ECO-CONVERGENCE ENVIRONMENTAL ENGINEERING LABORATORY

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

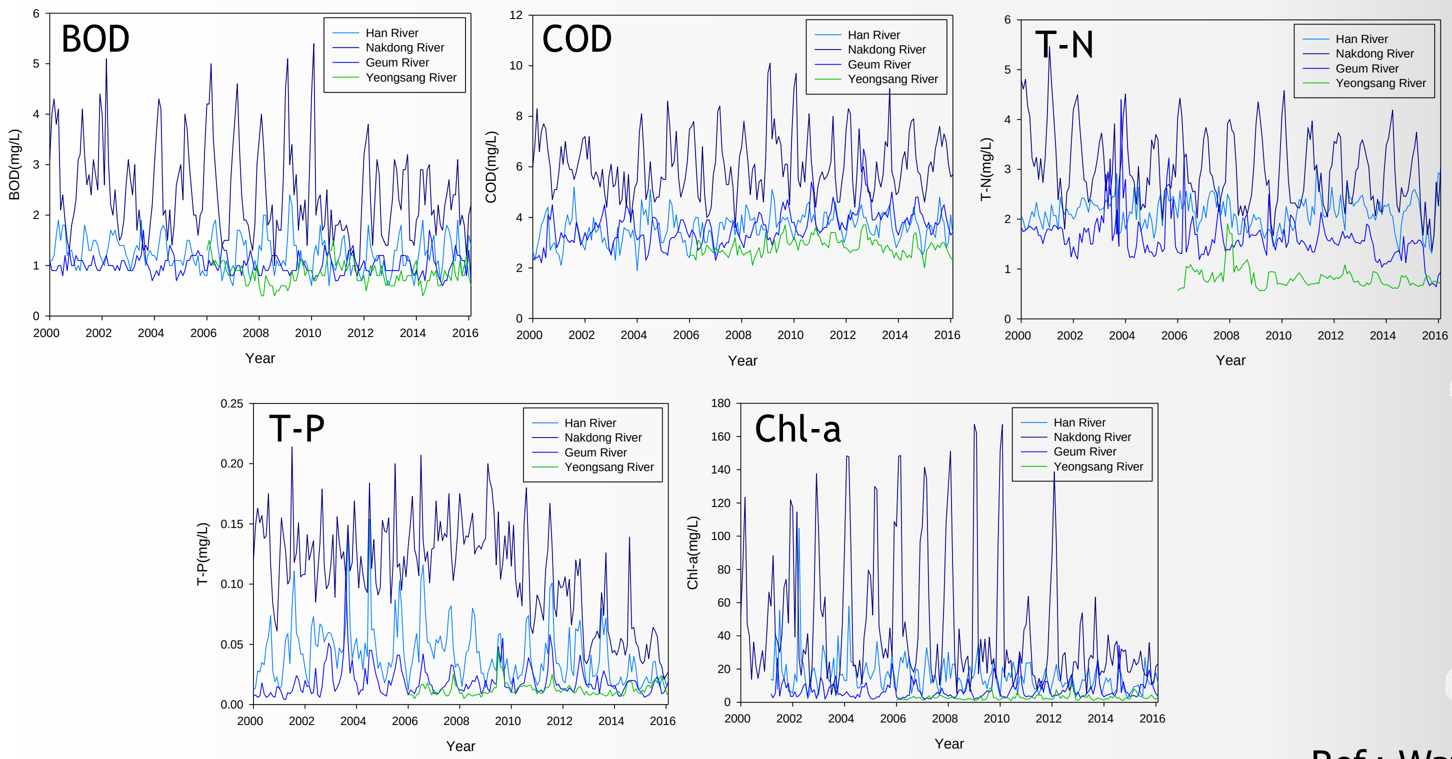
Harmful algal blooms

- 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.

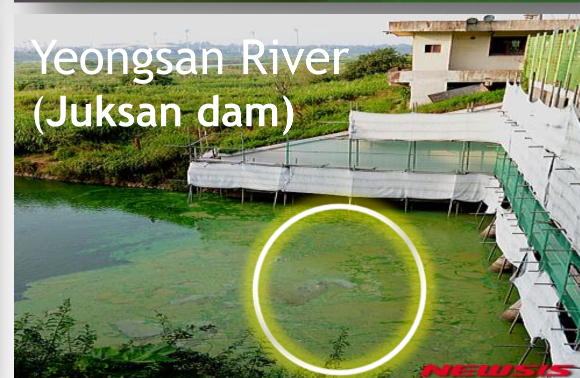


Ref.: Water Information System (water.nier.go.kr)

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

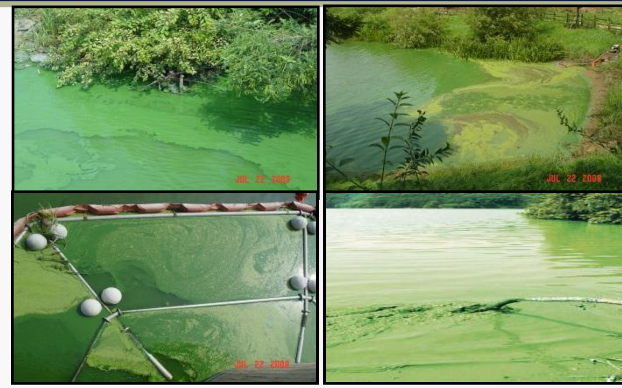
- Advanced drinking water treatment

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

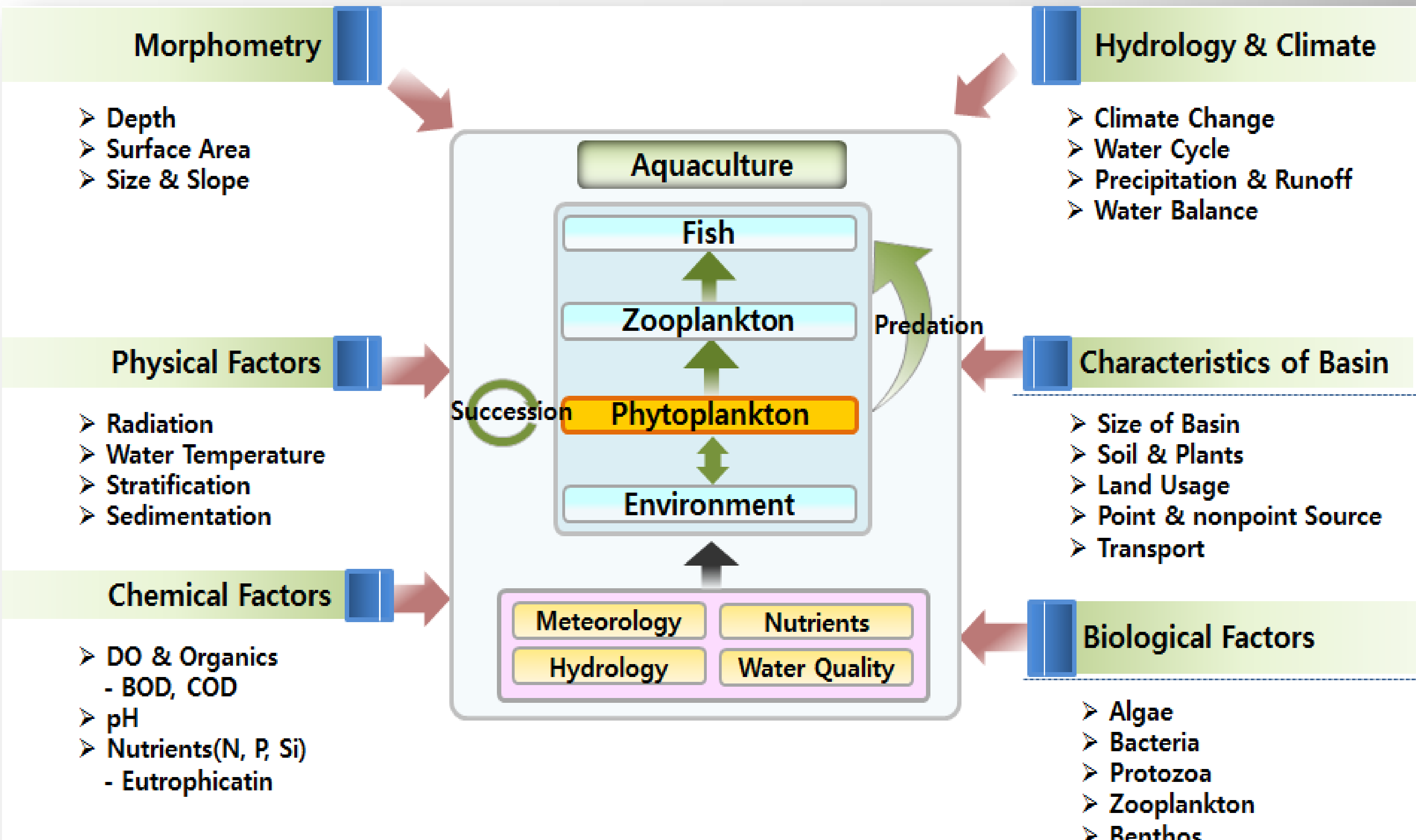
- No recreation activity
- Need more $$$ to treat

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)

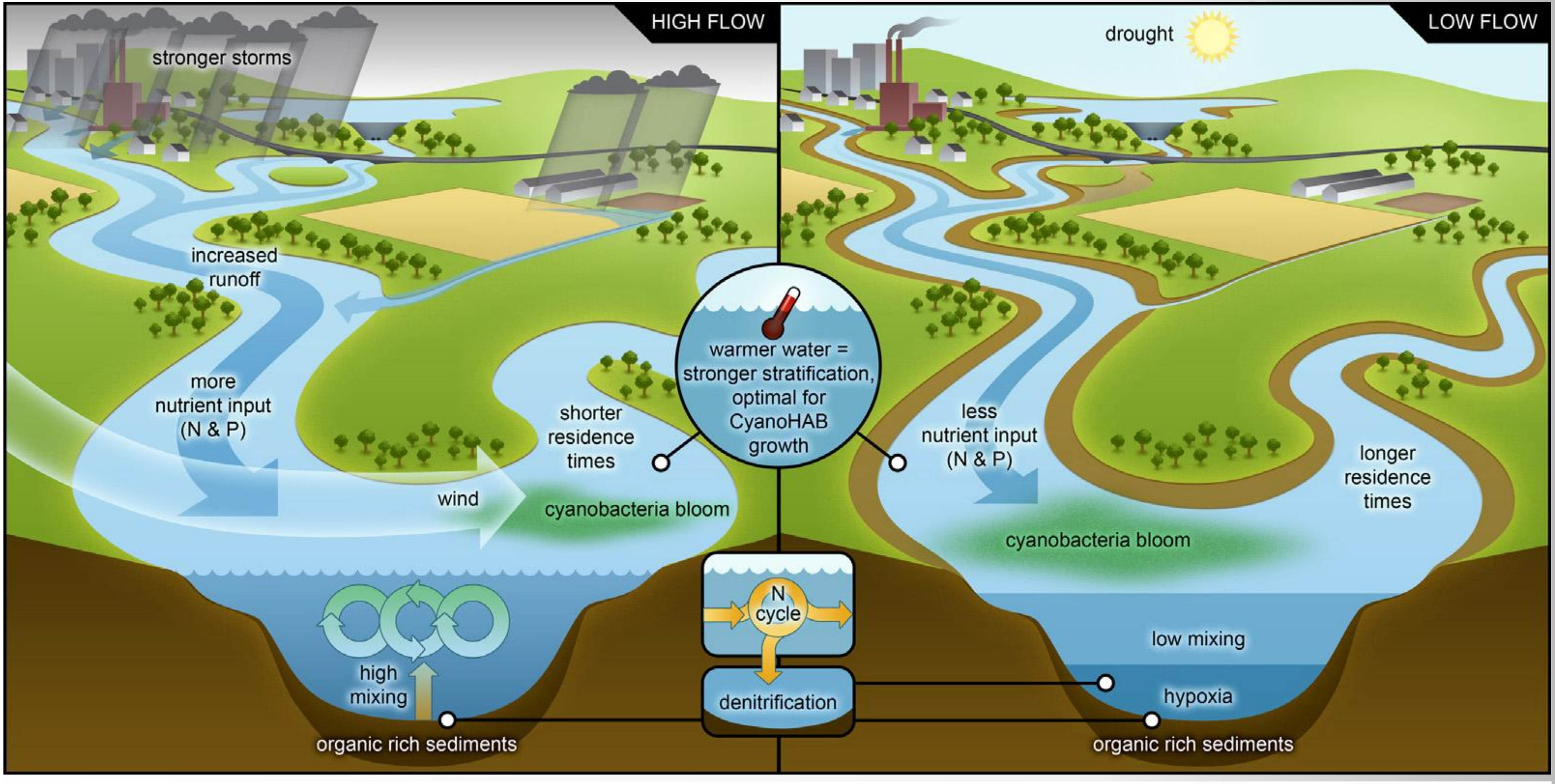
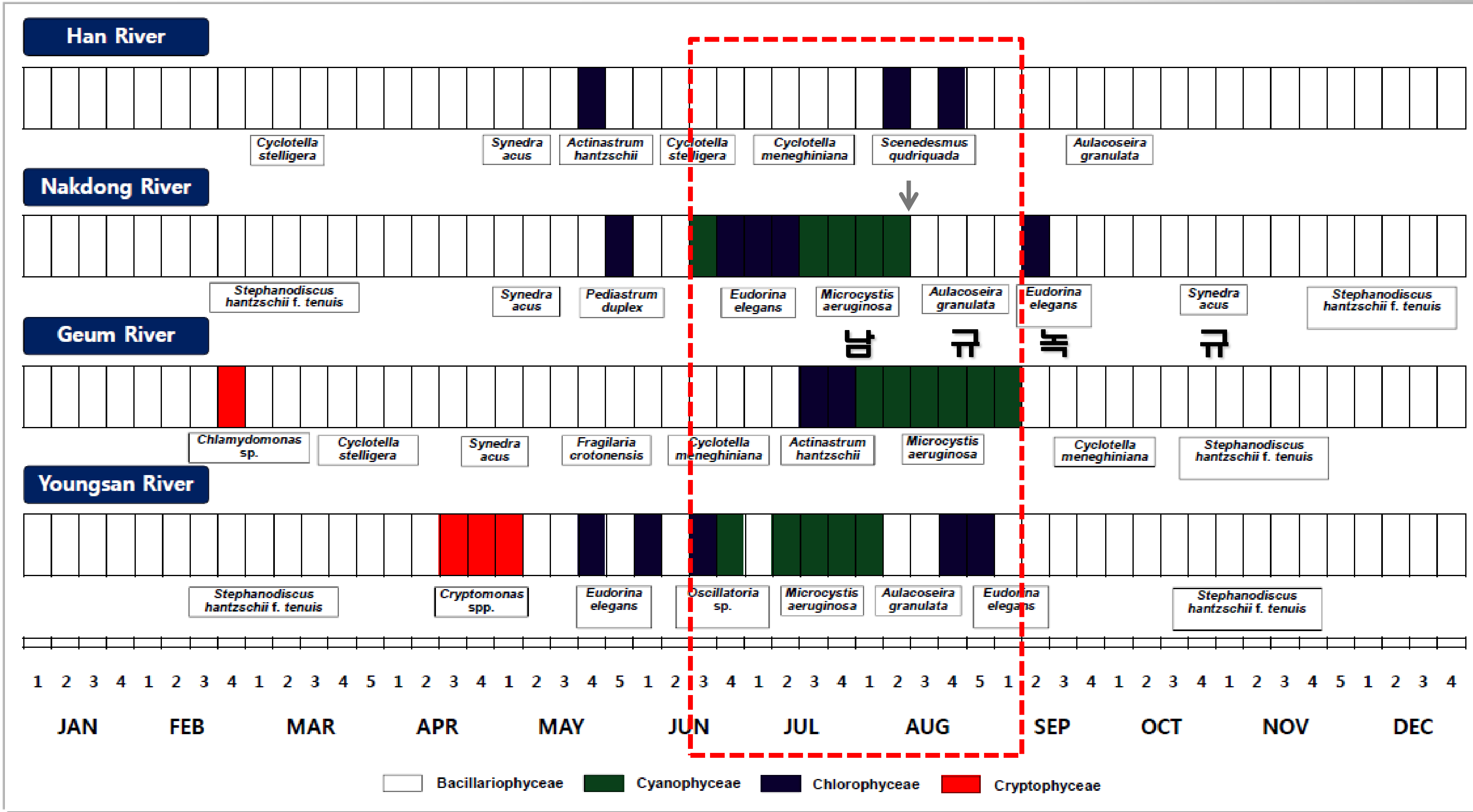


Fig. 2. Impacts of warming, increasing hydrologic variability, and extremeness on physical–chemical and biotic conditions that modulate CyanoHABs in shallow water ecosystems. Under high freshwater discharge conditions (left hand side) an increase in nutrient loading will occur, mixing depth will increase, 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)

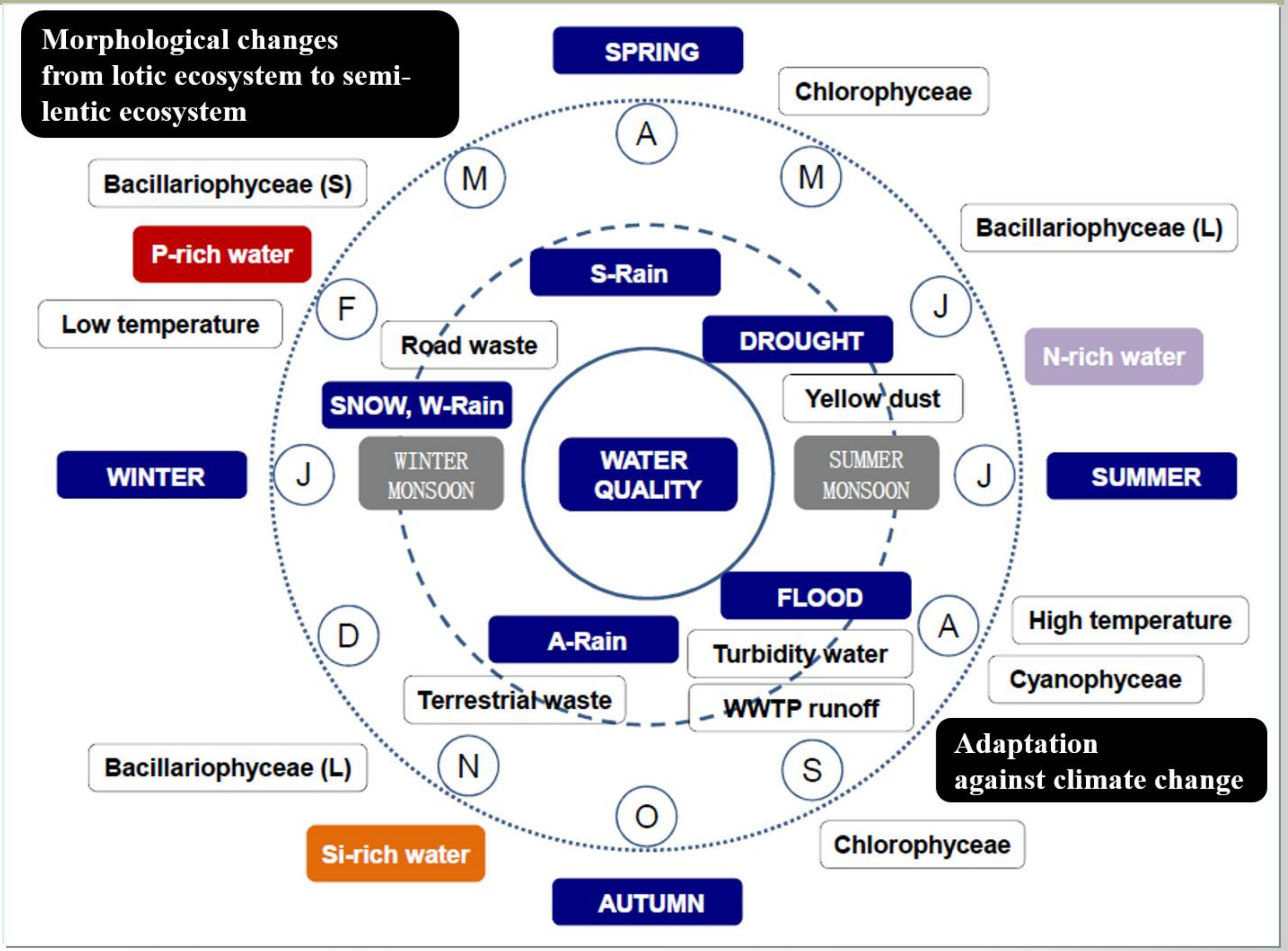
Spatial, seasonal and species variations in HABs (Shin, 2013)



- 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.

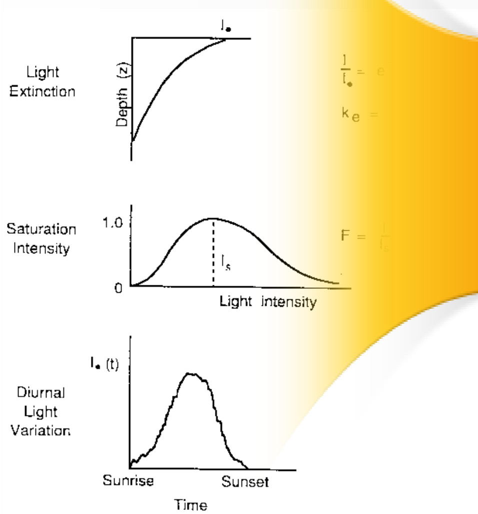
2. Prevention & Mitigation of HABs (5)

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)

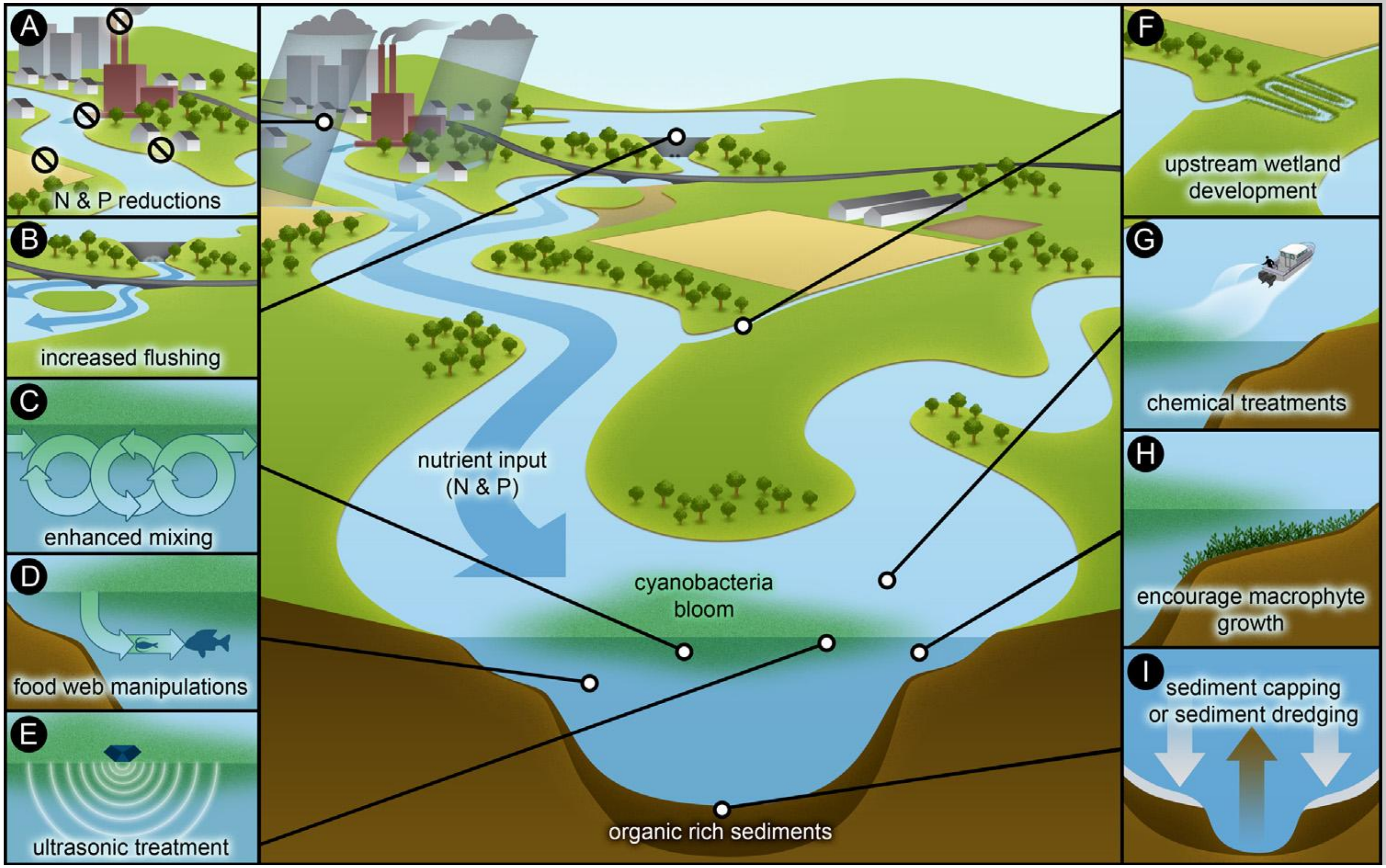


Fig. 1. Conceptual illustration of various approaches currently in use to control CyanoHABs, including control measures in the watershed and within the ecosystem. A. Point and non-point source nutrient (in most cases, both N and P) input reductions. B. Increasing flushing rates (decreasing water residence 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.

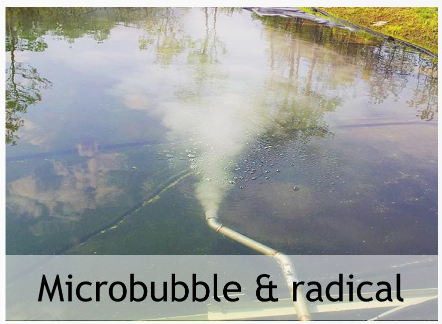


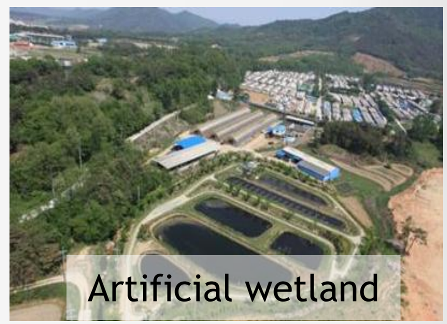

2. Prevention & Mitigation of HABs (9)

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.

