International Hydrological Programme

Risk Management of Water-related Disasters under Changing Climate

The Twenty-fifth IHP Training Course

30 November - 11 December, 2015

Kyoto, Japan

Water Resources Research Center, Disaster Prevention Research Institute, Kyoto University
Hydrospheric Atmospheric Research Center, Nagoya University

Supported by
Disaster Prevention Research Institute, Kyoto University

Outline

A two-week training course on risk management of water-related disasters under changing climate 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 technical visits to the Yodo River Basin will be held mainly at the Disaster Prevention Research Institute (DPRI), Kyoto University during the two weeks from 30 November to 11 December 2015.

Objectives

The number of human losses and economic damages linked to human practices has been exacerbated by water-related extreme events. Water-related risk might further increase for a number of reasons. The probability of extreme events which cause high impacts to society is expected to increase because of human activities and/or as a result of climate variability and change. On the other hand, increasing population and economic growth lead to intensive urbanization, often in flood prone areas. Frequent disaster will prevent from developing or exhaust society. Poor water governance coupled with lack of adequate emergency management institutions and infrastructures reduces society's capacity to cope with extreme events and therefore increases the risk to life and property. In order to realize sustainable development, appropriate risk management of water-related disasters is indispensable.

In light of the Focal Area 1.1 "*Risk management as adaptation to global change*" under the Theme 1 "*Water related disasters under hydrological change*" of the IHP-VIII, the 25th IHP training course is focused on three major objectives: (1) to acquire the latest knowledge on risk management on water-related disasters under changing climate at river basin scale, (2) to make practice on methodologies for risk assessment, and (3) to discuss alternatives of risk management at river basin scale.

Dates

30 November to 11 December, 2015

Venue

Disaster Prevention Research Institute, Kyoto University, Uji, Japan

Conveners

Convener: TANAKA, Shigenobu (Disaster Prevention Research Institute, Kyoto University)
Chief assistant: NOHARA, Daisuke (Disaster Prevention Research Institute, Kyoto University)

Lectures

Keynote 1 Resilience and urban floods management strategies — P. Gourbesville

Keynote 2 Water-related disaster risk, resilience and building back better — K. Takeuchi

Keynote 3 Role of data in flood modeling, flood management and Pakistan project — S. Khan

Lecture 1 Projected future meteorological environment - Heading to adaptation strategy - — E. Nakakita

Lecture 2 Fundamentals of basin-scale hydrological analysis — Y. Tachikawa

Lecture 3 Fundamentals in rainfall-runoff-inundation modelling — T. Sayama

Lecture 4 Data Integration and Analysis System (DIAS) for water-related disasters — A. Kawasaki

Lecture 5 Fundamentals in flood frequency analysis — S. Tanaka

Lecture 6 Efforts to develop disaster statistics in the world — Y. Ono

Lecture 7 Fundamentals in river basin modelling — Y. Sato

Lecture 8 Fundamentals in optimum operation of reservoir systems — T. Hori

Lecture 9 Wadi flash floods risk management under changing climate in the arid regions — S.A. Kantoush

Lecture 10 Flood risk assessment toward flood risk management — H. Tatano

Lecture 11 Integrated sediment and floating debris management — T. Sumi

Practices

Exercise 1 Self-introduction and country report on risk management of water-related disasters — (All participants)

Exercise 2 Fundamentals of data processing — T. Hamaguchi

Exercise 3 Data analysis of GCM and historical data — K. Tanaka

Exercise 4 Flood frequency analysis — S. Tanaka

Exercise 5 Rainfall-runoff-inundation modelling — T. Sayama

Exercise 6 Optimization of reservoir operation — D. Nohara

Technical visit and field workshop

Lake Biwa, Katsura River, Yodo River and Hiyoshi Dam

Schedule (30 November to 11 December)

Date	Time	Lectures/exercises
30 November (Monday)	9:30 – 11:00 11:15 – 12:30 14:00 – 16:00 16:30 – 18:00	Opening, Registration & Guidance Exercise 1 (by each participant) Keynote 1 by P. Gourbesville Welcome party (@ Room S-217D)
1 December (Tuesday)	9:00 – 10:30 10:45 – 12:15 14:00 – 16:30	Keynote 2 by K. Takeuchi Keynote 3 by S. Khan Exercise 2 by T. Hamaguchi
2 December (Wednesday)	9:30 – 12:00 13:00 – 13:30 14:00 – 16:30	Lecture 1 by E. Nakakita Short Lecture by M. Suzuki & T. Goto (JICA) Lecture 2 by Y. Tachikawa
3 December (Thursday)	9:00 – 12:00 13:30 – 15:15 15:30 – 17:15	Lecture 3 by T. Sayama Lecture 4 by A. Kawasaki Lecture 5 by S. Tanaka
4 December (Friday)	9:30 – 12:00 13:30 – 15:15 15:30 – 17:15	Exercise 3 by K. Tanaka Lecture 6 by Y. Ono Exercise 4 by S. Tanaka
5 December (Saturday)	9:30 – 17:15	(Technical visits to the Lake Biwa and the Uji River by Y. Takemon & D. Nohara)
6 December (Sunday)	10:00 – 17:00	(Technical visits and cultural exchange at the Kamo River and the Biwako Canal)
7 December (Monday)	9:30 – 12:00 14:00 – 16:30	Exercise 5 by T. Sayama Lecture 7 by Y. Sato
8 December (Tuesday)	9:30 – 12:00 14:00 – 16:30	Lecture 8 by T. Hori Exercise 6 by D. Nohara
9 December (Wednesday)	8:45 – 17:00	Field workshop at the Hiyoshi Dam and the Katsura River by S. Tanaka & D. Nohara
10 December (Thursday)	9:00 – 11:30 13:00 – 15:00 15:15 – 17:15	Lecture 9 by S.A. Kantoush Lecture 10 by H. Tatano Lecture 11 by T. Sumi
11 December (Friday)	9:30 – 11:00 11:00 – 11:30 11:30 – 13:00	Report presentation by each participant Completion ceremony Farewell party (@ Room S-217D)

Index of Lecture Materials

LECTURE MATERIALS

Keynote Lecture 1:
"Resilience and urban floods management strategies"

Philippe GOURBESVILLE (*Professor, Polytech Nice Sophia & Innovatice CiTy lab, Nice Sophia Antipolis University, France*)

Abstract: Floods that happen in urban areas are governed by increased frequency. Existing flood defence structures demonstrate its downsides. That signifies that primary protection regarding flood is not sustainable anymore. The solution is moving to risk culture and finding the balance between the shape of land use and urbanization through adaptation, mitigation, prevention, response and recovery strategies. Sensitivity analysis of urban systems implies a deeper investigation of urban flooding, condition of the built environment, way of mapping built environment, its interaction with nature and vulnerability evaluation. Further to that, a resilience approach to solve and assess the sensitivity of urban systems in respect to flooding becomes crucial. The traditional approaches promote the struggle against the water through implementation of structural measures while resilience approach underline flood friendly approach through implementation of non-structural measures that are more adaptable to increased flood frequency. Resilience approach divides responsibility to governmental and community level regarding urban flood risk management. It also considers the resilience of a population to floods and it's measured with time. The structure of urban system interpreted through functional analysis offer the possibility to evaluate resilience of each element of urban system as well as overall resilience. Assessing resilience of urban functions and services provide improved identification of „hot spots" and efficient recommendation of possible flood management strategies. An urban system is defined within city boundaries. The shape of urban systems is changing over time since urbanization is also a dynamic process. Change of urban systems over time does not imply just physical change of landscape. The change of system in social aspect is significant as well e.g. population density. Scaling of urban system allows being able to recognize main urban patterns. Common for each urban system is to have the necessary elements in order to be able to function. In order to break down the structure of urban pattern it is necessary to map system elements to physical components, map the elements to systems requirements. This allows listing all necessary tasks that urban system is performing. Physical components of the systems are urban functions and services. Physical components of urban system are buildings, streets, parks, water distribution network, shops, industrial buildings, electricity network, religion areas, etc. Some of them represent assets that the city needs to have in order to perform while others provide connections between different system components. Urban functions of a city are defined as physical components that urban system need to provide as fundamental needs to residents.

Urban resilience can be characterized through a Flood Resilience Index (FRI) that integrates five dimensions: natural, physical, economical, social and institutional. Within each dimension the set of

major indicators can be chosen. The set of indicators or variables is taken as a substitute because it is very difficult to quantify resilience in relative terms. The indicators are chosen according to the following criteria: Sensitivity, Availability, Affordability and Relevance. The methodology is set to take into account different spatial scales. The evaluation of the Flood Resilience Index (FRI) on parcel/building and the block scale focuses on urban function. The evaluation of FRI for the city and district/block scale is done through five dimensions: natural, physical, social, economic and institutional.

Analysis of urban resilience regarding flooding processes opens the door to a new approach regarding risk management in urban environments. At the same time, the approach clearly underlines the need to redefine urban environments in a more integrated way able to conciliate various objectives at the proper scale for the inhabitants.


Resilience and urban floods management strategies
Philippe GOURBESVILLE
Université Nice Sophia Antipolis
POLYTECH NICE-SOPHIA
I-CiTy
Innovative CiTy Lab


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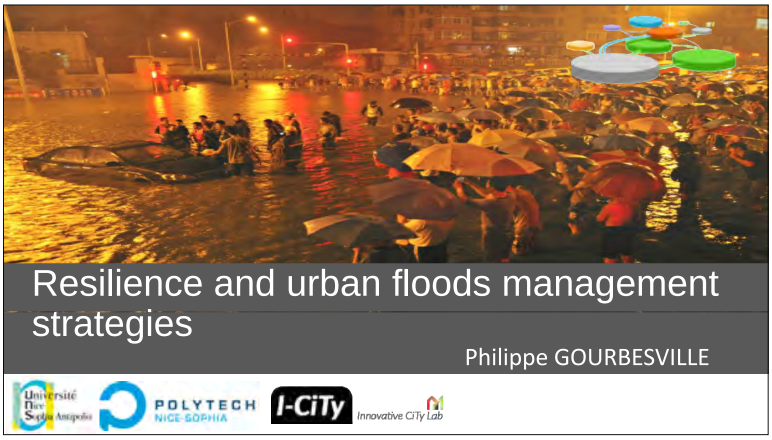
Resilience and urban floods management strategies
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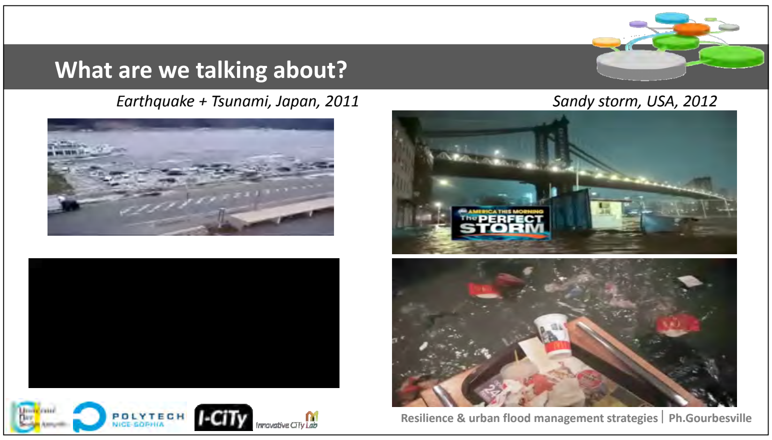
What are we talking about?
Earthquake + Tsunami, Japan, 2011
Sandy storm, USA, 2012
THE PERFECT STORM
POLYTECH NICE-SOPHIA
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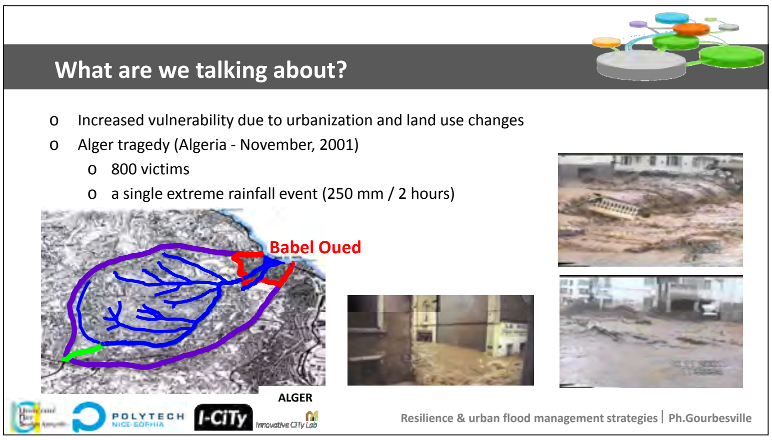
Resilience & urban flood management strategies | Ph.Gourbesville


What are we talking about?
o Increased vulnerability due to urbanization and land use changes
o Alger tragedy (Algeria - November, 2001)
o 800 victims
o a single extreme rainfall event (250 mm / 2 hours)
Babel Oued
ALGER
POLYTECH NICE-SOPHIA
I-CiTy
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What are we talking about?

Development of structural measures & awareness

Example: flood protection wall in Nashville ($ 100 M - 2015)

What are we talking about?

- Structural protection measures doesn't avoid disasters …

Japan, 2011

What are we talking about?

- Structural protection measures doesn't avoid disasters …

Bangladesh, 2015

What are we talking about?

- Extreme events have underlined vulnerability of modern societies & unpreparedness
- A Major impact on urban environments which have a high level of vulnerability due to sophisticate & complex infrastructures…

Japan, 2011

Thailand, 2011

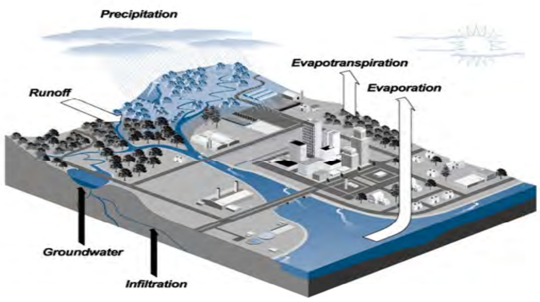
What are we talking about?

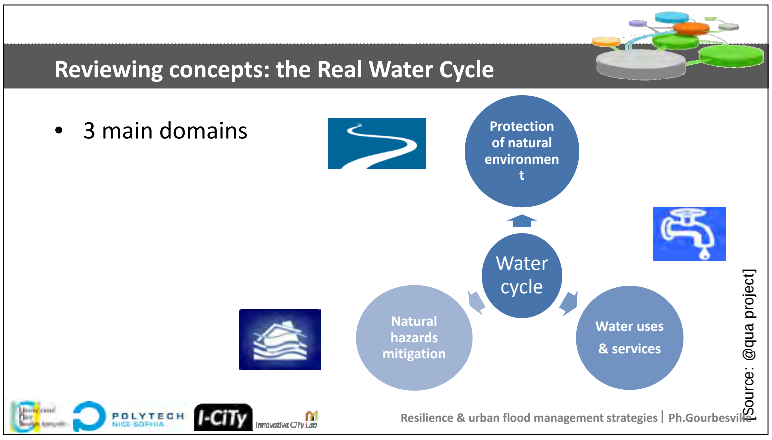
- A need for reviewing protection approach (and engineering design)
- Is protection the only way? Clearly no because 100% safety will be never achieved
- Reviewing engineering concepts… what if?

Japan, 2011

Thailand, 2011

Reviewing concepts: the Water Cycle




Reviewing concepts: the Real Water Cycle
3 main domains
Protection of natural environmen t
Water cycle
Natural hazards mitigation
Water uses & services
[Source: @qua project]
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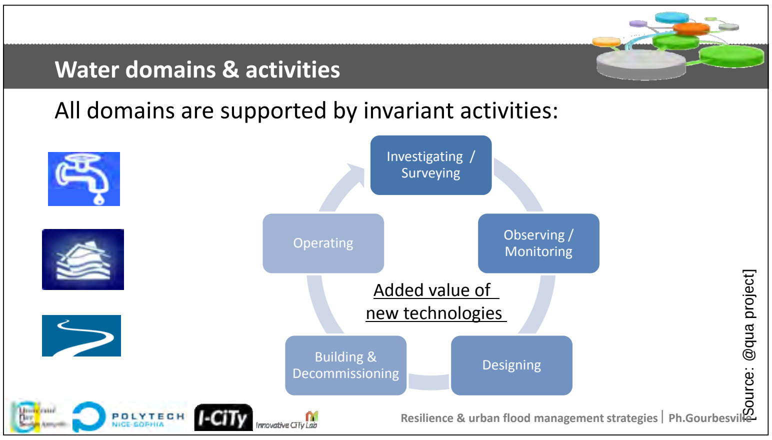
Water domains & activities
All domains are supported by invariant activities:
Investigating / Surveying
Observing / Monitoring
Designing
Building & Decommissioning
Operating
Added value of new technologies
[Source: @qua project]
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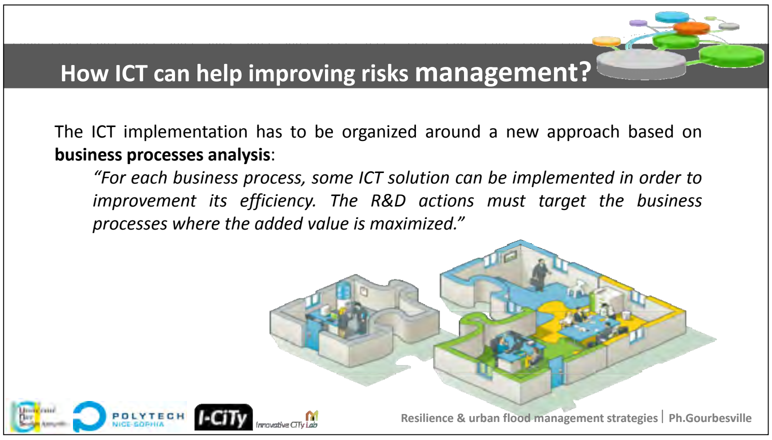
How ICT can help improving risks management?
The ICT implementation has to be organized around a new approach based on business processes analysis:
"For each business process, some ICT solution can be implemented in order to improvement its efficiency. The R&D actions must target the business processes where the added value is maximized."
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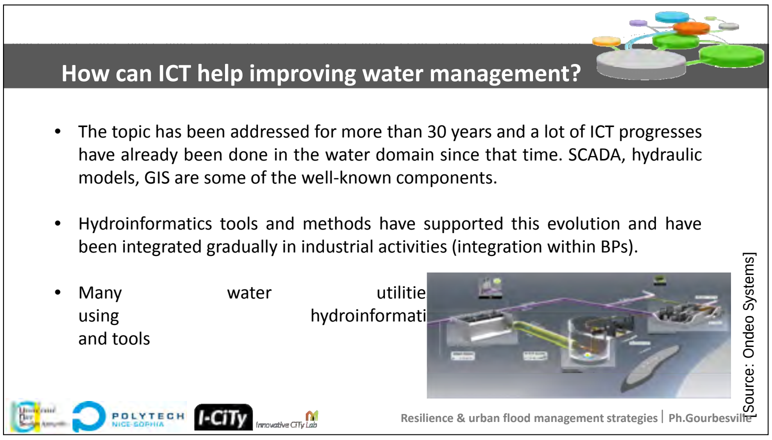
How can ICT help improving water management?
The topic has been addressed for more than 30 years and a lot of ICT progresses have already been done in the water domain since that time. SCADA, hydraulic models, GIS are some of the well-known components.
Hydroinformatics tools and methods have supported this evolution and have been integrated gradually in industrial activities (integration within BPs).
Many water utilitie
using hydroinformati
and tools
[Source: Ondeo Systems]
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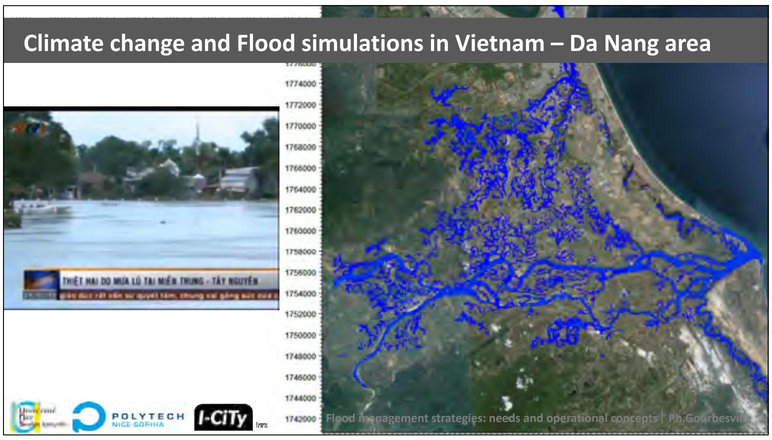
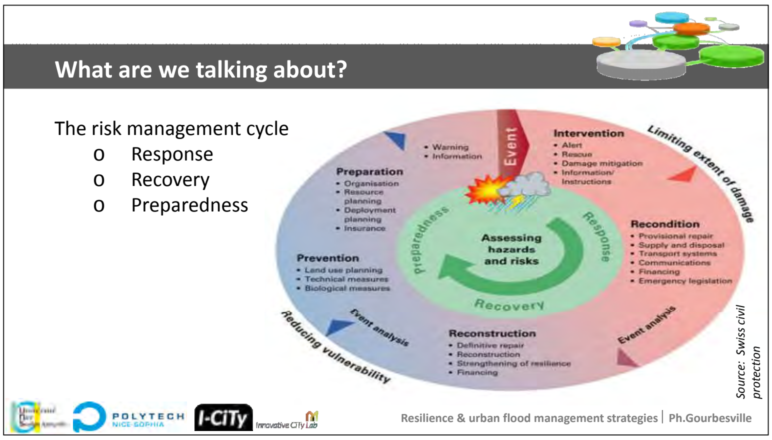
High resolution urban flooding simulation in Mexico city


Climate change and Flood simulations in Vietnam – Da Nang area
Flood management strategies: needs and operational concepts | Ph.Gourbesville


What are we talking about?
The risk management cycle
o Response
o Recovery
o Preparedness
Event
Intervention
Preparation
Prevention
Recondition
Reconstruction
Assessing hazards and risks
Preparedness
Response
Recovery
Limiting extent of damage
Reducing vulnerability
Event analysis
Source: Swiss civil protection
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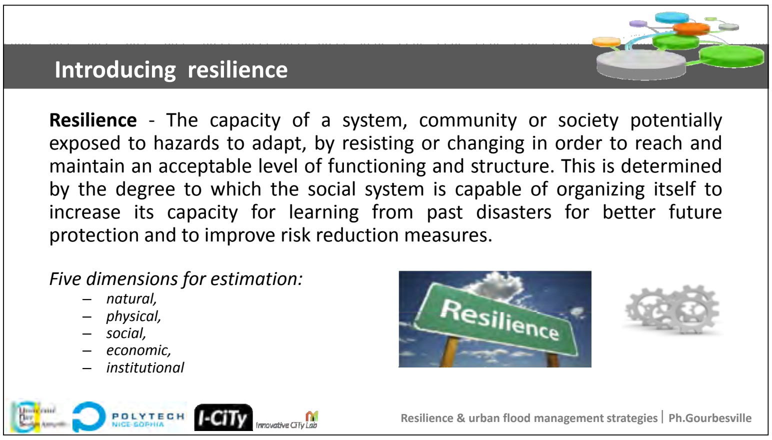
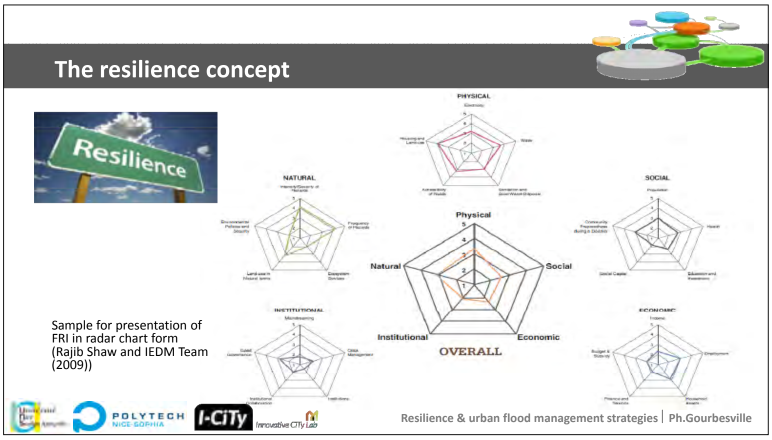

Introducing resilience
Resilience - The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.
Five dimensions for estimation:
– natural,
– physical,
– social,
– economic,
– institutional
Resilience
Resilience & urban flood management strategies | Ph.Gourbesville


The resilience concept
Resilience
PHYSICAL
NATURAL
SOCIAL
Physical
Natural
Social
Institutional
Economic
OVERALL
Sample for presentation of FRI in radar chart form (Rajib Shaw and IEDM Team (2009))
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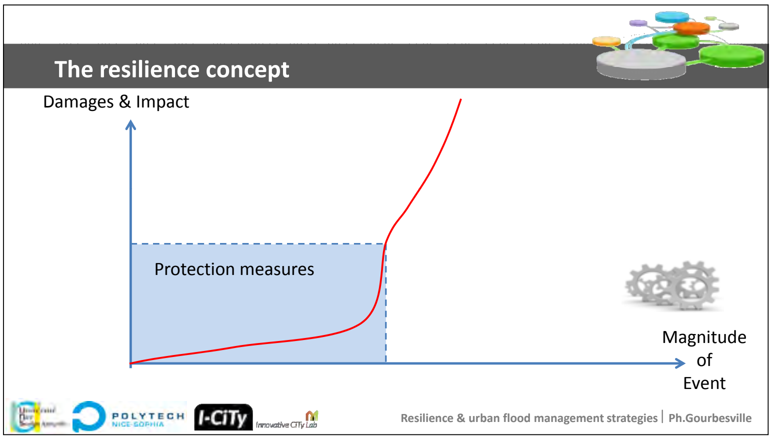
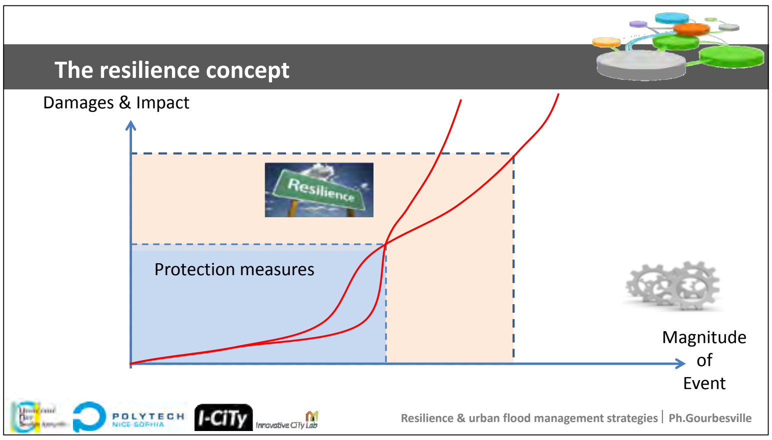

The resilience concept
Damages & Impact
Protection measures
Magnitude of Event
Resilience & urban flood management strategies | Ph.Gourbesville


The resilience concept
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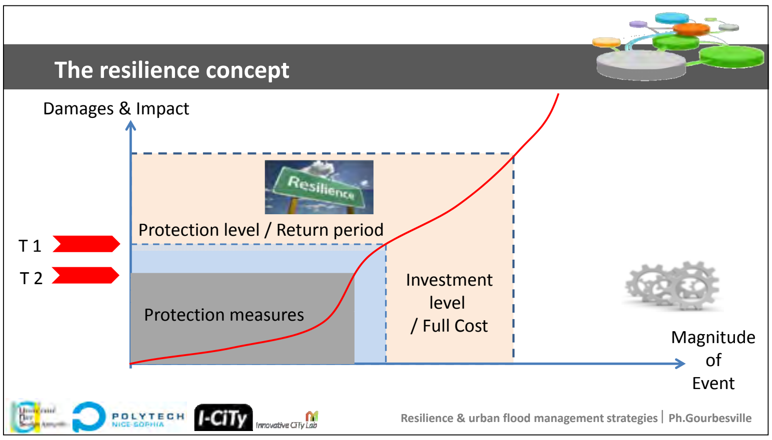
Magnitude of Event
Resilience & urban flood management strategies | Ph.Gourbesville


The resilience concept
Damages & Impact
Resilience
Protection level / Return period
T 1
T 2
Protection measures
Investment level / Full Cost
Magnitude of Event
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What means resilience?

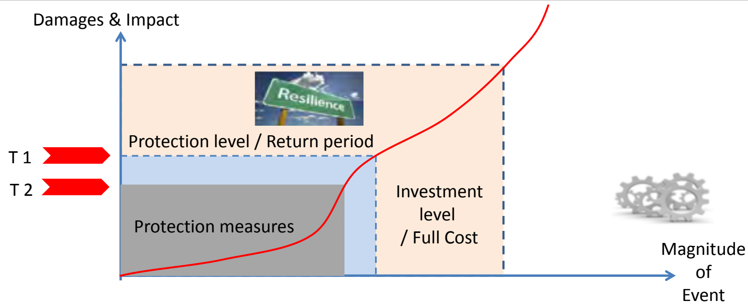
T1: high return period (100y) & limited damages – Choice of developed/old countries

- Nice but doesn't work really! Why it doesn't work?

