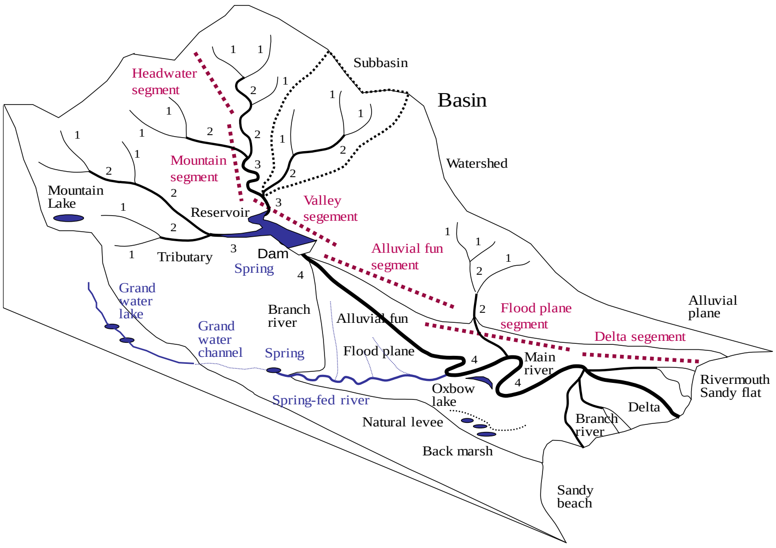
International Hydrological Programme

Ecohydrology for River Basin Management under Climate Change

-The Twenty-third IHP Training Course-



Water Resources Research Center, Disaster Prevention Research Institute,
Kyoto University

Supported by

Hydrospheric Atmospheric Research Center, Nagoya University

Disaster Prevention Research Institute, Kyoto University

Global Center for Education and Research on Sustainability Science for Resilient Society Adaptable to Extreme Weather Conditions, Kyoto University

Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan

International Hydrological Programme

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2 - 13 December, 2013

Kyoto, Japan

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Outline

A short training course on ecohydrology under climate change is programmed for participants from Asian-Pacific regions as a part of Japanese contribution to the International Hydrological Program (IHP). The course composed of a series of lectures, practice sessions, and field surveys along the Kizu River will be held mainly at Disaster Prevention Research Institute (DPRI), Kyoto University during the two weeks from 2 to 13 December 2013.

Objectives

Water is our most valuable natural resource. The availability and quality of fresh water not only impact human health and wellbeing, but also the functioning of essential ecosystems, including rivers, wetlands, lakes and coastal ecosystems. Without sound water resources management, human activities can upset the delicate balance between water resources and environmental sustainability.

Ecohydrology is an integrative science studying the relationships between hydrological and ecological processes in soils, rivers and lakes at the catchment scale. It deals with hydrological factors which determine the dynamics of natural and human-driven ecosystems, together with ecological factors which influence water dynamics and water quality. It proposes a “dual regulation” of a system by simultaneously studying ecological and hydrological processes to enhance the overall integrity of aquatic ecosystems in the face of human-driven alterations and Global Change. River basins have a hierarchical structure and natural boundaries, and can be considered as inherent integrators of the effects of many climatic and non-climatic factors. That is why river basins represent a suitable scale for integrated ecohydrological studies and modelling.

The 23rd IHP training course is focused on three major objectives: (1) to acquire the latest knowledge on hydrological and ecological assessment under climate changes at river basin scale, (2) to make practice for learning the methodologies for assessing the impact of climate change on hydrological and ecological processes, and (3) to discuss the possibility to include the hydrological and ecological responses to climate change into the water resources managements.

Course Contents

Convener: SUMI, Tetsuya (Disaster Prevention Research Institute, Kyoto University)

Chief assistant: TANAKA, Kenji (Disaster Prevention Research Institute, Kyoto University)

Lectures

Keynote 1 Overall concepts of Ecohydrology S. Kazama

Keynote 2 Ecohydrology: process oriented thinking towards sustainable enhancement, water resources, biodiversity, ecosystem services and resilience to climate change M. Zalewski

Lecture 1 Fundamentals of basin-scale hydrological processes Y. Tachikawa

Lecture 2 Projected future meteorological environment E. Nakakita

Lecture 3 Fundamentals of freshwater ecology Y. Takemon

Lecture 4 Sustainable management of water resources in marginal area: Study case in Indonesia Ignasius D. A. Sutapa

Lecture 5 Biodiversity and Ecosystem Services in the Context of Global Change O. Saito

Lecture 6 Integrated sediment management T. Sumi

Lecture 7 Interaction between river and coastal ecosystem Y. Suzuki

Lecture 8 IHP perspectives on ecohydrology and related demonstration projects S. Khan

Lecture 9 Fundamentals in optimum operation of reservoir systems T. Hori

Practices

Exercise 1 Fundamentals of Data Processing T. Hamaguchi

Exercise 2 Data analysis of GCM data, historical data K. Tanaka

Exercise 3 River basin modelling Y. Sato

Exercise 4 Impact assessment by hydrological model Y. Sato

Exercise 5 Impact assessment by ecological model S. Kobayashi

Exercise 6 Optimization of reservoir operation D. Nohara

Field Survey Ecological field survey at Kizu river Y. Takemon

Technical visits

Lake Biwa, Uji River, Katsura River

Schedule (1 to 14 December, 2013)

1 (Sunday)	Arrival at Kansai Airport and movement to Kyoto (El-INN Kyoto)
2 (Monday)	10:00-11:30 Opening & Registration & Guidance 13:00-14:30 Keynote 1 by S. Kazama 15:00-16:30 Keynote 2 by M. Zalewski 17:00-18:30 Welcome Party (@S217D)
3 (Tuesday)	09:30-12:00 Lecture 1 by Y. Tachikawa 14:00-16:30 Lecture 2 by E. Nakakita
4 (Wednesday)	09:30-12:00 Lecture 3 by Y. Takemon 14:00-16:30 Exercise 1 by T. Hamaguchi
5 (Thursday)	09:30-12:00 Lecture 6 by T. Sumi 14:00-16:30 Exercise 2 by K. Tanaka
6 (Friday)	09:30-12:00 Exercise 3 by Y. Sato 14:00-16:30 Exercise 4 by Y. Sato
7 (Saturday)	09:30-17:00 Technical visits to Lake Biwa and Uji River
8 (Sunday)	09:30-17:00 Technical visits and Cultural exchange with students at the Katsura river
9 (Monday)	09:30-12:00 Lecture 5 by O. Saito 14:00-16:30 Lecture 4 by I.D.A. Sutapa
10 (Tuesday)	09:30-12:00 Lecture 7 by Y. Suzuki 13:00-14:30 Lecture 8 by S. Khan 15:00-17:30 Exercise 5 by S. Kobayashi
11 (Wednesday)	09:30-17:00 Ecological field survey at Kizu river
12 (Thursday)	09:30-12:00 Lecture 9 by T. Hori 14:00-16:30 Exercise 6 by D. Nohara
13 (Friday)	09:30-11:30 Report presentation by each participant 11:30-12:00 Completion ceremony of this course 13:00-15:00 Farewell party (@S217D)
14 (Saturday)	Departure from Kansai Airport

Keynote 1: Overall Concepts of Ecohydrology -Application of Hydrological Models to Ecology-

So KAZAMA *(Dept. of Civil and Environmental Engineering, Tohoku University, Water Resources Research Center, DPRI, Kyoto University)*

Firstly, firefly habitat was estimated using a geographical information system (GIS) and hydrological simulation in the Natori River basin in Tohoku, Japan. To investigate suitable conditions for firefly habitat, the relationships between observed firefly habitat and physical environment, such as geological conditions, hydrological conditions and land use types obtained from digital maps were determined. Suitability criteria for firefly habitat were then defined based on habitat suitability index (HSI) estimation. We found that watershed areas smaller than 5000m^2 with flat plains (slopes less than 0.15) are ideal geological conditions for firefly habitat. Further, we found that non-urbanized areas with urban ratios less than 0.1, deciduous forests, agricultural lands, and paddy fields are the best land use types for firefly habitat. This evaluation also indicates that fireflies prefer to live in shallow and calm water environments (water depths less than 500mmand velocity less than 1.0 m/s). The habitat locations determined by these criteria were validated by comparing them to field observations of firefly habitat. The results indicate that this model was successful in estimating the existence of firefly habitat in hydroenvironments.

Secondly, the habitats of aquatic organisms, including freshwater fishes (*Oncorhynchus masou masou*, *Plecoglossus altivelis altivel*, and *Cyprinus carpio*), fireflies (*Luciola cruciata* and *Luciola lateralis*), and frogs (*Anura sp*.), were evaluated dynamically in the Natori River basin using water temperature as an environmental index. The HSI (habitat suitability index) and WUA (weighted useable area) of aquatic organisms were quantitatively calculated using a distributed runoff model coupled with a heat budget model, land cover data, and digital cartographic data. The results showed that the HSI values of *O. masou masou* and *P. altivelis altivel* tended to be high in locations where they were actually observed. The HSI distribution patterns of *L. cruciata* and *L. lateralis* showed different results, even though the two species are in the same genus and have similar life cycles.

This lecture shows some examples of HSI model application using hydrological models. The habitat maps are useful for understanding of ecological systems.

OVERALL CONCEPTS OF ECOHYDROLOGY
-Application of hydrological models to Ecology-

So KAZAMA

Department of Civil and Environmental Engineering, Tohoku University
Water Resources Research Center, DRPI, Kyoto University

Contents

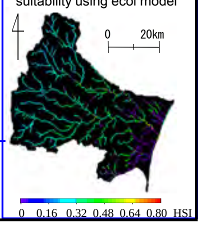
1. Introduction

・ In 1986, ICSU* decided to IGBP* to understand effects of earth system from human environment.

Based on IGBP decides, many researchers researched relationships water environments and ecological systems.
(e.g. Christoph et al., 2012, Wen-Chieh et al., 2011)

Recently, many researchers use ecological models such as PHABSIM* and HEP* to evaluate of habitat suitability of aquatic animals.

※e. g. Evaluation of habitat suitability using ecol model



ICSU* : The International Council for Science
IGBP* : International Geosphere-Biosphere Programme
HEP* : Habitat Evaluation Procedure
PHABSIM* : Physical Habitat Simulation Model

2. Objectives

- In this study, We focus Aquatic Insects

- Why focus aquatic insects?

Aquatic insects are used by index of river environment

But・・・

There are few researches on evaluating the habitat suitability of aquatic insects

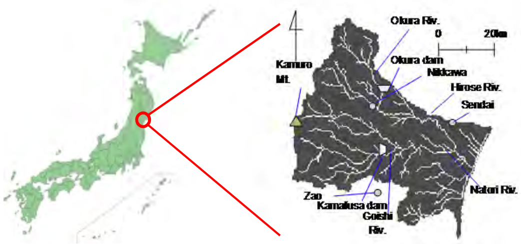
- Objectives

Evaluate spatial variations of habitat suitability of aquatic insects quantitatively combining dual approaches of using HSI* model analysis and hydrothermal simulation model.

HSI* : Habitat Suitability Index

3. Study Area

・ **Natori River basin**
Located : Miyagi Pref. (Northeastern Japan)
Catchment area : 939km^2
Arterial river length : 55km



4. Date Set

- **Land Cover Date**
- **Digital Cartographic Data**
  Digital National Land information database of Miyagi Pref. (generated by MILT*)
  J-IBIS* (generated by MOE*)

+

- **Hydrological Date**
  The Distributed runoff model and The heatbudget model (Nukazawa et al., 2011)

MILT* : Ministry of Land, Infrastructure and Transport
J-IBIS* : Japan Integrated Biodiversity Information System
MOE* : Ministry of the Environment

5. Studied Organisms

- Trichoptera

※We chose 9 aquatic insects

Net-spinners

Hydropsyche orientalis

Stenopsyche marmorata

Hydropsyche albicephale

Attachers

Limnocentropus insolitus

Crawlers

Glossosomatidae

5. Studied Organisms

- Others

Burrowers

Ephemera japonica MacLachlan

Tipula

Swimmers

Baetis

Case-Bearers

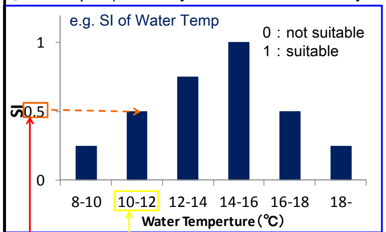
Psephenidae

➤Habitat Dates
We used Hamamoto's survey results
(45 survey points in Natori River Basin, 2006)

6. HSI(Habitat Suitability Index) Model

➡ Evaluate habitat suitability using environmental indicators

①Make up SI(Suitability Index from field survey ②Read environmental indicators



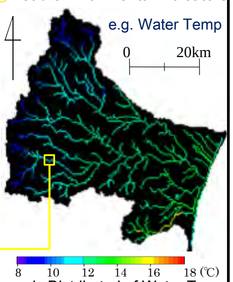


Figure is Distributed of Water Temp

③Decide of SI

$$(SI_1 \times SI_2 \times \cdots \times SI_p)^{1/p} = HSI$$

④HSI calculated using the geometric mean of SI values

p is the number of components.

6. HSI(Habitat Suitability Index) Model

- Environmental indicators

Land Cover Date
・ Land use

➕

Digital Cartographic Date
・ Slope
・ Urbanization ratio
・ Distance to urban areas
・ Distance to forests

➕

Hydrological Date

This Study Characteristic

The heatbudget model
・ Water temp

➕

The distributed runoff model
・ Flow velocity
・ Water depth

※Annual mean, annual maximum and annual minimum dates

6. HSI(Habitat Suitability Index) Model

- Calculate WUR(Weight Usable Ratio)

We developed a new index

WUR(Weight Usable Ratio)

Index for evaluate the overall habitat suitability throughout the catchment area

$$WUR = WUA / \text{catchment area} = \frac{1}{n}\sum_{i}^{n} HSI_i$$

➡

$$WUR = 0 \sim 1 \text{ points}$$

WUR = 0 : The catchment area has no habitat suitability

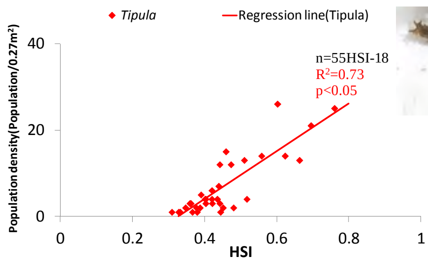
WUR = 1 : The catchment area has most habitat suitability

7. Results (Verification)

Verification of HSI

using Coefficient of determination (R^2) ＞0.5 and p value＜0.05

Example



Calculated coefficient of determination and p value using this graph

7. Results (Verification)

Coefficient of determination (R^2) > 0.5 and p value < 0.05

R^2=0.57

Hydropsyche orientalis

R^2=0.68

Hydropsyche albicephale

R^2=0.93

Limnocentropus insolitus

R^2=0.5

Ephemera japonica MacLachlan

R^2=0.73

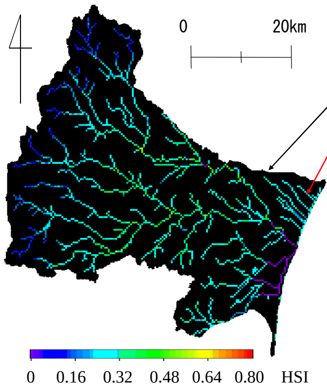
Tipula

R^2=0.56

Baetis

Six aquatic insects HSIs are properly made

7. Results



Make figures of spatial distribution of HSI

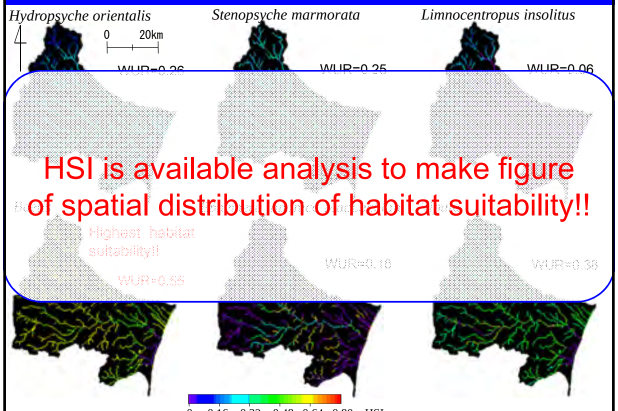
Black areas show not River Area

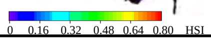
Color lines show River Line

HSI value is low
the spots have low habitat suitability

HSI value is high
the spots have high habitat suitability

7. Results





8. Conclusions

- We showed HSI amounts about nine aquatic insects in Natori River basin. Result of verification of HSI, we calculated that six aquatic insects HSI are properly made.
- We made figures of spatial distribution of HSI and evaluated habitat suitability using HSI and WUR about six aquatic insects. As a result, Baetis has the highest habitat suitability in Natori River basin.

Keynote 2: Ecohydrology: Process Oriented Thinking Towards Sustainable Enhancement, Water Resources, Biodiversity, Ecosystem Services and Resilience to Climate Change

Maciej ZALEWSKI (*European Regional Centre for Ecohydrology under auspices of UNESCO, Department of Applied Ecology , University of Łódż)*

The fundamental assumption of Ecohydrological theory is that water has been major driver of the biogeosphere evolution. That is why understanding water biota interplay for sustainable future of the planet. In the face of global challenges such as changes in geopolitical and economic centers, as well as demographic processes, combined with progressing degradation of the environment its resources and climate changes, there is an urgent need to formulate a new proactive strategy that harmonize the humanity needs with water resources and ecosystem potential. The one of the critical issues provided by the Ecohydrology to the integrated of the integrated water resources management IWRM is harmonisation of the human needs with the enhanced ecosystems carrying capacity understood as water, ecosystem services, biodiversity and resilience to climate instability and anthropogenic impacts. The ecosystems characteristics such as pattern of the distribution of the biomass in the catchment area, and its biodiversity, play important role in shaping the water cycle. On the other hand the surface/ground water interplay to great extent determine biological structure, productivity and related processes in terrestrial, freshwater and coastal zone ecosystems, with broad range of socioeconomic consequences.

Ecohydrology (EH) is defined as sub-discipline of hydrology that focuses on ecological processes occurring within the hydrological cycle and strives to utilize such processes for enhancing environmental sustainability, developed in the framework of the International Hydrological Programme of UNESCO is focused on regulation of water biota interplay from the top of the river basin up to the bottom of the reservoir and costal zones, toward slowing down transfer of water from sky to the sea, enhance groundwater resources and maintaining critical habitats for water, energy and nutrients circulation, which in turn maintain biodiversity. Also for reduction of the input and regulate allocation excess nutrients and pollutants toward reversing ecosystems degradation and improvement of human well being.

Follows the three criteria by ICSU, the science of the XXI century has to be (1) integrative, (2) problem solving and (3) policy oriented. Integrative because integrate ecology and hydrology with the special consideration of geomorphology. Problem solving because considering society priorities such as water quality, food production, flood protection, drought compensation, cultural aesthetic values and truism. Policy oriented because sustainable development and reversing biosphere degradation is the MDG GOAL.

What kind of “know how” ecohydrology proposes to achieve those three goals?

The general assumption is that water is determinant of carbon retention in terrestrial ecosystems, biomass and plant production and ecological succession in different climatic (temperature) (Zalewski 2002).On the other hand the diversified plant biomass efficiently reduce leakage of nutrients from terrestrial to aquatic ecosystems and to costal zones. Ecohydrology due to methodological specifics has been based on interconnected two phases- terrestrial and aquatic. The terrestrial has been focused on water plant soil/ground waters interactions and plant cover is first important filtering system and system enhancing the infiltration and stabilizing water circulation within the catchment. In the aquatic phase, the content of the nutrients in ground water which supplies freshwater and costal zone ecosystems to great extent determine its biological productivity and in consequence biodiversity.

As far as Ecohydrology is not only curiosity driven but also problem solving science three principles are provides framework for research and problem solving: Hydrological – focused on quantification hydrological cycle in the basin scale and identification of threats; Ecological – understanding water biota interplay; Ecological Engineering – the implementation of understanding water biota interplay "dual regulation" for enhancement caring capacity of WBSR towards harmonization catchment, ecological potential with society needs.

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Ecohydrology : process oriented thinking towards sustainable enhencemnt, water resources, biodiversity, ecosystem services and resilience to climate change

Prof. dr hab. Maciej Zalewski

Director of ERCE u/a UNESCO

Chairman of Department Applied Ecology , University of Łodź

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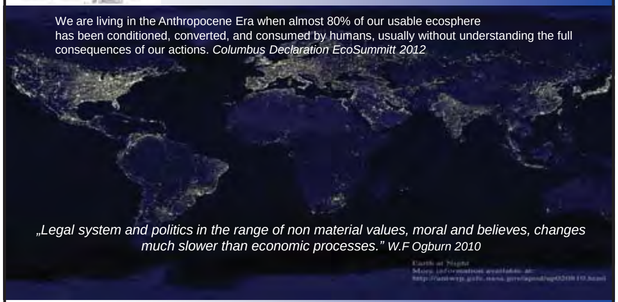

We are living in the Anthropocene Era when almost 80% of our usable ecosphere has been conditioned, converted, and consumed by humans, usually without understanding the full consequences of our actions. *Columbus Declaration EcoSummitt 2012*

„Legal system and politics in the range of non material values, moral and believes, changes much slower than economic processes." W.F Ogburn 2010

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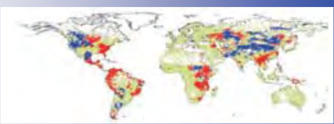
WATER is the key driver of biological evolution, food production and ecosystem services

The forecast of water resources limitation in 2025

Effect of climate change



Effect of demographic dynamics and economic development

Index of multiuse of water resources

(Vörösmarty i in. 2000)

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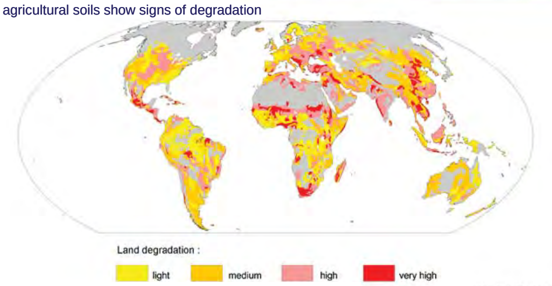
To solve sustainability of water, food and ecosystem services problems, the global processes perspective should be considered.

Degradation of soil resources:
All agricultural soils show signs of degradation



World map of severity of land degradation – GLASOD (FAO 2000)

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In the face of global processes such as:

- progressing degradation of the environment (water resources and soil quality),
- climate change,
- demographic processes, and
- geopolitical and socio-economic changes

the major challenge for science becomes the harmonization of human needs with ecosystem carrying capacity (CC)

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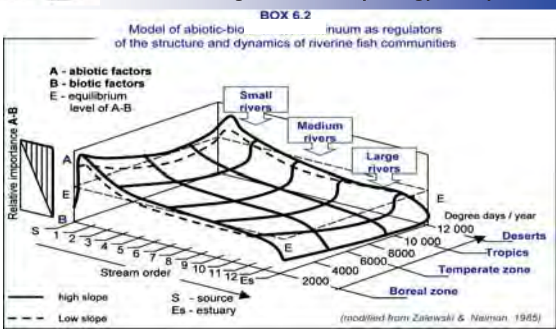
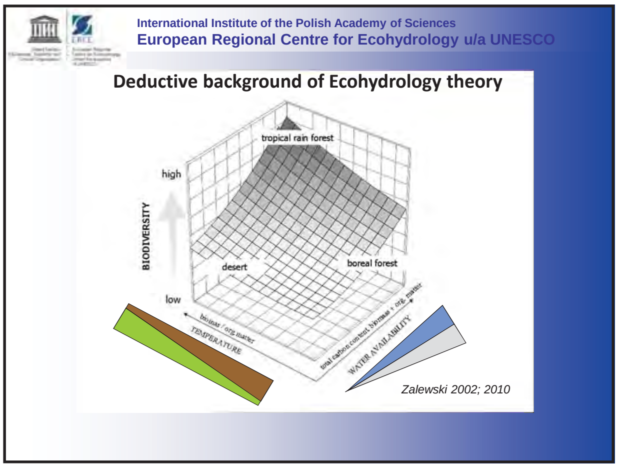
Deductive background of Ecohydrology theory

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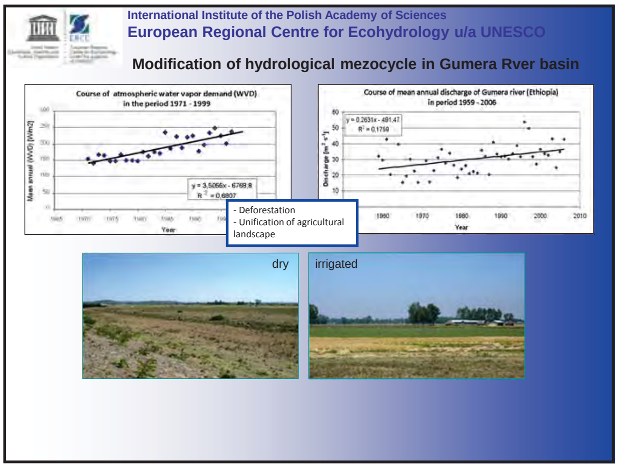
Deductive background of Ecohydrology theory
tropical rain forest
high
BIODIVERSITY
low
desert
boreal forest
TEMPERATURE
WATER AVAILABILITY
Zalewski 2002; 2010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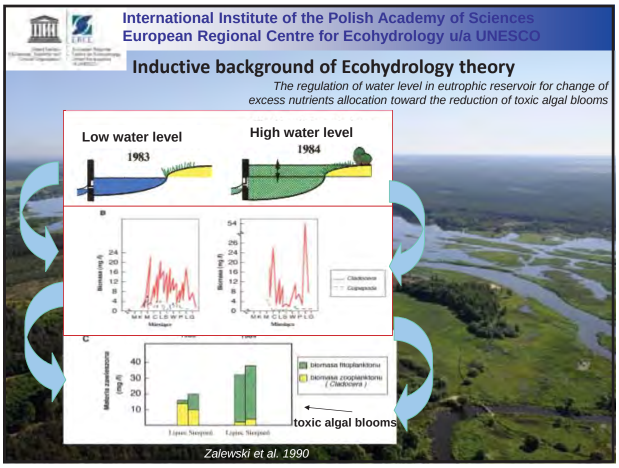
Modification of hydrological mezocycle in Gumera Rver basin
Course of atmospheric water vapor demand (WVD) in the period 1971 - 1999
Course of mean annual discharge of Gumera river (Ethiopia) in period 1959 - 2006
- Deforestation
- Unification of agricultural landscape
dry
irrigated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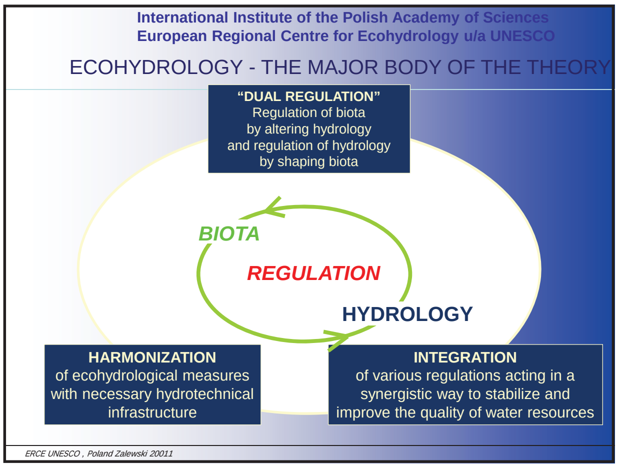
Inductive background of Ecohydrology theory
The regulation of water level in eutrophic reservoir for change of excess nutrients allocation toward the reduction of toxic algal blooms
Low water level
1983
High water level
1984
toxic algal blooms
Zalewski et al. 1990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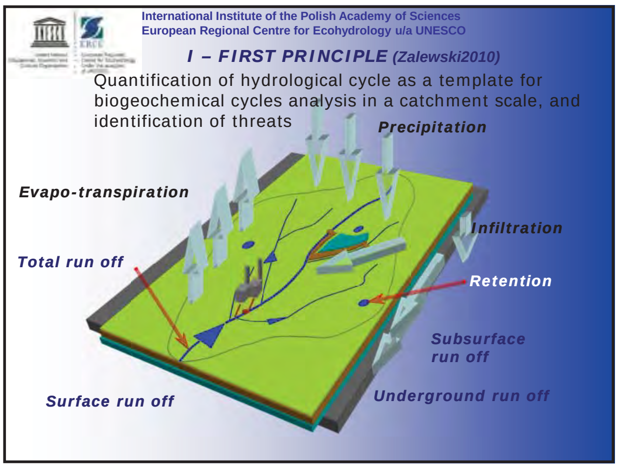
ECOHYDROLOGY - THE MAJOR BODY OF THE THEORY
"DUAL REGULATION"
Regulation of biota
by altering hydrology
and regulation of hydrology
by shaping biota
BIOTA
REGULATION
HYDROLOGY
HARMONIZATION
of ecohydrological measures
with necessary hydrotechnical
infrastructure
INTEGRATION
of various regulations acting in a
synergistic way to stabilize and
improve the quality of water resources
ERCE UNESCO , Poland Zalewski 20011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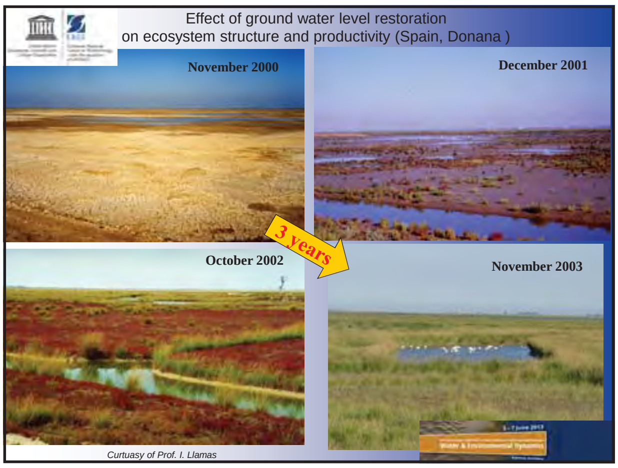
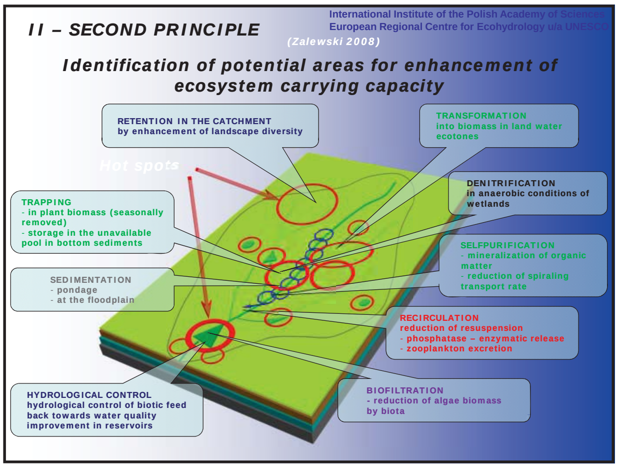
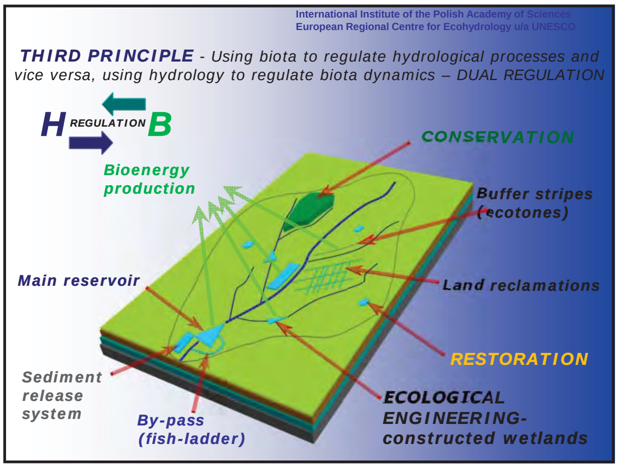
I – FIRST PRINCIPLE (Zalewski2010)
Quantification of hydrological cycle as a template for
biogeochemical cycles analysis in a catchment scale, and
identification of threats
Precipitation
Evapo-transpiration
Infiltration
Total run off
Retention
Subsurface
run off
Surface run off
Underground run off


Effect of ground water level restoration
on ecosystem structure and productivity (Spain, Donana)
November 2000
December 2001
3 years
October 2002
November 2003
Curtuasy of Prof. I. Llamas





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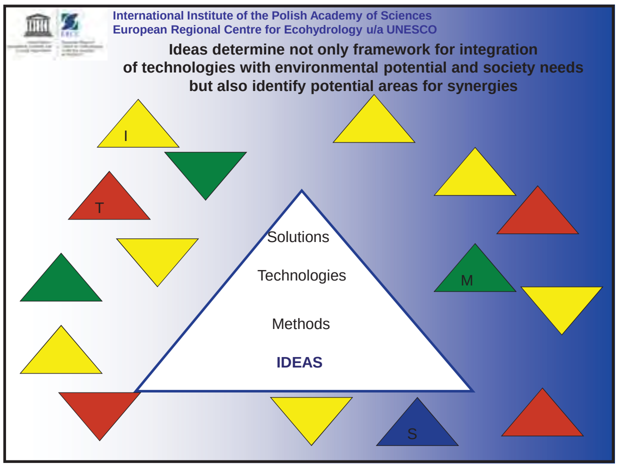
According to Romer (2006) the dynamics of economy and development in 50% depend on new technologies and 50% on ideas and systemic solutions

	Ecosystem structure		Process oriented thinking
CONSEQUENCES	**Progressing degradation of biosphere**	⇒	**Sustainable development**
Achievable goal	Overexploitation and overengineering	⇒	Harmonization of society needs with environmental potential
Approach	Mechanistic-deterministic	⇒	Evolutionary-systematic
Paradigm	Reductionistic-sectoral	⇒	Holistic-transdisciplinary

(Zalewski 2012)



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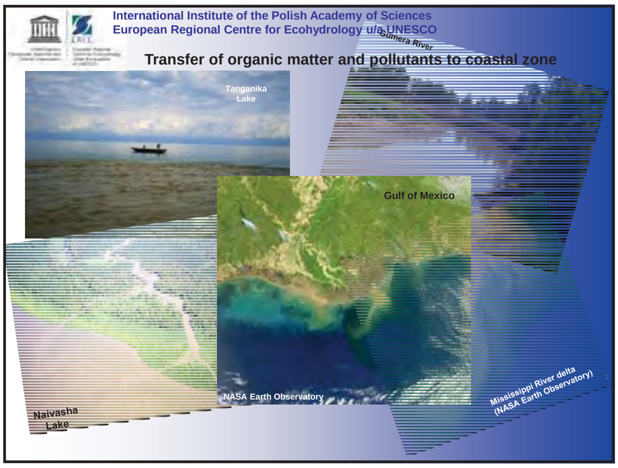
Transfer of organic matter and pollutants to coastal zone



Source pollution from agriculture landscape

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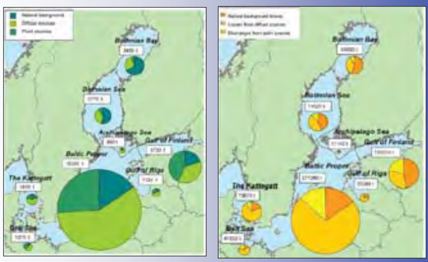
Proportion of sources contributing to phosphorus and nitrogen input into the Baltic Sea sub-regions



Phosphorus Nitrogen

(HELCOM 2004)

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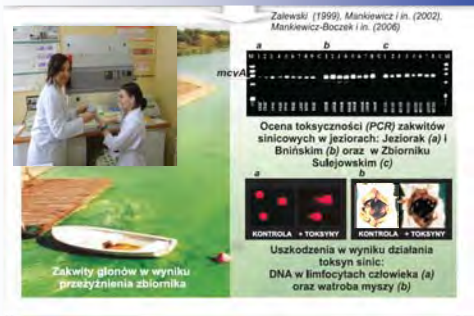
Molecular biology for Ecohydrology: methods for identification of threats and early warning



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European Regional Centre for Ecohydrology u/a UNESCO

Molecular biology for ecohydrological biotechnologies

Biodegradation of hepatotoxic cyanobacteria

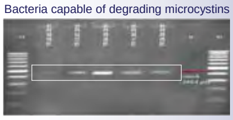
Cyanophage can degrade cyanobacterial cells

The BLAST homology search revealed 90% similar of the Polish samples to *g91* gene of cyanophage Ma-LMM01, described before by Yoshida et al. (2008).

(Mankiewicz-Boczek, Gągała, Dziadek in progress)

Bacteria can degrade microcystins

Bacteria capable of degrading microcystins in the Polish lowland reservoir



The BLAST homology search revealed 95% similar of the Polish samples to *mlrA* gene of *Sphingopyxis* sp. C1, described before by Okano et al. (2009).

(Mankiewicz-Boczek, Gągała, Dziadek in progress)

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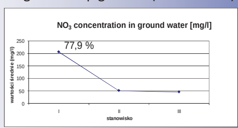
Ecohydrlogical biotechnologies - construction of high efficiency land water ecotones for reduction of diffuse pollution

Denitrification wall

Degradation of added organic material stimulates growth of denitrifying bacteria, and thus conversion of nitrate to nitrogen gas occurs.

Demosite: denitrification wall around the storage of manure located directly on the ground in pigs' farm (stock of 200).



(photo: ERCE)

(Bednarek, 2009)

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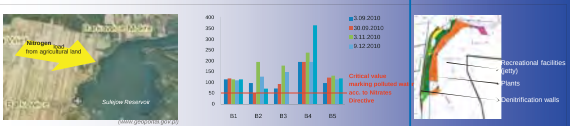
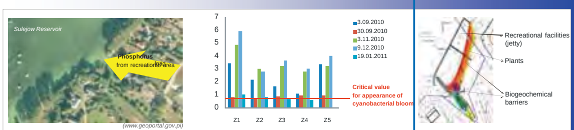
Ecohydrological biotechnologies for construction of high efficiency land-water ecotones for reduction of diffuse pollution LIFE+ EKOROB project

IDENTIFICATION OF PROBLEMS | DEVELOPMENT OF SOLUTIONS

Reduction of **nitrogen** pollution from diffuse source by enhancement of plant buffering zones with denitrification walls



Reduction of **phosphorus** pollution from diffuse source by enhancement of plant buffering zones with biogeochemical barriers



Izydorczyk, Frątczak, Zalewski, 2011

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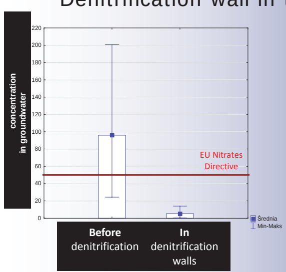
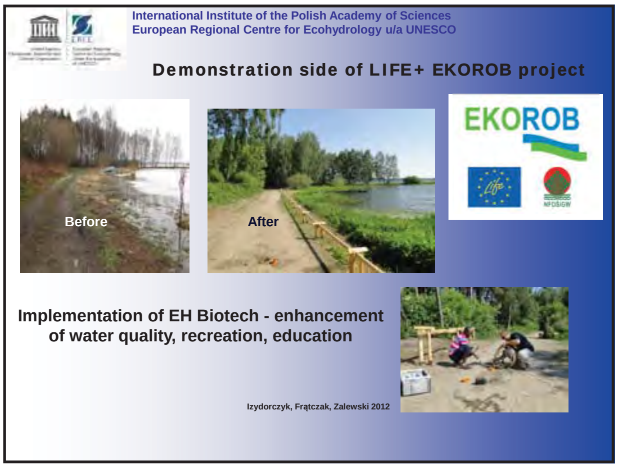
Denitrification wall in the ecotone buffer zone



(Izydorczyk,Bednarek, Zalewski 2012)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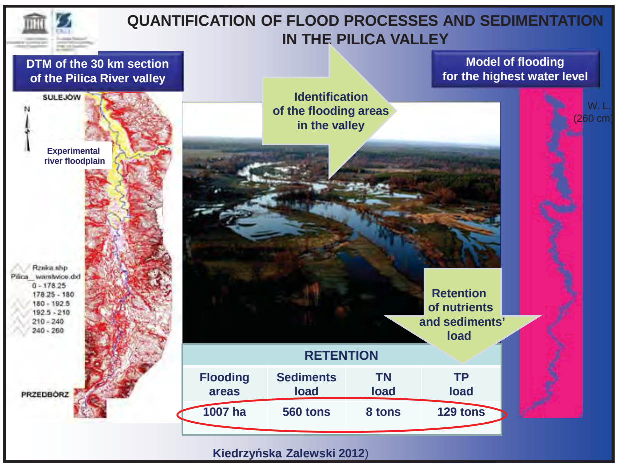
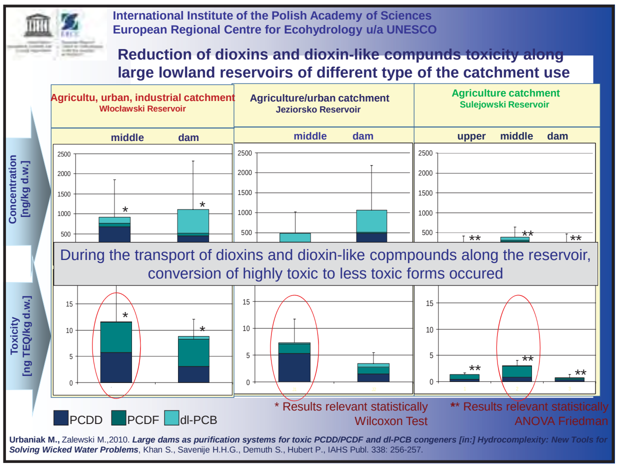
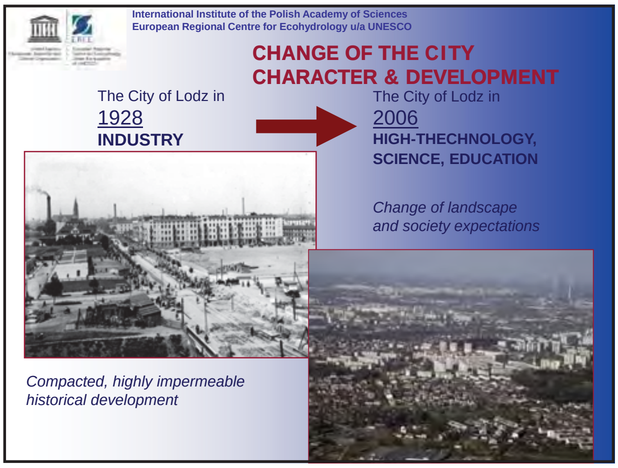
European Regional Centre for Ecohydrology u/a UNESCO
Demonstration side of LIFE+ EKOROB project
Before
After
EKOROB
Implementation of EH Biotech - enhancement of water quality, recreation, education
Izydorczyk, Frątczak, Zalewski 2012


QUANTIFICATION OF FLOOD PROCESSES AND SEDIMENTATION IN THE PILICA VALLEY
DTM of the 30 km section of the Pilica River valley
SULEJÓW
Experimental river floodplain
PRZEDBÓRZ
Identification of the flooding areas in the valley
Model of flooding for the highest water level
Retention of nutrients and sediments' load
RETENTION
Flooding areas | Sediments load | TN load | TP load
1007 ha | 560 tons | 8 tons | 129 tons
Kiedrzyńska Zalewski 2012)


International Institute of the Polish Academy of Sciences
European Regional Centre for Ecohydrology u/a UNESCO
Reduction of dioxins and dioxin-like compunds toxicity along large lowland reservoirs of different type of the catchment use
Agricultu, urban, industrial catchment
Włocławski Reservoir
Agriculture/urban catchment
Jeziorsko Reservoir
Agriculture catchment
Sulejowski Reservoir
middle
dam
upper
Concentration [ng/kg d.w.]
Toxicity [ng TEQ/kg d.w.]
During the transport of dioxins and dioxin-like copmpounds along the reservoir, conversion of highly toxic to less toxic forms occured
PCDD
PCDF
dl-PCB
* Results relevant statistically Wilcoxon Test
** Results relevant statistically ANOVA Friedman
Urbaniak M., Zalewski M., 2010. Large dams as purification systems for toxic PCDD/PCDF and dl-PCB congeners [in:] Hydrocomplexity: New Tools for Solving Wicked Water Problems, Khan S., Savenije H.H.G., Demuth S., Hubert P., IAHS Publ. 338: 256-257.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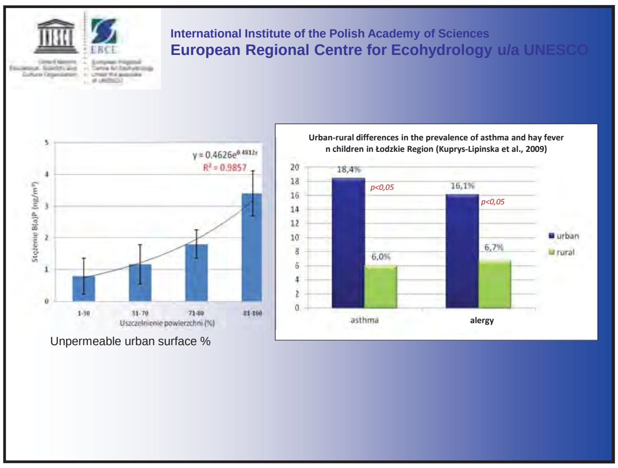
European Regional Centre for Ecohydrology u/a UNESCO
CHANGE OF THE CITY CHARACTER & DEVELOPMENT
The City of Lodz in 1928 INDUSTRY
The City of Lodz in 2006 HIGH-THECHNOLOGY, SCIENCE, EDUCATION
Change of landscape and society expectations
Compacted, highly impermeable historical development


International Institute of the Polish Academy of Sciences
European Regional Centre for Ecohydrology u/a UNESCO
R² = 0.9857
Uszczelnienie powierzchni (%)
Unpermeable urban surface %
Urban-rural differences in the prevalence of asthma and hay fever n children in Łodzkie Region (Kuprys-Lipinska et al., 2009)
18,4%
6,0%
16,1%
6,7%
p<0,05
asthma
alergy
urban
rural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European Regional Centre for Ecohydrology u/a UNESCO
Ecohydrological biotechnologies for purification of urban stormwater
Łódź, Sokołowka river
(Zalewski 2011)

System solutions: BIOTECHNOLOGIES
the sequential biofiltration system (SBS) for urban stormwater purification
on Sokołówka river

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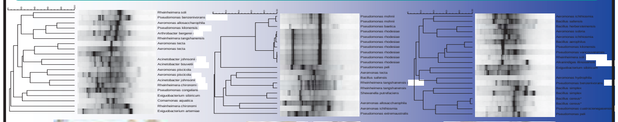
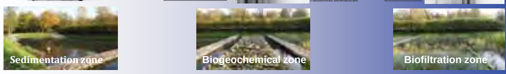
Molecular biology for ecohydrological biotechnologies

Diagnosis of quality of environment
Identification of patogenic bacterias
Increase of the effectiveness of stormwater purification

Bacterial diversity in different zones of the Sequentional Stormwater Purification System (SSPS) assessed by the TRS-PCR (1-3) and partial 16S RNA gene sequencing





Sequentional Stormwater Purification System

(Zalewski, Mankiewicz-Boczek, Parniewski et al., 2012)

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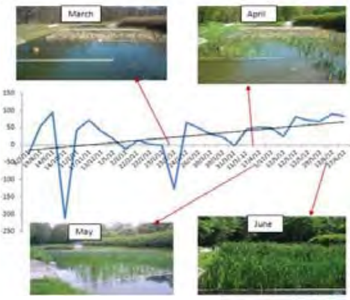
The progress in water purification efficiency



(Zalewski, Szklarek, Lont 2013)

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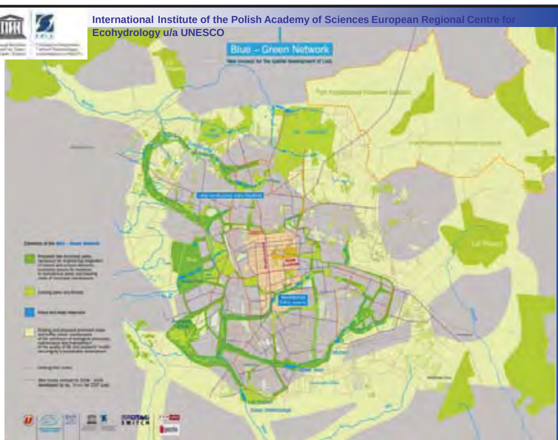
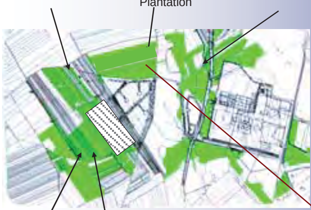


Conversion of sludge into bioenergy at willow plantations at the buffer zone of sewage treatment plant

Plantation



Comparative experiments on different species and varieties of willow

I: Salix viminalis clones;
II: Tordis (Salix schwerini x S. viminalis) x S. viminalis;
III: Salix viminalis gigantea;
IV: Salix viminalis (clone 192)

Drobniewska, Zalewski in press kb2

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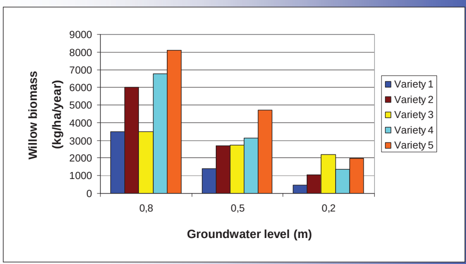
Groundwater level regulation as a key factor for bioenergy yield and economic efficiency



Min. **470**

Max. **8100**

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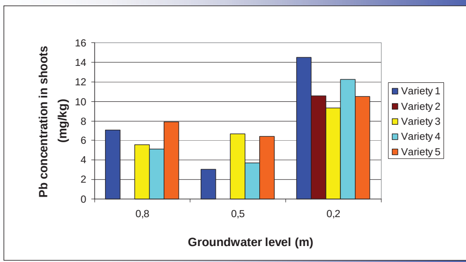
„EH Dual regulation" : The importance to use of hydrology groundwater level and the selection of the plant variety for optimisation of the process of heavy metals phytoextraction



Min. **3,1**

Max. **14,5**

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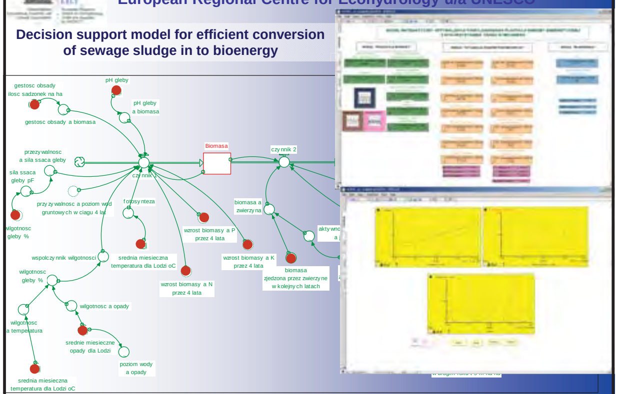
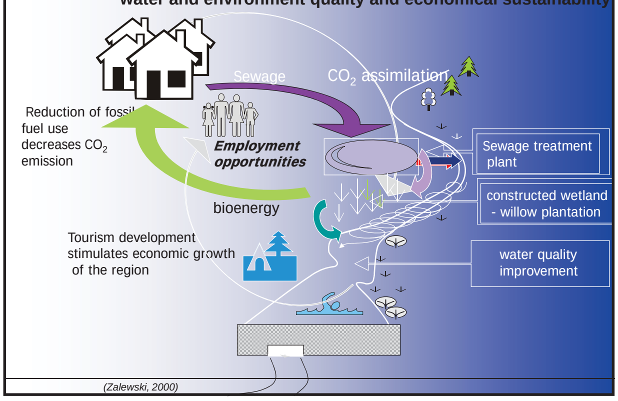
Decision support model for efficient conversion of sewage sludge in to bioenergy



(Drobniewska, Zalewski 2010)

International Institute of the Polish Academy of Sciences
European Regional Centre for Ecohydrology u/a UNESCO

System solutions for harmonisation of society needs with water and environment quality and economical sustainability



(Zalewski, 2000)

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To achieve the Millennium Development Goals and adapt to global changes understanding of the water/ biota interplay becomes crucial.
The ecohydrological regulation of water dynamics in catchment mezocycle has to be focused on:.

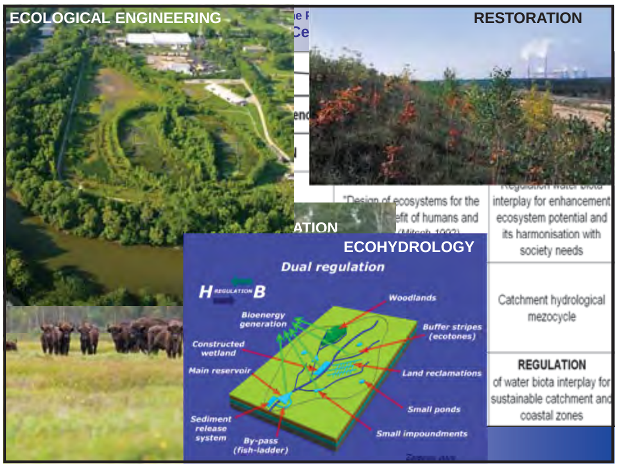
• slowing down water transfer from catchment to sea (enhencemnt of water retention in the landscape towards reduction of floods and droughts);

• improving water quality;

• maintaining and stabilizing the critical water, energy and nutrient fluxes, to support bioproductivity and biodiversity;

• restoration of the soil productivity potential;

• enhancing groundwater resources.



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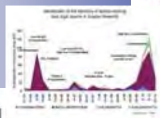
EDUCATION for sustainable future

System solutions – Transdisciplinary science
WISDOM
Use of information and knowledge for problem solving – Formulation of principles for action

Experimental testing -interdisciplinary science
KNOWLEDGE
Understanding patterns and processes,



Monitoring – sectoral science
INFORMATION
Understanding structure, states and relationships

Reductionistic — approach — Holistic

Problem identification → Problem solving

Zalewski 2012 changed

3 - 7 June 2013
Water & Environmental Dynamics

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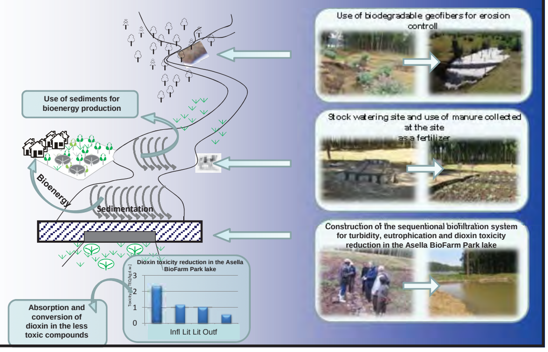
Use of ecohydrology based systemic solutions for reduction of sedimentation, eutophication and dioxin-induced toxicity in reservoir at the the Asella Bioeconomy Education Centre, Ethiopia

Polish Aid Progamme for Ethiopia (Zalewski, Urbaniak, Negussie 2013)



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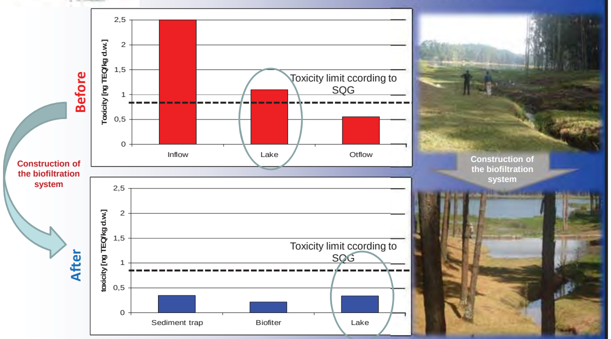
The EH demosite at Asella (Ethiopia) Concentration of the dioxins before and after construction of biofiltration system



Polish Aid Progamme for Ethiopia - Zalewski, Urbaniak, Negussie 2013

International Institute of the Polish Academy of Sciences
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The EH demosite at Asella (Ethiopia) – effect of the use sediments collected at biofiltration system for enhencemnt of food production.

Polish Aid Progamme for Ethiopia - (Zalewski, Urbaniak, Negussie 2013)

International Institute of the Polish Academy of Sciences
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The conditio sine qua non of harmonisation of human needs with biogeosphere carrying capacity for sustainable future is:

1. Reduction of energy and resource use per unit of GDP by implementation of the concept „Factor Four” von Weizsäcker

2. Enhancement of ecosystem carrying capacity (CC) - water resources, biodiversity, ecosystem services for society and resilience (WABIOSER)

The important steps should be :
-integration of understanding of the dynamics and regulatory mechanisms of the : socio-economic techno and ecological systems,

- development of the holistic, transdisciplinary environmental problem solving science , based on: integration of ecohydrology , biotechnology , engeenering .

- the translation of highly complex transdisciplinary knowledge to decision makers by decision support models,

- the use of foresight methodologies, to develop vision and scenarios for sustainability.

- education , communication and social dialogue.

Thank you

The inspiring cooperation of my colleagues from ERCE PAS u/a UNESCO, Department of Applied Ecology, UŁ and UNESCO Division of Water Sciences and IHP is highly appreciated and made the introduced projects happened

3 - 7 June 2013
Water & Environmental Dynamics

Lecture 1: Fundamentals of Basin-scale Hydrological Processes

Yasuto TACHIKAWA

Department of Civil and Earth Resources Engineering, Graduate School of Engineering, Kyoto University

1.1 The Science of Hydrology

Hydrology is the science which deals with the waters of the Earth, their occurrence, circulation and distribution on the planet, their physical and chemical properties and their interactions with the physical and biological environment, including their responses to human activity. Hydrology is a field, which covers the entire history of the cycle of water on the Earth (UNESCO International Hydrological Decade, 1964). Water is the source of all lives on the Earth and is a resource that is indispensable for our social and economic activities. The water cycle and its time and space distribution depend on the solar radiation, topography and various conditions of the Earth surface. Hydrology is a discipline that provides the understanding of the physical processes of the water movement and the foundations for proper use and protection of water resources.

Key word: hydrology, hydrologic cycle, waters budget, water resources

1.2 Water Resources under a Changing Climate

River discharge in Indochina Peninsula region and Japan was projected using a distributed flow routing model with kinematic wave flow approximation for three climate experiments: the present climate (1979-2008), the near future climate (2015 - 2044), and the future climate (2075-2104). The flow routing model 1K-FRM was fed with general circulation model (GCM) generated runoff data for three climate experiments. The GCM dataset used was the latest 20km spatial resolution general circulation model (MRI-AGCM3.1S and 3.2S), which was developed by Meteorological Research Institute, Japan Meteorology Agency. The changes of flow in Indochina Peninsula region and Japan under climate change were analyzed by comparing simulated river discharge for the present climate, the near future climate, and the future climate experiment. Analysis results show clearly changes of annual mean discharge, mean of annual maximum discharge and mean of annual minimum discharge with the degree of changes different according to location. The changes, which were detected in the near future climate conditions, become clearer in the future climate conditions. In some locations, the increase of flood and drought risk was found.

Key words: climate change, general circulation model, river discharge, 1K-FRM

Table of Contents

1. The Science of Hydrology

Hydrology is the science which deals with the waters of the Earth, their occurrence, circulation and distribution on the planet, their physical and chemical properties and their interactions with the physical and biological environment, including their responses to human activity. Hydrology is a field which covers the entire history of the cycle of water on the Earth (UNESCO International Hydrological Decade, 1964). Water is the source of all lives on the Earth and is a resource that is indispensable for our social and economic activities. The water cycle and its time and space distribution depend on the solar radiation, topography and various conditions of the Earth surface. Hydrology is a discipline that provides the understanding of the physical processes of the water movement and the foundations for proper use and protection of water resources.

Keywords : hydrology, hydrologic cycle, waters budget, water resources

1.1 The Science of Water Cycle: Hydrology

Water constantly circulates on the Earth due to solar energy and gravitational energy, and changes its phases (ice, liquid, and vapor). **Hydrology** is the science that clarifies the movement of water and the distribution of water in time and space on and beneath the surface of the Earth, involving transports of sediment, dissolved nutrients, and contaminants. Hydrology provides the basics for applied fields such as engineering and agricultural sciences, which aim for proper development, protection and management of water resources, mitigation of water-related disasters such as floods and droughts, and agricultural production by drainage and irrigation.

Fig. 1.1 illustrates the major components of the **water cycle**. **Precipitation** falls on the Earth surface. Part of the precipitation is intercepted by trees and vegetation, which does not reach the ground surface and is evaporated into the atmosphere. Precipitation which reaches on the land surface infiltrates into the soil layers and forms **subsurface flow** and **groundwater flow**. Rainfall which exceeds the **infiltration ca-**

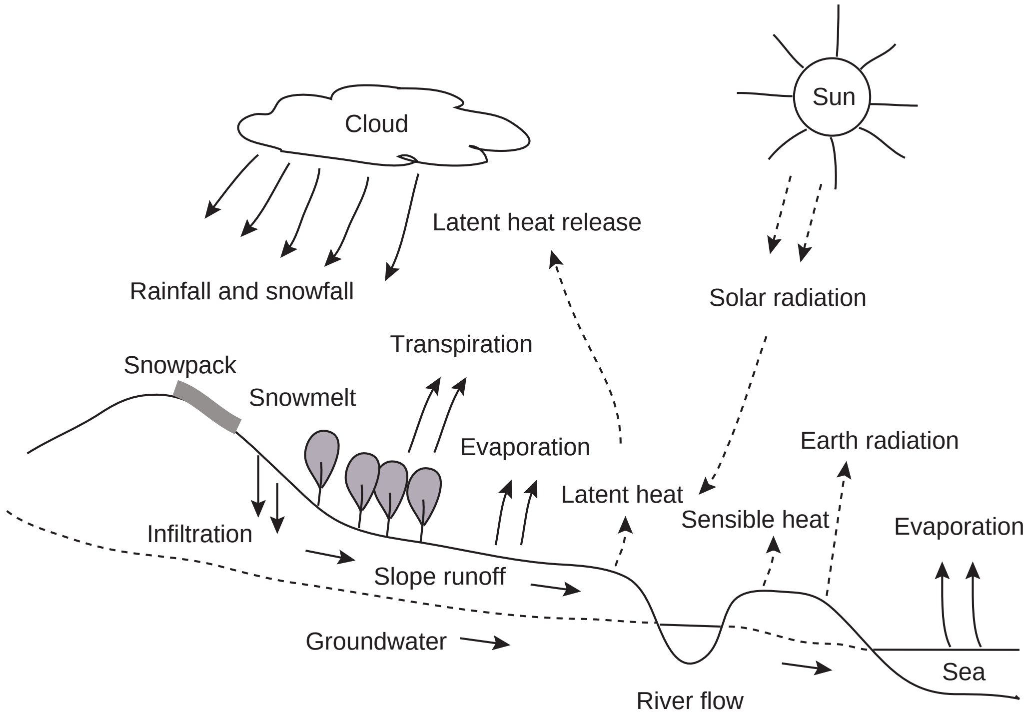


Fig. 1.1: Hydrologic processes and water and energy movement with change of water phase.

pacity forms **surface runoff**. Precipitation falling on the ground as snow is accumulated as snow cover, which melts and flows through similar routes to rainfall-runoff. The water in the surface layer evaporates and returns to the atmosphere. Trees and vegetation roots absorb the soil moisture from the roots and release the vapor through the stomata. This process is called **transpiration**. Cabining **evaporation** with **transpiration**, it is collectively called **evapotranspiration**.

The water cycle causes the **energy cycle**. When the soil moisture on the ground surface evaporates and changes the phase from water to vapor, the **latent heat** moves from the Earth surface to the atmosphere. When the vapor changes to raindrops, the latent heat is released to the atmosphere as **condensation heat**. In other words, the solar energy provided to the Earth surface is transferred to the atmosphere through evaporation and precipitation. The solar energy given to the Earth surface is different depending on time and location. Therefore, the water cycle and the energy cycle are closely related to the climate of the Earth and the spatiotemporal distribution of water.

To understand the water cycle and energy cycle, it is necessary to understand the physical mechanism of water and energy movements by solar radiation as well as the mechanism of water movement governed by the conservation of water mass (continuity equation) and the moment (momentum conservation). Water movement cause the movement of soils and chemical substances dissolved in water. These movements are closely associated with our lives and the environment. Therefore, the scope of hydrology includes the cycles of water, energy and physical, chemical, and biological processes associated with the cycles of water and energy.

1.2 Hydrologic Cycle and Water Resources

Hydrological science has both pure and applied aspects. The first aspect relates to questions about how the Earth works, and specifically about the role of water in natural processes. The second relates to using scientific knowledge to provide a sound basis for proper use and protection of water resources (Hornberger *et al.*, 1998). The second aspects is the main themes of water resources engineering. Research topics includes:

- flood and drought
- flood risk management
- water resources management
- climate change and water resources

【Example 1.1】Topics of hydrologic cycle and water resources

Describe any topics related to the hydrologic cycle and water resources in your countries. For example, flood, drought, water quality, water resources development, climate change and so on.

1.3 Water on the Earth

The radius of the Earth is 6,371km and the surface area is 5.1×10^8 km^2. 71% of the surface is ocean, and 29% is land. The total volume of water exiting on the Earth surface is estimated about 14.6×10^{20} kg (14.6×10^8 km^3). Approximately 97% of such water is seawater, and the remaining 3% is inland water, such as snow, ice, groundwater, lakes, and rivers. Vapor and cloud water in the atmosphere account for 0.001%.

【Example 1.2】The volume of water on the Earth

Using the numerical values provided above, calculate the average thickness of seawater, inland water, and atmospheric moisture supposing each of them is spread out evenly on the ocean, the land, and the surface of the Earth, respectively.

(Solution)

The average thickness of water in the ocean is given by dividing the volume of seawater by the area of the ocean:

$$\frac{14.6 \times 10^8 \text{ km}^3 \times 0.97}{5.1 \times 10^8 \text{ km}^2 \times 0.71} = 3,911 \text{ m}$$

The average thickness of water on the land is given by dividing the volume of inland water by the area of the land:

$$\frac{14.6 \times 10^8 \text{ km}^3 \times 0.03}{5.1 \times 10^8 \text{ km}^2 \times 0.29} = 296 \text{ m}$$

The average thickness of atmospheric water is given by dividing the volume of moisture in the atmosphere by the surface area of the Earth:

$$\frac{14.6 \times 10^8 \text{ km}^3 \times 0.00001}{5.1 \times 10^8 \text{ km}^2} = 28.6 \text{ mm}$$

1.4 The Water Budget and Water Resources

1.4.1 Water balance equation

To discuss the spatiotemporal distribution of water, suppose a closed compartment (referred to as a control volume) shown in **Fig. 1.2**. M_{in} is the rate of mass flowing into the control volume [M T^{-1}]; M_{out} is the one flowing out of the control volume [M T^{-1}]; and M is the mass stored in the control volume [M]. The equation of **conservation of mass** is given by

$$\Delta M = (M_{\text{in}} - M_{\text{out}})\Delta t \tag{1.1}$$

where ΔM is the change of the water mass in the control volume over time Δt. Using the **density** of water ρ, $M = \rho S$, $M_{\text{in}} = \rho I$, and $M_{\text{out}} = \rho O$, where S is the volume of the water stored in the control volume [L^3]; I is the volume inflow rate [L^{3}T^{-1}]; and O is

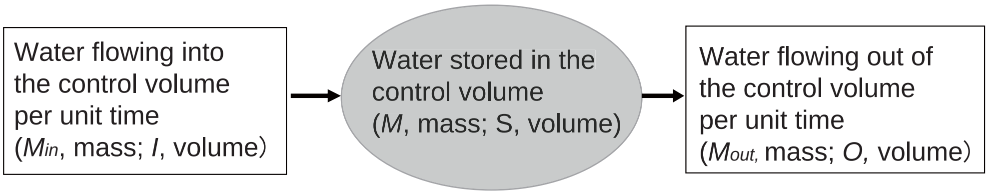


Fig. 1.2: Water budget and continuity relation.

the volume outflow rate [$\mathrm{L}^3\mathrm{T}^{-1}$]. Canceling the the density from both sides of Eq.(1.1)

$$\Delta S = (I - O)\Delta t \tag{1.2}$$

By dividing both sides by Δt and taking the limit of Δt, the equation of volume conservation (continuity equation) is given as:

$$\frac{dS}{dt} = I - O \tag{1.3}$$

Generally the density of water is regarded as constant and that the continuity equation is expressed with volume, not with mass. The continuity equation is often referred as a **water balance equation** or a **water budget equation**.

1.4.2 Global water budget

We can develop a global water budget equation using Eq.(1.3). For the land, S is the volume of water stored on and in the land, I is precipitation P [$\mathrm{L}^3\mathrm{T}^{-1}$], and O consists of evapotranspiration E [$\mathrm{L}^3\mathrm{T}^{-1}$] and runoff Q [$\mathrm{L}^3\mathrm{T}^{-1}$]. Integrating Eq.(1.3) over a time period τ, the continuity equation becomes

$$\int_\tau dS = \int_\tau I dt - \int_\tau O dt = \int_\tau P dt - \int_\tau (E + Q) dt \tag{1.4}$$

The integration of dS/dt over a year could be negligibly small. In the case, the continuity equation becomes

$$\int_\tau P dt = \int_\tau (E + Q) dt \tag{1.5}$$

and evapotranspiration is estimated from observed precipitation and discharge.

【Example 1.3】Annual precipitation

The motion of water is described in terms of reservoirs that store water and the movements between them. **Fig. 1.3** indicates the volume of water stored in the atmosphere, oceans and lands on the Earth and its annual movement volume. Using the values shown in **Fig. 1.3**, calculate the annual precipitation per unit area on the ocean, the land, and the surface of the Earth.

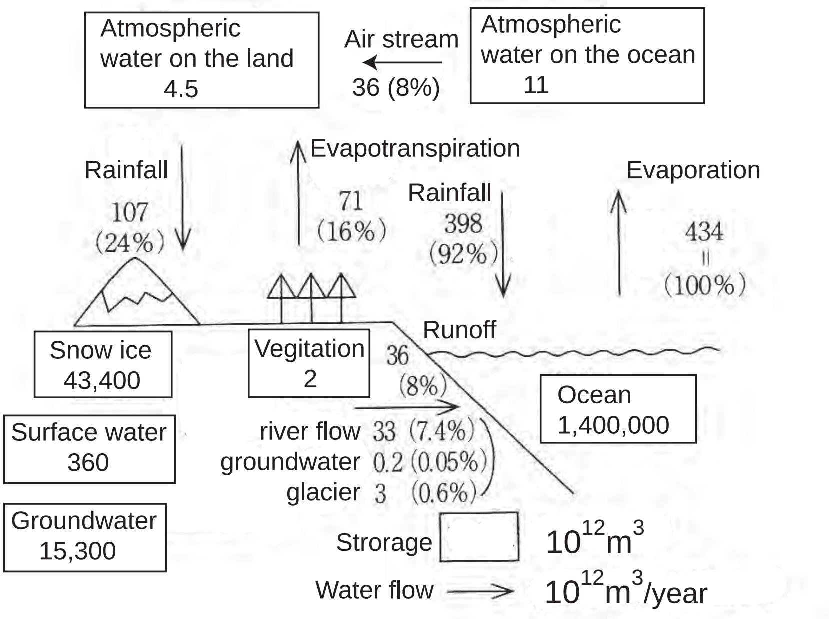


Fig. 1.3: The water stored on the Earth and the annual movement. The percentage represents the ratio when the annual evaporation from the ocean is 100%. (Takeda, T. *et al.*, Meteorology in water environment, University of Tokyo Press, 1992)

(Solution)

The annual precipitation per unit area on the ocean is given by dividing the total volume of the annual precipitation on the ocean by the sea surface area:

$$\frac{398 \times 10^{12}\ \mathrm{m^3 yr^{-1}}}{5.1 \times 10^8 \times 0.71\ \mathrm{km^2}} = 1,099\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual precipitation per unit area on the land is given by dividing the total volume of the annual precipitation on the land by the land surface area:

$$\frac{107 \times 10^{12}\ \mathrm{m^3 yr^{-1}}}{5.1 \times 10^8 \times 0.29\ \mathrm{km^2}} = 723\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual precipitation per unit area on the Earth surface is given by dividing the total volume of the annual precipitation on the Earth surface by its area:

$$\frac{(398 + 107) \times 10^{12}\ \mathrm{m^3 yr^{-1}}}{5.1 \times 10^8\ \mathrm{km^2}} = 990\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual precipitation amount in Japan is approximately 1,700 mm·yr^{-1} on average, which is substantially greater than the average annual precipitation on the land. **Fig. 1.3** indicates that approximately 66%(=71/107) of precipitation on the land originates from evapotranspiration from the land. Most of precipitation in Japan is brought in the rainy season and typhoons and the rainwater originates from the evaporation on the ocean.

【Example 1.4】 Annual evapotranspiration

Using the values shown in **Fig. 1.3**, calculate the annual evapotranspiration per unit area on the ocean, the land, and the surface of the Earth.

(Solution)

The annual evaporation per unit area from the ocean is given by dividing the annual total volume of evaporation from the ocean by the sea surface area:

$$\frac{434 \times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1 \times 10^8 \times 0.71\ \mathrm{km^2}} = 1,199\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual evapotranspiration per unit area from the land is given by dividing the annual total volume of evapotranspiration from the land by the land surface area:

$$\frac{71 \times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1 \times 10^8 \times 0.29\ \mathrm{km^2}} = 480\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual evapotranspiration per unit area from the Earth surface is given by dividing the total volume of the annual evapotranspiration from the Earth surface by its area:

$$\frac{(434 + 71) \times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1 \times 10^8\ \mathrm{km^2}} = 990\ \mathrm{mm{\cdot}yr^{-1}}$$

【Example 1.5】 Annual runoff and runoff ratio

Calculate the annual runoff per unit area and runoff ratio on the land using the values in **Fig. 1.3**.

(Solution)

The annual runoff per unit area from the land is given by dividing the total volume of the annual runoff by the land surface area:

$$\frac{36 \times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1 \times 10^8 \times 0.29\ \mathrm{km^2}} \times 10^3 = 243\ \mathrm{mm{\cdot}yr^{-1}}$$

or annual precipitation minus annual evapotranspiration ($723 - 480 = 243\ \mathrm{mm{\cdot}yr^{-1}}$).

The runoff ratio is given by dividing the annual runoff by the annual precipitation:

$$\frac{243\ \mathrm{mm{\cdot}yr^{-1}}}{723\ \mathrm{mm{\cdot}yr^{-1}}} = 0.34$$

1.4.3 Catchment water budget and water resources

A **catchment**, as shown in **Fig. 1.4**, is an area in which rain water drains into a **channel network** (river network) and finally flows into the river mouth. A catchment is separated by a topographically defined watershed boundary. Consider A is the area of a catchment basin [L^2]; r is the precipitation rate [LT^{-1}] (volume of precipitation falling on the catchment basin per unit time per unit area); e is the evapotranspiration rate [LT^{-1}] (the volume of water evaporating per unit time per unit area); and Q is the runoff rate flowing out of the catchment [L^{3}T^{-1}]. The inflow rate into the catchment I in Eq.(1.3) is

$$I = Ar$$

and the outflow rate is

$$O = Ae + Q$$

Substituting these into Eq.(1.3), the continuity equation in the catchment is defined as

$$\frac{dS}{dt} = A(r - e) - Q \tag{1.6}$$

Integrating Eq.(1.6) from time t_s to t_e, the continuity equation becomes

$$\int_{t_s}^{t_e} dS = S(t_e) - S(t_s) = A\left(\int_{t_s}^{t_e} r dt - \int_{t_s}^{t_e} e dt\right) - \int_{t_s}^{t_e} Q dt$$

If we take the start time t_s and the end time t_e as $S(t_s) = S(t_e)$, the continuity equation becomes

$$A\left(\int_{t_s}^{t_e} r dt - \int_{t_s}^{t_e} e dt\right) - \int_{t_s}^{t_e} Q dt \tag{1.7}$$

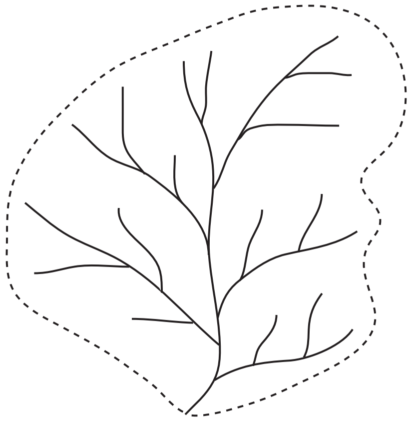


Fig. 1.4: Watershed divide and catchment basin.

For the time period, the total volume of water flowing into the catchment basin is equal to that flowing out of the basin. If we take t_s in the dry season and t_e after one year, the time-integrated value of dS/dt is negligible, and the evapotranspiration value for the time period can be estimated using the observed precipitation and discharge data.

【Example 1.6】Hydrologic characteristics in Asian regions

Table 1.1 shows the annual precipitation, evapotranspiration, and runoff at the Chao Phraya River basin (CPRB) in Thailand (157,925 km^2) and the Katsura River basin in Kyoto, Japan (887 km^2). Calculate the values in (1) and (2) in **Table 1.1** and discuss the difference of the catchment hydrologic variables from the view point of water resources.

Table 1.1: Annual catchment hydrologic variables.

Region	Precipitation	Evapotranspiration	Runoff
CPRB (Thailand)	1,144	962	(1)
Bandung (Indonesia)			
Hanoi (Vietnam)			
Kyoto (Japan)	1,796	708	(2)
World (mean)	723	480	243

*unit is mm/year.

(Solution)

(1) 1,144-962=182 mm/yr. (2) 1,796-708=1,088 mm/yr.

【Example 1.7】 Annual surface water resources in Thailand and Japan

Table 1.2 shows the estimated mean annual runoff in Thailand, Japan and the world. Calculate the per capita maximum water resources for one year for each area and discuss the difference of the water resources.

Table 1.2: Annual water resources in Thailand and Japan.

Region	Runoff (mm/yr)	Area (km^2)	Population (person)
Thailand	182	513×10^3	69.5×10^6
Japan	1,088	378×10^3	126.5×10^6
World	243	147.9×10^6	6,968×10^6

(Solution)

The maximum water resources per capita in Thailand is obtained by dividing the total annual runoff volume by the population, which is

$$\frac{182\text{mm/yr} \times 513 \times 10^3\text{km}^2}{69.5 \times 10^6\text{person}} = \frac{93,366 \times 10^6\text{m}^3/\text{yr}}{69.5 \times 10^6\text{person}} = 1,343\text{m}^3/\text{person/yr}$$

The maximum water resources per capita in Japan and the world are

$$\frac{1,088\text{mm/yr} \times 378 \times 10^3\text{km}^2}{126.5 \times 10^6\text{person}} = \frac{411,264 \times 10^6\text{m}^3/\text{yr}}{126.5 \times 10^6\text{person}} = 3,251\text{m}^3/\text{person/yr}$$

$$\frac{243\text{mm/yr} \times 147.9 \times 10^6\text{km}^2}{6,968 \times 10^6\text{person}} = \frac{35,940 \times 10^9\text{m}^3/\text{yr}}{6,968 \times 10^6\text{person}} = 5,158\text{m}^3/\text{person/yr}$$

【Example 1.8】 Surface water rewources under a changing climate in Thailand and Japan

Global warming could induce the change of the hydrologic cycle. If evapotranspiration increases in 5%, estimate the decrease percentage of river discharge, namely the maximum surface water resources for the Chao Phraya River basin and Japan using the values in **Table 1.1**.

(Solution)

In the Chao Phraya River basin, annual runoff is $1,144 - 962 \times 1.05 = 134$ mm/yr. The decrease ratio is

$$\frac{182 - 134}{182} \times 100 = 26\%$$

In Japan, annual runoff is $1,796 - 708 \times 1.05 = 1053$ mm/yr. The decrease ratio is

$$\frac{1088 - 1053}{1088} \times 100 = 3.3\%$$

Increase of evapotranspiration has high influence on surface water in Thailand.

【Example 1.9】Annual water resources in Thailand and Japan

Assuming the river flow is the value obtained in the above example and the population in Thailand increase in 5%, estimate the decrease percentage of water resources per capita. Discuss using the values in **Table 1.2**.

(Answer)

The maximum water resources per capita in Thailand is

$$\frac{134\text{mm/yr} \times 513 \times 10^3\text{km}^2}{69.5 \times 10^6 \times 1.05 \text{ person}} = \frac{68,742 \times 10^6\text{m}^3/\text{yr}}{73.0 \times 10^6\text{person}} = 942\text{m}^3/\text{person/yr}$$

The decrease ratio is

$$\frac{1,343 - 942}{1,343} \times 100 = 30\%$$

1.5 Mean Residence Time

The mean residence time refers to the times that are required for the water in the drainage basin to be completely replaced with new water flowing into the drainage basin. The mean residence time provides a time scale of the movement of water and substances that travel with water in the basin. Assuming the **steady state** condition ($dS/dt = 0$), the mean residence time is easily calculated by dividing the volume of water stored in a control volume by the volume of water that flows into the region per unit time, or by the volume of water that flows out of the region per unit time.

【Example 1.10】Mean residence time in global water budget

Calculate the mean residence time of water that exists on the land and in the atmosphere, using the values provided in **Fig. 1.3**.

(Solution)

The annual mean precipitation on the lands (sum of annual evapotranspiration and runoff from the land) is 107×10^{12} m^{3}yr^{-1}. The total volume of water stored on and beneath the land is $(43,400 + 360 + 15,300 + 2) \times 10^{12}$m^3. Therefore, the mean residence time of water on the land is:

$$\frac{(43,400 + 15,300 + 360 + 2) \times 10^{12}\ \mathrm{m}^3}{107 \times 10^{12}\ \mathrm{m}^3\mathrm{yr}^{-1}} = 552\ \mathrm{year}$$

The annual precipitation on the lands and oceans is $(107+398) \times 10^{12}$m^{3}yr^{-1}. The total volume of water stored in the atmosphere is $(4.5+11) \times 10^{12}$m^3. Therefore, the mean residence time of water in the atmosphere is:

$$\frac{(4.5 + 11) \times 10^{12}\ \mathrm{m}^3}{(107 + 398) \times 10^{12}\ \mathrm{m}^3\mathrm{yr}^{-1}} = 11.2\ \mathrm{day}$$

The mean residence time of water in the atmosphere is very short, indicating that water is frequently exchanged with heat energy.

The volume of water in snow ice and groundwater accounts for more than 99% of the water on and beneath the land, and runoff from snow ice and groundwater accounts for less than 10%. Assuming only surface water and water in vegetation move, the mean residence time of the water on the land is

$$\frac{(360 + 2) \times 10^{12}\ \mathrm{m}^3}{107 \times 10^{12}\ \mathrm{m}^3{\cdot}\mathrm{yr}^{-1}} = 3.4\ \mathrm{year}$$

Most of surface water is stored in lakes and soil layers. Movement such water is slower than that of water in rivers. Therefore, the mean residence time of water in rivers is estimated as several ten days.

【Example 1.11】Mean residence time in dam reservoirs

Table 1.3 shows the characteristics of the largest dams in Thailand and Japan. How many years it take to completely replace the water in the full storage capacity at the Bhumibol Dam, the Tokuyama Dam, and the Hiyoshi Dam? Use the annual hydrologic variables in **Table 1.1**.

Table 1.3: Characteristics of the dams in Thailand and Japan.

Dam	Storage capacity($\times 10^6$m^3)	Catchment area (km^2)
Bhumibol Dam	13,420	26,400
Tokuyama Dam	660	254.5
Hiyoshi Dam	66	290

(Solution)

The annual inflow to the Bhumibol Dam is 182 mm/yr $\times$ 26,400 km^2. The mean residence time of the dam reservoir is given by dividing the storage capacity by the annual inflow:

$$\frac{13,420 \times 10^6 \text{ m}^3}{26,400 \text{ km}^2 \times 182 \text{ mm/yr}} = 2.8 \text{ year}$$

Similarly for the Tokuyama Dam

$$\frac{660 \times 10^6 \text{ m}^3}{254.5 \text{ km}^2 \times 1088 \text{ mm/yr}} = 2.4 \text{ year}$$

and for the Hiyoshi Dam

$$\frac{66 \times 10^6 \text{ m}^3}{290 \text{ km}^2 \times 1088 \text{ mm/yr}} = 0.21 \text{ year}$$

References

[1] Hornberger, G. M., Raffensperger, J. P, Wiberg, P. L., and Eshleman, K. N: Elements of Physical Hydrology, The Johns Hopkins University Press, pp. 1–15, 1998.

[2] Maidment, D. R.: Hydrology, in Hydrology Handbook of Hydrology, edited by D. R. Maidment, McGraw-Hill, Chapter 1, pp. 1.1–1.15, 1993.

2. Water Resources under a Changing Climate

2.1 Climate Change Scenario and GCMs

General circulation models (GCMs) provide future atmospheric and hydrologic variables under various climate change scenarios. One of the latest GCMs is MRIAGCM3.1S, which is with about 20 km spatial resolution developed by the Meteorological Research Institute in Japan. The products of MRI-AGCM3.1S consist of various atmospheric and hydrologic variables for the present climate experiment (1979-2003), the near future climate experiment (2015-2039), and the future climate experiment (2075-2099), which were simulated under the SRES A1B scenario.

2.2 Water Resources Simulation in Thailand[1]

Fig. 2.1 shows the change ratio of the mean of the annual maximum hourly discharge for the near future climate experiment (a) and the future climate experiment (b), with respect to the present climate experiment. Generally, the mean annual maximum hourly discharge of the main stream of the Chao Phraya River did not change significantly in both near future and in future experiments; however, that of the tributaries changed from location to location. Notably, the mean of the annual maximum hourly discharge of some tributaries in the north-central and the southwestern part of the basin showed an increasing trend in near future experiments, and this trend was clearly visible in the future climate experiments.

To estimate dry basins, the mean annual potential evapotranspiration was calculated using the Hargreaves temperature based equation. **Fig. 2.2** shows the changes in the mean annual precipitation and the mean annual potential evapotranspiration estimated by the Hargreaves method. As shown in **Fig. 2.2**, we clearly observe that the mean annual

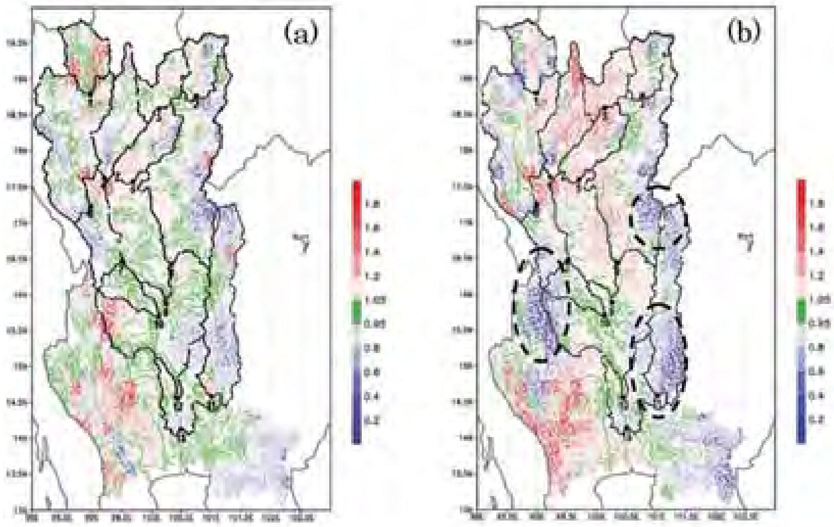


Fig. 2.1: The change ratio of the mean of the annual maximum hourly discharge for the near future climate experiment to the present climate experiment (a), and the future climate experiment to the present climate experiment (b).

