Nagoya Hydraulic Research Institute for River Basin Management

HydroEco´2011

Structure and Functions of River Ecosystem -Role of Subsurface Flow in Alternate Sand Bar-

3rd International Multidisciplinary International Conference on Hydrology and Ecology:
Ecosystems, Groundwater, Surface water –Pressures and Opinion

3. May, 2011, at Universität für Bodenkultur Wien (BOKU)

Tetsuro TSUJIMOTO
Nagoya University, Japan

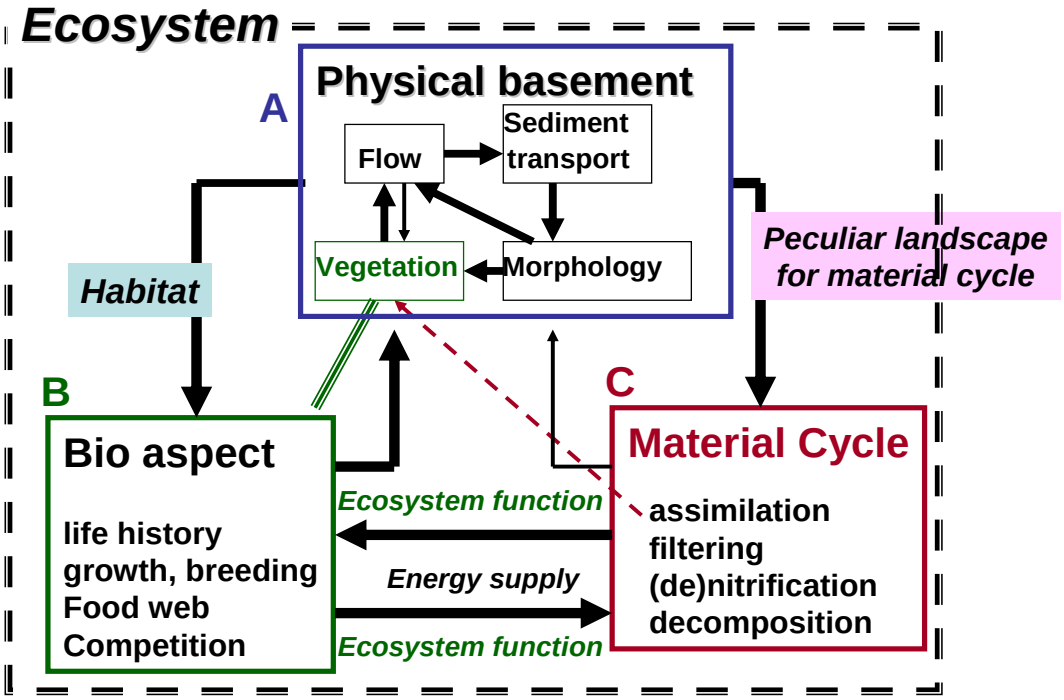
Understanding of River Ecosystem Dynamics

for Ecosystem Management in Rivers

as well as Flood Mitigation and Water Resources Management

Structure and Functions of River Ecosystem

(1) Interrelating system



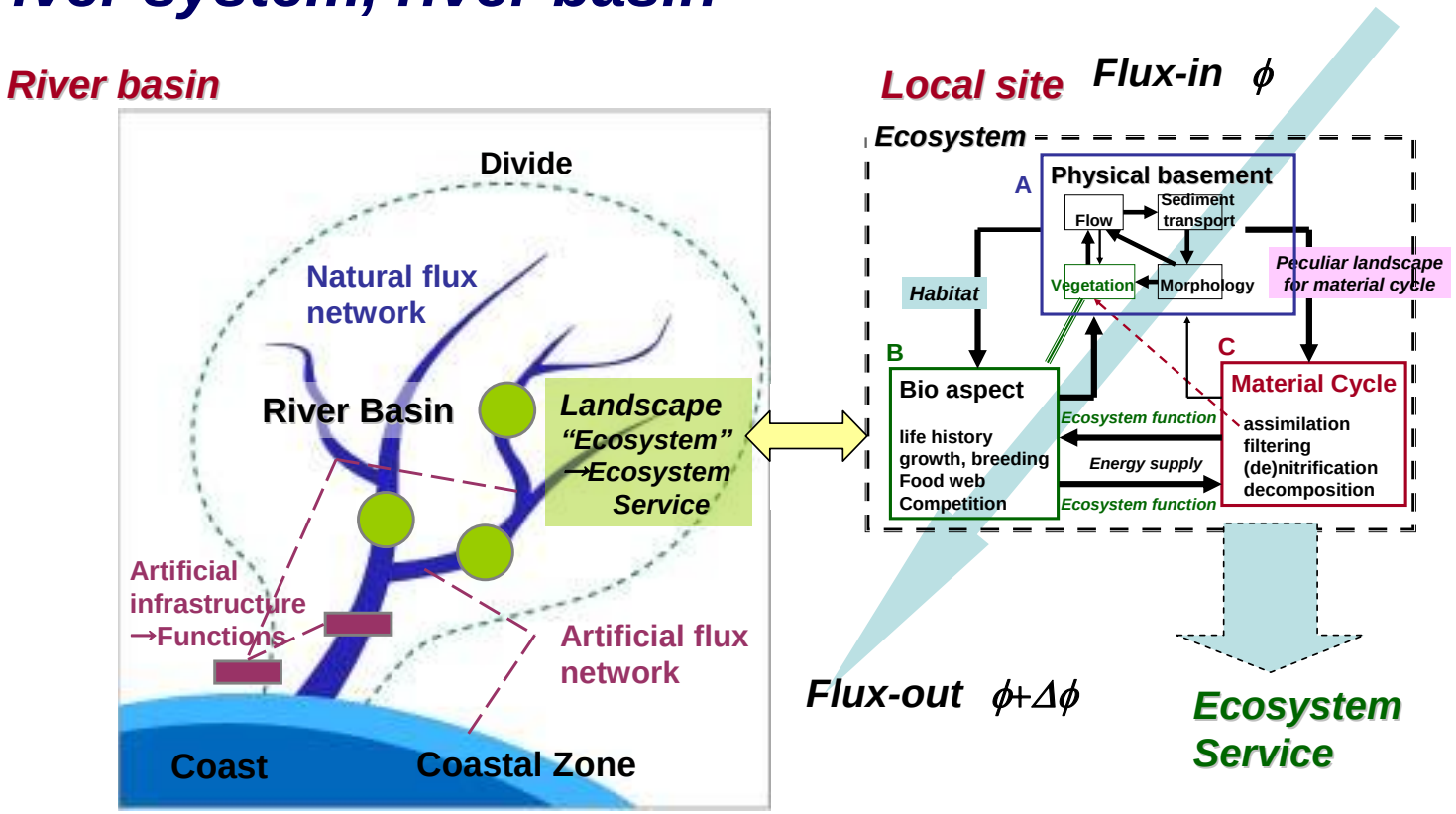
Interrelated subsystems →Ecosystem Structure

Interactions among subsystems →Ecosystem Function

(2) Ecosystem elements (Landscape units) are connected each other by water/material flux networks

Ecosystem composes an integrated system by various landscape units connected by water/material flux networks

→ river system, river basin



Functions of River Ecosystem

A→B to provide Habitat for Organisms

↓

Sound Ecosystem (Biodiversity), Food Production

A→C to provide peculiar spaces for elementary processes in Material Cycle (with biophilic elements)

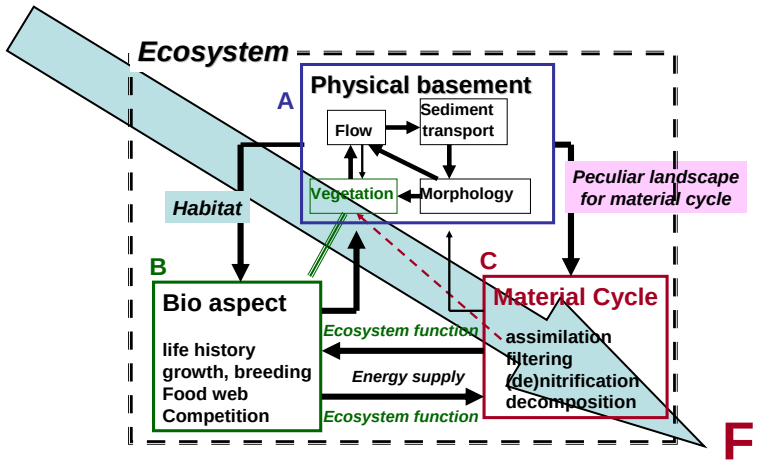
↓

Nutrients→Biological Richness, Water purification

C→B : energy to biological aspect
B→C : decomposition etc.

Ecosystem Service

Flux ϕ

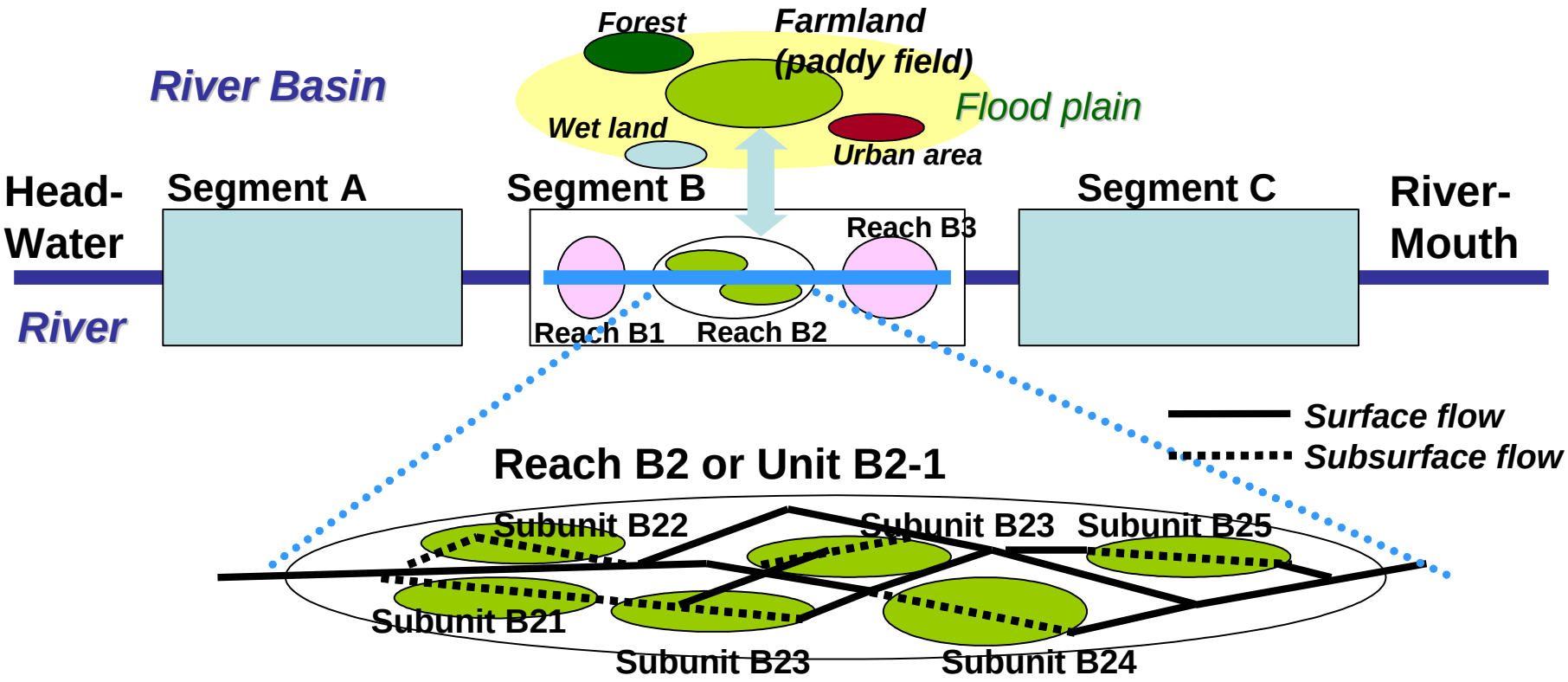


When the flux passes the ecosystem element (landscape Units), the flux is changed ($\Delta\phi$) to propagate, and ecosystem services are accumulated locally.

