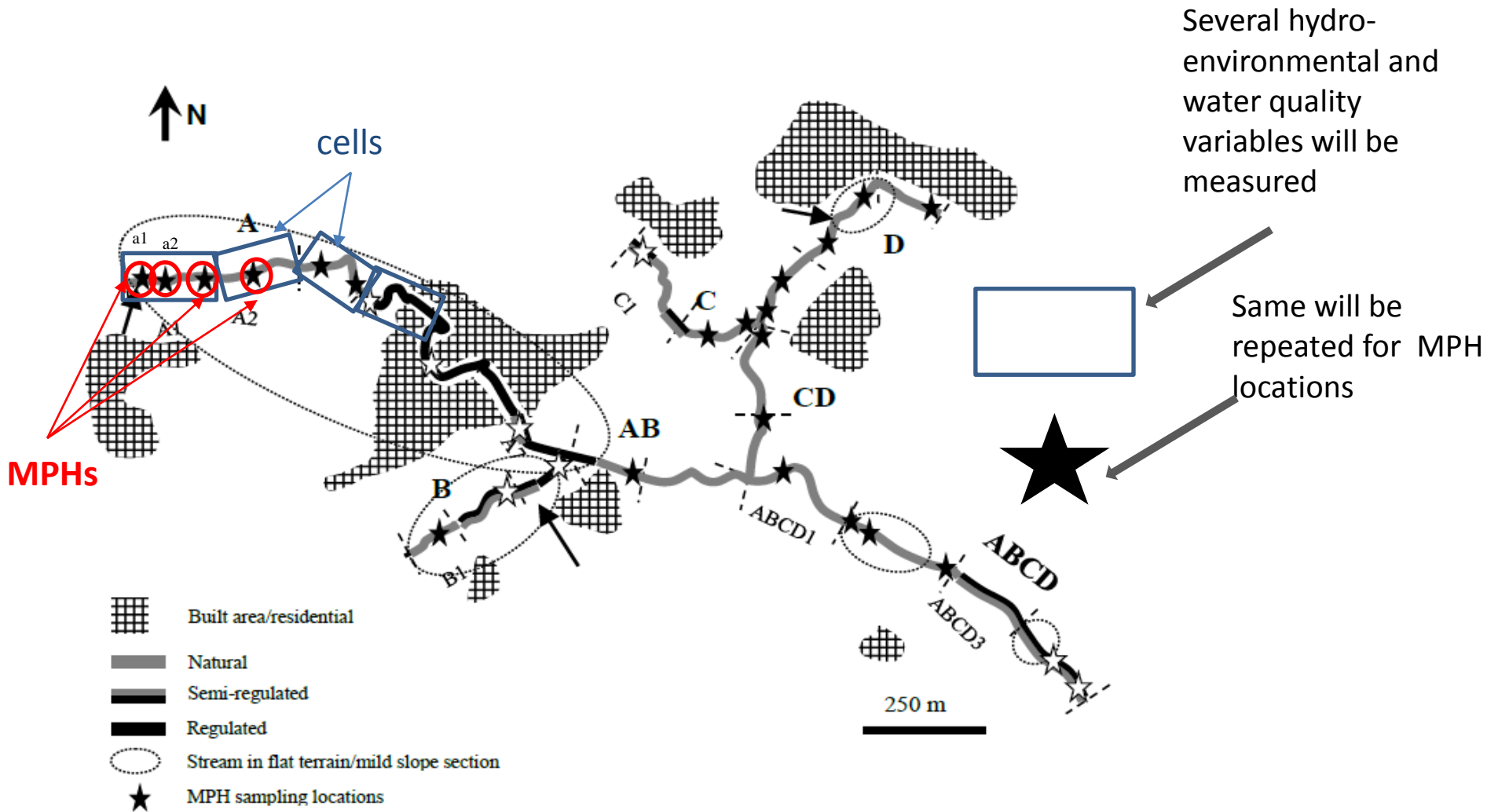
Selection of variables are dependent on the objective