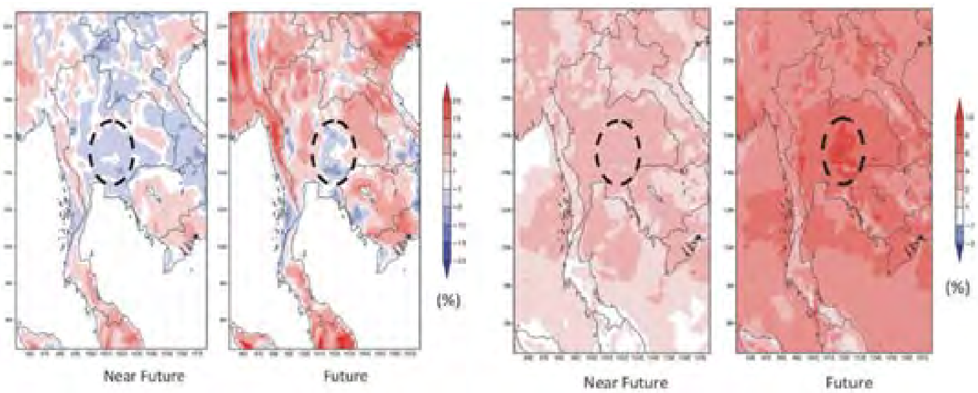


Fig. 2.2: Percentage difference of the mean annual precipitation (left) and potential evapotranspiration (right) in the near future and the future climate experiment with respect to the present climate experiment. The area designated by the circle corresponds to the Pasak River basin area.

precipitation tends to decrease significantly, while the potential evapotranspiration tends to increase in the circled areas of the figure. The rate of increase of the potential evapotranspiration may not be the same as the rate of increase of actual evapotranspiration in dry basins, as the soil moisture controls the latter.

Fig. 2.3 shows the change ratio of the mean rainy season (May to October) discharge in the near future climate experiment (a) and the change ratio in the future climate experiment (b) with respect to the present climate experiment. The mean rainy season

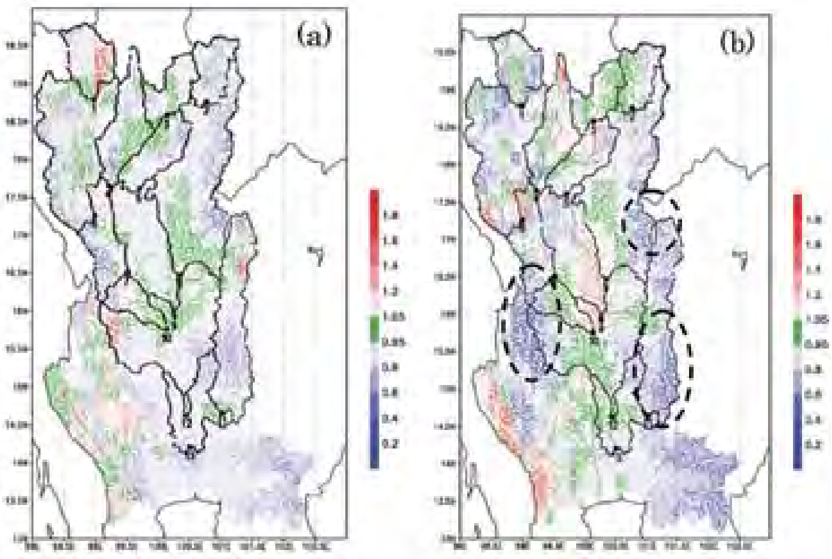


Fig. 2.3: The change ratio of the mean rainy season (May to October) discharge for the near future climate to the present climate experiment (a), the future climate to the present climate experiment (b).

river discharge of many tributaries and the main streams showed a decreasing trend in the near future climate. In the future climate experiment, the mean rainy season discharge of the main streams showed less change compared with the present climate. However, a decrease trend of the mean rainy season flow in small tributaries became clearer in the future climate experiment.

【Example 2.1】 Discharge change under a changing climate at the Chao Phraya River basin

Global warming will cause air temperature rise, which could induce the change of the hydrologic cycle. If evapotranspiration increases in 5%, estimate the decrease percentage of river discharge, namely the maximum surface water resources. Discuss using the values in **Table 1.1**.

(Solution)

Annual runoff is $1,144 - 962 \times 1.05 = 134$ mm/yr. The decrease ratio is

$$\frac{182 - 134}{182} \times 100 = 26\%$$

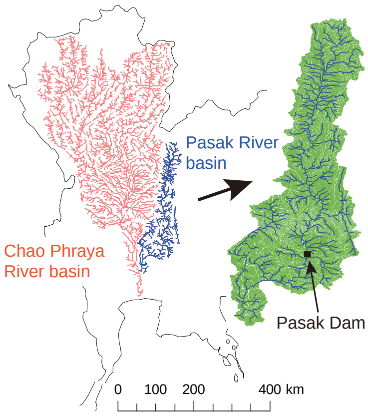


Fig. 2.4: Pasak River basin.

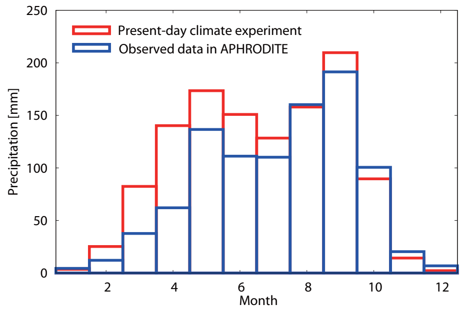


Fig. 2.5: Comparison of observed monthly precipitation (APHRODITE) and GCM precipitation.

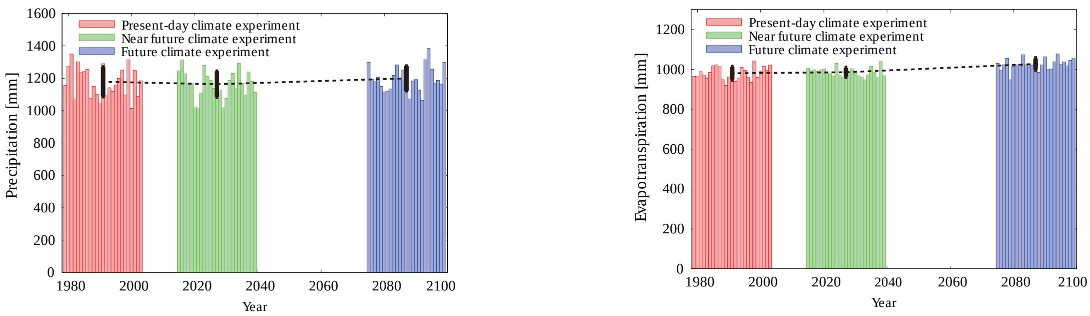


Fig. 2.6: Precipitation(left) and evapotranspiration (right) projected by MRI-GCM3.1S.

2.3 Water Resources Simulation at the Pasak Dam[2]

A change of water resources in the late 21st century at the Pasak River basin in Thailand (**Fig. 2.4**) is analyzed using a distributed rainfall-runoff model and a rainfall and evapotranspiration output projected by MRI-GCM3.1S. **Fig. 2.5** shows observed mean monthly precipitation (APHRODITE) and GCM precipitation. The GCM output overestimates in the beginning of the rainy season, however for other months both match well. **Fig. 2.6** shows the change of the GCM precipitation and evaportanspiration. The annual mean precipitation for the precent and future climate experiment are 1178mm and 1199mm, which shows 1.8% increase. The annual mean evapotranspiration for the precent and future climate experiment are 981mm and 1027mm, which shows 4.7% increase.

Fig. 2.7(left) shows a projected mean annual inflow to the Pasak Dam reservoir for the near future and the late 21st century experiments, which decrease by 3.8% and 3.5% compared with the present climate experiment. A projected mean monthly inflow using the output of the late 21st century experiment decreases except from July to September. **Fig. 2.7**(right) shows a change of water storage in the Pasak Dam assuming the dam

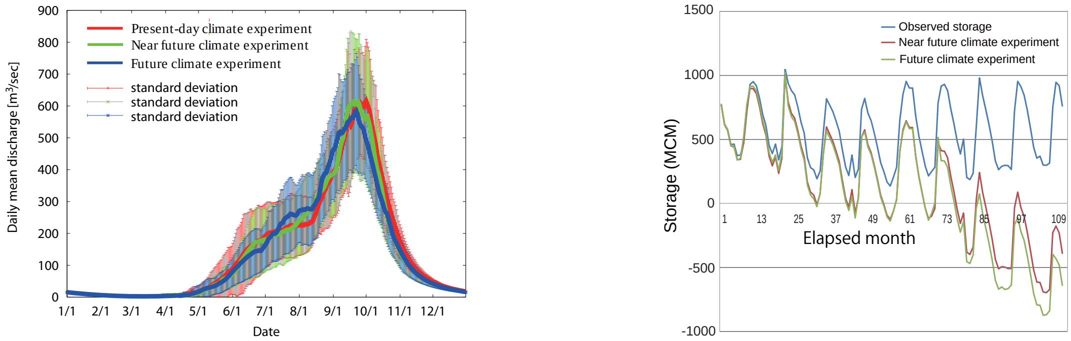


Fig. 2.7: Projected inflow to the Pasak dam and reservoir storage.

ourflow (water demand) does not chage. The result shows to maintain a present dam outflow is difficult in the future under a scenario of the same water demand.

2.4 Water Resources Simulation in Japan[3]

River discharges in the Japanese archipelago of a total of 75 years of the present day climate experiment, the near future climate experiment, and the end of the 21st century climate experiment were calculated with a 1-km spatial resolution, using information on future climate estimations by a 20-km-mesh global atmospheric model (MRI-GCM3.1S). Then, the annual maximum discharge with a return period of 100 years and the drought discharge with a return period of 10 years were calculated based on the river discharge data of each experiment period. **Fig. 2.8** spatially indicates the change ratio of the 100-year annual maximum discharge and the 10-year drought discharge of the end of the 21st century climate experiment to the present day climate experiment.

The results of an analysis show an increasing tendency in the 100-year annual maximum discharge in Hokkaido, the northern part of the Tohoku area, the Chugoku and Shikoku areas, and the northern part of the Kyushu area in the end of the 21st century climate experiment. However, the annual maximum discharge tends to decrease in areas where freshets are caused by accumulated snow or melting of snow such as the southern part of the Tohoku area and the Hokushinetsu area, due to a decrease in the snow accumulation or snowmelt. This tendency appears in the near future climate experiment and becomes more evident in the end of the 21st century climate experiment.

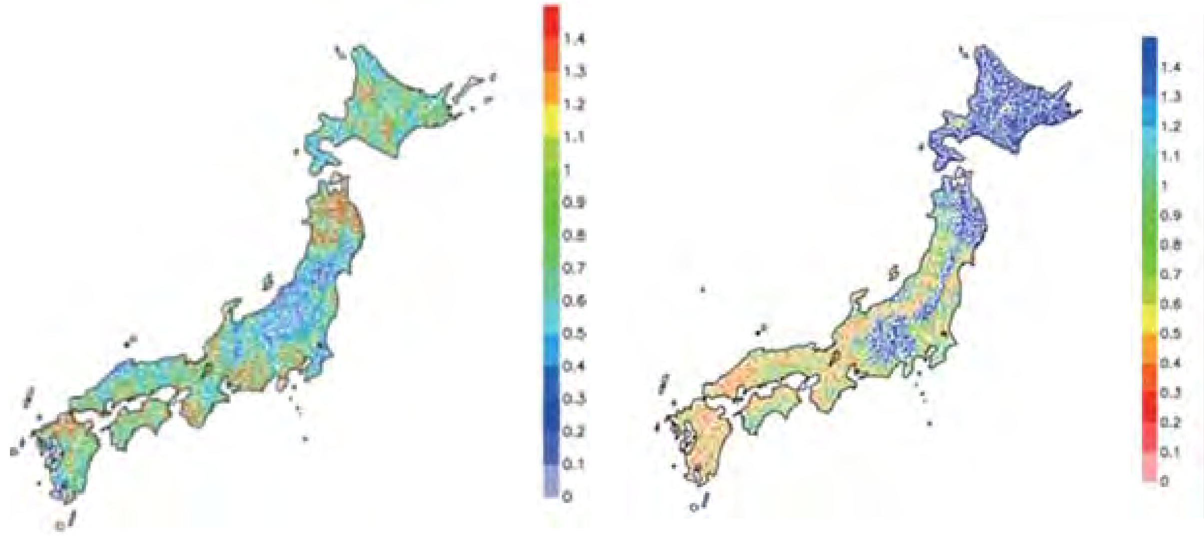


Fig. 2.8: Change ratio of the 100-year annual maximum discharge (left) and the 10-year drought discharge (right) from the present day climate to the end of the 21st century.

2.5 River Flow Simulation in Indochina Peninsula[4]

River discharge projection in Indochina Peninsula region was carried out for three climate experiments: the present climate (1979-2008), the near future climate (2015-2044), and the future climate (2075-2104). Daily mean discharge, max hourly discharge in day data is stored in 5-minute spatial resolution. The simulated river discharge was analyzed to locate possible hotspot basins with significant changes of floods, droughts and water resources.

2.5.1 Change of water resources

Annual mean simulated river discharge for three climate experiments was calculated and used to analyze changes in water resources in Indochina Peninsula region. **Fig. 2.9** shows the change ratio of annual mean discharge for the near future climate and the future climate to the present climate experiment. From **Fig. 2.9**(a), it can be seen that there are not so much changes in annual mean discharge in the near future. Slightly increases in annual mean discharge with the ratio smaller than 1.5 can be detected at the most upper parts of Salween and Mekong River basin, the lower part of Irrawaddy River basin, and western part of Vietnam. Only eastern part of Chao Phraya River basin shows a trend of decreasing in annual mean river flow with the ratio is between 0.5 and 0.9. **Fig. 2.9**(b) shows a similar trend with higher intensity in the future climate experiment. We can

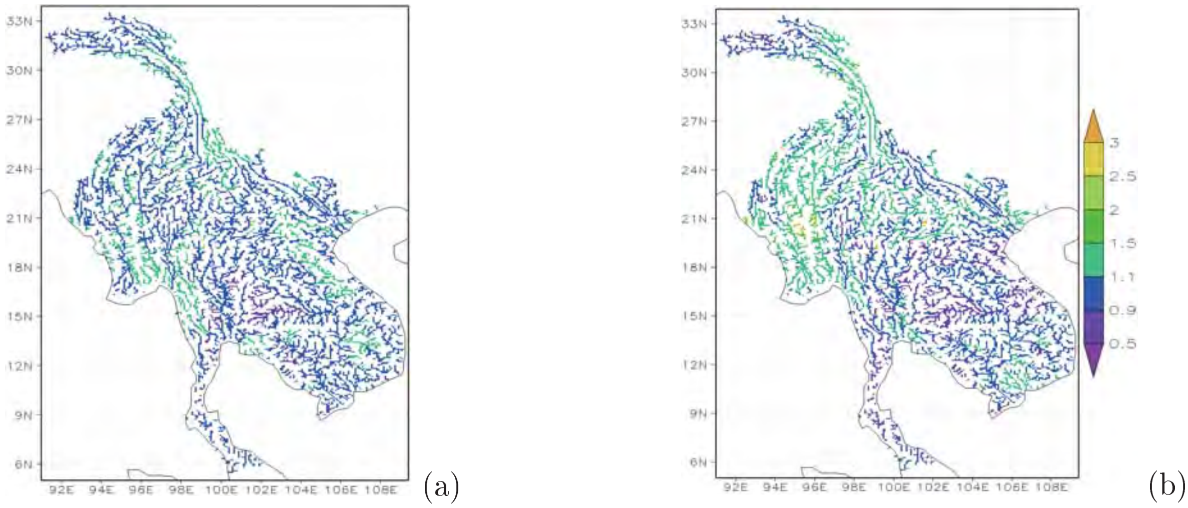


Fig. 2.9: Ratio of annual mean discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

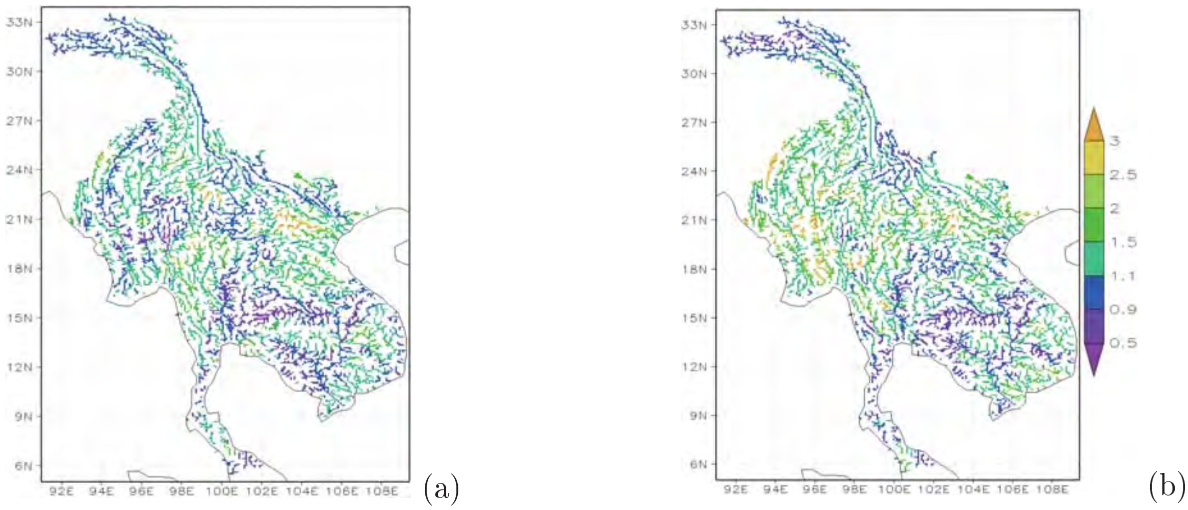
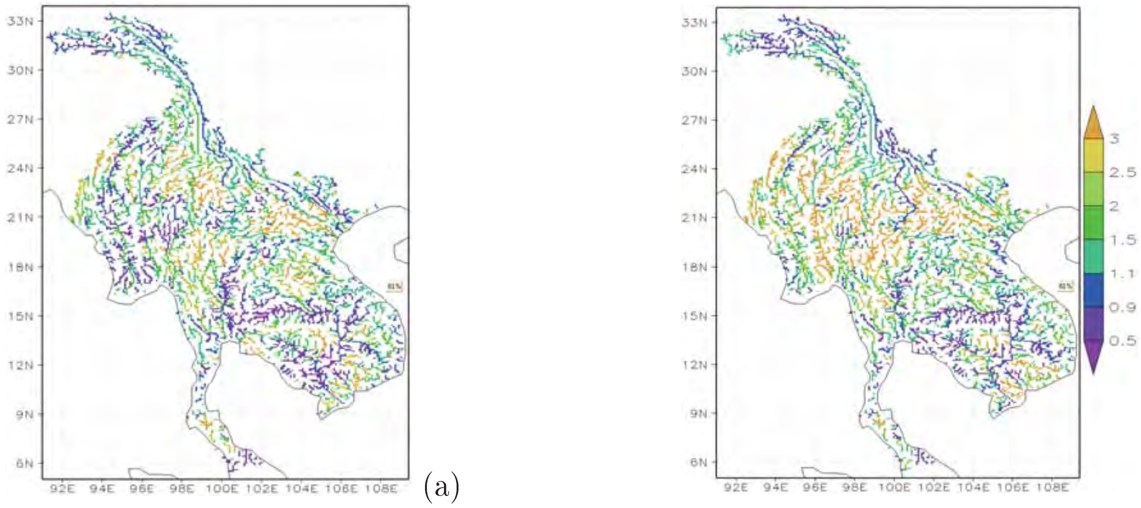


Fig. 2.10: Ratio of annual mean discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

see that the area with changes in annual mean discharge and ratio range become larger, especially at the middle and lower part of Irrawaddy River basin, and eastern part of Chao Phraya River basin. However, the annual mean flow in the future climate tended to decrease in the central part of Vietnam. The change ratio is lower than 0.9.

2.5.2 Change of flood risk

Annual maximum discharge data for three climate experiments were compiled and were analyzed. The change ratio of mean of annual maximum discharge for the near future climate and the future climate with respect to the present climate experiment



(a) (b)

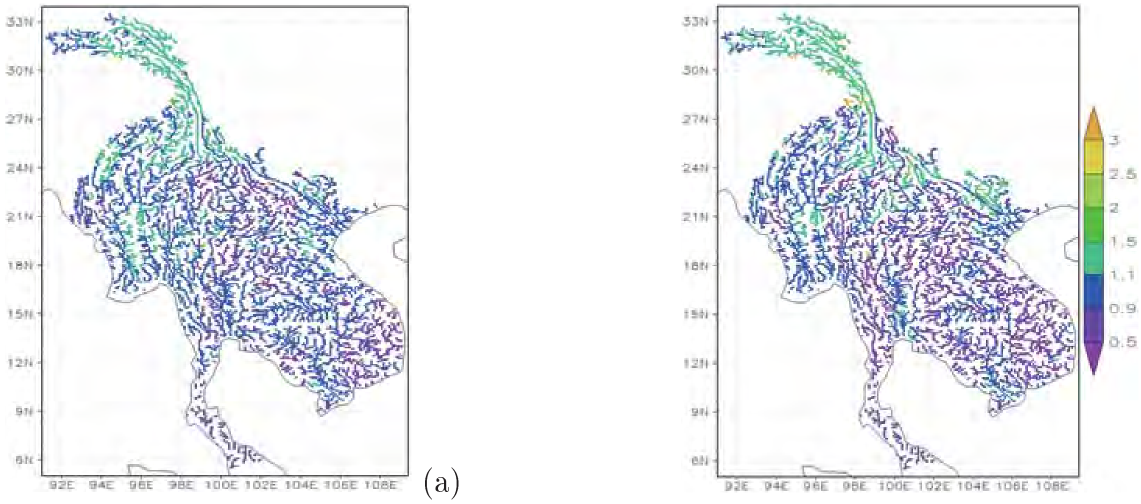
Fig. 2.11: Ratio of standard deviation of annual maximum discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

are shown in **Fig. 2.10**. For the near future climate experiment, the mean of annual maximum discharge has significant changes at the upper and lower part of Salween River basin, north-western part of Vietnam, and eastern part of Chao Phraya River basin. The changes, which were detected in the near future climate experiment, become more visible in the future climate experiment. Irrawaddy River basin and Red River basin showed a noticeable increasing of mean of annual maximum discharge in the future climate experiment. The ratio at some areas are larger than 2.5. It means that the risk of flooding at those areas will increase.

The ratio of the standard deviation of the annual maximum discharge for the near future climate and the future climate to the present climate experiment were also calculated and analyzed. The standard deviation also showed a similar trend to the changes of mean of annual maximum discharge. The increases of standard deviation of annual maximum discharge can be found in Irrawaddy River basin, Salween River basin, and Red River basin as shown in **Fig. 2.11**.

2.5.3 Change of drought risk

The change of drought risk in Indochina Peninsula region was also analyzed by comparing the mean of annual minimum discharge in the near future climate and the future climate experiment with those values in the present climate experiment. From **Fig. 2.12**, it can be seen that there is a decrease trend at the middle part of Mekong River basin in



(a) (b)

Fig. 2.12: Ratio of mean of annual minimum discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

the territory of Lao PDR, western part of Chao Phraya River basin, and the south-eastern part of Indochina Peninsula, especially the southern part of Vietnam. This trend becomes clearer in the future climate experiment.

References

[1] Hunumumbura, P. B. and Y. Tachikawa : River discharge projection under climate change in the Chao Phraya River Basin, Thailand, using the MRI-GCM3.1S dataset, Journal of the Meteorological Society of Japan, Vol. 90A, pp. 137-150, 2012, DOI:10.2151/jmsj.2012-A07.

[2] Tachikawa Y., M. Fujita, M. Shiiba, K. Yorozu, and S. Kim : Water resources projection at the Pasak River basin in Thailand under a changing climate (in Japanese). J. Japan Soc. of Civil Eng., B1 (Hydraulic Eng.), 69(4), I_445-I_450, 2013.

[3] Tachikawa Y., S. Takino, Y. Fujioka, K. Yorozu, S. Kim, and M. Shiiba : Projection of river discharge of Japanese river basins under a climate change scenario (in Japanese). J. Japan Soc. of Civil Eng., B1 (Hydraulic Eng.), 67(1), 1-15, 2011.

[4] Duong, D. T., Y. Tachikawa, M. Shiiba, K. Yorozu : River discharge projection in Indochina Peninsula under a changing climate using the MRI-AGCM3.2s dataset, J. Japan Socc of Civil Eng., Ser. B1 (Hydraulic Eng.), 69(4), I_37-I_42, 2013.

Fundamentals of Basin-scale Hydrological Processes

Department of Civil & Earth Resources Engineering,
Kyoto University

Yasuto TACHIKAWA

Class contents

■Hydrology and water resources engineering. (first 90minuts)

■Water resources under a changing climate. (after break)

■Exercise. Group discussion and presentation. (after lunch)

What is hydrology?

Water continuously circulates around the Earth by means of solar energy and gravitational energy, changing its phases (solid, liquid, and gas). We call the circulation as “hydrologic cycle”.

What is hydrology?

Water vapor evaporated from the ocean and the land surface; condenses and rainfall happens; reaches the ground. Some evaporates again and some flows as surface flow or groundwater flow, and reach to the ocean.

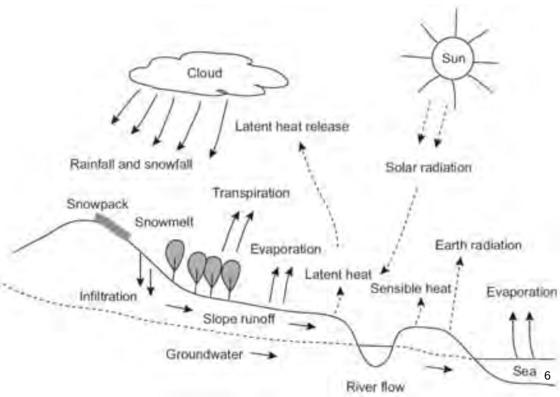
To understand the cycles of water and energy, and clarify the relation with human activities scientifically is hydrology.

Definition of Hydrology by UNESCO International Hydrological Decade, 1964

Hydrology is the science which deals with the waters of the Earth, their occurrence, circulation and distribution on the planet, their physical and chemical properties and their interactions with the physical and biological environment, including their responses to human activity.

Hydrology is a field which covers the entire history of the cycle of water on the Earth.

1.1 The science of Water Cycle: Hydrology



What you will study in this class?

■To understand the basic concept of the hydrologic cycle.

■Based of the understanding of the hydrologic cycle, to learn water resources under a changing climate.

1.2 Hydrologic cycle and water resources

Example 1.1

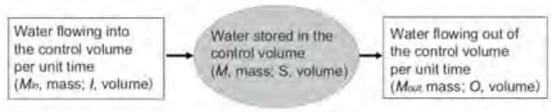
Topics of hydrologic cycle and water resources

1.3 Water on the Earth

Example 1.2

The volume of water on the Earth

1.4 Water Budget and Water Resources



$$\Delta S = (I - O)\Delta t$$

ΔS is change in water storage over the period of interest,
I is inflow to the control volume,
O is outflow from the control volume.

1.4.1 Water balance equation

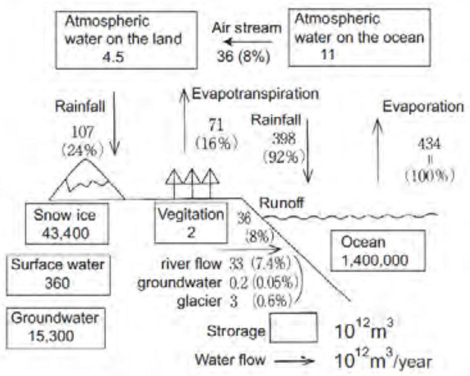
$$\frac{dS}{dt} = I - O$$

S is storage of the defined region,

I is inputs to the defined region, and

O is outputs from the defined region.

1.4.2 Global water budget



Example 1.3

Calculate annual precipitation per unit area (in height unit, mm).

Example 1.4

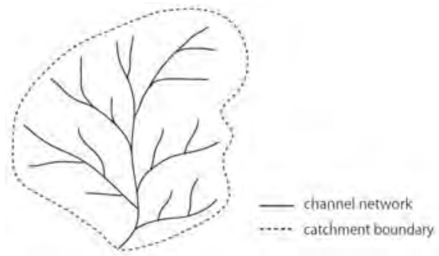
Calculate annual evapotranspiration per unit area (in height unit, mm).

Example 1.5

Calculate annual runoff and runoff ratio.

1.4.3 Catchment water budget

$$\frac{dS}{dt} = I - O = A(r - e) - Q$$



Example 1.6 Hydrologic Characteristics

Region	Precipitation (mm)	Evap. (mm)	Runoff (mm)
CPRB (Thailand)	1144	962	182
Jakarta	1800	900	900
Hanoi	1500	800	700
Dhaka	1300	900	400
Yangon			
Kyoto	1,796	708	1088
World (mean)	723	480	243

Example 1.7 Annual water resources

Region	Prec. (mm/year)	Evap. (mm/year)	Runoff (mm/year)	Area (km^2)	Population (person)
Thailand	1,144	962	182	513×10^3	69.5×10^6
Japan	1,796	708	1,099	378×10^3	126.5×10^6
World	723	480	243	148×10^6	$6,968 \times 10^6$

Example 1.8 Mean residence time in global water budget

Example 1.9 Mean residence time in dam reservoirs

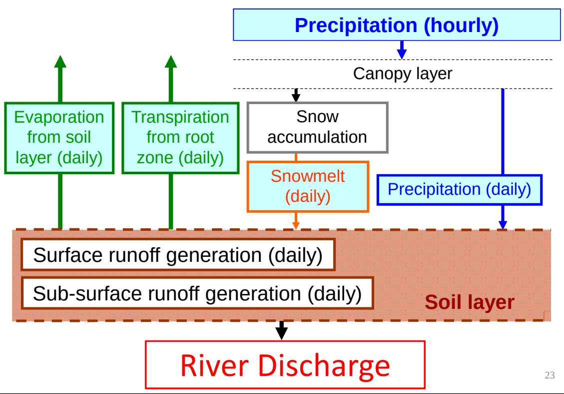
Dam	Storage capacity (10^6 m^3)	Catchment area (km^2)	Prec (mm/y)	Evap (mm/f)	Runoff (mm/y)
Bhumibol Dam	13,420	26,400	1,144	962	182
Tokuyama Dam	660	254.5	1,796	708	1088
Hiyoshi Dam	66	290	1,796	708	1088

Water Resources under Changing Climate

Department of Civil & Earth Resources Engineering, Kyoto University

Yasuto TACHIKAWA

2.1 Climate Change Scenario and GCMs



RESEARCH METHODOLOGY

■ Input data

20 km resolution future climate simulation data, MRI-AGCM3.2S made by Morological Research Institute, Japan.

Present climate experiment: 1979-2008
Near future experiment: 2015-2044
Future climate experiment: 2075-2104

⬇

■ River flow routing model

for estimating river flow discharge using the future climate data such as rainfall, evaporation and so on.

⬇

■ Analyzing

the changes river flow discharge for the assessment of water resources, flood risks and drought risks.

Flow Routing Model using DEMs

25

http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html

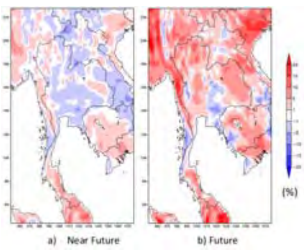
2.2 Water Resources Simulation in Thailand

26

Changes ; Basic meteorological parameters (a)Rainfall …

Percentage difference of the average annual rainfall with respect to present climate

% Percentage Difference = 100*(Near future-Present)/Present

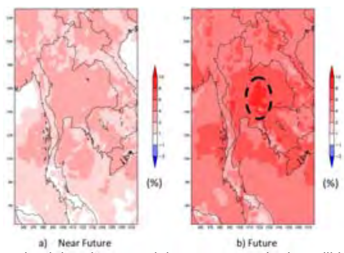


1% to 5% decreases of annual precipitation can be observed in the central region of Thailand and 1% to 10% of increase in annual precipitation can be observed in southern region in the near future climate (2015-2039).

Future climate conditions, it is expected to have 1% to 10% of increase in annual precipitation in north mountainous region and 5% to 10% increase in northeast region.

Changes ; Basic meteorological parameters (a) Potential evaporation

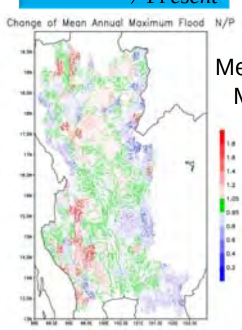
Percentage difference of the average annual daily potential evapotranspiration in near future and future climate with respect to the present climate



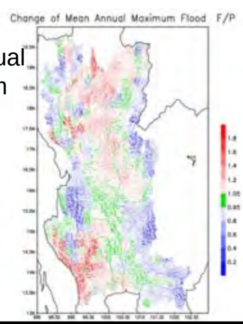
It can be clearly noticed that the potential evappotranspiration will increase by 4% to 6% in near future climate and 4% to 10% in future climate.

Results ; Flood…

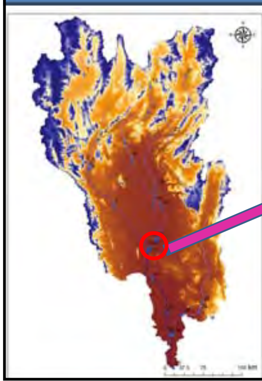
$\frac{NearFuture}{Present}$ $\frac{Future}{Present}$

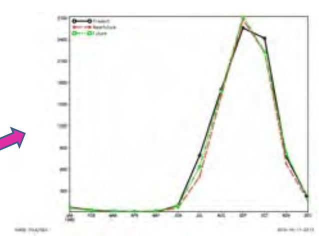


Mean Annual Maximum Flood

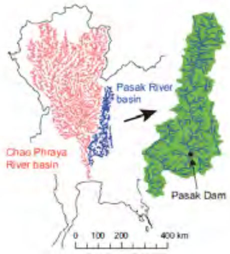


Results ; Water Resources

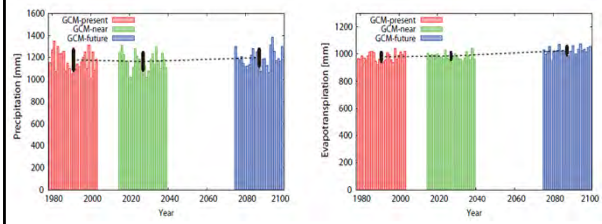




2.3 Water Resources Simulation at the Pasak Dam

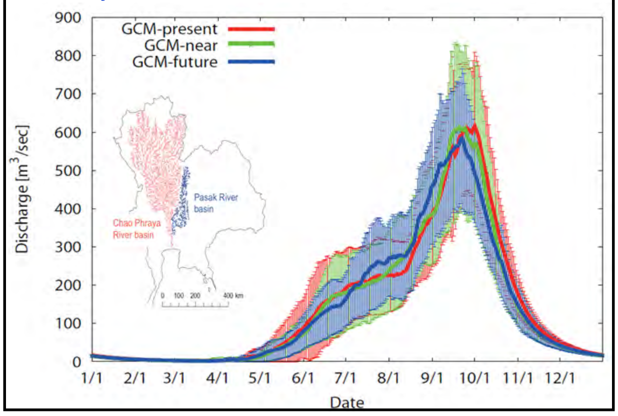


Change of Future Precipitation and Evapotranspiration Projected by MRI-GCM3.1S

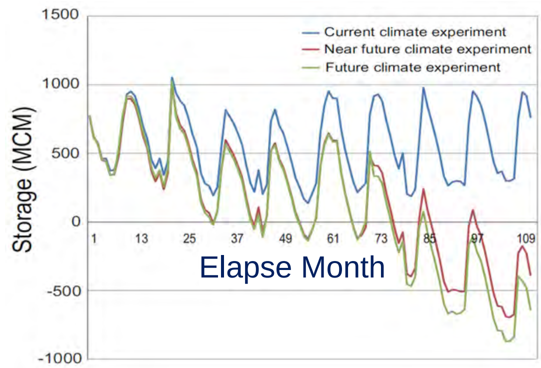


Precipitation Evapotranspiration

Projected Inflow to the Pasak Dam Reservoir



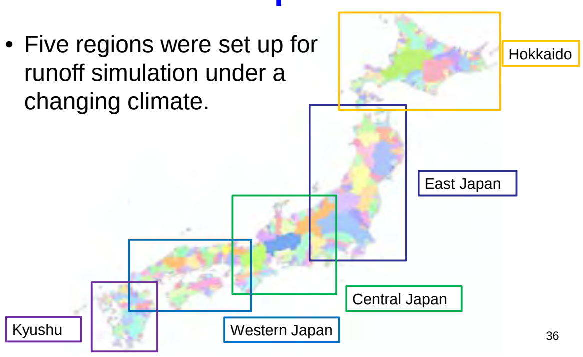
Projected Pasak Dam Storage under a Changing Climate



2.4 Water Resources Simulation in Japan

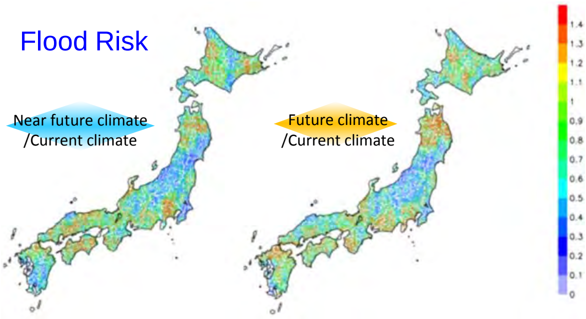
Runoff Simulation for the Entire Japan

- Five regions were set up for runoff simulation under a changing climate.



Change of 100-year annual maximum hourly discharge

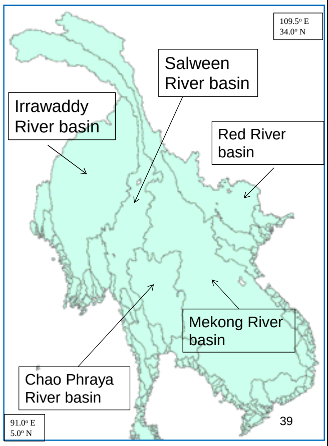
Flood Risk



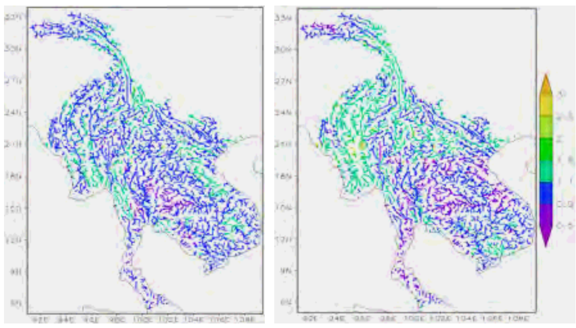
Quintiles of river discharge with 100-year return period estimated using GEV distribution.

2.5 River Flow Simulation in Indochina Peninsula

STUDY AREA

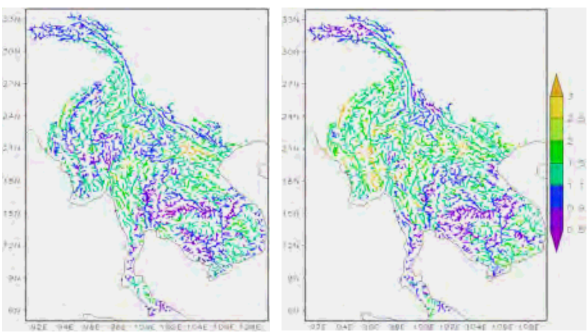


Change Ratio of Mean of Annual Discharge



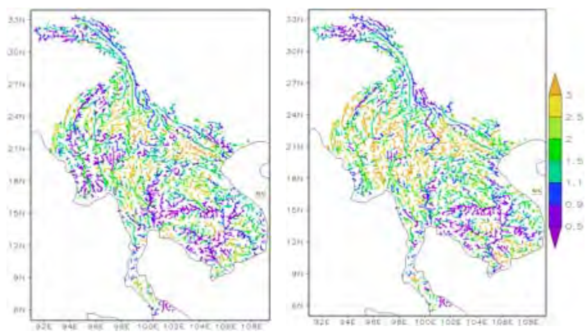
Near Future Climate to Present Climate Future Climate to Present Climate

Change Ratio of Mean of Annual Maximum Discharge



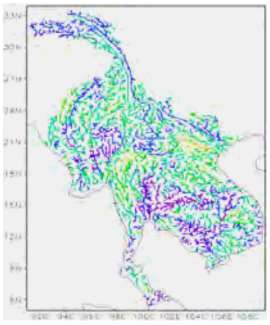
Near Future Climate to Present Climate Future Climate to Present Climate

Change Ratio of Standard Deviation of Annual Maximum Discharge

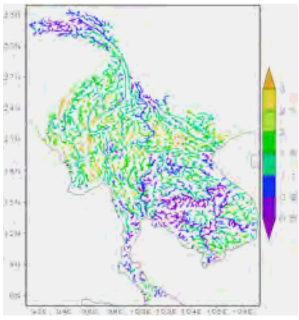


Near Future Climate to Present Climate Future Climate to Present Climate

Change Ratio of 10-year Annual Maximum Discharge

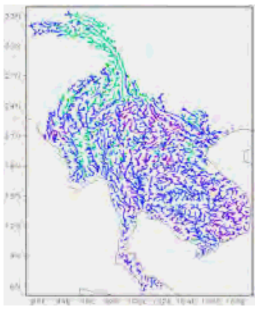


Near Future Climate to Present Climate

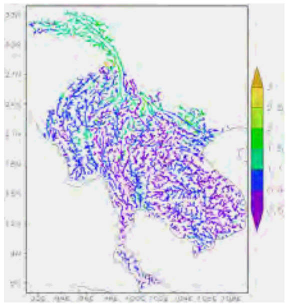


Future Climate to Present Climate

Change Ratio of Mean of Annual Minimum Discharge



Near Future Climate to Present Climate



Future Climate to Present Climate

Findings

- Clear changes of flood peak discharge, and monthly discharge were detected;
- The degree of the discharge changes differs according to location; and
- The changes appear in the near future climate experiment, which become clearer in the future climate experiment.

Summary

1) A regional distributed rainfall-runoff model for flood prediction was introduced and a simulation result of 2011 flood in Thailand was presented.

2) A river flow projection at the Chao Phraya River basin under a changing climate was presented.

3) A water resources simulation for the Pasak Dam reservoir storage under a changing climate was demonstrated.

4) A preliminary river flow simulation for the entire Indochina region using the latest climate change projection data was introduced.

Lecture 2: Projected Future Meteorological Environment

Eiichi NAKAKITA *(Division of Atmospheric and Hydrospheric Disasters, DPRI, Kyoto University)*

Climate change impact assessment on natural hazard such as flood, landslide, strong wind, storm surge and high wave had been realized under the Innovative Program on Climate Change Projection for the21st century “Kakushin Program”, supported by the Ministry of Education, Culture, Sports, Science and Technology. The Kakushin Program was followed by a Program for Risk Information on Climate Change “Sousei Program”, which aims to create risk information more aware of social adaptation to climate change. The lecture includes what kind of impact assessment in the Kakushin program has been realized, and what the risk information which aims at the Sousei Program is. (http://www.jamstec.go.jp/sousei/eng/index.html)

DPRI is performing prediction and evaluation of disaster environment in Japan with the sub-project title of “Integrated assessment of climate change impacts on watersheds in a disaster environment”. Impact assessment on disasters such as landslides, debris flows, floods, droughts, storm surges, and strong winds. Moreover, flood risk assessments are being extended to a global scale for cooperation with international projects on disaster mitigation by ICHARM, PWRI.

One of the important subjects in this sub-project is the interface between GCM and RCM, and various models on natural hazard. For example, MRI has changed its GCM and RCM so that they could output hourly rainfall from GCM, 30-minutes rainfall from 5-km and 2-km RCMs and 10-minutes rainfall from 1-km RCM for the use of hydrology-related various hazards and disasters.

As an example of flood risk assessment, the magnitude of 100-year flood for near future and the end of the 21st century were estimated using 1-km spatial resolution distributed hydrologic model with the input of the climate projection computed by the 20-km model. As other examples, changes in frequency of typhoon generation, approach to Japan, and heavy rainfall occurrence.

However, there are some important points which should be investigated and be thought more before moving on to adaptation research; (1) GCM and RCM with the super-high spacio-temporal resolutions (20 km-1 hour) makes it possible to evaluate extreme hazard (ex. Max. discharge).However, this does not mean that we can evaluate the changes in such a high spatial resolution. (2) We can get approximate projection on changes in return period of extreme events. However, there is a risk that the return period does not have enough accuracy. (3) Also, there is no guarantee that quite extreme events could be projected within the limited number of ensembles as GCM and nested RCM output. In this sense, it may be difficult to establish design hazard for water management and so on. (One of the ideas to overcome this for assessing storm surge will be separately presented.) (4) On the other hand, the risk management deals with phenomena beyond design hazards. In this sense, it is very important to take into account the result from the worst case scenario as a one of the forcing for risk management on climate change. (One of the ideas of producing the worst case scenario will be presented.)

Taking into consideration above items, I think, it is very and more important for climate change adaptation to discriminate between planning with uncertain design level and risk management with the worst case scenario.

DPRI-KU

Projected Future Meteorological Environment

Eiichi Nakakita
Atmosphere Hydrosphere Research Division
Disaster Prevention Research Institute
Kyoto University
Japan

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Outline

- **Climate change impact assessment**
  - **Impact of AGCM20 on extreme events climate impact assessment in Japan**
  - Typical climate change assessment on disaster environment in Japan – projection of change in design value
  - Heading to adaptation :importance of taking a worst case scenario into consideration.
- Real-time ensemble weather forecast

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Innovative Program of Climate Change Projection for the 21st Century

(KAKUSHIN Program)

by

Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Secretariat of the Outreach Committee of the Program
Frontier Research Center for Global Change
Japan Agency for Marine-Earth Science and Technology

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Background of national strategy : *3rd phase (FY2006-FY2010) of the Science and Technology Basic Plan*

- 3rd phase was launched (in April 2006) by the Cabinet
- The same **4 fields were prioritized** again for promotion as in the 2nd phase besides ***basic sciences***:
  - *Life science*;
  - *Information and Communications;*
  - ***Environment***; and
  - *Nanotechnology:*
- ***National core technology*** studies/projects were also identified for *overarching or cross-cutting themes.*

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Areas further prioritized in **Environment**

Promotional prioritization was formulated by the ***Council for Science and Technology Policy (CSTP)****:

- ***Climate change research*** *(including climate change mitigation technology)*
- ***Chemical substance*** *risk and security management research,*
- ***Water/material cycle and watershed,*** *ecosystem management research,*
- ***3R (reduce, reuse and recycle)*** *technology research,*
- ***Biomass usage and utilization*** *research*

* *established within the Cabinet Office in 2001, chaired by the Prime Minister, with members of 6 Ministers concerned and 8 Experts*

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Climate Change Research

categorized into:

- **P1:** *Integrated* ***monitoring studies*** *on global warming*
- **P2:** *Climate change* ***process studies***
- **P3:** ***Future projection of global warming*** *and* ***building of data base from climate change research outcomes***
- **P4:** *Studies on* ***global warming impact****, risk assessment, and adaptation measures*
- **P5:** *Studies on global scale water cycle variabilities*
- **P6:** *Studies on mitigation policies*

Reliable climate change projection and impact assessment with better managed global Earth observation

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Emerging Backgrounds from the IPCC/ AR4 outcomes

- "Warming of the climate system is **unequivocal**, …."
- "Most of the observed increase in globally averaged temperatures since the mid-20th century is ***very likely*** due to the observed increase in anthropogenic greenhouse gas concentrations[12]."

[12] Consideration of **remaining uncertainty** is based on current methodologies.

- "Cloud feedbacks remain **the largest source of uncertainty**."
- "Assessed upper ranges for temperature projections are larger than in the TAR (see Table SPM-2) mainly because the broader range of models now available suggests **stronger climate-carbon cycle feed backs**."
- "It is ***very likely*** that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent."

…………

→ **Strong concerns about global warming and its impacts on natural disasters, in particular,** from policy makers

→ **Increasing need** of further reliable projection

Research needs and issues to be addressed

- **Better simulation of physical and biogeochemical processes sufficiently reflecting feedbacks**
  → ***Advancing climate modeling and projection***
- **Addressing uncertainties in climate model projection**
  → ***Quantification and reduction of uncertainty***
- **Impact assessment on natural disasters by extreme events through sufficiently high resolution projection**
  → ***Application of regional projection to natural disasters***

Program Theme (A)

Advancing climate modeling and projection

- Developing more reliable and higher resolution climate models, through the sophisticated incorporation of physical and biogeochemical processes in the atmosphere, ocean and land surface, covering wider ranges from global to local urban scales.

- ***Further reliable climate change projection (or prediction) for the 21st century, with a specific focus on extreme events such as heat waves, severe storms, tropical cyclones, storm surges, etc. in the near future (about 25 years ahead)***
- ***Projection to be regionally detail enough for relevantly applicable to impact assessment and adaptation studies.***
- ***Projection of global environment change including carbon cycle feedback***

Program Theme (B)

Quantification and reduction of uncertainty

- Inter-comparison of climate models in their performance in terms of incorporated processes.
- Quantification of uncertainty among models through ensemble methodologies.
- Data assimilation to be further improved for validation.
- Comprehensive study for the reduction of uncertainty in projection.

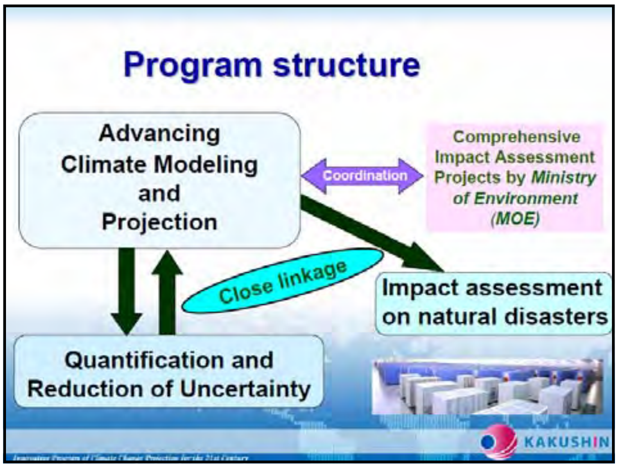
Program Theme (C)

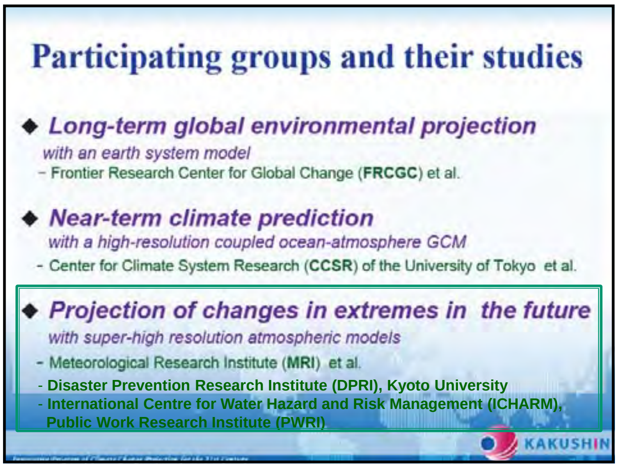
Impact assessment on natural disasters

- Analysis of the frequency and the strength of projected (or predicted) extreme events (tropical cyclones, heat waves, severe rainfalls, droughts, etc.) in the 21st century with special attention to near future (~25 years ahead)
- Impact assessment study on natural disasters due to extreme events to contribute to natural disaster reduction policies

Program plan

- ***A 5-year initiative (FY 2007-2011)*** by the ***MEXT*** (Ministry of Education, Culture, Sports, Science and Technology) launched in April 2007.
- The Program is to follow-up and develop the ***"Kyo-sei" Project (FY 2002-2006).***
- The ***Earth Simulator*** to be further utilized.
- The Program intends to ***contribute to the possible AR5.***
- ***Coordination*** *with studies outside the Program in impact, adaptation and response strategies to be closely kept.*


Program structure
Advancing Climate Modeling and Projection
Coordination
Comprehensive Impact Assessment Projects by Ministry of Environment (MOE)
Close linkage
Impact assessment on natural disasters
Quantification and Reduction of Uncertainty
KAKUSHIN


Participating groups and their studies
Long-term global environmental projection
with an earth system model
- Frontier Research Center for Global Change (FRCGC) et al.
Near-term climate prediction
with a high-resolution coupled ocean-atmosphere GCM
- Center for Climate System Research (CCSR) of the University of Tokyo et al.
Projection of changes in extremes in the future
with super-high resolution atmospheric models
- Meteorological Research Institute (MRI) et al.
- Disaster Prevention Research Institute (DPRI), Kyoto University
- International Centre for Water Hazard and Risk Management (ICHARM), Public Work Research Institute (PWRI)
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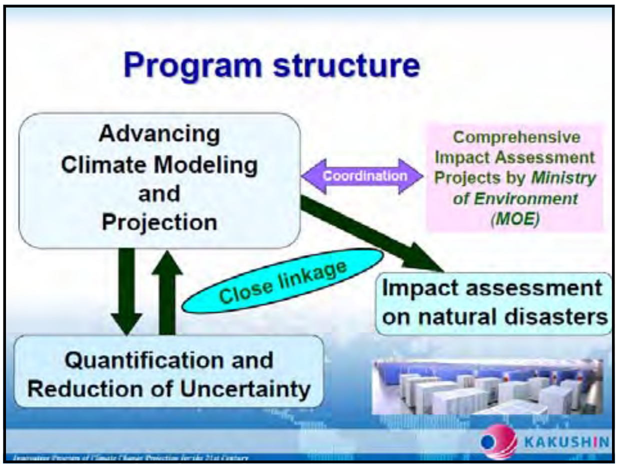
Program structure
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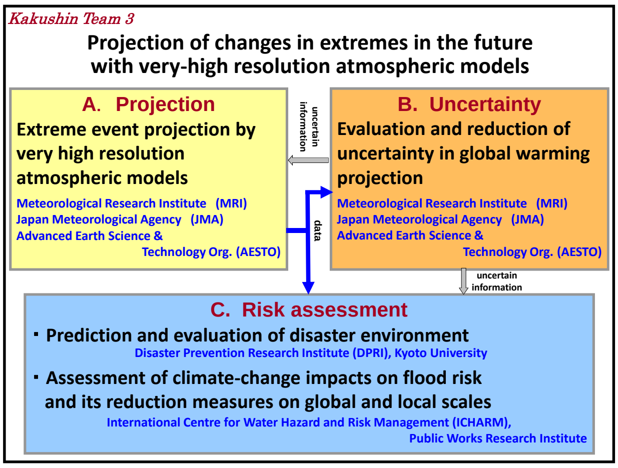
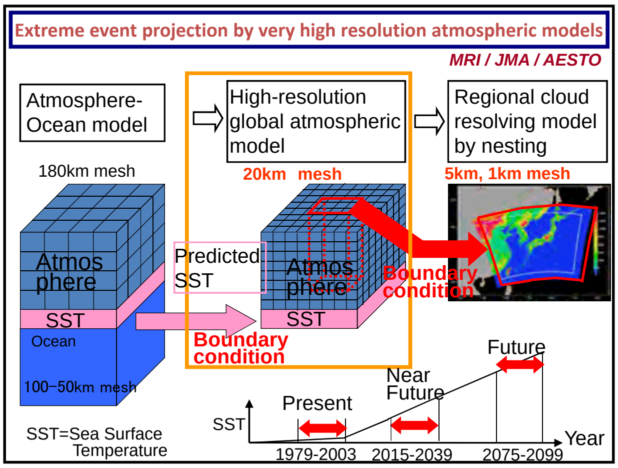
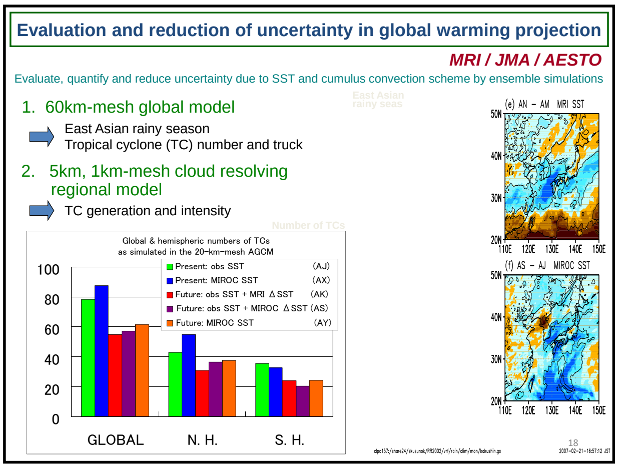
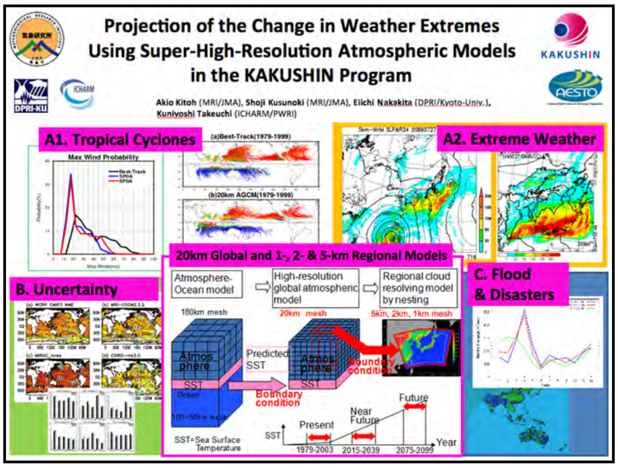
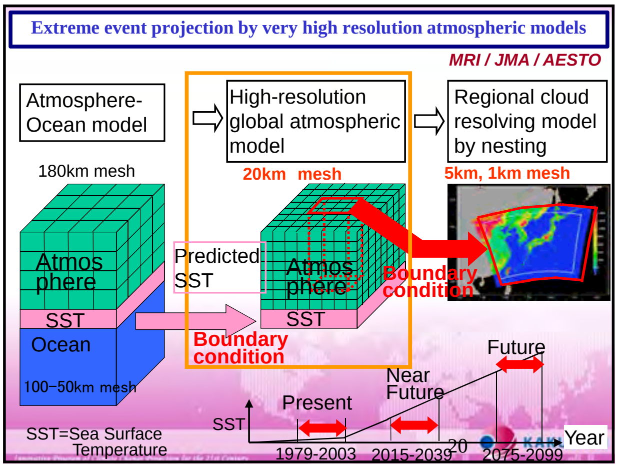
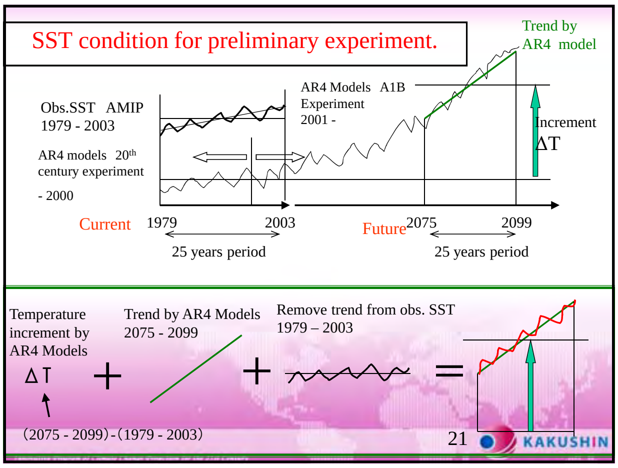

Kakushin Team 3
Projection of changes in extremes in the future with very-high resolution atmospheric models
A. Projection
Extreme event projection by very high resolution atmospheric models
Meteorological Research Institute (MRI)
Japan Meteorological Agency (JMA)
Advanced Earth Science & Technology Org. (AESTO)
uncertain information
data
B. Uncertainty
Evaluation and reduction of uncertainty in global warming projection
Meteorological Research Institute (MRI)
Japan Meteorological Agency (JMA)
Advanced Earth Science & Technology Org. (AESTO)
uncertain information
C. Risk assessment
Prediction and evaluation of disaster environment
Disaster Prevention Research Institute (DPRI), Kyoto University
Assessment of climate-change impacts on flood risk and its reduction measures on global and local scales
International Centre for Water Hazard and Risk Management (ICHARM), Public Works Research Institute

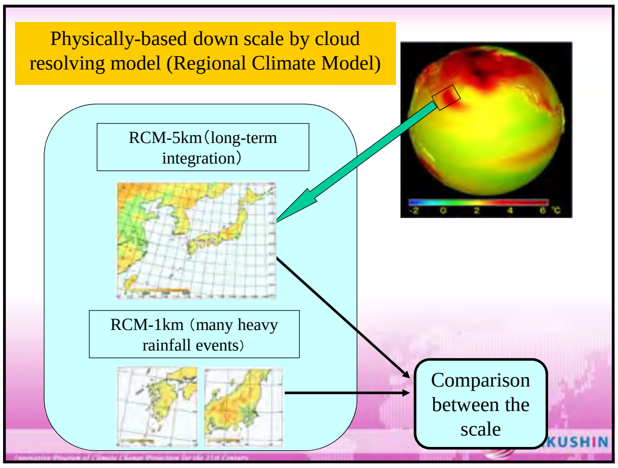

Extreme event projection by very high resolution atmospheric models
MRI / JMA / AESTO
Atmosphere-Ocean model
High-resolution global atmospheric model
Regional cloud resolving model by nesting
180km mesh
20km mesh
5km, 1km mesh
Atmos phere
SST
Ocean
100−50km mesh
Predicted SST
Boundary condition
SST=Sea Surface Temperature
Future
Near Future
Present
SST
Year
1979-2003
2015-2039
2075-2099

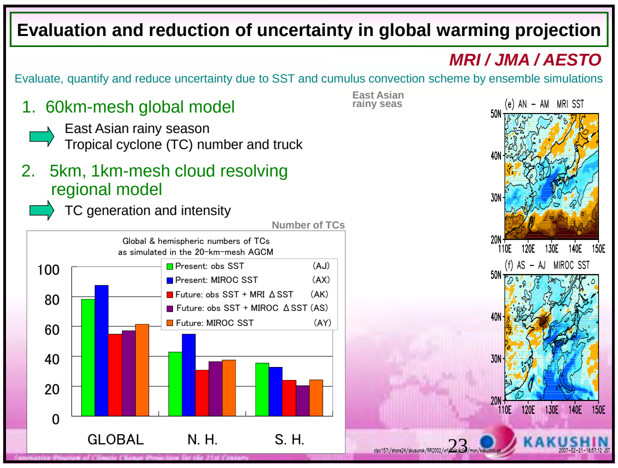

Evaluation and reduction of uncertainty in global warming projection
MRI / JMA / AESTO
Evaluate, quantify and reduce uncertainty due to SST and cumulus convection scheme by ensemble simulations
1. 60km-mesh global model
East Asian rainy season
Tropical cyclone (TC) number and truck
2. 5km, 1km-mesh cloud resolving regional model
TC generation and intensity
Global & hemispheric numbers of TCs as simulated in the 20-km-mesh AGCM
Present: obs SST (AJ)
Present: MIROC SST (AX)
Future: obs SST + MRI ΔSST (AK)
Future: obs SST + MIROC ΔSST (AS)
Future: MIROC SST (AY)
100
80
60
40
20
0
GLOBAL
N. H.
S. H.
(e) AN − AM MRI SST
(f) AS − AJ MIROC SST
18

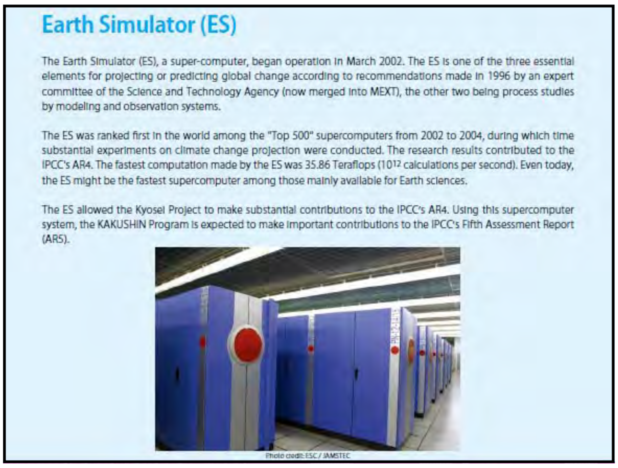

Projection of the Change in Weather Extremes
Using Super-High-Resolution Atmospheric Models
in the KAKUSHIN Program
Akio Kitoh (MRI/JMA), Shoji Kusunoki (MRI/JMA), Eiichi Nakakita (DPRI/Kyoto-Univ.),
Kuniyoshi Takeuchi (ICHARM/PWRI)
KAKUSHIN
AESTO
DPRI-KU
ICHARM
A1. Tropical Cyclones
(a)Best-Track(1979-1999)
(b)20km AGCM(1979-1999)
Max Wind Probability
A2. Extreme Weather
20km Global and 1-, 2- & 5-km Regional Models
Atmosphere-Ocean model
High-resolution global atmospheric model
Regional cloud resolving model by nesting
180km mesh
20km mesh
5km, 2km, 1km mesh
Predicted SST
Atmos phere
SST
Ocean
Boundary condition
Present
Near Future
Future
Year
SST=Sea Surface Temperature
1979-2003
2015-2039
2075-2099
B. Uncertainty
C. Flood & Disasters

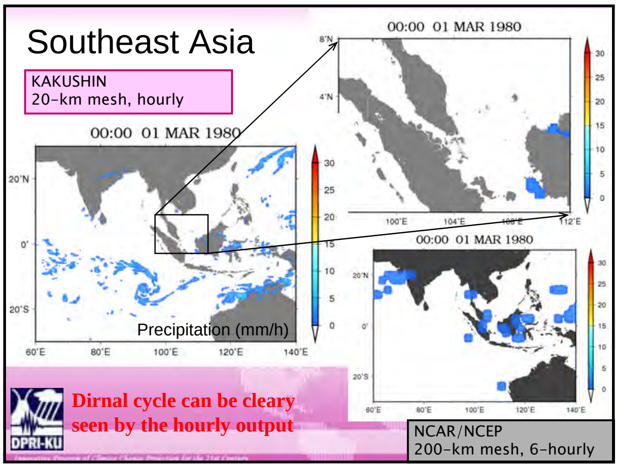

Extreme event projection by very high resolution atmospheric models
MRI / JMA / AESTO
Atmosphere-Ocean model
High-resolution global atmospheric model
Regional cloud resolving model by nesting
180km mesh
20km mesh
5km, 1km mesh
Atmos phere
Predicted SST
Atmos phere
Boundary condition
SST
Ocean
SST
Boundary condition
100~50km mesh
Future
Near Future
Present
SST
SST=Sea Surface Temperature
1979-2003
2015-2039
2075-2099
Year
20

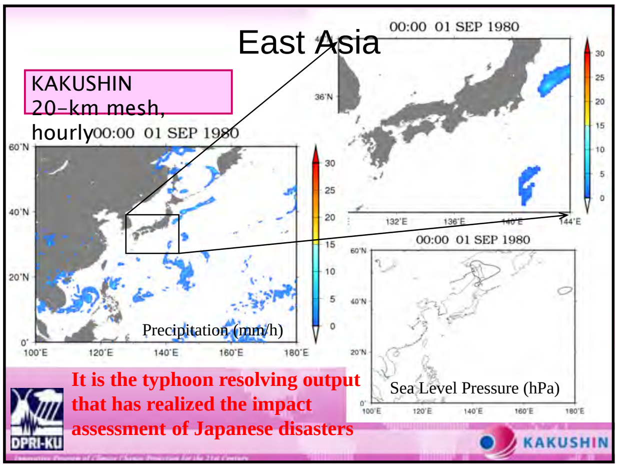

SST condition for preliminary experiment.
Trend by AR4 model
Obs.SST AMIP 1979 - 2003
AR4 Models A1B Experiment 2001 -
AR4 models 20th century experiment
- 2000
Increment ΔT
Current
1979
2003
Future
2075
2099
25 years period
25 years period
Temperature increment by AR4 Models
ΔT
Trend by AR4 Models 2075 - 2099
Remove trend from obs. SST 1979 – 2003
+
+
=
(2075 - 2099) - (1979 - 2003)
21
KAKUSHIN


Physically-based down scale by cloud resolving model (Regional Climate Model)
RCM-5km (long-term integration)
RCM-1km (many heavy rainfall events)
Comparison between the scale
KAKUSHIN

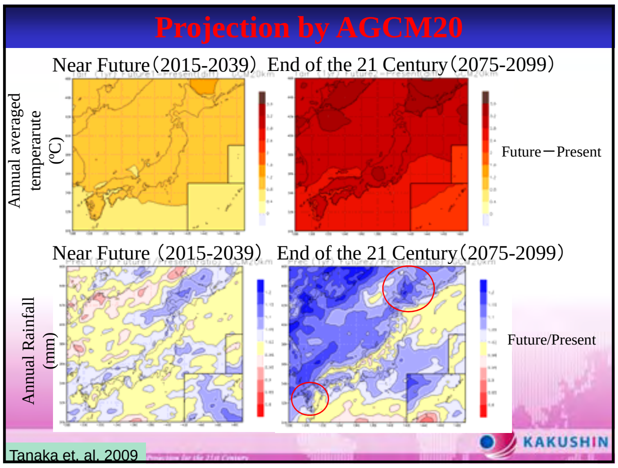

Evaluation and reduction of uncertainty in global warming projection
MRI / JMA / AESTO
Evaluate, quantify and reduce uncertainty due to SST and cumulus convection scheme by ensemble simulations
1. 60km-mesh global model
East Asian rainy season
Tropical cyclone (TC) number and truck
2. 5km, 1km-mesh cloud resolving regional model
TC generation and intensity
East Asian rainy seas
Number of TCs
Global & hemispheric numbers of TCs as simulated in the 20-km-mesh AGCM
Present: obs SST (AJ)
Present: MIROC SST (AX)
Future: obs SST + MRI ΔSST (AK)
Future: obs SST + MIROC ΔSST (AS)
Future: MIROC SST (AY)
100
80
60
40
20
0
GLOBAL
N. H.
S. H.
(e) AN – AM MRI SST
(f) AS – AJ MIROC SST
23
KAKUSHIN

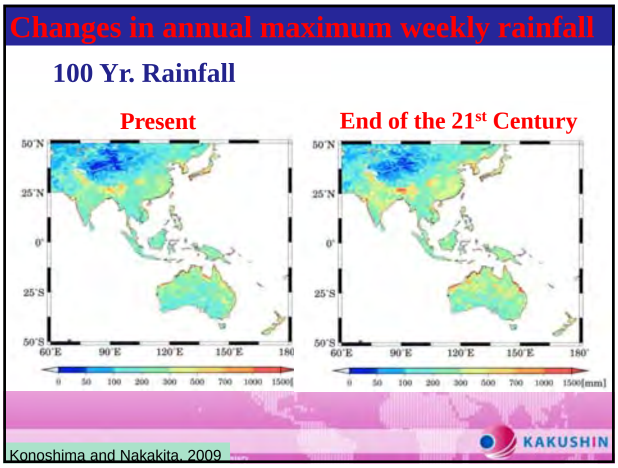

Earth Simulator (ES)
The Earth Simulator (ES), a super-computer, began operation in March 2002. The ES is one of the three essential elements for projecting or predicting global change according to recommendations made in 1996 by an expert committee of the Science and Technology Agency (now merged into MEXT), the other two being process studies by modeling and observation systems.
The ES was ranked first in the world among the "Top 500" supercomputers from 2002 to 2004, during which time substantial experiments on climate change projection were conducted. The research results contributed to the IPCC's AR4. The fastest computation made by the ES was 35.86 Teraflops (10^12 calculations per second). Even today, the ES might be the fastest supercomputer among those mainly available for Earth sciences.
The ES allowed the Kyosei Project to make substantial contributions to the IPCC's AR4. Using this supercomputer system, the KAKUSHIN Program is expected to make important contributions to the IPCC's Fifth Assessment Report (AR5).
Photo credit: ESC / JAMSTEC

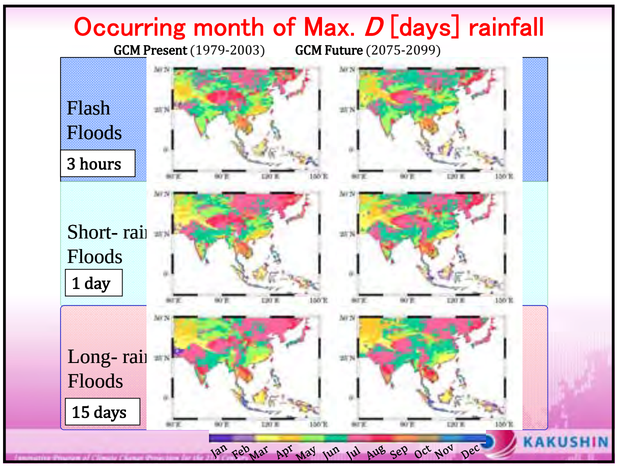

Southeast Asia
KAKUSHIN
20-km mesh, hourly
00:00 01 MAR 1980
Precipitation (mm/h)
Dirnal cycle can be cleary seen by the hourly output
NCAR/NCEP
200-km mesh, 6-hourly

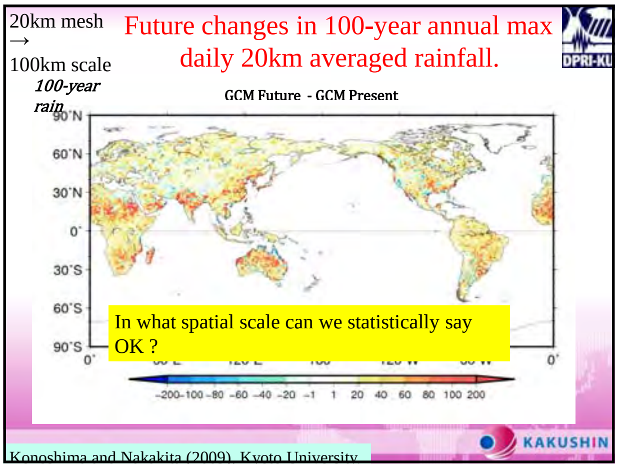

East Asia
KAKUSHIN
20-km mesh, hourly
00:00 01 SEP 1980
Precipitation (mm/h)
Sea Level Pressure (hPa)
It is the typhoon resolving output that has realized the impact assessment of Japanese disasters
KAKUSHIN

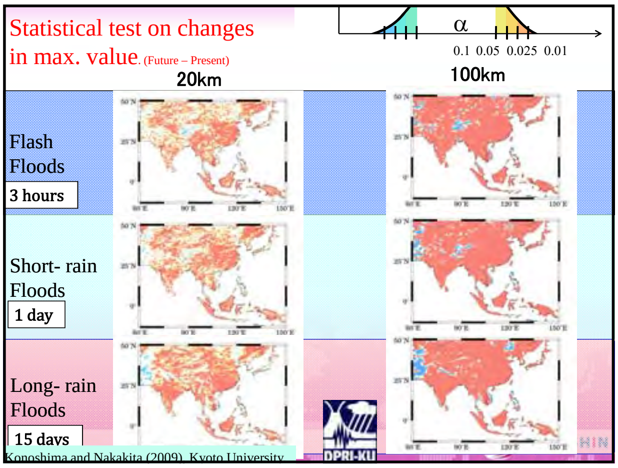

01 Sep 208X 00 UTC
©MRI,JMA,JAMSTEC,MEXT

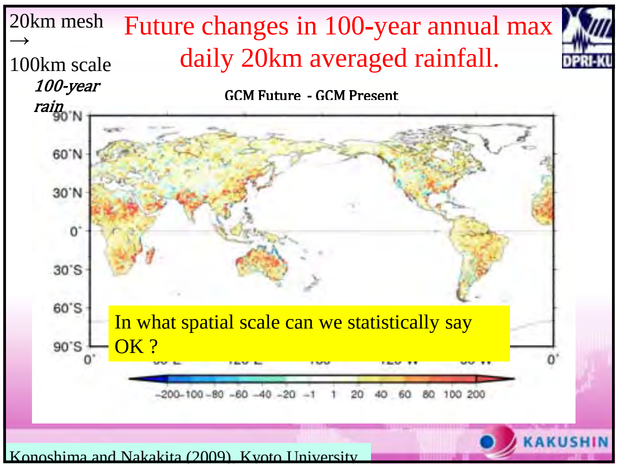

Projection by AGCM20
Near Future (2015-2039)
End of the 21 Century (2075-2099)
Annual averaged temperarute (℃)
Future－Present
Annual Rainfall (mm)
Future/Present
Tanaka et. al. 2009
KAKUSHIN

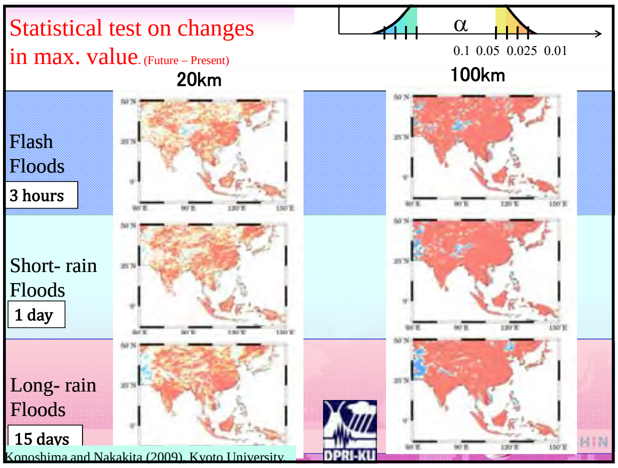

Changes in annual maximum weekly rainfall
100 Yr. Rainfall
Present
End of the 21st Century
Konoshima and Nakakita, 2009
KAKUSHIN


Occurring month of Max. D [days] rainfall
GCM Present (1979-2003)
GCM Future (2075-2099)
Flash Floods
3 hours
Short- rai
Floods
1 day
Long- rai
Floods
15 days
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
KAKUSHIN









Points in climate change assessment on Japanese hazard

- There are various types of hazards that bring disasters.
- Spacio-temporal information with high resolution is required for representing reasonable extreme river discharge in Japan.

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Points in climate change assessment on Japanese hazard

- There are various types of hazards that bring disasters.
- Spacio-temporal information with high resolution is required for representing reasonable extreme river discharge in Japan.

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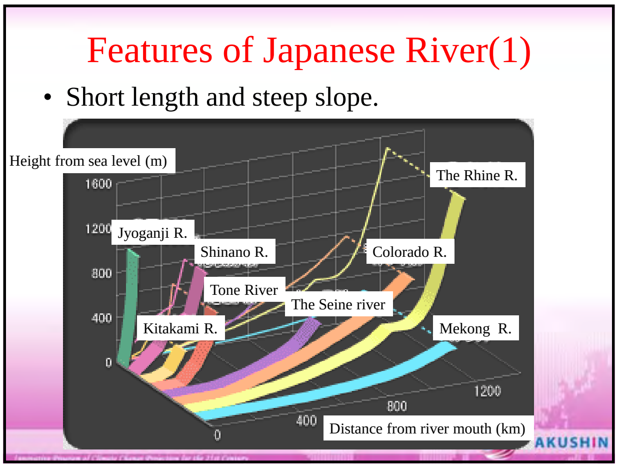
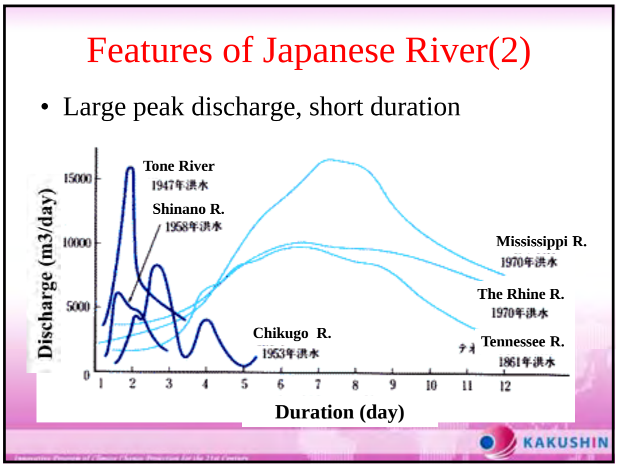

Features of Japanese River(1)
• Short length and steep slope.
Height from sea level (m)
1600
1200
800
400
0
Jyoganji R.
Shinano R.
Tone River
Kitakami R.
The Seine river
Colorado R.
The Rhine R.
Mekong R.
0
400
800
1200
Distance from river mouth (km)
AKUSHIN


Features of Japanese River(2)
• Large peak discharge, short duration
Discharge (m3/day)
15000
10000
5000
0
Tone River
1947年洪水
Shinano R.
1958年洪水
Chikugo R.
1953年洪水
Mississippi R.
1970年洪水
The Rhine R.
1970年洪水
Tennessee R.
1861年洪水
1 2 3 4 5 6 7 8 9 10 11 12
Duration (day)
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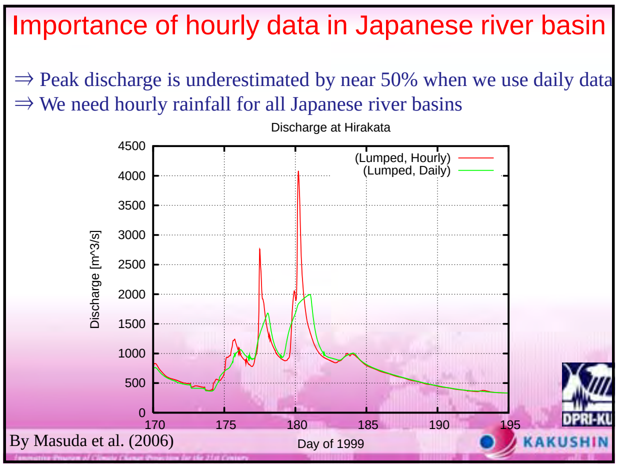
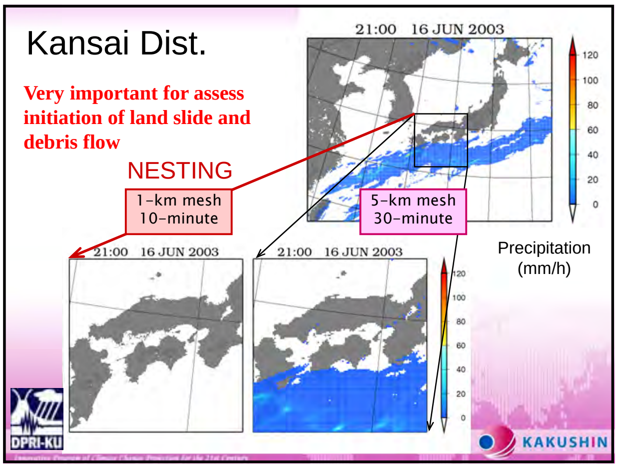
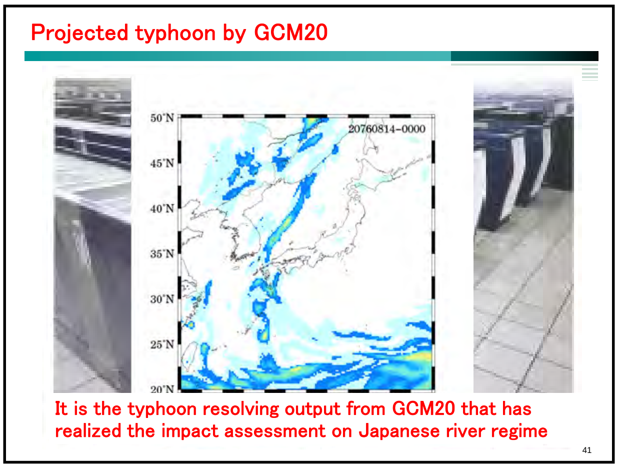
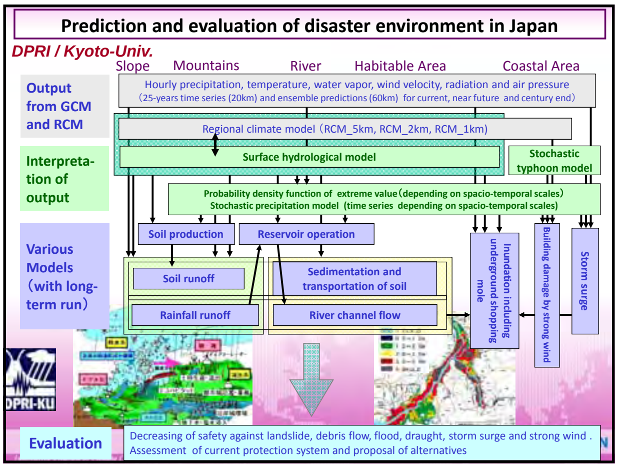
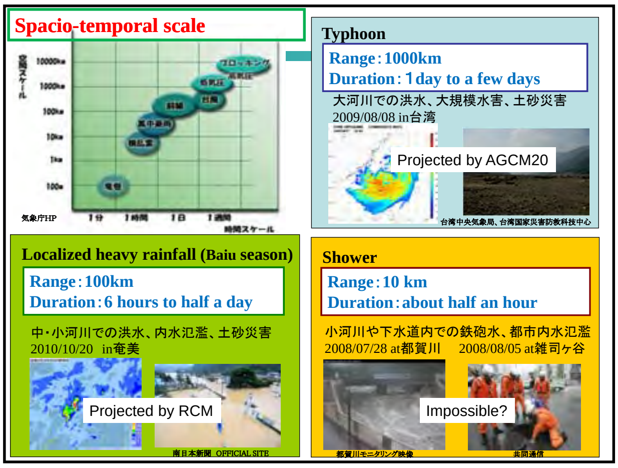

Importance of hourly data in Japanese river basin
⇒ Peak discharge is underestimated by near 50% when we use daily data
⇒ We need hourly rainfall for all Japanese river basins
Discharge at Hirakata
(Lumped, Hourly)
(Lumped, Daily)
Discharge [m^3/s]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
170
175
180
185
190
195
Day of 1999
By Masuda et al. (2006)
DPRI-KU
KAKUSHIN

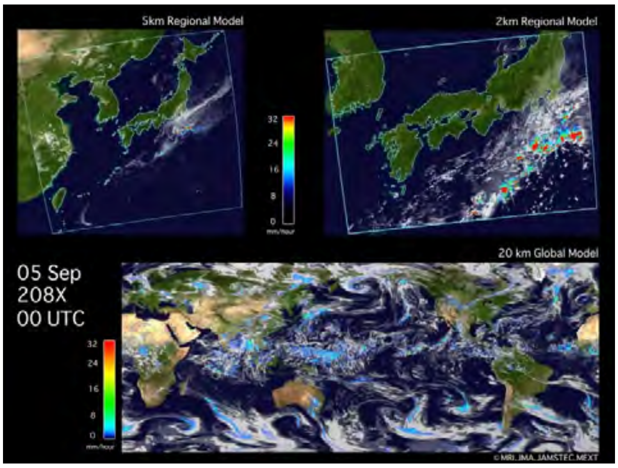

Kansai Dist.
Very important for assess initiation of land slide and debris flow
NESTING
1-km mesh
10-minute
5-km mesh
30-minute
21:00 16 JUN 2003
Precipitation (mm/h)
120
100
80
60
40
20
0
DPRI-KU
KAKUSHIN

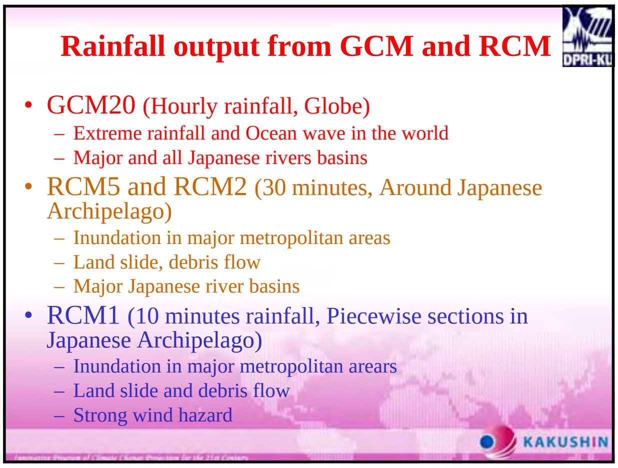

Projected typhoon by GCM20
50°N
45°N
40°N
35°N
30°N
25°N
20°N
20760814-0000
It is the typhoon resolving output from GCM20 that has realized the impact assessment on Japanese river regime
41


01 Sep 208X 00 UTC
©MRI,JMA,JAMSTEC,MEXT


Prediction and evaluation of disaster environment in Japan
DPRI / Kyoto-Univ.
Slope
Mountains
River
Habitable Area
Coastal Area
Output from GCM and RCM
Hourly precipitation, temperature, water vapor, wind velocity, radiation and air pressure
(25-years time series (20km) and ensemble predictions (60km) for current, near future and century end)
Regional climate model (RCM_5km, RCM_2km, RCM_1km)
Interpreta-tion of output
Surface hydrological model
Stochastic typhoon model
Probability density function of extreme value (depending on spacio-temporal scales)
Stochastic precipitation model (time series depending on spacio-temporal scales)
Various Models (with long-term run)
Soil production
Reservoir operation
Soil runoff
Sedimentation and transportation of soil
Rainfall runoff
River channel flow
Inundation including underground shopping mole
Building damage by strong wind
Storm surge
DPRI-KU
Evaluation
Decreasing of safety against landslide, debris flow, flood, draught, storm surge and strong wind .
Assessment of current protection system and proposal of alternatives


Spacio-temporal scale
Typhoon
Range：1000km
Duration：1 day to a few days
大河川での洪水、大規模水害、土砂災害
2009/08/08 in台湾
Projected by AGCM20
Localized heavy rainfall (Baiu season)
Range：100km
Duration：6 hours to half a day
中・小河川での洪水、内水氾濫、土砂災害
2010/10/20 in奄美
Projected by RCM
Shower
Range：10 km
Duration：about half an hour
小河川や下水道内での鉄砲水、都市内水氾濫
2008/07/28 at都賀川 2008/08/05 at雑司ヶ谷
Impossible?