Flux $\phi+\Delta\phi$

(3) Hierarchy structure

and each scales are connected each other by water/material flux network



Segment scale:

Ex. Sand river segment with alternate bars

Reach scale

composed of various textures in sub-reach scales

"Texture"

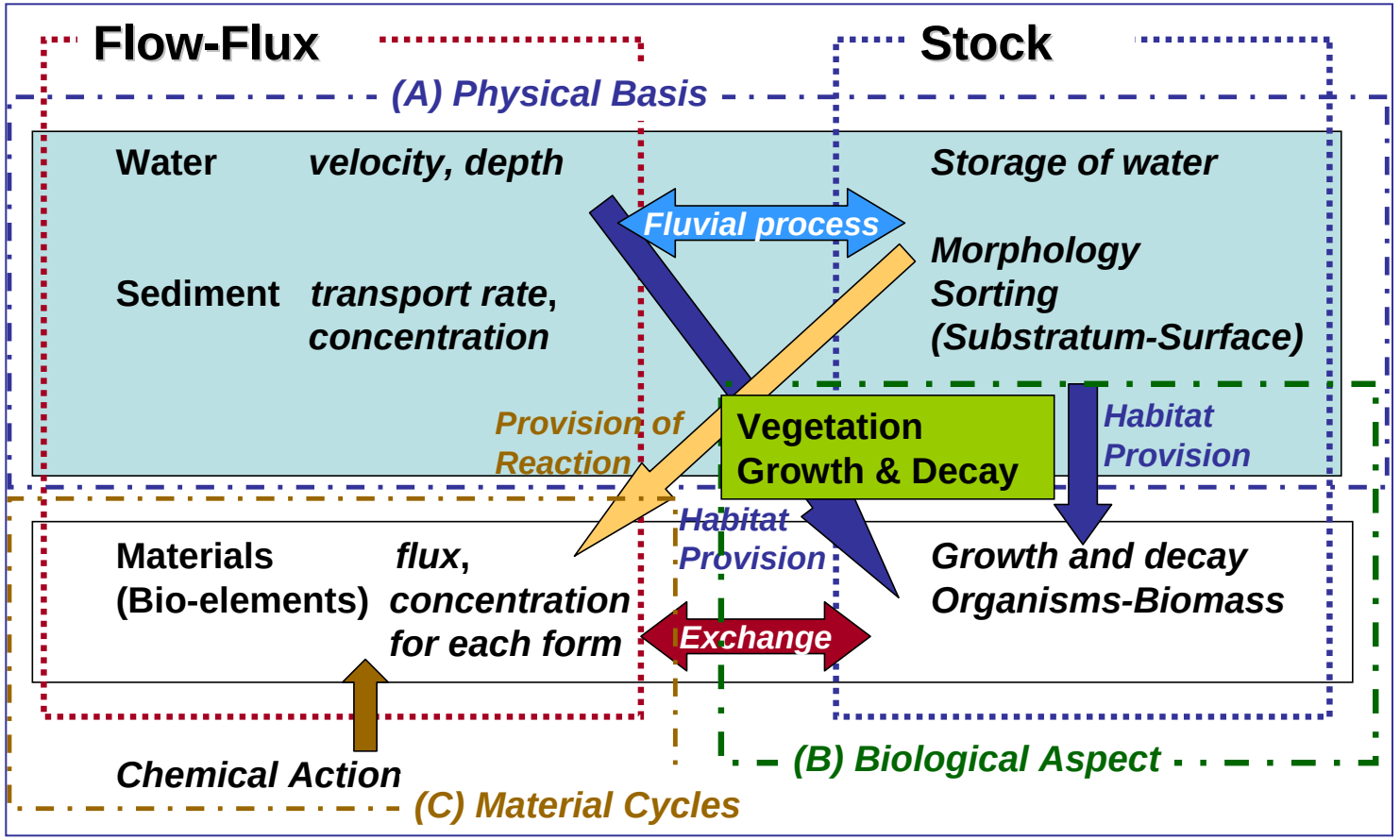
vegetation

main stream
secondary channel
embayment
side pools

sorting

subsurface flow route

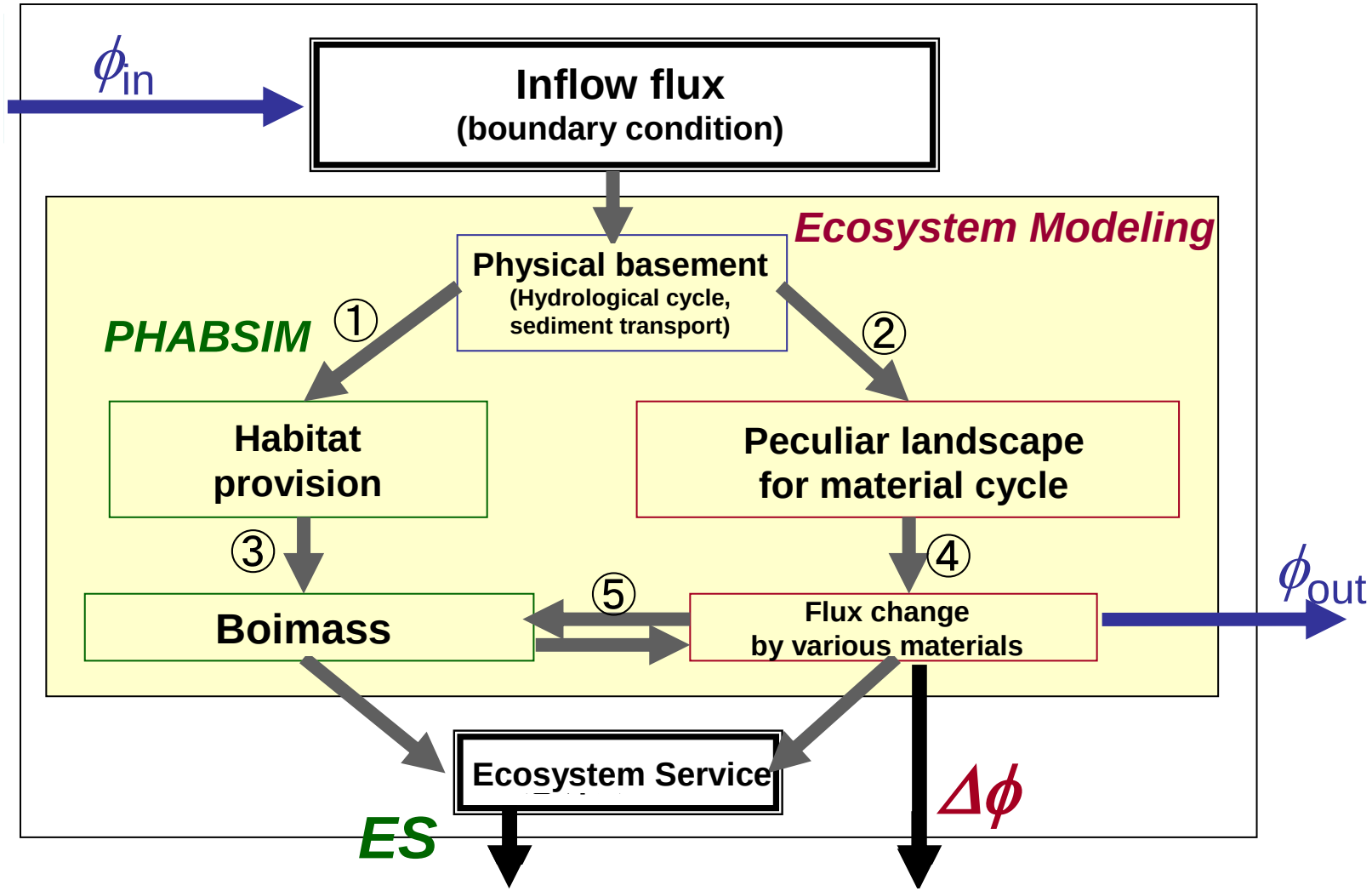
(4) River ecosystem is represented by a framework of Flow-Flux and Stock

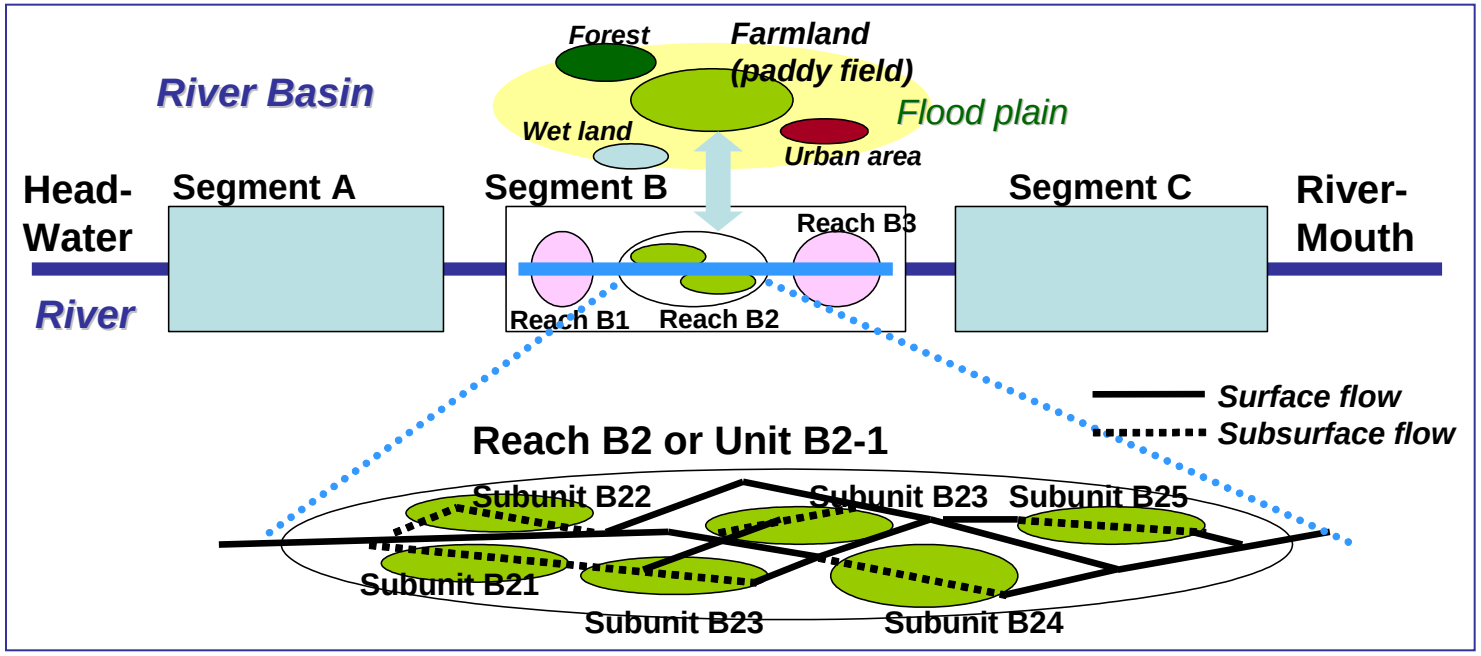


It is a key to make a mathematical model to demonstrate the mechanism of ecosystem.

Convection-Diffusion Production-Sink Continuity

How to make a model to demonstrate landscape unit to evaluate "ecosystem function"





"Texture"

vegetation

main stream
secondary channel
embayment
side pools

sorting

subsurface flow route

In alternate bars, various sub-reach scale landscape units play roles to provide habitat and proper spaces for peculiar elementary process

Processes on Sand Bars ……*Mechanism*

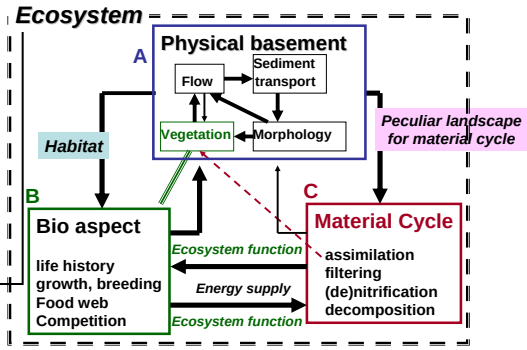
(A)

Fluvial processes in a stream with vegetation

flow with vegetation → morphological process

↑ ↓

vegetation dynamics (growth and decay)



(B)

<u>Habitat</u> Suitability for many organisms

(fish, macro invertebrate, attached algae, …….)

