Multi-function Green Municipal Wastewater Treatment Facility with Constructed Wetland: A Demonstration in Langgang, Shenzhen

Prof. Nora F.Y. Tam
Department of Biology and Chemistry,
City University of Hong Kong
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Aims

- Develop a highly efficient, multi-functional, green, and vertical municipal wastewater treatment system to recycle water and provide landscaping
- Integrate physical, chemical and biological treatment technologies to remove and recycle heavy metals, and degrade persistent organic pollutants (POPs) in municipal wastewater

Project Team

Shenzhen Research Institute of Xiamen University (SZRIXU)

Shenzhen Entry-Exit Inspection and Quarantine Bureau (SZIQB)

Funded by ITF, Hong Kong and Shenzhen Hong Kong Innovation Circle, Shenzhen
June 2009 – October 2011

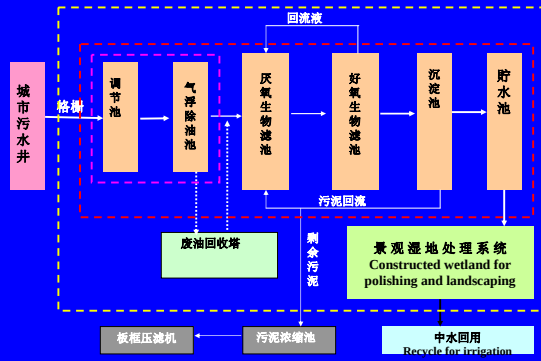
Why this Project?

- Geographically and economically close connections between HK and Shenzhen
- Threat of water contamination in Shenzhen to HK
- Drawbacks of conventional municipal wastewater treatment plants: Costly, large occupied area, treatment of single-type pollutant
- An integrated, small occupied area, cost-effective, environmentally sound, versatile wastewater treatment system in great demand

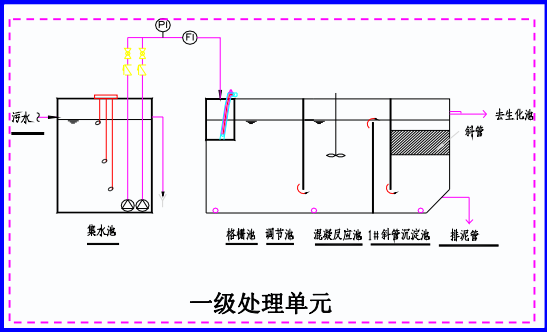
Collaborations

- HK: constructed wetland
  - tertiary processes to polish biologically treated effluent and serves as "green element" for landscaping, aesthetic and leisure purposes
  - secondary process to remove nutrients and toxic pollutants
- Xiamen: Integrate physical, chemical and biological treatment technologies to remove BOD, nutrients and heavy metals
- Shenzhen: water analysis and monitoring treatment efficiency of each process
- HK+Xiamen+Shenzhen: demonstration site in Longgang

Key treatment processes

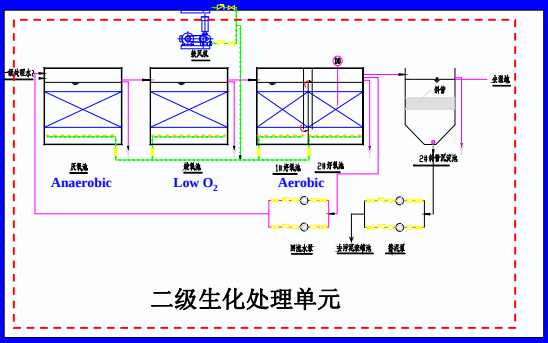


Primary treatment facility (一级处理单元)



一级处理单元

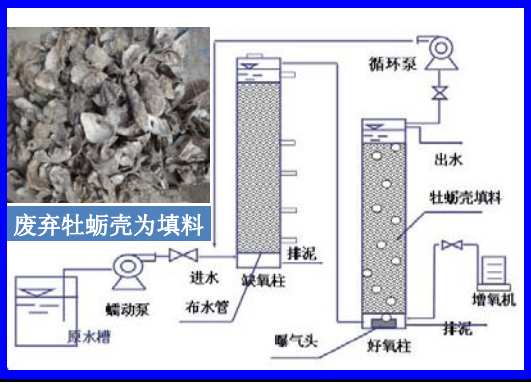
Secondary biological treatment (二级生化处理单元)



二级生化处理单元

Oyster Shells as Biofilters (袋装贝壳填料)

Oyster shells as biofilter 牡蛎壳填料污水处理工艺流程



Aerobic tank 好氧池的曝气情景

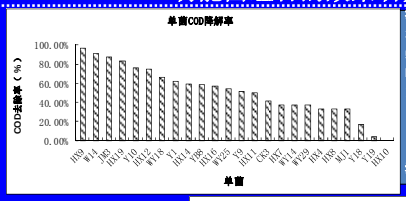
Secondary process: Oyster Biofilters

- Rough surface of oyster (waste from aquaculture) as the substrate for microorganisms to produce effective biofilms
- $CaCO_3$, main composition of oyster, acts as alkaline buffer for nitrification
- $CaCO_3$ converts to Ca^{2+} ions in removing COD, which then react with PO_4^{3-} ions and remove P
- Alternating anaerobic-aerobic reactors help reduce COD and oxygen consumption in N and P removal