5km Regional Model
2km Regional Model
20 km Global Model
05 Sep
208X
00 UTC
32
24
16
8
0
mm/hour


Rainfall output from GCM and RCM
GCM20 (Hourly rainfall, Globe)
– Extreme rainfall and Ocean wave in the world
– Major and all Japanese rivers basins
RCM5 and RCM2 (30 minutes, Around Japanese Archipelago)
– Inundation in major metropolitan areas
– Land slide, debris flow
– Major Japanese river basins
RCM1 (10 minutes rainfall, Piecewise sections in Japanese Archipelago)
– Inundation in major metropolitan arears
– Land slide and debris flow
– Strong wind hazard
DPRI-KU
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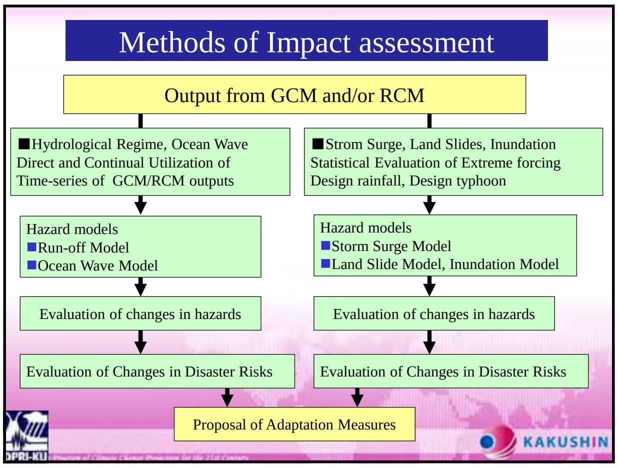
Methods of Impact assessment
Output from GCM and/or RCM
■Hydrological Regime, Ocean Wave
Direct and Continual Utilization of
Time-series of GCM/RCM outputs
■Strom Surge, Land Slides, Inundation
Statistical Evaluation of Extreme forcing
Design rainfall, Design typhoon
Hazard models
■Run-off Model
■Ocean Wave Model
Hazard models
■Storm Surge Model
■Land Slide Model, Inundation Model
Evaluation of changes in hazards
Evaluation of changes in hazards
Evaluation of Changes in Disaster Risks
Evaluation of Changes in Disaster Risks
Proposal of Adaptation Measures
DPRI-KU
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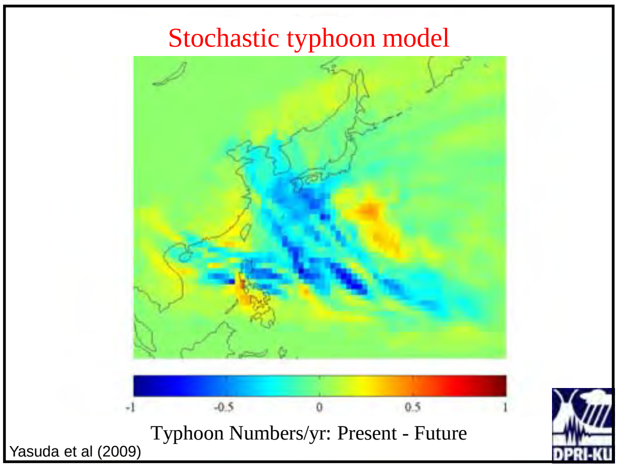
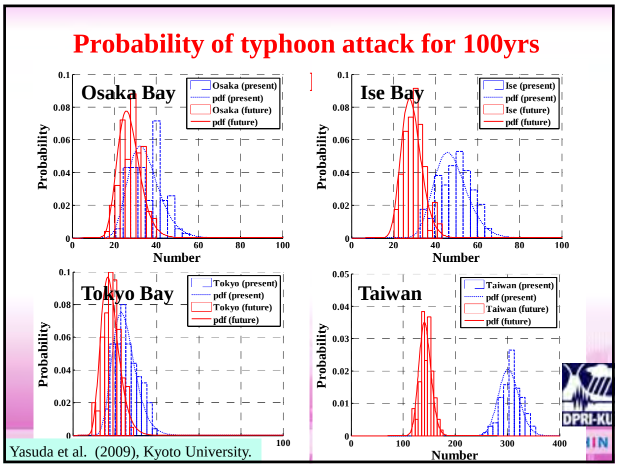
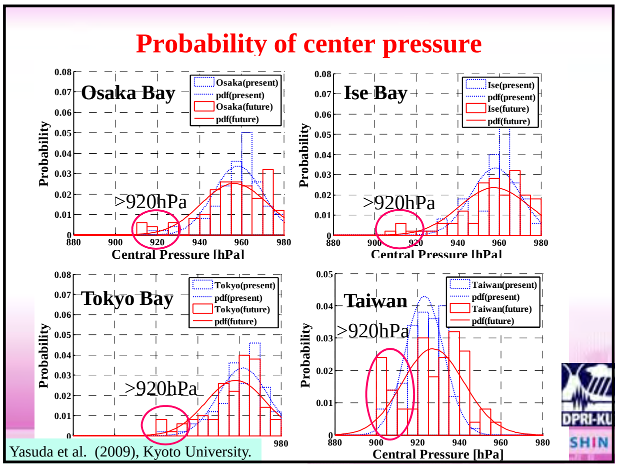
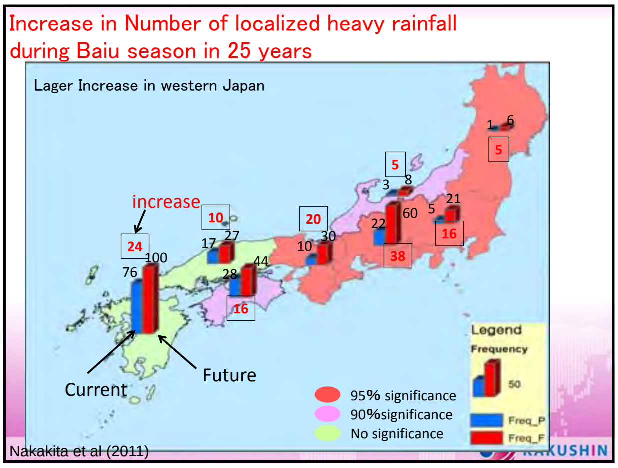
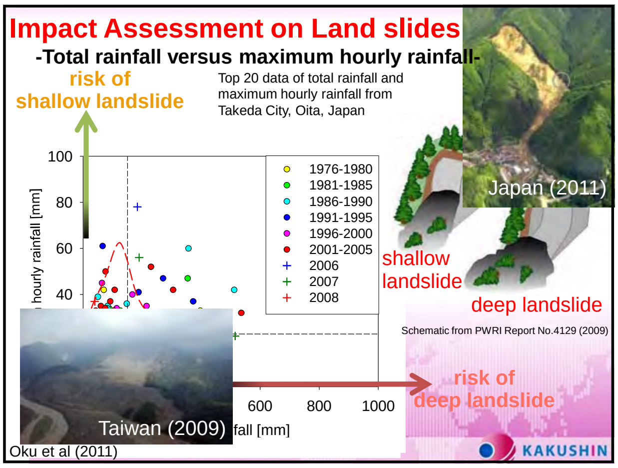
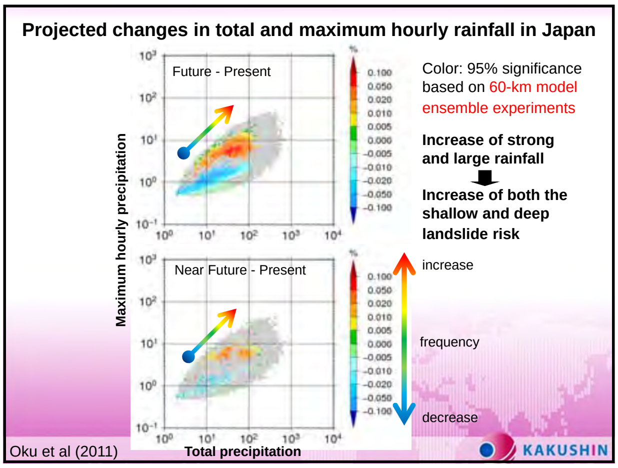

Stochastic typhoon model
-1
-0.5
0
0.5
1
Typhoon Numbers/yr: Present - Future
Yasuda et al (2009)
DPRI-KU

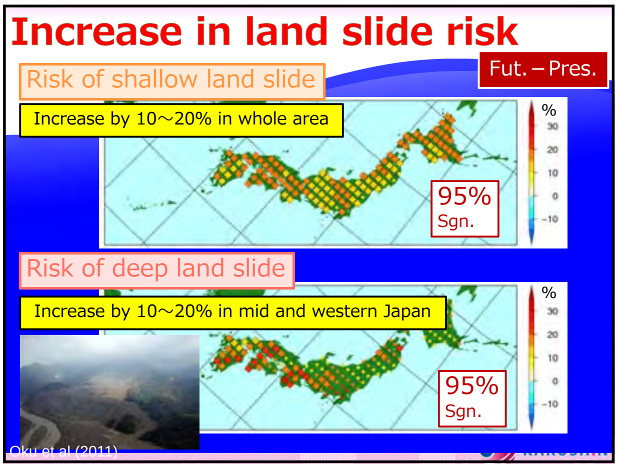

Probability of typhoon attack for 100yrs
Osaka Bay
Osaka (present)
pdf (present)
Osaka (future)
pdf (future)
Ise Bay
Ise (present)
pdf (present)
Ise (future)
pdf (future)
Tokyo Bay
Tokyo (present)
pdf (present)
Tokyo (future)
pdf (future)
Taiwan
Taiwan (present)
pdf (present)
Taiwan (future)
pdf (future)
Probability
Number
Yasuda et al. (2009), Kyoto University.
DPRI-KU

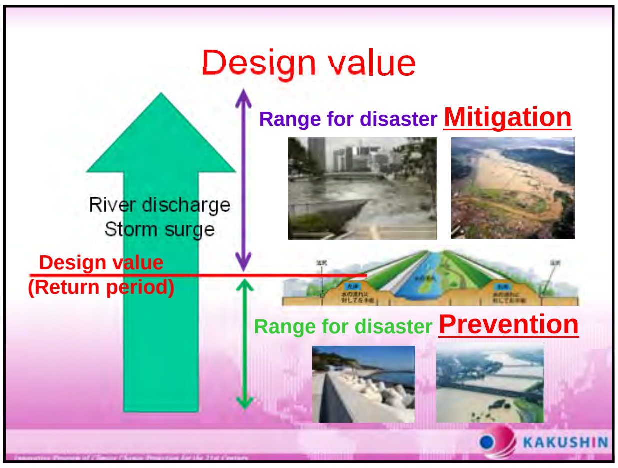

Probability of center pressure
Osaka Bay
Osaka(present)
pdf(present)
Osaka(future)
pdf(future)
Ise Bay
Ise(present)
pdf(present)
Ise(future)
pdf(future)
Tokyo Bay
Tokyo(present)
pdf(present)
Tokyo(future)
pdf(future)
Taiwan
Taiwan(present)
pdf(present)
Taiwan(future)
pdf(future)
>920hPa
>920hPa
>920hPa
>920hPa
Probability
Central Pressure [hPa]
Yasuda et al. (2009), Kyoto University.
DPRI-KU


Increase in Number of localized heavy rainfall
during Baiu season in 25 years
Lager Increase in western Japan
increase
Current
Future
95% significance
90%significance
No significance
Legend
Frequency
Freq_P
Freq_F
Nakakita et al (2011)
KAKUSHIN


Impact Assessment on Land slides
-Total rainfall versus maximum hourly rainfall-
risk of
shallow landslide
Top 20 data of total rainfall and
maximum hourly rainfall from
Takeda City, Oita, Japan
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006
2007
2008
Japan (2011)
shallow
landslide
deep landslide
Schematic from PWRI Report No.4129 (2009)
risk of
deep landslide
Taiwan (2009)
Oku et al (2011)
KAKUSHIN


Projected changes in total and maximum hourly rainfall in Japan
Future - Present
Near Future - Present
Maximum hourly precipitation
Total precipitation
Color: 95% significance
based on 60-km model
ensemble experiments
Increase of strong
and large rainfall
Increase of both the
shallow and deep
landslide risk
increase
frequency
decrease
Oku et al (2011)
KAKUSHIN


Increase in land slide risk
Fut.－Pres.
Risk of shallow land slide
Increase by 10～20% in whole area
95%
Sgn.
Risk of deep land slide
Increase by 10～20% in mid and western Japan
95%
Sgn.
Oku et al (2011)


Design value
Range for disaster Mitigation
River discharge
Storm surge
Design value
(Return period)
Range for disaster Prevention
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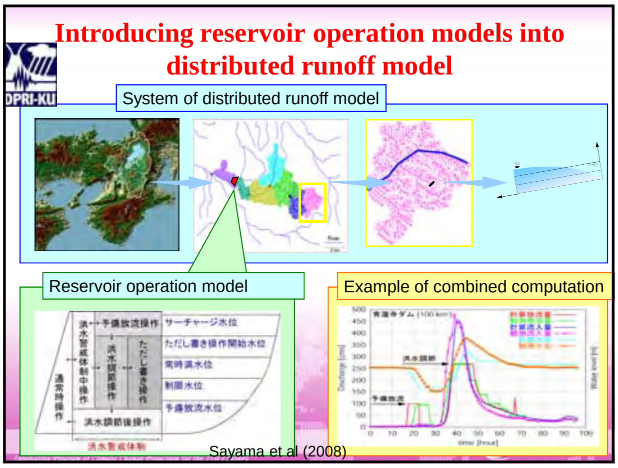
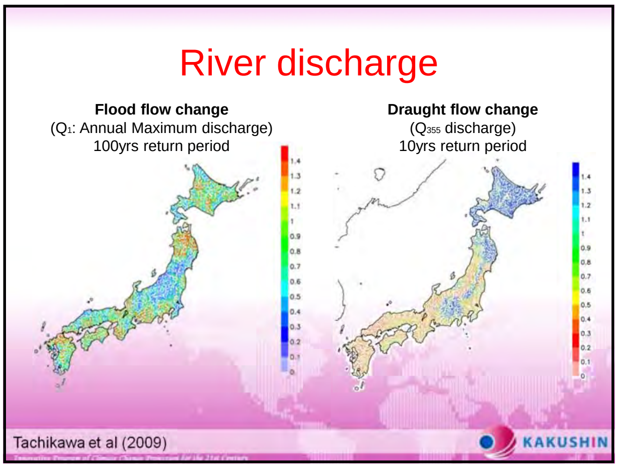
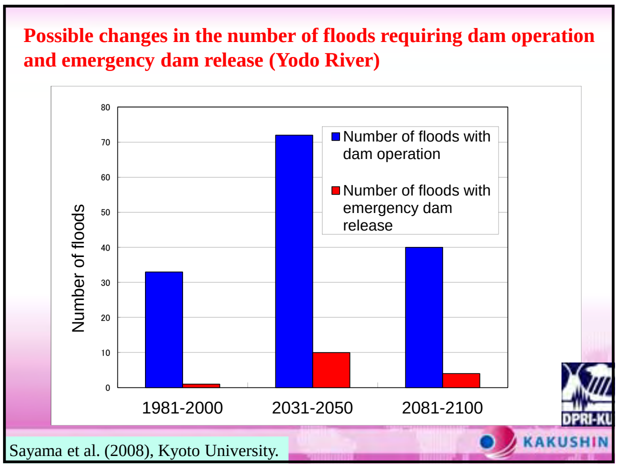
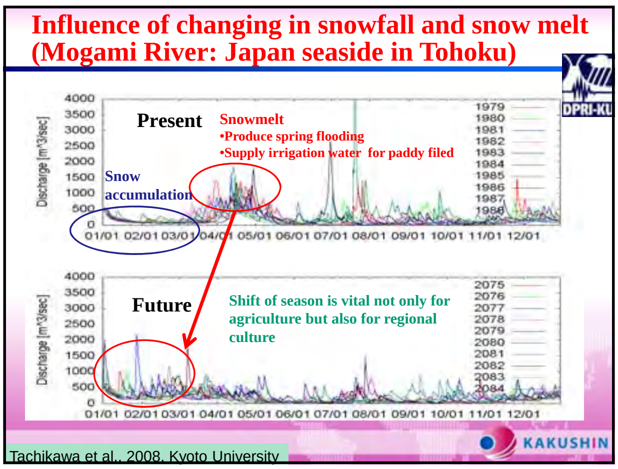
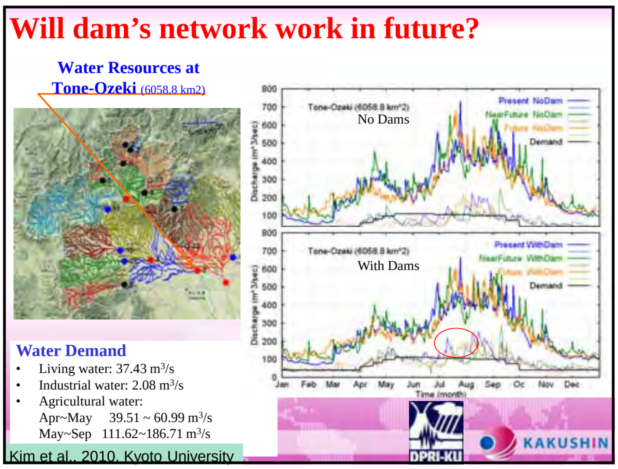

Introducing reservoir operation models into distributed runoff model
DPRI-KU
System of distributed runoff model
Reservoir operation model
Example of combined computation
Sayama et al (2008)


River discharge
Flood flow change
(Q1: Annual Maximum discharge)
100yrs return period
Draught flow change
(Q355 discharge)
10yrs return period
Tachikawa et al (2009)
KAKUSHIN


Possible changes in the number of floods requiring dam operation and emergency dam release (Yodo River)
Number of floods with dam operation
Number of floods with emergency dam release
Number of floods
1981-2000
2031-2050
2081-2100
DPRI-KU
Sayama et al. (2008), Kyoto University.
KAKUSHIN


Influence of changing in snowfall and snow melt
(Mogami River: Japan seaside in Tohoku)
DPRI-KU
Present
Snowmelt
•Produce spring flooding
•Supply irrigation water for paddy filed
Snow accumulation
Discharge [m^3/sec]
Future
Shift of season is vital not only for agriculture but also for regional culture
Tachikawa et al., 2008, Kyoto University
KAKUSHIN


Will dam's network work in future?
Water Resources at Tone-Ozeki (6058.8 km2)
No Dams
With Dams
Water Demand
• Living water: 37.43 m3/s
• Industrial water: 2.08 m3/s
• Agricultural water:
Apr~May 39.51 ~ 60.99 m3/s
May~Sep 111.62~186.71 m3/s
DPRI-KU
Kim et al., 2010, Kyoto University
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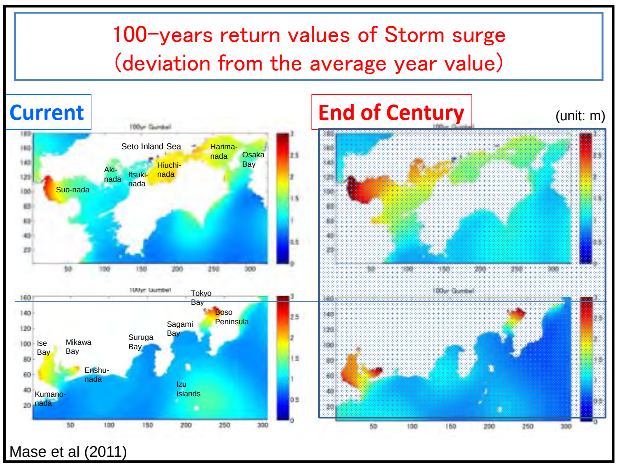

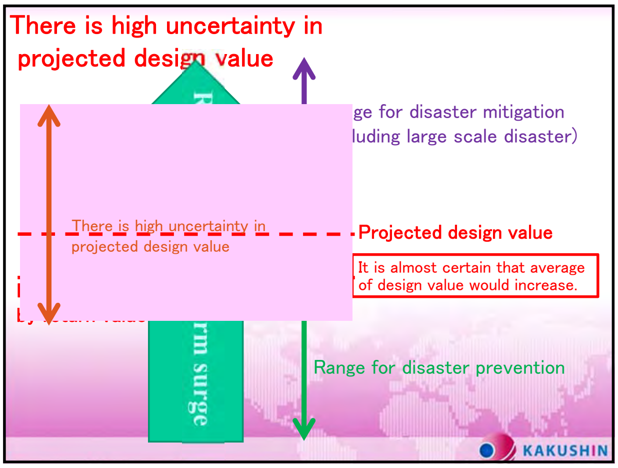

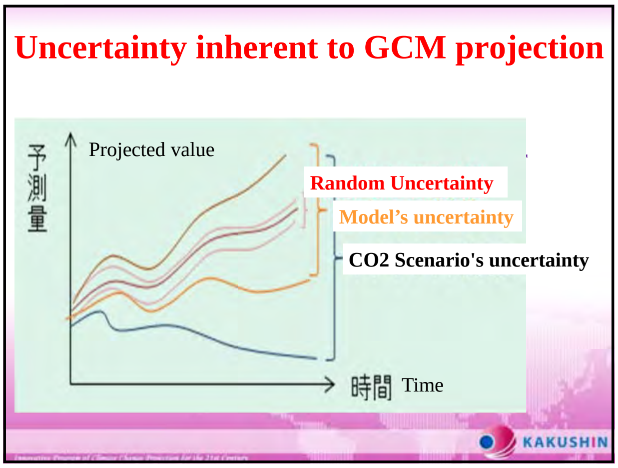

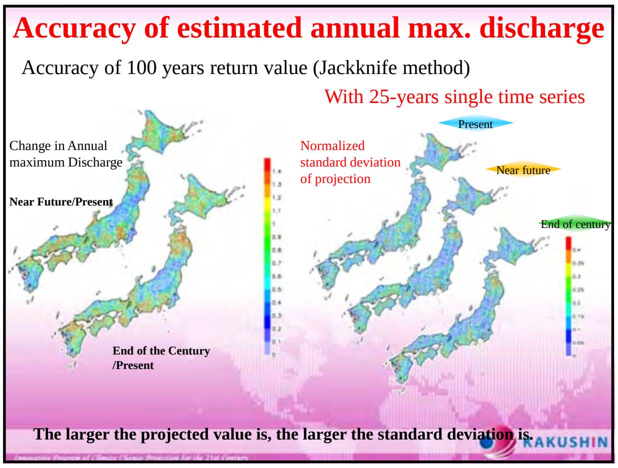

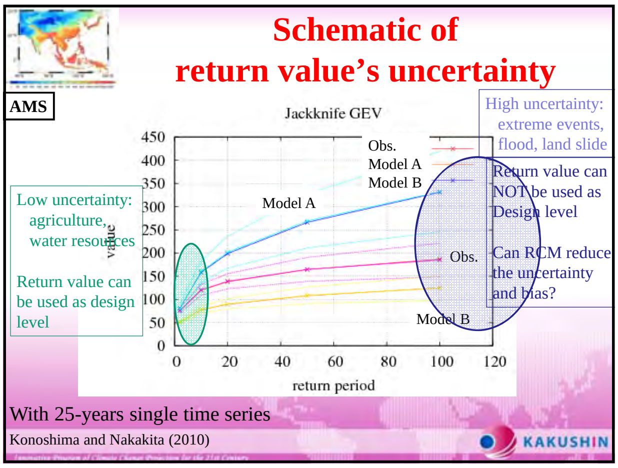

Outline

- **Climate change impact assessment**
  - Impact of AGCM20 on extreme events climate impact assessment in Japan
  - Typical climate change assessment on disaster environment in Japan – projection of change in design value
  - **Heading to adaptation :importance of taking a worst case scenario into consideration**
- Real-time ensemble weather forecast with high resolution

There is high uncertainty in projected design value

- We may be almost sure that average of extreme design value would increase.
- However, projected increase in the design value is merely rough estimation,
- because, for example, the worst case typhoon for a specific river basin may not be realized (computed) in a single projected time series.
- Therefore, it is very important to estimate river discharge when a worst case typhoon would pass through, even though we cannot estimate return period.

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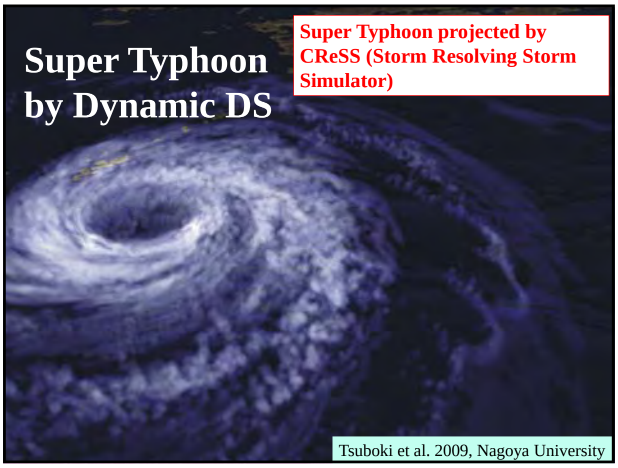
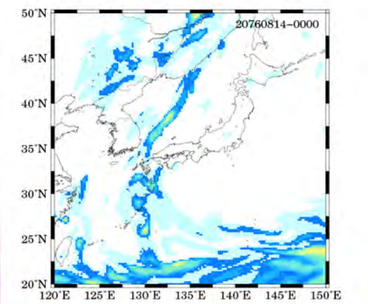


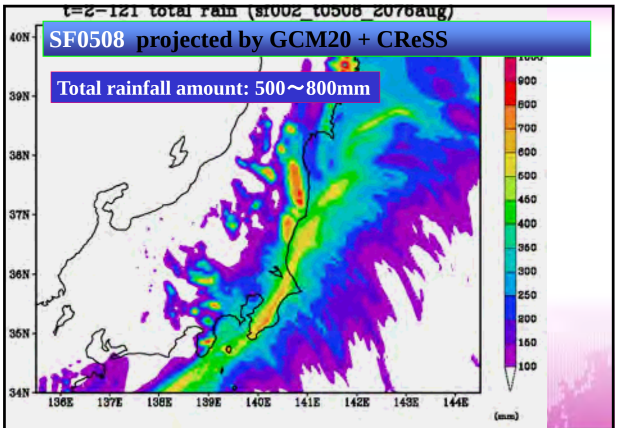
Tsuboki et al. 2009, Nagoya University

GCM20-Projection for Aug., 2076



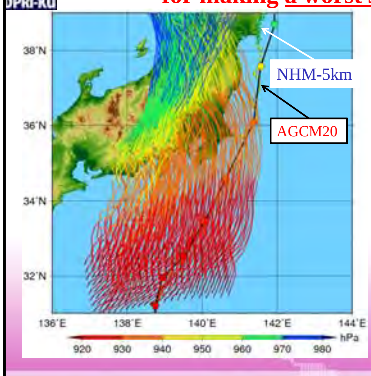
Animation by Konoshima and Nakakita (2010)

KAKUSHIN



Tsuboki et al., 2009, Nagoya University

Virtual Shifting of typhoon's initial position
- for making a worst scenario -



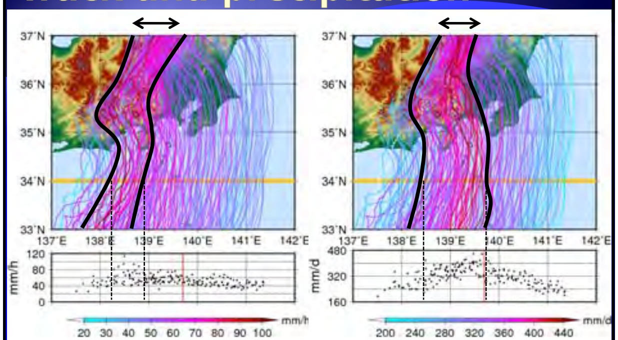
Virtual Shifting of typhoons initial position by keeping potential vorticity same
(a vorgas method)

Dynamic downscale by RCM

Worst case impact assessment on
- Land: extreme wind and rainfall
- Ocean: storm surge and wave height

Ishikawa et al (2009)

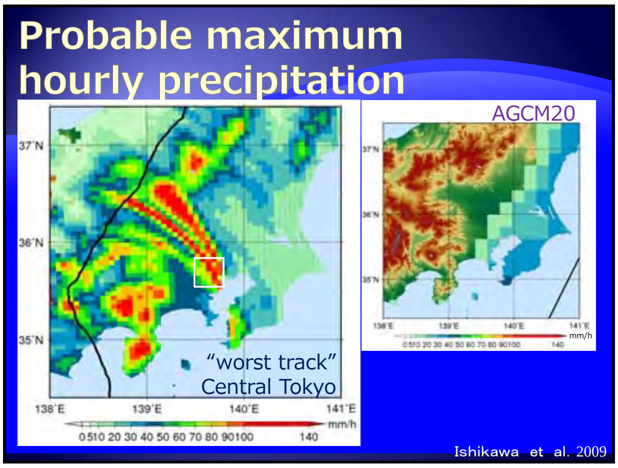
Track and precipitation

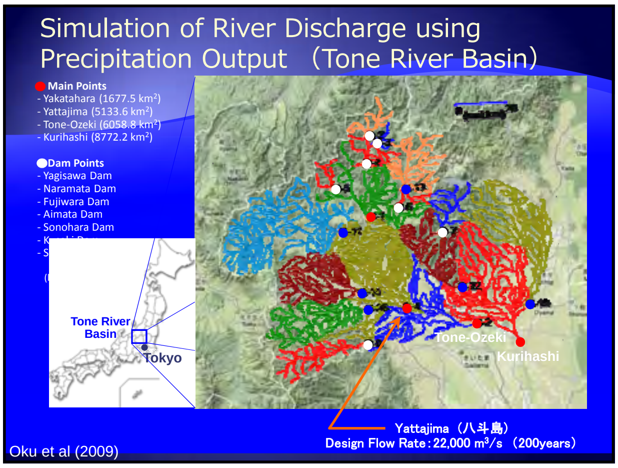


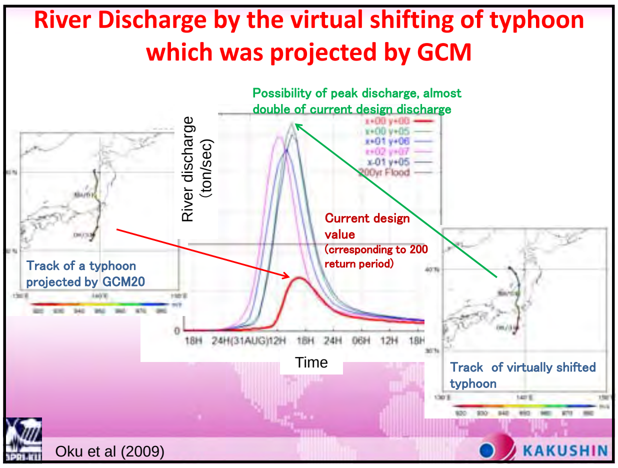
hourly precipitation

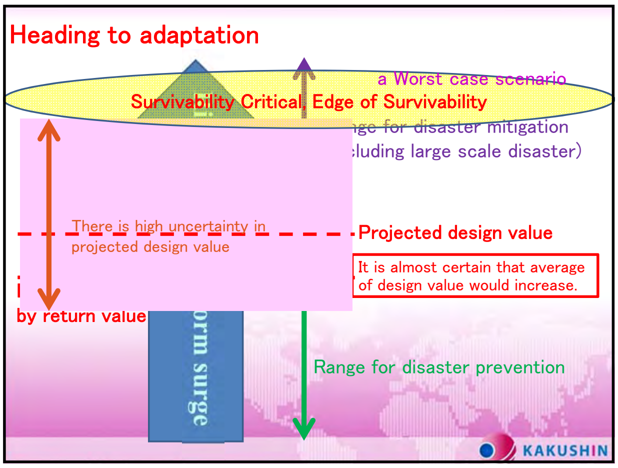
daily precipitation

Ishikawa et al. 2009









Summary (1)

1. The AGCM and RCM with super-high spatio-temporal resolutions (20 km-1 hour) made it possible to evaluate extreme hazard (ex. Max. discharge).
2. However, this does not mean that we can evaluate the changes in such a high spatial resolution.
3. We can get approximate projection on changes of return values of extreme events.
4. However, there is a risk that the return period does not have enough accuracy because there is no guarantee that quite extreme events could be properly projected within the limited number of ensembles. (Single time series output from the AGCM20 and RCM)
5. In this sense, it may be difficult to project correct design hazard for water management and flood control so on.

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Summary (2)

5. On the other hand, the risk management deal with phenomena beyond design hazards. In this sense, it is very important to take into account the result from a worst case scenario as one of the forcing hazard for disaster risk management under climate change.
6. Taking into consideration above items, I think, it is very important for climate change adaptation to discriminate more between planning with an uncertain design level and risk management with a worst case scenario.
7. Of cause, making the number of ensembles increase is essential for the Kakushin follow-up program.

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Launching of Sousei Program

- Kyousei(共生)Program:2002-2006
  - 20kmRCM
- Kakushin(革新)Program:2007-2011
  - 20kmGCM, 5,2,1kmRCM
  - Natural Disaster (Inc. water resources)
- Sousei(創生)Program:2012-2016
  - Impact assessment and producing adaptation methodologies (First priority)
  - for Natural Disaster, Water resources, Ecosystem and Eco service (Kyoto University will lead the nation wide assessment team)

SOUSEI

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Sousei (創生) Program (2012–2016)

Situation of output from Climate models

Sosei Program (post Kakushin) is the stage to take impact assessment as issue with the first priority under the mutual understanding among Japanese researchers.

We have been harvesting mutual understanding and respect among Japanese civil engineers, meteorologists and climatologists under the Kakushin Program, by hot discussions. (2007-2011).

Topics:
Natural hazard, Water Resources and Ecosystem and Eco-service

For adaptation decision making
Deterministic, Probabilistic and Beyond

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Groups in SOUSEI Program
(Program for Risk Information on Climate Change)

- A: **Prediction and diagnosis of imminent global climate change (Univ. of Tokyo)**
- B: **Climate change projection contributing to stabilization target setting (JAMSTEC)**
- C: **Development of Basic Technology for Risk Information on Climate Change (MRI)**
- D: **Precise impact assessments on climate change (Kyoto Univ.)**

SOUSEI

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Key issues in SOUSEI

- Generating PDF of extreme values with higher accuracy
  - Generating of PDF using a lot of 60km ensemble
  - Converting extreme values in 60km-scale into values in regional-scale using RCM5 and RCM2 daynamically dounscaled from GSM20.
- Proposing adaptation philosophy consistent with mitigation philosophy
  - Developing decision making methodology under high uncertainty of risk
  - Developing decision making methodology under no information on probability of a worst case

Precise impact assessments on climate change
(PI: E. Nakakita, KU (Kyoto University))

SOUSEI

- i. Climate change impacts on natural hazards (KU)
  - i-a Risk assessment of meteorological disasters under climate change (T. Takemi, KU)
  - i-b Risk assessment of water-related disasters under climate change (Y. Tachikawa, KU)
  - i-c Risk assessment of coastal disasters under climate change (N.Mori, KU)
  - i-d Measuring socio-economic impacts of climate change and effectiveness of adaptation strategies (H. Tatano, KU)
  - i-e Development of risk assessment and adaptation strategies for water-related disaster in Asia (S. Tanaka, ICHARM, PWRI)
- ii. Climate change impacts on water resources (K. Tanaka, KU)
  - ii-a Assessment of socio-economic impacts on water resources and their uncertainties under changing climate (K. Tanaka, KU)
  - ii-b Assessment of climate change impacts on the social-ecological systems of water resources and hydrological cycles (T. Oki, UT)
- iii. Climate change impacts on ecosystem and biodiversity (T. Nakashizuka, TU)
  - iii-a Assessment of climatic impacts on ecosystem and biodiversity (T. Nakashizuka, TU)
  - iii-b Economic evaluation of ecosystem service (S. Managi, TU)
  - iii-c Eco-climate system in Northeastern Eurasia and Southeast Asian tropics: impacts of global climate change (T. Kumagai, NU)
  - iii-d Assessment of multiple effects of climate change on coastal marine ecosystem (Y. Yamanaka, HU)

Sousei (創生) Program (2012–2016)

Proposing adaptation philosophy consistent with mitigation philosophy
- Developing decision making methodology under high uncertainty of risk
- Developing decision making methodology under no information on probability of a worst case

Generating PDF of extreme values with higher accuracy
- Generating of PDF using a lot of 60km ensemble
- Converting extreme values in 60km-scale into values in regional-scale using RCM5 and RCM2 dynamically downscaled from GSM20.

Topics:
Natural hazard, Water Resources and Ecosystem and Eco-service

For adaptation decision making
Deterministic, Probabilistic and Beyond

SOUSEI

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Conclusions

A) It should be emphasized that building up a new philosophy of adaptation for the climate change is very important.

B) It is also important to really re-recognize that improvement of understanding and real-time-forecasting accuracy of extreme weather should be one of the major countermeasures as adaptation.

Outline

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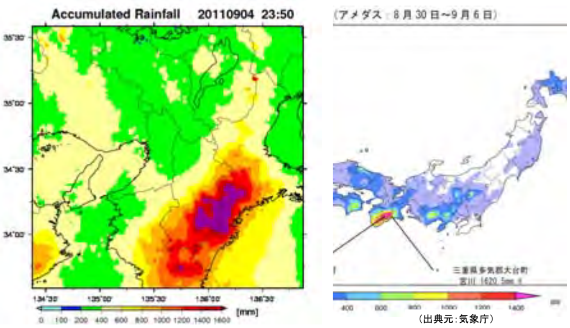
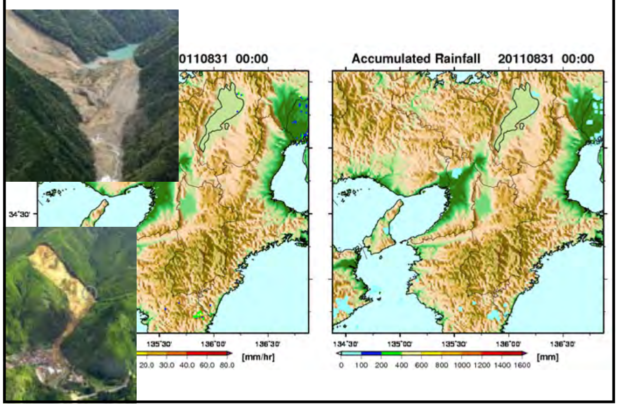
- **Real-time ensemble weather forecast with high resolution**

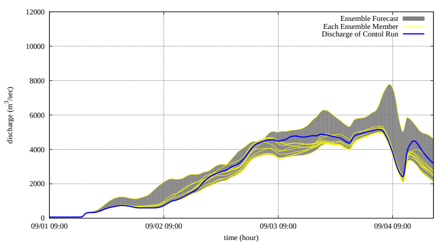
Heavy rainfall by typhoon(T1112)



Heavy rainfall by typhoon(T1112)



What is ensemble forecast

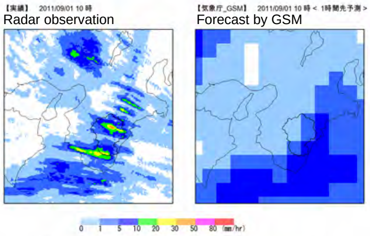


A number of trials (samples) of forecast, by which we can estimate statics of forecast such as mean, variable (uncertainty) and so on.

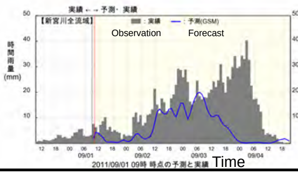
Real-time weather forecast

- **Ensemble forecast**
  - Numerical weather prediction with high resolution (20km)
  - Numerical weather prediction with super-high resolution (2km)
- Latest weather radar with high spacio-temporal resolution

Weather forecast with 20km NWP

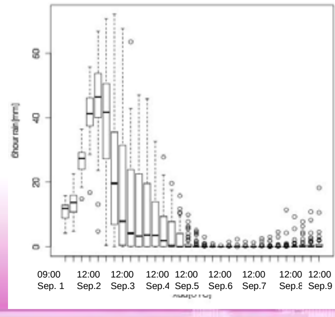


Hourly rainfall



By J-Power (2012)

Ensemble weather forecast for a week



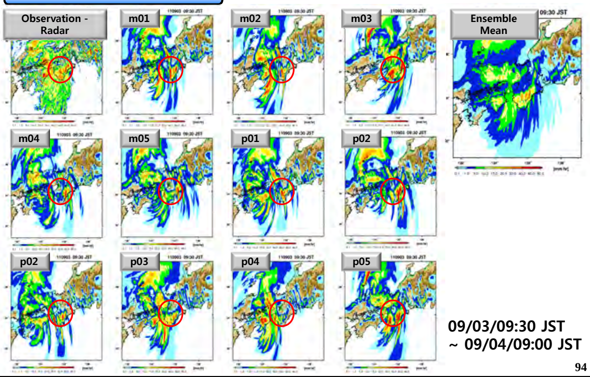
By Oishi (2012)

Real-time weather forecast

- **Ensemble forecast**
  - Numerical Weather Prediction with high resolution (20km)
  - Numerical Weather Prediction with super-high resolution (2km)
- Latest weather radar with high spacio-temporal resolution

Meso-Scale Ensemble NWP rainfall forecast

2km ensemble rainfall forecast

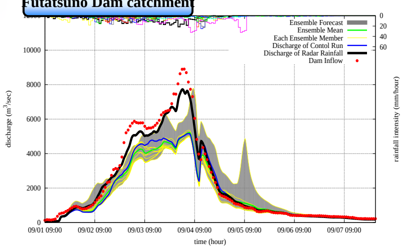


09/03/09:30 JST
~ 09/04/09:00 JST

Meso-Scale Ensemble NWP rainfall forecast

- **Hydrological application of the ensemble rainfall forecast**
  - The temporal distribution of Hydrograph generated by the ensemble are similar to the radar and dam inflow data, although it is underestimated at peak value.

Futatsuno Dam catchment

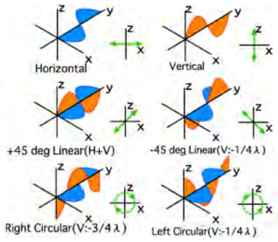


By Yu (2012)

Real-time weather forecast

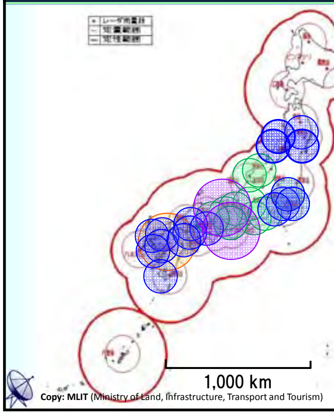
- **Ensemble forecast**
  - for a week with Numerical Weather Prediction
  - For 31 hours with Numerical Weather Prediction
- **Latest weather radar with high spacio-temporal resolution**

Polarimetric Doppler Radar



- This kind of weather radar can observe 3D structure of the rainfall and the wind in the rainfall system.
- This can observe various polarimetric parameters. (e.g. differential reflectivity Z_{DR}, correlation coefficient ρ_{HV}, differential phase shift K_{DP})
- We can estimate size, shape and type of hydrometeors.
- **These information will bring us not only a higher QPE accuracy but also a higher QPF accuracy through data assimilation by micro-physical process model.**

C and X band operational network by MLIT

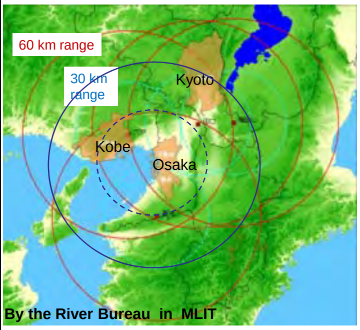


C-band Radar
Obs.: every 5 min
Distrib.: 5-10 min

X-band Radar
Obs.: every 1 min
Distrib.: 1-2 min

- 26 C-band Conventional
- 1 C-band full Polarimetric since April 2009
- 11 X-band Doppler Polarimetric since April 2010
- 17 X-band Doppler Polarimetric since April 2011
- 2 C-band Doppler full Polarimetric within 1-2 years

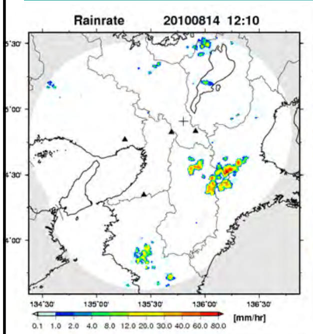
New operational network by X-band MP radars

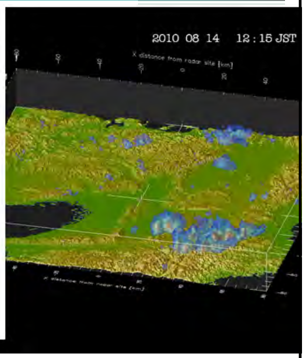


- Higher sensitivity by : X band radar
- Higher spatial resolution by : X band radar (250~500 m) Dense network
- Free from attenuation by : Polarimetric function (K_{DP}) Dense network together with C-band
- Higher QPE accuracy by : Polarimetric function (Z_{DR}, K_{DP})
- Shorter scan interval with low elevation : 1 minutes
- Shorter transmission time : 2 minute
- 3D image : Volume scan

New operational networks by X band polarimetric Doppler radars have been be in operation in various urban areas in Japan.

QPE and QPF by the new network





Automatic 3D detection and tracking system of baby cell aloft has been developed by Kyoto University.

Surveillance of natural dam breaking

Outline

- **Climate change impact assessment**
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Lecture3: Fundamentals of Freshwater Ecology

Yasuhiro TAKEMON *(Water Resources Research Center, DPRI, Kyoto University)*

River ecosystems provide us various “ecosystem services” including water supply, food provision, water purification through nutrient cycling, transportation of sediment and materials, flood regulation by water retention in the floodplain, and supporting recreation, culture and environmental education. In spite of these values, the ecosystems have been deteriorated under severe human impacts all over the world. In order to sustain those ecosystem services for the next generation, we should change ways of basin management to those enabling much wiser use of the services based on scientific knowledge of freshwater ecosystems.

In this lecture, several basic concepts in ecology, biodiversity, eco-hydraulics and eco-hydrology will be presented at first, and then, structure of freshwater ecosystems and its function will be explained from the aspects of habitat structure for various riparian organisms and material cycling in the ecosystem. Based on the knowledge of freshwater ecology, climate change impacts on river ecosystem will be discussed particularly in relation to “threshold temperature” and “cumulative temperature” as two key words in consideration with thermal impacts on organisms. The results will be applicable to environmental assessment of global warming impacts and thermal pollutions by nuclear power stations, sewage treatment facilities and other plants draining warm water.

Among human impacts on freshwater ecosystems, water pollution is still the most anxious matter of concern in some developing countries, whereas deterioration of hydro-geomorphologic dynamisms by dam construction and channel improvement leads to more serious changes in freshwater and coastal ecosystems all over the world. Biomass and biodiversity of freshwater community will be formed under a given condition of geomorphologic settings, and thus, physical habitat structure created by geomorphologic processes such as sediment erosion, transportation and deposition is an important basic factor for freshwater ecosystems. Therefore, a science for analyzing habitat structure and its maintenance mechanisms, named “Habitatology”, is required for development of future basin management. In this lecture, roles of disturbance in freshwater ecosystems and a conceptual scheme for the riverbed management will be shown with some examples investigated in the Tenryu River and the Yodo River systems. At last, we will discuss on future perspectives of integrated basin management rooted in freshwater ecology.

Note: Some of the concepts and knowledge introduced in this lecture will be applied practically to the ecological field surveys under the title of “Measurement of Riverbed Habitat Conditions for Aquatic Animals” at the Uji River and the Kizu River on 11th December.

Fundamentals of Freshwater Ecology

Yasuhiro TAKEMON
Water Resources Research Institute,
Disaster Prevention Research Institute,
Kyoto University

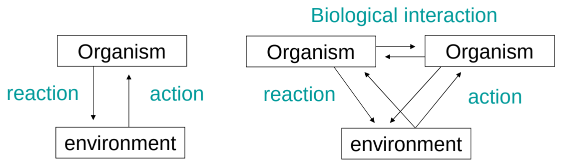
Contents

What is Ecology?

The branch of science that is concerned with the relationships between organisms and their environments (American Heritage Medical Dictionary)

Haeckel, E. (1869) : Okologie, from Gk. oikos "house, dwelling place, habitation" + -logia "study of."

Elton, C.(1927): Economics and/or Sociology based on interactions among organisms



What is ecosystem structure and function?

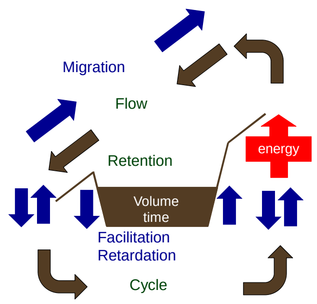
Structure

Flow
- Material flow
- Energy flow

Cycle
- Material cycling

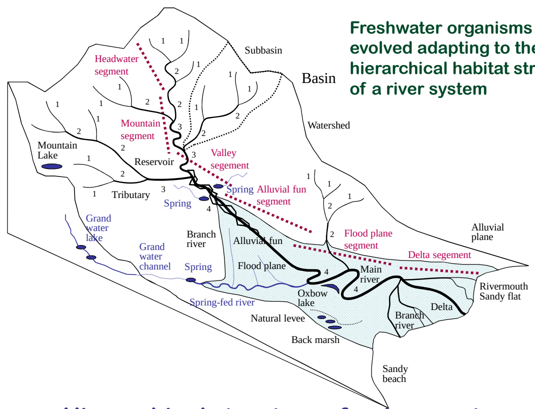
Function

Biological manipulation on the flow and cycle



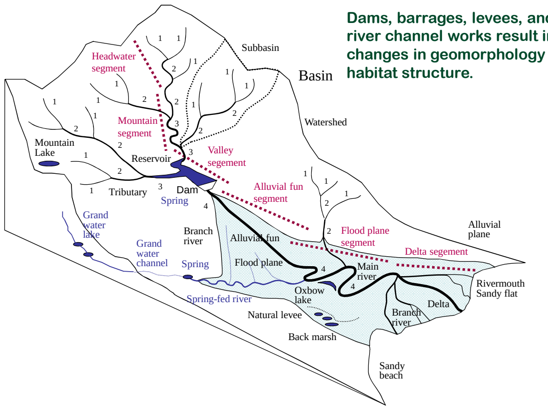
Contents

Freshwater organisms have evolved adapting to the hierarchical habitat structure of a river system



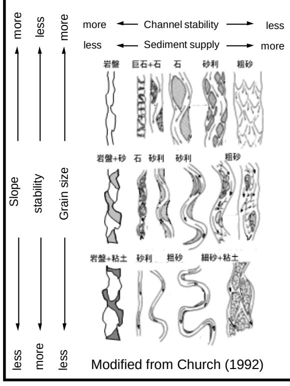
Hierarchical structure of a river system

Dams, barrages, levees, and river channel works result in changes in geomorphology and habitat structure.

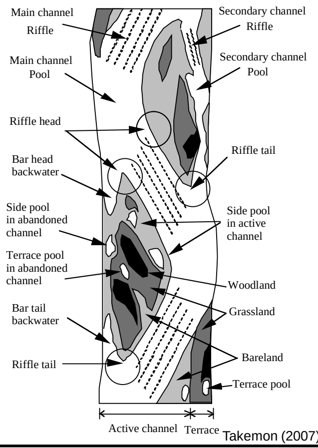


Human impacts on habitat structure of river systems

Classification of reach scale habitat structure

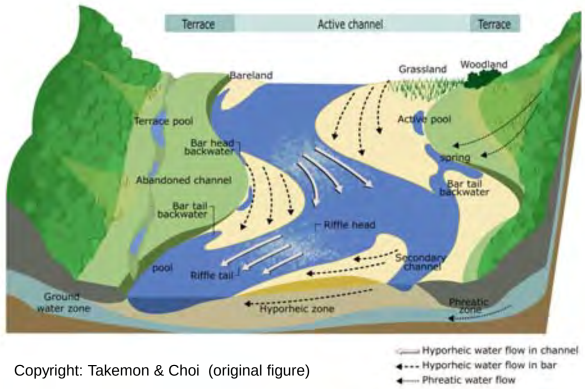


Modified from Church (1992)



Takemon (2007)

Classification of habitat structure in consideration with subsurface waters in the river channel



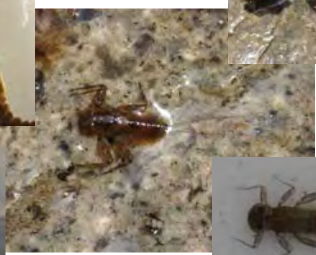
Copyright: Takemon & Choi (original figure)

Organisms living in the riffle beds

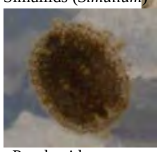
Requiring smooth surface of stones and rocks

Simuliids (*Simulium*)

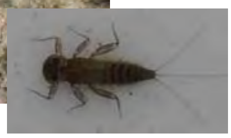
Blepharocerids



Heptageniids (*Epeorus*)



Psephenids



Heptageniids (*Rhithrogena*)

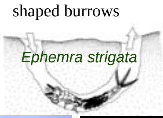
Organisms living in the sediment

Gliding burrowers
moving smoothly on the surface of stones buried in the sandy or muddy substrates

Free burrowers
moving freely in sandy or muddy substrates, sometimes building U-shaped burrows

Tube builders
moving smoothly on the surface of stones buried in the sandy or muddy substrates

Chroloperlidae gen.sp.

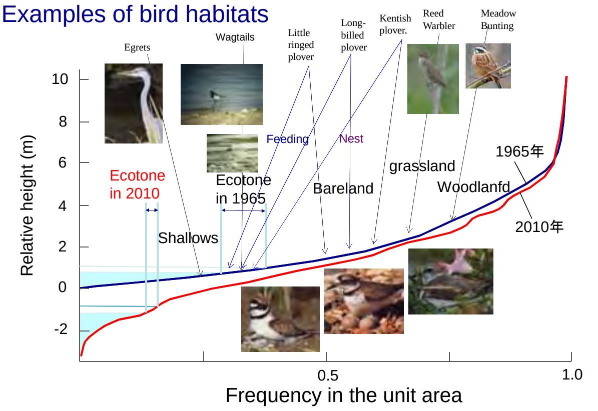


Naididae gen.spp.

Chironominae gen. sp.

erosional ⇦ Habitat structure ⇨ depositional

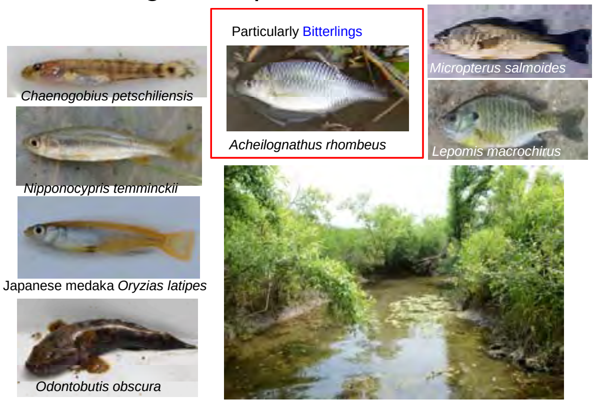
Examples of bird habitats



環境省 (編)(2006改定) 日本の絶滅のおそれのある昆虫類-レッドデータブック-5 昆虫類. 246pp. 編集/環境省自然環境局野生生物課, 発行/財団法人自然環境研究センター 発行.
京都府(2002)京都府レッドデータブック2002 上 野生動物編:935pp. 京都府文化環境部自然環境保全課.
竹門康弘, 土居秀幸, 谷田一三(2003)木津川砂州における河川水流入部の水質環境と間隙動物の分布様式. 木津川の総合研究:263-270. 河川学術研究会木津川研究グループ.
竹門康弘・若園美沙子・松原始・江崎保男(2009)2.2.3.鳥類の糞から得られた餌動物の特徴.木津川の総合研究II:121-134.

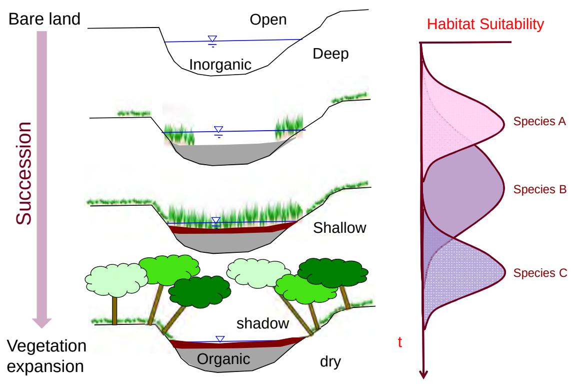
Terrace pool in the Kizu River

Fishes living in the pools and backwaters



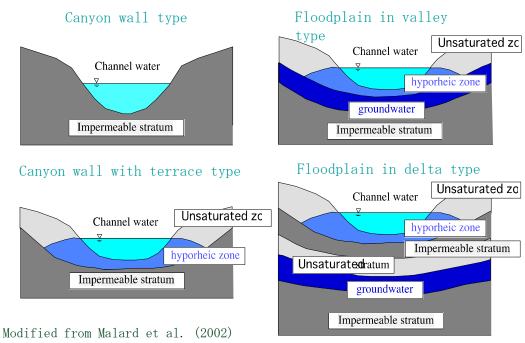
Other aquatic inhabitants

A succession pattern of terrace pools



Interspecific relations among pool dwellers

Patterns in relations of channel water level to ground water level



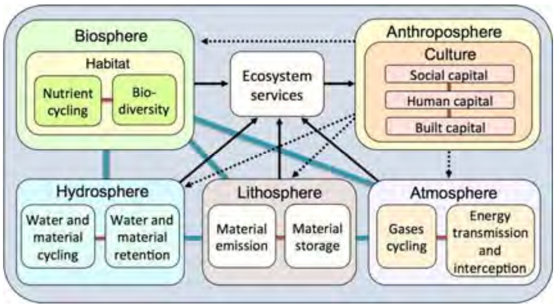
Modified from Malard et al. (2002)

Contents

Freshwater ecology is essential for understanding and utilization of "River Ecosystem Services "

Scheme of ecosystem services in relation to ecosystem components

Key Concept: Balance of material cycling and its retention within and among the ecosystem components



Modified from Costanza

River Ecosystem Services

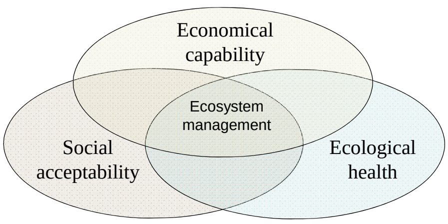
Classification	Examples	Function
Supply		
Water resources	Drink, Irrigation, Industrial	Resources
Energy	Hydro-power stations	
Materials	Sediment, Nutrient, Food	
Provision		
Habitat	Biodiversity	Resources and Environment
Field	Agriculture, Fishery	
Landscape	Recreation, Tourism	
Regulation		
Flood control	Drainage and mitigation	Disaster Reduction and Environment
Erosion-deposition	Riverbed level regulation	
Material cycling	Water quality regulation	

Function (overall): Culture Formation

Modified from Costanza et al.,1997

Ecosystem Management

Management of ecosystems authorized by government acts or assignments aiming at maintaining ecosystem structure and function by means of adaptive management based on monitoring and its feedback.



After Kamizaki (2000) "Ecosystem Management"

Fundamentals of Freshwater Ecology

Contents

Lecture 3 on 4th Dec 2013

Ecohydrology and Ecohydraulics

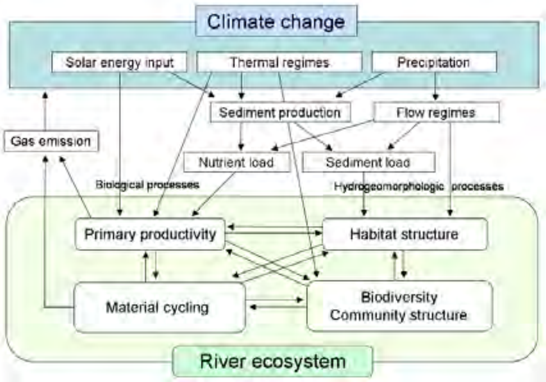
Ecohydrology: an interdisciplinary field studying the interactions between water and ecosystems

Ecohydraulics: an interdisciplinary field studying the hydraulic processes in ecosystems

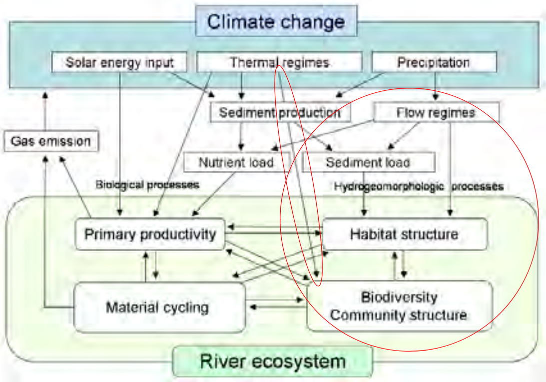
Ecogeomorphology: an interdisciplinary field studying the geomorhologic processes in ecosystems

Contents

Climate change impacts on river ecosystem



Climate change impacts on river ecosystem



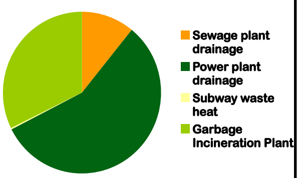
Causes for raising water temperature

1) Sewage plant drainage
   Japan: 328,000 Gcal/yr/ha

2) Power plant drainage
   Japan: 989 Kcal/Kwh

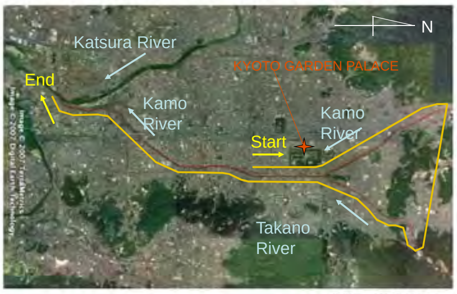
3) Subway waste heat
   Tokyo: 4,300 Gcal/yr•station
   Sapporo: 524Gcal/yr•station

4) Garbage Incineration Plant
   Japan: 2,000kca/kg



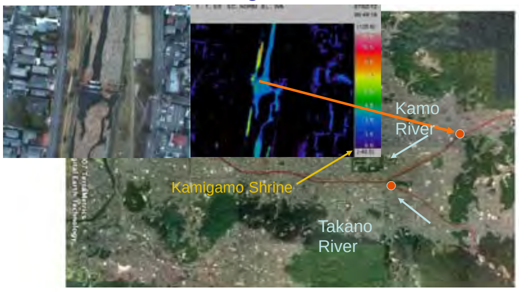
After NEDO (1990)

Method for detecting in-stream fountain site



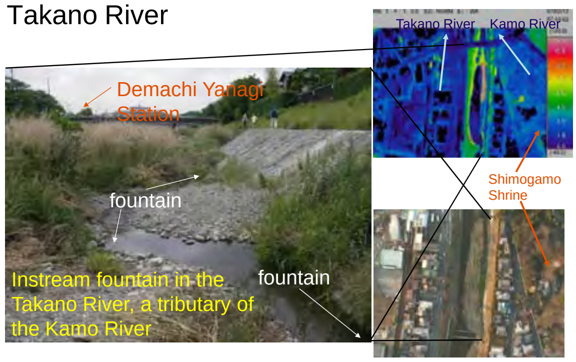
Aerial images of thermal infrared video were taken from a helicopter in the early morining (6:00–8:00) on 12 February 2007 at a hight of 210m with a resolution of 0.72m.

In-stream fountains at Nishigamo beside the Kamigamo Shrine

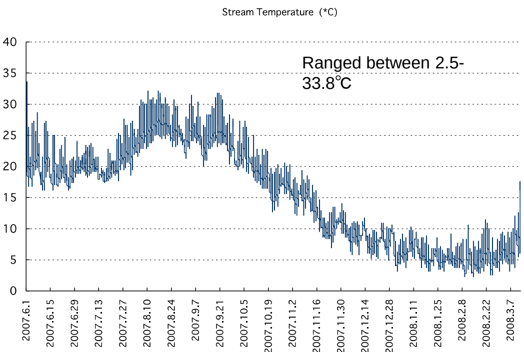


Aerial images of thermal infrared video were taken from a helicopter in the early morining (6:00-8:00) on 12 February 2007 at a hight of 210m with a resolution of 0.72m.

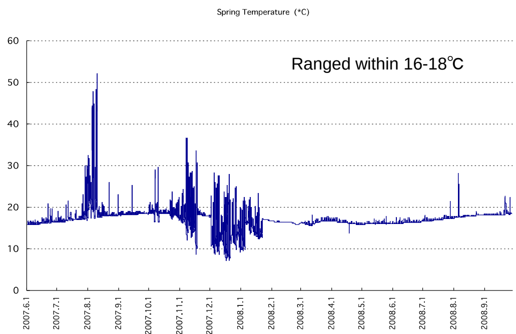
In-stream fountains at Demachi Yanagi beside the Shimogamo Shrine in the Takano River



Seasonal changes in water temperature of the main channel of the Takano River at Shimogamo site

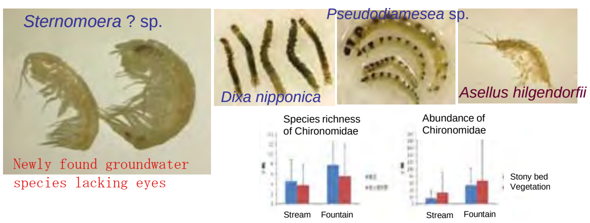


Seasonal changes in water temperature at the in-stream fountains of Shimogamo site



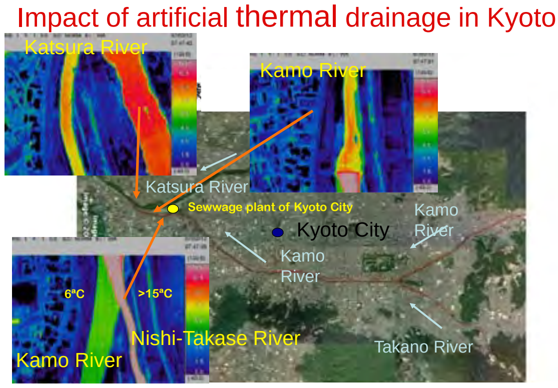
Benthic animals found at in-stream fountains

	Endemic species	Dominant species
Nishigamo (St.1)	*Paratya compressa compressa*	Tubificidae gen. spp.
Kamigamo (St.2)	*Nihonogomphus viridis*	*Tokunagayusurika akamushi*
Shimogamo (St.5)	*Sternomoera ? sp.* *Pseudodiamesea sp.*	*Asellus hilgendorfii*
Kojin-Bridge (St.7)	*Dixa nipponica*	*Siphlonurus yoshoensis*



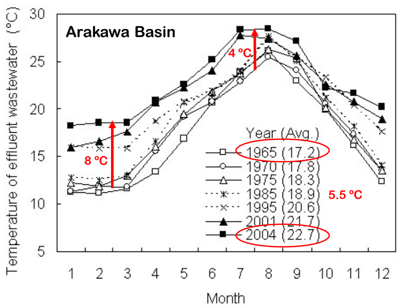
Fountain sites are characterized by a set of cold stenothermal species endemic to the fountains and abundant tolerant species against eutrophication.

Impact of artificial thermal drainage in Kyoto



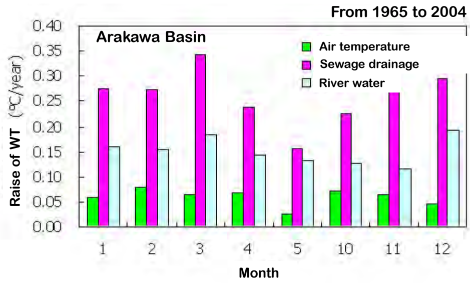
Aerial images of thermal infrared video were taken from a helicopter in the early morning (6:00–8:00) on 12 February 2007 at a hight of 210m with a resolution of 0.72m.

Water temperature raise of sewage plant drainage



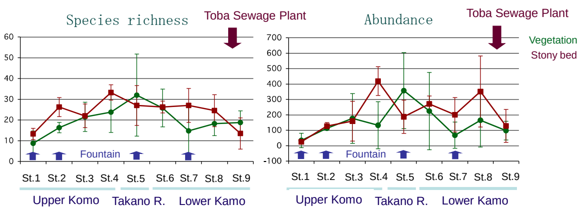
Kinouchi et al.(2005)

Sewage plant drainage contributes the raise of river water temperature



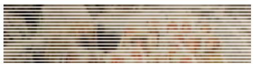
Kinouchi et al.(2005)

Longitudinal changes in benthos community characteristics along the Kamo River



・Both pecies richness and abundance showed a peak in the middle reaches of the Kamo River around the conjunction with the Takano River.

Homoiothermal vs Poikilothermic

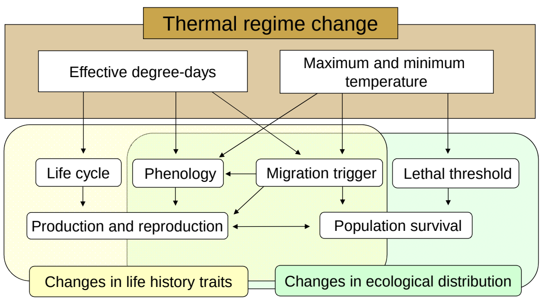


Since most of organisms in river ecosystem are poikilothermic, impact of temperature change is serious!

A “monkey ball” for warming up each other observed in winter in Japan, the northern boarder of wild monkey.

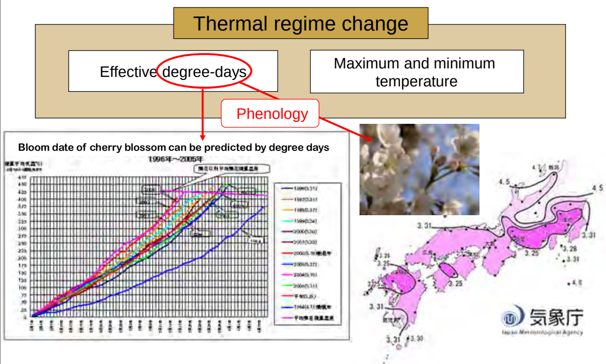
Fish has a narrower thermal range for survival than mammal. A secene of“Kaibori” , draining pond for fishing.

Impacts of thermal regime change on biological populations

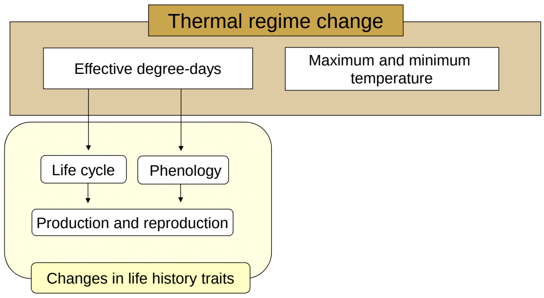


Arrows indicate causal directions of impact

Thermal regime affects poikilothermic organisms through degree days

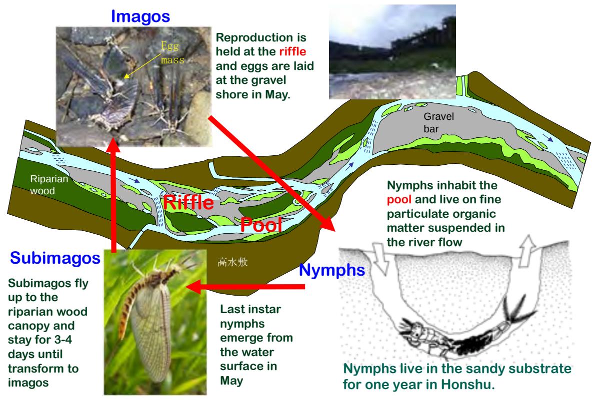


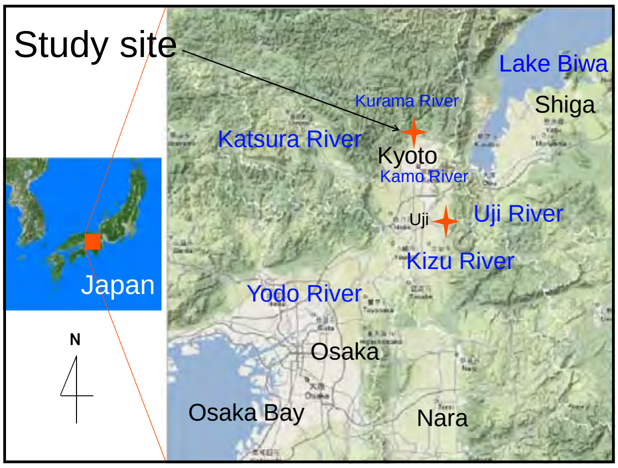
Relations of changes in thermal regimes to stream ecosystem



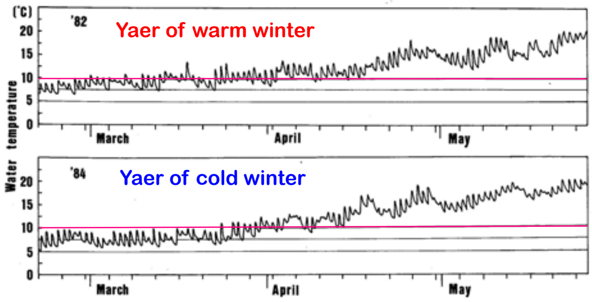
Arrows indicate causal directions of impact

Life cycle of the mayfly *Ephemra strigata*



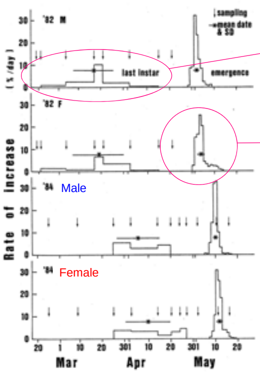


Difference of seasonal timing of the last instar recruitment and emergence between 1982 and 1984 seemed to be related to the thermal regimes

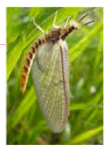


After Takemon (1990)

The mayfly *Ephemera strigata* has a distinctively synchronous emergence period in May



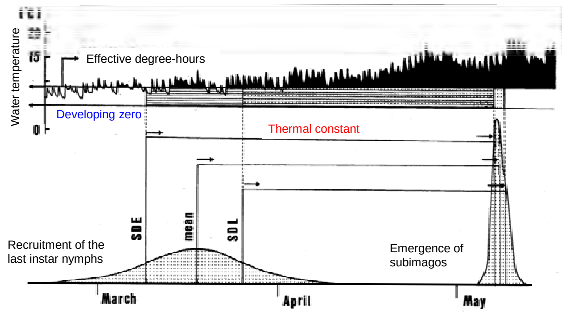
Nypmphs were collected weekly to estimate the last instar recruitment in the field



Emergence of subimagos were counted everyday using emergence traps in the field

The seasonal timing of the the last instar recruitment and emergence was significantly different between years

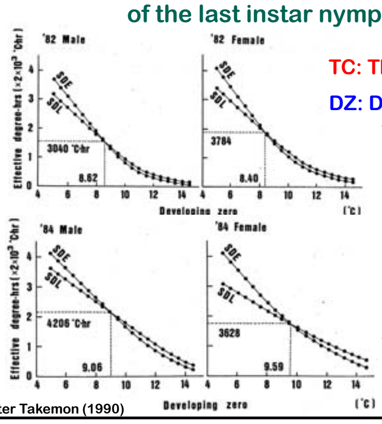
Conceptual model for calculation of thermal constant in the last instar nymphs of the mayfly



Thermal constant: effective degree-days /hours required for completion of development

Developing zero: the lower threshold temperature for development

Graphical method for determination of TC and DZ of the last instar nymphs



TC: Thermal constant

DZ: Developmental zero

TC and DZ could be estimated by assuming the nymphs of SDE and SDL have the same TC .

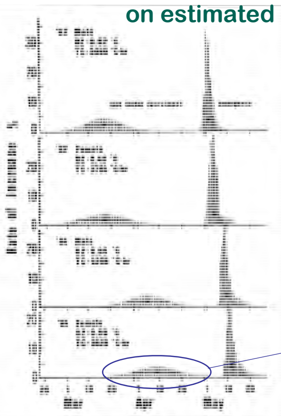
Male TC = 3624° C hr (151° C day)
Female TC = 3706° C hr (154° C day)

Male DZ = 8.8° C
Female DZ = 9.0° C

This method is widely applicable for poikilothermic organisms living in streams and rivers.

After Takemon (1990)

Simulation of the emergence curves based on estimated DZ and TC.

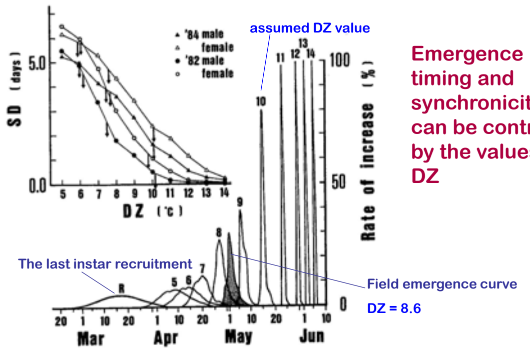


Effective degree hours/days methods can predict not only the emergence timing (phenology) but also the emergence syncronicity

Normal distribution curves with the same standard deviations of the field samples were used.

After Takemon (1990)

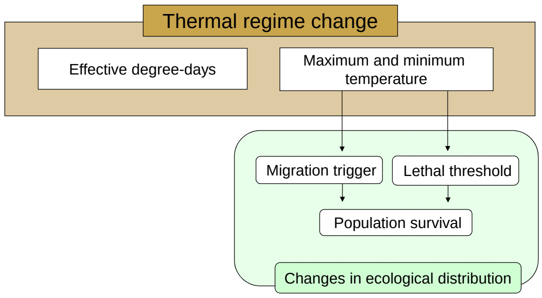
Simulation of the male emergence curves based on a set of different values of DZ



Emergence timing and synchronicity can be controlled by the values of DZ

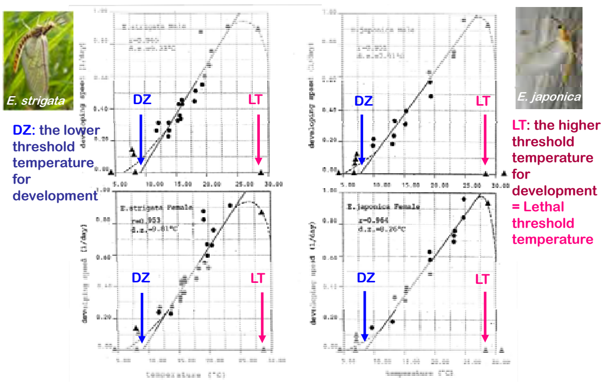
After Takemon (1990)

Relations of changes in thermal regimes to stream ecosystem



Arrows indicate causal directions of impact

Ordinary method for determination of DZ by rearing the animals under different constant temperature conditions



DZ: the lower threshold temperature for development

LT: the higher threshold temperature for development = Lethal threshold temperature

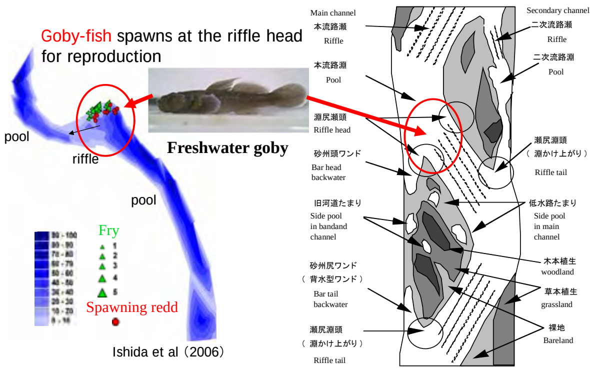
Fundamentals of Freshwater Ecology

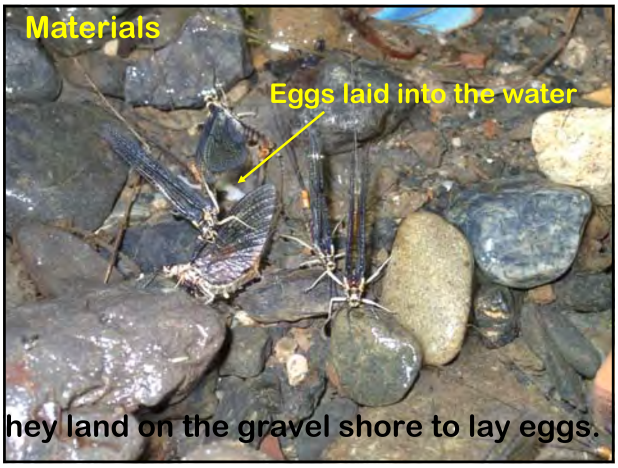
Contents

Lecture 3 on 4th Dec 2013

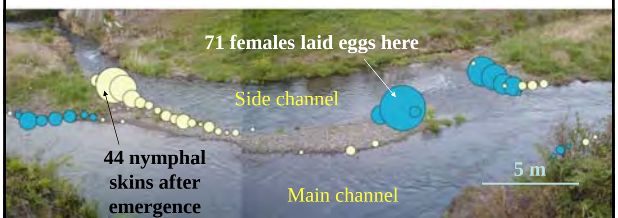
Habitat evaluation perspectives

Habitats of aquatic animals are determined by geomorphology





An example of the concentrated distribution of oviposition sites of *Ephemera strigata* (Eaton)



After Tanaka et al (2003)

Methods

Habitat survey

- •Geomorphology measurement (contour of cm resolution)
- •Permeability test of hyporheic zone (→ current speed)
- •Measurement of substrate diameter
- •Water quality (WT, DO, EC, pH, NO_3, etc)
- •Measurement of canopy coverage (using fisheye lens)

Biological survey

Distribution pattern of oviposition sites	Field experiment of egg hatchability and survival ratio

Correlation analyses

Finding out factors governing fitness of the oviposition sites

Packer method was adopted for measuring permeability

Darcy's low for flow: $v = ki$

V: mean current speed, *i: hydraulic* gradient

Stand pipe was set at the depth of 15 cm from the bottom in channel and from groundwater surface on the bar.

Packer method

$$k = \frac{Q}{2\pi hl}\sinh^{-1}\left(\frac{l}{2r}\right)$$

k: Hydralulic conductivity
Q: Flow volume
l : Length of sediment column
h: Height of water column under equilibrium condition

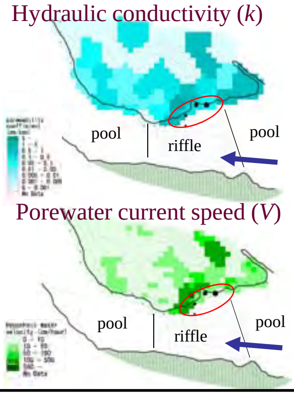
Piezometer method

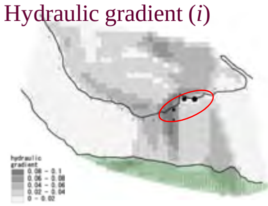
$$k = \frac{r^2}{2l\left(t_2 - t_1\right)}\ln\left(\frac{h_1}{h_2}\right)\sinh^{-1}\left(\frac{l}{2r}\right)$$

t_1: Initial time of water injection
t_1: Completion time of penetration

Inner diameter (r) =4.6cm、*length (l)*=5cm

Results: spatial variations in hyporheic current velocity at Site B





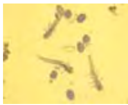
Distribution of the oviposition sites corresponding well to the sites of high hydraulic conductivity and gradient, and therefore, high current speed of hyporheic water.

Experimental design for rearing eggs and young instar larvae in the field at site B

Burying sites

Burying case

Collected eggs



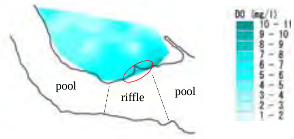
Collected nymphs

Cases with 1,000-2,000 eggs were buried on 2 May and collected on 24 May, 7th June, 22nd June, and 9th July 2003.

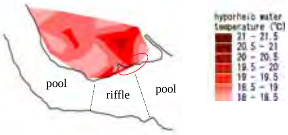
Total number of eggs
Living | **Dead** | **Hatched**
Hatched: **Living** | **Dead**

Egg mortality = Number of dead eggs / Total number of eggs
Hatchability = Number hatches / Total number of eggs
Survival ratio = Hatchability *Number of living nymphs / Total number of hatches

Distribution of DO concentration and water temperature of hyporheic water at site B.