Several reasons:

- difficult to asses extreme events (obs. & statistics)
- all protections will failed (but no included in design hypothesis)
- human environments are dynamic and change in time and space (design hypothesis are not relevant anymore) and vulnerability as well.
- non stationarity of natural processes (incl. climate evolution)

The resilience concept



Resilience as a new strategy?

T2: lower return period with affordable financial & technical capacity – Situation of developing and emerging countries

Damages?... In some places, less than for developed countries (implicit resilience)

Several reasons:

- better understanding and awareness of processes due to higher frequency
- limited vulnerability (individual & collective)

T2 could be a starting point for developing more resilient environments (avoiding mistakes from others)

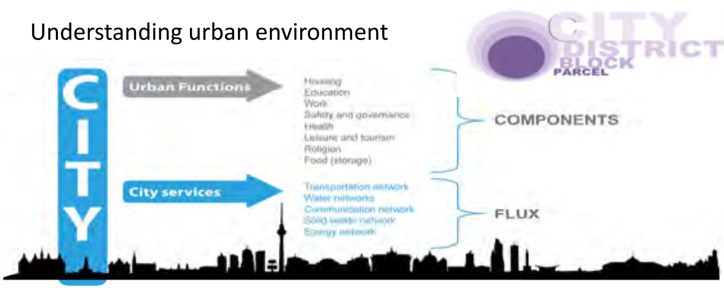
T2 could be an option for rethinking risk management strategies in developed countries (financial & technical constraints)

Flood Resilience Index (FRI)

- Development of urban flood resilience assessment tools with indicators enables a comprehensive overview of resilience of a city and community
- The relationship between the nature of interaction and the structure of an urban system is fundamental
- Developing a simple approach that could be operational in all situations
- Was developed within CORFU FP7 project and applied in European and Asian major cities (exposed to flooding events)

Flood Resilience Index (FRI)

Understanding urban environment



Flood Resilience Index (FRI)

Availability level	Description
0	Not available
1	Poor availability – major interruptions
2	Low availability – interruptions provide minimum availability
3	Medium – small interruptions that are tolerable for small flood durations
4	Medium-high – interruptions that are tolerable for long flood durations
5	Requirement fully provided

Requirements for urban function	Availability level (0 – 5)	Weights (1-5)
EXTERNAL SERVICES		
Energy	0,1,2,3,4,5	1,2,3,4,5
Water	0,1,2,3,4,5	1,2,3,4,5
Waste	0,1,2,3,4,5	1,2,3,4,5
Communication	0,1,2,3,4,5	1,2,3,4,5
Transport	0,1,2,3,4,5	1,2,3,4,5
INTERNAL SERVICES		
Food availability	0,1,2,3,4,5	1,2,3,4,5
Occupation of urban function	0,1,2,3,4,5	1,2,3,4,5
Access to the urban function	0,1,2,3,4,5	1,2,3,4,5
FRI (parcel/building scale)		

$$FRI_{building} = \frac{\sum_{i=0}^{5} r_e \times w_i + \sum_{i=0}^{3} r_i \times w_i}{\sum_{1}^{8} w_i}$$

Flood Resilience Index (FRI)

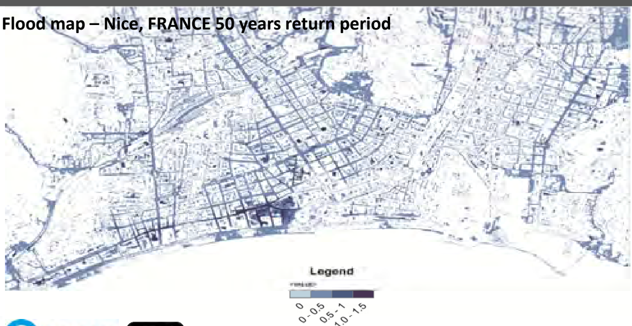
Application to Nice – France

Flood Resilience Index (FRI)

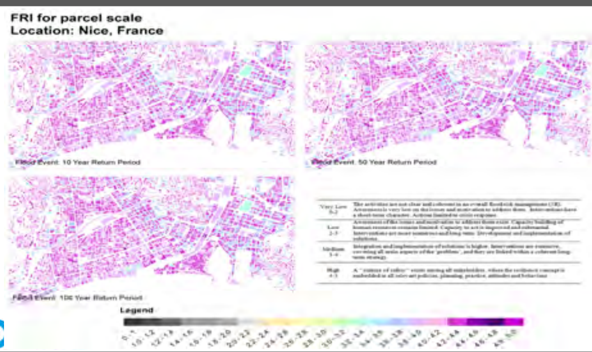
3/10/2015 Nice – France

Flood Resilience Index (FRI)

Flood map – Nice, FRANCE 50 years return period

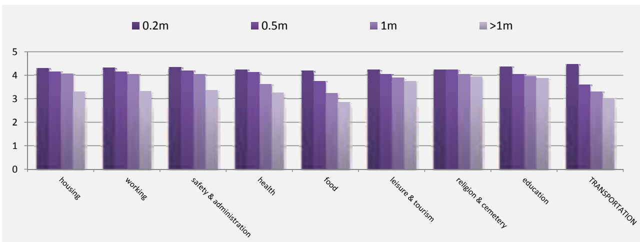


Flood Resilience Index (FRI)



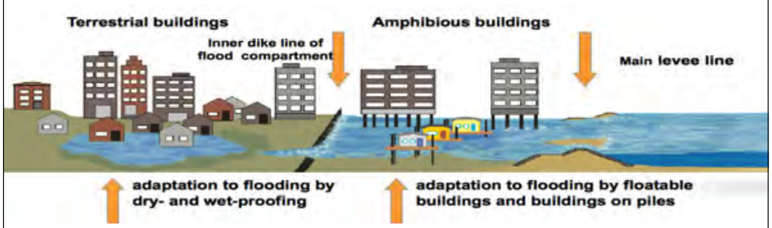
Flood Resilience Index (FRI)

FRI for different water depths



Resilience as a new strategy?

Implementing resilience in urban design & planning



Conclusions & perspectives

- A tremendous task to achieve!!
- Improve understanding of processes
- Rethink cities and be resilient!
- Develop a "risk culture" & improve governance with relevant ICT solutions
- Rethink all concepts (incl. engineering) for a new holistic approach



Thanks for you attention!

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Resilience & urban flood management strategies | Ph.Gourbesville

Keynote Lecture 2:
Water-related disaster risk, resilience and building back better

Kuniyoshi TAKEUCHI (*Advisor, International Centre for Water Hazard and Risk Management, Public Works Research Institute; Professor-Emeritus, Yamanashi University*)

Abstract:

In the Sendai Framework for Disaster Risk Reduction, "resilience" has been markedly emphasized as compared with the Hyogo Framework for Action. Resilience is defined by UNISDR (2009) as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." Thus it is a combination of both resistive capacity and recovery capacity and its difference from risk reduction is the emphasis of recovery capacity.

The four priorities of the Sendai Framework for Action are: understanding risk, risk governance, investing for resilience, and "Enhancing preparedness for effective response, and building back better in recovery and reconstruction." The emphasis of building back better reflects the emphasis of resilience in the Sendai Framework. While such an emphasis is not necessarily popular among those who emphasize the importance of developmental stage before disaster occurs as compared with the humanitarian recovery stage after disaster happens, it is deadly important for resilience building. It is because regardless of the enormous efforts of disaster risk reduction, disaster does occur anywhere anytime and so does disaster recovery. Disaster recovery is a precious occasion to reduce risk and transform society by building back better.

In Banda Aceh, Sumatra, Indonesia, its recovery from the Indian Ocean Tsunami in 2004 was rather quick responding to its Master Plan aiming at "Reconstruction of disaster affected cities by restoring them into their initial state of order". On the other hand, the recovery of Tohoku cities from the devastating Great East Japan Earthquake and Tsunami in 2011 has been rather slow reflecting the Basic Act on Reconstruction that says "promoting dramatic measures … which does not limit itself to recovery from disaster which simply restores affected facilities to its original state".

In the light of resilience building, the benefit of quick recovery is obvious as the cost of supporting evacuees in tolerable condition is tremendous. If recovery time is short, such investment and efforts can be directed for building back better. Prolonged stay in temporal location is hard for people and makes them difficult to move back to the original location as life is already adjusted in the temporal location. On the other hand, if disaster affected people are allowed to move back to the original place before enough risk reduction infrastructure is developed, it is extremely difficult to reintroduce low-risk land-use design after recovery is made. In such cases, different resilience building strategy should be taken. Building back better needs a pre-disaster recovery plan.

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Water-related disaster risk, resilience and building back better

Kuniyoshi Takeuchi
International Centre for Water Hazard and Risk Management under the auspices of UNESCO (ICHARM)
Public Works Research Institute (PWRI)
Tsukuba, Japan

Contents

- From Hyogo to Sendai
- Risk and Resilience
- Building Back Better
  - Banda Aceh
  - Tohoku
  - Tacloban

Hyogo Framework for Action 2005-2015

World Conference on Disaster Reduction (A/CONF.206/6)
Kobe, Hyogo 2005 adopted by 168 nations

Priorities for Action

1. Ensure that disaster risk reduction is a **national and a local priority** with a strong institutional basis for implementation.
2. **Identify, assess and monitor** disaster risks and enhance **early warning**.
3. Use **knowledge, innovation and education** to build a culture of safety and resilience at all levels.
4. Reduce the **underlying risk** factors.
5. Strengthen **disaster preparedness** for effective response at all levels.

Sendai Framework for Disaster Risk Reduction 2015-2030

3rd World Conference on DRR, 18 Mar 2015 (A/CONF.224/CRP.1)

Priorities for Action

- Understanding **disaster risk**.
- **Strengthening governance and institutions** to manage disaster risk.
- **Investing** in economic, social, cultural, and environmental resilience.
- Enhancing **preparedness** for effective response, and **building back better** in recovery and reconstruction.

Seven Global Targets

Sendai Framework for DRR 2015-30

(a) **Substantially reduce** global disaster **mortality** **by 2030**, aiming to lower average per 100,000 global mortality between 2020-2030 compared to 2005-2015.

(b) SR the number of **affected people** globally by …

(c) R direct disaster **economic loss in relation to global GDP** by 2030.

(d) SR disaster **damage to critical infrastructure** and **disruption of basic services** … **through developing resilience** by 2030.

(e) **Substantially increase** the number of **countries with national and local drr strategies** **by 2020**.

★ (f) Substantially **enhance international cooperation to developing countries** through adequate and sustainable support to complement their national actions for implementation of the present Framework by 2030.

(g) Substantially increase **the availability of and access to multi-hazard early warning systems** and **disaster risk information and assessments** to the people by 2030.

Global Sustainability

Disaster Risk

R = H x V

There is no such thing as a natural disaster.

R: **disaster risk** — The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

H: **hazard** — A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation..

V: **vulnerability** — The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

UNISDR (2009) Terminology on Disaster Risk Reduction

ICHARM

Vulnerability

- The characteristics and circumstances of a community, system or asset that **make it <u>susceptible</u> to the damaging effects of a hazard**.

Resilience

- The ability of a system, community or society exposed to hazards to **resist, absorb, accommodate to and recover from the effects of a hazard** in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

ICHARM

Building Back Better

- Disaster occurs anywhere anytime and recovery takes place.
- For recovery large humanitarian budget is invested. Use it for development.
- It is an indispensable occasion to build back better for higher resilience.
  - Turn disasters to opportunities.

ICHARM

Some examples of recovery

Mechanism of building back better

ICHARM

http://yamada-cmjv.jp/

ICHARM

Master Plan for the Rehabilitation and Reconstruction

of the Regions and Communities of the Province of Nanggroe Aceh Darussalam and the Islands of Nias, Province of North Sumatera (Republic of Indonesia, April 2005)

- Section 5.2 (16) "**Reconstruction of disaster affected cities by restoring them into their initial state of order**" and "The cities stricken by earthquake and tsunami are to **be reconstructed by immediate empowerment of the affected people, restoring the initial physical order, social order and economic system**, …, self-restructuring of settlements by the communities concerned, …"

Basic Act on Reconstruction

in response to the Great East Japan Earthquake

(Heisei 23 Law 76, 2011) 24 June 2011

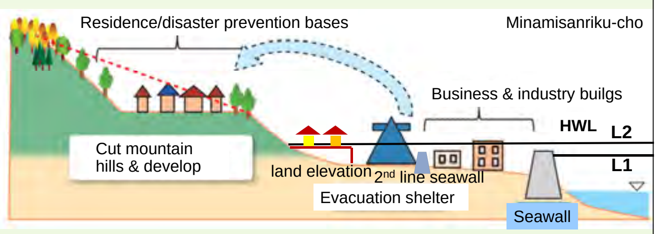
- Article 2 "2) … communities will be **restored with the vision of Japan appropriate for mid-twenty-first century**. Such will be accomplished by promoting dramatic measures with the perspective of revitalizing vibrant Japan which **does not limit itself to recovery from disaster which simply restores affected facilities to its original state**, as well are construction measures which aim to facilitate each individual to overcome the disaster and lead prosperous lives."

Reconstruction principles

(28 Sept 2011)

Two levels Approach

Level 1 Tsunami (Frequent scale: 50-150 years)
Life, prop & livelihood
- Sea walls, highways:



Level 2 Tsunami (Maximum scale: 1000 yr) Life
- Move to higher lands
- Tall buildings to evacuate
- Landuse (park, factories, farmland; commercial/business, residential areas)

Selection of recovery trajectory 1

- It is very costly to maintain temporary houses in tolerable living conditions and public services.
- Prolonged stay in temporal location make people difficult to move back to the newly built original location.
- Consensus building on where to move or elevate, real estate procedures, budgets allocation, moving earth etc. need much time.
- Lack of engineers, machines, companies, too.
- The proper speed and trajectory depend on society: economic conditions, people's perception on a seldom but high impact event, disaster literacy and culture etc.
- Only history would tell the right decision in the future.

Selection of recovery trajectory 2

- Can we stand several years of temporary residence?
  - School, hospital, livelihood, neighbors,
- Do we give up the benefit of everyday convenience for once every 1000-year event? (Ex. in Tohni, back to lowland)
- Low protection with evacuation preparedness would be a practical solution. Next tsunami is not necessarily the largest one. Preparedness works for any.
- How to cope with the fading memory? By memorials, festivals etc. Education leads to safety culture.
- Predesign (pre-disaster recovery plan) reduces waiting time.

Keynote Lecture 3:

Water Security: Responses to Local, Regional, and Global Challenges with Special Reference to Asia-Pacific Region

Shahbaz Khan

UNESCO Regional Science Bureau for Asia and the Pacific, Jakarta, Indonesia

Email: s.khan@unesco.org

The overall theme of International Hydrological Program (IHP) Phase VIII (2014-2021) has been decided by the Member States of UNESCO as Water Security. This is based on the challenges of water availability, both in quality and quantity, for supplying increasing population and demand, and also responding to the needs of ecosystems. It addresses water security challenges at local and global levels. Six themes have been scoped to deliver IHP-VIII: (1) water-related disasters and hydrological change, (2) groundwater in a changing environment, (3) addressing water scarcity and quality, (4) water and human settlements of the future, (5) eco-hydrology, engineering harmony for a sustainable world and (6) water education. The IHP VIII strategy also includes cross-cutting issues such as IWRM, trans-boundary waters and the human dimension. IHP VIII is very important to the Asia-Pacific region which supports about 60 per cent of the world's population with 38 per cent of the world's water resources. The ASPAC region has twenty seven IHP National Committees, seven of which are in LDCs. IHP has been very active in international research through publications for the FRIEND network, including a Catalogue of Rivers for the region.

UNESCO is promoting the use of remote-sensing-based climate and flood warning technology to upgrade flood management of Pakistan. The project will help build the capacity of Pakistan Meteorological Department and other agencies responsible for flood forecasting, early warning and management at the national, provincial and district levels. This project will enable the institutional capacity of Pakistan, to predict floods as prior as 1 to 14 days by tracking weather and flood waves. This would be major milestone in achieving the better capacity to mitigate extreme floods like 2010 floods in Pakistan. The project will not only bring state of the art technology but will also harness linkages between Pakistani institutions such as Pakistan Meteorological Department (PMD), SUPARCO, Federal Flood Commission (FFC), NDMA and Japanese institutions such as International Centre for Water Hazards and Risk Management (ICHARM), a UNESCO Category II Centre, and Japan Aerospace Exploration Agency (JAXA).

Water Security: Responses to Local, Regional, and Global Challenges with Special Reference to Asia-Pacific Region

25th IHP Nagoya-Kyoto Training Course on "Risk Management of Water-related Disasters under Changing Climate"

Professor Dr Shahbaz Khan
UNESCO Regional Science Bureau for Asia and the Pacific, Jakarta, Indonesia

General Description of IHP (International Hydrological Programme)

United Nations Educational, Scientific and Cultural Organization

- Education Sector
- Sciences Sectors
  - Social and Human Sciences
  - Natural Sciences
    - International Hydrological Programme (IHP);
    - Intergovernmental Oceanographic Commission (IOC);
    - Man and the Biosphere Programme (MAB);
    - International Geosciences Programme (IGCP);
    - International Basic Sciences Programme (IBSP).
- Culture Sector

International Hydrological Programme
-UNESCO's Intergovernmental Scientific Cooperative Programme in Hydrology and Water Resources
-The only intergovernmental programme of the UN system devoted to water research, water resources management, and education and capacity building
-Established in 1970's, now that prepared the eighth phase of IHP (IHP-VIII) for 2014 - 2021

IHP- VIII 2014-2021

Water Security:
Response to Global, Regional and Local Challenges

UNESCO IHP Network

UNESCO-IHP in the Asia Pacific Region

- 17 IHP National Committees
- 6 UNESCO Water Centres
- 6 UNESCO Water Chairs in the Asia Pacific Region.
- Regional Steering Committee for Southeast Asia and the Pacific

UNESCO's Actions for Disaster Reduction
Long-term Goals

- Observation and early warning networks of natural hazards
- Hazard risk mapping
- Disaster-resistant building codes
- Education for disaster reduction
- Help make schools safer
- Promotion of public awareness through communication
- Protection of cultural monuments and sites

Strategic Strengthening of Flood Warning and Management Capacity of Pakistan - Phase 1-

Funded by the Government of Japan

7

Extreme Weather Events in Pakistan

8

Extreme Weather Anomalies During 2010

- Jan & February, 2010:
  Drought condition in the country
- June 2010:
  Extreme Heat wave condition. At many places temperatures exceeded 50° C
- July & August 2010:
  Worst Floods in about 100 years

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Executive summary of the 2010 floods

Recorded the historical Maximum (blue)

Recorded above the Designed Capacity (red)

Table 5: Historic Maximum vs 2010 Maximum Peak Discharges of Major Rivers of Pakistan

River	Barrages/ Head-works/ Bridges	Designed Capacity	Historic Maximum Peak (cusecs)		Maximum 2010 Peak (cusecs)	
			Flood	Date	Flood	Date
Indus	Tarbela	15,00,000	5,10,000	31-7-89	8,33,000	30-7-10
	Kalabagh	9,50,000	9,50,000	14-7-42	9,37,453	30-7-10
	Chashma	**9,50,000**	7,86,600	3-8-76	**10,36,673**	01-8-10
	Taunsa	11,00,000	7,88,646	22-7-58	9,59,991	02-8-10
	Guddu	12,00,000	11,99,672	15-8-76	11,48,738**	8&9-8-10
	Sukkur	15,00,000*	11,66,574	15-8-76	11,31,000#	9&11-8-10
	Kotri	**8,75,000**	9,81,000	14-8-56	**9,64,900**	27-8-10
Jhelum	Mangla	10,60,000	9,33,000	10-9-92	3,44,400	30-7-10
	Rasul	8,50,000	9,32,000	10-9-92	2,63,800	30-7-10
Kabul	Warsak	5,40,000	1,50,680	8-7-78	1,52,710	30-7-10
	Nowshera	-	-	-	2,49,100^	10-8-10
Chenab	Marala	11,00,000	11,00,000	26-8-57	3,14,378	06-8-10
	Qadirabad	8,07,000	9,48,530	11-9-92	3,29,483	07-8-10
	Trimmu	6,45,000	9,43,225	8-7-59	3,28,926	11-8-10
	Panjnad	7,00,000	8,02,516	17-8-73	3,10,000	13-8-10
Ravi	Balloki	2,25,000	3,89,845	28-9-88	69,900	23-8-10
	Sidhnai	1,50,000	3,30,210	2-10-88	27,600	28-7-10
Sutlej	Sulemanki	3,25,000	5,97,000	8-10-55	58,300	03-9-10

10

Executive summary of the 2010 floods

11

Problem revealed by the flood 2010 and counter measures taken in this project

Upper Indus

There was limited or no flood forecasting ability for the areas severely damaged by the floods ⇒ Flood forecasting including upper-Indus will be introduced by a new system utilizing satellite data (A1)

Lower Indus

The flood devastated the areas where had no inundation experience in the past ⇒ Updating flood hazard maps in lower Indus to cover the new inundated areas (A2)

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Executive summary of the 2010 floods

Flood affected area : 78/121 districts(64%)
Population affected : 20 million (1/9 of population)
Deaths : 2000 approx.
Injured : 3000 approx.
Houses damaged : 1.6 million
Area affected : 100,000 km2
Economic losses : US$10.0 billion
(Direct 6.5billion, Indirect3.6billion)
Reconstruction cost : US$8.74-10.85billion

* Source: Preliminary Damage and Needs Assessment by ADB&WDB

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UNESCO Post 2010 Floods Actions in Pakistan

1) UNESCO DG sent a team of flood management experts to Pakistan on 22nd August 2010.

2)Based on the mission to Pakistan, UNESCO prepared response project with the Pakistani authorities to reinforce the country's capacity in:

- integrated flood and watershed management
- groundwater resources for emergency situations
- landslides and ground instability especially for relocation of affected population.

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Japanese ODA and UNESCO project

JICA Japan International Cooperation Agency

Press Releases

July 12, 2011

Japan funds UNESCO for strengthening flood warning system in Pakistan

The grant amount of Japanese Yen 284 million will be utilized by UNESCO for following three interrelated pillars of the captioned project.

A) Strategic augmentation of flood forecasting and flood risk and hazard mapping capacity.

B) Knowledge platform for sharing transboundary databases and community flood management information.

C) Capacity development for flood forecasting and hazard mapping.

Mr. Takatoshi Nishikata exchanging Grant Agreement with Dr. Kozue Kay Nagata

< 3million USD

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Component of the Pakistan Flood Project

A. Strategic Augmenting of Flood Forecasting and Hazard Mapping Capacity

A-1 Development of Indus IFAS
A-2 Floodplain and Hazard Mapping of Lower Indus

B. Knowledge Platforms for Sharing Transboundary and Community Data

B-1 International Networking for Sharing of Transboundary Data
B-2 Knowledge platform for timely national, provincial and district level data sharing

C. Capacity Development for Flood Forecasting and Hazard Mapping

- *Master degree training course for the Pakistan government staff*
- *Short training courses for the senior water managers*
- *Training workshops on use of flood forecasting models and flood hazard maps*

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Implementation Framework

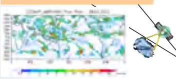
Pakistan Authorities

- PMD — Development of Flood Forecasting System Component
- PCRWR — Soils and Hydrological data, Component: A1
- SUPARCO — Flood Risk Hazard Mapping, Component: A2
- NDMA (Including NIDM) — National Policy and Flood Management at National, Province, District level, Component: B2, C
- FFC — Coordination for flood management at provincial level, Component: B2
- Indus River Commission — Transboundary Data sharing, Component:B1

Data support

- Flood forecasting and early warning system
- Hazard mapping

- GSMAP Local Calibration
*Satellite based rainfall



UNESCO — Project Implementation

International Partners

UNESCO International Network
- Experts, UNESCO Network, Component: A1, A2

UNESCO Water Center
- ICHARM — International Centre for Water Hazard and Risk Management under the auspices of UNESCO, Component: A1, C

- JAXA — Japan Aerospace Exploration Agency, Component: A1, A2

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Project Component

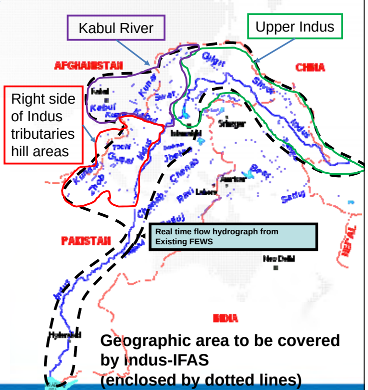
A1 IFAS — Integrated Flood Analysis System

IFAS Introduction

- Indus-IFAS has been developed in collaboration with UNESCO & ICHARM
- Test operation in 2012
- Validation and update in 2013*

*The result was published through FFD/PMD website

- Models have been made operational toward flood season in 2014



Geographic area to be covered by Indus-IFAS (enclosed by dotted lines)

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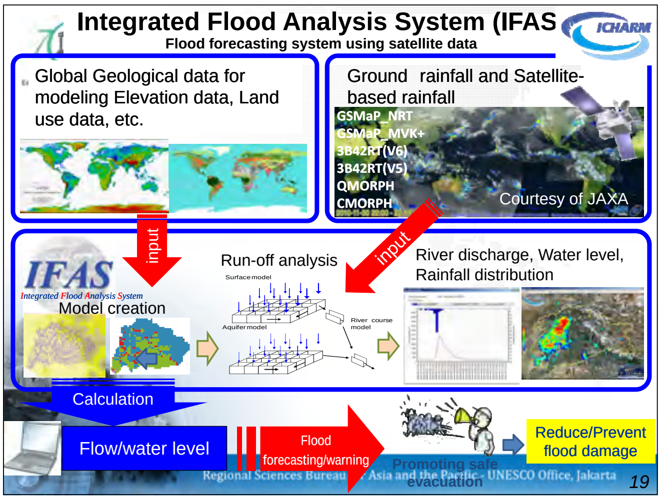
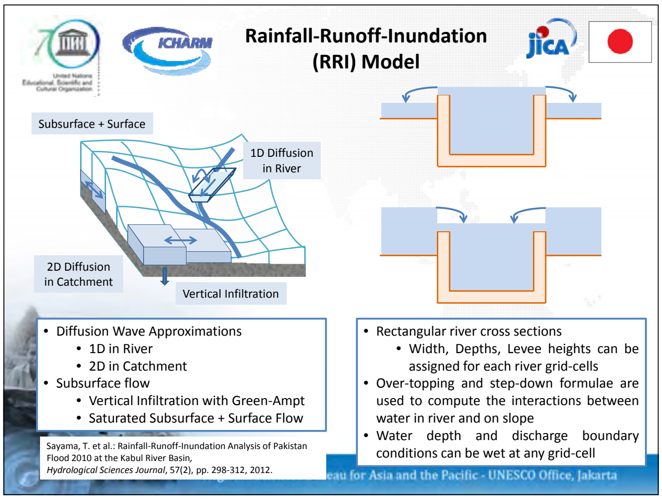
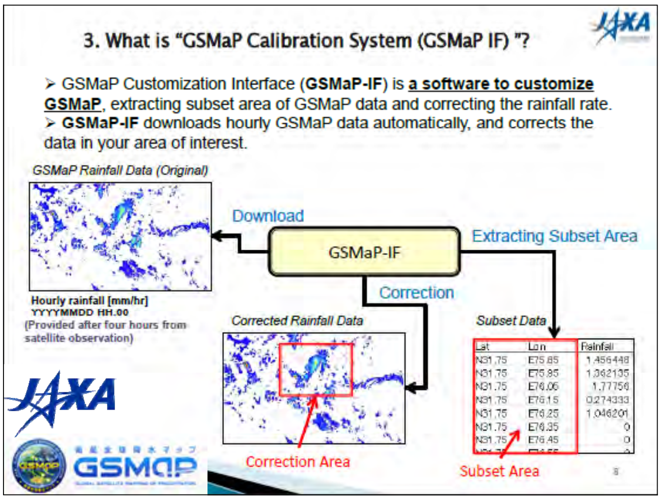


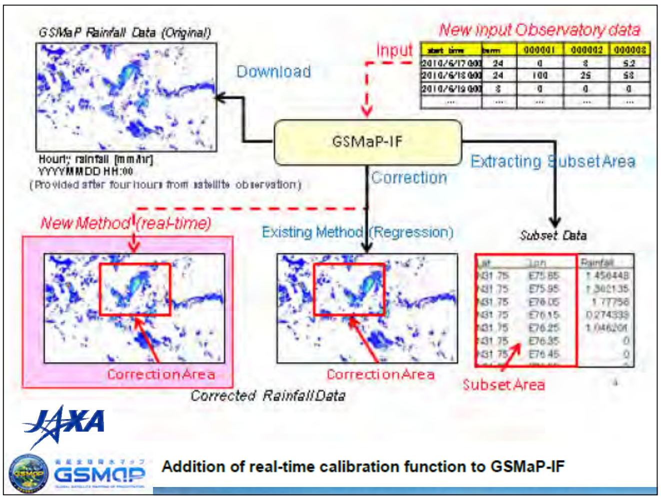
Integrated Flood Analysis System (IFAS
Flood forecasting system using satellite data
Global Geological data for modeling Elevation data, Land use data, etc.
Ground rainfall and Satellite-based rainfall
GSMaP_NRT
GSMaP_MVK+
3B42RT(V6)
3B42RT(V5)
QMORPH
CMORPH
Courtesy of JAXA
input
IFAS
Integrated Flood Analysis System
Model creation
Run-off analysis
input
River discharge, Water level, Rainfall distribution
Calculation
Flow/water level
Flood forecasting/warning
Promoting safe evacuation
Reduce/Prevent flood damage
19



Rainfall-Runoff-Inundation (RRI) Model
Subsurface + Surface
1D Diffusion in River
2D Diffusion in Catchment
Vertical Infiltration
Diffusion Wave Approximations
1D in River
2D in Catchment
Subsurface flow
Vertical Infiltration with Green-Ampt
Saturated Subsurface + Surface Flow
Rectangular river cross sections
Width, Depths, Levee heights can be assigned for each river grid-cells
Over-topping and step-down formulae are used to compute the interactions between water in river and on slope
Water depth and discharge boundary conditions can be wet at any grid-cell
Sayama, T. et al.: Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, Hydrological Sciences Journal, 57(2), pp. 298-312, 2012.