Effective microbial consortium for pollutant removal

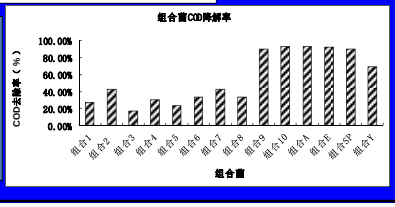
- Isolate, identify and culture a number of active and effective microbial consortia for removing specific pollutants such as COD and PAH from mangrove sediment and activated sludge
- Test the best combinations of different isolates and consortia for bioaugmentation
- Apply to wastewater treatment system, enhance formation of biofilms

Effectiveness of different isolates and consortia
功能菌组合的效果研究



测定条件：
培养基（人工废水）：
蜂蜜１０００mg/L,
KH２ＰＯ４ 44mg/L,
ＭｇＳＯ４ 75 mg/L,
ＮａＣｌ 50 mg/L,
$(NH_4)_2SO_4$ ７４０mg/L
１５０ｒｐｍ ２８℃ ３ｄ
测定方法：重铬酸钾法

组合１～１０：取去除率最高的前五株菌两两组合
组合Ａ：去除率最高的前五株菌组合
组合Ｙ：芽孢杆菌组合
组合ＳＰ：各个属中降解率最高菌的组合
组合Ｅ：真菌组合



Constructed Wetlands

- Technology designed to mimic processes found in natural wetland ecosystems but can control parameters like
  - Plant species
  - Substrate or soil properties
  - Hydrology and flow pattern
  - Pollution loading
  - Retention time

Benefits of Constructed Wetland

- No sludge disposal problem
- Simple, flexible and robust
- Easy to operate
- Cost-effective
- Ultimate solution
- Natural and environmental friendly
  - Restore wetland habitat
  - Enhance aesthetic values and biodiversity
  - Reuse as re-circulated water and maintain sustainable use of water resource

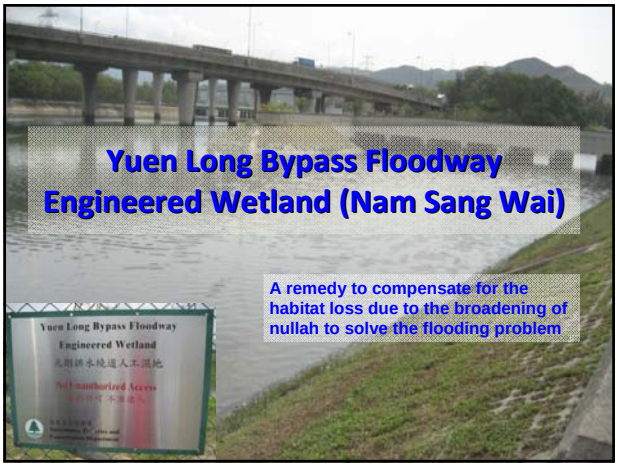
Wetland Treatment Mechanisms

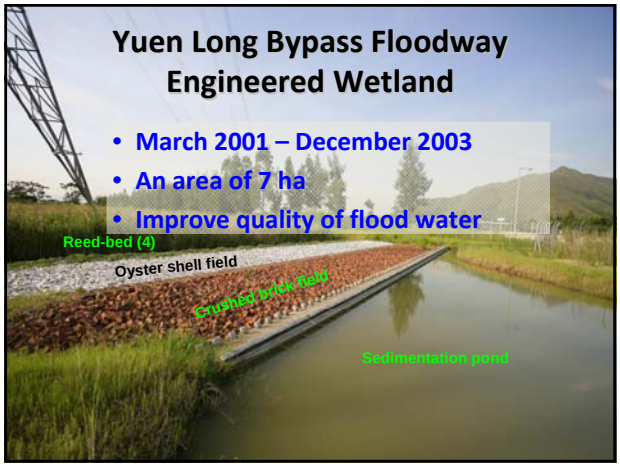
- Plant uptake and assimilation
- Transformation and degradation by micro-organisms (e.g. nitrification and denitrification):
  - Rhizosphere 根際
  - Soil particles (bio-films)
- Soil immobilization (e.g. binding of P by Al, Fe, Ca-oxides, hydroxides and organic matter):
  - Adsorption and sorption
  - Oxidation and reduction
  - Ion precipitation and exchange

Soil-plant-microbe in wastewater purification
Species-specific

Constructed Wetland Plants

- **Most CW for sewage treatment use freshwater plants:**
  - ***Typha* (cattails)香蒲**
  - ***Canna* 美人蕉**
  - ***Acorus* 菖蒲**
  - ***Scripus* (bulrush)藨草**
  - ***Cyperus*莎草**
  - ***Iris* 鸢尾**
  - ***Eichhornia* (water hyacinths水浮蓮)**
  - ***Phragmites* (common reeds 蘆葦)**
  - **Others**





