DSD Research & Development Forum 2015

Session 2 – Revitalising Water Bodies

Relation of In-stream Physical Heterogeneity and Ecological Quality: Implications to Sustainable ECO-Flood Channel Design

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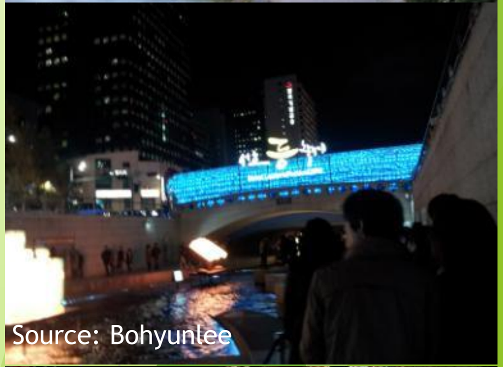
Channel Rehabilitation: Cheonggyecheon, Korea

Cheonggyecheon restoration involved the rebuilding of a 10.9 km long waterway, replacing the heavily polluted gully covered under concrete highway. Construction took place from 2002 to 2005, costing USD$281million.

Source: WWF


Source: Schellack


Source: madmarv00


Source: Bohyunlee


Source: Erik Möller


Source: stari4ek


Source: http://cheonggye.seoul.go.kr/

Channel Rehabilitation:

Bishan-Ang Mo Kio Park and Kallang River, Singapore

Source: Atelier Dreiseitl

This is one of the flagship projects under Singapore's ABC (Active, Beautiful and Clean) Waters Programme, which transformed the concreted Kallang River into a meandering, near-natural river crossing the entire park. Construction took place from 2009-2012, and the project budget was Euro€39million.

Source: Atelier Dreiseitl

Source: Atelier Dreiseitl

2015 Policy Address

Water-friendly Culture and Activities

We will adopt the **concept of revitalising water bodies** in **large-scale drainage improvement works** and planning drainage networks for **NDAs** (new development areas) so as to build a better environment for the public.

(Paragraph 181)

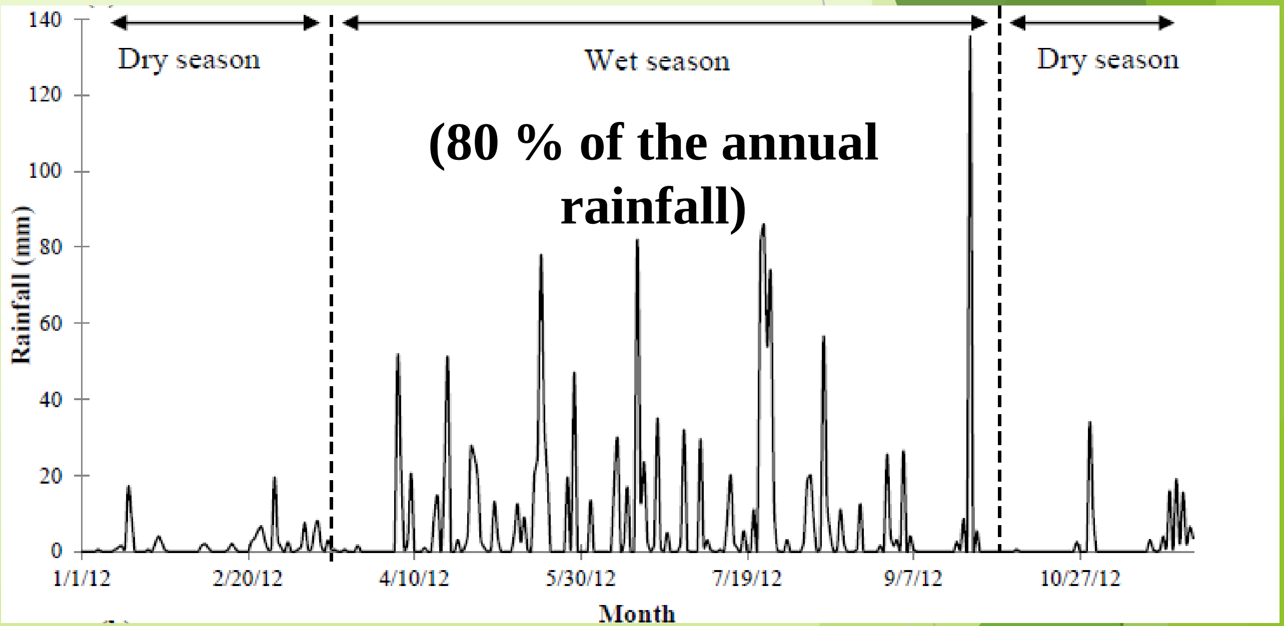
The Ecology of Hong Kong and its Streams

Conventional perception of Hong Kong………….

However, it has a variety of habitats: forests, waterfalls and streams, farms, etc…

Characteristics of Hong Kong streams

- Steep and short (many without a distinctive middle course)
- Contrasting wet and dry seasons
  - Streams are densely distributed.
  - Several tributaries/sections are ephemeral.
  - Poor drainage during the dry season, specially the ones with discrete pools/flat terrains.



Status of Hong Kong streams, government policy and societal views

- Former engineering practices advocated designs that minimize flood related hazards.
- With the changes in socio-economic conditions, public tend to look for more natural looking waterways; DSD the custodian of most of the regulated lotic waters has taken the initiative to incorporate eco-friendly features. (2015 Policy Address)
- For more ecological friendly features and sustainable river channel designs, **new research is needed.**

Yuen Long Main Nullah (in total ~5 km are like this; perhaps the best reference for a hydraulically sound, but ecologically dead regulated lotic water in Hong Kong)

Jordan Valley Nullah (aesthetic uplift)

Ho Chung River fish ladder (ecological uplift)

What's the problem here?

Two major interactive pathways (at least) are disturbed:
No lateral (stream-floodplain) and vertical (stream-aquifer) connections

Thus four dimensional framework concept / spatiotemporal hierarchy doesn't satisfy

No flora/fauna, especially macroinvertebrates such as shredders, grazers
No proper nutrient decomposition along the stream

Thus river continuum concept doesn't satisfy

Yuen Long Nullah

No biodiversity in the boundary of terrestrial and freshwater system
No flora/fauna in both low/high flow flood plains

Thus boundary / interface perspective (concept) doesn't satisfy

No flow-landscape interaction
No cycling of nutrients even in the low flow hydrologic landscape

Thus flood pulse concept doesn't satisfy

Hydraulically excellent,
Ecologically dead!!!!

Restoration Concepts

“The science and practice of river restoration” (Wohl et al. 2015a)

- Common restoration approaches
  - Structure-orientated approach:
    Restoration by engineering a river to an identified form that has been lost (e.g. meandering).
  - System function approach:
    Restoring a desired process in the river system, and the system is allowed to develop in response to the restoration.
  - Hybrid approach:
    Restoring a crucial element of the river’s structure and function (e.g. pool-riffle sequence), and the system is allowed to evolve.

Restoration Concepts

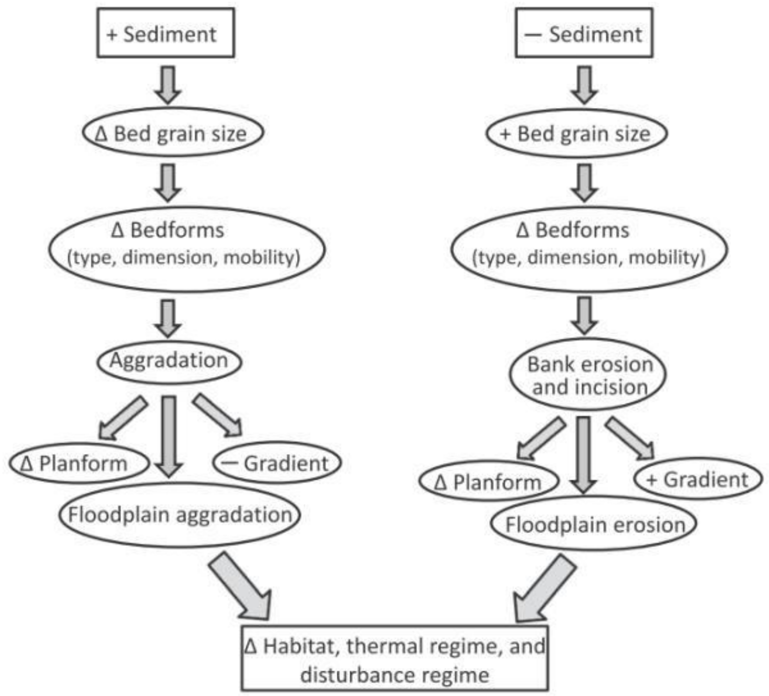
Adaptive Management for River Restoration

- Adaptive management a structured, iterative process of robust decision making to reducing uncertainty over time via system monitoring

Figure 1. CMP *Open Standards* Project Management Cycle Version 3.0

The Conservation Measures Partnership, 2013

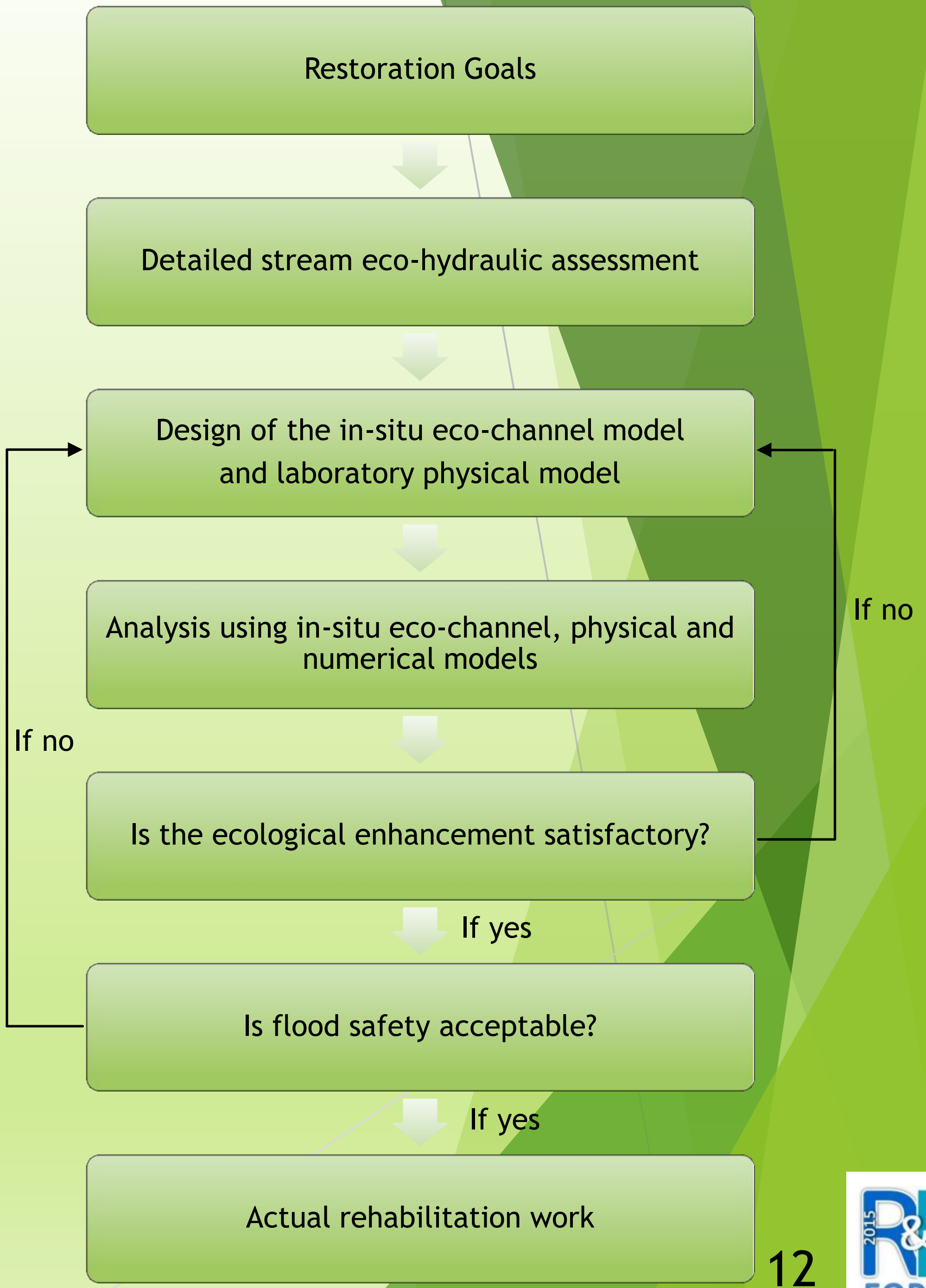
- Example: Sediment Regime
  - Major role in determining geomorphology, habitats, ecological disturbance regime, etc.
  - Water and sediment inputs are non-linear and episodic.
  - River response changes at different temporal and spatial scale.
  - Data of sediment regime (historical and present) are difficult to obtain.
  - Also influenced by human activities.



(Wohl et al. 2015b)

Project Objectives

1. Maintain flood control function and sediment balance, supply organic matters to downstream reaches;
2. Establish appropriate pools, riffles, in-stream covers and sediment which support macroinvertebrate and fish colonization;
3. Establish appropriate controlled habitats for submerged, floating and emergent flora;
4. Enhance overall water quality, especially at the downstream reaches where anaerobic conditions exist;
5. Provide a basis for future rehabilitation work and prepare of guidelines.

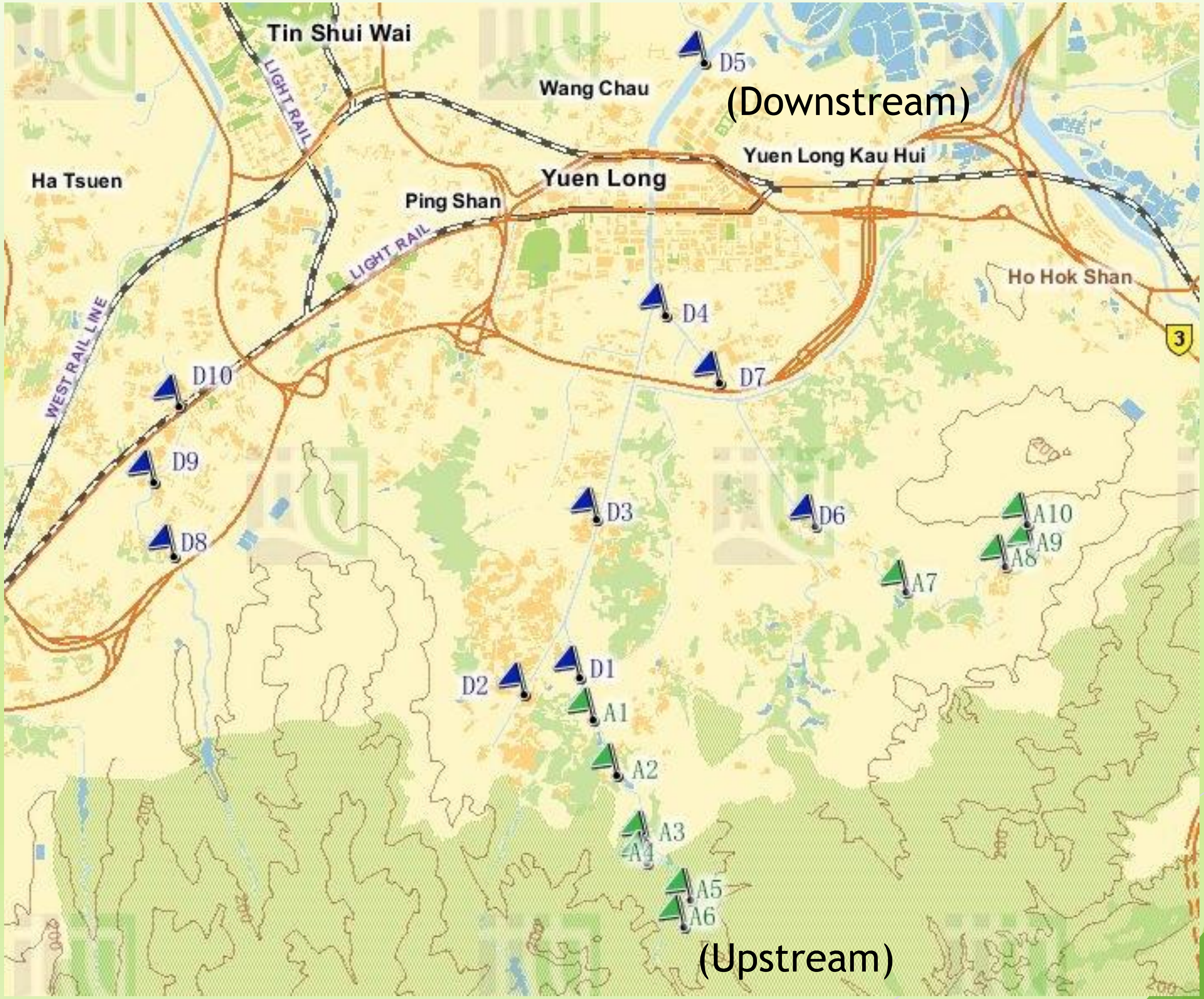


Ecological Assessment

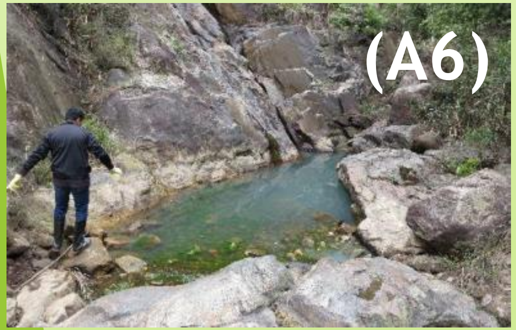
- To understand the existing condition and site characteristics, and provide baseline information for future comparison.