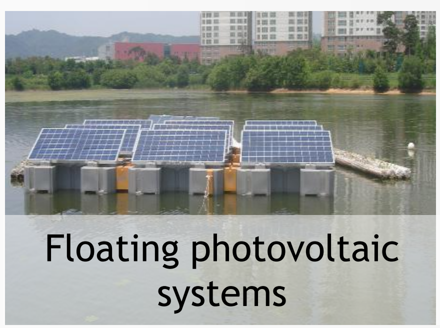

Water flow device


Microbubble & radical


Artificial wetland


Algae harvesting ship


Circulation system

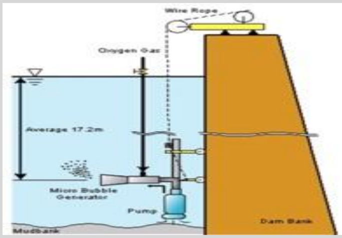
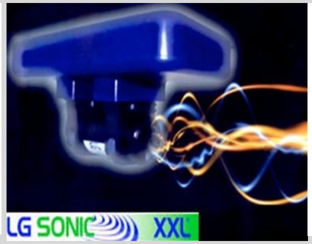
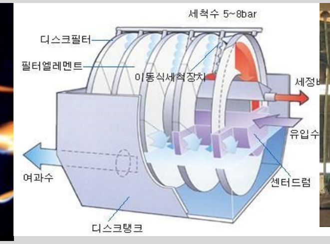

Floating photovoltaic systems


Ecological restoration


Algae harvesting ship

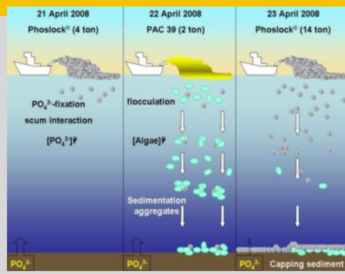
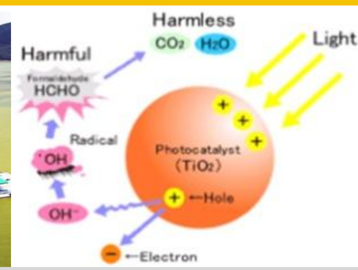
2. Prevention & Mitigation of HABs (10)

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

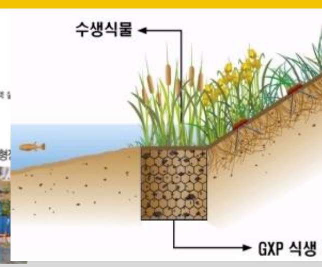
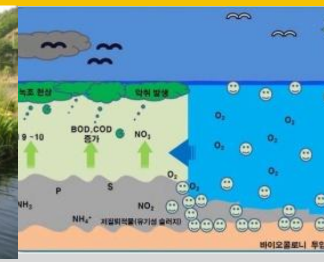
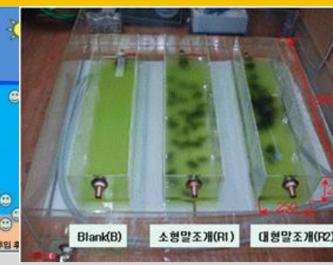
2. Prevention & Mitigation of HABs (11)

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
C : Chemical Control
B : Biological Control
S : Stagnant (≤0.2 m/s)
F : Flow (>0.2 m/s)
○ : 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)

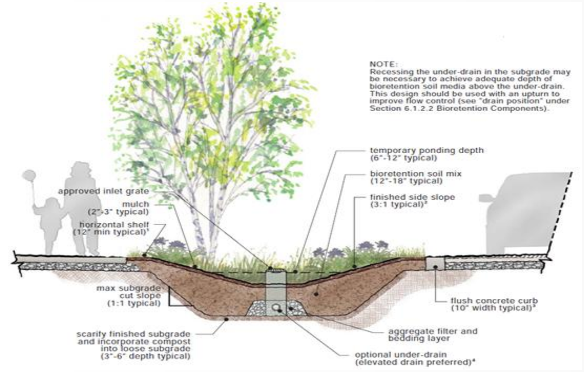
Low Impact Development (1)

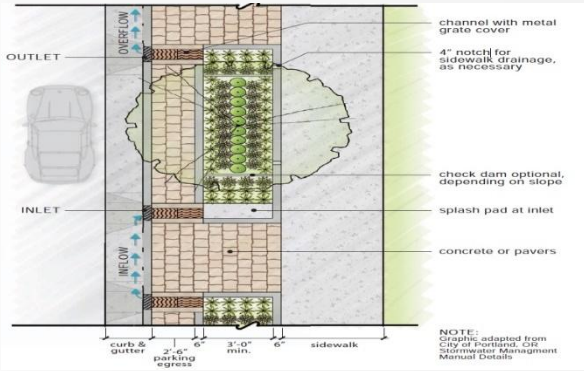
프라이부르크 (독일)

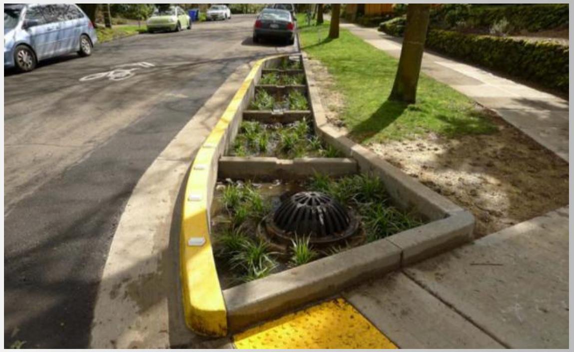
- 불투수면 저감
- 조경공간 활용
- 경관성 향상
- 녹색공간 확대
- 그린 인프라 배수

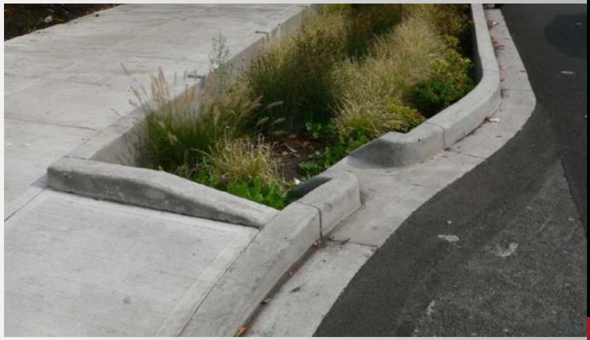
3.1 Application of nonpoint source input control (2)

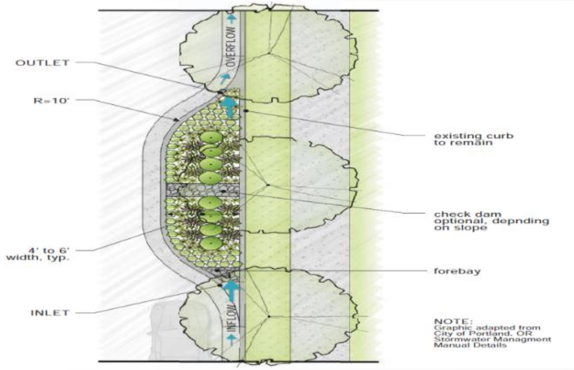
Low Impact Development (2)

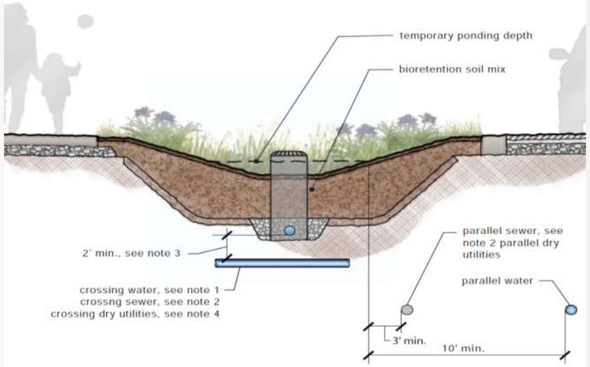










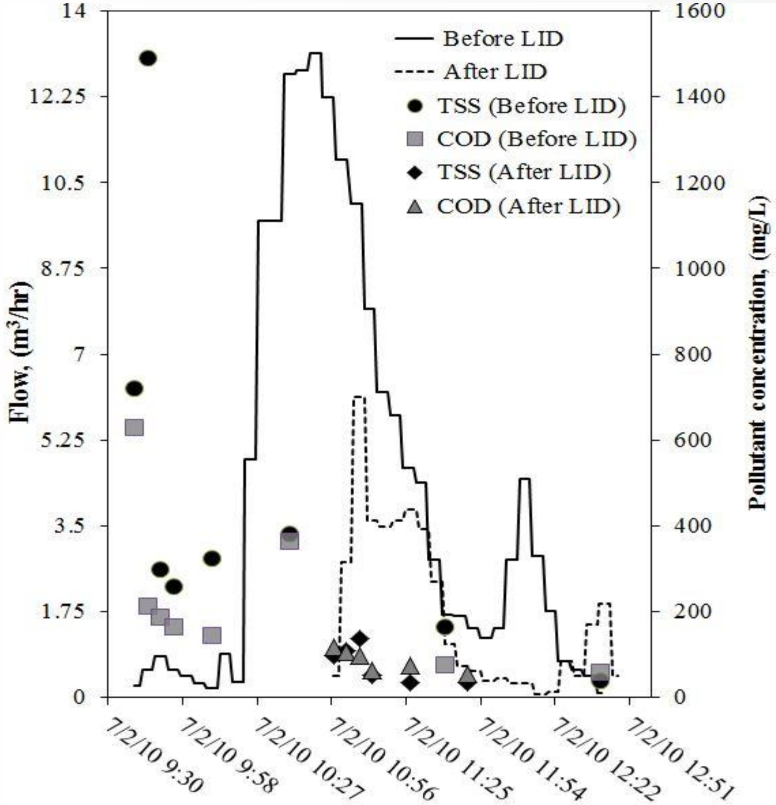


3.1 Application of nonpoint source input control (3)

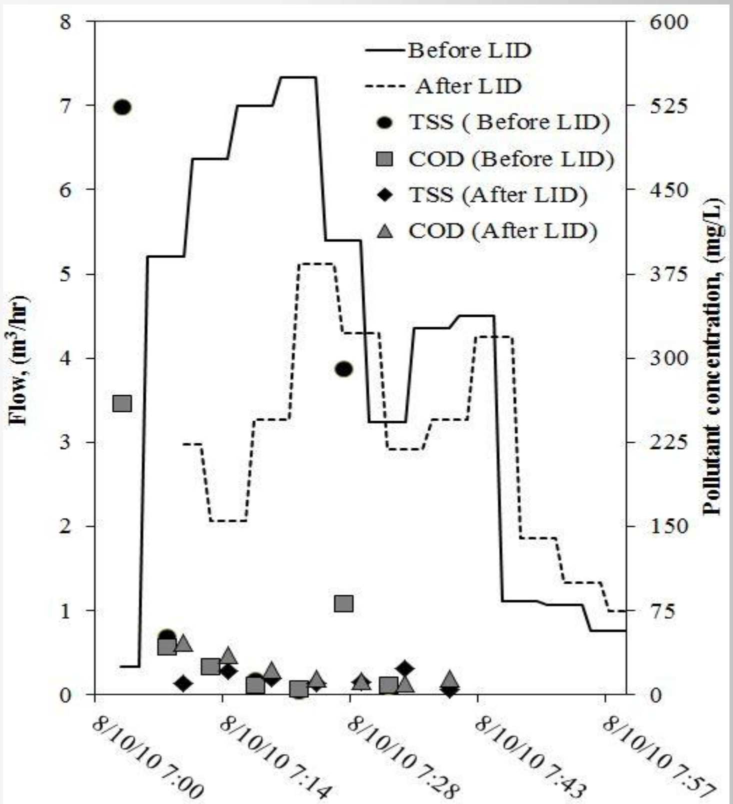
Low Impact Development (3) (Kim, 2014)

Before LID application

After LID application



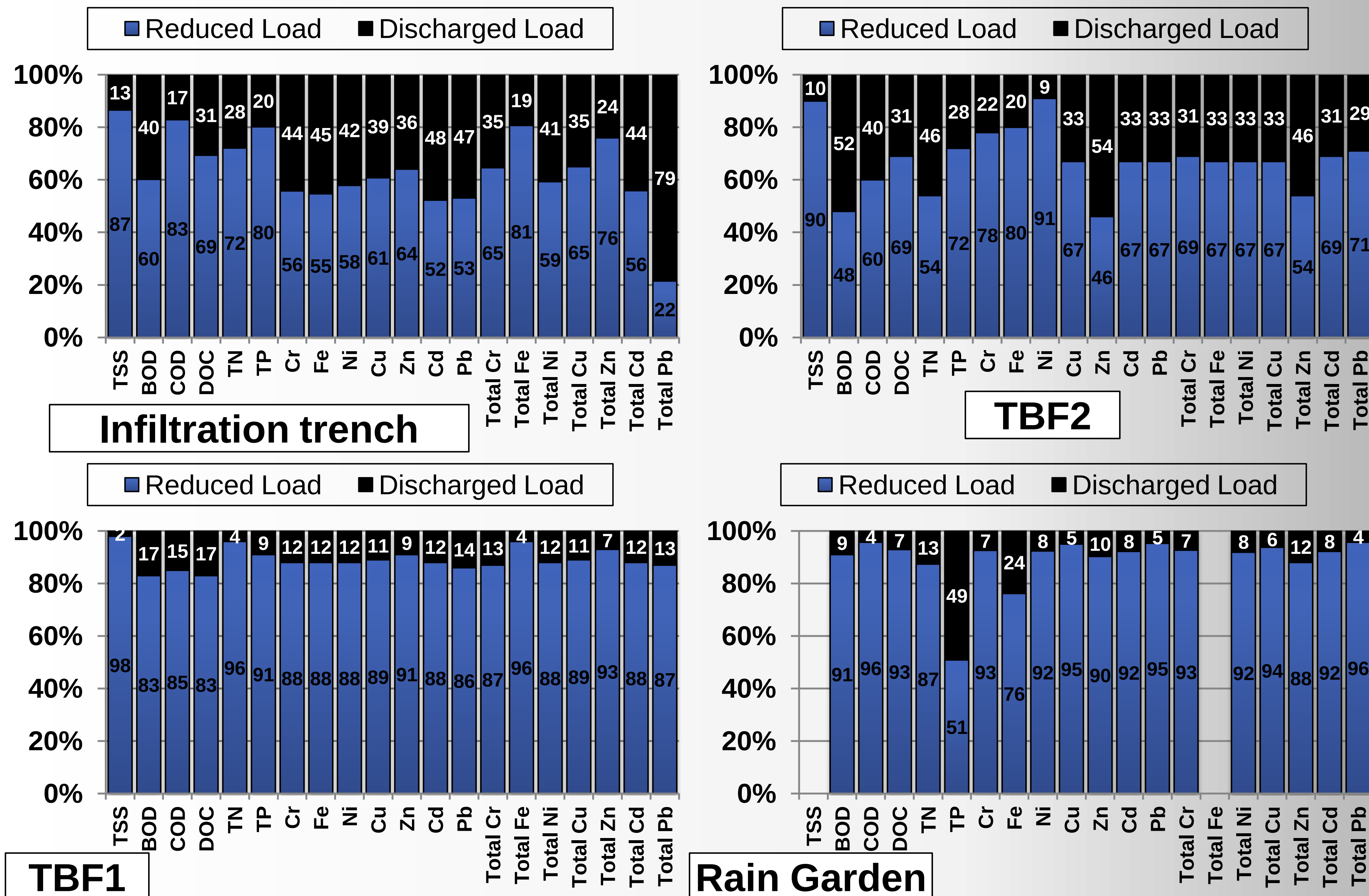
Infiltration trench



Tree box filter

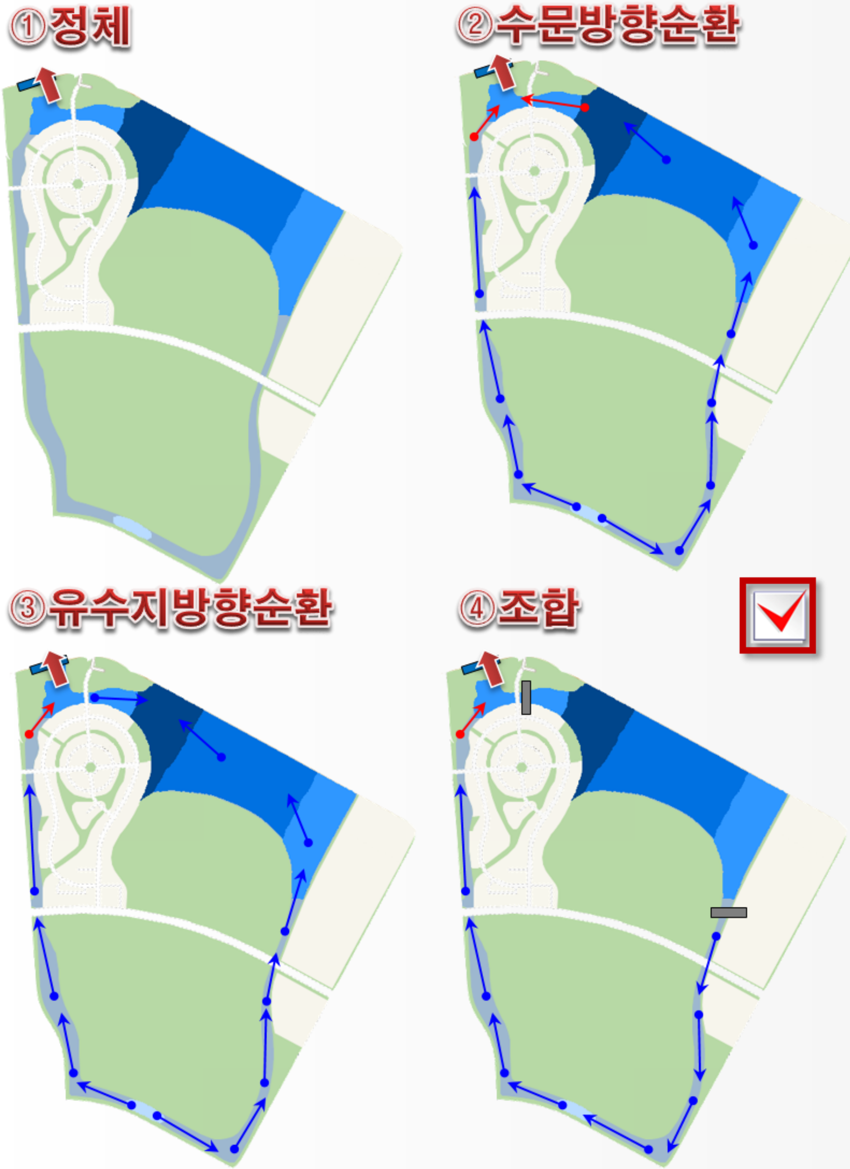
3.1 Application of nonpoint source input control (4)

Low Impact Development (4) (Kim, 2014)



3.1 Application of nonpoint source input control (5)

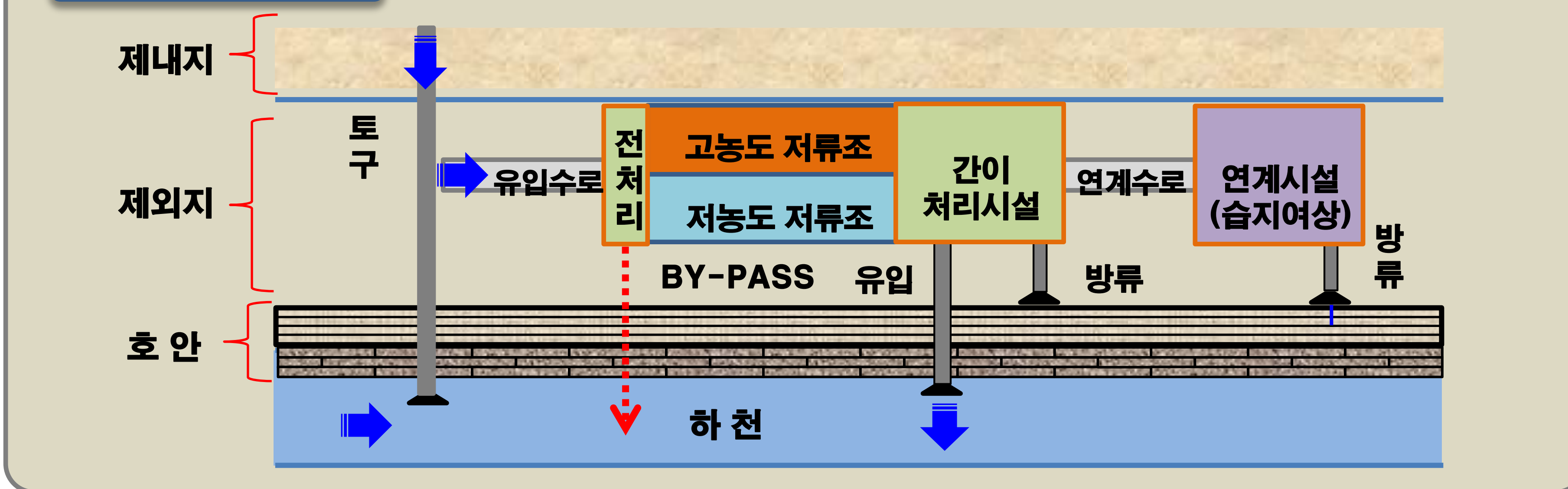
Artificial drainage & discharge of input pollutant loadings (Joo, 2014)



3.1 Application of nonpoint source input control (6)

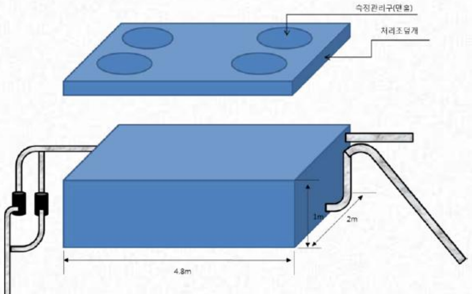
Artificial drainage & discharge of input pollutant loadings (2)

제외지 설치



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

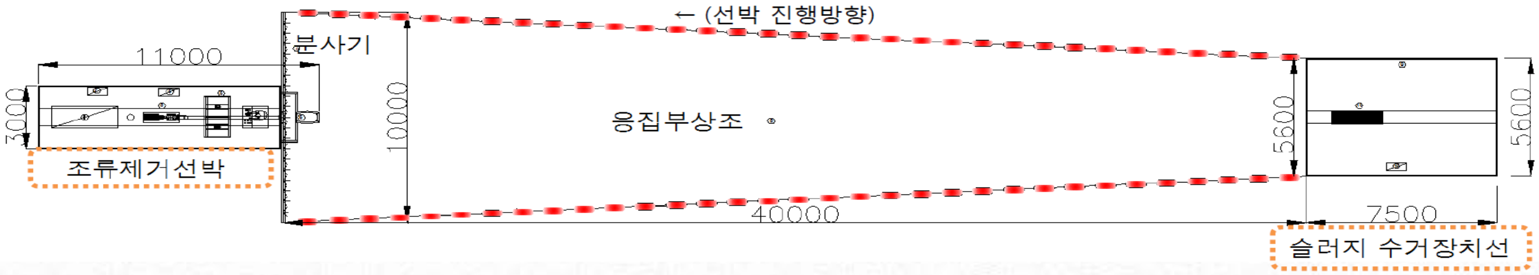
탈수system (녹조슬러지 탈수장치)

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

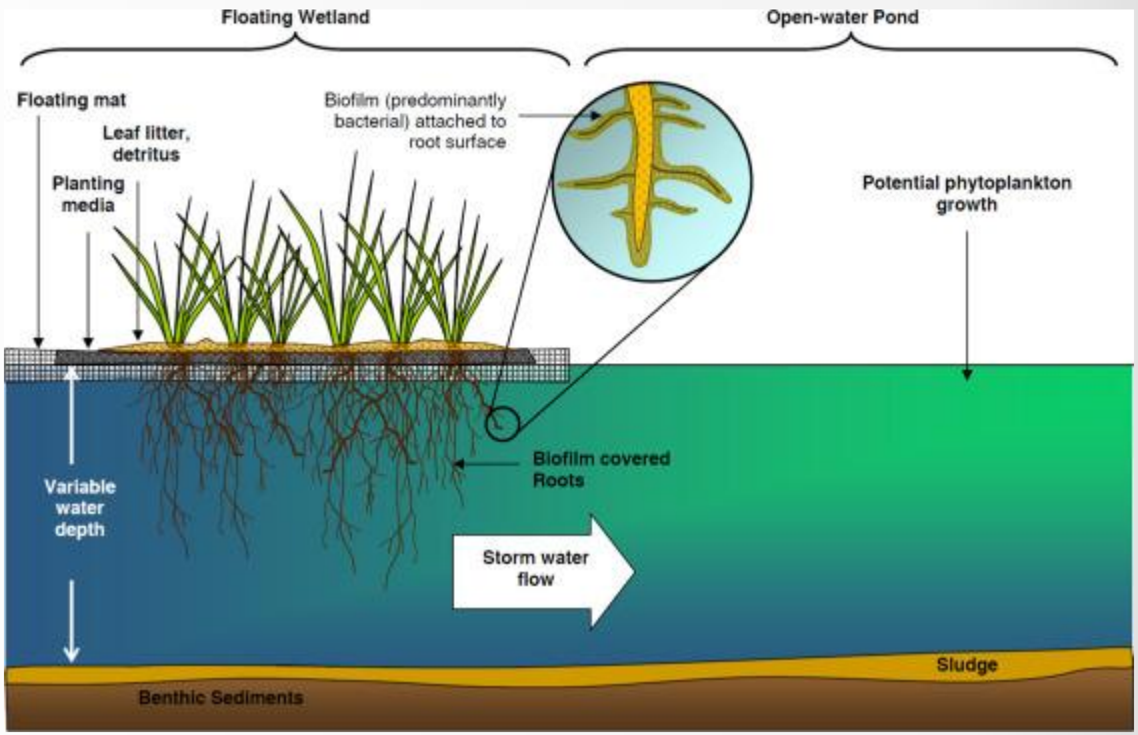


응집제 살포 → 응집+미세기포 부착 → 부상 및 농축(스컴) → 조류 회수

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.

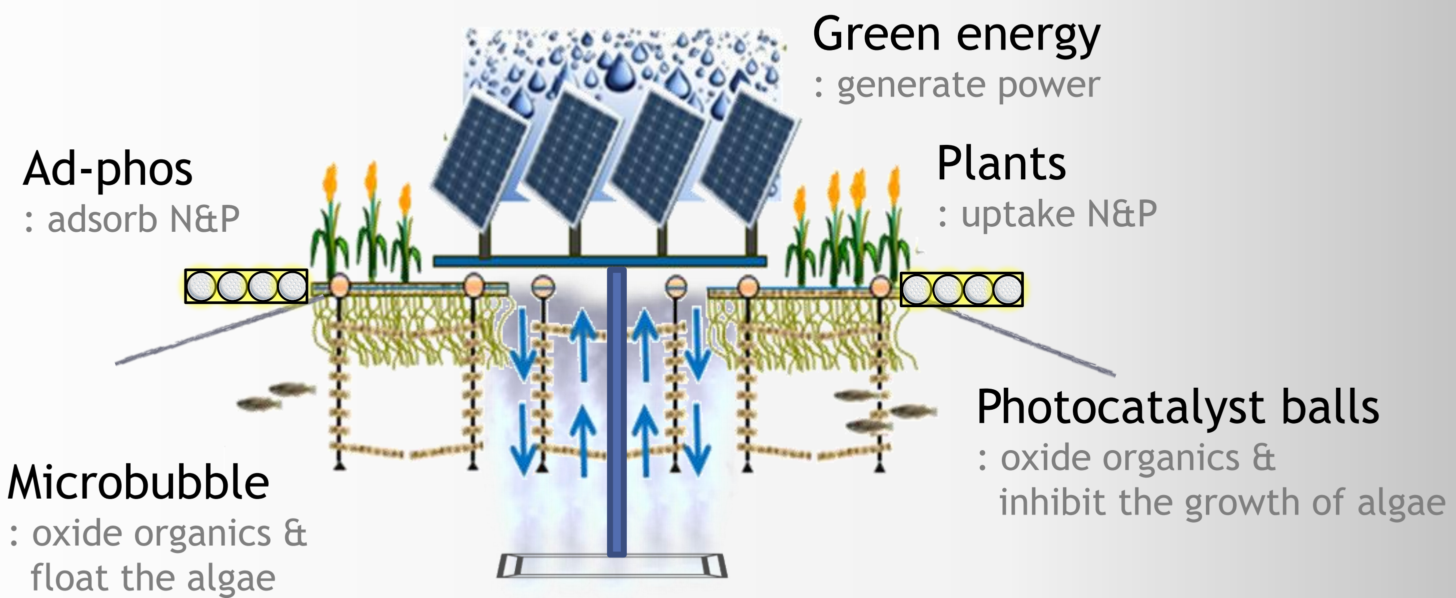


3.3 Multifunctional AFIs (2)

Schematics of multifunctional artificial floating island

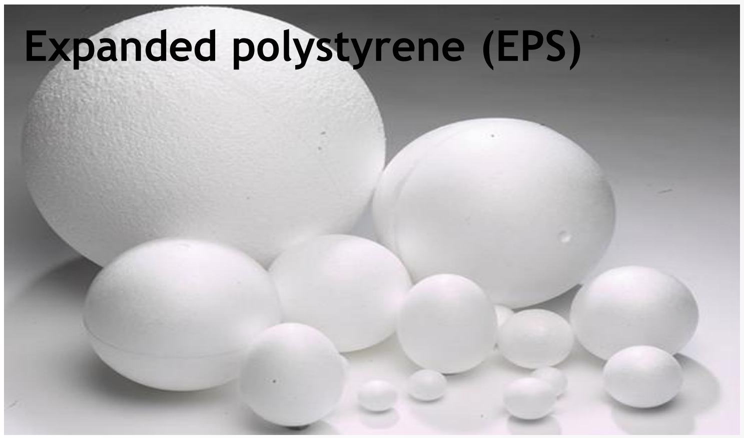
Multifunctional artificial floating island (AFI) using microbubble and photocatalyst balls

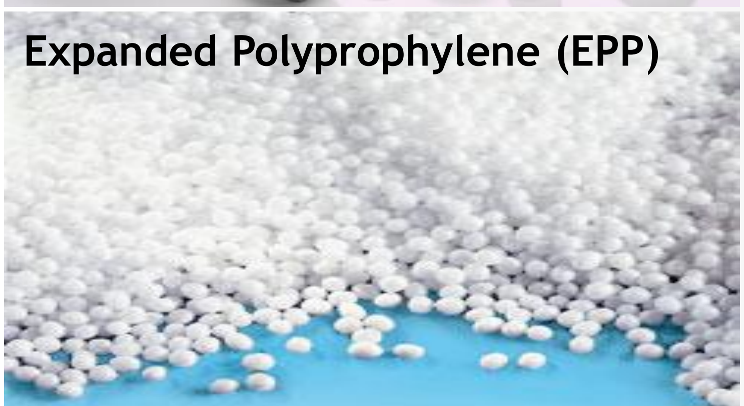
- Solar panels to generate the power for aerators;
- Ad-phos to adsorb the nitrogen and phosphorous;
- Plants to uptake the nitrogen and phosphorous and to provide the habitats;
- Microbubble to oxide organics and to float the algae
- Photocatalyst balls to oxide organics and to inhibit the growth of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



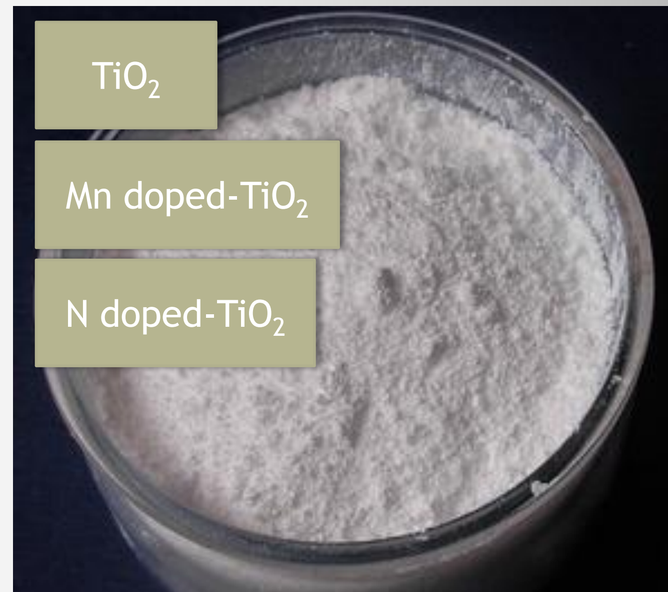
3.3 Multifunctional AFIs (3)

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.