Summary of Constructed Wetlands for Wastewater Polishing in Hong Kong

Project Name	Development purpose	Other use(s)	Dominant Vegetation	Area (ha)
Hong Kong Wetland Park	Urban development	Education, sightseeing and conservation	*Phragmites*	~1
Yuen Long Bypass Floodway	Drainage	Flood control	*Phragmites*	~7
Lok Ma Chau Spur Line	Transport	Conservation	*Phragmites*	~5

Only *Phragmites* (蘆葦) is used in constructed wetlands for wastewater treatment in Hong Kong and no mangrove species has been attempted

Modified from Lau (2004)

Problems with commonly used wetland plants

- Herbaceous plants
- Strongly recommend for annual harvests
- Restrict to fresh wastewater as plants would die off rapidly under chronic salt stress
- Often design as a tertiary treatment unit for water polishing

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How to solve the problems of common wetland plants?

- Use plants do not require routine harvesting, e.g. perennial woody wetland plants
- Wetland plants can tolerate salinity and pollutants
- Mangroves: common in our coastal areas and robust

What Are Mangroves?

- Trees and shrubs that grow in saline coastal habitats in the tropics and subtropics
- Developed physiological adaptations to overcome the problems of anoxia, high salinity and frequent tidal inundation
- Significant ecological and economic functions, e.g., protection of coastal area from erosion; breeding ground for young organisms; migration sites for birds and wildlife

Great potential in constructed wetlands for wastewater treatment

Constructed mangrove wetland treatment belt in Shenzhen

Close-up showing vigorous plant growth due to wastewater

Constructed Non-mangrove Wetlands in China

Table 1. Performance of constructed wetlands in China

Parameter	Influent in mg L^{-1} (± SD)	Effluent in mg L^{-1} (± SD)	Average removal rate (%)	Effluent standards (mg L^{-1}) of China (SEPA 2007) GB3838-2002 Class III	GB18918-2002 Class 1B	Number in dataset
NH_4^+-N	14.6 (12.5)	5.9 (5.4)	59.8	1	8	31
NO_3^--N	2.1 (0.8)	1.8 (0.8)	14.1	nd	nd	99
TN	24.1 (21.4)	13.4 (15.8)	44.3	1	20	149
TP	2.9 (1.6)	1.1 (1.0)	62.1	0.2	1	140
BOD_5	113 (109.7)	20.6 (26.1)	81.8	4	20	168
COD	234.7 (236.8)	62.5 (67.8)	73.4	20	60	187

Notes: nd = no data, since NO_3^--N is not set as a pollutant parameter in Chinese effluent standards. GB3838-2002 are the environmental quality standards for surface water, while Class III applies mainly to [illegible] and GB18918-2002 are the discharge standards of pollutants in municipal wastewater treatment plants as reusable water in China.

BOD and COD easier to be removed

(Liu et al., 2008)

Constructed Non-mangrove Wetlands World-wide

Vegetation *	DOC	NH_3^+	TKN	PO_4^{3-}	TP	References
Lg	68.9	NR**	NR	NR	NR	Ran et al. 2004
Pm	43	55.1	NR	36.9	NR	Okurut et al. 1999
Sl	74	90	87	99	95	Soto et al. 1999
Cp	63.3	39	NR	16.4	36.9	Okurut et al. 1999
Pm & Tl	58.5	24.2	NR	NR	NR	Kaseva 2003
Tl & Sa	NR	50	37	82	90	Cameron et al. 2003
Average	61.5	51.7	62.0	58.6	74.0	

* Lg, *Lemna gibba*, Pm, *Phragmites mauritianus*, Tl, *Typha latifolia*, Sl, *Scirpus lacustris* Sa, *Scirpus acutis*, Cp, *Cyperus papyrus*
**NR, Not reported

Removal efficiencies similar to those in China practice

Average effluent conc (mg/L） and removal % in 4-year treatment in Futian Field Trial

Species	COD	BOD_5	TN	NH_3-N	TP	SP
Influent	119.03	53.02	16.17	13.53	1.61	1.26
S. caseolaris	43.35	13.38	8.56	6.87	0.65	0.45
	64.9%	75.5%	53.6%	52.6%	65.0%	69.2%
A. corniculatum	37.75	13.61	7.98	6.00	0.45	0.32
	67.8%	74.1%	55.1%	58.4%	74.5%	76.9%
K. candel	41.98	13.75	8.25	7.27	0.64	0.47
	62.8%	73.8%	50.0%	45.2%	62.2%	64.8%

Percentages of effluent samples complied with the discharge standards set by the Chinese Government (Environment Bureau of the State, 1997)