MPH and CIS sample distribution

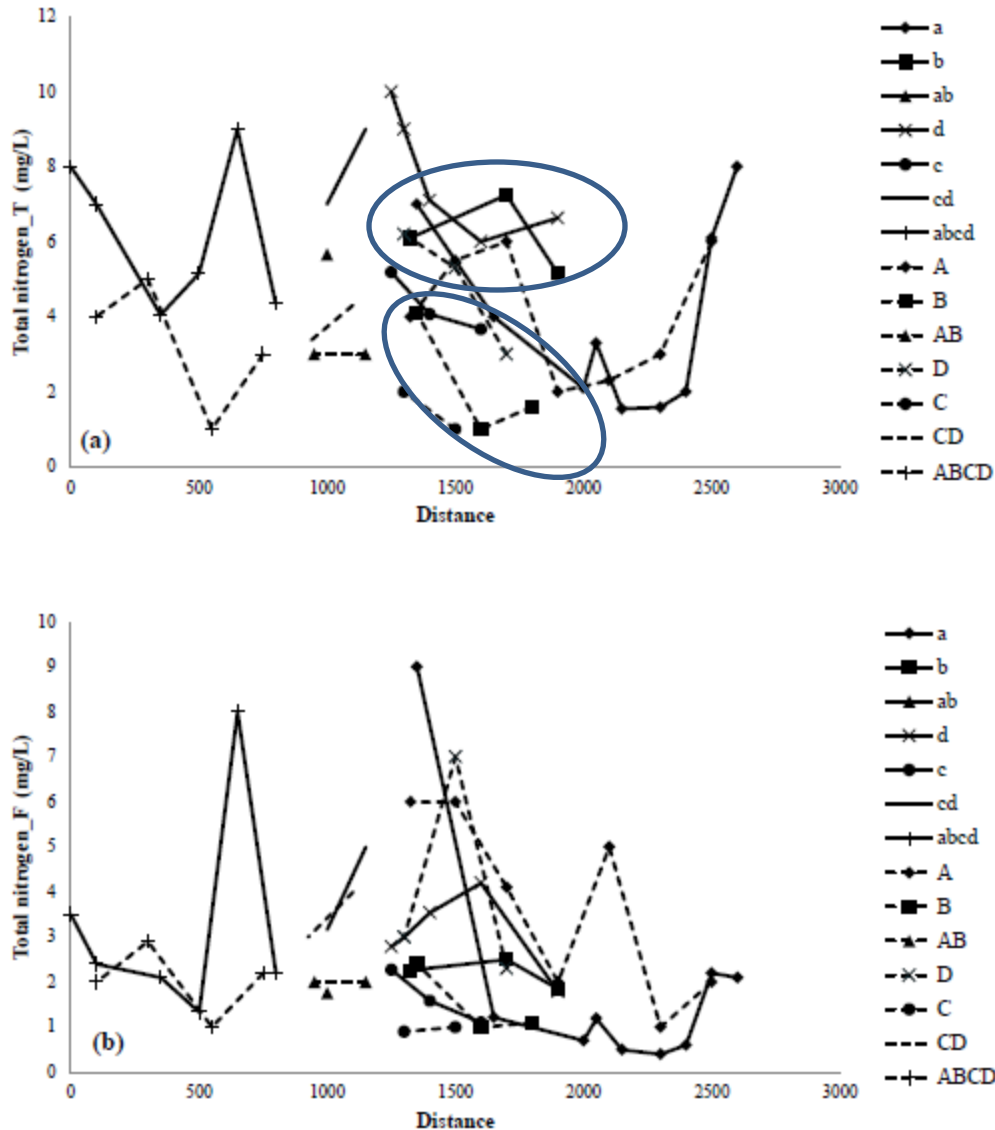
Results and discussion

Applicability of MPHs as sampling units



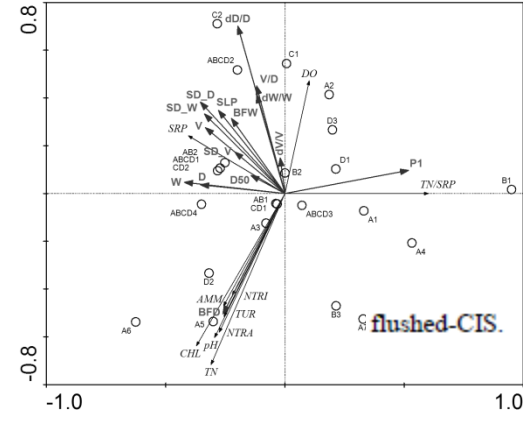
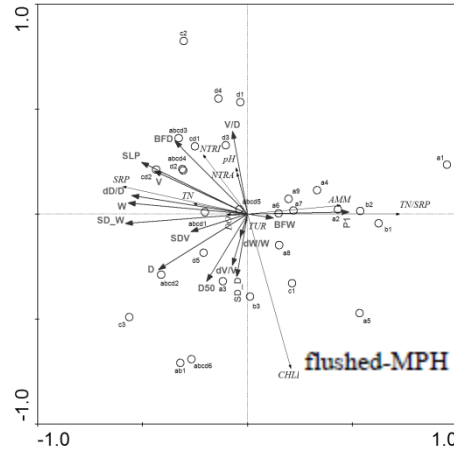
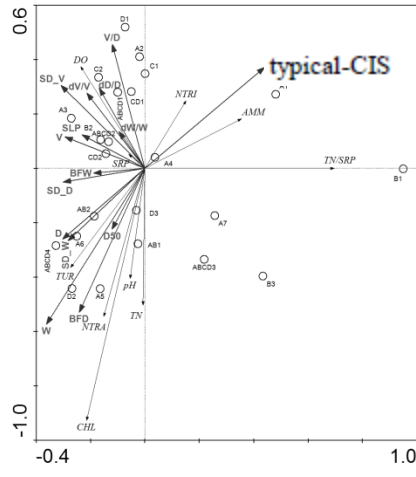
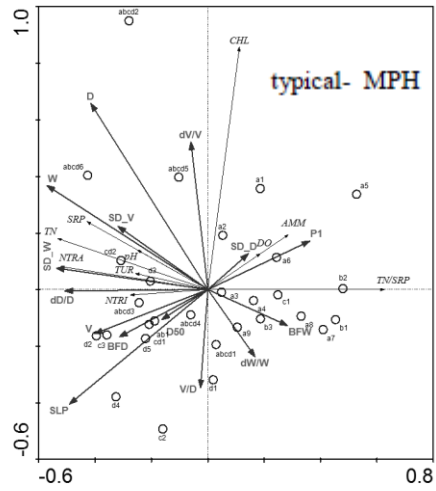
MPH and CIS sample distribution