Twice every year		
dry season(Jan-Feb)	wet season (Jul-Aug)	
Sampling sites (total 20 sites)		
A1-A10 (natural stream bed sections)	D1-D10 (concreted channel sections)	
Measurements		
Physical / Geomorphological	Chemical	Biological
flow depth, velocity, width, Froude number, pool and riffle distribution, etc.	pH, conductivity, turbidity, DO, nitrite, nitrate, ammonia, reactive phosphorous, sulfate, sulfide, TS, TSS, chlorophyll-a, etc.	benthic algae, submerged and floating plants, emergent plants, riparian vegetation, fish, avi-fauna, benthic macroinvertebrates, diatoms, etc.

Map of the 20 Sites



Sampling Sites A1-A10 (Natural Stream Bed)

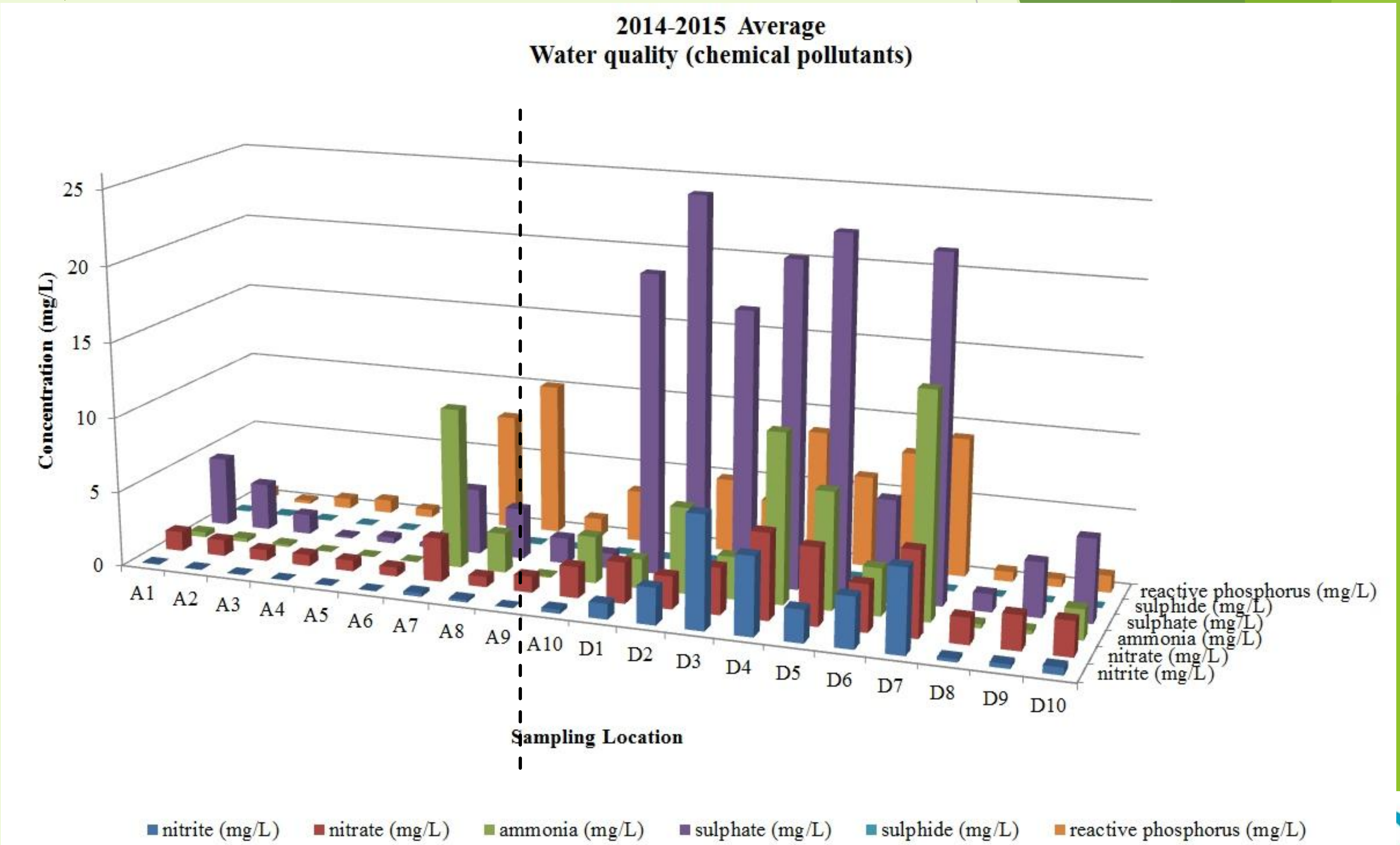


Sampling Sites D1-D10 (Concreted Channel)

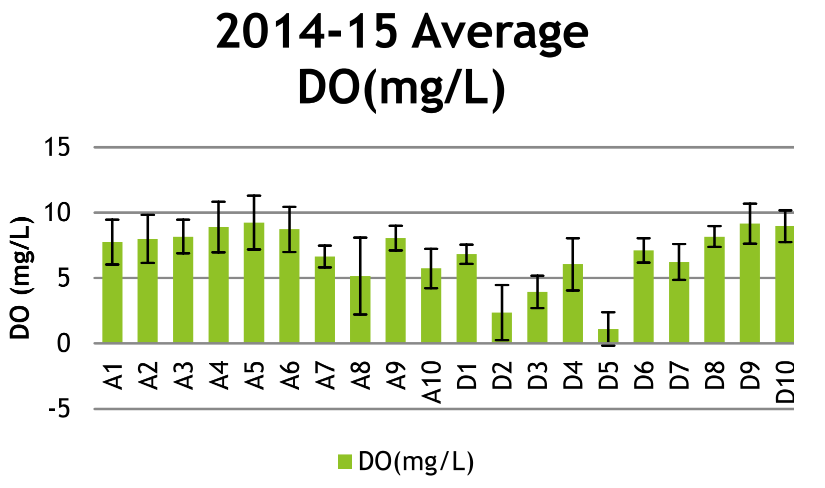
Water Quality Results (2014-2015 averaged)

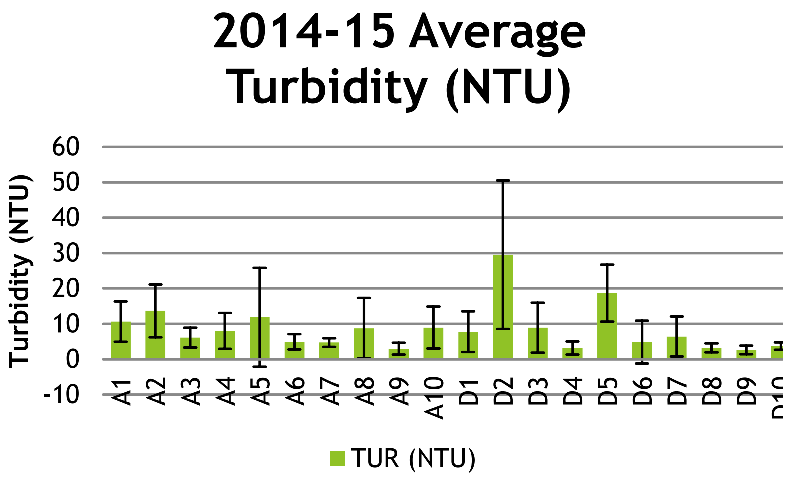
- Contrast between A-sites (natural bed, except A8) and D-sites (concreted channel sections)

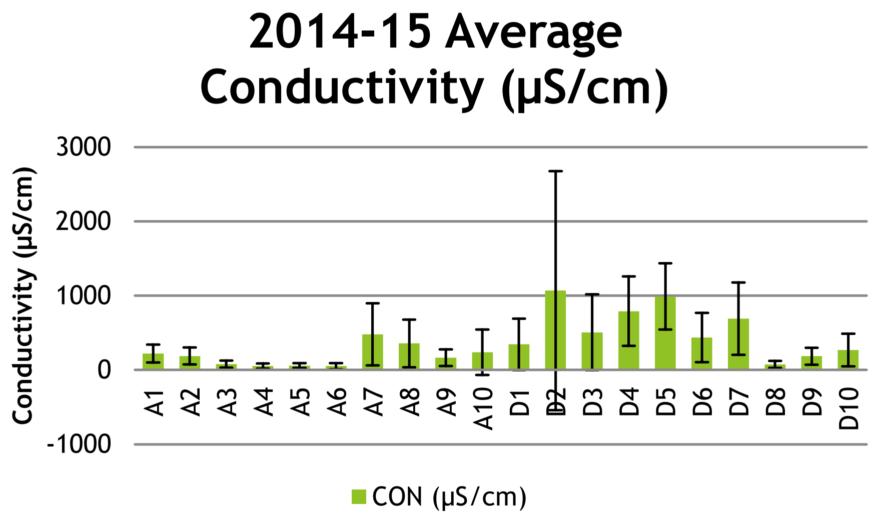
- Within the D-sites:
  - Less polluted: D6, D8, D9 and D10
  - More heavily polluted: D2, D4, D5, D7

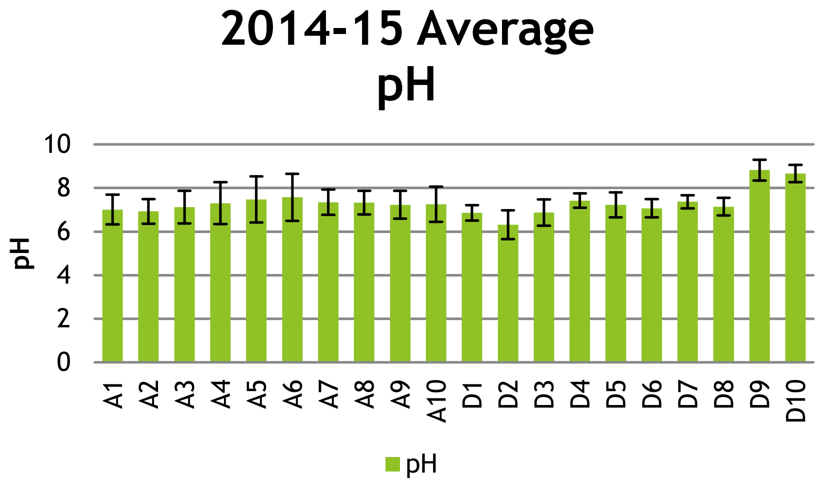


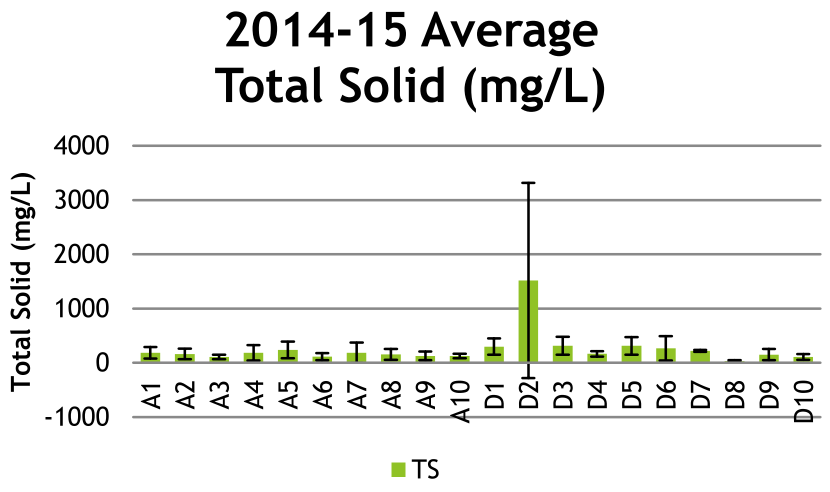
Water Quality

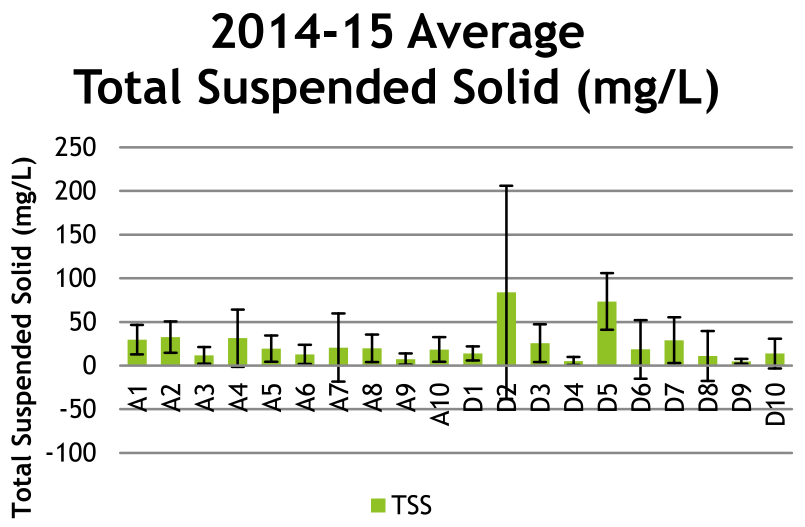






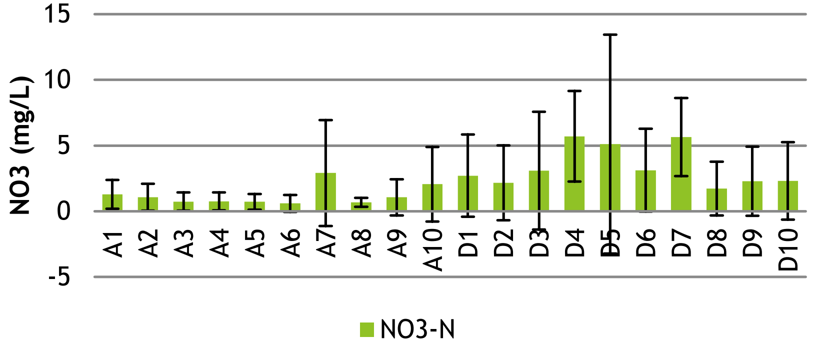




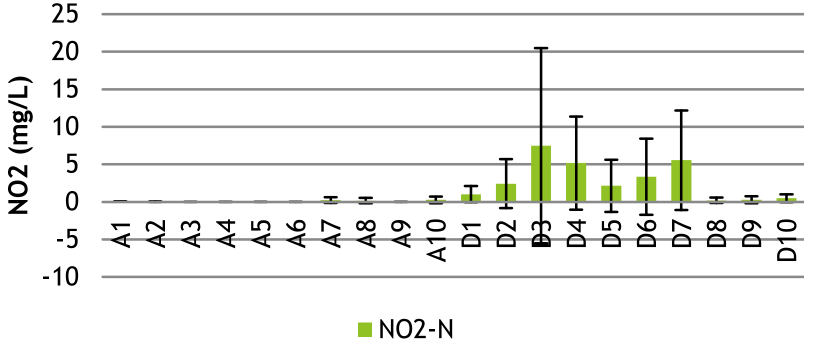


Water Quality

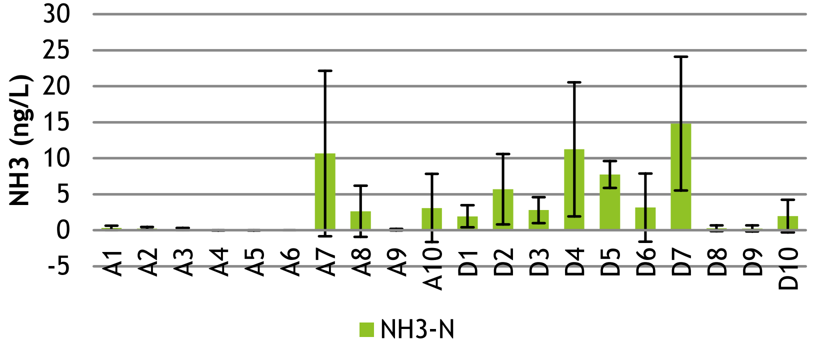
2014-15 Average Nitrate-Nitrogen (mg/L)