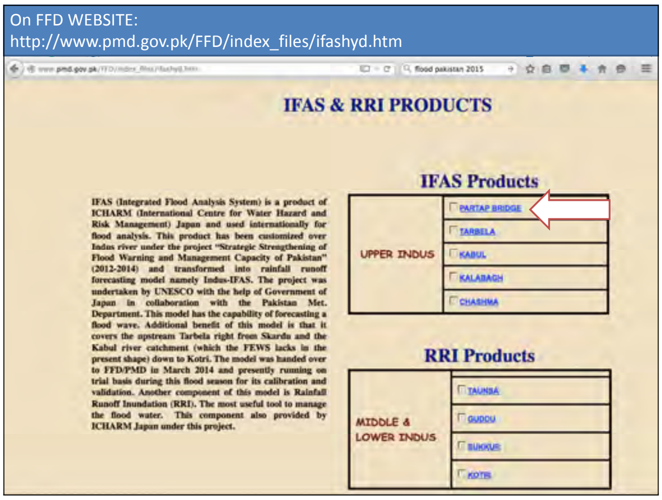


3. What is "GSMaP Calibration System (GSMaP IF) "?
➤ GSMaP Customization Interface (GSMaP-IF) is a software to customize GSMaP, extracting subset area of GSMaP data and correcting the rainfall rate.
➤ GSMaP-IF downloads hourly GSMaP data automatically, and corrects the data in your area of interest.
GSMaP Rainfall Data (Original)
Download
GSMaP-IF
Extracting Subset Area
Correction
Hourly rainfall [mm/hr]
YYYYMMDD HH.00
(Provided after four hours from satellite observation)
Corrected Rainfall Data
Subset Data
Correction Area
Subset Area
JAXA
GSMaP

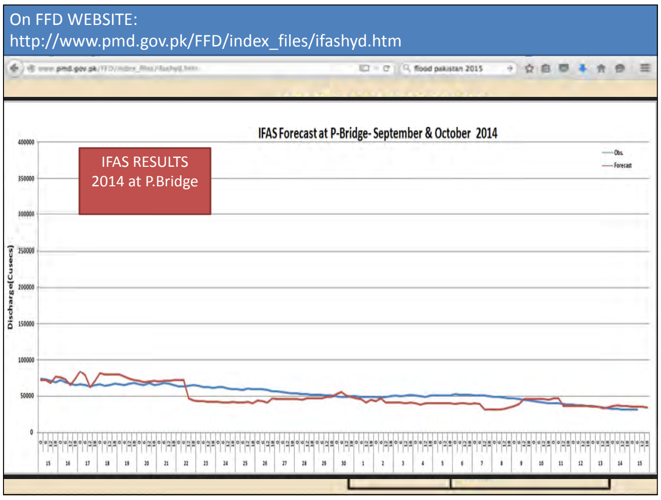


GSMaP Rainfall Data (Original)
New input Observatory data
Input
Download
GSMaP-IF
Extracting Subset Area
Correction
New Method (real-time)
Existing Method (Regression)
Subset Data
Correction Area
Correction Area
Subset Area
Corrected Rainfall Data
JAXA
GSMaP
Addition of real-time calibration function to GSMaP-IF

Project Component
Flood Forecasting Division
46-Jail Road, Lahore-Pakistan
23



On FFD WEBSITE:
http://www.pmd.gov.pk/FFD/index_files/ifashyd.htm
IFAS & RRI PRODUCTS
IFAS Products
IFAS (Integrated Flood Analysis System) is a product of ICHARM (International Centre for Water Hazard and Risk Management) Japan and used internationally for flood analysis. This product has been customized over Indus river under the project "Strategic Strengthening of Flood Warning and Management Capacity of Pakistan" (2012-2014) and transformed into rainfall runoff forecasting model namely Indus-IFAS. The project was undertaken by UNESCO with the help of Government of Japan in collaboration with the Pakistan Met. Department. This model has the capability of forecasting a flood wave. Additional benefit of this model is that it covers the upstream Tarbela right from Skardu and the Kabul river catchment (which the FEWS lacks in the present shape) down to Kotri. The model was handed over to FFD/PMD in March 2014 and presently running on trial basis during this flood season for its calibration and validation. Another component of this model is Rainfall Runoff Inundation (RRI). The most useful tool to manage the flood water. This component also provided by ICHARM Japan under this project.
UPPER INDUS
PARTAP BRIDGE
TARBELA
KABUL
KALABAGH
CHASHMA
RRI Products
MIDDLE & LOWER INDUS
TAUNSA
GUDDU
SUKKUR
KOTRI


On FFD WEBSITE:
http://www.pmd.gov.pk/FFD/index_files/ifashyd.htm
IFAS Forecast at P-Bridge- September & October 2014
IFAS RESULTS
2014 at P.Bridge
Discharge(Cusecs)
Obs.
Forecast


On FFD WEBSITE:
http://www.pmd.gov.pk/FFD/index_files/ifashyd.htm
IFAS & RRI PRODUCTS
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UPPER INDUS
PARTAP BRIDGE
TARBELA
KABUL
KALABAGH
CHASHMA
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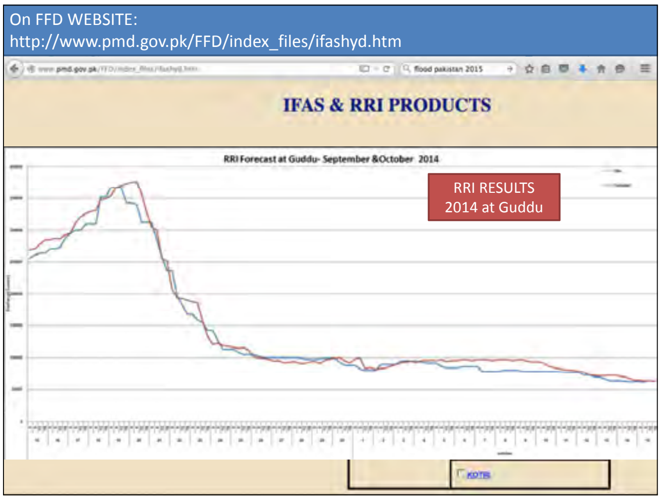
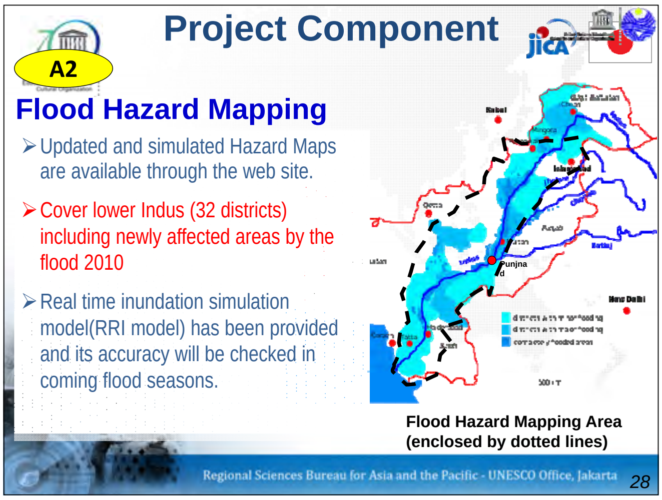
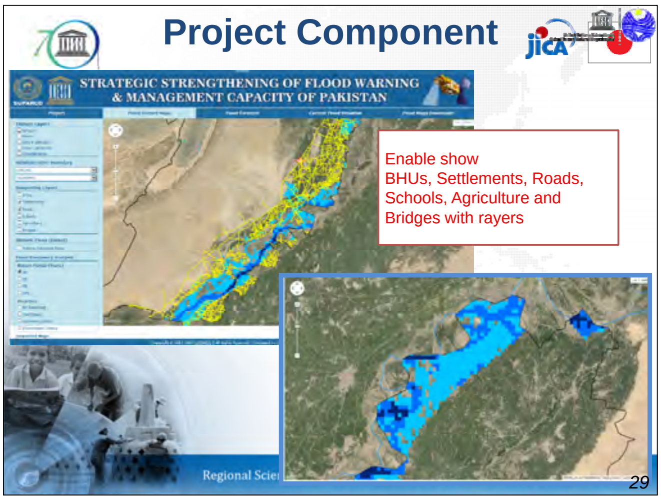
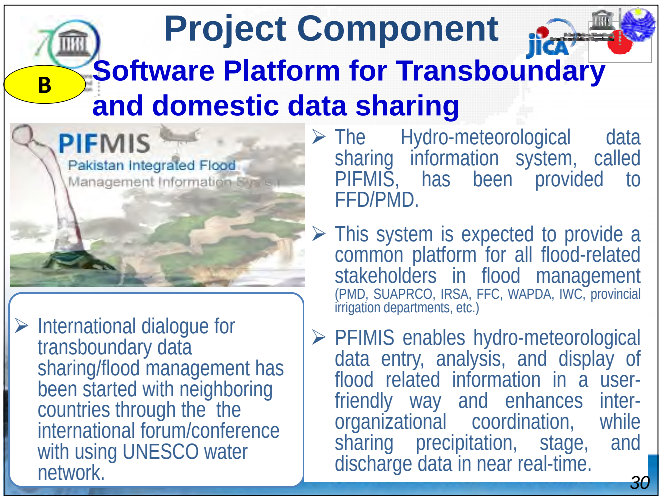
MIDDLE & LOWER INDUS
TAUNSA
GUDDU
SUKKUR
KOTRI


On FFD WEBSITE:
http://www.pmd.gov.pk/FFD/index_files/ifashyd.htm
IFAS & RRI PRODUCTS
RRI Forecast at Guddu- September &October 2014
RRI RESULTS
2014 at Guddu
KOTRI


Project Component
A2
Flood Hazard Mapping
Updated and simulated Hazard Maps are available through the web site.
Cover lower Indus (32 districts) including newly affected areas by the flood 2010
Real time inundation simulation model(RRI model) has been provided and its accuracy will be checked in coming flood seasons.
Kabul
Islamabad
Punjna
New Delhi
Flood Hazard Mapping Area
(enclosed by dotted lines)
Regional Sciences Bureau for Asia and the Pacific - UNESCO Office, Jakarta
28


Project Component
STRATEGIC STRENGTHENING OF FLOOD WARNING & MANAGEMENT CAPACITY OF PAKISTAN
Enable show BHUs, Settlements, Roads, Schools, Agriculture and Bridges with rayers
29


Project Component
B
Software Platform for Transboundary and domestic data sharing
PIFMIS
Pakistan Integrated Flood Management Information System
The Hydro-meteorological data sharing information system, called PIFMIS, has been provided to FFD/PMD.
This system is expected to provide a common platform for all flood-related stakeholders in flood management (PMD, SUAPRCO, IRSA, FFC, WAPDA, IWC, provincial irrigation departments, etc.)
PFIMIS enables hydro-meteorological data entry, analysis, and display of flood related information in a user-friendly way and enhances inter-organizational coordination, while sharing precipitation, stage, and discharge data in near real-time.
International dialogue for transboundary data sharing/flood management has been started with neighboring countries through the the international forum/conference with using UNESCO water network.
30

Project Component

B **Software Platform for Transboundary and domestic data sharing**

➢ A media centre equipped with advanced devices was newly established in PMD-FFD in Lahore within the framework of the project and it enables to directly provide the real time flood forecasting and warning to the public.

Project Component（3/3）

C **Human Capacity Development**

Master Degree Course training

Flood fighting drill & Flood forecasting/ operation room observation (short term training)

➢ Several human capacity building activities were conducted for Pakistan agencies.

➢ 6 Pakistan professionals(PMD, SUPARCO, Irrigation department) have graduated and obtained Master's Degrees through ICHARM training course in Japan.

➢ Intensive short term trainings were conducted for senior managers in Japan and 11 experts have received trainings on flood forecasting and management in Japan.

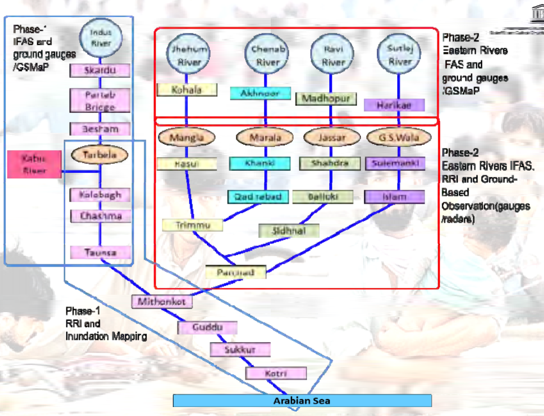
Operationalization of Indus-IFAS

Some examples of links and products distributed during 2015 floods:

- http://reliefweb.int/map/pakistan/pakistan-floods-2015-simulated-inundations-rajanpur-muzaffargarh-rahim-yar-khan-28-july
- http://reliefweb.int/sites/reliefweb.int/files/resources/Map_RRI%20Indus_Rajanpur%20RYK_MGarh_270715.pdf
- http://disasterwatch.sgs-suparco.gov.pk/maps/disasters

Strategic Strengthening of Flood Warning and Management Capacity of Pakistan - Phase 2-

Funded by the Government of Japan



The rivers covered by the previous project (Phase-1) and by the proposed project (Phase-2)

Component of the Pakistan Flood Project -Phase 2-

A. **Establishment of the technical foundation for sustainable capacity development on the flood management, forecasting, early warning and flood hazard analysis in Pakistan agencies**

A-1 Technical studies on the improvement of the accuracy of flood forecasting and early warning system in Pakistan
A-2 Strengthening the flood forecasting and warning capacity in Eastern Rivers (Jhelum, Chenab, Ravi and Sutlej rivers)
A-3 Strategic and continuous enhancement of the flood management capacity in Pakistan

B. **Technical studies to promote strengthening of cooperation with Indus river basin countries for transboundary flood management and transboundary data sharing**

B-1 Technical studies on strengthening of the transboundary flood management capacity of the Indus river basin countries
B-2 Reinforcement of the relationship within the Indus river basin countries for transboundary flood management and data sharing

C. **Capacity building and education to community on flood management for proper utilization of flood hazard information and tools**

Component of the Pakistan Flood Project -Phase 2-

A. **Establishment of the technical foundation for sustainable capacity development on the flood management, forecasting, early warning and flood hazard analysis in Pakistan agencies**

B. **Technical studies to promote strengthening of cooperation with Indus river basin countries for transboundary flood management and transboundary data sharing**

C. **Capacity building and education to community on flood management for proper utilization of flood hazard information and tools**

(i) Technical studies on utilization of the hazard information for better understanding of the local people;
(ii) Education on flood management, response and evacuation for schoolteachers and children;
(iii) Creation of the modular education and training program for school teachers tailored for flood risk reduction with NIDM, NDMA and universities in Pakistan; and
(iv) Training workshops on flood management for local government officers and local leaders (2 times per year - 4 in total);

Current Status

1) Government of Japan and UNESCO signed an agreement of $ 4.05 million for strengthening flood warning system in Pakistan (Islamabad, 10 March 2015)

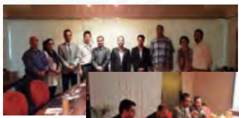
2) Partners contracting.

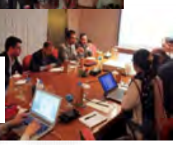
3) International Partners Technical and Capacity Building Meeting (5-8 Aug 2015), Avari Hotel, Lahore with ALL PARTNERS gathered for the first time.

Strategic Strengthening of Flood Warning and Management Capacity of Pakistan (phase2)
International Partners Technical and Capacity Building Meeting (5-8 Aug 2015)

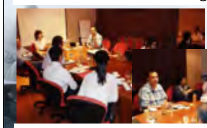
Participants: Pakistan Government (FFD/PMD, PCRWR, SUPARCO), Pakistani Universities and Institutes (NUST, LET Lahore, Peshawar Univ. Beaconhouse National Univ. COMSATS, Soil and Water Conservation Research Institute), Japanese Partners (JAXA, ICHARM), UNESCO, JICA

Partners Technical Meetings（7 Aug）





Meeting with Afghan Partners (8 Aug)



Meeting with Pakistani and Japanese Partners (8 Aug)

Field Trip for Marala Barrage (6 Aug)

Link with Japanese expertise and other JAK activities through JFIT.

25th IHP Nagoya Training course:

"Risk Management of Water-related Disasters under Changing Climate"

Dates : 30 November to 11 December, 2015
Venue : Disaster Prevention Research Institute, Kyoto University, Uji, Japan
Conveners : Prof TANAKA, Shigenobu (DPRI)
Chief assistant: NOHARA, Daisuke (DPRI)

This training is extremely relevant for our project as it will include:

- a comprehensive overview of Water-related disaster risk management with leaders in the region on the topic (ICHARM, KU,TU, UNESCO).
- hands on trainings on RRI with Prof Sayama and frequency analysis with Prof Tanaka.

Thanks
Contact for further information:
s.khan@unesco.org

Lecture 1: Projected future meteorological environment
- Heading to adaptation strategy -

Eiichi NAKAKITA (*Professor, Disaster Prevention Research Institute, Kyoto University, University*)

Abstract:

First, the physical science basis on the climate change reported by the IPCC WG1 in the fifth assessment report of IPCC will be outlined in the lecture. In the report, very important results such as

- Warming of the climate system is unequivocal.
- Human influence on the climate system is clear.
- Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

are reported. Regarding the water cycle, it is predicted that changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

Second, it will be shown what Japanese program on risk information on climate change is. The program is called “SOUSEI program”. Using the world-class supercomputers, such as Earth Simulator, we are pursuing research and development in which all themes are organically linked. Our research and development include prediction and diagnosis of imminent global climate change expected to occur within a few years or decades, research on greenhouse gas emission scenarios and associated long-term climate change projections, development of probabilistic climate change projection techniques, and development of technology for precise impact assessment, etc. Under the program, the theme for precise impact assessments on climate change aims to scientifically demonstrate the connection between the aforementioned increase in natural disasters and global warming and to look 100 years into the future to see how serious it may become. The research results are to be presented as “actual figures” and are expected to be used as data for the government and municipalities to consider how to protect the lives of people in urban and rural areas, coastal areas, and river areas. A “100 year impact assessment” was proposed by this program’s antecedent, KAKUSHIN, but this is the first attempt to produce an actual figure for “the maximum predicted amount of future rainfall.” To generate this kind of specific figure, detailed data with a high degree of precision is required. Even with all the data that we can collect, the sample size and precision are still inadequate. So, it is very important to take on the challenge of developing an assessment model that can produce predictions even given the data limitations, and we endeavor to assess extreme phenomena.

The Twenty-fifth IHP Training Course
(30 November - 11 December, 2015,
Kyoto University, Uji, Kyoto, Japan)

Projected future meteorological environment
- heading to adaptation strategy -

Eiichi Nakakita
Research Division of Atmospheric and Hydrospheric Disaster
Disaster Prevention Research Institute (DPRI)
Kyoto University
nakakita@hmd.dpri.kuoto-u.ac.jp
Leader of Group D

Warming of the climate system is unequivocal.

Human influence on the climate system is clear.

Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

Observations

Understandings

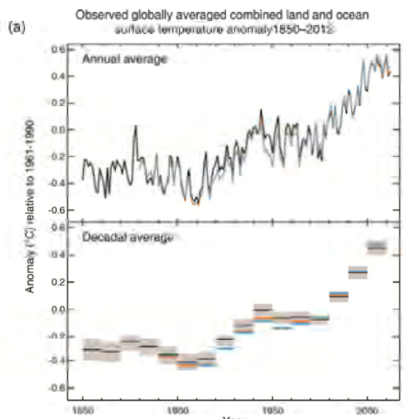
Future

Warming of the climate system is unequivocal.

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

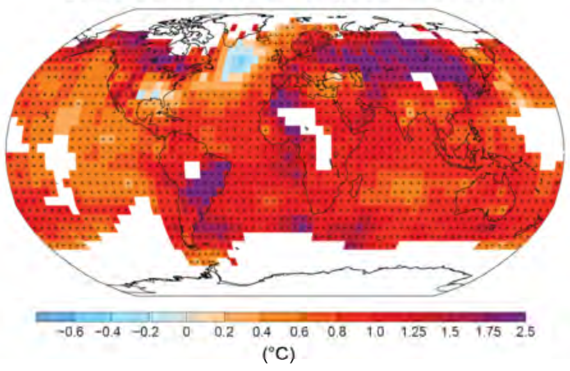
Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850

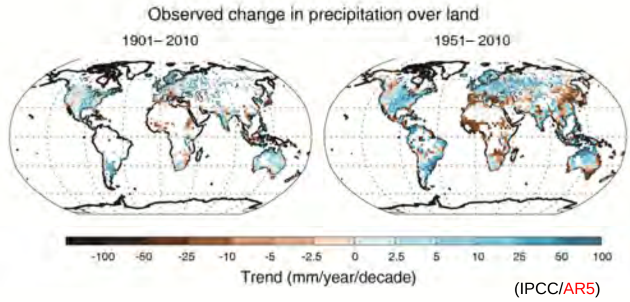


(IPCC/AR5)

Observed change in surface temperature 1901–2012



Precipitation



(IPCC/AR5)

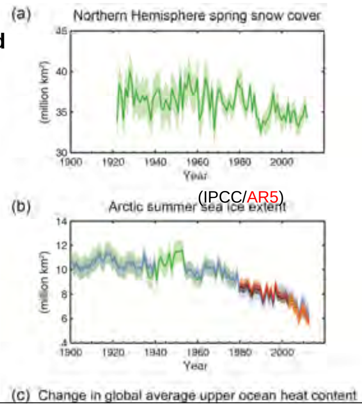
Confidence in precipitation change averaged over global land areas since 1901 is low prior to 1951 and medium afterwards. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951).

Extreme events

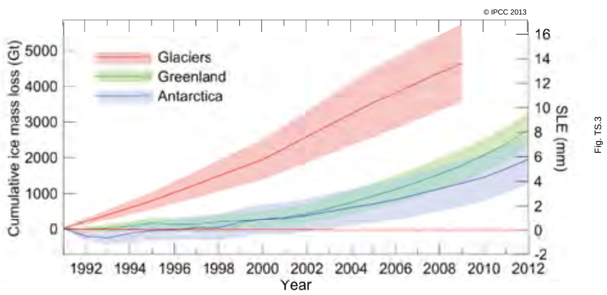
- **Changes in many extreme weather and climate events have been observed since about 1950.**
- **It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale.**
- **It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia.**
- **There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has likely increased in North America and Europe. In other continents, confidence in changes in heavy precipitation events is at most medium.**

Snow and sea ice

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (*high confidence*)

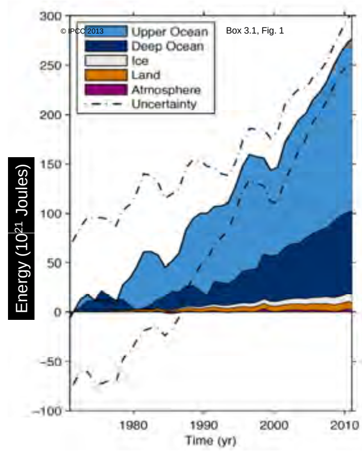


(IPCC/AR5)



Ice loss :	Glaciers	226 (±60%) Gt yr^{-1} (1993-2003)
	Green Land	215 (±25%) Gt yr^{-1} (2002-2011)
	Antarctica	147 (±50%) Gt yr^{-1} (2002-2011)

100 Gt yr^{-1} of ice loss corresponds to 0.28 mm yr^{-1} of global mean sea level rise

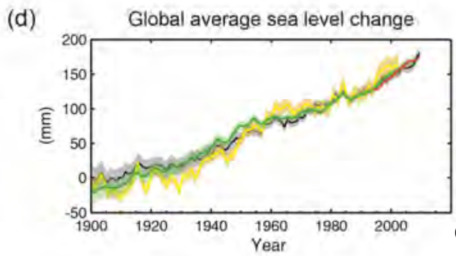


Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*). It is *virtually certain* that the upper ocean (0−700 m) warmed from 1971 to 2010 (see Figure SPM.3), and it *likely* warmed between the 1870s and 1971.

Upper ocean: above 700m

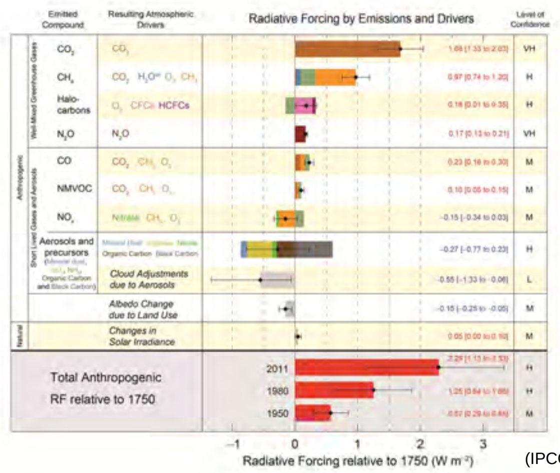
Deep ocean: below 700 m; including below2000 m estimates starting from 1992

Global average sea level



(IPCC/AR5)

The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.

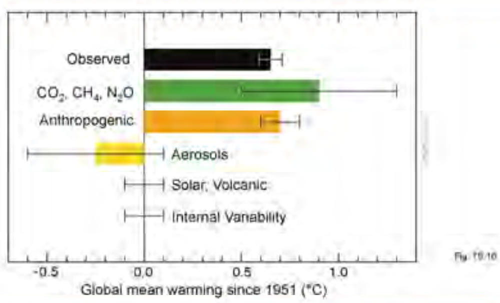


(IPCC/AR5)

Observations

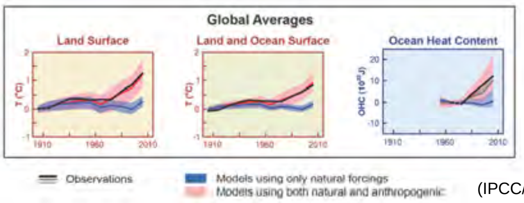
Understandings

Future



Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.