Parameters	Mangrove species	Mean value and range (in bracket) in effluent	The discharge standard	Percentage of samples meeting the discharge standard
COD (mg L^{-1})	*S. caseolaris*	25.31 (3.03–39.10)	60	100
	K. candel	37. 26 (4.05–81.12)		71.43
	A. corniculatum	37.57 (4.20–96.13)		85.71
BOD_5 (mg L^{-1})	*S. caseolaris*	6.28 (0.33–13.24)	20	100
	K. candel	12.68 (2.50–34.10)		85.71
	A. corniculatum	7.03 (0.61–13.24)		85.71
TN (mg L^{-1})	*S. caseolaris*	8.27 (0.47–17.50)	NA	NA
	K. candel	9.13 (1.43–15.70)		NA
	A. corniculatum	9.55 (2.40–18.98)		NA
NH_3-N (mg L^{-1})	*S. caseolaris*	6.28 (0.33–13.24)	15	100
	K. candel	8.36 (2.62–15.13)		85.71
	A. corniculatum	7.03 (0.61–13.24)		100
TP (mg L^{-1})	*S. caseolaris*	0.65 (0.00–1.37)	0.5	57.14
	K. candel	0.84 (0.27–2.08)		42.86
	A. corniculatum	0.53 (0.13–1.04)		74.43
TC (cfu 100 mL^{-1})	*S. caseolaris*	1.5×10^4 (200–8.4×10^4)	NA	NA
	K. candel	1.9×10^4 (300–6.0×10^4)		NA
	A. corniculatum	5.4×10^3 (40–1.0×10^4)		NA
FC (cfu 100 mL^{-1})	*S. caseolaris*	1.1×10^3 (90–4.0×10^3)	100	28.57
	K. candel	1.9×10^3 (200–5.0×10^3)		0
	A. corniculatum	1.3×10^3 (5–6.0×10^3)		14.29

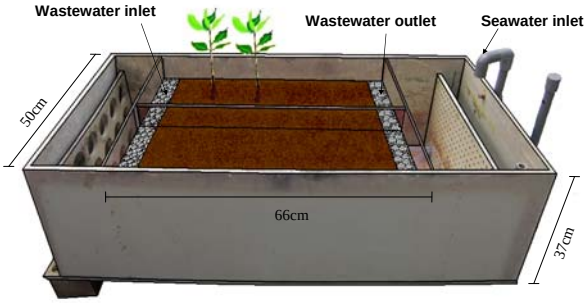
NA: not applicable as no discharge standard is set by the government.

- Treatment performance satisfactory
- >70% of samples meeting the discharge standard for COD, BOD, TN and NH_3
- >40% for TP

(Yang et al. 2008)

Removal Efficiency:
Mangrove VS. Non-mangrove

Greenhouse study: Simulation mangrove wetland (Tide-tank)



Mangrove plants in greenhouse

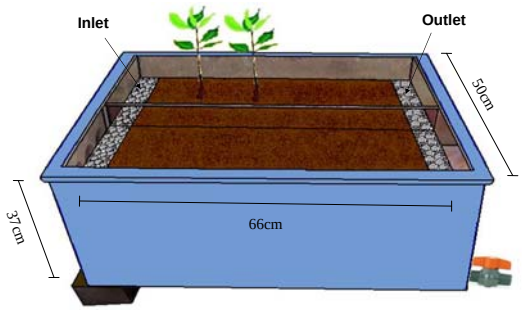
Unplanted control | 桐花树 (*Aegiceras corniculatum*) | 木榄 (*Bruguiera gymnorrhiza*)

Selected Mangrove Species

- Higher root/shoot
- High tolerance
- Comparable/higher treatment efficiency
- Require no frequent harvesting
- Adaptive to saline water

Bruguiera gymnorrhiza (Bg) 木欖 | *Aegiceras corniculatum* (Ac) 桐花樹

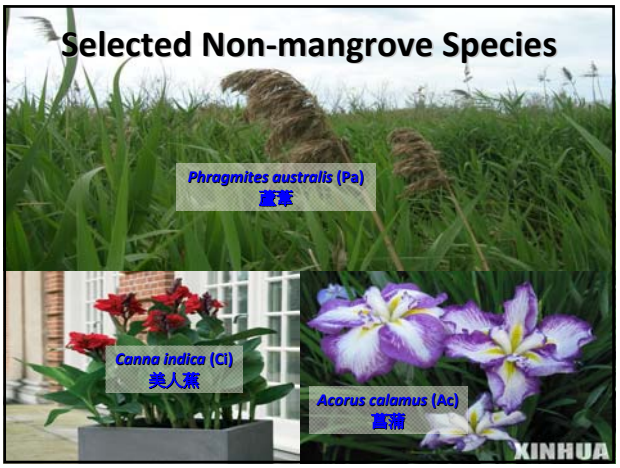
Greenhouse study: Simulation Non-mangrove wetland



Non-mangrove Species

- *Phragmites australis*, *Acorus calamus* and *Canna indica*: common emergent macrophytes used in constructed wetlands
- Wetlands planted with *Canna indica*, and *Phragmites communis* had higher removal rate for TN and TP than those planted with other species (Yang *et al.*, 2007)
- Addition of esthetic values