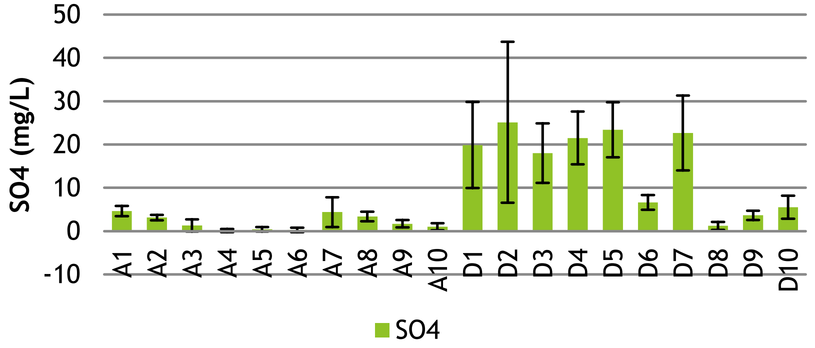
2014-15 Average Nritrite-Nitrogen (mg/L)



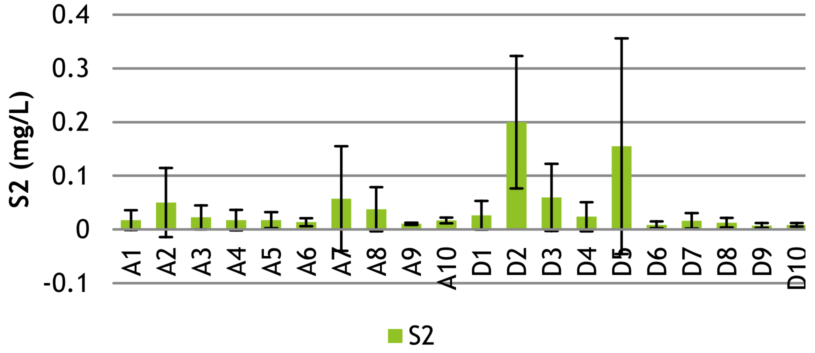
2014-15 Average Ammoniacal-Nitrogen (mg/L)



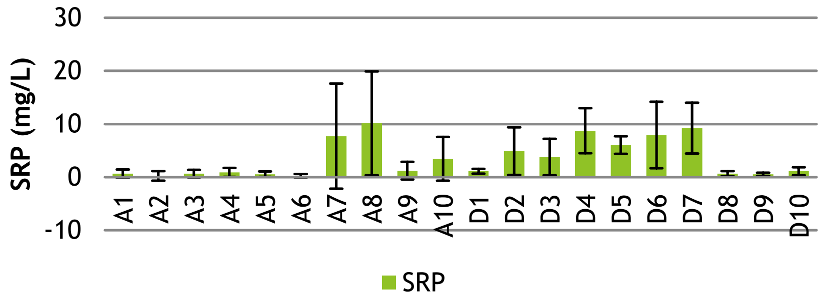
2014-15 Average Sulfate (mg/L)



2014-15 Average Sulfide (mg/L)



2014-15 Average Soluble Reactive Phosphorus (mg/L)

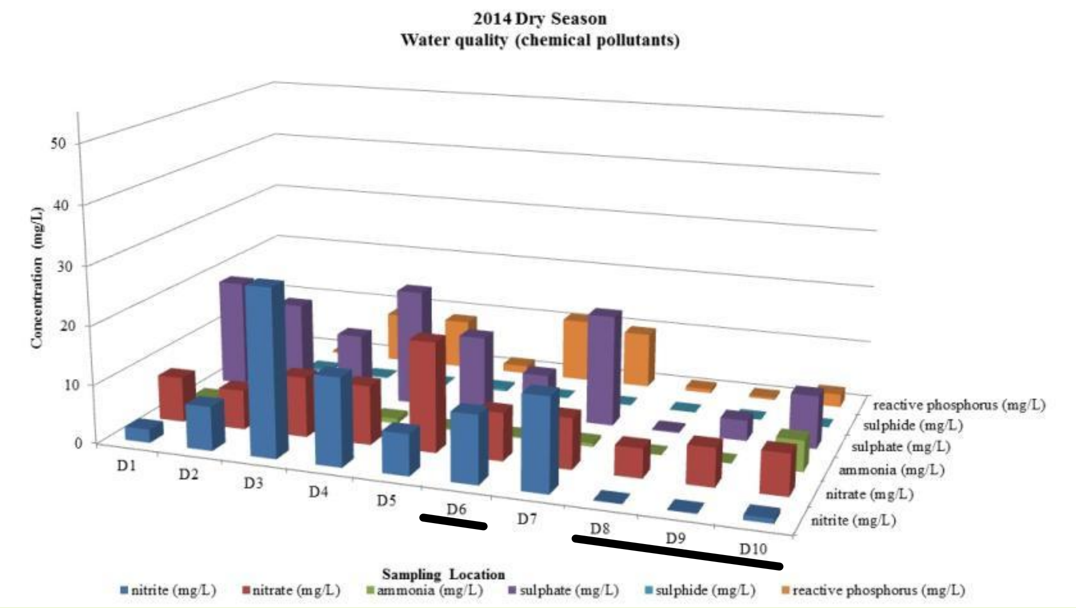


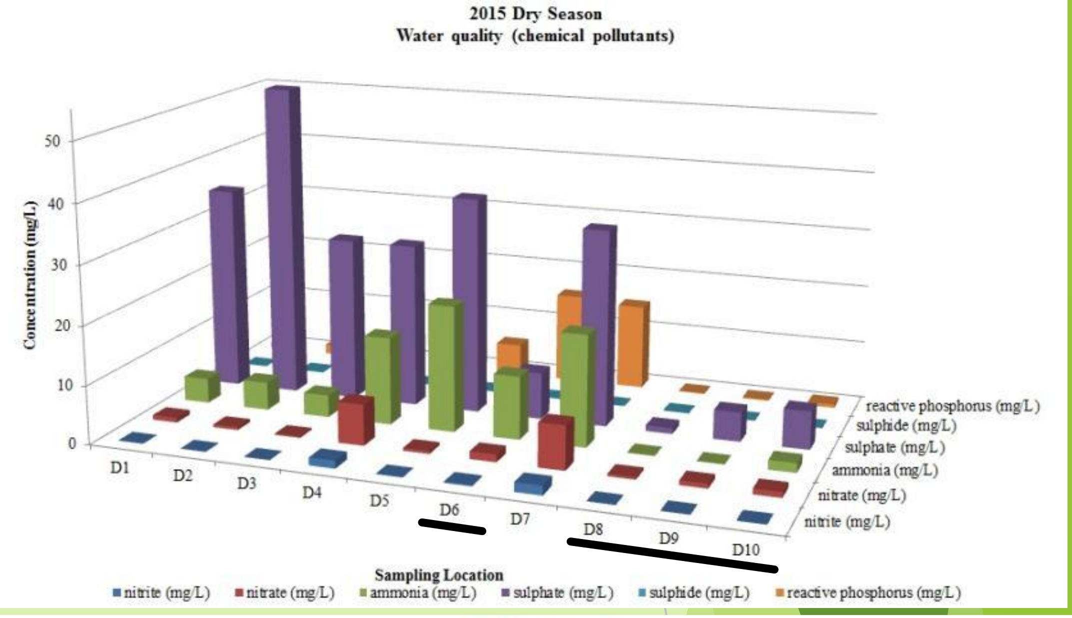
Water Quality

2014

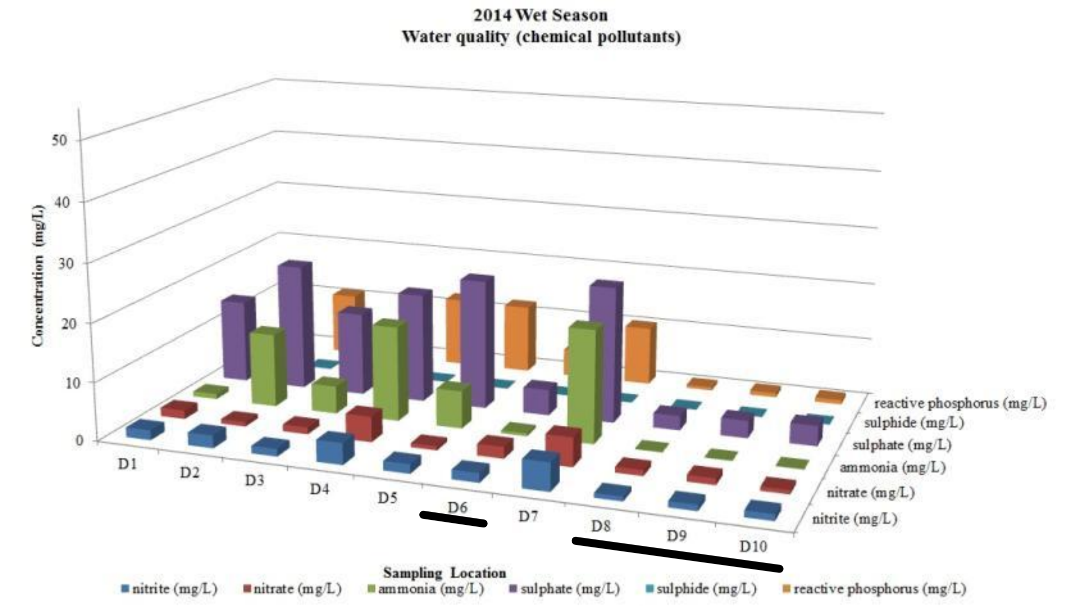
2015

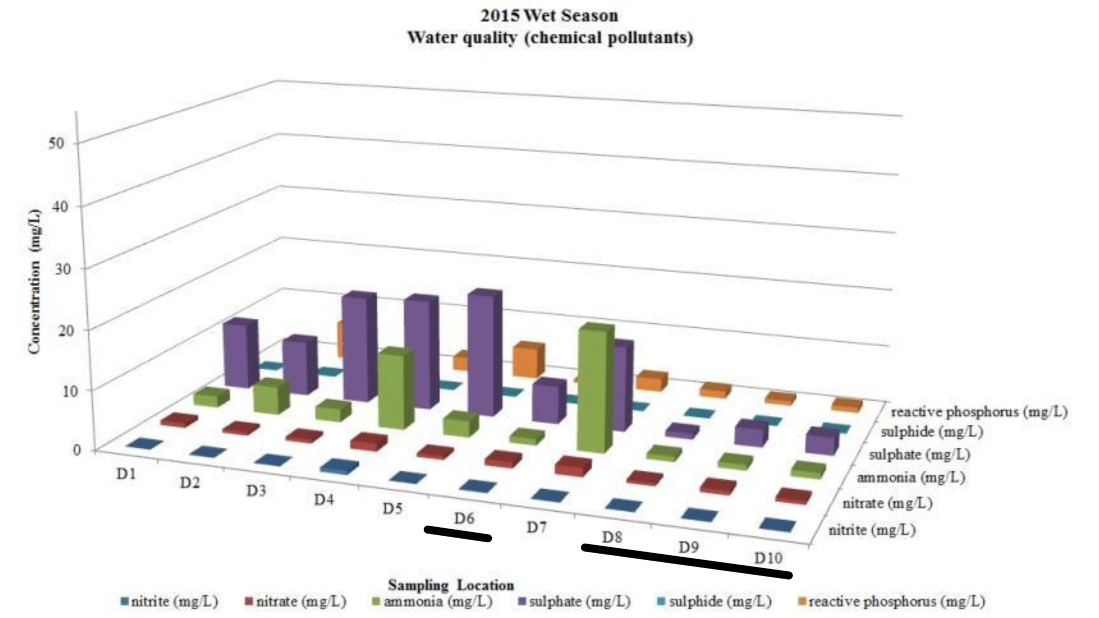
Dry Season





Wet Season (Pollution becomes less serious)





FORUM

Better Water Quality Concrete Channel Sections (Upstream)

- Characteristics
  - Examples: D8-D10
  - Connected to a high quality upstream.
  - Better water quality than other channel sites and some several natural stream bed sites.
  - Appearance of macro-invertebrate species with low pollution tolerance, and fish communities.
  - Recovery after flood events and/or change of season.
- Rehabilitation Opportunities
  - Consistent flow rate and water depth in the low flow channel through all seasons.
  - Natural supply of organisms from upstream.
  - Pollution is low.
  - Likely to be self-sustainable.