Spatial variation of water quality with MPH and CIS approaches

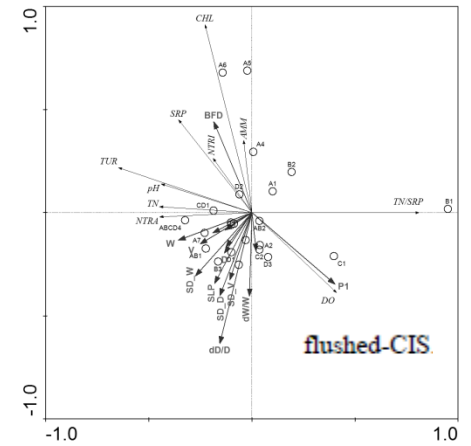
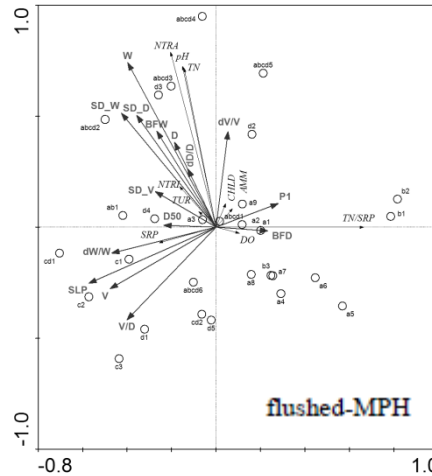
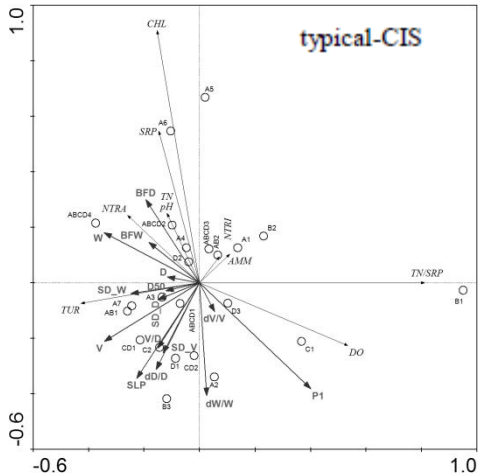
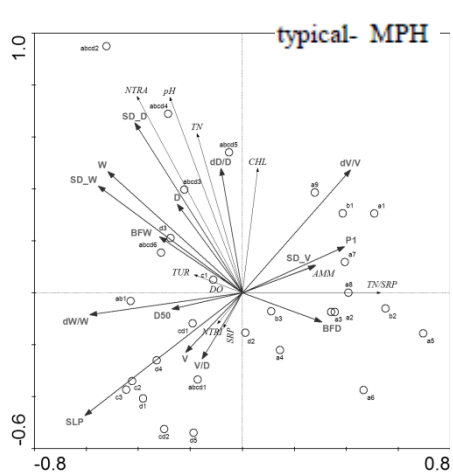


- Figure shows total nitrogen (TN) variation with MPH and CIS methods in dry season typical (**top**) and flushed (**bottom**) states
- It is conspicuous (except for few locations) that the two methods showed distinct TN trends for the typical as well as for flushed states.
- Similar observations were evident for the wet season
- Many water quality parameters other than dissolved oxygen behaved similar to TN

- Redundancy analysis (RDA) was used as a multivariate modeling tool to assess the % variance explained by each sampling approach
 - RDA is a direct multivariate analysis method (both explanatory and response variables are known)
 - Also, the behavior of response variables were linear
- Modeling was carried out for both seasons and in each season for two stream states
 - Dry and wet seasons had flow rates $\sim 0.05 \text{ m}^3/\text{s}$ and $\sim 0.14 \text{ m}^3/\text{s}$ measured at the outflow point of the stream
 - Typical and flushed states were different in terms of overall pollution level of the stream. As an example flushed states total nitrogen always showed a $\sim 20\text{-}50\%$ reduction than the typical state (it was statistically significant; $P < 0.05$)