Selected Non-mangrove Species



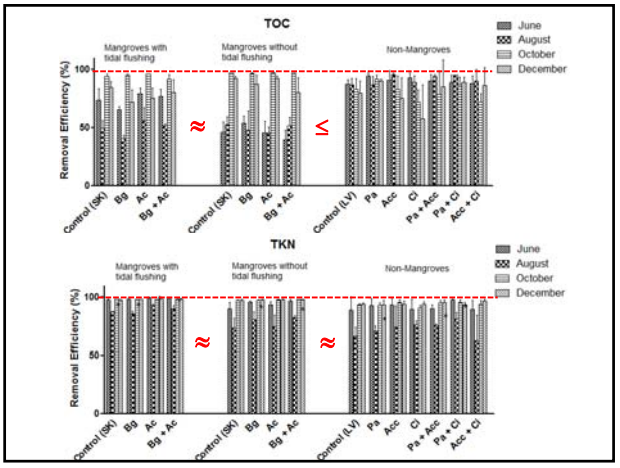
Non-mangroves in greenhouse

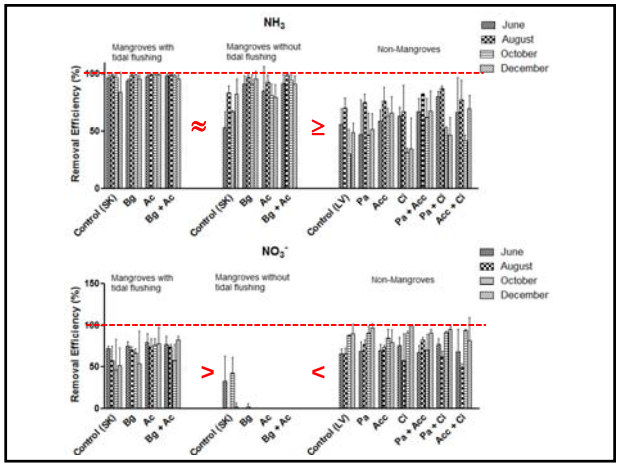
Phragmites australis (Pa) 蘆葦 | *Acorus calamus* (Ac) 菖蒲 | *Canna indica* (Ci) 美人蕉

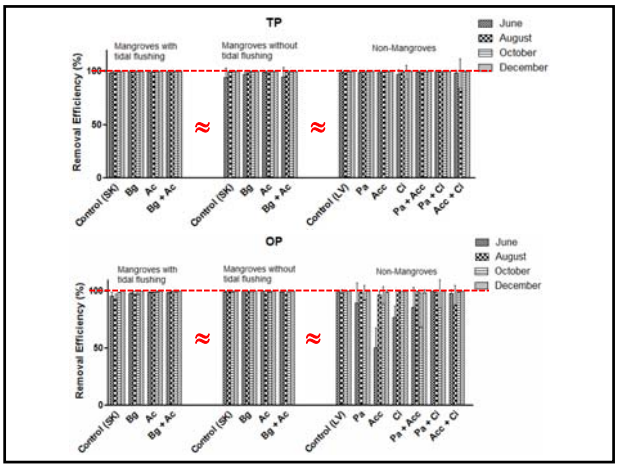
Acclimatization in greenhouse

Artificial wastewater: Simulate domestic + industrial wastewater

Nutrient/ Organic Pollutant	Concentration (mgL^{-1})	Heavy metal	Concentration (mgL^{-1})
DOC	60	Zn	5
TKN	45	Mn	5
NH_4^+-N	25	Fe	30
NO_3^--N	0.5	Cu	2
PO_4^{3-}-P	5	Pb	1
Phenanthrene	1	Ni	1
Pyrene	0.5	Cr	0.5
Benzo[a]pyrene	0.1	Cd	0.1
Phenol	10		







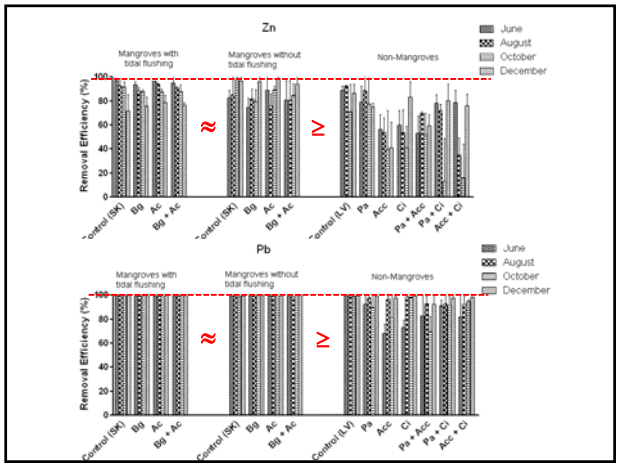
Mangrove VS. Non-mangrove: organic matter and nutrients