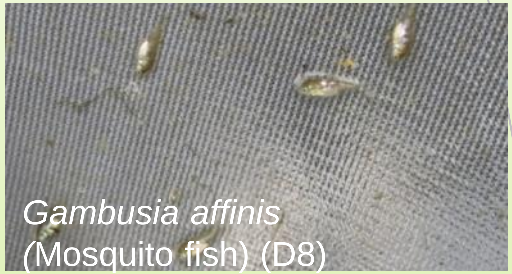

Site D8


Site D9

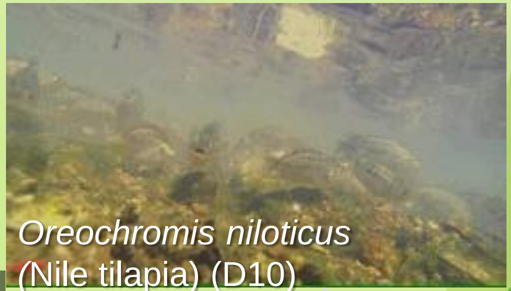

Site D10


Ardeola bacchus
(Chinese Pond Heron) (D10)


Tilapia Nest (D8)


Gambusia affinis
(Mosquito fish) (D8)


Egretta garzetta
(Little Egret) (D10)


Oreochromis niloticus
(Nile tilapia) (D10)


Xenochrophis piscator
(Checkered keelback) (D8)


Xenochrophis piscator
(Checkered keelback) (D10)


Crested Myna community
(D10)

Sites D8 - D10

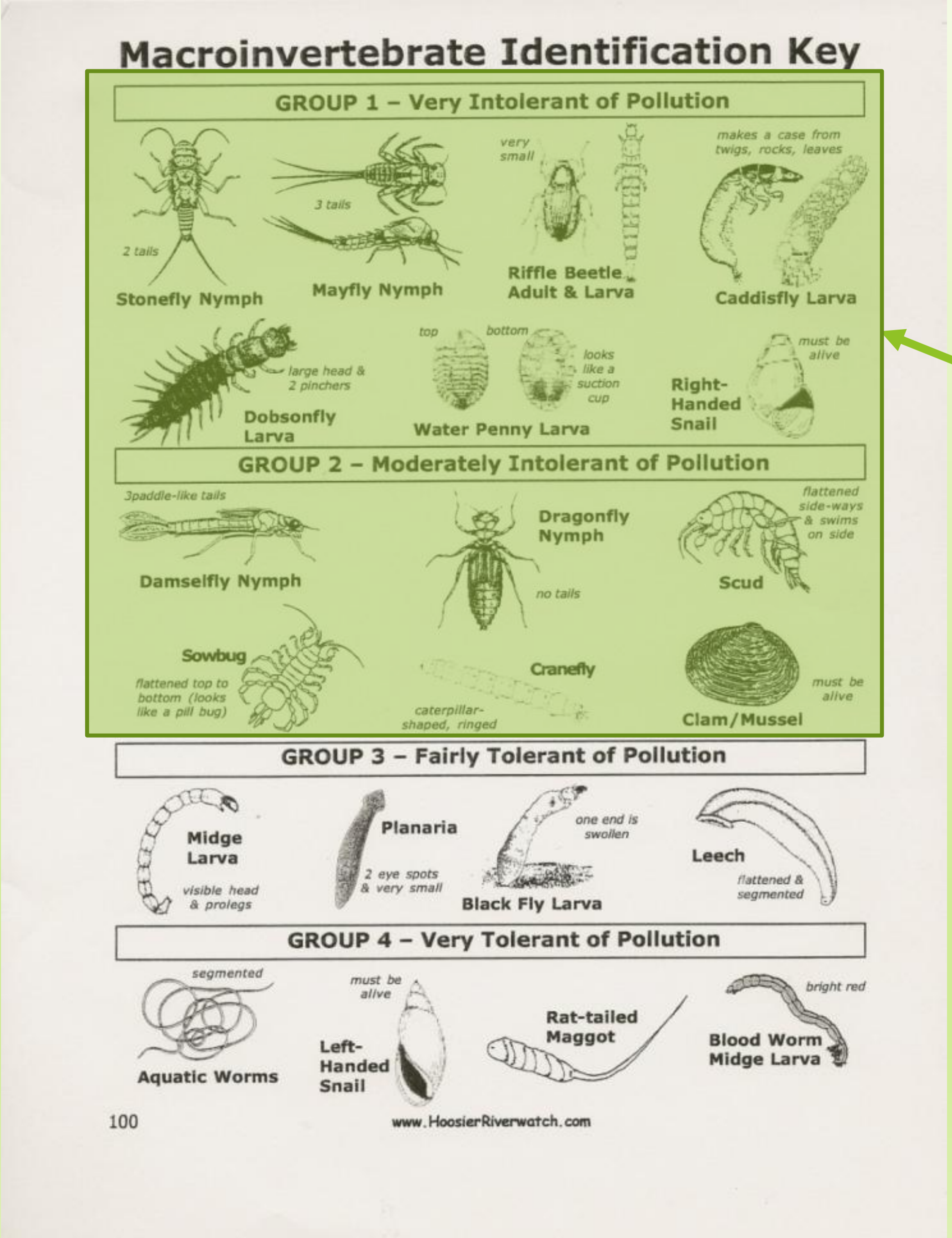
- Physical heterogeneity in channel is higher than other D-sites
  - Pools, meandering channel, and vegetated embankment.
- Connected to a natural stream with good water quality (the Hung Shui Hang Irrigation Reservoir).
- Human activities is minimal
  - Pollution is relatively low.
  - Generally rural environment.

Downstream D8 Upstream (Further up)

Trees along the channel

D10 (Downstream) D10 (Upstream) D9

Sites D8 - D10


Macroinvertebrate Identification Key

GROUP 1 – Very Intolerant of Pollution

Stonefly Nymph — 2 tails
Mayfly Nymph — 3 tails
Riffle Beetle Adult & Larva — very small
Caddisfly Larva — makes a case from twigs, rocks, leaves
Dobsonfly Larva — large head & 2 pinchers
Water Penny Larva — top; bottom; looks like a suction cup
Right-Handed Snail — must be alive

GROUP 2 – Moderately Intolerant of Pollution

Damselfly Nymph — 3paddle-like tails
Dragonfly Nymph — no tails
Scud — flattened side-ways & swims on side
Sowbug — flattened top to bottom (looks like a pill bug)
Cranefly — caterpillar-shaped, ringed
Clam/Mussel — must be alive

GROUP 3 – Fairly Tolerant of Pollution

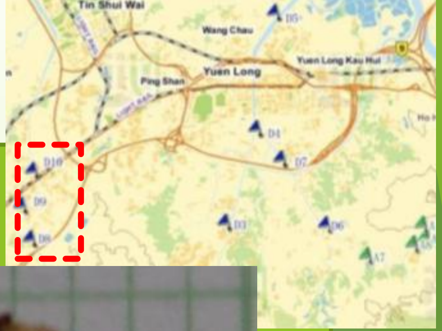
Midge Larva — visible head & prolegs
Planaria — 2 eye spots & very small
Black Fly Larva — one end is swollen
Leech — flattened & segmented

GROUP 4 – Very Tolerant of Pollution

Aquatic Worms — segmented
Left-Handed Snail — must be alive
Rat-tailed Maggot
Blood Worm Midge Larva — bright red

100

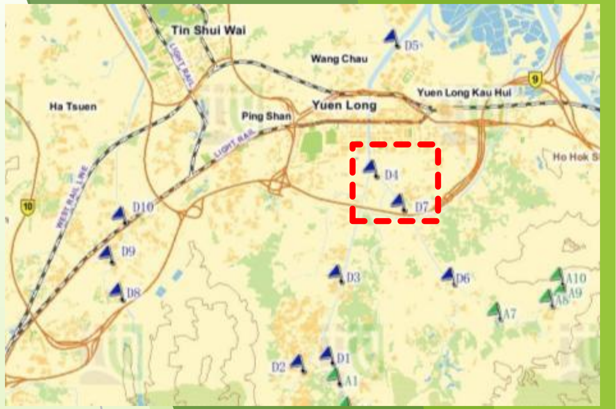
www.HoosierRiverwatch.com



Macroinvertebrates collected via Kick-sampling.

Palaemonetes sp. (freshwater shrimp); Location D8 (Left: lab; Right: field)

Sections with Pollution Tolerant Species



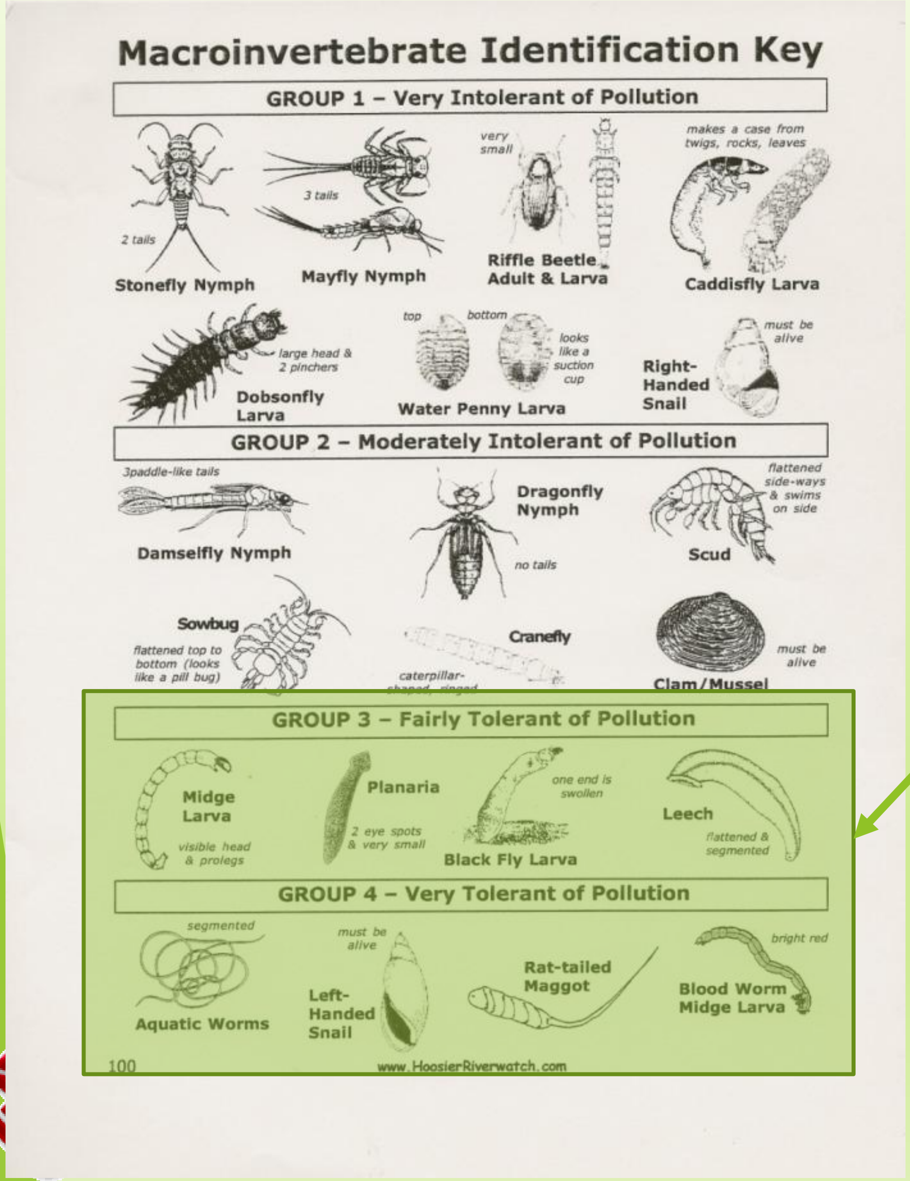
- Characteristics
  - Examples: Sites D4, D7.
  - Relatively downstream, and received domestic and/or industrial pollution along the channel.
    - High nitrogen, sulfate and phosphorus; Relatively low DO.
  - Abundance of filamentous algae.
  - Appearance of macro-invertebrate species with medium to high pollution tolerance, sometimes Tilapia fish.
- Rehabilitation Opportunities and Challenges
  - High nutrient content for plant growth.
  - Instream structures (e.g. deflectors) may improve habitat complexity, DO content and algae control.
  - Efforts on pollution control and maintenance is essential.

Tilapia caught at D4 (Dry2014) (released afterward)

Algae washed by the flow after a trial deflector was installed (in-situ experiment, 24Sep2015)

2015 R&D FORUM

Sites D4 and D7



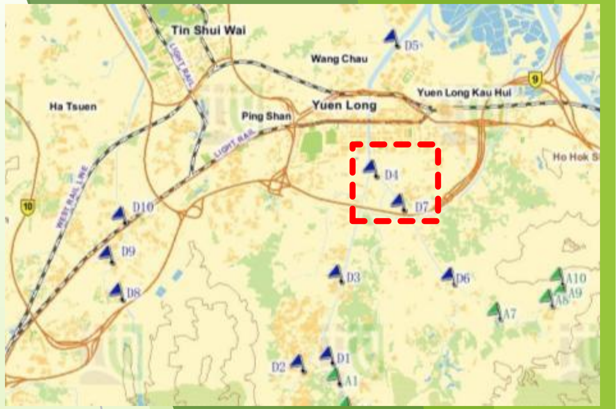
Pomacea spp. (Apple Snail) and eggs

Chironmidae larvae (non-biting midge larvae)

Planorbidae (Ramshorn snail)

Hirudinea (leech)

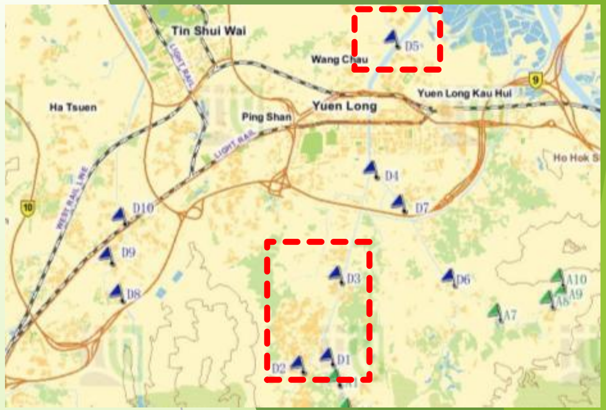
Tubifex tubifex (red worm)



Macroinvertebrates collected via Kick-sampling.

Sections with very few living organisms

- Characteristics
  - Sites D1 and D3.
  - Very high flow rate all year long (self-cleansing).
  - Very frequent maintenance (e.g. weed control and channel bed scrapping).
- Characteristics
  - Sites D2 and D5.
  - Highly polluted (e.g. extremely low DO), and/or affected by tidal flow (i.e. D5).
- Rehabilitation Challenges
  - Pollution control and site-specific rehabilitation design is needed.




Clearing weeds


Bed scrapping


Site D5

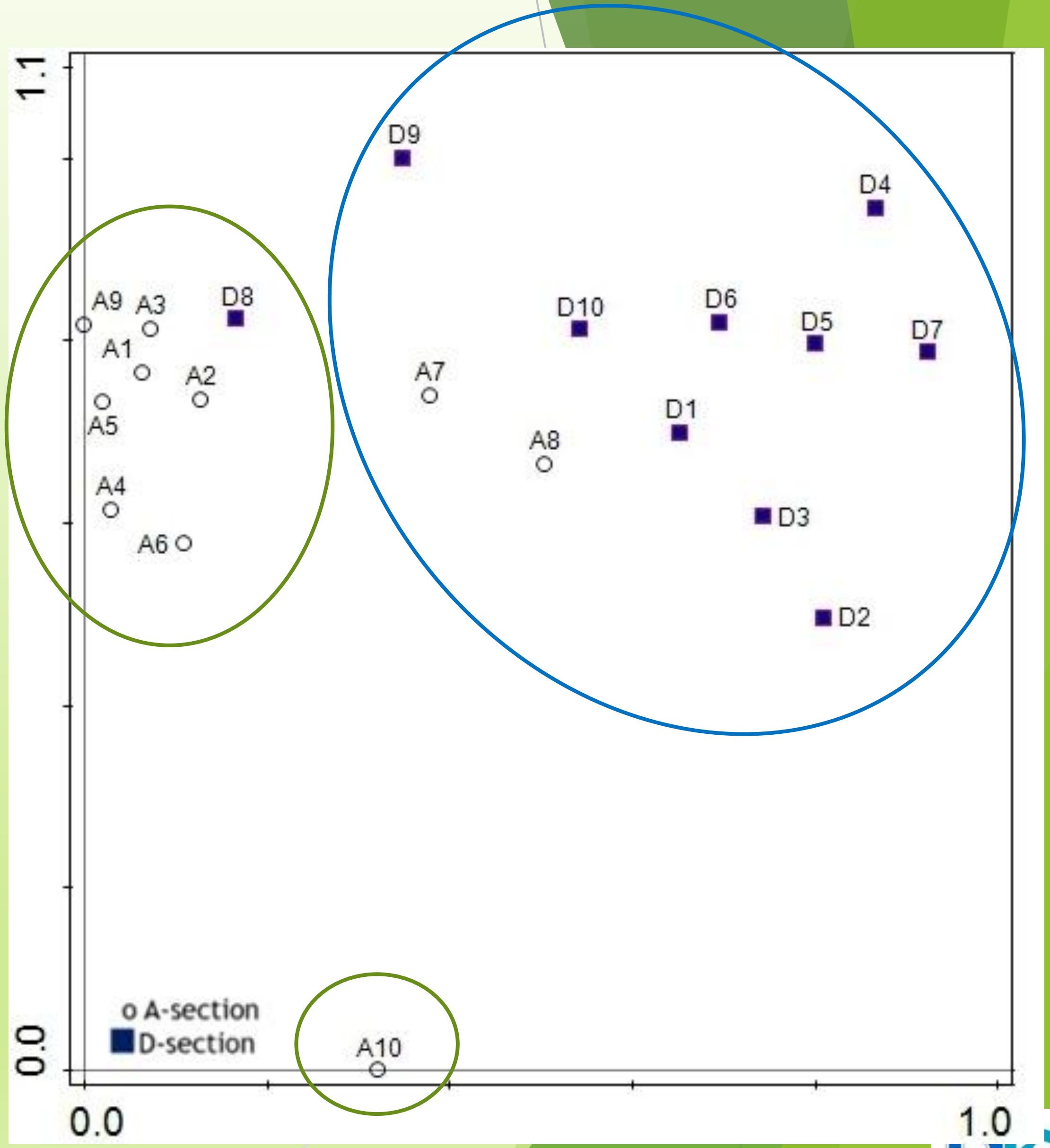

Site D2

Multivariate Analysis

DCA (Detrended Correspondence Analysis) Plot

- Using all data from ecological surveys in 2014-2015:
  - Hydraulic variables
  - Water quality variables
  - Biological variables

- General Observations
  - Distinction between A-sites and D-sites (with a few exceptions: A7, A8, D8, and A10).
  - D8 shares many similarity with natural stream sections.