↓

Biomass dynamics

life cycle
food web
competition

Single species→multiple
Production of POM

(C)

Peculiar spaces for elementary processes in material cycle

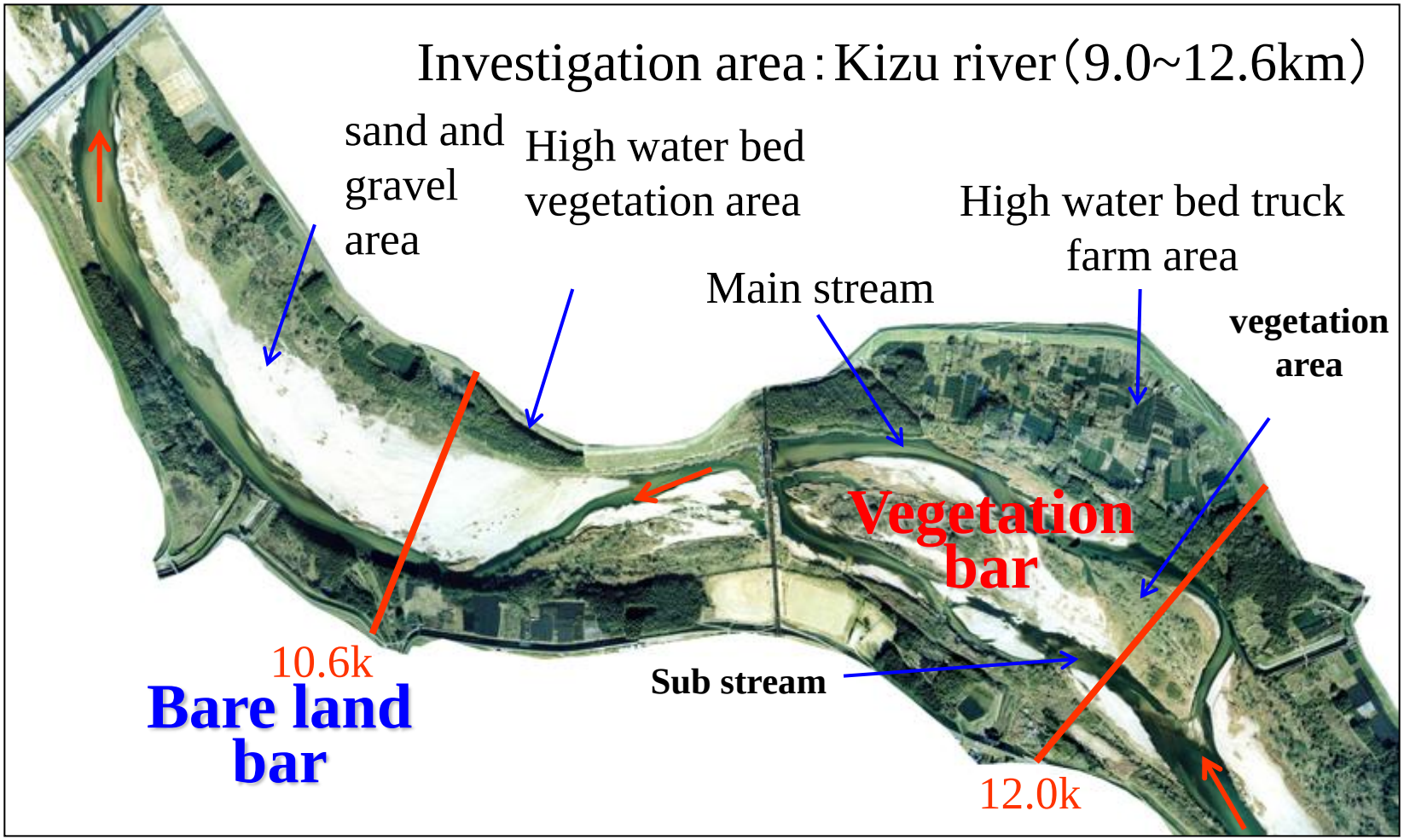
capture and release of POM

decomposition,……

nitrification, denitrification, ….

"Landscape" is closely related to ecosystem function

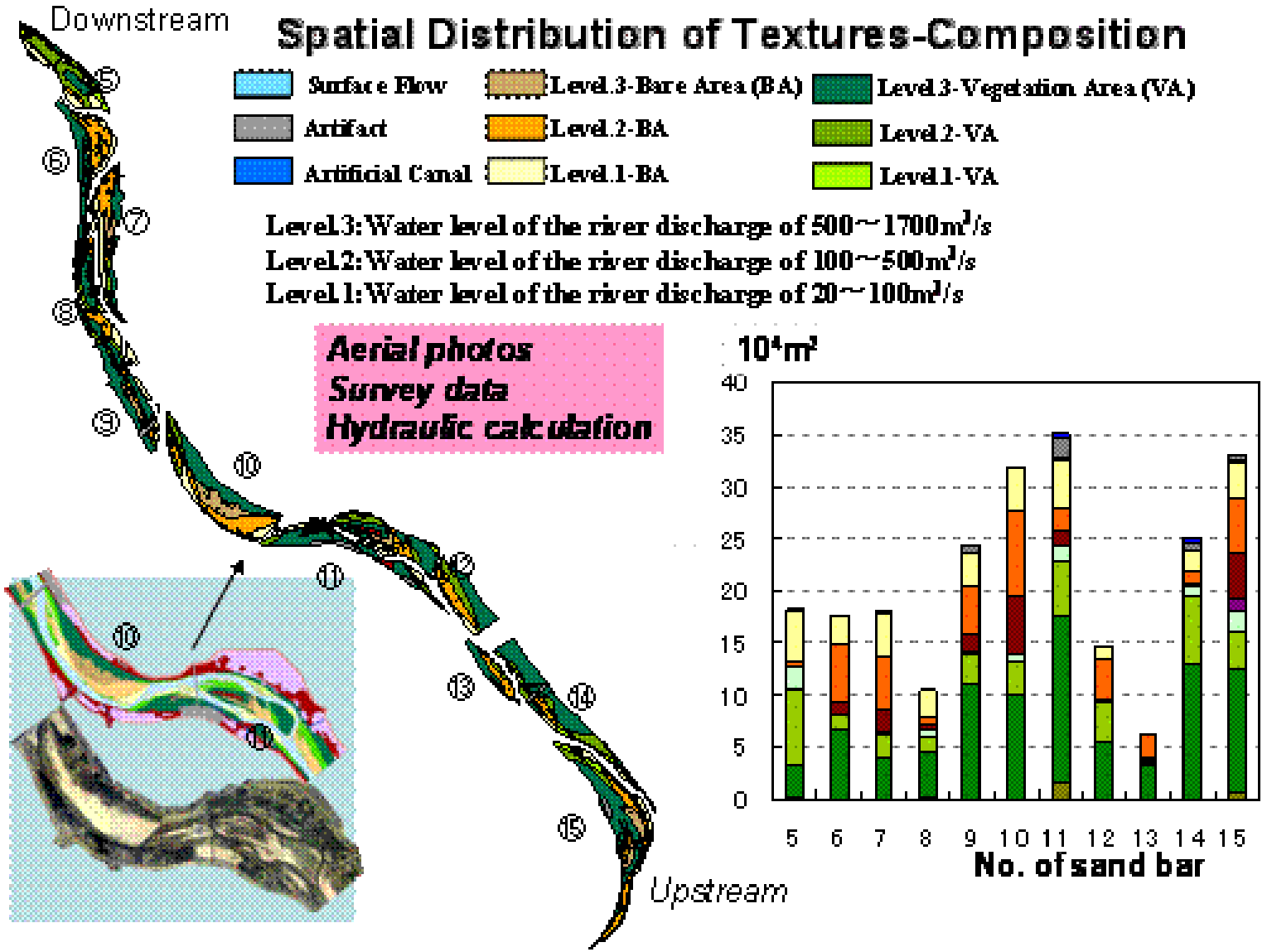
Ecosystem Management = Landscape Management ←GIS