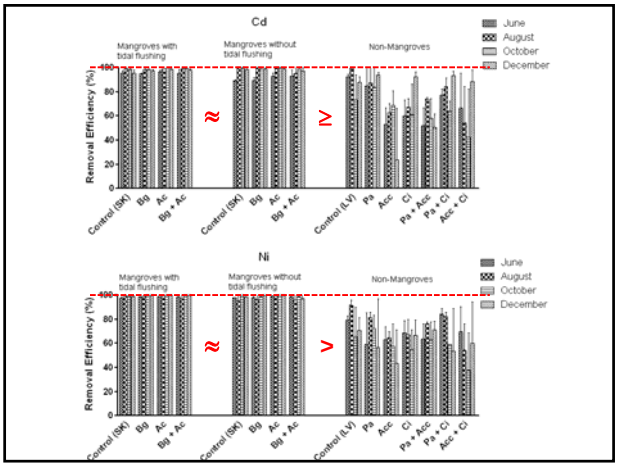
Vegetation	DOC	NH_3^+	TKN	PO_4^{3-}	TP
Non-mangrove	61.5	51.7	62.0	58.6	74.0
Mangrove	73.4	84.0	90.6	97.5	94.6

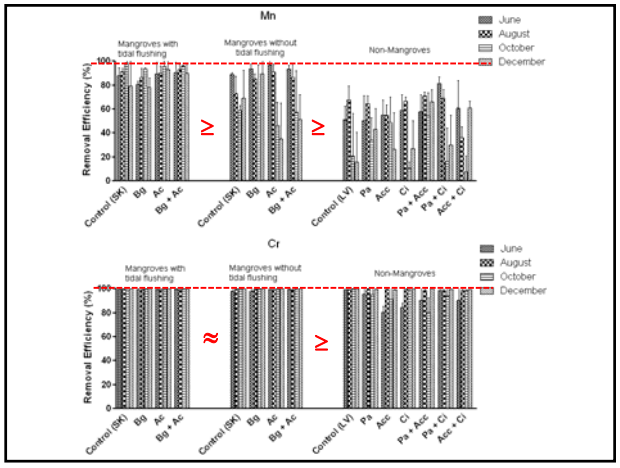
Mangrove > Non-mangrove

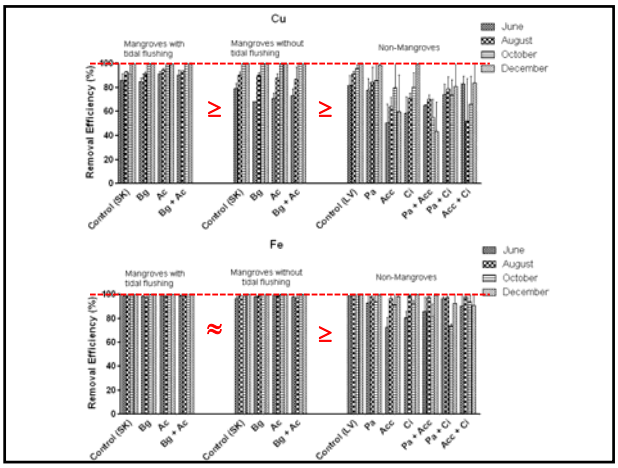
Mangrove VS. Non-mangrove: organic matter and nutrients

- At the start, non-mangroves had higher TOC removal than mangroves but as the system stabilized, no difference between mangrove and non-mangrove
- No difference in TP and OP removal (close to 100%)
- Mangroves were better in removing NH_3-N (close to 100%) than non-mangroves
- Tidal flushing and mixed plant cultures had no significant effect on TOC、TP、OP









Mangrove VS. Non-mangrove: Heavy metals

- Heavy metals in mangrove treated effluent mostly fulfill national (景观水质二级标准) and HK standard, but Zn, Mn and Cu in non-mangrove effluent sometimes exceed the standard
- Mangroves > non-mangroves
- No significant differences among different mangrove species but for non-mangrove, *Phragmites*芦苇> *Canna*美人蕉> *Acorus*菖蒲
- Tidal flushing and mixed plant culture did not affect heavy metal removal efficiency

Phenol and PAHs

- PAHs
  - Influent: Phe 1 ppm, Pyr 0.15 ppm, Bap 0.01 ppm
  - Effluent: All three PAHs were not detected (MDL:
  - Phe: 2.78 ppb Pyr: 3.41 ppb Bap: 2.18 ppb)
- Phenol
  - Influent: 10 ppm
  - Effluent: ND~89 ppb <HK discharge std. (100 ppb) (MDL: 0.55 ppb)

Both mangrove and non-mangrove wetland reached 100% removal of PAHs and phenil and fulfill discharge standards

Effluent quality and discharge standard

	Zn	Pb	Cd	Ni	Mn	Cr	Cu	Fe	Phenol	COD	TP	NH_3-N	NO_3-N
排放标准(mg/L)	1	1	0.1	1	1	1	1	10	0.4	80	10	20	50
非红树系统	×	×	×	×	×	√	×	×	√	√	√	×	√
红树系统	√	√	√	√	×	√	√	√	√	√	√	√	√