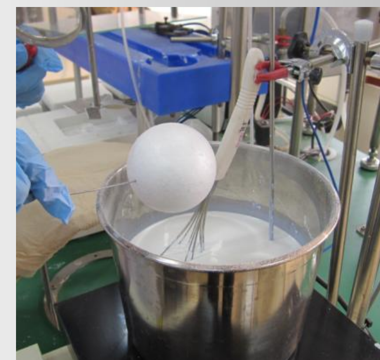
3.3 Multifunctional AFIs (4)

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



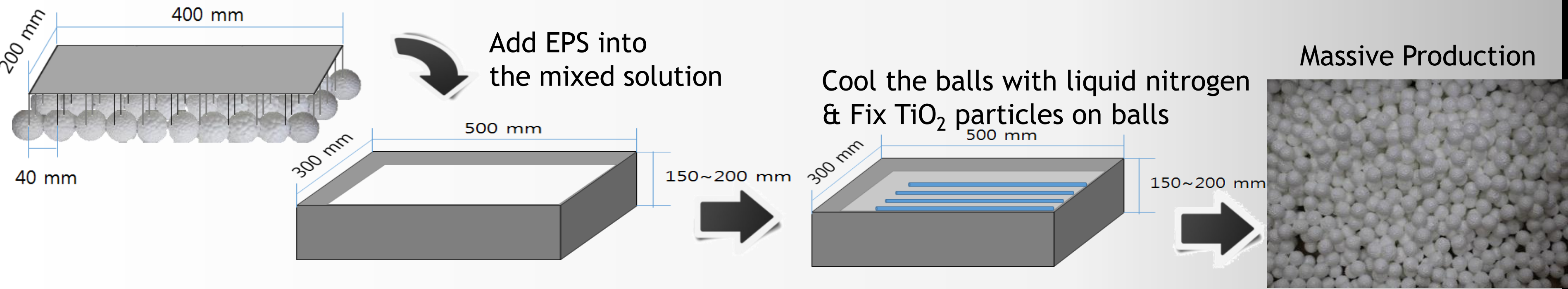
4. Add EPS into the mixed solution(at melting point of EPS, 140~145 ℃)

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

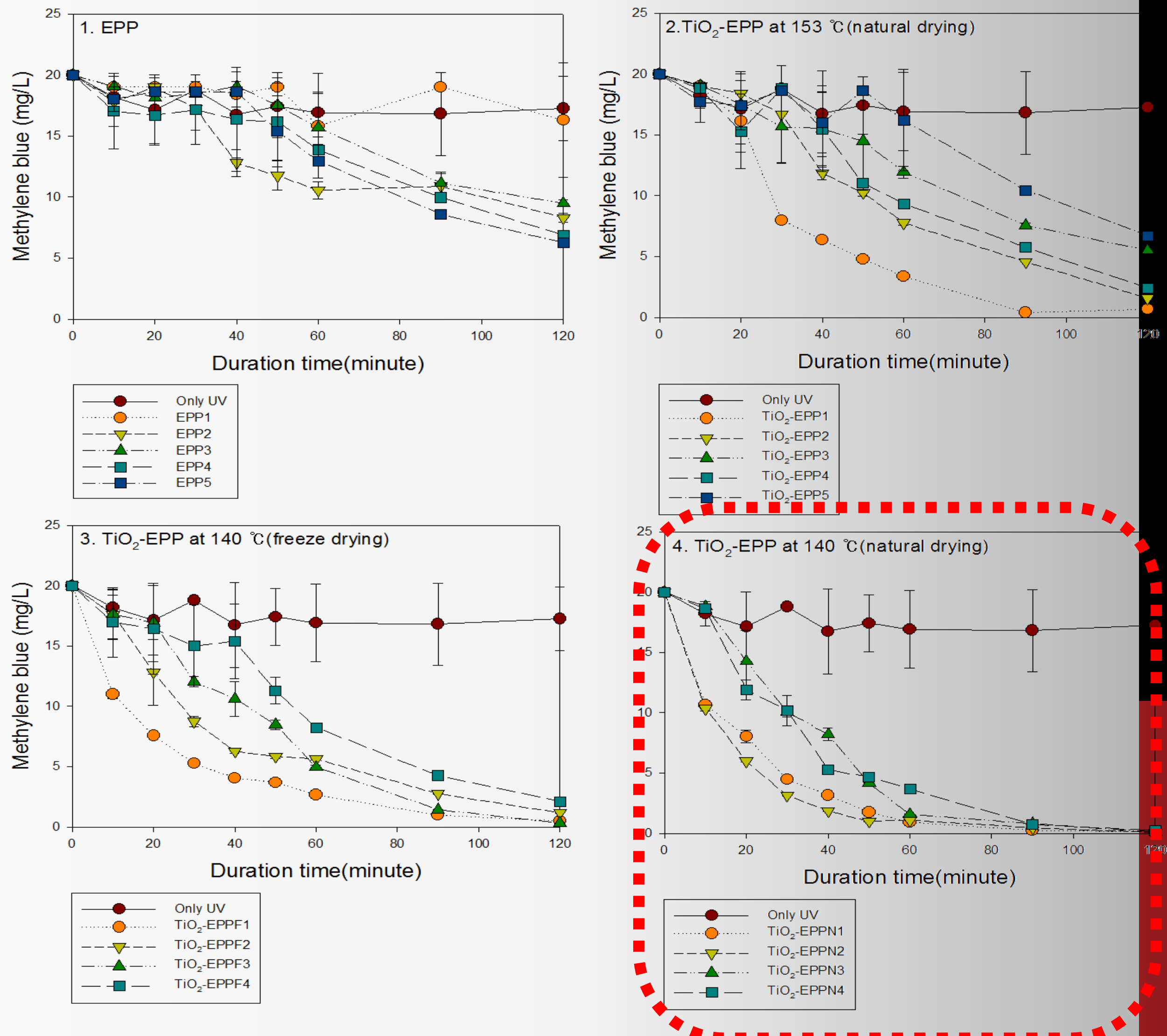
3.3 Multifunctional AFIs (6)

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	-

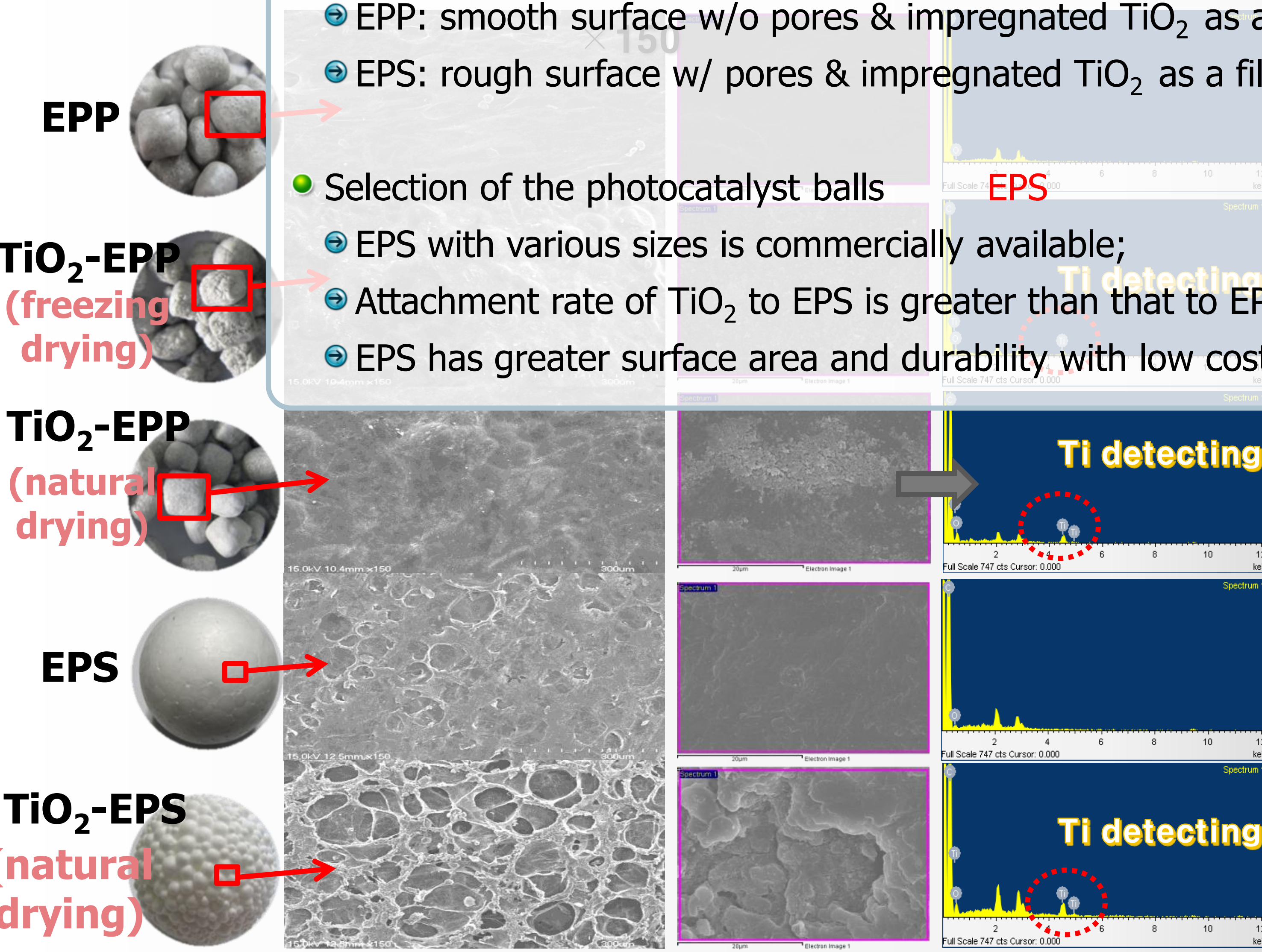
- Fast degradation of methylene blue under the UVC irradiation;
- Temperature of 140 ℃ and natural drying are better than other methods.



3.3 Multifunctional AFIs (7)

SEM, SEM-

- 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.



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	

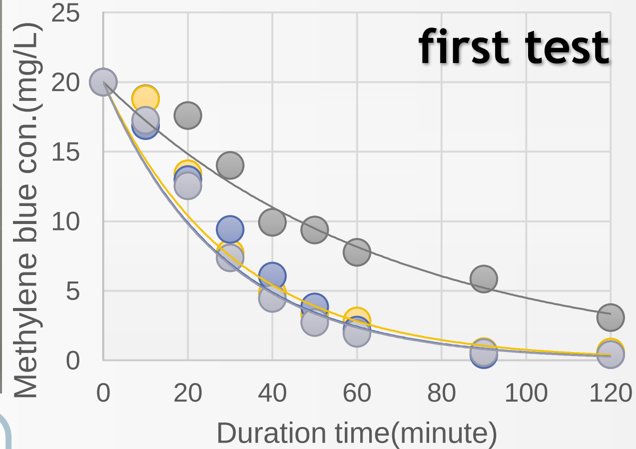
Element	Weight%	Atomic%
C	80.57	87.54
O	13.19	10.76
Ti	6.24	1.70
Totals	100.00	

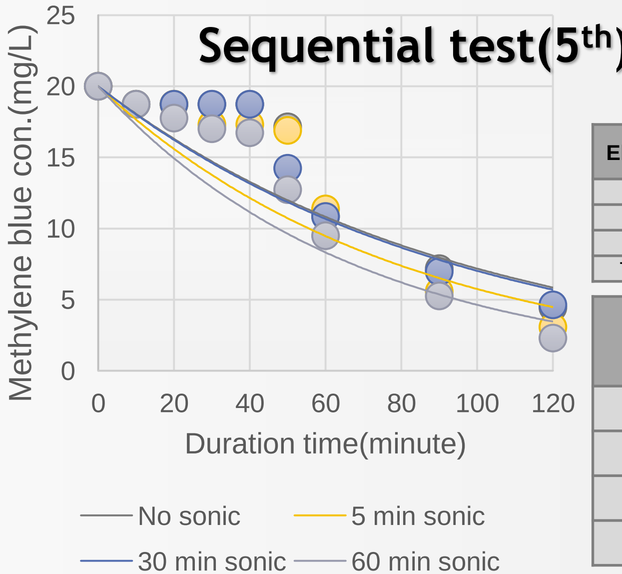
Element	Weight%	Atomic%
C	95.42	96.52
O	4.58	3.48
Totals	100.00	

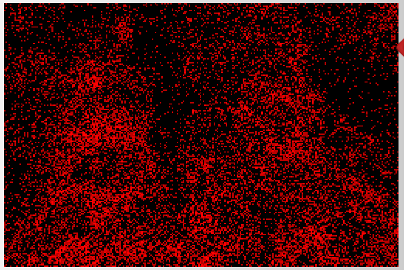
Element	Weight%	Atomic%
C	76.50	85.66
O	13.79	11.59
Ti	9.71	2.68
Totals	100.00	

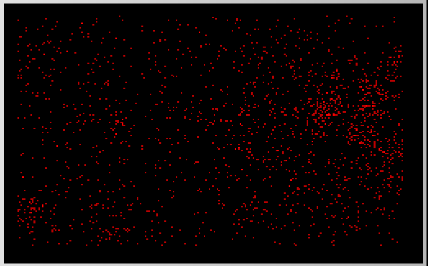
3.3 Multifunctional AFIs (8)

Detachment of TiO_2 by external shocks









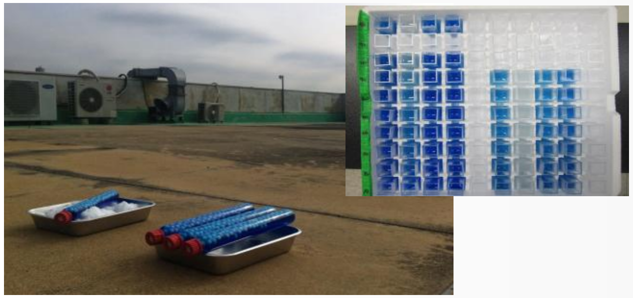
- After sonication, TiO_2 particles were still imbedded;
- After sonication, photodegradation efficiency became greater due to decoating of the glycerin film;
- After five sequential tests, photodegradation still works;
- Long-term durability of TiO_2 photocatalyst balls were proved

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

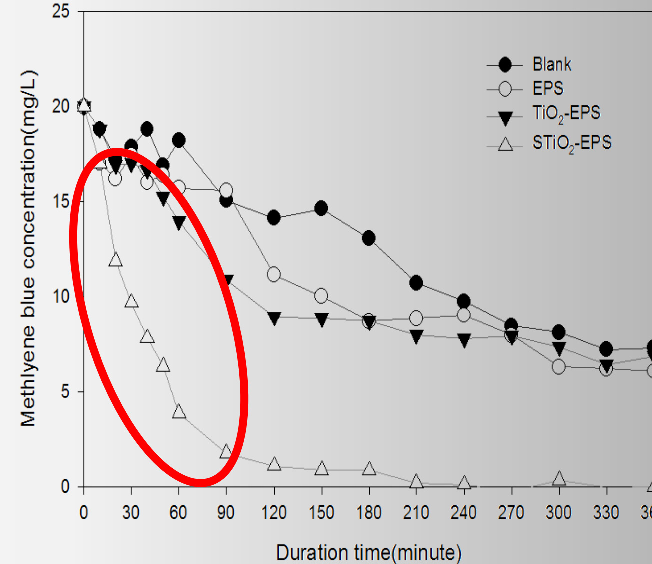
3.3 Multifunctional AFIs (9)

Sunlight activity and temperature, pH effect

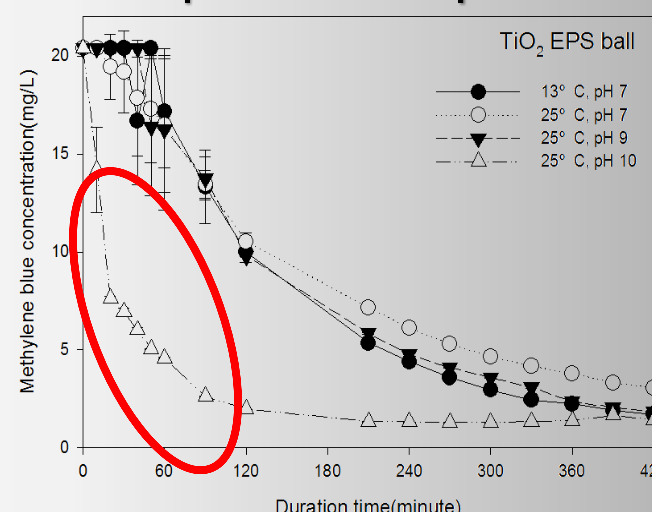


- The methylene blue was 99% removed within two hours using TiO_2-coated EPS under the natural sunlight;
- The removal efficiency of methylene blue was better at pH 10 and at low temperature;
- Considering the pH of natural rivers and lakes is around 7-9, application of TiO_2-coated EPS is feasible.

<Sunlight activity test>



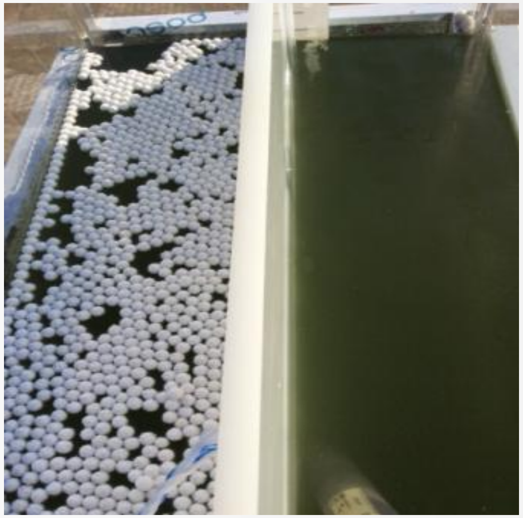
<Temperature and pH effect>



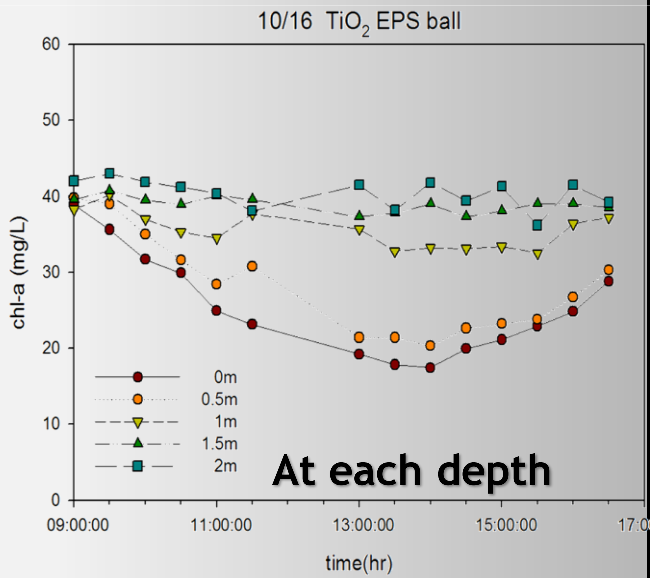
3.3 Multifunctional AFIs (10)

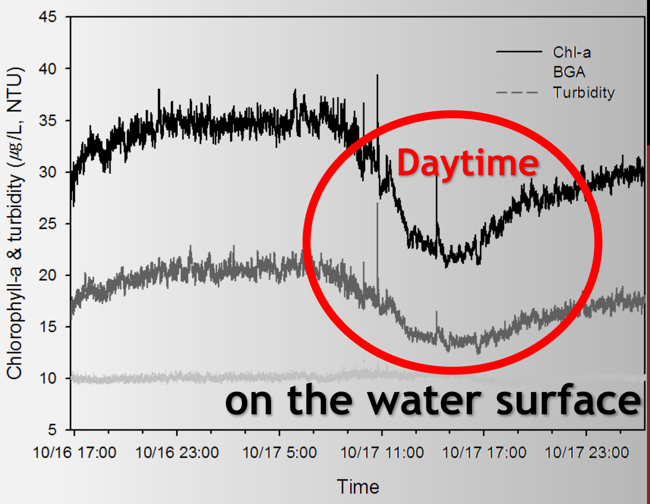
Inhibition of algal growth

- 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.



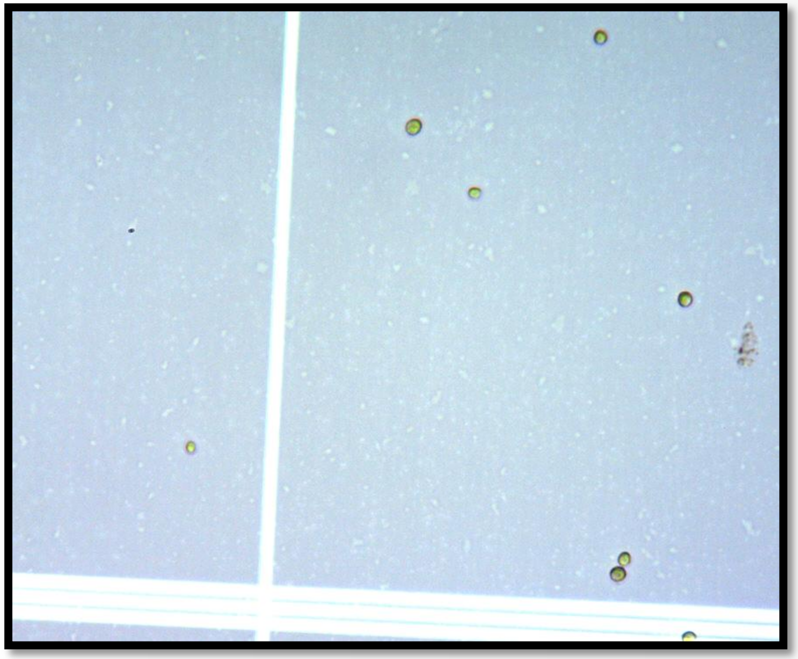
<Concentration of chlorophyll-a>



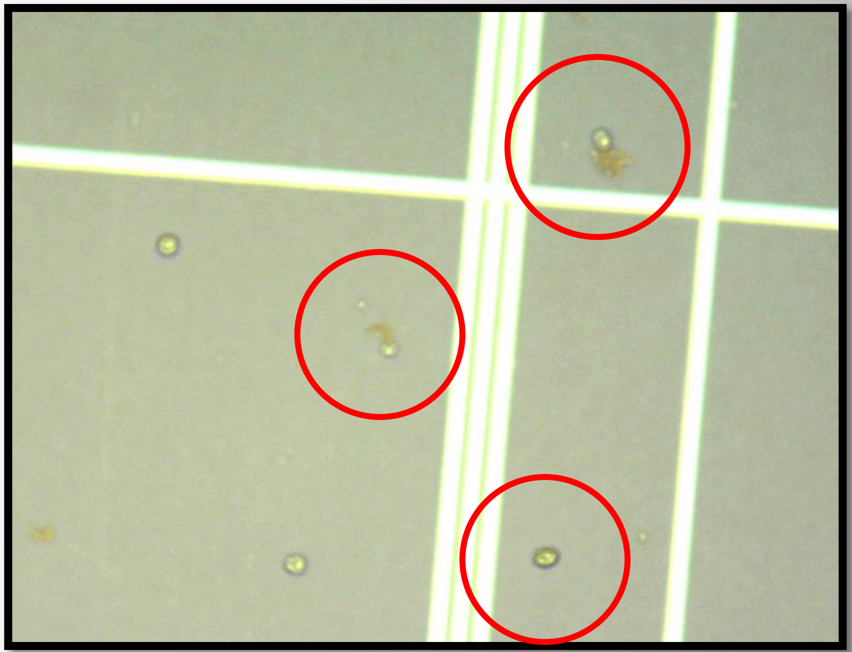


3.3 Multifunctional AFIs (11)

Damages in cell wall



Under the sunlight (after 100 hrs)



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

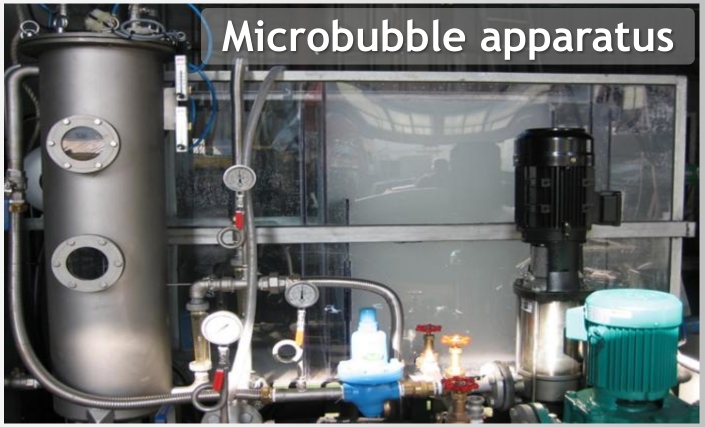
- Damages in cell wall & extraction of inner organisms of algal community by TiO_2-EPS balls under the natural sunlight were proved.

3.3 Multifunctional AFIs (12)

Optimal operation parameters of microbubble apparatus

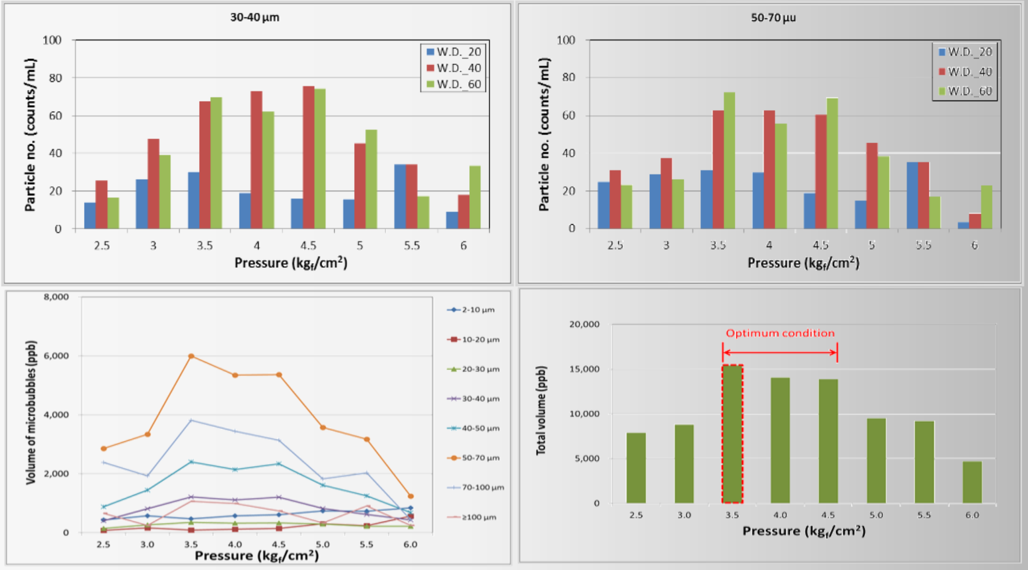
<Test condition>

	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

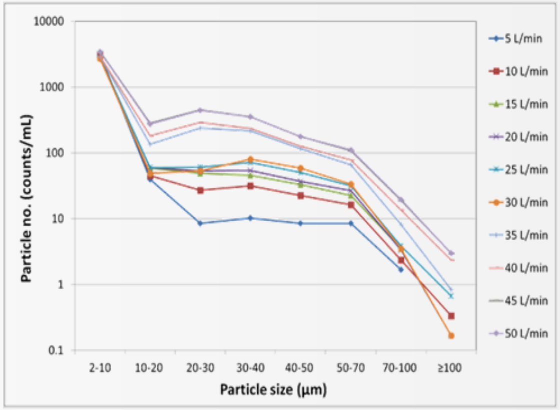
- 3.5~4.5 kgf/cm^2 is the optimal operating pressure to produce the microbubbles;
- Size of bubbles were sub-micro ranges with average diameter of 1~20 μm.