DO concentration (mg/l)

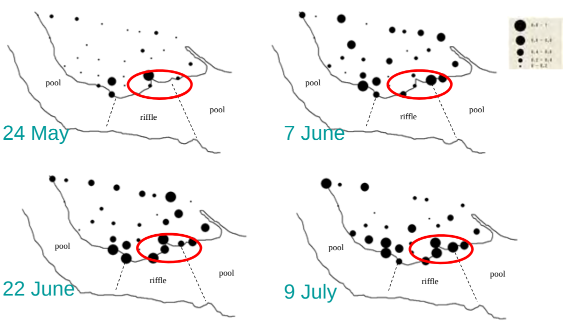


Water temperature (℃)

1）DO concentration was high around the shore area of upper riffle corresponding to down welling zone of the channel water.

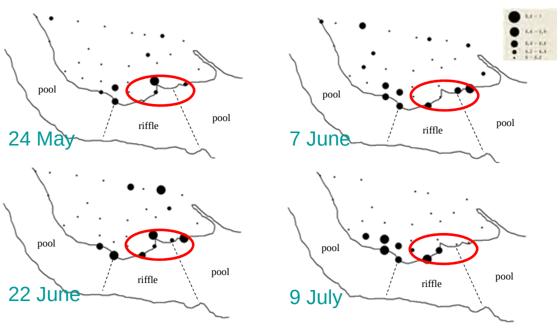
2）Water temperature was high inner area of the bar.

Results: distribution of egg hatchability



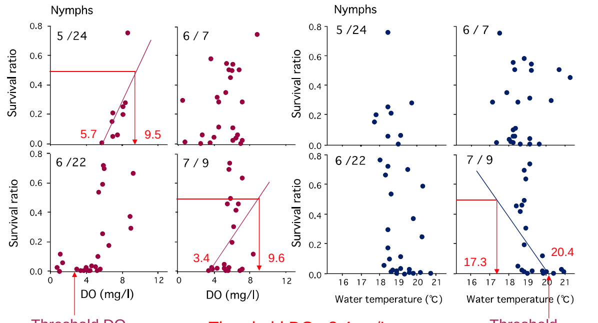
1) Although egg hatchability was higher along the riffle shores, eggs could hatch even in lad areas of the bar.

Results: distribution of survival ratio



Nymphs can survive only near the riffle shore

Relations of survival ratio to DO concentration and water temperature in hyporheic zone



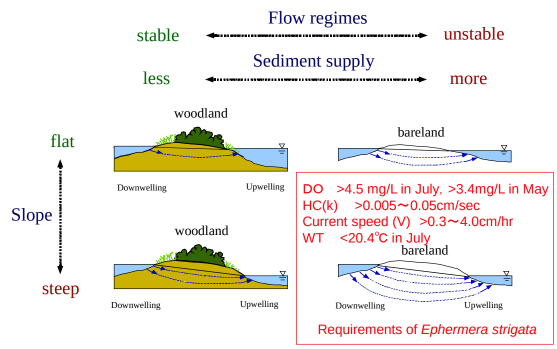
Threshold DO concentration for survival

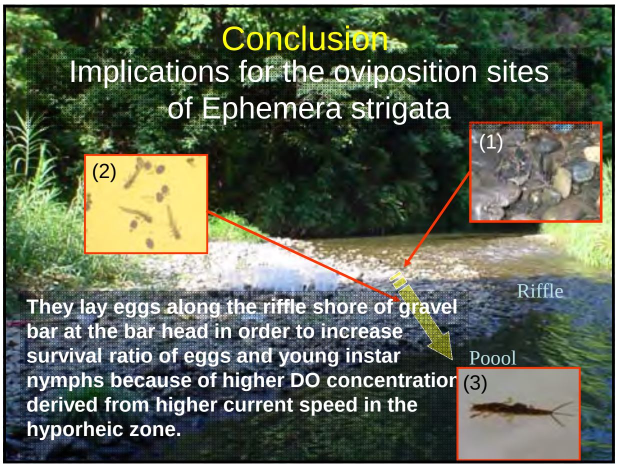
Threshold DO : 3.4mg/L

Threshold WT : 20.4℃

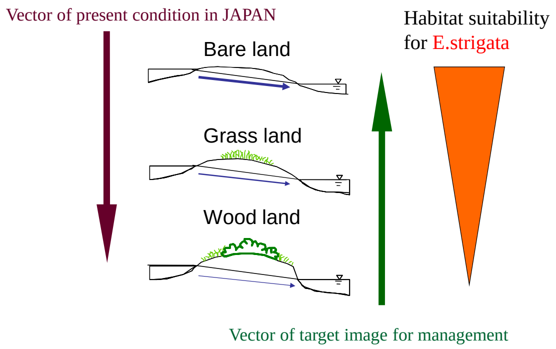
Threshold temperature for survival

Environmental conditions required for increasing fitness of mayflies

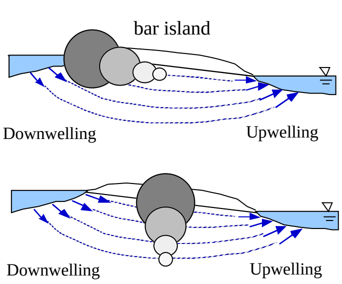




Discussion: Aquatic insects using hyporheic zone need fresh sandy bar with high permeability



Better habitat conditions are reincarnated by disturbance

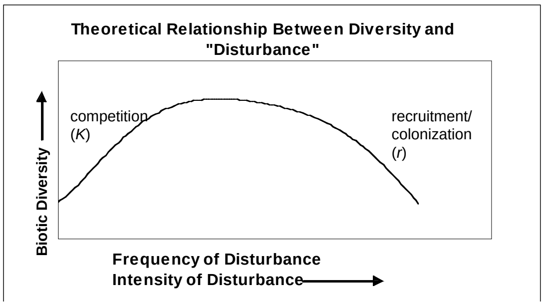


More species live in higher density in the downwelling zone and the surface layer of the phreatic zone.
(Takemon et al. 2003)

Species diversity and abundance

Contents

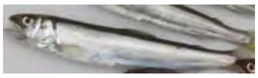
Why disturbance is necessary?
Intermediate-Disturbance Hypothesis



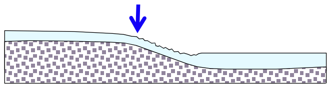
Interspecific relations are used for the reason after Connel (1978) but habitat creation and conditioning are more important function of disturbance at least in ecosystems.

Habitat conditions required for Ayu fish reproduction

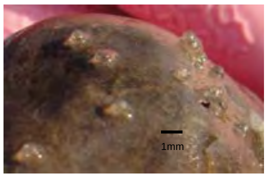
Ayu fish



Spawning redd location



Eggs of Ayu fish



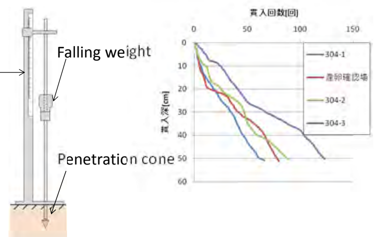
Why they select riffle head for spawning?

Riffle suitable for the spawning red

Tenryu River

Method for measurement of riverbed softness

Scale

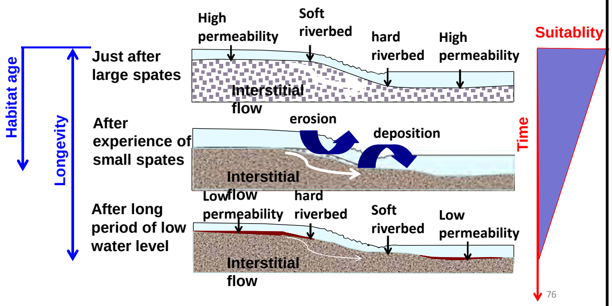


Penetration cone	20[mm]φ ,Toe angle60°
Falling weight	2[kg]
Falling distance	50[cm]

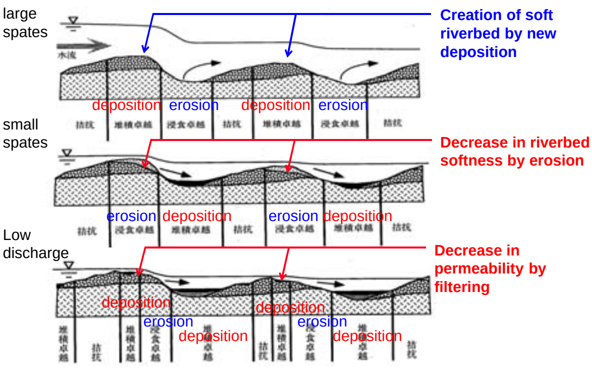
Cone penetration test

Suitable habitat age for spawning redd of Ayu fish

Suitability of riffle habitat for spawning redd of Ayu fish will decrease linearly after creation



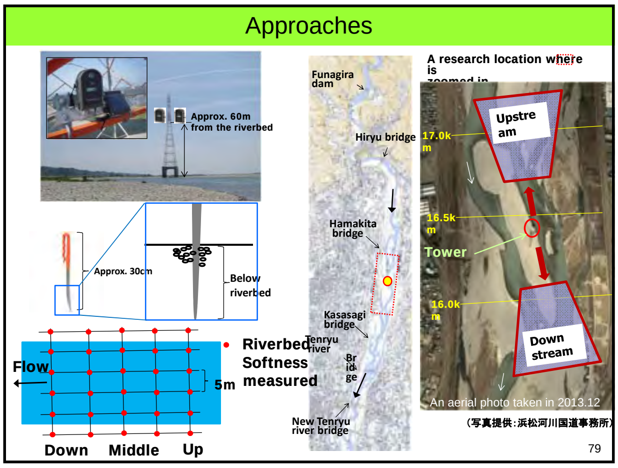
Hyporthesis on habitat changes in riffles

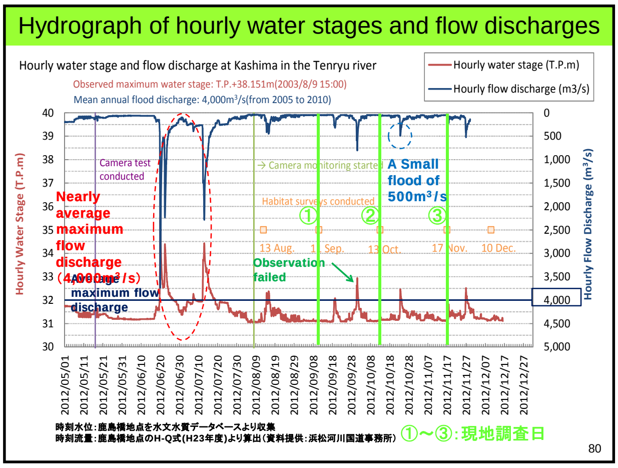


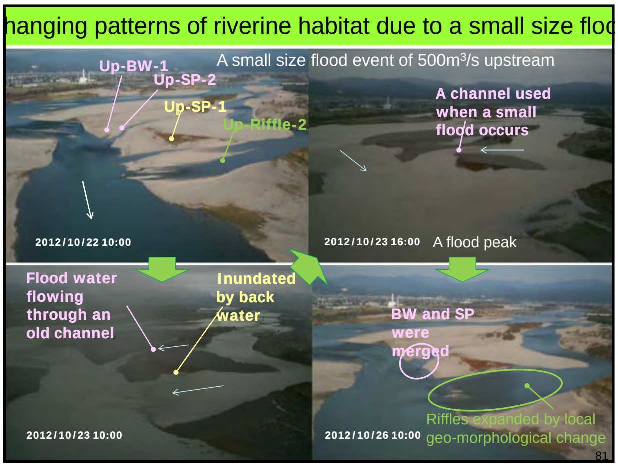
A Geo-morphological Monitoring Method for Analyzing Spatiotemporal Patterns of Riverine Habitat

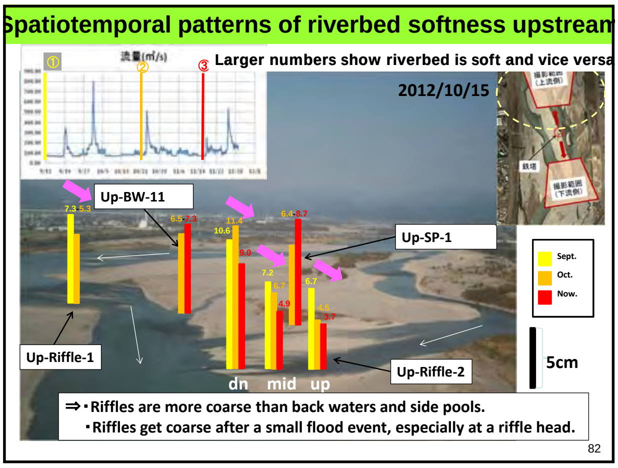
Kyoto University Disaster Prevention Research Institute
IDEA Consultants. Inc.
Makoto Hyodo

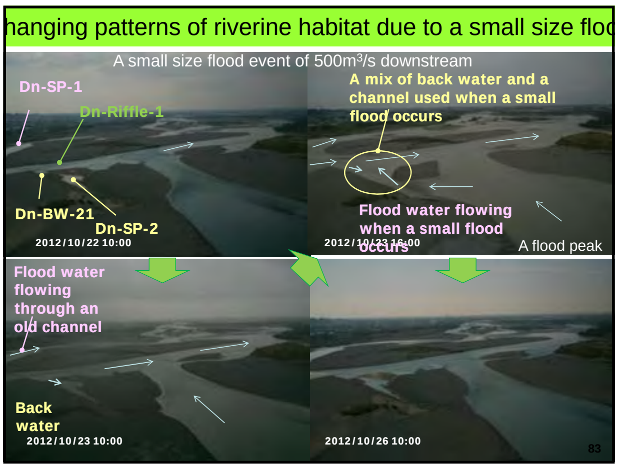
8 July 2013 A Seminar at Trento University

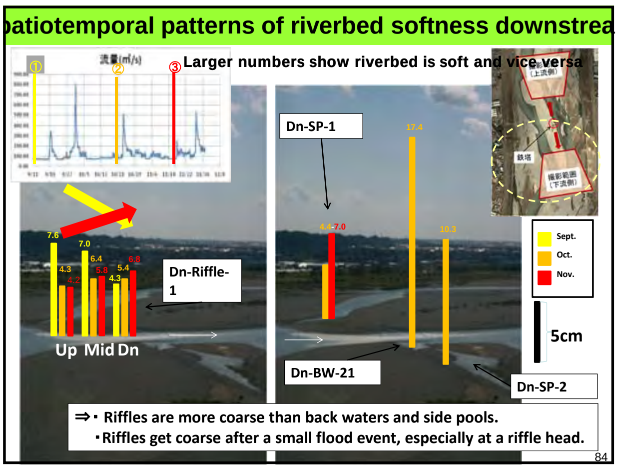

Approaches
Approx. 60m from the riverbed
Approx. 30cm
Below riverbed
Flow
5m
Riverbed Softness measured
Down
Middle
Up
Funagira dam
Hiryu bridge
Hamakita bridge
Kasasagi bridge
Tenryu river
New Tenryu river bridge
A research location where is zoomed in
Upstream
17.0km
16.5km
Tower
16.0km
Downstream
An aerial photo taken in 2013.12
(写真提供：浜松河川国道事務所)
79


Hydrograph of hourly water stages and flow discharges
Hourly water stage and flow discharge at Kashima in the Tenryu river
Observed maximum water stage: T.P.+38.151m(2003/8/9 15:00)
Mean annual flood discharge: 4,000m3/s(from 2005 to 2010)
Hourly water stage (T.P.m)
Hourly flow discharge (m3/s)
Hourly Water Stage (T.P.m)
Hourly Flow Discharge (m3/s)
Camera test conducted
Camera monitoring started
Habitat surveys conducted
A Small flood of 500m3/s
Nearly average maximum flow discharge (4,000m3/s)
maximum flow discharge
Observation failed
13 Aug.
13 Sep.
13 Oct.
17 Nov.
10 Dec.
時刻水位：鹿島橋地点を水文水質データベースより収集
時刻流量：鹿島橋地点のH-Q式(H23年度)より算出(資料提供：浜松河川国道事務所)
①〜③：現地調査日
80


hanging patterns of riverine habitat due to a small size floo
A small size flood event of 500m3/s upstream
Up-BW-1
Up-SP-2
Up-SP-1
Up-Riffle-2
2012/10/22 10:00
A channel used when a small flood occurs
2012/10/23 16:00
A flood peak
Flood water flowing through an old channel
Inundated by back water
2012/10/23 10:00
BW and SP were merged
Riffles expanded by local geo-morphological change
2012/10/26 10:00
81


Spatiotemporal patterns of riverbed softness upstream
Larger numbers show riverbed is soft and vice versa
流量(m3/s)
2012/10/15
Up-BW-11
Up-SP-1
Up-Riffle-1
Up-Riffle-2
dn
mid
up
Sept.
Oct.
Nov.
5cm
⇒・Riffles are more coarse than back waters and side pools.
・Riffles get coarse after a small flood event, especially at a riffle head.
82


hanging patterns of riverine habitat due to a small size floo
A small size flood event of 500m3/s downstream
Dn-SP-1
Dn-Riffle-1
Dn-BW-21
Dn-SP-2
2012/10/22 10:00
A mix of back water and a channel used when a small flood occurs
Flood water flowing when a small flood occurs
2012/10/23 16:00
A flood peak
Flood water flowing through an old channel
Back water
2012/10/23 10:00
2012/10/26 10:00
83


patiotemporal patterns of riverbed softness downstrea
Larger numbers show riverbed is soft and vice versa
流量(m3/s)
Dn-SP-1
Dn-Riffle-1
Dn-BW-21
Dn-SP-2
Up
Mid
Dn
Sept.
Oct.
Nov.
5cm
⇒・Riffles are more coarse than back waters and side pools.
・Riffles get coarse after a small flood event, especially at a riffle head.
84

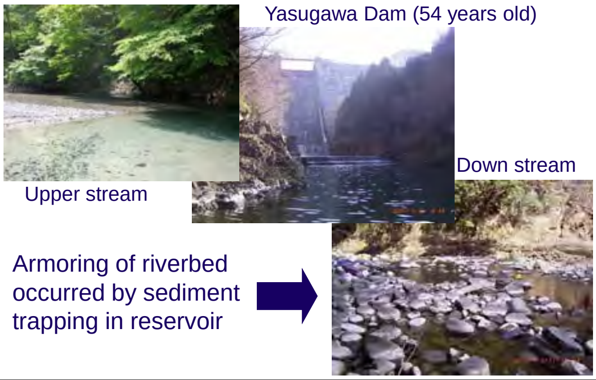
Fundamentals of Freshwater Ecology

Contents

1. Definition of Ecology and Biodiversity
2. Structure of Freshwater Ecosystems
3. Necessity of Freshwater Ecology
4. Field and Methods of Freshwater Ecology
5. Climate Change Impacts on River Ecosystem
6. Importance of Habitat Ecology
7. Roles of Disturbance in Freshwater Ecosystems
8. **Application to riverbed management**

Lecture 3 on 4th Dec 2013

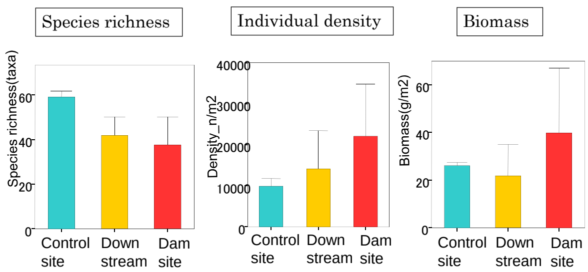
Riverbed degradation by dams



Reservoir dam impacts on river ecosystems

Landscape at 2km below the Ohtaki Dam in Japan after construction

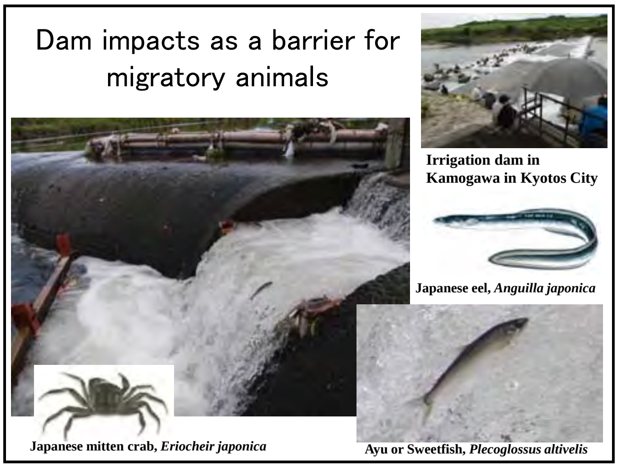
Changes in benthos community in tail-waters

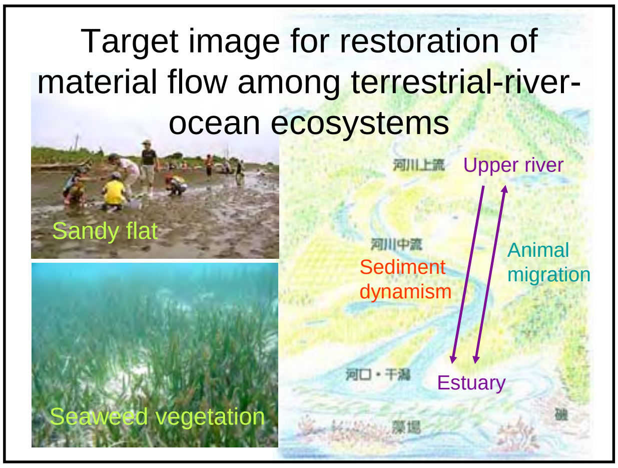


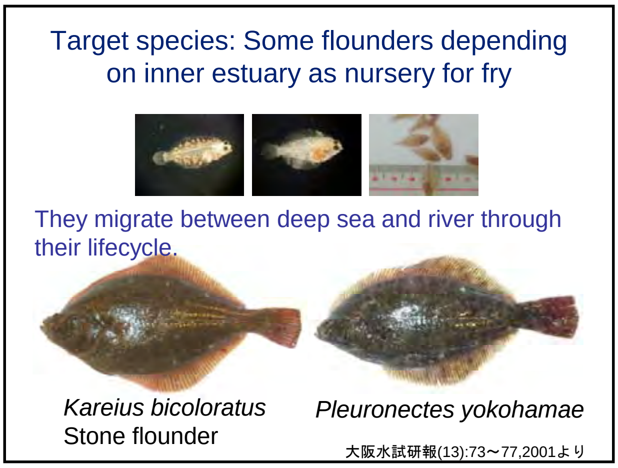
Species richness decreased and abundance of particular species increased in the tail waters of reservoir dams.

Target Image for countermeasure: a natural river without dams upstream

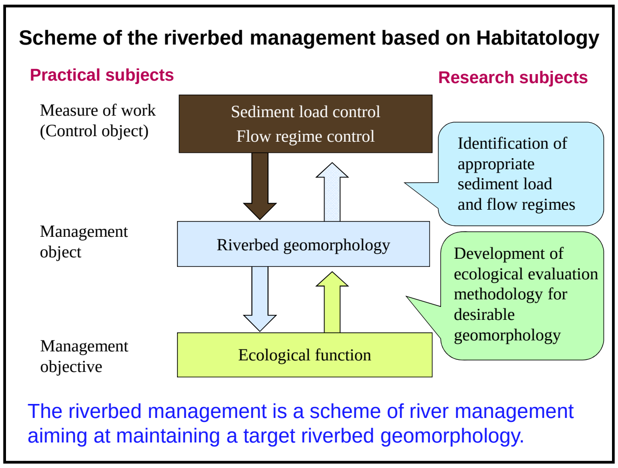
Riverbed landscape of the Tonda River in Japan

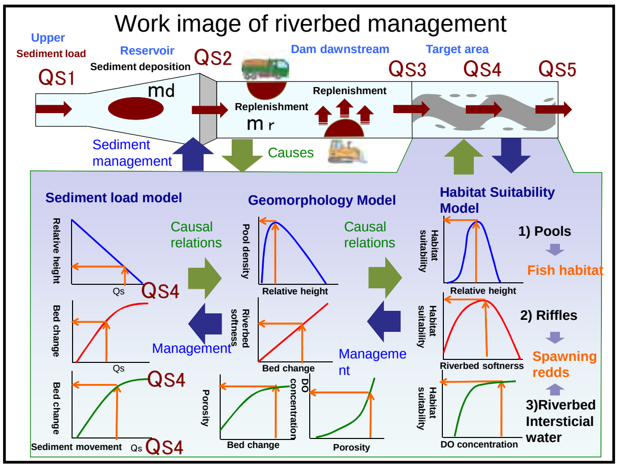

Dam impacts as a barrier for migratory animals
Irrigation dam in Kamogawa in Kyotos City
Japanese eel, Anguilla japonica
Japanese mitten crab, Eriocheir japonica
Ayu or Sweetfish, Plecoglossus altivelis


Target image for restoration of material flow among terrestrial-river-ocean ecosystems
Sandy flat
Seaweed vegetation
河川上流
Upper river
河川中流
Sediment dynamism
Animal migration
河口・干潟
Estuary
藻場


Target species: Some flounders depending on inner estuary as nursery for fry
They migrate between deep sea and river through their lifecycle.
Kareius bicoloratus
Stone flounder
Pleuronectes yokohamae
大阪水試研報(13):73～77,2001より

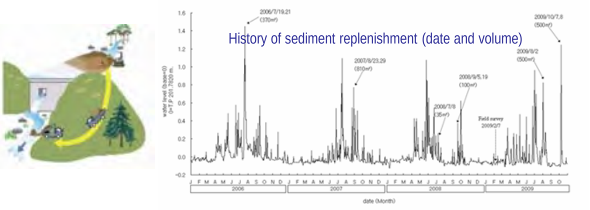

Target species: marine shrimps using estuary for reproduction
"Shiba-ebi" migrates between deep sea and river through their lifecycle.
Metapenaeus ensis


Scheme of the riverbed management based on Habitatology
Practical subjects
Research subjects
Measure of work (Control object)
Sediment load control
Flow regime control
Identification of appropriate sediment load and flow regimes
Management object
Riverbed geomorphology
Development of ecological evaluation methodology for desirable geomorphology
Management objective
Ecological function
The riverbed management is a scheme of river management aiming at maintaining a target riverbed geomorphology.


Work image of riverbed management
Upper
Sediment load
QS1
Reservoir
Sediment deposition
md
QS2
Dam dawnstream
Replenishment
m r
QS3
Target area
QS4
QS5
Sediment management
Causes
Sediment load model
Geomorphology Model
Habitat Suitability Model
Causal relations
Causal relations
1) Pools
Fish habitat
2) Riffles
Spawning redds
3)Riverbed Interstician water
Management
Manageme nt
Relative height
Bed change
Sediment movement
Pool density
Riverbed softness
Porosity
DO concentration
Habitat suitability
Riverbed softness
DO concentration

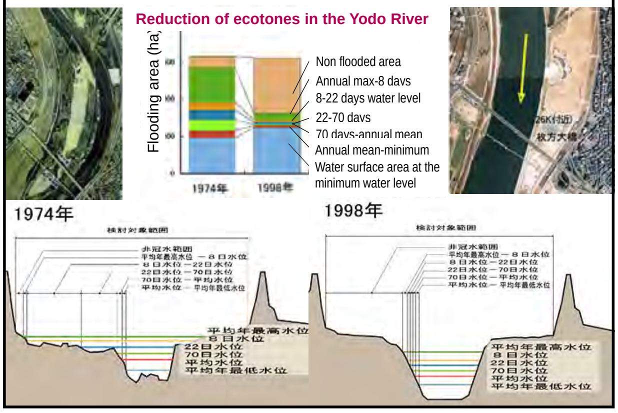
Sediment Replenishment in Nunome Dam

a total of 2,585 m^3 sediment was supplied with flushing operation



(a) Before (2009/10/2) sediment volume: 500㎥ | (b) Under replenishment (2009/10/8) discharge: 81㎥ | (c) After (2009/10/14)

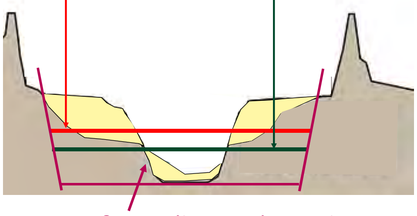
Needs: Present feature of Japanese rivers



Matching of requirements

We need to estimate upper limit of the riverbed height for disaster prevention

We need to estimate lower limit of the riverbed height for environmental requirements

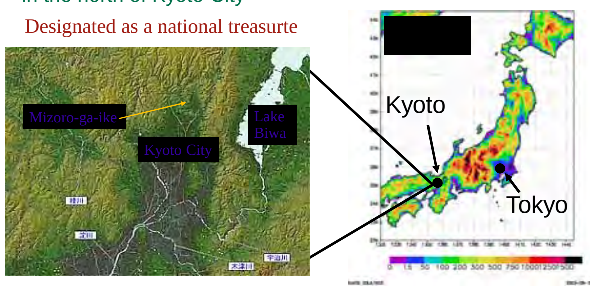


rooms for sediment dynamism

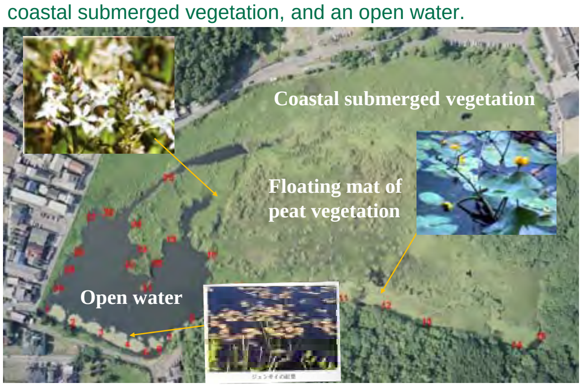
A case study in the Mizoro-ga-ike Pond

a semi-natural pond of 9 ha in area and 1 km in circumference, located in the north of Kyoto City

Designated as a national treasurte



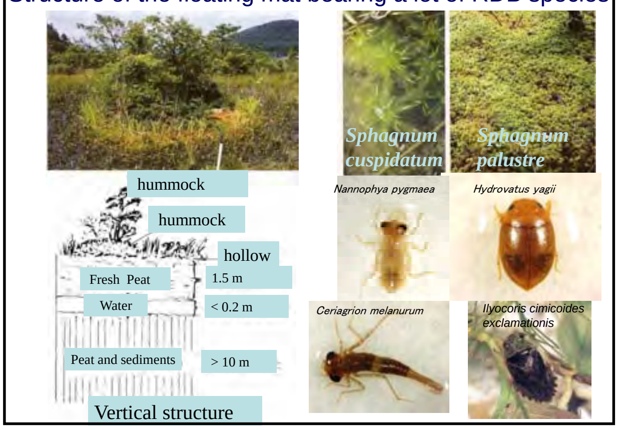
Mizoro-ga-ike is composed of a floating mat of peat vegetation, coastal submerged vegetation, and an open water.



100m

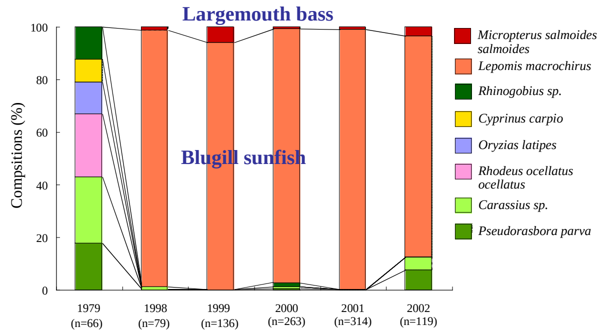
Visit http://mizoro.org/index.html for information

Structure of the floating mat bearing a lot of RDB species

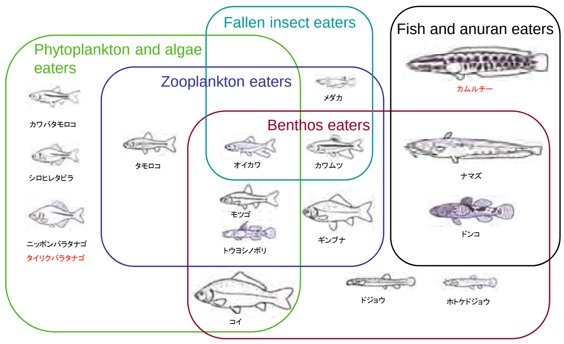


Alien fish intruders in Mizoro-ga-ike

Changes in fish species composition in Mizoro-ike

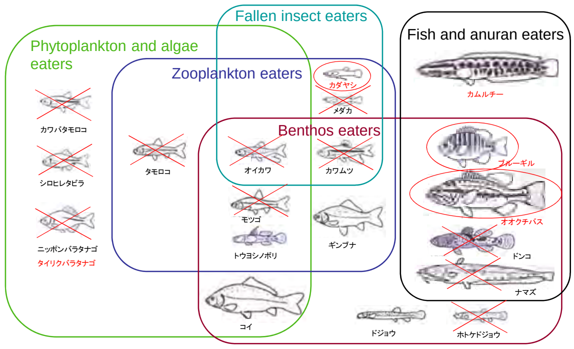


Fish community structure in 1970s in Mozoro-ga-ike



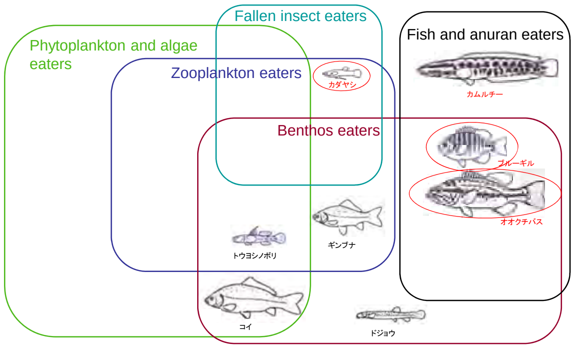
Before invasion of alien fishes smal cyprinid species are abundant. They took a role for preventing water eutrophication by consuming phytoplankton.

Alien fish intrusion in late 1970s in Mozoro-ga-ike



Before invasion of alien fishes smal cyprinid species are abundant. They took a role for preventing water eutrophication by consuming phytoplankton.

Fish community structure in 1990s after alien fish invasion



Before invasion of alien fishes smal cyprinid species are abundant. They took a role for preventing water eutrophication by consuming phytoplankton.

Citizens participating in the net fishing

Eri-ami fishing net

Setting of fishing net

Visit http://mizoro.org/index.html for information

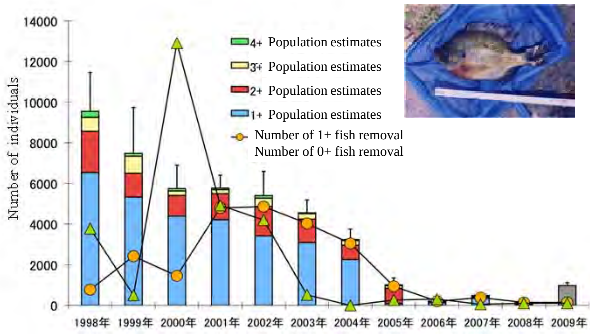
Collecting fishes on a boat

Traps used for alien fish control in Mizoro-ga-ike

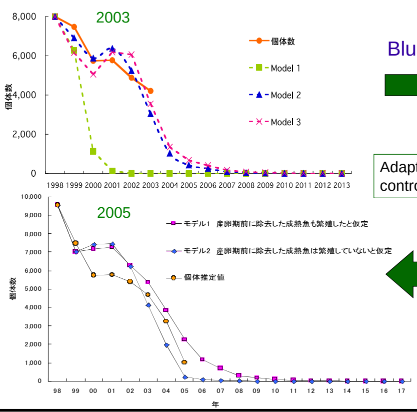
Bait is no need for trapping the bluegill sunfish

Action of adaptive management

Results of population control for Bluegill sunfish



Present state and future prediction of population



Bluegill sunfish

Adaptive management for control efforts

Conclusion and Discussion

Strategy for ecosystem management

River ecosystem

1. Community structure

Physical disturbance reset the interspecific interactions

2. Material Cycling

Being in a dynamic equilibrium state

Wetland ecosystem

1. Community structure

Interspecific interactions overwhelm physical disterbance

2. Material Cycling

Apt to change into one way direction to eutrophication

Strategy

Priority in management

Manipulation of physical process such as flow regimes and sediment dynamism

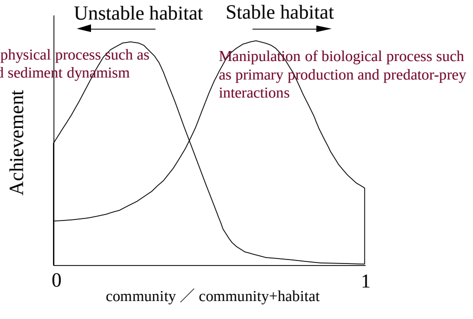
Manipulation of biological process such as primary production and predator-prey interactions

Conclusion and Discussion

Strategy for ecosystem management

River ecosystem

Wetland ecosystem



Investment ratio of manipulation

Lecture 4: Sustainable Water Resources Management in Marginal Area : Case Study in Indonesia

Ignasius D.A. SUTAPA *(Asia Pacific Center for Ecohydrology - UNESCO Category II Center)*

Water is recognized as the most essential of all natural resources and, obviously, there is no environmental diversity and even social and economic development can be sustained without water. However, soon water became a limited resource as the demand is increasing following the increasing of world's population and the expanding use of water in other sectors. Gleick *et al* (2002) report that in the last century, the world population grew from 1.6 billion in 1900, to 6.0 billion in 2000 and according to the UN (2204) projections this figures is expected to reach 8.9 billion by the year 2050 yet freshwater supply that can immediately satisfy human and ecosystem needs is very limited and it is unevenly and irregularly distributed.

Indonesia's attention to the issue of environmental damage is increasingly intensifying. One cause of the worsening environmental conditions is due to natural resource management that cannot be renewed or can be renewed has exceeded its carrying capacity. Environmental sustainability and ecosystem levels are not maintained anymore, therefore the parties involved, in this case, the private and state enterprises, governments and communities need to develop good cooperation and synergy for sustainable environmental management.

Water resources in marginal areas are water resources in areas with the following characteristics: peatland areas, brackish areas, areas of pollution and post-disaster areas. One of the major problems in Indonesia today is to manage water in peatland areas. Indonesia has vast peatlands spreading across several islands: Sumatra, Kalimantan and Papua. Water resources in the peatland areas have the following characteristics:

- Has a low pH levels (2-4) that is highly acidic
- Have high levels of organic
- High levels of iron and manganese
- Yellow or dark brown

These charactheristics can be explained by the process of peat water formation as shown in Figure 1.

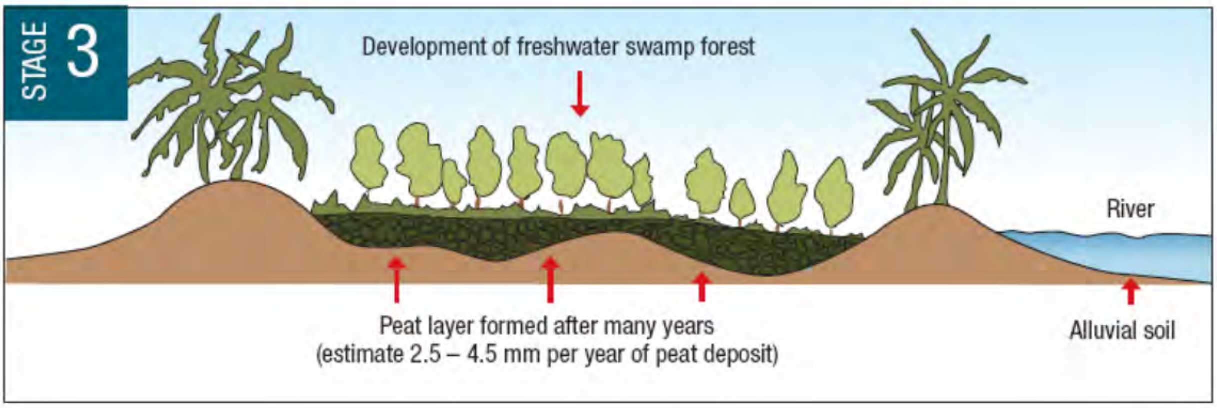


Figure 1 Mechanisms of peat water formation (UNDP, 2006)

Part I

ROLE OF APCE AS LOCAL WISDOM CATALYST FOR SUSTAINABLE WATER RESOURCES MANAGEMENT

Dr. Ignasius D.A. Sutapa
Executive Secretary
Asia Pacific Center for Ecohydrology
(APCE) – UNESCO Category II Center

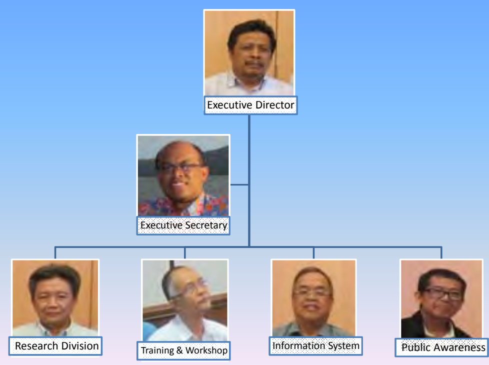
ASIA PACIFIC CENTRE FOR ECOHYDROLOGY APCE – UNESCO CATEGORY II CENTRE

Research Centre for Limnology Campus
Cibinong Sciences Centre – Jl. Raya Bogor Km 46
Cibinong – Bogor – West Java - INDONESIA
Tel.: 021-8757071 Email : ignasdas@yahoo.co.id

BACK GROUND

- The Asia Pacific Centre for Ecohydrology (APCE) is a category II center of the United Nations Educational, Scientific and Cultural Organization (UNESCO).
- It focuses on ecological approaches to water resources management, to provide sustainable water for the people by harnessing science and technology, education and culture.
- APCE is committed to contributing towards overcoming current and important issues of national, regional and global interest, such as poverty, climate change adaptation and disaster risk reduction.

Organization Structure



- Executive Director :
  - Prof. Dr. Hery Harjono
- Executive Secretary :
  - Ass. Prof. Dr. Ignasius D.A. Sutapa
- Head of Reasarch Division :
  - Prof. Dr. Hidayat Pawitan
- Head of Training and Workshop Division :
  - M. Fakhrudin
- Head of Information System :
  - Prof. Dr. Robert Delinom
- Head of Public Awareness :
  - Dr. Munasri

APCE DIRECTIVE

- **VISION**
  - To be an Internationally Reputed Asia Pacific Center in Urban and Rural Ecohydrology by 2021
- **MISSION**
  - Develop understanding and practices of ecohydrology through research, training and knowledge exchanges, information systems and public awareness.
- **VALUES**
  - Wisdom
  - Integrity
  - Harmony

STRATEGIC GOAL

1. To promote local resources base ecohydrological research
2. To strengthen local capacity to adopt ecohydrological concept and approach
3. To provide easy access to local resources based ecohydrological information and knowledge
4. To enhance public awareness of local resources based ecohydrological practices

RECENT ACTIVITIES

IFAS TRAINING COURSE

- A technical course was organized based on the frame- work of the Flood Forecasting and Warning System which was conducted in 10 countries (Australia, Cambodia, China, Indonesia, Lao People's Democratic Republic, Malaysia, the Philippines, the Republic of Korea, Thailand and Vietnam).
- This Integrated Flood Analysis System (IFAS) course was realized in collaboration with the International Centre for Water Hazard and Risk Management, the UNESCO Jakarta Office and LIPI.

Flooding events in Indonesia

IFAS course activities

Demo Site for Community-Based Water Management

- The objective of the demo site for ecohydrology development is to act as a field station for the implementation of ecohydrology concepts in the field.
- The demo site ecohydrology campaign is expected to be significant in socializing the sustainable management of water resources in accordance with the concept of ecohydrology. It will also serve as a natural laboratory for the future development of ecohydrology, especially as a tropical Indonesian concern.
- Ecohydrology demo site development in Indonesia will be directed to a location demo site representing the concept of sustainable water resources management in several different groups, namely an ecohydrology demo site for the community-based management of water resources.

Problem of Water resources in Islamic boarding school

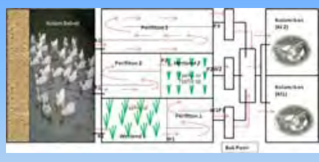
- Indonesia : 26.000 Pondok Pesantren (islamic boarding school)
- Number of people in Ar-Risalah : 850 p
- Average needs of clean water :
  - 850 x 100 l/p/day = 85.000 l/day = 85 m3/day
- Problem of wastewater
  - 85 m3/day discharged directly to the environment
  - High degree of pollution
- Urgent to be solved

Raw Water Condition

Water for domestic use (bathing, washing, cooking)

Importance of water in preparation of daily prayer for the BS Students

Constructed Wetland



Reduce pollution
Recycle wastewater

Capacity building of community leaders

Way of paradigm shift
Increase in community awareness and participation

Best practice enlightment

Way of Heartware Concept Implementation

Discussing with Islamic Leaders community

Artificial constructed wetland

Cultural Landscape and Subak System in Bali

- Subak is the name of the water management (irrigation) system for paddy fields on Bali island, Indonesia, developed more than 1,000 year ago.
- Over that time, this traditional ecologically sustainable irrigation system has constantly adjusted to changing situations.
- The result is an intricate system which is strongly interlinked with Bali's natural, social, cultural and religious environment.

Rice Field in Jatiluwih world heritage site

Subak system : Pura, paddy field and water

IPAG60: Alternative Technology for Clean Water in Peatland Areas

- The majority of areas in Riau Province and Central Kalimantan Province have land with peat surface water, which characteristically has:
  - low pH levels (2-4), making it highly acidic
  - high levels of organic matter
  - high levels of iron and manganese
  - yellow or dark brown colour.
- Peat water treatment technology that has been established in previous studies (2009-2011), by Ignasius D.A. Sutapa and team enables peat areas to have peat water treatment facilities for the drinking water supply.
- A lot of territory in some areas in Indonesia – especially Sumatra and Kalimantan – have clean water source issues.
- Implementation of this technology in the wider area is necessary to support the increase in water services in the region.

IPAG 60 : from peatwater to clean water

Clean water produced by local people with IPAG60

Important Points

- Main problems of water resources management in Indonesia : pollution, conflict of interest, lack of community participation
- With around 26.000 of islamics boarding schools in Indonesia, important gate to introduce SWRM concept
- Strengthening tha capacity buliding of Ar-Risalah Islamic Boarding School in wastewater management increase water quality released to the environment

THANK YOU...

Part II

Problems of Water Resources Management in Peatland Area

Dr. Ignasius D.A. Sutapa
Executive Secretary
Asia Pacific Center for Ecohydrology
(APCE) – UNESCO Category II Center

Sustainability

- The Bruntland Report popularized the term *sustainability* for human and environmental development when it was published in 1987. In the report, *sustainable* activities were defined as ones where the needs of the present generation are met without compromising the needs of future generations
- What the Bruntland definition implies is an equitable distribution of the resource not only spatially between users in a given location, but temporally between users over time. The idea is to allocate the resource in such a way as for all, including the environment, to have an adequate share without making any one group worse off, both now and in the future.

- To achieve sustainability, there must be a rethinking of what we consider a *basic need*. It is common in our society to say that we *need* a given resource, but how much of it do we really *need* to use?
- How do we decide what the basic needs of our ecosystem and the organism living within it are?
- Defining what constitutes a basic need is perhaps the greatest challenge to adopting sustainable practices in our daily lives, as interpretations of *need* vary widely from region to region, village to village and even from person to person.

Manage a Resource

- There has been a shift in recent years from the traditional 'top-down' approach to a more open management system where all levels have a say in the allocation and use of the resource. If properly done, this system ensures that the needs and concerns of those most affected by the use of the resource are addressed, without loosing sight of the wider issues touching the society as a whole.
- Understanding the needs of the stakeholders, as well as the possibilities and limitations of the resource, is needed to manage it effectively. This requires sharing both indigenous and modern scientific knowledge, as well as establishing a dialogue between individuals and large institutions. With the right information, appropriate strategies can be formulated to deal with the realities of resource management, such as distribution, access, rights, etc.

Sustainable Water Management (SWM)

- Sustainable Water Management (SWM), : simply to manage our water resources while taking into account the needs of present and future users
- The International Hydrological Programme, a UNESCO initiative, noted:
  - *"It is recognised that water problems cannot be solved by quick technical solutions, solutions to water problems require the consideration of cultural, educational, communication and scientific aspects. Given the increasing political recognition of the importance of water, it is in the area of sustainable freshwater management that a major contribution to avoid/solve water-related problems, including future conflicts, can be found."*
- SWM attempts to deal with water in a holistic fashion, taking into account the various sectors affecting water use, including political, economic, social, technological and environmental considerations.

- Since the Mar del Plata Water Conference hosted by the UN in 1977, SWM has been high on the international agenda. Later conferences and workshops have addressed the issue and have attempted to refine the concept as more and more research has been done in the area. The current understanding of SWM is based primarily upon the principles devised in Dublin during the International Conference on Water and the Environment (ICWE) in 1992, namely:
  - Freshwater is a finite and valuable resource that is essential to sustain life, the environment and development.
  - The development and management of our water resources should be based on a participatory approach, involving users, planners and policy makers at all levels.
  - Women play a central role in the provision, management and safeguarding of water resources.
  - Water has an economic value and should therefore be seen as an economic good.
- These principles reflect the importance of water in our daily lives and the need for proper communication, gender equity, and economic and policy incentives to manage the resource properly.

Status and Values of Peatlands

- In addition to acting as repositories for unique and important biodiversity, peatlands in Southeast Asia is of global importance because of its ability to store an estimated 120 billion tonnes of carbon or approximately 5% of the world's terrestrial carbon.
- Peatlands also play a critical role in the socio-economic well-being of the country, particularly for their ecological and hydrological value, their timber and non-timber forest products, water supply, flood control and many other social, environmental and economic benefits.

Important Values of Peatlands

- **Water Regulation**
  - Peatlands in their natural state are water-logged due to a high water table and act as a large water reservoir, consequently playing an important role in water regulation. Important functions in this aspect are flood mitigation and water supply, which contributes to the environmental security of human populations and ecosystems in its surrounding areas.
- **Carbon Sequestration and Storage**
  - Peatlands in the Southeast Asia play a role of global importance in storing an estimated 120 billion tonnes of carbon or approximately 5% of the global terrestrial carbon. Malaysia has the second largest extent of peatlands in Southeast Asia after Indonesia, most of which are still intact thus contributing to sequestering carbon from the atmosphere and acting as a store for large amounts of carbon

Biodiversity

- Peat swamp forests are habitats or are part of the home range for rare and endangered mammals such as Malayan Tiger (Panthera tigris malayensis), Tapir (Tapirus indicus), Sumatran Rhino (Dicerorhinus sumatrensis) and Orang Utan (Pongo pygmaeus).
- Peat swamp forests also support a diverse bird community. Prentice and Aikanathan (1989) recorded 173 species of bird in the North Selangor Peat Swamp Forest of which 145 were breeding residents. Birds present include endangered species such as hornbills and the Short Toed Coucal.
- Peatland rivers, also known as 'black-water rivers' are important aquatic habitats for fish. These rivers often have a higher degree of localised endemism for fish species compared to other rivers, and they are also an important source of aquarium fish. Ng et al (1992) recorded more than 100 fish species in the North Selangor Peat Swamp Forest. Approximately 50% of these are restricted to black-water rivers.

Socio-Economic Values

- Peat swamp forests have been a source of timber and non-timber forest products. They are rich in high quality timber species such as Ramin (Gonystylus bancanus), Durian Paya (Durio carinatus) and a number of Shorea species.
- There are at least 120 timber species of commercial value and if harvested in a sustainable manner will continue to provide these resources for a very long period of time.
- Other non-timber plant products include rattan, asam kelubi, palm trees, Pandanus, scented wood trees species, medicinal plants, resin-producing trees and ornamental plants, for eg. wild ferns which are utilised and traded by local communities living around peatland areas

Management Issues, Threats & Root Causes of Peatland Degradation

- Increasing pressures for land development (e.g. agriculture, infrastructure) have affected peatlands in Indonesia over the past 20 years.
- A number of these threats directly stem from or are associated to land conversion, especially for agricultural practices, that have been managed in an unsustainable manner.
- These threaten the integrity of peat ecosystems and have resulted in significant loss of ecological support services eg. flood mitigation, prevention of saline water intrusion, sediment and toxic removal, groundwater recharge, micro-climate regulation etc.
- Many agricultural and plantation projects for oil palm, pulpwood, rice and various other crops on peatlands have failed due to unsuitable conditions and the application of inappropriate methods.
- The land conversions have direct negative physical impacts on peatland ecosystems and its associated biodiversity. These impacts also have associated effects on remaining peatlands due to drainage, such as peat subsidence, fire and loss of vital ecological services

Issues in the Harvesting of Timber

- Peat soils are generally marginal to poor for agriculture, particularly those exceeding 2m in depth.
- Poor or unsustainable practices and the abandonment of agricultural projects leave the degraded peatlands vulnerable and susceptible to more negative impacts and threats, leading to further peatland degradation.

Peatland Fires and the Associated Haze Pollution

- Peatland fires in the country and in the SE Asian region have had one common phenomenon in the past 20 years. They are often associated with periodic drought occurrences and closely-linked with forest clearance and drainage activities by the forestry and agricultural sectors.
- The El Niño cycles also play a significant role in peatland fire incidents. Detrimental impacts associated with peatland fire incidences are the negative effects on the socio-economy of local communities who are dependent on peatland resources, environmental pollution and the significant decrease or loss of important floral and faunal populations.

Inadequate Policies and Weak Institutional Framework

- Currently, there is still a lack of specific policies and guidelines related to sustainable peatland management in Indonesia.
- Existing policies and guidelines do not provide proper peatland management guideline, which further contributes to the unsustainable use and degradation of peatlands and their resources.

Inadequate Information on Peatland Management

- There is currently inadequate information on sustainable peatland management due to a poor understanding of peatland ecosystems.
- It is also difficult to access existing information from the respective government agencies, departments and ministries which relate to peatlands and their resources

Water Management Issues

- One of the prominent characteristics of peatlands is its high water table. This naturally-occurring high water table is an important factor in their formation and for sustaining their stability.
- Over-drainage of peatlands can have detrimental effects to the ecosystem. The threats of over-drainage stem from forestry and agricultural practices in peatlands.
- Agricultural and forestry practices generally attribute to poor water management practices in peatlands, which significantly lower the water table leading to the drying and breaking-down of peat soils (i.e. peat subsidence).
- This in turn will affect the floral and faunal biodiversity. In severe cases of over-drainage, subsidence of up to 5m have been recorded over a period 20 years and such negative impacts could also be further enhanced during the dry season or droughts.

Thank You...

Part III

LOCAL PARTICIPATION IN PEATLAND AREA OF GIAM SIAK KECIL – BUKIT BATU BIOSPHERE RESERVE – RIAU PROVINCE

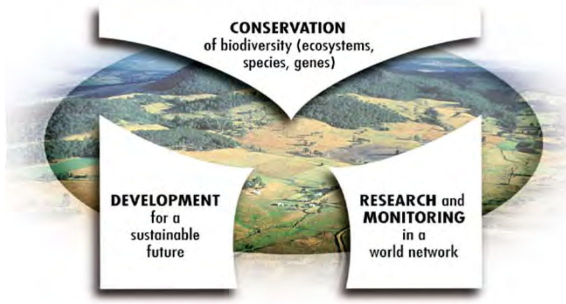
Dr. Ignasius D.A. Sutapa

Asia Pacific Center for Ecohydrology (APCE) – UNESCO Category II Center

Outline

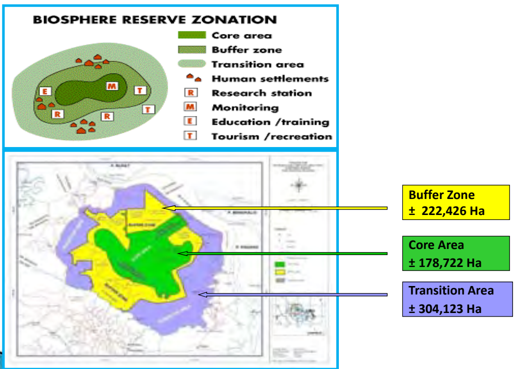
- Background
- Objectives
- Distribution of Peatlands in Indonesia
- Characteristics of peat water
- How to treat peat water?
- Conclusion

BIOSPHERE RESERVE



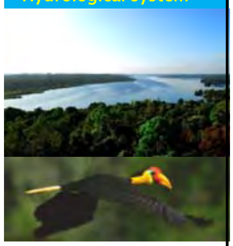
Emerging challanges and potential role of BR in addressing Climate Change, Provision of Ecosystem Services and Urbanization as a principal driver for ecosystem-wide pressures (MAP)

How to Manage ?



Ecological characteristics

- Peat swamp forest
- High biodiversity value
- Unique small lakes
- Hydrological system

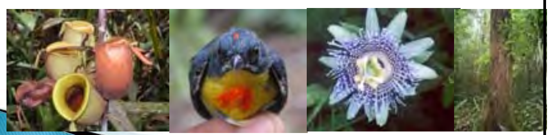


Development Opportunity and Prospect CB GSK-BB

- Improve the image of Indonesia in Riau and global level
- Encourage the establishment of the Regional Center for Peat Swamp Forest and build south south cooperation (South-South Cooperation)
- An example of the application of the ecosystem landscape management by integrating conservation and development of knowledge-based economy
- Tourism industry with a capital of cultural and biological richness
- Develop economic activity through the use of natural resources science-based swamp
- GSK-BB CB making safe of all the activities that damage the sustainability of the biosphere reserve.

Values in the Future of CB GSK-BB

1. A model of ecosystem management in Indonesian peatland
2. Being a peat swamp forest research center · Regional Research Center for Peat-Forest Land Conservation management partnership model with private sector
3. A model of the development of ecological services (ecotourism and trade Carbon).



DEVELOPMENT of BIOSPHERE RESERVE GIAM SIAK KECIL-BUKIT BATU, RIAU

1. INSTITUTIONAL STRENGTHENING MANAGEMENT AGENCY
2. PLANT IMPROVEMENT OF MANAGEMENT AND ACTION
3. RESEARCH & DEVELOPMENT
4. EMPOWERMENT THROUGH
   - ECONOMIC DEVELOPMENT BASED LOCAL RESOURCES
   - THE ROLE OF SOCIAL DEVELOPMENT ECONOMIC COMMUNITY
   - INCREASING ROLE OF CIVIL SOCIETY trough NETWORKING AND COORDINATION
5. FUND RISING

Scope of Technology Aplication

1. Peat Water Treatment Plant into clean water;
2. Horticulture Plant Pot To Increase Capacity of Farmers Rural Household Economy In Transition Buffer Zone and Area of Biosphere Reserves;
3. Innovation Through Cultivation Vegetable Gardening Normal and Inverted Utilizing Local Resources in the Transition Area and Buffer Zone Biosphere Reserve
4. Integration of beef cattle farming business and Electricity Production (Bio-Electric) For lighting and bio-gas substitute for firewood / kerosene / LPG for cooking in the village at the Transition Area and Buffer Zone Biosphere Reserve, and
5. Freshwater Fish Farming In Peat Inland Buffer Zone in the Transition Area and Biosphere Reserve.

GOALS

1. Provide alternative water treatment technologies for peat water;
2. S pot cultivation as a water saving alternative model of economic resources in the form of new and institutionalize SME village level;
3. Utilizing local raw materials (microbial functional and peat) for vegetable production with normal and inverted gardening technology.;
4. Integrating the cultivation of beef cattle and Electricity Production (Bio-Electric) For lighting and bio-gas substitute for firewood / kerosene / LPG for cooking;
5. Freshwater Fish Farming In Peatwater

Increase well-being and public health at BR GSK-BB :

Pro poor,
Pro job,
Pro growth,
Pro green

Increasing Water Acess Possibility in Peatland Area

Background

- Human dependence on water in line with population increases.
- As presented in the WHO forum by the former UN Secretary General Kofi Annan: "*That we are almost impossible to eradicate AIDS, tuberculosis, malaria or other infectious diseases that are endemic in developing countries, so that we could win the battle for safe drinking water, sanitation and fundamental health care* ".
- The statement shows the meaning of the importance of water for survival and life on earth.

Objectives

- Provide alternative water treatment technologies that can be used in peat land area in GSK-BB BR
- Conduct field observations in order to determine the mounting location of IPAG
- Know the readiness and willingness of local communities to adopt appropriate technologies that will be implemented

Distribution of Peat lands in Indonesia

(BB Litbang SDLP., 2008)

Island	Province	Land Area (Ha)	Available to agriculture (Ha)
Sumatera		6.244.101	2.253.733
	Riau	4.043.600	774.946
	Jambi	716.839	333.936
	South Sumatera	1.483.662	1.144.851
Kalimantan		5.072.249	1.530.256
	Middle Kalimantan	3.010.640	672.723
	West Kalimantan	1.729.980	694.714
	South Kalimantan	331.629	162.819
Papua		7.001.239	2.273.160
TOTAL		18.317.589	6.057.149

Note: If the peat lands in the Province of Nanggroe Aceh Darussalam, North Sumatra, West Sumatra, Bengkulu and East Kalimantan are considered, then the total area of peat lands in Indonesia is around 21 million ha

Characteristics of peat water

- Low pH levels (2-4) that is highly acidic
- High levels of organic matters
- High levels of iron and manganese
- Yellow or brown (dark) color

IMPACT OF PEAT WATER ON HUMAN HEALTH

- Low pH water can cause tooth decay and gastrointestinal illness.
- High content of organic matters causes odor and provides optimal condition for microbial growth.
- If chlorine is used as disinfectant, Three Halo Methane (THM) compounds such as carcinogenic organo-chlorine can be resulted.
- Chemical bound of Iron and manganese increases metals compounds in water that can cause lethal effect to human if continuously consumed.

Water Needs

- Drinking water for the survival : 5 liters / person / day
- Water for food preparation : 10 liters / person / day
- Water for sanitation :20 liters / person / day
- Water for hygiene : 15 liters / person / day
- Volume :
  - 50 liters / person / day (minimum requirement)
  - 100 liters / person / day
  - 150 liters / person / day

Location

- 2 villages : Tanjung Leban and Tasik Betung.
- IPAG installation plan focused on the village of Tanjung Leban for reasons :
  - access
  - Strategic location
  - supporting factors are sufficient

IPAG : Instalasi Pengolahan Air Gambut
(Peat Water Treatment Plant)

Existing People Condition

- During this time, the public use of peat water directly to meet the needs of day-to-day (bathing, washing, cooking and even drinking)
- Communities have some difficulties to get clean water and clean water availability is very urgent

Methods

No	Parameter	Method	Location
1	pH	pH meter	In situ
2	Turbidity	Turbidimeter	Laboratory
3	TDS	Conductivity / TDS meter	In situ
4	Salinity, Temp	Water Quality Checker (WQC)	In Situ
5	Conductivity	Conductivity / TDS meter	In Situ
6	TOM	Titrimetry	Laboratory
7	Fe - Mn	Spectrophotometry	Laboratory
8	Nitrite, Nitrate, Ammonium, TN, TP,Sulfat, Colour	Spectrophotometry / Spectrophotometer DR 2000	Laboratory
9	*E. Coli*, Coliform	Platecount	In Situ

Photos of Sampling Site

Site 1 (Parit Desa)

Site 2 (Air Raja River)

Site 3 (Lintas Dusun River)

Site 4 (Tanjung Leban river)

Well Water Sampling Site

Site 5 (Jauhari well)

Site 6 (Zein Well, mineral soil)

Site 7 (Amirrudin well)

Site 8 (SM deep well)

How to treat peat water?

- Neutralize the pH
- Absorb the color
- Precipitate particles

Prototype of IPAG30 tested in Middle Kalimantan

(Patent No. : P00201000586)

Peat Water : before and after treatment

Physical Analysis

No	Parameter	Unit	Standard	Peat water	Clean water
1	Color	TCU	**15**	**462 - 503**	**2**
2	Odour	-	Odourless	Odour	Odourless
3	Taste	-	Tasteless	Acid	Tasteless
4	Conductivity	mS/cm		98.9 - 103	92
5	Turbidity	NTU/FAU	5	4 - 11	1
6	DO	mg/l		3.9 – 8.2	4.6
7	Temperature	° C	Air temp.	29 – 30.2	24.3
8	Salinity	%		0	0

Chemical Analysis

No	Parameter	Unit	Standard	Peat water	Clean water
1	pH	-	6.5 – 8.5	**3.52**	6.7
2	Ammonia (NH3-N)	mg/l	1.5	0.511	0.310
3	Nitrat (NO3-N)	mg/l	50	1.109	0.064
4	Nitrit (NO2-N)	mg/l	3	0.042	0.002
5	Total N	mg/l		0.323	0.167
6	Total P	mg/l		0.109	0.030
7	Sulphate (SO4)	mg/l	250	38.80	71.53
8	TOM	mg/l	-	**438.2**	19.86
9	TDS	mg/l	500	**735**	353

Microbial Analysis

No	Parameter	Unit	Standard	Peat water	Clean water
1	*E. Coli*	Col/100 ml	0	70	0
2	Coliform	Col/100 ml	0	630	0

Tanjung Leban Communities

- People are starting to understand the importance of clean water for health
- Society received with open arms IPAG installation plan in the village
- Tanjung Leban Communities willing to operate properly and maintain IPAG in the future
- IPAG mounting location has been agreed with the Air Raja river (Site 2)

Tanjung Leban Community Leaders

Conclusion

- Water quality in the village of Tanjung Leban in the form of dug wells, boreholes and peat water from rivers and lakes : most did not qualify as a source of clean water or drinking water.
- Most of the main parameters (physical, chemical and biological) did not meet the allowable threshold based on the Health Minister of Republic Indonesia of. 492 in 2010
- Efforts are needed to improve the quality of the peat surface water into clean water to provide the everyday needs of local people
- Jar test trials conducted in two villages to treat water peat has managed to find the optimal combination of ingredients needed, so that the water produced meets health standards

Thank You...!!!

Part IV

LOCAL PARTICIPATION IN WATER RESOURCES MANAGEMENT

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Map of Indonesia

Background

- Provision of clean water is a major human need for survival and becomes the deciding factor of human health and welfare.
- The availability of clean water reduced day by day not in accordance with the human population growth.

Drinking water services

- PDAM is the one of local company (belong to local government) having task to deliver clean water.
- Level of coverage in clean water
  - 41,88 % of people in big cities
  - 13,94 % of people in villages
  - 27,05 % national average
- Difficulties to deliver clean water in marginal area :
  - Peatland areas
  - Coastal and small island areas
  - Flooding areas
  - Water polluted ares

Peatland Area

- Peat water has characteristics including :
  - brownish red color,
  - containing high organic matter,
  - pH 2-5 and
  - sour taste
  - low hardness (Herlambang and Said 2005)
- The total area of peatlands in Indonesia reaches ± 21 million ha, of which includes the island of Sumatra, Kalimantan, and Papua
- Based on the data from Litbang BB SDLP (2008), distribution of the largest peatland is located on the island of Sumatra in Riau Province and Kalimantan, Central Kalimantan province

Distribution of the peat surface area in Indonesia (BB Litbang SDLP, 2008)

Island	Province	Land Area (Ha)	Worthy of Agriculture (Ha)
Sumatera		6.244.101	2.253.733
	Riau	4.043.600	774.946
	Jambi	716.839	333.936
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	South Kalimantan	331.629	162.819
Papua		7.001.239	2.273.160
TOTAL		18.317.589	6.057.149

- The results of preliminary showed that Sala River water, in Katingan Central Kalimantan and Air Raja river water in Bengkalis Riau Province. In terms of quality, belongs to the class C with polluted status based on method STORET score (Minister of Health Regulation No. 115/2003).
- Peat water has very limited use such as for local fisheries.
- The purpose of this study was to test IPAG60 in improving the quality of peat water into clean water, in two locations : Tanjung Leban village in Riau Province and Bana Hiyang village in Central Kalimantan Province.

Peatwater for daily needs

Peat Water Treatment Plant : IPAG60

- Peat water treatment into clean water : IPAG60
- Two locations: Katingan, Central Kalimantan Province and Bengkalis, Riau Province.
- IPAG characteristics :
  - continuous flow
  - production capacity of 3600 liter/hour
  - type IPAG60
  - serie no IPAG 60-16DA5-001/V/2011

Peat water treatment plant (IPAG)

Training course of IPAG60

Training of IPAG60

Parameters Analysis

Physical quality analysis

- These parameters are taken to see the characteristics of the peat water including: color detected by a colorimeter at 455 nm wave length, taste, conductivity measured by conductivity TDS meter, turbidity using turbidymeter, temperature and salinity measured by Water Quality Checker (WQC).

Chemical quality analysis

- Water quality measurements based on non-metallic and metallic parameters content. Analysis of non metallic content with titration method include: pH, sulphate, total organic mater (TOM), ammonia, nitrate, nitrite, hardness, cyanide, fluoride, total N, phosphate, total P, and phenol. Analysis of the metal content includes: Hg, As, Fe, Cd, Zn, Cu, Pb, Mn, Ca, Mg, total Cr by the method of spectrophotometry with DR 2000 Spectrophotometer.

Biological quality analysis

- Pollutant indicator bacteria observed were total E. coli and Coliform. Colony count methods (OLIVER 1999) using peat water samples from selected rivers. 0.45 nm porous cellulose membrane placed on a sterile filter device using tweezers.

Method of classification

- Water quality analysis and assessment were done by the of STORET scoring method (Minister of Health Regulation No. 115/2003).
- This method aims to determine the status of water quality that is commonly used.
- The principle of this method is to determine water quality status by comparing water quality data with water quality standards in accordance with its designation (MOE Decree No. 115 of 2003).

Classification of water quality status

Number of Parameter	Values	Parameter		
		Physical	Chemical	Biologycal
<10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Average	-3	-6	-9
>10	Maximum	-2	-4	-6
	Minimum	-2	-4	-6
	Average	-6	-12	-18

Classification	Status	Water quality	Score
Class A	Good	Meet the standard	0
Class B	Fair	Ligthly polluted	-1 s/d -10
Class C	Bad	Polluted	-11 s/d -30
Class D	Very Bad	Highly polluted	≥ -31

Physical analysis for Sala River

No	Parameter	Unit	Standard *)	Peat water	Score	Clean water By IPAG	Score
1	Colour	TCU	15	374	-1	4	0
2	Odour	-	No odour	Odour	-1	No odour	0
3	Taste	-	No taste	Acid	-1	No taste	0
4	Turbidity	NTU/FAU	5	25	-3	0	0
Total skor					-6		0

Physical analysis for Air Raja River

No	Parameter	Unit	Standard *)	Peat water	Score	Clean water By IPAG	Score
1	Colour	TCU	15	462 - 503	-1	2	0
2	Odour	-	No odour	Odour	-1	No odour	0
3	Taste	-	No taste	Acid	-1	No taste	0
4	Turbidity	NTU/FAU	5	7.5	-1	1	0
	Total skor				-4		0

Chemical analysis for Sala River

No	Parameter	Unit	Standard *)	Peat water	Score	Clean water By IPAG	Score
1	Total (Fe)	mg/l	0,3	0,414	-2	0.021	0
2	Manganese (Mn)	mg/l	0,1	0,061	0	0.038	0
3	pH	-	6.5 - 8.5	2.82	-2	7.0	0
4	Ammonia (NH3-N)	mg/l	1.5	ttd	0	0.027	0
5	Nitrate (NO3-N)	mg/l	50	0.177	0	0.308	0
6	Nitrite (NO2-N)	mg/l	3	0.036	0	0.006	0
7	Total N	mg/l	-	0.566	0	0.859	0
8	Phosphate (PO4-P)	mg/l	0.2	0.429	-2	0.014	0
9	Total P	mg/l	0.2	0.9398	-2	0.017	0
10	Sulphate (SO4)	mg/l	400	32.21	0	3.894	0
11	TOM	mg/l	-	619.42	0	0.617	0
12	Hardness	mg/l	500	Ttd	Ttd	ttd	0
	Total score				-8		0

Chemical analysis for Air Raja River

No	Parameter	Unit	Standard*)	Peat water	Score	Clean water By IPAG	Score
1	Total (Fe)	mg/l	0.3	0.174	0	< 0.009	0
2	Manganese (Mn)	mg/l	0.1	0.071	0	0.039	0
3	pH	-	6.5-8.5	3.52	-2	6.7	0
4	Ammonia (NH3-N)	mg/l	1.5	0.511	0	0.310	0
5	Nitrate (NO3-N)	mg/l	50	1.109	0	0.064	0
6	Nitrite (NO2-N)	mg/l	3	0.042	0	0.002	0
7	Total N	mg/l	-	0.323	0	0.167	0
8	Total P	mg/l	0.2	0.109	0	0.030	0
9	Sulphate	mg/l	250	38.80	0	71.53	0
10	TOM	mg/l	-	438.16	0	19.86	0
11	Hardness		500	735	-2	353	0
	Total score				-4		0

Microbial analysis

No	Parameter	Standard*)	Peat water	Score	Clean water By IPAG	Score
1	E. Coli (col/100ml)	0	78	-3	0	0
2	Coliform (Col/100ml)	0	109	-3	0	0
	Total			-6		0

No	Parameter	Standard*)	Peat water	Score	Clean water By IPAG	Score
1	E. Coli (col/100ml)	0	70	-3	0	0
2	Coliform (col/100ml)	0	630	-3	0	0
	Total			-6		0

Peat Water : before and after treatment

River water quality before and after treatment by IPAG60

No	Parameter	Before	After
1	Physical	-5	0
2	Chemical	-8	0
3	Biology	-6	0
Total		-19	0
Status of water quality		Polluted	Meet the standard

No	Parameter	Before	After
1	Physical	-4	0
2	Chemical	-4	0
3	Biology	-6	0
Total		-16	0
Status of water quality		Polluted	Meet the standard

CONCLUSION

- IPAG60 was tested in two locations: Sala River in Central Kalimantan Province and Air Raja River in Riau Province.
- Based on water quality analysis using the classification score, it can be concluded that IPAG60 has been able to increase the quality of peat water coming from two different rivers, from class C (polluted status) to class A (good status).
- It will provide an alternative technology to provide clean water access in peat land areas

Thank You...!

Lecture 5: Biodiversity and Ecosystem Services in the Context of Global Change

Osamu SAITO *(Institute for Sustainability and Peace, United Nations University)*

This session is intended to provide graduate students with a multidisciplinary perspective and understanding of biodiversity, ecosystems and agriculture, and their interactions, and integration of human needs and ecosystem functioning in land management systems. The session will overview global consequences of ecosystem changes and drivers of these changes, to introduce sustainable approach to ecosystems management at different levels.

The session will introduce biodiversity in the context of global change with overview of several global initiatives on assessment of biodiversity and ecosystem services. The session will then disuses condition and trend of food and biofuel production and explore the potential of ecosystem service and agrodiversity for sustainable food and biofuel production. Finally, the session will examine the linkage of land use to global environment challenges, especially land degradation, climate change and loss of biodiversity in production landscapes and also look at sustainable land management approaches to integrate full range of ecosystem services at various levels. The session will give particular attention to local knowledge and innovations in dealing with global environmental changes.

1. Global change and challenges of biodiversity
- Assessment Landscape
- Global Environmental Outlook (GEO) & Global Biodiversity Outlook (GBO)

2. Convention on Biological Diversity (CBD)
- International Target and Strategy
- National Target, Strategy, Policy Tools

3. Millennium Ecosystem Assessment (MA)
- MA Conceptual Framework
- Global and sub-global assessments and scenario analysis

4. Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES)
- Focus and functions of IPBES
- Traditional knowledge and ecosystem management

5. Agrodiversity and resilience for sustainable bioproduction
- Agrodiversity and Resilience
- Management approaches

6. Summary and conclusion

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Biodiversity and Ecosystem Services in the Context of Global Change

9 December 2013

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Institute for Sustainability and Peace
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Outline

1. **Global change and challenges of biodiversity**
   - Assessment Landscape
   - Global Environmental Outlook (GEO) & Global Biodiversity Outlook (GBO)
2. **Convention on Biological Diversity (CBD)**
   - International Target and Strategy
   - National Target, Strategy, Policy Tools
3. **Millennium Ecosystem Assessment (MA)**
   - MA Conceptual Framework
   - Global and sub-global assessments and scenario analysis
4. **Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES)**
   - Focus and functions of IPBES
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5. **Agrodiversity and resilience for sustainable bioproduction**
   - Agrodiversity and Resilience
   - Management approaches
6. **Summary and conclusion**

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1. Global change and challenges of biodiversity

Global Assessment Landscape

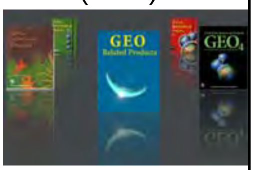
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GIWA	GIWA	GIWA	GIWA							
	MA	MA	MA	MA	MA					
WWDR	WWDR	WWDR	WWDR	WWDR2	WWDR2	WWDR2		WWDR3	WWDR3	
	FRA2005	FRA2005	FRA2005	FRA2005	FRA2005	FRA2010	FRA2010	FRA2010	FRA2010	FRA2010
	LADA	LADA	LADA	LADA	LADA	LADA	LADA	LADA	LADA	
IPCC3	IPCC3	IPCC4	IPCC4	IPCC4	IPCC4	IPCC4	IPCC4		IPCC5	IPCC5
				GBO2	GBO2	GBO2		GBO3	GBO3	GBO3
				CAWMA	CAWMA	CAWMA	CAWMA	CAWMA	CAWMA	
GEO2	GEO3	GEO3		GEO4	GEO4	GEO4	GEO4		GEO5	GEO5
					IAASTD	IAASTD	IAASTD	IAASTD		
							AoA(GMA)	AoA(GMA)	AoA(GMA)	

GIWA – Global International Water Assessment; **MA** – Millennium Ecosystem Assessment; **WWDR** – World Water Development Report; **FRA** – Forest Resources Assessment; **LADA** – Land Degradation Assessment; **IPCC** – Intergovernmental Panel on Climate Change; **GBO** – Global Biodiversity Outlook; **CAWMA** – Comprehensive Assessment of Water Management in Agriculture; **GEO** – Global Environmental Outlook; **IAASTD** – International Assessment of Agricultural Science and Technology for Development; **AoA (GMA)** – building the foundations for Regular Process for the Global Reporting and Assessment of the state of the marine environment, including socio-economic aspects.

(Source) A.K. Duraiappah (2009) Ecosystem Services: The Global Assessment Landscape

Global Environment Outlook (GEO)

- GEO is a consultative, participatory process that builds capacity for conducting integrated environmental assessments for reporting on the state, trends and outlooks of the environment.
- GEO is also a series of products that informs environmental decision-making and aims to facilitate the interaction between science and policy.
- The rigorous assessment process aims to make GEO products scientifically credible and policy relevant - providing information to support environmental management and policy development.



http://www.unep.org/geo/pdfs/geo5/GEO5_report_full_en.pdf

The GEO approach to integrated environmental assessment

- Five Key Questions for GEO's integrated approach:
  1. **what is happening to the environment and why?**
  2. **what are the consequences for the environment and humanity?**
  3. **what is being done and how effective is it?**
  4. **where are we heading? and**
  5. **what actions could be taken for a more sustainable future?**
- The "integrated approach" to answering the questions above is an umbrella term for:
  - linking the analysis of environmental state and trends with the policy analysis;
  - incorporating global and sub-global perspectives;
  - incorporating historical and future perspectives;
  - covering a broad spectrum of issues and policies; and
  - integrating the consideration of environmental change and human well-being.

DPSIR Model

The Driver-Pressure-State-Impact-Response (DPSIR) framework/approach has been broadly applied in environmental assessments and analysis.

Drivers are factors that result in pressures that in turn cause changes in the system. Both natural and anthropogenic forcing factors are considered; an example of the former is climate variability while the latter include factors such as human population size, associated urban development, demand for food, energy, etc.

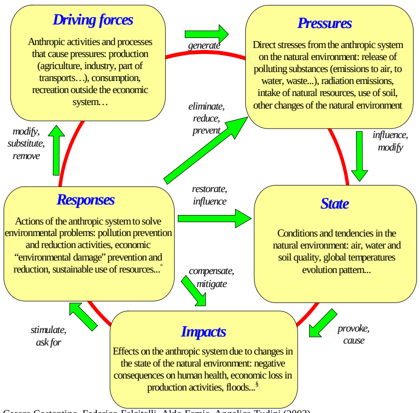
Pressures include factors such as pollution, habitat loss and degradation. For example, coastal development results in increased coastal armoring and the loss of associated intertidal habitat.

State variables are indicators of the condition of the ecosystem (including physical, chemical, and biotic factors).

Impacts comprise measures of the effect of change in these state variables such as loss of biodiversity, declines in productivity and yield, etc. Impacts are measured with respect to management objectives and the risks associated with exceeding or returning to below these targets and limits.

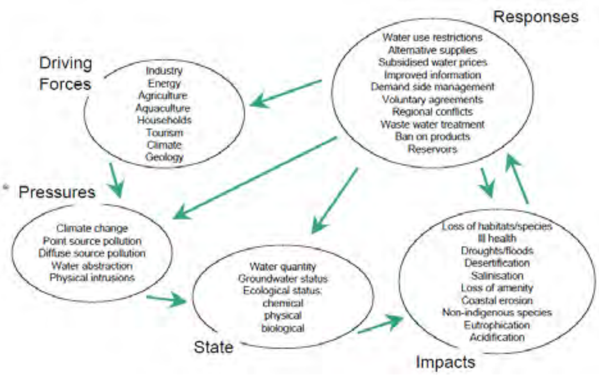
Responses are the actions (regulatory and otherwise) that are taken in response to predicted impacts. Forcing factors under human control trigger management responses when target values are not met as indicated by risk assessments.

An analytical framework for the economy-environment interaction



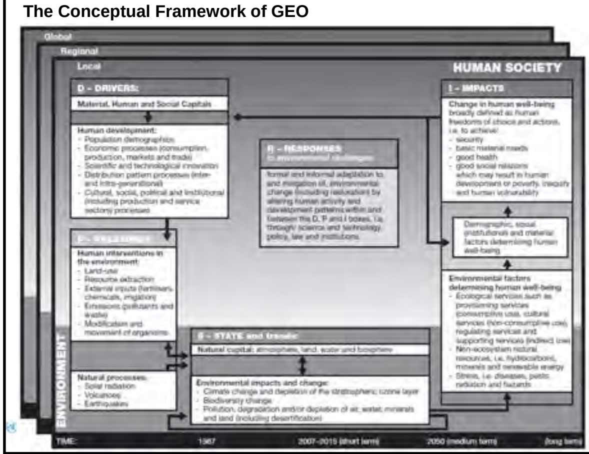
(Source) Cesare Costantino, Federico Falcitelli, Aldo Femia, Angelica Tudini (2003)

A generic DPSIR framework for water



(Source) Peter Kristensen (2004)The DPSIR Framework

The Conceptual Framework of GEO



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2. Convention on Biological Diversity (CBD)

Multilateral Environmental Agreements (MEAs)

- The MEAs include global biodiversity-related treaties and the "Rio Conventions":

<Global biodiversity-related treaties>

- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES),
- Conservation on Migratory Species (CMS),
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA),
- Ramsar Convention on Wetlands (Ramsar), and
- World Heritage Convention (WHC),

<Rio Conventions>

- Convention on Biological Diversity (CBD/UNCBD)
- UN Framework Convention on Climate Change (UNFCCC)
- UN Convention to Combat Desertification (UNCCD)

CBD entered into force on 29 December 1993. It has 3 main objectives:

1. The conservation of biological diversity
2. The sustainable use of the components of biological diversity
3. The fair and equitable sharing of the benefits arising out of the utilization of genetic resources

What is biological diversity?

"**Biological diversity**" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. (from Article 2. Use of Terms)

"**Biological resources**" includes genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity.

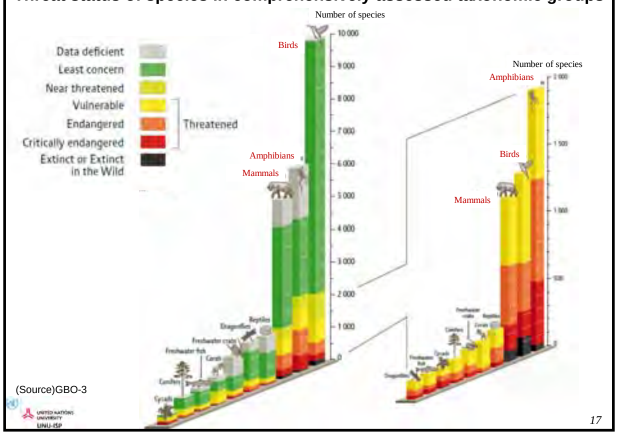
Definition of key terms

- "**Ecosystem**" means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.
- "**Habitat**" means the place or type of site where an organism or population naturally occurs.
- "**Sustainable use**" means the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations.

Global Biodiversity Outlook (CBO)

- Global Biodiversity Outlook is the flagship publication of the CBD.
- Drawing on a range of information sources, including National Reports, biodiversity indicators information, scientific literature, and a study assessing biodiversity scenarios for the future, the third edition of Global Biodiversity Outlook (GBO-3) summarizes the latest data on status and trends of biodiversity and draws conclusions for the future strategy of the Convention.

Threat status of species in comprehensively assessed taxonomic groups

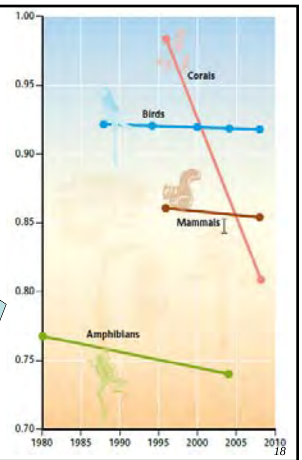


(Source)GBO-3

Red List Index

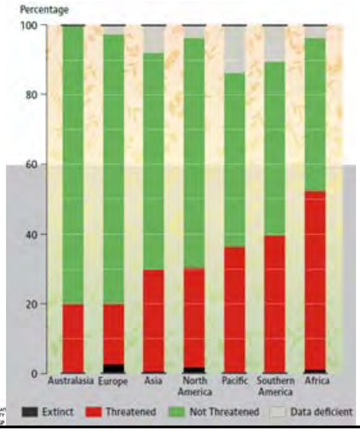
A Red List Index value of 1.0 indicates that all species in a group would be considered as being of Least Concern, that is not expected to become extinct in the near future. At the other extreme, a value of 0 indicates that all species in a group have gone extinct.

The proportion of warm-water coral, bird, mammal and amphibian species expected to survive into the near future without additional conservation actions has declined over time. The Red List Index (RLI) for all these species groups is decreasing. Coral species are moving most rapidly towards greater extinction risk, while amphibians are, on average, the group most threatened.



(Source)GBO-3

Conservation status of medicinal plant species in different geographic regions



The greatest risk of extinction occurs in those regions, Africa, South America and the Pacific, where medicinal plants are most widely used.

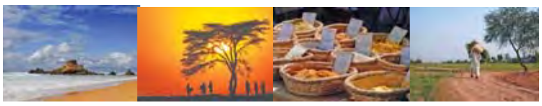
(Source)GBO-3

Strategic Plan for Biodiversity 2011-2020

- In decision X/2, the tenth meeting of the Conference of the Parties (COP 10) held from 18 to 29 October 2010, in Nagoya, Aichi Prefecture, Japan, adopted a revised and updated Strategic Plan for Biodiversity, including **the Aichi Biodiversity Targets**, for the 2011-2020 period.
- This new plan will be the overarching framework on biodiversity, not only for the biodiversity-related conventions, but for the entire United Nations system.
- COP10 agreed to translate this overarching international framework into national biodiversity strategies and action plans within two years.

