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Streamwater Hydrochemistry in Headwaters: Mixing, Inter Catchment Groundwater Transfer, and Instream Processes

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1. Introduction

Where does water go when it rains?
How is water chemistry controlled by hydrological processes?

➔ *What is the Dominant Processes on Hydrology and Hydrochemistry at Each Landscape in 2-Order Catchment?*

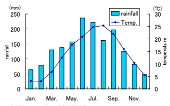
Hydrochemistry in small catchments
- Many studies, Many findings
- Intensive Observations

➔ **Remarkable Processes**
- Groundwater flow within Bedrock(e.g. Katsuyama et al.,in press)
- Inter catchment groundwater transfer(e.g. Genereux et al.,2002)
- Instream Processes (e.g. Hyporheic Exchange) (e.g. Gooseff et al.,2002;McHale et al.,2004)

➔ **Questions**
- Generality of the findings
- Scaling Effects
- Water and Nutrient Budget Imbalance

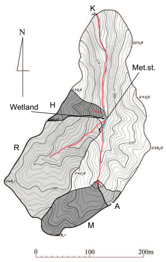
➔ **Objective**
- Test the findings from one site to other locations
- Understanding of the effects of Remarkable Processes on Hydrochemistry

2. Site description (http://www.bluemoon.kais.kyoto-u.ac.jp/kiryu-e/contents.html)



Kiryu Experimental Watershed(KEW)

Location	Central part of Japan(34°58'N, 136°00'E)
Bedrock material	Weathered Granite
Vegetation	Japanese Cypress(Artificial Forest)
	Japanese Red Pine(Dieback)
	Riparian Forest(Wetland)
Climate	Temperate
Annual Temperature	13.6℃(1997-2003)
Precipitation	1639.9mm/yr(1972-2003)
Mainstream Gradient	9.23°



Topography of KEW

Bird's-eye view of KEW

V-notch weir at the outlet of Site K

Japanese Cypress forest

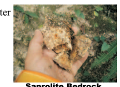
Site

- Kiryu Experimental Watershed(K;5.99ha, 2-order catchment)
  4 subcatchments(M,A,R,H;0-1 order,0.086-1.75ha) within K
  Wetland in K catchment
- M:Reference site...Mixing model approach with Na^+ and Cl^- tracers
  (About this site and sampling methods...e.g. Katsuyama et al.(2000); Katsuyama & Ohte(2002); Katsuyama et al., in press)
- K,R,H,A:Test sites...Apply the End-members from M(Ref. site) and test

Data Set

Name	Area(ha)	ratio(%)		Sampling Period	Sample Size
M	0.68	11.4	Streamwater	6/'96-10/'04	189
			Groundwater	6/'96(6/'01)-10/'04	58-194
			Rainfall	7/'96-10/'04	177
K	5.99	100	Streamwater	6/'00-10/'04	84
R	1.75	29.2	Streamwater	3/'02-10/'04	43
H	0.4	6.7	Streamwater	3/'02-10/'04	43
A	0.086	1.4	Streamwater	3/'99-10/'04	115
Wetland	0.003	0.05	Groundwater	5/'02-5/'03	17-23

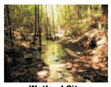
Bedrock in this study (Katsuyama et al., in press)
- N_4 >100
  (N_4 ... Number of blows required for a 4-cm penetration by the Cone Penetrometer (cone diameter: 19.5 mm, mass: 1.17 kg, fall distance: 20 cm))
- Bedrock chunks could be excavated by chopping with a shovel and crushed into grains using bare hands (Saprolite)
- *Ks* of the bedrock: 10^{-6} m/sec order
  (*Ks* of the forest soil at KEW: 10^{-4} m/sec order)



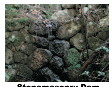
Saprolite Bedrock

Wetland Site

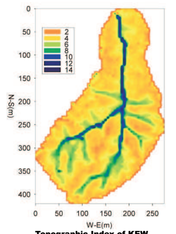
- Stonemasonry dams constructed to prevent soil erosion along the main stream.
- A small wetland is formed in sedimentation area, where 4 subcatchment streams confluent
- The area of the wetland corresponds to 0.5% of the area of KEW



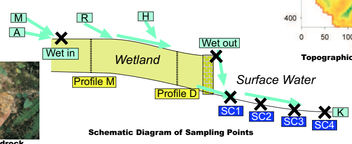
Wetland Site



Stonemasonry Dam



Topographic Index of KEW

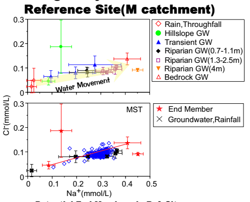


Schematic Diagram of Sampling Points

3. Results and Discussion

3-1.Mixing Analysis

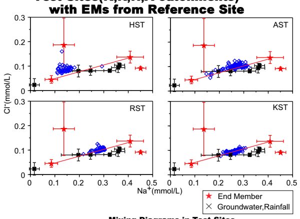
Reference Site(M catchment)



up:Potential End-Members in Ref. Site
bottom:Mixing diagram in Ref. Site

- Potential *EMs* are on one line
- Conc. of Potential *EMs* increased with water transport, though large variations in Hillslope GW
- Streamwater are between shallow, Hillslope GW (or rainfall) and deep, Bedrock GW(2-componets Mixing)
- Riparian GW(0.7-2.5m) are similar to Streamwater