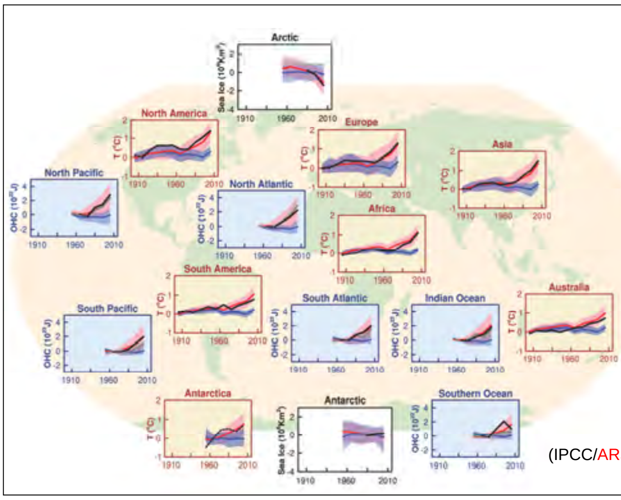
IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis



(IPCC/AR5)

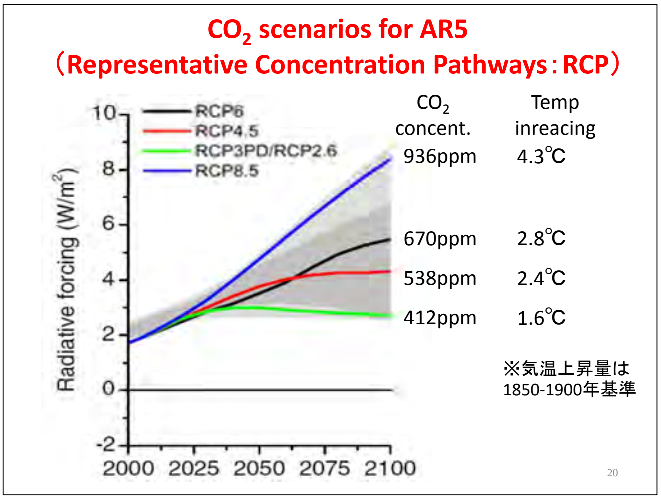
Detection and Attribution of Climate Change

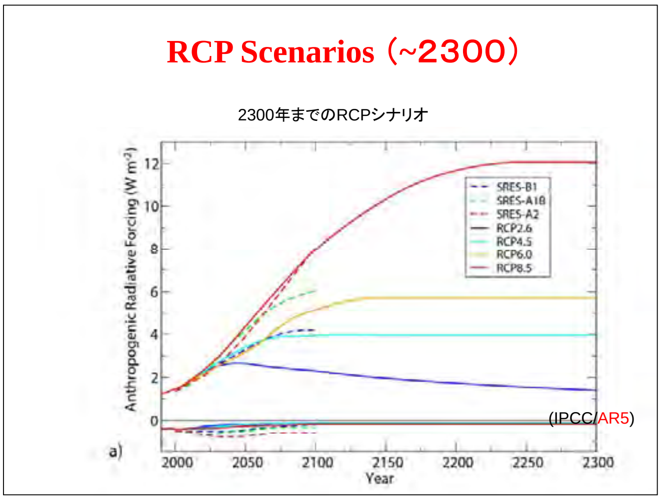
- It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together.
- It is very likely that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s.
- It is likely that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content in the atmosphere (medium confidence), to global-scale changes in precipitation patterns over land (medium confidence), to intensification of heavy precipitation over land regions where data are sufficient (medium confidence), and to changes in surface and sub-surface ocean salinity (very likely). 。

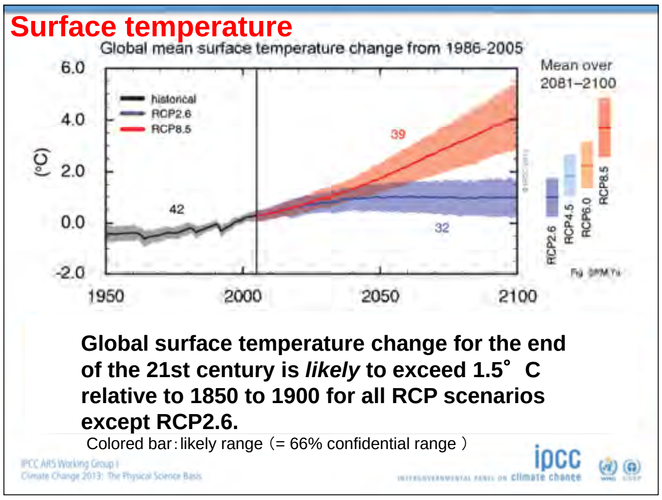


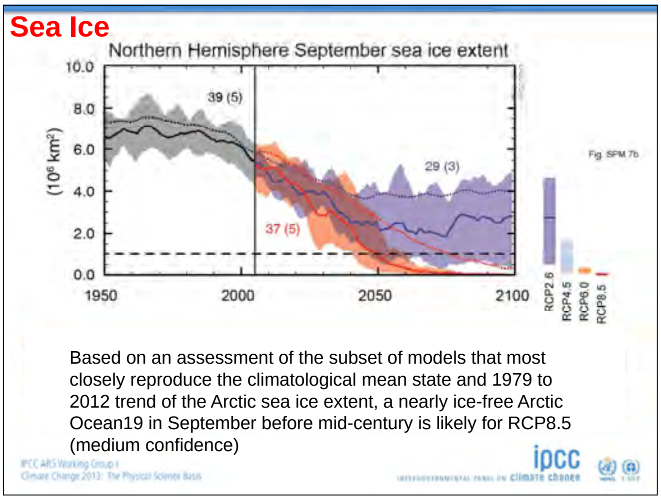
(IPCC/AR5)

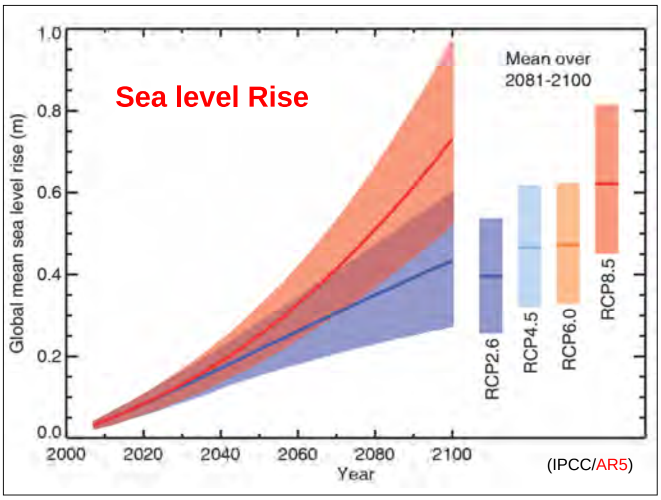

Observations
Understandings
Future
ipcc
INTERGOVERNMENTAL PANEL ON climate change
CLIMATE CHANGE 2013
The Physical Science Basis
WORKING GROUP I CONTRIBUTION TO THE
FIFTH ASSESSMENT REPORT OF THE
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

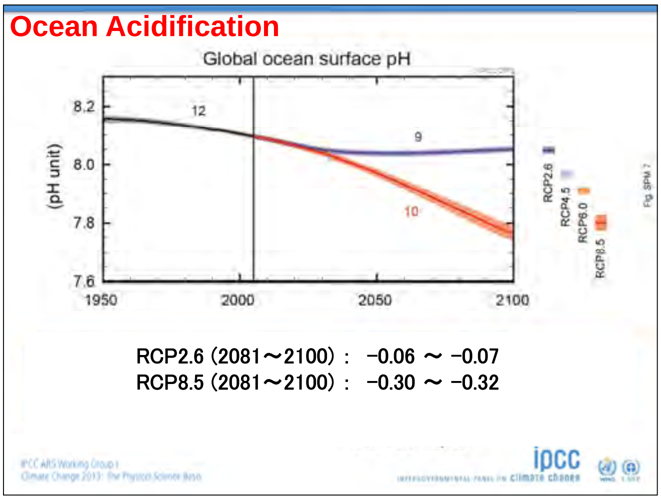

CO2 scenarios for AR5
（Representative Concentration Pathways：RCP）
RCP6
RCP4.5
RCP3PD/RCP2.6
RCP8.5
CO2 concent.
Temp inreacing
936ppm 4.3℃
670ppm 2.8℃
538ppm 2.4℃
412ppm 1.6℃
※気温上昇量は
1850-1900年基準
Radiative forcing (W/m2)
2000 2025 2050 2075 2100
20

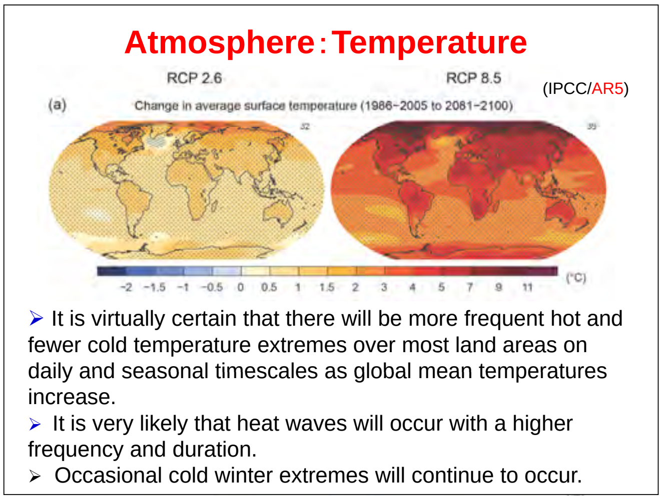

RCP Scenarios（~2300）
2300年までのRCPシナリオ
Anthropogenic Radiative Forcing (W m-2)
SRES-B1
SRES-A1B
SRES-A2
RCP2.6
RCP4.5
RCP6.0
RCP8.5
(IPCC/AR5)
a)
2000 2050 2100 2150 2200 2250 2300
Year

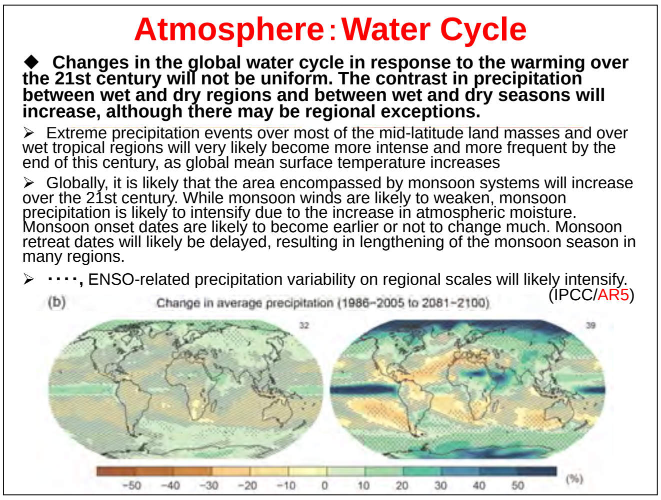

Surface temperature
Global mean surface temperature change from 1986-2005
Mean over 2081–2100
historical
RCP2.6
RCP8.5
(°C)
39
42
32
1950 2000 2050 2100
RCP2.6 RCP4.5 RCP6.0 RCP8.5
Global surface temperature change for the end of the 21st century is likely to exceed 1.5° C relative to 1850 to 1900 for all RCP scenarios except RCP2.6.
Colored bar：likely range（= 66% confidential range ）
ipcc

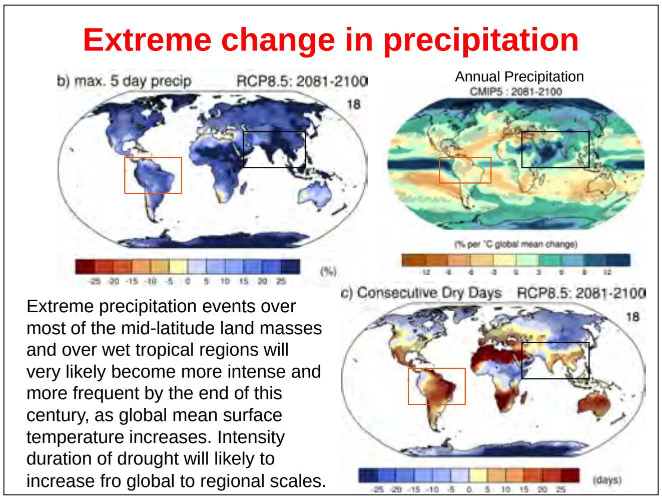

Sea Ice
Northern Hemisphere September sea ice extent
(10⁶ km²)
39 (5)
29 (3)
37 (5)
1950 2000 2050 2100
RCP2.6 RCP4.5 RCP6.0 RCP8.5
Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice extent, a nearly ice-free Arctic Ocean19 in September before mid-century is likely for RCP8.5 (medium confidence)
ipcc

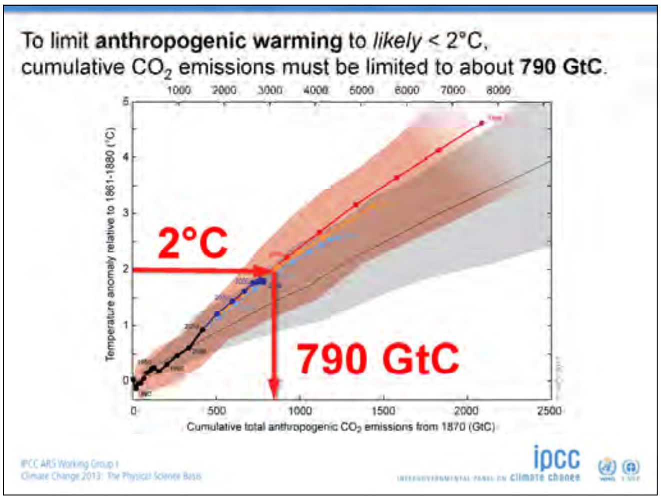

Sea level Rise
Mean over 2081-2100
Global mean sea level rise (m)
2000 2020 2040 2060 2080 2100
Year
RCP2.6 RCP4.5 RCP6.0 RCP8.5
(IPCC/AR5)

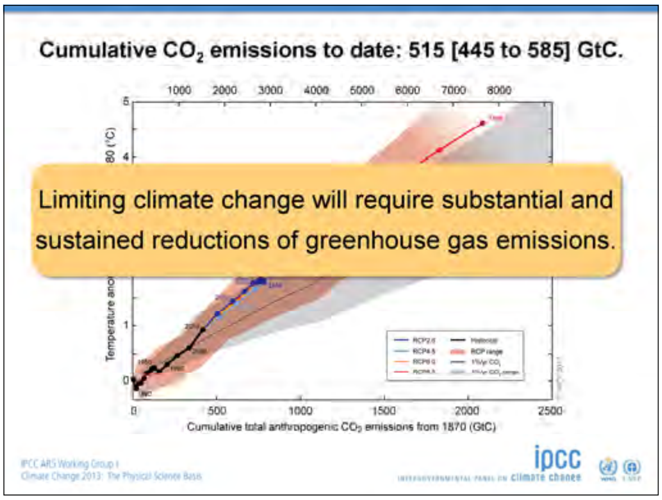

Ocean Acidification
Global ocean surface pH
(pH unit)
8.2
8.0
7.8
7.6
1950
2000
2050
2100
12
9
10
RCP2.6
RCP4.5
RCP6.0
RCP8.5
RCP2.6 (2081～2100)： −0.06 ～ −0.07
RCP8.5 (2081～2100)： −0.30 ～ −0.32

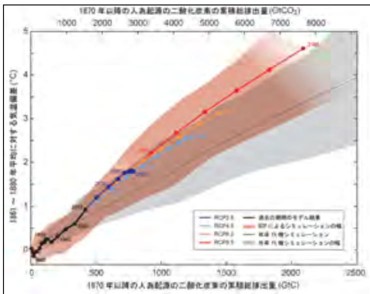

Atmosphere：Temperature
RCP 2.6
RCP 8.5
(IPCC/AR5)
(a)
Change in average surface temperature (1986−2005 to 2081−2100)
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(°C)
➢ It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase.
➢ It is very likely that heat waves will occur with a higher frequency and duration.
➢ Occasional cold winter extremes will continue to occur.


Atmosphere：Water Cycle
◆ Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.
➢ Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases
➢ Globally, it is likely that the area encompassed by monsoon systems will increase over the 21st century. While monsoon winds are likely to weaken, monsoon precipitation is likely to intensify due to the increase in atmospheric moisture. Monsoon onset dates are likely to become earlier or not to change much. Monsoon retreat dates will likely be delayed, resulting in lengthening of the monsoon season in many regions.
➢ ・・・・, ENSO-related precipitation variability on regional scales will likely intensify.
(IPCC/AR5)
(b)
Change in average precipitation (1986−2005 to 2081−2100)
−50 −40 −30 −20 −10 0 10 20 30 40 50
(%)


Extreme change in precipitation
b) max. 5 day precip
RCP8.5: 2081-2100
Annual Precipitation
CMIP5 : 2081-2100
(% per °C global mean change)
(%)
Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases. Intensity duration of drought will likely to increase fro global to regional scales.
c) Consecutive Dry Days
RCP8.5: 2081-2100
(days)


To limit anthropogenic warming to likely < 2°C,
cumulative CO_2 emissions must be limited to about 790 GtC.
2°C
790 GtC
Cumulative total anthropogenic CO_2 emissions from 1870 (GtC)
0 500 1000 1500 2000 2500
ipcc


Cumulative CO_2 emissions to date: 515 [445 to 585] GtC.
Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.
Cumulative total anthropogenic CO_2 emissions from 1870 (GtC)
0 500 1000 1500 2000 2500
ipcc

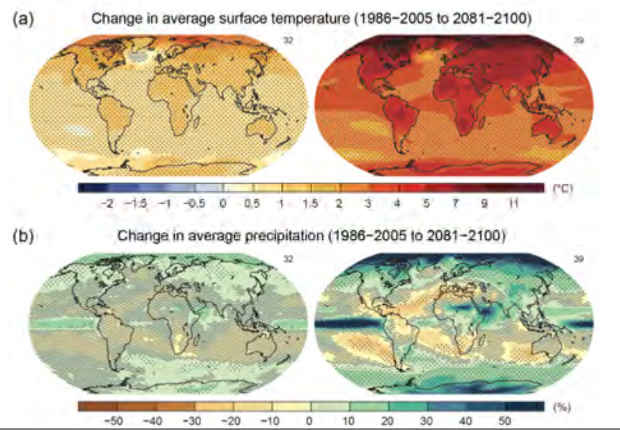


Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

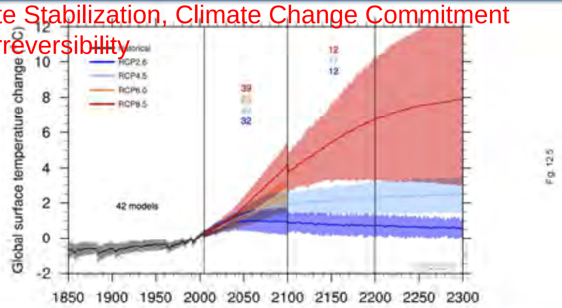
Budget for the 2°C target:	790 Bill. t C
CO_2 emitted until 2011:	−515 Bill. t C
Remaining emissions:	**275 Bill. t C**
CO_2 emissions 2012:	***9.7 Bill. t C/yr***

RCP2.6
CO_{2eq} = 475 ppm

RCP8.5
CO_{2eq} = 1313 ppm

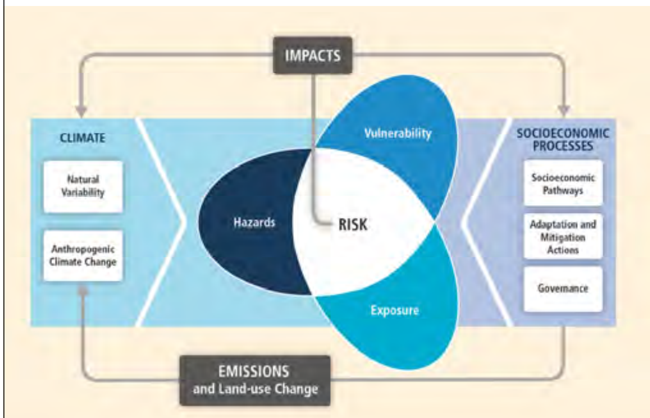


Climate Stabilization, Climate Change Commitment and Irreversibility



Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond (see Figure SPM.10). Most aspects of climate change will persist for many centuries even if emissions of CO2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO2.

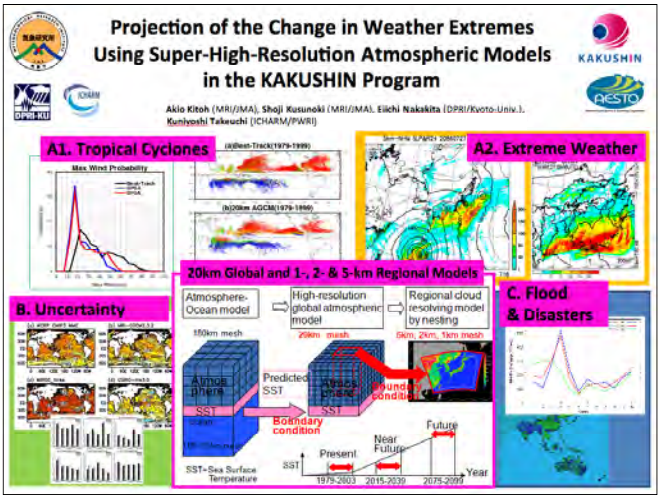
Factors related to risk induced by climate change

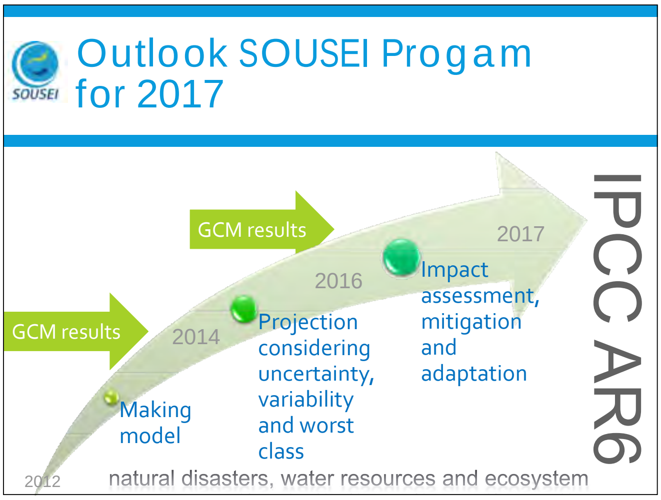


(IPCC WGII SPM, 2014)

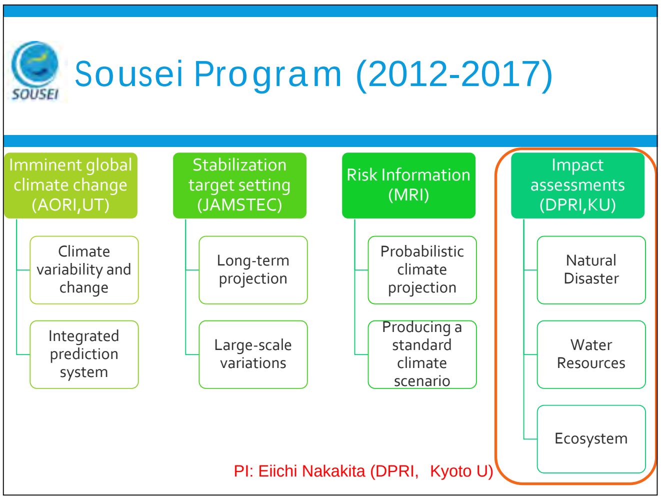
Launching of Sousei Program

- Kyousei(共生)Program:2002-2007
  - 20kmRCM (daily rainfall)
- Kakushin(革新)Program:2007-2012
  - 20kmGCM, 5,2,1kmRCM (hourly rainfall)
  - Natural Disaster (Inc. water resources)
- Sousei(創生)Program:2012-2017
  - 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)



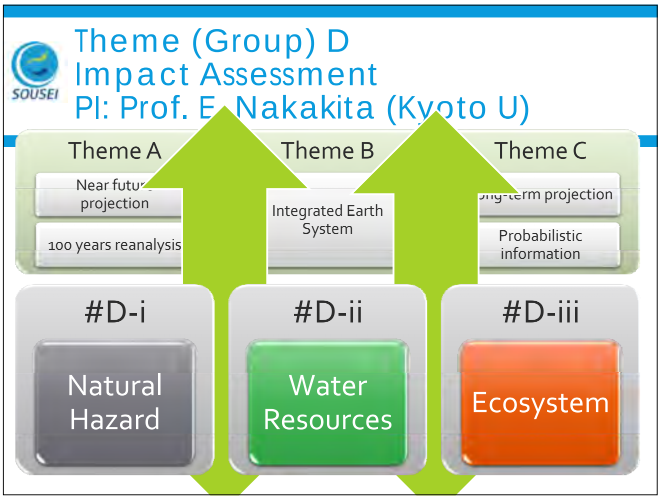


Outlook SOUSEI Progam for 2017
SOUSEI
GCM results
GCM results
2012
2014
2016
2017
Making model
Projection considering uncertainty, variability and worst class
Impact assessment, mitigation and adaptation
IPCC AR6
natural disasters, water resources and ecosystem

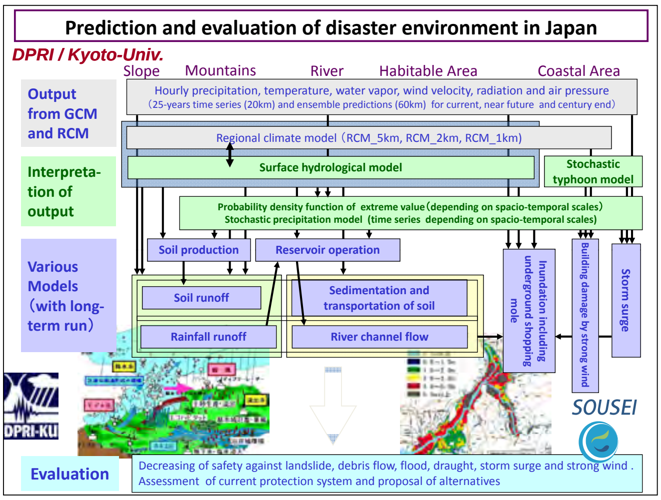


Sousei Program (2012-2017)
SOUSEI
Imminent global climate change (AORI,UT)
Climate variability and change
Integrated prediction system
Stabilization target setting (JAMSTEC)
Long-term projection
Large-scale variations
Risk Information (MRI)
Probabilistic climate projection
Producing a standard climate scenario
Impact assessments (DPRI,KU)
Natural Disaster
Water Resources
Ecosystem
PI: Eiichi Nakakita (DPRI, Kyoto U)

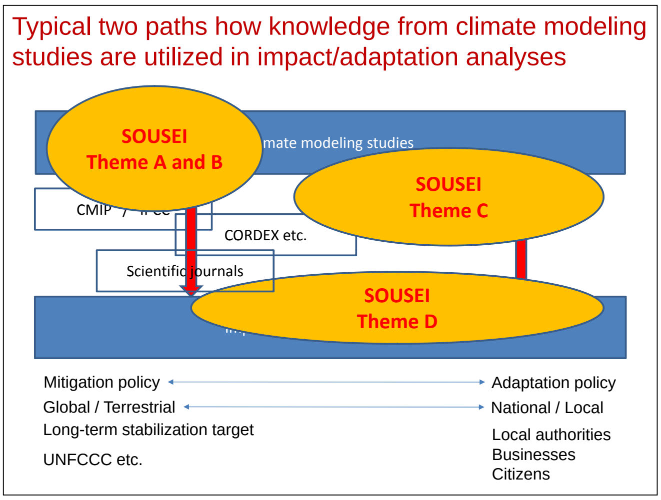
Sousei Program (2012-2017)
Group A: CC Pred. and Anal.
Group B: CC Pred. and Anal.
Group C: CC Pred. and Anal.
Group D: CC Impact Analysis



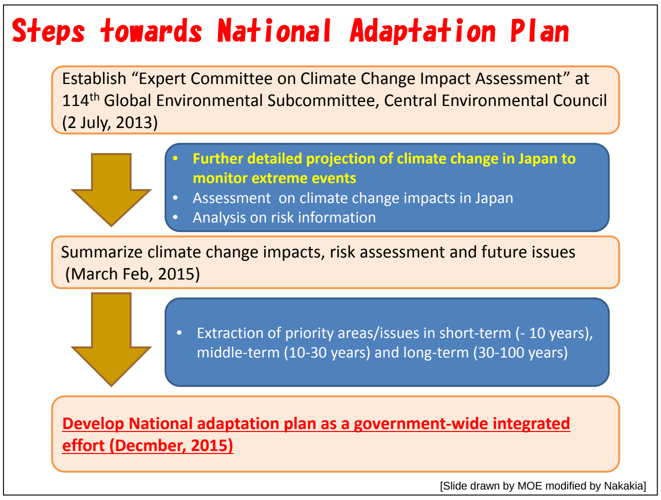
Theme (Group) D
Impact Assessment
PI: Prof. E. Nakakita (Kyoto U)
SOUSEI
Theme A
Theme B
Theme C
Near future projection
100 years reanalysis
Integrated Earth System
Long-term projection
Probabilistic information
#D-i
Natural Hazard
#D-ii
Water Resources
#D-iii
Ecosystem

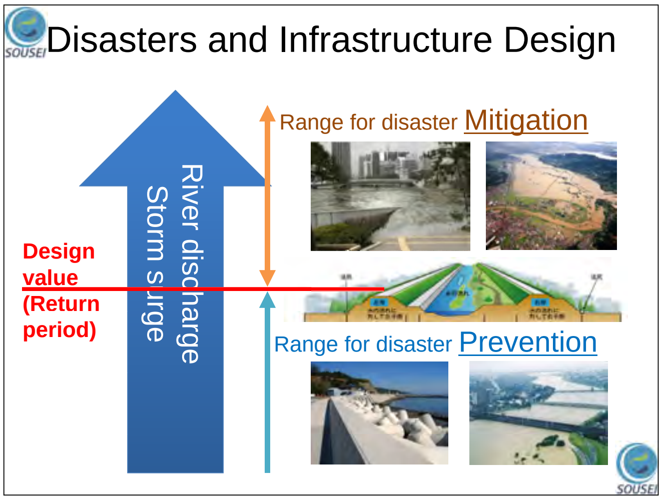


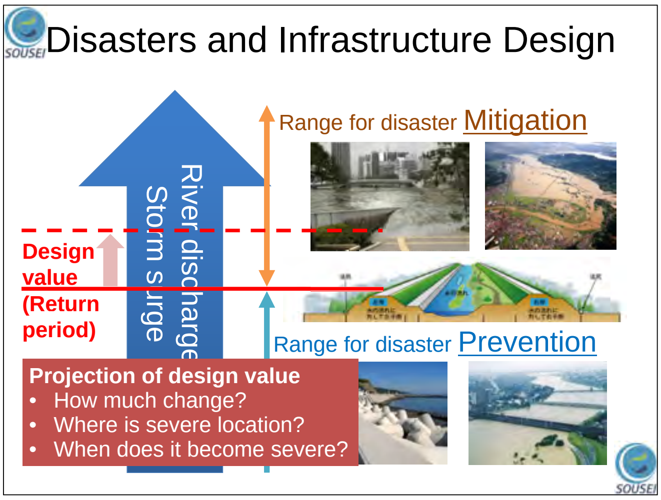
Prediction and evaluation of disaster environment in Japan
DPRI / Kyoto-Univ.
Slope
Mountains
River
Habitable Area
Coastal Area
Output from GCM and RCM
Hourly precipitation, temperature, water vapor, wind velocity, radiation and air pressure
(25-years time series (20km) and ensemble predictions (60km) 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
SOUSEI
Evaluation
Decreasing of safety against landslide, debris flow, flood, draught, storm surge and strong wind .
Assessment of current protection system and proposal of alternatives