2011-2020 Strategy: Strategic Goals

- Address the underlying causes of biodiversity loss
- Reduce the pressures on biodiversity
- Safeguard biodiversity at all levels
- Enhance the benefits provided by biodiversity
- Provide for capacity-building



2011-2020 strategy: Selected Targets

- At least halve and where feasible bring close to zero the rate of loss of natural habitats including forests
- Protect 17 per cent of terrestrial and inland water areas and 10 per cent of marine and coastal areas
- Restore at least 15 percent of degraded areas
- Make special efforts to reduce the pressures faced by coral reefs
- Substantially increase in the level of financial resources in support of implementation of the Convention

2011-2020 strategy: Implementation

- The "Aichi Target" will be the overarching framework on biodiversity not only for the biodiversity-related conventions, but for the entire United Nations system.
- Parties agreed to translate this overarching international framework into national biodiversity strategy and action plans within two years
- Actions in support will also take place at sub-national and local levels

2011-2020 Strategy: Strategic Goals	The Aichi Biodiversity Targets "Living harmony with nature"
Address the underlying causes of biodiversity loss	**Strategic Goal A**: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society
Reduce the pressures on biodiversity	**Strategic Goal B**: Reduce the direct pressures on biodiversity and promote sustainable use
Safeguard biodiversity at all levels	**Strategic Goal C**: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity
Enhance the benefits provided by biodiversity	**Strategic Goal D**: Enhance the benefits to all from biodiversity and ecosystem services
Provide for capacity-building	**Strategic Goal E**: Enhance implementation through participatory planning, knowledge management and capacity building

(Source) http://www.cbd.int/doc/strategic-plan/2011-2020/Aichi-Targets-en.pdf

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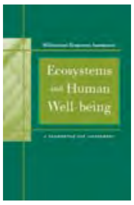
3. Millennium Ecosystem Assessment (MA)



First MA Product (2003)

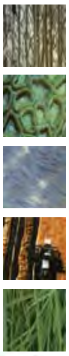
MA Synthesis Report (2005)

MA Full Reports (2005)

The Millennium Ecosystem Assessment (MA) is:

- Designed to meet a portion of the assessment needs of
  - Convention on Biological Diversity (CBD),
  - Convention to Combat Desertification (CCD),
  - Ramsar Wetlands Convention,
  - other partners including the private sector and civil society
- Focused on the consequences of changes in ecosystems for human well-being
- Undertaken at multiple scales (local to global)
- Designed to both provide information and build capacity to provide information
- Expected to be repeated at 5-10 year intervals if it successfully meets needs

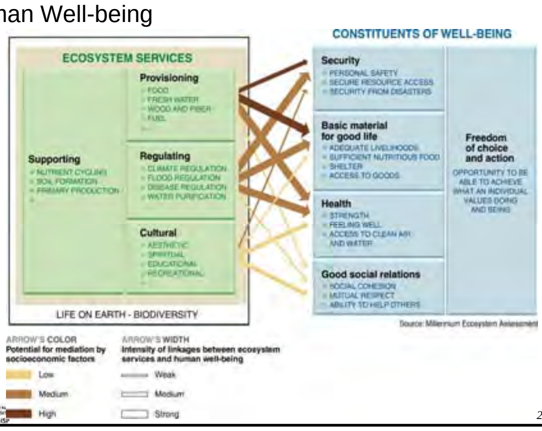
The MA focuses on:



- Ecosystem services
- The consequences of changes in ecosystems for human well being
- The consequences of changes in ecosystems for other life on earth

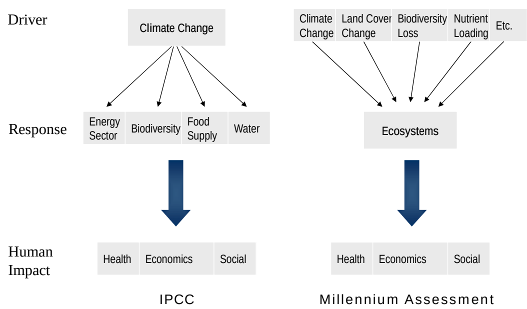
Focus: Ecosystem Services
The benefits people obtain from ecosystems

Focus: Consequences of Ecosystem Change for Human Well-being

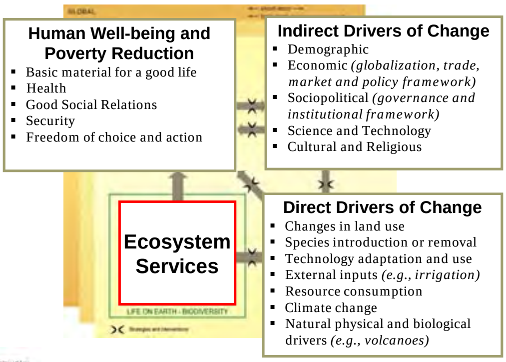


The MA is an Integrated Assessment

IPCC looks at impacts of one driver (climate) on different systems; MA will integrate the effects of multiple drivers on all ecosystems

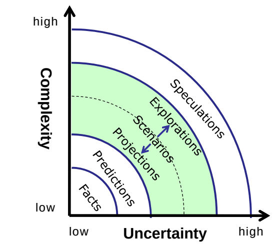


MA Framework



Scenarios are not predictions

- Methods to help decision makers systematically think about the future and draw lessons for today's decisions include predictions, projections, explorations, and scenario analysis.
- **Scenario planning** (or **scenario analysis**) has emerged as the most appropriate tool for complex systems.
- The goal of scenario planning is to consider **a variety of possible futures** reflecting important uncertainties, rather than to focus on an accurate prediction of a single outcome.
- Scenarios are stories about the future, told as a set of "plausible alternative futures" about what might happen under particular assumptions (MA 2003).

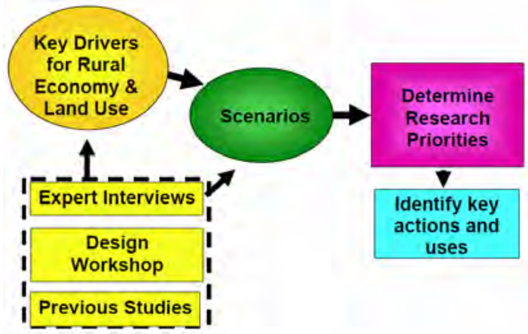


Tools for Addressing Future Uncertainty and Complexity

(Source) WRI (2008) Ecosystem Services: A Guide for Decision Makers,

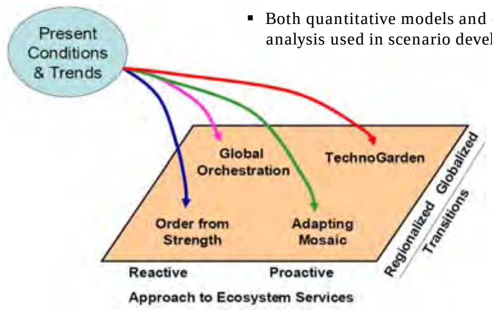
Scenario making process

(e.g. UK's Rural Futures)



Millennium Ecosystem Assessment's (MA) Scenarios

- Not predictions – scenarios are plausible futures
- Both quantitative models and qualitative analysis used in scenario development



MA(2005) Millennium Ecosystem Assessment Findings

MA Scenarios

Globalization

Global Orchestration:

A world with a "socially conscious" globalization that emphasizes economic growth, social reform, and equity, but decision makers take a reactive approach toward environmental problems.

TechnoGarden:

This society explores the possibilities of "green" technologies to manage all categories of ecosystem services to support human systems in a more globalized world

Reactive → **Proactive**

Order from Strength:

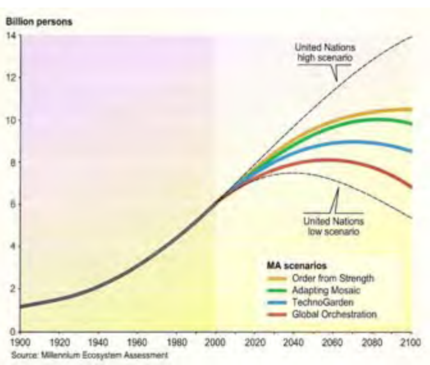
Decision makers also only deal with environmental degradation when it starts to seriously affect humans (reactive); at the same time they focus on national security issues and economic improvements only for their own countries.

Adapting Mosaic:

More regionalized world with a focus on experimentation, local learning, and adaptations to ecosystem change and the introduction of more flexible local governance structures for environmental and social management.

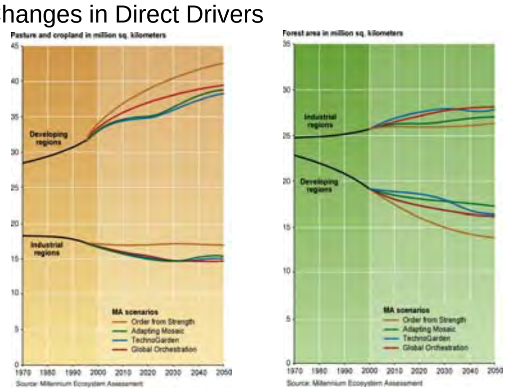
Regionalization/Localization

Population changes under different scenarios



(Source) Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being Synthesis

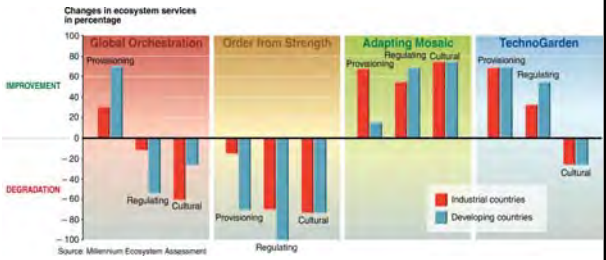
Changes in Direct Drivers



Crop Land **Forest Area**

(Source) Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being Synthesis

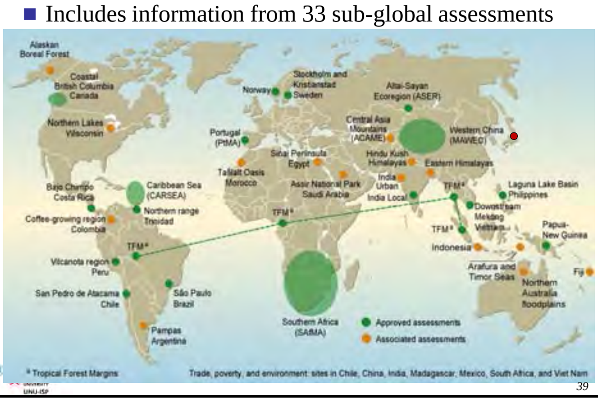
Improvements in services can be achieved by 2050

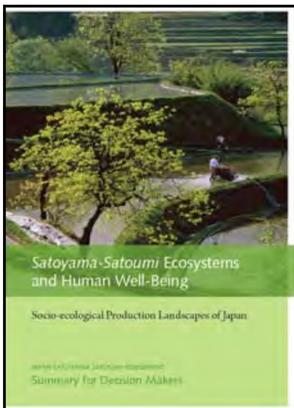


(Source) Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-being Synthesis

Multi-scale assessment

- Includes information from 33 sub-global assessments





The Japan Satoyama Satoumi Assessment (JSSA)

- Sub-global assessment of the Millennium Ecosystem Assessment (MA)
- The main objective of the JSSA is to provide scientifically credible and policy-relevant information on the significance of ecosystem services provided by *satoyama* and *satoumi* and their contributions to economic and human development
- Studied from 2006 to 2010, and the assessment report was just published in 2010 for CBD/COP10 at Nagoya

(Source)
Japan Satoyama Satoumi Assessment, 2010. Satoyama-Satoumi Ecosystems and Human Well-being: Socio-ecological Production Landscapes of Japan – Summary for Decision Makers. United Nations University, Tokyo, Japan.
http://www.ias.unu.edu/resource_centre/SDM-EN_24Feb2011.pdf

Local and Indigenous Knowledge (LINK) in Socio-Ecological Production Landscapes (*Satoyama and Satoumi*)

Japan *Satoyama Satoumi* Assessment (2010) defines *satoyama* and *satoumi* landscapes as **dynamic mosaics of managed socio-ecological systems producing a bundle of ecosystem services for human well-being**: **Socio-Ecological Production Landscapes**

Satoyama *Satoumi* (JSSA, 2010)

Satoyama and *Satoumi* Landscapes providing a "Bundle of Ecosystem Services"

Links between abundant rice paddy environments and local people involved in rice production (JSSA, 2012)

Provisioning :

- **Rice; Rice bran** (used as fertilizer or for the production of Japanese pickles); **rice straw** (for roofing materials, ropes and straw sandals); **seven spring herbs**

Regulating :

- **Flood control**; **Water retention**, etc.

Cultural:

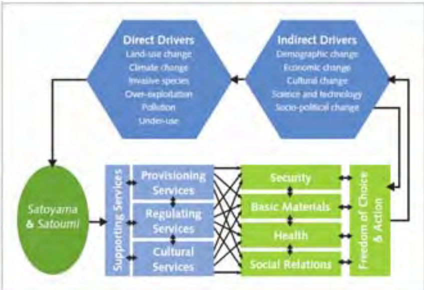
- **Festival and events** (including warship of the "god of the water", "god of rice paddies"); **Various cooperative systems**

Biodiversity:

- **Habitat for biological organisms** benefited from year-round warm and shallow water, and fertile soil (Japanese crested ibis, oriental stork, Crucian carp, dojo loach, river snails, etc.)

Conceptual framework of JSSA

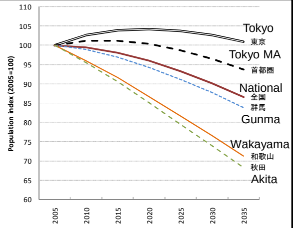
- The timeframe of the assessment is changes that have occurred in *satoyama* and *satoumi* in the last fifty years
- The human impact upon ecosystem services includes "direct" and "indirect" drivers.

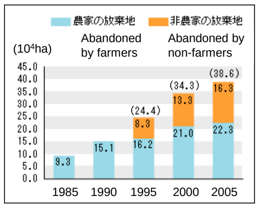


(Source)Japan Satoyama Satoumi Assessment, 2010. Satoyama-Satoumi Ecosystems and Human Well-being: Socio-ecological Production Landscapes of Japan – Summary for Decision Makers. United Nations University, Tokyo, Japan.

Depopulation and Underuse

- **Under-use** of satoyama forest brought about by decreases in rural population, a shift from biomass energy to fossil fuel and importation of cheap timber
- **Under-use** or even abandonment of traditional satoyama and satoumi landscape, which has led to negative trends in health and overall well-being in Japan
- Major consequences: Expansion of wild animals, deterioration of quality of domestic forest resources, degradation of regulating services (carbon, flood control, etc.,) and losing cultural services





(Source)国立社会保障・人口問題研究所編(2007)日本の都道府県別将来推計人口　平成19年5月推計, 厚生統計協会

Positioning and characteristics of four scenarios in JSSA

- The JSSA examines four prospective scenarios for satoyama and satoumi in the year 2050.
- The vertical axis examines governance and economic development in terms of localised versus globalised approaches.
- Horizontal axis looks at ecosystem service management as nature oriented versus technology oriented.

(Source) JSSA(2010)

Findings and data:

- *Summary for Decision Makes (SDM) in English and Japanese*
- *Policy Brief in English*
- *6 cluster reports in Japanese*
- *National Report in English (2012 through UNU Press)*
- *National Report in Japanese (2012 through Asakura Publishing)*

SATOYAMA Initiative

Vision: Societies in harmony with nature
長期目標：自然共生社会

Three-Fold Approach:

1. Consolidate wisdom on securing diverse ecosystem services and values
2. Integrate traditional ecological knowledge and modern science
3. Explore new forms of co-management systems

3つの行動指針：

1. 多様な生態系のサービスと価値の確保のための知恵の結集
2. 伝統的知識と近代科学の融合
3. 新たな共同管理のあり方の探求

- Resource use within the carrying capacity and resilience of the environment 環境容量・自然復元力の範囲内での利用
- Cyclic use of natural resources 自然資源の循環利用
- Recognition of the value and importance of local traditions and cultures 地域の伝統・文化の価値と重要性の認識
- Multi-stakeholder participation and collaboration 多様な主体の参加と協働
- Contributions to socio-economies 社会経済への貢献

Five Key Perspectives in the approach
５つの視点

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4. Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES)

IPBES: Current Status

Scientific Background:

- Many ecosystem services related assessments
- Fragmented, multiple frameworks and methodologies
- Scientific credibility varies
- Regularize the Millennium Ecosystem Assessment (MA) which focused on ecosystem services and human well-being

Institutional Background:

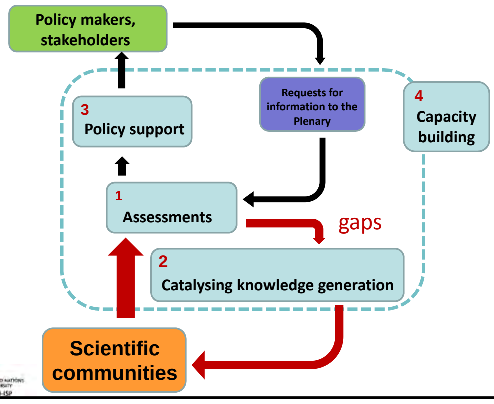
Established on 21 April 2012 in Panama, IPBES is an independent intergovernmental body which aims to provide scientific support for policy-making in the area of biodiversity and ecosystem services. The four key functions of IPBES are to provide:

1. Regular and timely assessments
2. Knowledge generation
3. Support policy formulation and implementation
4. Capacity building

The Multidisciplinary Expert Panel (MEP) of IPBES is preparing a common conceptual framework that facilitates and realizes these four functions by the next IPBES Plenary (IPBES-2) scheduled for December 2013 in Antalya, Turkey.

IPBES Plenary-1 in Bonn, Germany, 21-26 Feb. 2013

IPBES and Scientific communities



IPBES Work Programme Objectives

The Plenary in its decision IPBES/1/2 requested a draft work programme for 2014-2018 with a sequenced and prioritized set of objectives, deliverables, actions and milestones for advancing the four functions of IPBES at relevant scales. In order to deliver on the four functions of IPBES at relevant scales in a coherent and integrated manner, five cross-cutting objectives are proposed, and the work programme deliverables are clustered under these objectives. The five objectives are to:

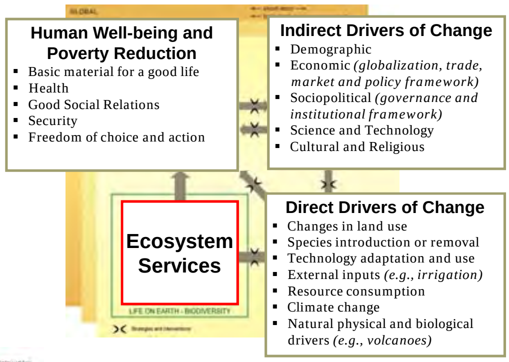
a) enhance the enabling environment for the knowledge-policy interface for biodiversity and ecosystem services;
b) strengthen the knowledge-policy interface on biodiversity and ecosystem services on regional and sub-regional levels;
c) strengthen the knowledge-policy interface with regards to thematic and methodological issues;
d) strengthen the knowledge-policy interface on the global dimensions of changes in biodiversity and ecosystem services; and
e) communicate and evaluate IPBES activities, deliverables and findings.

IPBES goal: strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development

IPBES functional approach: strengthen the science-policy interface at all levels through:

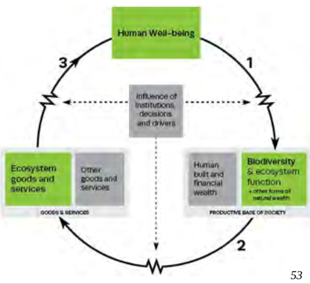
- identifying scientific information needs and catalyzing knowledge generation
- implementing and promoting assessments of various geographic and thematic scope
- promoting the accessibility and further development of identified policy support tools
- addressing identified capacity building needs through integration and by catalyzing financial support

Conceptual Framework used by Millennium Ecosystem Assessment (MA)



Key Questions derived from proposed IPBES conceptual framework

1. How have changes in HWB caused changes of the productive base from biodiversity and ecosystem functioning? (Arrow1)
2. How have changes in biodiversity & ecosystem functioning and other forms of wealth influenced the supply of the ecosystem goods &services and other services? (Arrow 2)
3. How have changes in the access and use of ecosystem goods &services and other goods & services influenced HWB? (Arrow 3)
4. What policy interventions in the form of institutions and decisions might be needed to mainstream management of ecosystem into broader social, economic, and environmental planning?
5. How to take into the impacts of decisions by harnessing synergies and resolving trade-offs among natural and other forms of wealth.



IPBES/1/INF/9

Objectives of IPBES Conceptual Framework (CF)

- The IPBES CF is a model of how social-ecological systems work, a concise summary in the form of a narrative and graphics that depicts key social and ecological components, and the relationships between these components, providing common terminology and structure for the variables that are of interest in the systems under analysis and facilitating scaling up and down between assessments conducted at different scales.
- IPBES recognizes and considers knowledge systems other than science, including indigenous and local knowledge systems, which can be complementary to science-based models and can reinforce the delivery of IPBES functions.
- CF is a tool to achieve a common vision and a shared language across the different disciplines, knowledge systems and stakeholders that are expected to be active participants in the Platform.
- IPBES CF is intended to be a working agreement, a basic common understanding on how social-ecological systems work, as a basis for coordinated action towards the achievement of the four functions and the ultimate goal of the Platform.

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5. Agrodiversity and Resilience for sustainable bioproduction

- Agrodiversity and Resilience
- Management approaches

Agrodiversity

- **Agrodiversity** broadens the concept of **agricultural biodiversity** from meaning simply genetic resources to meaning the landscape level biodiversity, and the diversity of local social organizations and technologies that support biodiversity and reduce agricultural and ecological risks.
- Substantial knowledge gaps remain regarding multiple functions and values of agrodiversity for livelihoods (food security, income generation, and resilience to market fluctuation and environmental change, etc.) and ecosystem health (conservation of biodiversity, pest regulation, nutritional and water cycles, carbon sequestration, and etc).
- Special attention should be placed on integrated approaches to management of interactions of agrodiversity components rather than one single component per se, especially diversity management at landscape level.


Terminology used by the Resilience Alliance (according to Holling & Gunderson, 2002)

Term	Definition
Ecosystem resilience	Ecological resilience can be measured in terms of the magnitude of disturbance that can be absorbed before the ecosystem reconfigures itself. It focuses on the requirement to maintain existence of function, accepts variability and the concept of multiple states of equilibrium. This approach recognises the inextricability of the dynamics linking society, natural processes and man-made systems understanding that the longer a social system is 'locked in' to an established power structure or set of behaviours and beliefs, the greater its vulnerability to unexpected and unforeseen changes in the environment.
Engineering resilience	Rate and speed of return to pre-existing conditions after disturbance. It focuses on a requirement for efficiency and predictability in man-made systems and processes and assumes the existence of a single, optimal state. It treats ecological system feedbacks as separable and manageable externalities. It strives to contain or remove risks, and tends to assume the existence of a global, rational actor, rather than acknowledging the different motivations of individuals, or social complexity. This concept of resilience is currently most pervasive within society, organisations and institutions.

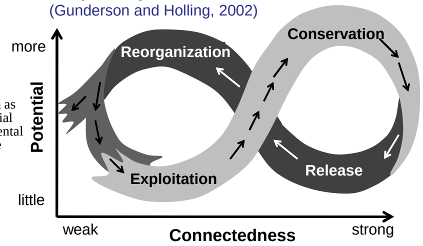
Adaptive Cycle and Resilience

The approach of the Stockholm Resilience center and the Resilience Alliance

The Adaptive cycle as it proceeds through the four phases: exploitation (organization into a new political/social system), conservation (maintenance and proliferation of the new system), release (revolution) and reorganization (regime change/a new paradigm).
By understanding adaptive cycles you gain insight into how and why a system change; develop a capacity to manage for a system's resilience.

Adaptive Cycle
(Gunderson and Holling, 2002)

The range of accumulated resources such as economic, social and environmental capital that are available and accessible



The internal controllability of a system

Specified vs. General Resilience (Walker, 2009)

- **"Specified" resilience** deals with the resilience "of what, to what" (e.g., the resilience of crop production to a drought).
- **"General" resilience** does not consider any particular kind of shock, or any particular aspect of the system that might be affected.

The distinction between these two aspects of resilience is important because there is a danger in focusing too much on known or suspected thresholds. If all the attention and resources of management are channeled into managing for identified (specified) resilience and associated thresholds, the management may inadvertently be reducing resilience in other ways – resilience to completely novel 'surprises'. There is therefore a need to consider both general and specified resilience.

Diversity, Redundancy, Resilience

- **Diversity:**

"The combination of a diversity of ecological function at specific scales and the replication of function across a diversity of scales produces resilient ecological function."

"Ecological organization at a specific scale is determined by interactions between species and processes operating within that scale. Competitive interactions are strongest among species that have similar functions and operate at similar scales. These interactions encourage functional diversity within a scale, and the distribution of ecological function across scales, enhancing cross-scale resilience.

- **Redundancy**:

"The apparent redundancy of similar function replicated at different scales adds resilience to an ecosystem: because disturbances are limited to specific scales, functions that operate at other scales are able to persist."

"Overlap of ecological function enables an ecosystem to persist. Compensation masks ecosystem degradation, because while a degraded system may function similarly to an intact system, the loss of redundancy decreases the system's ability to withstand disturbance or further species removal."

(Source) Peterson, Garry; Allen, Craig R.; and Holling, C. S., "Ecological Resilience, Biodiversity, and Scale" (1998). Nebraska Cooperative Fish & Wildlife Research Unit -- Staff Publications. Paper 4.
http://digitalcommons.unl.edu/ncfwrustaff/4

Building Resilience (Walker, 2011)

- **Step 1: Define systems**
  - Resilience of what
  - Resilience to what
- **Step 2: System dynamics (resilience analysis)**
  - Specific resilience
  - General resilience
  - Transformability
- **Step 3: Intervention options**
  - Preparedness, option & capacity
  - Intervention

(Source) 2011/03/13 09:55 Brian Walker, "Resilience Propositions on Trial: Briefing for the Mock Court", Resilience 2011, Arizona State University, http://coevolving.com/commons/20110313-0955-walker-resilience-propositions-on-trial

How to assess resilience?

Step 1: Define systems
- Resilience of what
- Resilience to what

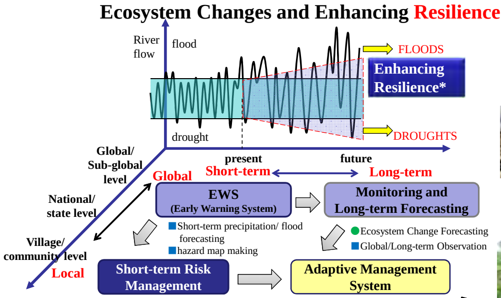
Step 2: System dynamics (resilience analysis)
- Specific resilience
- General resilience
- Transformability

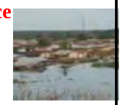
Step 3: Intervention options
- Preparedness, option & capacity
- Intervention

System	Shock/ Disturbance	Threshold/ limit	Adaptability	Preparedness	Intervention
Socio-ecological systems, bio-production system	Climate and ecosystem changes	Environmental degradation and adaptation of agricultural field	Traditional knowledge, technology, coping strategy, alternate crop species	Early warning system, education, biodiversity, information technology	Governance, tax, penalty, regulation, payment to ecosystem services (PES)

Based on Walker (2011)

Increasing Extreme Weather Events Caused by Climate and Ecosystem Changes and Enhancing Resilience





Agroforestry

- ● Enhancing agricultural productivity and storage capacity, combined with the use of indigenous species (drought resistant, early maturing variety etc.)
- ● Value adding to tree crops through the promotion of agroforestry
- ■ Wider scale irrigation/water management system building, using the existing infrastructure (dam, reservoir, well etc)
- ■ Rainwater harvesting system
- ▲ Risk management via EWS and adaptive management based on future scenario
- ▲ Commercialization of ecosystem services and spontaneous natural resource management (terroir management)

Resilience enhancement option:
● Agro-ecosystematic
■ Engineering
▲ Social

(Source)CECAR-Africa, 2011

Payment for ecosystem services (PES)

- The practice of offering incentives to farmers or landowners in exchange for managing their land to provide some sort of ecological service.
- "a transparent system for the additional provision of environmental services through conditional payments to voluntary providers."(Tacconi, 2012)

A Step-by-Step Approach to Developing PES Deals

Step 1: Identifying Ecosystem Service Prospects & Potential Buyers
Defining, measuring, and assessing the ecosystem services in a particular area
Determining marketable value
Identifying potential buyers who benefit from the service
Considering whether to sell as individuals or as a group

Step 2: Assessing Institutional & Technical Capacity
Assessing legal, policy, and land ownership context
Examining existing rules for PES markets and deals
Surveying available PES support services and organizations

Step 3: Structuring Agreements
Designing management and business plans to provide the ecosystem service that is the focus of the PES deal
Reducing transaction costs
Reviewing options for payment types
Establishing the equity and fairness criteria for evaluating payment options
Selecting a contract type

Step 4: Implementing PES Agreements
Finalizing the PES management plan
Verifying PES service delivery and benefits
Monitoring and evaluating the deal

(Source)
- Tacconi, L. (2012). Redefining payments for environmental services. Ecological Economics, 73(1): 29-36
- UNEP (2008) Payments for Ecosystem Services: Getting Started: A Primer, http://www.unep.org/pdf/PaymentsForEcosystemServices_en.pdf

Traditional Homegarden Systems in Rural Asia

Based on the field survey of homegarden systems in Vietnam, Indonesia and Sri Lanka, we found that traditional homegarden systems have relatively higher resilience against various changes including demographic change, climate changes, and commercialization of bio-production system.

Common Features

- Bundle of various ecosystem services from integrated agriculture–aquaculture system (joint production) with higher biodiversity
- Higher resilience: Securing multiple alternatives against unforeseen shocks or disturbances
- New business models: transform traditional production system to modern business models

Typical Layout / **Unique Characteristics**

VAC system in Viet

- Garden-Pond-Livestock bioproduction system
- High biodiversity and material circulation within VAC
- Many combination variety of local business models and ecosystem management systems

Pekarangan in Indonesia

- Combined system of agroforestry and livestock production including inland aquaculture (e.g. catfish)
- Function as important food source to survive at Asian currency crisis

Kandyan homegarden in Sri Lanka

- Spice cultivation is a typical source of cash income from homegardens
- Certification scheme has been introduced to homegardens and the their harvests (spices) to improve livelihood of small farmers with protecting biodiversity and natural environment.

Mohri et al (2013) Assessment of ecosystem services in homegarden systems in Indonesia, Sri Lanka, and Vietnam, *Ecosystem Services*,5: 124-136.

Case Study: General Resilience of Homegarden in Asia

- Homegarden systems provide a broad bundle of ecosystem services that can provide more general resilience against unforeseen events other than climate unpredictability, such as sources of diverse and nutritious diets where food price shocks render market sources unaffordable, or stored value in multilayered timber canopies providing insurance against unanticipated or infrequent family expenditure.
- Homegardens do not always require full-time maintenance and are to some extent self-sufficient, but partial reduction of labor inputs for weed removal, drainage, harvesting, replanting, fencing, and composting can lead to secondary forest succession, resulting in loss of services important to well-being.
- On the other hand, commercial simplification, especially for nutmeg in Kulugammuna and pepper in Godammuna, increases some provisioning services (primarily income) but has negative implications for regulating, supporting, and cultural services.

- Generally, abandonment and commercialization of homegardens can reduce the resilience of local livelihoods by risking a number of ecosystem service benefits, especially:
  - reduced income diversity from harvested produce;
  - lost traditional knowledge;
  - reduced species diversity, especially in cultivation of annuals;
  - increased soil erosion, loss of fertile topsoil, and downstream paddy siltation in heavy rains due to reduced drainage management;
  - increased wild animal incursion as abandoned plots become attractive habitats; and
  - increased reliance on rising prices in import-heavy markets for food security.

Options to enhance resilience and cope with various drivers

International level

- **Certification system:** premium price to environmentally friendly value-added products

Regional to national

- **Improvement of** irrigation systems and governance for better allocation of water
- **Payment to ES** or local procurement incentives
- **Amending Seed Act** to permit local resilient seed banking and trade

Community level

- **Crop variety**: incorporating higher yield, locally sourced crop varieties with lower water requirements and higher resilience to high temperatures
- **Animal control:** Locally appropriate wild animal control
- **Soil erosion control**: traditional lock-and-spill drains
- Community-pooled labour

Household level

- Incentives to multi-cropping and multiple ecosystem services
- Introduction of Drought and animal resilient crops
- On-site rainfall collection

lock-and-spill drain

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6.Summary and conclusion

(Source) UNEP (2008) Payments for Ecosystem Services: Getting Started: A Primer, http://www.unep.org/pdf/PaymentsForEcosystemServices_en.pdf

Summary

1. Global change and challenges of biodiversity
2. Convention on Biological Diversity (CBD)
3. Millennium Ecosystem Assessment (MA)
4. Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES)
5. Agrodiversity and Resilience for sustainable bioproduction

Conclusion

Credible scientific assessment of biodiversity and ecosystem services is crucial and provides a base to develop and implement effective policy options for their sustainable use and enhancement of resilience.

Lecture 6: Integrated Sediment Management

Tetsuya SUMI *(Water Resources Research Center, DPRI, Kyoto University)*

Dam construction dramatically influences the river basin balance with respect to water sediment inflow and outflow, which upsets downstream reaches. The objective of water and sediment incorporation is to manipulate the river-reservoir system to achieve sediment balance while maximizing the beneficial storage, and minimizing environmental impacts and socioeconomic costs. Such costs could be avoided if reservoir sedimentation was minimized and dams were allowed to live forever.

In order to improve the above situations, the following measures are currently proposed and implemented in Japan which is one of leading countries conducting intensive research and development on reservoir sedimentation management.

Conservation of flow regime

- River instream flow
- Flexible dam operation
- Flushing flow

Conservation of sediment flow

- Sediment augmentation (replenishment)
- Large scale sediment management measures (Sediment bypass, Sediment flushing)

Several methods for sediment management are available and have been implemented in practice. These methods can be categorized as shown in Figure 1.

The necessity for the reservoir sediment management in Japan can be summarized as: (1) to prevent the siltation of intake facilities and aggradations of upstream river bed, accompanied by the sedimentation process in reservoirs; (2) to maintain storage function of reservoirs, and realize sustainable water resources management for the next generation; (3) to release sediment from dams as a perspective on comprehensive sediment management in a sediment routing system.

The objectives of this lecture are: (a) to make a general review of impacts of reservoir sedimentation both on reservoir sustainability and downstream river reach; (b) to select suitable options for sediment management; (c) to study in detail several sediment management options such as sediment bypassing, flushing and sediment augmentation/replenishment; (d) to consider environmental impacts of sediment management; (e) to draw some general conclusions in terms of future strategies for sediment management.

It is common practice to remove accumulated coarse sediment by excavation and dredging, and to make effective use of the removed sediment. Sediment augmentation/replenishment method is one of new measures of sediment management. In this method, trapped coarse sediment is periodically excavated (or dredged depending on the site conditions) and then transported and placed temporarily on the channel downstream of the dam, in a manner decided according to the sediment transport capacity of the channel and the environmental conditions. The augmentation/replenishment process is efficient to restore the bed load transport and the associated habited by coupling reintroduction with floodplain habitat restoration.

Sediment flushing is one of the most attractive methods from the costs and sediment supply point of view. It is important to predict how anticipated phenomena will impact on the environment and to conduct studies to develop feasible measures that minimize them. An analysis of sediment flushing operations to date, the effect of sediment flushing on the river's sediment balance and physical environment is presented. Sediment bypassing is also unique and effective sediment routing measure which is suitable to steep rivers with high sediment yield such as in Japan and Swiss Alps. How to design and operate the sediment bypass tunnel is now interesting topic on hydrology, hydraulics and stream ecology.

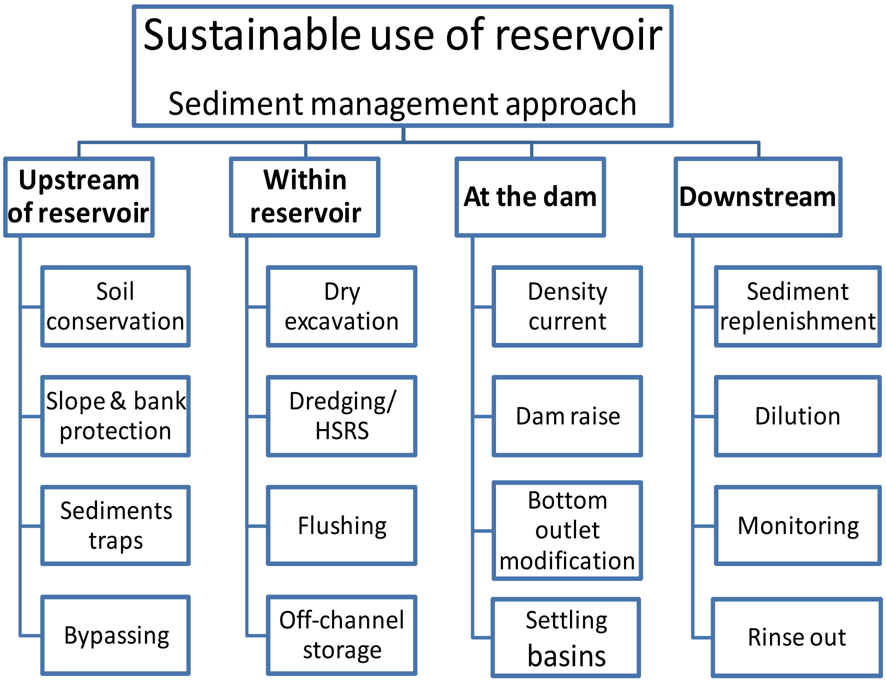
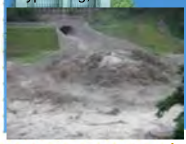


Figure 1: Inventory of measures for sediment management

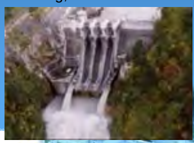
INTEGRATED SEDIMENT MANAGEMENT

Tetsuya SUMI
WRRC, DPRI, Kyoto University

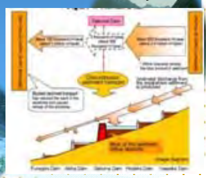
Bypassing, Miwa dam



Flushing, Dashidaira dam



Cascade Dams, Tenryu river

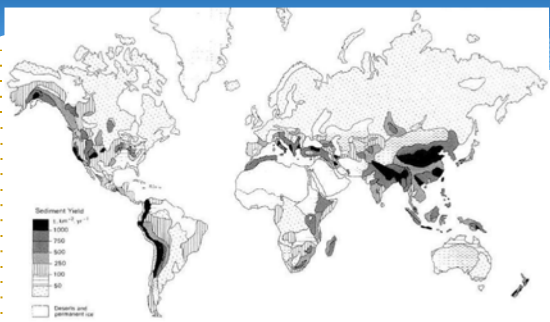


The Twenty-third UNESCO - IHP Training Course on Ecohydrology for River Basin Management under Climate Change, Dec.2-13, 2013.

Worldwide distribution of dams

Data from the GRanD database © Global Water System Project, 2011

Sediment yield map of the world



Walling and Webb, 1983

Dam Impacts caused by reservoir sedimentation

- Dam construction dramatically influences the river basin balance for water / sediment inflow and outflow.

Dam Impacts
- Discontinuity of sediment transport downstream
- Modification of flow regimes downstream

Sedimentation in reservoir
- Reduction of storage capacity

Downstream geomorphology
- Bed armouring and degradation

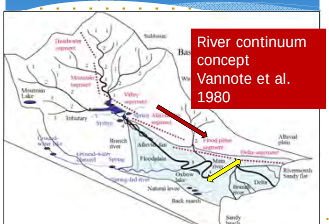
Downstream hydrology
- Water table lowering, changes in seasonal flow, flood frequency and magnitude

Downstream ecosystem
- Reduced ecosystem health (Biodiversity, Quality and quantity of food resources, Water quality)

Change of flow and sediment transport regimes

- Flow regime
  - Water conveyance and intake
    - Decrease of river flow
  - Storage of middle and small floods, flood control
    - Decrease of flow fluctuations, disturbances of river channel
- Sediment transport regime
  - Sediment trap
    - Decrease of sediment concentration and sediment load

River channel is formed by natural fluvial process caused by combination of 'water flow and sediment transport' (Leopold 1957)



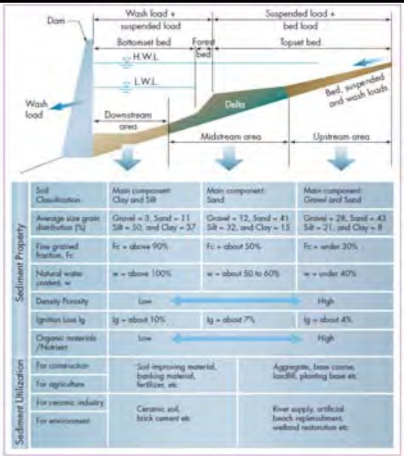
River continuum concept
Vannote et al. 1980

Natural flow regime
Poff et al. 1997

Flood pulse concept
Junk et al. 1989

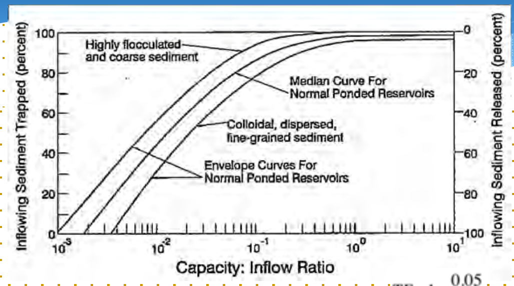
Fluvial river systems composed of 6 segments (Takemon 2010)

River channel as conveyor belt for sediment (Kondolf 1994)



Source: S. A Kantoush, T. Sumi and Y.Takemon MAY 2011, INTERNATIONAL WATER POWER & DAM CONSTRUCTION

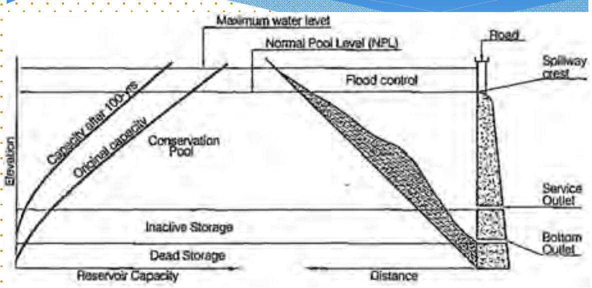
Brune curve (1953) Sediment trapping efficiency of reservoirs



$$TE = 1 - \frac{0.05}{\sqrt{CI}}$$

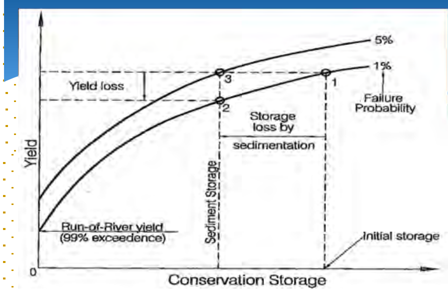
Source: Reservoir Sedimentation handbook, Morris and Fan(1996)

Shift of stage-storage and stage-area curves due to sedimentation



Source: Reservoir Sedimentation handbook, Morris and Fan(1996)

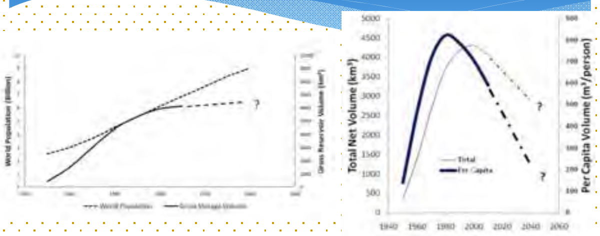
Reservoir Yield change by reservoir sedimentation



Source: Reservoir Sedimentation handbook, Morris and Fan(1996)

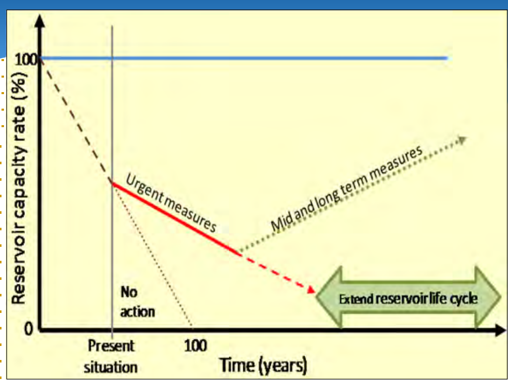
General shape of a reservoir storage-yield curve, in which yield asymptotically approaches the mean watershed yield, less evaporative and seepage losses, as storage becomes very large. Two yield curves are shown for different levels of service. The impact of sediment accumulation in the conservation pool may be expressed as either a reduction in yield at a given level of reliability (point 1 to 2) or a reduction in reliability at a fixed yield (1 to 3).

Global net reservoir storage by accounting for the effects of storage loss due to reservoir sedimentation



Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

Illustration of prolongation of reservoir lifetime

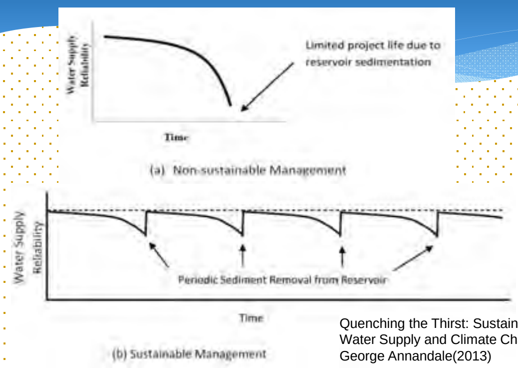


Source: T.Sumi and S.A. Kantoush
ICOLD Annual Meeting, Luzern 2011

Conventional design life approach and Life cycle management approach

Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

Water supply reliability based on (a) the design life approach and (b) the life cycle management approach



Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

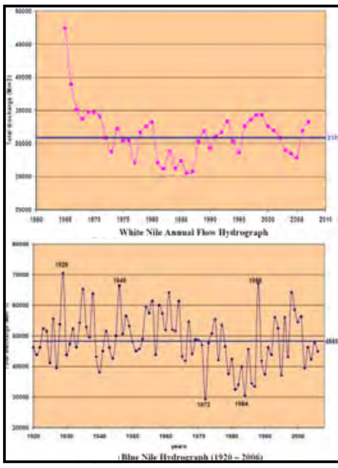
Egyptian case study

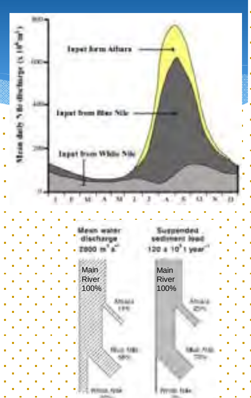
Sediment Yield
Reservoir Sedimentation
Reservoir Sustainability

Nile Basin Rivers Environments

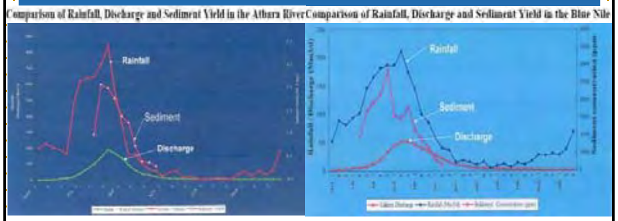
- Length is 6,825 km;
- Sources 3 main tributaries, White Nile, Blue Nile and Atbara River;
- Area of almost 3 Mio km^2
- Ten different geographical, topographical and climate regions;
- Over 180 million people live;
- Runoff from NB around 2 % of the total runoff from African continent;
- Spatial pattern of rainfall inputs across the NB is highly variable;
- Water resources are minimal in arid, semi arid areas of Egypt, Sudan; evaporation losses are high.

Nile Basin Hydrology

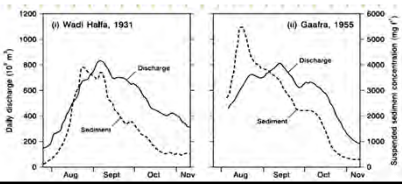




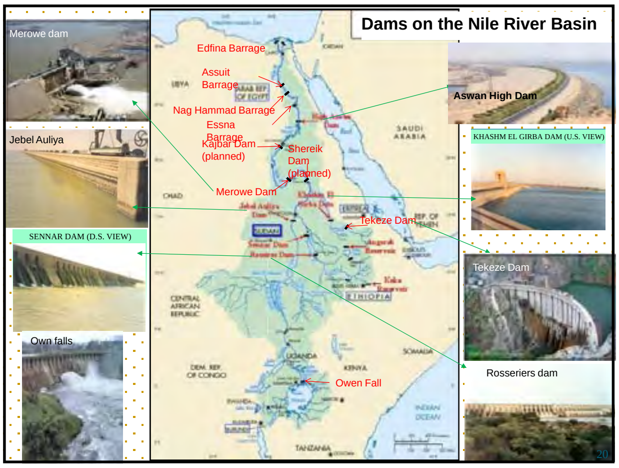
Sediment Yield and Suspended Sediment Budget



Discharge and Suspended Sediment Concentration SSC for summer floods at Wadi Halfa and Gaafra



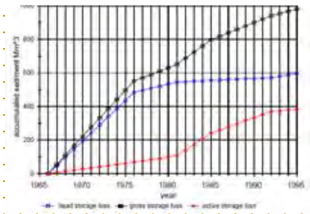
Dams on the Nile River Basin



Current State of Reservoir Sedimentations in the Nile Basin

Roseires dam passing flood water in July 1966, (Siyam, 2005)

- Initial reservoir storage capacity of 3000 Mm³
- In the early eighties of the last century it was raised to 3300 Mm³ (level to 481 instead of 480)
- Recently the dam will be raised to 10 m 7.4Mm³
- Sediment measure is dredging the deposited silt ahead of the power intakes and sluicing

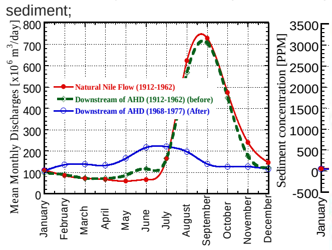


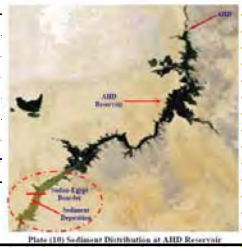
Storage loss of Roseires Reservoir (1966-1995)

From 1966 to 1976 drop in the capacity was 550 Mm³

Aswan High Dam Reservoir Sedimentation

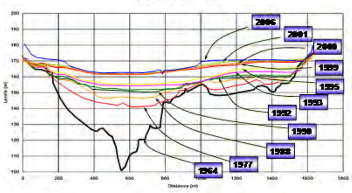
- Trap efficiency of Lake Nasser/Nubia is close to 100 %, only particles<2 μm is transported;
- Deposition started at the tail zone of the reservoir and advanced northward along the river bed
- Dead storage capacity is sufficient for 500 yrs and the rocky-narrow channel of the southern part of Lake Nubia work as a place for a new delta formation on the sides of the lake;
- We should clarify what are the impacts of the upstream dams on inflow water and sediment;





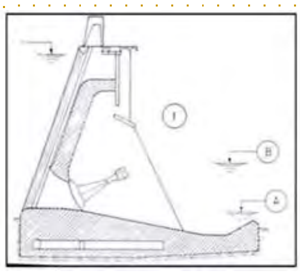
Aswan High Dam Reservoir Sedimentation

- No sediment control measure;
- We should clarify what are the impacts of the upstream dams on inflow water and sediment;
- Significant volumes of sediment may be transported to the dam when large flood events follow a sustained low flow periods;
- A modification to the water and sediment budget of AHD reservoir will follow the completion of the new dam at Merowe.

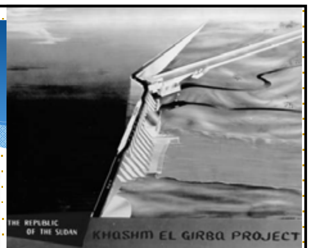


Kashm El Girba, Sudan 1964

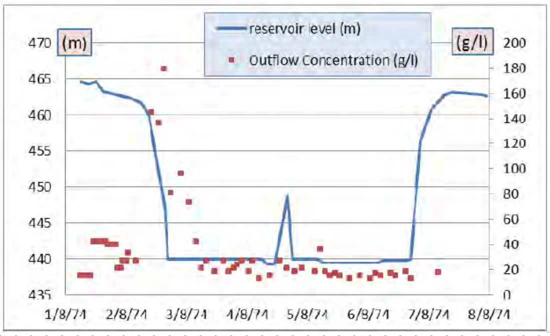
CAP=1.3BCM
MAR=12BCM, MAS=95MCM



Source: C. Guilbaud et al.

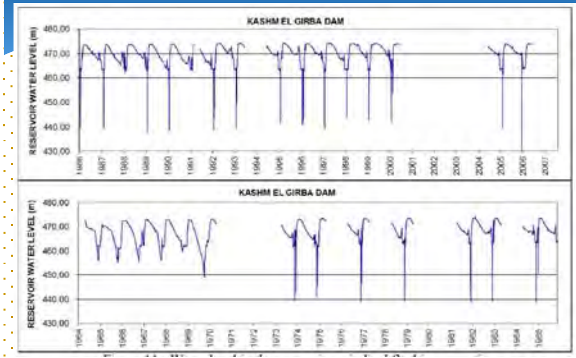


Draw down sediment flushing



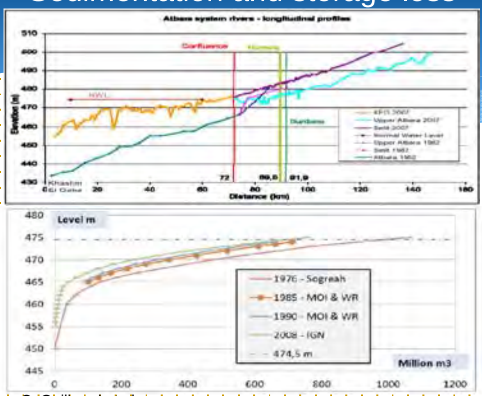
Source: C. Guilbaud et al.

Reservoir water level changes



Source: C. Guilbaud et al.

Sedimentation and storage loss



Source: C. Guilbaud et al.

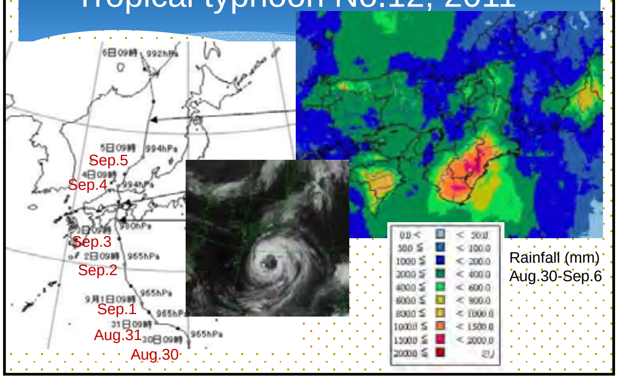
Japanese case study

Sediment Yield
Reservoir Sedimentation
Reservoir Sustainability

High sedimentation rates in Japan

- High precipitation
  - Typhoon, Front Annual average 1,700 mm
    - Hourly up to 50- 100 mm, Daily up to 200 - 500 mm
- Geological condition
  - Two large faults
  - Median Tectonic Line, Itoigawa-Shizuoka Tectonic Line
- Geographical condition
  - 2000-3000m high mountains, Steep valleys
- Earthquake
- Volcano activity

Catastrofic Flood Disasters
Tropical typhoon No.12, 2011

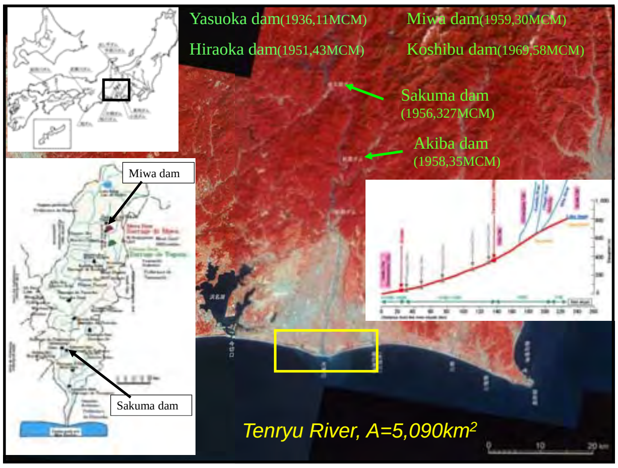


Upstream regions

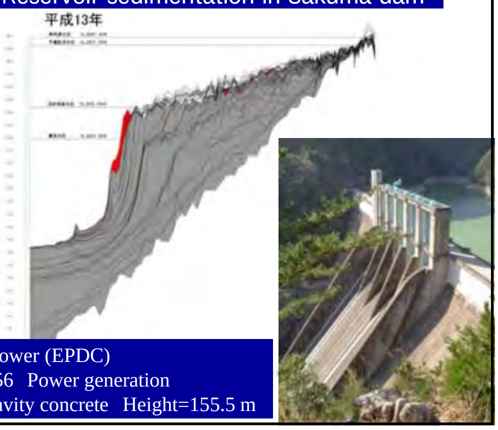
Land slide dam

Debris flow

Source: MLIT

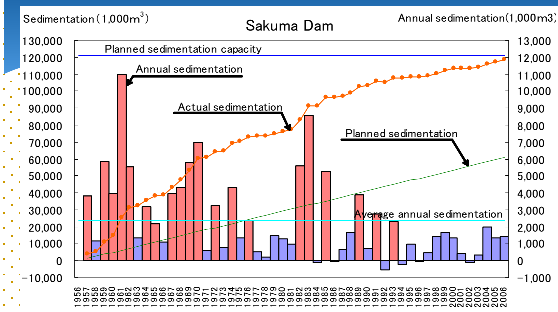


Reservoir sedimentation in Sakuma dam



J-Power (EPDC)
1956 Power generation
Gravity concrete Height=155.5 m

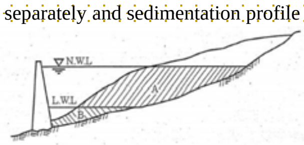
Annual sedimentation records in Sakuma dam



High rates up to 4.3 million m3/yr had been recorded for 1957-1969. After that, it has been gradually decreased because of slope protection works in the upstream catchments, construction of another new dams, slightly reduction of extreme flood events caused by large typhoons.

History of guidelines on reservoir sedimentation design

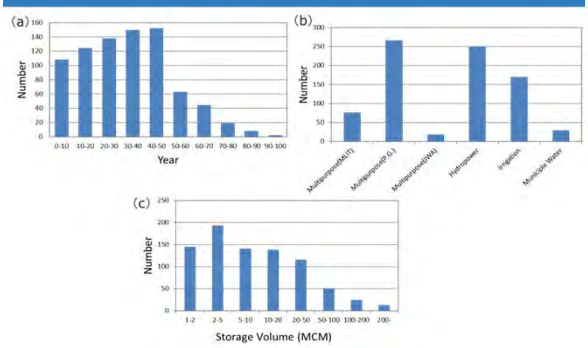
- 1958, Technical Criteria for River Works, Ministry of Construction
  - Necessary volume for reservoir sedimentation is 100 years
- 1966, Reservoir sedimentation database guideline, MOC
  - To check riverbed aggradation in order to prevent flooding risks upstream of reservoirs caused by sedimentation
- 1982, National reservoir sedimentation database, MOC
  - All reservoirs over 1 MCM should report accumulated sedimentation volume of B, below LWL, and A, LWL to NWL, separately and sedimentation profile almost annually to MOC.



In Japan, 2730 dams (>15m high) with 23 BCM capacity

Target dams : 971 dams of 18.2 BCM capacity

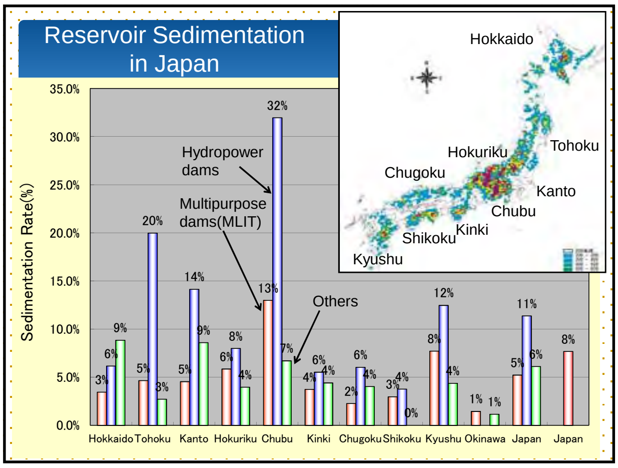
Target dams

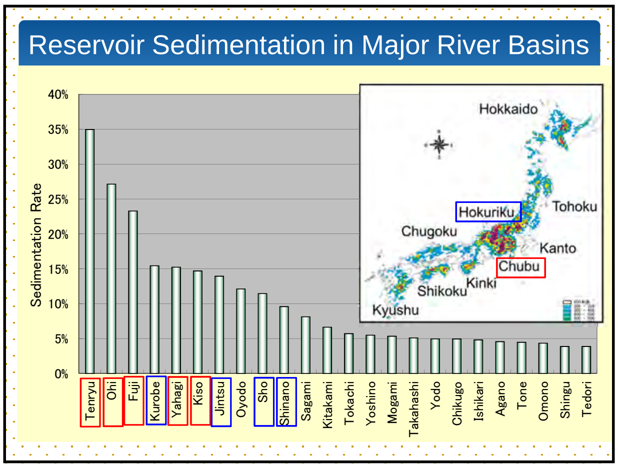


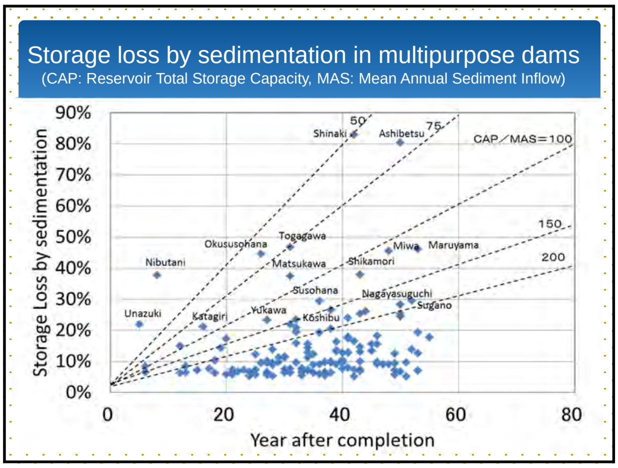
Reservoir sedimentation database

Total
971 dams

No.	Region	Dam	River	Dam Owner	Catchment (km2)	Year	Total Capacity (1000m3)	2006 Sed. Volume (1000m3)	Sed. Rate (%)
215	関東	雨畑	富士川	日本軽金属㈱	99.7	42	13650	11659	85.4%
479	中部	平岡	天竜川	中部電力㈱	3,650.0	55	42425	35457	83.6%
217	北海道	岩知志	沙流川	北海道電力㈱	567.0	48	5,040.0	4,204.0	83%
216	中部	泰阜	天竜川	中部電力㈱	2,980.0	71	10761	8146	75.7%
307	中部	大井	木曽川	関西電力㈱	2,083.0	83	29400	22030	74.9%
6	北海道	清水沢	石狩川	北海道企業局	506.0	67	5,576.0	3650.0	65.46%
305	九州	岩屋戸	耳川	九州電力（株）	354.4	64	8,309.0	5355.0	64.45%
483	北陸	小原	庄川	関西電力㈱	814.5	63	11741	7549	64.3%
488	北海道	岩松	十勝川	北海道電力㈱	605.0	64	9,026.0	5487.0	60.79%
309	東北	上郷	最上川	東北電力㈱	1,810.0	45	7,660.0	4636.0	60.52%
813	中部	笹間川	大井川	中部電力㈱	68.0	46	6,340.0	3687.0	58%
312	北陸	神一	神通川	北陸電力㈱	1,960.0	53	11346	6559	57.8%
152	北海道	川端	石狩川	国土交通省北海道	780.0	43	6,479.0	3464.0	53.47%
487	北海道	芦別	石狩川	北海道電力㈱	2,172.5	53	6,250.0	3176.0	50.82%
489	北陸	祖山	庄川	関西電力㈱	929.4	76	33850	16492	48.7%
314	北陸	出し平	黒部川	関西電力㈱	461.2	21	9,010.4	4352.8	48.31%
748	四国	小見野々	那賀川	四国電力（株）	266.8	38	16750	8051	48.1%
816	中部	丸山	木曽川	国土交通省中部地	2,409.0	53	79520	36669	46.1%
154	中部	美和	天竜川	国土交通省中部地	311.1	48	29952	13656	45.6%
317	北陸	奥裾花	信濃川	長野県土木部	65.0	26	5,400.0	2410.0	44.63%
815	東北	夏瀬	雄物川	東北電力㈱	556.0	53	9,350.0	4131.0	44%
11	北陸	神二	神通川	北陸電力㈱	2,060.0	53	11265	4382	38.9%
494	中部	畑薙第一	大井川	中部電力㈱	318.0	44	107400	41542	38.7%
316	北陸	鹿瀬	阿賀野川	東北電力㈱	6,264.0	78	16525	6192	37.5%
498	中部	松川	天竜川	長野県土木部	60	31	7400.0	2766.0	37.38%
495	北陸	成出	庄川	関西電力㈱	723.0	54年	9,709.0	3626.2	37.35%
817	中部	佐久間	天竜川	電源開発㈱	3,827.0	51	326848	118628	36.3%
502	中部	秋葉	天竜川	電源開発㈱	4,490.0	49	34703	11918	34.3%



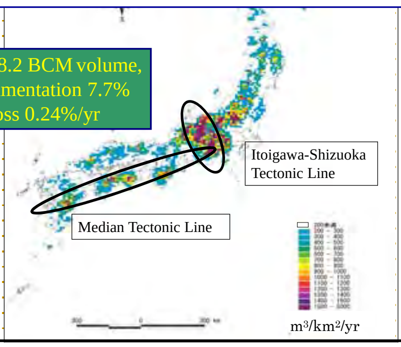


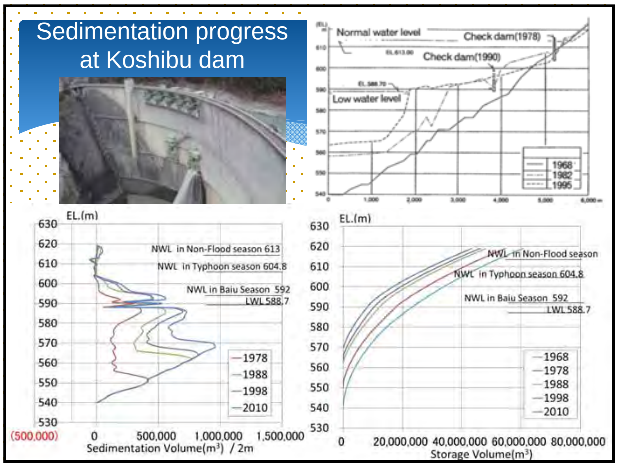


- In Japan, 2730 dams (>15m high) with 23 BCM capacity.
- National reservoir sedimentation database
  Sedimentation progress of all reservoirs over 1 MCM have been reported annually to the central government from 1980s.

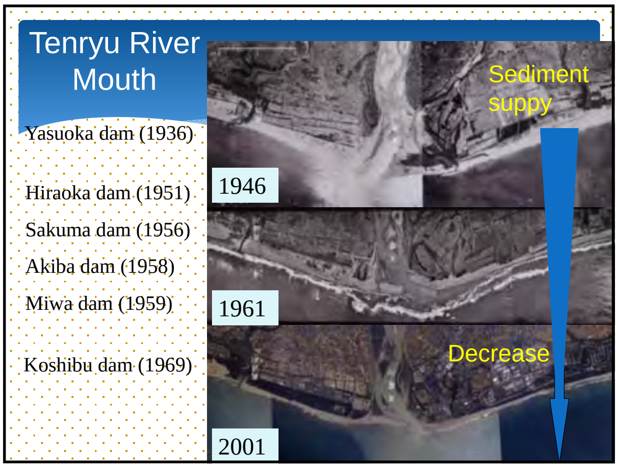
In 971 dams of 18.2 BCM volume,
→ total sedimentation 7.7%
annual loss 0.24%/yr

Sediment yield potential map of Japan

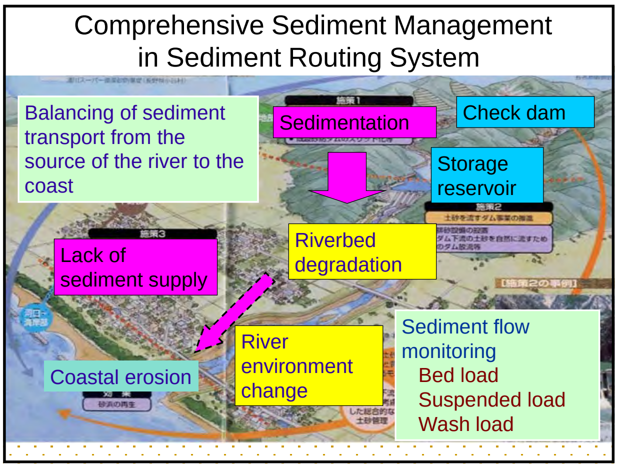


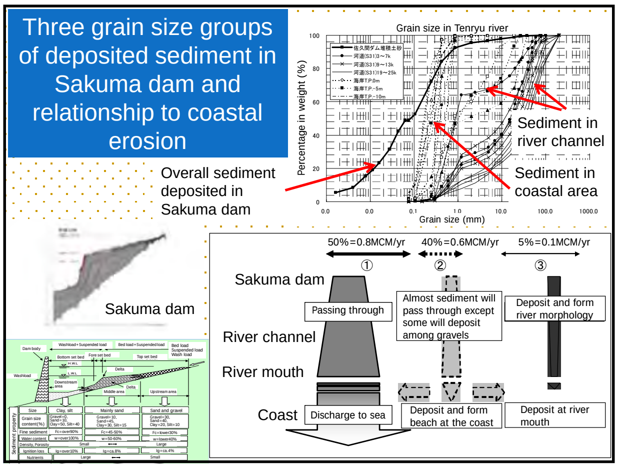


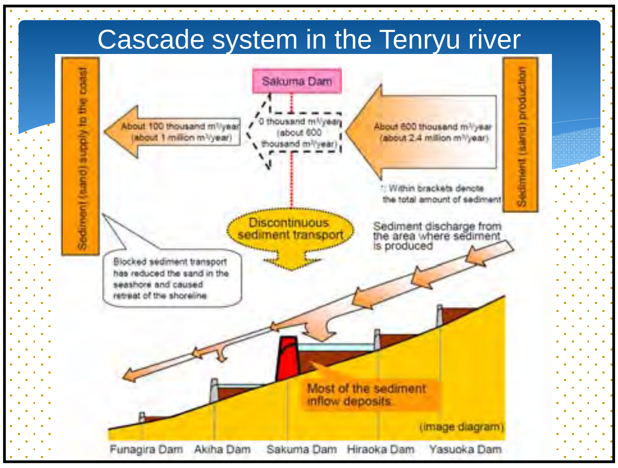

Environmental changes in downstream rivers
River channel change
Fixed sand bars, degradation of water course
Degradation of river channel
Tree growth in river channels
Riverbed material change
Armoring (granulation)
Decrease of small porosity


Tenryu River Mouth
Yasuoka dam (1936)
Hiraoka dam (1951)
Sakuma dam (1956)
Akiba dam (1958)
Miwa dam (1959)
Koshibu dam (1969)
1946
1961
2001
Sediment suppy
Decrease

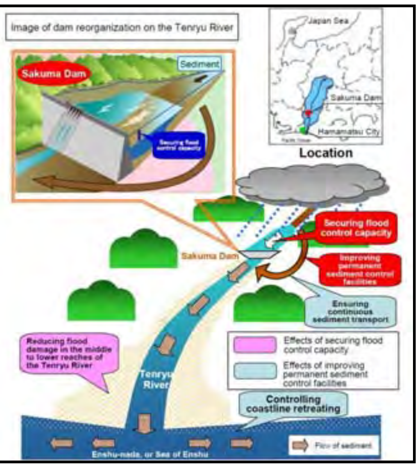

Nakatajima Sand Dune and Sea Turtle (Sep.14, 2008)
The Sea Turtle's World


Comprehensive Sediment Management in Sediment Routing System
Balancing of sediment transport from the source of the river to the coast
Sedimentation
Check dam
Storage reservoir
Lack of sediment supply
Riverbed degradation
Coastal erosion
River environment change
Sediment flow monitoring
Bed load
Suspended load
Wash load


Three grain size groups of deposited sediment in Sakuma dam and relationship to coastal erosion
Grain size in Tenryu river
Percentage in weight (%)
Grain size (mm)
Sediment in river channel
Sediment in coastal area
Overall sediment deposited in Sakuma dam
Sakuma dam
50%=0.8MCM/yr
40%=0.6MCM/yr
5%=0.1MCM/yr
①
②
③
Sakuma dam
Passing through
Almost sediment will pass through except some will deposit among gravels
Deposit and form river morphology
River channel
River mouth
Coast
Discharge to sea
Deposit and form beach at the coast
Deposit at river mouth


Cascade system in the Tenryu river
Sakuma Dam
Sediment (sand) supply to the coast
Sediment (sand) production
About 100 thousand m³/year (about 1 million m³/year)
0 thousand m³/year (about 600 thousand m³/year)
About 600 thousand m³/year (about 2.4 million m³/year)
Within brackets denote the total amount of sediment
Discontinuous sediment transport
Sediment discharge from the area where sediment is produced
Blocked sediment transport has reduced the sand in the seashore and caused retreat of the shoreline
Most of the sediment inflow deposits
(image diagram)
Funagira Dam
Akiha Dam
Sakuma Dam
Hiraoka Dam
Yasuoka Dam

Comprehensive sediment management in the Tenryu River

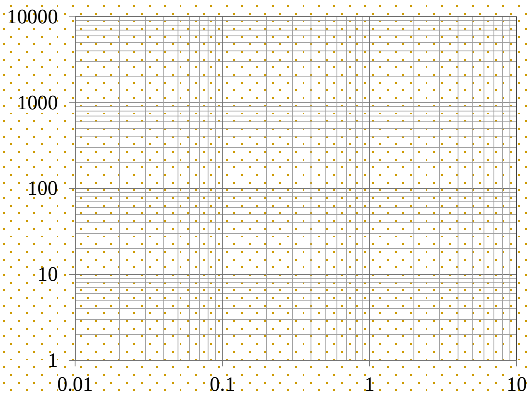


How to select suitable sediment management options?

Reservoir size, Watershed size, Water availability, Sediment Yield

Reservoir Size, Sediment Management Options

Dam Name	AREA Catchment Area (km2)	CAP (BCM) Reservoir Gross Capacity	MAR (BCM) Mean Annual Runoff	MAR/ AREA (mm)	MAS (BCM) Mean Annual Sediment Inflow	MAS/ AREA (mm)	CAP/ MAR	CAP/ MAS
High Aswan, Egypt-Sudan,	2,849,000	168	55.5		0.12			
Kashm El Girba, Sudan	100,000	1.3	12		0.095			
Sanmenxia, China	688,400	16.2	43.1		1.231			
Three Gorges, China	1,000,000	39.3	424		0.18			
Kurobe, Japan	184.5	0.199	0.525		0.000739			
Unazuki, Japan	461.2	0.0247	0.641		0.00062			



Reservoir Sedimentation Management Options

Reducing Inflow

- Catchment Management
  - Revegetation
  - Warping
  - Contour Farming
  - Check Dams

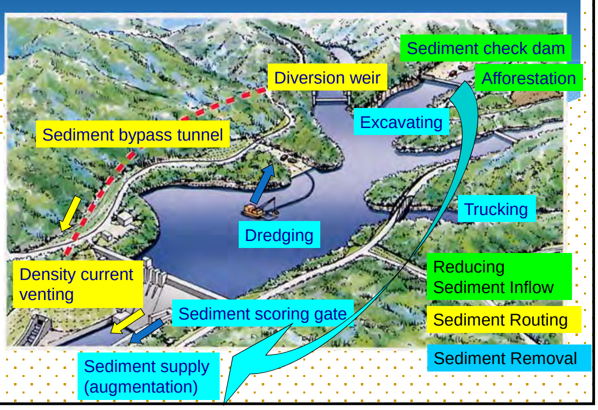
Preventing Deposition

- Sediment Routing
  - Bypassing
    - Tunnels
    - River Modification
    - Sediment Exclusion
    - Off-Channel Storage
  - Sluicing
  - Density Current Venting

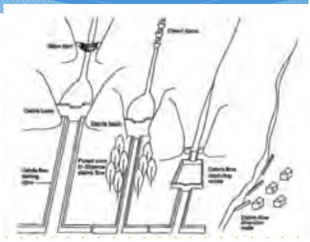
Removing Sediment

- Removal of Deposited Sediment
  - Dredging
  - Dry Excavation
  - Hydro-Suction
  - Drawdown Flushing
  - Pressure Flushing

Reservoir sediment management measures in Japan

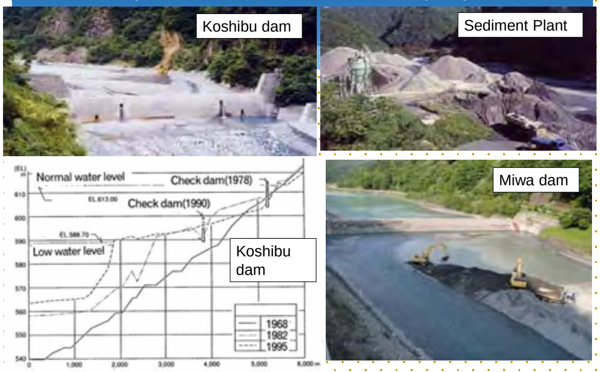


Check dam in the upstream river (Sabo Dam) (Tenryu River, Japan)

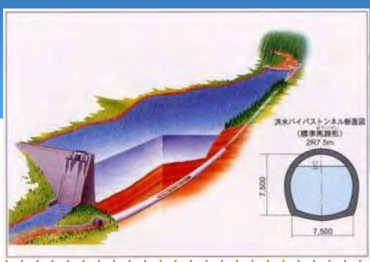


Source: Reservoir Sedimentation handbook, Morris and Fan(1996)

Check Dam just upstream of reservoirs (Chosha Dam) (Koshibu and Miwa dam, Japan)



Sediment Bypassing



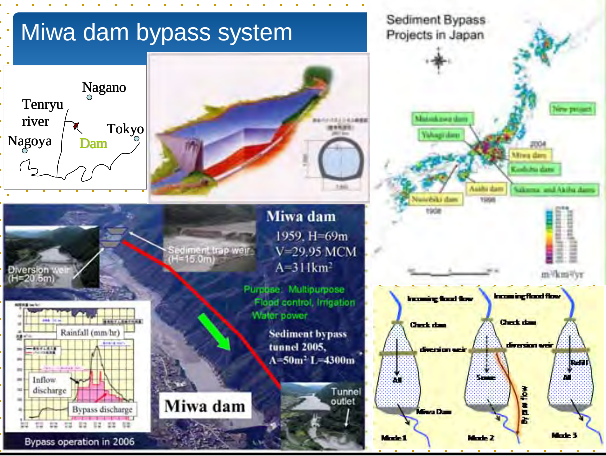
Sediment Routing in Reservoirs

Sediment Bypass Dam in the Japan and Switzerland

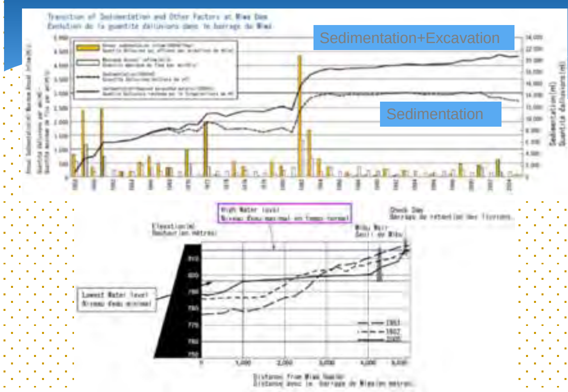
No	Name of Dam	Country	Tunnel Completion	Tunnel Shape	Tunnel Cross Section (B×H(m))	Tunnel Length (m)	General Slope (%)	Design Discharge (m^3/s)	Design Velocity (m/s)	Operation Frequency
1	Nunobiki	Japan	1908	Hood	2.9×2.9	258	1.3	39	-	-
2	Asahi	Japan	1998	Hood	3.8×3.8	2,350	2.9	140	11.4	13 times/yr
3	Miwa	Japan	2004	Horseshoe	2r = 7.8	4,300	1	300	10.8	2 times/yr
4	Matsukawa	Japan	Under constr.	Hood	5.2×5.2	1,417	4	200	15	-
5	Koshibu	Japan	Under constr.	Horseshoe	2r = 7.9	3.982	2	370	9	-
6	Egshi	Switzerland	1976	Circular	r = 2.8	360	2.6	74	9	10days/yr
7	Palagnedra	Switzerland	1974	Horseshoe	2r = 6.2	1,800	2	110	9	2～5days/yr
8	Pfaffensprung	Switzerland	1922	Horseshoe	A= 21.0m2	280	3	220	10～15	～200days/yr
9	Rempen	Switzerland	1983	Horseshoe	3.5×3.3	450	4	80	～14	1～5 days/yr
10	Runcahez	Switzerland	1961	Horseshoe	3.8×4.5	572	1.4	110	9	4 days/yr

New Projects at Koshibu dam (Japan), Solis dam (Switzerland)

Miwa dam bypass system



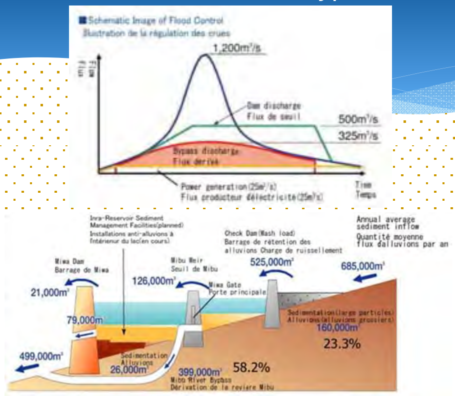
Sedimentation record in Miwa dam



Background and Objectives

- Sediment bypass tunnel is an effective measure to stop or reduce sedimentation.
- Miwa dam sediment bypass tunnel is the first experience for multipurpose dams in Japan.
  - Multiobjective operation is needed including flood control
  - Divert mainly suspended fine sediment.
- It is important to study the following points to improve the bypass performance:
  - (1) How to trap coarse sediment in the upstream reservoir area
  - (2) How to effectively divert the suspended sediment and high turbid flow through the tunnel
  - (3) How to minimize the downstream environmental impacts

Flood control and sediment bypass scheme

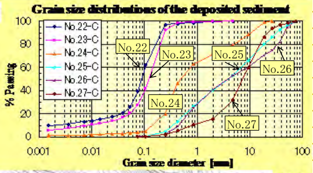


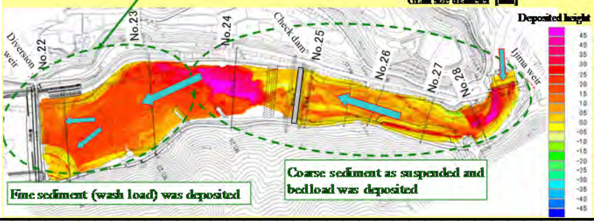
(2) How to trap coarse sediment in the upstream reaches of reservoir by check dam

The amount of Wash load after September 2007 flood

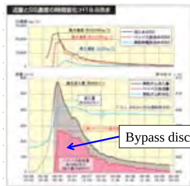
Flood date	Measured Deposited volume	Estimated deposited volume
September 2007	About 50,000m³	57,000m³

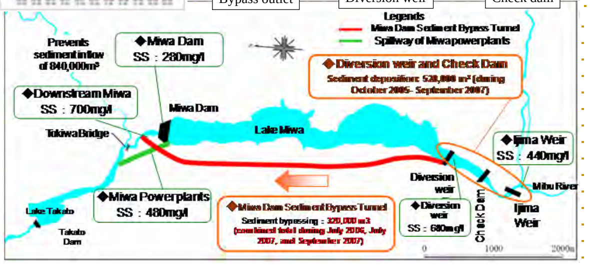
Grain size distributions of the deposited sediment



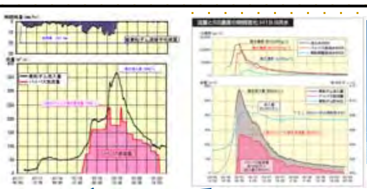


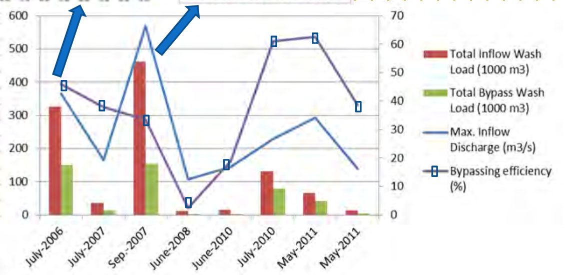
Bypass operation in 2007





Bypass efficiency

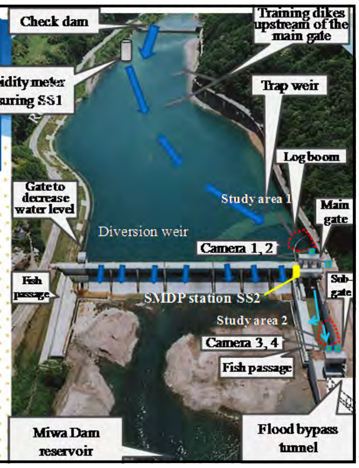




How to effectively divert suspended sediment and high turbid flow through the tunnel

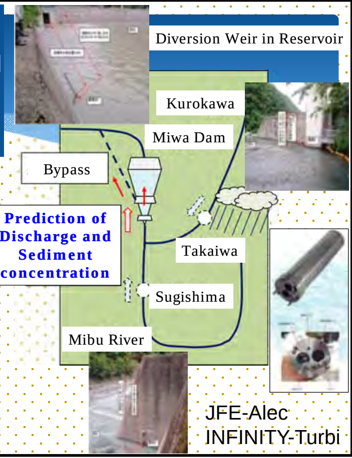
Turbid flow monitoring

- 2D surface velocity measurement by Large-Scale Particle Image Velocimetry (LSPIV)
- Suspended Sediment Concentration (SSC) measurement by Turbidity(INFINITY-Turbiditymeter (JFE-Advantech Company))

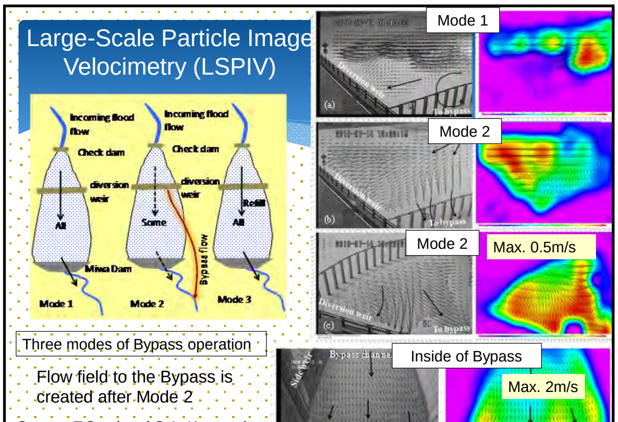


How to utilize upstream hydrological data to optimize bypass operation

- Rainfall and turbidity are monitored by real-time basis to predict inflow discharge and sediment concentrations
- Effective bypass operation by using sediment concentration predictions



Large-Scale Particle Image Velocimetry (LSPIV)

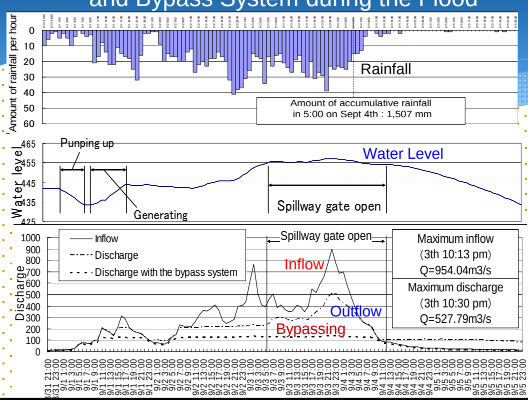


Source: T.Sumi and S.A. Kantoush IAHR, Brisbane 2011

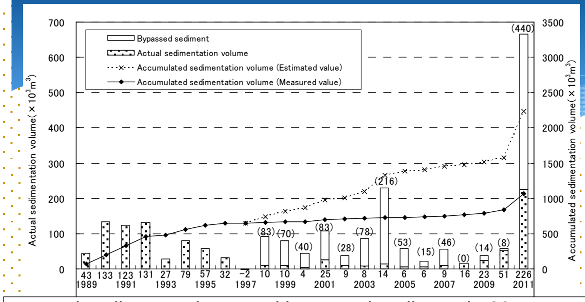
How to minimize the downstream environmental impacts

Sediment bypass system at Asahi Dam

Operational Results of Asahi Dam and Bypass System during the Flood

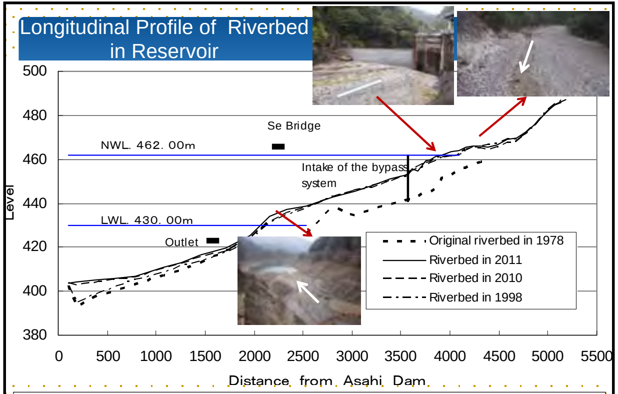


Reduction of Sediment Volume in Reservoir



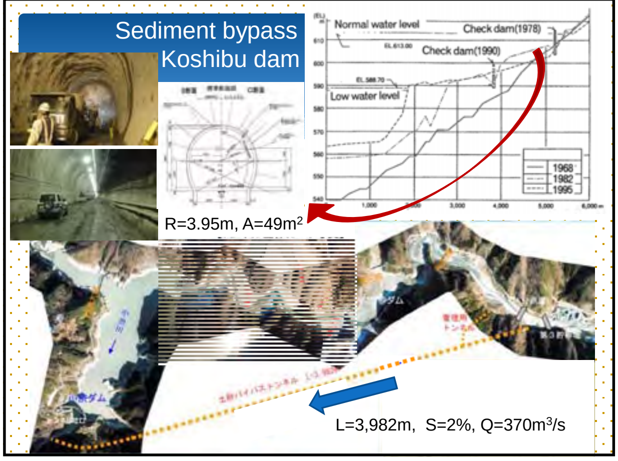
- Annual sediment volume and bypassed sediment in 2011 were the largest volume since the start of the bypass operation.
- Without bypass system, about 74% of sediment volume would have been accumulated in the reservoir. This sediment have now positive effects on downstream river environment.