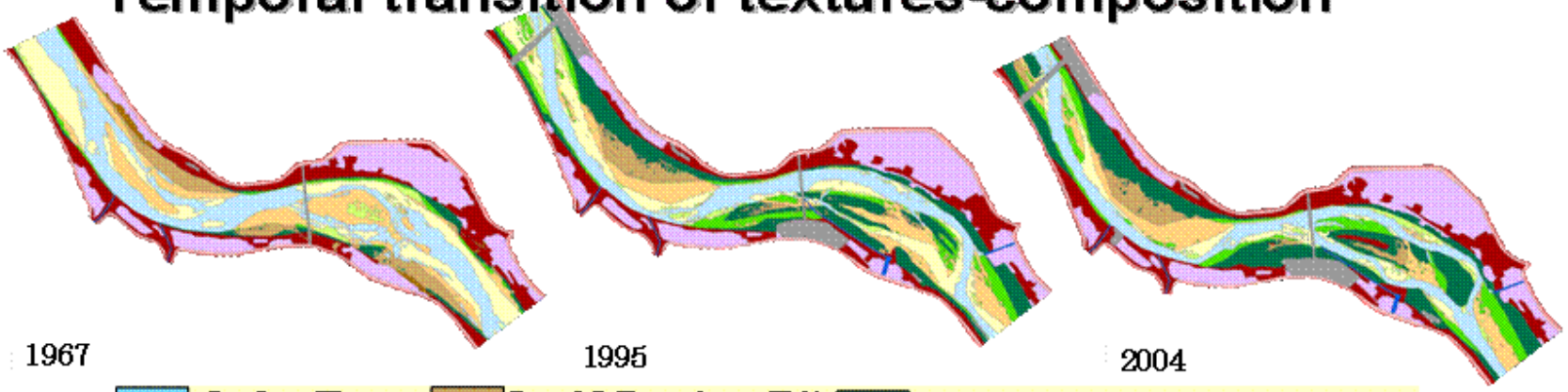
Categorization of landscape

←Ecosystem mechanism

←Practical monitoring and management ←*Survey, Aerial photo*

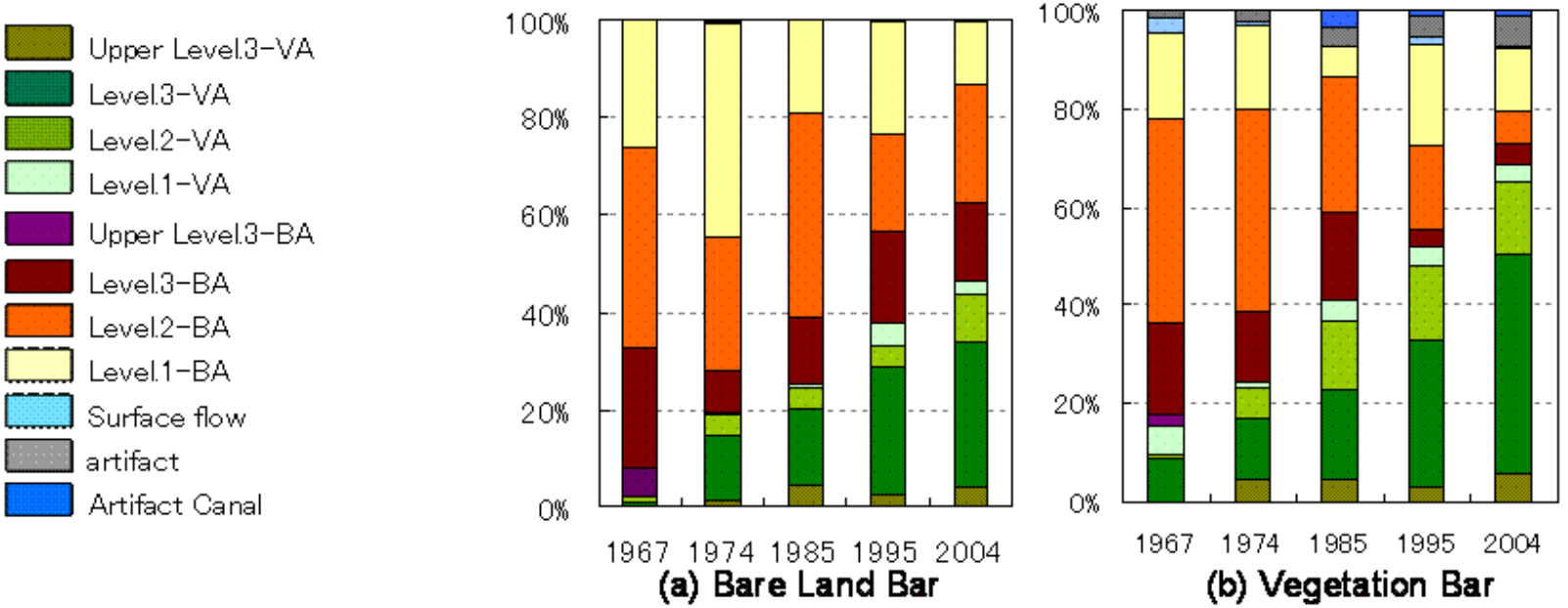


Temporal transition of textures-composition

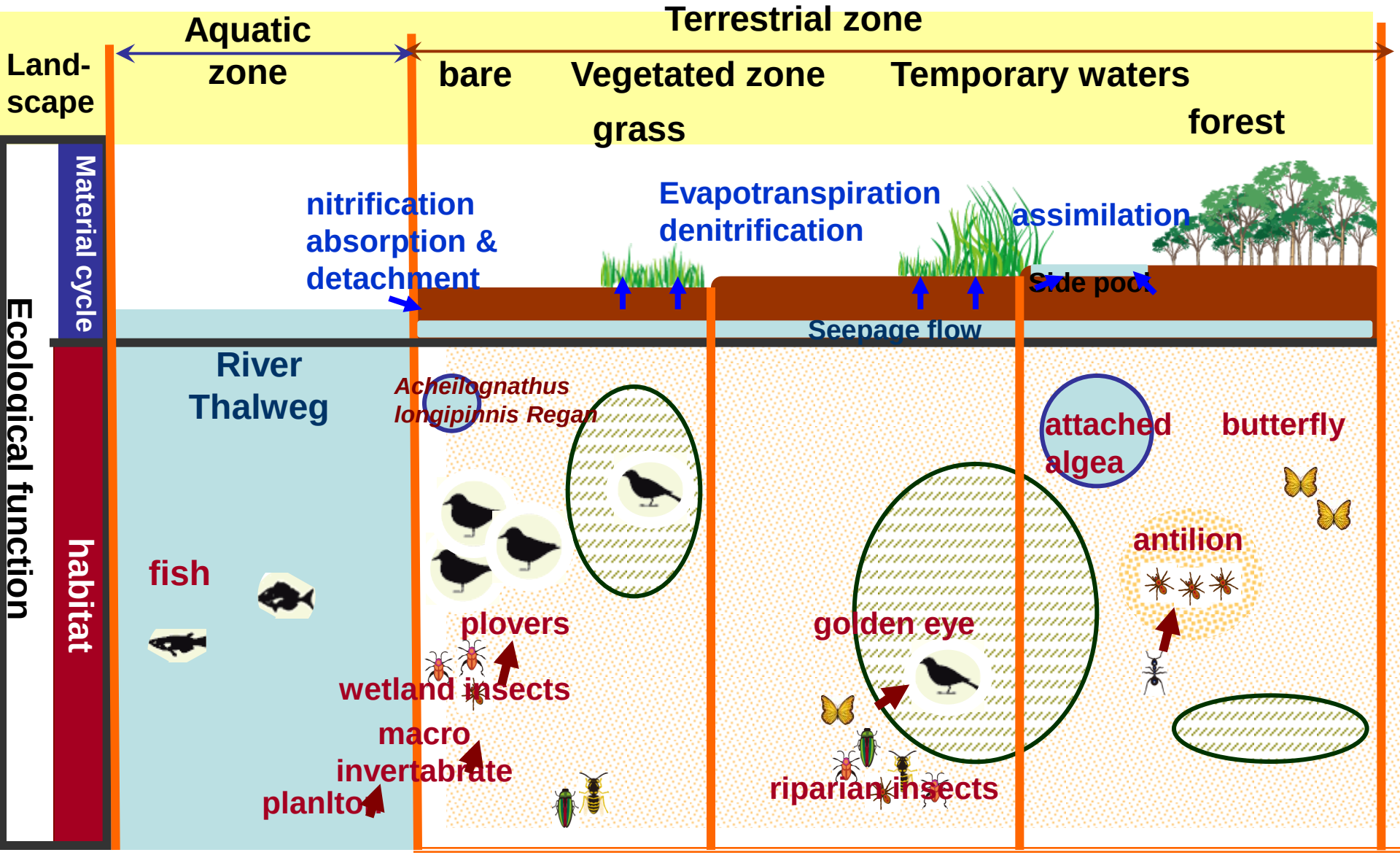


Surface Flow
Artifact
Artificial Canal
Level.3-Bare Area (BA)
Level.2-BA
Level.1-BA
Level.3-Vegetation Area (VA)
Level.2-VA
Level.1-VA

Level.3:Water level of the river discharge of 500～1700m^3/s
Level.2:Water level of the river discharge of 100～500m^3/s
Level.1:Water level of the river discharge of 20～100m^3/s



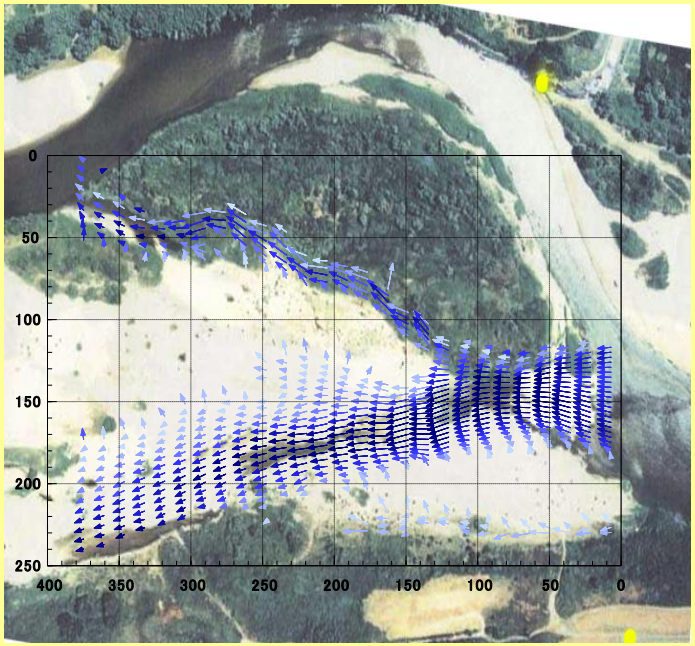
Relation between landscape unit and ecological function



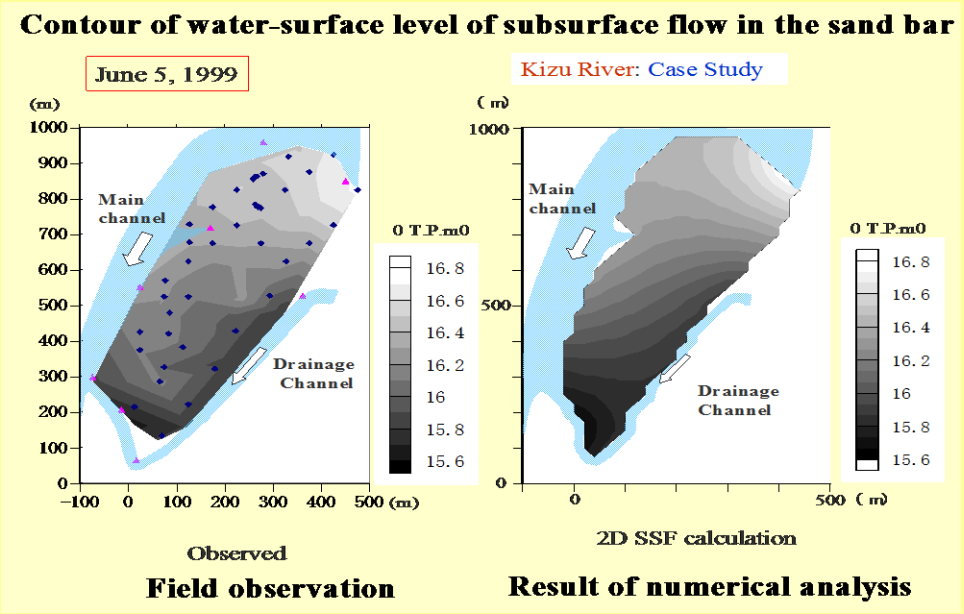
Based on Research Cooperation in the Kizu River Group, 2007

Flow Computation for Specialized Textures

For surface flow



For subsurface flow



Textures can be related to "ecological functions"

Habitat evaluation for various organisms with various life stage

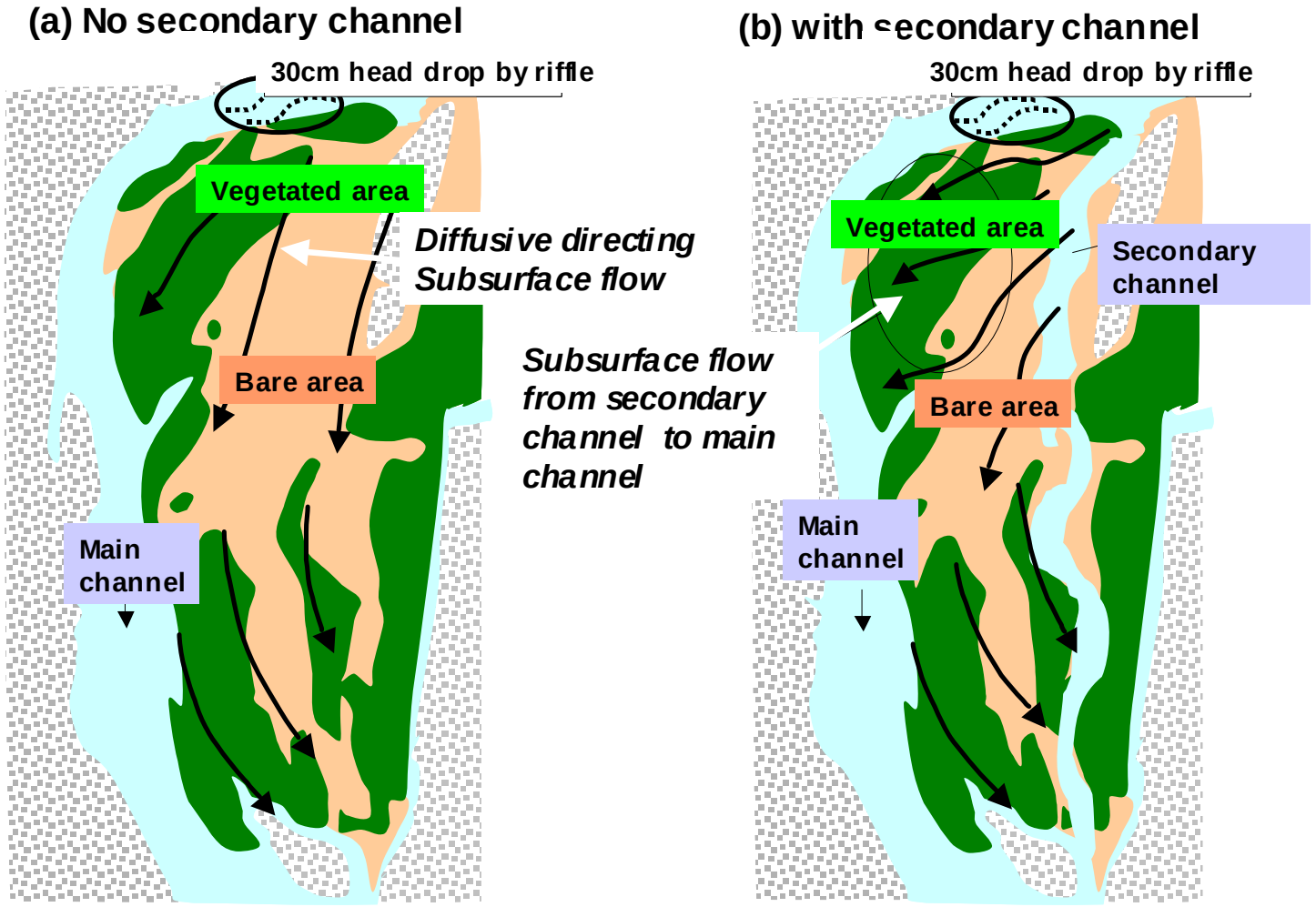
- ***Spawning area and nursery for endangered fish***
- ***Nesting spot and feeding zone of plovers***

