In situ algal bloom control in stagnant water

Principles & Field Applications

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1. Introduction

1. Introduction (1)

Changes in the Environment

Climate change

- Heavy rain events
- Increased temperature
- Frequent drought

Water pollution

- Point sources
- Non-point sources
- Groundwater pollution

Need Appropriate technologies for water quality

River environ-ment change

- Four rivers restoration
- Lakes restoration
- Increased depth & HRT
- Decreased water flow

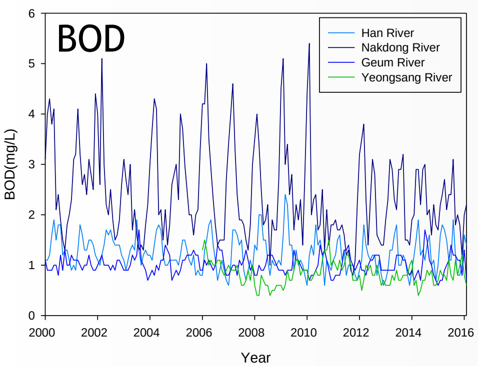
Harmful algal blooms

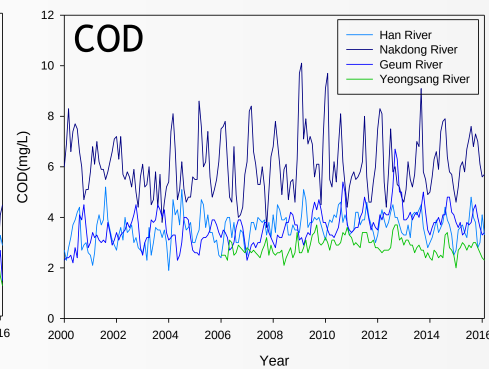
- Neurotoxins & illness
- Oxygen depletion
- Further water treatment

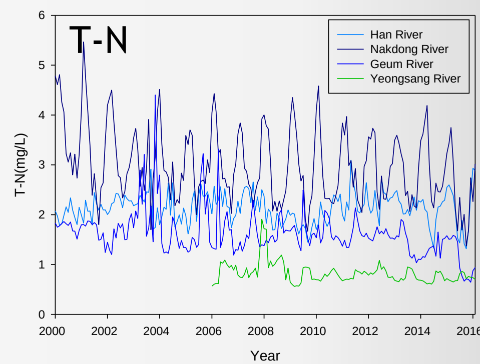
1. Introduction (2)

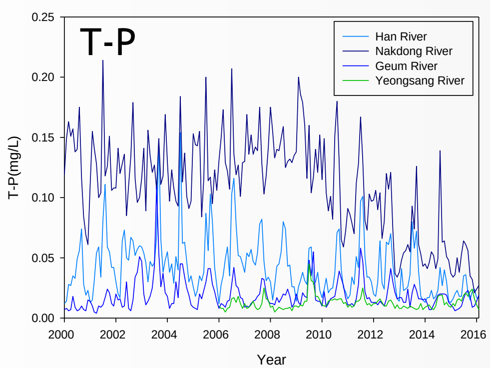
Water quality changes in major four rivers (2000~2016)

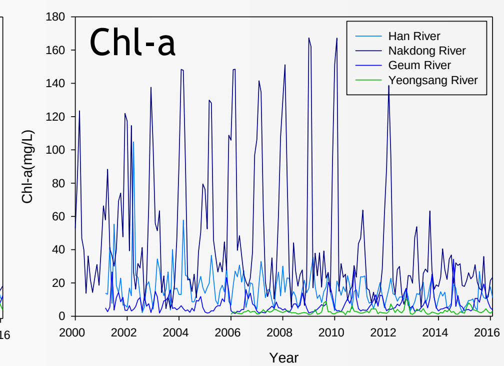
- **Water qualities change.**
  - Water qualities such as BOD, COD, T-N, and T-P have been partially improved;
  - Chl-*a* has been increased in several stagnant zones after construction of small dams;
  - Changes in river regime (i.e., flow rates, depth, ecosystem, etc.) have been observed.









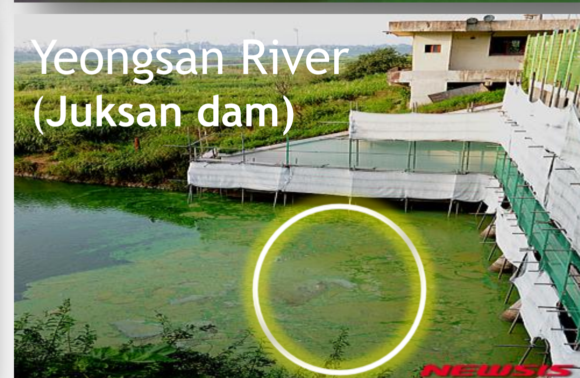


Ref.: Water Information System (water.nier.go.kr)

1. Introduction (3)

Increased stagnant water zones

- **Water stagnation zones increase.**
  - Water stagnation occurs around the river lateral and vertical structures;
  - Stable conditions (flow rate<0.2 m/s) make blooms of blue-green algae;
  - Most BGAs prefer low flows, long RT, light winds and minimal turbulence.



1. Introduction (4)

Cynobacterial bloom effects (Shin et al., 2013)

Drinking Water

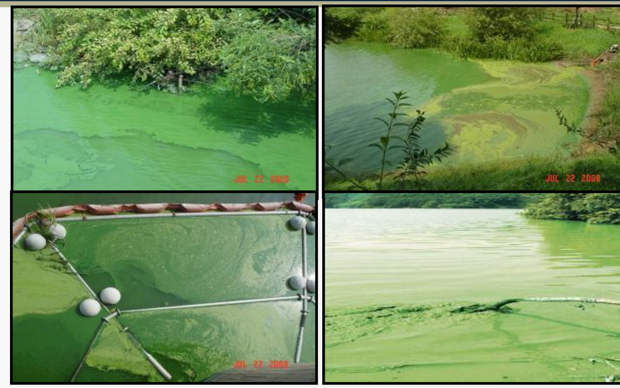
- Advanced drinking water treatment

Visual

- Scum, Pigmentation

Aqua–culture

- Destruction of aquaculture system



Large Dam   Agricultural Lake

Green-tide

- **Blue-green algae**
- *Microcystis*
- *Anabaena*
- *Oscillatoria*
- *Aphanizomenon*

- Scum
- *Geosmin*
- *2-MIB*
- Deteriation
- *microcystin*

Scum & Pigment O_2 depletion

Animal

- O_2 depletion, Animal massacres

Public Health

- Serious damage to health

Economy

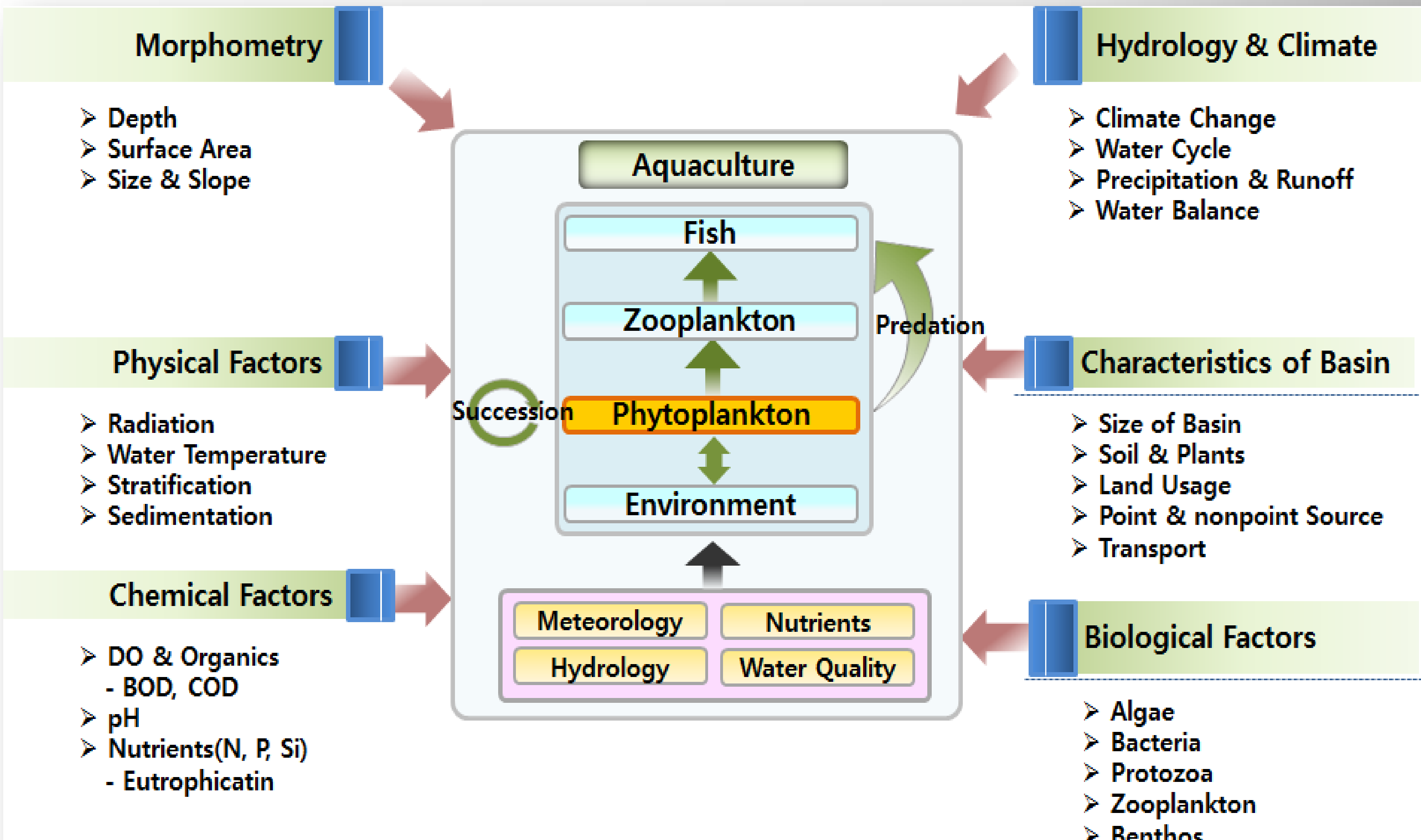
- No recreation activity
- Need more $$$ to treat

Expansion of HABs is a serious threat to the ecological integrity, ecosystem services, safe use, and sustainability of water.

2. Prevention & Mitigation of Harmful Algal Blooms

2. Prevention & Mitigation of HABs (1)

Environmental factors for HABs? (KEC, 2012)



- Complex and cumulative effects in modulating HABs due to varying environmental factors. CAN PREVENT & MITIGATE HABS?

2. Prevention & Mitigation of HABs (2)

| Primary environmental factors for HABs? (Paerl, 2016)

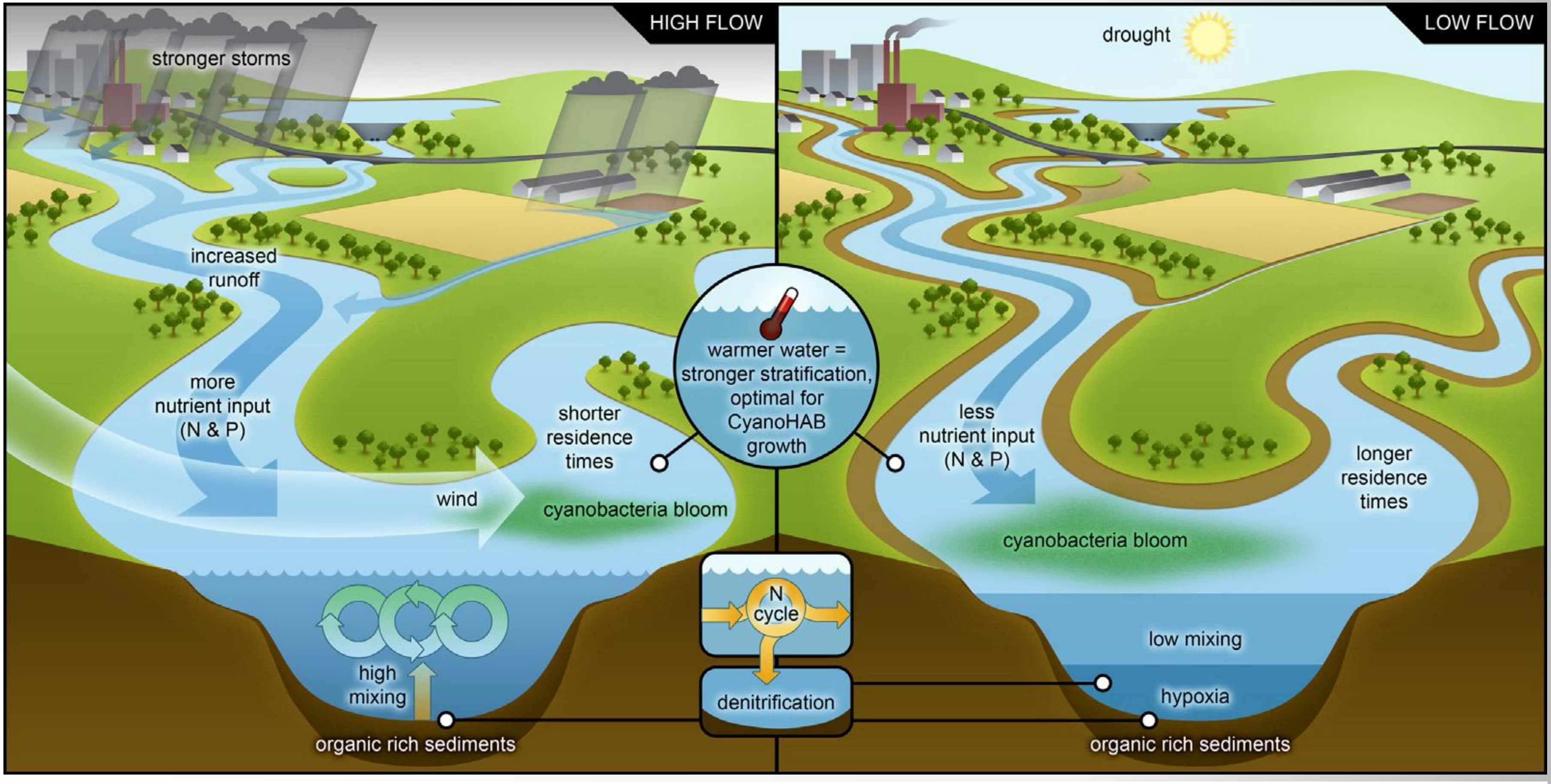
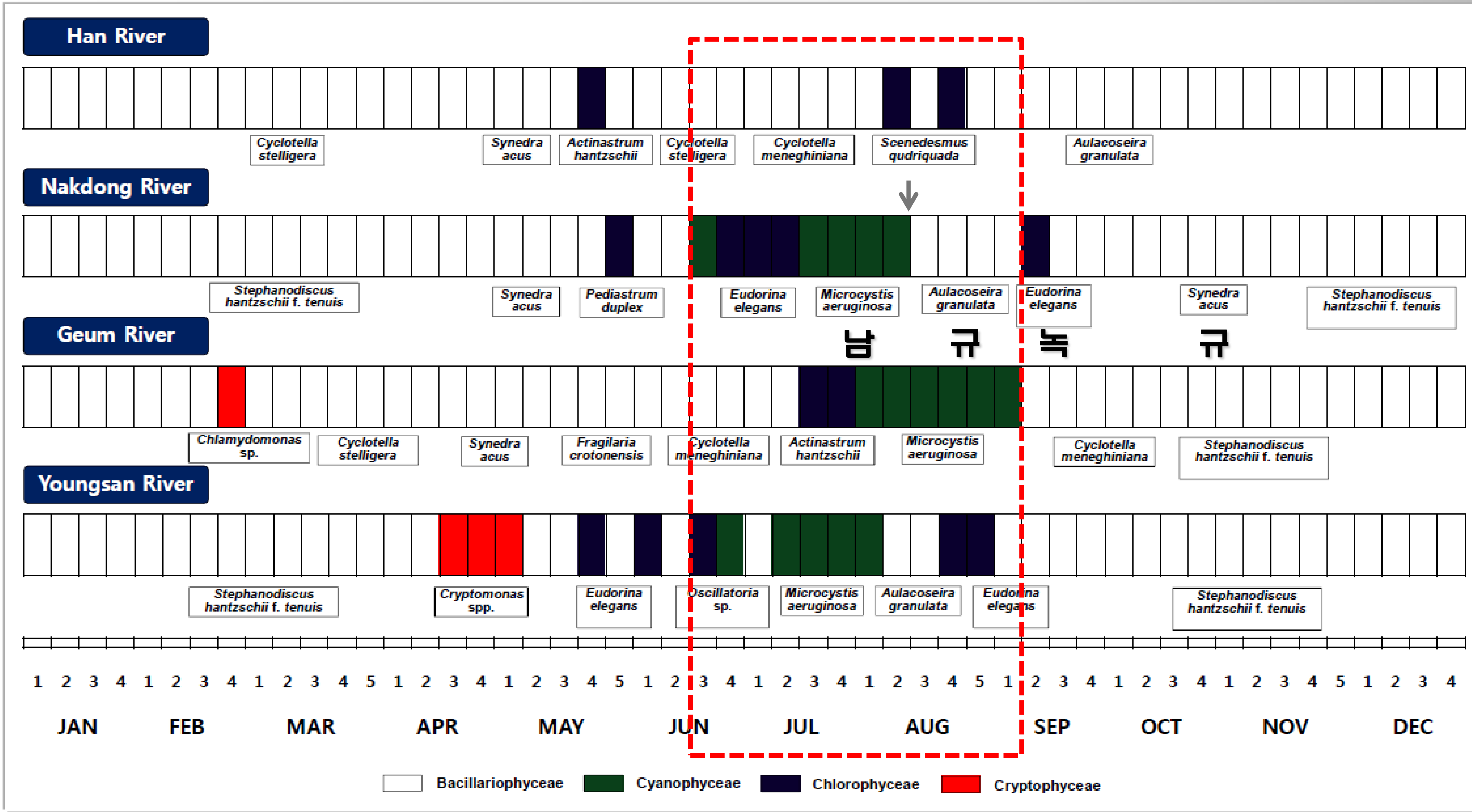


Fig. 2. Impacts of warming, increasing hydrologic variability, and extremeness on physical–chemical and biotic conditions that modulate CyanoHABs in shallow water ecosystems. Under high freshwater discharge conditions (left hand side) an increase in nutrient loading will occur, mixing depth will increase, with enhanced nutrient cycling and regeneration in the water column. Even though external nutrient loads will increase, higher rates of flushing (shorter water residence times) will tend to offset algal growth rates and biomass accumulation. Under low freshwater discharge conditions (right hand side), external nutrient loads will decrease, but reduced flushing will lead to longer residence times, which will optimize algal nutrient removal and biomass accumulation. In addition, relatively low vertical mixing rates will lead to more sustained periods of vertical stratification, which will allow buoyant CyanoHABs to dominate. Stronger dissolved oxygen gradients associated with enhanced vertical stratification will enhance internal nutrient cycling and denitrification as an N loss mechanism.