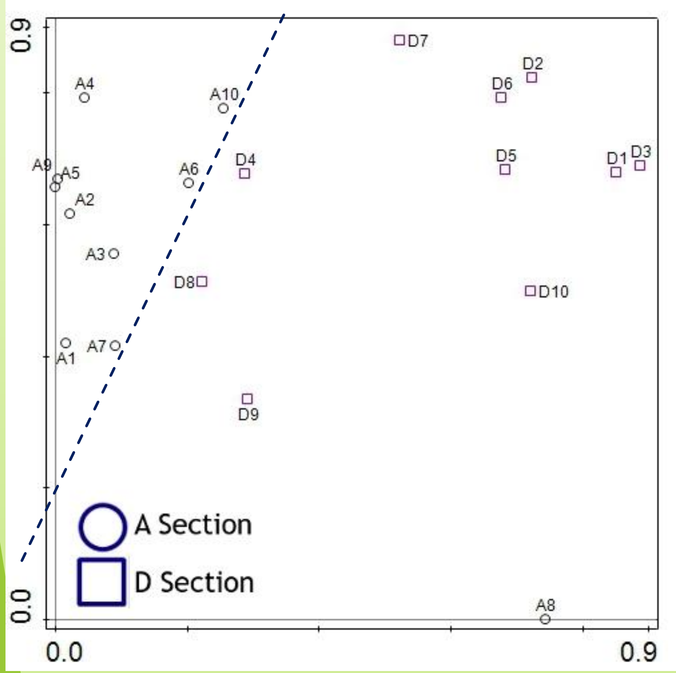


FORUM

Individual DCA plots:

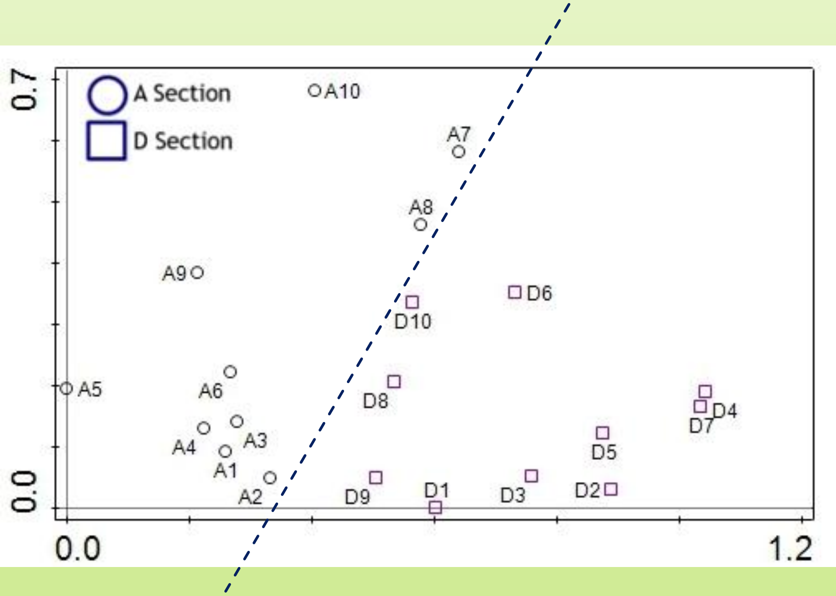
A-sites and D-sites can be differentiated in terms of their hydraulics and water quality, but not so clear in terms of biological variables.
(i.e. some of the D-type channel sections have rather high benthic richness and abundance)

Hydraulics Variables 2014-2015



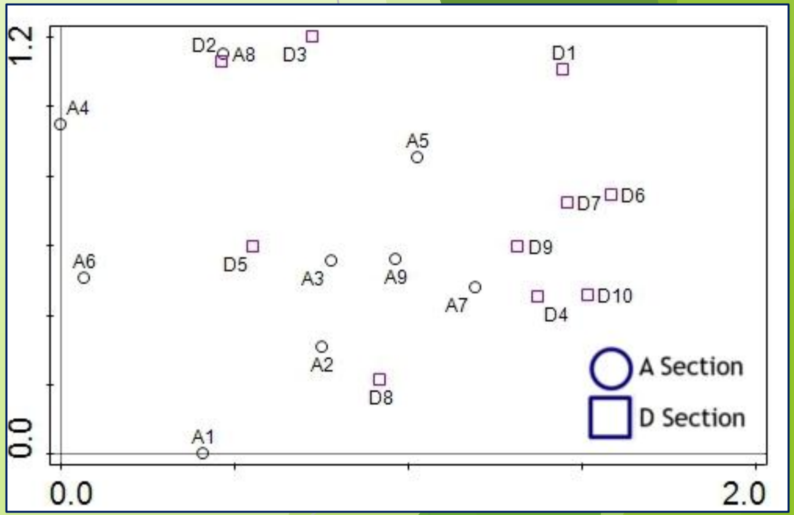
- Hydraulic variables: Velocity, SD of depth, SD of width and Froude number show statistically significant difference between A and D type of samples (t-test, P<0.05)

Water Quality Variables 2014-2015



- Water quality variables: Conductivity, TS, Nitrate, Nitrite, Ammonia, Sulphate show statistically significant difference between A and D type of samples (t-test, P<0.05)

Biological Variables 2014-2015



- Biological variables: DPS (diatom pollution sensitivity), GR (Gastropoda richness) do not show significant difference between A and D type of samples (t-test, P<0.05)

Bird Observation


Ardeola bacchus
(Chinese Pond Heron 池鷺)


Orthotomus sutorius
(Common Tailorbird 長尾縫葉鶯)


Copsychus saularis
(Oriental Magpie-Robin 鵲鴝)


Ardeola bacchus
(Chinese Pond Heron (Juvenile) 池鷺(幼鳥))


Egretta garzetta
(Little Egret 小白鷺)


Pica pica
(Common Magpie 喜鵲)


Spilopelia chinensis
(Spotted Dove 珠頸斑鳩)


Motacilla alba
(White Wagtail 白鶺鴒)


Acridotheres cristatellus
(Crested Myna 八哥)


Crested Myna community


Photos of night herons
夜鷺

Vegetation Observation

Benthic:

filamentous algae 絲狀藻 (Photo at D7)

Sphaerotilus natans (sewage fungus 球衣菌) (Photo at A8)

Floating:

Monochoria vaginalis (heartshape false pickerelweed 鴨舌草) *(Photo at A1)*

Lemna minor L. (Common Duckweed 浮萍) (Photo at A7)

Commelina diffusa Burm. f. (Climbing Dayflower節節草) (Photo at A5)

Riparian/River bank:

Colocasia esculenta (Taro 芋) *(Photo at A10)*

Grown along the concrete channel:

Cyperus difformis L. (Difformed Galingale 異型莎草) (Photo at

Rumex sp. (Goat-hoof 羊蹄) (Photo at D3)

Ludwigia erecta (L.) H.Hara (yerba de jicotea 美洲水丁香) (Photo near YL Bypass Floodway)

Odonata Observation


Anax immaculifrons
(Fiery Emperor 黃偉蜓)


Urothemis signata
(Scarlet Basker 赤斑曲鈎脈蜻)


Trithemis festiva
(Indigo Dropwing 慶褐蜻)


Brachydiplax chalybea flavovittata
(Blue Dasher 藍額疏脈蜻)


Orthetrum chrysis
(Red-faced Skimmer 華麗灰蜻)


Ictinogomphus pertinax
(Common Flangetail 霸王葉春蜓)


Neurothemis fulvia
(Russet Percher 網脈蜻)


Dragonfly laying eggs


Pantala flavescens
(Wandering Glider 黃蜻)


Trithemis aurora
(Crimson Dropwing 曉褐蜻)


Orthetrum glaucum
(Common Blue Skimmer 黑尾灰蜻)

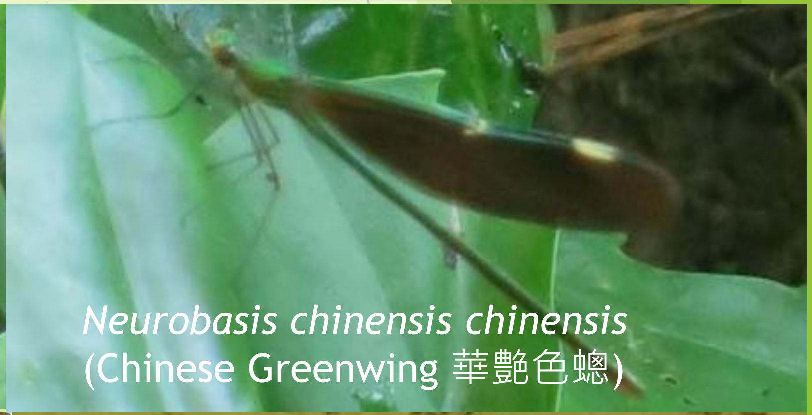
Odonata Observation


Matrona cyanoptera 白痣珈蟌
(Damselfly nymph)


Chlorocyphidae 鼻蟌科
(Damselfly nymph)


(dragonfly nymph)


Copera marginipes
(Yellow Featherlegs 黃狹扇蟌)


Neurobasis chinensis chinensis
(Chinese Greenwing 華艷色蟌)


Pseudagrion rubriceps rubriceps
(Orange-faced Sprite 丹頂斑蟌)


Rhinocypha perforata perforata
(Common Blue Jewel 三斑鼻蟌)


Chlorocyphidae
鼻蟌科*(Damselfly nymph)*

In-situ and Laboratory Experiments

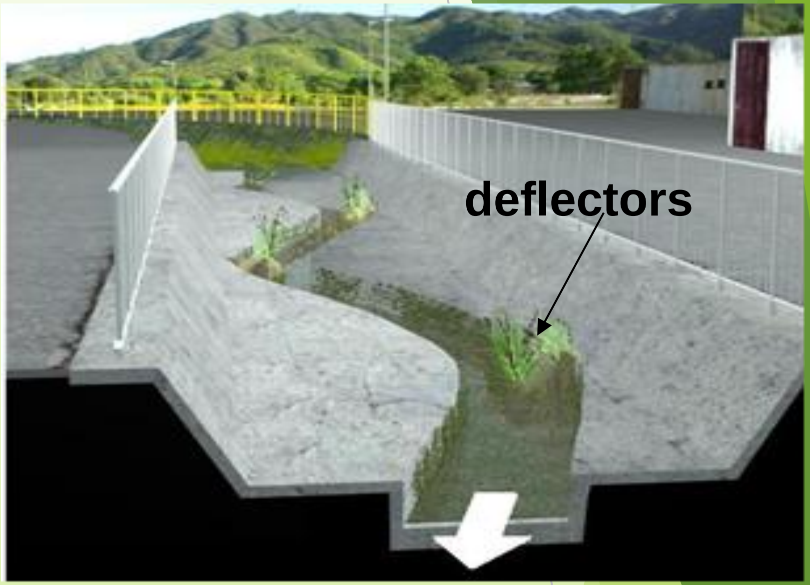
Proposed design

- Original
- Meander
- Sediment
- Deflector
- Vegetation

Modifications of Low-Flow Channels

In-situ experiments

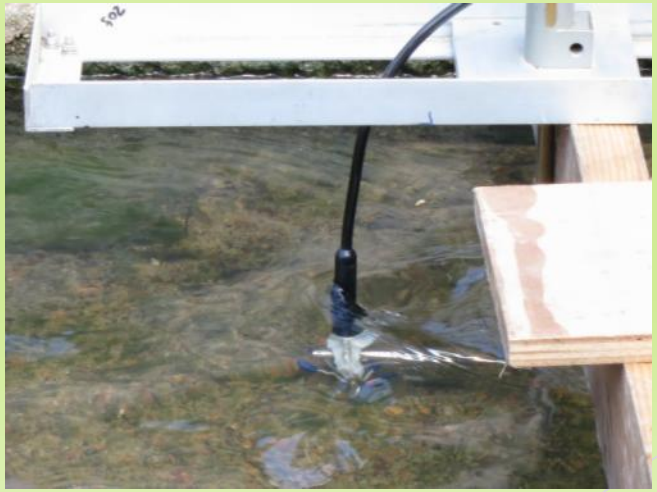
Locations proposed by DSD



In a channelized stream with natural bottom, placing instream structures such as current deflectors or low weirs at strategic locations will ensure the stream with enough energy and sediment transport load will scour out pools and create pool-end riffles.

In-situ Experiments

- In-situ experiment at site D9 (24-9-2015)



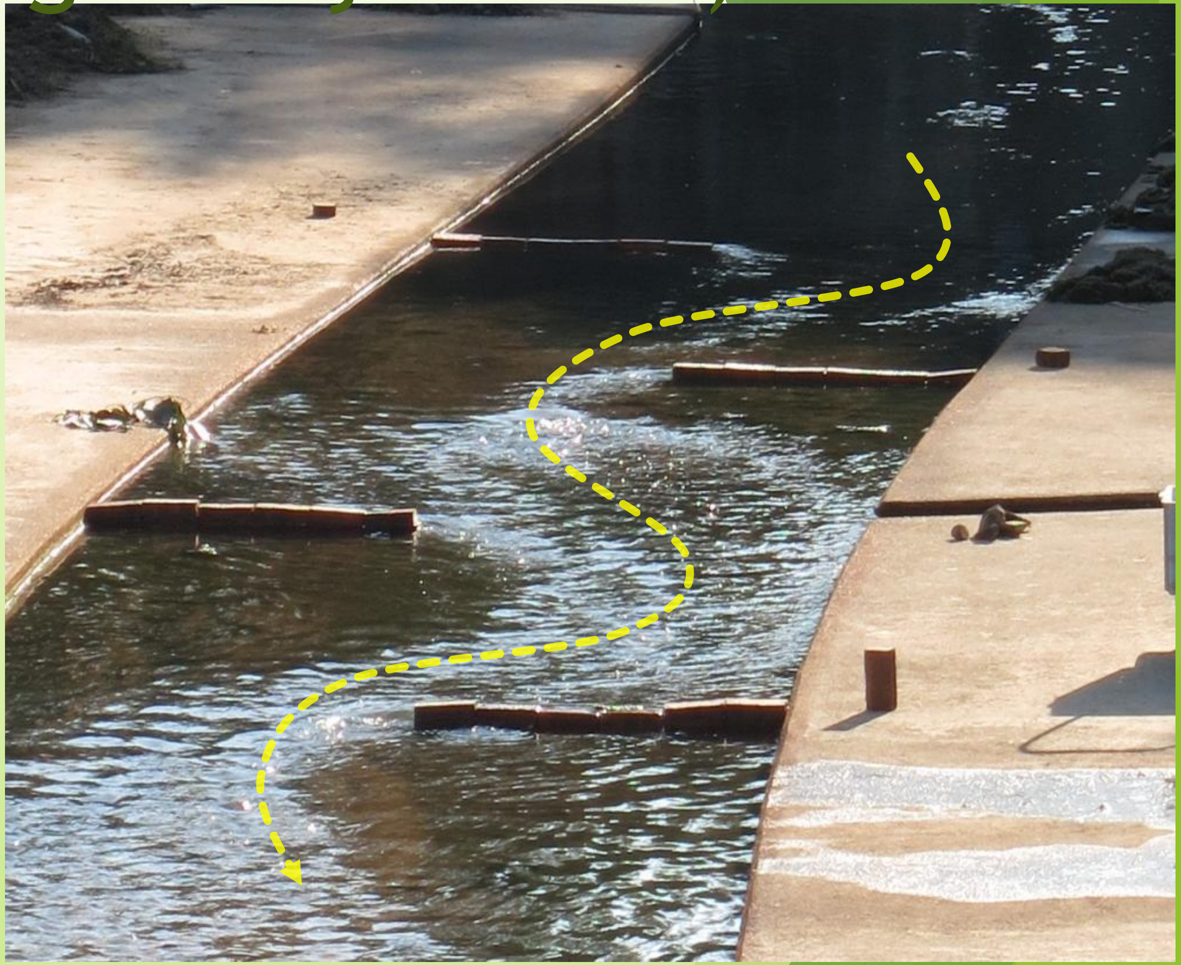
Little Egret

Tilapia spp.