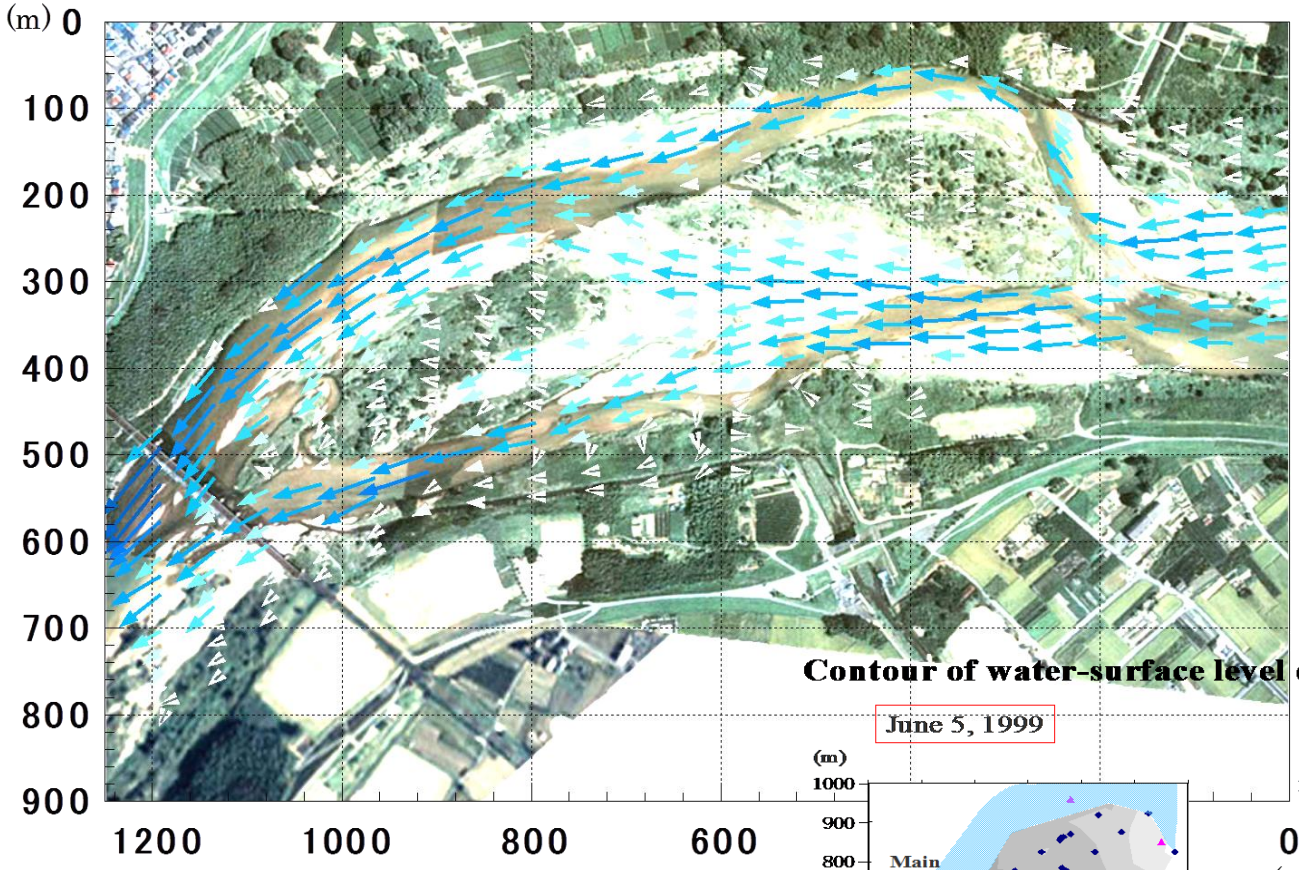
Potential evaluation for elementary processes in material cycles

- ***Nitrification, Denitrification***
- ***Capture and stock of particulate organic matters***

Subsurface flow is driven by water-stage drop at riffle

Subsurface flow is subjected to the spatial distribution of free-surface

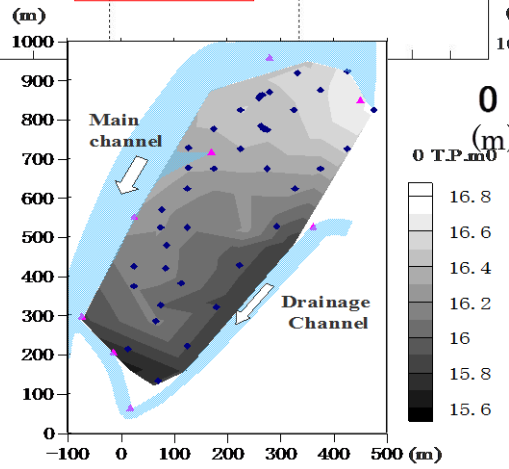




Contour of water-surface level of subsurface flow in the sand bar

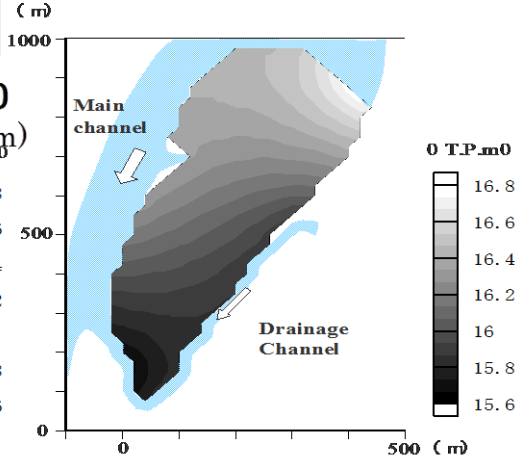
June 5, 1999

Kizu River: Case Study



Observed

Field observation



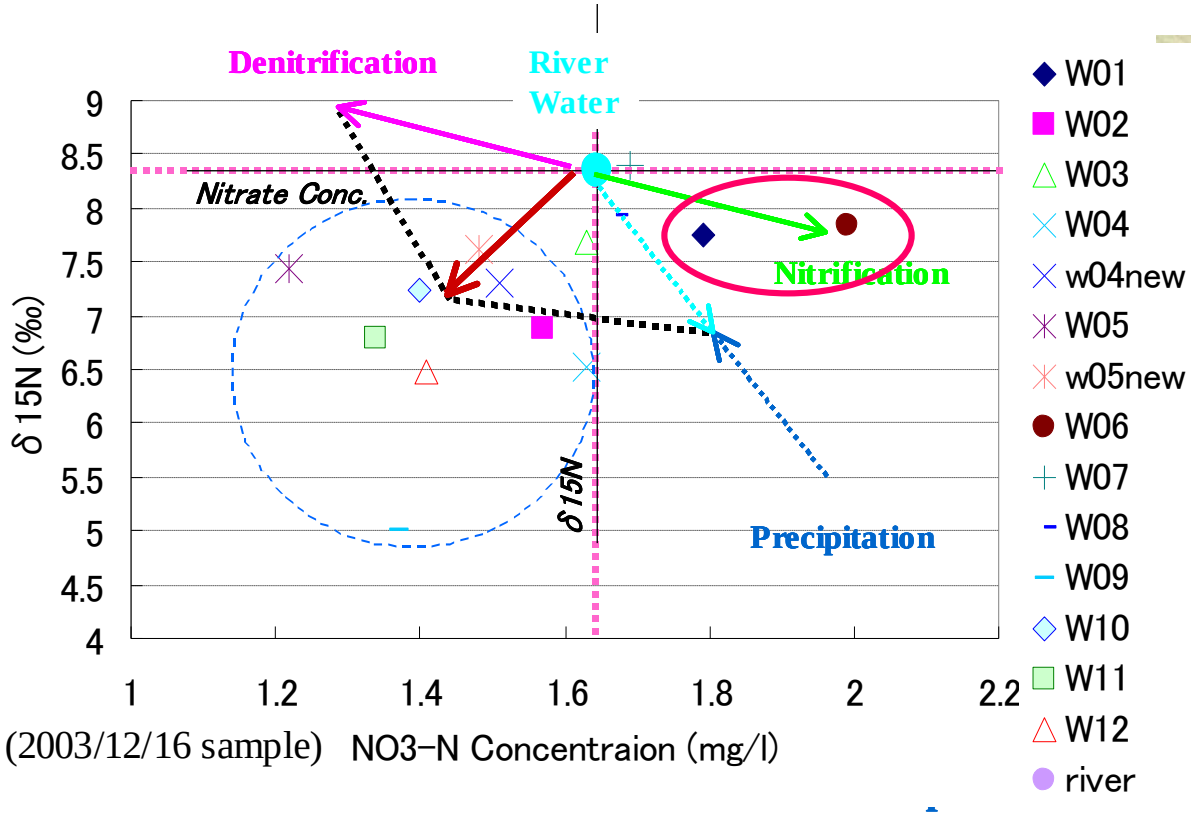
2D SSF calculation

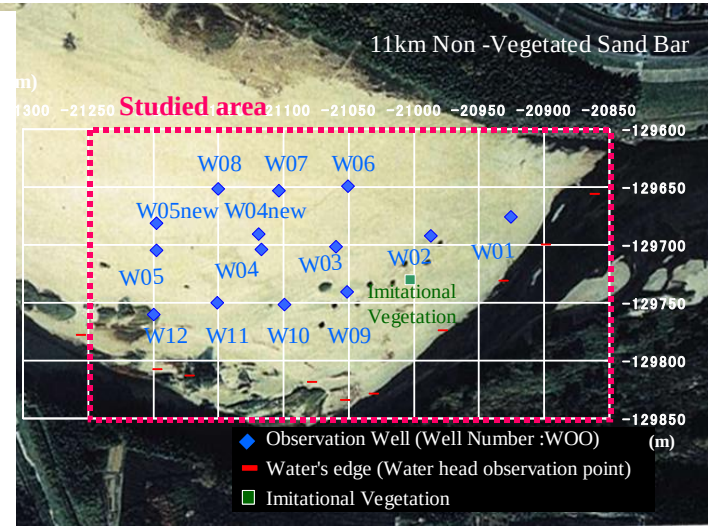
Result of numerical analysis

Flow is analyzed in 2DH both for surfaceflow and Subsurface flow

Monitoring: Nitrate ion conc. & $\delta^{15}N$

Nitrification ($NH_4^+ \rightarrow NO_3^-$ decrease of $\delta^{15}N$) & Denitrification ($NO_3^- \rightarrow N_2$ Increase of $\delta^{15}N$)



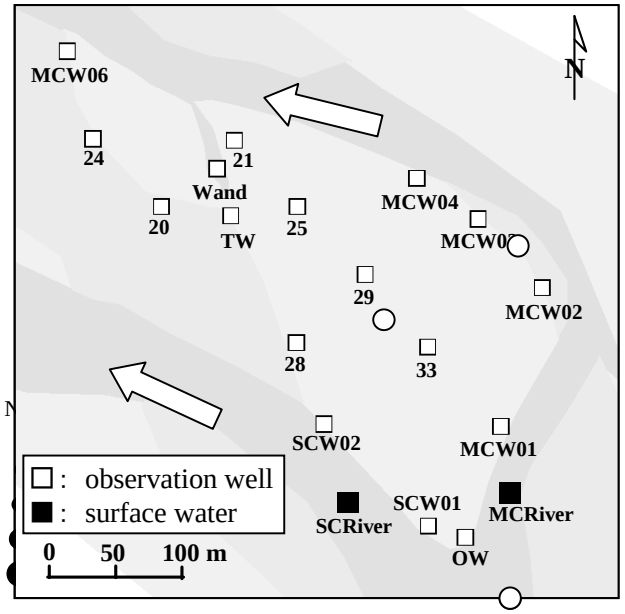


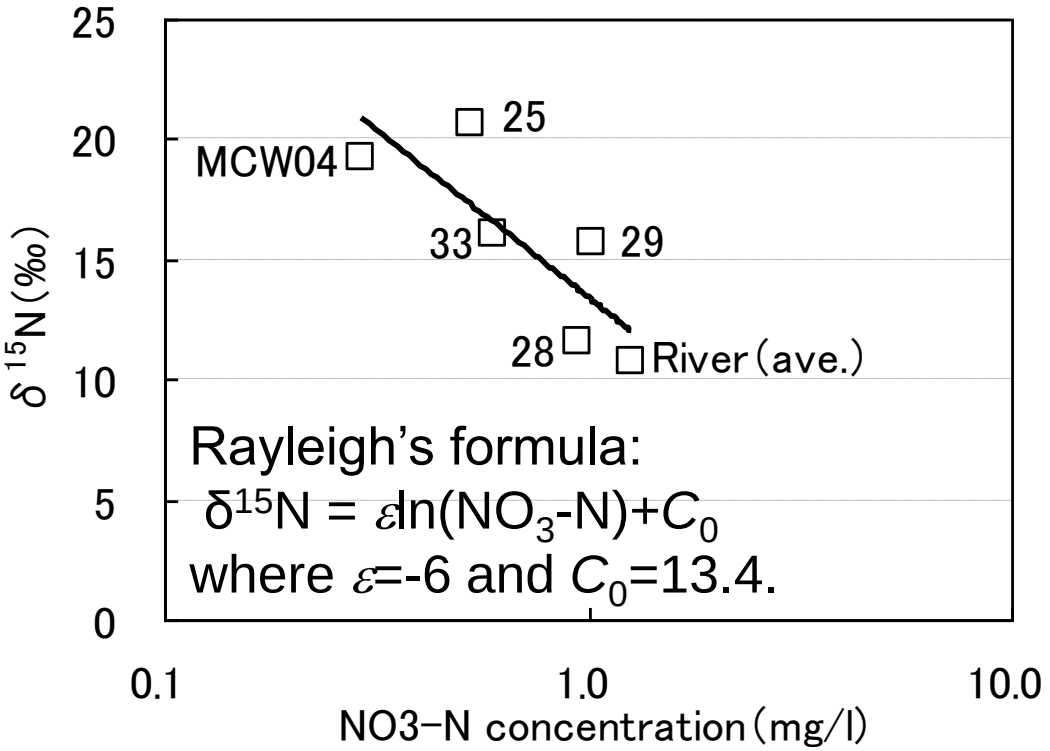
Arrangement Of Constructed Well (Total:14pipes)