2. Prevention & Mitigation of HABs (3)

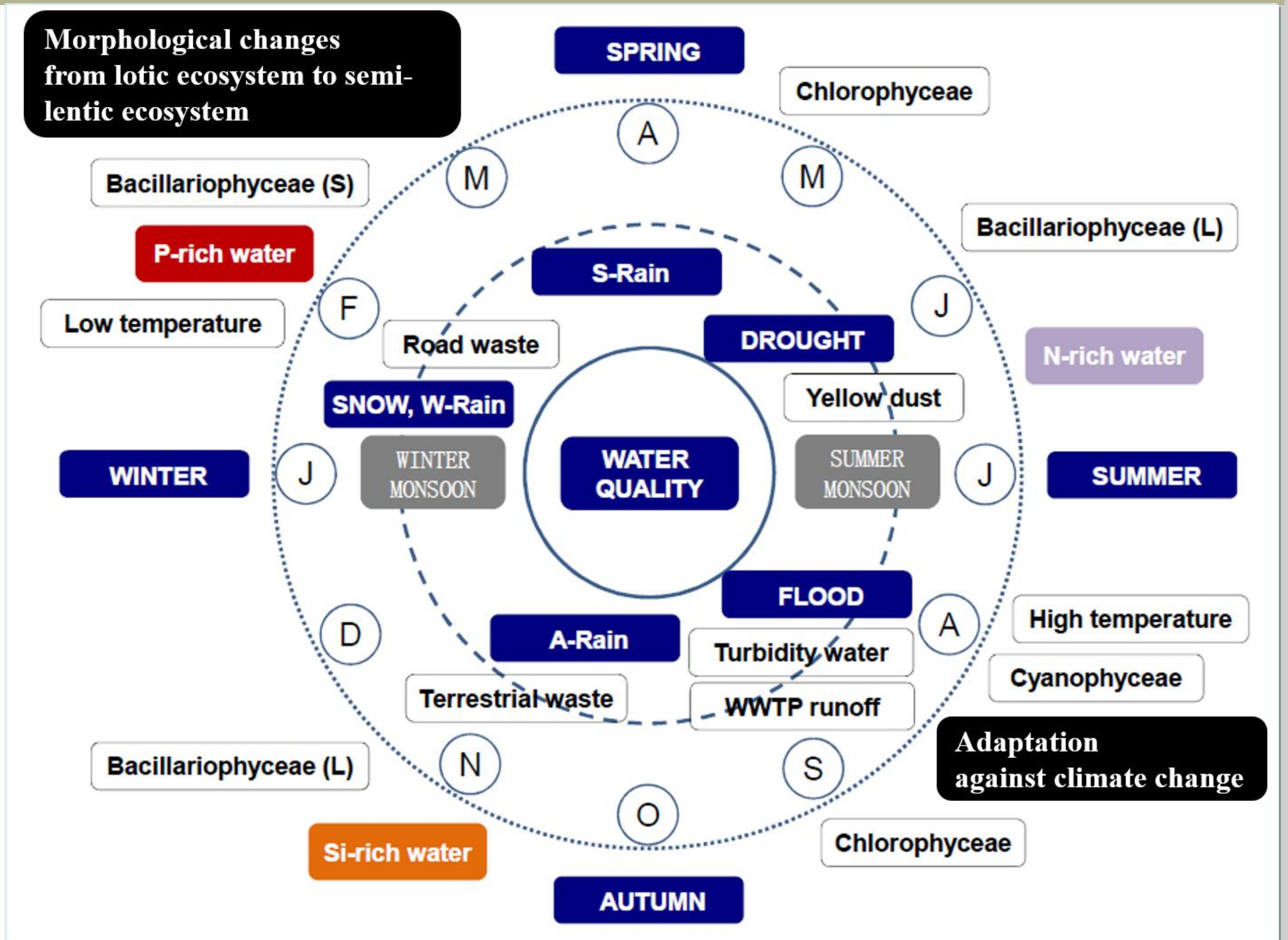
Spatial, seasonal and species variations in HABs (Shin, 2013)



- Overall effect of nutrient over-enrichment on harmful algal species is clearly species specific.

2. Prevention & Mitigation of HABs (4)

Spatial, seasonal and species variations in HABs (Shin, 2013)



- Spatial, seasonal and species variations in HABs should be considered to effectively prevent and mitigate HABs.

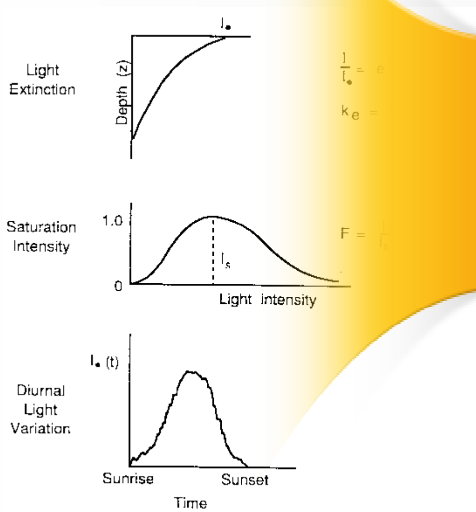
2. Prevention & Mitigation of HABs (5)

Artificial control of Cyanobacterial blooming ?

✓ Temperature

$$X_T = \theta_G^{T-20}$$

✓ Light



✓ Hydraulic Retention Time

External Loading

Point sources

Non-point sources

Sediment

Internal Loading

✓ Nutrients

2. Prevention & Mitigation of HABs (6)

Artificial control of Cyanobacterial blooming is NOT simple!

Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment

PNAS (2008) 105(32): 11254-8.

David W. Schindler*†, R. E. Hecky‡, D. L. Findlay§, M. P. Stainton§, B. R. Parker*, M. J. Paterson§, K. G. Beaty§, M. Lyng§, and S. E. M. Kasian§

Limnol. Oceanogr., 56(4), 2011, 1545–1547

doi:10.4319/lo.2011.56.4.1545

Comment: Lake 227 shows clearly that controlling inputs of nitrogen will not reduce or prevent eutrophication of lakes

M. J. Paterson,[a,*] D. W. Schindler,[b] R. E. Hecky,[c] D. L. Findlay,[a,1] and K. J. Rondeau[b]

[a] Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Manitoba, Canada
[b] Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada
[c] Department of Biology, University of Minnesota, Duluth, Minnesota

- **Nutrient-growth threshold responses for HABs have been altered as physical (e.g., temperature) and geochemical (e.g., nutrient fluxes) controls on these thresholds also change.**

2. Prevention & Mitigation of HABs (7)

Control measures in the watershed and within the ecosystem (Paerl, 2016)

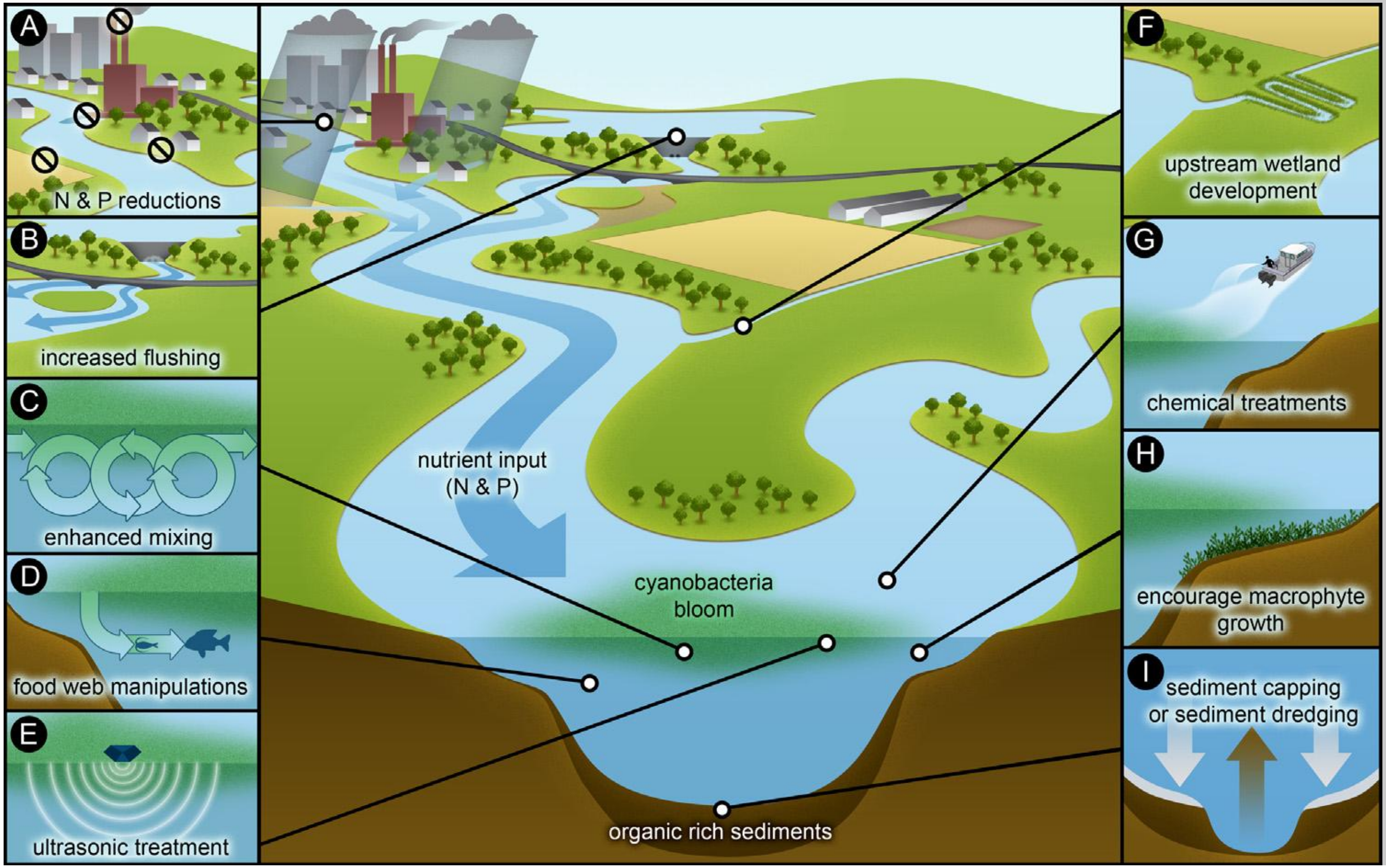


Fig. 1. Conceptual illustration of various approaches currently in use to control CyanoHABs, including control measures in the watershed and within the ecosystem. A. Point and non-point source nutrient (in most cases, both N and P) input reductions. B. Increasing flushing rates (decreasing water residence times). C. Mechanically-enhanced vertical mixing. D. Manipulating food webs to encourage filtering and consumption of CyanoHABs. E. Utilizing ultrasound waves to control algal growth. F. Nutrient attenuation/removal through upstream wetland development. G. Application of algaecides, including copper salts, hydrogen peroxide. H. Encourage growth of submersed and emergent aquatic vegetation for nutrient attenuation and removal. I. Dredging and capping of bottom sediments to reduce sediment-water column nutrient regeneration.

2. Prevention & Mitigation of HABs (8)

Range of potential mitigation strategies (Paerl, 2016)

	Mitigation options (numbered in order of priority)								
	Nutrient input reductions	Encourage macrophyte growth	Manipulate turbidity	Lake depth and photic zone	Upstream wetland dev.	Enhanced flushing[a]	Enhanced mixing[a]	Sediment capping[a,b]	Dredging[c]
Anabaenopsis	1	2	3	4	5	6	7	8	9
Aphanizomenon	1	2	3	4	5	6	7	8	9
Cylindrospermopsis	1	2			3	4		5	6
Dolichospermum	1	2	3	4	5	6	7	8	9
Gloeotrichia	1				2	3			
Lyngbya	1	3			4	2		5	6
Microcystis	1	2	4	5	3	6	7	8	9
Nodularia	1				2	3	4	5	6
Nostoc	1				2			3	
Phormidium	1				2	3		4	5
Planktothrix	1			2	3	5	4	6	7
Raphidiopsis	1				2	4	3	5	6
Synechococcus	1				2	3			

S, some species; M, most species.
[a] Only feasible in relatively small system.
[b] Only in systems that exhibit vertically-stratified conditions during bloom periods.
[c] Following environmental assessment and only if dredge spoils can be deposited outside the watershed.




2. Prevention & Mitigation of HABs (9)

Classification of conventional algae control technologies

- **Algae control technologies.**
  - Physical : aeration, microbubble, circulation, sonication, filtration etc.
  - Chemical : coagulants, OH radical, ozone, photocatalysts (TiO_2) etc.
  - Biological : microbial cultures, (floating) artificial island etc.


Water flow device


Microbubble & radical


Artificial wetland


Algae harvesting ship


Circulation system

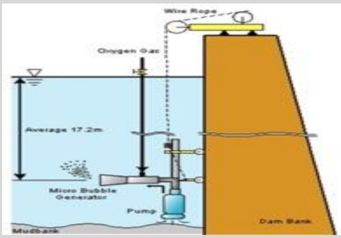
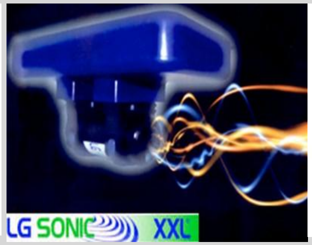
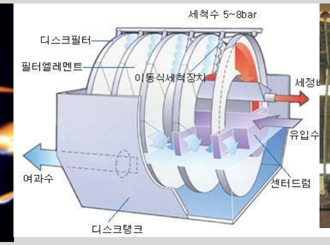

Floating photovoltaic systems


Ecological restoration


Algae harvesting ship

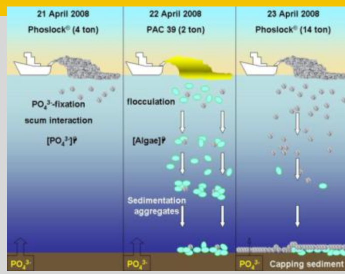
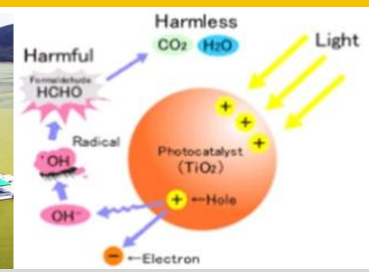
2. Prevention & Mitigation of HABs (10)

Physical algae control technologies

구분	심층 폭기	초음파 조류제어	여과	밀도류 확산장치	부상처리기술
사진					
명칭	심층 마이크로 버블	LG Sonic	DiscFilter	마린 포럼	DAF 조류부상제거
원리 및 특징	•수체 직접 산소공급 •심층 폭기 가능	•초음파로 조류(algae)의 기낭 파괴	•디스크필터를 이용한 부유물질 여과	•하층의 저수온수를 확산시켜 성층 파괴	•공기입자에 조류를 부착시켜 부상후 제거
장점	•유기물 산화 촉진 •사용 및 운영 편리	•조류를 목표하여 선택적으로 제거	•여과를 통한 탁도 제거 및 주기적 역세	•성층 파괴로 인한 계절적 부영양화 억제	•저층 유기물 및 조류 제거 가능 •수집조류는 탈수처리
단점	•주기 유지관리 필요 •동력 소모 필요	•휴면포자 발생 가능성 •대규모 운전사례 적음	•필터 유지관리 •플랜트 시설 필요	•시설의 대형화 필요 •시설 비용 증대	제거된 조류 및 유기물 후속처리 필요
키워드	공기, 폭기	초음파, 조류	디스크필터, 여과	밀도류, 성층 파괴	DAF, 조류
관련업체	OBOX	Magic Pool Tech	유천앤바이로	환경시설관리공사	벽산엔지니어링㈜ ㈜지오마린

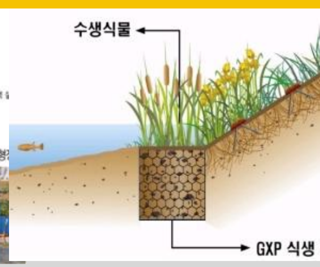
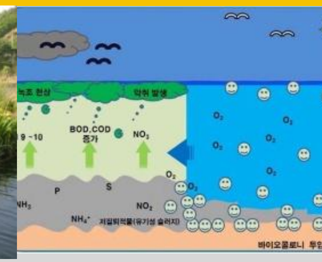
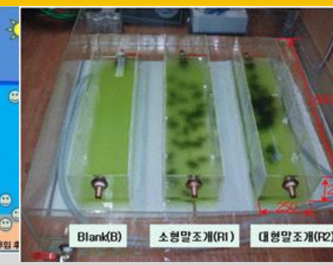
2. Prevention & Mitigation of HABs (11)

Chemical algae control technologies

구분	흡착	응집제 살포	광촉매	생물유래 추출물	약품 살포
사진					
명칭	Phoslock	조류제거선	광촉매 산화	키토산, 목초액, EM 등	MCEK
원리 및 특징	•양이온(La^{3+})을 활용한 PO$_4^{3-}$ 흡착	•선박이 이동하며 직접 조류제거(여과, 응집)	•광촉매 산화를 통한 유기물질 제거	•생물을 가공하여 생산된 재료로 자체적 흡착, 분해 , 미생물 성장 증진	•약품 살포로 부유 및 부착조류 제거
장점	•조류 제한영양염 선택적 제거 •환경에 비교적 무해	•적극적인 정체수역 수질 개선 •선택적 수질정화 가능	•별도의 동력 없이 수질 정화 가능 •2차 오염 영향 적음	•비교적 환경에 무해한 성분들로 구성 •특별한 공정 없음	•액상 약품을 통한 탁도 및 조류 제거 •반응속도 빠른편
단점	•주기적 살포 필요 •살포시 탁질 발생	• 선박 동력비 발생 •수면적, 수심 제한	•가시광 영역 효과 증대 연구 필요	•화학약품에 비해 신속한 저감이 어려움	•소규모 시설 용이 •슬러지 처리 필요
키워드	흡착, La^{3+}	선박, 살포	광촉매, TiO$_2$	생물 유래 추출	액상 약품
관련업체	㈜지오앤비텍	한국수자원공사	NOX KOREA	EM환경센터	엠씨이코리아㈜

2. Prevention & Mitigation of HABs (12)

Biological algae control technologies

구분	천적생물 정화	식생정화	인공식물섬	미생물 살포	패류 수질정화
사진					
명칭	포식성 천적생물 배양	GXP호안식생매트	인공식물섬, 부도	바이오콜로니	패류 수질정화
원리 및 특징	•동물플랑크톤의 섭식을 활용한 조류 제거	•식생의 성장을 유도하여 수질정화	•수면 위에 식생을 부유시켜 수질정화	•미생물 살포 및 증식에 따른 유기물 제거	•패류의 섭식으로 조류 제거
장점	•현장 맞춤형 생물정화작용 가능 •생태계 기능 강화	•녹지조성, 자연형 하천 조성 가능 •경관 창출 효과	•부유체로 깊은 수심에 부유습지 조성 •생태복원에 순기능	•선택적인 저질 관리 •미생물 제제를 통한 순기능	•생물 섭식에 의한 수질정화로 생태계 영향 적음
단점	•실규모 적용성 낮음 •계절적 변동 있음	•효율 비교적 낮음 •계절적 변동 있음	•효율 비교적 낮음 •계절적 변동 있음	•비교적 천천히 반응 •소규모 수체에 적합	•한정된 공간 및 현장 조건 영향 큼
키워드	동물플랑크톤, 천적	식생매트	식생, 부유체	미생물 제재	패류
관련업체	한국농어촌공사	YUPUNG	㈜아썸	BIO-KAKEN	-

2. Prevention & Mitigation of HABs (13)

Combined algae control technologies

구분	태양전지 물순환	식물섬 수면포기	생태부도 미세기포	독립발전 수순환	접촉산화공법
사진					
명칭	태양전지+물순환	식물섬+ROSTER	생태부도+미세기포	자체전력생산+순환	Biomedia흡착산화
원리 및 특징	•태양광 에너지를 물리적 순환에 활용	•식생 정화 및 표면 폭기 장치로 순환 유도	•미세기포의 분사 및 생태부도의 수질정화	•회전수조중력낙하식 발전으로 순환	•지하구조물에서 침전, 흡착, 산화 분해
장점	•별도의 에너지 공급 없음 •정체구역 순환 유도	•수면 폭기로 유수역 및 DO 증대 • 경관적 효과	•복합적 작용으로 유기물 무기물 억제 기능 •정체수역에 적합	•독립형 수질정화 •수류순환으로 물리적 정화 유도	•미생물 정화작용 및 여재의 여과작용 •지하 공간 활용
단점	•비교적 가격 고가 •장비 이동 어려움	•동력 발생 •소규모 정체수역 적합	•별도의 동력 필요 •유지관리 요구	•초기투자비 발생 •적정 부지 필요	•일정 시설물 필요 •유지관리 필요
키워드	태양전지, 물순환	수면폭기	생태부도, 미세기포	Zero-WPT	Bio-media
관련업체	신영상사	㈜한일이에스티	㈜한일이에스티	㈜대성이앤비	(주)준수이앤텍