3.3 Multifunctional AFIs (13)

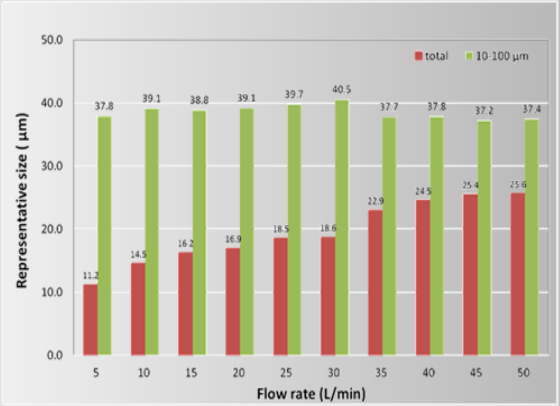
B. Optimal flow rate

- 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>

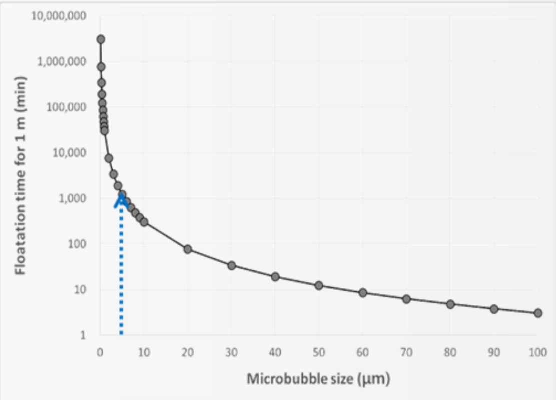
(n=5)



<마이크로버블 대표입경의 변화>

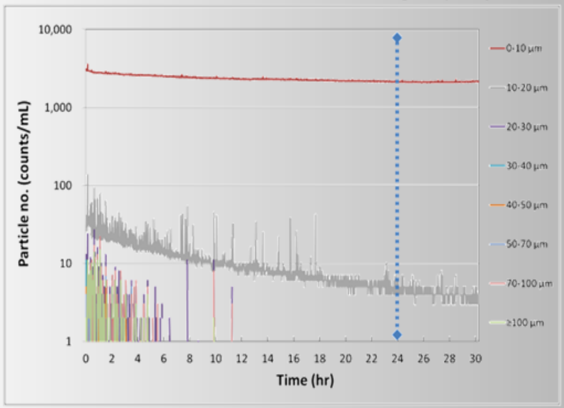
C. Rising speed and sustainability of micro-bubble

- 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)

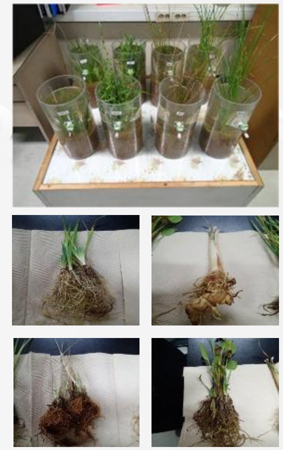


<운전 정지 후 마이크로버블 잔류특성>

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

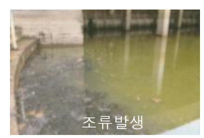
- Among the various adsorption media, Ad-phos media had better SS, COD, T-N and T-P removal efficiencies;
- The adsorption amounts of T-P to Ad-phos media was found to be greater.

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)

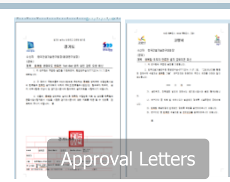
Test-bed Construction

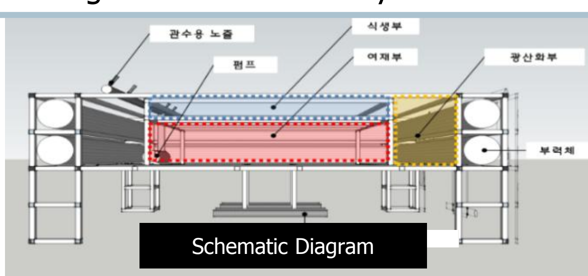
- Target area: Hallyu stream, Ilsandong-gu, Goyang-si, Gyeonggi-do, Korea;
- River extension: 1.3 km, Bed slope: 1/2,600;
- Plan(‘15. 01), Making(‘15. 02), Construction(‘15. 03);
- Period of operation: 2015. 04 ~ 2017. 06.



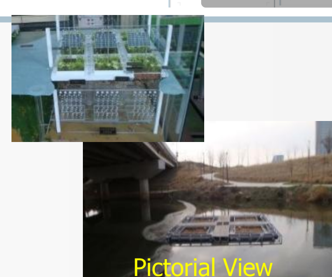
The main points of test-bed for selection

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


Approval Letters

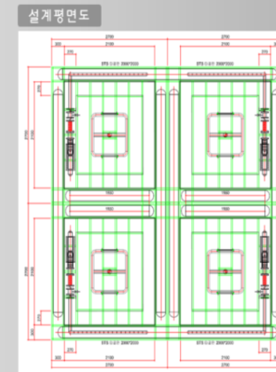


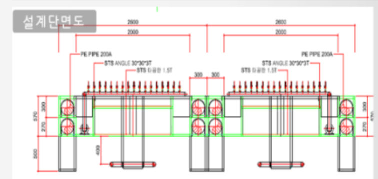
Schematic Diagram

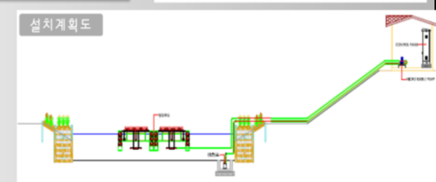

Pictorial View

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







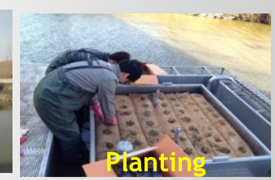
Construction

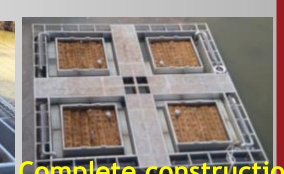

Making framework


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



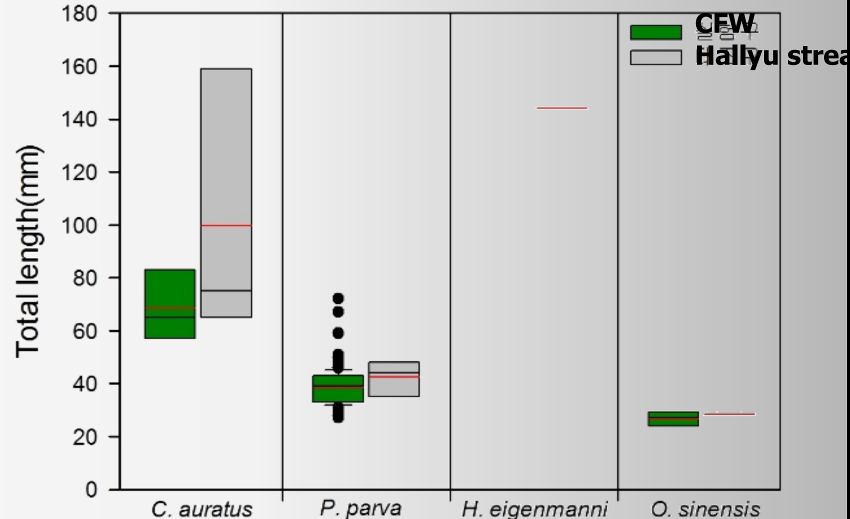
Winter: Ice was covered due to low depth



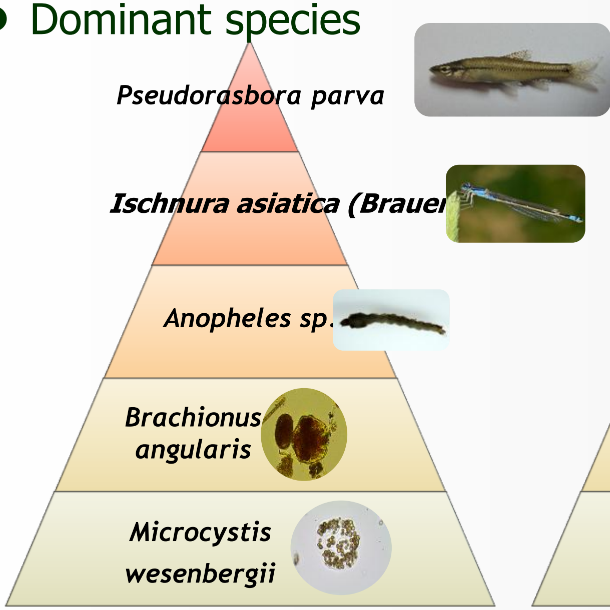
3.3 Multifunctional AFIs (17)

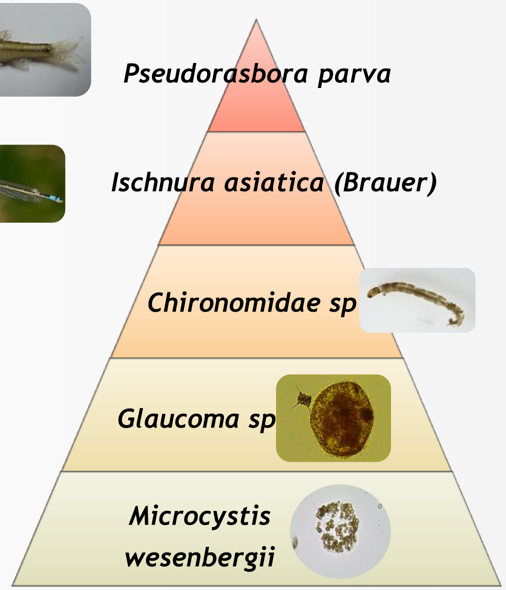
Ecological research

<Compare the length of the fish>



- 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

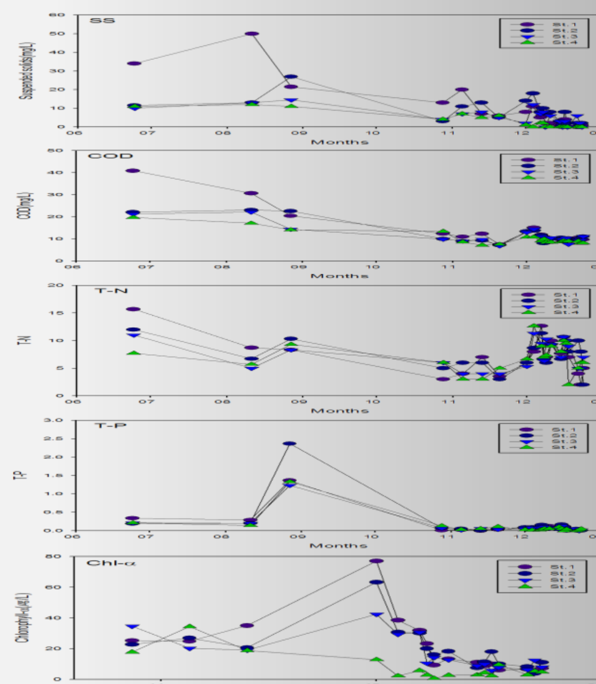
St. 1 Stream
Hallyu stream

St. 2 Micro bubble
Bottom up water by micro bubble

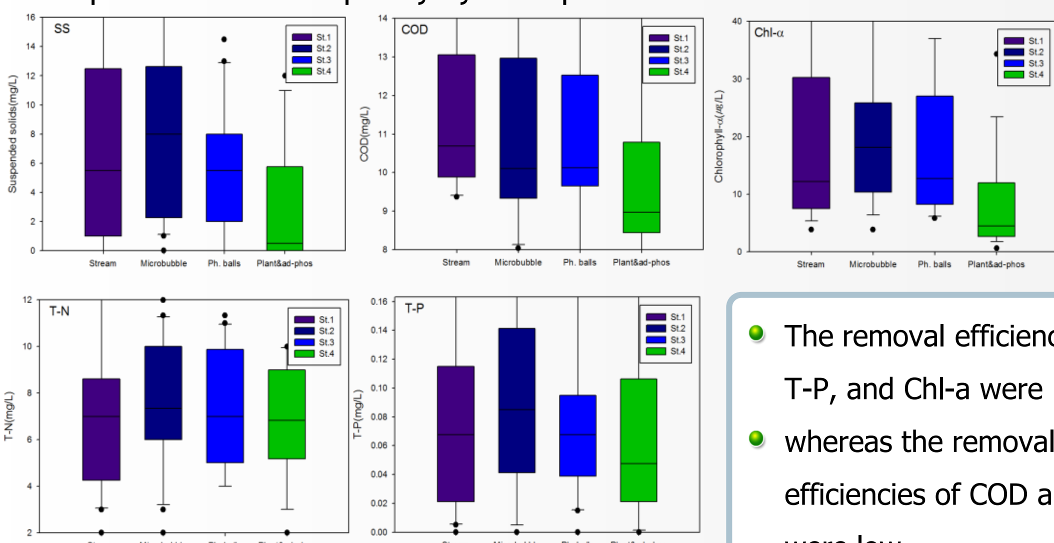
St. 4 Plants & Ad-phos
After plants uptake and adsorption of Ad-phos including the prior steps

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

Seasonal variation of water quality



Comparison of water quality by each process



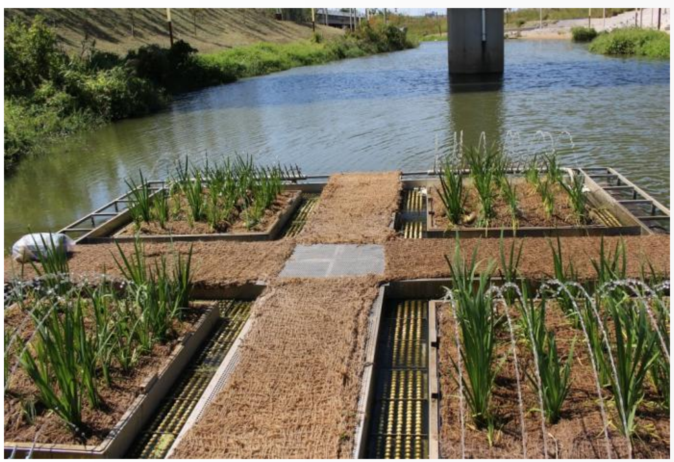
- The removal efficiencies of SS, T-P, and Chl-a were high;
- whereas the removal efficiencies of COD and T-N were low.

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

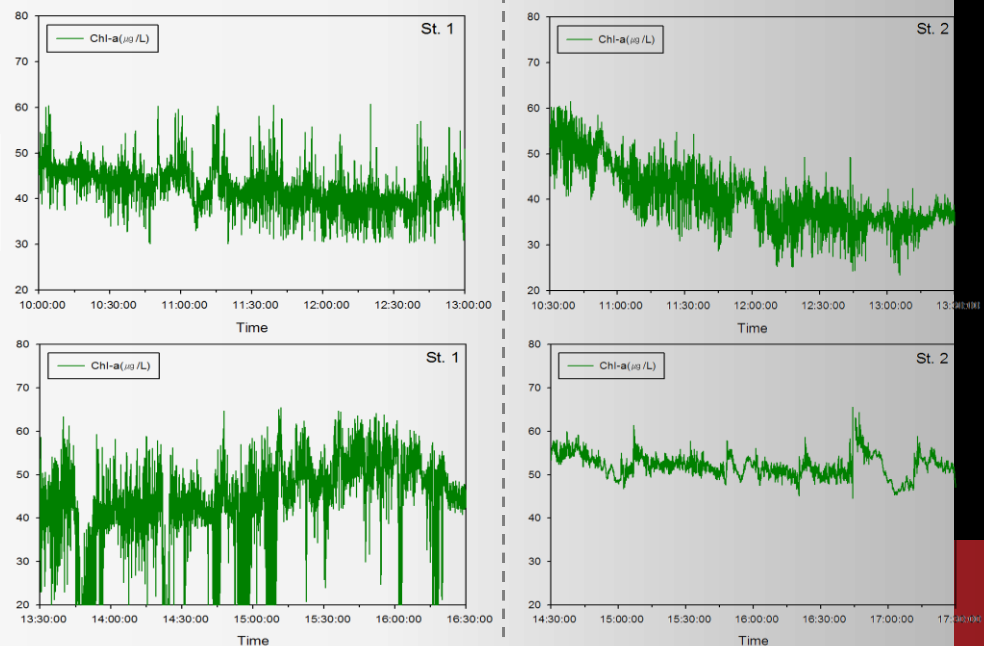
3.3 Multifunctional AFIs (19)

Real-time monitoring of Chl-*a*



AM (10:00 ~13:00)

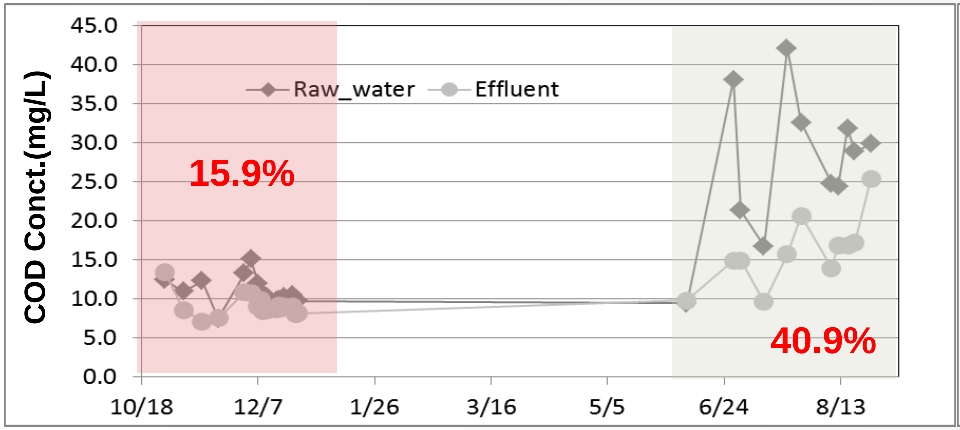
PM (13:00 ~18:00)

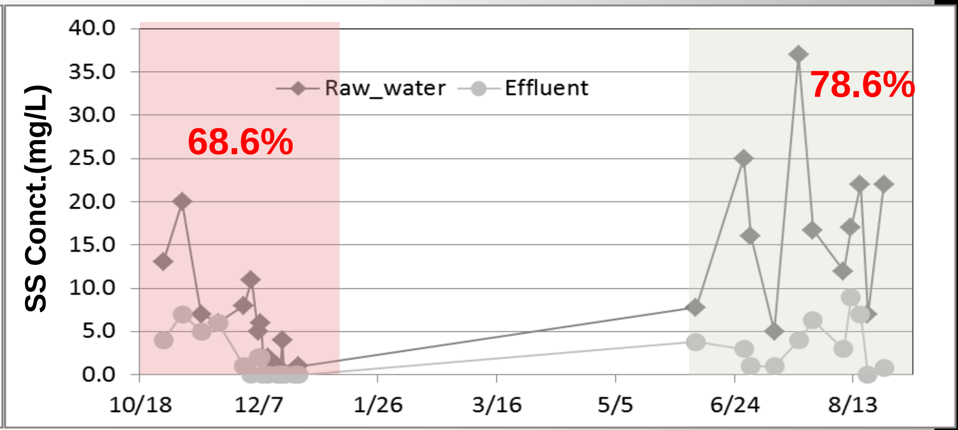


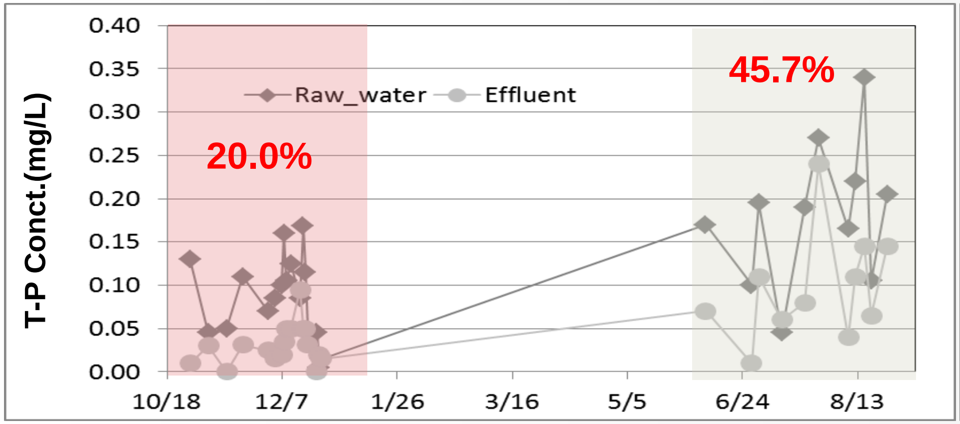
- The removal efficiency of Chl-*a* was monitored using Chl-*a* sensor inside/outside multifunctional AFI;
- The decrease in Chl-*a* concentration was not significant during the morning;
- The decrease in Chl-*a* concentration was significant during the day time;
- Multifunctional AFI can inhibit the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

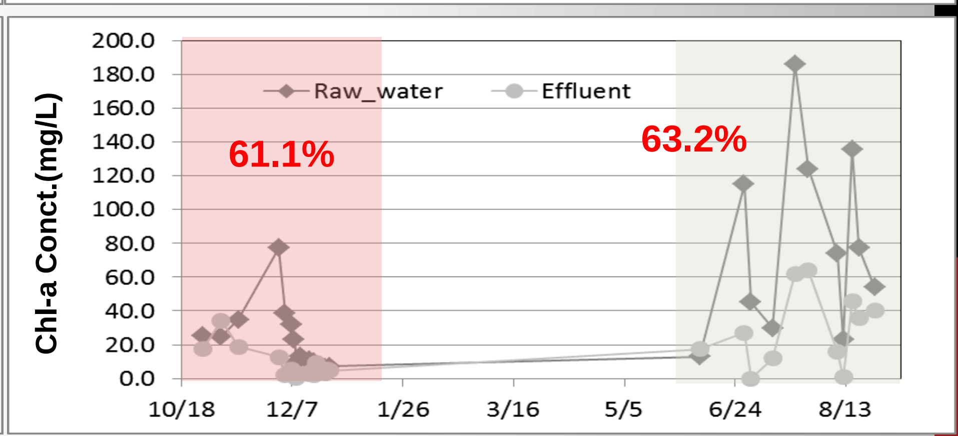
3.3 Multifunctional AFIs (20)

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

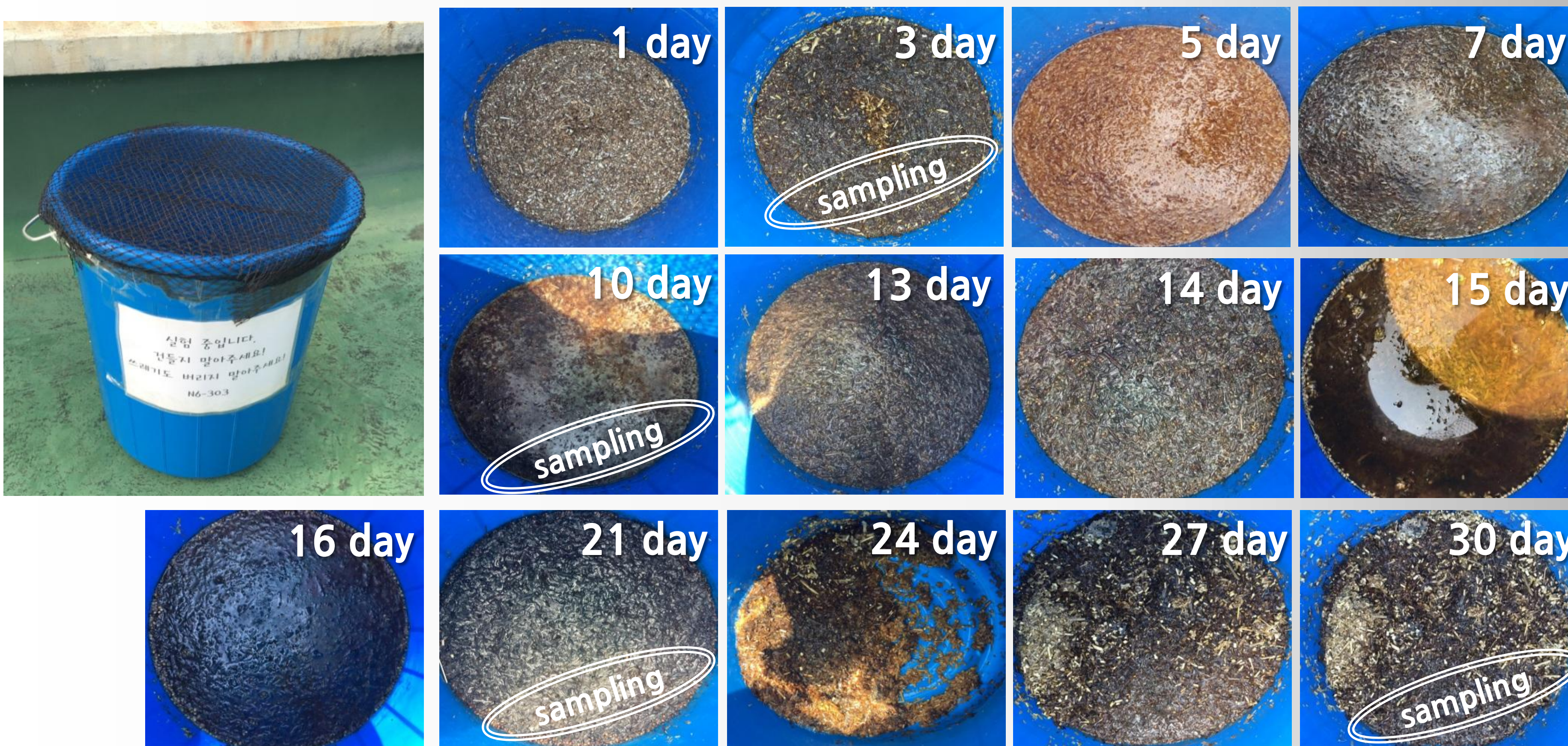

Contamination of photocatalyst balls


Accumulation of wastes around AFI


Moving of AFI

3.4 Application of Barley Straw (1)

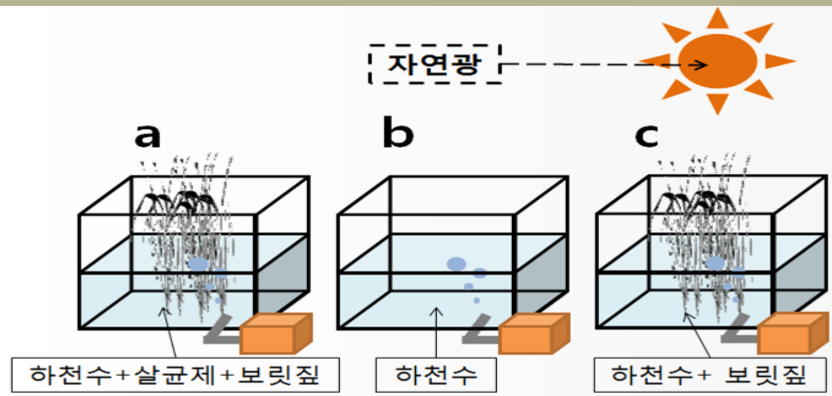
Degradation of barley straw

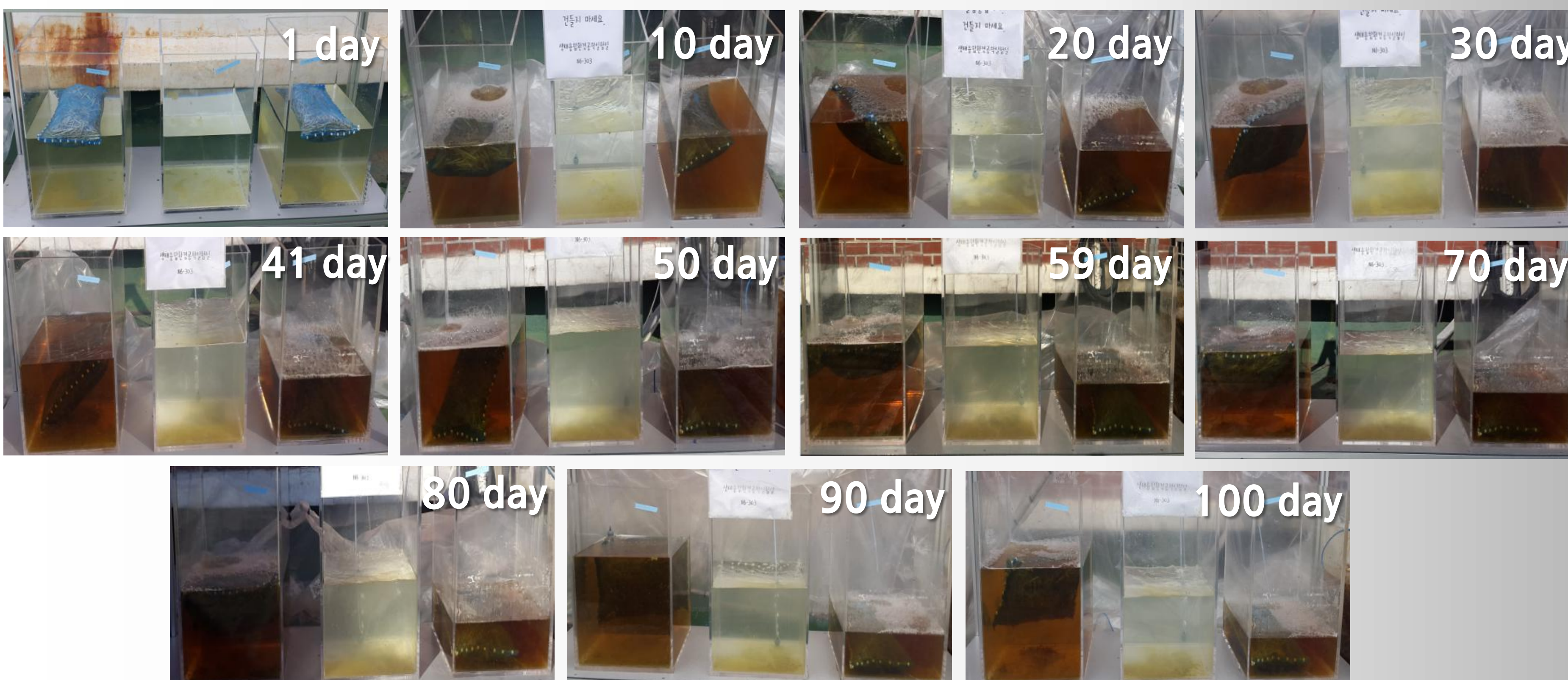


- Fungi decompose the barley in water, causing some chemicals to be released;
- The specific chemicals were identified as oxidized polyphenolics and hydrogen peroxide;
- The activity of barley straw is usually described as being algistatic (prevents new growth of algae); and,
- Barley straw may reduce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