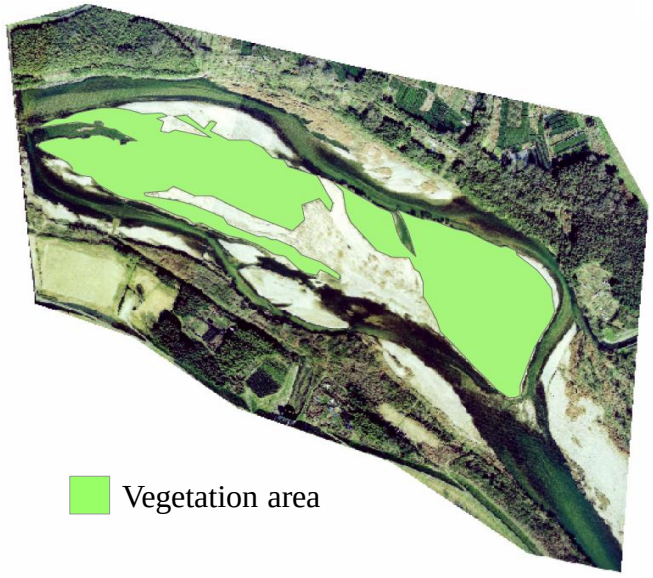
In Bare bar

Mixing by vertical seepage during rainfall and/or inundation
←solving deposit with higher NO_3^- (decrease of $\delta^{15}N$)

Vegetated sand bar







Vegetation

trap and stock fine material
→coating→no seepage (mixing)
in spite of higher stock

Subsurface Flow characteristics
←2D horizontal analysis

Assumption:

2D non-pressurized flow

Constant porous layer on impervious boundary

Dupuit-Forchheimer assumption

Depth average flow in porous medium

$$\lambda \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(kh \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y}\left(kh \frac{\partial h}{\partial y} \right)$$

*h:*water level of seepage flow,

λ*:*porosity, *k:*permeability

	Bare area	Vegetated area	N.B.
Permeability	0.005 m/s	0.0002 m/s	Insitu test
porosity	0.45	0.45	

Boundary Condition :

- **at water edge → river flow surface level**
- **at bank → zero gradient of water surface level**

Governing Equation of Materials

←*Convection-Dispersion Equation with Reaction Terms*

$$\frac{\partial C_i}{\partial t} + u\frac{\partial C_i}{\partial x} + v\frac{\partial C_i}{\partial y} = \frac{\partial}{\partial x}\left(D\frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(D\frac{\partial C_i}{\partial y}\right) + R_i$$

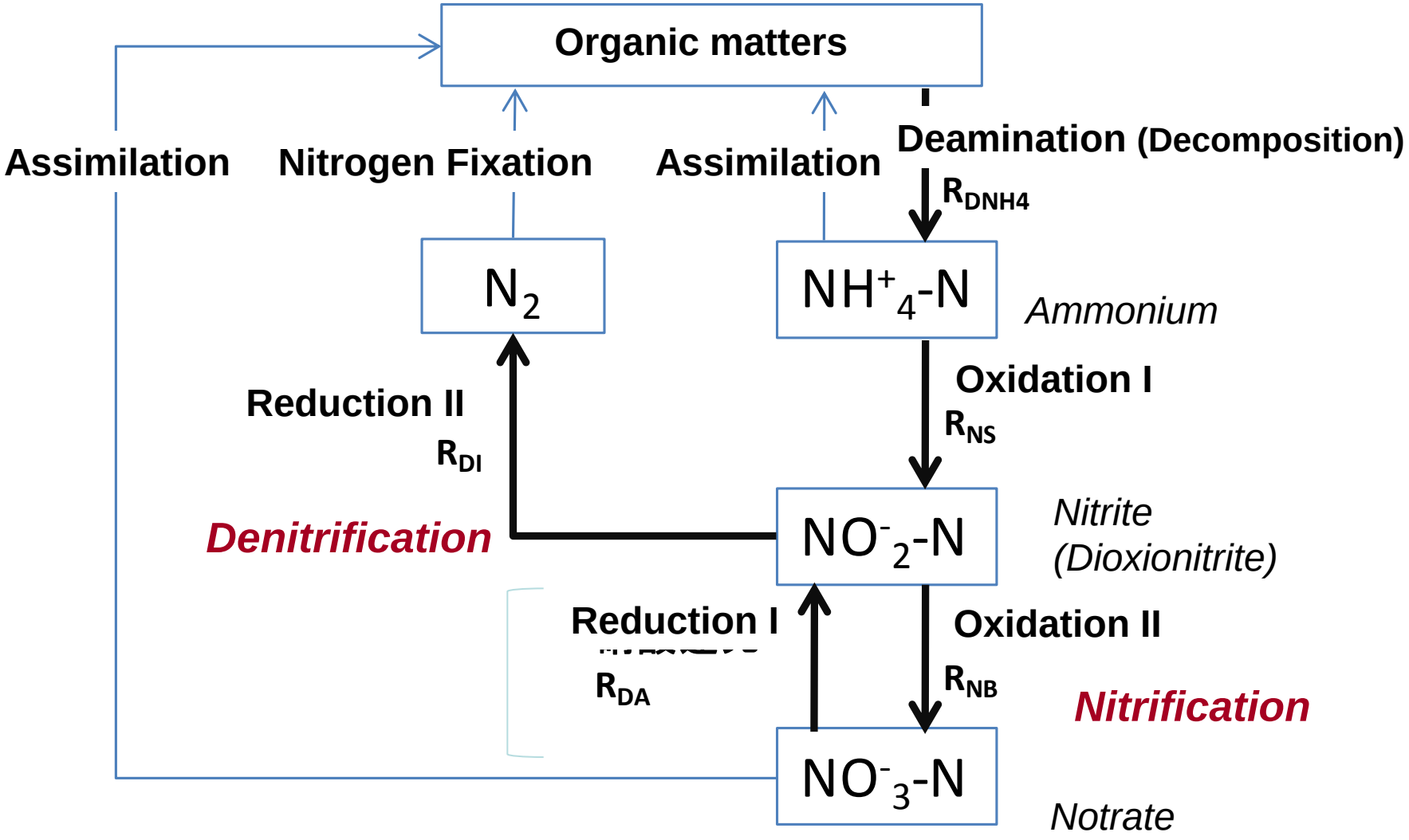
u, v : Average velocity of seepage flow
D : Dispersion coefficient
R_i : Reaction terms due to micro-organisms

Boundary condition :

- At shoreline → water quality in a river
- At bankside → zero transverse gradient of material concentration

Material Changing Process (Biophilic elements)

→*Focusing on Nitrogen*



$$R_{\mathrm{NH4-N}} = R_{\mathrm{DNH4}} - R_{\mathrm{NS}}$$

$$R_{\mathrm{NO2-N}} = R_{\mathrm{NS}} - R_{\mathrm{NB}} + R_{\mathrm{DA}} - R_{\mathrm{DI}}$$

$$R_{\mathrm{NO3-N}} = R_{\mathrm{NB}} - R_{\mathrm{DA}}$$

Michaelis-Menten's reaction term

$$R_{\mathrm{DNH4}} = k_{\mathrm{DON\cdot\ NH4}} \cdot C_{\mathrm{DON}} \cdot X_{\mathrm{H}}$$

$$R_{\mathrm{NS}} = \frac{1}{Y_{\mathrm{NS}}} \mu_{\mathrm{NS}} \cdot \frac{C_{\mathrm{DO}}}{K_{\mathrm{S\cdot NS\cdot DO}} + C_{\mathrm{DO}}} \cdot X_{\mathrm{NS}} \cdot \frac{C_{\mathrm{NH4}}}{K_{\mathrm{S\cdot NS\cdot NH4}} + C_{\mathrm{NH4}}}$$

$$R_{\mathrm{NB}} = \frac{1}{Y_{\mathrm{NB}}} \mu_{\mathrm{NB}} \cdot \frac{C_{\mathrm{DO}}}{K_{\mathrm{S\cdot NB\cdot DO}} + C_{\mathrm{DO}}} \cdot X_{\mathrm{NB}} \cdot \frac{C_{\mathrm{NO2}}}{K_{\mathrm{S\cdot NB\cdot NO2}} + C_{\mathrm{NO2}}}$$

$$R_{\mathrm{DA}} = \frac{1}{Y_{\mathrm{DA}}} \mu_{\mathrm{DA}} \cdot \left(1 - \frac{C_{\mathrm{DO}}}{K_{\mathrm{S\cdot DA\cdot DO}} + C_{\mathrm{DO}}}\right)\left(\frac{C_{\mathrm{DOC}}}{K_{\mathrm{S\cdot DA\cdot DOC}} + C_{\mathrm{DOC}}}\right) \cdot X_{\mathrm{DI}} \cdot \frac{C_{\mathrm{NO3}}}{K_{\mathrm{S\cdot DA\cdot NO3}} + C_{\mathrm{NO3}}}$$

$$R_{\mathrm{DI}} = \frac{1}{Y_{\mathrm{DI}}} \mu_{\mathrm{DI}} \cdot \left(1 - \frac{C_{\mathrm{DO}}}{K_{\mathrm{S\cdot DI\cdot DO}} + C_{\mathrm{DO}}}\right)\left(\frac{C_{\mathrm{DOC}}}{K_{\mathrm{S\cdot DI\cdot DOC}} + C_{\mathrm{DOC}}}\right) \cdot X_{\mathrm{DI}} \cdot \frac{C_{\mathrm{NO2}}}{K_{\mathrm{S\cdot DI\cdot NO2}} + C_{\mathrm{NO2}}}$$

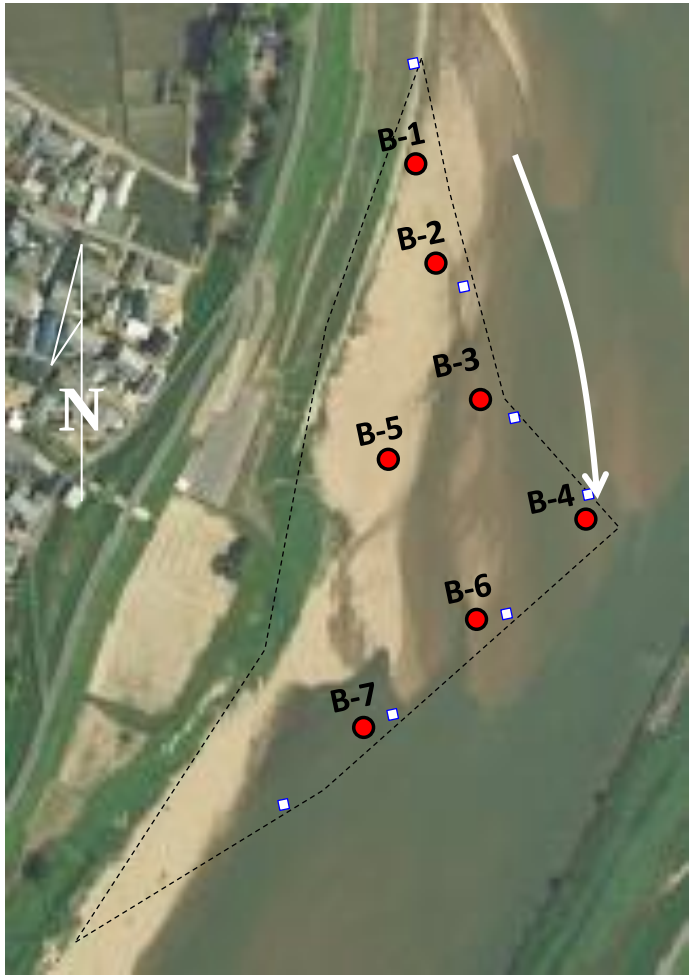
Parameters for Biological Reactions:

	R_{DNH4}	R_{NS}	R_{NB}	R_{DA}	R_{DI}	Reference
X(mg/l)	0.50	0.30	0.10	1.0	3.0	Somiya
Y(mg.cell/mg)		0.13	0.05	0.60	0.72	Kusuda
μ(s^{-1})		5.3×10^{-6}	8.3×10^{-6}	1.1×10^{-5}	2.0×10^{-4}	Kusuda
K_S (mg/l)		1.7×10^{-2}	5.0×10^{-4}	1.0×10^{-3}	5.0×10^{-4}	Kusuda
$K_{S.DO}$ (mg/l)		2.0	0.20	0.20	0.20	Kusuda
$K_{S.DOC}$ (mg/l)				0.70	9.0	
k (l/mg/s)	2.2×10^{-7}					Kusuda

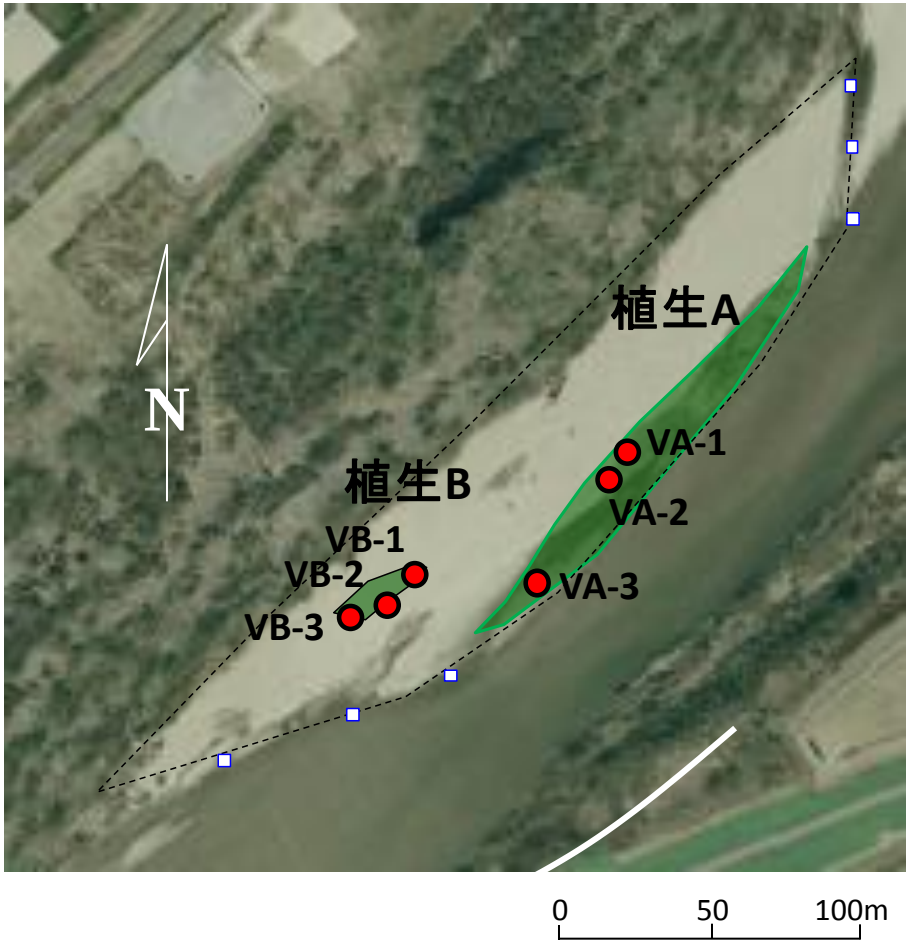
Potential of subsurface flow in each characteristic space

	C_{DON}	C_{DOC}	C_{DO}
Bare area	0.04	0.75	4.0
Vegetated area	0.08	1.5	2.0

Bare sand bar



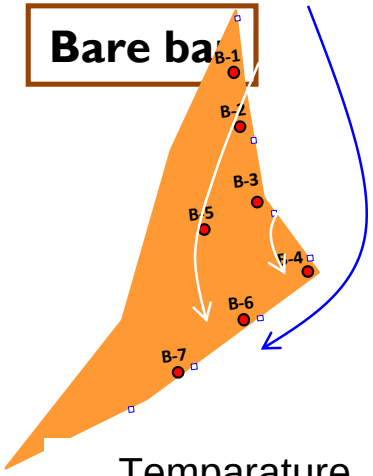
Vegetated sand bar

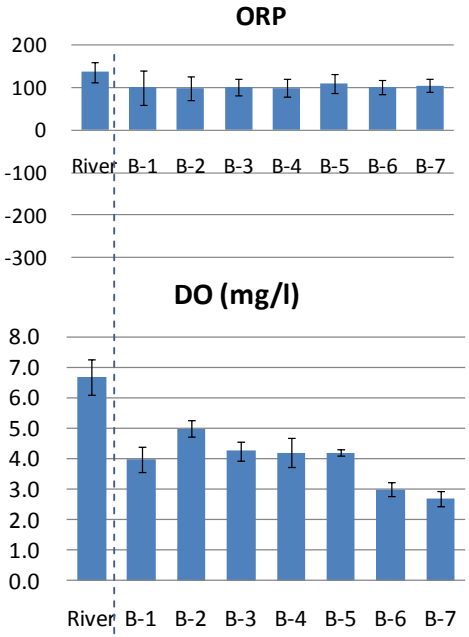


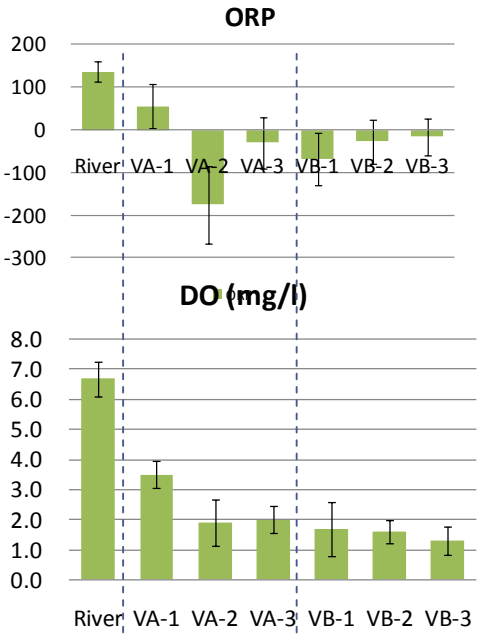
- **Survey August 19,20/2009**
- **Hydro/Morphological data**
- **Soil characteristics**

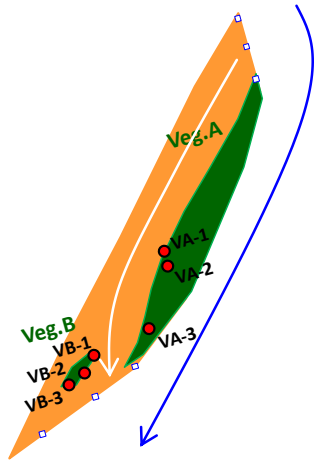
Sampling of water quality of seepage and river flows

Seepage Water Quality



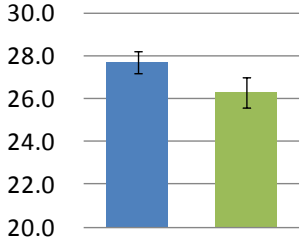




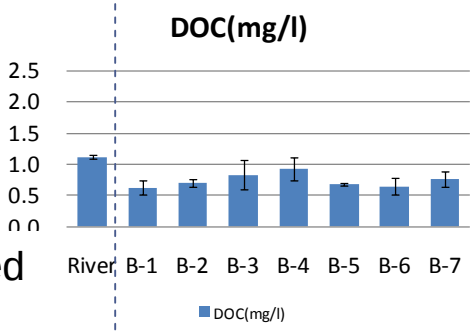


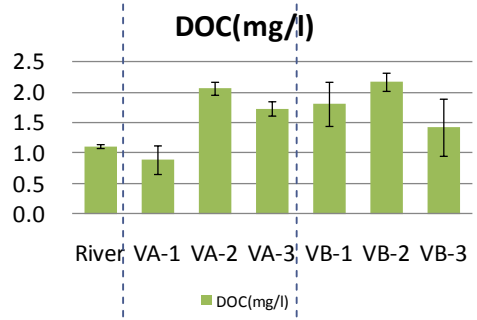
Vegetated bar

Temparature



Bare Vegetated





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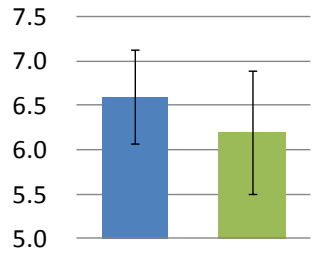
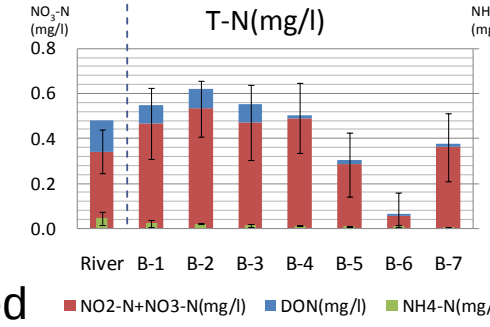
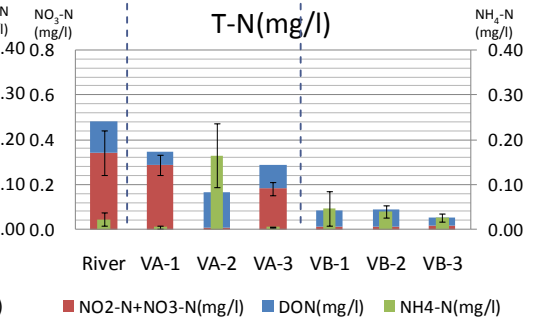


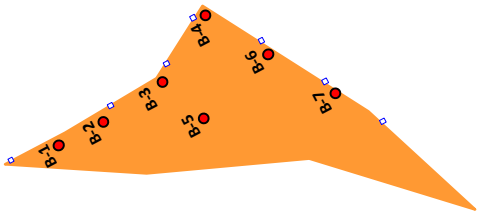
Bare Vegetated

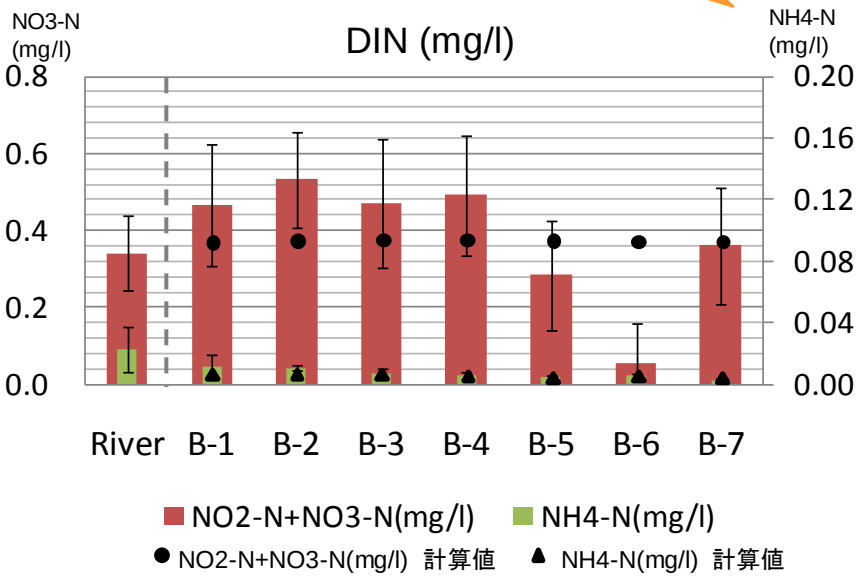




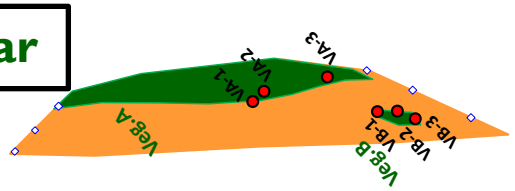
Comparison of numerical simulation and field monitoring