2. Prevention & Mitigation of HABs (14)

Evaluation of conventional algae control technologies (1)

No	Algae control technology	Category I	Category II	Waterbody flow rate	Application period
1	Mixed microbial culture	B	Microbial culture	S	○ ◐
2	Mixed bacteria culture attached on clay	B		S	○ ◐
3	Mixed microbial culture in titanium balls	B/C		S	○ ◐
4	Zeolite coagulant with attached microbial culture	B		S	○ ◐
5	Biomanipulation with zooplankton	B	Zoo-plankton	S	○ ◐
6	Naphthoquinone product	C	Naphtho-quinone	S	◐ ●
7	Natural coagulant with additional minerals	C	Coagulant	S	◐ ●
8	Bentonite coagulant with additional minerals	C		S	◐ ●
9	Natural floating coagulant	C		S	◐ ●
10	Algae harvesting ship with filtration	P/C	Harvest-ing ship	S/F	◐ ●
11	Algae harvesting ship with dissolved air flotation	P/C		S/F	◐ ●
12	Dissolved air flotation device with skimming	P/C	Micro-bubble	S	◐ ●
13	Microbubble device	P		S	◐ ●
14	Microbubble device with ozone	P/C		S	◐ ●
15	Microbubble device with coagulant & harvesting	P/C		S	◐ ●
16	Water circulation ship	P	Water circulation	S/F	○ ◐
17	Water circulation device with spraying	P		S/F	○ ◐
18	Water circulation device with impeller	P		S/F	○ ◐
19	Water density current generator	P		S/F	○ ◐
20	Surface water circulation device	P		S/F	○ ◐
21	Floating artificial wetlands	B	Wetland	S	○ ◐
22	Artificial wetlands	B		S	○ ◐
23	Pressurized filtration	P	Filtration	S	○ ◐
24	Disk filtration with coagulants	C		S	◐ ●
25	Mobile ultrasonic device	P	Ultra sound	S	○ ◐
26	Fixed ultrasonic device	P		S	○ ◐
27	Photodegradation device with adsorbents	C	Photo-degradation	S	○ ◐
28	Plasma device	C	Plasma	S	○ ◐

P : Physical Control S : Stagnant (≤ 0.2 m/s)
C : Chemical Control F : Flow (>0.2 m/s)
B : Biological Control
○ : Precautionary Period
◐ : Initial Period
● : Bloom & Harvesting Period

Ref.: Byun et al. (2016)

2. Prevention & Mitigation of HABs (15)

Evaluation of conventional algae control technologies (2)

No	Algae control technology	Field applic-ability	Economic evaluation	Effect durability	Eco frie-ndliness
1	Mixed microbial culture	◐	●	◐	●
2	Mixed bacteria culture attached on clay	◐	●	◐	●
3	Mixed microbial culture in titanium balls	○	◐	◐	●
4	Zeolite coagulant with attached microbial culture	●	●	◐	●
5	Biomanipulation with zooplankton	◐	◐	○	●
6	Naphthoquinone product	○	○	◐	◐
7	Natural coagulant with additional minerals	●	●	◐	●
8	Bentonite coagulant with additional minerals	●	◐	◐	●
9	Natural floating coagulant	●	◐	●	●
10	Algae harvesting ship with filtration	●	◐	●	◐
11	Algae harvesting ship with dissolved air flotation	●	◐	●	◐
12	Dissolved air flotation device with skimming	◐	○	○	◐
13	Microbubble device	◐	○	○	◐
14	Microbubble device with ozone	◐	○	○	◐
15	Microbubble device with coagulant & harvesting	●	○	●	◐
16	Water circulation ship	◐	●	○	●
17	Water circulation device with spraying	◐	●	◐	◐
18	Water circulation device with impeller	●	◐	◐	●
19	Water density current generator	◐	◐	◐	●
20	Surface water circulation device	●	●	◐	◐
21	Floating artificial wetlands	◐	◐	◐	●
22	Artificial wetlands	◐	◐	◐	●
23	Pressurized filtration	◐	◐	○	◐
24	Disk filtration with coagulants	◐	○	◐	◐
25	Mobile ultrasonic device	◐	○	○	○
26	Fixed ultrasonic device	○	○	○	○
27	Photodegradation device with adsorbents	◐	◐	◐	◐
28	Plasma device	○	○	○	○

○ : Poor
◐ : Fair
● : Good

Ref.: Byun et al. (2016)

2. Prevention & Mitigation of HABs (16)

Application of conventional algae control technologies (K-water, 2016)

3. Recent Developments

3.1 Application of nonpoint source input control (1)

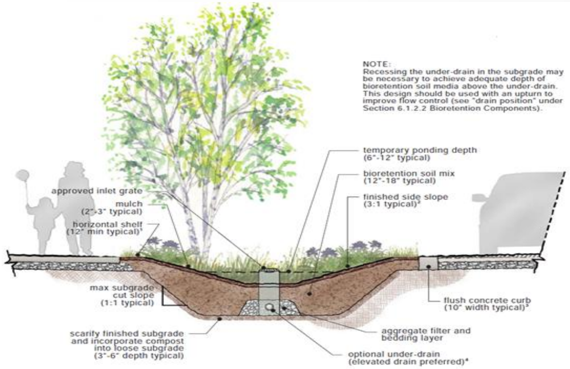
Low Impact Development (1)

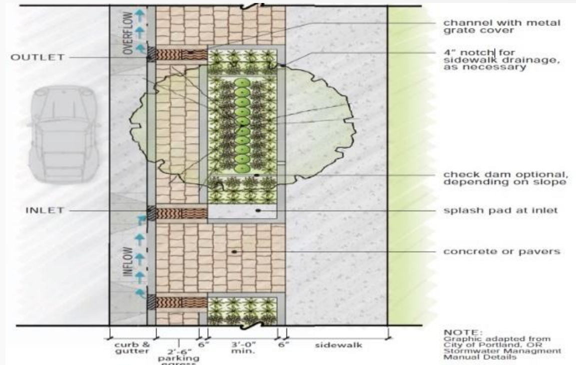
프라이부르크 (독일)

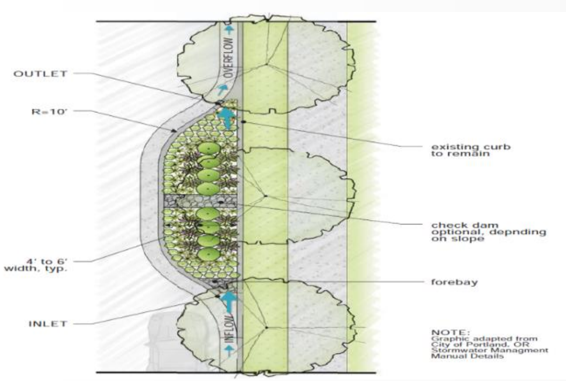
- 불투수면 저감
- 조경공간 활용
- 경관성 향상
- 녹색공간 확대
- 그린 인프라 배수

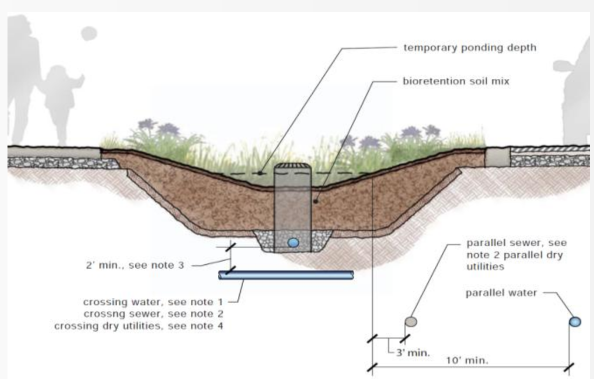
3.1 Application of nonpoint source input control (2)

Low Impact Development (2)







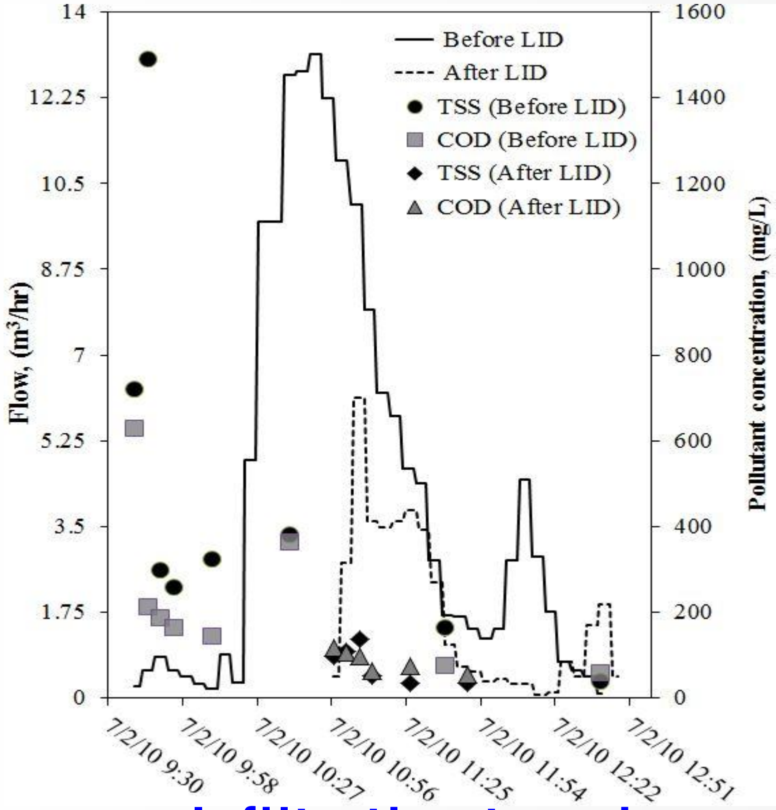


3.1 Application of nonpoint source input control (3)

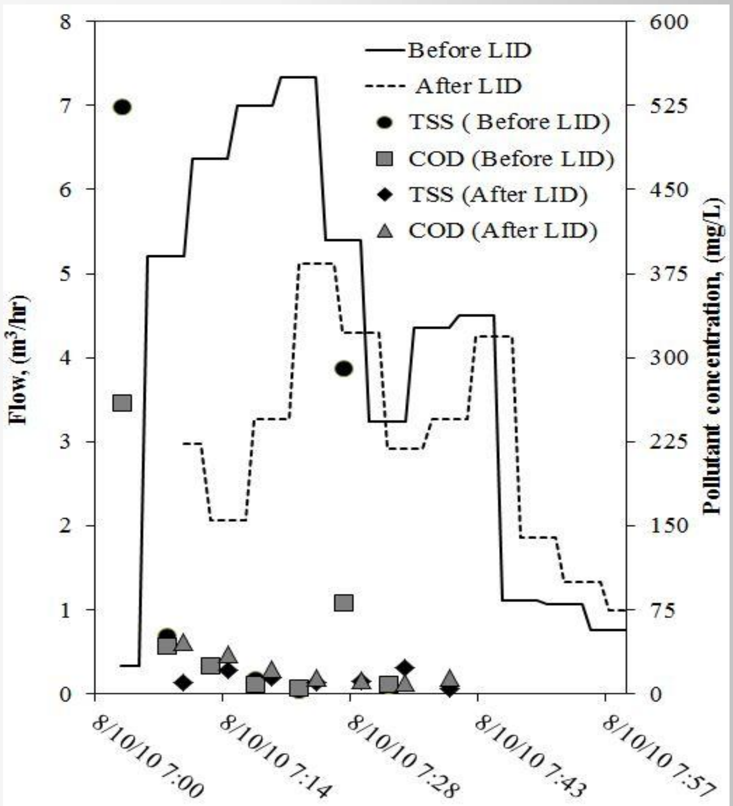
Low Impact Development (3) (Kim, 2014)

Before LID application

After LID application



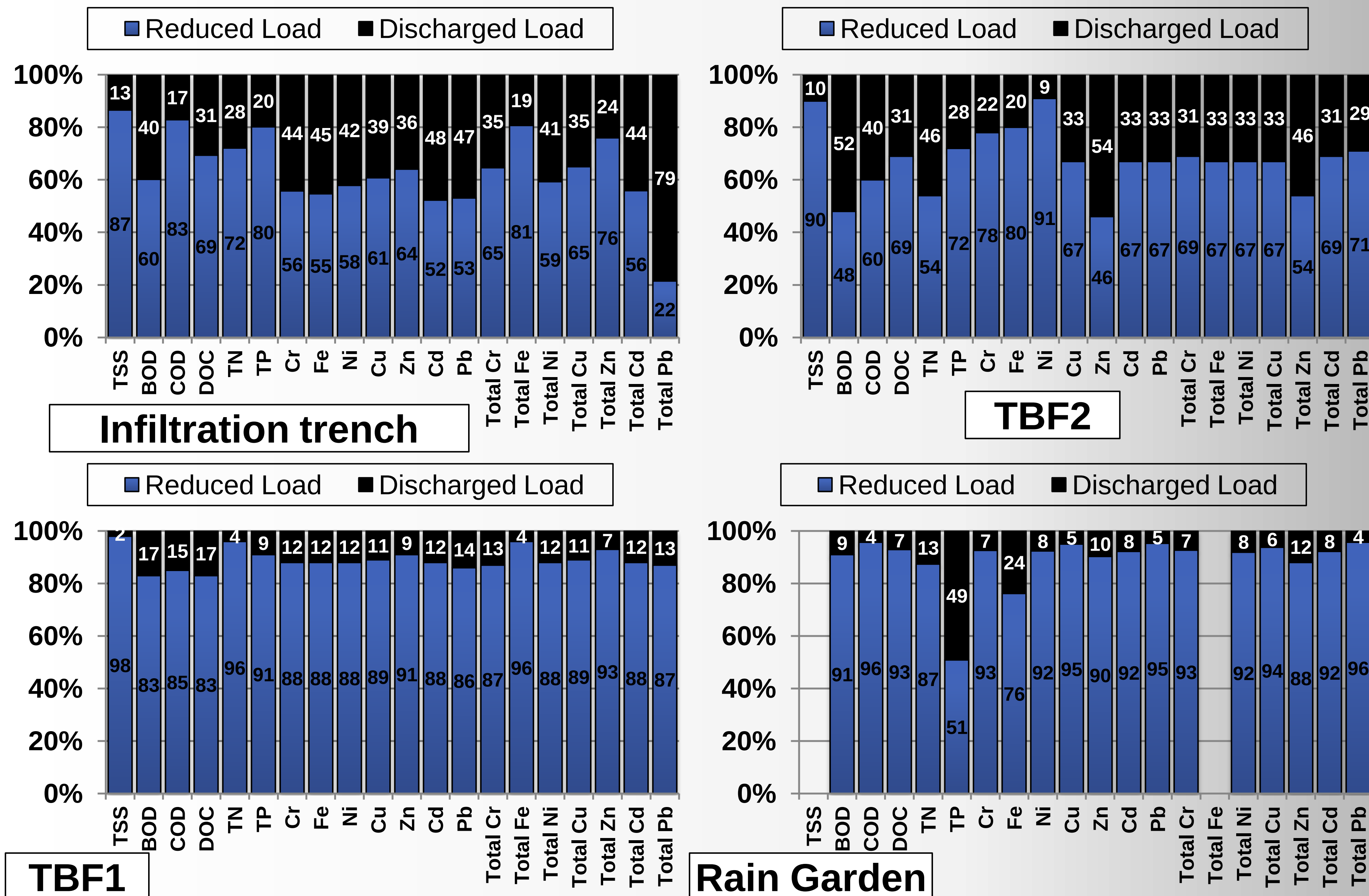
Infiltration trench



Tree box filter

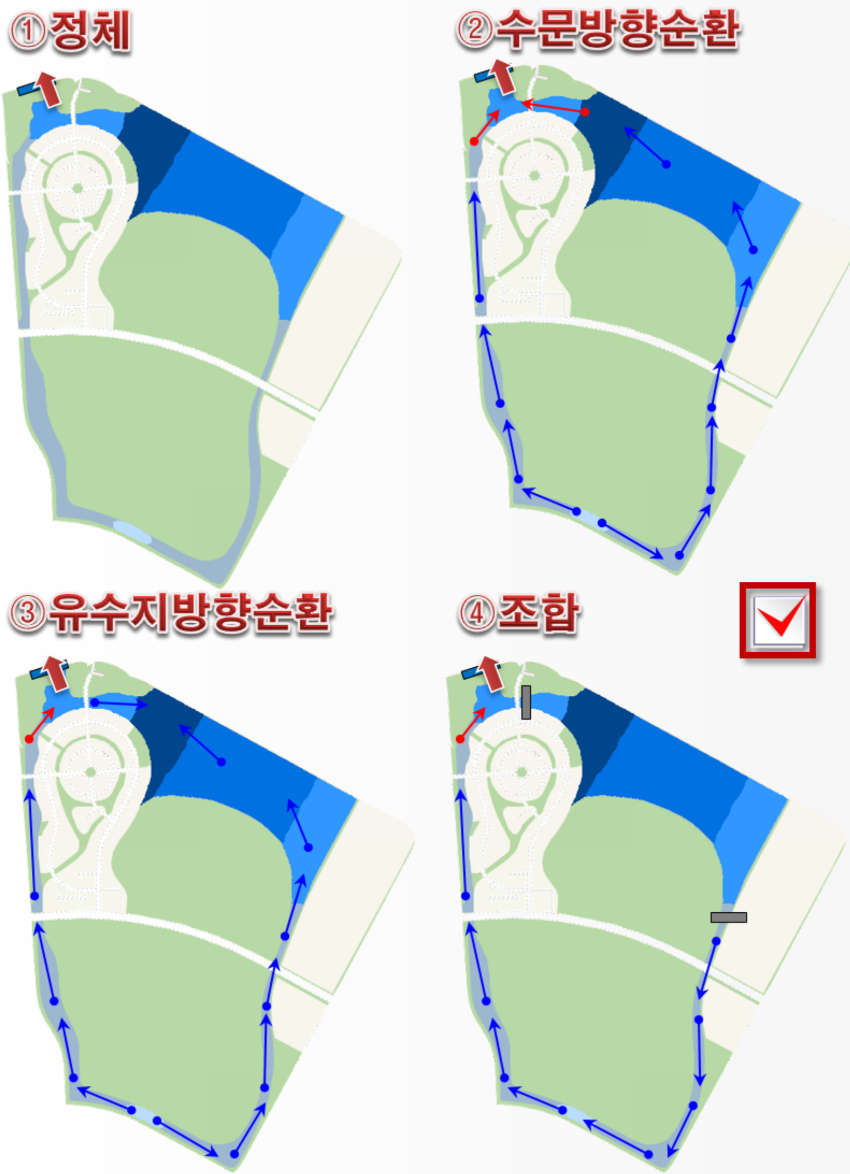
3.1 Application of nonpoint source input control (4)