Common Pond Snails

In-situ Experiments (heterogeneity effect)

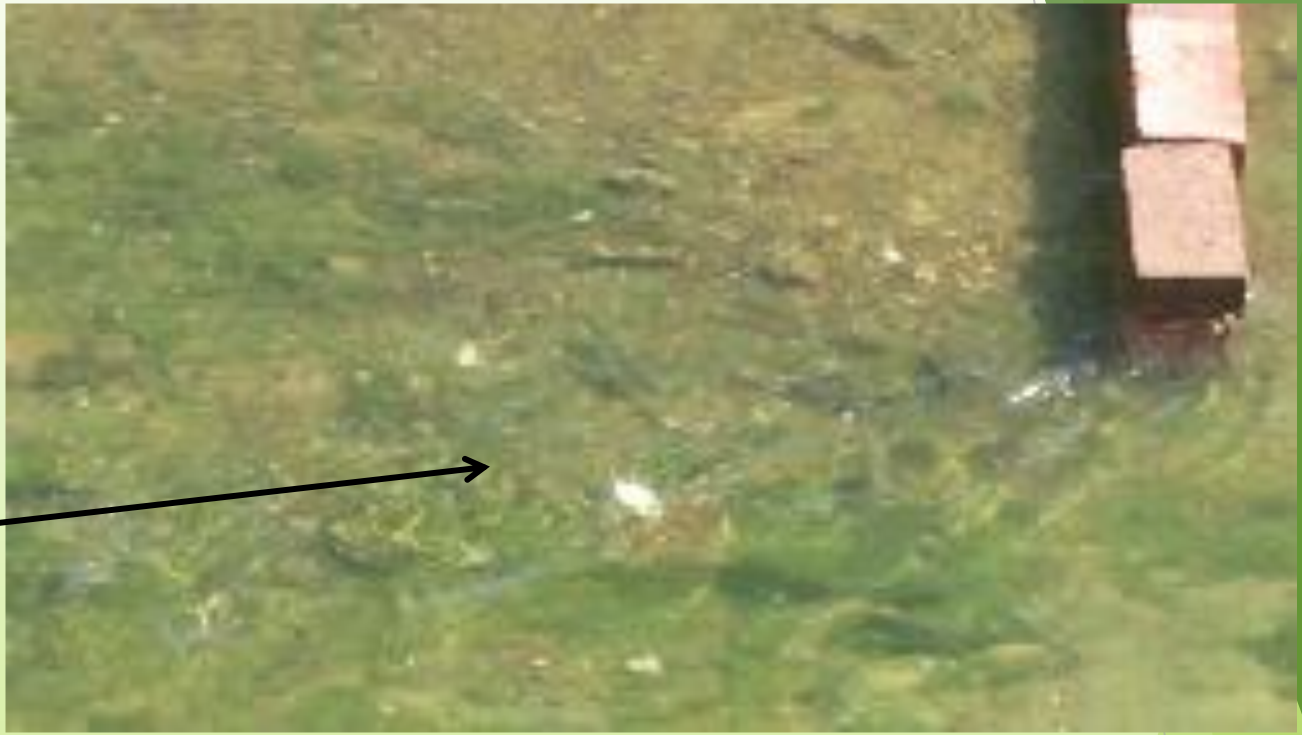
Without deflector



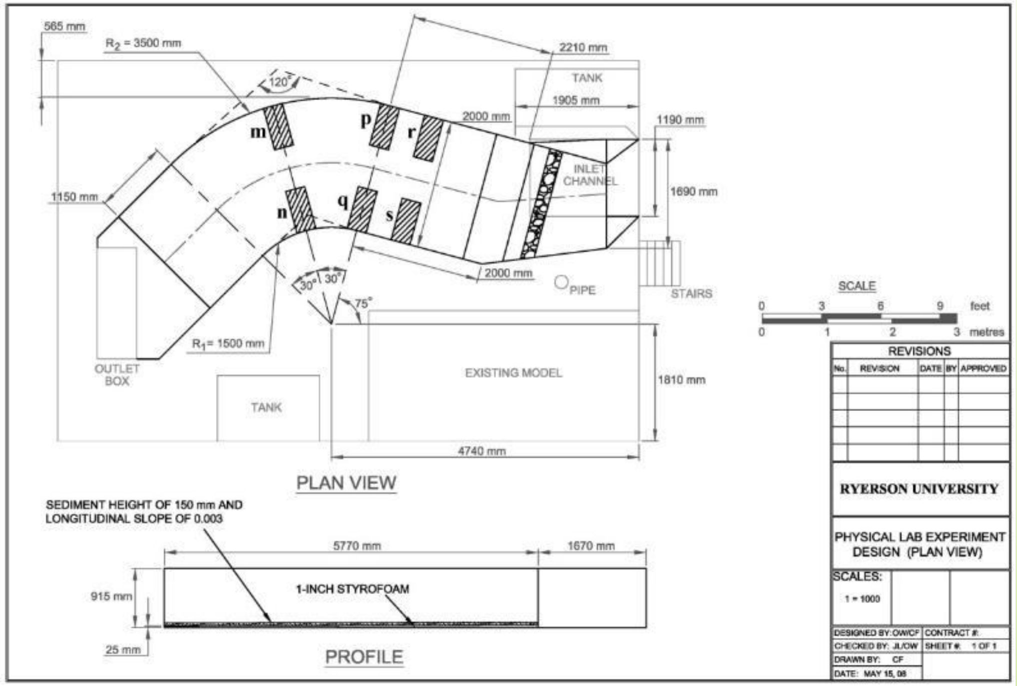
With deflectors

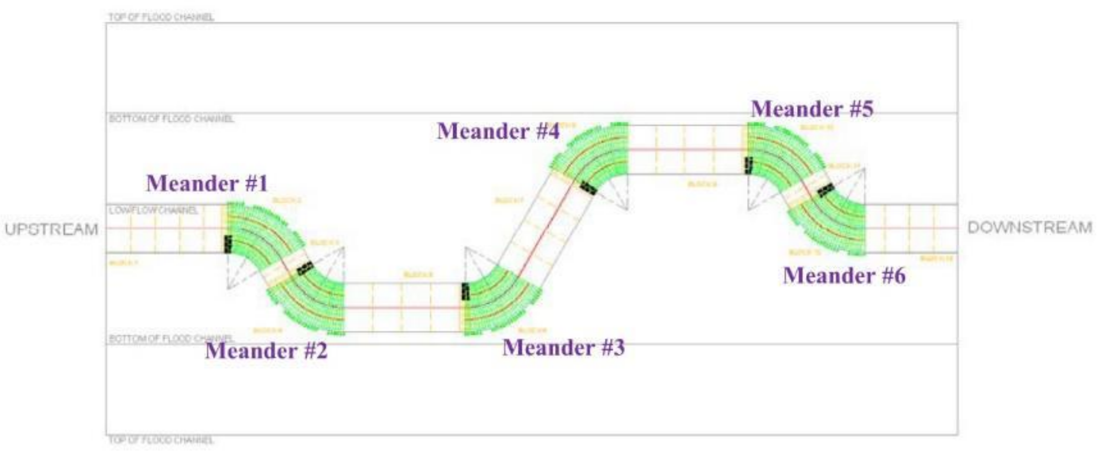
In-situ Experiments

- Deflectors as wildlife attraction
  - fish hiding behind deflectors and swimming upstream;
  - Snails attaching on deflectors (bricks).



Laboratory Experiments (with sediments/2m wide)





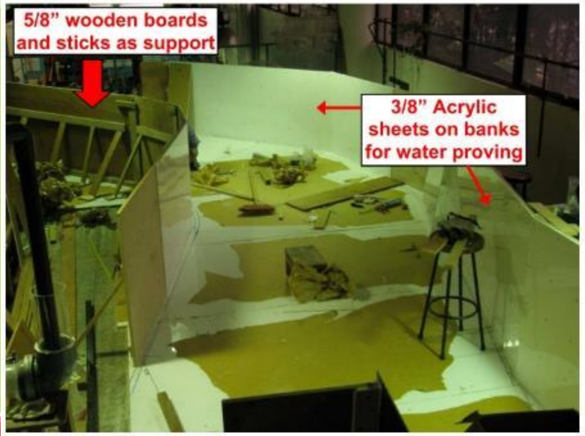


Figure 44: Construction process (1) of the physical model.

Figure 65: Sediment bed preparation.

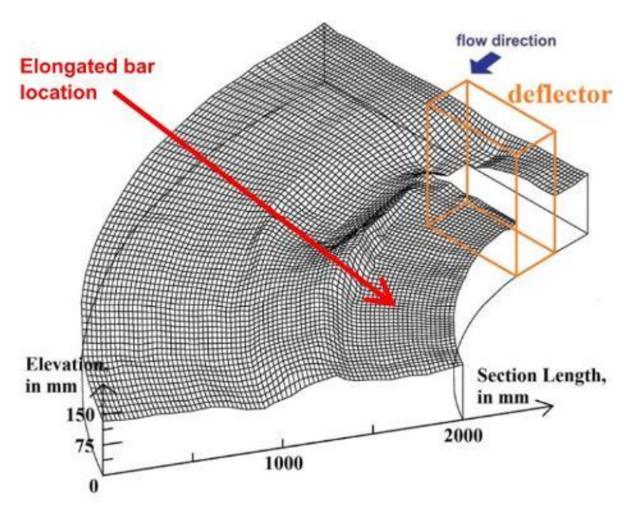
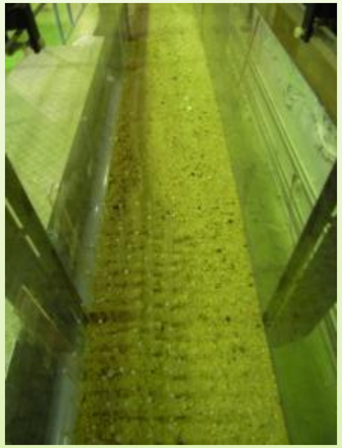
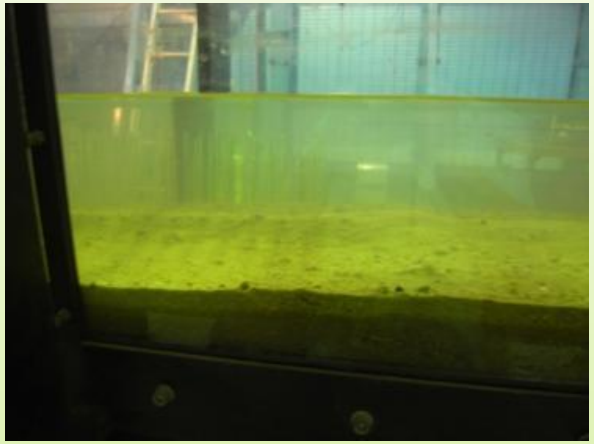
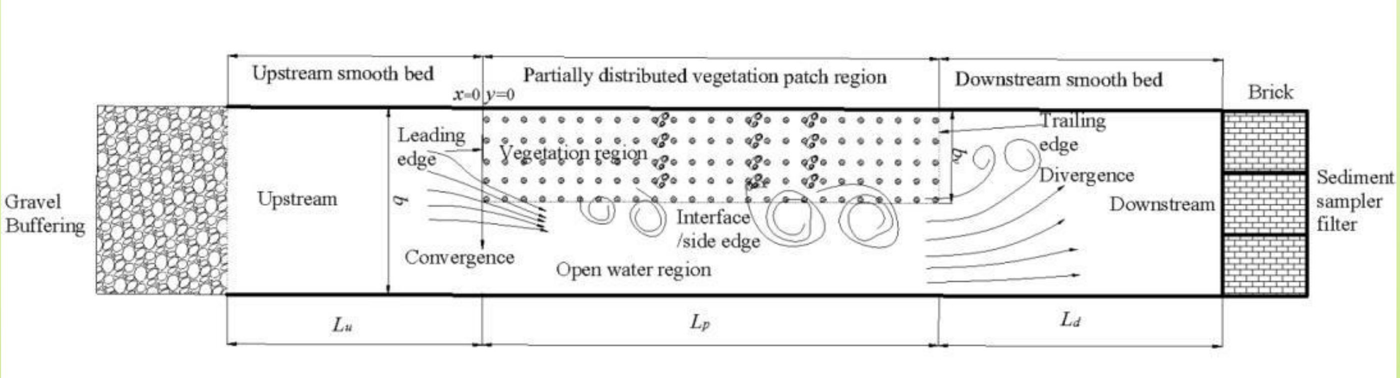


Figure 72: Bed profile for Experiment #B7 after 21-hour run.

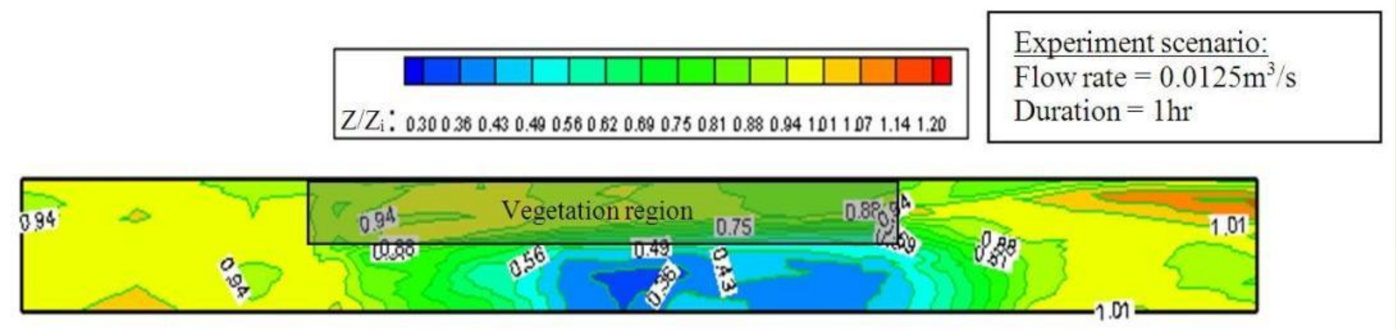
Laboratory Modeling Test (partially vegetated)