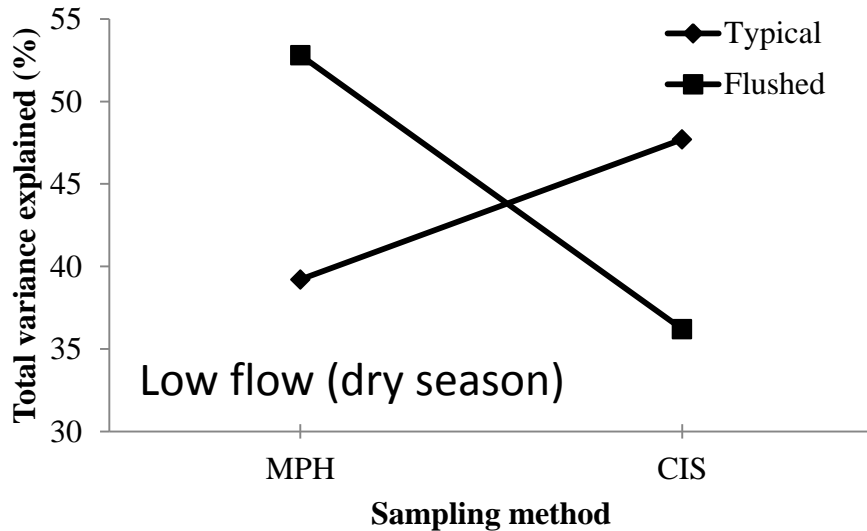


Tri-plots for dry season



Tri-plots for wet season

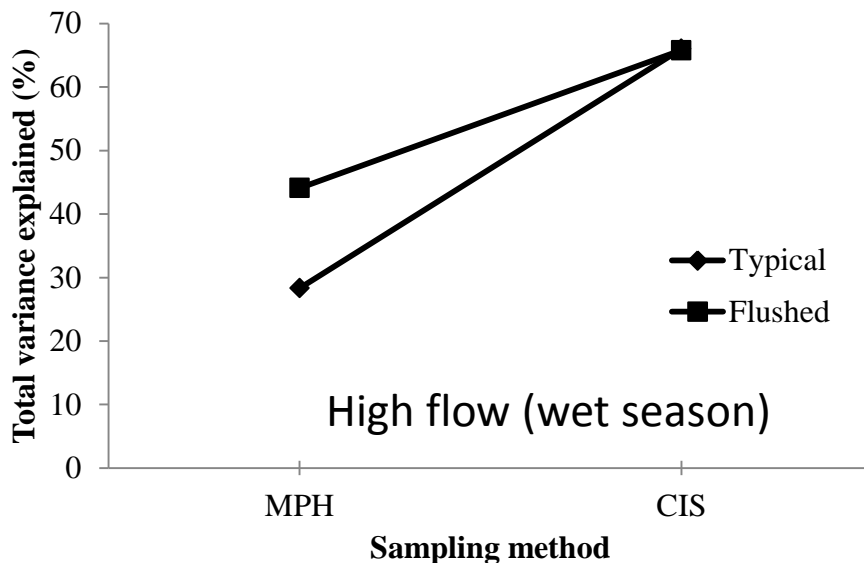
Explanatory powers (% variation explained by each approach) for different scenarios



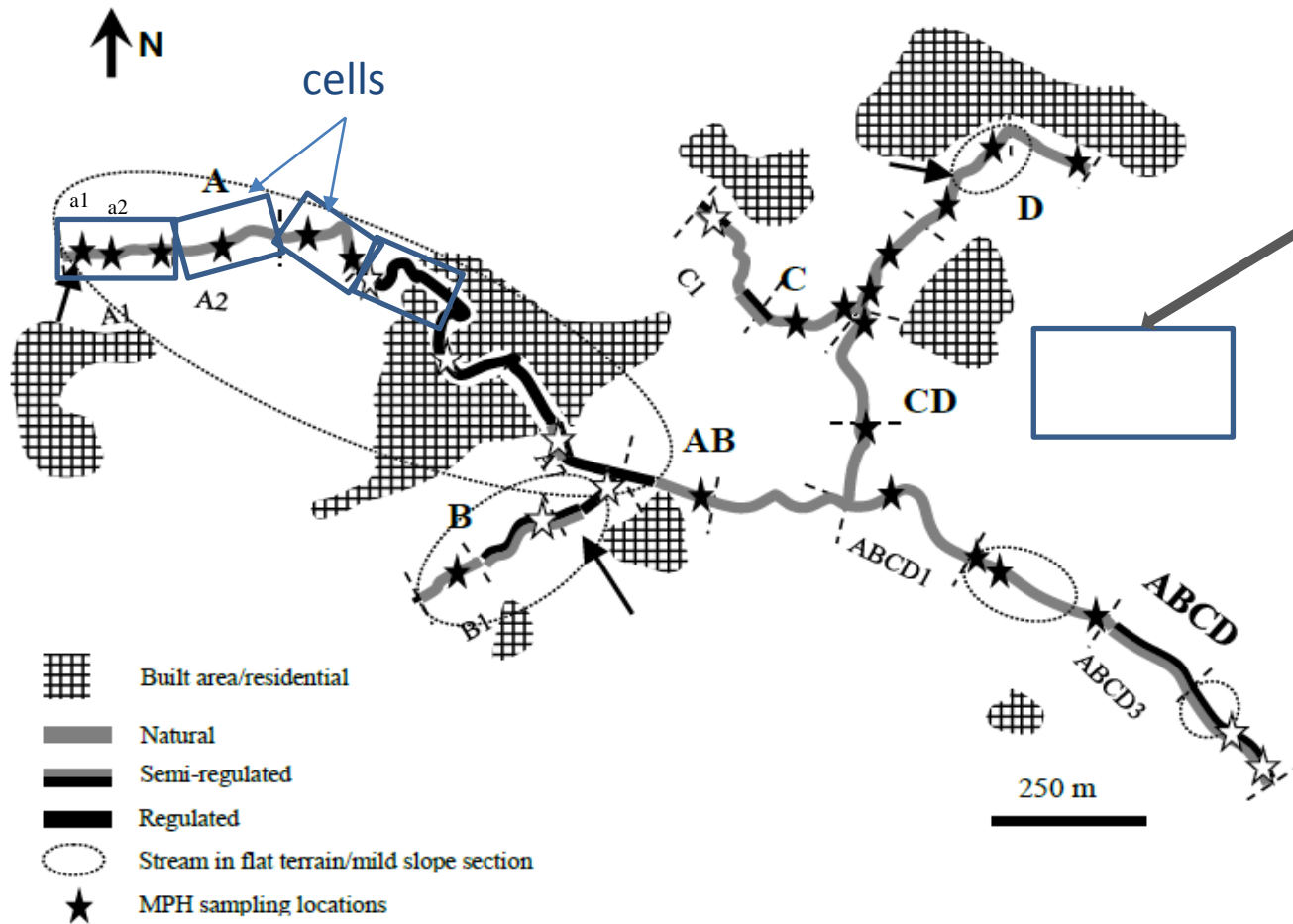
Explanatory power with the MPH approach is relatively high for low flow events, particularly for the flushed state

- MPHs are more suitable for low flow, rather the high flow (e.g. Identifying a riffle from a pool is easy in low flow than the high flow; in an extreme high flow case both features act as pools)