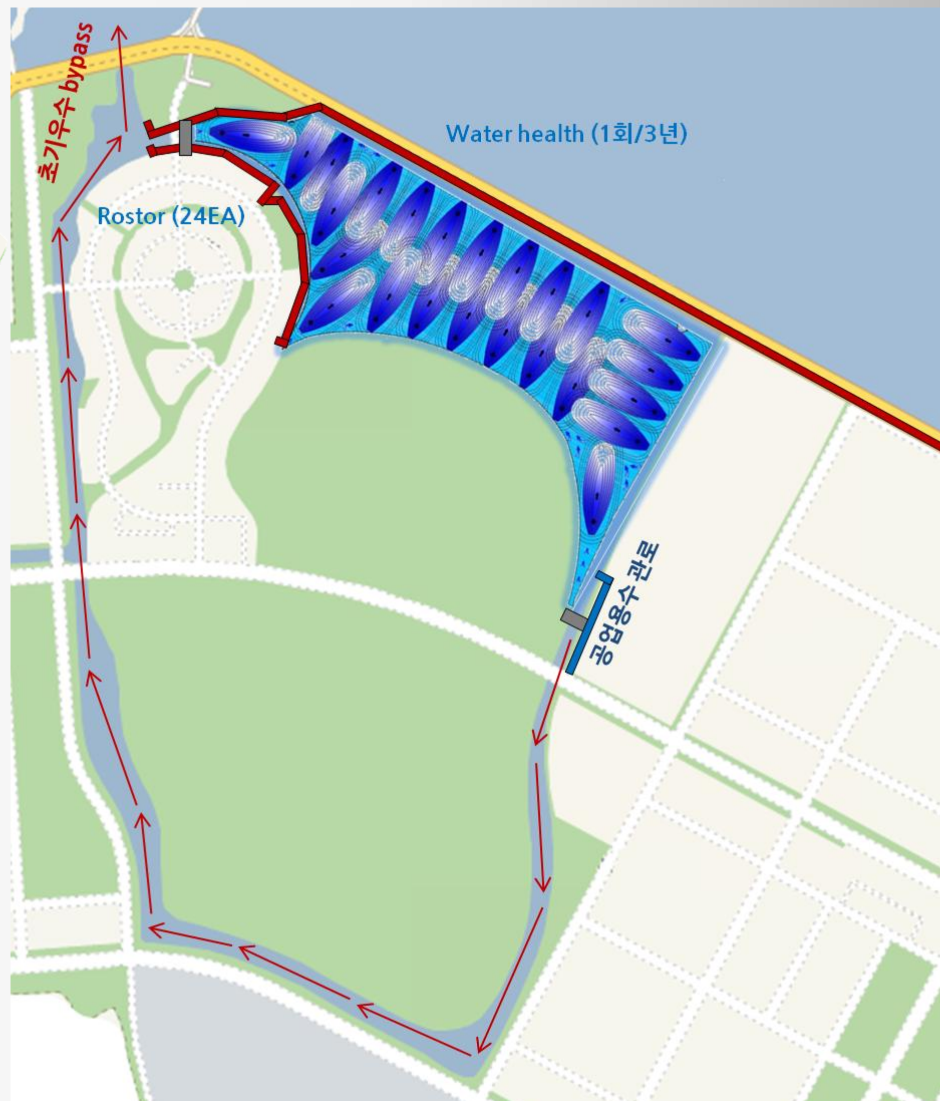
Low Impact Development (4) (Kim, 2014)



3.1 Application of nonpoint source input control (5)

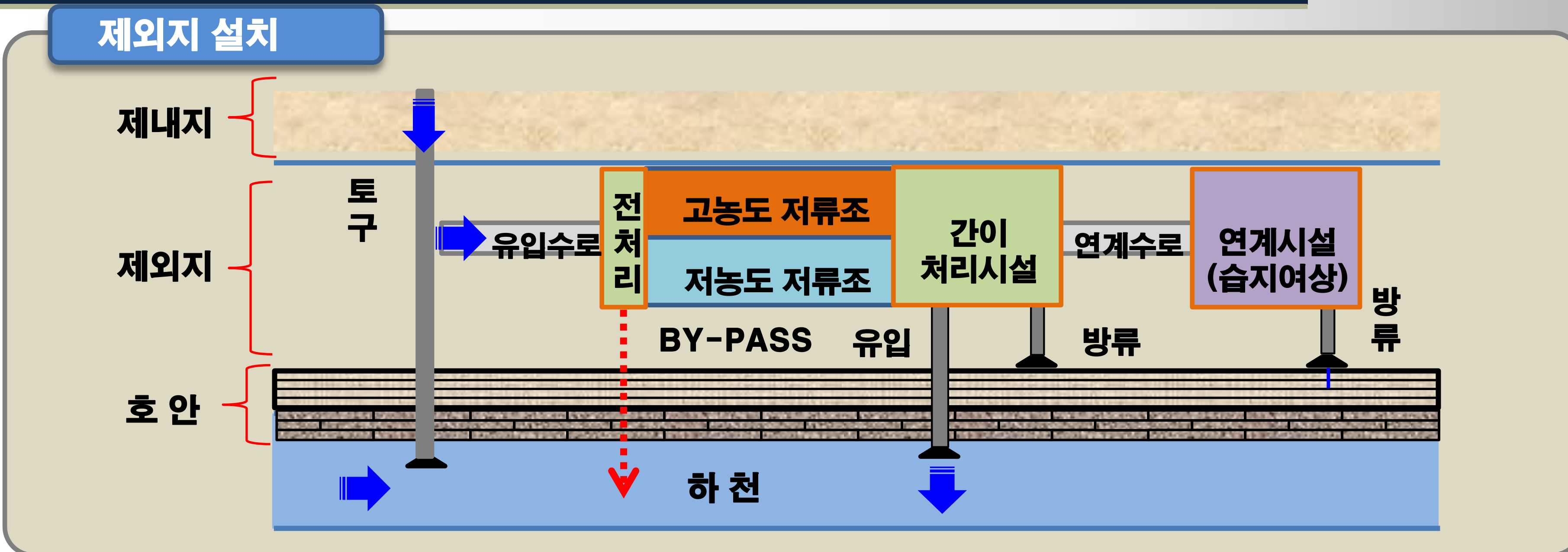
Artificial drainage & discharge of input pollutant loadings (Joo, 2014)





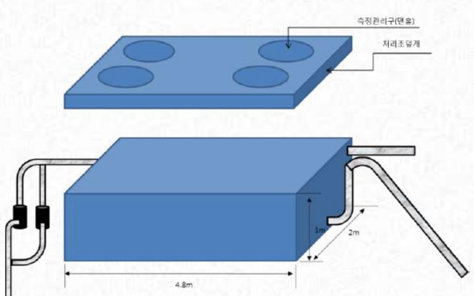
3.1 Application of nonpoint source input control (6)

Artificial drainage & discharge of input pollutant loadings (2)



3.1 Application of nonpoint source input control (7)

Artificial drainage & discharge of input pollutant loadings (3) (KICT, 2015)



분석항목	유입수 (mg/L)	처리수 (mg/L)	처리효율 (%)
SS	29.0	10.0	65.6
COD	14.3	12.2	14.7
T-P	0.08	0.02	70.8
T-N	6.0	4.0	33.3

※ 11월 12일 모니터링 분석 결과

3.2 Application of algae harvesting ship (1)

Various alage harvesting ship with different processes

3.2 Application of algae harvesting ship (2)

Alage harvesting ship with natural coagulants & recovery (MCE, 2015)

녹조제거선 : 고효율 조류제거 및 회수장치

- 전처리 : 조류제거제 Water-Health 혼합 및 살포 / 수초제거
- 회수장치 : 살조된 조류슬러지 제거 및 회수
- 후처리 : 탈수처리system (자연탈수)

조류제거 및 회수장치/수초제거

1. 조류제거제 워터헬스의 수상살포
2. 조류의 응집-부상과정
3. 부상된 조류슬러지의 회수장치
4. 회수된 조류슬러지의 자연탈수System

☞ 댐, 저수지의 효율적인 조류제거

전처리

천연조류제거제 원터헬스 혼합 및 살포

반응과정

조류슬러지 응집-부상과정

회수과정

슬러지회수과정

분리과정

조류와 이물질의 분리과정

후처리

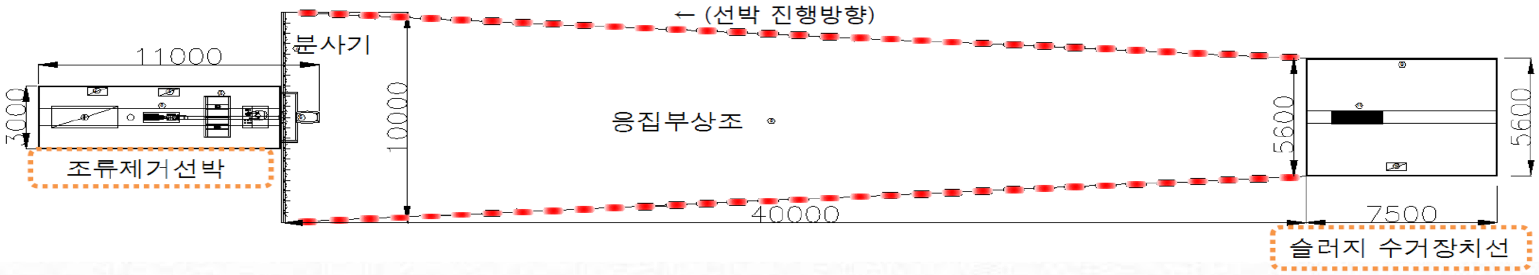
탈수system (녹조슬러지 탈수장치)

3.2 Application of algae harvesting ship (3)

Alage harvesting ship with rapid coagulants & dissolved air flotation (SD, 2015)

- 응집제+미세기포 → 조류,영양염류 제거량中
- 조류증식률을 넘는 조류수거량 확보에 어려움
- 부유슬러지 미회수 가능성, 슬러지량中
- 중급 호소 정도의 처리수량에 적합함

- 응집제+미세기포 → 조류,영양염류 제거량大
- 조류증식률을 넘는 수거량 확보, 신속한 상황개선
- 폐쇄계 구성, 미회수 거의 없음, 슬러지량大
- 댐, 보 등 대형 호소 급 처리수량에 적합함

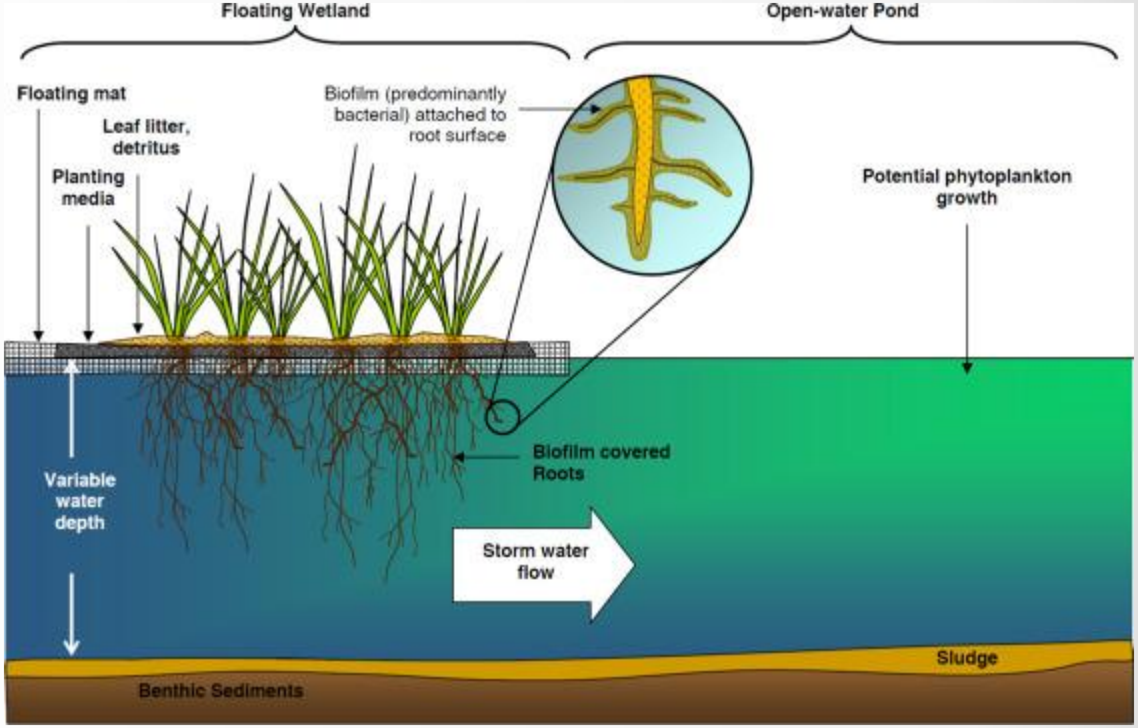


응집제 살포 → 응집+미세기포 부착 → 부상 및 농축(스컴) → 조류 회수

3.3 Multifunctional AFIs (1)

Conventional artificial floating island (Yeh et al. 2015)

- **Artificial Floating Island (AFIs)**
  - Planting structure constructed with floating mats, floating aquatic plants, sediment-rooted emergent wetland plants and related ecological communities;
  - Removal of excess nutrients (N & P) & Providing the floating habitat platforms;
  - Inhibition of potential phytoplankton growth by shielding and removing nutrients.

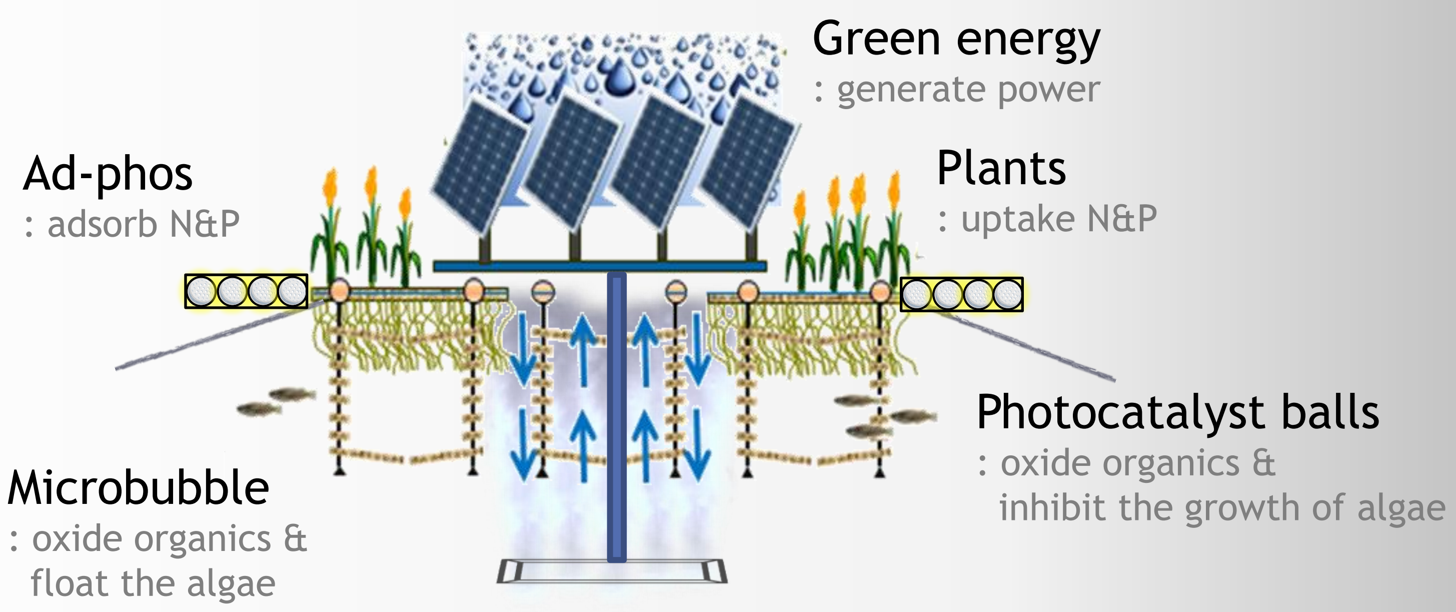


3.3 Multifunctional AFIs (2)

Schematics of multifunctional artificial floating island

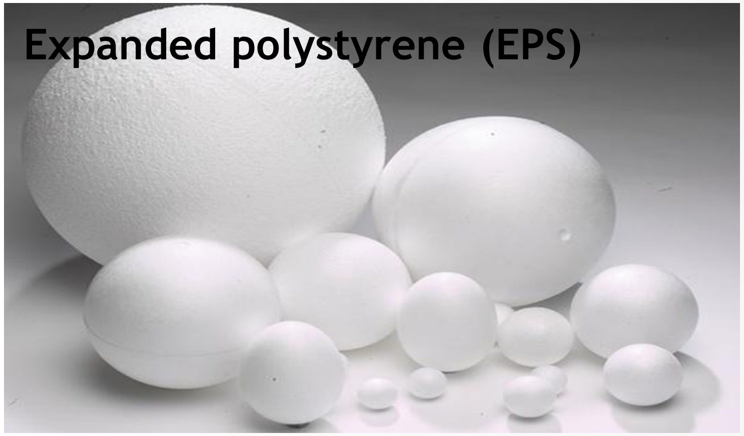
Multifunctional artificial floating island (AFI) using microbubble and photocatalyst balls

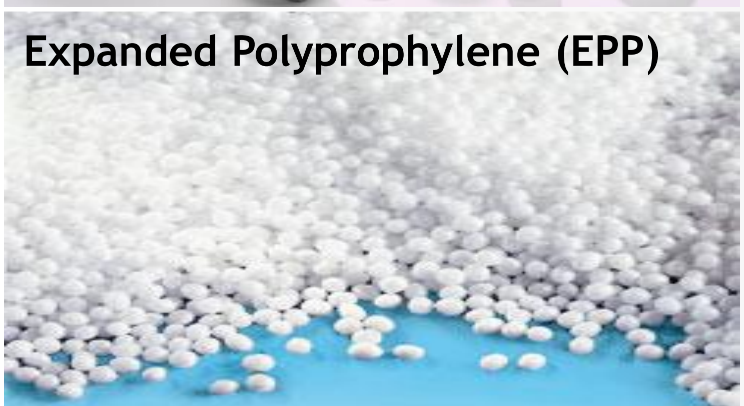
- Solar panels to generate the power for aerators;
- Ad-phos to adsorb the nitrogen and phosphorous;
- Plants to uptake the nitrogen and phosphorous and to provide the habitats;
- Microbubble to oxide organics and to float the algae
- Photocatalyst balls to oxide organics and to inhibit the growth of algae



3.3 Multifunctional AFIs (3)

Materials & Methods





Combination

- Photocatalyst balls for rivers and lakes
  - Self-floating with good flexibility;
  - High resistance to chemicals and fatigues;
  - Non-toxic to environment;
  - Field applicability with low cost;
  - Sun light-activated photocatalysts; and,
  - Simple and easy massive production.