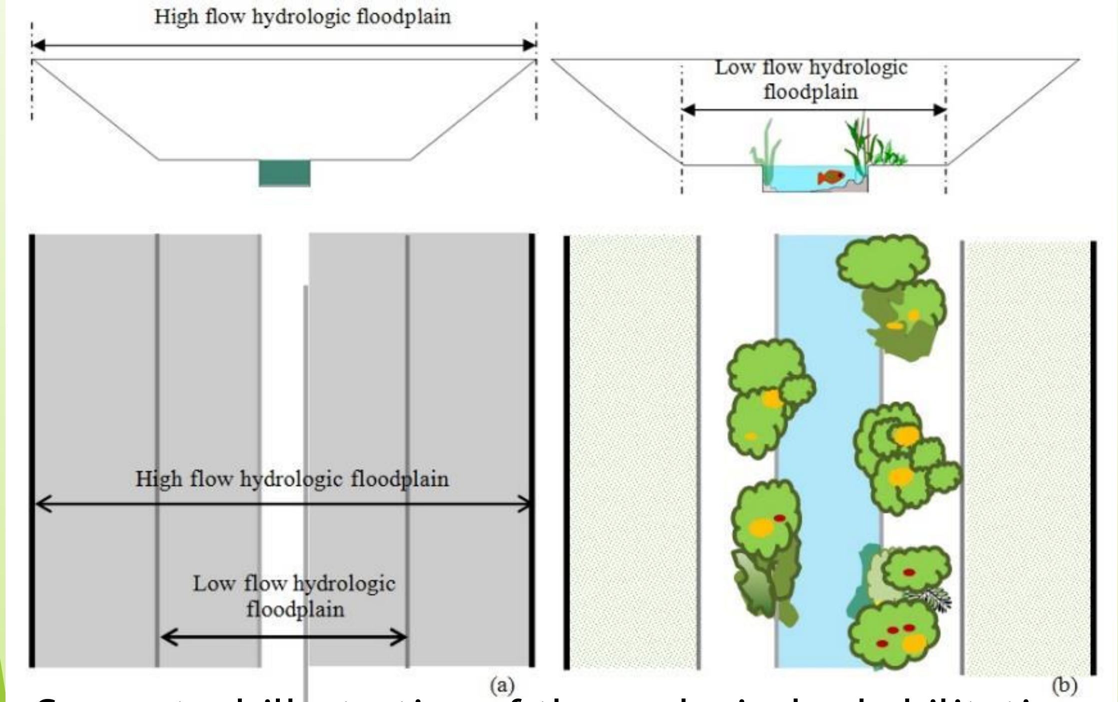




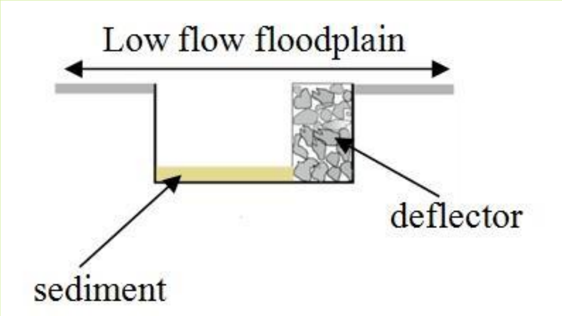
Photos and preliminary results from an on-going laboratory sediment transport study on open channel flow with a partially vegetated region



Ecohydraulics Laboratory – 10m open channel



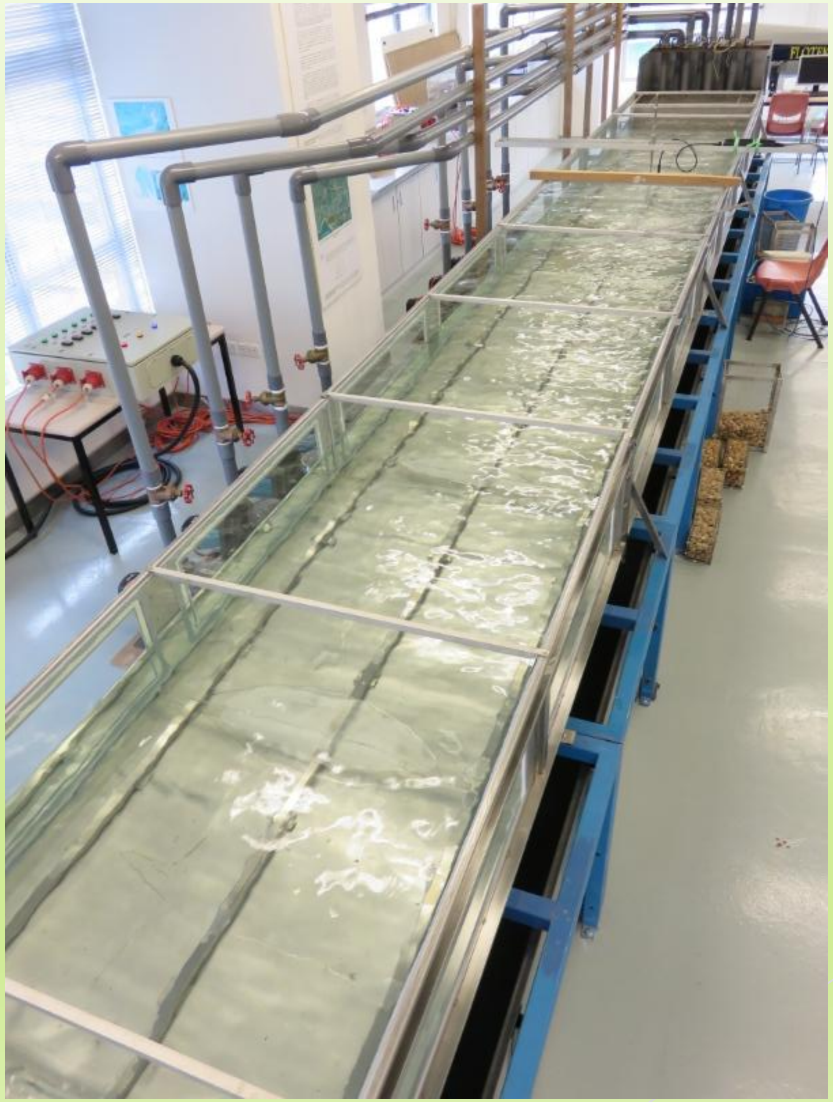
Conceptual illustration of the ecological rehabilitation of the flood channel, before (a) and after (b)



Laboratory physical modeling experiments

Summary of Deflector Experiment Design

Parameter	Experiment Design
Deflector Type	Gabion basket with pebbles; 40% void
Location of Deflector	- Single deflector - Paired (side-by-side) - Paired (alternate)
Channel Flow Scenario	Wet season: 20cm depth, 60L/s Dry season: 13cm depth, 30L/s (from field survey data)
Sediments	Unsorted sediment sample from site A1

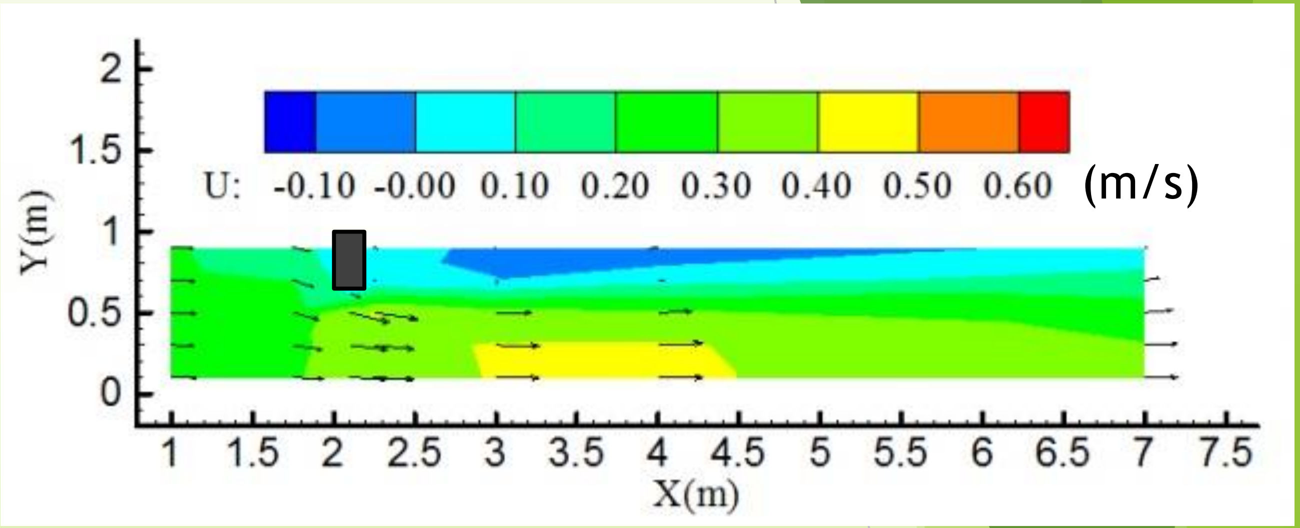


Preliminary Results

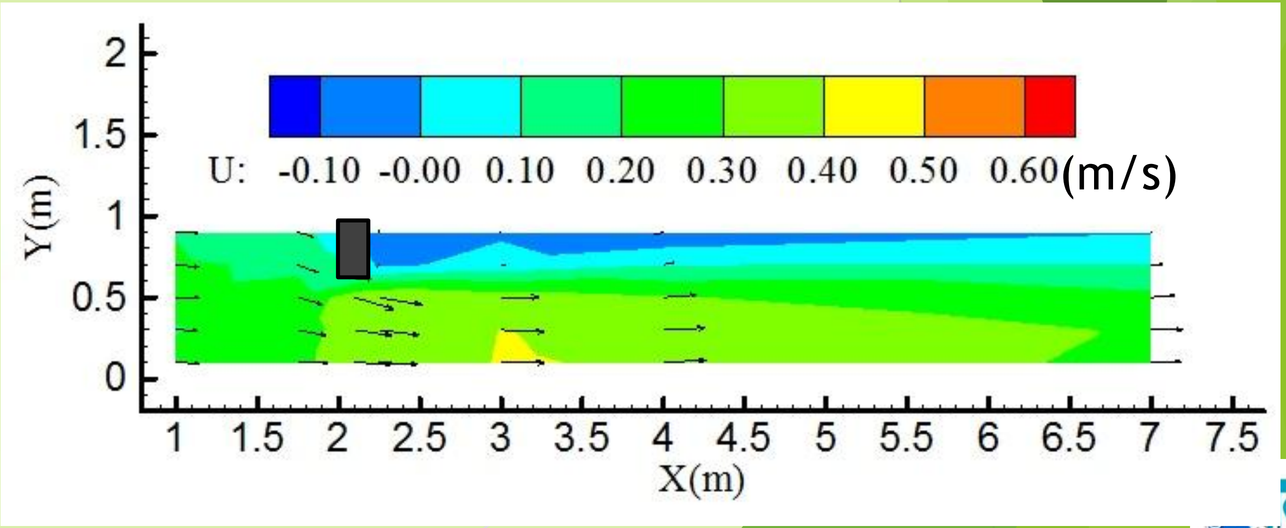
Single deflector
Dry season flow (0.030m^3/s, 0.13m water depth)

Under this scenario:

- Pebble deflector is effective (i.e. 40% void, width=30% channel width) in forming pool and riffle.
- Blocking effect observed behind deflector (backwater zone) but not in front of deflector.



Flow field at 50% water depth



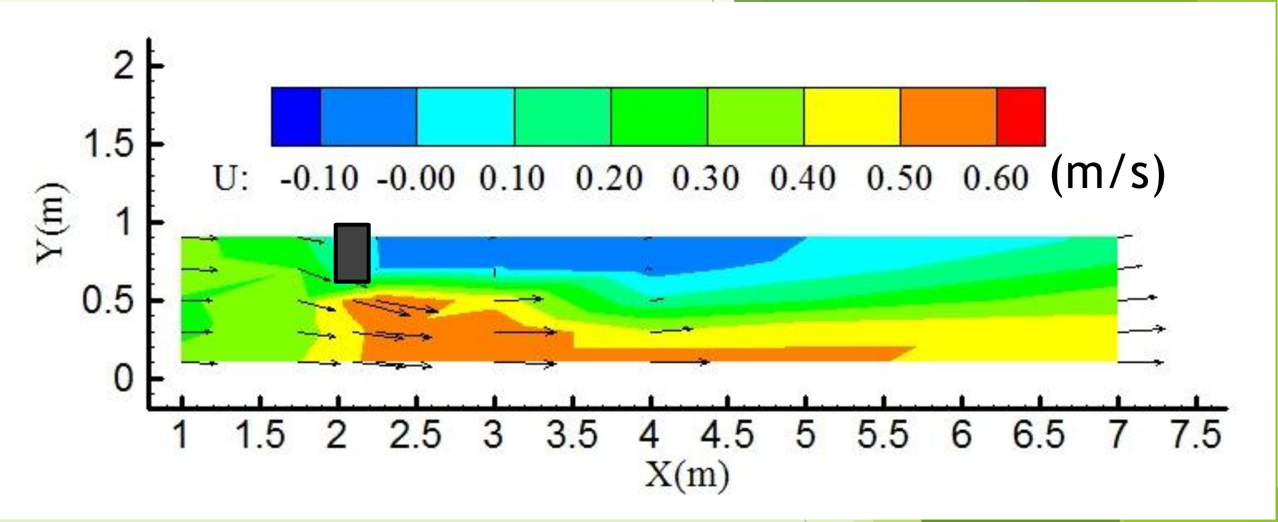
Flow field at 20% water depth

Preliminary Results

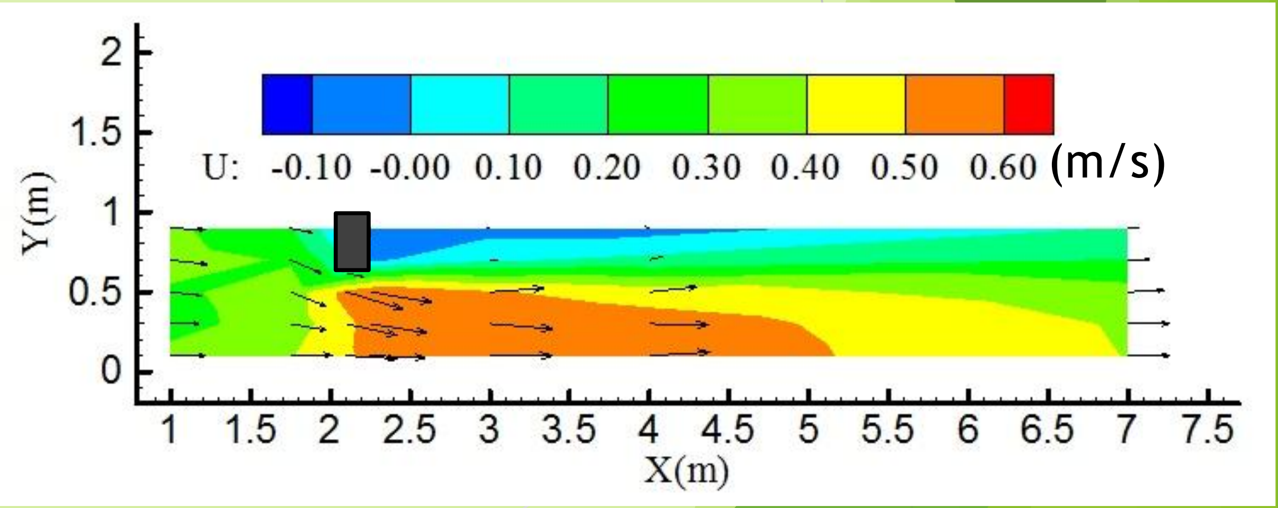
Single deflector
Wet season flow (0.060m^3/s, 0.2m water depth)

Under this scenario:

- Pebble deflector is effective (i.e. 40% void, width=30% channel width) in forming pool/riffle.
- Flow reversal zone is smaller than the one in dry season flow.
- Difference of flow magnitudes between deflector side and opposite side.