- High flow enhances longitudinal mixing making CIS approach more suitable



Role of in-stream physical heterogeneity in water quality variation

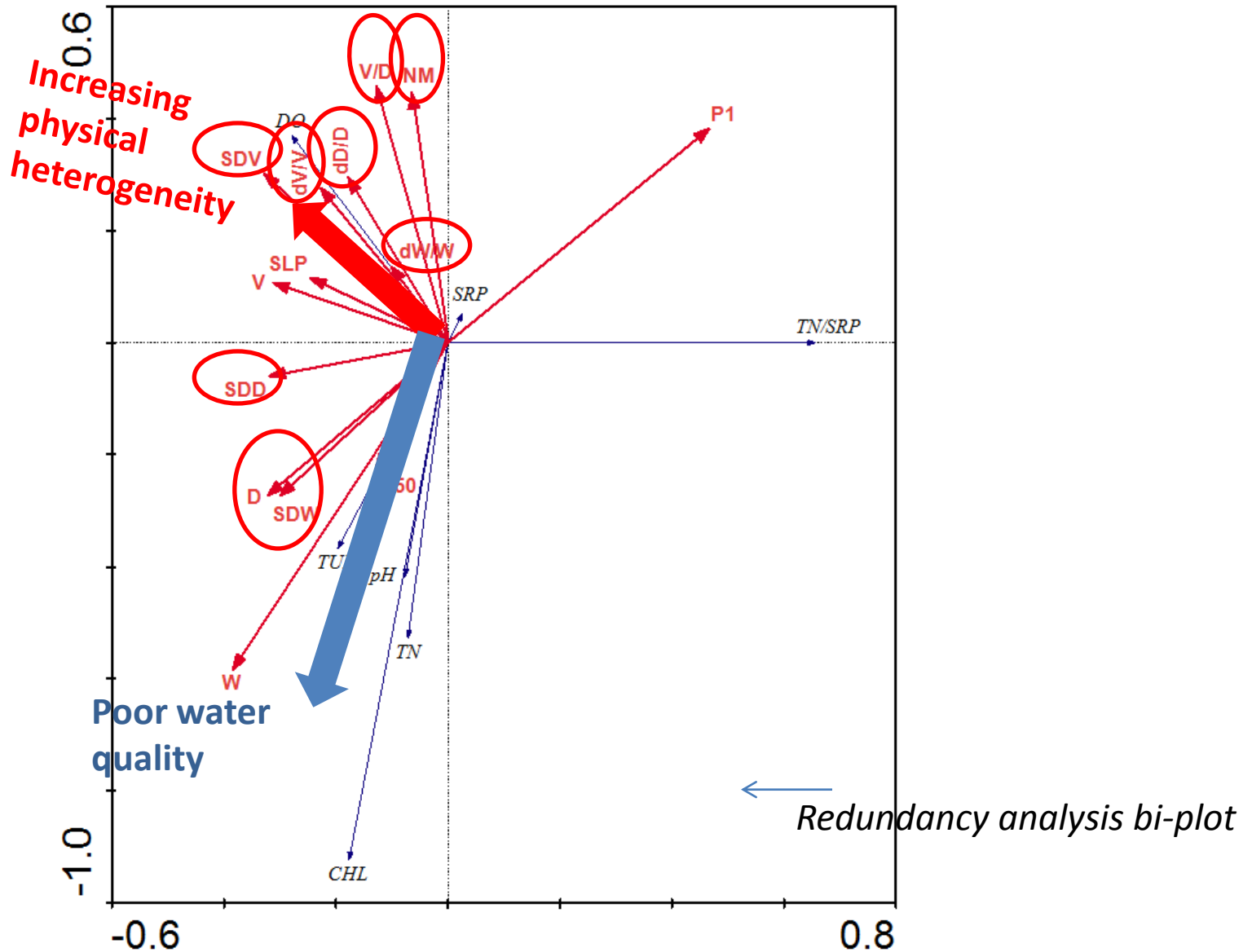


- Several hydro-environmental and water quality variables were measured for a cell (i.e. equal reaches)
- No sampling at MPH locations
- Number of MPHs (NM) will be treated as a hydro-environmental variable representing the physical heterogeneity

MPH and CIS sample distribution

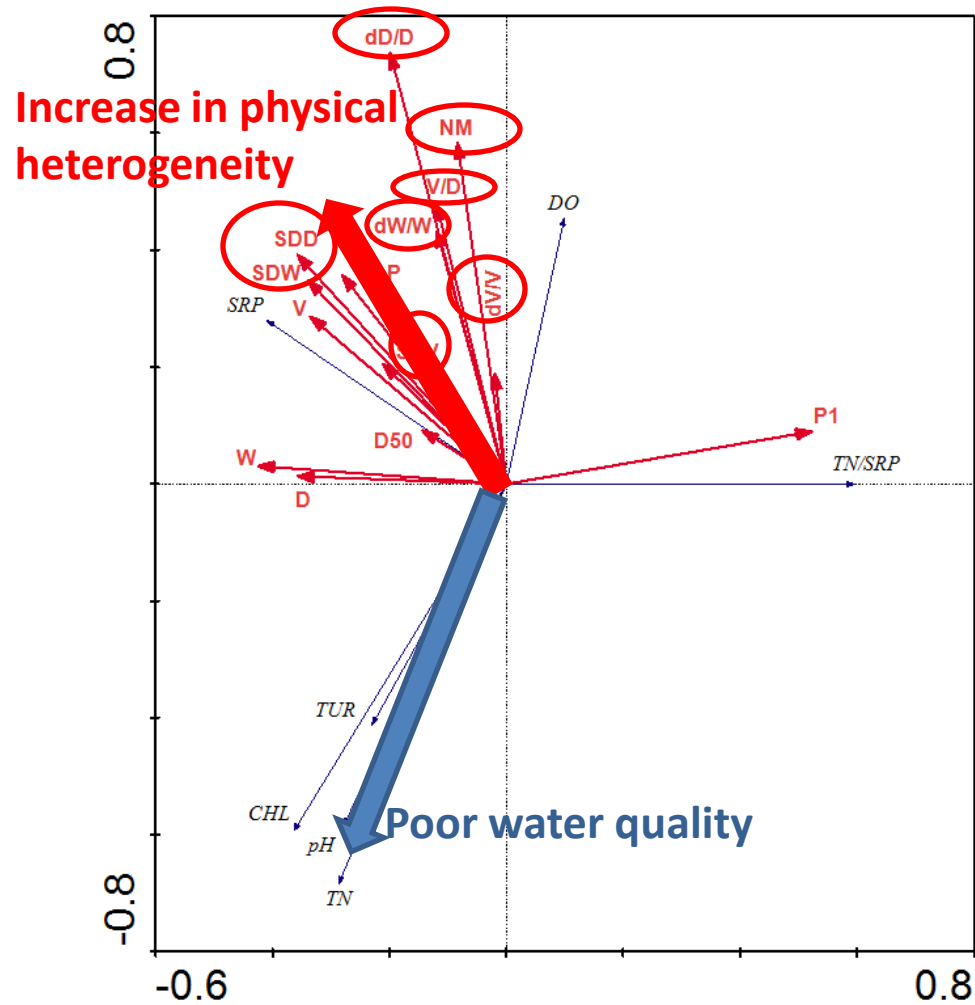
Water quality and physical heterogeneity