Longitudinal Profile of Riverbed in Reservoir



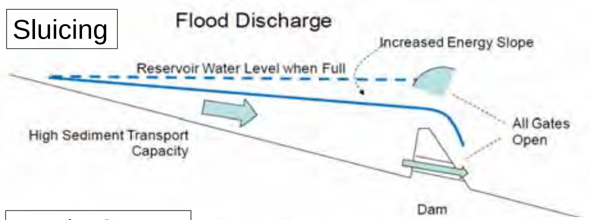
・Since the bypass operation started in 1998, it is likely that the riverbed shapes inside the reservoir have been relatively stable, though the riverbed of 2011 rises higher than before in this flood.

Sediment bypass Koshibu dam

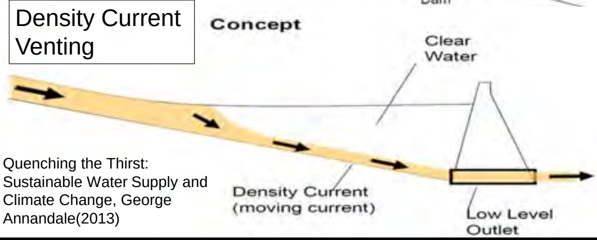


Sluicing and Density Current Venting

Sluicing

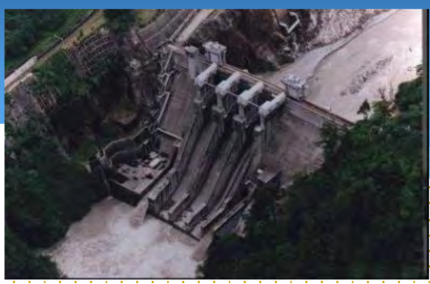


Density Current Venting



Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

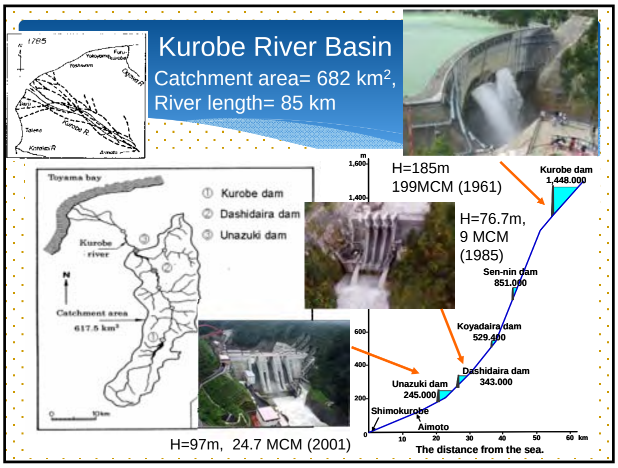
Sediment Flushing



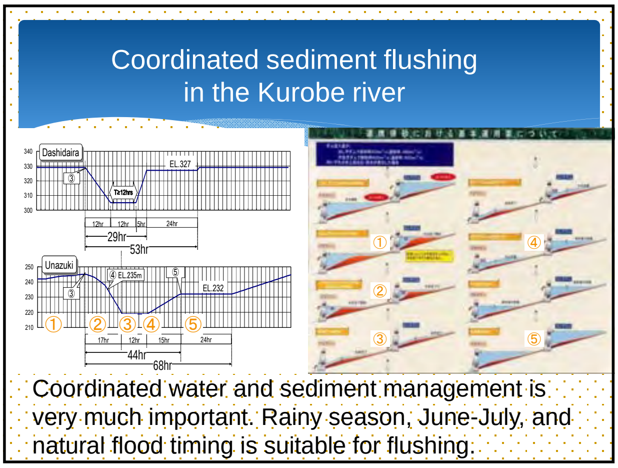
Sediment flushing dams in the World

Name of Dam	Country	Dam completed	Dam Height (m)	Initial Storage Capacity (CAP) (million m^3)	Mean Annual Sediment Inflow (MAS) (million m^3)[1]	1／(Mean Annual Runoff) (=CAP/MAR)	Reservoir Life (=CAP/MAS)	Average Flushing Discharge (m3/s)	Flushing Duration (hrs)	Flushing Frequency (1/ yr)
Dashidaira	Japan	1985	76.7	9.01	0.62	0.00674	14.5	200	12	1
Unazuki	Japan	2001	97	24.7	0.96	0.014	25.7	300	12	1
Gebidem	Switzerland	1968	113	9	0.5	0.021	18.0	15	70	1
Verbois	Switzerland	1943	32	15	0.33	0.00144	45.5	600	30	3
Barenburg	Switzerland	1960	64	1.7	0.02	0.000473	85.0	90	20	5
Innerferrera	Switzerland	1961	28	0.23	0.008	0.00018	28.8	80	12	5
Genissiat	France	1948	104	53	0.73	0.00467	72.6	600	36	3
Baira	India	1981	51	9.6	0.3	0.00489	32.0	90	40	1
Gmund	Austria	1945	37	0.93	0.07	0.00465	13.3	6	168	N.A.
Hengshan[2]	China	1966	65	13.3	1.18	0.842	11.3	2	672	2～3
Santo Domingo	Venezuela	1974	47	3	0.08	0.00667	37.5	5	72	N.A.
Jen-shan-pei[2]	Taiwan	1938	30	7	0.23	N.A.	30.4	12.2	1272	1
Guanting	China	1953	43	2270	60	1.5	37.8	80	120	N.A.
Guernsey	USA	1927	28.6	91	1.7	0.0433	53.5	125	120	N.A.
Heisonglin	China	1959	30	8.6	0.7	0.6	12.3	0.8	72	N.A.
Ichari	India	1975	36.8	11.6	5.7	0.00218	2.0	2.16	24	N.A.
Ouchi-Kurgan[2]	Former USSR	1961	35	56	13	0.00376	4.3	1000	2400	N.A.
Sanmenxia[2]	China	1960	45	9640	1600	0.224	6.0	2000	2900	N.A.
Sefid-Rud[2]	Iran	1962	82	1760	50	0.352	35.2	100	2900	N.A.
Shuicaozi	China	1958	28	9.6	0.63	0.0186	15.2	50	36	N.A.

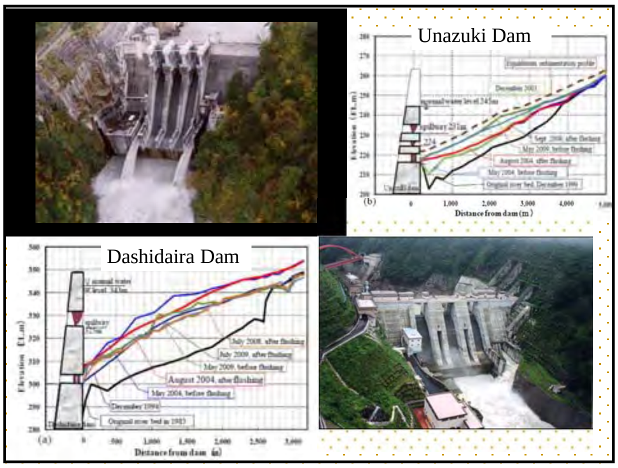
1）Average after dam completion,　　2）Sluicing dams



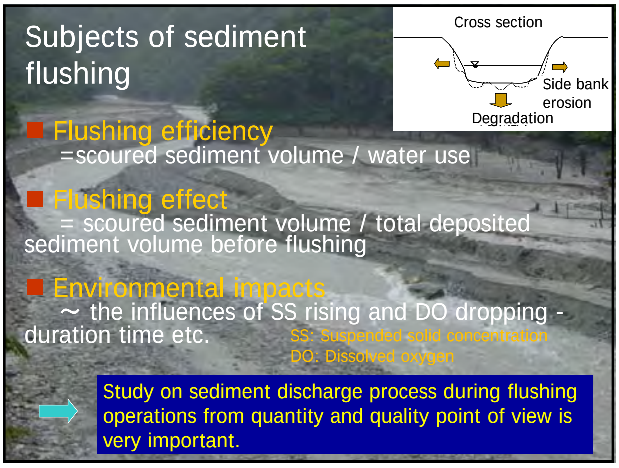
Kurobe River Basin
Catchment area= 682 km², River length= 85 km
Toyama bay
① Kurobe dam
② Dashidaira dam
③ Unazuki dam
Kurobe river
N
Catchment area 617.5 km²
H=185m
199MCM (1961)
H=76.7m,
9 MCM
(1985)
Kurobe dam 1,448.000
Sen-nin dam 851.000
Koyadaira dam 529.400
Dashidaira dam 343.000
Unazuki dam 245.000
Shimokurobe
Aimoto
H=97m, 24.7 MCM (2001)
The distance from the sea.



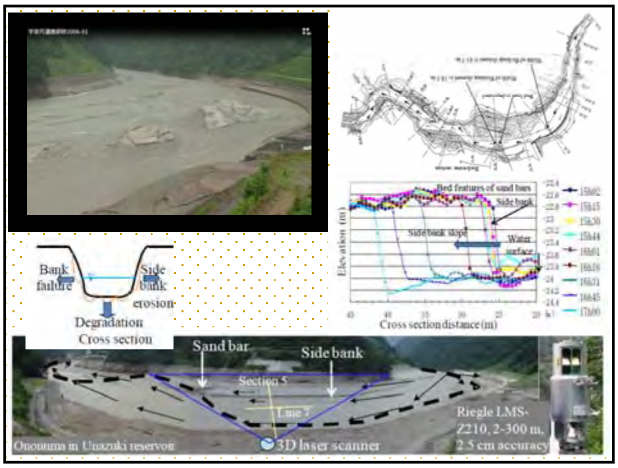
Coordinated sediment flushing
in the Kurobe river
Dashidaira
EL.327
29hr
53hr
Unazuki
EL.232
44hr
68hr
Coordinated water and sediment management is very much important. Rainy season, June-July, and natural flood timing is suitable for flushing.



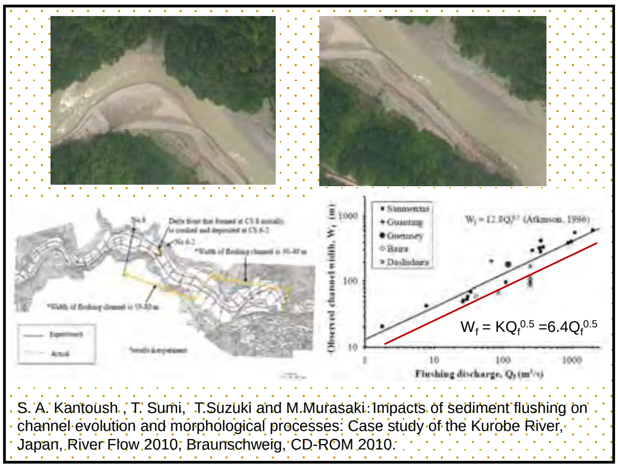
Unazuki Dam
Distance from dam (m)
Dashidaira Dam
Distance from dam (m)



Subjects of sediment flushing
Cross section
Side bank erosion
Degradation
Flushing efficiency
=scoured sediment volume / water use
Flushing effect
= scoured sediment volume / total deposited sediment volume before flushing
Environmental impacts
～ the influences of SS rising and DO dropping - duration time etc.
SS: Suspended solid concentration
DO: Dissolved oxygen
Study on sediment discharge process during flushing operations from quantity and quality point of view is very important.

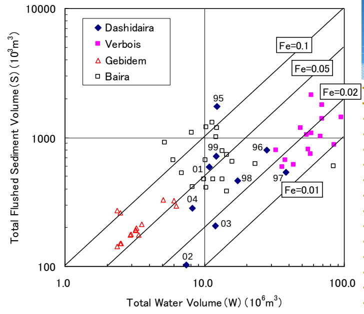


Bank failure
Side bank erosion
Degradation
Cross section
Bed features of sand bars
Side bank
Side bank slope
Water surface
Cross section distance (m)
Sand bar
Side bank
Section 5
Line 2
Ononuma in Unazuki reservoir
3D laser scanner
Riegle LMS-Z210, 2-300 m, 2.5 cm accuracy



W_f = KQ_f^0.5 =6.4Q_f^0.5
Flushing discharge, Q_f (m³/s)
Observed channel width, W_f (m)
S. A. Kantoush , T. Sumi, T.Suzuki and M.Murasaki: Impacts of sediment flushing on channel evolution and morphological processes: Case study of the Kurobe River, Japan, River Flow 2010, Braunschweig, CD-ROM 2010.

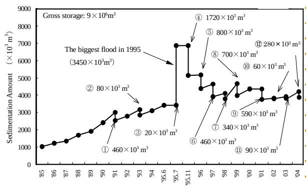
Total water use and flushed sediment volume in sediment flushing dams

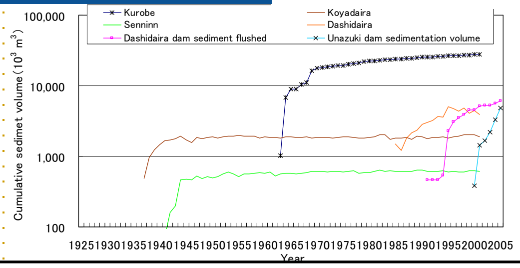


F_e: Flushing efficiency =Total flushed sediment volume/ Total water volume

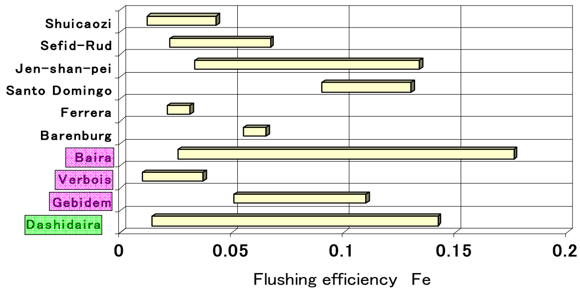
Sedimentation volume changes in Kurobe river

Dashidaira dam: 9.0MCM
Sedimentation : 4.0MCM
Flushing : 12times, 5.6 MCM





Flushing efficiency of Sediment flushing dams



F_e: Flushing efficiency =Total flushed sediment volume/ Total water volume

Efficiency of Sediment Flushing

Application of Sediment Flushing from the view point of water use

$$\frac{CAP}{MAS} > \frac{\dfrac{CAP}{MAR}}{F_e\left(\beta - \dfrac{CAP}{MAR}\right)}$$

CAP/MAR : Capacity-inflow ratio or Retention time *(yr)*

CAP/MAS : Reservoir life *(yr)*

CAP : Storage capacity

MAR : Mean annual runoff

MAS : Mean annual sediment inflow

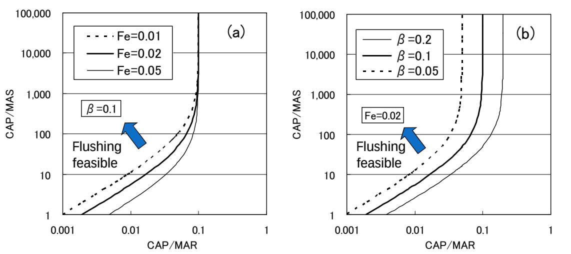
F_e : Flushing efficiency $= V_s / V$

V_s : Sediment discharge volume(m^3)

V : Water use(m^3)

β : Ratio of water use for sediment flushing to the mean annual runoff $= V / MAR$

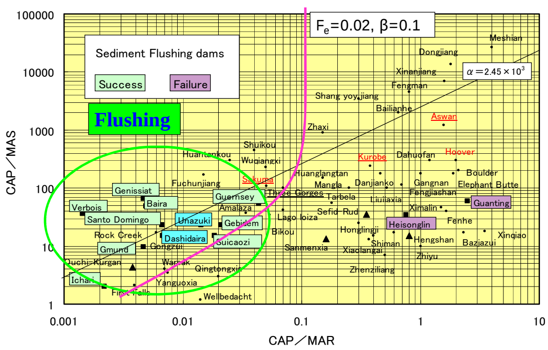
Application of Sediment Flushing from the view point of water use (β) and flushing efficiency (F_e)



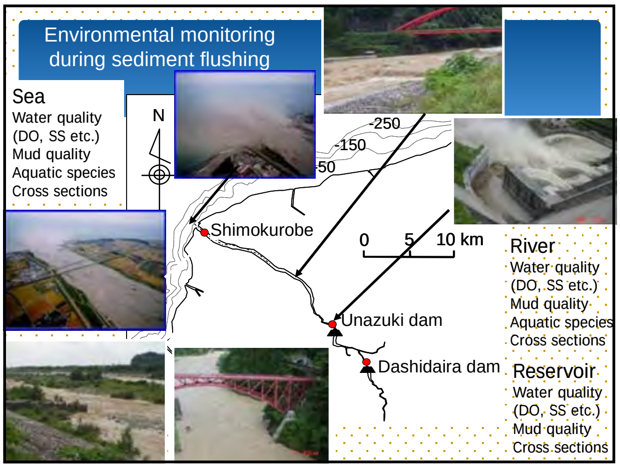
F_e: Flushing efficiency =Total flushed sediment volume/ Total water volume

β: Ratio of water use for sediment flushing to the mean annual runoff (MAR)

Application of Sediment Flushing from the view point of water use

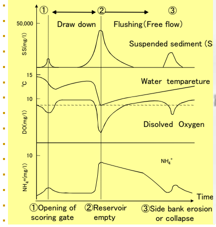


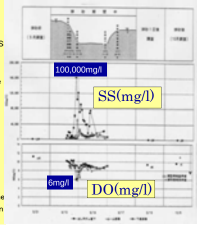
Environmental monitoring during sediment flushing



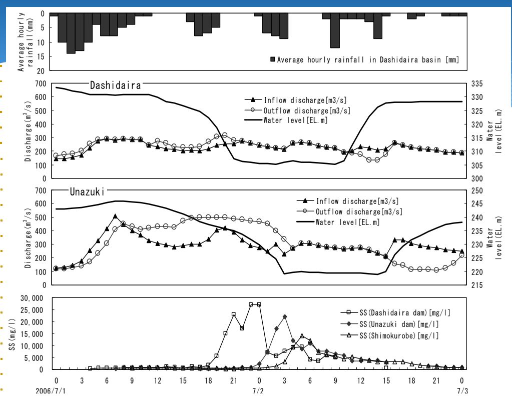
Environmental issues relating sediment management

- Minimize negative environmental impacts
  - Water quality changes caused by discharging accumulated sediment containing organic matters and those impacts on the aquatic ecosystem
    - Estimate the influences of SS quick rising and DO quick dropping
    - Establish minimizing measures（ex. Sediment Discharge Rule）





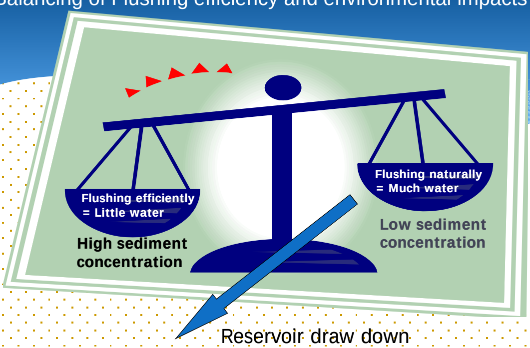
Coordinated sediment flushing operation in 2006



Actual sediment flushing and sluicing operations at the Dashidaira Dam

	Maximum Discharge Inflow (m^3/s)	Average Discharge Inflow (m^3/s)	Flushing Volume (10^3 m^3)	Maximum SS (mg/l)	Average SS (mg/l)
2001 Flushing	333	277	590	90,000	15,000
2001 Sluicing	491	273		29,000	6,700
2002 Flushing	362	215	60	22,000	4,500
2003 Flushing	777	217	90	69,000	7,100
2004 Flushing	356	229	280	42,000	10,000
2004 Sluicing	1,152	281		16,000	7,300
2005 Flushing	958	290	510	47,000	17,000
2005 Sluicing 1	835	275		90,000	16,000
2005 Sluicing 2	790	250		40,000	7,300
2006 Flushing	308	246	240	27,000	6,500
2006 Sluicing 1	378	203		12,000	2,500
2006 Sluicing 2	685	264		27,000	5,200
2006 Sluicing 3	529	196		7,400	1,800
2007 Flushing	418	245	120	25,000	3,500
Average of Flushing	502	246	270	46,000	9,100
Average of Sluicing	694	249		31,600	6,700
Average of All Data	598	247	270	38,800	7,900

Balancing of Flushing efficiency and environmental impacts



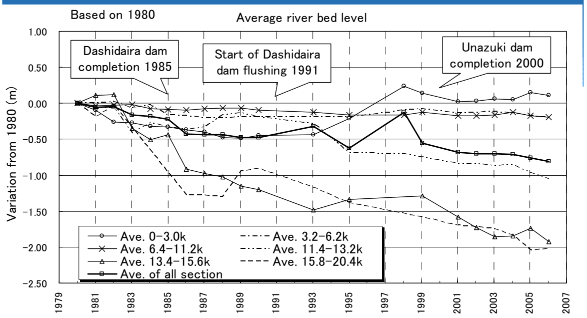
Water use

Reservoir draw down
Enough flushing discharge water
Rinsing discharge after flushing, etc.

'Ayu (鮎)', (Sweet fish,香魚,銀魚）Typical fish in Japanese rivers

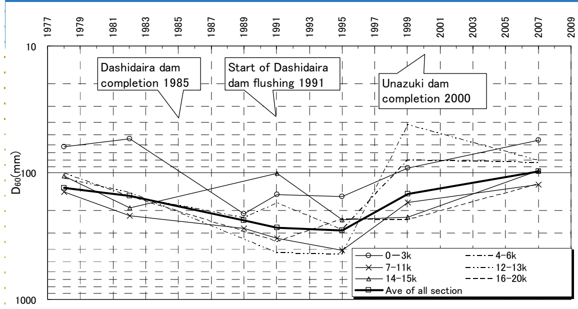
Ca. 20cm

Riverbed elevation change from 1980



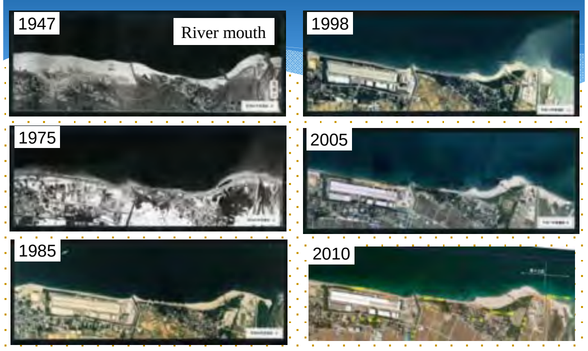
River channel bed is gradually recovering in the river mouth area.

Grain size distribution change from 1980



Grain size is gradually recovering to 1970s by changing from 200-400mm to 50-100mm

Shoreline change of the Kurobe river mouth area



Shoreline is gradually recovering after 2000.

Consensus-building procedure

Drawing up of sediment flushing plan and environmental survey plan (execution organizations)

Opinion reflected

Advance explanation given to fishing and farming groups and government organizations / Correct opinions

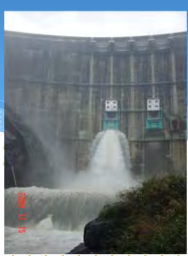
Opinion reflected

Kurobe River Sediment Flushing Evaluation Committee (composed of experts in environment, biology, and fishery etc.)

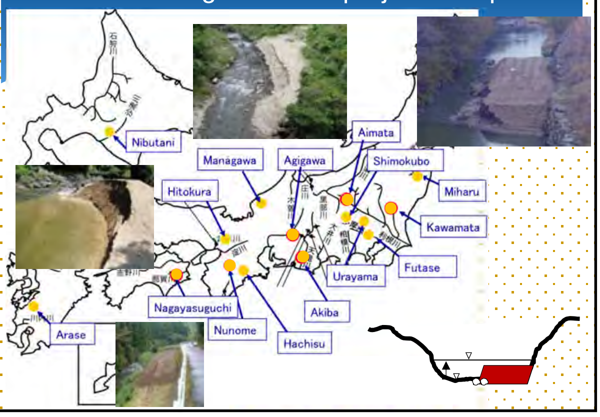
Kurobe River Sediment Management Council (composed of relevant government agencies)

Sediment flushing carried out by Ministry of Land, Infrastructure and Transport and The Kansai Electric Power Co. Inc.

River Restoration and Reservoir Sediment management



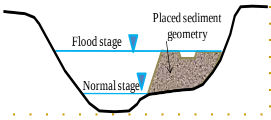
Sediment augmentation project in Japan



Sediment augmentation in Nunome dam

Table 1. History of the sediment replenishment tests downstream of Nunome dam

	sediment period		remained sediment (m³)	placed sediment (m³)	eroded sediment (m³)
2004	28-9-2004	29-9-2004	0	190	190
2005	9-8-2005	4, 5-10-2005	0	540	80
2006	NA	19, 21-7-2006	460	0	370
2007	9-8-2007	23, 29-8-2007	90	720	810
2008	27-6-2008	8-7-2008	0	100	35
	7-8-2008	5, 19 -9-2008	0*	100	100
	12-11-2008	NA	0	500	0
2009	NA	2-8-2009	500	0	500
	2-10-2009	7,8-10-2009	0	500	500

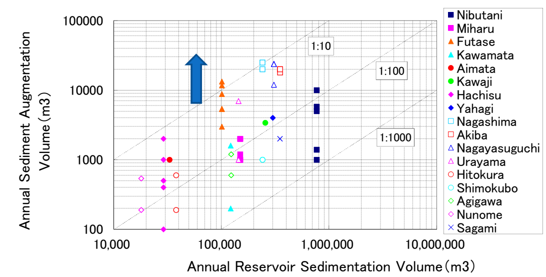


Source: T.Sumi and S.A. Kantoush
ICOLD Annual Meeting, Luzern 2011

Downstream geomorphological monitoring

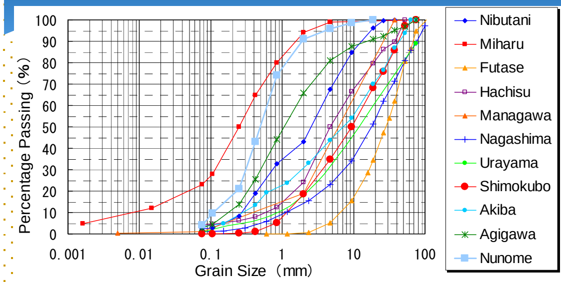
Source: T.Sumi and S.A. Kantoush
ICOLD Annual Meeting, Luzern 2011

Sediment augmentation volumes vs. Annual reservoir sedimentation



Source: T.Sumi and S.A. Kantoush
ICOLD Annual Meeting, Luzern 2011

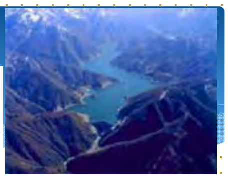
Sediment grain sizes for sediment augmentation



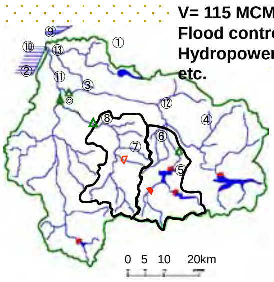
Source: T.Sumi and S.A. Kantoush
ICOLD Annual Meeting, Luzern 2011

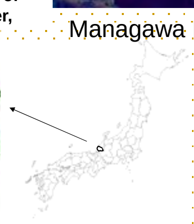
Kuzuryu River Basin

Completion 1979
H=127.5m
V= 115 MCM
Flood control
Hydropower, etc.



Managawa Dam

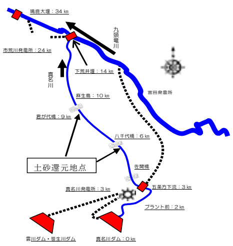




Managawa dam

Purpose：Improvement of river environment

- Increase of downstream river flow discharge
- Improve downstream river landscape
- Improve habitat for aquatic species



Flexible dam operation

River instream flow

Test results from 2000 to 2002 show that habitat for sweet fishes has been improved by the increase of instream flow.

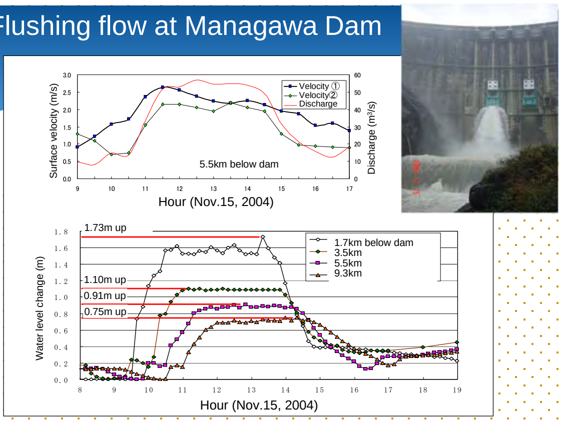
River instream flow
0.28m³/s→0.67m³/s

Flushing flow

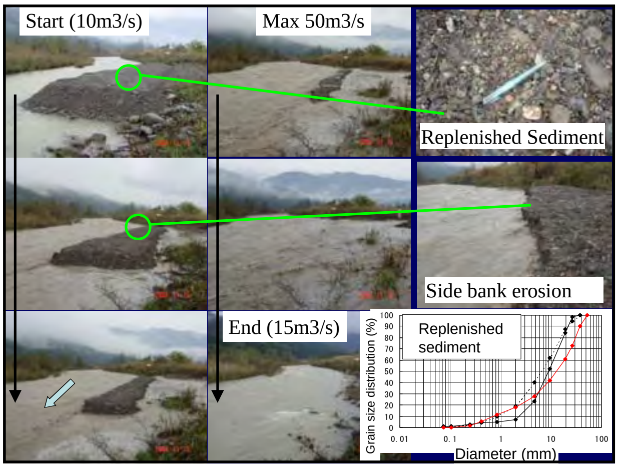
Aug. 2003（30m³/s）
Nov. 2004（50m³/s＋Sediment）
Aug.2005(30m³/s),Dec.(50m³/s＋Sediment)
Nov.2006(50m³/s＋Sediment)

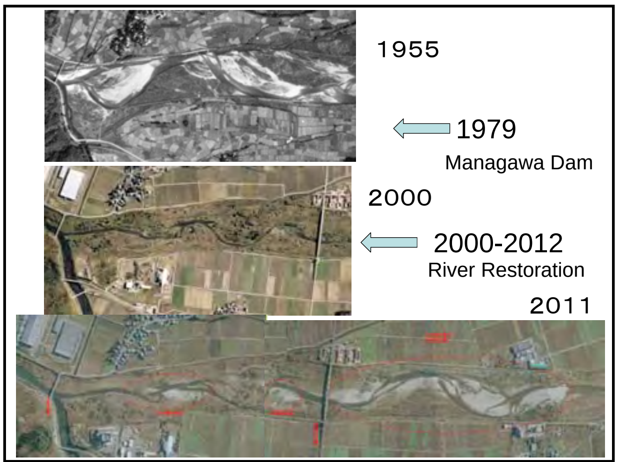
Nov. 8, 2007
(50m³/s + Sediment + River channel)

Flushing flow at Managagawa Dam



Water level and velocity change during flushing flow



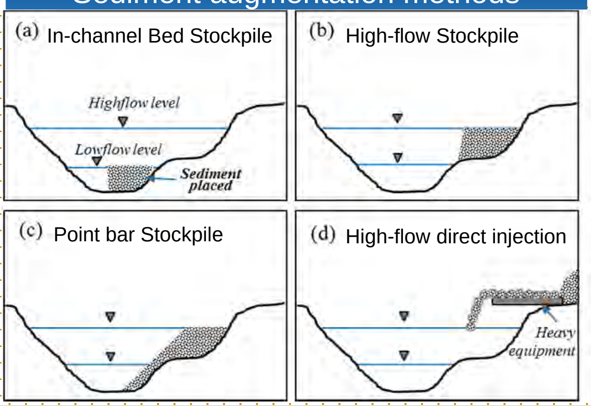


Sediment Augmentation in other countries

Keswick Dam (Downstream of Shasta dam) Sacrament River California, USA

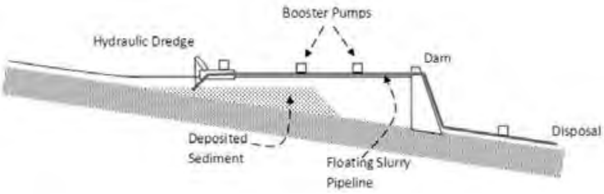
Rhine River, Germany

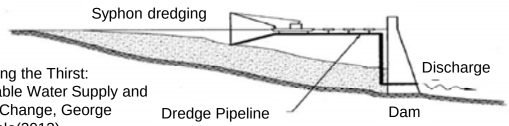
Sediment augmentation methods



Dredging
and
HSRS (Hydro Suction Sediment Removal System)

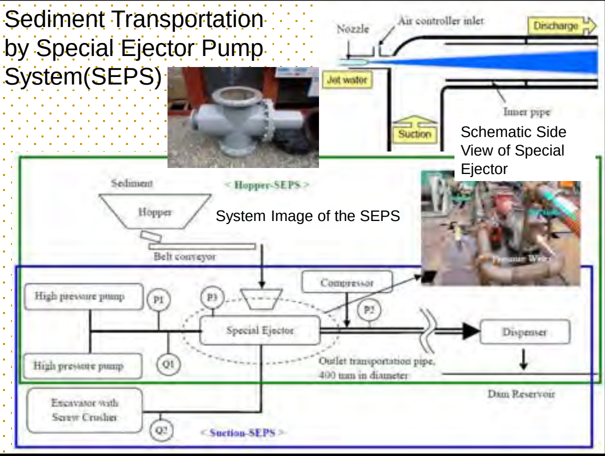
Dredging and HSRS (Hydro Suction Sediment Removal System)





Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

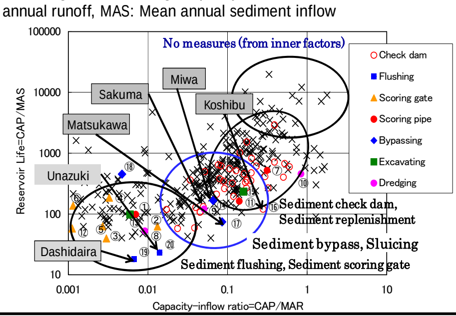
Sediment Transportation by Special Ejector Pump System(SEPS)



Appropriate selection of reservoir sediment management strategy

Appropriate selection of reservoir sediment management strategy (Japanese Case Study)

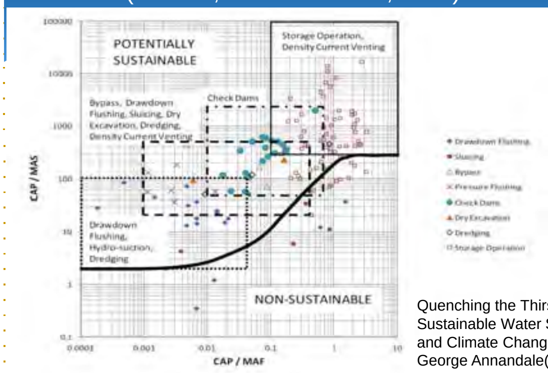
CAP: Original total storage capacity volume, MAR: Mean annual runoff, MAS: Mean annual sediment inflow



1	大井	Oi	D, SP
2	千頭	Senzu	SG
3	泰阜	Yasuoka	SG, D, PF
4	笠置	Kasagi	SG, PF
5	大間	Ooma	SG, PF
6	常盤	Tokiwa	SG
7	三浦	Miura	SP
8	平岡	Hiraoka	D, PF
9	佐久間	Sakuma	D
10	八久和	Hakuwa	E, D
11	井川	Ikawa	SP, E, D, PF
12	山口	Yamaguchi	SG, PF
13	秋葉	Akiba	E, D, PF
14	美和	Miwa	B, E, D, CD
15	牧尾	Makio	E, D, CD
16	小渋	Koshibu	E, CD
17	松川	Matsukawa	B, E, CD
18	旭	Asahi	B
19	出し平	Dashidaira	F
20	宇奈月	Unazuki	F

CD : Check dam
F : Flushing (Draw down)
PF : Flushing (Partial draw down)
SG : Scoring gate
SP : Scoring pipe
B : Bypassing
E : Excavating
D : Dredging

Reservoir sedimentation management approaches (Basson, 2009 and Sumi, 2003)



Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

Lecture 7: Interaction Between River and Coastal Ecosystem

Yasushi SUZUKI *(Japan Weather Association)*

1. Climate change information database

GCM outputs such as CMIP3 are available via network access to PCMDI web site. Meteorological researchers are familiar with the usage of the GCM data, but the most of researchers other than meteorology such as agriculture, civil engineering, etc., are not familiar with the GCM. There are some difficulties to use GCM; 1) to download the enormous quantity of data, 2) to understand the netCDF data format, 3) to understand the GCM methodology, parameters and grids.

In order to provide a quick access way to GCM, Climate Change Information Database for Hydrological Analysis is developed. The purpose of the database is to bridge the users and meteorological specialists. The resolution of the data is unified, and climate change amount or factors for each meteorological element are provided from the database (http://hes.dpri.kyoto-u.ac.jp/database/). All data in the database are interpolated on the same 80km mesh. Available data are the present-future projections of 27 GCMs, 2 validation dataset, 16 meteorological elements (precipitation, temperature, etc.), 3 emission scenarios (A1B, A2, B1), and validation results (correlation, RMSE).

2. Development of coupled river and ocean model

It is necessary to evaluate the long term change of ecosystems from rivers to ocean, in order to keep the sustainable water environment near the river mouse and coast. In order to research the mechanism of rivers and ocean, integrated water environment coupled river and ocean model is developed.

The model consists of the distributed Hydrological River Basin Environment Assessment Model (Hydro-BEAM), RIAM ocean circulation model (RIAMOM), and the advective diffusion model for Ise Bay. River outflow, water temperature and sediment transport are nested at the river mouse, and JCOPE2 re-analysis data are used as an open sea boundary condition. For the case study, model result of sediment transport on 27/Apr/2003 is compared with the satellite image by the Aqua MODIS sensor. The results correspond well with the satellite data.

3. Climate change impact on the habitat of sweetfish

Future water temperature change of Kiso river and Ise Bay are calculated by coupled river-ocean model under the CMIP3 A1B scenario. Water temperature increase of Kiso river is about 3 degrees, and sea surface temperature change of Ise Bay is about 2 degrees. Coastal areas are more strongly influenced.

By the analysis of observed data, river run-up time of sweetfish has negative correlation with water temperature difference (sea–river). Calculated future water temperature difference is smaller than that of present, which results in the early start of river run-up time of sweetfish.

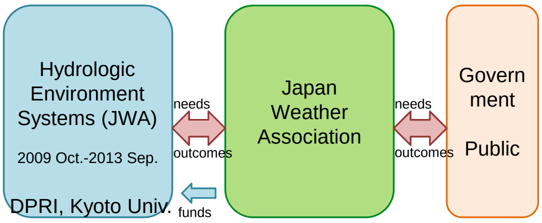
Interaction between river and coastal ecosystem

Yasushi Suzuki
Japan Weather Association (JWA)
Previous affiliation: Hydrologic Environment Systems, DPRI

Contents

- Introduction of Hydrologic Environment Systems funded by JWA
- Development of climate change information database
- Development of a coupled river and ocean model
- Impact of future changes in water temperature on the habitat of sweetfish
- Conclusions

Hydrologic Environment Systems (JWA)



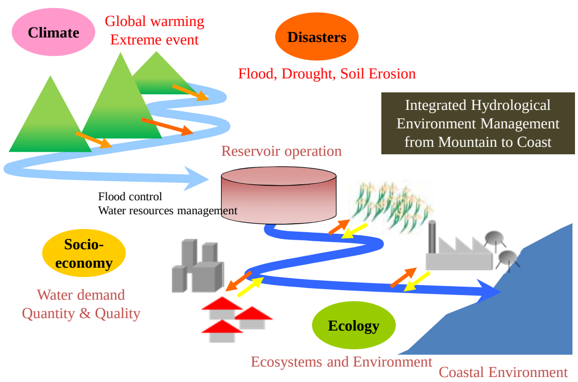
Hydrologic Environment Systems (JWA)

To clarify mechanisms of environment issues and disasters associated with the hydrologic cycle.
To consider how society should adapt to climate change and social changes.

- Developing downscaling methods of climate model outputs, and climate change information database
- Developing applied use of hydro-meteorological information
- Analyzing climate change impacts and social dynamics on the water environment

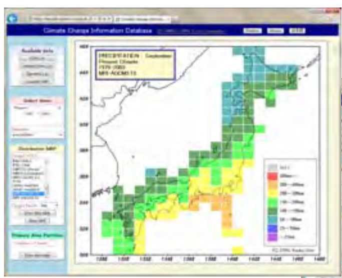
Outcomes:
Climate change information database, Advanced Hydro-BEAM, Coupled river and ocean model, etc.

Hydrologic Environment Systems (JWA)

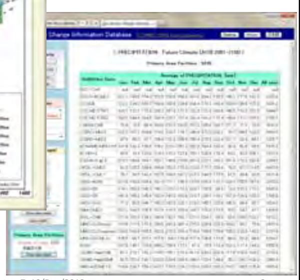


Climate Change Information Database

http://hes.dpri.kyoto-u.ac.jp/database/



Map images and numerical data are available



Monthly and annual mean data

Climate Change Information Database

<u>Objectives:</u>
To provide quick access way to persons, who are not familiar with GCMs.

<u>Users:</u>
River administration, Dam operation, Agriculture, Private companies, Citizens, etc.

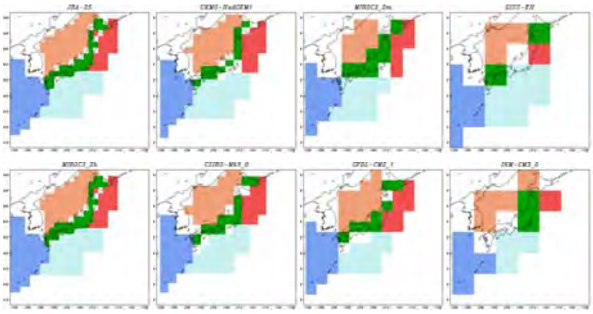
<u>Merits:</u>
To avoid difficulties of enormous data download, handling of netCDF format, difference in model resolution, etc.

Climate Change Information Database

- All data in the database are interpolated on the same 80km grid
- 27 GCM results of CMIP3 and AGCM20 (present and future projections)
- 3 emission scenarios (A1B, A2, B1)
- 16 meteorological elements (precipitation, temperature, snowfall, wind, humidity, heat flux, etc.)
- 2 validation dataset (AMeDAS observation and JRA-25 reanalysis)
- Validation results (correlation, RMSE).

Difference of Model Resolution and Land Sea Mask

Green area is defined as that fraction of land exceeds 50 %.



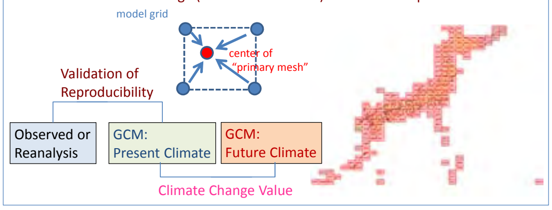
← Fine Resolution Coarse →

JRA-25 and 7 models from CMIP3

Development of Climate Change Information Database

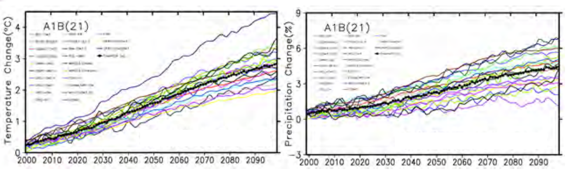
Pickup the essence of enormous GCM outputs
Arrangement of GCM outputs by unit "primary mesh"

1. Average 4 grid data near from center of "primary mesh"
2. Validation GCM outputs by unit "primary mesh" with observation value or Reanalysis data
3. Evaluate Climate Change (ratio or difference) from GCM outputs

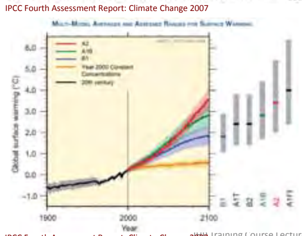


Comparison and model ensemble are enabled with Database arranging by unit "primary mesh"

Variability of GCM and SRES scenario



IPCC Fourth Assessment Report: Climate Change 2007



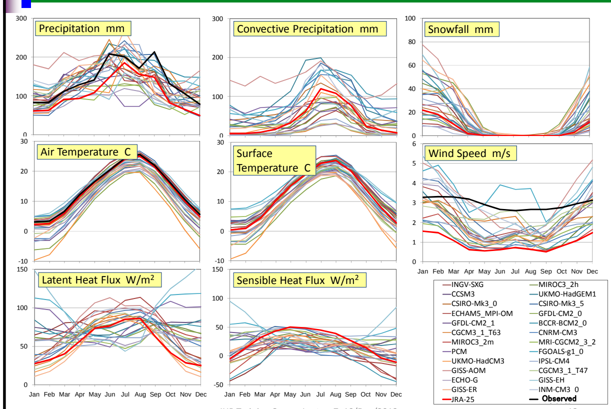
↑ Large Variability in GCM

← Large Variability in SRES

Uncertainty is Unavoidable

IPCC Fourth Assessment Report: Climate Change 2007

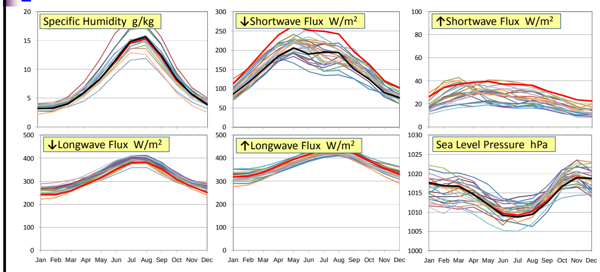
CMIP3 Reproducibility over Japanese Land



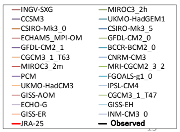
20C3m: 1971-2000

Michihiro et al. (2011)

CMIP3 Reproducibility over Japanese Land



Monthly Change over Japanese Land



Some GCMs are good and others are not.

GCM screening is necessary

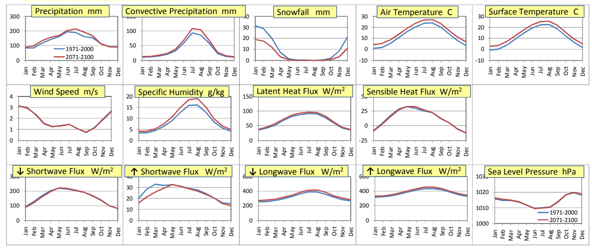
20C3m: 1971-2000

Michihiro et al. (2011)

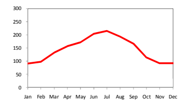
Best 10 GCMs

Multi-GCM Ensemble

20C3m: 1971-2000 A1B: 2071-2100



Monthly Change over Japanese Land



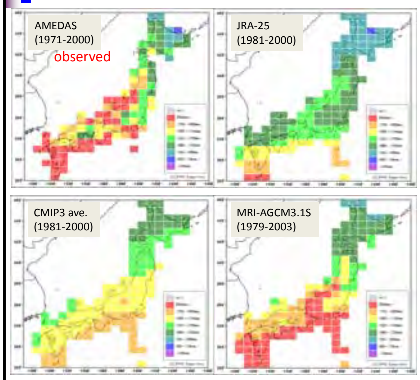
Screening by using RMSE and correlation

Ensemble Mean: Robust prediction of Climate Change

Variability : Uncertainty of GCM

Michihiro et al. (2011)

Reproducibility of Annual Mean Precipitation



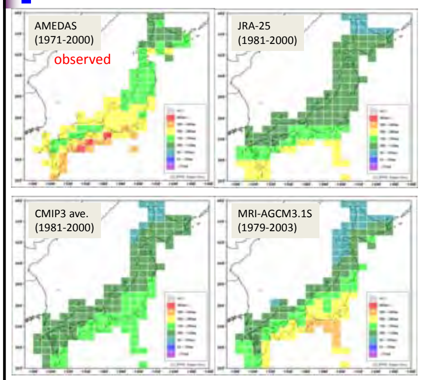
Comparison of Reproducibility: annual precipitation

JRA-25 Reanalysis underestimates

Super High Resolution MRI-AGCM3.1S(20km) is good

CMIP3 is not good with single GCM, but could be better with multi GCM ensemble

Reproducibility of Monthly Mean Precipitation



Comparison of Reproducibility: monthly precipitation in September

Both JRA-25 Reanalysis and MRI-AGCM3.1S underestimate in some local areas

CMIP3 ave. is similar to MRI-AGCM3.1S

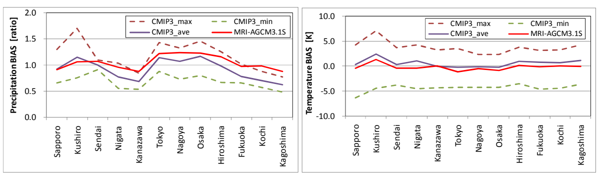
Any GCM are not comparable to observed value

Advantage of Multi GCM Ensemble

Reproducibility of Present Climate

Comparison with AMEDAS (observed; 1971-2000)

Screening GCM on condition that correlation coefficient is higher than 0.6



Comparison of Reproducibility in Japanese typical cities

AGCM3.1S gives good reproducibility.
Reproducibility of CMIP3 ave. is comparable to AGCM3.1S.

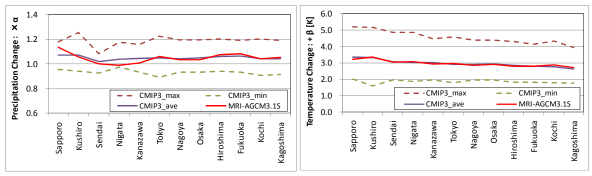
Michihiro et al. (2011)

Advantage of Multi GCM Ensemble

Climate Change of Future Climate

P: 1981-2000 F: 2081-2100

Screening GCM on condition that correlation coefficient is higher than 0.6



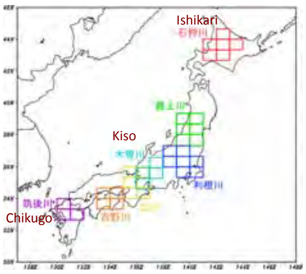
Comparison of Climate Change of annual value in Japanese typical cities

CMIP3 ave. shows similar results compared to AGCM3.1S.

Michihiro et al. (2011)

Application to River Basin Analysis

Major 7 river basins in Japan
Mesh shows 80km x 80km grid in database



Data
- CMIP3 25 models
- MRI-AGCM 3.1S, 3.2S
- AMeDAS observation

Period
- Present 1980-1999
- Future 2080-2099

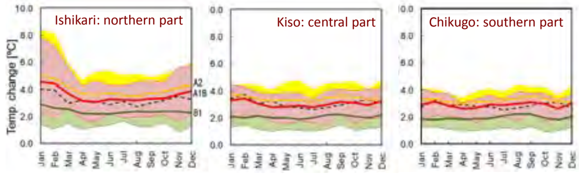
Elements
- Monthly precipitation
- Monthly temperature

Michihiro et al. (2012)

Temperature Change in some River Basins

The analysis of an arbitrary basin is possible by "Database".

Climate Change: air temperature [C]   P: 1981-2000 F: 2081-2100



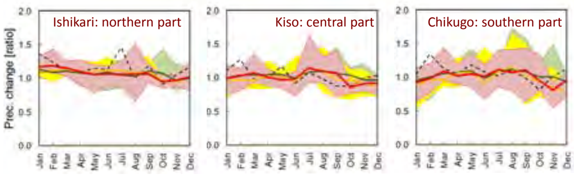
solid: CMIP3 ave. (Best 7 GCMs as Reproducibility)   dashed: MRI-AGCM3.1S
--A1B --A2 --B1

- SRES scenario differences are remarkable
- Temperature variability increases in the northern part
- CMIP3 ave. is similar to MRI-AGCM3.1S

Michihiro et al. (2012)

Precipitation Change in some River Basins

Climate Change: precipitation [ratio]   P: 1981-2000 F: 2081-2100

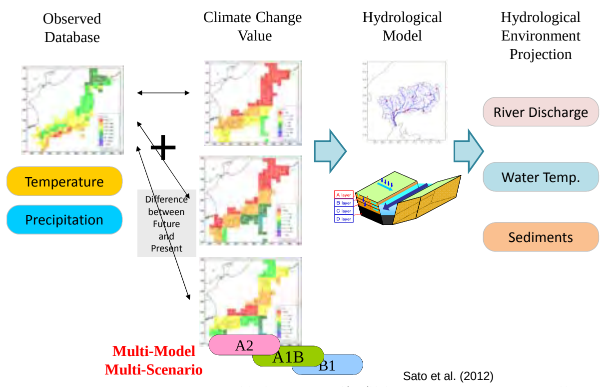


solid: CMIP3 ave. (Best 7 GCMs as Reproducibility)   dashed: MRI-AGCM3.1S
--A1B --A2 --B1

- SRES scenario differences are not remarkable
- Precipitation variability increases in the southern part
- Fluctuation of monthly variability exists in MRI-AGCM3.1S

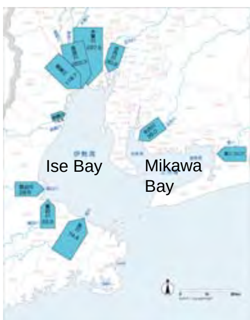
Michihiro et al. (2012)

Application to Hydrological Analysis



Sato et al. (2012)

Outline of Ise Bay



Environmental database of Ise Bay
http://www.isewan-db.go.jp/about/index.asp

Bay	Area km²	Volume km³	Mean depth m	Basin area km²
Ise Bay	1738	33.90	19.5	13411
Mikawa Bay	604	5.54	9.2	3624

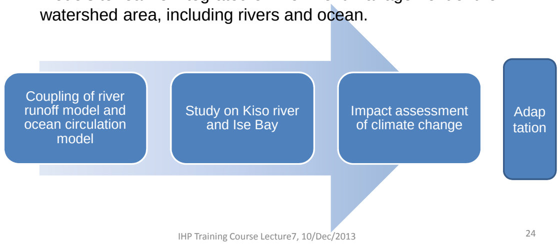
Volume of Ise Bay
= 1.9 years x river discharge

Volume of Mikawa Bay
= 2.8 years x river discharge

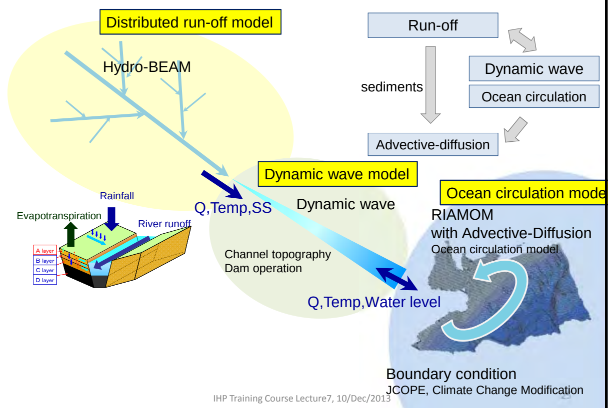
Impacts of river discharge on Ise Bay and Mikawa Bay are larger than those on Tokyo Bay(7 years) and Osaka Bay (5 years).

Objectives of Coupled River and Ocean Model

- The hydrologic environment of coasts and bays is strongly influenced not only by ocean circulation from tides and wind, but also by river influx such as fresh water, nutrients, sediments and others.
- It is necessary to connect river runoff and ocean circulation models to realize integrated environment management of the watershed area, including rivers and ocean.



Schematics of coupled river and ocean model



Specifications of coupled river and ocean model

Hydro-BEAM

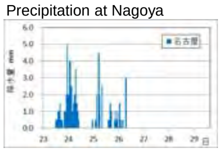
Item	Contents
Cell size	Horizontal: 1 km Vertical: 4 layers
Hydrologic processes	Rainfall, evapotranspiration, snowmelt, outflow, underground seepage
Runoff process	Surface: kinematic wave model Subsurface: storage function model
River channel	50 m mesh DEM
Land use	Forest, grass, paddy field, city, water
Hydrologic parameters	Roughness, albedo, moisture content, hydraulic permeability, soil porosity
Meteorological data	Rainfall, temperature, wind speed, pressure, water vapor pressure, sunshine duration
Outputs	River discharge, water temperature, density of suspended sediment, others

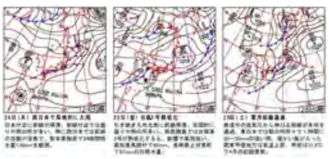
RIAMOM

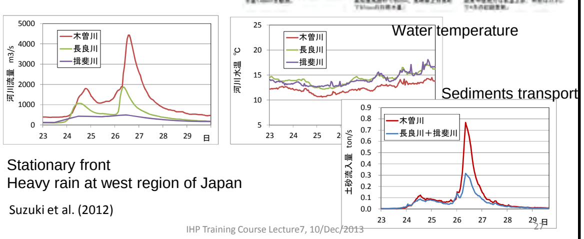
Item	Contents
Basic equations	Equations of motion Equation of continuity Hydrostatic equation Advective equation of tracer
Variables	Current vector (u,v,w), pressure (surface height), water temperature, salinity
Coordinate	Z (60 layers)
Horizontal grid	Latitude and longitude (1/72 degree)
Open Ocean Boundary	JCOPE2 re-analysis data (1/12 degree)
Tidal data	NAO tide model
Meteorological data	Wind, temperature, sea surface pressure, humidity, cloud amount, rainfall
Outputs	Current (u,v,w), water temperature, salinity, sea surface level

Case study 2003/Apr.

Precipitation at Nagoya



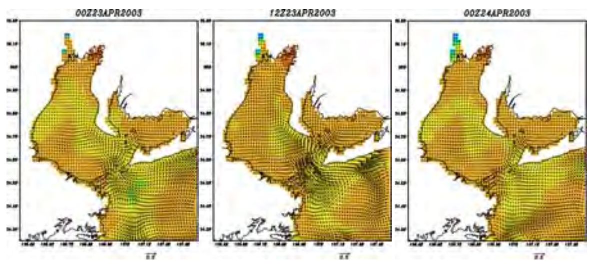




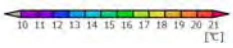
Stationary front
Heavy rain at west region of Japan

Suzuki et al. (2012)

Sea surface water temperature



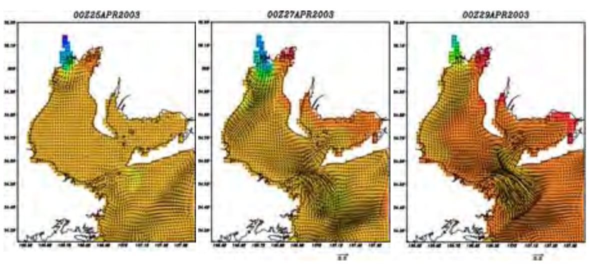
Initial 12hours 24 hours



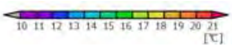
Observed river water temperatures are set as boundary conditions of advective-diffusion calculation.

Suzuki et al. (2012)

Sea surface water temperature

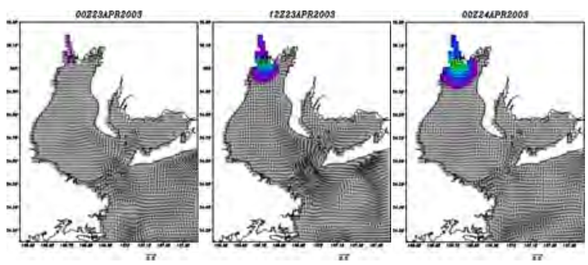


2 days 4 days 6 days



Suzuki et al. (2012)

Suspended sediments

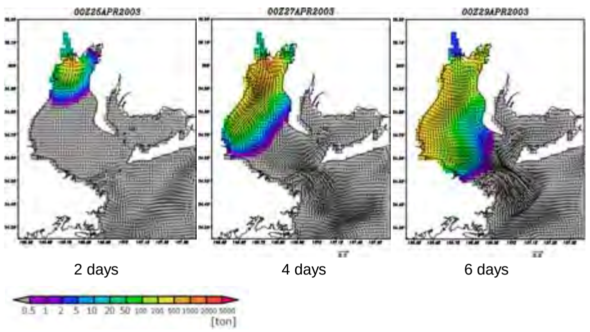


Initial 12hours 24 hours

Boundary conditions are set by the relation between observed SS (suspended solid) and river discharge rate.

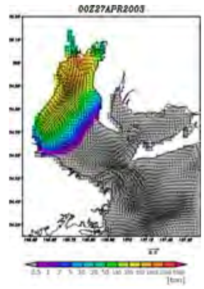
Suzuki et al. (2012)

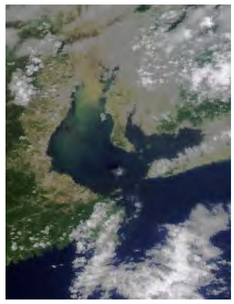
Suspended sediments



Suzuki et al. (2012)

Comparison with the satellite image





Suspended sediments calculation at 9 JST 27/Apr/2003.

Muddy water distribution from Aqua MODIS satellite image at 13:15 27/Apr/2003.

Suzuki et al. (2012)

Present climate calculation

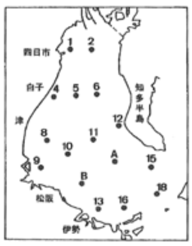
Conditions of present calculation

- Period from 2004/Jan to 2004/Dec.
- Monthly calculation from 16 day of previous month to the last day of this month
- Atmospheric boundary conditions are JMA MSM GPV (5km mesh)
- Open ocean boundary conditions are JAMSTEC JCOPE2 analysis (5 min mesh)
- River boundary conditions are observed river discharge, water temperature and suspended sediments
- Ise Bay is represented by 1.5 km mesh

Suzuki et al. (2013)

Observed data at Ise Bay

Reference:
Mie Prefecture Fisheries Research Institute: Fish and marine information report, 2000-2010.



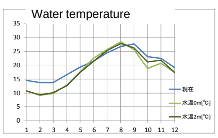
Interval : Every month

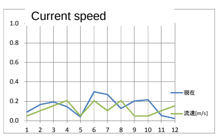
Points : 16 points

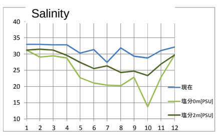
Observation elements :

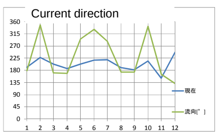
water temperature, salinity, current, suspended solids, DO, chl-a, pH, COD, NH4-N, NO2-N, NO3-N, PO4-P, plankton

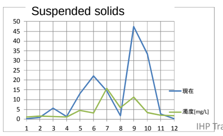
Verification of model result against observation











Comparison between observation (green) and model (blue)
Model water temp. is larger than observation in winter
Model salinity and SS are larger than observation
Current direction does not correspond with observation due to small current speed

Future projection

Calculation conditions

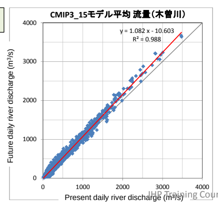
① CMIP3 climate change values are added to the atmospheric and open ocean boundary conditions.

② River discharge is estimated using relation between present and future calculation of Hydro-BEAM.

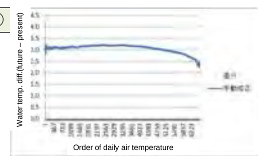
③ River water temperature is estimated from the difference between present and future calculation.

①	CMIP3 average		
	Rain	Temp.	SST
1月	1.038	3.249	2.075
2月	1.071	3.445	2.076
3月	1.057	3.126	2.101
4月	1.027	2.870	2.033
5月	1.065	2.933	1.976
6月	1.039	2.939	1.981
7月	1.109	2.787	1.947
8月	1.129	2.953	1.923
9月	1.067	3.133	1.923
10月	0.991	3.081	1.991
11月	0.913	2.963	1.986
12月	0.955	3.158	2.028

②

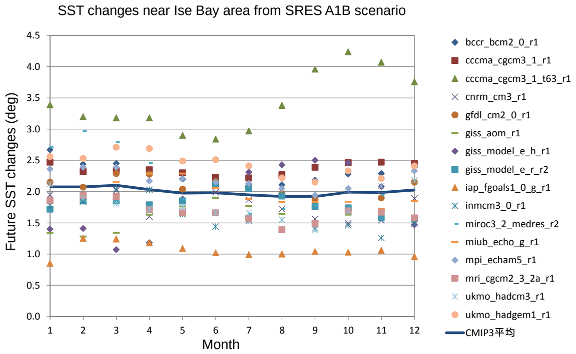


③



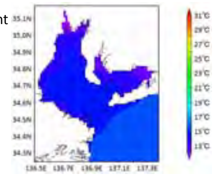
Suzuki et al. (2013)

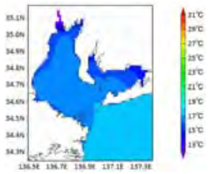
Future SST changes by CMIP3 models



Monthly mean SST distribution and future change in February

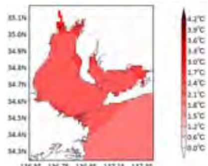
Present





Future

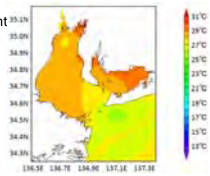
Future change

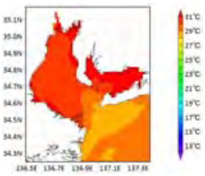


SST increase by about 2 deg.
Increase at coastal area is large.
3 deg. Increase at river mouth.

Monthly mean SST distribution and future change in August

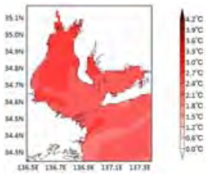
Present





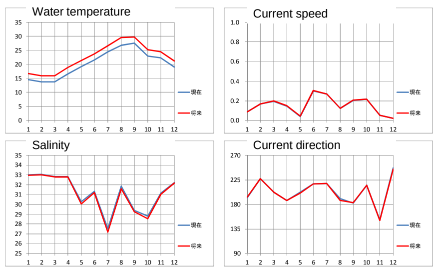
Future

Future change



Future SST exceeds 30 deg.
Increase at coastal area is large.
SST increase is larger than winter.
→effect of temperature stratification

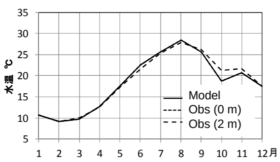
Future changes



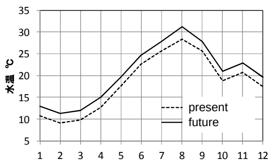
Comparison between present calculation (blue) and future calculation (red)
Future water temp. will increase by about 2-3 deg.
There are no clear difference among other elements.

Bias correction of water temperature calculation

Present water temperature



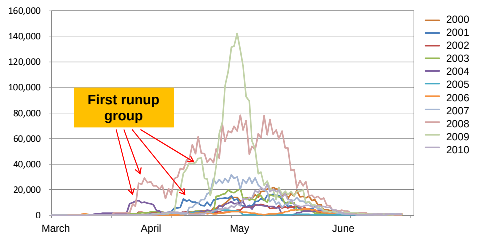
Future and present water temperature



Future water temperature becomes not less than 10 deg. in winter, and exceeds 30 deg. in summer.

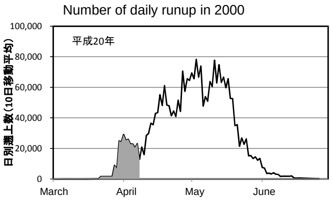
Sweetfish data at Nagara river estuary barrage

Count the number of sweetfish runup in the fishway



Data source: Nagaragawa Estuary Barrage Operating & Maintenance Office

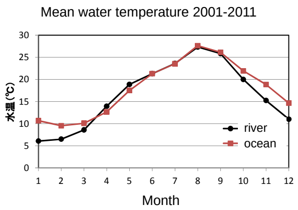
Definition of the first runup group

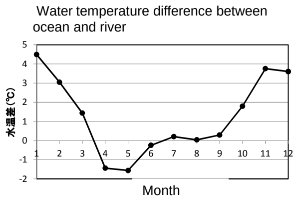


Year	Last date of first group	Number of first group	5% excess date of first group
2000	–	–	–
2001	–	–	–
2002	–	–	–
2003	4/12	35,972	3/21
2004	3/26	15,153	3/15
2005	4/9	6,317	4/2
2006	3/21	3,928	3/11
2007	4/14	17,426	3/4
2008	4/10	295,822	3/28
2009	4/23	407,244	4/12
2010	4/16	22,417	3/27

The first runup group is defined as the peak to valley of the first, which is shaded gray.

Seasonal change of water temperature





From autumn to winter : ocean temperature > river temperature
From spring to summer : river temperature > ocean temperature

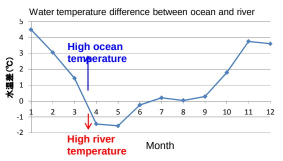
Relation between sweetfish runup and water temperature

River temperature is larger than ocean in winter

River temperature increases in early spring

Sweetfish starts to runup when water temperature of river and ocean is at the same level

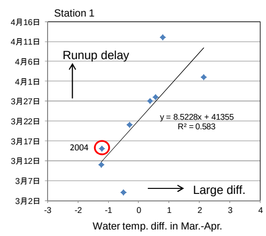
In the book of Isao Takahashi, he says that this relation is misunderstanding.

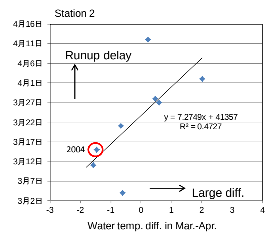


If water temperature difference is large in spring, the time of same level temperature is delayed.

Which results in the delay of sweetfish runup

Water temperature difference and date of the first group runup



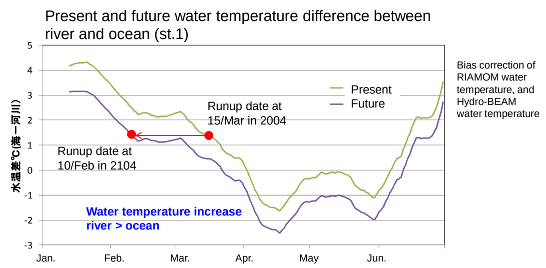


Station 1
Depth 10m

In the year of high water temperature difference, sweetfish runup of the first group is delayed.

Station 2
Depth 24m

Future change of sweetfish runup date



Bias correction of RIAMOM water temperature, and Hydro-BEAM water temperature

Assumption: Runup threshhold temperature 1.4deg does not change during this 21st Century.

Then future sweetfish runup date may become earlier by about 1 month at the end of this century.

Conclusions

- Climate Change Information Database for Hydrological Analysis is developed and the data are provided freely from web (http://hes.dpri.kyoto-u.ac.jp/database/)
- The objective of the database is to provide quick access way to persons, who are not familiar with GCMs.
- Coupled river and ocean model was developed, which was applied to the sediment transport calculation from Kiso river to Ise Bay.
- Future water temperature increase of Kiso river is about 3 degrees, and that of Ise Bay is about 2 degrees. Coastal areas are more strongly influenced.
- Sweetfish runup time has negative correlation with water temperature difference (sea – river). Calculated future water temperature difference is smaller than that of present, which results in the early start of river run-up time of sweetfish.

Lecture 8: IHP Perspectives on Ecohydrology and Related Demonstration Projects

Shahbaz KHAN *(Regional Science Bureau for Asia and the Pacific, UNESCO)*

UNESCO's IHP Ecohydrology Programme is focused on an integrated understanding of biological and hydrological processes at a catchment scale in order to create a scientific basis for a socially acceptable, cost-effective and systemic approach to the sustainable management of freshwater resources. The aims of the program are to:

- advance the integration of social, ecological and hydrological research; and
- generate outcomes that enable the development of effective policies and practices.

The Ecohydrology theory is based upon the assumption that sustainable water resources management can be achieved by:

- Reversing degradation and regulating the evolutionarily-established processes of water and nutrient circulation and energy flows at a catchments scale;
- Enhancing the carrying capacity of ecosystems against human impact (resilience, robustness, biodiversity, ecosystem services for societies)
- Using water biota interplay as water management tools.

The EHP has been formulated as a key theme of the Seventh Phase (2008-2013) of the International Hydrology Program's (IHP) action oriented and policy relevant knowledge generation, sharing and technical capacity building. This theme is contributing to a better understanding of water as both an abiotic resource and as a service delivered by ecosystems. The EHP aims to exemplify trans-disciplinary, cost-effective solutions to water related issues in variety of ecosystems and climatic zones. EHP remains a key area IHP Phase VIII (2014-2021) as eco-hydrology, engineering harmony for a sustainable world.

The main purpose of a network of Demonstration Projects is to showcase how to identify, quantify and improve the critical interrelationships between water, biota and social systems for sustainable water management, following the principles of the concept of UNESCO IHP Ecohydrology.

The Ecohydrology concept should operate in Demonstration Projects on four levels:

- Information (monitoring, collecting of empirical data, defining interactions and hydrology-biota-society feedbacks),
- Knowledge (defining patterns, describing and explaining processes)
- Wisdom (ability to formulate policy, principles for action, problem solving by system solutions, stakeholders involvement, education, implementation)
- Cooperation for solving problems (willingness of different stakeholders to effectively contribute actively to the implementation of the EH approach in the demonstration site – this will ensure cooperation among all sectors and the achievement of the demonstration site goals)

There are three key objectives of this network:

- Synthesize knowledge gaps for addressing ecohydrological issues related to water ecosystems under pressure.

- Showcase how better knowledge of the biological and hydrological interrelationships in aquatic ecosystems can promote the long term sustainable carrying capacity of ecosystems and thus contribute to more cost-effective and environmental-friendly water management.
- Demonstrate systems solutions and technology transfer opportunities through North-South and South-South linkages.

The ASPAC Ecohydrology program now has three operational projects and twelve evolving projects.

IHP Perspectives on Ecohydrology and Related Demonstration Projects

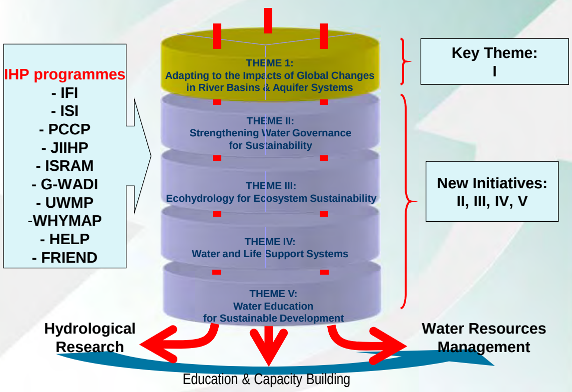
Shahbaz Khan
UNESCO Regional Science Bureau for Asia and the Pacific Region

UNESCO and Water

Division of Water Sciences

- **International Hydrological Programme** — Intergovernmental programme +regional presence
- **World Water Assessment Programme** — Inter agency Programme led by UNESCO
- **UNESCO-IHE Institute for Water Education**
- **Water Centers under the auspices of UNESCO** — R&D, Training and Policy Advice

IHP-VII (2008-2013)



IHP-VIII 2014-2021

IHP-VII THEME III Ecohydrology for Sustainability

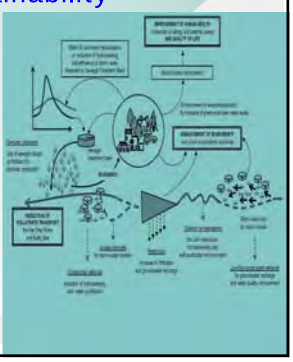
Objective:
Enhance the designation of water both as an abiotic resource and as a service, delivered by ecosystem processes; identify, quantify and improve the critical linkages for environmental sustainability.

Focal Area III-1: Ecological measures to protect andremediate catchments process.

Focal Area III-2: Improving ecosystem quality and services by combining structural solutions with ecological biotechnologies.

Focal Area III-3: Risk-based environmental management and accounting.

Focal Area III-4: Groundwater-dependent ecosystems identification, inventory and assessment.



How Do We Work

DEMONSTRATION

The Programme has developed a criteria to recognize sites where sustainable, innovative and transdisciplinary water management practices based on ecohydrology principles are implemented. At the same time, the new Demonstration Projects call was launched in 2010 to identify opportunities to demonstrate the application of the ecohydrology approach to solve issues surrounding water, environment and people. These sites will also be featured in scientific research and training activities under the programme.

GENDER & SOCIAL CULTURAL BIODIVERSITY

The Programme is aiming to bridge the gap between the hydrology, social and ecological/environmental sciences by exploring community cultural values and in so doing reframe the policy discourse in language that is more appropriate to the purpose of engaging the 'grass-roots' community in the eco-social action planning processes as a basis for social change.

INTEGRATION AND UPSCALING

We are investigating the key intersections between socio-economics sciences and the hydrological/ ecological cycles. In developing ecohydrology from its core beliefs and principles, using the systems approach, there has been a conscious effort to assimilate new paradigms and thinking into it. The strategy for enhancing ecohydrology science includes:

- Understanding the past efforts
- Integrating various disciplines
- Harmonizing societies priorities by increasing the carrying capacity of an ecosystem
- The formulation of a vision for sustainable water ecosystem.

MODELLING AND VISUALIZATION

The Programme is working on tools to inform and support water managers and planners in making integrated water resource management decisions using ecohydrology approach. This working group is aiming to cross boundaries across disciplines such as water systems, economics and social science to promote integration to develop software tools for solving real problems.

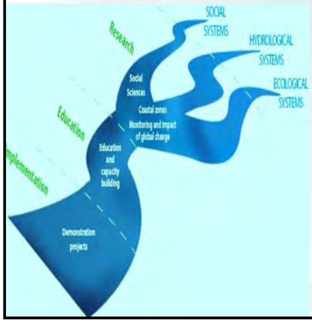
EDUCATION & CAPACITY BUILDING

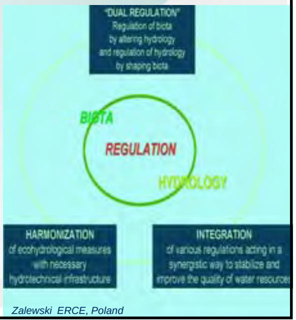
The Education and Capacity Building in Ecohydrology includes development of a curriculum of academic courses and practitioner trainings to enhance ecohydrology knowledge and implementation on the ground. The Erasmus Mundus Master of Science in Ecohydrology is a good experience.

More information can are available under the link www.ecohyd.org

Ecohydrology Actions

Action Areas | **Local Solutions Global Impact**



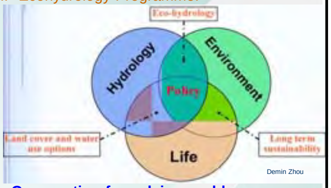


Zalewski ERCE, Poland

Demonstration Projects

Showcase how to identify, quantify and improve the critical interrelationships between water, biota and social systems for sustainable water management, following the principles of the concept of UNESCO's IHP Ecohydrology Programme.

The four levels of Project Demonstration



1. **Information** (monitoring, collecting of empirical data, defining interactions and hydrology-biota-society feedbacks),
2. **Knowledge** (defining patterns, describing and explaining processes),
3. **Wisdom** (ability to formulate policy, principles for action, problem solving by system solutions, stakeholders involvement, education, implementation),
4. **Cooperation for solving problems** (willingness of different stakeholders to effectively contribute actively to the implementation of the Ecohydrology approach in the demonstration site – this will ensure cooperation among all sectors and the achievement of the demonstration site goals).

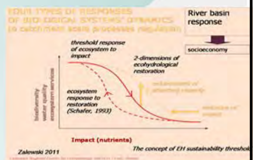
Key Objectives of Demonstration Projects

1. Synthesize knowledge gaps for addressing ecohydrological issues related to water ecosystems under pressure.
2. Showcase how better knowledge of the biological and hydrological interrelationships in aquatic ecosystems can promote the long term sustainable carrying capacity of ecosystems and thus contribute to more cost-effective and environmental-friendly water management.
3. Demonstrate systems solutions and technology transfer opportunities through North-South and South-South linkages by closing with the UNESCO IHP Water Family.

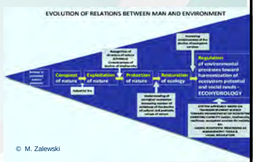
Demonstration Projets Network

Global Reference Projects

I - Ecohydrology based urban water management and city planning for human health and sustainable development. City of Lodz, Poland.



II - Development and implementation of the Ecohydrology concept for reduction cyanobacterial blooms in a man-made reservoir.
Pilica River Catchment, Poland.



Demonstration Projets Network

OPERATIONAL PROJECTS

I - Improving land use policy at Lacar Lake Watershed based on an Ecohydrological approach. San Martín de los Andes, Neuquén. Argentina.

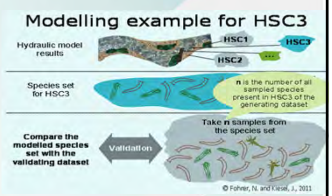
II - Management of Regional Water Resources linking with Maintaining of Wetland Biodiversity in the Suburban Area of Metropolitan Beijing, China.

Demonstration Projets Network

OPERATIONAL PROJECTS

III - Watershed management in Northeast China: hydrological processes, vegetation optimization and sustainability.

IV - Ecohydrological analyses in the lowland river catchment Kielstau, Germany, for sustainable water resources management and education in rural landscapes.



V - Sustainable water resources management plans in the Tiber river basin for environment protection, minimum instream flows regulation and the Trasimeno Lake ecosystem preservation. Italy.

Demonstration Projets Network

OPERATIONAL PROJECTS

VI - An Initiative to move the Naivasha Basin towards sustainable use.: A proposal to the supermarket buyers of flowers from Lake Naivasha, Kenya.

VII - Integrated Catchment Management of Putrajaya Lake and Wetland, Malaysia.

Demonstration Projets Network

EVOLVING PROJECTS

I - Developing fit-for-purpose tools to address complex social, ecological and economic issues in water planning, Australia.

II - Ecohydrology in action: Addressing changing hydrology, ecological condition and community attitudes to water at the Ord River, Western Australia

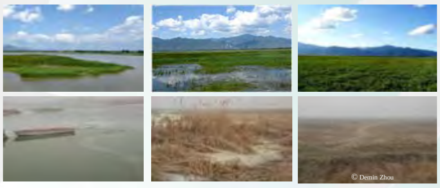
III - Ecohydrology of Western Sydney Australia– Developing Solutions for Environmental-friendly Water Management in Peri-urban Landscapes.

IV - Integration of Eco-hydrological Processes Demonstration Research in Heihe River Basin, Northwest of China.

Demonstration Projets Network

EVOLVING PROJECTS

V – Linkage of wetland ecology and hydrology with support of information techniques for assessing the degrated inland fresh water wetland habitat in Sanjiand Plain Northeast China.



VI - Study of irrigation management practices and impacts of soil salinization in Manas River Valley, Northwest China.

Demonstration Projets Network

EVOLVING PROJECTS

VII - A methodology to estimate compensatory runoff in Costa Rica, RANA-ICE study.

VIII - Central American Integration under the Trifinio Plan: Study of integrated management of natural capital in El Salvador, Guatemala and Honduras.

IX - Development of advanced ecohydrology tools for the sustainable management of coastal wetlands: The case of Nestos River lagoons. Greece.

X - Improved ecosystem management to control euthrophication at the Saguling reservoir and relevant hydro-meteorological disasters by wetland construction and river flow regulation. West Java Province. Indonesia.

Demonstration Projets Network

EVOLVING PROJECTS

XI - Integrating watershed management activities with the protection of coastal coral reef ecosystems in Micronesia.