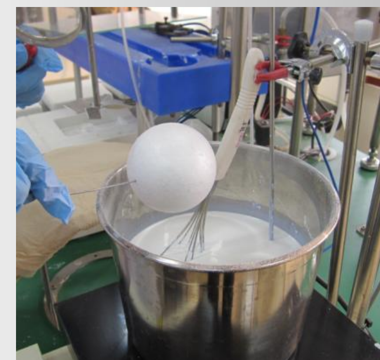
3.3 Multifunctional AFIs (4)

Materials & Methods

1. Pour a glycerin in stainless bowl

2. Add a TiO_2 powder into glycerin

3. heat up(at 140 ℃) and mix TiO_2 powder, glycerin until well blended



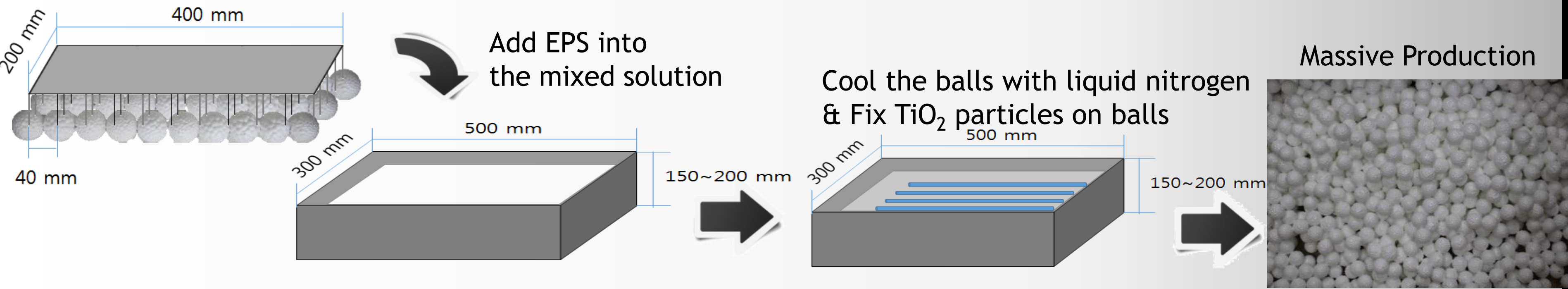
4. Add EPS into the mixed solution(at melting point of EPS, 140~145 ℃)

5. Cool the TiO_2 embedded EPS in a bowl placed in ice water

6. Natural drying Vs. freeze drying

3.3 Multifunctional AFIs (5)

Materials & Methods



Produce 25 balls per minutes

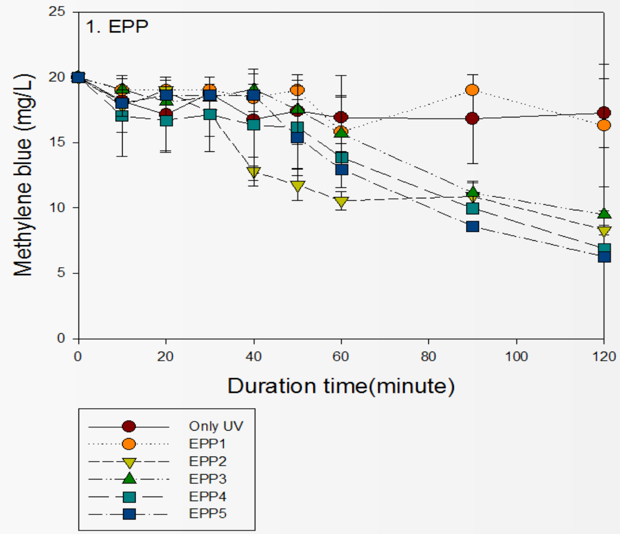
3.3 Multifunctional AFIs (6)

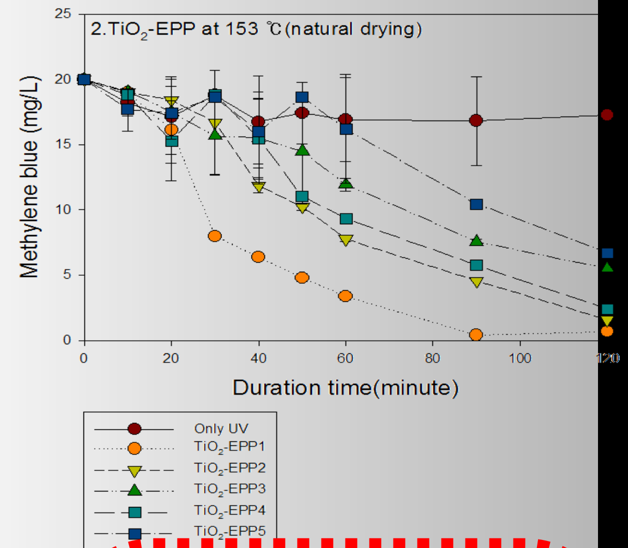
Methylene blue(MB) decomposition w/ different manufacturing process of balls

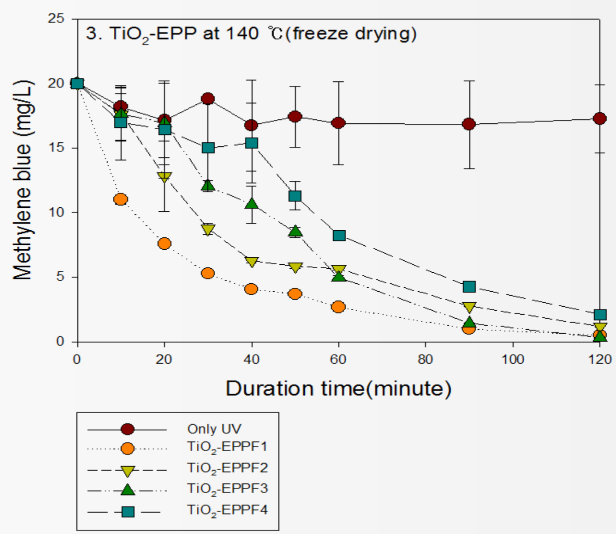
<Decomposition efficiency of MB> (unit:%)

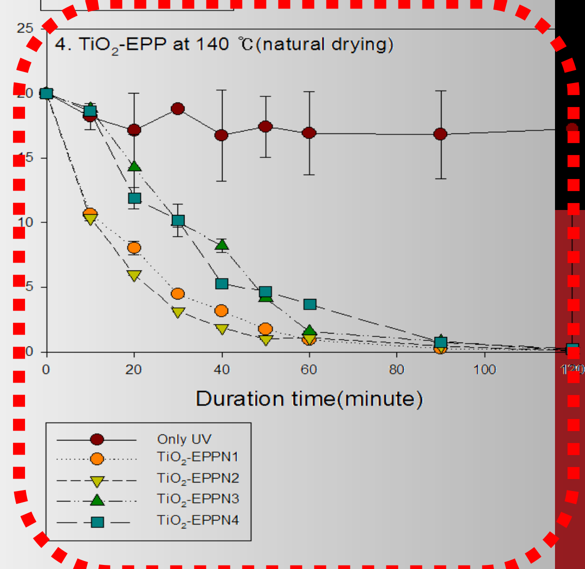
	T1	T2	T3	T4	T5
1.EPP	18.5	58.5	52.6	65.5	68.7
2.TiO_2-EPP at 153℃ (natural drying)	96.7	92.1	72.5	87.9	66.4
3.TiO_2-EPP at 140℃ (freeze drying)	96.5	94.1	98.3	89.4	-
4.TiO_2-EPP at 140℃ (natural drying)	99.4	99.5	99.5	98.9	-

- Fast degradation of methylene blue under the UVC irradiation;
- Temperature of 140 ℃ and natural drying are better than other methods.









3.3 Multifunctional AFIs (7)

SEM, SEM-EDS analysis

- Results of surface and component analysis
  - EPP: smooth surface w/o pores & impregnated TiO_2 as a patch
  - EPS: rough surface w/ pores & impregnated TiO_2 as a film
- Selection of the photocatalyst balls → EPS
  - EPS with various sizes is commercially available;
  - Attachment rate of TiO_2 to EPS is greater than that to EPP;
  - EPS has greater surface area and durability with low cost.

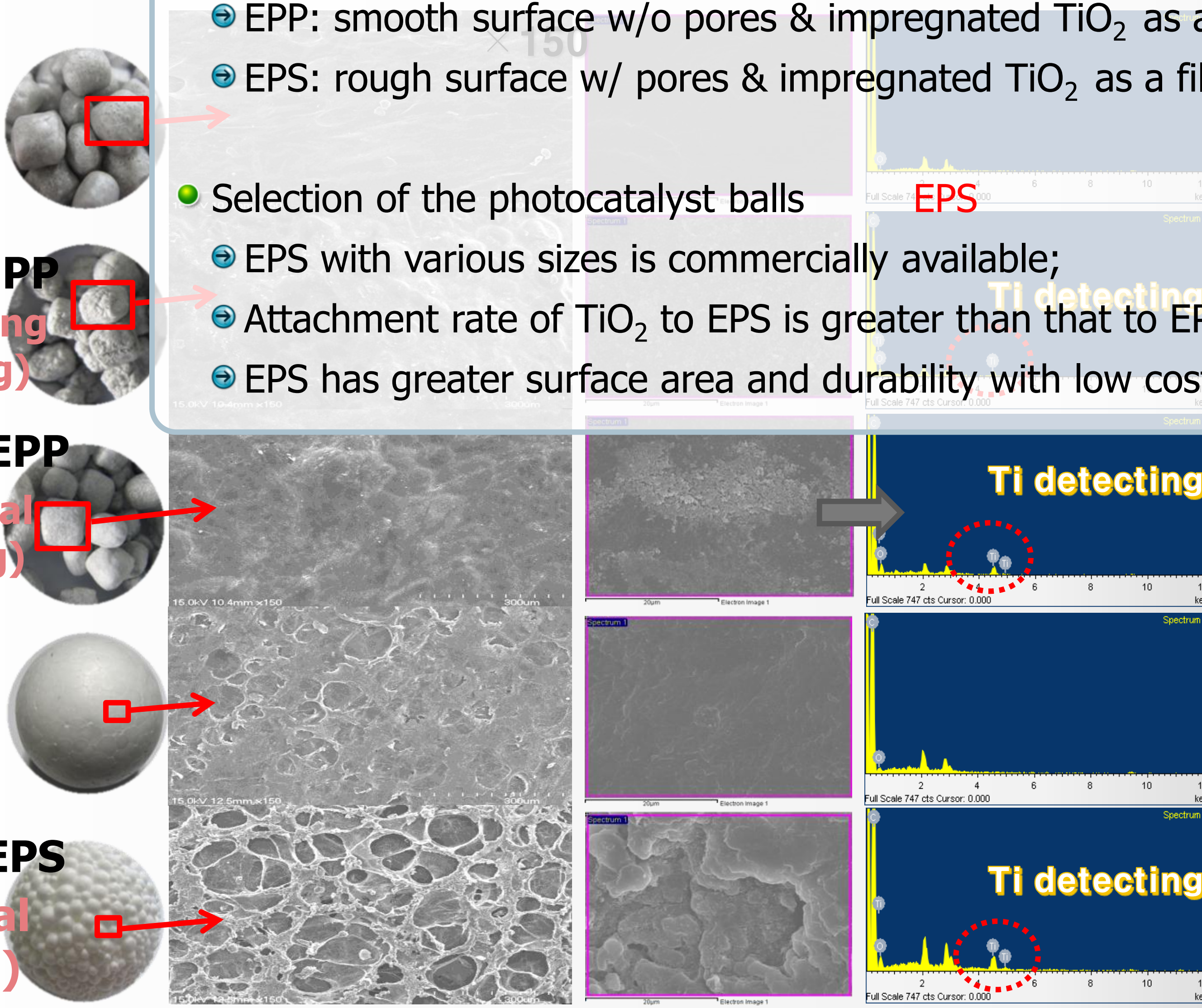
EPP

TiO_2-EPP (freezing drying)

TiO_2-EPP (natural drying)

EPS

TiO_2-EPS (natural drying)



Element	Weight%	Atomic%
C	94.59	95.88
O	5.41	4.12
Totals	100.00	

Element	Weight%	Atomic%
C	85.39	90.55
O	10.49	8.35
Ti	4.12	1.09
Totals	100.00	

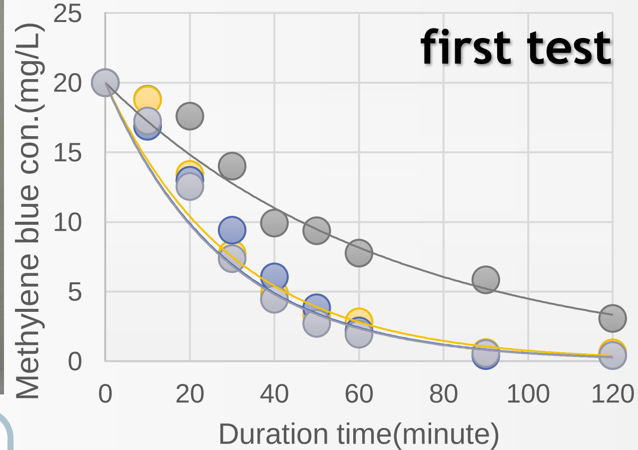
Element	Weight%	Atomic%
C	80.57	87.54
O	13.19	10.76
Ti	6.24	1.70
Totals	100.00	

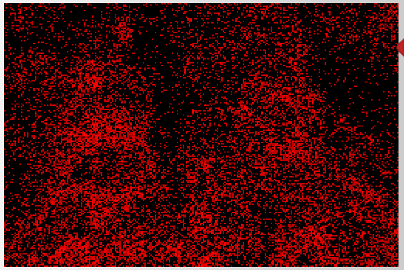
Element	Weight%	Atomic%
C	95.42	96.52
O	4.58	3.48
Totals	100.00	

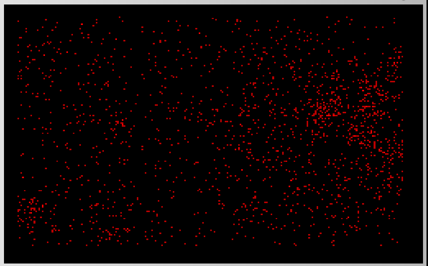
Element	Weight%	Atomic%
C	76.50	85.66
O	13.79	11.59
Ti	9.71	2.68
Totals	100.00	

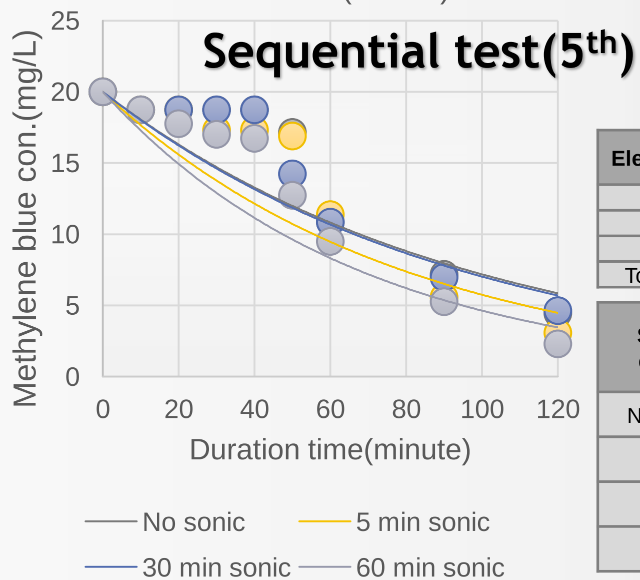
3.3 Multifunctional AFIs (8)

Detachment of TiO_2 by external shocks









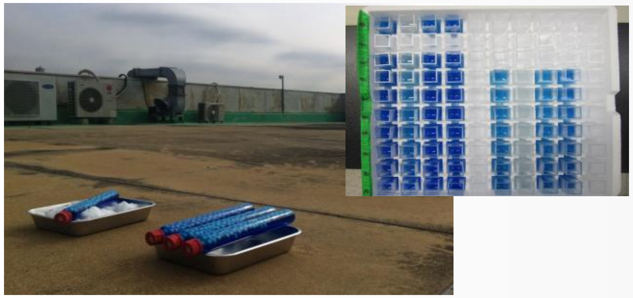
- After sonication, TiO_2 particles were still imbedded;
- After sonication, photodegradation efficiency became greater due to decoating of the glycerin film;
- After five sequential tests, photodegradation still works;
- Long-term durability of TiO_2 photocatalyst balls were proved.

Element	First test		Rerun a test(5th)	
	Weight%	Atomic%	Weight%	Atomic%
C	76.5	85.7	76.6	83.5
O	13.8	11.6	18.5	15.2
Ti	9.7	2.7	4.9	1.3
Totals	100.0	100.0	100.0	100.0

Sonication effect time	First test		Rerun a test(5th)	
	k	R^2	k	R^2
No sonication	0.015	0.9744	0.010	0.8224
10 min	0.033	0.9562	0.012	0.8212
30 min	0.035	0.9485	0.010	0.8653
60 min	0.036	0.9690	0.015	0.8733

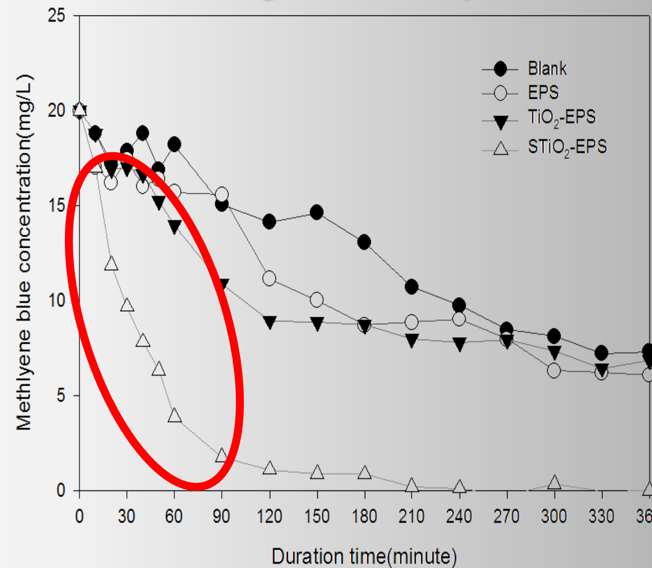
3.3 Multifunctional AFIs (9)

Sunlight activity and temperature, pH effect

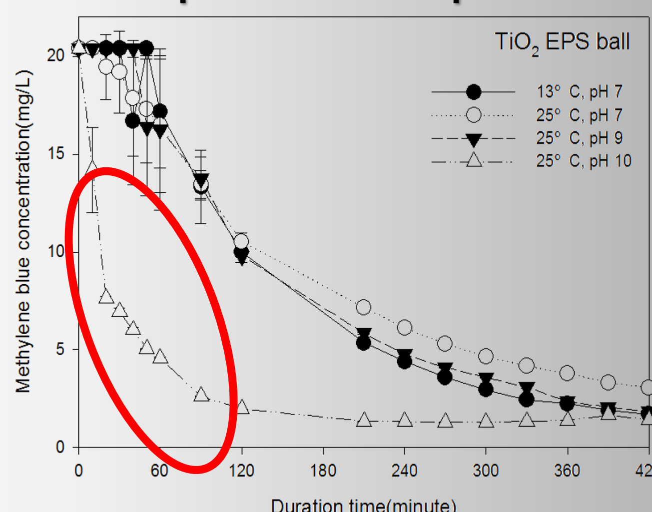


- The methylene blue was 99% removed within two hours using TiO_2-coated EPS under the natural sunlight;
- The removal efficiency of methylene blue was better at pH 10 and at low temperature;
- Considering the pH of natural rivers and lakes is around 7-9, application of TiO_2-coated EPS is feasible.