Dry season-typical state



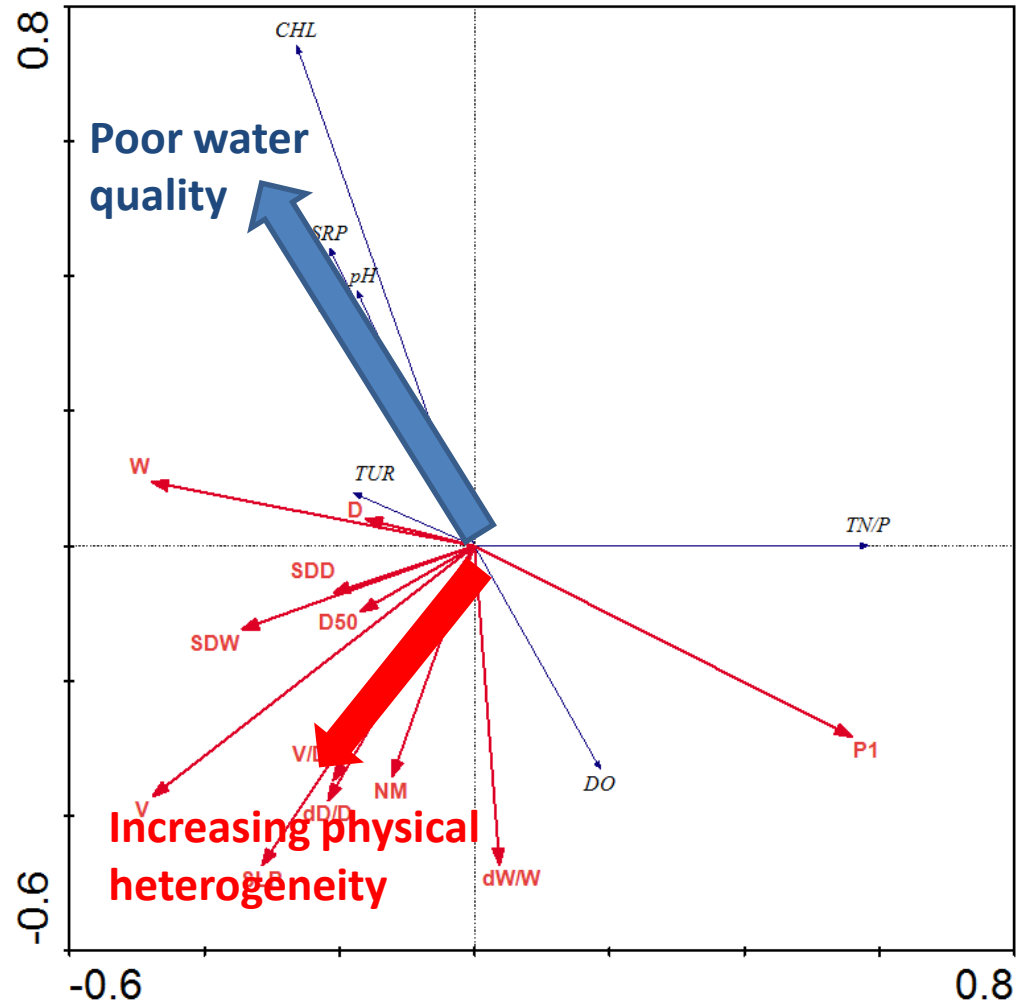
Physical heterogeneity resulted in an improved water quality (**strong correlation**)