Test Sites(K,R,H,A catchments) with EMs from Reference Site



Mixing Diagrams in Test Sites

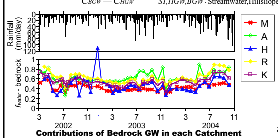
- Every site is on the same Mixing Line(2-components Mixing)
  Validity of *EMs* across catchments were confirmed
- Contributions of each *EM* are different

3-2.Contributions of Bedrock GW

Chemical Mixing Calculations to quantify the contribution of Bedrock GW to each streamwater (Genereux et al., 2002)

$$f_{water} = \frac{C_{ST} - C_{HGW}}{C_{BGW} - C_{HGW}}$$

f_{water}: Contributions of Bedrock GW to Streamwater
C: Tracer concentration(Cl^-)
ST, HGW, BGW: Streamwater,Hillsliope GW, and Bedrock GW



Contributions of Bedrock GW in each Catchment

- BGW contributions decreased after the heavy storms *i.e.*, HGW contributions increased after the rainstorm
- BGW sustained the perenial baseflow

Average Contributions of Bedrock GW during 3/'02-4/'04

	M	A	H	R	K
f_{water}	0.41	0.60	0.46	0.59	0.52

- Drainage Area of Soil Surface and Bedrock Surface are disagree in Subcatchment

M,H...Soil:Bedrock = 6:4   R,A...Soil:Bedrock = 4:6   K...Soil:Bedrock = 5:5

Mixing Ratio of Soil and Bedrock GW in each Catchment

3-3.Inter Catchment GW Transfer -Water and Nutrient Imbalance-

Annual Budget of Water and Nutrient in 2003

		M	A	H	R	K
Rainfall(R)	(mm)			1970.7		
Discharge(Q)	(mm)	678.5	903.5	226.1	941.1	1097.9
ratio to K	(volumetric)	0.07	0.01	0.01	0.25	
Runoff ratio		0.35	0.46	0.12	0.48	0.56
Cl^- Load	(kg)	13.2	2.8	2.8	56.6	211.6
ratio to K		0.06	0.01	0.01	0.27	
Na^+ Load	(kg)	32.1	5.1	2.9	104.0	393.1
ratio to K		0.08	0.01	0.007	0.26	
NO_3^- Load	(kg)	11.6	1.6	1.0	6.0	81.1
ratio to K		0.14	0.02	0.01	0.07	

Maximal GW transfer between subcatchments ★
= Observed Q from each subcatchment
- Averaged Q from 4 subcatchments(780.7mm/yr)

		M	A	H	R
Loss/Gain	(mm)	-102.2	122.8	-554.6	160.4
	(m^3)	-694.8	105.6	-2218.3	2807.5

★ Assumption:
All groundwater, except for deep seepage, transfer among the subcatchment, and no groundwater supplied from other catchment

- Discharges in subcatchments were smaller than in Main stream
- Discharges from H and M were especially small
  ★ Among Subcatchments
  M,H:Loss ⇒ A,R:Gain
  ➔ ★ Between Subcatchments and Mainstream
  M,H,A,R:Loss ⇒ K:Gain

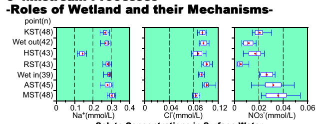
GW transfer from subcatchment to mainstream

Sub/Main ratio

Area		49%
Discharge		34%
Load	Cl^-	35%
	Na^+	37%
	NO_3^-	25%

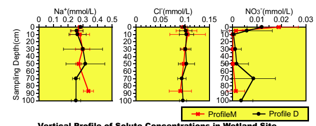
➔ **Undetected component supply 66% of Annual Discharge and more Solute !!**

3-4.Instream Processes -Roles of Wetland and their Mechanisms-



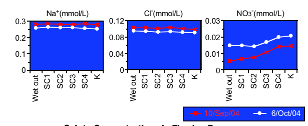
Solute Concentrations in Surface Water

Passing through the Wetland...
Na^+, Cl^- = invariable
NO_3^- = decreased
Denitrification in reduced condition!!
HOWEVER
NO_3^- at K is higher than in Wet out!!



Vertical Profile of Solute Concentrations in Wetland Site

Profile of Conc. in Wetland...
Na^+, Cl^- = invariable
NO_3^- = lower in GW
Hyporheic Exchange!!
Preferential Pathway in deep layer!!



Solute Concentrations in Flowing Processes

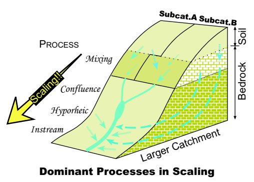
from Wetland outlet to K...
Na^+, Cl^- = invariable
NO_3^- = gradually increased
Undetected GW with High NO_3^- Contribute in Flowing Processes

Hillslope GW from Side slope
... High NO_3^- ?
(Small TPI = Small Water Volume)
and/or
Undetected Bedrock GW
... Large Water Volume?
(Long Residence Time = Low NO_3^-)

- Small Wetland affect the streamwater Hydro-Biogeochemistry by the Redox Condition
- Groundwater, which was Undetected in Small Subcatchment, gradually contributed in Flowing Processes

4. Conclusion

- End-Members of Streamwater in this region are defined...**Hillslope Groundwater**& **Bedrock Groundwater**
- Mixing Ratio of End-Members are different in Each Catchment
- **Inter Catchment Groundwater Transfers**, both among subcatchments and from subcatchments to mainstream, are important for Water and Nutrient Imbalance
- Streamwater Hydro-Biogeochemistry is controled by **Hyporheic Process in Wetland** and **Flowing Process**, as well as **Mixing Process**
- Each Process are important to consider **Scaling Effect**



Dominant Processes in Scaling

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