XII - Understanding ecohydrological connectivity in multiple catchments to conserve groundwater, protect surface water and contain risks in a globalizing city. Philippines.

XIII - Adaptive water management in response to hydro-climatic change effects on ecosystem services and biodiversity of the Swedish Norrström drainage basin. Sweden.

Demonstration Projets Network

EMERGING PROJECTS

I - Assessing performance of ETP (Effluent Treatment Plant) using Duck weeds and activated sludge management system and sustainably managing limnology to develop hydro ecological regime. Bangladesh.

II - Restoration of Victoria Pond: Restoring wetland habitat in historic George Town, Great Exuma for sustainable management to control eutrophication and enhance near shore fish habitat. Bahamas.

III - Capacity Building in Ecohydrology and promotion of eco-farming practices at YEHA Institute Farmers' Academy, Ethiopia.

Demonstration Projets Network

EMERGING PROJECTS

IV - Integrated Water Resources Management as tool to control impact of Small-scale Diamond Mining Operations in selected communities in the Eastern Region of Ghana.

V - Caring for Cikapundung River by Reforestation, Fetiver Plantation, Biopores, Relocation of Squatter, Settlements along the River Banks, Long Storage, and Eco-Technonology for Sustainable of Water Supply for Bandung City. Indonesia

VI - **Study of avian community during wetland restoration of Zhalong Nature Reserve in China.**

VII - Rehabilitation of Balagunan Watershed to restore biodiversity and flood control in Carmen, Davao del Norte. Philippines.

Demonstration Projets Network

EMERGING PROJECTS

VIII - Restoration of Fluvial Territory in the lower reaches of Aragón and Arga rivers (Navarra-Spain), as a means to increase biodiversity and reduce flood risk and damages.

IX - Sustainable estuarine zone management for control of eutrophication, toxic blooms and conservation of biodiversity in the Kaštela Bay (Croatia, Adriatic Sea).

Geographical situation of UNESCO-IHP Ecohydrology Programme Demonstration Projects

Demonstration Projects Network

Ecohydrology Demonstration Projects Evaluation : Overall Impressions

- Level of EH approach application differentiates the projects.
- Many new players.
- People interacting with the program have submitted proposals.
- Longer standing commitments of institutions.
- Web sites for global reference and operational sites.
- Scale and focus is important for all sites.
- Integration of issues is very important.
- Special volume on demo site projects using a standard template.
- Africa needs more demonstration projects.
- Latin and North America need to have further projects.
- Eastern Europe not well represented.
- Ecological responses to flow regimes may be strengthened.
- EH of Dry land areas need to be emphasized.
- Cold regions need to be brought in.
- In many countries still engineers dominate the water field. There is a need to bring. Ecohydrology approaches.
- Possible participation funds for Ecohydrology projects.
- The meeting of March 21-23, 2011 held in Jakarta was to invite EH Demo projects as a first step to make them active.

Thank you

Lecture 9: Fundamentals in Optimum Operation of Reservoir Systems

Tomoharu HORI *(Water Resources Research Center, DPRI, Kyoto University)*

A reservoir system is one of the most powerful and commonly used tools for water resources management. It regulates the river discharge in order to increase the availability of water resources and also to prevent flood disasters. Because the temporal distribution of river discharge, especially the extreme value, brings water-related disasters, the operation of reservoirs have been of great concern in the field of operational hydrology. It has been pointed out recently that the distribution of precipitation will change according to the impact of climate change. This implies that the design flood with the return period of one hundred years, for example, will come to be the one with shorter return period in future. It is not easy, however, to construct new facilities to cope with the situation and then the non-facility-based countermeasures such as higher degree application of dam reservoirs are getting more important.

From these points of view, a lot of research works have been done so far about reservoir operation. Many techniques and algorithms have been proposed and huge amount of case studies have been reported in research journals. When trying to study about reservoir operation, beginners may find some difficulty to know where to start. This course will introduce the fundamentals in optimum reservoir operation theory, which may be of great help for class participants to do more detailed study. The lecture comprises of three parts; the introduction of reservoir operation, optimization framework of reservoir operation and measures to cope with uncertainty.

In the first part, basic concept related to reservoir operation is introduced. Various purposes of dam reservoirs are summarized and how the operation policy can differ according to the purposes. The difference of on-line real time control and off-line control is also discussed. Some examples of actual reservoir operation will be shown before going into theoretical approach.

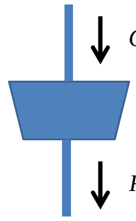
In the second part, the typical reservoir control problem is formulated in mathematical expression. Types of objective function and constraints peculiar to reservoir control problems are shown. Then it is discussed how the sequence of release discharge which gives the best value of objective function can be obtained. Dynamic programming (DP) for deterministic treatment of inflow discharge is introduced as the most fundamental optimum operation scheme. Recurrence function formula of DP application is derived for the optimum release sequence. The computational burden to obtain optimum solution is also discussed to understand the effeteness and limitations DP approach.

In the third part, coping with uncertainty in reservoir operation is the main concern. In order to consider the uncertainty of inflow to the reservoir, first-order Markov chain is introduced and formulation of operation is modified. Then the algorithm to derive the optimum release policy is discussed and the solution search process, which is called Stochastic Dynamic Programming (SDP), is introduced. It is also shown that introduction of stochastic information requires a lot of memory area in the solution search process (curse of dimensionality). Some techniques to avoid this problem are briefly explained at the end of the class.

Fundamentals in Optimum Reservoir Operation

T. Hori
Water Resources Research Center
Disaster Prevention Research Institute
Kyoto University

Key variables to describe state of a reservoir



$Q(t)$: Storage volume at time t

$S(t)$: Storage volume at time t

$R(t)$: Storage volume at time t

Continuity equation of a reservoir $\frac{dS(t)}{dt} = Q(t) - R(t)$

Objective Function (1)

Evaluation function

Damage or Loss in case of flood control

➡ Minimization problem

Benefit or Income in case of water supply and power generation

➡ Maximization problem

Conceptually can be expressed as an function of release discharge and storage

$$J(R(t),\ S(t))$$

Objective Function (2)

Evaluation of the performance of operation

Analytical expressed when the assessment can be done directly in terms of reservoir variables:

$$J(R(t), S(t)) = \{R(t) - R_{\text{target}}\}^2 + \{S(t) - S_{\text{target}}\}^2$$

In many cases, some simulation process such as flood routing and runoff is included :

$$J(R(t), S(t)) = \left(\frac{Q_{\text{ref}}(t) - D(t)}{D(t)} \times 100 \right)^2$$

where $D(t)$ denotes the demand at intake (reference) point

$J(R(t), S(t)) = f$ (mximum inundation depth)

$R(t) \rightarrow$ flood flow $\rightarrow$ inundation

Formulation

$$\max_{\substack{R(t) \\ 0 \le t \le T}} \left[\int_0^t J(R(t), S(t))\, dt \right]$$

subject to

$$\frac{dS(t)}{dt} = Q(t) - R(t)$$

$$0 \le R(t) \le R_{\max}$$

$$S_{\min} \le S(t) \le S_{\max}$$

$$(0 \le t \le T)$$

Design operation and Real time operation

Inflow discharge sequence $Q(t) : 0 \le t \le T$

Known for all time horizon

Design operation (off-line operation) : to derive optimum release sequence for historical hydrographs

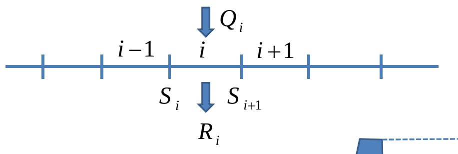
Unknown in future from the current time

Real time operation (on-line operation) : to derive optimum release at current time in consideration with future income (current release which maximizes total benefit for the period between current time and time horizon)

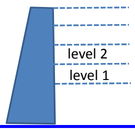
Discretization in time and volume

From actual viewpoint, release cannot be changed continuously in time

Discrete time system is introduced



Hydrologic variables such as storage, inflow, release are also discretized in level expression



The most fundamental case

The case where values of inflow discharge sequence $Q_i \ (i = 1, \cdots, I)$ is known (given).

- Design operation
- Inflow values (levels) are explicitly given -> Deterministic
- Single reservoir system

Deterministic Dynamic Programming Operation (referred as DDP hereafter)

Deterministic DP operation

Problem Formulation

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

subject to

$$S_{i+1} = S_i + Q_i - R_i$$
$$0 \le R_i \le R_{\max}$$
$$S_{\min} \le S_i \le S_{\max}$$
$$(i = 1, \cdots, I)$$

where

Q_i and R_i : inflow and release at step i, S_i :storage at the beginning of step i

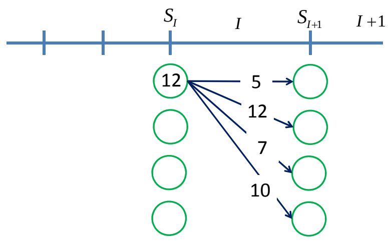
$J(\bullet,\bullet)$: assessment function

$R_{\max}$:upper limit of release, $S_{\min}$ and $S_{\max}$: lower and upper limit of storage.

Deterministic DP operation

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

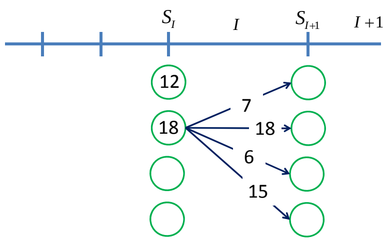
$$= \max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$



Deterministic DP operation

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

$$= \max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$



Deterministic DP operation

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$

$$= \max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + \max_{\substack{R_I \\ \text{for given } S_I}} \left[J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right] \right]$$

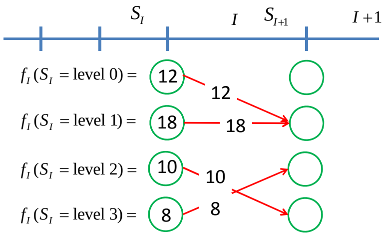
$$= \max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + f_I(S_I) \right]$$

where

$$f_I(S_I) = \max_{\substack{R_I \\ \text{for given } S_I}} \left[J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$

Deterministic DP operation

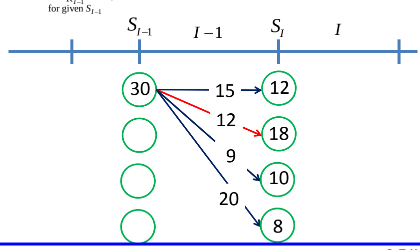
$$f_I(S_I) = \max_{\substack{R_I \\ \text{for given } S_I}} \left[J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$



$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

$$= \max_{\substack{R_i \\ i=1,\cdots,I-2}} \left[\sum_{i=1}^{I-2} J(R_i, \frac{S_i + S_{i+1}}{2}) + \right.$$

$$\left. + \max_{\substack{R_{I-1} \\ \text{for given } S_{I-1}}} \left\{ J(R_{I-1}, S_{I-1} + \frac{Q_{I-1} - R_{I-1}}{2}) + f_I(S_{I-1} + Q_{I-1} - R_{I-1}) \right\} \right]$$



Defining

$$f_{I-1}(S_{I-1}) = \max_{\substack{R_{I-1} \\ \text{for given } S_{I-1}}} \left\{ J(R_{I-1}, S_{I-1} + \frac{Q_{I-1} - R_{I-1}}{2}) + f_I(S_{I-1} + Q_{I-1} - R_{I-1}) \right\}$$

produces

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

$$= \max_{\substack{R_i \\ i=1,\cdots,I-3}} \left[\sum_{i=1}^{I-3} J(R_i, \frac{S_i + S_{i+1}}{2}) + \right.$$

$$\left. + \max_{\substack{R_{I-2} \\ \text{for given } S_{I-2}}} \left\{ J(R_{I-2}, S_{I-2} + \frac{Q_{I-2} - R_{I-2}}{2}) + f_{I-1}(S_{I-2} + Q_{I-2} - R_{I-2}) \right\} \right].$$

Recursive functions derived

$$f_{I-i}(S_{I-i}) = \max_{\substack{R_{I-i} \\ \text{for given } S_{I-i}}} \left\{ J(R_{I-i}, S_{I-i} + \frac{Q_{I-i} - R_{I-i}}{2}) + f_{I-i+1}(S_{I-i} + Q_{I-i} - R_{I-i}) \right\}$$

for $i = 0, \cdots, I-1$

$$f_{I+1}(S_{I+1}) = 0.$$

Applying the recursive function backward from the end period to the beginning one gives the optimal release as the function of storage levels at the beginning of each period.

Consideration of uncertainty

In the Deterministic DP model, values of inflow level are given. Actually the inflow level differs year by year even in the same day in the year.

Stochastic approach is required.

Inflow level in each period is not independent: High correlation between inflow levels at neighboring time periods is usually observed.

One-order Markov Chain

Conditional probability of inflow levels during time period i, Q_i, for the levels of inflow in the previous perid, Q_{i-1}.

$$\Pr[\, Q_i \mid Q_{i-1}]$$

$$= \begin{pmatrix} \Pr[Q_i = 1 \mid Q_{i-1} = 1] & \Pr[Q_i = 1 \mid Q_{i-1} = 2] & \Pr[Q_i = 1 \mid Q_{i-1} = 3] \\ \Pr[Q_i = 2 \mid Q_{i-1} = 1] & \Pr[Q_i = 2 \mid Q_{i-1} = 2] & \Pr[Q_i = 2 \mid Q_{i-1} = 3] \\ \Pr[Q_i = 3 \mid Q_{i-1} = 1] & \Pr[Q_i = 3 \mid Q_{i-1} = 2] & \Pr[Q_i = 3 \mid Q_{i-1} = 3] \end{pmatrix}$$

$$= \begin{pmatrix} 0.6 & 0.3 & 0.1 \\ 0.3 & 0.5 & 0.2 \\ 0.3 & 0.3 & 0.4 \end{pmatrix}$$

One-order Markov Chain

$$\Pr[\,Q_i \mid Q_{i-1}] = \begin{pmatrix} 0.6 & 0.3 & 0.1 \\ 0.3 & 0.5 & 0.2 \\ 0.3 & 0.3 & 0.4 \end{pmatrix}$$

If the probability distribution of Q_{i-1} is given as $\Pr[\,Q_{i-1}] = \begin{pmatrix} 0.3 \\ 0.5 \\ 0.2 \end{pmatrix}$

you can get the probability distribution of Q_i as follows

$$\Pr[Q_i] = \Pr[Q_i \mid Q_{i-1}]\cdot \Pr[Q_i] = \begin{pmatrix} 0.6 & 0.3 & 0.1 \\ 0.3 & 0.5 & 0.2 \\ 0.3 & 0.3 & 0.4 \end{pmatrix} \cdot \begin{pmatrix} 0.3 \\ 0.5 \\ 0.2 \end{pmatrix}$$

$$= \begin{pmatrix} 0.6\times 0.3 + 0.3\times 0.5 + 0.1\times 0.2 \\ 0.3\times 0.3 + 0.5\times 0.5 + 0.2\times 0.2 \\ 0.3\times 0.3 + 0.3\times 0.5 + 0.4\times 0.2 \end{pmatrix}.$$

One-order Markov Chain

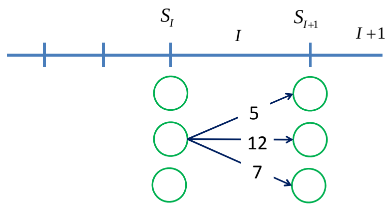
Once you have observed that the inflow discharge at the previous time period, Q_{i-1}, is level 2, then you can obtain the probability distribution of inflow at current time stage as:
$\Pr[Q_{i-1} \mid Q_{i-1} = \text{level } 1] = (0.3 \quad 0.5 \quad 0.2)$.

Note that if you specify the release discharge at level 2 when the storage level at the beginning of period i is level 2, the storage level at the beginning of period $i+1$ cannot be specified uniquely. We can get instead the probability distribution of S_{i+1} as:

$$\Pr[S_{i+1}] = \begin{pmatrix} 0.3 & (\text{for} \quad S_{i+1} = 2+1-2=1) \\ 0.5 & (\text{for} \quad S_{i+1} = 2+2-2=2) \\ 0.2 & (\text{for} \quad S_{i+1} = 2+3-2=3) \end{pmatrix}$$

Stochastic Dynamic Programming

Then the expected benefit when you select release discharge during period i as level 1 in case the inflow level has been observed as level 2 will be given by
$5\times 0.3 + 12\times 0.5 + 7\times 0.2 = 8.9$.



Stochastic Dynamic Programming

$$f_{I-i}(S_{I-i}, Q_{I-i-1}) = \max_{\substack{R_{I-i} \\ \text{for given } S_{I-i},\, Q_{I-i-1}}} \left\{ \sum_{Q_{I-i}=1}^{K} \Pr[Q_{I-i} \mid Q_{I-i-1}] \cdot \left(J(R_{I-i}, S_{I-i} + \frac{Q_{I-i} - R_{I-i}}{2}) + f_{I-i+1}(S_{I-i} + Q_{I-i} - R_{I-i}) \right) \right\}$$

for $i = 0, \cdots, I-1$

Summary

- There are two types of operational approach: namely design operation and real time operation according to the inflow information.
- The most fundamental approach to optimal reservoir operation is optimization be deterministic dynamic programming.
- Uncertainty is inherent in reservoir operation and one of the commonly used optimum control under the uncertainty is called stochastic dynamic programming, which employ the one –order Markov chain as the model of inflow variations.

Exercise 1: Fundamentals of Data Processing

Toshio HAMAGUCHI *(Water Resources Research Center, DPRI, Kyoto University)*

The aim of this lecture is to learn the fundamentals of the practical exercises on data processing in scientific fields. We have nowadays many computer languages to be interpreted into the machine language. In this lecture, we highlight the FORTRAN language and give you the significant information on it at first. Secondly, we teach you how to install the software of FORTRAN in freeware version (named as “gfortran”). Thirdly, how to program it based on the structured formulation of “FORTRAN90” is mainly lectured while the source codes of available and applicable commands are seen as the typical examples in the given slides. Next, how to compile the programs you described is introduced, and finally how to execute it is mentioned. Four exercises concerning data processing are given during the above lecture contents. Based on the basic knowledge of this lecture, when you increase the knowledge of the FORTRAN commands, you can apply to the numerical analysis by making your program for yourself without commercial software because you can customize the self-programmed codes according to the special condition of boundaries, irregular sink/source terms, and domain discretization. It can be concluded that the fundamental study in this lecture is pretty important to make any programs in numerical processing.

UNESCO IHP Training Course
Exercise 1
Fundamentals of Data Processing

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What is digital data?

Digital data in Engineering fields:

- serially discrete digitals during observation,
- scattered statistics in space or time,
- random numbers adjoining true numbers,
- numerical results of scientific calculation with a machine language,
- etc

We need to deal with digital data on the screen/paper to find out some features in statistics or in numerical analysis and to grasp/interpret scientific implicitness from the features.

Interpreter of the machine language (binary code)

Binary codes; 0 or 1 / off- or on- electric signal

Hexadecimal codes; 0, 1, 2, … , 9, A, B, …, F, 10, 11, …

It differs from decimal codes; 0,1, 2, … , 9, 10, 11, …

Character code: defined with 2-orderd hexadecimal codes

BASIC developed by Bill Gates; IF THEN, PUT, PRINT, GOTO, NEXT, RUN, LOCATE, DATA, …

Others: FORTRAN, C, Pascal, perl, Ruby, JAVA, csh, bash…

FORTRAN Language

Deveolped by *John Warner Backus* in 1954.

Main purpose : use in scientific digitals

Formulation change process:

FORTRAN(1957)→FORTRAN II(1958)→FORTRAN III(1958)

→FORTRAN IV(1961)→FORTRAN66→FORTRAN77

→FORTRAN90→ FORTRAN95→ FORTRAN2003

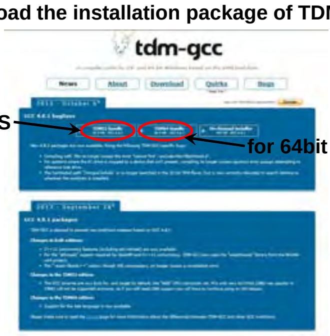
→FORTRAN2008→?

We use it herein! (FORTRAN90)

Fundamentals (FORTRAN77)

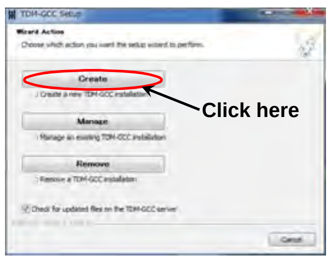
How to install gfortran system (1)

Please browse the following webpage :
http://tdm-gcc.tdragon.net
and download the installation package of TDM-GCC.



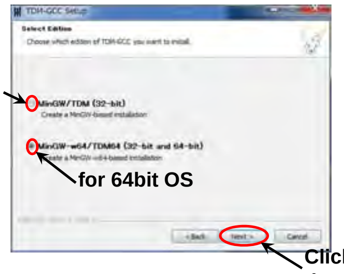
How to install gfortran system (2)

Run the downloaded execution file,
and click the [Create] button in the following window.



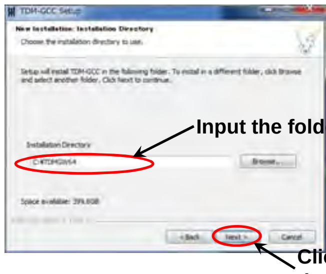
How to install gfortran system (3)

Choose and click the radio button according your OS, and click the [Next] button in the bottom.



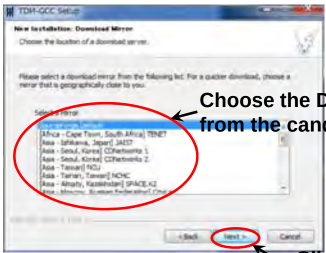
How to install gfortran system (4)

Ex. in case of 64bit OS, input the folder name to be installed.



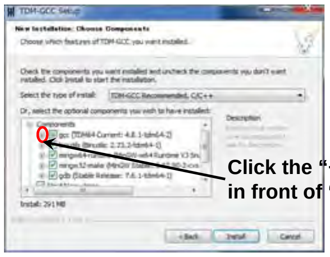
How to install gfortran system (5)

Choose the download site.
(Default one would be better.)



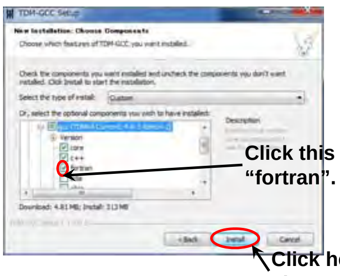
How to install gfortran system (6)

Click the plus mark in front of "gcc" to select the compiling languages to be installed.



How to install gfortran system (7)

Additionally click the mark in the box of "fortran."
(Preferred languages can be installed at the same time.)

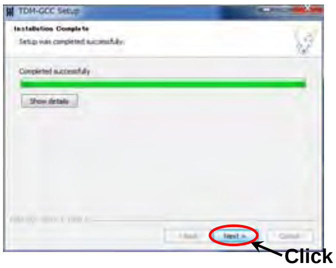


How to install gfortran system (8)

Wait for finishing the download and installation process.

How to install gfortran system (9)

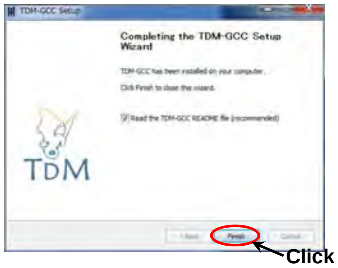
When you get to the following window, you can successfully finish the installation of "TDM-GCC."



Click here.

How to install gfortran system (10)

This is the last window of installation.



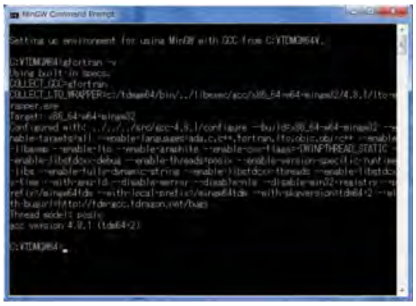
Click here.

How to examine the feasibility of gfortran system (1)

Open the command prompt window of "TDM-GCC" in "START" menu on your screen.

How to examine the feasibility of gfortran system (2)

Input "gfortran -v" on the prompt. If you get the following outputs on the screen, you'll successfully install it.



Exercise 1: output command

1. Start the text-editor such as "Memo pad."
2. you try to open a new file and input the following 4-line codes in it:

```
write(*,*) 'Hello, UNESCO IHP TC'
write(6,*) 'I am ???'
stop
end
```

Please input your name in "???" part.

where "write(n,m)" : "n" is the number of outputted place. "m" is the number of prescribed format.

3. After saving it as "test.f90" in the current folder, enter the command of "gfortran test.f90 (enter)" on the command line.

Exercise 1: output command (Cont.)

So that, you can get the execution file "a.exe" and run a(.exe).

If successful, you can display the following output on the command line.

```
Hello, UNESCO IHP TC
I am ???
```

What is "write(6,*)" different from compared with "write(*,*)" ? → (Ans.) No difference

"*" : used as a wild card (Default). Default of outputted place and format are given as "on the display (prompt line)" and "proper format."

So that, "write(*,*)" means "write(6,*)"

Exercise 1: output command (Cont.)

Edit the test.f90 as follows:

```
write(*,*) 'Hello, UNESCO IHP TC'
write(16,*) 'I am ???'
stop
end
```

Recompile "test.f90" (gfortran test.f90) and run it.

You can find 1-line output

```
Hello, UNESCO IHP TC
```

and moreover the new file "fort.16" in the current folder by inputting the command "dir /w".

After that, input the command "type fort.16"

```
I am ???
```

to display the contents of "fort.16"

Exercise 1: output command (Cont.)

Re-edit the test.f90 as follows:

```
write(*,*) 'Hello, UNESCO IHP TC'
open(16,file="out16.dat")
write(16,*) 'I am ???'
stop
end
```

Recompile "test.f90" (gfortran test.f90) and run it again.

You will find the new file "out16.dat" in the current folder.

Exercise 1: output command (Cont.)

Edit the test2.f90 as follows:

```
write(*,*) 'Input the integer number'
read(*,*) I
write(*,*) I+3
stop
end
```

Compile "test2.f90" (gfortran test2.f90) and run it.

If successful, you will find the following outputs on the screen.

```
Input the integer number
5
          8
```

Exercise 2: Looping operation command

Default of the REAL and INTEGER numbers

- INTEGER type: Number starting with I, J, K, L, M and N
- REAL type (number with floating point): Number starting with the rest of the other letters (A, B, …, H, O, …, Z)

The following codes are the summation from 1 to 10.

```
write(*,*) 'Summation of integer numbers'
J=0
do I=1,10
  J=J+I          <- "Do" loop concerning "I"
end do
write(*,*) J
stop
end
```

Exercise 2: Looping operation command (Cont.)

Q1. Program the integer summation codes in any ranges.

Q2. Program the output codes of an arithmetic sequence "3n−1" where n: natural numbers.

Exercise 3: Conditional command

The below codes are to calculate the integer summation from 25 to 75 in the range of 1 to 100.

```
write(*,*) 'IF-code test'
j=0
do i=1,100
if (i>=25 .and. i<=75) j=j+i
end do
write(*,*) j
stop
end
```

Exercise 3: Conditional command (Cont.)

The below codes are to calculate the integer summation from 25 to 75 in the range of 1 to 100.

```
write(*,*) 'IF-code test'
j=0
do i=1,100
if (i>=25 .and. i<=75) then
  j=j+i
end if
end do
write(*,*) j
stop
end
```

Exercise 3: Conditional command (Cont.)

The below codes are the same as previous one without "integer do-loop" (using if-else-then codes).

```
write(*,*) 'IF-code test'
i=1
j=0
do
 if (i>=25 .and. i<=75) then
  j=j+i
 else if (i==100) then
  exit
 end if
i=i+1
end do
write(*,*) j
stop
end
```

Exercise 3: Conditional command (Cont.)

The below codes are the same as previous one without "integer do-loop" (using "case").

```
write(*,*) 'IF-code test'
i=1
j=0
do
select case(i)
 case(100)
  exit
 case(:24)
  write(*,*)  'No calc. (n<25)'
 case(25:75)
  j=j+i
  write(*,*)  'Calc.'
case default
     write(*,*)  'No calc. (n>75)'
end select
i=i+1
end do
write(*,*) j
stop
end
```

Exercise 4: Dimension command

The below codes are to calculate the matrix production using the Dimension command.

```
real dimension(3,3) :: a=0.0
real dimension(3) :: b=0.0,c=0.0
write(*,*) 'Dimension-code test'
do i=1,3
 do j=1,3
  write(*,*) 'a(' ,i, ',' j, ')='
  read(*,*) a(i, j)
 end do
  write(*,*) 'b(' ,i, ')='
  read(*,*) b(i)
end do
do i=1,3
 do j=1,3
  c(i)=c(i)+a(i,j)*b(j)
 end do
end do
write(*,*) 'c:'(c(i),i=1,3)
stop
end
```

$$\begin{bmatrix} 1.0 & -1.0 & 2.0 \\ 4.0 & 1.0 & -2.0 \\ -3.0 & 2.0 & 1.0 \end{bmatrix} \begin{pmatrix} 1.0 \\ 2.0 \\ 3.0 \end{pmatrix} = \begin{pmatrix} 5.0 \\ 0.0 \\ 4.0 \end{pmatrix}$$

Exercise 4: Dimension command (Cont.)

When the input data are prescribed, the below codes are available.

```
real dimension(3,3)::a=reshape((/1.,4.,-3.,-1.,1.,2.,2.,-2.,1./),(/3,3/))
real dimension(3)::b=(/1., 2., 3./),c=0.0
write(*,*) 'Dimension-code test'
do i=1,3
 do j=1,3
  c(i)=c(i)+a(i,j)*b(j)
 end do
end do
write(*,*) 'c:'(c(i),i=1,3)
stop
end
```

$$\begin{bmatrix} 1.0 & -1.0 & 2.0 \\ 4.0 & 1.0 & -2.0 \\ -3.0 & 2.0 & 1.0 \end{bmatrix} \begin{pmatrix} 1.0 \\ 2.0 \\ 3.0 \end{pmatrix} = \begin{pmatrix} 5.0 \\ 0.0 \\ 4.0 \end{pmatrix}$$

Exercise 5: Data arrangement

The below codes are to arrange given data from disordered one to elder one.

```
real*8 dimension(21):: a
data a/-0.9,0.8,0.3,-0.5,-0.8,0.2,&
-0.4,0.6,-1.0,0.9,-0.7,1.0,0.0,0.5,&
-0.6,-0.3,0.7,-0.1,0.4,-0.2,0.1/
write(*,*) 'data arrangement test'
b=0.0
do i=1,20
 b=a(i)
 mx=i
 do j=i+1,21
  if (a(j)>b) then
   b=a(j)
   mx=j
  end if
 end do
 if (mx /= i) then
  a(mx)=a(i)
  a(i)=b
 end if
end do
do i=1,21
 write(*,'(A,I2,A,F6.3)') 'Rank',i,':',a(i)
end do
stop
end
```

Exercise 5: Data arrangement (Cont.)

Q3. Program the data arrangement codes in younger order.

Q4. Program the data arrangement codes to find its median and to calculate its average.

Exercise 2: Data Analysis of GCM Data, Historical Data

Kenji TANAKA *(Water Resources Research Center, DPRI, Kyoto University)*

Global/Regional climate model (GCM/RCM) might be indispensable on predicting detailed climate change. Although GCMs/RCMs have accomplished remarkable development in recent years, the requirement from user side on the resolution and the accuracy has been increasing more and more. Thus, there is still a gap between precision realized by models and that required from users.

This exercise aims to introduce the method for detecting and correcting the bias information of GCMs/RCMs. A new bias correction method that can reproduce the extreme values while keeping the monthly mean value was developed. This system is designed to be general so that it can easily fit the difference of grid coordinate or change in model setting.

From the location of observation station and model grids, corresponding model grid is decided for each station where historical data are available. When there are more than two observation stations for one grid, average of these available data is used for evaluation.

The results of monthly mean bias show that the model bias varies greatly in time and space. Many cases can be found from the results that even though the model bias is small enough in monthly mean value, the shape of frequency distribution might be so different.

23rd IHP Training Course(2013/12/5)

Data analysis of GCM data, historical Data

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Back ground

Recently, a sense of impending crisis for the global warming came to be realized.
Social needs for the concrete description of future climate has been increasing.

Although RCMs have accomplished remarkable development in recent years, the requirement from user side on the resolution and the accuracy has been increasing more and more for detailed assessment of climate change impact.

Thus, there is still a gap between precision realized by models and that required from users.

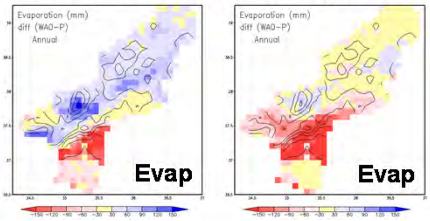
Importance of feedback process between data user and modeler

RCM output v1 → Bias detection → RCM output v2 → Bias detection → RCM output v3 → Bias detection & correction

Through the exchange of bias information, RCM is tuned or updated. Then, model bias of the next product will be reduced.

Effect of bias correction on the climate change impact assessment (from ICCAP)

No correction | Bias corrected



Result of climate change signal can be opposite when raw RCM output has large bias, suggesting the importance of bias correction for climate change impact assessment.

Before bias correction

Unit(mm)	Prec	Evap	Runoff	Irrig
Present	1189.6	456.8	804.3	61.4
Warm-up	897.0	481.1	503.1	73.4
Diff(W-P)	-292.6	+24.3	-301.2	+12.0

After bias correction

Unit(mm)	Prec	Evap	Runoff	Irrig
Present	634.0	411.3	281.5	53.8
Warm-up	464.3	373.9	168.9	69.7
Diff(W-P)	-169.7	-37.4	-112.6	+15.9

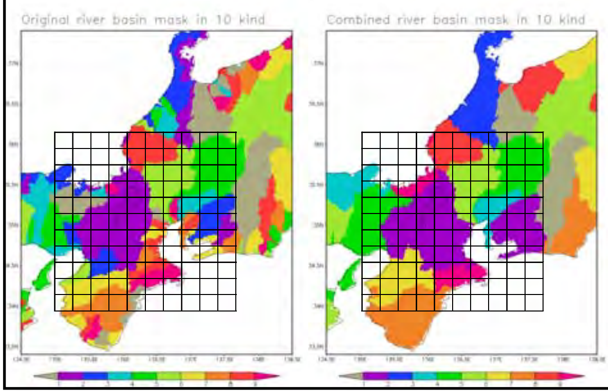
Providing bias information of GCM/RCM output

- Bias evaluation for each prefecture / river basin unit
- Not only mean value, but also frequency distribution
- Designed to be general so that it can easily fit the difference of grid coordinate or change in model setting
- Items to be evaluated (forcing variables for Land Surface Hydrological model)
  Prec, Tair, Eair, SWdown, LWdown, Wind, Psfc

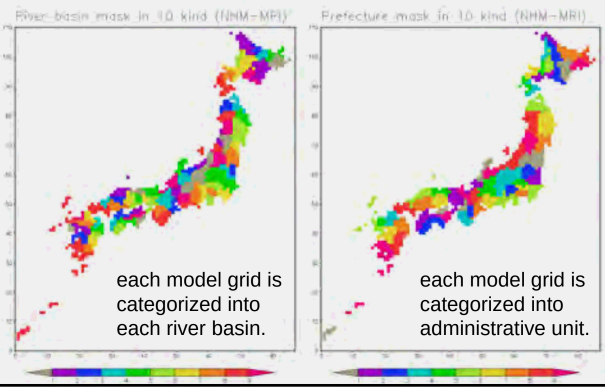
Procedure of bias correction

1. Creation of river basin mask and administration mask (basmask1.f)
2. Finding corresponding grid for each observation station
3. Re-ordering model output
4. Detection of model mean bias, calculating frequency distribution
5. Bias correction considering frequency distribution

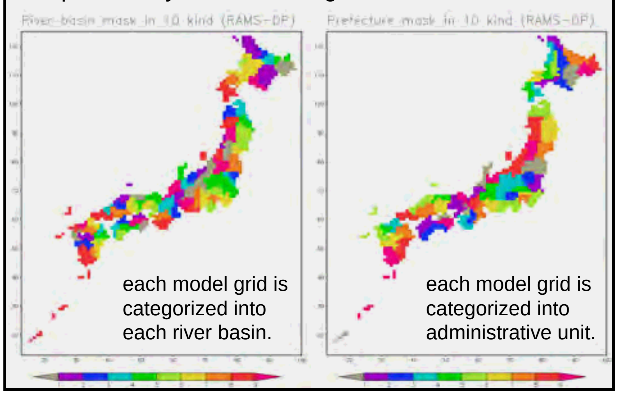
Original Watershed code   Combined Watershed



River basin mask and prefecture mask expressed by MRI-NHM grids



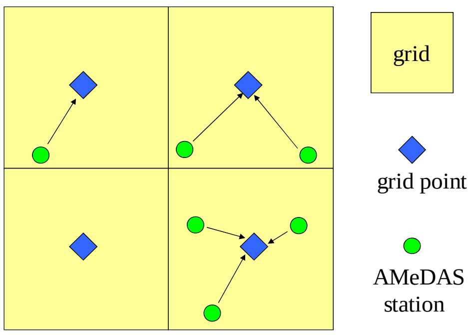
River basin mask and prefecture mask expressed by NIED-RAMS grids



Procedure of bias correction

1. Creation of river basin mask and prefecture mask
2. Finding corresponding grid for each observation station
3. Re-ordering model output
4. Detection of model mean bias, calculating frequency distribution
5. Bias correction considering frequency distribution

Finding corresponding grid

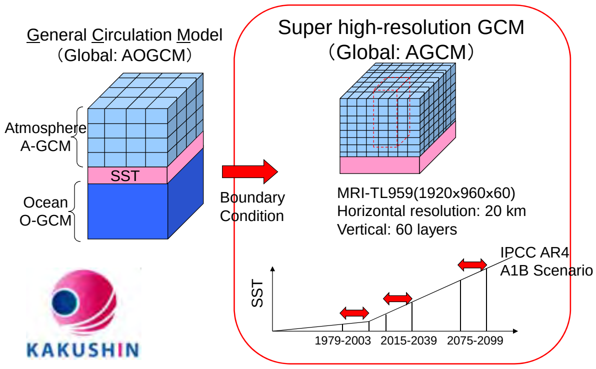


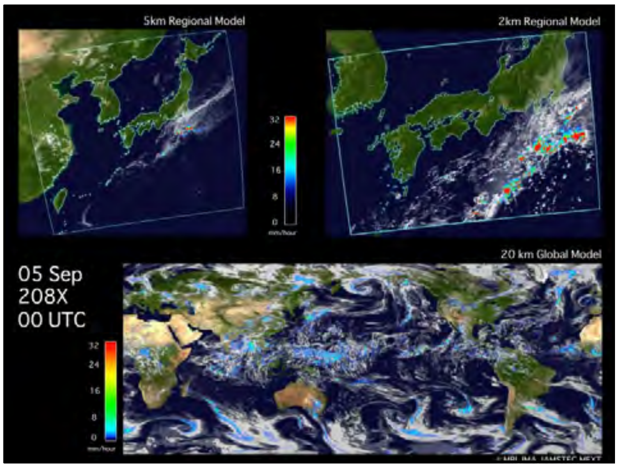
Available 20km model output

Organization	model	version	name (fmod)	period
MRI	NHM	Ver2	NHMMRI2	20yr (1985-2004)
NIED	RAMS	Ver1	RAMSDP1	29yr (1979-2007)
Tsukuba Univ.	RAMS	Ver1	RAMSTU1	20yr (1985-2004)
Tsukuba Univ.	WRF	Ver1	WRF-TU1	20yr (1985-2004)
MRI	GCM		GCM20km	25yr (1979-2003)

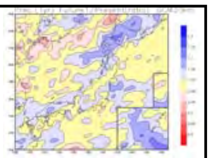
name	mx	my	mr	mp	im	iamax
NHMMRI1	105	115	60	60	54	1076
NHMMRI2	131	121	61	60	49	1047
RAMSDP0	130	140	62	60	57	1094
RAMSDP1	128	144	62	60	57	1094
RAMSTU0	130	140	62	60	57	1094
RAMSTU1	130	140	62	60	57	1094
WRF-TU1	129	139	56	60	47	958
GCM20km	163	162	67	60	69	1275

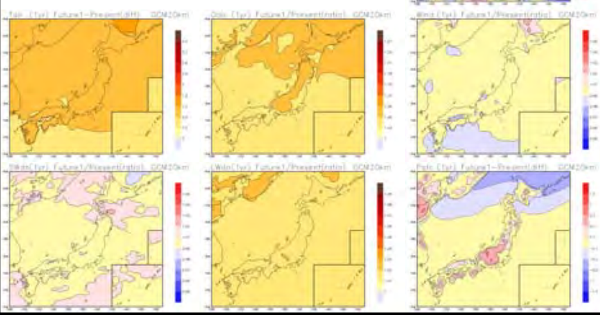
Detecting hydrological impact using super-high resolution GCM



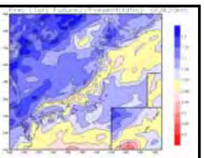


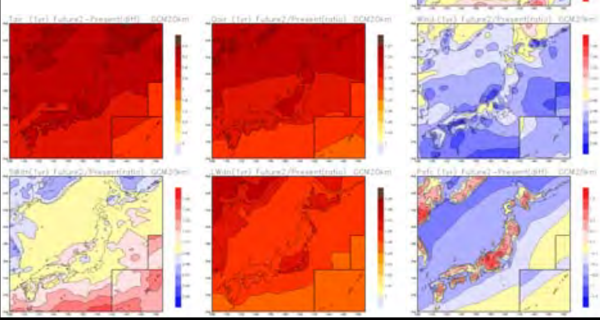
Difference(ratio) between Near future and present





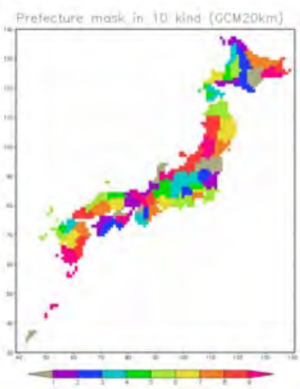
Difference(ratio) between End of 21st C and present





Bias detection/correction for each prefecture unit

1	Souya	宗谷支庁	31	Fukui	福井
2	Kamikawa	上川支庁	32	Yamanashi	山梨
3	Rumoi	留萌支庁	33	Nagano	長野
4	Ishikari	石狩支庁	34	Gifu	岐阜
5	Sorachi	空知支庁	35	Shizuoka	静岡
6	Shiribeshi	後志支庁	36	Aichi	愛知
7	Abashiri	網走支庁	37	Mie	三重
8	Nemuro	根室支庁	38	Shiga	滋賀
9	Kushiro	釧路支庁	39	Kyoto	京都
10	Tokachi	十勝支庁	40	Osaka	大阪
11	Iburi	胆振支庁	41	Hyogo	兵庫
12	Hidaka	日高支庁	42	Nara	奈良
13	Oshima	渡島支庁	43	Wakayama	和歌山
14	Hiyama	檜山支庁	44	Tottori	鳥取
15	Aomori	青森	45	Shimane	島根
16	Iwate	岩手	46	Okayama	岡山
17	Miyagi	宮城	47	Hiroshima	広島
18	Akita	秋田	48	Yamaguchi	山口
19	Yamagata	山形	49	Tokushima	徳島
20	Fukushima	福島	50	Kagawa	香川
21	Ibaraki	茨城	51	Ehime	愛媛
22	Tochigi	栃木	52	Kochi	高知
23	Gunma	群馬	53	Fukuoka	福岡
24	Saitama	埼玉	54	Saga	佐賀
25	Chiba	千葉	55	Nagasaki	長崎
26	Tokyo	東京	56	Kumamoto	熊本
27	Kanagawa	神奈川	57	Oita	大分
28	Niigata	新潟	58	Miyazaki	宮崎
29	Toyama	富山	59	Kagoshima	鹿児島
30	Ishikawa	石川	60	Okinawa	沖縄

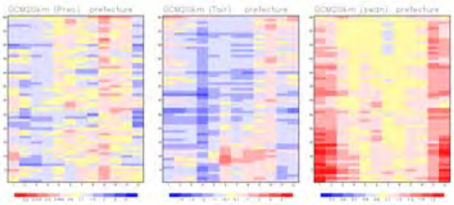
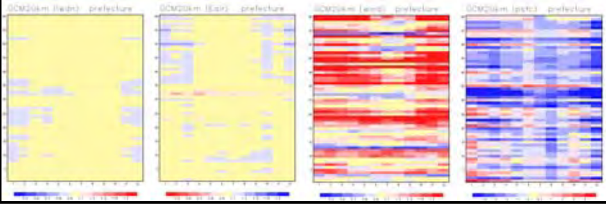


Bias correction system was developed in S-5-3 project (MOE fund)

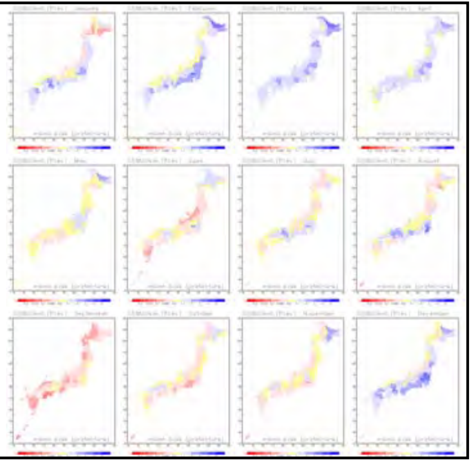
Model bias of 7 surface meteorological elements

Observation:
SDP, AMeDAS

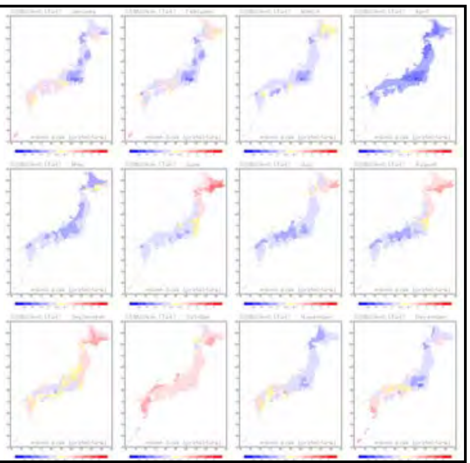
X: month
Y: prefecture

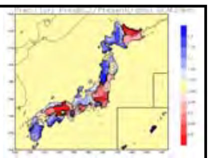
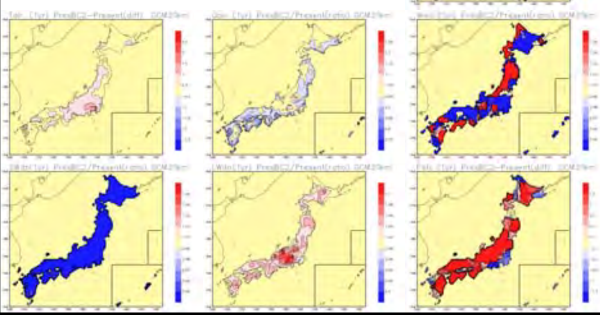
Prec



Tair

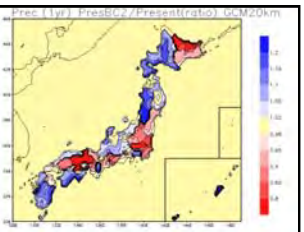


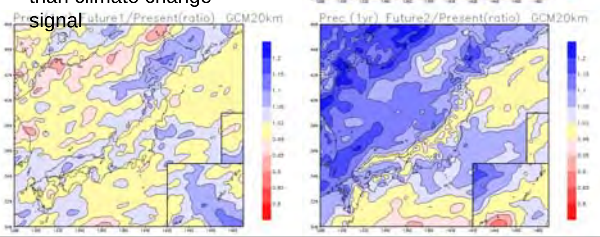
Difference(ratio) between Bias corrected and raw output

Bias Corrected / raw GCM
Near future / Present
End of 21st C / Present

bias corrected amount is comparable or even larger than climate change signal





New algorithm for adjustment of frequency distribution

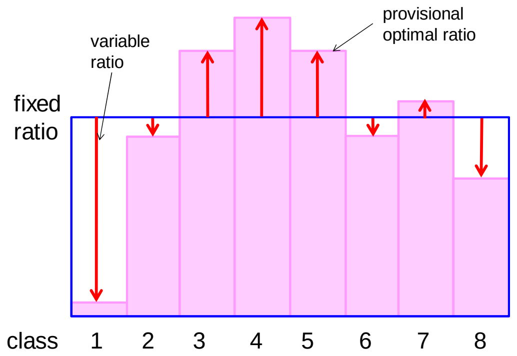
- every 1hr data are classified for each month
  8 class (Prec) / 10 class (Tair)
- 2 steps correction

Temporal correction with fixed ratio — Monthly mean value

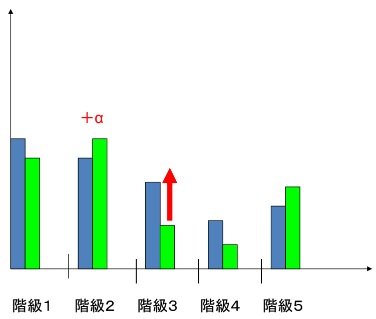
↓

Adjustment of correction factor for each class — Frequency distribution

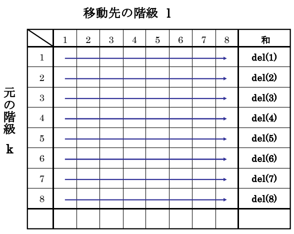
fixed ratio and variable ratio

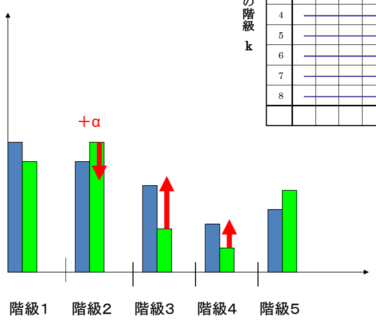


Store（α,i,j)　: change of class j amount due to the change of correction factor of class i by α



delS(α,i) : total change due to the change of correction factor of class i by α



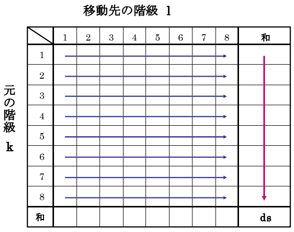


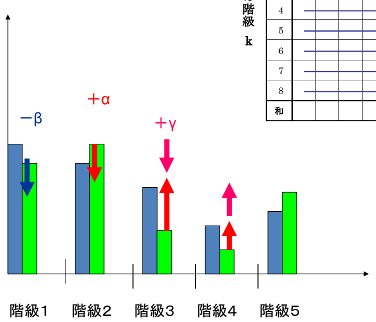
Example of Store(α,i,j), delS(α,i)

1	−0.14	−80.68	0	0	0	0	0	0	0	−80.68
2	−0.14	55.43	−118.42	0	0	0	0	0	0	−62.99
3	−0.14	0	141.69	−302.68	0	0	0	0	0	−161
4	−0.14	0	0	−17.17	−27.84	0	0	0	0	−45
5	−0.14	0	0	0	−18.38	0	0	0	0	−18.38
6	−0.14	0	0	0	16.61	−20.76	0	0	0	−4.15
7	−0.14	0	0	0	0	0	0	0	0	0
8	−0.14	0	0	0	0	0	0	0	0	0

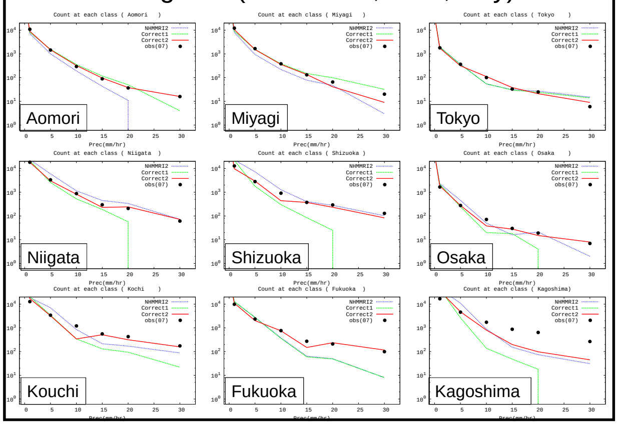
1	0.14	80.68	0	0	0	0	0	0	0	80.68
2	0.14	−76.28	139.27	0	0	0	0	0	0	62.99
3	0.14	0	−100.84	261.84	0	0	0	0	0	161
4	0.14	0	0	−63.31	108.31	0	0	0	0	45
5	0.14	0	0	0	−36.19	54.58	0	0	0	18.38
6	0.14	0	0	0	0	4.15	0	0	0	4.15
7	0.14	0	0	0	0	0	0	0	0	0
8	0.14	0	0	0	0	0	0	0	0	0

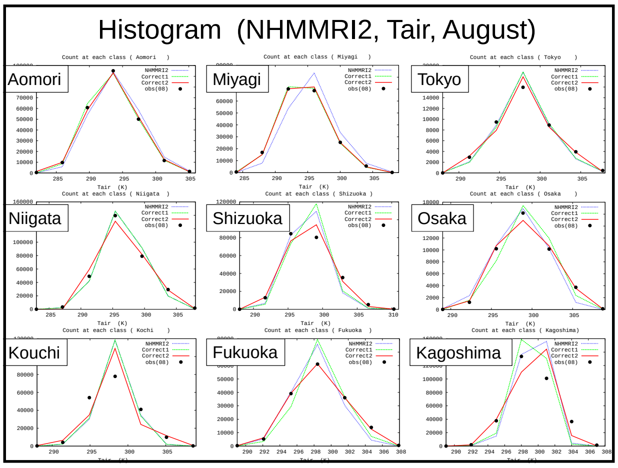
Finding the best combination of variable ratio while keeping monthly mean value

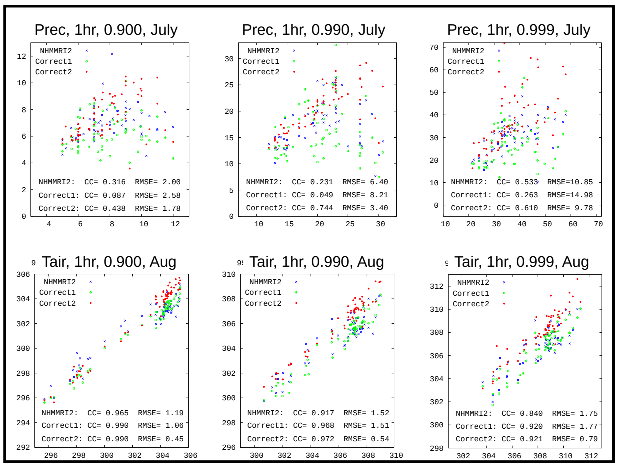


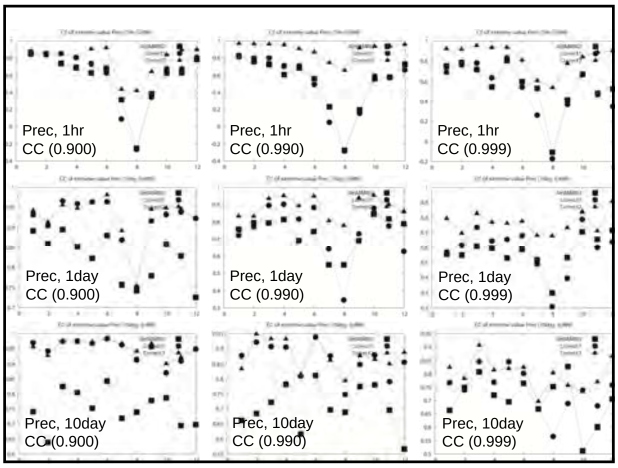


Histogram (NHMMRI2, Prec, July)









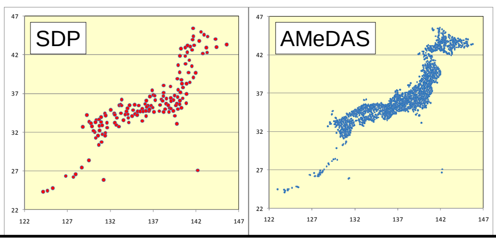
Program and Data list

GSI/basmask1.f
basinareaMODEL.txt
prefecareaMODEL.txt
gridriverMODEL.gad
gridprefecMODEL.gad
table-riverMODEL.txt
table-prefec.txt
AMEDAS/amedas1hrYYYY.gad
addramd.txt
SDP/sdp1hrYYYY.gad
addrsdp.txt
Work/MODEL/stnmatch3.f
readmodel.f
biaspdfvar3.f
PARAMV.txt (V=P,T,S,…)
VDIM3.txt
orgMODEL.txt
adpame/VARMODELYYYYA.gad (VAR=Prec, Tair, swdn,…A=r,p)
corect/gnuVAR/weightMMA.txt (MM=01～12, A=r,p)
biaspdfMM-NNA.txt (MM=01～12, NN=01-60, A=r,p)

Available surface meteorological observation

- SDP (meteorological observatory) 155stations
  items: Psfc, Psea, Tair, Eair, RH, Wdir, Wind, cloud, weather, Tdew, SShr, SWdown, Prec

- AMeDAS (Automatic weather station) ～1600stations
  items: Prec, Tair, SShr, Wdir, Wind



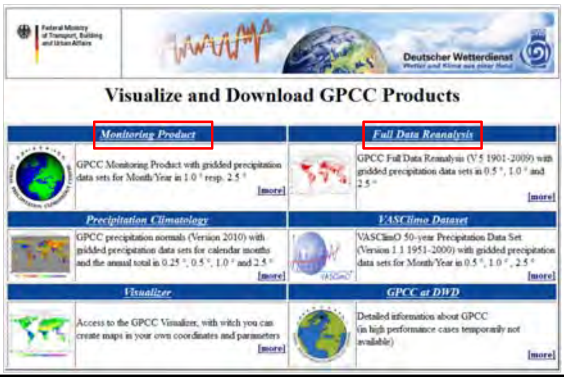
In-situ measurement is not enough?

Let's use global products!

It's free!

GPCC (Global Precipitation Climatology Center)

ftp://ftp.dwd.de/pub/data/gpcc/html/Gate_to_the_GPCC_Products.html

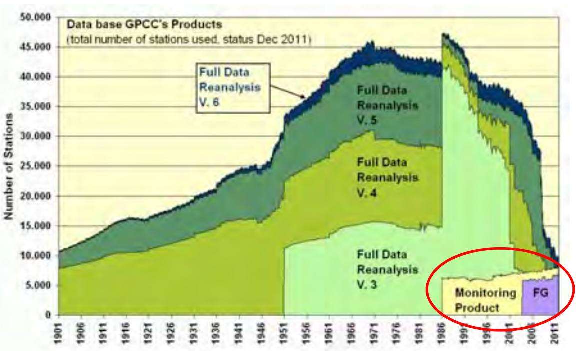


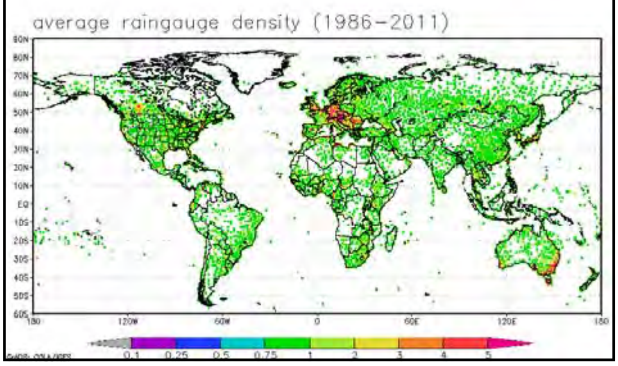
Download page for Monitoring Product

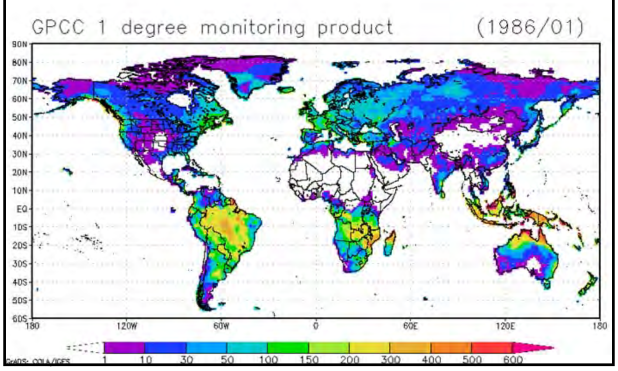
Monitoring Product for Month/Year	1.0 ° (.zip)	2.5 ° (.zip)
01-12 1986 (archive)	download	download
01-12 1987 (archive)	download	download
01-12 1988 (archive)	download	download
01-12 1989 (archive)	download	download
01-12 1990 (archive)	download	download
01-12 1991 (archive)	download	download
01-12 1992 (archive)	download	download
01-12 1993 (archive)	download	download
01-12 1994 (archive)	download	download
01-12 1995 (archive)	download	download
01-12 1996 (archive)	download	download

Download page for Full Data Reanalysis

Full Data Reanalysis for 10 years	0.5 ° (.zip ~ 55 MByte)	1.0 ° (.zip ~ 15 MByte)	2.5 ° (.zip ~ 3 MByte)
01.1901 - 12.1910 (archive)	download	download	download
01.1911 - 12.1920 (archive)	download	download	download
01.1921 - 12.1930 (archive)	download	download	download
01.1931 - 12.1940 (archive)	download	download	download
01.1941 - 12.1950 (archive)	download	download	download
01.1951 - 12.1960 (archive)	download	download	download
01.1961 - 12.1970 (archive)	download	download	download
01.1971 - 12.1980 (archive)	download	download	download
01.1981 - 12.1990 (archive)	download	download	download
01.1991 - 12.2000 (archive)	download	download	download
01.2001 - 12.2009 (archive)	download	download	download





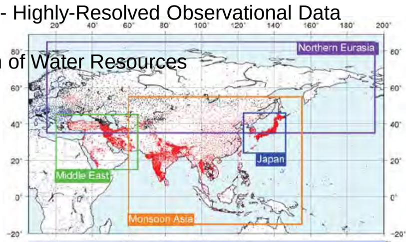


APHRODITE

(http://www.chikyu.ac.jp/precip/index.html)

Asian Precipitation - Highly-Resolved Observational Data Integration

Towards Evaluation of Water Resources



Current version: V1101 Download »Readme

Name	Domain	Resolution	Period
Monsoon Asia (MA) (Yatagai et al. 2011)	60°E-155°E, 15°S-55°N	0.5° and 0.25°, daily	1951-2007
Middle East (ME) (Yatagai et al. 2011)	20°E-65°E, 15°N-45°N		
Russia (RU) (Yatagai et al. 2011)	15°E-165°W, 34°N-84°N		

Procedure of data analysis

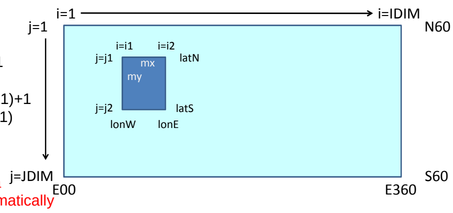
Step0: unpack the data (gzipped file)
Step1: select the region for analysis (GSMaP)
(GSMAP/daily/cutgsmap.f)
Step2: select the region for analysis (GPCC)
(GSMAP/daily/cutgpcc.f)
Step3: calculate climatological value and correction factor
(GSMAP/daily/climanal.f)
Step4: select the region for analysis (gsmap hourly)
(GSMAP/hourly/cutgsmap.f)
Step5: change resolution to fit to the model grid
(GSMAP/hourly/chgres.f)
Step6: bias correction of GSMaP by GPCC climatology
(GSMAP/hourly/bcgsmap.f)
Step7: re-ordering the data for HydroBEAM (2D → 1D)
(GSMAP/hourly/hbinput.f)

Step1: select the region for analysis (GSMaP) (GSMAP/daily/cutgsmap.f)

```
parameter(IDIM=3600, JDIM=1200)
parameter(latN=35.,latS=-5.,lonW=20.,lonE=45.)  Set the analysis region

i1=int(lonW/0.1)+1
i2=int(lonE/0.1)
j1=int((60.-latN)/0.1)+1
j2=int((60.-latS)/0.1)
mx=i2-i1+1
my=j2-j1+1
```

Size of target area
Is calculated automatically




```
do iy=2000,2010     loop for year
write(cy,'(i4.4)') iy     write the year information in cy
open(22,file='NILE/GSMAP-Nile-1mon'//cy//'.gad'
,form='unformatted',access='direct',recl=mx*my*4)
```

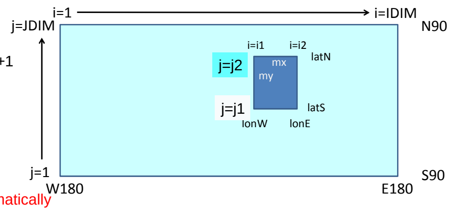
Use cy (year information) in file name automatically

Step2: select the region for analysis (GPCC) (GSMAP/daily/cutgpcc.f)

```
parameter(IDIM=360, JDIM=180)
parameter(latN=35.,latS=-5.,lonW=20.,lonE=45.)  Set the analysis region

i1=int(lonW+180.)+1
i2=int(lonE+180.)
j1=int(latS+90.)+1
j2=int(latN+90.)
mx=i2-i1+1
my=j2-j1+1
```

Size of target area
Is calculated automatically

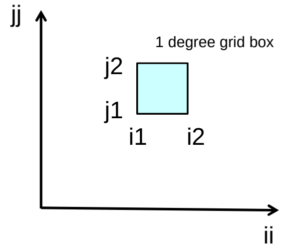



```
do iy=1986,2011     loop for year
write(cy,'(i4.4)') iy     write the year information in cy
open(22,file='NILE/GPCC-Nile-1mon'//cy//'.gad'
,form='unformatted',access='direct',recl=mx*my*4)
```

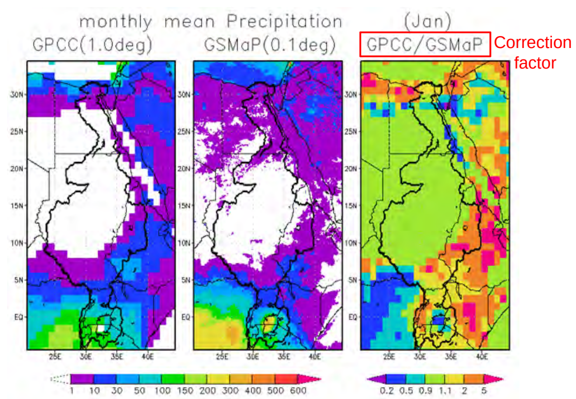
Use cy (year information) in file name automatically

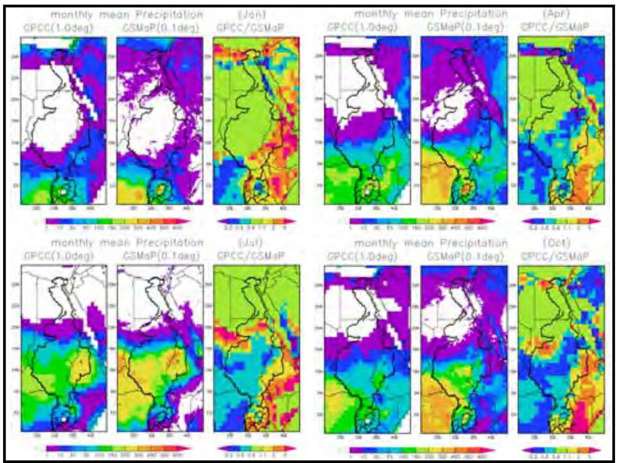
Step3: calculate climatological value and correction fac (GSMAP/daily/climanal.f)

```
do ii=1,mx
do jj=1,my          loop for 1 degree data
i1=(ii-1)*10+1
i2=ii*10
j1=(jj-1)*10+1
j2=jj*10
bias(ii,jj,imon)=1.
avevar(ii,jj)=0.     Initialization for averaging
icon2=0
do i=i1,i2          loop for 0.1 degree data
do j=j1,j2
if(clim2(i,j,imon).ge.0.) then
avevar(ii,jj)=avevar(ii,jj)+clim2(i,j,imon)
icon2=icon2+1
endif
enddo
enddo
avevar(ii,jj)=avevar(ii,jj)/real(icon2)   calculate 1 degree average value
if(avevar(ii,jj).ge.1..and.clim1(ii,jj,imon).ge.1.)
bias(ii,jj,imon)=clim1(ii,jj,imon)/avevar(ii,jj)  Correction factor (GPCC/GSMaP)
```



Comparison of monthly mean precipitation





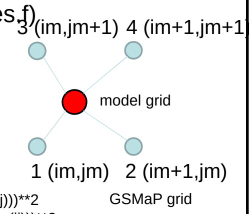
Step5: change resolution to fit to the model grid

(GSMAP/hourly/chgres.f)

```
parameter(mx1=250, my1=400)     GSMaP grid
parameter(mx2=150, my2=240)     model grid

do ii=1,mx2          data matching
im(ii)=nint((xlon2(ii)-lonW-0.5*res1)/res1)+1
enddo
do jj=1,my2
jm(jj)=nint((xlat2(jj)-latS-0.5*res1)/res1)+1
enddo

dis1=(xlon2(ii)-xlon1(im(ii)))**2+(xlat2(jj)-xlat1(jm(jj)))**2
dis2=(xlon2(ii)-xlon1(im(ii)+1))**2+(xlat2(jj)-xlat1(jm(jj)))**2
dis3=(xlon2(ii)-xlon1(im(ii)))**2+(xlat2(jj)-xlat1(jm(jj)+1))**2     distance x distance
dis4=(xlon2(ii)-xlon1(im(ii)+1))**2+(xlat2(jj)-
xlat1(jm(jj)+1))**2
www=1./dis1+1./dis2+1./dis3+1./dis4
weight(ii,jj,1)=1./(dis1*www)        weight for interpolation
weight(ii,jj,2)=1./(dis2*www)        Total weight should be 1
weight(ii,jj,3)=1./(dis3*www)
weight(ii,jj,4)=1./(dis4*www)
```

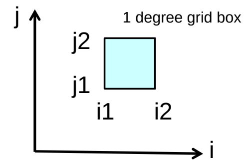


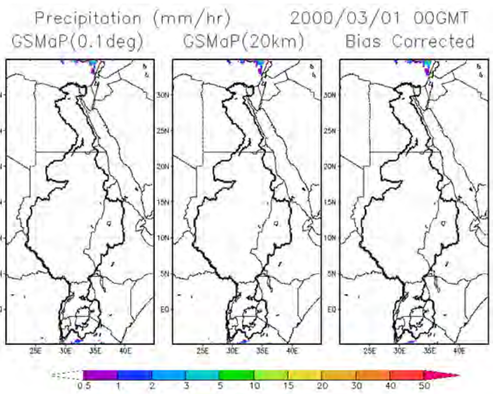
Step6: bias correction of GSMaP by GPCC climatology

(GSMAP/hourly/bcgsmap.f)

```
parameter(mx1=25, my1=40)       correction factor (1 degree)
parameter(mx2=150, my2=240)     model grid (1/6 degree)

do imon=1,12
read(11,rec=imon) ((bias(i,j,imon),i=1,mx1),j=1,my1)     reading correction factor
do i=1,mx1
do j=1,my1          loop for 1 degree data
i1=(i-1)*iave+1
i2=i*iave
j1=(j-1)*iave+1
j2=j*iave
do ii=i1,i2         loop for model grid
do jj=j1,j2          (1/6 degree data)
bias2(ii,jj,imon)=bias(i,j,imon)
if(bias2(ii,jj,imon).gt.5.0) bias2(ii,jj,imon)=5.0
if(bias2(ii,jj,imon).lt.0.2) bias2(ii,jj,imon)=0.2
```





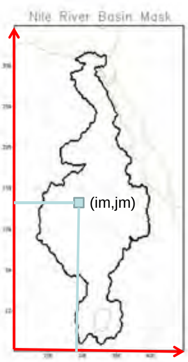
Step7: re-ordering the data for HydroBEAM (2D → 1D)

(GSMAP/hourly/h

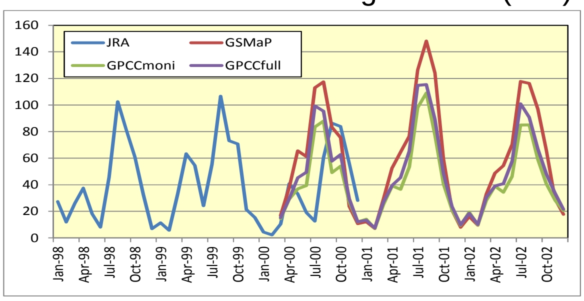
```
parameter(mx=150, my=240, nmax=9846)

do ii=1,nmax        loop for HB grid
read(11,*) i1,i2,clon,clat,zzz
im(ii)=nint((clon-lonW-0.5*res)/res)+1
jm(ii)=nint((clat-latS-0.5*res)/res)+1
mask(im(ii),jm(ii))=1.
topo(im(ii),jm(ii))=zzz
enddo
```

Finding the grid number (im,jm) in 2-D dataset



Nile River Basin average rainfall (mm)



JRA: JRA reanalysis (Prof.Sato)
GSMaP: GSMaP (raw data)
GPCCmoni: GSMaP corrected by GPCC monitoring product
GPCCfull: GSMaP corrected by GPCC full analysis

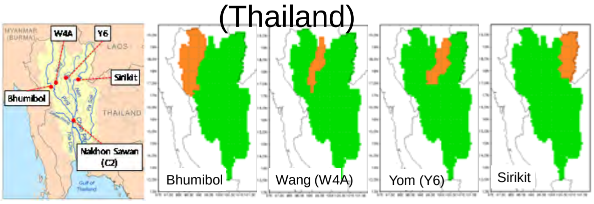
At this moment, we cannot say which product is better.
Quality of input rainfall data should be evaluated by

1. Collecting more rain gauge data
   (some rain gauge information are not opened to research community)

2. Collecting river discharge (dam inflow) data
   (check water balance of each sub-catchment)

Quality of input rainfall data is the base of water resources analysis. In the area where evapotranspiration
is dominant in water balance component, just a small

Example in Chao-Phraya river (Thailand)



	Product A				Product B			
	Prec	Evap	Runoff	Obs	Prec	Evap	Runoff	Obs
Nakhon Sawan	1005	892	113	182	1144	949	195	182
Bhumibol	989	884	105	180	1101	933	168	180
Sirikit	1086	977	109	322	1246	1037	209	322
Y.6 (Yom)	992	884	108	184	1164	962	202	184
W.4A (Wang)	935	832	103	88	1101	912	189	88

10% difference in rainfall results in 50 – 100% difference in runo

GrADS

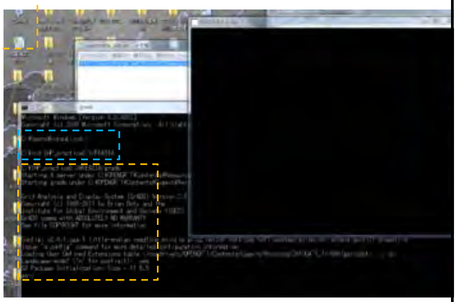
- The Grid Analysis and Display System (GrADS)
  - Free Software to display 2 Dimensional data
- Install
  - *Activate* :grads-2.0.1.oga.1-win32_superpack.exe

    memory This installer is included in USB flash (GSMAP/grads/)
  - Source : http://sourceforge.net/projects/opengrads/files/

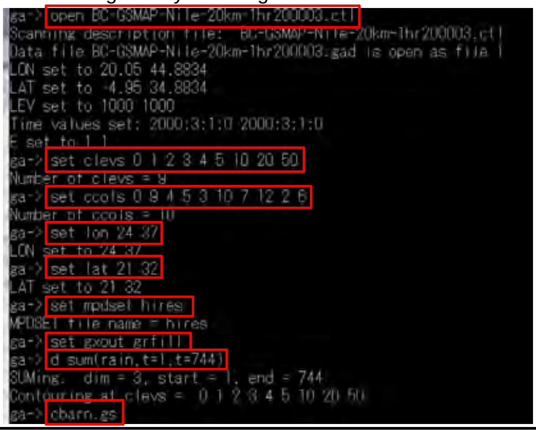
    grads2: OpenGrADS Bundle Distribution (Windows/Mac/Linux/Unix)

How to use "Grads" ?

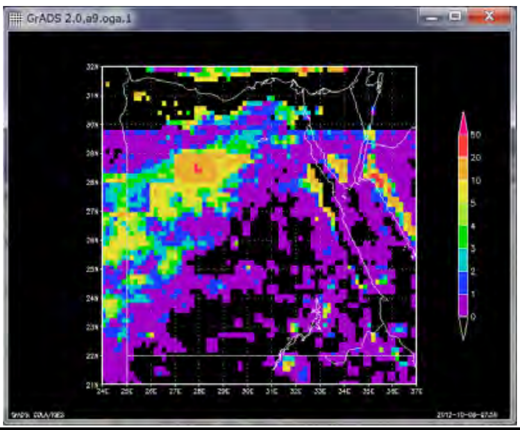
1. *Activate*: Command Prompt
   - All programs/accessory/command_prompt.exe
2. *Change Directory* to C:¥GSMAP/hourly/NILE/
3. *Activate*: Grads
   - Grads
   - yes



Please test grads by following command



```
ga-> open BC-GSMAP-Nile-20km-1hr200003.ctl
Scanning description file:  BC-GSMAP-Nile-20km-1hr200003.ctl
Data file BC-GSMAP-Nile-20km-1hr200003.gad is open as file 1
LON set to 20.05 44.8834
LAT set to -4.95 34.8834
LEV set to 1000 1000
Time values set: 2000:3:1:0 2000:3:1:0
E set to 1 1
ga-> set clevs 0 1 2 3 4 5 10 20 50
Number of clevs = 9
ga-> set ccols 0 9 4 5 3 10 7 12 2 6
Number of ccols = 10
ga-> set lon 24 37
LON set to 24 37
ga-> set lat 21 32
LAT set to 21 32
ga-> set mpdset hires
MPDSET file name = hires
ga-> set gxout grfill
ga-> d sum(rain,t=1,t=744)
SUMing.  dim = 3, start = 1, end = 744
Contouring at clevs =  0 1 2 3 4 5 10 20 50
ga-> cbarn.gs
```



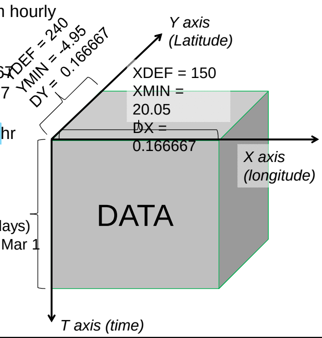
Data description file (ctl file)

Ex. BC-GSMAP-Nile-20km-1hr200003.ctl

DSET ^BC-GSMAP-Nile-20km-1hr200003.gad Data file name
TITLE bias corrected GSMaP 20km hourly
UNDEF -9999.9 Undefined value
OPTIONS LITTLE_ENDIAN
XDEF 150 LINEAR 20.05 0.166667
YDEF 240 LINEAR -4.95 0.166667
zdef 1 levels 1000
tdef 744 linear 00:00z01mar2000 1hr
VARS 1 Number of variables
rain 0 99 hourly precip(mm/hr)
ENDVARS

Variable name

Tdef = 744
(24 hours x 31 days)
Start from 2000 Mar 1



Exercise 3: River Basin Modelling
Exercise 4: Impact Assessment by Hydrological Model

Yoshinobu SATO *(Water Resources Research Center, DPRI, Kyoto University)*

In this exercise 3 and 4, you will learn how to operate a distributed hydrological model (Hydro-BEAM) for the impact assessment on flood disasters, water resources management and the river ecosystems under changing climate. At first, we have to create a river basin model as an input variable for the hydrological mode using a river basin modeling tools. We will use elevation, basin boundary, channel position and land use dataset. Then, we will prepare the precipitation dataset for the input data for the runoff simulation. In the data preparation, the inverse distance weighting (IDW) method will be used for data interpolation. By using several data preparation tools, we can run a distributed hydrological model called Hydro-BEAM (**Hydro**logical river **B**asin **E**nvironment **A**ssessment **M**odel) applied for the Yodo River basin.

All the dataset and the program source code for the analysis will be provided by the USB memory stick. All the program source codes are written by 'gFortran (.f90)'. So, you have to install gFortran compiler in your PC. The compatibility of other Fortran compiler (such as g77) will not support in this exercise except for the TDM-GCC 64bit version (tdm64-gcc-4.8.1) gfortran. Thus, all the participants who want to use the River basin modeling tools, the data preparation tools, and the distributed hydrological model (Hydro-BEAM), are requested to bring your own windows based PC (Windows 7 is recommended) with gfortran compiler is installed. (Microsoft Excel is also used for output data analysis)

The free gfortran complier can be obtained from "http://tdm-gcc.tdragon.net/download".

In this exercise, we will create the Yodo River basin with the 1km resolution. For the runoff analysis, we will use 114 rain gage station's data (hourly data) from 14 - 20 Sep, 2013 during the period of Typhoon No.18. Then, we will run the Hydro-BEAM and check the simulation results with observation data at several points of the Yodo River basin. Then, we will discuss about how to modify or improve our simulation results through the parameter calibration. Furthermore, the results obtained in this exercise will be linked with the Exercise 5 (Impact assessment by ecological model).