HK discharge standard for general amenity and secondary contact recreation

Multi-function Green Wastewater Treatment Demonstration Site: Longgang, Shenzhen

Infrastructure construction

Completion of primary and secondary treatment processes

Design Parameters for 2º treatment

Influent 原水特征	Wastewater from Surrounding 园区污水包括生活、实验室、周边工厂
Hydraulic loading 处理负荷	50m³/d
HRT 水力停留时间	16h
Sludge Age 污泥龄	60d
DO溶解氧	4-6 mg/L
pH	7.0-7.5
Temp 温度	15-30ºC

Inoculum菌种：EM菌，脱氮菌（0.3%的体积比投加）挂膜期每周投加一次，连续投加3-4次
外加营养源：面粉，尿素，磷肥

Design Parameters for CW

Floor Area: 240 m²
Wastewater: Effluent from 2º biofilters
Hydraulic loading: 50m³/d (up to 150 m³/d)
Equivalent pop size: 250
HRT: 24h
Flow Type: 4-stage tandem-type sub-surface flow
Substrate: 0. 85 m in depth with 3 layers: gravel (0.15 m at bottom); soil (0.35 m in middle) and sand (0.35 m on surface)
Vegetation: Mixed culture of mangrove and non-mangrove plants

Design of Constructed Wetland

- Both mangrove and non-mangrove plants can remove pollutants
- Possible to use different species to enhance landscaping and aesthetic values
- Non-mangrove plants
  - *Canna indica* 美人蕉
  - *Cyperus alternifolius* 輪傘莎草
  - *Cyperus papyrus* 細葉紙莎草
  - *Thalia dealbata* 再力花
  - *Arundo donax var. vesicolor* 花葉蘆竹
  - *Acorous calamus* 菖蒲
  - *Iris tectorum* 鳶尾

Non-mangrove Wetland Plants

Mangrove plants

木欖

秋茄

桐花樹

Longgang Constructed Wetland

- Mangrove plants
  - ***Bruguiera gymnorrhiza* 木欖**
  - ***Kandelia obovata* 秋茄**
  - ***Aegiceras corniculatum* 桐花樹**
- Most pollutant-tolerant and robust mangrove species, such as *Bruguiera* are planted near the inlet
- Other plants are in middle and outlet

Layout of constructed wetland

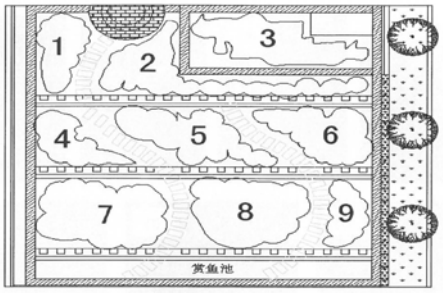


Figure 4.4 Area number assigned in the constructed wetland

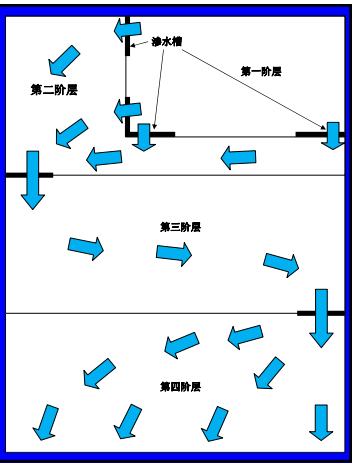
Areas of each plant species

Table 4.1 Plant species and vegetated area (m^2) in the constructed wetland. The assigned area # is shown in Figure 4.4

	Vegetated	Non-mangrove species							Mangrove species		
Area #	area	Ca	It	Ci	Ad	Acc	Td	Cp	Bg	Ko	Ac
1	10	5	-	-	3	-	-	-	1	-	1
2	20	4	2	2	4	-	2	-	4	2	-
3	15	-	1.5	3	-	1.5	3	3	3	-	-
4	10.8	3.6	1.8	1.8	-	1.8	-	-	-	-	1.8
5	15	3	-	3	-	1.5	1.5	3	-	-	3
6	10.8	3.6	-	-	3.6	1.8	-	-	-	1.8	-
7	15	5	-	5	-	1.2	1.3	2.5	-	-	-
8	16	4	-	2	-	2	4	4	-	-	-
9	5	2.5	-	2.5	-	-	-	-	-	-	-
Total	117.6	30.7	5.3	19.3	10.6	9.8	11.8	12.5	8	3.8	5.8

Ca, *Cyperus alternifolius*; It, *Iris tectorum*; Ci, *Canna indica*; Ad, *Arundo donax* var. versicolor; Acc, *Acorus calamus*; Td, *Thalia dealbata*; Cp, *Cyperus papyrus*; Bg, *Bruguiera gymnorrhiza*; Ko, *Kandelia obovata*; Ac, *Aegiceras corniculatum*