Dry season-flushed state



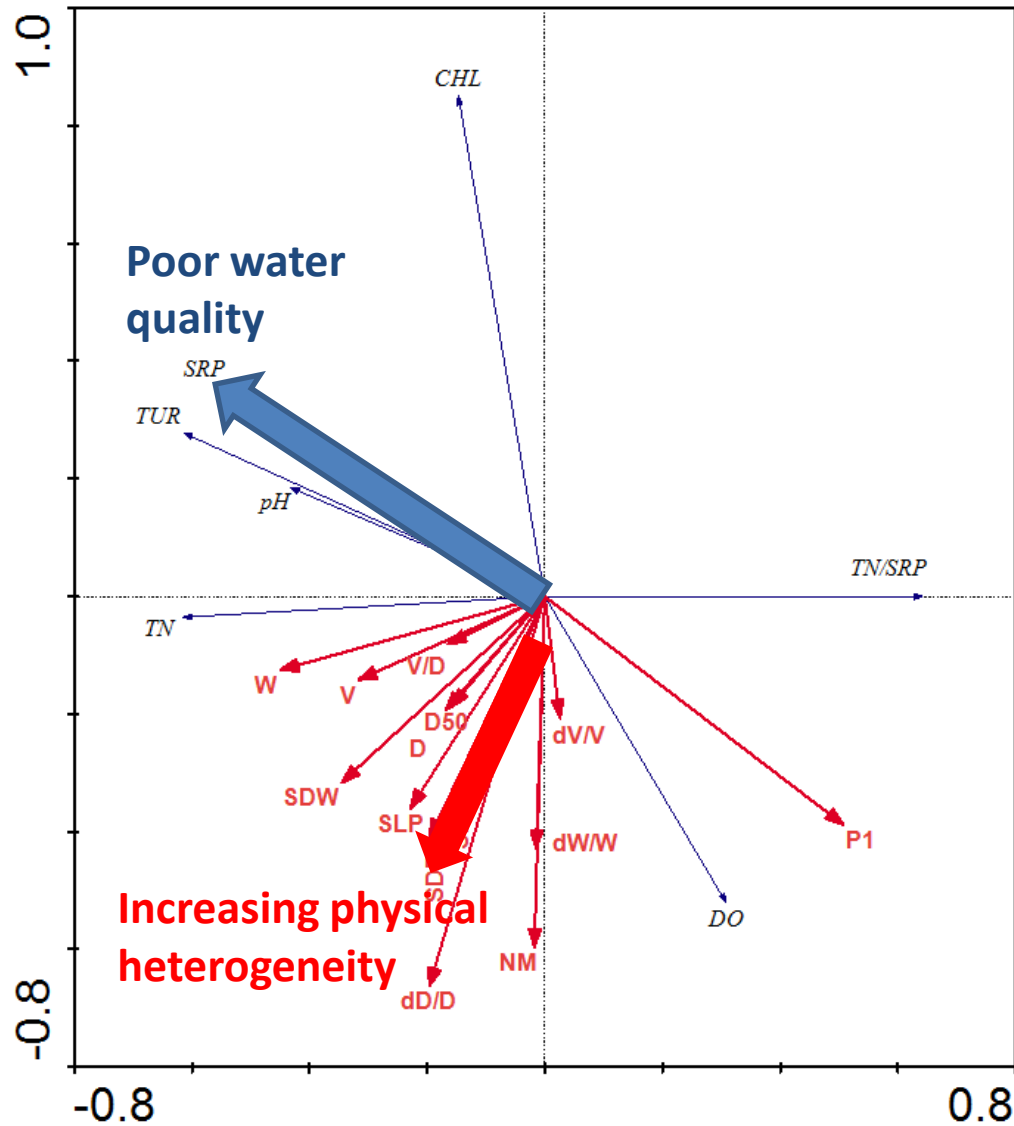
Physical heterogeneity resulted in an improved of water quality (**strong correlation**)

Wet season-typical state



Physical heterogeneity resulted in an improved of water quality. **But almost no correlation**

Wet season-flushed state



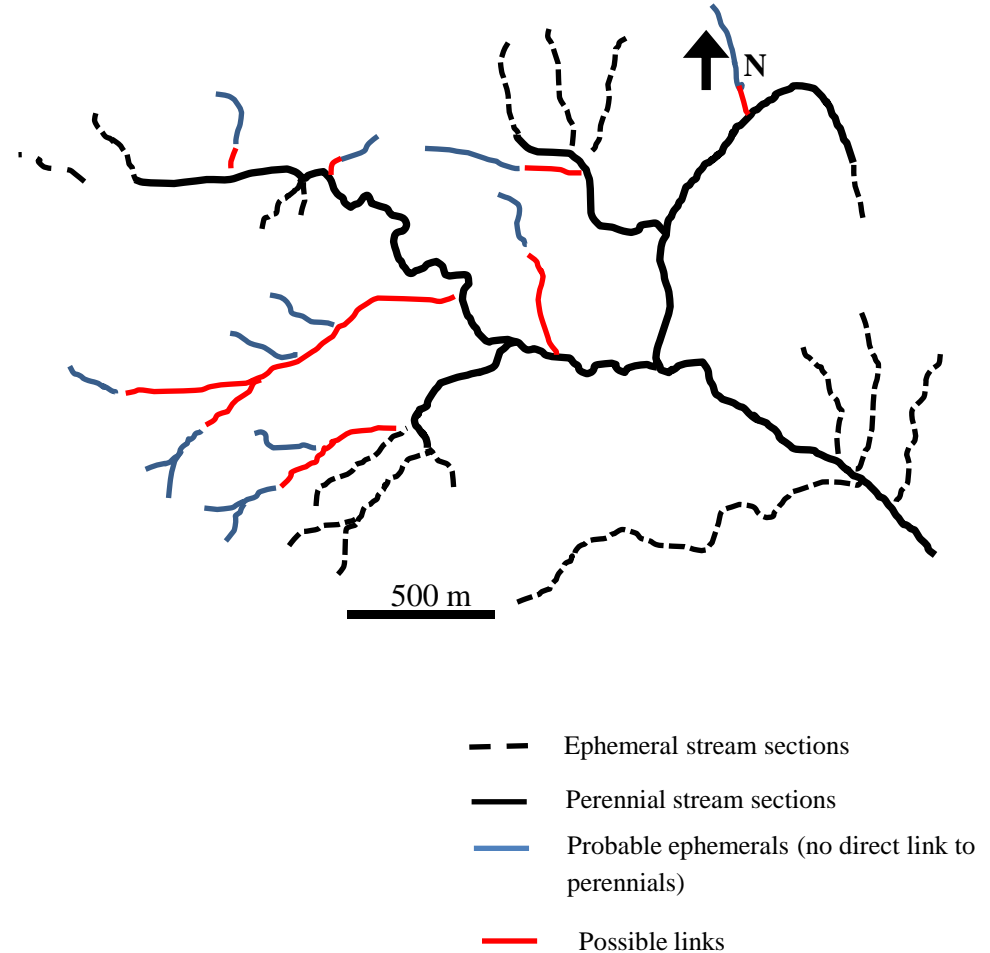
Physical heterogeneity and improved water quality has **no correlation**