Ex. 3：River basin modeling

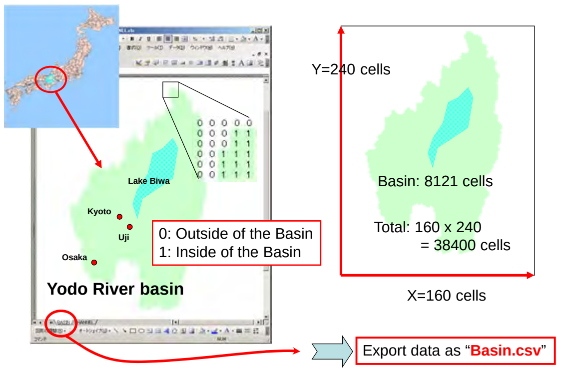
Yoshinobu Sato

Water Resources Research Center

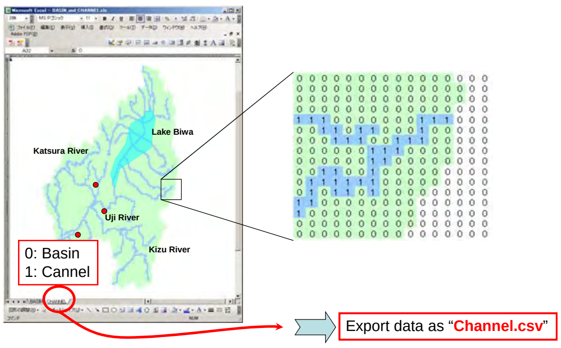
Disaster Prevention Research Institute

Kyoto University

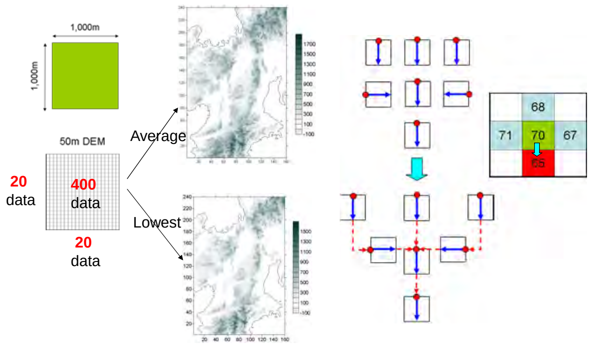
1.Create River Basin Cells



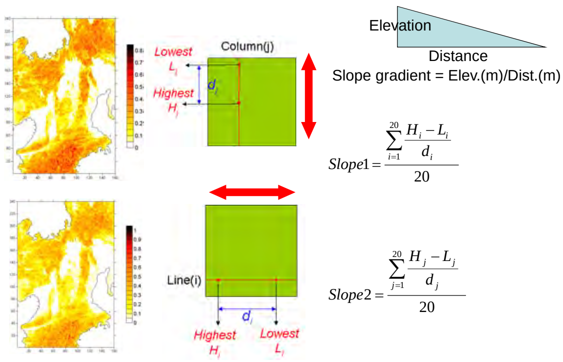
2.Select Major Channel Cells



3.Preparation Elevation data



4.Preparation of Slope data

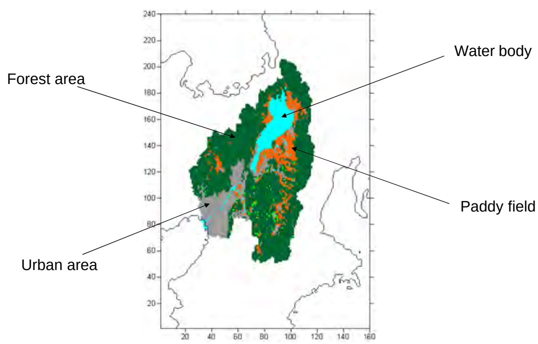


Slope gradient = Elev.(m)/Dist.(m)

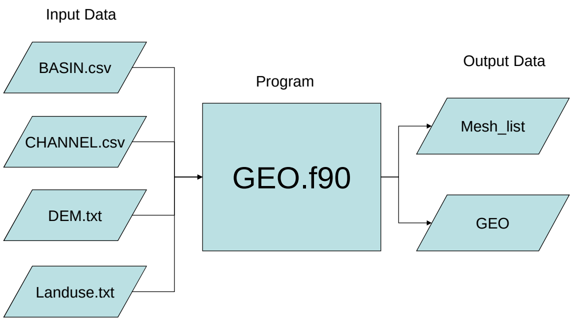
$$Slope1 = \frac{\sum_{i=1}^{20} \frac{H_i - L_i}{d_i}}{20}$$

$$Slope2 = \frac{\sum_{j=1}^{20} \frac{H_j - L_j}{d_j}}{20}$$

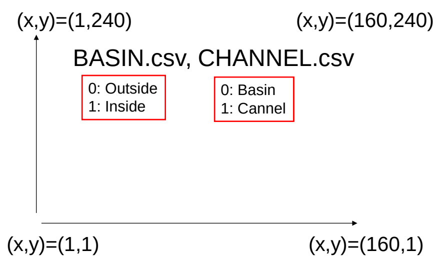
5. Land use type data



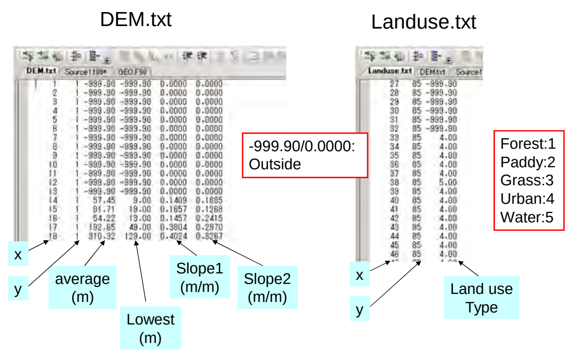
6. River Basin Modeling



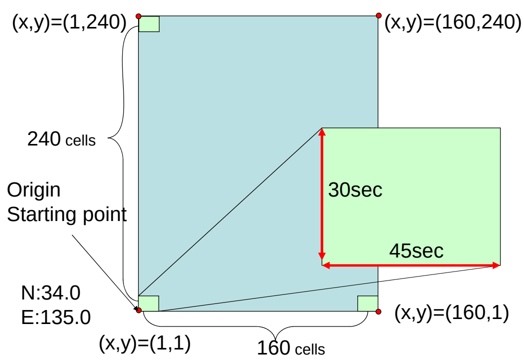
7. Data Format (1)



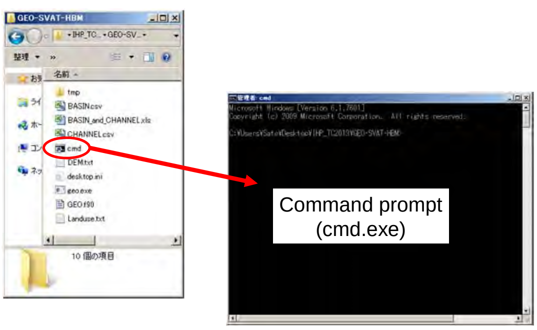
8. Data Format (2)



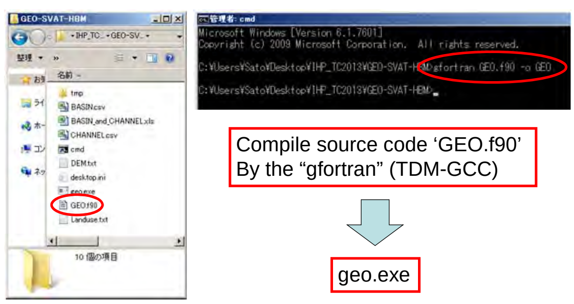
9. Coordination System



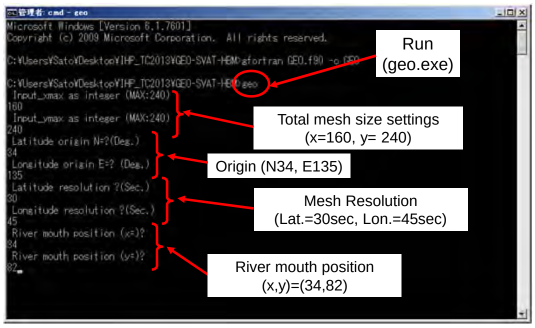
10. Execution Procedure 1



11. Execution Procedure 2

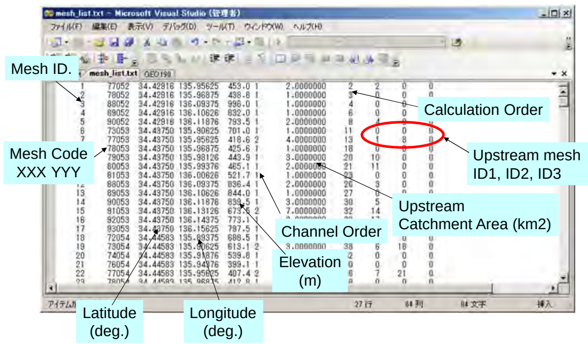


12. Execution Procedure 3



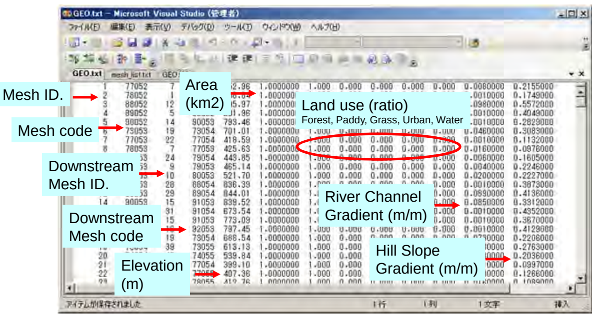
13. Data Format (3)

Mesh_list.txt

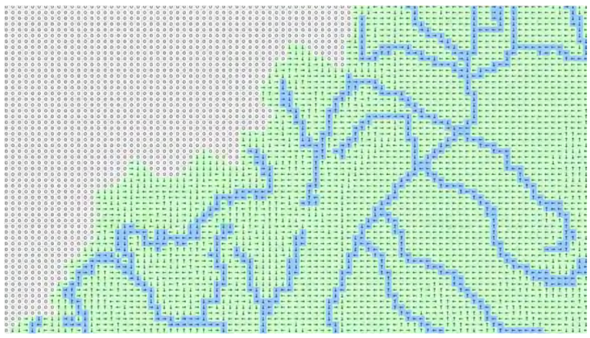


14. Data Format (4)

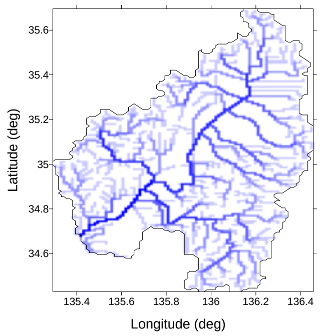
GEO.txt



15. Flow Direction Map



16. Channel Network



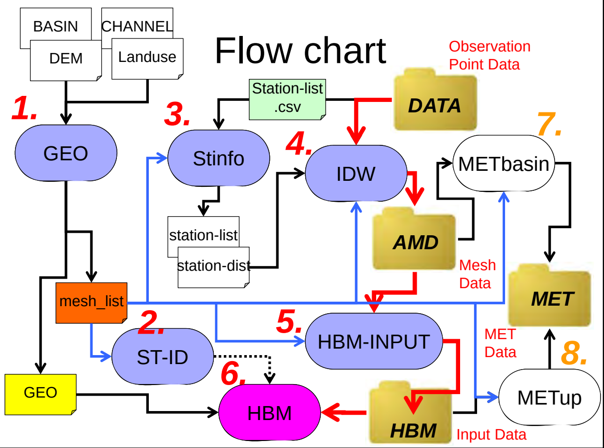
17. Summary (Basin Modeling)

- River channel runs through the **mesh lowest elevation**
- direction type: **4 direction**
- flow direction: **Steepest slope**
- Follow the actual river channel position
- Depression is corrected automatically by changing mesh elevation
  (at least 1m higher than the adjacent mesh)

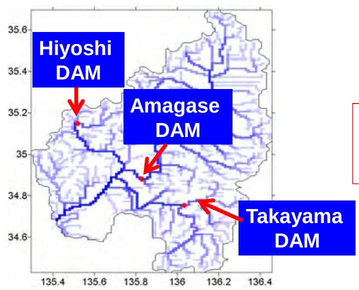
Ex. 4：Impact Assessment by hydrological model

Yoshinobu Sato
Water Resources Research Center
Disaster Prevention Research Institute
Kyoto University

Flow chart



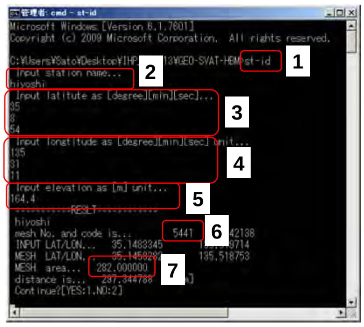
ST-ID (Station ID)



Mesh_list.txt

Hiyoshi : 5441
Amagase: 2732
Takayama: 1612

ST-ID.f90/exe



1. Run st-id.exe
2. Input station name "hiyoshi"
3. Input latitude "35/8/54"(d:m:s)
4.Input longitude "135/31/11"(d:m:s)
5.Input elevation "164.4"(m)

6. Mesh ID
5441
7. Catchment Area
282 km2

Practice

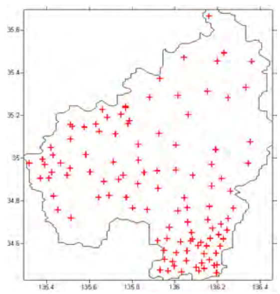
- Obtain mesh ID of the Amagase and Takayama Dam using ST-ID.
- Amagase Dam

Lat:34/52/47, Lon:135/49/04, Alt: 58m

- Takatama Dam

Lat:34/45/11, Lon: 136/02/00, Alt: 104m

Data preparation



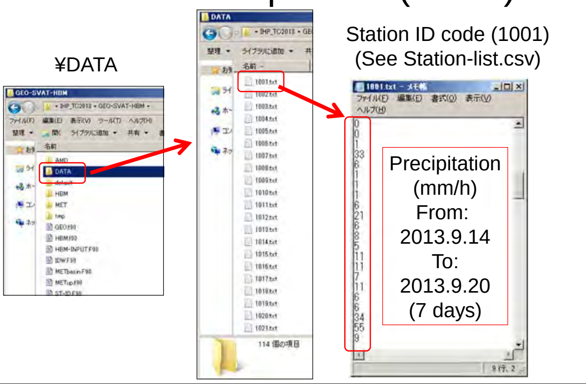
Input data:

Precipitation **(mm/h)**

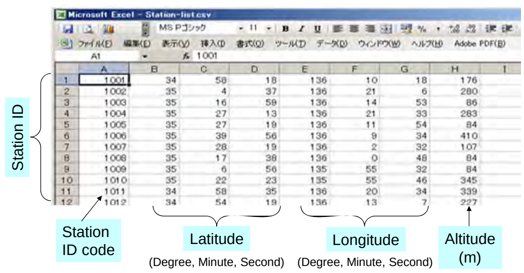
Each observation **Point Data**

1km **Mesh Data**

DATA: Precipitation (mm/h)

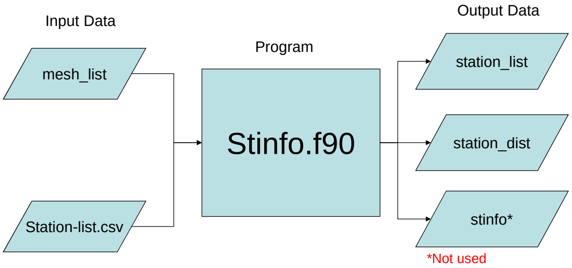


Station-list.csv

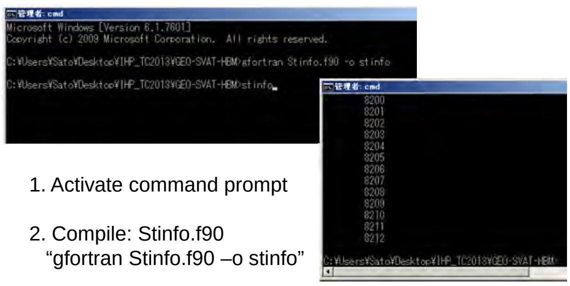


In this practice we will use 144 observation points data.

Stinfo(Station Information)



Stinfo.f90/exe

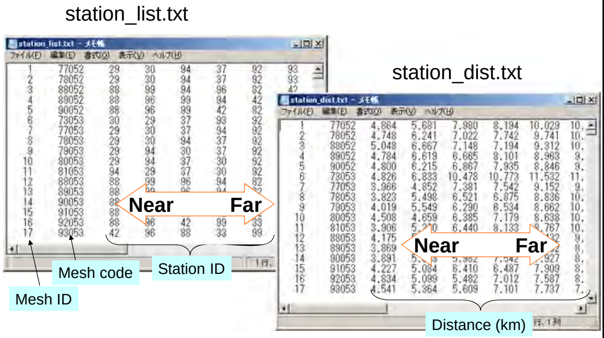


1. Activate command prompt
2. Compile: Stinfo.f90
   “gfortran Stinfo.f90 –o stinfo”
3. Run “stinfo.exe”
   “stinfo”

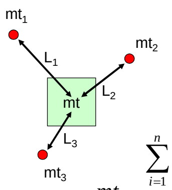
Yodo River basin: 8212 mesh

Approx. 1 min.

Station_list/dist.txt



Data interpolation method
Inverse Distance Weighting (IDW)



$$L_i = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}$$

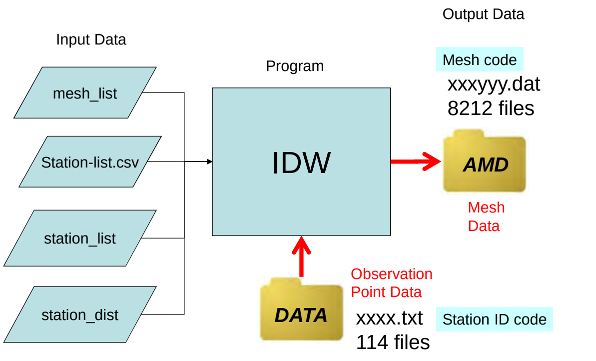
$$mt = \frac{\sum_{i=1}^{n} \frac{mt_i}{L_i^2}}{\sum_{i=1}^{n} \frac{1}{L_i^2}}$$

$X_i = (N_i + h_i) \cdot \cos\phi_i \cdot \cos\lambda_i$,
$Y_i = (N_i + h_i) \cdot \cos\phi_i \cdot \sin\lambda_i$,
$Z_i = (N_i \cdot (1 - e^2) + h_i) \cdot \sin\phi_i$

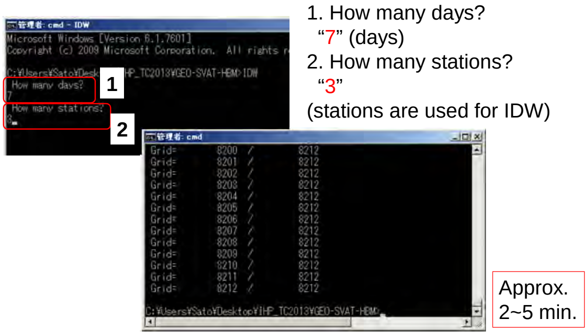
$N_i = R / \sqrt{(1 - e^2 \cdot \sin\phi_i)}$
ϕ_i: Latitude
λ_i: Longitude

Eccentricity: e=0.08181974
Equatorial radius: R=6,378,136m

IDW



IDW.f90/exe



1. How many days?
   "7" (days)
2. How many stations?
   "3"
(stations are used for IDW)

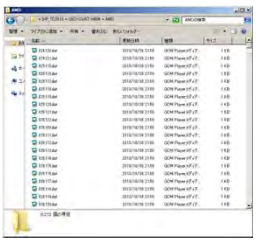
Yodo River basin: 8212 mesh

Data format (xxxyyy.dat)

25 data

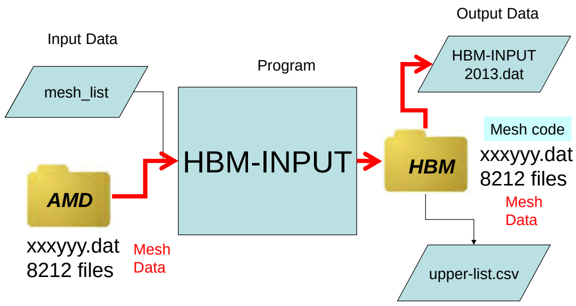
7 lines

Day1, data1,data2,….,data24 (Prec.: mm/h)
Day2, …
Day3, …
…
Day7, …

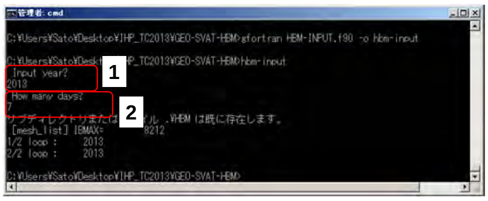


¥AMD
8212 files

HBM-INPUT



HBM-INPUT/exe



1. Input year?
   "2013"
2. How many days?
   "7"

Approx.
1~2 min.

Data format (HBM-INPUT.dat)

1.(Ta,Ts,Snm,E,data1,data2,…data24,PR,PRR,PRS) x 8212 mesh

2.(…)

…

7. (…)

31 data x 8212 mesh = 254,572 data / day
x 7 days = 1,782,004 data

*Ta: Air temperature (deg C)
*Ts: Land Surface temperature (deg C)
*Snm: Snow melt (mm/d)
*E: Evapotranspiration (mm/d)
Data1~2: Precipitation (mm/h)
*PR: Precipitation (mm/d)
*PRR: Rainfall (mm/d), *PRS: Snowfall (mm/d)

*Not used

Data format (xxxyyy.dat)

5 data

24 hours x 7 days = 168 lines

Year,day,PRup,PRRup,PRSup

Upper catchment average

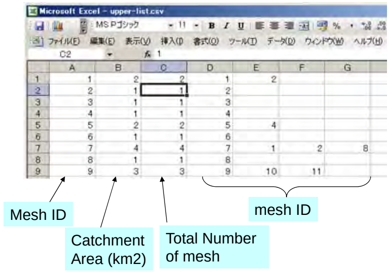
PRup: Precipitation (mm/h)
*PRRup: Rainfall (mm/h),
*PRSup: Snowfall (mm/h)

*Not used

¥HBM
8212 files

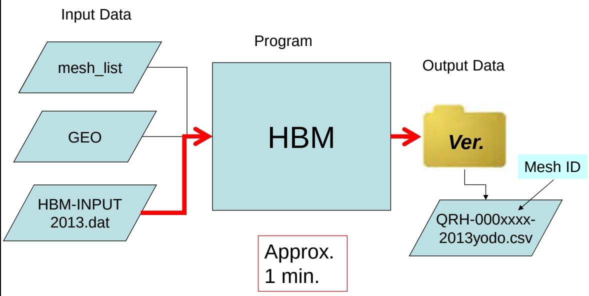
This data is used for METup

Data format (upper-list.csv)

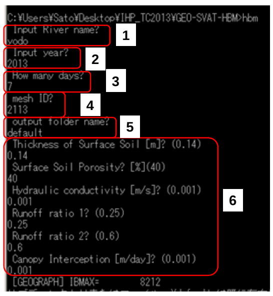


This data is used for METup

HBM (Hydro-BEAM)



HBM.f90/exe



1. River Name: "yodo"
2. Year: "2013"
3. Days: "7" (days)
4. Mesh ID: "5441" (hiyoshi dam)
5. Output: "default" (version)

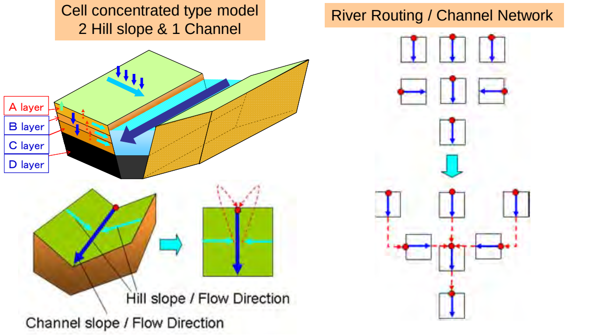
Parameter Settings
- Soil Thickness [m] 0.14
- Porosity [%] 40
- Hydraulic Conductivity [m/s] 0.0001
- Runoff ratio 1, 2 0.25/0.6
- Canopy interception [m] 0.001

Hydro-BEAM

Hydrological river Basin Environment Assessment Model

Cell concentrated type model
2 Hill slope & 1 Channel

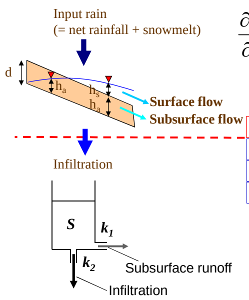
River Routing / Channel Network

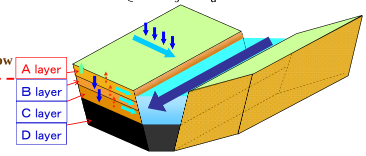


Basic Structure

Kinematic wave model

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=r \qquad \begin{cases} q=f(h)=\alpha(h-d)^m+ah \\ h=h_s+h_a \end{cases}$$

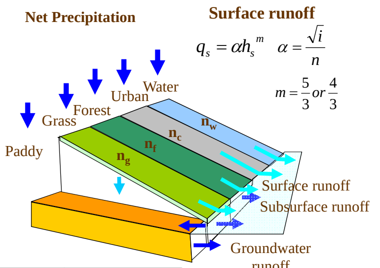




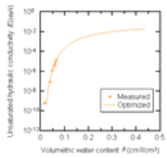
Multi-layer Storage function model

$$\frac{dS}{dt}=I-O \qquad O=(k_1+k_2)\cdot S$$

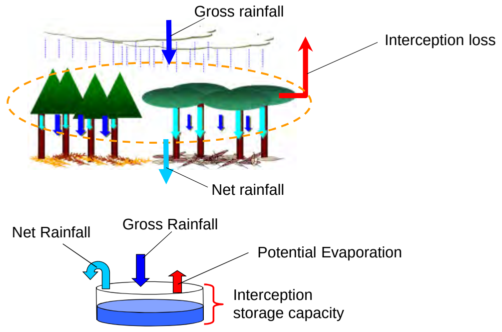
Hill Slope Runoff Process



	Forest	Grass	City	Water
Roughness	0.70	0.30	0.03	0.04
Soil depth (m)	0.025	0.025	0.025	-
Porosity	0.40	0.40	0.40	-



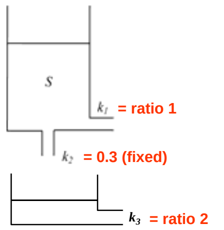
Rainfall Interception



Linear Storage Function Model

$$\frac{dS}{dt} = I - O$$

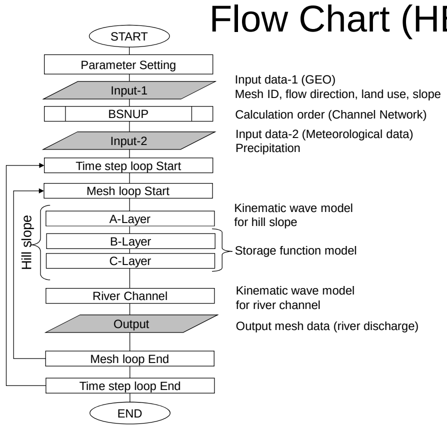
$$O = (k_1 + k_2) \cdot S$$



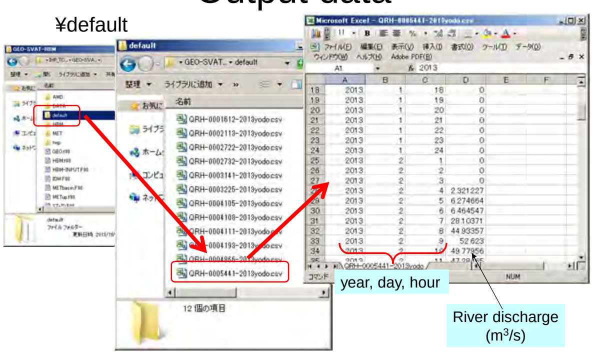
S : warter storage [m]
I : inflow [m/s]=(1-f)･r
O : outflow [m/s]
k_1*, *k_2 : coefficient

Initial setting value
B layer: KH=0.14/86400
B layer: KV=0.3/86400
C layer: KH=0.6/86400

Flow Chart (HBM)

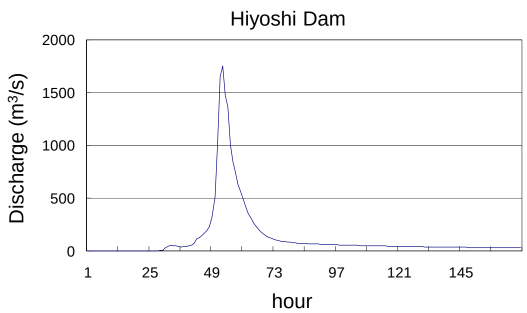


Output data

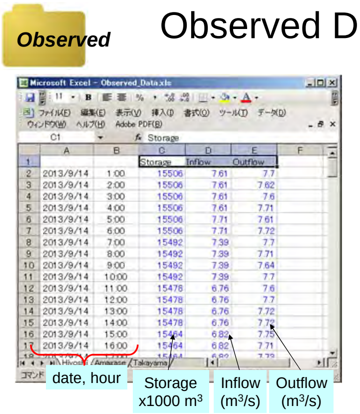


QRH-0005441-2013yodo.csv 2013.9.14 ~ 9.20

Output Data Sample



Observed Data

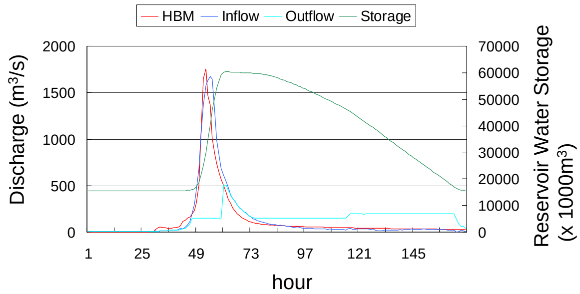


Observed-Data.xls

Hiyoshi dam
Amagase dam
Takayama dam

2013.9.14
~ 2013.9.20 (7days)

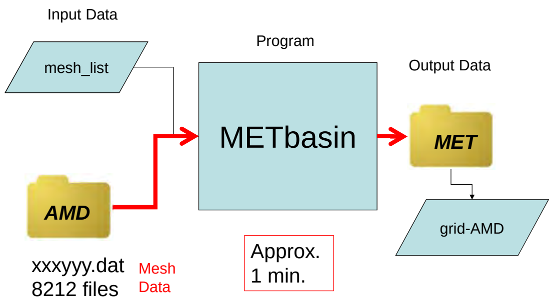
Reservoir Operation (Flood Control)



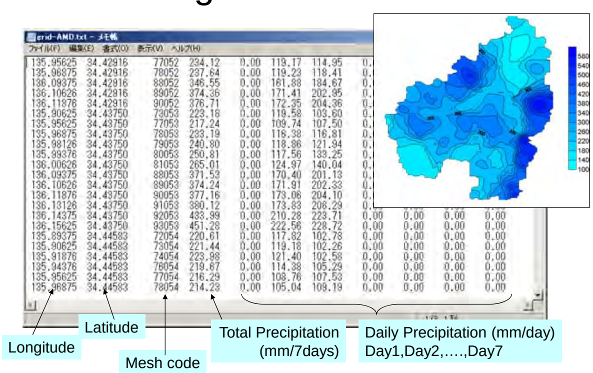
Practice

- Calculate inflow to Amagase and Takayama dam using HBM.
- Compare these results with observed data.
- Discuss about the reason why these differences occurs.
- Try to improve calculation results by changing parameters (calibration).

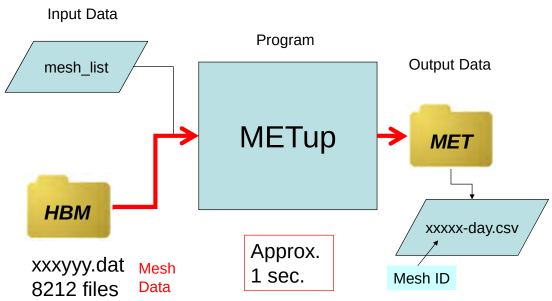
Input Data Analysis 1 (METbasin.f90/exe)



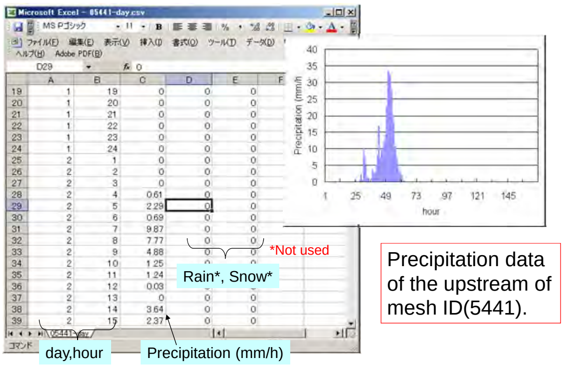
grid-AMD.txt



Input Data Analysis 2 (METup.f90/exe)



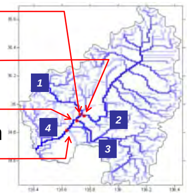
05441-day.csv



Practice

- Compare the flow characteristics of main tributaries of the Yodo river basin.
  (1.Katsura R., 2. Uji R., 3. Kizu R., 4. Yodo R)

1. Katsura River (Hazukashi)
   N34/55/40, E135/43/47, 9.234m
2. Uji River (Yodo)
   N34/55/0, E135/45/30, 11.017m
3. Kizu River (Yawata)
   N34/52/59, E135/42/25, 11.335m
4. Yodo River (Hirakata)
   N34/48/49, E135/38/04, 6.868m



Result 1

- Mesh ID and Area? Use “ST-ID”

1. Katsura River (Hazukashi)?
   A. ____________
2. Uji River (Yodo)?
   A. ____________
3. Kizu River (Yawata)?
   A. ____________
4. Yodo River (Hirakata)?
   A. ____________

Result 2

- River discharge (average, peak)? Use “HBM”

1. Katsura River (Hazukashi)?
   A. ____________
2. Uji River (Yodo)?
   A. ____________
3. Kizu River (Yawata)?
   A. ____________
4. Yodo River (Hirakata)?
   A. ____________

Result 3

- Precipitation (Total, Peak)? Use “METup”

1. Katsura River (Hazukashi)?
   A. ____________
2. Uji River (Yodo)?
   A. ____________
3. Kizu River (Yawata)?
   A. ____________
4. Yodo River (Hirakata)?
   A. ____________

Discussion

- Compare the result of each point.
- Discuss about the reason why these differences occurs.
- Discuss about how to mitigate flood disaster, increase available water resources, and improve environment for river ecosystem of the Yodo River basin.

Exercise 5: Impact Assessment by Ecological Model

Sohei KOBAYASHI *(Water Resources Research Center, DPRI, Kyoto University)*

River ecosystems usually consist of diverse plant and animal species within a site, and all of the species are more or less interconnected to create a complex food web. Interactions between different organisms and between organisms and environment always affect the community composition, primary and secondary production, and water quality. Future climate change will surely impact river ecosystems and availability of ecosystem resources for humans through hydrologic and hydraulic processes, though ecological processes are complex and difficult to make predictions for future changes.

In this exercise, I firstly explained about the basic concept of an ecological model, named "compartment model". The model consists of several compartments, each of which represents a group of species or elements (e.g., nutrient, organic matter) with similar ecological status. Basically, all of the possible connections (ecological processes) between compartments and influences of various abiotic factors (e.g., light, temperature, flow) to each of the processes should be considered. So a large number of reaction formula and parameter are usually required. At least, a basic structure of formula should be understood to solve an ecological phenomenon for each particular case. Depending on focus topic, all of the compartments are not always required in the model.

There are some ideas to make use of the output results of hydrological model (i.e., discharge, water temperature) in an ecological model. Some methods to relate discharge values to habitat availability of aquatic species are already familiar. Discharge is also an index of disturbance that reduces the size of population (density, biomass) and resets community members. Water temperature governs the rate of all biological processes, and also affects the annual cycle and the timing of important life history events, all of which can ultimately influence population persistence, population size and function of species.

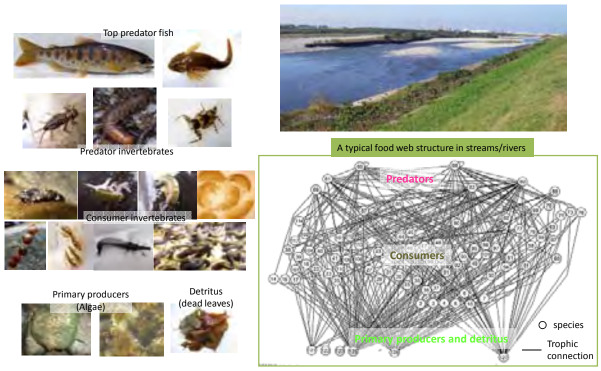
We will finally try to simulate the response of an aquatic species to change in hydrological and temperature regimes by making use of the output data of Hydro-BEAM. The target species is a caddisfly, whose outbreak is now a serious issue in the Uji City, Kyoto. The number of emergence of caddisfly is assumed to increase if water temperature increased, while assumed to decrease if the number of flood increased. Simple assumptions are considered in the model and Microsoft Excel will be used for the calculation.

23rd IHP Training Course **12th Dec. 2013**

Exercise 5: Impact assessment by ecological model

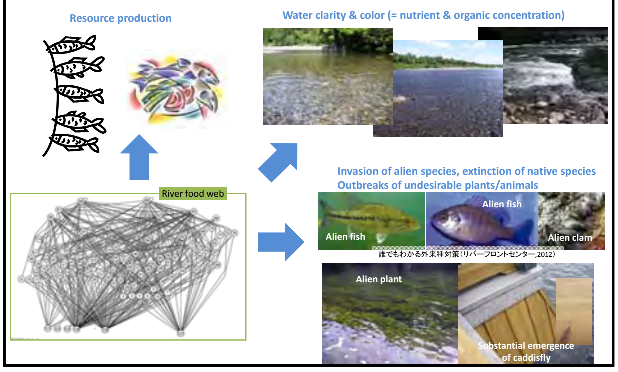
Sohei KOBAYASHI
(Disaster Prevention Research Institute, Kyoto Univ.)

Aquatic ecosystems support diverse plant and animal species.
All of them are more or less interconnected.

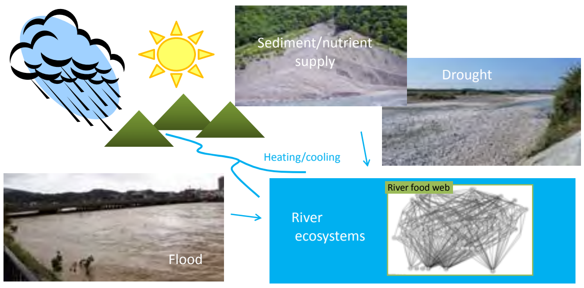


Allan & Castillo (2006) Stream Ecology

Interactions of organisms-organisms and organisms-water always affect the community composition, production and aquatic environment (water chemistry, etc.).



Future climate changes will surely impact aquatic ecosystems through hydrological and hydraulic processes, but ecological processes are so complicated and difficult to predict



Need a clear/simple idea that connects hydrol and ecol processes

---

Outline

1. Basic ideas of ecological model
   - Compartment model
   - Shape of biological reaction
   - Previous case studies
2. Key processes between hydrology and ecology
3. Simulating ecological processes

My talk is mainly concerned with river ecosystems

---

1. Basic ideas of ecological model

Compartment model

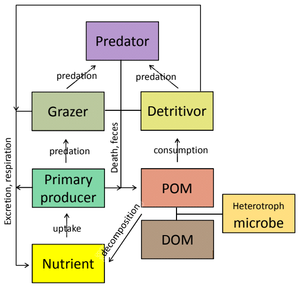
Consisting of several compartments and the interactions between the compartments that satisfies the material cycle of the target phenomenon. Each compartment represents a group of species (elements) with similar ecological status.

Frequently used compartments in aquatic ecosystems are follows.

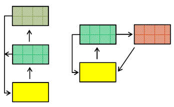
Nutrient (N,P,) DOM Heterotroph microbe
Primary producer POM
Grazer Detritivore
Predator

Specifying the processes of interaction

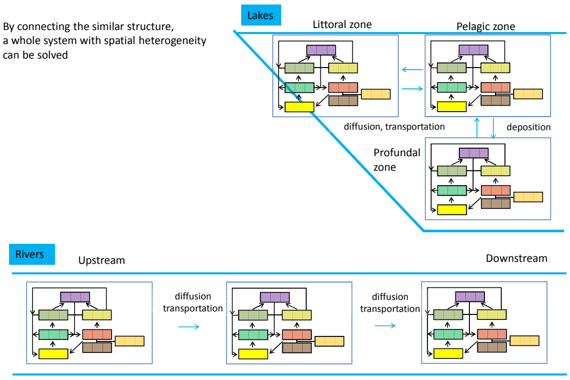
uptake, predation, respiration, decomposition, etc...



Model structure is dependent on the objective.

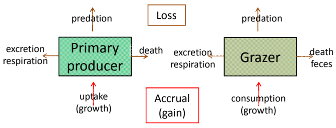


By connecting the similar structure, a whole system with spatial heterogeneity can be solved



Equation formula

The basic form of equation is similar among compartments. The parameters are different.



Primary producer

Accrual / Loss

$$\frac{dX_p}{dt} = \left[\mu_p - \left(r_p + \eta_{gp}\mu_g X_g + k_p\right)\right]X_p$$

Growth rate, Respiration rate, Predation rate, Mortality rate

$$\mu_p = \mu_{p\,\max}\, f_n\, f_I\, f_{pT}\, f_{X_p}$$

Maximum growth rate

Growth limitation function by nutrient (*n*), light (*I*), temperature (*pT*), its own density/biomass (*Xp*)

Grazer

Accrual / Loss

$$\frac{dX_g}{dt} = \left[\mu_g - \left(r_g + \eta_{tg}\mu_t X_t + k_g\right)\right]X_g$$

Growth rate, Respiration rate, Predation rate, Mortality rate

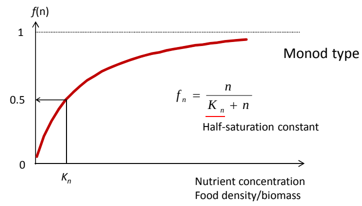
$$\mu_g = \mu_{g\,\max}\, f_p\, f_{gT}\, f_{X_g}$$

Maximum growth rate

Growth limitation function by primary producer (*p*), temperature (*gT*), its own density/biomass (*Xg*)

Growth limitation function

by resource (e.g., nutrient, food)



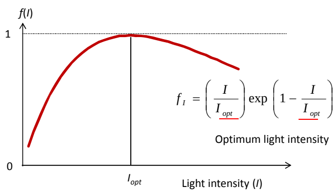
Monod type

$$f_n = \frac{n}{K_n + n}$$

Half-saturation constant

Growth limitation function

by light

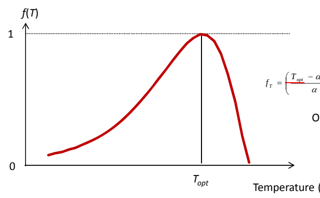


$$f_I = \left(\frac{I}{I_{opt}}\right)\exp\left(1 - \frac{I}{I_{opt}}\right)$$

Optimum light intensity

Growth limitation function

by temperature

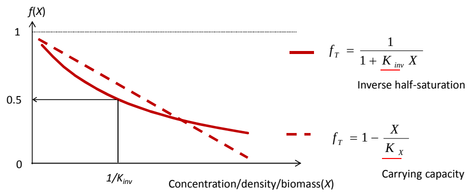


$$f_T = \left(\frac{T_{opt} - \alpha - T}{\alpha}\right)^{\beta}\exp\left(\beta - \beta\frac{T_{opt} - \alpha - T}{\alpha}\right)$$

Optimum temperature

Growth limitation function

by its own concentration/density/biomass



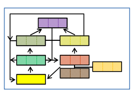
2. Key processes between hydrology and ecology

Make use output values of hydrological model

Discharge
(water level, flow velocity, etc)

Temperature

Ecological processes



Concept of PHABSIM & WUA

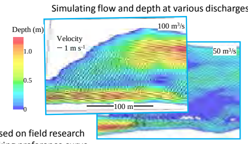
Simulating flow and depth at various discharges

Discharge
(water level, flow velocity, etc)

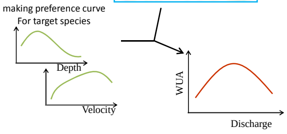
Frequency / Spatial distribution of flow velocity and depth

II

Potential habitat availability for a plant/animal species



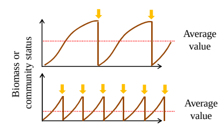
Based on field research making preference curve For target species



Frequency / magnitude of flood or drought

II

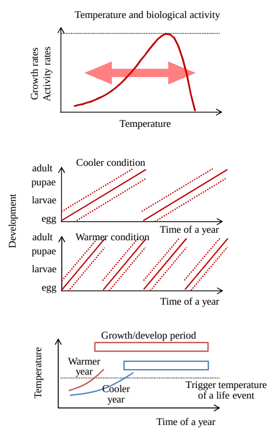
Disturbance that increase mortality and reset community succession



Affects carrying capacity of species

Temperature

- Rates of biological processes (growth, mortality, etc.,,)
- Rates of development (length of life-cycle)
- Timings of life history events



Growth and survival of individuals
Persistence of populations

3. Simulating ecological processes

Simulating ecological processes

Uji River and City

The river flows the middle of the Uji city and is one of the major rivers of Yodo basin. The city has **2 world heritage buildings** (Byodo-in, Ujigami, since 10th century) near the river, and long & various histories of rivers and people exist.

Uji is the **city of mountains and rivers as well as Japanese tea**. Better use of river resources and pleasant environment is expected also in the future.

Simulating ecological processes

Ecological values in Uji River

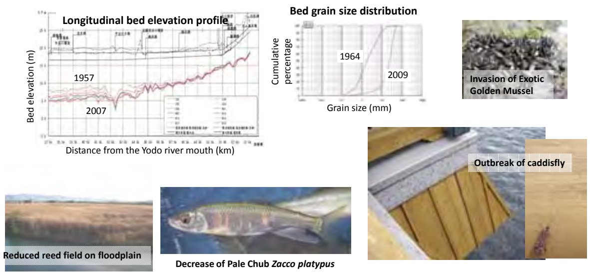
Due to locating downstream of the Biwa Lake, many species have been **evolved to adapt specific flow environments of the Uji River**. Some animal species are known to **occur only in the Uji River** (or are abundant in Uji River). Preservations of these species are surely important for the nature and citizens.

Simulating ecological processes

Environmental issues in Uji River

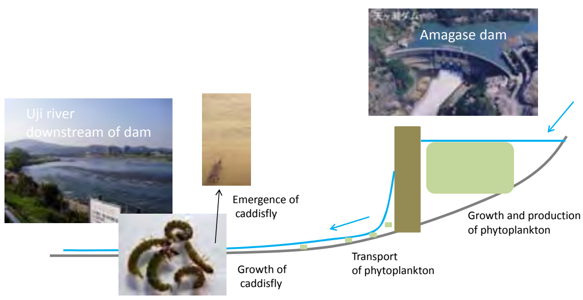
Channel degradation is a common problem in Japanese rivers. In the Uji River, a large reed vegetation area is endangered due to a decreased river-floodplain connection, and spawning areas of some fish have been lost due to bed coarsening.

The **outbreak of caddisflies** is an another big issue. They have increased due to **bed stabilization and rich supply of phytoplankton** from the upstream Amagase dam. Although they are harmless, their crowd make residence and tourists uncomfortable.



Simulating ecological processes

Simulating the growth and emergence of caddisflies and predicting the effect of a climate change



Exercise 6: Optimization of Reservoir Operation

Daisuke NOHARA *(Water Resources Research Center, DPRI, Kyoto University)*

Optimizing reservoir operation policies considering hydrological data is crucially important for effective management of reservoirs for both the flood control and water use purposes. In this exercise, we will learn how to prepare and conduct optimization of reservoir operation by using dynamic programming (DP) techniques through tackling to sample problems. The exercise will consist of two parts.

The first part aims at learning a general procedure of calculation to optimize reservoir operation by DP techniques with a simple example problem. A simplified single multi-purpose reservoir is employed here, and reservoir operation for water supply is optimized by use of deterministic DP approach. We will practice typical backward algorithm to estimate optimized release policies of the reservoir.

In the second part of the exercise, we will tackle to practical optimization problems considering a simplified multi-purpose reservoir, whose hydrological and reservoir data are derived from existing Sameura Reservoir in the Yoshino River basin in Japan. The exercise problems will deal with optimization of the reservoir operation for water supply by use of deterministic DP and stochastic DP models. Through tackling the problems, it will be introduced what we must prepare to set up the calculation for optimization of reservoir operation, including: choosing numbers of levels to discretize time step and states of the reservoir; setting objective functions according to the objective to optimize the reservoir; setting constraints for storage volume or release water defined by the physical constraints or regulations; preparation of hydrological data and target release of the target reservoir; and setting the time horizon to optimize the water release strategy. The optimization of operation of the target reservoir will be computed and be demonstrated with a computer program developed for DP based optimization of reservoir operations.

Exercise 6:
OPTIMIZATION OF RESERVOIR OPERATION

Daisuke NOHARA
Water Resources Research Centre
Disaster Prevention Research Institute
Kyoto University

CONTENTS

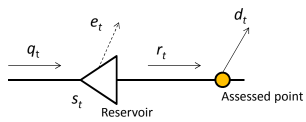
INTRODUCTION

Optimization of reservoir operations based on dynamic programming (DP) approaches

- Richard Bellman's Principle of Optimality:
  - Original problem can be divided into a set of sub problems which need less computational effort to solve
- Suitable for reservoir operation simulation, which is sequential process
- Applicable to any problem including nonlinear problems which have non-linear objective functions such as damage functions
- Compatible to computer-based solving

SIMPLE EXAMPLE

Optimization of water supply operation of a single reservoir so as to minimize drought damage caused by deficit in water supply from the reservoir for three time steps



q_t: Inflow during time step t (MCM)
s_t: Storage volume at the beginning of time step t (MCM)
r_t: Release amount during time step t (MCM)
e_t: Loss from the reservoir during time step t (MCM)
d_t: Demand (target release amount) during time step t (MCM)

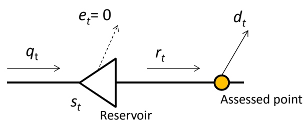
Physical constraints of the reservoir:

- $S_{min} = 0$, $S_{max} = 40$
- $R_{min} = 0$, $R_{max} = 40$

Matrix for Inflow / Target release (MCM):

	t=1	t=2	t=3
q_t	10	10	10
d_t	20	30	30

SIMPLE EXAMPLE



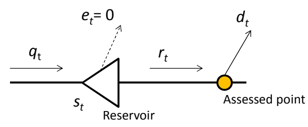
Assumptions to simplify the problem:

- No consideration of losses from the reservoir [i.e. $e_t = 0$]
- The assessed point locates just downstream the reservoir [i.e. r_t is identical to flow amount at the assessed point]

Other settings:

- Drought damage function:
  $H(r_t) = \{\max[d_t - r_t, 0]\}^2$
- Discretizing states into five levels considered for s_t, q_t and r_t with increment of 10 (MCM) from 0 to 40.

SIMPLE EXAMPLE



Objective function:

$$\min_{r_t} \sum_{t=1}^{3} H(r_t)$$

subject to:

- $S_{min} = 0$, $S_{max} = 40$, $S_{min} \le s_t \le S_{max}$
- $R_{min} = 0$, $R_{max} = 40$, $R_{min} \le r_t \le R_{max}$
- $s_{t+1} = s_t + q_t - r_t - e_t$

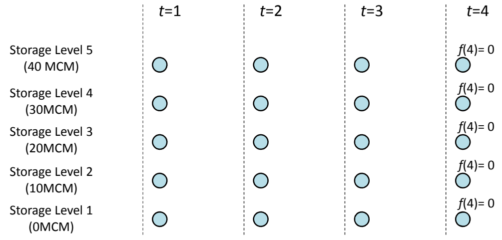
Recursive equation:

$$f(s_t) = \min_{r(t)} \left[H(r_t) + f(s_{t+1}) \right]$$

$f(\cdot)$: Future damage function

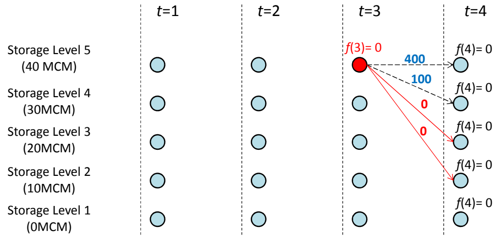
SIMPLE EXAMPLE

Calculation backward considering no damage after the last time step ($t \geq 4$)



SIMPLE EXAMPLE

Calculation of $f(3)$ for each storage state s_3



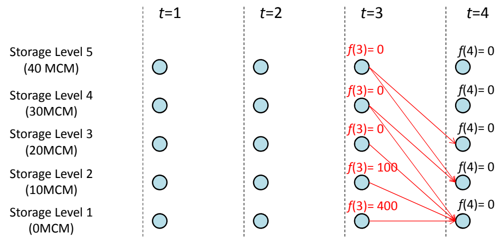
For Level 5 (s_3=40MCM),

- r_3=0 Not feasible (s_4>s_{max})
- r_3=10 $H(r_3)$ = $(30\text{-}10)^2$ =400, s_4=s_3+q_3-r_3= 40, $f'(3)$ = 400 + $f(4|s_4$=40) = 400
- r_3=20 $H(r_3)$ = $(30\text{-}20)^2$ =100, s_4=30, $f'(3)$ = 100 + $f(4|s_4$=30) = 100
- r_3=30 $H(r_3)$ =0, s_4=20, $f'(3)$ = 0 + $f(4|s_4$=20) = 0
- r_3=40 $H(r_3)$ = 0, s_4=10 $f'(3)$ = 0 + $f(4|s_4$=10) = 0

Optimal policies for the storage state

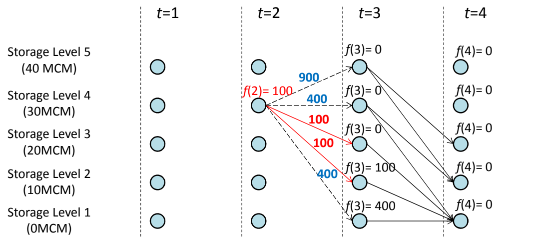
SIMPLE EXAMPLE

Calculation of $f(3)$ for each storage state s_3



SIMPLE EXAMPLE

Calculation of $f(2)$ for each storage state s_2



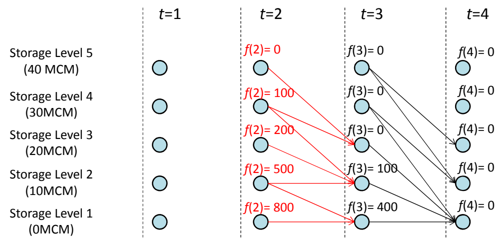
For Level 4 (s_2=30MCM),

- r_2=0 $H(r_2)$ = $(30\text{-}0)^2$ =900, s_3=s_2+q_2-r_2= 40, $f'(2)$ = 900 + $f(3|s_3$=40) = 900
- r_2=10 $H(r_2)$ = $(30\text{-}10)^2$ =400, s_3=30, $f'(2)$ = 400 + $f(3|s_3$=30) = 400
- r_2=20 $H(r_2)$ = $(30\text{-}20)^2$ =100, s_3=20, $f'(2)$ = 100 + $f(3|s_3$=20) = 100
- r_2=30 $H(r_2)$ =0, s_3=10, $f'(2)$ = 0 + $f(3|s_3$=10) = 100
- r_2=40 $H(r_2)$ = 0, s_3=0 $f'(2)$ = 0 + $f(3|s_3$=10) = 400

Optimal policies for the storage state

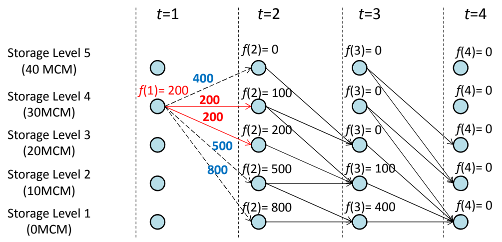
SIMPLE EXAMPLE

Calculation of $f(2)$ for each storage state s_2



SIMPLE EXAMPLE

Calculation of $f(1)$ for each storage state s_2



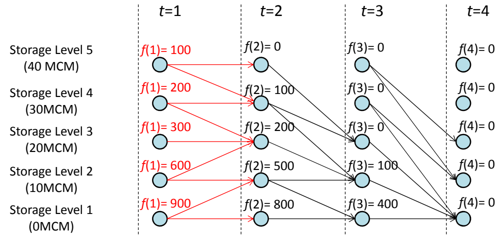
For Level 4 (s_1=30MCM),

- r_1=0 $H(r_1)$ = $(20\text{-}0)^2$ =400, s_2=s_1+q_1-r_1= 40, $f'(1)$ = 400 + $f(2|s_2$=40) = 400
- r_1=10 $H(r_1)$ = $(20\text{-}10)^2$ =100, s_2= 30, $f'(1)$ = 100 + $f(2|s_2$=30) = 200
- r_1=20 $H(r_1)$ =0, s_2= 20, $f'(1)$ = 0 + $f(2|s_2$=20) = 200
- r_1=30 $H(r_1)$ =0, s_2= 10, $f'(1)$ = 0 + $f(2|s_2$=10) = 500
- r_1=40 $H(r_1)$ = 0, s_2= 0, $f'(1)$ = 0 + $f(2|s_2$=0) = 800

Optimal policies for the storage state

SIMPLE EXAMPLE

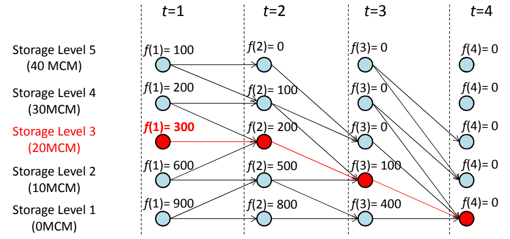
Calculation of $f(1)$ for each storage state s_2



SIMPLE EXAMPLE

Getting optimal policies (decision and state trajectories) for each storage level at each time step

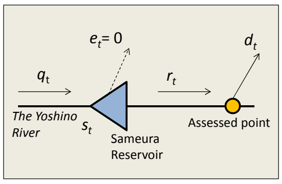
If you want to know the optimal release policy for storage level 3 at time step 1…



EXERCISES

Exercise with the simplified Sameura Reservoir system

- Located in the Yoshino River basin, Shikoku Island, Japan
- A multipurpose reservoir for flood control, power generation and water supply
- Controlling seasonal variability in streamflow (not for inter-annual storage)



Schematic view of simplified Sameura Reservoir system

Allocation of storage capacity for each purpose to operate Sameura Reservoir

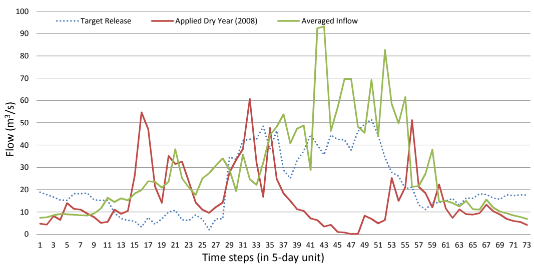
Purposes	Storage capacity	
	Dry season (Oct. 11th - Jun. 30th)	Wet season (Jul. 1st - Oct. 10th)
Water supply	173 MCM	173 MCM
Flood control	80 MCM	90 MCM
Power gen.	36 MCM	26 MCM

EXERCISE 1: OPTIMIZATION FOR WATER SUPPLY (1)

- Optimize water release strategy from a single reservoir for each storage state at each time step **considering the historical streamflow regime in a dry year**
- Consider only water supply operation with the storage capacity for that purpose (173 MCM)
- Off-line optimization (not online optimization)
- Optimize with **deterministic DP (DDP)** for one year from January to December

FLOW REGIME AND TARGET RELEASE

Flow regime in the applied dry year (2008) and assumed water demand just downstream Sameura Reservoir (assumed target release of Sameura Reservoir)



SETTING UP OPTIMIZATION PROBLEM

Objective function

$$\min_{r_t} \sum_{t=1}^{T} H(r_t)$$

subject to:

- $S_{min} \leq s_t \leq S_{max}$
- $R_{min} \leq r_t \leq R_{max}$
- $s_{t+1} = s_t + q_t - r_t - e_t$

Recursive equation:

$$f(s_t) = \min_{r(t)} \left[H(r_t) + f(s_{t+1}) \right]$$

Drought damage function:

Employing the one proposed by Ikebuchi et al. (1990):

$$H(r_t) = \begin{cases} (d_t - r_t)^2 / d_t & (r_t < d_t) \\ 0 & (r_t \geq d_t) \end{cases}$$

SETTING PARAMETERS FOR SOLVING DP

Descretization of states and time steps

The number of descretized levels of states and time steps must carefully be chosen.

- Enough many to describe reservoir and hydrological states according to the objective of optimization
- But as small as possible to secure feasibility in computation

For this exercise (drought management):

- Time Step: 5-day unit (73 time steps in a year)
- Flow (inflow and release): 100 levels (4 m^3/s for each level)
- Storage: 100 levels (1.73 MCM for each level)

Constraints:

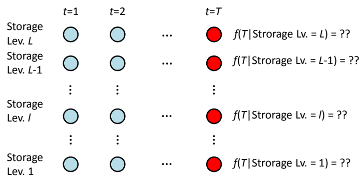
$S_{min} = 0$, $S_{max} = 173$ MCM
$R_{min} = 0$, $R_{max} = 400$ m^3/s (≈ 173MCM for 5 days)

Other assumptions:

$e_t = 0$ (No loss from the reservoir considered)

SETTING PARAMETERS FOR SOLVING DP

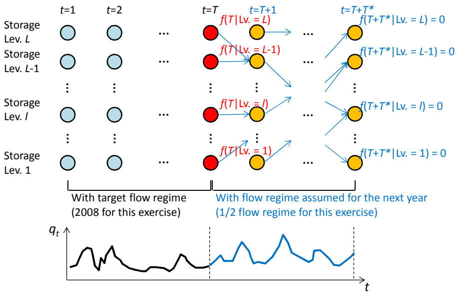
Future damage function at the last time step of optimization
Necessary to define for backward calculation of *f*()



SETTING PARAMETERS FOR SOLVING DP

Future damage function at the last time step of optimization

- Estimating by optimizing water release for a period (e.g. until end of the next year)
- Adding penalty to small storage levels which can admit drought after the final time step of the optimization

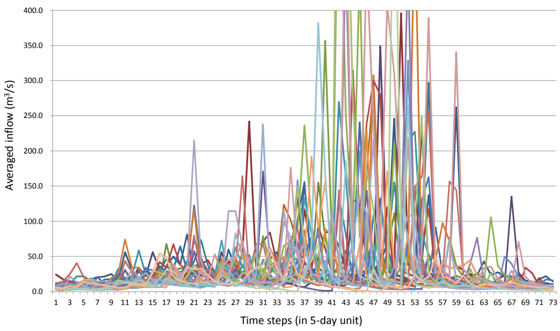


EXERCISE 2: OPTIMIZATION FOR WATER SUPPLY (2)

- Optimize water release strategy from a single reservoir for each storage state at each time step **considering historical streamflow regimes observed for 30 years**
- Consider only water supply operation with the storage capacity for that purpose (173 MCM)
- Off-line optimization (not online optimization)
- Optimize with **stochastic DP (SDP)** for one year from January to December

HISTORICAL HYDROLOGICAL DATA

Inflow sequences observed for 30 years (1979-2008)



SETTING UP OPTIMIZATION PROBLEM FOR SDP

Objective function

$$\min_{r_t} \sum_{t=1}^{T} E_{q_t}\left[H(r_t,\ q_t)\right]$$

subject to:

- $S_{min} \le s_t \le S_{max}$
- $R_{min} \le r_t \le R_{max}$
- $s_{t+1} = s_t + q_t - r_t - e_t$

Recursive equation:

$$f(s_t) = \min_{r(t)} E_{q_t}\left\{H(r_t,\ q_t) + f_{t+1}(s_t)\right\}$$

(Neglecting persistence in streamflow)

Drought damage function:

Same as the one employed in Exercise 1:

$$H(r_t) = \begin{cases} (d_t - r_t)^2 / d_t & (r_t < d_t) \\ 0 & (r_t \ge d_t) \end{cases}$$

FOR FURTHER DISCUSSIONS

The further discussions about DP based optimization of reservoir operation can be seen in the following references.

DP based optimization of reservoir operation

- Nandalal, K.D.W. and Bogardi, J.J. (2007): Dynamic programming based operation of reservoirs – Applicability and limits -, UNESCO, Cambridge University Press, 130pp, ISBN 978-0-521-87408-3.
- Loucks, D. and Van Beek, E. (2005): Water resources systems planning and management – An introduction to methods, models and applications, Studies and Reports in Hydrology, UNESCO Publishing, 680pp. (with contributions from J.R. Stedinger, J.P.M. Dijkman and M.T. Villars), ISBN 92-3-103998-9.

Application of DP models to optimize actual reservoir systems

- Kumar, D.N., Baliarsingh, F. and Raju, Srinivasa (2010): Optimal reservoir operation for flood control using folded dynamic programming, *Water Resources Management*, 24, 1045-1064.
- Faber, B.A. and Stedinger, J.R. (2001): Reservoir optimization using sampling SDP with ensemble streamflow prediction (ESP) forecasts. *Journal of Hydrology*, 249, 113-133.
- Turgeon, A. (1980): Optimal operation of multireservoir power systems with stochastic inflows, *Water Resources Research*, 16(2), 275-283.
- Tilmant, A. Vanclooster, M., Duckstein, L. and Persoons, E. (2002): Comparison of fuzzy and nonfuzzy optimal reservoir operation policies, *Journal of Water Resources Planning and Management*, 128(6), 390-398.

Ecological Field Survey

Measurement of Riverbed Habitat Conditions for Aquatic Animals

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[1]Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji 611-0011, Japan

In the course of exercises for ecological field surveys, we will visit two river sites different in sediment dynamism of the riverbed. One site locates in the Uji River below the Amagase Dam with less sediment supply because there remain few basins for sediment production. The other site is in the Kizu River where the sediment movement is comparatively preserved because the main river has no high dams and sand supply has been continues to occur in spite of several high dams constructed in tributaries.

Study sites

The first study site will be established in the Uji River at 43.0km from the river mouth of the Yodo River (Figure 1 and 2). The Yodo River and the Uji River has the basin area of 8,240 km^2 and that of 4,354 km^2, respectively. The study site locates 10km below the Amagase Dam constructed in 1964. There is a point bar with a length of ca. 200m and a width of ca. 80m at the site. Since there are only a few remain basins below the Dam, the sediment supply from the upper basin to the Uji River has been stopped for more than 46 years and distinctive riverbed degeneration can be observed in the reaches (Figure 3a).

The second study site will be established in the Kizu River at 44.0km from the river mouth of the Yodo River (Figure 1 and 2). The Kizu River has the basin area of 1,596 km^2. There is a very wide sandy bar with a length of ca. 1,100m and a width of ca. 300m at the site (Figure 3b). The site locates 40km below the Takayama Dam constructed in 1969. Since there are no high dams in the main river and there are a lot of tributaries producing sediment, the sediment dynamism of the Kizu River has been fairy active comparing with other tributaries of the Yodo River.

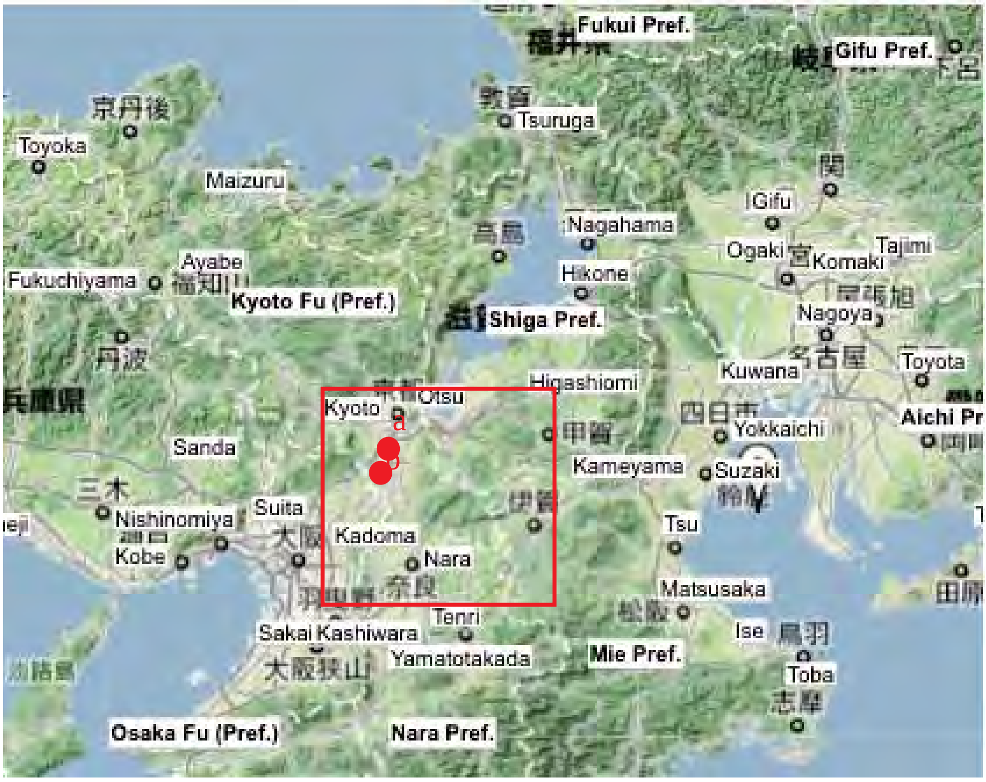


Figure 1 Map of the two study sites in Western Japan. The open square indicates the area of the map in Figure 2 and the circle a and b corresponds to the Uji River site and the Kizu River site, respectively.

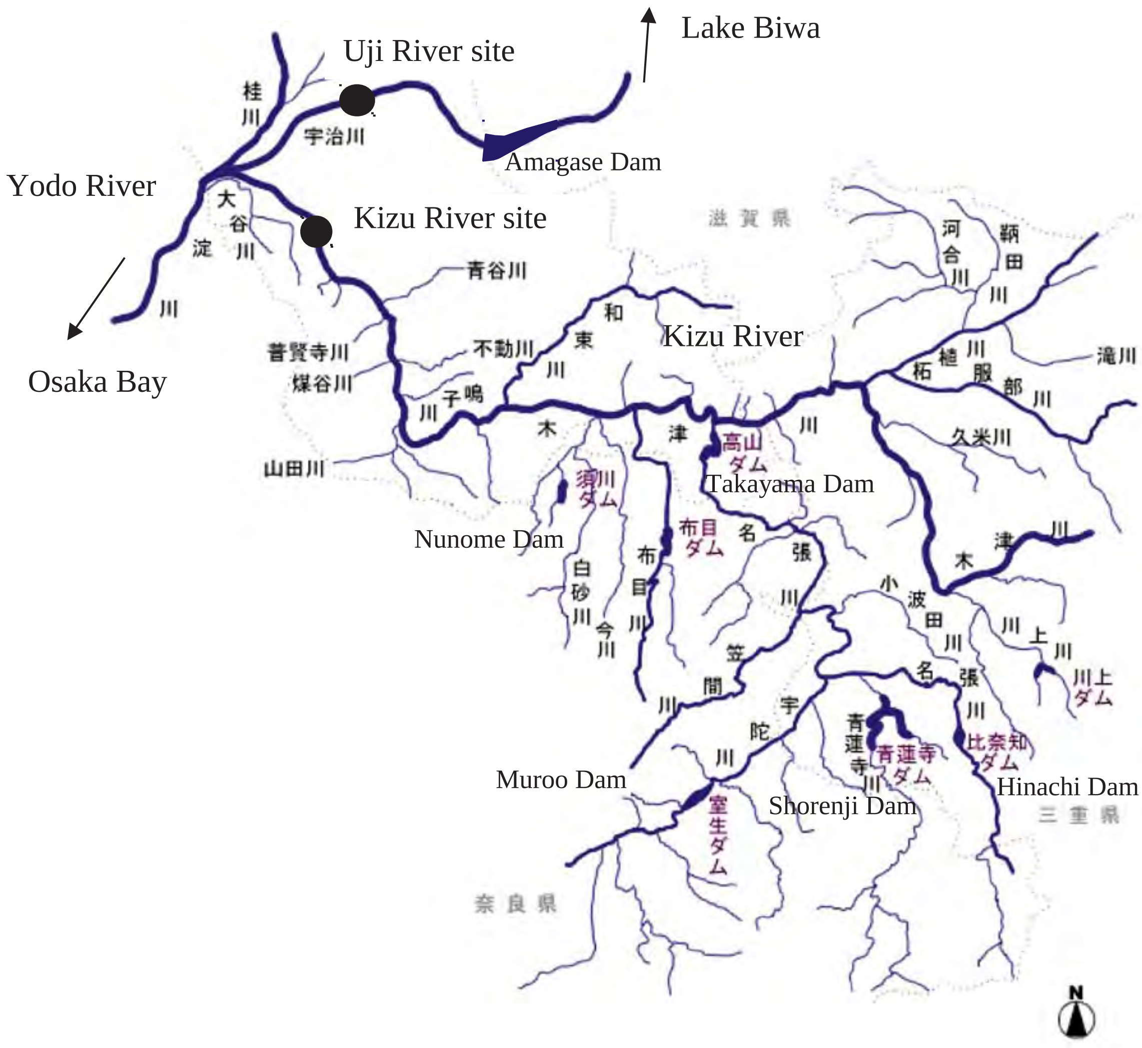


Figure 2 Map of the two study sites for the exercise of field surveys. One in the Uji River and the other in the Kizu River, indicated by black circles.

(a)

(b)

Figure 3 Picture of the two study sites for the exercise of field surveys. (a) The Uji River at 43.0 km from the river mouth and (b) the Kizu River at 44.0 km from the river mouth.

Route and Schedule of Field Survey

On 11th December 2013 in the IHP training course, the field survey on the measurement of riverbed environmental conditions will be carried out at two sites shown in Figure 4. The schedule of the survey will be as follows.

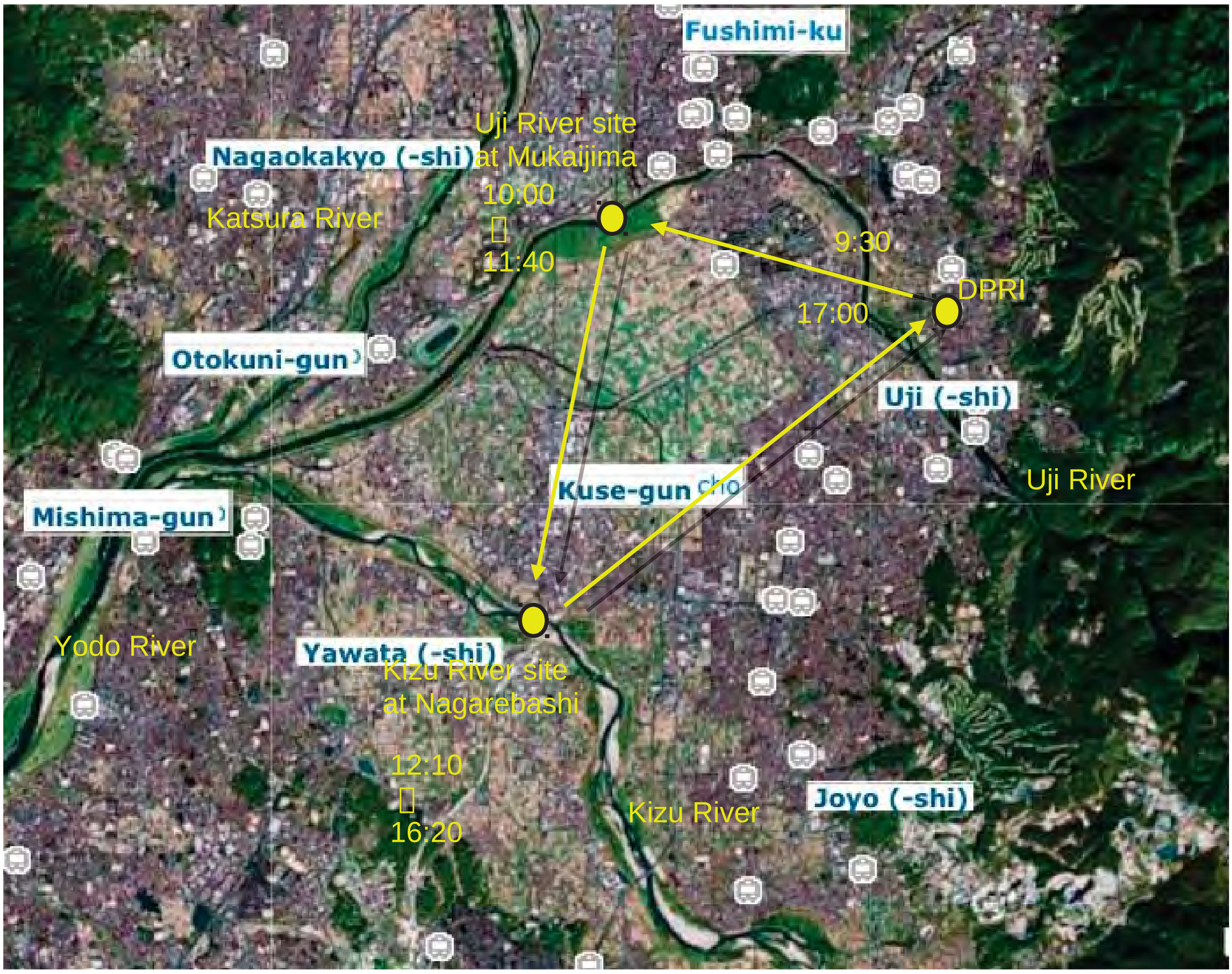


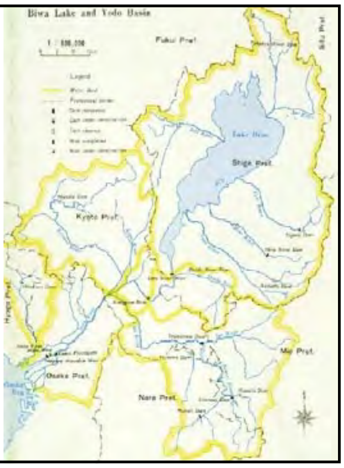
Figure 4 A route map of the field surveys at the Uji River and the Kizu River.

【Schedule】

9:20 Assemble in front of DPRI
9:30 Leave for the Uji River by microbus
10:00 Habitat mapping on the point bar of the Uji River Site (Figure 3a)
10:30 Measurement of environmental factors in the hyporheic zone
11:40 Leave for the Kizu River by microbus
12:10 Lunch at the Kizu River Site (Figure 3b)
13:00 Habitat mapping on the point bar
14:00 Measurement of environmental factors in the hyporheic zone
16:20 Leave for DPRI by microbus
17:00 Dismissal in front of DPRI

Brief Guide of the Lake Biwa and the Uji River
for
Technical excursion of IHP Training Course on Dec 7 (Sat) 2013

Edited by
Yasuhiro TAKEMON
(DPRI, Kyoto Univ)



Time Schedule

Meeting place: in front of lecture room 1 at Obaku Plaza
9:20 Bus arrival
9:30 Departure: Bus travel via local road
10:00 Amagase Dam: walking on the dam
10:20 Departure: Bus travel via highway
11:00 Seta Barrage: Lecture by the engineer, Mr. Kitano
(Government officer of the Lake Biwa)
12:00 Departure: Bus travel via local roa
12:40 Biwa Lake Museum: Lunch at Cafeteria of the Museum
13:30 Biwa Lake Museum: Lecture by the researcher, Dr. Nakai
+ free time inside
15:30 Departure: Bus travel via highway
16:15 DPRI Open Laboratory: Watching the riverbed degradation
in the Uji River
16:30 Departure: Bus travel via local road
17:00 Obaku Plaza: Breakup

Amagase Dam

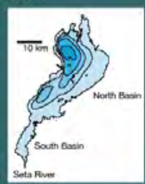
天 ヶ 瀬 ダ ム
Amagase Dam

Lake Biwa

Lake Biwa is a member of ancient lakes older than 100,000 years. The Lake Biwa region has a lake history stretching back four million years, when Lake Oyamada formed. Such ancient lakes often contain endemic species that have evolved in the lakes. The secret to lake longevity is subsidence of the bedrock.

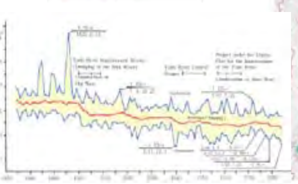
Lake Biwa Facts

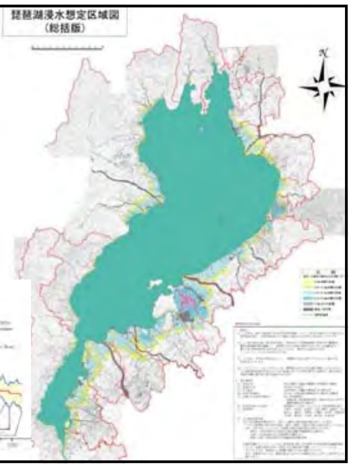
- Size: 674 square km
- Volume: Total 27.5 cubic km
  - North Basin 27.3 cubic km
  - South Basin 0.2 cubic km
- Max depth:
  - North Basin 104 m
  - South Basin 8 m
- Mean depth:
  - North Basin 44 m
  - South Basin 3.5 m
- Length of shoreline: 235 km
- Catchment area: 3,174 square km
- No. of inflowing rivers: 120
- No. of outflowing rivers: 1 (the Seta River)
- Trophic status:
  - North basin mesotrophic
  - South basin eutrophic
- Conservation Status:
  - Lake Biwa was designated a quasi-national park in 1950
  - The entire Lake Biwa region was designated as a wildlife sanctuary in 1971
  - Lake Biwa was registered with the Ramsar Convention on Wetlands in 1993 as a wetland of international importance
- No. of endemic species/subspecies: 59, including:
  - 11 species/subspecies of fish (19% of total)
  - 9 species of bivalves (56% of total)
  - 11 species of gastropods (39% of total)



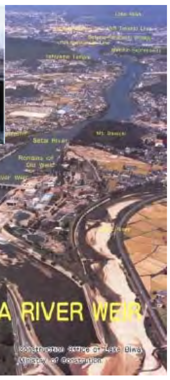
Hazard Map of Lake Biwa Area

凡　例
Area of < 0.5m inundation
Area of 0.5-1.0m inundation
Area of 1.0-2.0m inundation
Area of 2.0-5.0m inundation
Area of >5.0m inundation

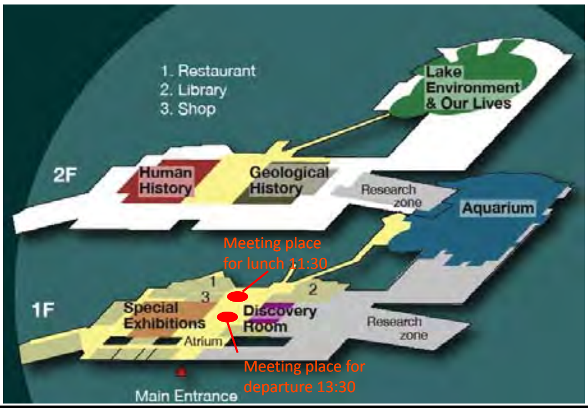




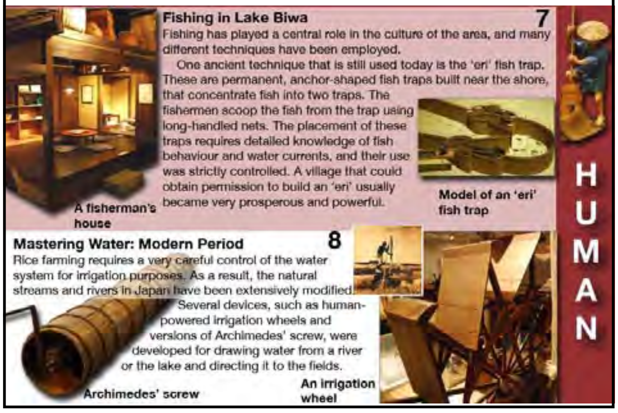
Setagawa weir (Nango-Araizeki)



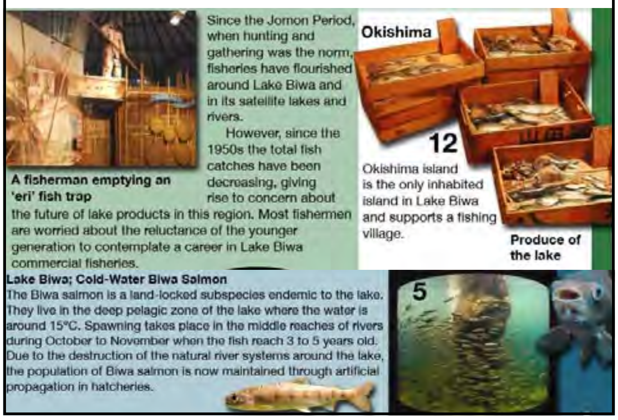
Visit of the Lake Biwa Museum



Natural Resources Exploitation in Lake Biwa



Fisherman's life in Lake Biwa

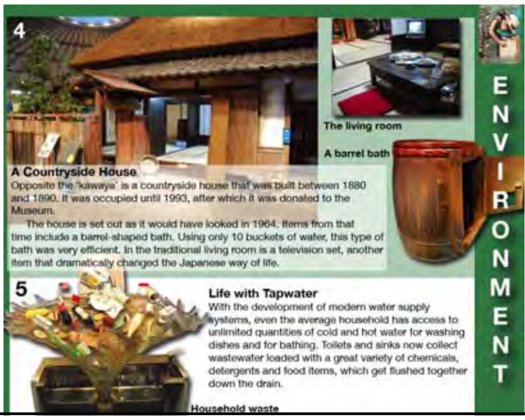


History of flood control in Lake Biwa

Physical Characteristics of the Lake

The waters of the lake can be classified into two types according to light availability and the potential for photosynthesis. The upper zone where light can penetrate sufficiently for photosynthesis is called the euphotic zone, and below that is the decomposition zone. During the summer Lake Biwa is stratified thermally. The sun heats up the top layer of the lake and this warm water rests on top of the colder water below. During the winter the top layer of water gets colder than the underlying water and because cold water is denser than warmer water, it sinks causing vertical mixing of the water column.

Environmental problems in Lake Biwa



You can observe living planktons

You can see a lot of freshwater fishes of Lake Biwa in the aquarium

Lake Biwa; The Biwa Catfish
Known as the guardian spirit of Lake Biwa, the endemic Biwa catfish is one of the largest fish in the lake. It can grow up to 1.2 m in length and weigh over 10 kg.
It is a nocturnal predator, spending the day at over 40 m depth and coming up into shallower water at night to prey on smaller fish.

3

4

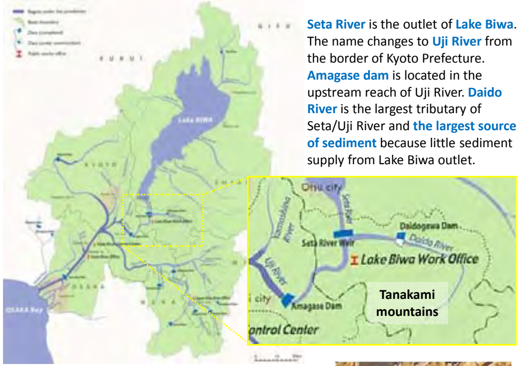
Lake Biwa; Ko-Ayu
Although small in size, the ko-ayu is one of the most abundant fish in Lake Biwa, and also comprises the highest-value fishery in the lake. The ko-ayu spawns either in rivers or on wave-washed pebble beaches along the lake shore.

Mukaijima area of the Uji River

Severe riverbed degradation has been occurring derived from sediment discontinuity by the Amagase Dam and sediment dredging in the Yodo River.

Sedimentation of Amagase-dam

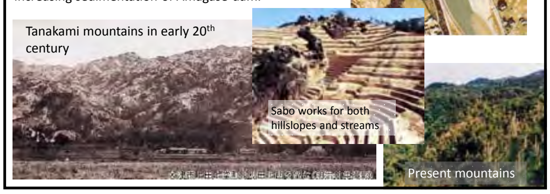
1. Upstream watershed and sediment yield



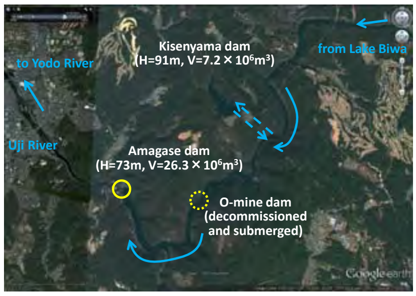
Seta River is the outlet of **Lake Biwa**. The name changes to **Uji River** from the border of Kyoto Prefecture. **Amagase dam** is located in the upstream reach of Uji River. **Daido River** is the largest tributary of Seta/Uji River and **the largest source of sediment** because little sediment supply from Lake Biwa outlet.

Tanakami, upstream basin of Daido river, has yield substantial amount of sediment **since >1200 year ago** due to heavy logging (for temple construction) and **deforestation of granite hillslopes**.

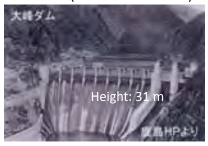
Vegetation has been recovered after **Sabo works**, which started in early 20th century. Sediment yield has been reduced, though Daido River still contributes to increasing sedimentation of Amagase-dam.



2. Construction and operation of dams in Uji River



O-mine dam (constructed in 1923)

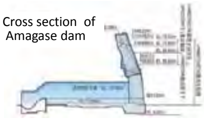


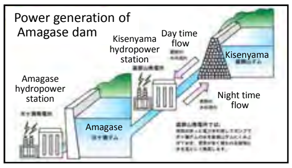
O-mine dam was constructed for hydro-power after an increase of energy demand of Kansai area. It was **the first concrete-gravity dam** in Japan. The **dam was decommissioned** (submerged) by the Amagase dam construction.

Amagase dam (constructed in 1964)

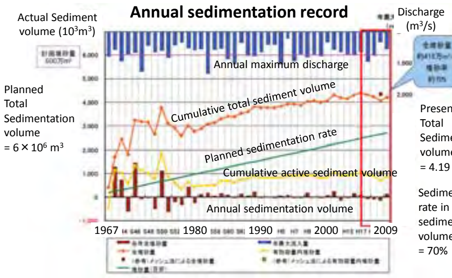
The construction of **Amagase dam** was initiated by **a big typhoon in 1953** that caused heavy damage in the downstream Yodo River and Osaka. It is **a multipurpose dam** (hydro-power, flood mitigation, drinking water supply) supporting Kansai area. **Pumped storage hydro-power station** is also installed between Amagase and Kisenyama dams.

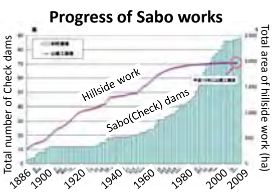
Cross section of Amagase dam





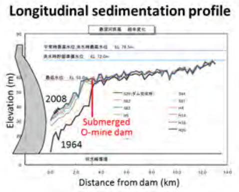
3. Reservoir sedimentation in Amagase dam



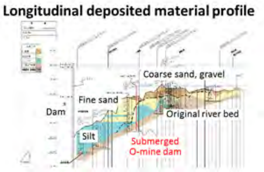


Sedimentation rate was greater in 1960s and 70s. Hillside work and check dam construction have been intensively implemented in 1890-1970 and 1950-2000 respectively. **These Sabo works have drastically reduced sediment yield** from Daido River to Amagase dam.

Almost 70% of planned sedimentation volume has been already filled. Capacity loss of total storage is 16%.

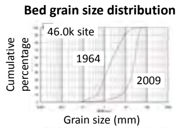


Most sediment deposit can be observed in the downstream of submerged O-mine dam, where deposit depth is almost 20 m.

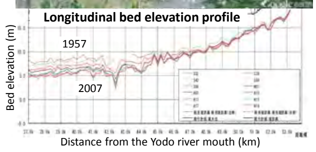


Deposited materials change at submerged O-mine dam, coarse sediment in the upstream, while fine one in the downstream.

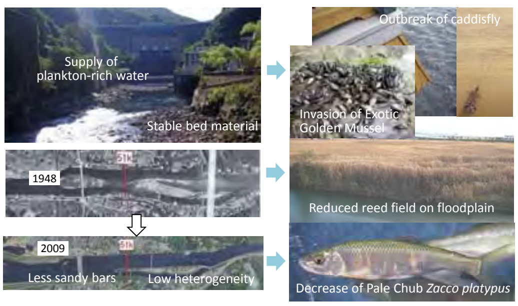
4. Dam and environmental issues in Uji River



In the downstream of Amagase dam, the **channel was degradated** (bed lowered for >3 m in the downstream part) due to **reduced sediment supply from upstream** and channel excavation. Bed materials have been coarsened.



Environmental issues and future works



Sandy bars and river-floodplain ecotones have decreased in area, which negatively impacted habitats of various aquatic plants and animals, while encouraged increase of particular organisms including exotic species. Supply of sediment, especially coarse sand and gravel, is essential for the recovery of biodiversity and ecosystem function of Uji River. The issues should be solved together with sedimentation of Amagase dam.