3.4 Application of Barley Straw (2)

Chemicals from barley straw decomposition

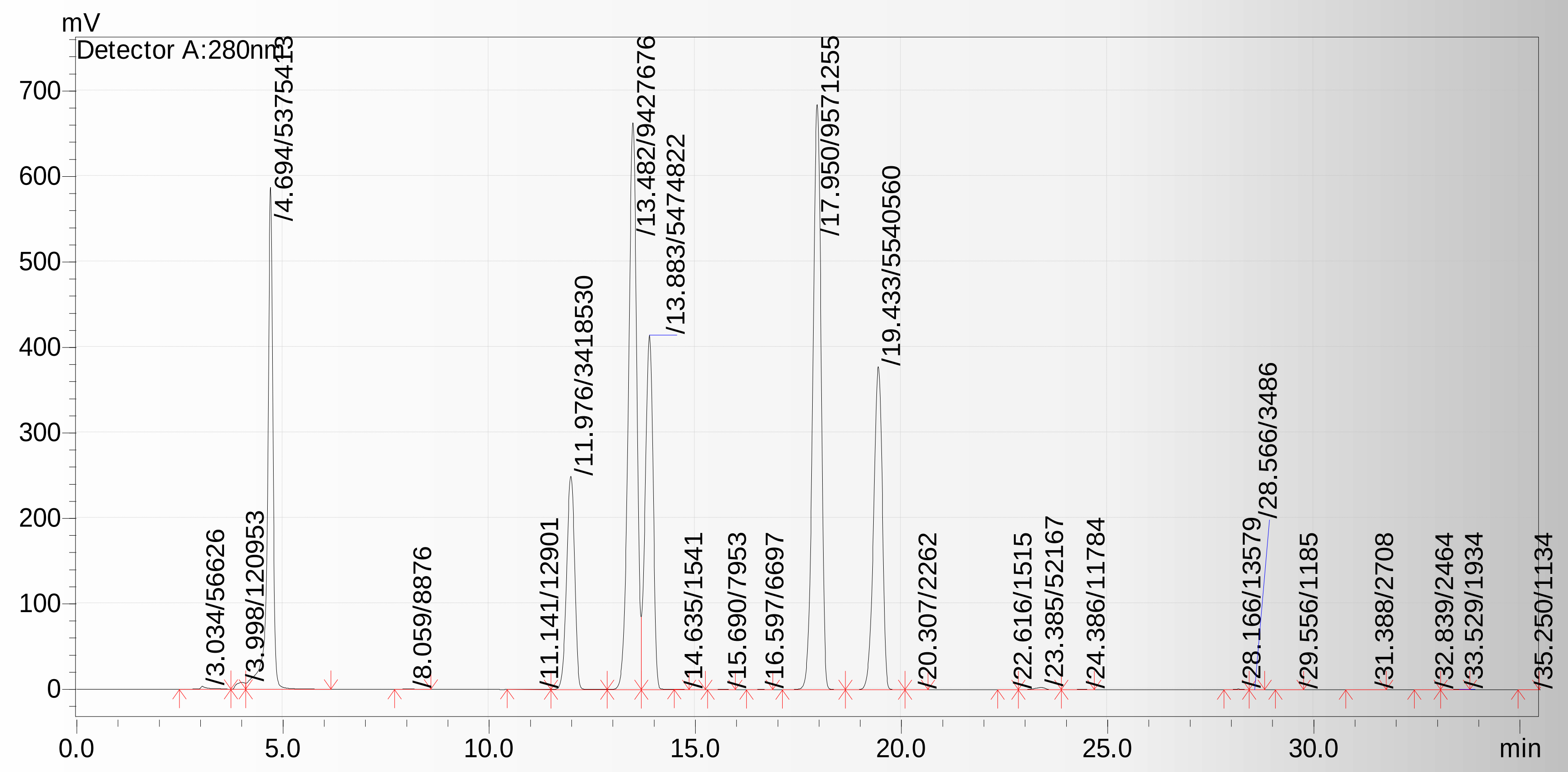




3.4 Application of Barley Straw (3)

Analysis of chemicals from barley straw decomposition

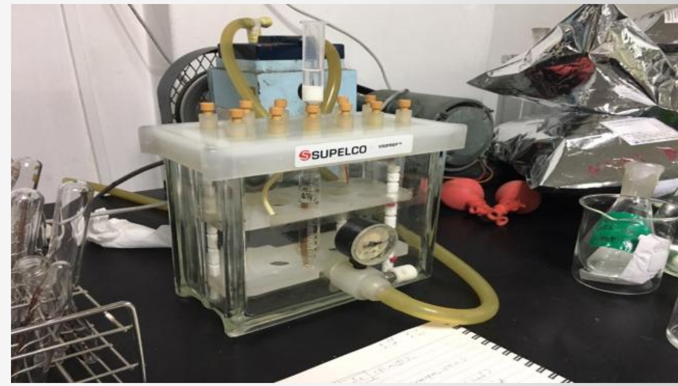
< Peak Sequence >
Gallic acid-Hydroxybenzoic acid – Vanillic acid,Caffeic acid – Syringic acid – Coumaric acid – Ferulic acid



3.4 Application of Barley Straw (4)

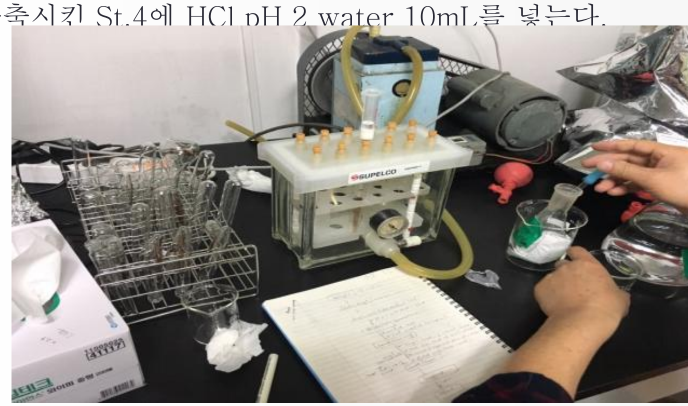
Analysis of chemicals from barley straw decomposition

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

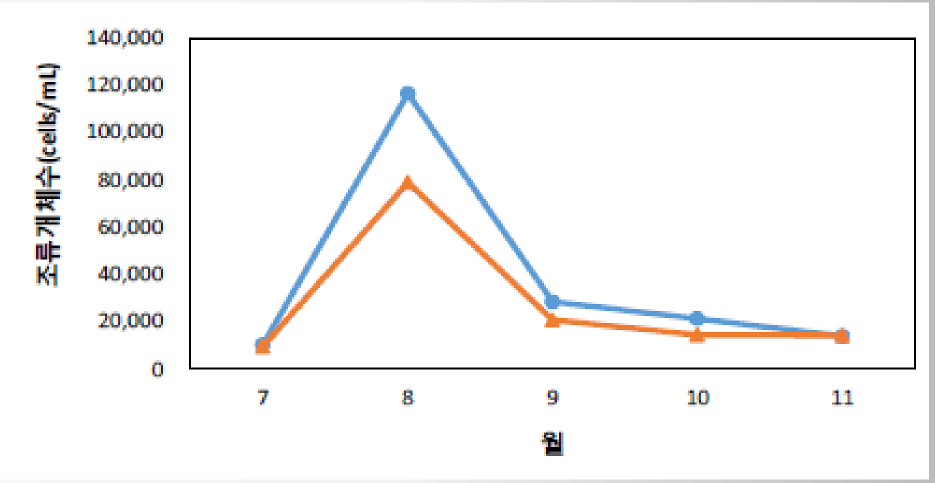


4. 안정화된 Filter에 농축된 시료 10mL를 1mL/min으로 흘려보낸다.

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)

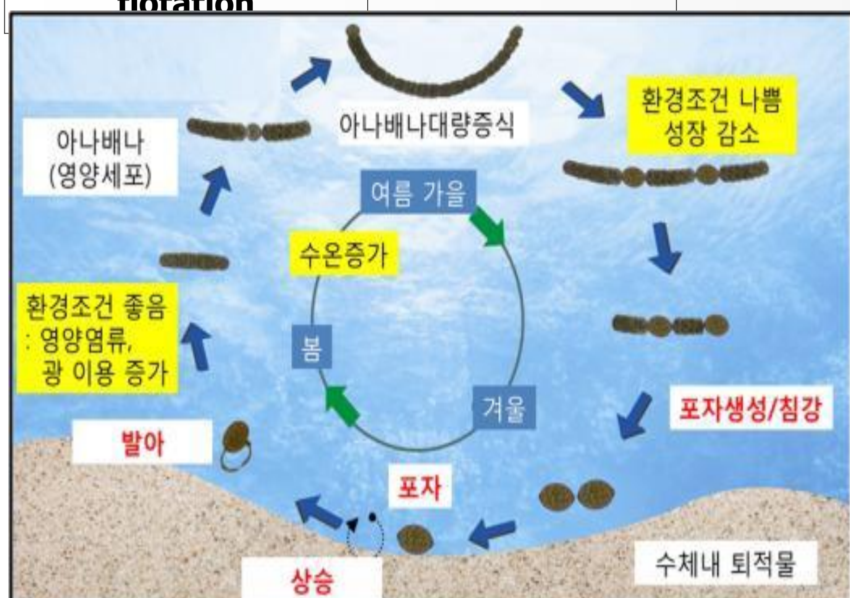
Various application of amphibious dredging machine

	Ilsan lake park	*Songdo central park*	*Sejong lake park*
Large man-made lake			
	Shihwa lake	*Shihwa lake*	*Sorae lake*
Large Natural lake			
	Hallu world	*Cheongla canal*	*Songdo canal*
Large man-made canal			
	Mitchuhall pond	*National museum pond*	*National assembly pond*
Small 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 m^2
	November	28,522	14.02	22,980 m^2
Water treatment facilities with coagulation and dissolved air flotation	Sum	365	3.93	Treated Amount
	July	248	2.41	12,050 m^3
	November	117	1.52	7,800 m^3



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 biogeoche-mical 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!

충청남도의 지속 가능한 수자원(생.공용수 중심)확보 방안

2017. 10. 18

K-water 김 종 신

CONTENTS

K water

I

충남도 장래 인구 추계 현황

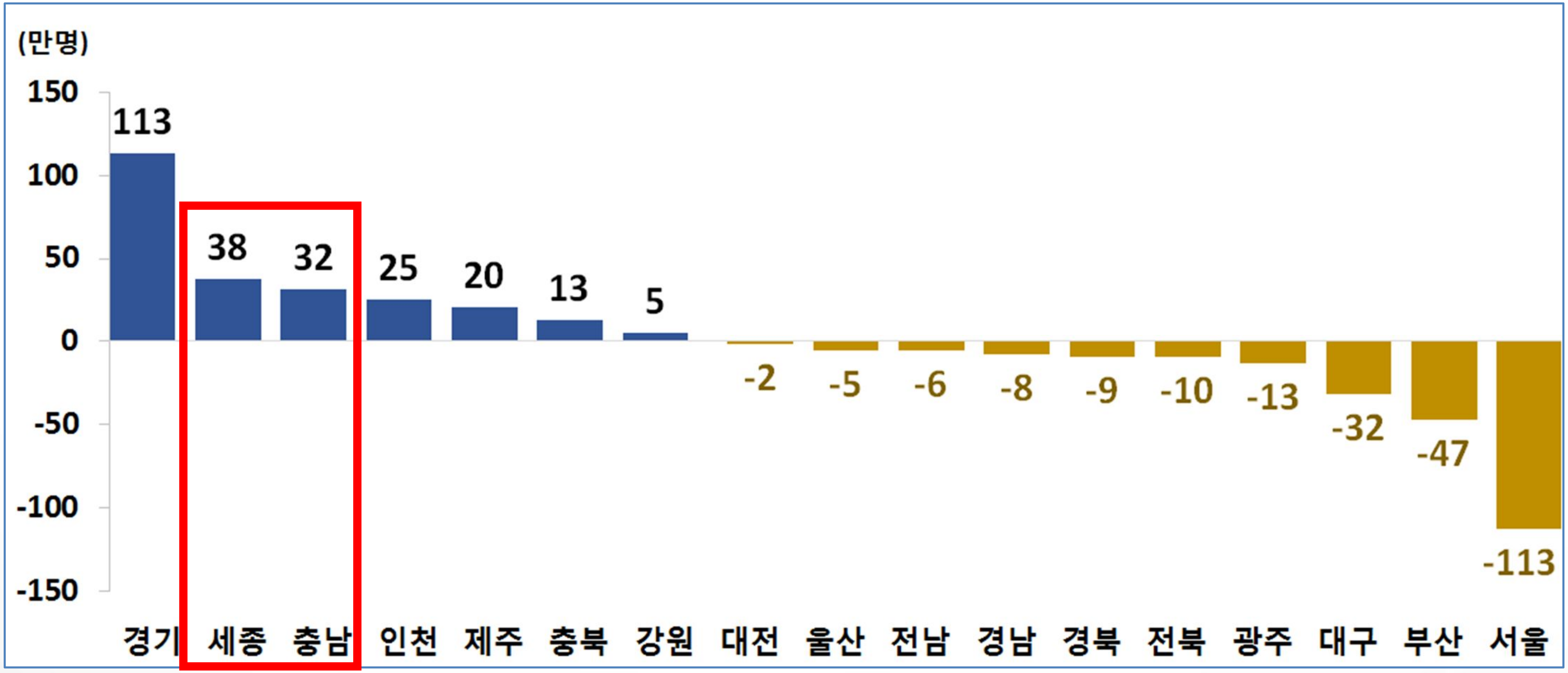
K water

전국 장래 인구 추계 ('17. 6 통계청 발표)

지역	인구(만명)								
	2015년	2020년	2025년	2030년	2035년	2040년	2045년	15년 대비 45년	
								증감	증감률(%)
전국	5,101	5,197	5,261	5,294	5,283	5,220	5,105	4	0.1
서울	994	964	955	943	926	906	881	-113	-11.3
부산	345	340	334	328	321	310	298	-47	-13.7
대구	247	245	241	237	231	224	215	-32	-12.8
인천	288	298	308	315	319	318	314	25	8.8
광주	151	150	149	148	146	142	138	-13	-8.6
대전	154	152	154	156	156	155	152	-2	-1.2
울산	116	117	119	119	118	115	111	-5	-4.4
세종	19	38	43	47	51	54	56	38	201.0
경기	1,242	1,322	1,364	1,390	1,397	1,385	1,356	113	9.1
강원	152	153	155	157	158	158	157	5	3.4
충북	159	163	167	171	173	174	172	13	8.3
충남	210	220	229	236	241	243	242	32	15.1
전북	184	182	182	181	180	178	174	-10	-5.2
전남	180	179	179	179	178	177	174	-6	-3.1
경북	268	268	269	269	268	265	259	-9	-3.3
경남	333	339	341	342	340	335	325	-8	-2.3
제주	60	68	72	76	79	80	80	20	34.2

전국 장래 인구 추계 ('17. 6 통계청 발표)

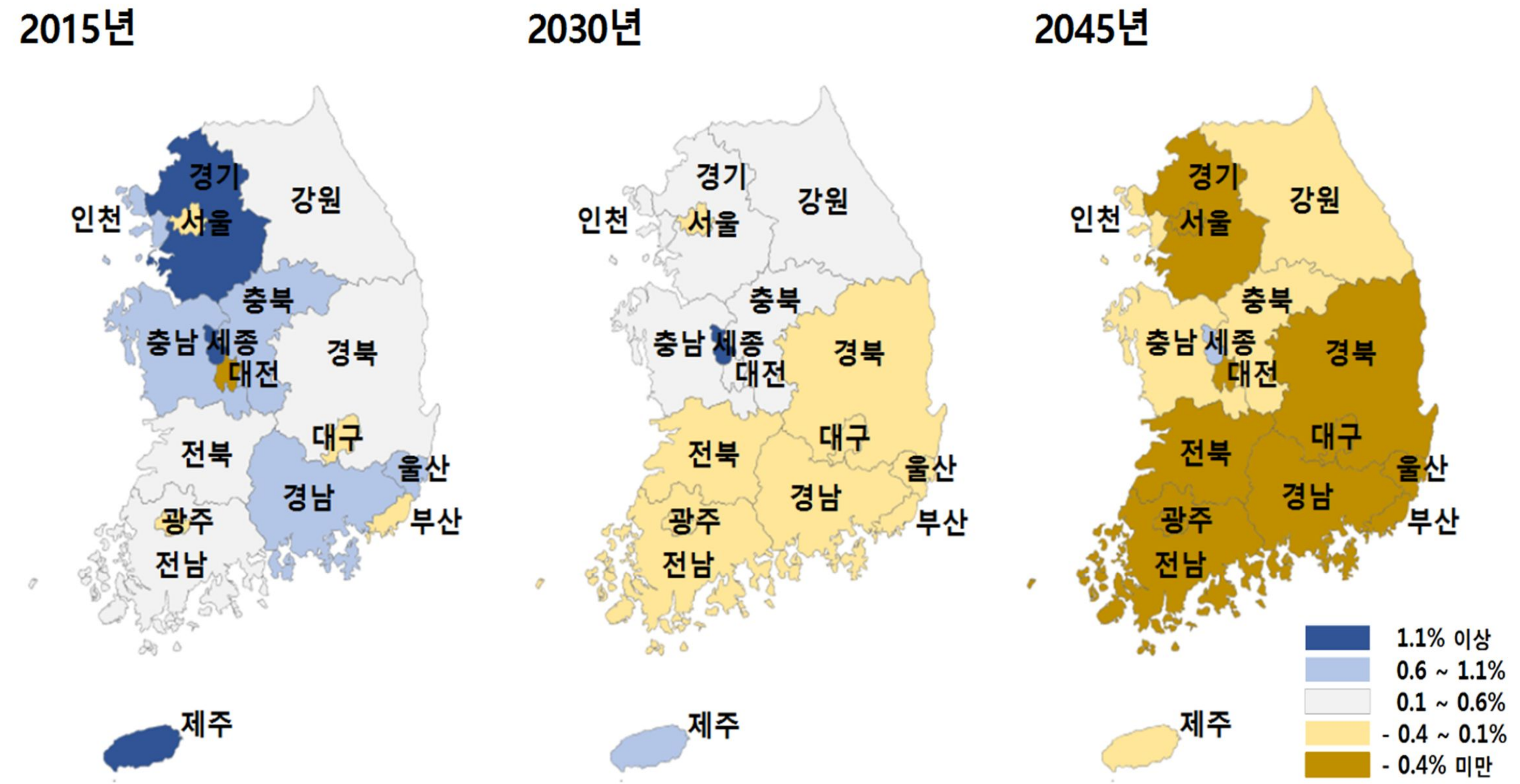
충남, 세종지역은 '45년까지 약70만명 증가 예상



시도별 총인구 증감, 2015년 대비 2045년

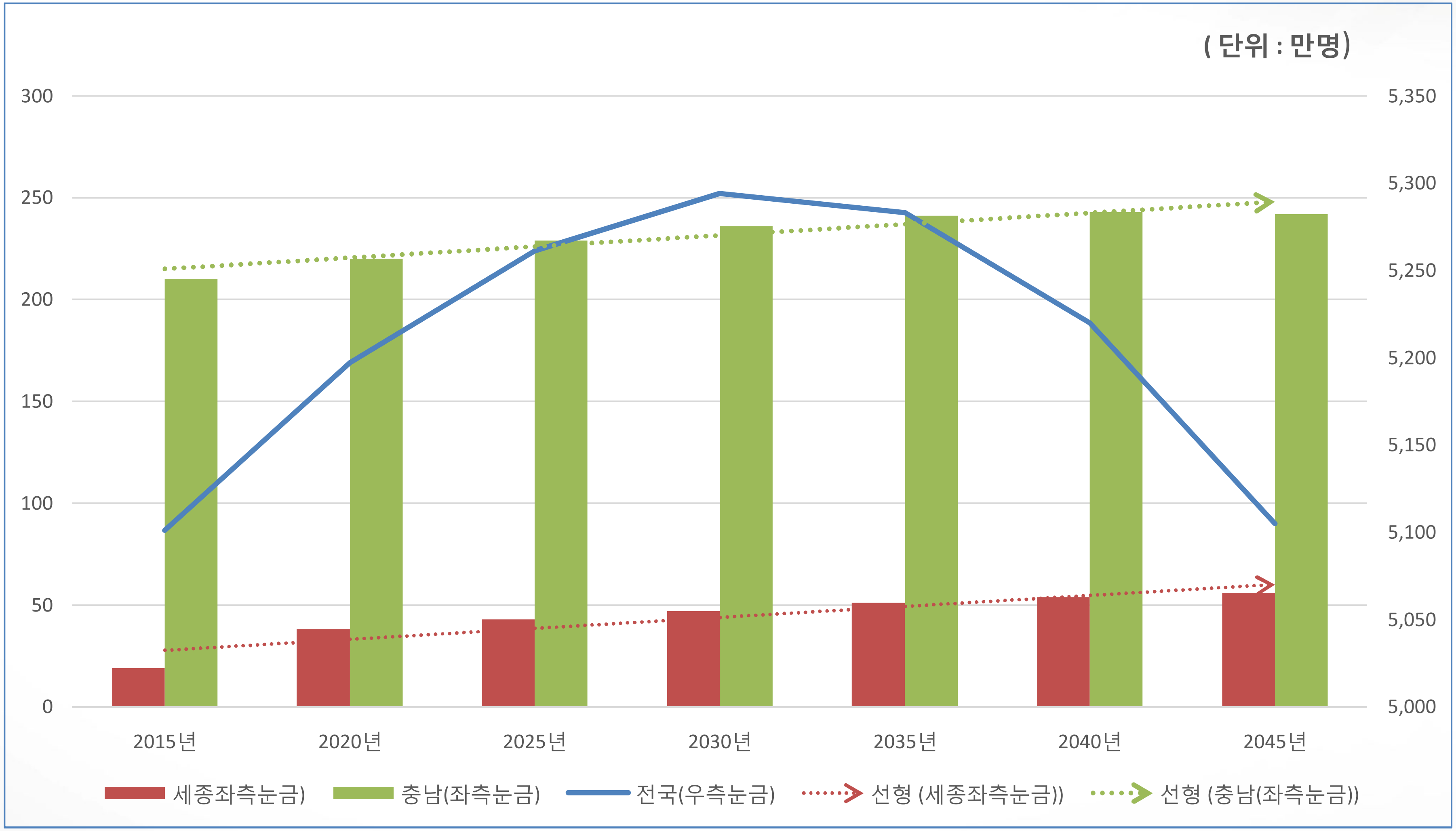
전국 장래 인구 추계 ('17. 6 통계청 발표)

시도별 인구성장률, 2015~2045년



전국 장래 인구 추계 ('17. 6 통계청 발표)

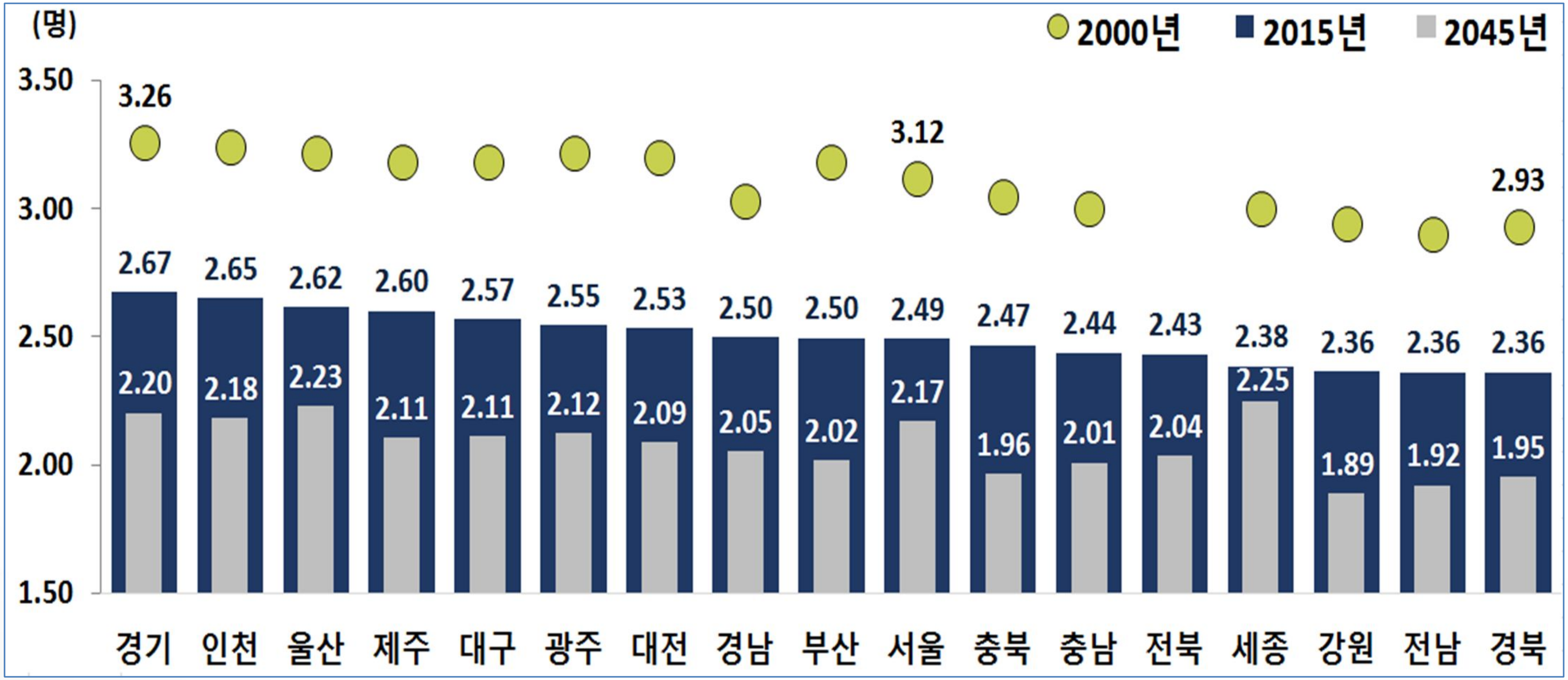
K water



전국, 충남, 세종지역 인구 증감 현황

전국 장래 가구 추계 ('17. 8 통계청 발표)