<Sunlight activity test>



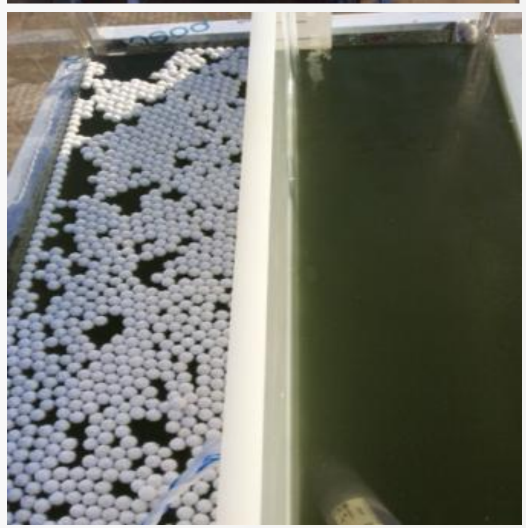
<Temperature and pH effect>



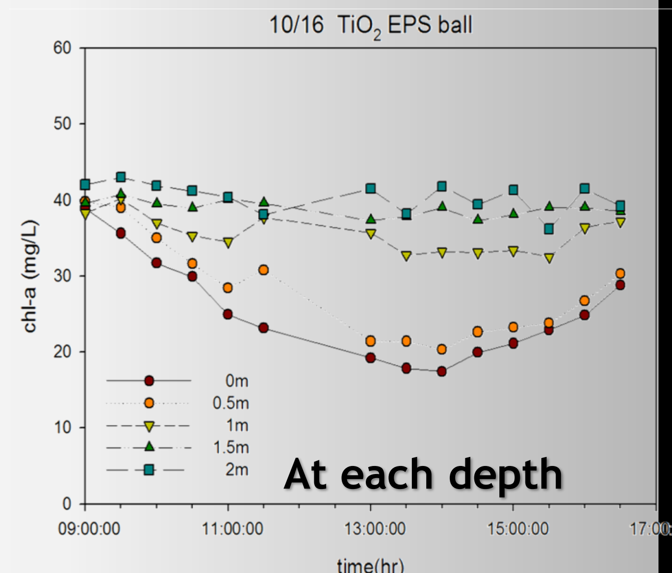
3.3 Multifunctional AFIs (10)

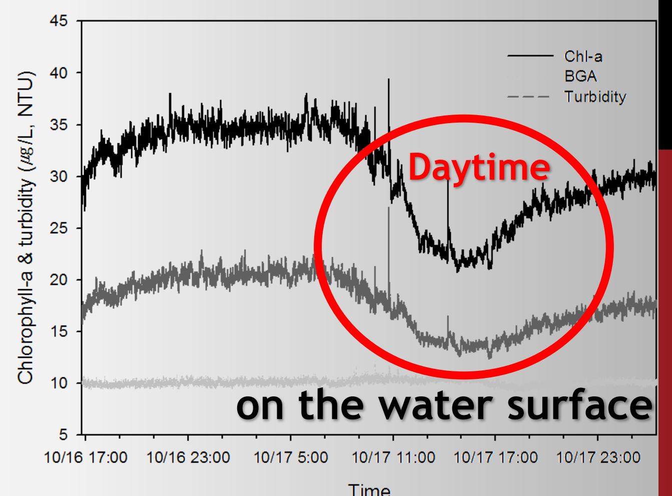
Inhibition of algal growth

- Chl-*a* concentration was monitored using the real time sensor;
- Under the photocatalyst balls, Chl–*a* values on the water surface decreased during the day time;
- The growth of algae can be inhibited using TiO_2-coated EPS balls due to both shielding of sunlight and radical attack to algae;
- Further field study is in progress.



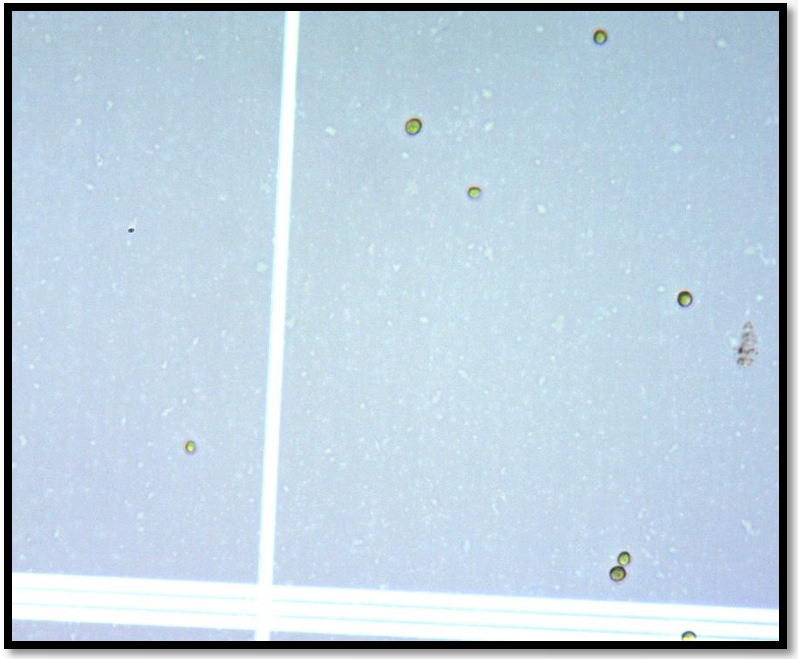
<Concentration of chlorophyll-a>



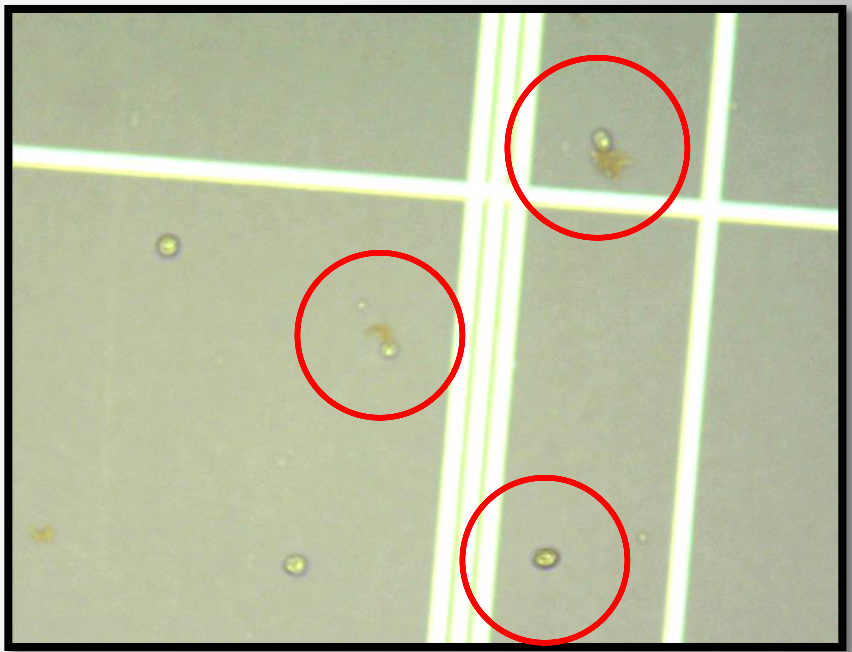


3.3 Multifunctional AFIs (11)

Damages in cell wall



Under the sunlight (after 100 hrs)



With the TiO_2-EPS balls under the natural sunlight (after 100 hrs)

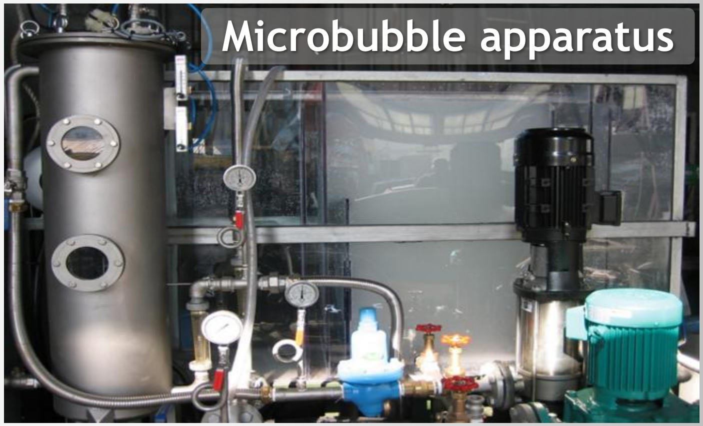
- Damages in cell wall & extraction of inner organisms of algal community by TiO_2-EPS balls under the natural sunlight were proved.

3.3 Multifunctional AFIs (12)

Optimal operation parameters of microbubble apparatus

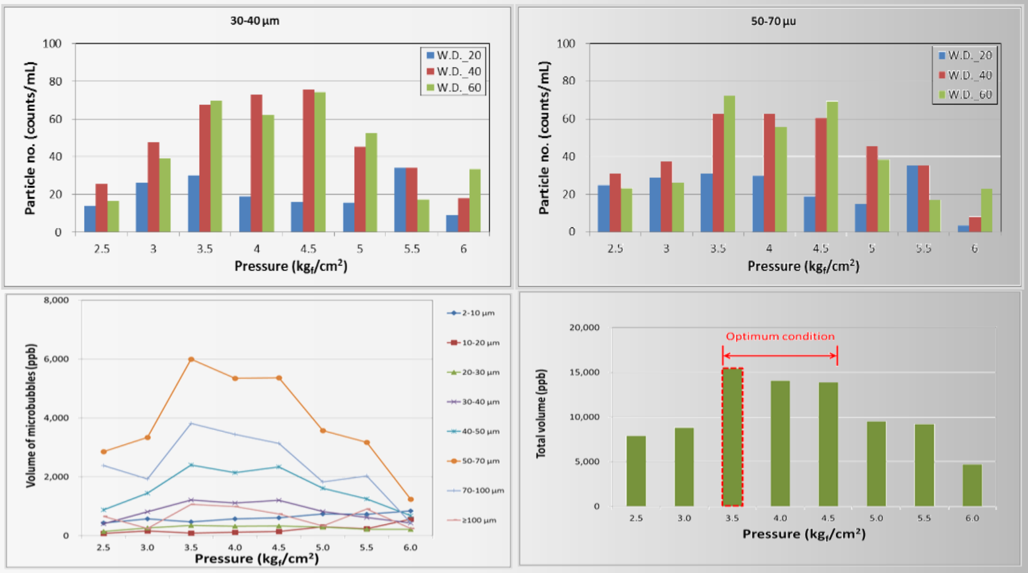
<Test condition>

	Test A	Test B	Test C
Pressure (kg_f/cm^2)	2.5~6.0	2.5~6.0	3.5
Flow(L/min)	16	16	5~50
Depth(cm)	20, 40, 60	40	40



A. Optimal operating pressure

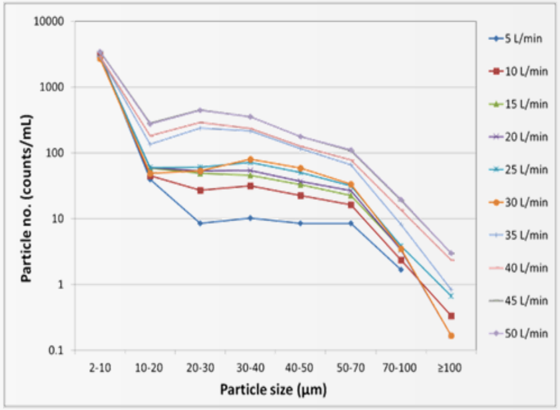
- 3.5~4.5 kgf/cm^2 is the optimal operating pressure to produce the microbubbles;
- Size of bubbles were sub-micro ranges with average diameter of 1~20 μm.



3.3 Multifunctional AFIs (13)

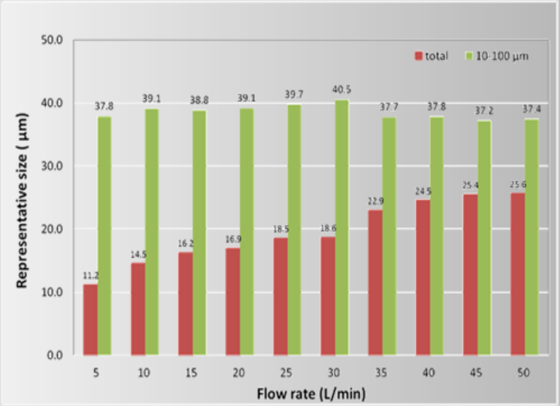
B. Optimal flow rate

- The optimal flow rate was found to be 35~50 L/min;
- The particle size hasn't changed during floatation (range: 10-100 μm).



<입경대별 마이크로버블 입자수 변화>

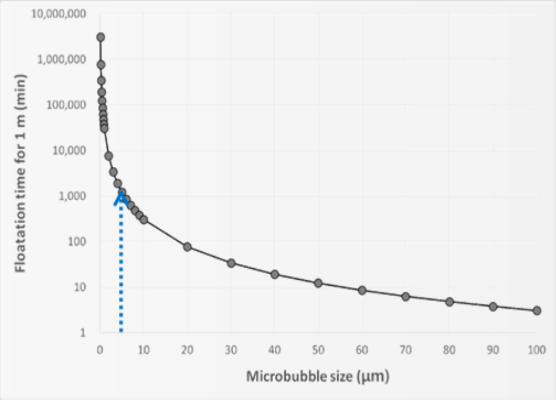
(n=5)



<마이크로버블 대표입경의 변화>

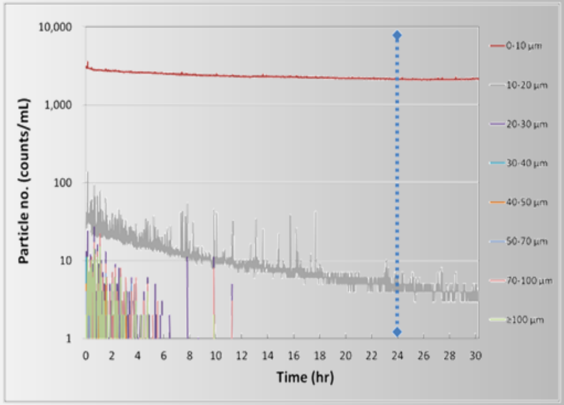
C. Rising speed and sustainability of micro-bubble

- Micro-bubbles with less than 20 ㎛ size still remain in water after 24 hours;
- Field application of microbubbles is in progress.



<마이크로버블의 이론적 상승속도 및 지속특성(Stokes' law)>

(Measuring frequency: 1 min)

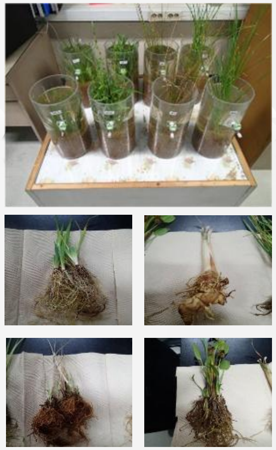


<운전 정지 후 마이크로버블 잔류특성>

3.3 Multifunctional AFIs (14)

Water purification plant

- The removal efficiencies of each contaminant were different for each plant;
- *Iris pseudoacorus* was found to better remove the nitrogen in water;
- COD(photocatalyst ball) and T-P(media) can be removed from other processes in AFIs.



Average Removal Rates	COD (%)	T-N (%)	T-P (%)
Acorus calamus L.	25.2	30.8	25.6
Iris pseudacorus L.	38.9	63.9	16.0
Juncus effuusus var.	24.0	32.4	22.0
Typha orientalis C.Presl	40.4	44.4	25.9
Oenanthe javanica (Blume) DC.	21.1	38.8	65.3
Pennisetum alopecuroides (L.) Spreng.	22.2	41.9	9.4
Alisma orientale (Sam.) Juz.	16.7	27.6	-

Phosphorus adsorption media

- Among the various adsorption media, Ad-phos media had better SS, COD, T-N and T-P removal efficiencies;
- The adsorption amounts of T-P to Ad-phos media was found to be greater.


Zeolite


Volcanic stone


Ad-phos

Remove rate (%)	SS	COD	T-N	T-P
Zeolite	-	6.7	59.3	4.4
Volcanic stone	41.7	8.8	12.9	69.1
Ad-phos	74.7	28.8	65.5	**81.7**

3.3 Multifunctional AFIs (15)

Test-bed Construction

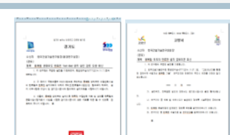
- Target area: Hallyu stream, Ilsandong-gu, Goyang-si, Gyeonggi-do, Korea;
- River extension: 1.3 km, Bed slope: 1/2,600;
- Plan('15. 01), Making('15. 02), Construction('15. 03);
- Period of operation: 2015. 04 ~ 2017. 06.

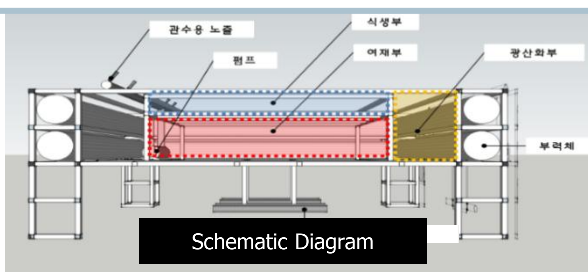

정체구간형성


조류발생

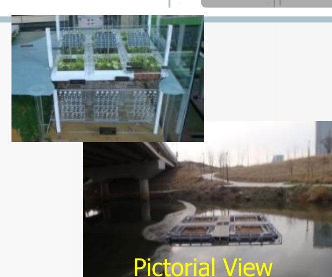
The main points of test-bed for selection

- Easy to verify water quality improvement;
- Convenience of maintenance control;
- Stagnant water and easy to access.


Approval Letters



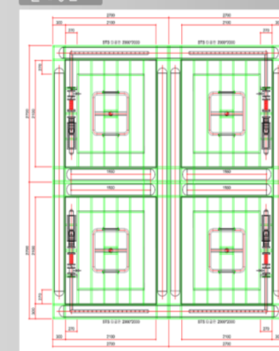
Schematic Diagram


Pictorial View

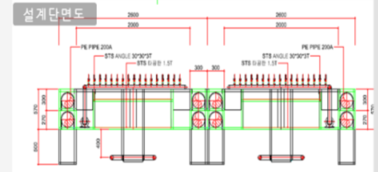
Design

구분	내용
형태	정사각형 구조
규격	2.7 m × 2.7 m (총 4개 연결 설치)
재질	프레임 (SUS), 부력체 (PE 파이프)
마이크로버블 발생 방식	압력펌프 직결식
광산화 흡착 ball	TiO_2 코팅 자연광 촉매형
여재 및 충고	적용여재 (adphos), 여재층 (30 cm)
식재 및 기반	식재 (꽃창포), 기반 (경량인공토 10 cm)
제어방식	PLC 기반 on-site 자동제어

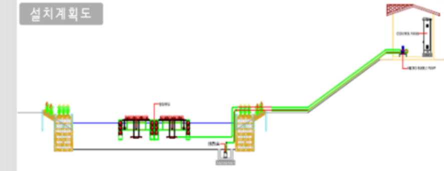
설계평면도



설계단면도



설치계획도



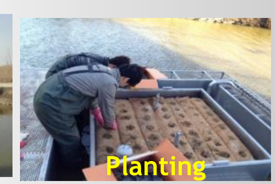
Construction

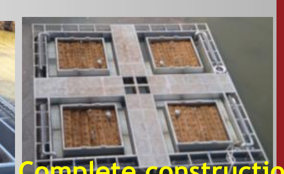

Making framework


Micro-bubble


Assembly


Installation


Planting


Complete construction

3.3 Multifunctional AFIs (16)

Seasonal variations

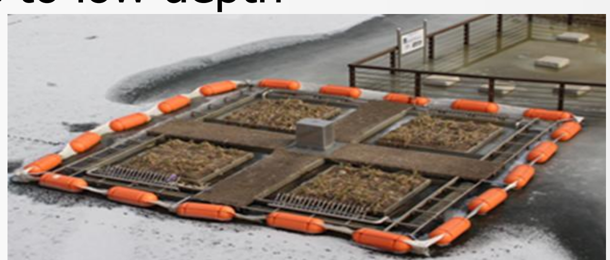
Early summer(rainy season): turbid water by nonpoint and point sources