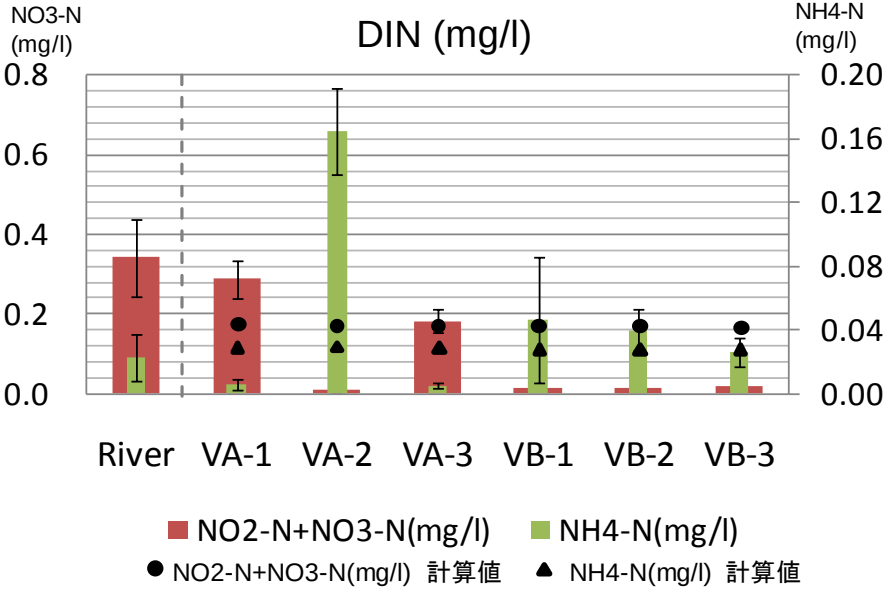
Bare bar





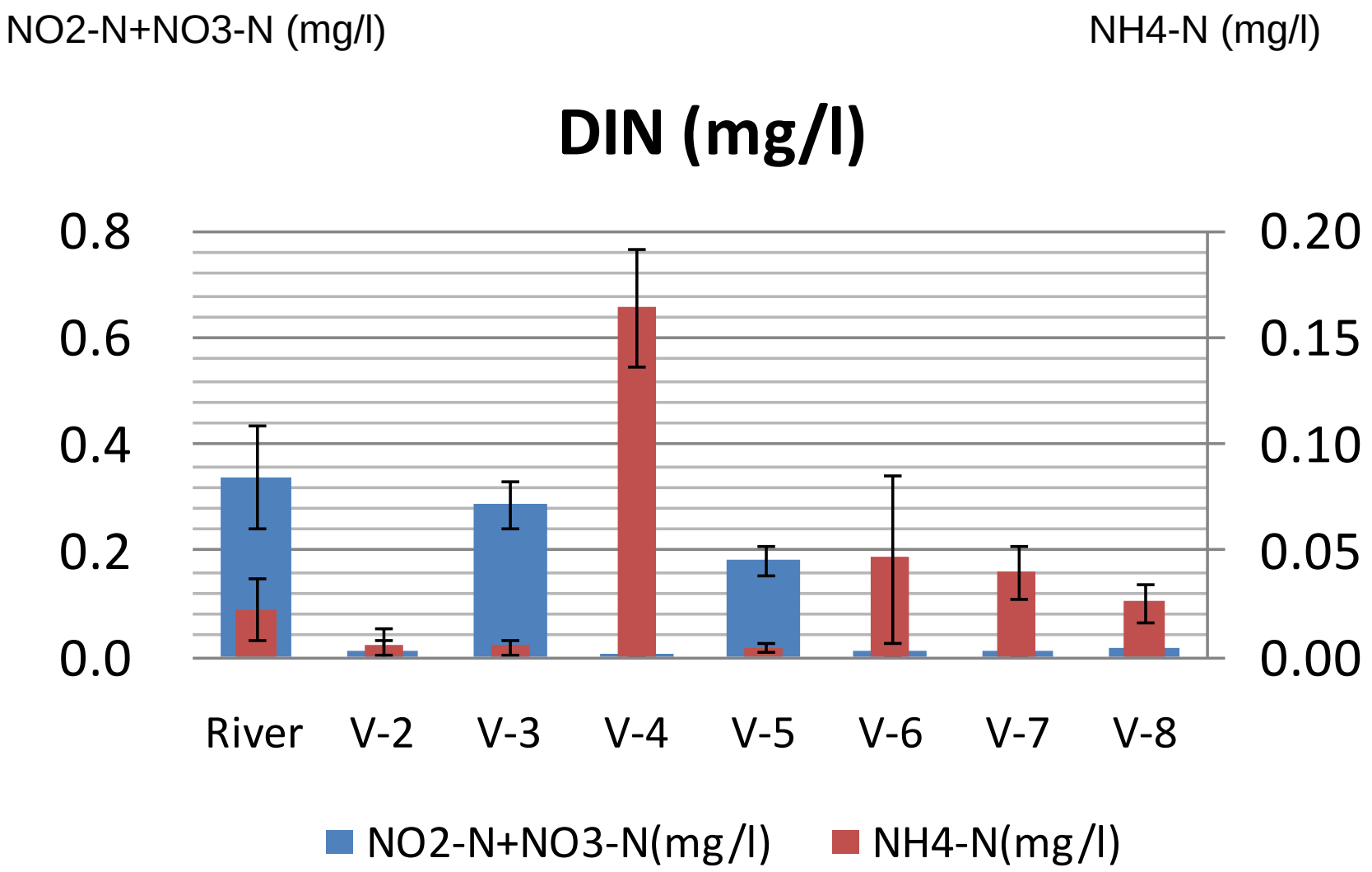
Vegetated bar





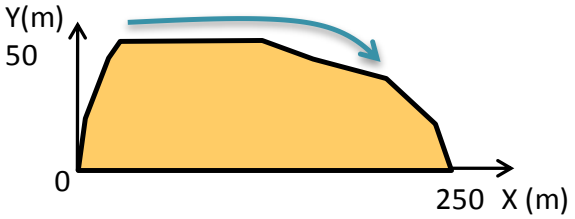
	Bare bar	Vegetated bar
Total denitirification (g/day)	1003.3	208.0
Denitirification rate (mg/m²/day)	33.1	18.3

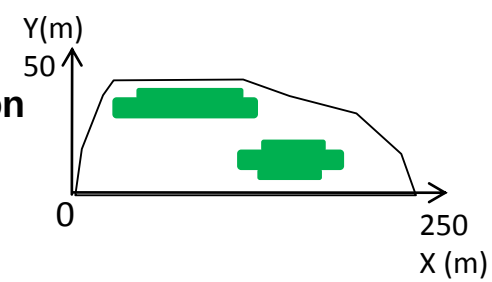
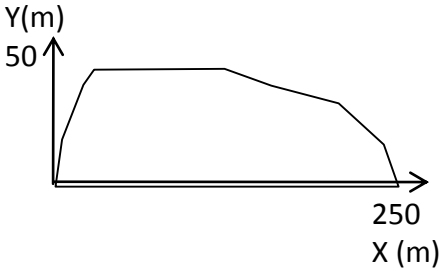
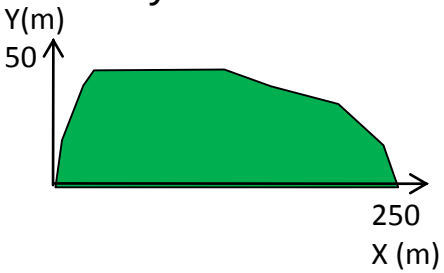
(1600.9, 52.3 with vegetation cover)

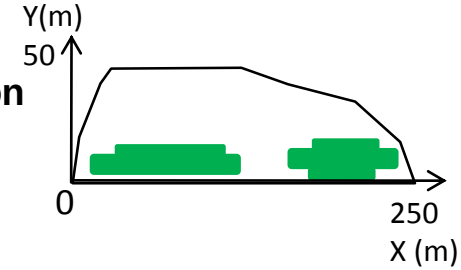
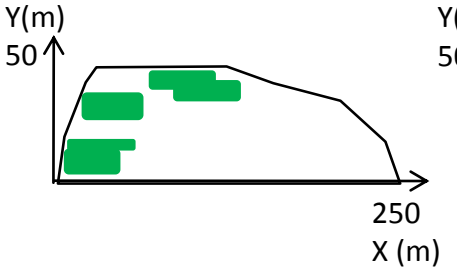
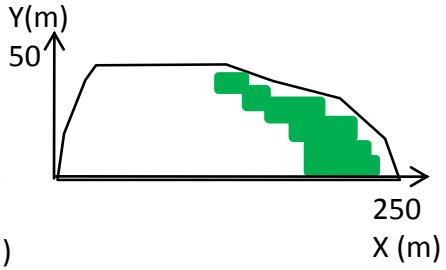

NO2-N+NO3-N (mg/l)
NH4-N (mg/l)
DIN (mg/l)
0.8
0.6
0.4
0.2
0.0
0.20
0.15
0.10
0.05
0.00
River
V-2
V-3
V-4
V-5
V-6
V-7
V-8
NO2-N+NO3-N(mg/l)
NH4-N(mg/l)

Vegetation patterns
To be investigated

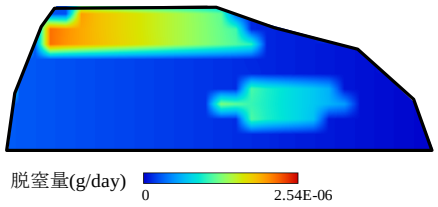
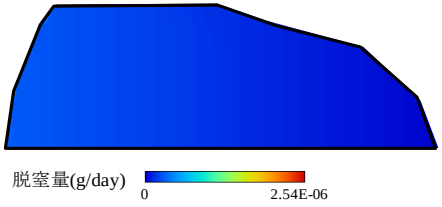
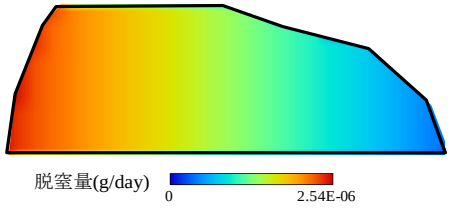
Bar geometry

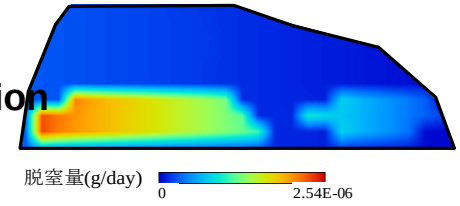
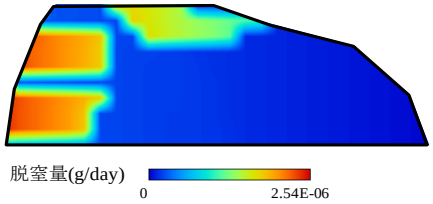
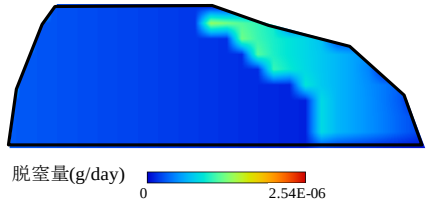


	Case 1-1	Case 1-2	Case 1-3
Vegetation ratio	30	0	100
Vegetation growth	Middle of bar	–	totally covered
Spatial distribution			

	Case 2-1	Case 2-2	Case 2-3
Vegetation ratio	30	30	30
Vegetation growth	Near bank	Upstream side	Downstream side
Spatial distribution			

Computed results:

	Case 1-1	Case 1-2	Case 1-3
Vegetation growth	Shoreline/Middle		Totally covered
Denitirification Amount (g/day)	18.0	10.6	32.1
DA Spatial distribution Contour			

	Case 2-1	Case 2-2	Case 2-3
Vegetation growth	Near bank	Upstrem side	Downstream side
Denitirification Amount (g/day)	16.5	18.7	13.6
DA Spatial distribution Contour			

CONCLUSIONS

River ecosystem **is clarified from the view point of its structure and functions.**

Structure=Interrelating system composed of physical basement, biological activity and biophilic elements cycle.

Functions=interactions : habitat, material cycle

Ecosystem is composed of *landscape units* connected by water/material flux networks.

Landscape units has *hierarchy structure*: Bar has various textures (vegetation, micro-morphology, substratum,…) which are connected by surface and subsurface flows.

Nitrogen transport and changing process are focused on:

Denitirification **is recognized in vegetated area in particular.**

←Monitoring in the field (ion and stable isotope)

Numerical simulation scheme is designed, and the *effect of spatial distribution of vegetation* area on denitrification is discussed.