평균가구원수 `00년: 3명 → `15년: 2.44명→ `45년: 2.01명

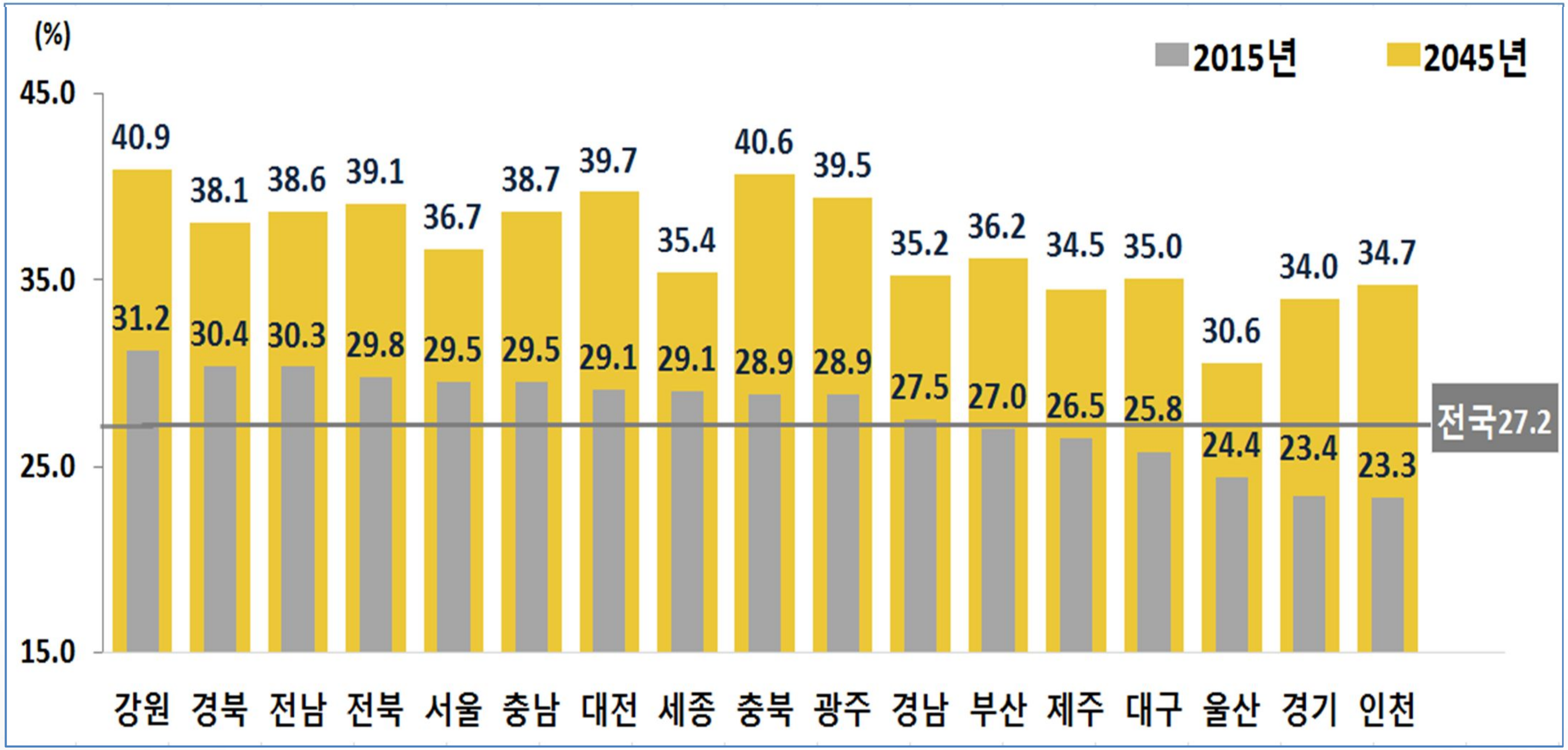


시도별 평균가구원수, 2015년~2045년

전국 장래 가구 추계 ('17. 8 통계청 발표)

K water

'인구' 도 늘고 '1인가구' 도 늘면? →1인당 물사용량 ↑



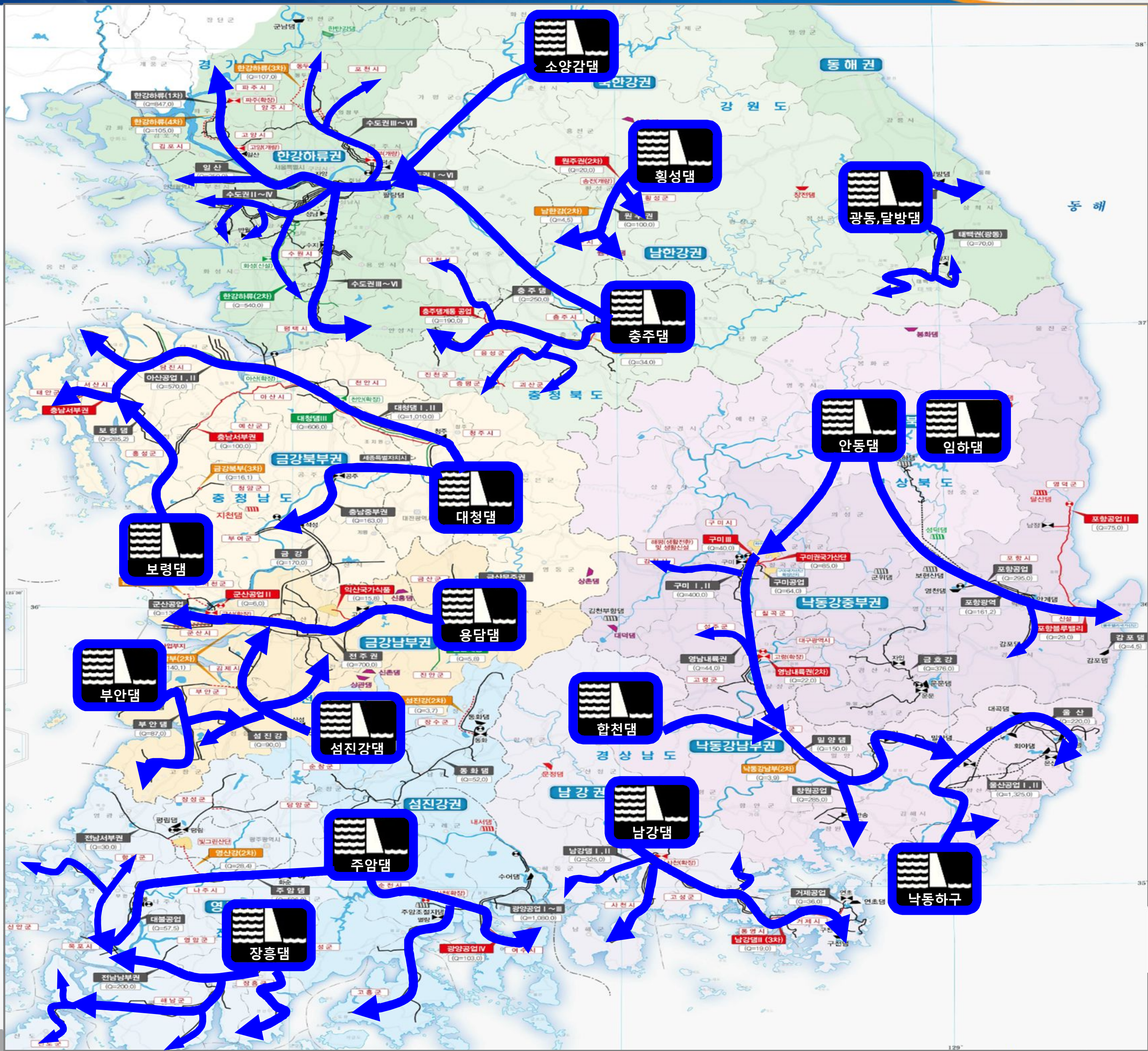
시도별 1인 가구 구성비, 2015년~2045년

Ⅱ

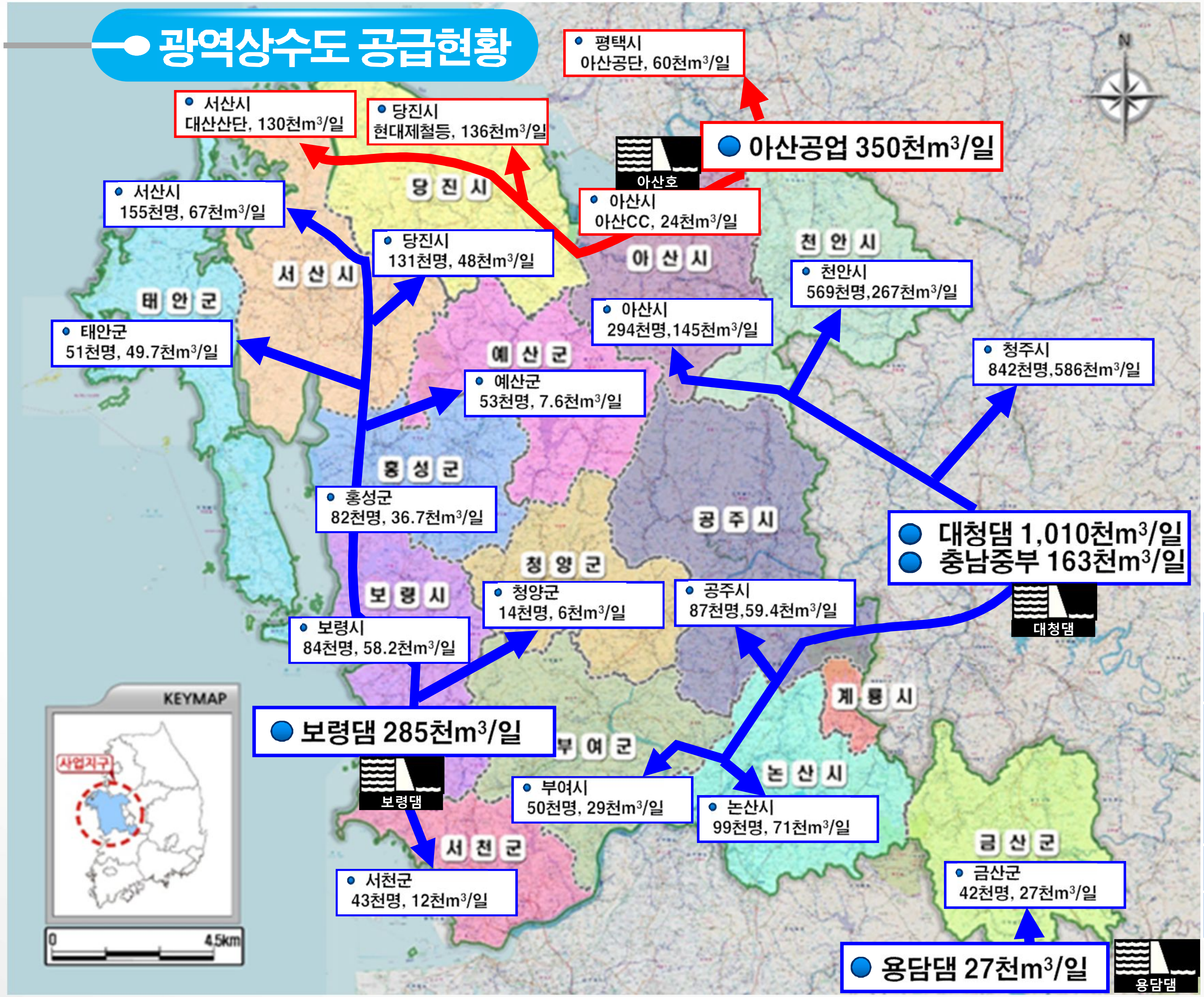
충청남도 수자원 및 사업 현황

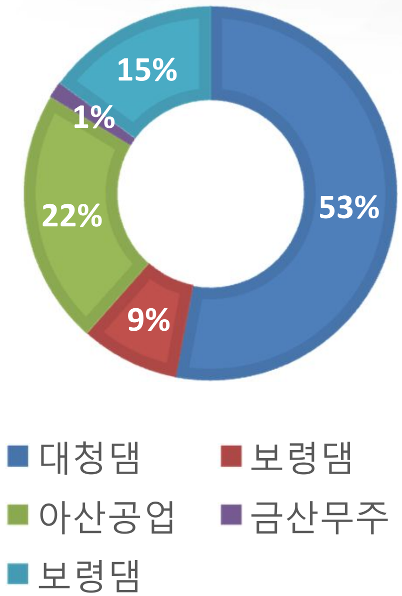
K water

전국 수자원 공급 현황


소양강댐
횡성댐
광동,달방댐
충주댐
안동댐
임하댐
대청댐
보령댐
용담댐
부안댐
섬진강댐
합천댐
남강댐
낙동하구
주암댐
장흥댐
한강하류권
북한강권
남한강권
동해권
금강북부권
금강남부권
낙동강중부권
낙동강남부권
섬진강권
남 강 권
강 원 도
충 청 북 도
충 청 남 도
경 상 남 도
동 해

충청남도 용수공급 현황





구 분	시 설 명	공급량 (천m³/일)
외부유역	대청댐	1,010
	충남중부	163
	금산무주	27
혼합유역	아산공업	421
자체유역	보령댐	285

• 혼합유역 : 충남과 타지역이 혼합된 유역

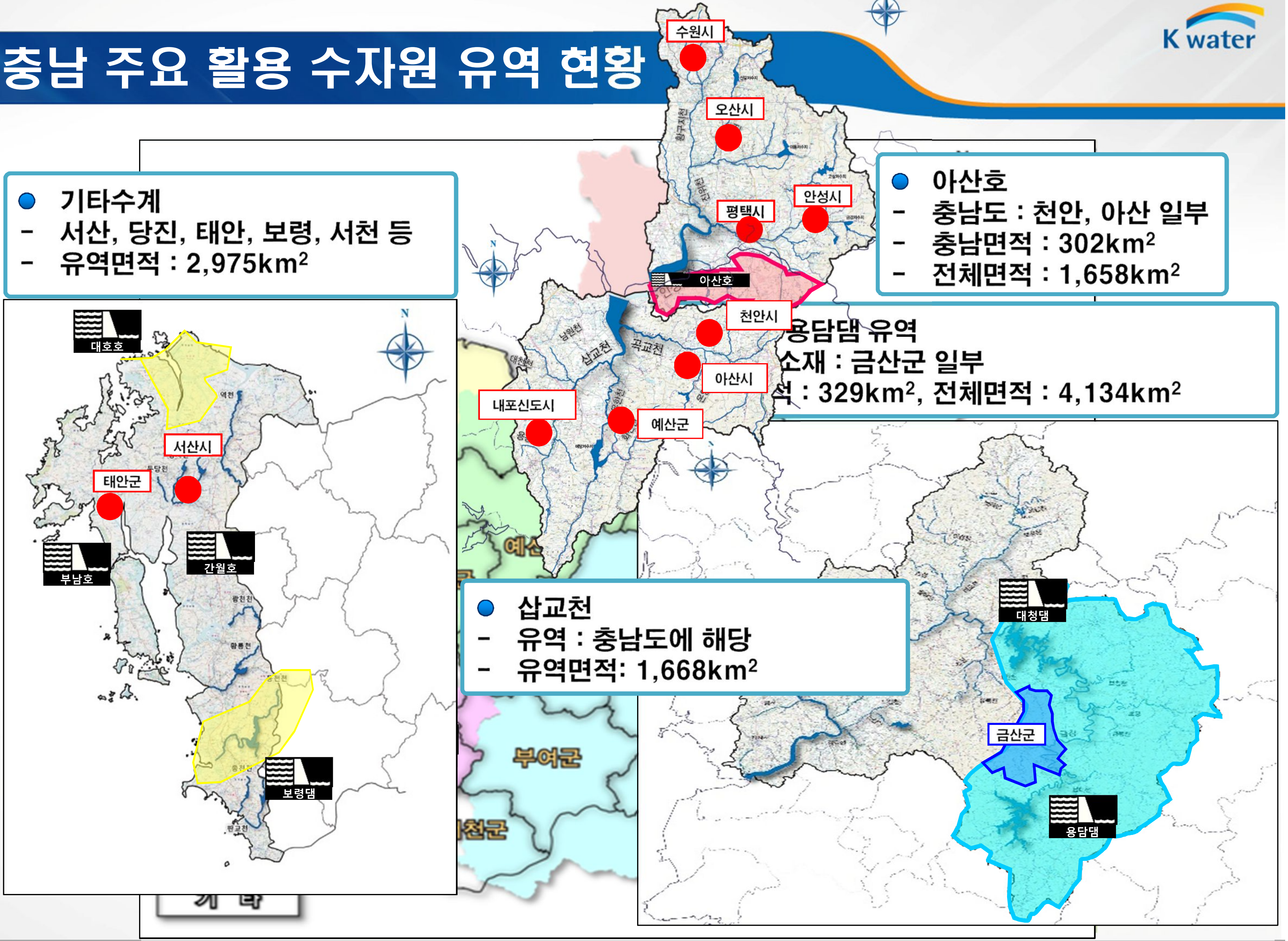
충남 주요 활용 수자원 유역 현황

- 기타수계
  - 서산, 당진, 태안, 보령, 서천 등
  - 유역면적 : 2,975km²

- 아산호
  - 충남도 : 천안, 아산 일부
  - 충남면적 : 302km²
  - 전체면적 : 1,658km²

- 용담댐 유역
  - 소재 : 금산군 일부
  - 적 : 329km², 전체면적 : 4,134km²

- 삽교천
  - 유역 : 충남도에 해당
  - 유역면적: 1,668km²



현재 추진중인 광역상수도 사업

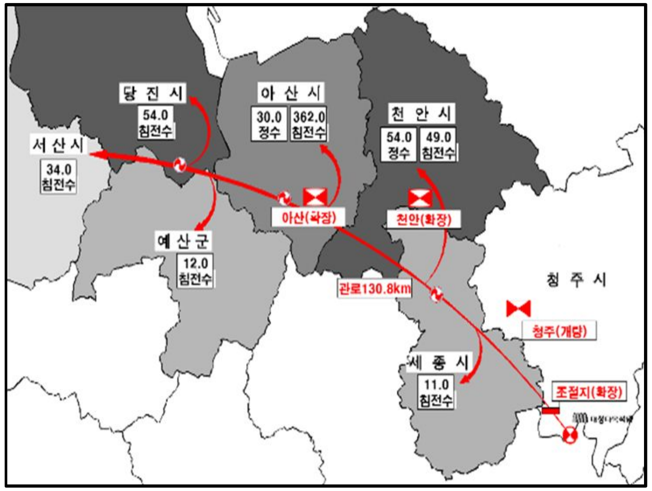
K water

● 대청 Ⅲ단계 광역상수도 사업 ('13~'19)

✓ 기존 대청댐 공급지역의 **개발계획 고려한 시설 확충**

* 대청댐 → 6개 시군(세종, 천안, 아산, 서산, 당진, 예산), 일 61만㎥

* 사업착수 ('13) → 사업준공 ('19) → 용수공급 개시('20)



● 충남서부권 광역상수도 건설 ('17~'22)

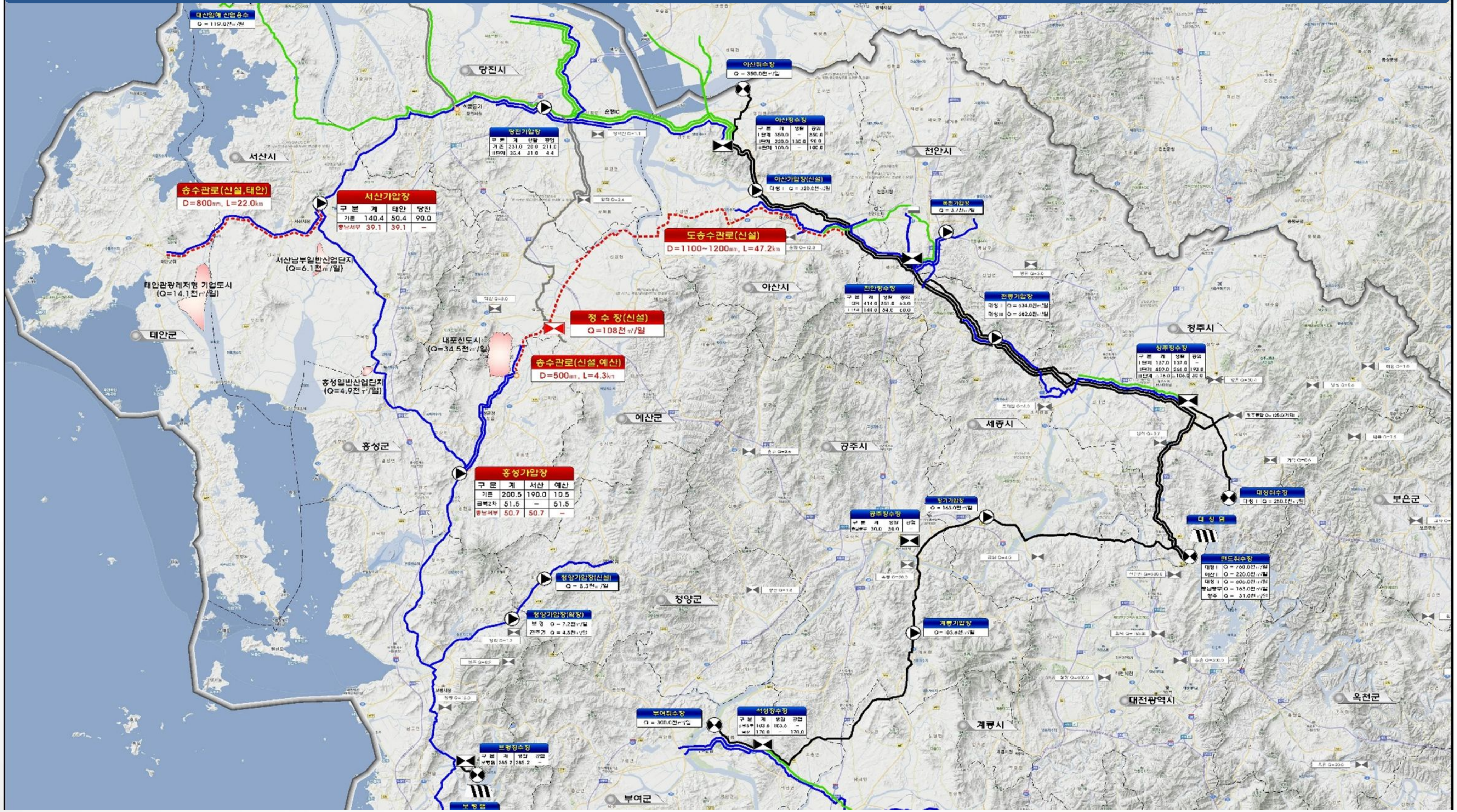
✓ 도시개발 등 **용수수요 증가에 따른 공급대책 마련**

* 대청Ⅲ단계 여유량 → 5개 시군(서산,당진,홍성,예산,태안), 일 10만㎥)

* 타당성조사('17) → 기본 및 실시설계('18) → 공사 및 준공 ('22)

사업 도면

대청댐계통3단계광역 및 충남서부권광역상수도 사업



III

수자원 확보 방안별 고려사항

K water

정부정책 (총리주재 국정현안점검조정회의 '17. 8. 24)

농림축산 식품부	경기, 충남 물 부족난 해소를 위한 아산호 활용 수계연결('21년 완료) * 아산호–안성시 금광·마둔저수지 연계('18~'20년) * 아산호–삽교호–대호호 수계연결('18~'21년)
국토 교통부	* 충남서부권 광역상수도 사업('18~'22년) * 대산임해산업단지 해수담수화 사업('18~20년) * 대청Ⅲ단계 광역상수도 사업('11~19년) 등을 집중 추진
환경부	* 지방상수도 현대화사업 추진('17~'28년) * 하수처리수 우선사용 검토 의무화 * 수자원 이용 우선순위 정립(수도정비기본계획 수립지침 반영) ① 빗물 활용 확대 및 누수 저감→ ② 하수처리수 재이용→ ③ 대체취수원 개발 → ④ 여유량 전환·활용(인근 지자체 및 광역상수도)

아산호-삽교호-대호호 수계연결 공급

K water

- **항구적 가뭄대책 방안으로 추진(한국농어촌공사)**

- 양수장 2개소, 수로 62km(신설 14, 기존 48km)
- 사업기간 : 2년
- 추정사업비 : 830억원

고려사항

✓ **비상 공급 외에 상시 공급량 확보를 위해서는 사회적 합의 필요**

☞ 아산호 유역의 90%이상이 경기도(평택, 안성, 수원, 화성 등) 지역에 해당

✓ **방조제의 특성상(하수처리수 등) 수질 적합성 여부 검토 필요**

☞ 대산석유화학단지 및 현대제철 등은 추가 역삼투압(RO막) 처리를 위한 비용 부담

✓ **가뭄이 농번기와 겹치게 되면 생.공용수 공급 보장 불가**

☞ 대호지의 경우, 저수율 20% 미만 저하 시 용수공급 중단 계약서 명시

폐쇄된 지방상수도 복원/활용

● 수원 다원화 실현으로 물 공급 다양성 확보

고려사항

✓ 유역면적이 작고 기본 유하량이 많지 않아 가뭄에 취약한 곳이 대부분

☞ 금년 가뭄시, 수원 파장정수장 및 남해군 상수원 고갈로 광역상수도 대체 공급

✓ 취수원이 농업용수와 함께 사용하는 곳이 많아, 가뭄 시 농민들과 물 확보 갈등 발생 우려

✓ 상수원보호구역 재지정 ↔ 지역주민 재산권 보장, 지역발전 견인

✓ 선택과 집중, 예산 확보의 어려움으로 가뭄 등의 항구대책 마련 지난

☞ (사례) '보령댐 도수로' 범정부 차원의 대책 마련 및 투자비 적기 확보, 최단기간 공사(인허가 등 포함) 완료로 적기 공급

하수처리수 재이용 확대 (정부 정책 부응)

- 하수처리수를 공업용수 등의 용도에 맞게 재처리하여 재이용
  - ☞ 사례 : 포항(10만), 아산(3.5만)
- 완벽한 재이용은 무방류 구현
  - ☞ 하천 오염부하량 획기적 감소

고려사항

✓ 충남도 하수처리수는 방조제(아산, 천안 하수처리수→삽교방조제, 서산 하수처리수→간월방조제)를 통해서 농업용수 등으로 이미 활용 중

☞ 하수처리수 재이용 확대시, 방조제 유입량 감소로 농업용수 부족 문제 발생 우려

✓ 아산호 여유량은 경기도 대도시(수원, 평택, 화성 등)의 하수처리수에 기인

☞ 경기도 대도시 재이용 확대정책 본격 추진 시, 아산호 유입량 감소 가능성 높음

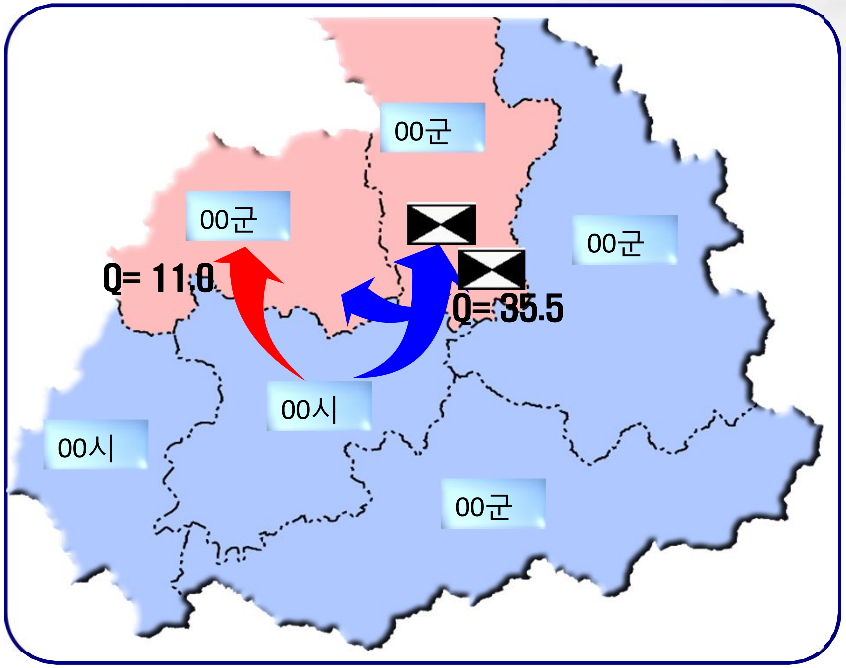
광역상수도 여유량의 급수체계 조정

00시 여유량

(Q= 46.5천m³/일)