Summer and early autumn(dry season): Occurrence of algal blooms

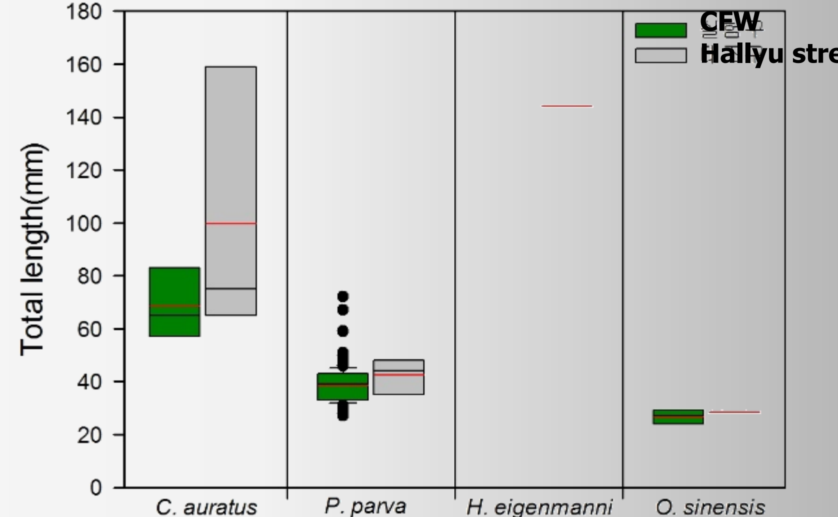


Winter: Ice was covered due to low depth

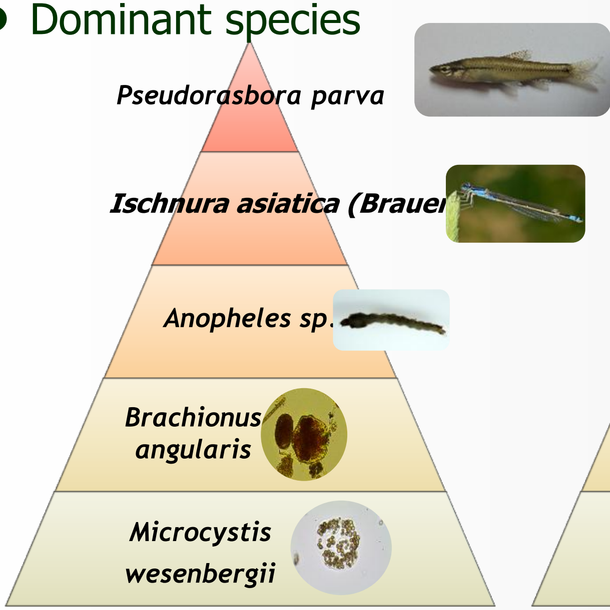



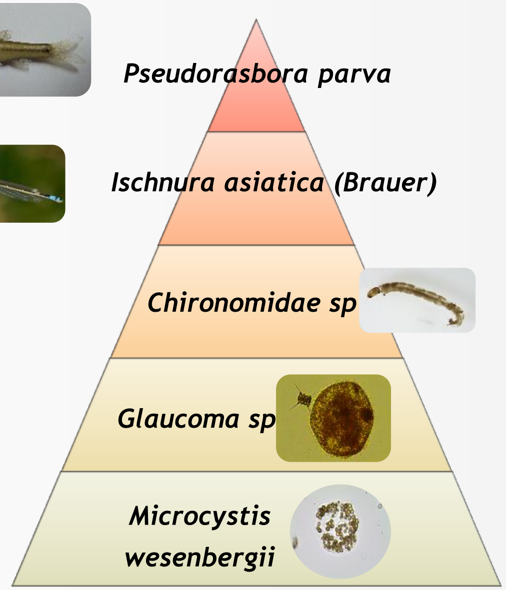

3.3 Multifunctional AFIs (17)

Ecological research



- Dominant species





- More benthic organism and phytoplankton were monitored below the converged floating wetlands;
- Since the new environment was built around the converged floating wetlands, Various and diverse mesocosm was monitored;
- However, hallyu stream was found to be severely polluted, and ecosystem needs to be restored;

3.3 Multifunctional AFIs (18)

Effect of water quality improvement

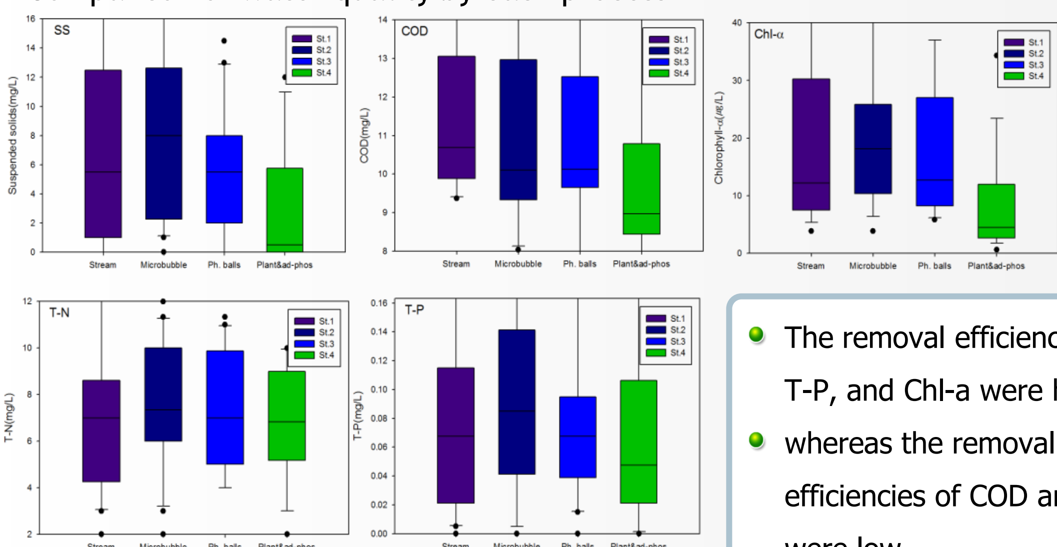
St. 1 Stream
Hallyu stream

St. 2 Micro bubble
Bottom up water by micro bubble

St. 4 Plants & Ad-phos
After plants uptake and adsorption of Ad-phos including the prior steps

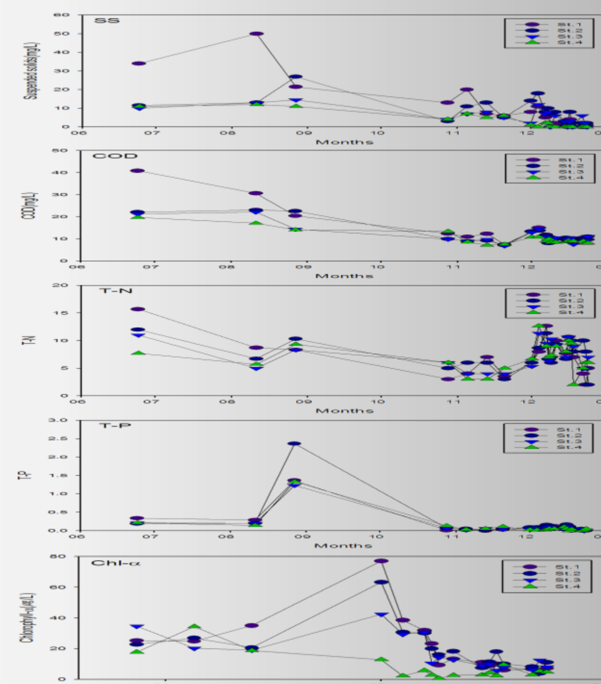
St. 3 Photocatalyst balls
After photocatlyst balls including the prior steps

Comparison of water quality by each process



- The removal efficiencies of SS, T-P, and Chl-a were high;
- whereas the removal efficiencies of COD and T-N were low.

Seasonal variation of water quality

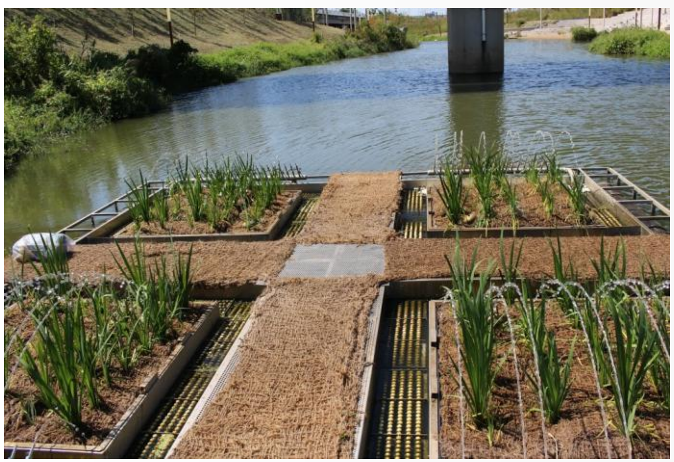


Process control rate of CFW and comparison with hallyu stream

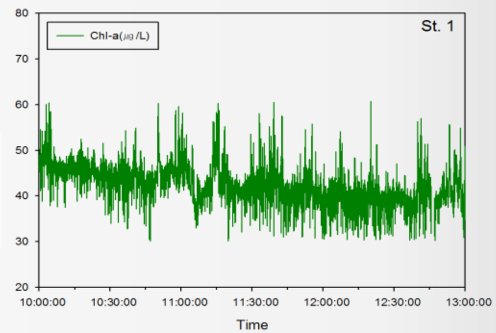
Average	SS (mg/L)	COD (mg/L)	Chl-a (㎍/L)	T-N (mg/L)	T-P (mg/L)
Removal rate of FAI (%)	77.5	15.7	63.9	28.8	65.3
Treatment water quality	3.05	10.1	6.4	6.6	0.15
Water quality in the stream	10.1	14.1	21.6	3.0	0.20

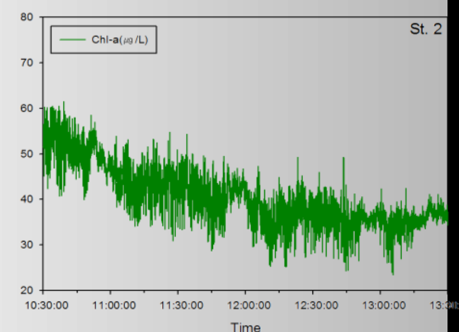
3.3 Multifunctional AFIs (19)

Real-time monitoring of Chl-*a*

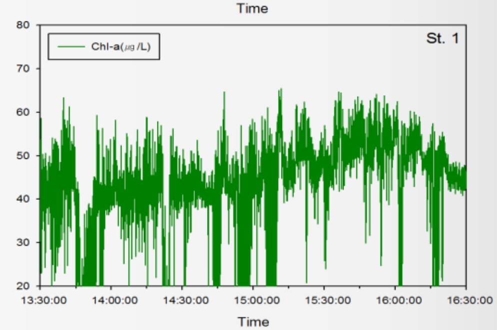


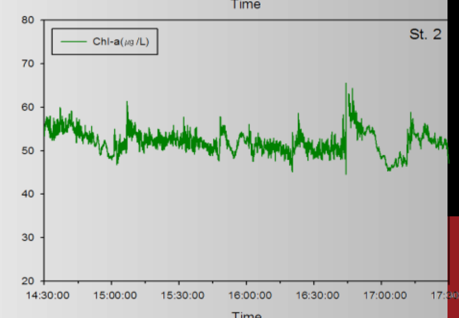
AM
(10:00
~13:00)





PM
(13:00
~18:00)

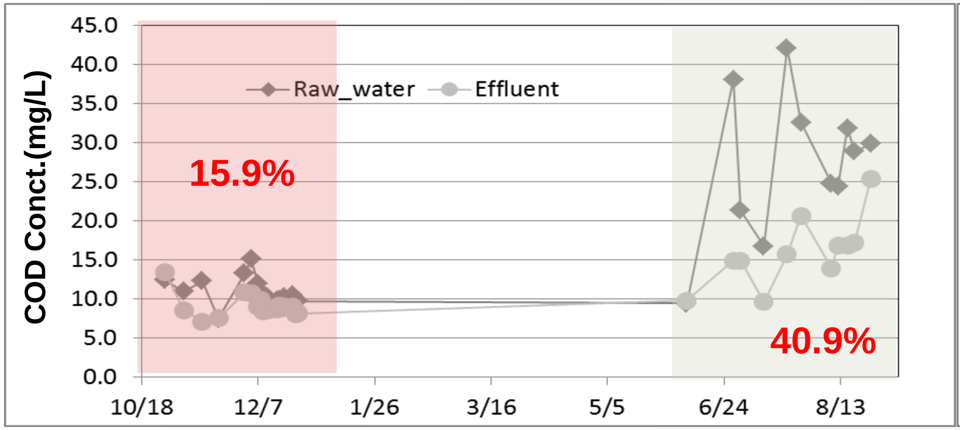


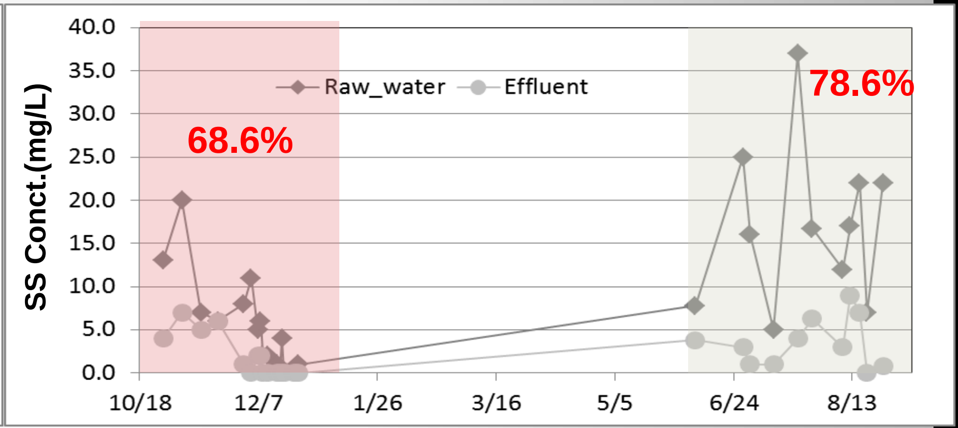


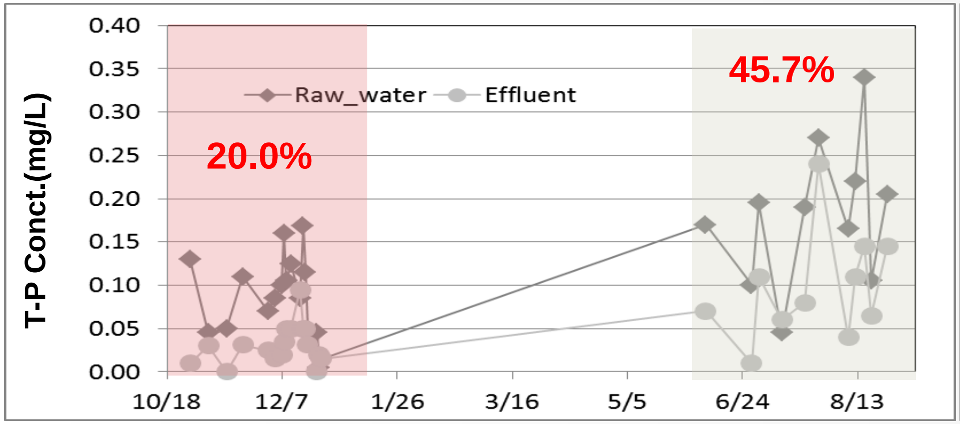
- The removal efficiency of Chl-*a* was monitored using Chl-*a* sensor inside/outside multifunctional AFI;
- The decrease in Chl-*a* concentration was not significant during the morning;
- The decrease in Chl-*a* concentration was significant during the day time;
- Multifunctional AFI can inhibit the growth of algae, and degrade the algae during the day time; and,
- The synergistic effects from microbubble, Ad-phos, and photocatalyst balls are expected.

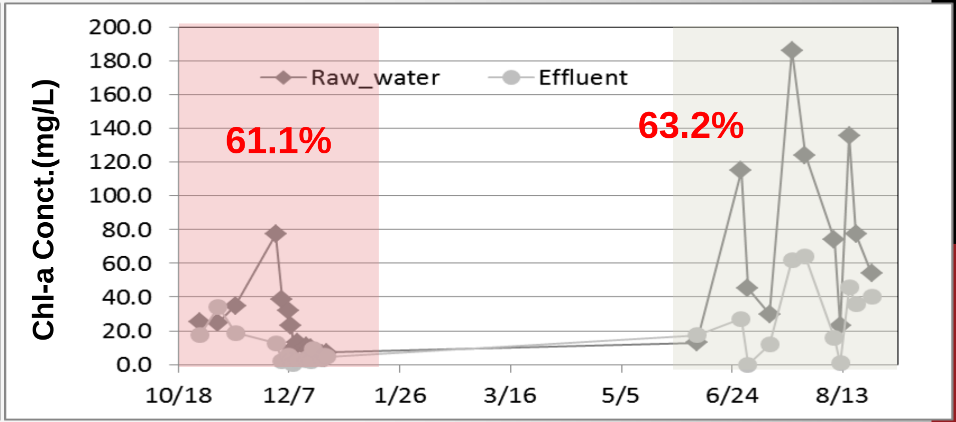
3.3 Multifunctional AFIs (20)