Final Remarks

- In dry season, physical heterogeneity showed positive correlation with improved water quality
- However, in wet season, physical heterogeneity only plays a minor role. Water quality was mainly governed by high flows brought by rainstorms
- Physical heterogeneity and rain aided flushing showed seasonal importance
- It should be noted that physical heterogeneity and rain fall aided flushing are rather conflicting- more heterogeneity means less flushing
- Therefore, a good understanding of these two factors is necessary for stream under consideration.
- Future study—the hydrological permanence of ephemeral (non-perennial) streams in headwaters

Headwater streams and spatiotemporal variations of non-perennial and perennial flows

- Quantification of stream flow generation is vital for flood safety as water quality (or other ecological reasons)
- Consideration of different flow paths is essential in stream flow generation studies, and ephemeral streams are one such important component
- This is particularly relevant to HK, as > 50% of its stream sections are non-perennial (ephemeral/intermittent)
- No data available for ephemerals
- Seems there are several ephemeral sections that do not meet the perennial section





From Ho Chung river



From Tseng Lan Shue stream



Sai Kung Country park



- The ephemeral streams in steep (left figure) as well as flat terrains (right figure) had typical channel profiles with an identifiable bankfull width and depth

Thank you.

Acknowledgements

The Hong Kong Research Grants Council General Research Fund (Account no.: PolyU 5296/10E)

The Hong Kong Polytechnic University CEE Research Grants (Account no.: 4-ZZAE)

References

- Anojika K. G. M. S, Kumari G. M. N. R, Priyankara T. D. P. (2011). Integrated ecological assessment of lotic waters and implications for ecological engineering methods. Department of Civil and Environmental Engineering, University of Ruhuna, Galle, Sri Lanka
- Asaeda, T., Gomes, P. I. A, & Takeda, E. (2010). Spatial and temporal tree colonization in a midstream sediment bar and the mechanisms governing tree mortality during a flood event. *River Research and Applications*, 26(8), 960-976.
- CEDD (Civil Engineering and Development Department) (2013) <http://www.cedd.gov.hk/eng/index.htm> date accessed 30-09-2013
- Friedman, J. M., & Lee, V. J. (2002). Extreme floods, channel change, and riparian forests along ephemeral streams. *Ecological Monographs*, 72(3), 409-425.
- Fritz, K. M., Johnson, B. R., & Walters, D. M. (2006). Field operations manual for assessing the hydrologic permanence and ecological condition of headwater streams. United States Environmental Protection Agency, Office of Research and Development.
- Genereux, D. P., Hemond, H. F., & Mulholland, P. J. (1993). Spatial and temporal variability in streamflow generation on the West Fork of Walker Branch Watershed. *Journal of Hydrology*, 142(1), 137-166.
- Gomes, P. I. A. , & Wai, W. H. O. (2013c) Sampling at mesoscale physical habitats to explain headwater stream water quality variations: comparison with sampling at equal distances and implications of season and rainfall aided flushing (to be submitted)
- Green, J. C. (2005). Modelling flow resistance in vegetated streams: review and development of new theory. *Hydrological processes*, 19(6), 1245-1259.
- Newson, M.D., Newson, C.L., 2000. Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. *Prog. Phys. Geog.*24, 195-217.
- Maddock, I., 1999. The importance of physical habitat assessment for evaluating river health. *Freshwater Biol.* 41, 373-391.
- Clifford, N., Wright, N., Harvey, G., Gurnell, A., Harmar, O., Soar, P., 2010. Numerical Modeling of River Flow for Ecohydraulic Applications: Some Experiences with Velocity Characterization in Field and Simulated Data. *J. Hydraul. Eng.* 136, 1033–1041.
- Pawliszyn, J., 2002. Sampling and sample preparation for field and laboratory: Fundamentals and New Directions in Sample Preparation. Elsevier Science, Amsterdam.
- Moir, H. J., & Pasternack, G. B. (2008). Relationships between mesoscale morphological units, stream hydraulics and Chinook salmon (< i> Oncorhynchus tshawytscha</i>) spawning habitat on the Lower Yuba River, California. *Geomorphology*, 100(3), 527-548.
- <http://www.fhwa.dot.gov/engineering/hydraulics/pubs/07033/6.cfm>
- <http://www.kunenerak.org/en/river/hydrology/principles+of+hydrology/surface+water/stream+order.aspx>
- <http://www.manometmaine.org/headstream.html>
- <http://www.niwa.co.nz/publications/wa/vol10-no2-june-2002/stream-restoration-in-christchurch>