Q= 35.5 → 00군 부족량

Q= 11.0 → 00군 부족량



- 인근지역 **여유량 전환** ➔ **한정된 수자원 효율적 이용**
- 광역 및 지방상수도 **연계** 고려 ➔ **효율적 운영 도모**

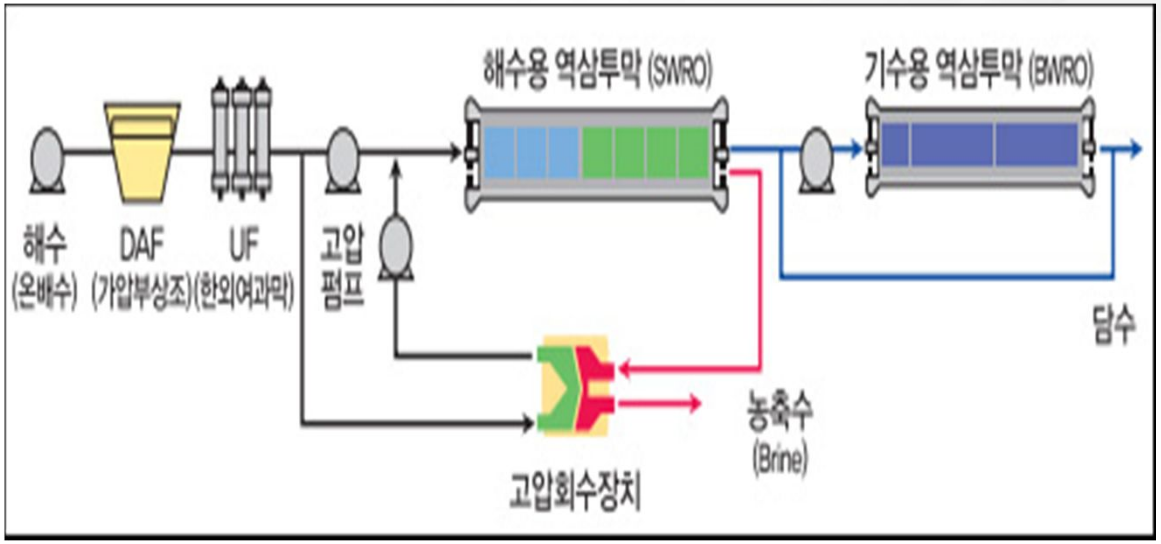
고려사항

✓ 대청댐은 생.공용수 기본 계획량 소진으로 추가 배분 불가

☞ 대청3단계 및 충남서부권광역상수도에 잔여 기본계획량 모두 할애된 상태

✓ 수도권 광역(수원 : 소양강댐, 충주댐)과 전주권광역(수원 : 용담댐) 급수체계 조정을 위해서는 많은 비용 수반과 지역간 합의 필요

해수담수화 개발

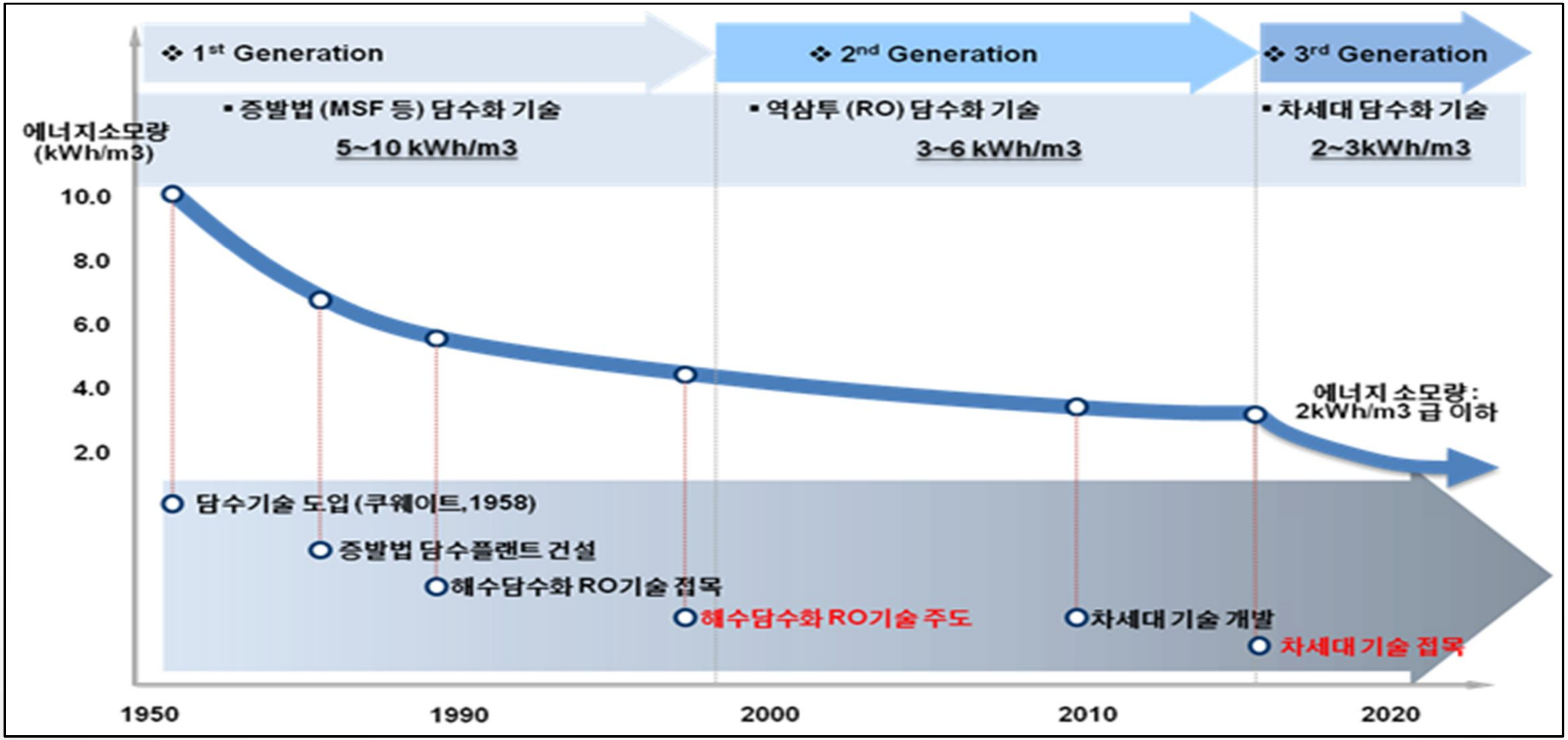


고려사항

- ✓ 해안가를 접하고 있는 충남도는 물자급률을 높일 수 있는 대안
  - ☞ 물자급율 = (지자체 관내 확보량/총 사용량)*100
- ✓ 높은 전력원단위로 생산단가에 대한 부담이 단점
- ✓ 고순도의 물을 요구하는 공업용수로는 우선적으로 활용 가능
  - ☞ 석유화학단지의 공정수, 발전단지의 보일러 용수 등

해수담수화 에너지 소비 개선 현황

- 지속적인 기술개발 및 운영 경험 축적으로 현재 3~4kWh/㎥ 정도
- 정부-산업-학계에서 기술개발 집중 투자 중으로 더욱 개선 전망



지방상수도 현대화 사업 우선적 추진

● 지방상수도 현대화사업 ➔ 누수저감(경영개선) ➔ 댐용수 비축(수자원 추가확보 효과)

* 2017년 추진중인 3개 지역(부여, 서천, 태안)과 함께 2018년 대상지역(청양, 홍성, 예산)도 조기 추진 필요
* 충남서부권 지방상수도의 누수율은 21.3%로(전국 평균 10.9%) 매우 높아 현대화사업을 통한 누수저감이 시급

※ (해외사례) **미국 뉴욕의 물 수요관리 대책**

✓ 1980년 가뭄 이후, 수요관리를 통해 인구 증가에도 불구하고 2010년 수요는 1960년 이후 최저 수준

✓ 뉴욕시는 Water Demand Management Plan을 수립하고 2020년까지 물 수요 5% 절감을 목표로 추진 중

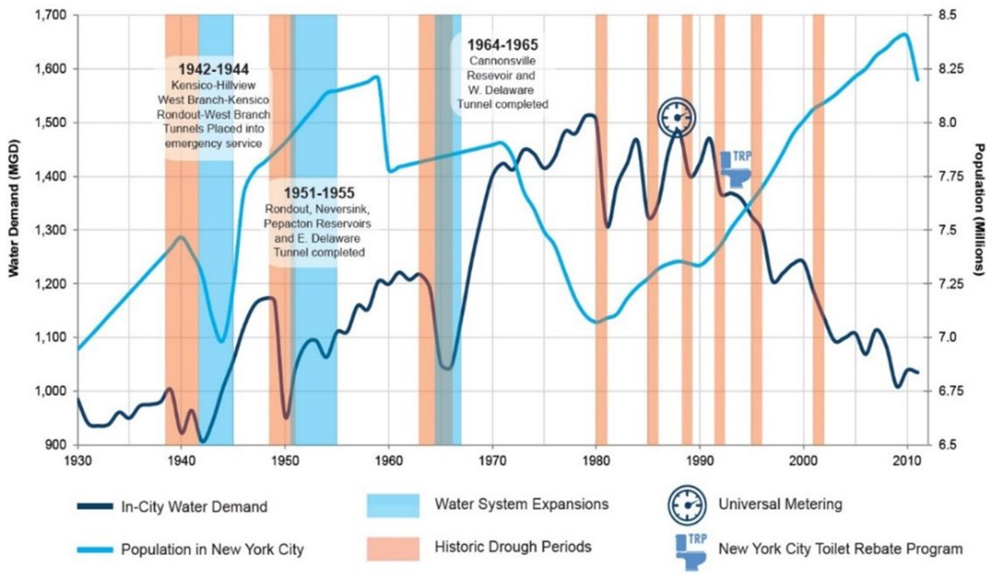
STRATEGY 1 Municipal Water Efficiency Program

STRATEGY 2 Residential Water Efficiency Program

STRATEGY 3 Non-Residential Water Efficiency Program

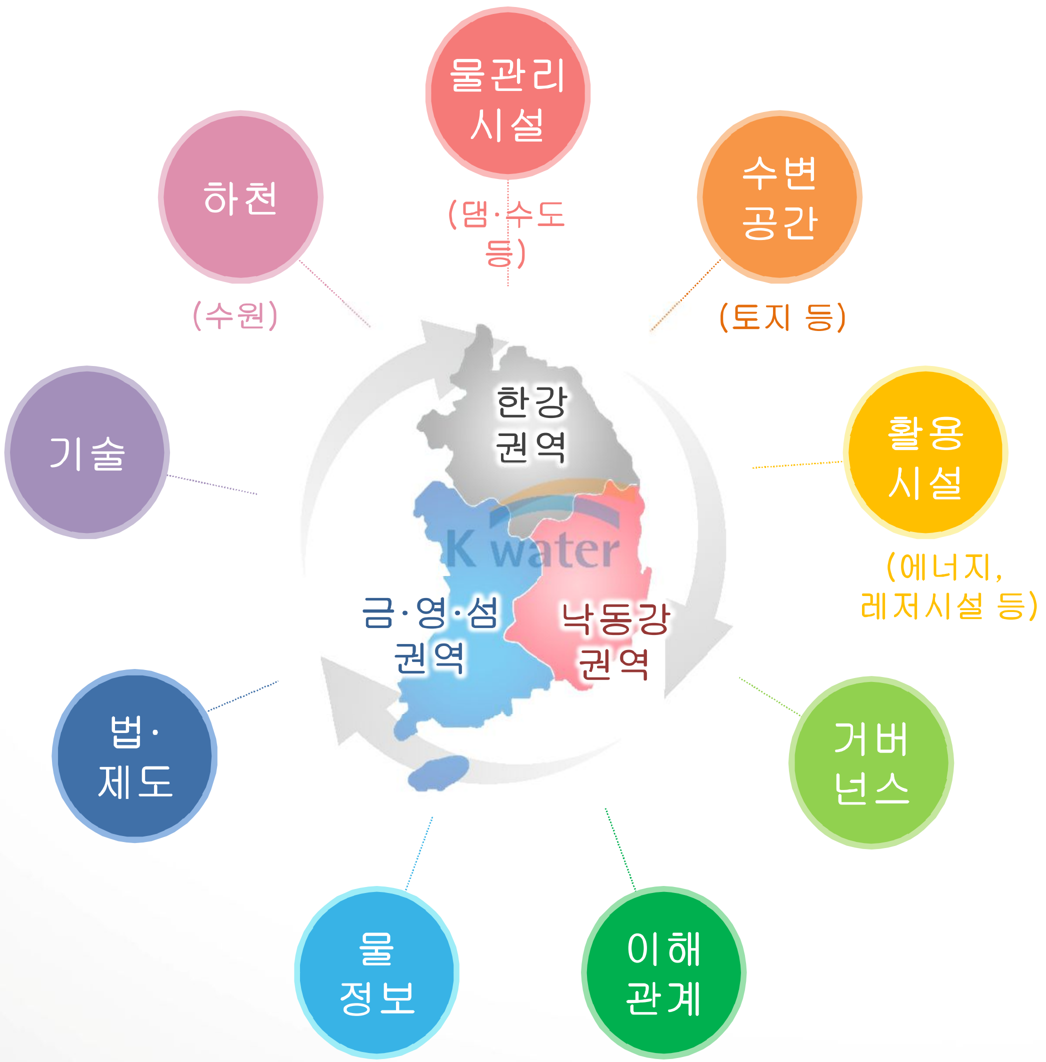
STRATEGY 4 Water Distribution System Optimization

STRATEGY 5 Water Supply Shortage Management



• 수요관리의 가장 중요한 시점은 화장실에 소용량 변기의 도입 (New York City Toilet Rebate Program)

통합물관리 확대 추진



✓ 물관리를 '잘' 하기 위해

(효율성, 형평성, 지속성 제고)

✓ 유역내 물관리에 영향을 미치는 모든 것(H/W, S/W)을 고려하여

✓ 개별적으로 관리하던 수량, 수질, 생태, 환경 등을

✓ 통합적으로 관리하는 것

통합물관리 적용 사례

충남서부지역 가뭄 극복

보령댐 고갈 위기시 수요관리 및
대체수원확보로 단수없이 가뭄 해소
(일공급량의 76% 확보)

댐 관리체계 개선

한수원 발전용 댐을 다목적댐과 실시간
연계 운영하여 수도권 제한급수 예방
('15년 한강수계 댐 통합운영으로 19.1억㎥ 비축)

IV

대산 해수담수화 사업 현황

대산 해수담수화 사업 현황

사업목적

- 대산 산업지역의 지표 수원은 기후변화에 따른 반복적 가뭄과 신규 산업단지 조성 및 공장증설로 공급안정성 취약, 수자원의 수량부족 등 한계에 도달한 상황
- 해수담수화 세계시장은 지속성장 중이나 국내 수요한계로 중대규모 시설 건설/운영 실적 확보가 어렵고 연관산업 육성 한계로 해외 시장 진출이 어려운 실정임

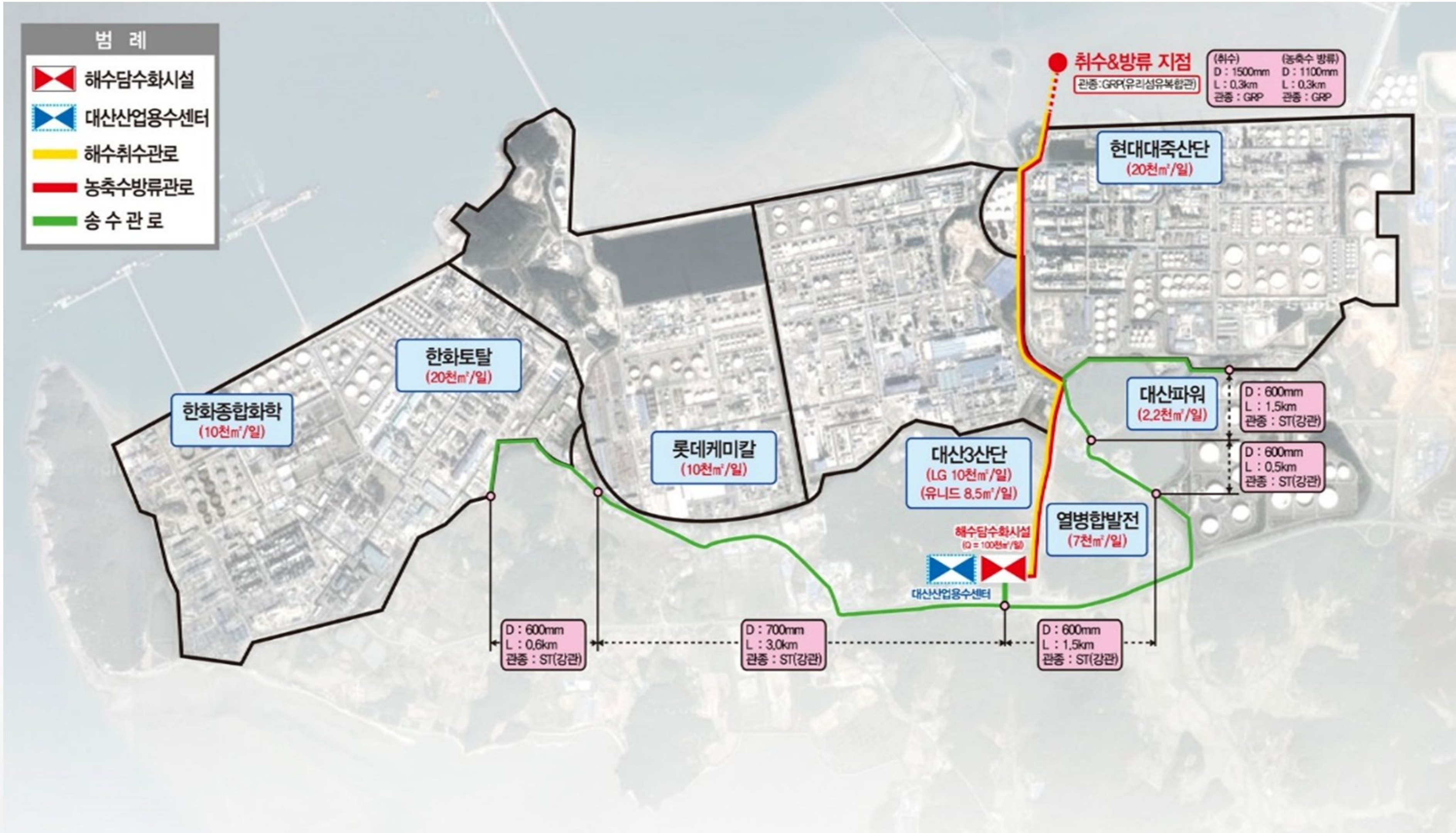
해수담수화 개발을 통한 물 문제 해결과 선도사업을 통한 국가 경쟁력 강화

사업개요

- ✓ 총사업비 : 2,200억원 (국고 660억원, K-water 1,540억원)
- ✓ 사업기간 : 2018 ~ 2020 (3년간) *예타 수행 일정에 따라 사업기간 순연 가능
- ✓ 취수원 및 급수지역 : 해수(서해) , 대산임해산업지역 입주기업 8개社
- ✓ 주요시설 : 해수담수화시설 (100,000㎥/일) 및 취 ·송수시설 1식, 관로 12.7km 등

대산 해수담수화 사업 현황

용수공급 계획도



대산 해수담수화 사업 현황

K water

추 진 전 략

"국가 물 공급 패러다임 전환 및 신성장동력 창출"

안정적인 수자원확보

지역경제발전 연관산업 육성

해외진출 기반마련

1 안정적인 수자원확보

- 기후변화에도 문제없는 항구적인 수자원 확보
- 선도사업 추진을 통한 전국 물 패러다임 전환

2 지역경제발전 및 연관산업육성

- 기업 투자계획에 맞춘 적시 용수공급
- 신규시장 육성을 통한 고용창출
- 관련기업 육성 및 기술개발을 위한 Test-Bed 지원

3 해외진출 기반마련

- 해외시장 진출 확대 및 선성장동력 사업화
- 기술역량 확보를 통한 중소기업 연계강화로 해외 동반진출 기반 조성

대산 해수담수화 사업 현황

기 대 효 과

손실방지	극한 가뭄시 용수공급 중단에 따른 수용가 매출손실 방지 (466억원/일)
리스크해소	기존 광역네크워크와 연계한 비상사태 대처능력 확보
경제활성화	매출액 연간 17조원 증가 및 일자리 창출효과 연간 22.1천명
원가절감	공업용수 통합공급에 따른 규모의 경제 실현
해외진출	국내 최대규모 해수담수화 도입을 통해 해외수주기반 마련 및 관련산업 육성

향 후 계 획

K water

향후 추진일정

'17.1 ~	'18년	'20년
예비타당성조사	발주 및 F/T분 착공	공사준공 및 용수공급

건설 (24개월) 후 용수 공급 개시

※ 예비타당성조사 이후 발주전 사전 수행 업무

- 타당성조사 및 기본계획, 총사업비 협의, 대형공사 입찰심의, 투자심사 등 내부 업무절차 수행, 관련 인허가 등

감사합니다

WATER POLLUTION IN THE MEKONG DELTA: SOURCES, PRESENT, FUTURE, ECOLOGICAL IMPACTS AND MITIGATION

Le Trinh, Institute for Environmental Science and Development (VESDEC),

Vietnam Association for Environmental Impact Assessment

ABSTRACT:

The Mekong River Delta (MD) with an area of 40,548 km^2 and a population of over 17.5 mil inhabitants, is the main food production region of Vietnam. In the MD there many big rivers and hundreds creeks and canals, creating favourable conditions for growth of biological resource, agriculture, fishery, waterway transport and human activities. However, this region is facing and will be challenged by the increased water pollution caused by the natural factors: high water flow in the rainy season, low flow and high salinity intrusion in the dry season; high acidity at acid sulfate soils areas and by human activities in water use, hydroelectric, industry, agriculture, aquaculture, waterway transport development from the upstream countries and in the Delta, changed hydrological regime and created great amount of many types of wastes, polluting the water environment and damaging ecological resource.

This paper summarizes the pollution sources, present state of water quality in the main rivers and canals; impacts of water pollution on aquatic ecology in the MD. At present, the main rivers are slightly polluted but almost all small rivers, canals and some sections of the main rivers are evidently polluted by organic matters, nutrients and bacteria, which impacted on the aquatic organisms and aquaculture. With the increased consequences of upstream activities and rapid economic development in the MD combining with climate change in the coming decade's river water quality in the MD would be more degraded. To properly control water pollution and improve water quality in the MD this paper suggestes various international and national actions to be considered by Vietnam, the riverine countries and international organizations.

Key words: Mekong Delta, Water Quality, Water Quality Monitoring, Pollution Sources, Ecological Impact; Climate Change.

1. INTRODUCTION ABOUT THE MEKONG DELTA OF VIETNAM

The Mekong is a trans-boundary river in South-East Asia. It is the World's 10th-longest river. Its estimated length is 4,800 km, and it drains an area of 795,000 km^2 [1], annually discharging 475 km^3 of water. Originated from Tibet–Qinghai plateau the river runs through Yunnan province of China, Myanmar, Laos, Thailand, Cambodia and Vietnam (*Figure 1, left*).

The Mekong Delta – MD (Vietnamese: *Đồng bằng Sông Cửu Long* - "Nine Dragon River Delta" also known as the South-Western Region (Vietnamese: *Vùng Tây Nam Bộ*) is the region in Southwestern Vietnam where the Mekong River approaches and empties into the East Sea through a network of distributaries (*Figure 1, right*). The MD Region encompasses a large portion of Southwestern Vietnam of over 40,548 km^2. The region comprises 13 provinces with the total population of 17.5 million inhabitants (about 19% of the total population of Vietnam) [2].

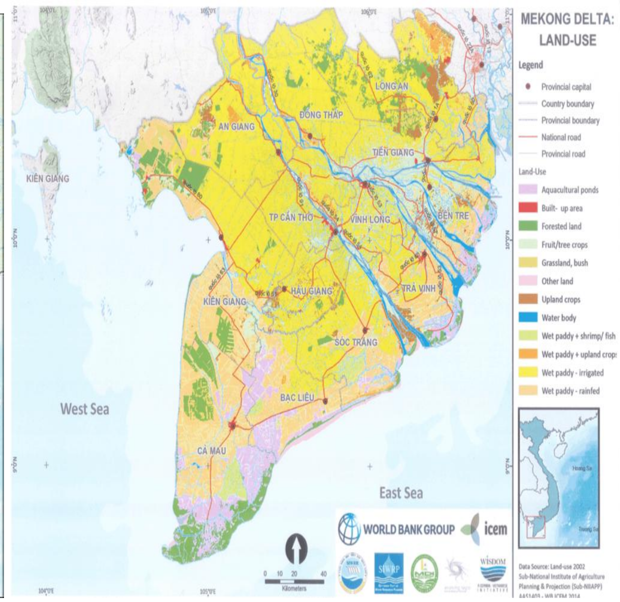


Figure 1: Left: The Mekong River Basin Right: The Mekong Delta in Vietnam

Figure 2: Left: The main stream of the Mekong River in Tiengiang Province Right: There are over 7,500 km of creeks and canals in the Mekong Delta (photos from Internet).

The MD is the largest wetland area of Vietnam, where there are 5 national parks, 2 biosphere reserves, 4 nature reserves and 3 species conservation sites at the inland wetland and coastal wetland areas with rich biological resources and biodiversity. In the Delta there are 23 mammal species, 386 bird species, 6 amphibian species and 260 fish species [3]. Fish is one of the main food sources for people in the Delta as well as for the country.

Cranes Grus Antigone sharpii in Tramchim Natural Park (Inland wetland zone) Birds in a coastal mangrove forest (coastal wetland zone)

A giant catfish catched in the Delta River *Monkey in mangrove forest of Camau National Park*

Figure 3: Some photos about biological resource of the Mekong Delta (photos from Internet).

The MD is the main agricultural region of Vietnam. In the recent years, it supplies more than 56 % of rice, 65% of fish, and 75% of fruits for the country and contributes 90% of the total rice export of Vietnam. The annual GDP growth rate of the MD was over 7.0%. In the case of no serious change of natural resources the MD may produce foods meeting the demand of 120 – 150 mil inhabitants.

However, this region is still poor, comparing with other regions of Vietnam: in 2015 its GDP/capita was only USD1,850, while the average of Vietnam was USD2,215 [2].

The Mekong River and its tributaries are the main water resource in the Delta for irrigation, fishing, aquaculture, domestic use, tourism, biodiversity conservation and waterway transport etc. The entire population of the MD now depends and will continue to depend on this resource for its livelihood. With the rapid increased urbanization, industrialization, increased impacts from trans-boundary sources, especially with the increased impacts of climate change, the region is facing more and more severe water environmental problems. They are flooding in the rainy season, shortage of fresh water and increased salinization in the dry season; increased water pollution by domestic, industrial, agriculture, aquaculture and waterway transport wastes. These environmental matters are and will be serious impact sources to water quality and water use in the MD. Therefore, protection of water resource, especially, water quality is utmost important task of Vietnam Government and people in the MD.

2. FACTORS AFFECTING THE WATER QUALITY IN THE MEKONG DELTA

2.1. Natural Factors

Hydrological Regime

From Cambodia the Mekong flows to the MD by 2 branches: the Mekong (the Tien River) and the Bassac (the Hau River). These 2 rivers discharge water into the East Sea through 8 branches. In the MD there are also very dense river and canal network with over 7,500km, and 36,000 km of irrigation canals, dredged by Vietnamese in the recent 300 years for irrigation, drainage and transport.

Greatly depending on rainfall in the basin, the Mekong river seasonal flows are quite variable from month to month. Discharge of the Mekong river in the Delta in the rainy season, lasting from May to November may get up over 37,000 m^3/s (in September) but it is only 2,220 m^3/s in the driest month (March) [1]. With this hydrological regime, in the flooding season inundation occurs at large area and water contain high suspended solids, but low salinity, acidity and and organic, nutrient, hazardous pollutants. In the dry season, especially in March and April shortage in freshwater at many places in the MD and increased water salinity at the coastal area commonly occur. In this season, water pollution caused by domestic, industrial and agriculture wastes is increased.

Climate

The Mekong Delta has an average rainfall of approximately 1,800 mm, but with an uneven distribution both in space and time. The Western region has the most rainfall with annual average from 2,000-2,400 mm, while the East has from 1,600-1,800 mm rainfall on average [4]. The central plains stretching from Chaudoc - Cantho to Travinh - Gocong have the lowest rainfall, with averages of 1,200-1,600 mm. The amount of rain is very unevenly distributed over the year. Approximately over 85% of annual rainfall is concentrated in the rainy months. Rainfall in the dry season accounts for only under 15%, with months January to March having almost no rain (often triggering severe droughts). In the rainy season occasionally, there is continuous rain, which may last for 3-5 days, with a relatively large amount of rain, causing flooding, increase of water levels and reduction of water salinity. In the first months of the rainy season (May, June) storm water may bring great amount of acidic materials from acid sulfate soil areas and organic matters, nutrients, bacteria and other pollutants causing heavy pollution for receiving water sources.

Soil Properties

At present, acid sulfate soils occupy over 1.6 mil ha (or 40% of the total natural area of the MD) (*Figure 4*). With high content of pyrite (FeS_2) under condition of contacting with sunlight and water, acidification can be formed, causing high acidity (low pH), high contents of Fe, Al for receiving water sources. At various small rivers and canals in provinces of Dongthap, Kiengiang, Angiang values of pH are only 4.5 – 5.5, concentrations of Fe, Al may be over 2.0 mg/L and 0.5 mg/L, respectively. This polluted water may last 3-6 months affecting growth of aquatic animals, damaging fish species, rice, vegetables and water supply for irrigation and domestic use.