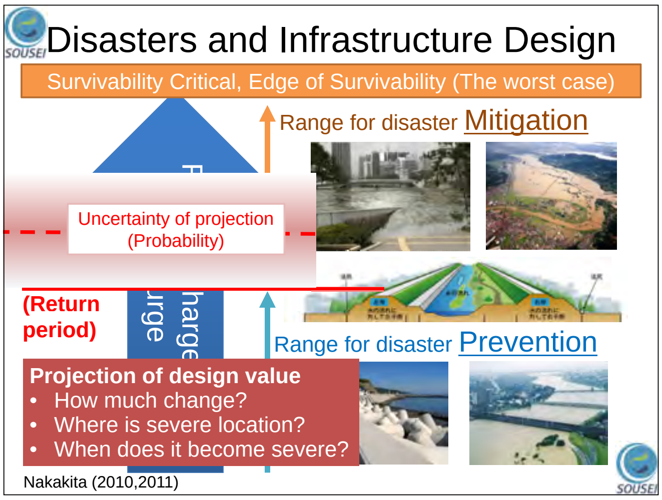


Typical two paths how knowledge from climate modeling studies are utilized in impact/adaptation analyses
SOUSEI Theme A and B
mate modeling studies
SOUSEI Theme C
CMIP
CORDEX etc.
Scientific journals
SOUSEI Theme D
Mitigation policy
Adaptation policy
Global / Terrestrial
National / Local
Long-term stabilization target
UNFCCC etc.
Local authorities
Businesses
Citizens

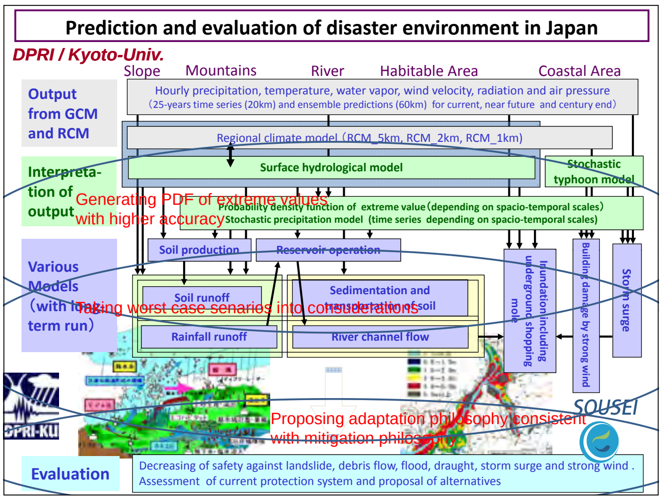

Steps towards National Adaptation Plan
Establish "Expert Committee on Climate Change Impact Assessment" at 114th Global Environmental Subcommittee, Central Environmental Council (2 July, 2013)
Further detailed projection of climate change in Japan to monitor extreme events
Assessment on climate change impacts in Japan
Analysis on risk information
Summarize climate change impacts, risk assessment and future issues (March Feb, 2015)
Extraction of priority areas/issues in short-term (- 10 years), middle-term (10-30 years) and long-term (30-100 years)
Develop National adaptation plan as a government-wide integrated effort (Decmber, 2015)
[Slide drawn by MOE modified by Nakakia]


Disasters and Infrastructure Design
Range for disaster Mitigation
Design value (Return period)
River discharge
Storm surge
Range for disaster Prevention
SOUSEI


Disasters and Infrastructure Design
Range for disaster Mitigation
Design value (Return period)
River discharge
Storm surge
Range for disaster Prevention
Projection of design value
How much change?
Where is severe location?
When does it become severe?
SOUSEI


Disasters and Infrastructure Design
Survivability Critical, Edge of Survivability (The worst case)
Range for disaster Mitigation
Uncertainty of projection (Probability)
(Return period)
Range for disaster Prevention
Projection of design value
How much change?
Where is severe location?
When does it become severe?
Nakakita (2010,2011)
SOUSEI


Sousei (創生) Program (2012-2017)
Ultimate Goal
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.
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
Post Sousei
創生
Sousei (2012-2016)
Kakushin (2007-2011)
革新
Worst case senarios
Worst case typhoon
Multi-hazard
Social Senario
For adaptation decision making
Deterministic, Probabilistic and Beyond
SOUSEI
Nakakita (2012, 2015)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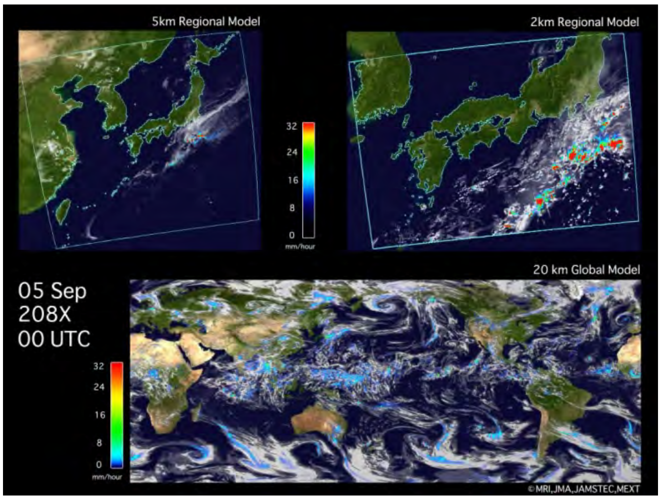
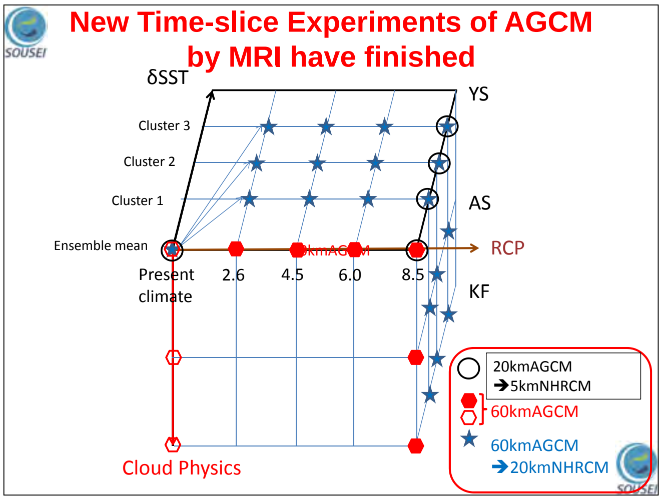
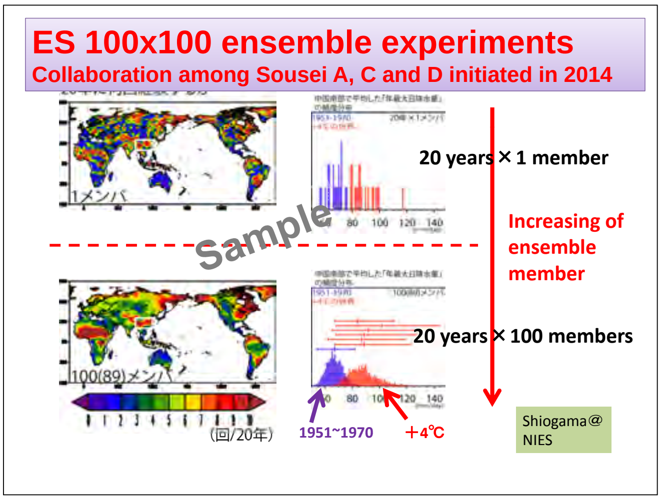
Interpretation of output
Surface hydrological model
Stochastic typhoon model
Generating PDF of extreme values with higher accuracy
Various Models
Soil production
Reservoir operation
Soil runoff
Sedimentation and
Taking worst case senarios into considerations
Rainfall runoff
River channel flow
Storm surge
Proposing adaptation philosophy consistent with mitigation philosophy
SOUSEI
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







Sub-groups in Group D

updated 2013/8/1

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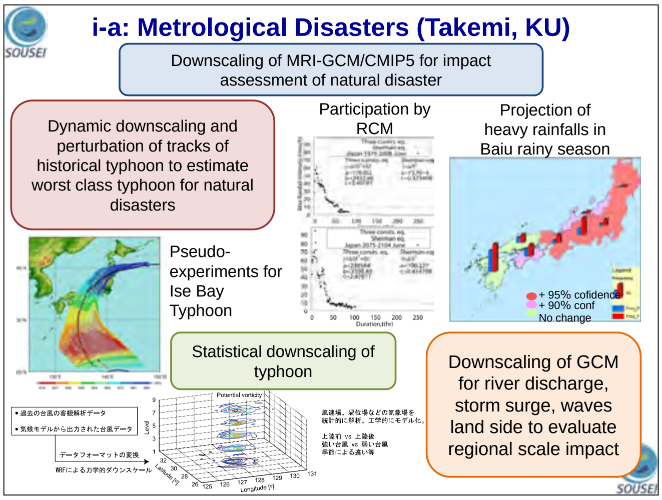
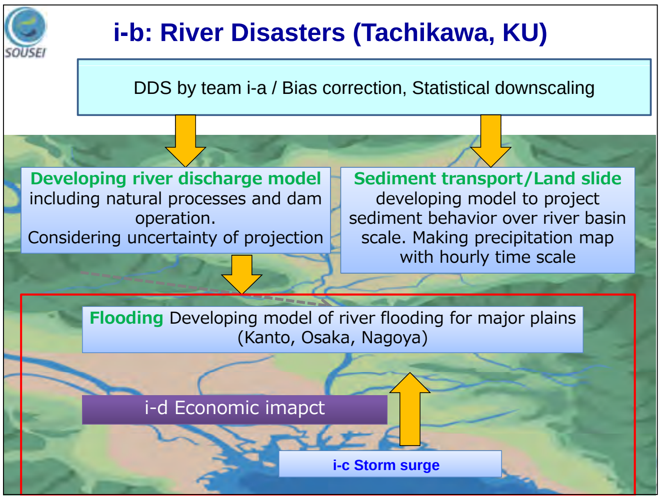
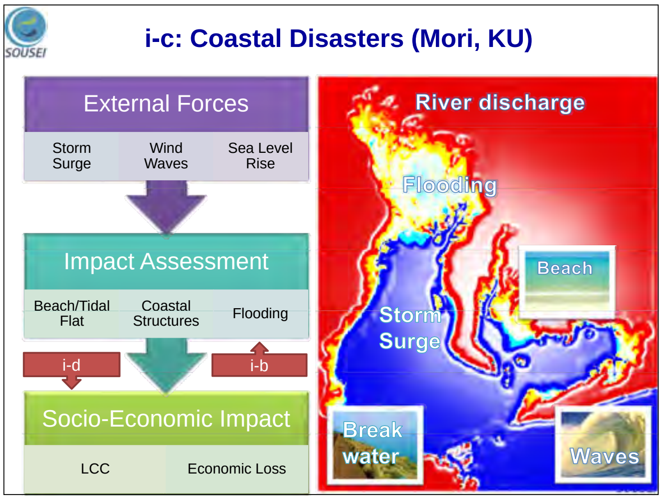
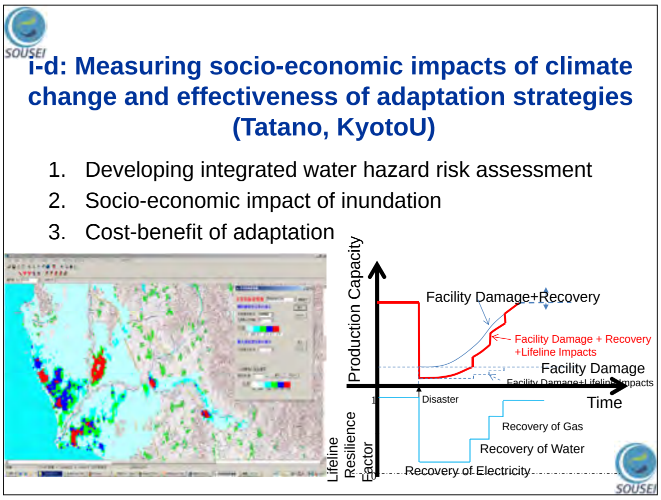
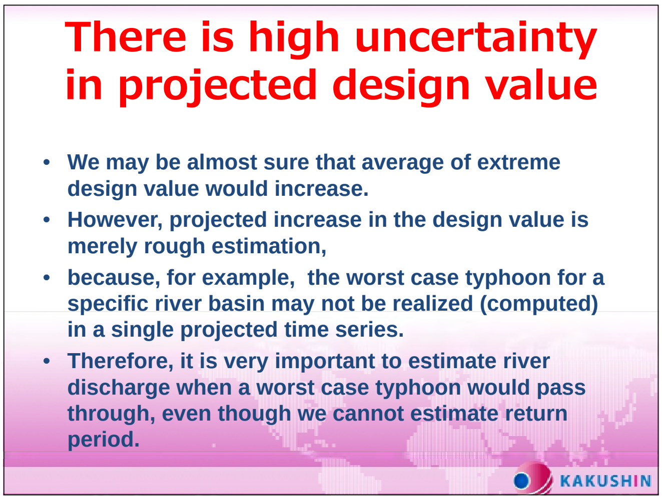
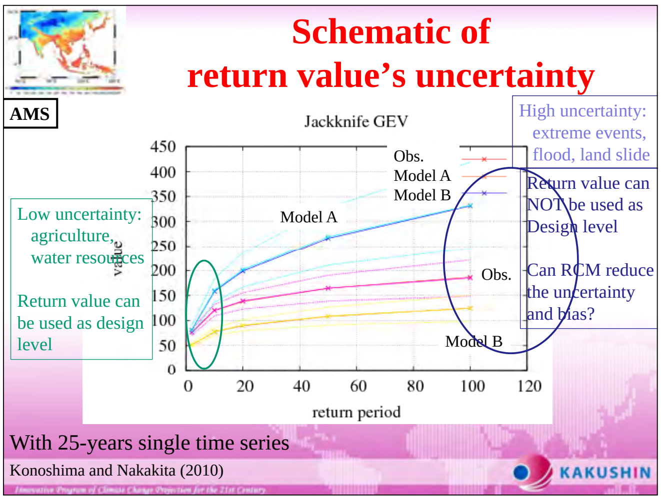


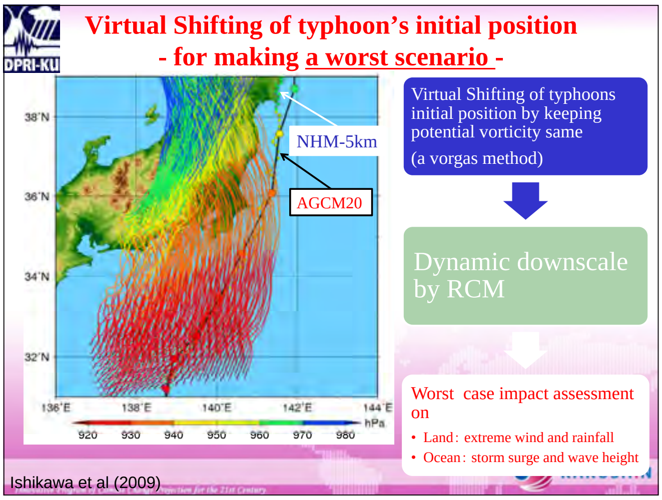

SOUSEI
i-b: River Disasters (Tachikawa, KU)
DDS by team i-a / Bias correction, Statistical downscaling
Developing river discharge model including natural processes and dam operation. Considering uncertainty of projection
Sediment transport/Land slide developing model to project sediment behavior over river basin scale. Making precipitation map with hourly time scale
Flooding Developing model of river flooding for major plains (Kanto, Osaka, Nagoya)
i-d Economic imapct
i-c Storm surge

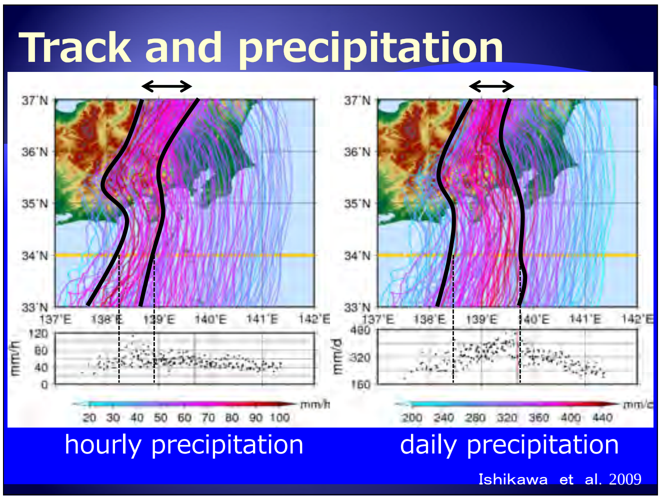

SOUSEI
i-c: Coastal Disasters (Mori, KU)
External Forces
Storm Surge
Wind Waves
Sea Level Rise
Impact Assessment
Beach/Tidal Flat
Coastal Structures
Flooding
i-d
i-b
Socio-Economic Impact
LCC
Economic Loss
River discharge
Flooding
Beach
Storm Surge
Break water
Waves

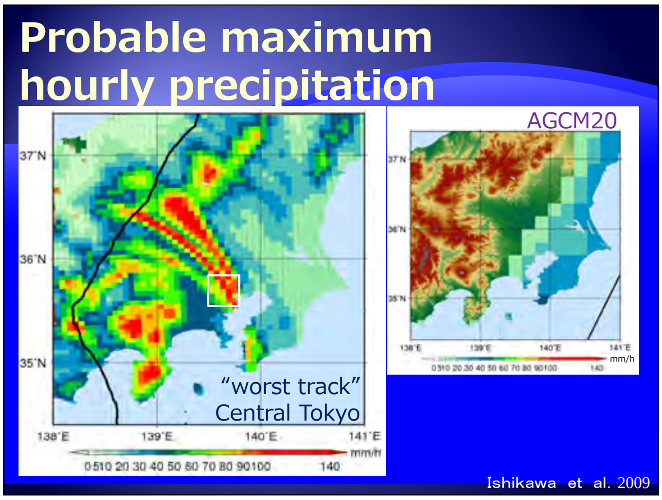

SOUSEI
i-d: Measuring socio-economic impacts of climate change and effectiveness of adaptation strategies (Tatano, KyotoU)
1. Developing integrated water hazard risk assessment
2. Socio-economic impact of inundation
3. Cost-benefit of adaptation
Production Capacity
Facility Damage+Recovery
Facility Damage + Recovery +Lifeline Impacts
Facility Damage
Disaster
Time
Recovery of Gas
Recovery of Water
Recovery of Electricity
Lifeline Resilience Factor
SOUSEI

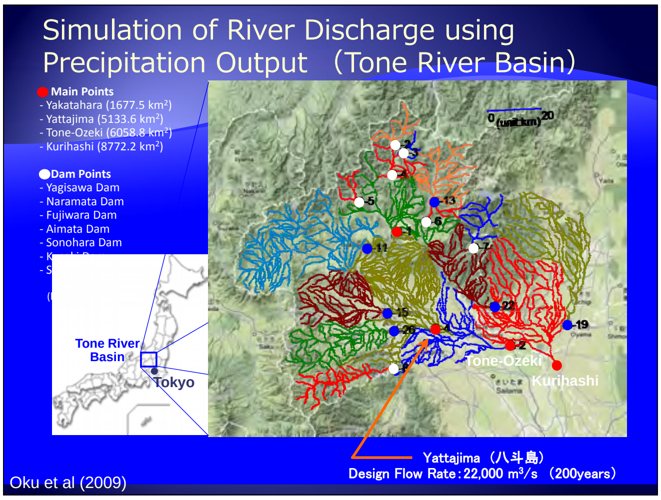

There is high uncertainty in projected design value
• We may be almost sure that average of extreme design value would increase.
• However, projected increase in the design value is merely rough estimation,
• because, for example, the worst case typhoon for a specific river basin may not be realized (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.
KAKUSHIN

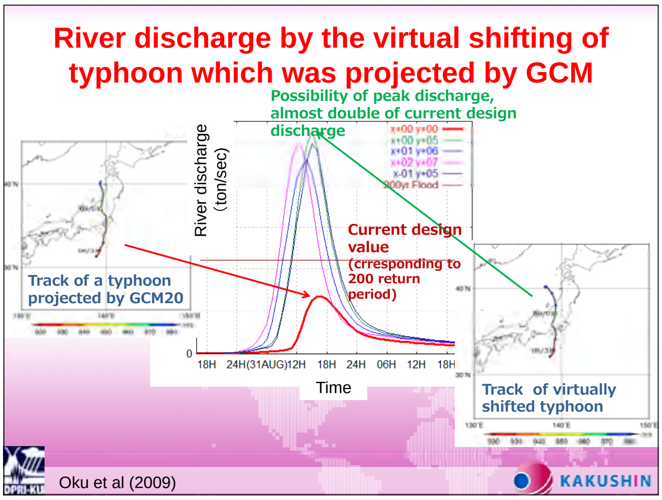

Schematic of return value's uncertainty
AMS
Jackknife GEV
Obs.
Model A
Model B
High uncertainty: extreme events, flood, land slide
Return value can NOT be used as Design level
Can RCM reduce the uncertainty and bias?
Low uncertainty: agriculture, water resources
Return value can be used as design level
value
return period
With 25-years single time series
Konoshima and Nakakita (2010)
KAKUSHIN

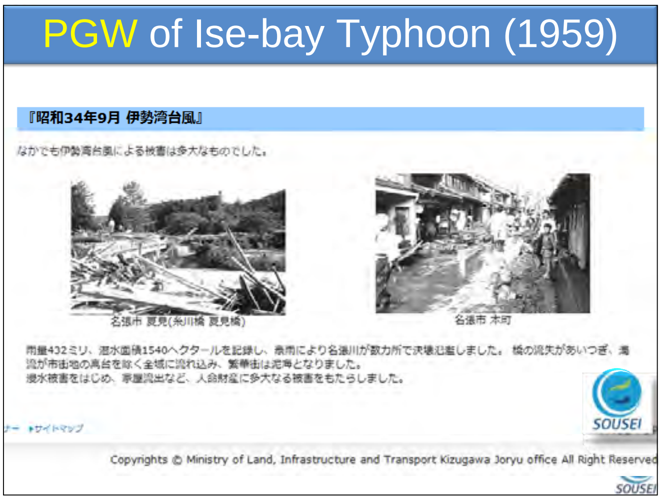

DPRI-KU
Virtual Shifting of typhoon's initial position - for making a worst scenario -
NHM-5km
AGCM20
Virtual Shifting of typhoons initial position by keeping potential vorticity same (a vorgas method)
Dynamic downscale by RCM
Worst case impact assessment on
• Land: extreme wind and rainfall
• Ocean: storm surge and wave height
Ishikawa et al (2009)

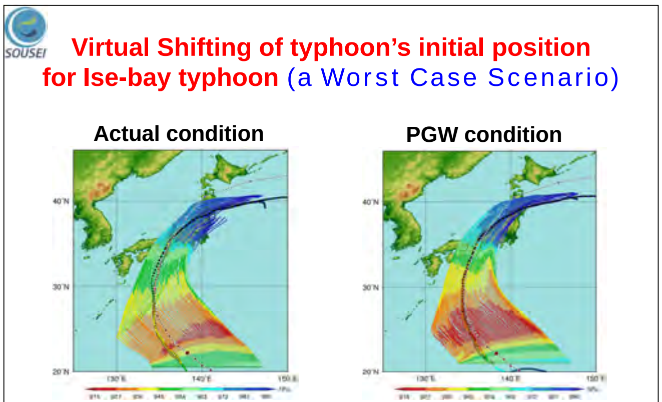




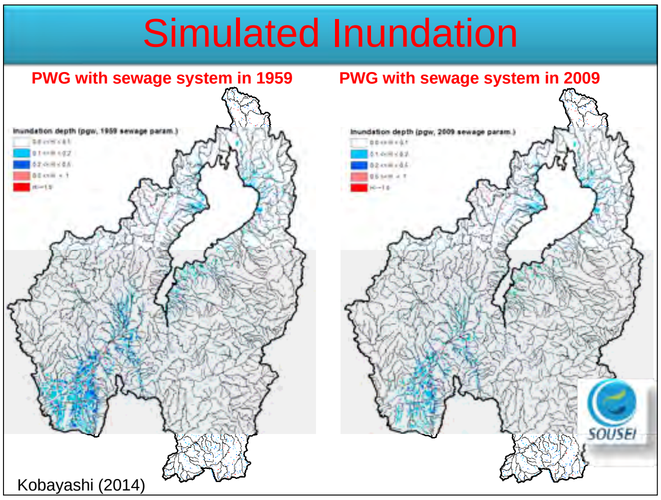


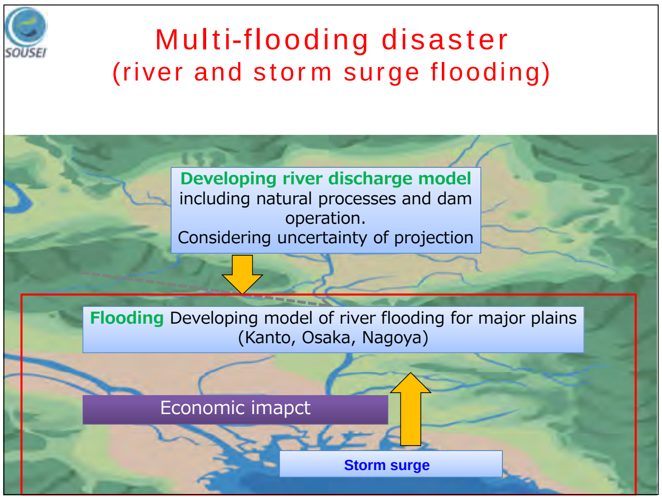


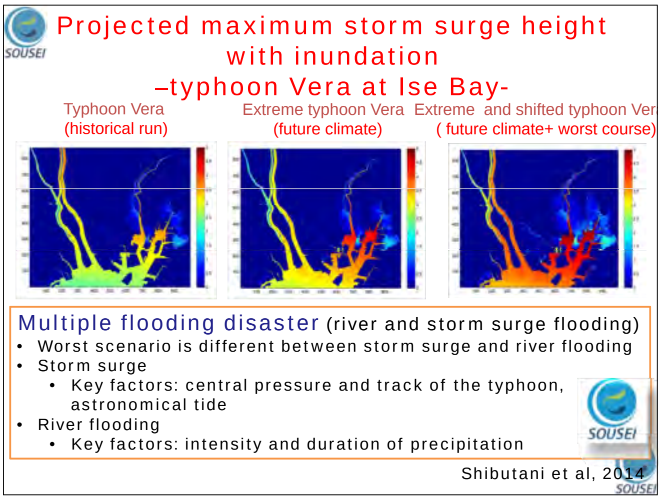


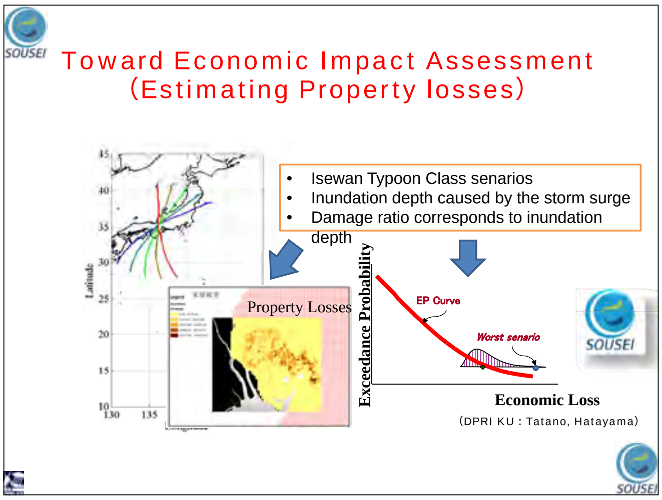


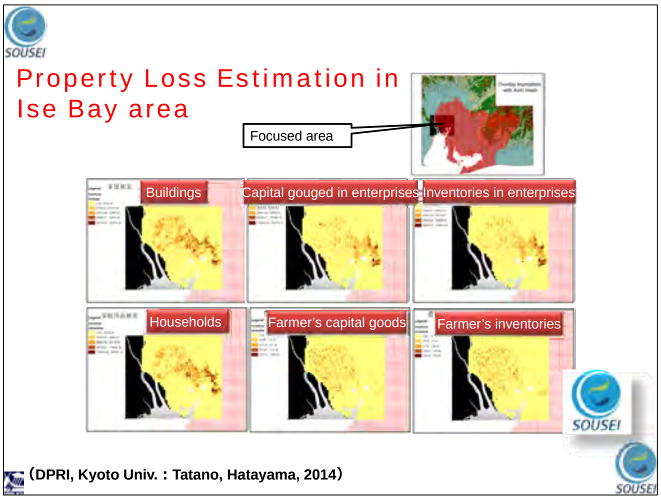
Max. wind	Reproduced	PWG	diffrence
Ise Bay	35.7(m/s)	41.1(m/s)	+5.4(m/s)
Osaka Bay	32.3	36.3	+4.0