Flow field at 50% water depth



Flow field at 20% water depth

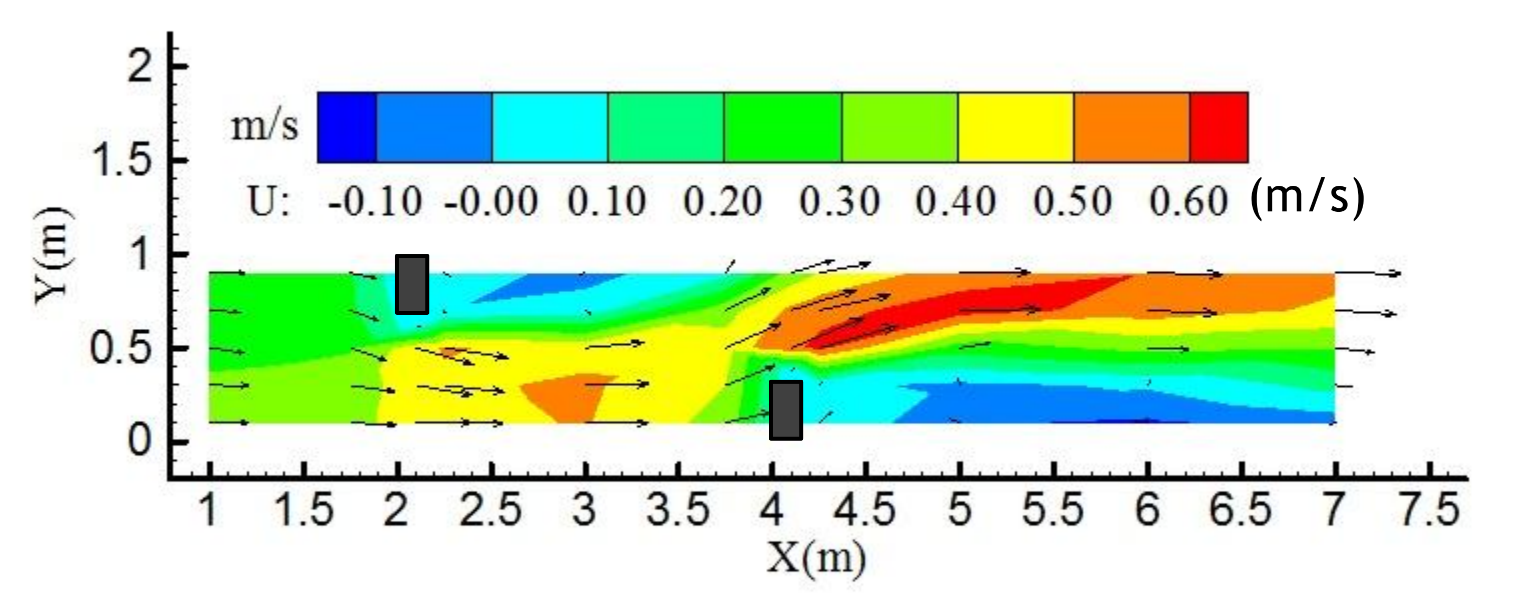
Preliminary Results

Double deflectors

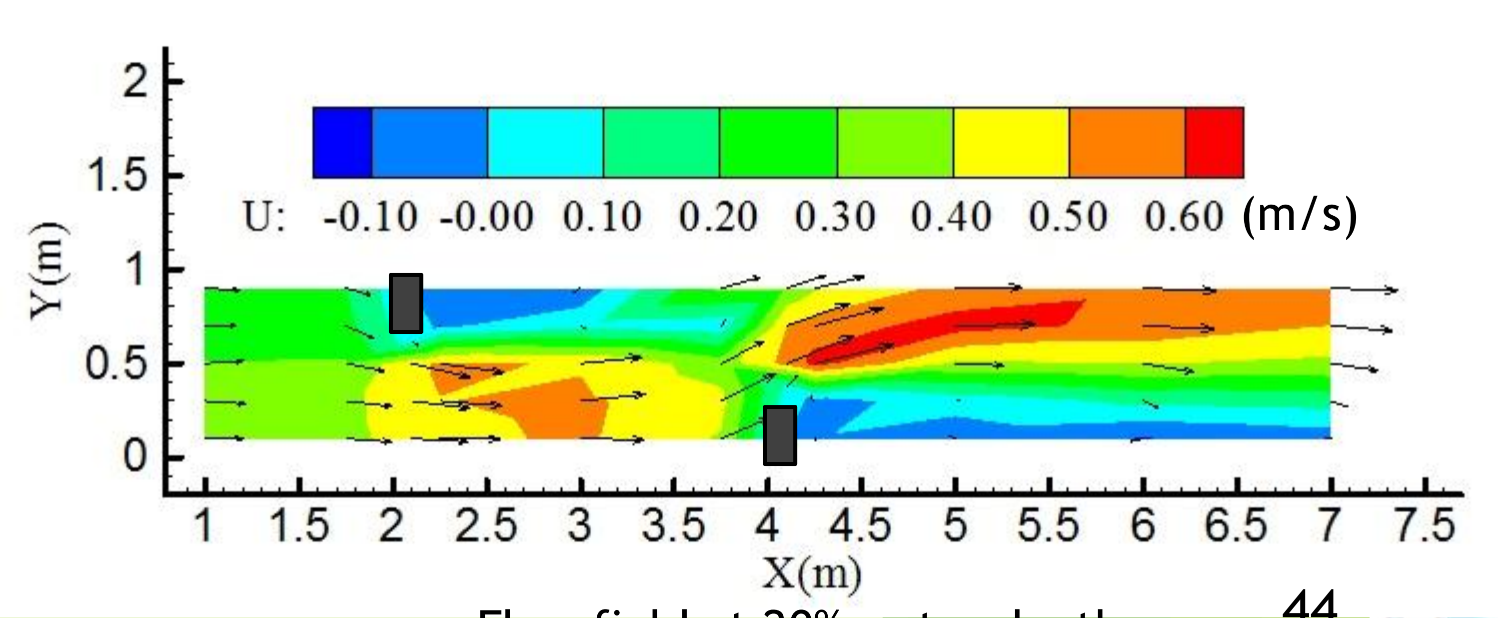
Wet season flow (0.060m³/s, 0.2m water depth)

Under this scenario:

- Pebble deflector is still effective in forming pools and riffles.
- Flow reversal zones appear after each deflector.
- Difference in flow magnitudes between the deflector side and opposite side.



Flow field at 70% water depth



Flow field at 20% water depth

FORUM

In-situ and Laboratory Experiments (on-going and up-coming)

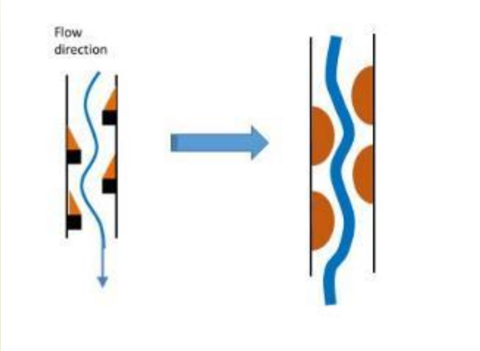
Stage I:
Open Channel Flow with Deflectors

Stage II:
Sediment Transport

Stage III:
Plant Colonization

Stage IV:
Fish Performance

Stage V:
Cyclic Rejuvenation Ability

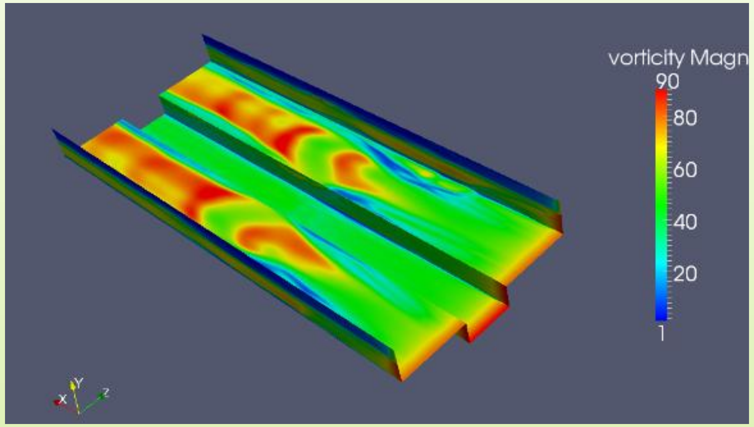


Sediment analysis

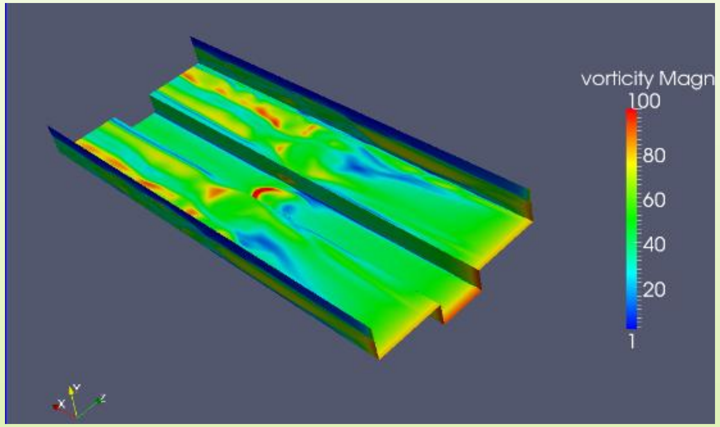
Washed sediment and dead plants after rainstorm

Tilapia nesting on sand (D8)

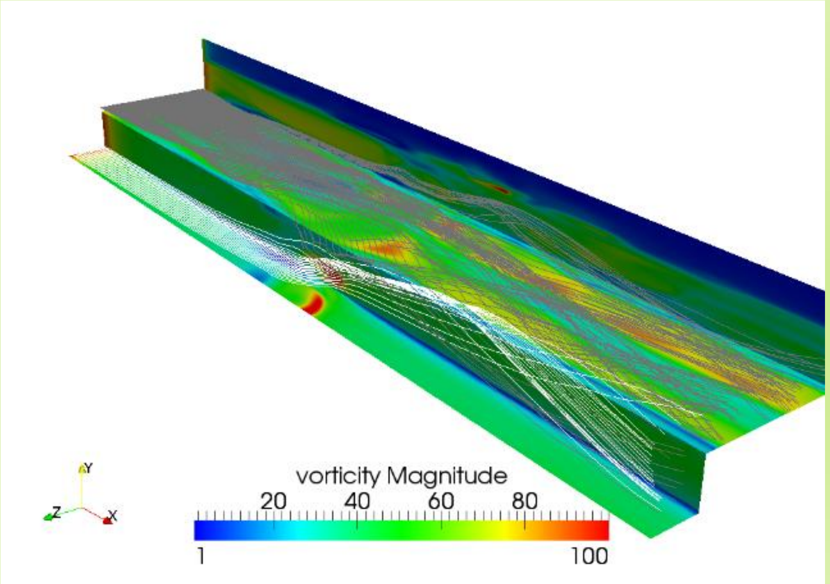
Numerical Modeling Test (preliminary)



(Coarse grid)



(Fine grid)



River bed evolution under the influence of gabions (deflectors) is a complex sediment transport phenomenon.
During high flow rates, vortices may occur around edges of the defectors generating air bubbles with high velocity which may be detrimental to habitats and aquatic life.
To accurately simulate these complex phenomenon numerically, interactions between the three dimensional turbulent flow field around the gabions and the mobile river bed as well as occasionally air entrainment have to be properly addressed in the numerical model.

Concluding Remarks

- Ecological assessments of natural stream bed sections and concreted channel sections under different level of water quality degradation have been conducted.
- Natural stream sections are not significantly better than concreted channel sections in terms of overall ecological quality.
- Concreted sections with better ecological quality usually have more diverse hydraulic features (pools and riffles, bed roughness, meanders, etc.) and/or connection to better water quality and sediment quality upstream.
- The present results are interesting as well as important, as the study clearly shows evidence that the instream structure heterogeneity is directly related to the ecological quality. This supports the original hypothesis in this project of using gabion deflectors and introducing sediments from the upstream natural sections.

Future Work

- Numerical Simulation and Flood Risk Assessment
- More In-situ Experiments
  - Vegetation Performance Tests
- Comparative study on other concrete channels and natural stream sections in Hong Kong (beyond Yuen Long)

Thank you!

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References

- Wai, O., Chen, Y. C., Lu, Q., and Li, Y. S. 1998.A Multi-Layer Finite Element Formulation for Suspended Sediment Transport in Tidal Flows. International Journal of Computational Fluid Dynamics, Gordon and Breach Science Pub., 9, 137-149.
- Asaeda, T., Gomes, P. I. A., and Takeda, E. 2010a. The spatial and temporal development of tree colonization in a midstream sediment bar and the governing mechanisms of tree mortality during flood. River Research and Applications, 26, 960-976.
- Nakamura, K., and Tockner, K., and Amano, K. 2006. River and wetland restoration: Lessons from Japan. Bioscience, 56, 419-429.
- Nilsson, C., Svedma.,M. 2002. Basic Principles and Ecological Consequences of Changing Water Regimes: Riparian Plant Communities. Environmental Management, 30, 468–480.
- Norris, R.H., and Thoms, M.C. 1999. What is river healthy? Fresh water biology, 41,197-209
- Gomes, P. I. A., and Asaeda, T. 2009a. Spatial and temporal heterogeneity of Eragrostiscurvula in the downstream flood meadow of a regulated river, and the implications for flood plain management. Annales de Limnologie- International Journal of Limnology, 45, 1-13.
- Leung, A. S., & Dudgeon, D. (2011). Scales of spatiotemporal variability in macroinvertebrate abundance and diversity in monsoonal streams: detecting environmental change. Freshwater Biology, 56(6), 1193-1208.
- Leung, A. S., Li, A. O., & Dudgeon, D. (2012). Scales of spatiotemporal variation in macroinvertebrate assemblage structure in monsoonal streams: the importance of season. Freshwater Biology, 57(1), 218-231.
- Dudgeon, D. (2003). Hillstreams. Agriculture Fisheries and Conservation Department, Government of Hong Kong SAR & Wan Li Book, Co. Ltd., Hong Kong: 133 pp.
- Hughes, R.M. 1995. Defining acceptable biological status by comparing with reference conditions. pp. 31-47 in Biological Assessment and Criteria. Lewis Press
- http://www.greenpower.org.hk/river/eng/location_sp.asp
- http://ordination.okstate.edu/overview.htm
- http://whiteclay.org/adopt-a-stream/
- http://news.sciencemag.org/2004/09/diatoms-deciphered
- http://westerndiatoms.colorado.edu/taxa/genus/Gomphonema
- http://onlinelibrary.wiley.com/doi/10.1002/iroh.200410806/pdf
- http://university.uog.edu/botany/lobban/periphyton.pdf
- http://www.equatica.com.au/pdf/Knights%20et%20al%202012%20-%20EI%20and%20stream%20health.pdf
- http://www.schweizerbart.de/papers/algol_stud/detail/111/74693/Benthic_diatom_flora_in_a_small_Hungarian_tributar
- http://au.riversinfo.org/library/contents.php?subdir=nrhp/diatoms_indicators/&send=book&view=print#ch3
- http://www4.uwsp.edu/geo/faculty/lemke/geomorphology/lectures/02_stream_flow.html
- http://stream.fs.fed.us/news/streamnt/jan96/jan96a3.htm
- Wohl. E., Lane, S.N., and Wilcox, A.C., 2015 (a). The science and practice of river restoration. Water Resources Research, 51, 5974-5997.
- Wohl, E., Bledsoe, B.P., Jacobson R.B., Poff, N.L., Rathburn S.L., Walters D.M., and Wilcox A.C., 2015 (b). The Natural Sediment Regime in Rivers: Broadening the Foundation for Ecosystem Management. BioScience, 65(4): 358-371.
- AFCD HK, 2015. A photographic guide to aquatic plants of Hong Kong. ISBN: 978-988-12021-8-5
- AFCD HK, 2004. Field Guide to the Freshwater Fish of Hong Kong. ISBN: 988-201-638-3.
- Wilson K.D.P. and AFCD HK, 2003. Field Guide to the Dragonflies of Hong Kong. ISBN: 988-201-614-6.
- http://cmp-openstandards.org/wp-content/uploads/2014/03/CMP-OS-V3-0-Final.pdf
- http://blogs.gsd.harvard.edu/loeb-fellows/files/2012/11/AD-Ref_Singapore_Bishan-Park.pdf
- http://wwf.panda.org/?204454/Seoul-Cheonggyecheon-river

Restoration Concepts

“The science and practice of river restoration” (Wohl et al. 2015a)

- Common restoration challenges
  - Reach-scale urban restoration/rehabilitation is not effective in mitigating the ecological degradation
  - Limited monitoring and evaluation of restoration achievements, quantitatively and objectively
  - Improvement in river function (e.g. water quality and biological communities) is usually not significant
  - Challenge of incorporating non-scientific community into river restoration planning and practice
- Examples of good restoration aims
  - To adapt to important controlling factors, such as position in the watershed, surface-subsurface exchanges, flow regime, and nitrogen concentration
  - To achieve the least degraded and most **ecologically dynamic** state possible, given the regional context
  - Restoration as “returning to a sustainable state by understanding how the river works and how it was impacted”, as oppose to “restoring the river channel’s structure and form in the past” which is usually not feasible or desirable