Flow pattern in constructed wetland: Subsurface flow, also try to enhance HRT



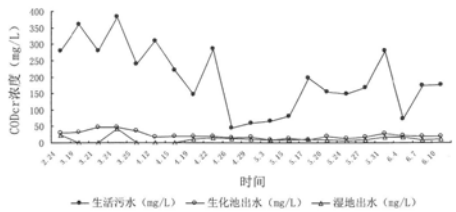
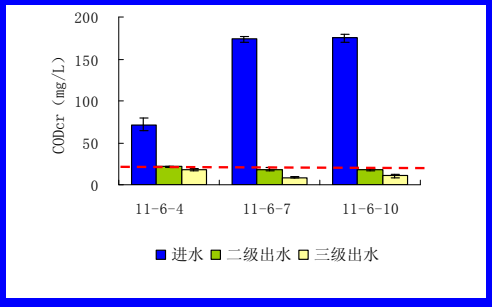


Figure 4.6 Concentrations of COD in water samples before and after treated by the Long Gang wastewater treatment system

COD Removal 处理效果



进水COD值在200-400 mg/L变化；出水COD已低于20mg/L，平均去除率已达到90％以上，已达到中水水质要求（50 mg/L）。

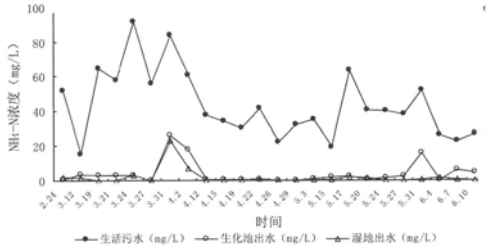
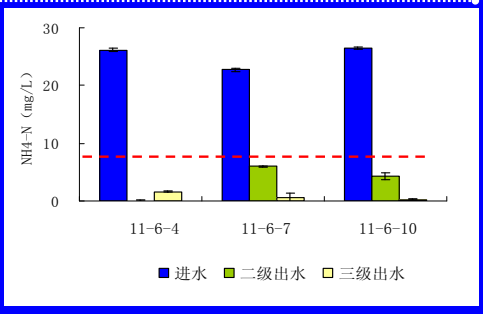


Figure 4.7 Concentrations of NH_4^+-N in water samples before and after treated by the Long Gang wastewater treatment system

NH_4-N Removal 处理效果



进水NH_4-N浓度在30 ～ 92 mg/L的范围变化；稳定时的出水NH_4-N在1 mg/L左右，去除率达到95％以上，已达到中水水质要求（5 mg/L 以下）

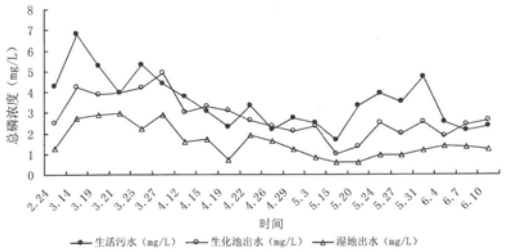
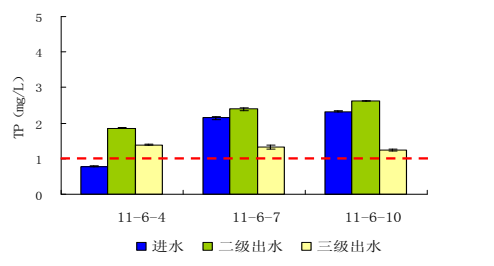


Figure 4.8 Concentrations of TP in water samples before and after treated by the Long Gang wastewater treatment system

TP Removal 处理效果



进水TP在1.7- 6.8 mg/L范围变化；湿地对TP的去除率基本维持在40 - 65％；出水TP已接近中水水质要求（1.0 mg/L）。

Heavy metals treatment and recovery
重金属回收处理系统

Heavy Metals in Wastewater at Demonstration Site, Longgang, Shenzhen (μg L^{-1})

	Cr	Ni	Cu
Dissolved (n=7)	7.3	96.6	59.2
Range	0.3 - 27.9	15.2 – 246.6	1.3 – 139.1
Total (n=4)	41.8	126.6	292.0
Range	4.79 – 129.5	12.6 – 248.4	37.7 – 731.4
Standard (HK)	100-1000	100-1000	100-1000
Standards (China)	1500	1000	500

*nd: Not detectable

	Zn	As	Cd	Pb
Dissolved (n=7)	46.1	0.99	0.05	99.3
Range	3.9 – 152.7	0.55 – 1.56	nd* – 0.11	0.27 – 661.5
Total (n=4)	119.7	1.53	nd	301.7
Range	4.58 – 331.0	1.44 – 1.72	nd	8.3 – 712.9
Standard (HK)	100-1000	100-1000	1-100	100-1000
Standards (China)	2000	500	100	1000

Conclusions

- Modular systems integrating different treatment processes to fit various types of wastewater
- Oyster shells under alternating anaerobic-aerobic conditions provide good surface for biofilms and remove BOD, N and P simultaneously
- Constructed wetlands with mixed mangrove and non-mangrove plants not only polish effluent but also provide green area, serve landscaping and leisure purposes
- Occupy small footprints
- No odorous smell and environmentally friendly

Treatment facility in Long gang

Innovation and Technology Commission
The Government of the Hong Kong Special Administrative Region

- HK ITC
- SZRIXU, SZIQB, and Longgang Marine Industrial Park

Thank You ! 谢 谢 !