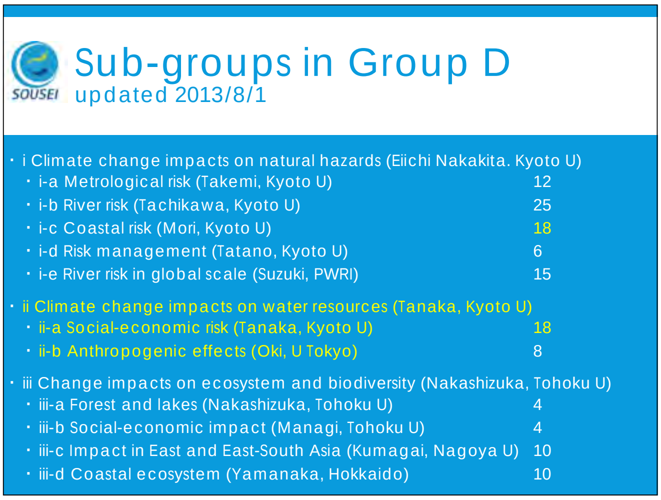

Simulated Inundation
PWG with sewage system in 1959
PWG with sewage system in 2009
SOUSEI
Kobayashi (2014)


SOUSEI
Multi-flooding disaster
(river and storm surge flooding)
Developing river discharge model
including natural processes and dam operation.
Considering uncertainty of projection
Flooding Developing model of river flooding for major plains (Kanto, Osaka, Nagoya)
Economic imapct
Storm surge


SOUSEI
Projected maximum storm surge height with inundation
–typhoon Vera at Ise Bay-
Typhoon Vera
(historical run)
Extreme typhoon Vera
(future climate)
Extreme and shifted typhoon Ver
(future climate+ worst course)
Multiple flooding disaster (river and storm surge flooding)
• Worst scenario is different between storm surge and river flooding
• Storm surge
• Key factors: central pressure and track of the typhoon, astronomical tide
• River flooding
• Key factors: intensity and duration of precipitation
Shibutani et al, 2014
SOUSEI


SOUSEI
Toward Economic Impact Assessment
(Estimating Property losses)
• Isewan Typoon Class senarios
• Inundation depth caused by the storm surge
• Damage ratio corresponds to inundation depth
Latitude
Property Losses
Exceedance Probability
EP Curve
Worst senario
Economic Loss
(DPRI KU : Tatano, Hatayama)
SOUSEI


SOUSEI
Property Loss Estimation in Ise Bay area
Focused area
Buildings
Capital gouged in enterprises
Inventories in enterprises
Households
Farmer's capital goods
Farmer's inventories
SOUSEI
(DPRI, Kyoto Univ. : Tatano, Hatayama, 2014)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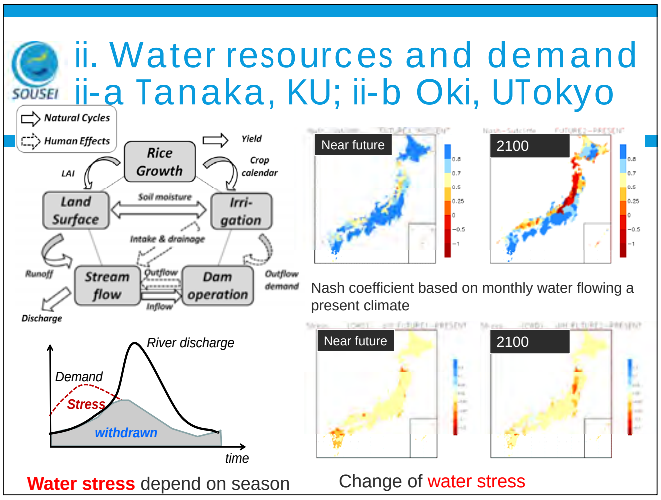

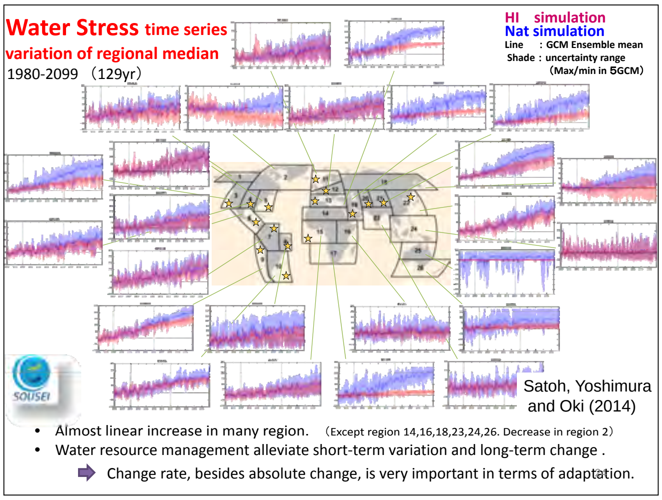

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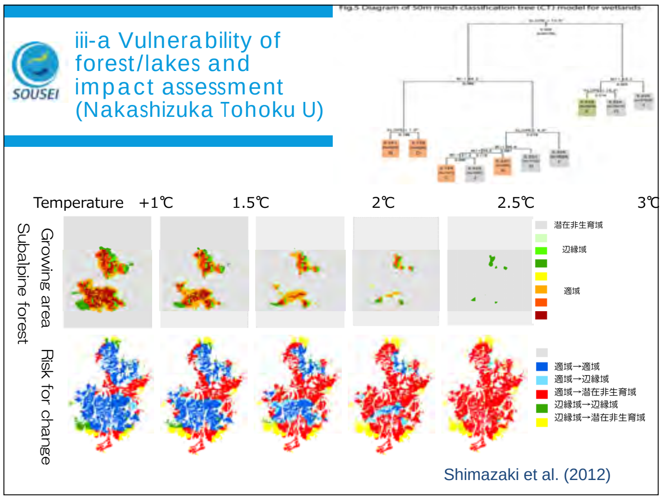
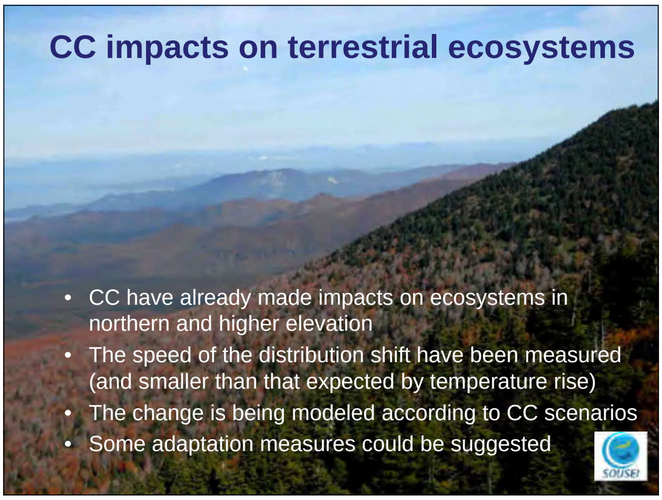
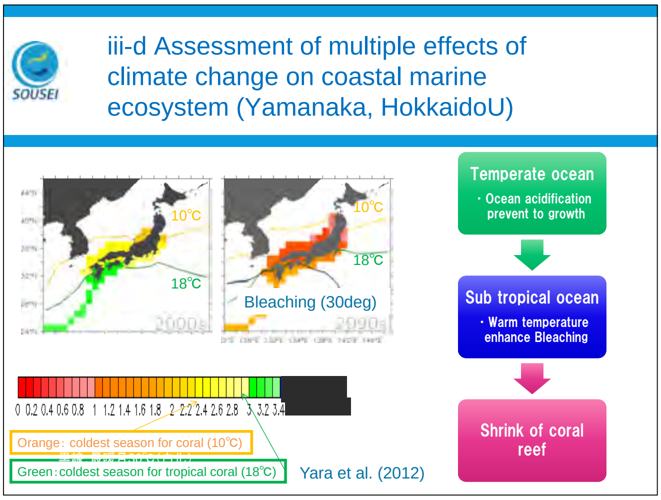


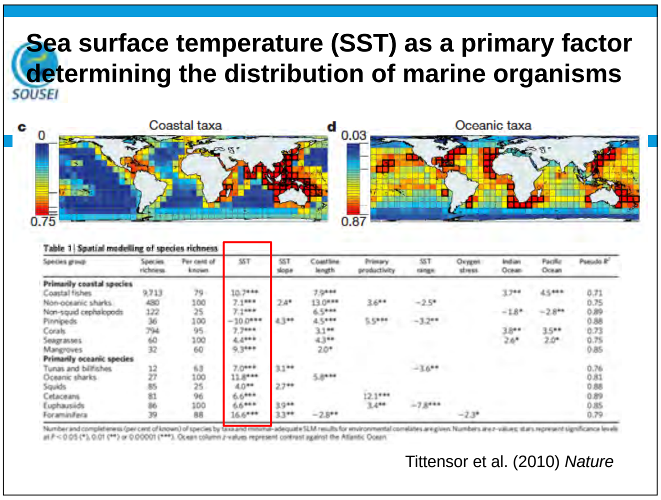
Planned activities of SOUSEI for TE

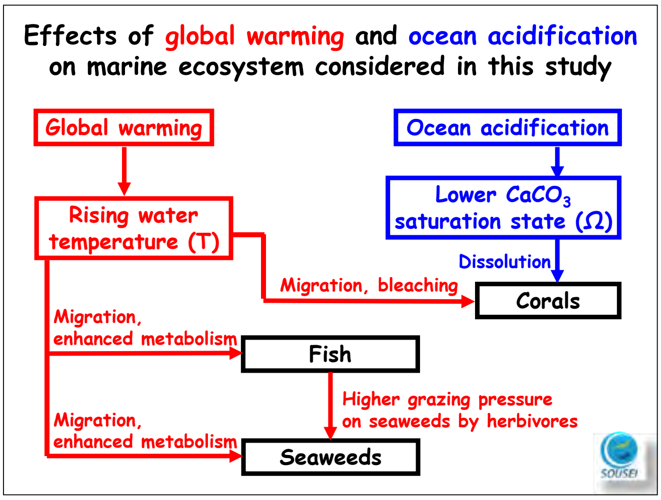
Ecosystems	Methods	Ecosystem services	Risks	Adaptation measure
Bamboo f.	Distribution model	(−) Invasion into cropland	Expansion to northward	Not to plant Intensify management
Alpine plants	Distribution model	Tourism	Extinction risk	Secure refugia
	Tree line shifts		Value decrease	Protection area
	Genetic model			
Forests	Distribution shift Typhoon damage Disease expansion	Matter cycling Water quality Disaster RR Disease RR	Acceleration Pollution incl. Disaster risk Disease risk	Networking Restoration Structural improve
Lakes	Trophic structure	Water quality	Pollution risk	Intensify management
Watershed	Watershed model	Water quality	Pollution risk	Land use management
Agricultural	Yield model	Pollination	Yield decrease	Land use management

Red: ongoing Orange: started

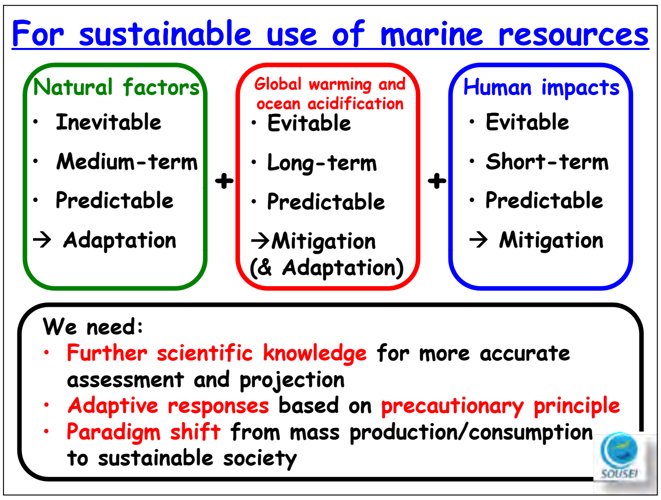



iii-d Assessment of multiple effects of climate change on coastal marine ecosystem (Yamanaka, HokkaidoU)
SOUSEI
10℃
18℃
Bleaching (30deg)
2000s
2090s
Temperate ocean
・Ocean acidification prevent to growth
Sub tropical ocean
・Warm temperature enhance Bleaching
Shrink of coral reef
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2 3.4
Orange: coldest season for coral (10℃)
Green: coldest season for tropical coral (18℃)
Yara et al. (2012)


Sea surface temperature (SST) as a primary factor determining the distribution of marine organisms
SOUSEI
Coastal taxa
Oceanic taxa
Table 1 | Spatial modelling of species richness
Tittensor et al. (2010) Nature


Effects of global warming and ocean acidification on marine ecosystem considered in this study
Global warming
Ocean acidification
Rising water temperature (T)
Lower $CaCO_3$ saturation state (Ω)
Dissolution
Migration, bleaching
Corals
Migration, enhanced metabolism
Fish
Higher grazing pressure on seaweeds by herbivores
Migration, enhanced metabolism
Seaweeds
SOUSEI


Who will suffer from ocean acidification?
SOUSEI


For sustainable use of marine resources
Natural factors
・Inevitable
・Medium-term
・Predictable
→ Adaptation
+
Global warming and ocean acidification
・Evitable
・Long-term
・Predictable
→Mitigation (& Adaptation)
+
Human impacts
・Evitable
・Short-term
・Predictable
→ Mitigation
We need:
・Further scientific knowledge for more accurate assessment and projection
・Adaptive responses based on precautionary principle
・Paradigm shift from mass production/consumption to sustainable society
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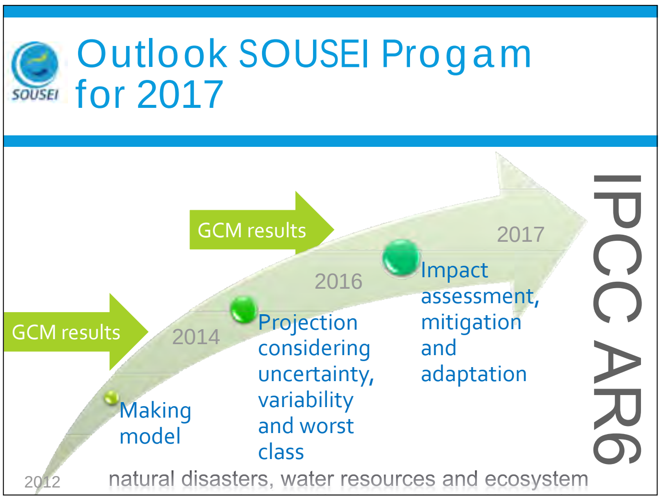
Outlook SOUSEI Progam for 2017
SOUSEI
GCM results
GCM results
2012
2014
2016
2017
Making model
Projection considering uncertainty, variability and worst class
Impact assessment, mitigation and adaptation
IPCC AR6
natural disasters, water resources and ecosystem

Steps towards National Adaptation Plan

Establish “Expert Committee on Climate Change Impact Assessment” at 114th Global Environmental Subcommittee, Central Environmental Council (2 July, 2013)

- **Further detailed projection of climate change in Japan to monitor extreme events**
- Assessment on climate change impacts in Japan
- Analysis on risk information

Summarize climate change impacts, risk assessment and future issues (March Feb, 2015)

- Extraction of priority areas/issues in short-term (- 10 years), middle-term (10-30 years) and long-term (30-100 years)

Develop National adaptation plan as a government-wide integrated effort (Decmber, 2015)

[Slide drawn by MOE modified by Nakakia]

Joint Symposium on Adaptation with Japanese Ministry of Land, Infrastructure and Transportation (MLIT)

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MLIT issued a guideline on strategy on adaptation for water related disaster such as flood, storm surge, land slide and so on under the climate change in July.

2015/5/29　国立オリンピック青少年金総合センター
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後援　土木学会　水工学委員会/地球環境委員会

Thank you for your kind attention

Joint Symposium between Sousei C and D

Photo: Uji, Kyoto

Lecture 2: Fundamentals of Basin-scale Hydrological Analysis

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 Modeling of Rainfall-Runoff System

One of the main tasks of the hydrologists is to predict the hydrograph from knowledge of rainfall, snowmelt and evapotranspiration information under an initial condition (initial soil water) and catchment physical characteristics (topography, soil, vegetation) of the study basin. The hydrologic cycle of a river basin can be regarded as a runoff system in which hydrologic processes such as evaporation, transpiration, infiltration, subsurface runoff, and surface runoff interact with each other. A straightforward way to predict the hydrograph is to represent the runoff system by combining mathematical descriptions of dominant hydrologic processes. This mathematical representation is called a rainfall-runoff model. A rainfall-runoff model plays a major role for river planning and river basin management. Simple conceptual runoff models have been used for a long time. Detailed spatially distributed models and land surface hydrologic models have been developed based on the advancement of observation technology and hydrologic information such as radar rainfall observation, remote sensing of land surface information, and geographical information of river basins.

Key words: runoff system, rainfall-runoff model, distributed rainfall-runoff model, land surface hydrologic model

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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 capacity**

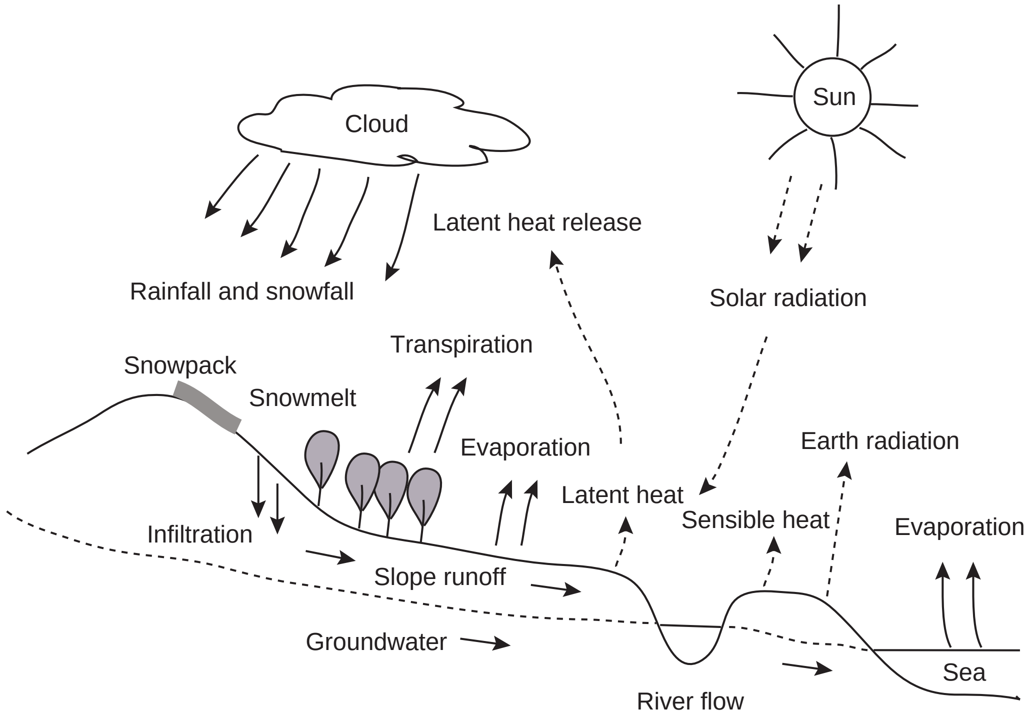

Fig. 1.1: Hydrologic processes and water and energy movement with change of water phase.

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 absorb the soil moisture from the roots and release the vapor through the stomata. This process is called **transpiration**. Combining **evaporation** with **transpiration**, it is collectively called **evapotranspiration**.

The water cycle is inextricably associated with 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 spatially and timely distributed, which determines the climate of the Earth. 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 causes 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.

(Note) Hydrology and water resources engineering

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 the use of 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. The research topics include:

- 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.

1.2 Water Budget and Hydrologic Cycle

1.2.1 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:

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

1.2.2 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}];

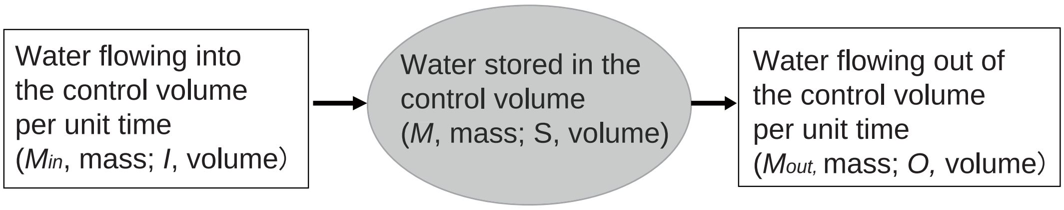

Fig. 1.2: Water budget and continuity relation.

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^3T^{-1}]; and O is the volume outflow rate [L^3T^{-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**.

1.2.3 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 [L^3T^{-1}], and O consists of evapotranspiration E [L^3T^{-1}] and runoff Q [L^3T^{-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.

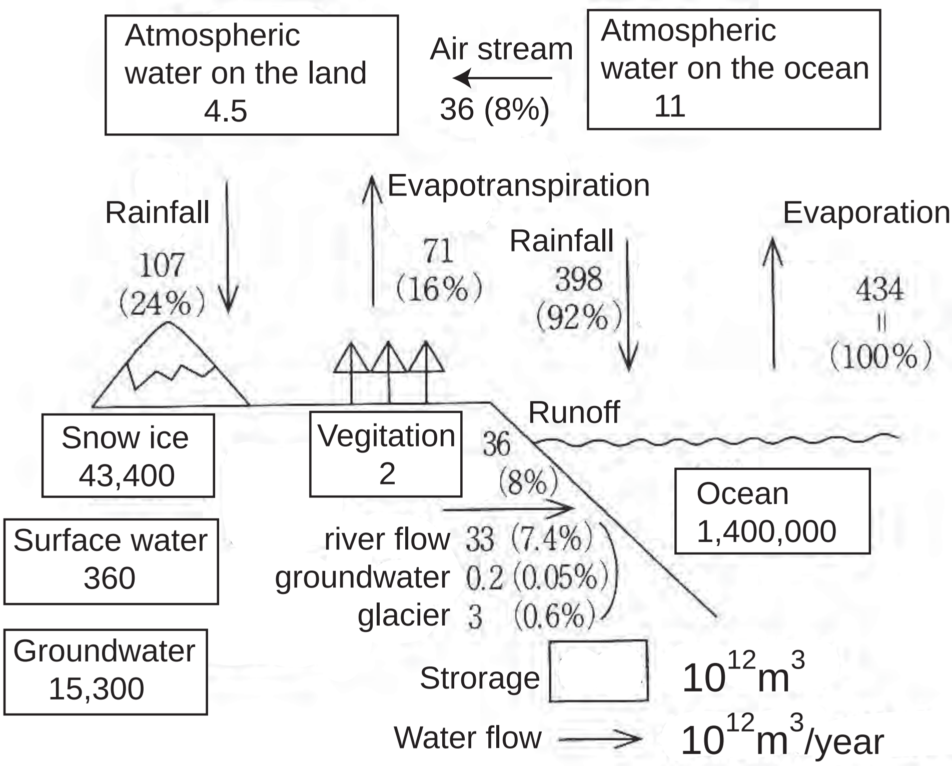

Fig. 1.3: The water stored on the Earth and the annual movement. The percentage represents the ratio when the annual evaporation from the ocean is 100%. (Takeda, T. *et al.*, Meteorology in water environment, University of Tokyo Press, 1992)

(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:

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

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:

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

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:

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

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:

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

【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:

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

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

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

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

1.2.4 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

$$O = Ae + Q$$

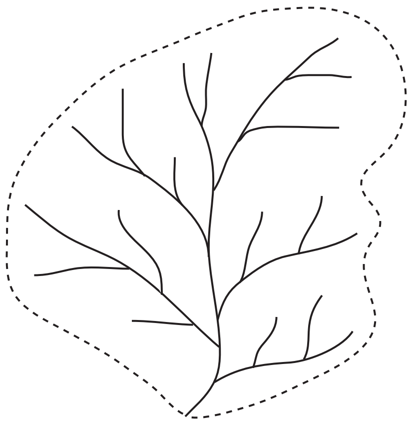

Fig. 1.4: Watershed divide and catchment basin.

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

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

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
Chao Phraya River (Thailand)	1,144	962	(1)
Katsura River (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)
Chao Phraya River (Thailand)	182	513×10^3	69.5×10^6
Katsura River (Japan)	1,088	378×10^3	126.5×10^6
World (mean)	243	147.9×10^6	$6{,}968\times10^6$

(Solution)

The maximum water resources per capita in the Chao Phraya River basin 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 the katsura River basin in Japan and the mean value of 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 resources 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 in Thailand the Katsura River basin in Kyoto, 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 the Katsura River basin, 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.

1.3 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 1.9】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 × 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

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

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[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.

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2. Modeling of Rainfall-Runoff System

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Keywords : runoff system, rainfall-runoff model, distributed rainfall-runoff model, land surface hydrologic model

2.1 Runoff System and Runoff Model

2.1.1 Rainfall-runoff system

Rainfall on a catchment moves through various pathways and goes into a river channel. This process can be regarded as a **runoff system** that consists of various interrelated subsystems that transform inputs into outputs. **Runoff analysis** is to analyze the runoff system to clarify a physical or statistical principle that subsystems are governed, to elu-

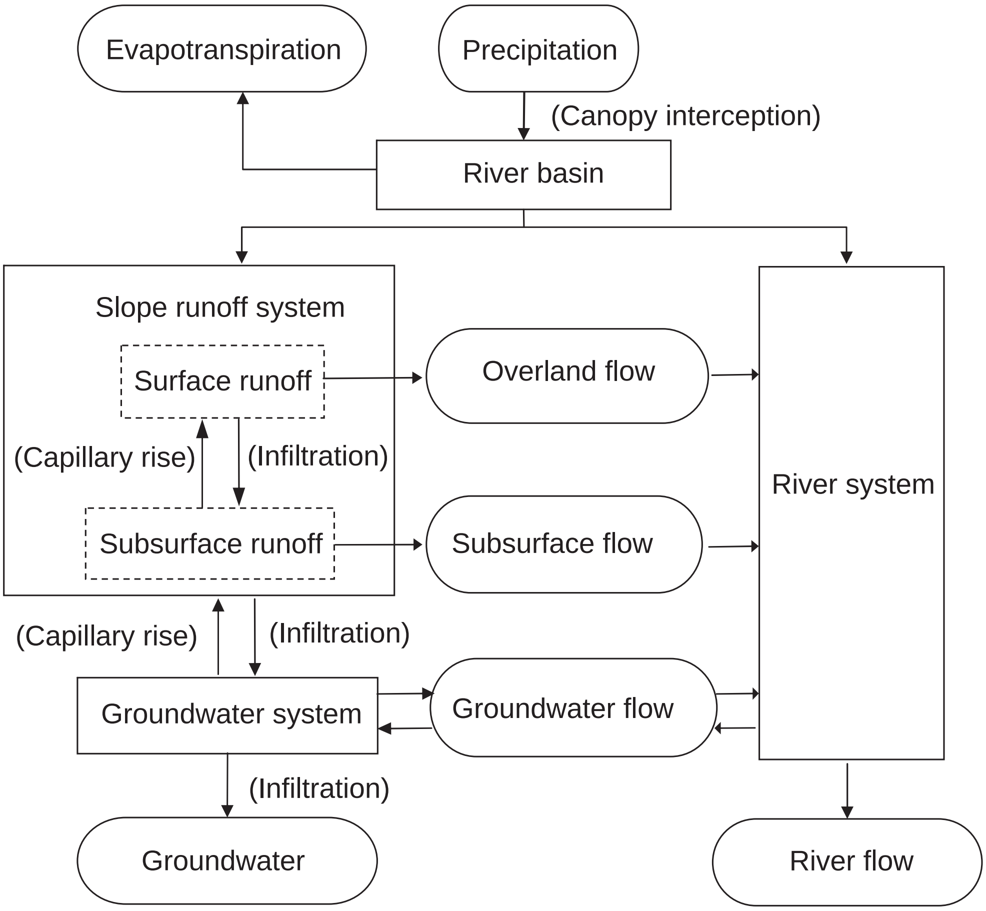


Fig. 2.1: Runoff system (Takasao, 1967, 1975).

cidate the interrelationship among the subsystems, and to create a mathematical model that represents a behavior of a subsystem and an interrelationship of subsystems, and to predict rainfall-runoff phenomena. Takasao clearly defines a runoff system and the research direction to understand the runoff system as below (Takasao, 1967, 1975):

> A runoff system refers to an ordered set of homogeneous subsystems that are governed by a physical or statistical principle. Therefore, to understand the characteristics of a runoff system consistently and quantitatively, it is necessary to clarify the mechanism of subsystems and the interrelationship among the subsystems, and to express the entire system systematically.

Fig. 2.1 shows a block diagram of a runoff system, which represents the route of precipitation which fall on a catchment, in other words, the interrelationship of hydrologic subsystems. A rectangular block stands for a subsystem; a circular block for an input or output; and an arrow for the direction of input and output. There are three major physical quantities that characterize the runoff system;

Input An external cause that acts on the system, for example, rainfall.