Seasonal variation of removal efficiencies









3.3 Multifunctional AFIs (21)

Several maintenance issues

Loss of soil materials

Input of floating wastes

Clogging of water input

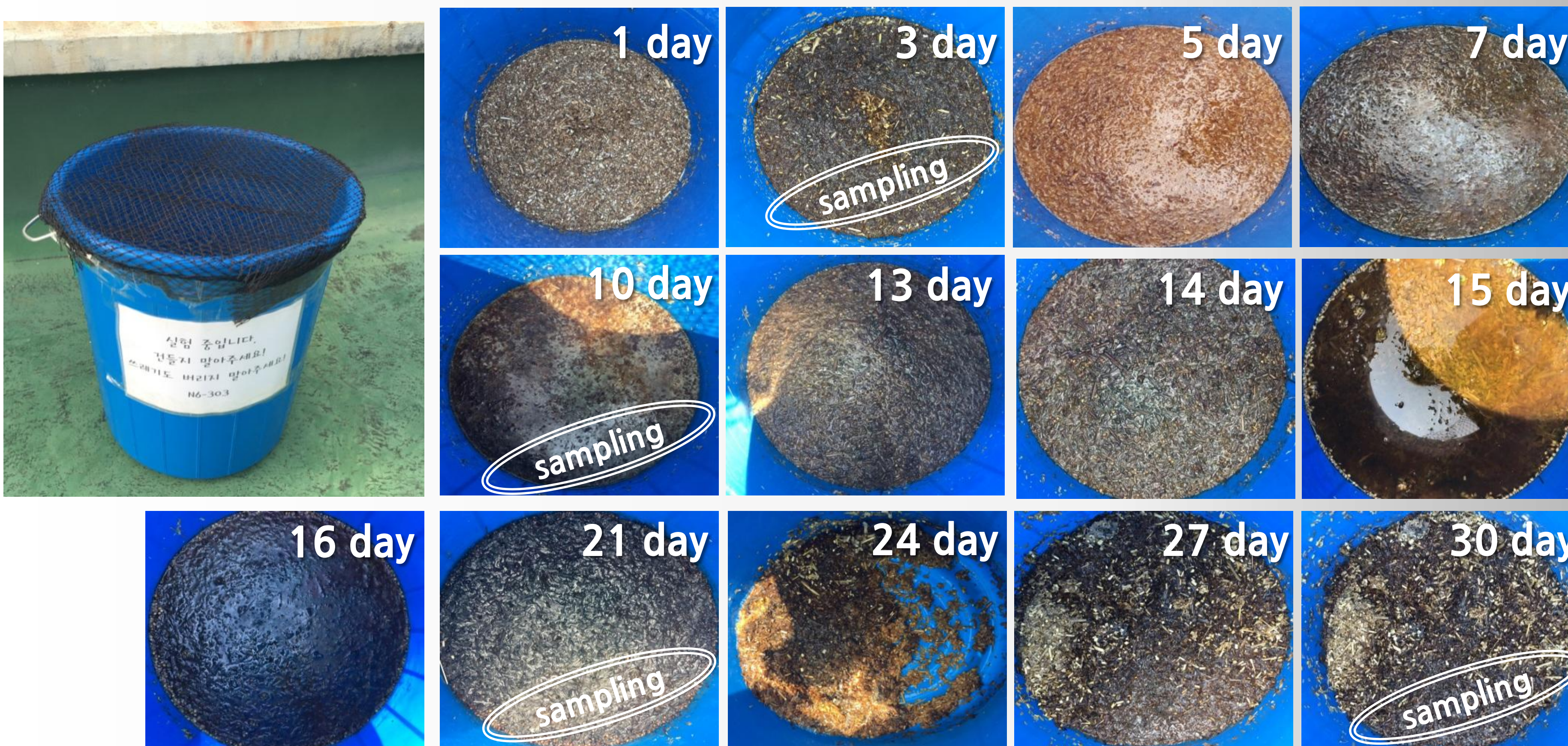
Contamination of photocatalyst balls

Accumulation of wastes around AFI

Moving of AFI

3.4 Application of Barley Straw (1)

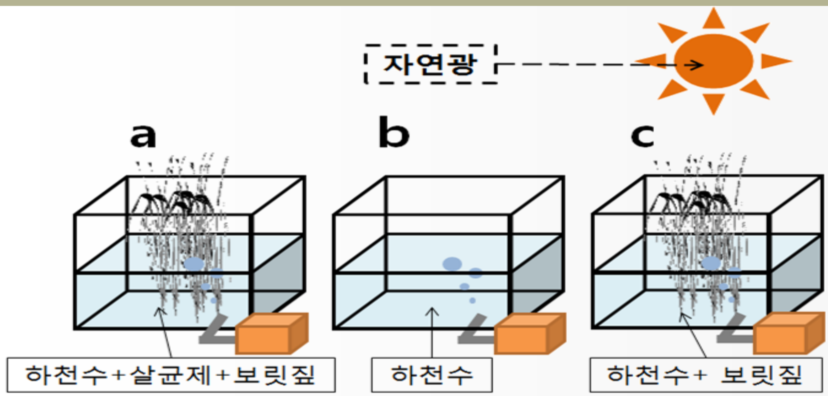
Degradation of barley straw

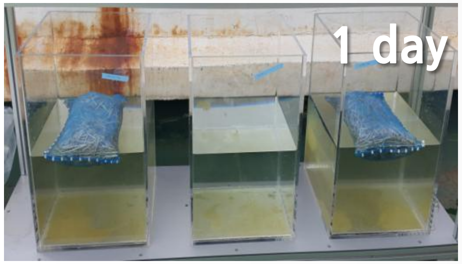


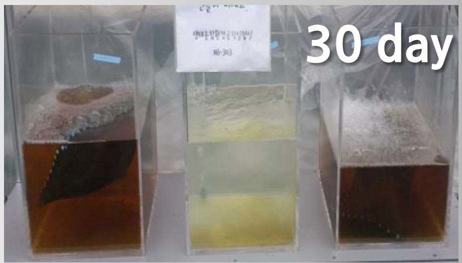
- Fungi decompose the barley in water, causing some chemicals to be released;
- The specific chemicals were identified as oxidized polyphenolics and hydrogen peroxide;
- The activity of barley straw is usually described as being algistatic (prevents new growth of algae); and,
- Barley straw may reduce phosphorus concentrations which in turn reduce phytoplankton growth

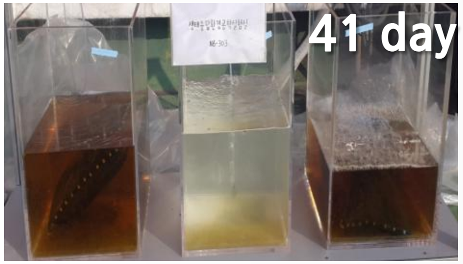
3.4 Application of Barley Straw (2)

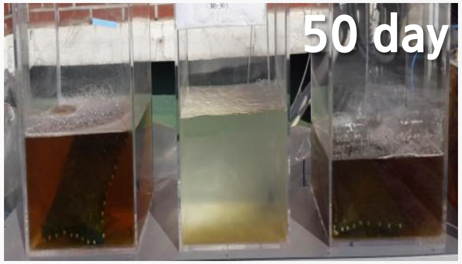
Chemicals from barley straw decomposition

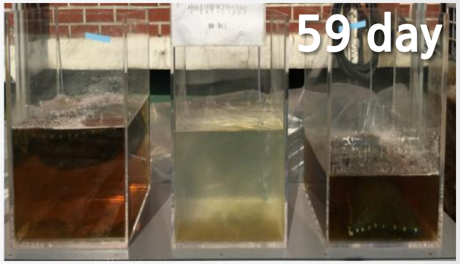


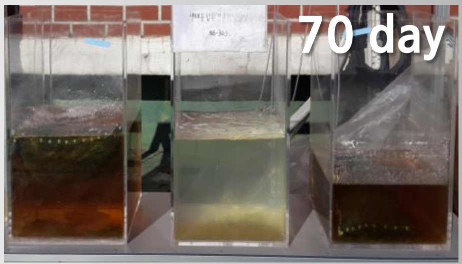


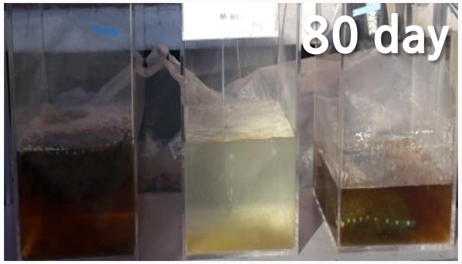


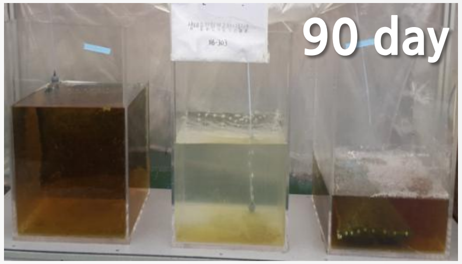


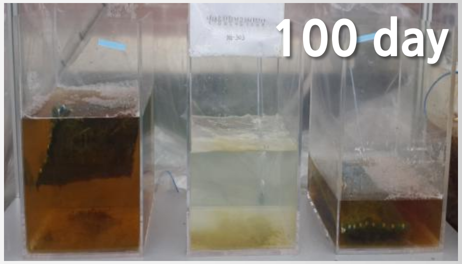








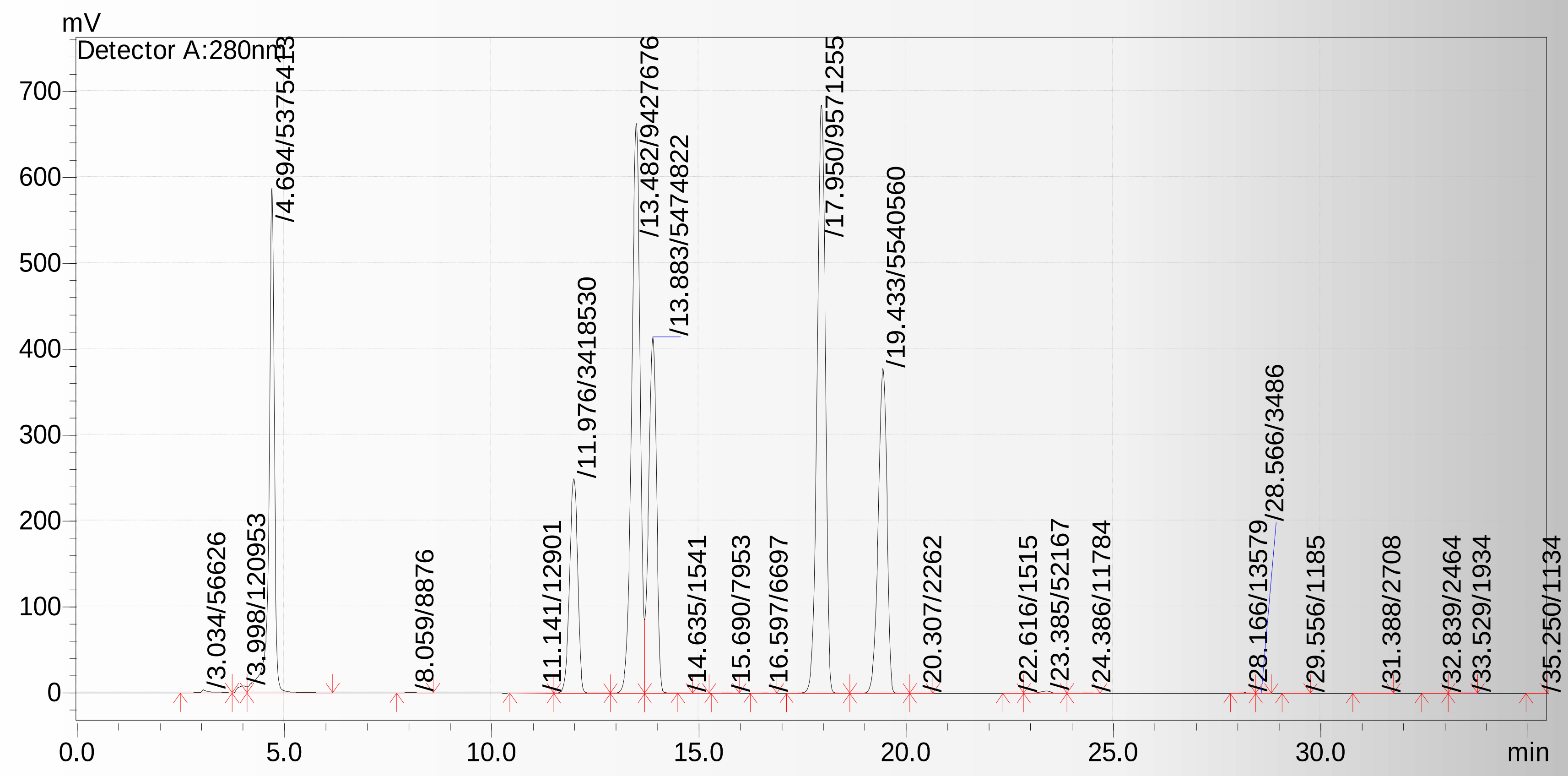




3.4 Application of Barley Straw (3)

Analysis of chemicals from barley straw decomposition

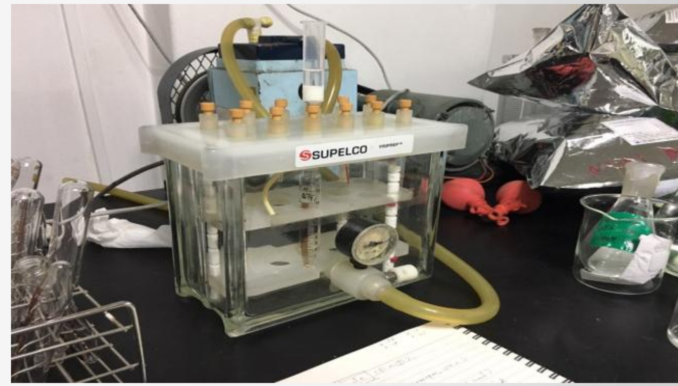
< Peak Sequence >
Gallic acid-Hydroxybenzoic acid – Vanillic acid,Caffeic acid – Syringic acid – Coumaric acid – Ferulic acid



3.4 Application of Barley Straw (4)

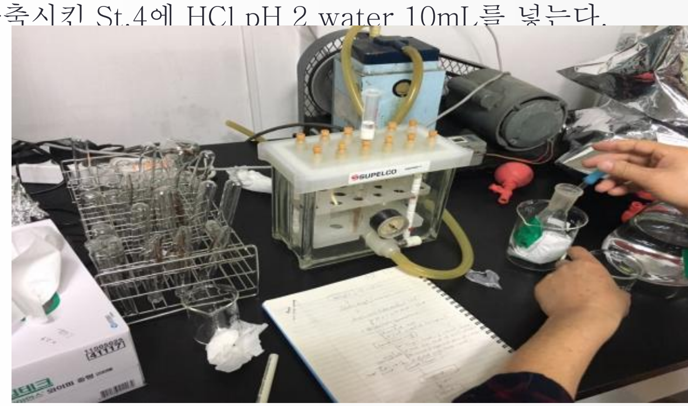
Analysis of chemicals from barley straw decomposition

1. St.4(1ppm) 10mL를 Vaccum Evaporater를 이용하여 농축시킨다.
   (Temp : 50℃)
2. 농축시킨 St.4에 HCl pH 2 water 10mL를 넣는다.



3. Strata cartridge Filter 안정화 시킨다. (Methanol 5mL와 pH 2 water 5mL를 1mL/min으로 차례대로 서로 섞이지 않게 흘려보낸다.)

* Strata-X 33u Polymeric Reversed Phase 200mg/6mL

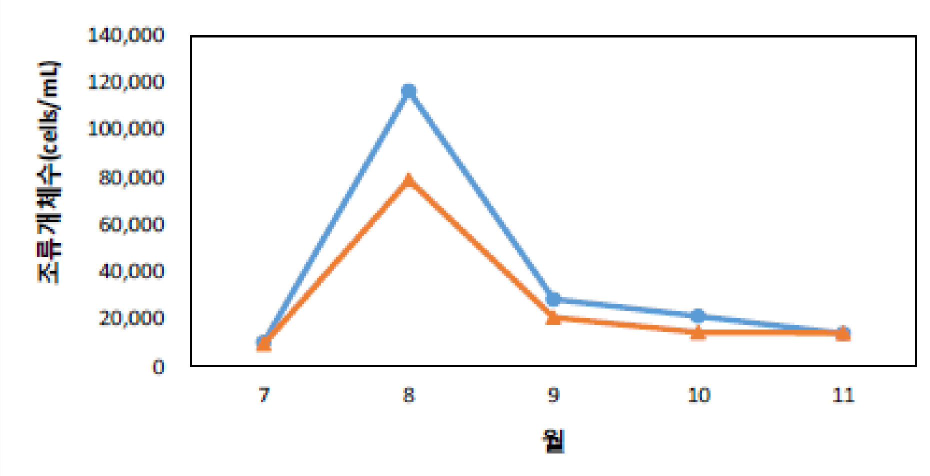


4. 안정화된 Filter에 농축된 시료 10mL를 1mL/min으로 흘려보낸다.

5. pH 2 water 10mL를 1mL/min으로 Filter를 washing 한다.
6. Methanol : Acetic acid = 9:1 용액 10mL를 1mL/min 흘려보내서 Vaccum Evaporater로 건조시켜 Acetic acid : ACN (9:1) 10mL를 첨가한다.
7. HPLC로 분석한다 (Q : 1mL/min, Time : 35.5min, Temp : 30℃)

3.4 Application of Barley Straw (5)

Algae control using barley straw decomposition



3.5 Application of Dredging Machine (1)

Amphibious dredging machine

	Scrub Rotating Brush	*Brush Housing*	*Suction Casing*
Picture			
Specfi-cation	▪ Cylindrical rotating polyethylene brush ▪ Scrub sediments, periphyton, plants etc.	▪ Anti-corrosion steel brush housing ▪ Cover the brush & prevent the suspended solids	▪ Anti-corrosion steel suction casing ▪ Cover the brushing area & pump sediments, periphyton, plants etc.

	Water-level response operating	*Light-weight crawler*	*Amphibious machine*
Picture			
Specfi-cation	▪ Water-level response driver's compartment ▪ Dash board with hydraulic pressure, fuel level, chronometer & engine RPM	▪ Light-weight crawler ▪ Distribute the weight, and minimize the ground pressure	▪ Amphibious scrubbing/ dredging machine ▪ Move, scrub, dredge pump in sensitive environments

3.5 Application of Dredging Machine (2)

Application of amphibious dredging machine

3.5 Application of Dredging Machine (3)

Various application of amphibious dredging machine

Large man-made lake


Ilsan lake park


Songdo central park


Sejong lake park

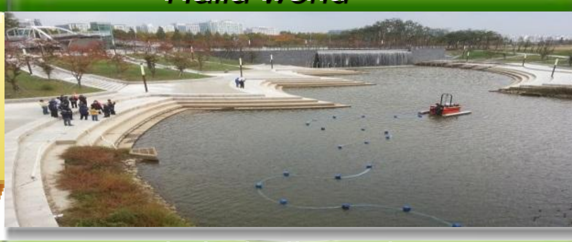
Large Natural lake


Shihwa lake


Shihwa lake


Sorae lake

Large man-made canal


Hallu world


Cheongla canal


Songdo canal

Small pond


Mitchuhall pond

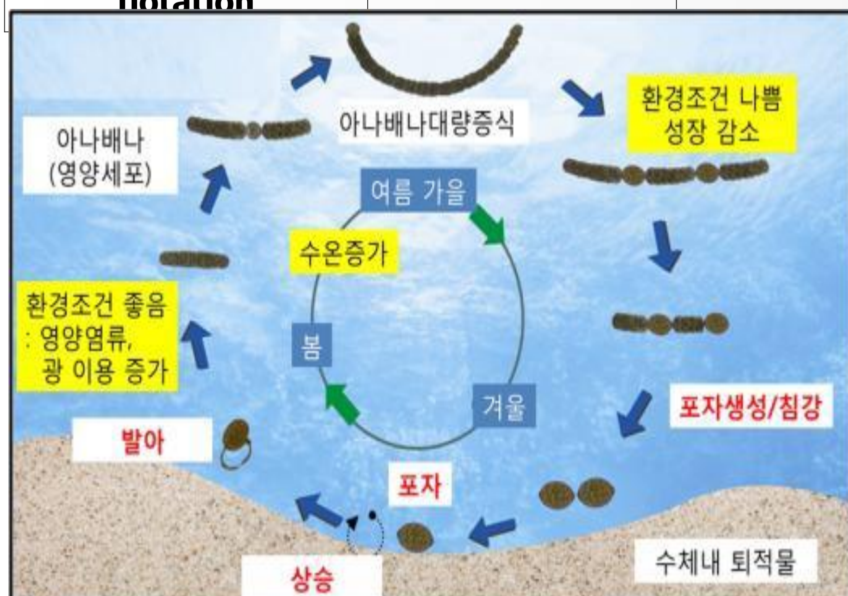

National museum pond


National assembly pond

3.5 Application of Dredging Machine (4)

Removing the sediments with algae Akinete

Removed contaminant amounts (kg)		Suspended Solids (SS)	Total Phosphorous (T-P)	Note
Aphibious scrubbing/ dredging machine	Sum	84,565	34.67	Treated Area
	July	56,043	20.65	22,980㎡
	November	28,522	14.02	22,980㎡
Water treatment facilities with coagulation and dissolved air flotation	Sum	365	3.93	Treated Amount
	July	248	2.41	12,050㎥
	November	117	1.52	7,800㎥



Akinete density (cells/g)

Depth	0~5㎝	5~10㎝	10~15㎝	15~20㎝
1	70	26	30	40
2	110	110	80	40
3	143	70	70	20
4	110	70	70	70
5	40	40	40	30
6	70	10	20	0
7	110	30	0	

4. Conclusions

4. Conclusions

- **Many factors facilitating HABs in inland waters, and the wide range of measures employed to control (with limited success) HABs frequency of occurrence, intensity, and impacts were discussed;**
- **Also, climate change can change local hydrologic and biogeochemical processes, including rainfall and runoff (amount and temporal dynamics), nutrient export from watersheds, mixing regimes, internal nutrient cycling, and food web dynamics;**
- **These changes present a significant challenge to resource managers aiming to control HABs in a future favoring bloom occurrence;**
- **We should apply new approaches to incorporate various algae control processes into nutrient control strategies and watershed loading reduction to suppress the frequency of occurrence, intensity, and impacts of HABs.**
- **Current mitigation strategies and the potential options for adapting and optimizing them are required.**

Thank you for your attention!