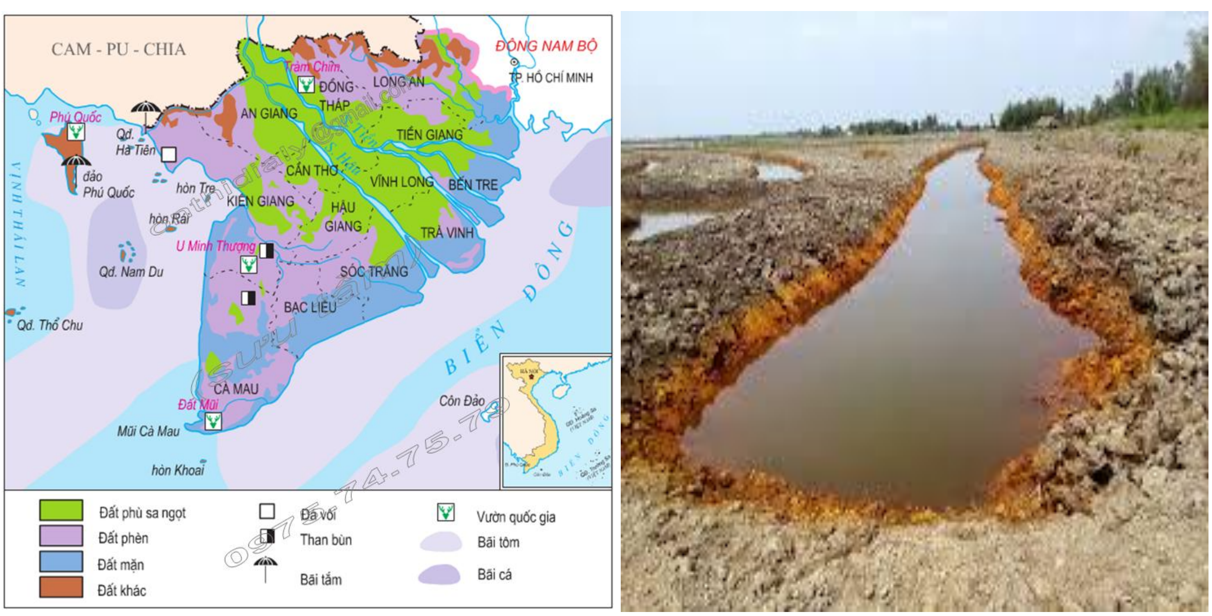


Figure 4: Left: Soil map of the Mekong Delta (pink color is area of acid sulfate soils); Right: Acid sulfate soil and canal receiving storm water (photos from Internet).

In the MD 790,000 ha of saline soils (blue color in *Figure 4)* and about 2.0 mil. ha of land affected by salinity from the East and West Seas. Saline and brackish water may be well used for saline aquaculture and growth of mangrove forests, but water salinization may cause great constraints for water supply for rice, fruit, vegetable cultivation, fresh aquaculture and domestic use. With influence of sea water, especially in the dry season, salinity intrusion is strong at the coastal area of the MD (*Figure 5*).

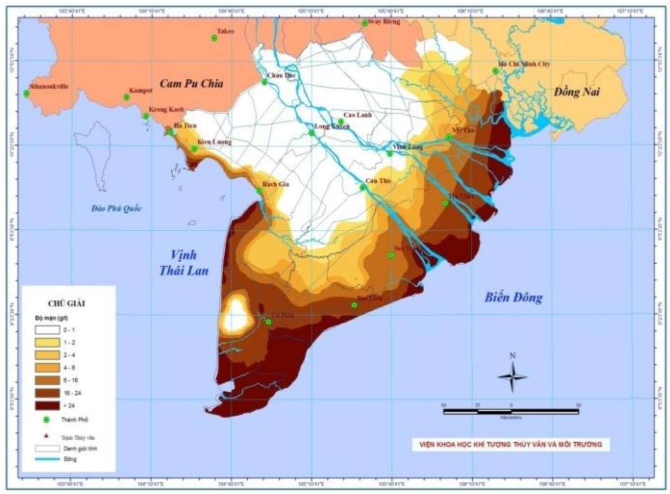


Figure 5. Present salinity intrusion in the Mekong Delta

2.2. Human Factors

Agriculture Impact Sources

Agriculture, included cultivation, aquaculture and animal husbandry is the important economy for over 70% of the population in the MD. However, at present agriculture is the highest pollution source for the rivers and canals in the MD because its wastes.

(i) With area of rice, vegetable and fruit cultivation of over 2.5 million ha, annually farmers use about 750,000 – 1,000,000 tons of fertilizes (N, P_2O_5 and K - Pham Sy Tan, 2012 [5]). Residues of N and P from fertilizers may cause nutrient pollution for canals and rivers.

(ii) According to a VESDEC study for Vinhlong Province (2016) average amount of pesticides used is 3.5 kg/ha for vegetables, 7.5 kg/ha for rice; 15 kg/ha for fruit (mango) cultivation [6], which is still lower than Japan (14.30 kg/ha) and South Korea (10.70 kg/ha) but 2-3 times higher than in the Red River Delta (Vietnam) and much higher than other developing countries like the Philippines (1.56 kg./ha) or Bengladesh (1.50 kg /ha) (UNEP 2005). Total amount of pesticides used may be 10,000 to 20,000 tons/year, included 97 trade marks of 20 chemical groups: conazole, pyrethroids, carbamates, buprofezin, organophosphates, chlorinated phenoxyacetic acids, amides … (Pham Van Toan, Cantho University, 2015 [7]). After use a large part of pesticide containing bags are disposed into the fields, gardens or canals. Pesticide containing bags occupy about 1.0 – 1.8 % of the weight of pesticide and bag. Therefore, annually, about 120 – 360 tons of used bags may be released into the environment in the MD. Residue pesticides and pesticide containing bags are sources of water pollution and ecological impacts.

(iii) At present, in the MD area of aquaculture is 685,800 ha producing over 2.2 mil tons of shrimps and fish (Pangasius and other fish species). According to information from MONRE annually, an amount of 456.6 mil m^3 of sediments and wastes is discharged from aquaculture farms [8]. This type of wastes contain high acidic or saline materials, organic matters, nutrients, bacteria, pathogens which may serious pollute water of the receiving water sources and damage aquatic animals.

(iv) Animal husbandry is also well developed with over 2.6 mil pigs, 260,000 buffalos and 40 million ducks. Daily, an amount of 22,500 tons of solid wastes and 40,000 m^3 of wastewaters is discharged from animal cages to the environment. Annually, the environment in the MD receives about 432.9 tons BOD, 16,438 tons COD, 31,700 tons N and 14,800 tons P [9] and high amount of bacteria and pathogens. Therefore, animal husbandry is the great organic, nutrient and bacteria pollution source for rivers and canals.

Industrial Impact Sources

Although in the Mekong Delta industry is less developed but at present in this Region 120 industrial parks and clusters with 25,000 ha have been planned, of which thousands of factories are under operation. According to MONRE [8]: annually, 220,000 tons of solid wastes and 47,000 m^3 wastewaters are discharged from industrial parks while only 44% of the industrial parks installed centralized wastewater treatment plants. Industrial wastes are new pollution sources and they may cause serious ecological impacts for rivers and canals in the MD. They may be increased in amount and hazardous composition in the coming decades.

Figure 6: Industrial park on the Mekong River in Tiengiang Province (left) Paper Mill (Lee & Man, Taiwan) on the Hau River in Haugiang Province are pollution sources for the MD water environment. The second has obtained many complaints from people.

Population Impacts

At present, over 17.5 million inhabitants in the MD, of which over 70% are in rural areas. Traditionally, to use rivers and canals as main source for drinking water, fishery, aquaculture, transport and prevention of inundation for hundreds year until now the residents in this region like to settle along the canal banks (*Figure 7*). With this living way, almost all domestic wastewater and solid waste are directly discharged into canals.

Figure 7: Settlement along river/canal banks (left) and cage fish culture on the rivers (right) are sources of water pollution

In urban areas, annually, 102 mil m^3 municipal wastewater, 606,000 tons of solid wastes, included 4,000 tons medical wastes are generated, of which over 85% of solid wastes, 100% of medical wastes are collected and treated but only 30% of effluents are treated [8]. Therefore, wastes generated by local residents are great pollution source for rivers and canals in the MD.

2. PRESENT WATER QUALITY IN THE MEKONG DELTA

With the impacts from the natural factors as well as human activities at present water quality in the MD is degraded. However, levels of water pollution are very differ from the locations on a river and from the main rivers to small rivers or canals. According to the monitoring system of the Mekong River Commision (MRC) and many national study projects at almost monitoring sites at the main rivers (the Tien and Hau rivers) water quality is slightly polluted, but still meeting the conditions for domestic water supply and tourism (Source A2, according to the Vietnam National Technical Regulation for Surface Water Quality QCVN08-MT: 2015/BTNMT). But at some monitoring sites at the main rivers and at all small rivers and canals where receive wastewater or run-off water from urban, industrial or aquaculture sites water pollution is evident. The main types of pollution are: organic pollution, nutrient pollution, oil pollution, acidic pollution and bacteria pollution. Pollution by toxic chemicals as heavy metals or pesticides is not detected in all monitoring sites on rivers but it is found in some special cases where water directly receive effluents from the factory or field newly treated by pesticides. Some data on the present water quality at the main rivers and small canals in various provinces are given below for demonstration.

3.1. Data of Water Quality Monitoring of Angiang DONRE

Report of Department of Natural Resources and Environment (DONRE), Angiang Province on the results of water monitoring in July 2017 [10] indicated:

(i) Tien (Mekong) River:

At Tanchau, at the border with Cambodia: TSS, BOD_5, COD, P-PO_4^{3-}, Coliforms exceed at 1.5 – 9.6 (by each parameter) the permissible for the A2 Source (water used for domestic supply) in QCVN 08-MT: 2015/BTNMT.

(ii) Hau (Bassac River**):**

- At Long Binh (border with Cambodia): evident pollution: TSS, BOD_5, COD, P-PO_4^{3-}, Coliforms exceed at 1.7 – 18.4 times (by each parameter) the permissible for the A2 Source in QCVN 08-MT: 2015/BTNMT.

Above data show that at present water of the main rivers transported from Cambodia is evedently polluted already.

- At Longxuyen City: TSS, COD, P-PO_4^{3-}, BOD_5, and Coliforms exceed at 2.0 – 9.6 times (by each parameter) the permissible for the A2 Source in QCVN 08-MT: 2015/BTNMT.

3.2. Data of Water Quality Monitoring of Vinhlong DONRE

According to information of Vinhlong DONRE [11]: in June 2017 at all monitoring sites on the Mekong River and small rivers: water was slightly polluted. However, values of pH, BOD_5, COD, Fe and Cl^- met the permissible limits for Source A2 in QCVN 08-MT: 2015/BTNMT. Comparing with the monitoring data in June 2016: values of TSS, turbidity, BOD_5, COD, phosphate, Fe and Cl^- are slightly increased.

3.3. Data of Water Quality Monitoring of Tiengiang DONRE

In the project of “Environmental planning for Tiengiang Province…”[12] VESDEC has conducted sampling and analyzing water quality at 20 monitoring sites on the main rivers and various canals/creeks in the whole province in the dry season (March) and rainy season (August) 2013. From the monitoring results some findings may be given below:

(i) Organic Pollution:

- DO in the Tien river was higher than 5.0 mg/L (Sites NM2, NM5 and NM6) but in small rivers and canals it was low. At 12/20 monitoring sites DO was under 5.0 mg/L.

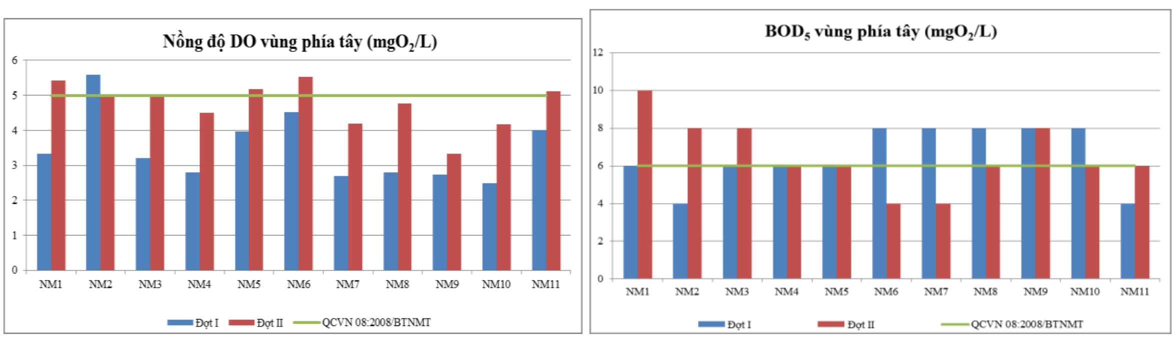


Figure 8: DO (left) and BOD (right) at some monitoring sites in Tiengiang Province (blue: in March, red: in August, 2013)

- BOD values at the monitoring sites at the main rivers and canals were varied from 4 to 10 mg/L, while the permissible limit for Source A2 of QCVN 08-MT/2015/BTNMT is 6.0 mg/L. At the main rivers BOD met the standard (5 mg/L) but at almost all canals and some times at the main rivers organic pollution was evident with BOD higher than 6.0 mg/L.

(ii) Nutrient Pollution

Concentrations of ammonium (NH_4) at most of the monitoring sites greatly varied from month to month and were higher than the permissible limit for A2 Source, indicating high nutrient pollution at the rivers and canals. With this level of nutrient pollution and in cases of stagnant water eutrophication may be created.

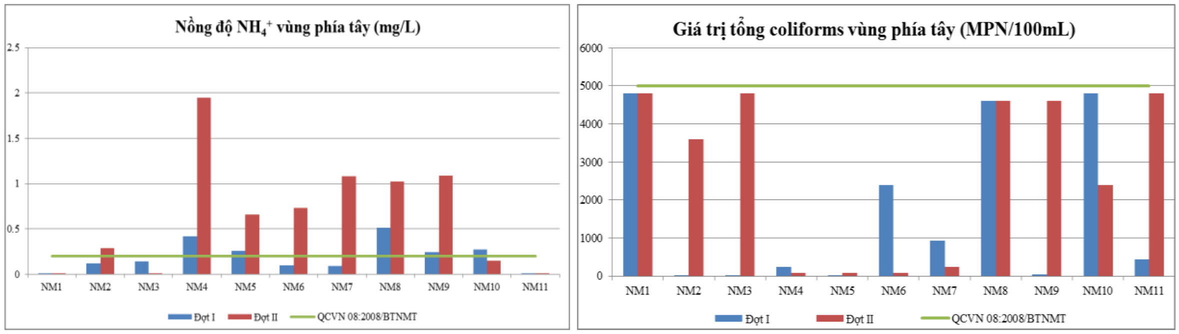


Figure 9: NH_4^+ (left) and T. Coliform (right) at some monitoring sites in Tiengiang Province (blue: in March, red: in August, 2013)

(iii) Bacteria Pollution

Bacteria pollution was evident at the main rivers and canals but it still met the permissible limit for Source A2 in QCVN 08-MT/2015/BTNMT which is 5,000 MPN/100 mL.

(iv) Pollution by Toxic Chemicals

The monitoring data indicated that at present, water in the main rivers and canals in Tiengiang Province is not polluted by heavy metals, pesticides and other toxic pollutants.

3.4. Monitoring Data at Aquaculture Sites

According to the monitoring of the Fishery Department of Cantho City in July 2017 [13] all parameters of DO, pH, temperature(nhiệt độ), COD, PO_4^{3-}, NO_3^-, NH_4^+, SO_4^{2-}, TSS in the Hau (Bassac) River at Thotnot District, and rivers in Omon, Vinhthanh Districts meet the water quality for aquaculture (QCVN 02-20:2014/BNNPTN) and met the permissible limits for Source A1 in QCVN 08-MT:2015/BTNMT and Boyd (1998). However, at some monitored ponds the parameters of NH_4^+ (0.60 – 1.90 mg/L), PO_4 (0.37 – 0.52 mg/L) exceed the permissible limits in QCVN 02-20:2014/BNNPTNT and Boyd 1998.

3.5. Evidences of Pesticide Pollution

From 1995, the high persistent and high toxic pesticides like organochlorines and organophosphates were banned in Vietnam, therefore, residues of these compounds are very small. However, some studies indicated their presence in water, soils and animal tissues with very low contents.

A paper of Zita Sebesvari et al. (2012) [14] indicates that in the MD, Minh et al. (2007) reported DDT contents in sediments ranging from 0.01 to 110 ng/g dry weight along the Hau River with the higher contents found near urban areas such as Cantho City. Carvalho et al. (2008) monitored more than 70 pesticide residues and polychlorobyphenyl compounds (PCBs) and found sediment contents of DDT ranging from 0.45 to 67.49 ng /dry g weight and contents in the soft tissues of bivalve molluscs ranging from 5.46 to 123.03 ng/g dry weight. Other organochlorines detected in sediments but at much lower contents were hexacyclochlorohexane (HCHs), endosulfans and chlordane.

A study project conducted by VESDEC for Vinhlong DONRE (2016) [6] indicates that 2/9 soil samples collected near tanks containing pesticide bags content of Lindane is 0.0025 mg/kg dry weight and 0.0045 mg/kg dry weight, which are much lower than the permissible limit in Vietnam National Technical Regulation for Soils (QCVN 15:2008/BTNMT: 0,01 mg/kg dry weight); 5/9 soil samples contain Chlorpyrifos (-ethyl) with 0.015 to 0.055 mg/kg dry weight.

4. ECOLOGICAL IMPACTS OF WATER POLLUTION

As indicated in *Section 3*, at present, the main pollution types of the Mekong Rivers and its branches in the MD are organic, nutrient, bacteria pollution. They are caused by untreated domestic, animal husbandry, aquaculture and industrial (food processing, paper and other industries) wastes and run-off water from field treated by fertilizers. Acidic pollution is also common at the acid sulfate soil areas. So far, there are not many researchs on ecological impacts of water pollution in this region. However, from observations by the author and information from newspapers the following evidences may be given for demonstation of damages caused by water pollution on aquatic ecosystems.

(i) With high contents of organic matters dissolved oxygen (DO) may be reduced. At DO of under 3.0 mg/L most of shrimp species and various small white fish species (*Esomus* spp., *Carassius spp.*). At DO of under 2.0 mg/L many big white fish species (carp, *Hypophthalmichthys spp.*, *and Mylopharyngodon spp.)* may die. In the MD many massive death of fish were caused by untreated effluents from aquaculture and or industries depleting DO in water.

(ii) High concentration of N and P salts in water may create eutrophication of water bodies with a depletion of DO in the water column, algal blooms, increased turbidity, reduction in aquatic animal populations and cause difficulty for water treatment. This phenomenon is very common in small rivers and canals in the MD: water hyacynth densely growth – an indicator of water eutrophication may be found in all ponds and canals in this region.

Additionally, ammonium (NH_4) is a toxic pollutant for shrimp and fish: FAO guides NH_4 is lower 0.2 mg/L for Salmonid spp., and 0.8 mg/L for Cyprinid spp.

(iii) At actual acid sulfate soil areas in the beginning of rainy season, storm water brings acidic materials to the rivers and/or ponds. At high acidity (pH under 4.5) all shrimp species and many white fish species may die. At pH lower than 3.5 almost all species of white and black fish can not survive. Massive shrimp death at the shrimp farms caused by acidic water transported from acid sulfate soil area were reported in the MD.

Box:

a. Massive Fish Death at Cage Fish Farms in Angiang Province

On 4rd to 6th February 2016 at the cage fish farms on the Caivung river in Angiang and Dongthap Provinces over 1,000 tons of fish at 119 fish cages die. The main fish species were Oreochromis sp. (điêu hồng, in Vietnamese), Oreochromis sp. (rô phi, in Vietnamese) Barbonymus sp (cá he, in Vietnamese) [15]. Loss due to the massive fish death was estimated as USD 500,000.

Growth of fish Oreochromis in a fish cage

Massive fish death in Caivung river, 6th February 2016

b. Massive Fish Death in Camau Province

According to "Thanhnien Newspaper" [16]: from November 2016 to 24 April 2017 there were massive fish death at Bayhap and Ganhhao rivers in Camau Province. Water in the rivers was grey and rotten. Polluted water from the polluted rivers discharged to shrimp farms caused massive death for shrimps.

4. CHALLENGES OF WATER QUALITY IN THE MEKONG DELTA IN THE COMING DECADES

4.1. Increased Economic Growth

According to Decree N245/QĐ-TTg 12 Feb./ 2014 of the Governmant on the Master Plan for the Focus Mekong Delta Economic Zone, included Cantho, Kiengiang, Angiang and Camau Provinces [17]: in the period 2016 – 2020: the annual growth rate is planned as 10.5 %; in which industrial sector will be 10-12%/year; population growth rate will be under 1.0%/year; ratios of economic sectors will be industry – construction: 37.4%, service: 45.3 %, agriculture – fishery – forestry: 17.3%; GDP/capita: USD4,400 in 2020 and USD9,300 in 2030. In 2020 100% industrial parks and cities will have wastewater treatment plants meeting the environmental standards and 100% urban and industrial solid wastes will be collected and treated.

This tendency of rapid economic growth may cause various impacts on the water environment, particularly on water quality, due to rapid increase of domestic, agriculture, aquaculture and industrial wastes, included hazardous wastes.

4.2. Increased Impacts of Climate Change

Due to very flat and low land and with diurnal tidal regime, the MD is region where is most serious impacted by climate change. Consequences of climate change in the MD are increased draws in the dry months and increased salinity intrusion from the Seas to inland. At present, climate change evidently affects water resource, it will cause more serious impacts in the coming decades.

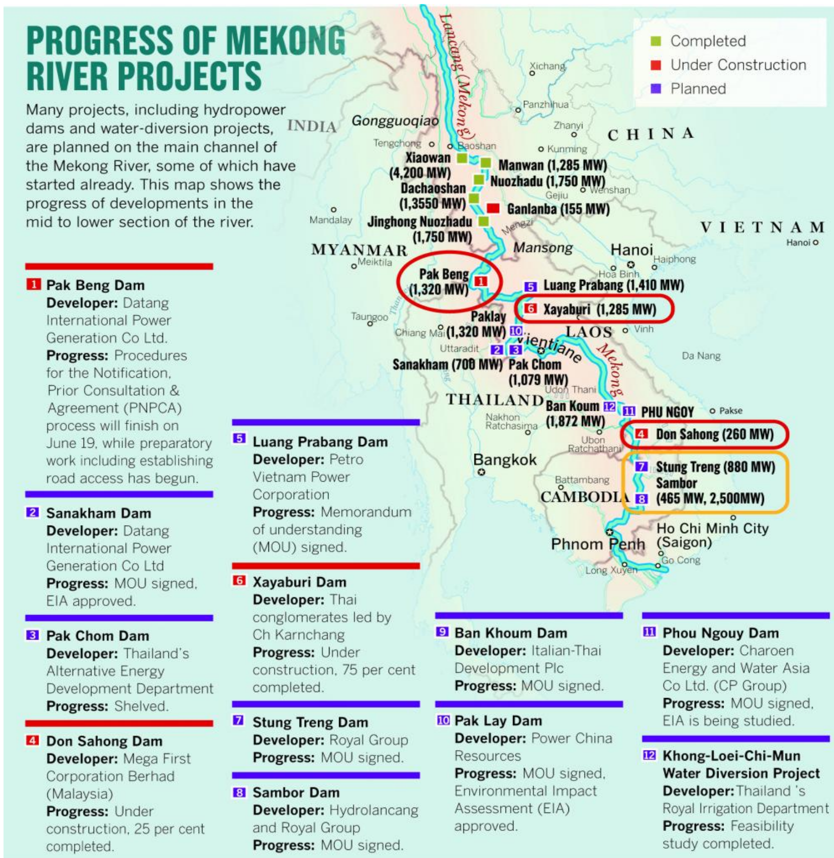
According to MONRE [18] in the MD with the average scenario of GHG emission sea level rise in 2050 will be 20 – 30 cm or 57 -73 cm in 2100; with the high scenario of GHG emission sea level rise in 2050 will be 40 – 60 cm and 78 – 95 cm in 2100

With strong increase of sea levels, salinity will intrude along the rivers into inland area, changing water quality of the rivers from fresh to brackish, affecting water supply for domestic use, for cultivation and freshwater aquaculture.

With strong salinity intrusion, land will be salinized. According to a study of the Water Resource Management Department (MONRE) [19] in the coming 50 years area of land affected by salinity of over 4‰ will be 1,851,200 ha (47% of the total Delta area) increased at 439,200 ha; area of land affected by salinity of over 1‰ will be 2,524,100 ha (64% of the total Delta area), increased at 456,100 ha, comparing with that in 1991-2000.

4.3. Increased Impacts from Mekong Upstream Activities

According to the master plans for hydroelectricity and water resource development of the upstream countries over 20 large size projects are under operation and over 50 other projects were planned on the Mekong main stream and its tributaries. *Figure 10* shows some of them.



Source: International Rivers, The Nation NATION GRAPHICS

Figure 10. Some projects in water resource and hydroelectric development in the Mekong river basin

The hydropower and water diversion projects, included dams and reservoirs may strongly reduce the Mekong flow and increase of salinity intrusion into the MD. This will cause strong impacts on water quality: increase of water pollution by wastes; reduction of TSS and nutrients affecting cultivation and aquaculture; increase of water salinity etc.

With increased sea level rise by climate change plus reduced upstream discharge by the hydropower, dam projects of China, Laos, Thailand the environment, in general, and water quality in the Mekong Delta will face with many challenges for protection and use.

5. RECOMMENDATIONS OF ACTIONS FOR WATER POLLUTION CONTROL AND IMPROVEMENT OF WATER QUALITY FOR THE MEKONG DELTA

Water quality of the rivers, creeks and canals in the MD greatly depends on water flow from the upstream area, rainfall, soil properties, salinity intrusion from the Seas and from human activities in the region and upstream countries. Therefore, to properly prevent water pollution for the Mekong Delta integration of internal and external actions is necessary. Because of limitation of a paper, the following suggestions give only the titles of the important actions without explanations.

5.1. External Actions – International Cooperation

The following external actions are suggested:

(i) Improvement of the MRC in its functions, manpower, financial and technical sources to have suitable capacity in management of water resource, environmental and social assessment of the policies, plans, projects related with the basin development and in coordination with all upstream, downstream countries and international organizations in sustainable use and protection of the Mekong river.

(ii) Increase of participation of international organizations (UN and its organizations: UNDP, UNESCO, FAO, WHO; WB, ADB) and countries outside the Mekong basin (US, Japan, Korea, India etc. into protection of water resource, ecology and water quality in the Mekong basin.

(iii) Careful implementation of EIA/ESIA for the proposed projects in water resource, dam, hydroelectric development in the Mekong river basin with participation of international and riverine country organizations, experts and with targets of protection the aquatic ecology, water resource and sustainable development in the basin.

(iv) Improvement of water quality monitoring programs of the MRC.

(v) Improvement of waste management of the riverine countries.

5.2. Internal Actions: Water Pollution Control in the Mekong Delta

General Actions

(i) Increase of awareness on impacts of water pollution and protection of water quality for local communities, especially, for farmers in waste management in cultivation and aquaculture and for all people in management of wastes.

(ii) Strictly implement the Law of Water Resource, Environmental Protection Law, Law on Biodiversity and the National Technical Regulations (Standards) for Surface Water Quality, for Industrial Effluents; for Domestic Wastewater.

(iii) Strictly implement the target of the Master Plan for the Focus Economic Zone of the MD: by 2030: 100% of industrial parks and all cities should have wastewater treatment plants meeting the environmental standards.

(iv) Ministries of Natural Resource and Environment (MONRE) and Agriculture and Rural Development (MARD) and Provincial DONREs and DARDs must stricter implement water quality monitoring, supervision on wastewater discharge and punishment on infrigements in water resource protection.

(v) Development of projects in studies on changes of water quality caused by human activities and natutal factors; water quality monitoning, impacts of climate change on water quality and measures for pollution control in the Mekong Delta.

Specific Actions for Economic Sectors

(i) For Industrial Sector:

- Strictly comply with the national technical regulations for wastewaters: all industrial parks and companies must build and operate wastewater treatment plants to treat wastewaters complying with the National Regulations.

- Rehabilitation and compensation for ecological and social damages caused by water pollution from industrial facilities.

(ii) For Agricultural Sector:

- Development and improvement of integrated pest management (IPM) and other models to reduce use of pesticides and chemical fertilizers.

- Properly control storm water from treated field by agrochemicals and used pesticide containers to avoid impact on quality of receiving rivers.

- Properly control acidic materials released from acid sulfate soil areas.

(iii) For Aquacultural Sector:

Properly control solid and wastewater from shrimp and fish culture farms to avoid impact on quality of receiving rivers.

(iv) For Resettlement Sites:

- Rapidly relocate houses and other constructions on canals and rivers to avoid water pollution.

- Install sanitation facilities complying with the requirements for all houses.

- Cities and towns must build and operate wastewater treatment plants to treat municipal wastewaters complying with the National Regulation.

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