Output A result brought by the system with one or more inputs, for example, slope runoff.

System parameter Parameters that control the dynamic behaviors of the system, for example, topography gradient, runoff recession constant and so on.

An output of a subsystem may serve as an input to other subsystems that the arrow indicates, and vice versa.

Clarification of a runoff system requires wide range of studies, which are classified into two types: (1) observation of runoff phenomena and (2) development of a mathematical model that expresses the behaviors of a runoff system. These studies are closely associated with each other. An observation target and its time and space resolutions depend on a mathematical model, and a representation of a mathematical model is definitely based on the observation of runoff phenomena. To recognize the observation and the model development interact for each other is the way to understand a runoff system properly.

A runoff system consists of the natural processes shown in **Fig. 2.1** and various human interventions such as water intake from river and groundwater, dam reservoir operations, as well as the transfer/diffusion process of sediment, substances, water quality and temperature that occur in association with the hydrologic cycle.

To predict the runoff phenomena, understanding of the subsystems and the interrelation among subsystems are fundamental. The entire system model is developed by combining the mathematical subsystem models which represent the hydrologic behaviors of subsystems.

2.1.2 Components of runoff system and runoff model

Fig. 2.2 shows an example of a spatial division of a catchment to identify the subbasin that connect to each channel segment. A runoff system of each sub-basin as shown

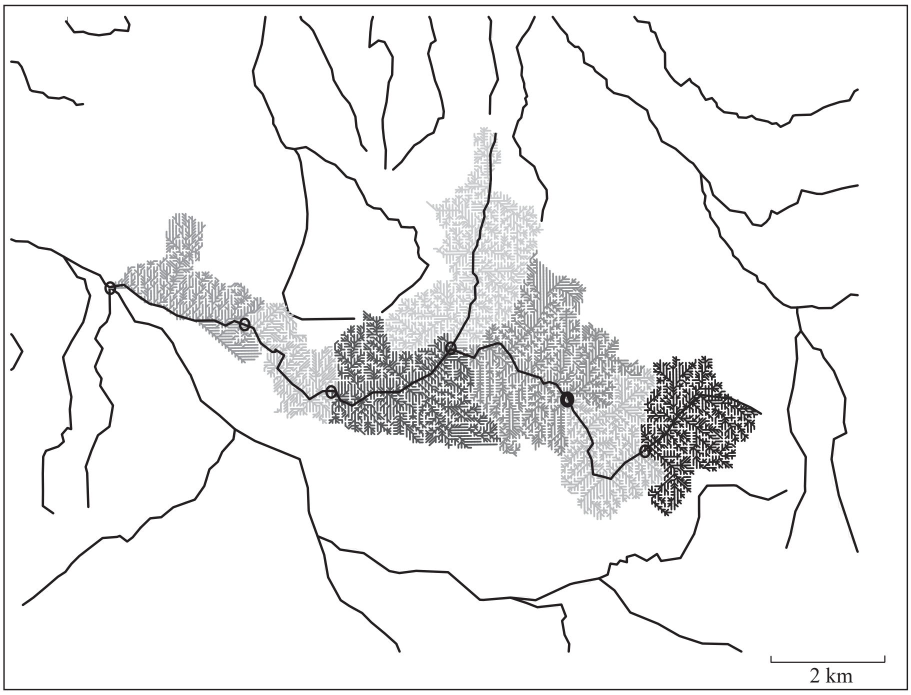


Fig. 2.2: Sub-catchment that forms a part of the entire hydrologic system.

in **Fig. 2.1** is modeled as a sub-basin rainfall-runoff model and the sub-basin models are connected to develop the entire runoff system model. Major subsystem components in a runoff system are as follows:

Hillslope runoff system that receives precipitation and transforms it into surface runoff and subsurface runoff.

River flow system that receives hillslope discharge and groundwater discharge, and routes them downstream.

Groundwater system that receives infiltration from the hillslope system and provides groundwater discharge to the river system. The groundwater system and the river system interactively exchange the discharge. In an alluvial fan and its downstream area, the river water may be supplied from the river system to the groundwater system.

Inundation system that receives precipitation and flood water from the river system and distributes flood water to a flood plain or urban district.

Human system that gives an impact on the natural hydrologic cycle such as dam reser-

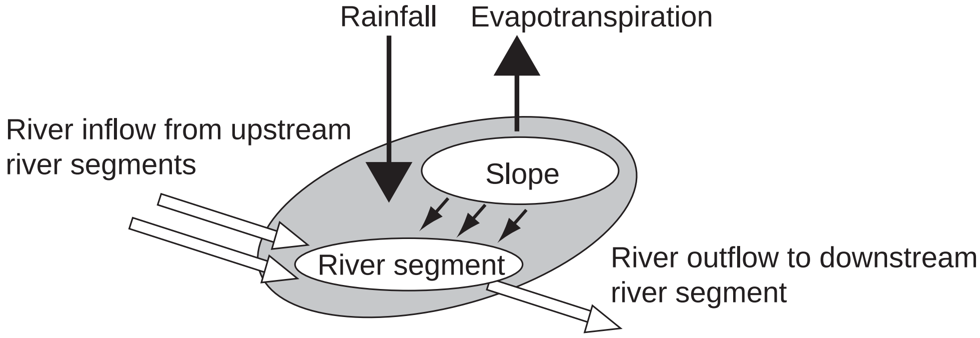


Fig. 2.3: Water movement in a sub-basins.

voir control for flood disaster mitigation/prevention, water supply for agricultural, industrial and urban use; water intake from the river system and the groundwater system for agricultural, industrial and urban use.

Various subsystems in association with the hydrologic cycle such as sediment runoff, substances movement, water quality and water temperature change, vegetation growth.

A runoff model refers to a mathematical system model that expresses the hydrologic behaviors of a subsystem using governing equations, which enables to predict runoff phenomena. Adding components of a runoff system described above, a rainfall system and an evaporation system also play an important role of subsystems. **Fig. 2.3** illustrates the flow of water in a sub-basin, where hillslpe flow and river flow routing are dominant hydrological processes. Runoff and flood routing of an entire basin are modeled by spatially combining sub-basin models representing hillslope flow and river flow processes.

In the hydrologic cycle, people use the water and modify the natural hydrologic cycle. Irrigation and drainage projects for agriculture, water supply and sewage system development, reservoir operations for flood control and various water use are major human intervention for the natural hydrologic cycle. These processes influence each other and constitute an actual runoff system. River flow is no longer a natural process, which receives impact of human activities. For river planning and river basin management, a hydrologic simulation model that explicitly includes the effect of human activities on the hydrologic cycle can reproduce actual runoff behaviors and predict future runoff phenomena.

2.1.3 Purposes of rainfall-runoff modeling

One of the purposes of a rainfall-runoff model is to understand a runoff system and clarify the interrelationship of subsystems. Engineering purposes include to design of hydraulic structures for flood control and water resources, to predict the river flow for mitigation of flood and drought disasters, and evaluation of river flow change due to basin environment change such as

1. understanding of the hydrologic cycle
2. river flow prediction for river planning
3. real-time river flow forecasting
4. long-term river flow predictions for water resources
5. prediction of the hydrologic cycle under environmental change
6. predictions in ungauged basins

The structure of a runoff model is different due to its purpose.

(1) Understanding of the hydrologic cycle

Hydrological observation cannot provide all aspects the hydrologic cycle. To deepen the understanding of a runoff system, not only to observe the runoff system, but also to develop the theory that explains the runoff system in the river basin is important. A rainfall-runoff model is a mathematical representation that expresses the theory. **Runoff Analysis** includes observation of the hydrologic cycle, development of a theory that explains it, and understanding it through the observations and the theory. A rainfall-runoff model that provides a spatiotemporal distribution of hydrological variables inside the river basin helps the understanding of the runoff system. A framework that enables to simulate the spatiotemporal distribution of hydrologic variables is indispensable to link the observation and the theory.

(2) River flow prediction for river planning

To reduce and prevent flood disasters, construction and reinforcement of hydraulic structures such as levees, a flood control basin, and a dam reservoir are effective. To effectively design the sizes and locations, to predict a flood hydrograph (design flood) using a rainfall-runoff model is a fundamental task.

(3) Real-time river flow forecasting

For issuing flood alert and efficient operation of hydraulic facilities, real-time river flow forecasting is effective. A rainfall-runoff model and rainfall forecasts for several hours are helpful to realize a real-time river flow forecasting.

(4) Prediction of the hydrologic cycle under environmental change

The hydrologic cycle may change significantly due to the changes of river basin environment, social conditions, and climate. To predict the hydrologic cycle under environmental change is one of the main tasks of a rainfall-runoff model. A runoff model for this purpose should allow proper model parameter setting due to the environmental changes. A conceptual model whose model parameters are determined only by observation data is less likely helpful for this purpose. Because it is impossible to determine the model parameters under the environmental change. A physically-based rainfall-runoff model may be useful for the case if possible values of parameters under the changed conditions can be estimated.

(5) Predictions in ungauged basins

Hydrological observation forms the basis of the hydrologic prediction for flood prevention and water resources. However, there are some regions that hydrological observation is insufficient and to realize this is difficult, though hydrologic prediction is quite important. A physically-based rainfall-runoff model and a meteorological/climate model are only tools to realize the prediction in ungauged basins.

2.2 Classification of Rainfall-Runoff Models

A rainfall-runoff model is expressed as follows in general:

$$Q(x,t) = f(R(x,t), \text{catchment characteristics}, \text{initial condition})$$

where $Q(x,t)$ is the river flow rate at a spatial point x at time t; $R(x,t)$ is the precipitation intensity associated with the river flow at x and t; and f is a rainfall-runoff model that represents the runoff process for transforming rainfall intensity to the river flow rate. The catchment characteristics include topography, land use, geology of the river basin and these characteristics are introduced as model parameters of the rainfall-runoff model. The initial condition means the initial values of state variables in the rainfall-runoff model such as soil moisture which represents the wet and dry condition of the river basin.

A rainfall-runoff model is constructed by combining the hydrologic processes, such as evapotranspiration, interception, infiltration, hillslope runoff, and channel routing. Consider a rainfall-runoff model that aims for flood prediction in small river basin (several thousand km^2). Rainfall amount which causes a flood disaster reaches 100 mm or greater per day. Meanwhile, the amount of evapotranspiration is as small as 6 mm per day even under the conditions in summer sunny day. Therefore, the important hydrologic processes in the rainfall-runoff model is the hillslope runoff and the channel routing. Meanwhile, taking into account the long-term river flow prediction, evapotranspiration plays a major role to determine the river flow rate. In such a case, a rainfall-runoff model needs to include the process of evapotranspiration.

As described above, hydrological processes and data required for a rainfall-runoff model vary depending on the purpose. The type of a rainfall-runoff model is also different depending on whether the runoff model is aimed at forecasting the river flow rate only at the outlet of the river basin or spatiotemporal changes of hydrologic variables. **Fig. 2.4** shows the classification of rainfall-runoff models.

2.2.1 Short-term and long-term rainfall-runoff models

In terms of the duration of forecasting, runoff models are categorized into the short-term and long-term runoff models. A **short-term rainfall-runoff model** is used for reproducing/forecasting runoff with the duration of several hours to several days. A short-term runoff model is often called a **flood runoff model**. A **long-term runoff**

- ○ Duration of forecasting
  - Short-term runoff model
  - Long-term runoff model
- ○ Model construction
  - response model
  - conceptual model
  - physically-based model
- ○ Lumped and distributed
  - Lumped model
  - Distributed model

Fig. 2.4: Classification of rainfall-runoff models.

model is used for forecasting water resources conditions. The model is requested to reproduce/forecast for long-term flow conditions over several months to years.

2.2.2 Response, conceptual and physical hydrologic models

In terms of model construction, runoff models are categorized into a **response model**, a **conceptual model**, and a **physically-based model**. Taking a short-term runoff model as an example, the input to the model is rainfall intensity, and the output from the model is flow rate. Only realizing the input and output as a time series data, a **response model** aims to determine the relationship between input and output just systematically. A response model is sometimes called a **black box model**, because it does not explicitly treat the physical processes in the runoff system.

A **conceptual model** expresses rainfall-runoff system conceptually. The Tank model (Sugawara, 1972), the storage function method (Kimura, 1962), the TOPMODEL (Beven and Kirkby, 1979) are major conceptual models. The Tank model treats catchment storage as combinations of several tanks. A **physically-based model** consists of the physical equations of the continuity and momentum conservation. The kinematic wave model is a major physically-based rainfall-runoff model.

2.2.3 Lumped and distributed rainfall-runoff models

In terms of the spatial structure of a rainfall-runoff model, it is classified into a **lumped model** and a **distributed model**. When the priority is placed on forecasting a specific point of river flow and spatial distribution of rainwater and substances within the drainage basin are not necessary, a lumped rainfall-runoff model is constructed for a river basin upstream from the point. The input data to a lumped runoff model is a spatial average of rainfall and evapotranspiration intensity in the basin. A lumped model does not include the space coordinate in the governing equations, which are generally formed as ordinary differential equations with time as an independent variable.

On the other hand, sometimes predictions of spatial distribution of soil moisture and flow movement is requested. For the purpose, a rainfall-runoff model that predicts a spatiotemporal distribution of hydrological variables is required. A runoff model of this type is called a **distributed runoff model**. The input of a distributed rainfall-runoff is the spatiotemporal rainfall observation such as radar observed rainfall intensity, the spatial distribution of topography, land use, geological condition of the river basin. A rainfall-runoff model that takes into account spatial hydrological variables can also be constructed by spatially combining several lumped models for sub-basins. Usually, such a hydrologic model is not called a distributed runoff model.

2.3 Lumped Rainfall-Runoff Model

2.3.1 Rational formula

A relational formula is used for estimating the maximum flow rate from a drainage basin during a rainstorm. Suppose that spatial mean rainfall intensity in the study basin is R [mm·h^{-1}]; the area is A [km^2]. Then the maximum flow rate Q [m^{3}s^{-1}] from the outlet is expressed as

$$Q = f \times r \ [\text{mm}\cdot\text{h}^{-1}] \times A \ [\text{km}^2] = \frac{1}{3.6} f R A \quad [\text{m}^3\text{s}^{-1}]$$

where f is a non-dimensional coefficient having a value of 1 or less, called the **runoff coefficient**, considering rainwater that does not contribute to the flood runoff by interception and infiltration etc. The constant 1/3.6 is a coefficient required to transform the unit. The rational formula expresses the relationship between the rainfall intensity and the flow rate at the time at which the flow rate reaches its maximum when the rainfall continues at a constant intensity. Theoretically, elucidated by the kinematic wave model, this formula holds in the state after the time at which the characteristic curve departing from the upper end of the hillslope has reached the lower end when the rainfall continues at a constant intensity. The rational formula is used for the design of hydraulic facilities for small-scale basins (10km^2 or smaller).

2.3.2 Unit hydrograph method

Suppose that in the case where rainfall whose size is 1 at time $t-\tau, \tau \geq 0$ is applied. Then, the runoff intensity at time t is expressed as $u(\tau)$, and the runoff intensity at time t due to the rainfall intensity $r(t-\tau)$ at time $t-\tau$ is expressed as $u(\tau)r(t-\tau)$. This $u(\tau)$ is the **unit hydrograph method** and is known as the unit impulse response function. The unit hydrograph method is a way of modeling the process of transformation of rainfall to runoff by overlapping the runoff intensities.

When the rainfall intensity is expressed as $r_e(t)$, the runoff intensity (height of runoff) is expressed as $q(t)$, the runoff intensity at time t due to the rainfall intensity $r_e(t-\tau_1)$ at time $t-\tau_1$ is expressed as $u(\tau_1)r(t-\tau_1)$, and the runoff intensity at time t due to the rainfall intensity $r_e(t-\tau_2)$ at time $t-\tau_2$ is expressed as $u(\tau_2)r_e(t-\tau_2)$. Add them together, and we find the runoff intensity at time t, as shown in **Fig. 2.5**, as follows:

$$q(t) = u(\tau_1)r_e(t-\tau_1) + u(\tau_2)r_e(t-\tau_2)$$

Therefore, the runoff intensity due to the continuous rainfall intensity $r_e(t)$ is given by integrating the runoff intensity due to the rainfall before time t:

$$q(t) = \int_0^\infty u(\tau)r_e(t-\tau)d\tau, \int_0^\infty u(\tau)d\tau = 1 \tag{2.1}$$

Here, we derive an equation using the unit hydrographs of discrete time. Consider specific time T, and suppose that when $\tau > T$, $u(\tau) = 0$, and that

$$\int_0^T u(\tau)d\tau = 1$$

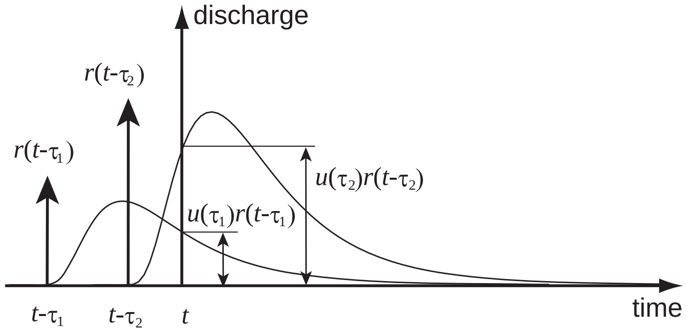


Fig. 2.5: Concept of unit hydrograph method

We set $\Delta t = T/N$, where N is a positive integer. Suppose that an amount of rainfall is obtained at an interval of this time, and the amount of rainfall $P_{t-k\Delta t}$ between time $t-(k+1)\Delta t$ to $t-k\Delta t$ is

$$P_{t-k\Delta t} = \int_{k\Delta t}^{(k+1)\Delta t} r_e(t-\tau)d\tau$$

Suppose also that the rainfall intensity is constant at an interval of time divided by Δt and that the amount of rainfall between time $t-(k+1)\Delta t$ to $t-k\Delta t$ is $P_{t-k\Delta t}/\Delta t$. Here, on the basis of Eq.(2.1), $q(t)$ is expressed as

$$\begin{aligned} q(t) &= \int_0^\infty u(\tau)r_e(t-\tau)d\tau = \int_0^T u(\tau)r_e(t-\tau)d\tau \\ &= \frac{P_t}{\Delta t}\int_0^{\Delta t} u(\tau)d\tau + \frac{P_{t-\Delta t}}{\Delta t}\int_{\Delta t}^{2\Delta t} u(\tau)d\tau + \cdots \\ &\quad + \frac{P_{t-k\Delta t}}{\Delta t}\int_{k\Delta t}^{(k+1)\Delta t} u(\tau)d\tau + \cdots + \frac{P_{t-(N-1)\Delta t}}{\Delta t}\int_{(N-1)\Delta t}^{N\Delta t} u(\tau)d\tau \end{aligned}$$

Here, suppose that

$$U_k = \frac{1}{\Delta t}\int_{(k-1)\Delta t}^{k\Delta t} u(\tau)d\tau,\ k = 1, 2, \cdots, N \tag{2.2}$$

U_k is the offset of the hydrograph of the discrete time. Using Equation (7.7), we can express the height of runoff $q(t)$ of time t as

$$\begin{aligned} q(t) &= P_tU_1 + P_{t-\Delta t}U_2 + \cdots + P_{t-(k-1)\Delta t}U_k + \cdots + P_{t-(N-1)\Delta t}U_N \\ &= \sum_{k=1}^{N} P_{t-(k-1)\Delta t}U_k \end{aligned} \tag{2.3}$$

and the amount of runoff from the drainage basin is given by multiplying $q(t)$ by the area of the drainage basin. As shown in **Fig. 2.6**, a flow rate hydrograph represents the

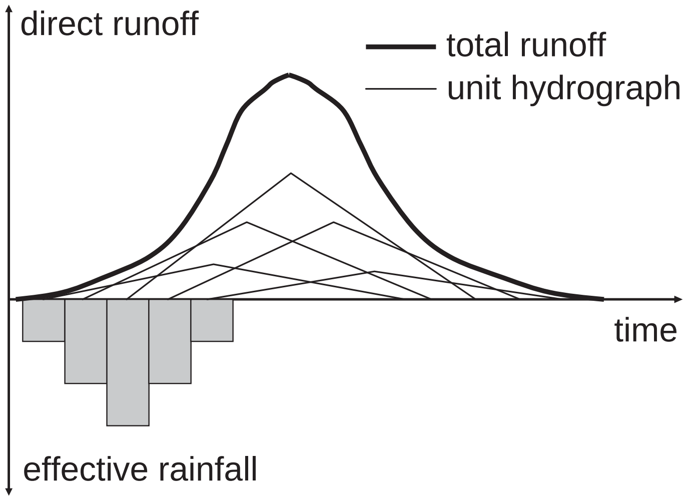


Fig. 2.6: Estimation of runoff by overlapping unit hydrographs

addition of unit hydrographs multiplied by the amount of rainfall per unit time for every specific period of time.

2.3.3 Tank model

Tank models express the runoff of rainwater from a drainage basin conceptually by combining tanks with orifices at their side and bottom. While there are innumerable combinations of, for example, the arrangement of tanks, the number of tanks, and the number of orifices, the four-layer tandem tank model, as shown in **Fig. 2.7**, is often used in Japan. Conceptually, the amount of side runoff from the upper tank is considered the amount of surface runoff, the amount of runoff from the upper to lower tank as the amount of infiltration, and the amount of side runoff from the lower tank as the amount of groundwater runoff.

Suppose that in the tank model shown in **Fig. 2.7**, the rainfall intensity is r, the evapotranspiration intensity is e, the height of the runoff of the overland flow q_1, the height of runoff of saturation side flow is q_2, and the amount of runoff to the second tank is q_3. Suppose also that the height of storage of the first tank is s_1, the heights of the outlets of overland flow and saturation side flow are h_1 and h_2, respectively, the proportional constants of the runoff to these outlets are a_1 and a_2, respectively, and the proportional constant of the runoff from the bottom of the tank is a_3. Then, the equation of continuity of the first tank is given by

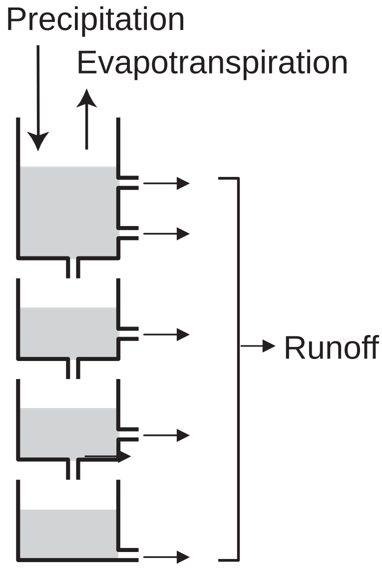


Fig. 2.7: Structure of the tank model.

$$\frac{ds_1}{dt} = r - e - q_1 - q_2 - q_3$$

The amounts of runoff of the side flow and the downward flow are

$$q_1 = \begin{cases} a_1(s_1 - h_1), \text{ if } s_1 > h_1 \\ 0, \text{ if } s_1 \leq h_1 \end{cases} \quad q_2 = \begin{cases} a_2(s_1 - h_2), \text{ if } s_1 > h_2 \\ 0, \text{ if } s_1 \leq h_2 \end{cases} \quad q_3 = a_3 s_1$$

2.3.4 Storage function method with effective rainfall model

A storage function method with an effective rainfall model is often used for flood simulation for Japanese catchments. Suppose that the height of storage is s; the direct runoff height is q; the effective rainfall intensity is r_e; and model parameters as k, p and T_L. The storage function method consists of the following equation of continuity and the relation between the amounts of storage and runoff:

$$\frac{ds}{dt} = r_e(t - T_L) - q, \;\; s = kq^p \tag{2.4}$$

Suppose that $r(t)$ and t_0 denote the catchment mean rainfall intensity and the time of starting calculation, respectively. The effective rainfall intensity $r_e(t)$ is given by

$$r_e(t) = \begin{cases} f_1 r(t), & \text{when } 0 \leq \int_{t_0}^{t} r(\tau)d\tau < R_{sa} \\ r(t), & \text{when } \int_{t_0}^{t} r(\tau)d\tau \geq R_{sa} \end{cases} \tag{2.5}$$

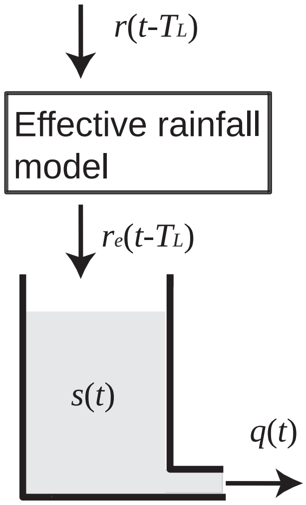
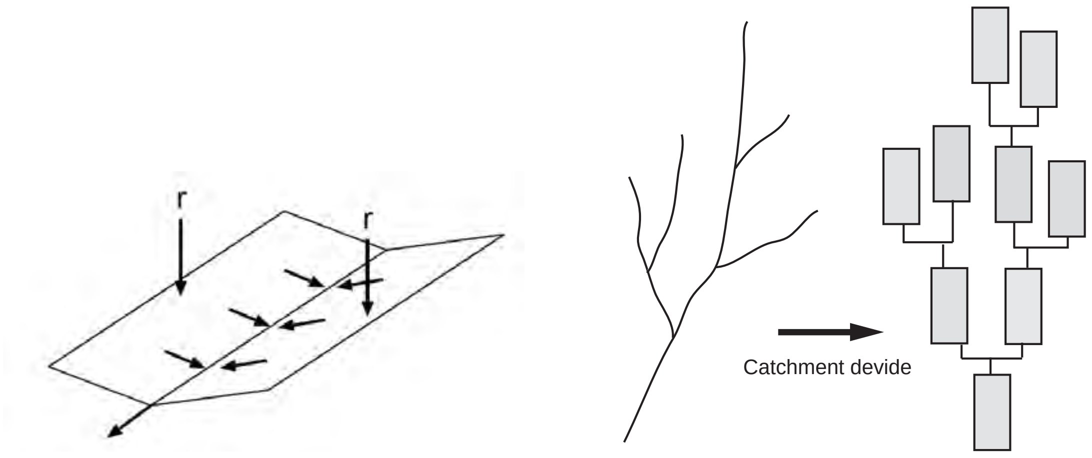


Fig. 2.8: Storage function method with effective rainfall model.

where f_1 $(0 < f_1 < 1)$ is the parameter relating to effective rainfall. The value of f_1 is usually determined by the relationship between the total amount of rainfall observed in the basin and the direct runoff height. The total amount of runoff $Q(t)$ is expressed as the sum of direct runoff $q(t)$ multiplied by the area of the basin A and the base flow rate Q_b as

$$Q(t) = Aq(t) + Q_b(t)$$

Note that this storage function method is different from Kimura's storage function method in terms of the model structure. Kimura's storage function method deals with two types of storage amount: the amount of storage in the runoff region and that in the infiltration region. f_1 means the ratio of the area of the runoff region to the area of the entire drainage basin. Effective rainfall is considered a part of the model of flow. On the other hand, this storage function method deals with one type of storage amount. f_1 and R_{sa} are used as parameters of the effective rainfall model that is separated from the model of flow. The effective rainfall model may vary, because it is independent of the model of flow.



(a)Schematic drawing of an open-book catchment model

(b)Cascade of the open-book catchment models

Fig. 2.9: Catchment modeling.

2.4 Basic Concept of Distributed Rainfall-Runoff Model

2.4.1 Open-book type catchment modeling

A simple representation of basin topography is probided by an open-book catchment model as shown in **Fig. 2.9**(a). As its name implies, an open-book catchment model consists of two rectangular planes and a stream. Rain water flows on the planes and flows into the stream, and then the stream flow is routed to the basin outlet. The flows on the rectangular plane and the stream are routed using a flow model such as the kinematic wave model. This forms a simple approximation of catchment hydrology. The entire system model is constructed by a cascade of the open-book element models as shown in **Fig. 2.9**(b). Spatial distribution information of topography, soil characteristics, land cover and rainfall intensity are used for each modeling of sub-catchment.

2.4.2 Catchment modeling using digital elevation model

Digital elevation models (DEMs) are available at any catchments with a high spatial resolution enough to describe local catchment topography. For example, HydroSHED (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales, http://hydrosheds.cr.usgs.gov/index.php) provides hydrographic information for regional

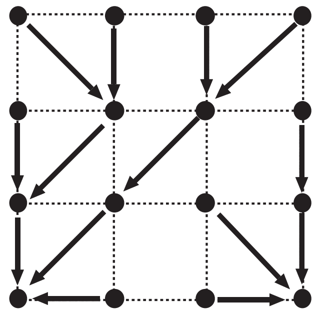


Fig. 2.10: Flow direction information generated from a digital elevation model.

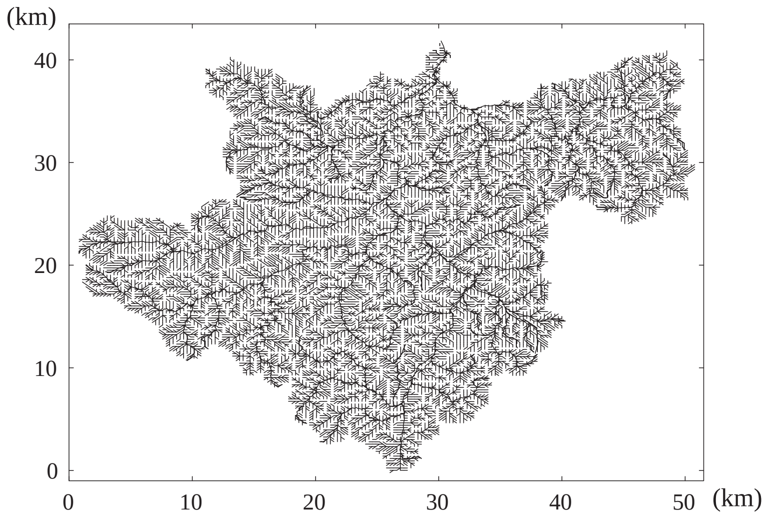


Fig. 2.11: Flow direction map for the Maruyama River basin.

and global-scale, which includes digital elevations, flow directions determined by the steepest gradient with the eight direction method (**Fig. 2.10**), and flow accumulation with the spatial resolutions of 3 arc-second (about 100m), 15 arc-second (about 500m) and 30 arc-second (about 1km).

After deriving the flow direction information, it is easy to define a river basin to contribute the outlet of a basin. as shown in **Fig. 2.11**, which is formed a set of slope units connected according to the flow direction using a 250m resolution DEM. **Fig. 2.12** is a schematic drawing of distributed flow modeling on the derived flow direction information. For each slope unit, its area, length and gradient used for a flow model are easily calculated using DEMs. A rainfall-runoff is applied to slope units and generated runoff is routed according to the flow direction information. Not only water movements, sediment and substance movements are also calculated based on the spatial distribution of rainfall

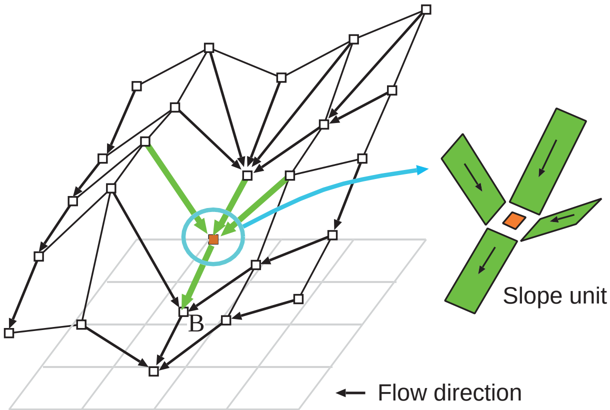


Fig. 2.12: Slope element based on flow information.

intensity, topography, geography, and land use. One of typical distributed models is the 1K-FRM http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html.

2.4.3 Flow modeling in hillslopes and channel network

To represent flows in hillslopes and a channel network, various numerical models are used. To calculate runoff from hillslopes, rainfall-runoff models such as Tank Model, TOPMODEL, the kinematic wave model are used. To calcurate river flow, a flow routing model such as Muskingum method, kinematic wave model, dynamic wave method is used. Model selection is due to the purpose of hydrologic and hydraulic analysis.

A physically-based flow model for hillslope flow is the kinematic wave model. Assuming a rectangular slope as shown in **Fig. 2.13**, x is the distance measured perpendicularly from the upper end of the hillslope t is time; $r(x,t)$ is rainfall intensity; $e(x,t)$ is evapotranspiration rate; $p(x,t)$ is infiltration rate; $q(x,t)$ is unit width flow rate from of the hillslope; $h(x,t)$ is water depth measured perpendicularly from the hillslope; and L is the hillslope length. Subtraction of evaporation and infiltration intensity from rainfall intensity forms the effective rainfall intensity r_e, and suppose that it is supplied to the hillslope. The equation of continuity and the equation of motion of the hillslope flow are

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r_e(x,t) = \{r(x,t) - p(x,t) - e(x,t)\}\cos\theta$$

$$q = f(x,h)$$

The unit width flow rate at the lower end of the hillslope is given as $q(L,t)$.

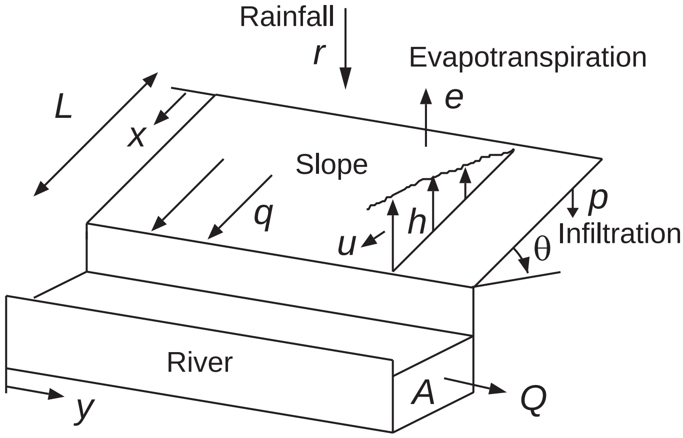


Fig. 2.13: Flow modeling using the kinematic wave model.

The hillslope runoff is the input to the river routing model. The continuity and momentum equations of the channel flow routing are expressed as

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial y} = q_L(y,t)$$

$$Q = g(y, A)$$

where $q_L(y,t)$ is the slope runoff at distance y along the river channel, $Q(y,t)$ i the flow rate of the river channel, $A(y,t)$ is the flow area. By connecting flow routing model spatially, an entire distributed rainfall-runoff model is constructed.

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Lecture 3: Fundamentals in rainfall-runoff-inundation modelling

Takahiro SAYAMA (*Associate Professor, Disaster Prevention Research Institute, Kyoto University*)

Abstract:
Flooding is a global phenomenon which causes widespread devastation, economic damage and loss of human lives. In steep mountainous landscapes, severe storms rapidly raise river water levels and occasionally cause abrupt levee breaches, which often result in devastating flood disasters. On the other hand, in flat landscapes such as large river deltas, river floods and additional precipitation on floodplains cause long-term inundations. Although seasonal flooding benefits agriculture and fisheries, as symbolized by "living with floods", changes in flooding patterns and scales due to recent climate changes may cause significant instability in maintaining sustainable societies.

Hydrologic modeling can predict such floods and contribute to mitigate the disasters in various ways. It helps issue flood warnings based on real-time flood predictions and analyze flood risks for better river basin management. In fact, many rainfall-runoff models have been in use for these objectives, but their primary goal has been the prediction of river discharges, not the prediction of flood inundations. Many flood inundation models have also been developed, but they often require discharge or water level boundary conditions at levee breach or overtopping points; therefore, these model structures are not always ideal for real-time flood runoff and inundation predictions or flood risk assessment at the large river basin scale.

The lecture introduces the idea behind the development of a Rainfall-Runoff-Inundation (RRI) model, which is a two dimensional hydrologic model simulating for both rainfall-runoff processes and flood inundation processes simultaneously at the river basin scale. The lecture covers also some basics of runoff generation mechanisms and their model representations. Furthermore, some application studies in various large scale flooding such as 2010 Pakistan Floods and 2011 Thailand Floods are presented to discuss the new approach for flood predictions and risk assessment.

Exercise 5: Fundamentals in rainfall-runoff-inundation modelling

Takahiro SAYAMA (*Associate Professor, Disaster Prevention Research Institute, Kyoto University*)

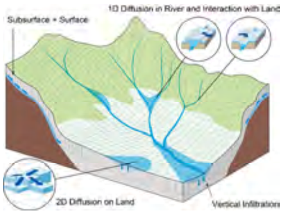
Abstract:

Rainfall-Runoff-Inundation (RRI) model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012). The model deals with slopes and river channels separately. At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell. The channel is discretized as a single line along its centerline of the overlying slope grid cell. The flow on the slope grid cells is calculated with the 2D diffusive wave model, while the channel flow is calculated with the 1D diffusive wave model. For better representations of rainfall-runoff-inundation processes, the RRI model simulates also lateral subsurface flow, vertical infiltration flow and surface flow. The lateral subsurface flow, which is typically more important in mountainous regions, is treated in terms of the discharge-hydraulic gradient relationship, which takes into account both saturated subsurface and surface flows. On the other hand, the vertical infiltration flow is estimated by using the Green-Ampt model. The flow interaction between the river channel and slope is estimated based on different overflowing formulae, depending on water-level and levee-height conditions.

RRI model and its related various tools are originally developed with Fortran 90 language. Although the model is fairly simple with limited numbers of parameters, to learn the model application requires some basic understanding of the command prompt and GIS, which required before some time investment to learn at the initial stage. To decrease the technical barrier, especially for practitioners without much experience in hydrologic modeling, ICHARM, Public Works Research Institute (PWRI) has been developing a Graphical User Interface (GUI) for smooth applications and visualizing modeling procedures and results. RRI-GUI uses basically HydroSHEDS dataset, global scale topography and flow direction dataset, so that any of a river basin (or multiple river basins) in the world can be fairly easily modeled at least to start with. This lecture provides RRI model with the GUI interface and introduces how to apply the GUI at river basins. It also covers some basic idea about how to properly set model parameters based on observed records. Since the model is freely available, we hope the model can be used in practice after participants being more familiar with the model.

Takahiro Sayama, Go Ozawa, Takahiro Kawakami, Seishi Nabesaka, Kazuhiko Fukami, Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, Hydrological Sciences Journal, 57(2), DOI: 10.1111/jfr3.12147, pp. 298-312, 2012.

Fundamentals in rainfall-runoff-inundation modelling



Disaster Prevention Research Institute, Kyoto University

Takahiro Sayama

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Outline

1. Basics of flood forecasting and warnings: Japanese case
2. Three types of “Flood Hazard Models” and objectives
3. Basics in Rainfall-Runoff Modeling
4. Introduction to Rainfall-Runoff-Inundation (RRI) Model

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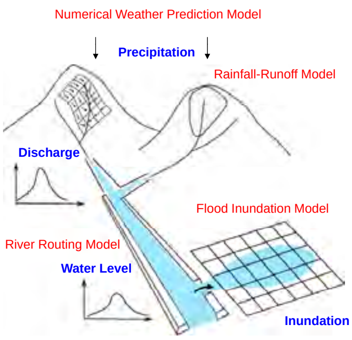
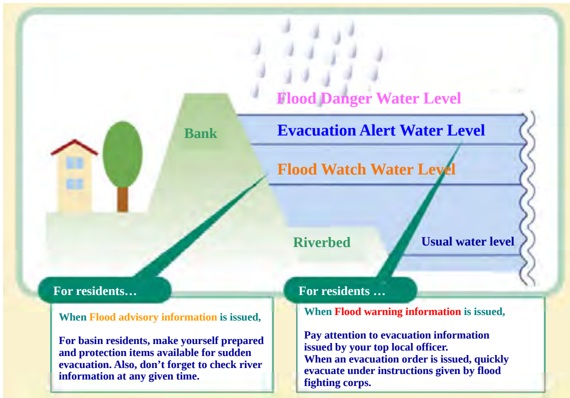
Flood Forecasting

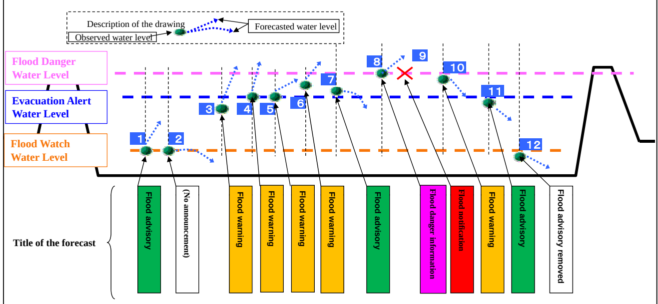


- Numerical Weather Prediction Model: Quantitative Precipitation Forecasting (QPF).
- Rainfall-Runoff Model: simulating streamflow discharge with rainfall input.
- River Routing Model: tracking flood wave movement along a open channel with upstream hydrograph.
- Flood Inundation Model: simulating flooded water spreading on floodplains with inflow discharge.

Water Level Criteria for Flood Warning (Japan)



Water Level Criteria for Flood Warning (Japan)

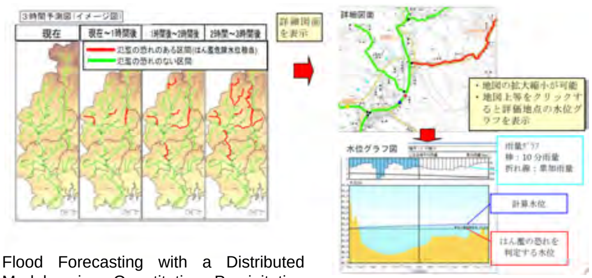


Flood advisory : when water level reaches Flood Watch Water Level and is expected to increase

Flood warning : when water level reaches to Evacuation Alert Water Level and is expected to reach Flood Danger Water Level

(MLIT)

Distributed Flood Forecasting System

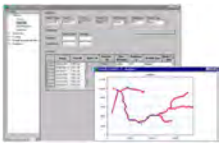


Flood Forecasting with a Distributed Model using Quantitative Precipitation Forecasting: 3 hours read-time, every 10 minutes,
at every a few kilometer

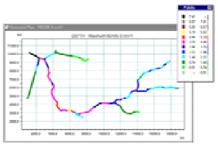
(Hyogo Prefecture)

MIKE

Danish Hydraulic Institute (DHI)
http://mikebydhi.com/



- MIKE11
  - One-dimensional river routing model
  - NAM: A lumped, conceptual rainfall-runoff model simulating overland flow, interflow and baseflow as a function of the water storage in each of four mutually interrelated storages representing the storage capacity of the catchment.
  - SHE: Complex fully distributed process-based oriented modeling
- MIKE21
  - Flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas and seas in two dimensions



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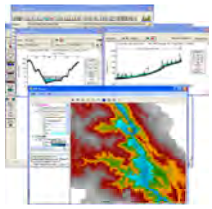
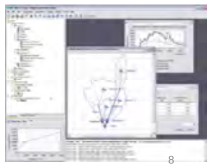
HEC

US Army Corps of Engineers
Hydrologic Engineering Centers (HEC)
http://www.hec.usace.army.mil/



- HEC-RAS (River Analysis System)
  (1) steady flow water surface profile computations
  (2) unsteady flow simulation
  (3) movable boundary sediment transport
  (4) water quality analysis
- HEC-HMS (Hydrologic Modeling System)
  - Elements: subbasin, reach, junction, reservoir, diversion, source, and sink
  - SCS curve number, Green Ampt
  - linear quasi-distributed unit hydrograph method
  - kinematic wave or Muskingum-Cunge
  - Priestley-Taylor method (PET)
  - Snow melt



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Steps in the Modeling Process

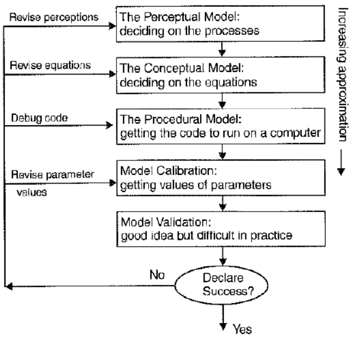

Figure 1.2 A schematic outline of the different steps in the modelling process

"Rainfall-Runoff Modelling, The Primer", by Keith Beven

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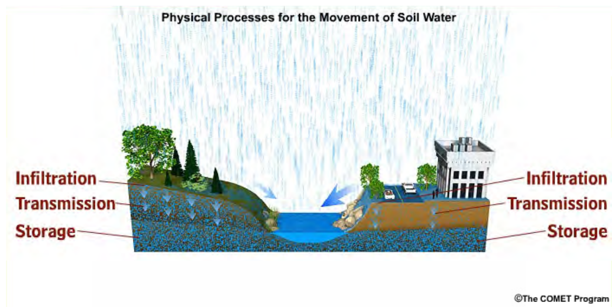
Importance of Perceptual Modeling



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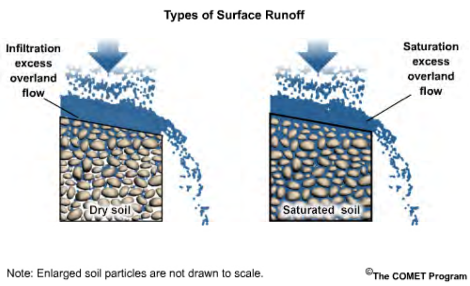
Surface Runoff Generation



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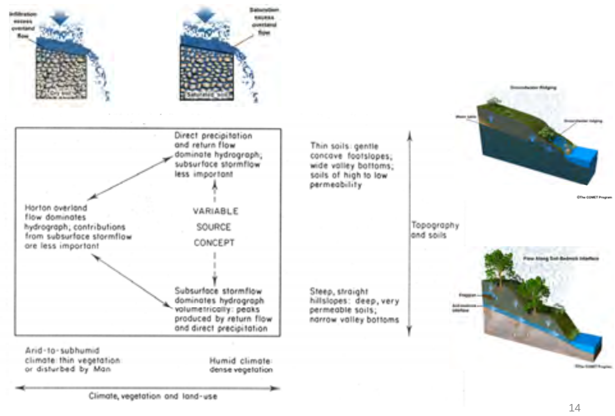
Peter Kienzler, ETH Zurich

Runoff Generation Mechanisms

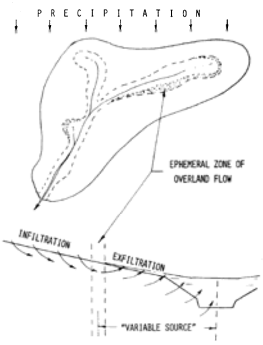


Bloschl et al., Runoff Prediction in Ungauged Basins, Cambridge Press

Variable Source Area (VSA) Concept

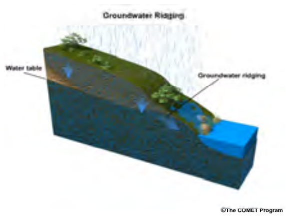
Petra Fackle, ETH Zurich

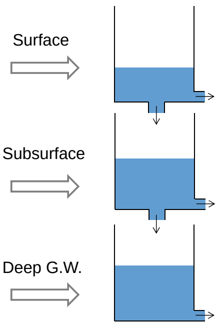
Courtesy J.J. McDonnell



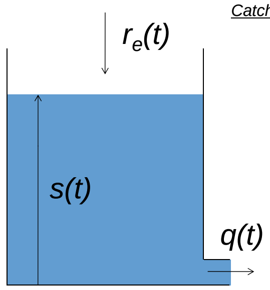
Hewlett and Hibbert (1967)
Hewlett and Troendle (1975)

Tank Model





Storage Function Model



r_e: effective rainfall (mm/h)
q: specific discharge (mm/h)
Q : q x A / 3.6: discharge (m^3/s)
A: catchment area (km)

Catchment is represented as a single storage tank

$$\frac{ds}{dt} = r_e(t - T_L) - q$$

$$s = kq^p,$$

$$r_e = fr \qquad f = \begin{cases} f_1 & \left(\sum_t r(t) < R_{sa}\right) \\ 1.0 & \left(\sum_t r(t) \geq R_{sa}\right) \end{cases}$$

Example of finite difference scheme

$$\frac{s(t+\Delta t) - s(t)}{\Delta t} = r_e(t - T_L) - q(t)$$

Kinematic Wave Rainfall-Runoff Model

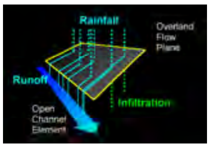
Continuous Equation

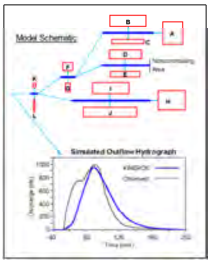
$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r$$

Kinematic wave model

$$q = \frac{\sqrt{i}}{n} h^{5/3}$$

q : discharge
h : water depth
r : rainfall
i : slope
n : Manning's roughness





KINEROS

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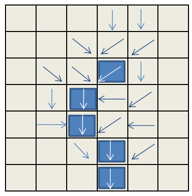
Grid-cell based Kinematic Wave Rainfall-Runoff Model



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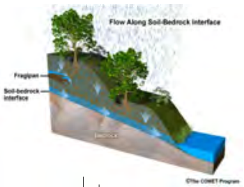
Kinematic Wave Rainfall-Runoff Model for subsurface and surface flow

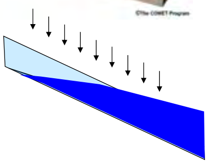
Continuous Equation

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r$$

Kinematic wave model
for saturated subsurface and surface flow

$$q = \begin{cases} kih & (h < d) \\ \frac{\sqrt{i}}{n}(h-d)^{5/3} + kih & (h > d) \end{cases}$$





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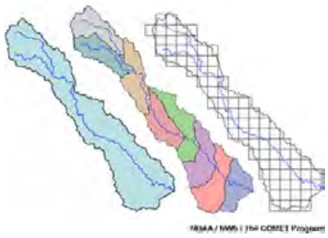
Lumped Model vs. Distributed Model



What are the limitation of lumped models?
- cannot reflect the spatial distributions of
  - rainfall, topography, state variables
- cannot obtain stream flow at various points in a basin

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Introduction to Rainfall-Runoff-Inundation (RRI) Model

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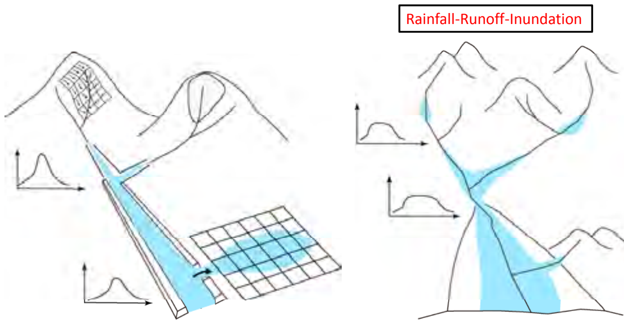

Motivations of using Rainfall-Runoff-Inundation Model

1. Rainfall-runoff and inundation cannot be separated with large inundation
2. Kinematic wave is not suitable for flat topography
3. Important for representing inundation process for better river predictions
4. Inundation itself may be of interest in flood forecasting or risk assessment

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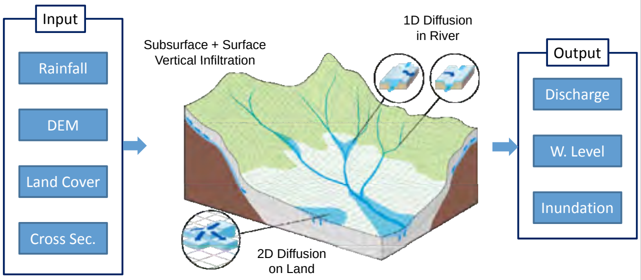
Rainfall-Runoff-Inundation Model



- Two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously
- The model deals with slopes and river channels separately
- At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell

Sayama, T. et al.: Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, *Hydrological Sciences Journal*, 57(2), pp. 298-312, 2012.

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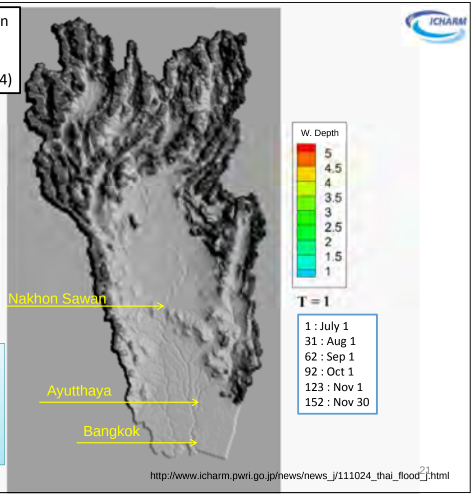
Rainfall-Runoff-Inundation Prediction
of Thailand Flood 2011
(conducted on 2011/10/14)



Simulation Domain : 163,293 km²
Grid Size : 60sec (1776 x 1884 m)
Simulation Period :
2011/07/01 – 2011/11/30
Input Rainfall:
✓2011/07/01 – 2011/10/14
3B42RT (Satellite Based Rainfall)
(Every 3hours, Spatial Resolution: 0.25 deg)
✓2011/10/14 – 2011/10/21
JMA- GSM Weekly Weather Forecasting
(Forecasting Lead Time: 8 days, Update every 12 hours)
✓2011/11/15 – 2011/11/30
(Previous year's 3B42RT rainfall in the same period)

1 : July 1
31 : Aug 1
62 : Sep 1
92 : Oct 1
123 : Nov 1
152 : Nov 30

http://www.icharm.pwri.go.jp/news/news_j/111024_thai_flood_j.html

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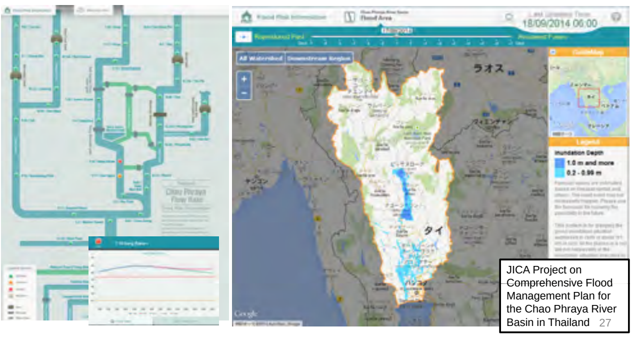
Example of RRI Model Application (1)

Real-time flood runoff and inundation forecasting system
for the Chao Phraya River Basin based on RRI Model
(developed by JICA/FRICS and operated under RID, Thailand)

http://floodinfo.rid.go.th/index_en.html



JICA Project on Comprehensive Flood Management Plan for the Chao Phraya River Basin in Thailand

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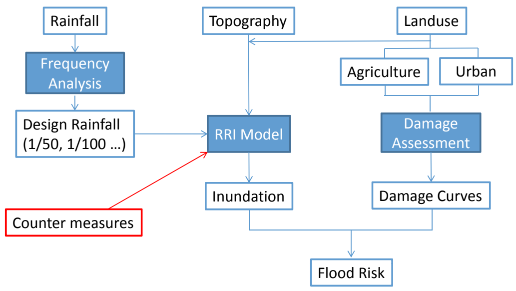
Example of RRI Model Application (2)

1. Flood Risk Assessment with RRI



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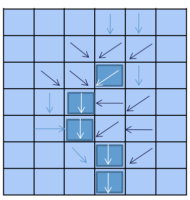
Main difference between typical distributed R-R models and RRI?

Distributed R-R Model

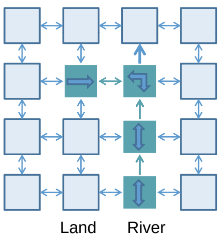
Flow directions are fixed based on topography



1D Kinematic (or similar)

RRI Model

Flow directions change based on water levels



2D Diffusive

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One-dimensional Saint-Venant Equation

$$\frac{\partial q}{\partial t}+\frac{\partial uq}{\partial x}+gh\frac{\partial h}{\partial x}-ghi_0+\frac{gn^2q^2}{h^{7/3}}=0$$

Kinematic Wave

Diffusive Wave

Dynamic Wave

Basic Equations

Shallow water equations for typical 2D inundation

Mass balance equation

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=r$$

Momentum equations

$$\frac{\partial q_x}{\partial t}+\frac{\partial u q_x}{\partial x}+\frac{\partial v q_x}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho_w}$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial u q_y}{\partial x}+\frac{\partial v q_y}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho_w}$$

⇩

Cell storage based model with diffusion wave approx.
(e.g. Hunter et al. 2007.)

Mass balance equation

$$\frac{dh^{i,j}}{dt}=\frac{q_x^{i-1,j}-q_x^{i,j}}{\Delta x}+\frac{q_y^{i,j-1}-q_y^{i,j}}{\Delta y}+r^{i,j}$$

Momentum equations

$$q_x=-\frac{1}{n}h^{5/3}\sqrt{\left|\frac{\partial H}{\partial x}\right|}\operatorname{sgn}\left[\frac{\partial H}{\partial x}\right]$$

$$q_y=-\frac{1}{n}h^{5/3}\sqrt{\left|\frac{\partial H}{\partial y}\right|}\operatorname{sgn}\left[\frac{\partial H}{\partial y}\right]$$

$r^{i,j}$: Rainfall, $h^{i,j}$: Water depth, $q_{x,y}^{i,j}$: Discharge between grid-cells

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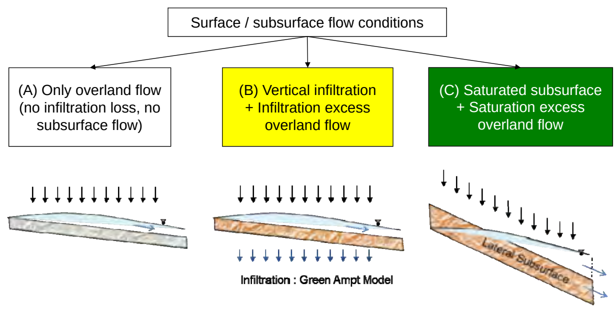
Three Conditions of Surface / Subsurface Flow



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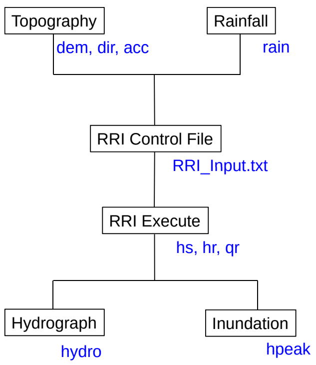
Key Steps in RRI Modeling



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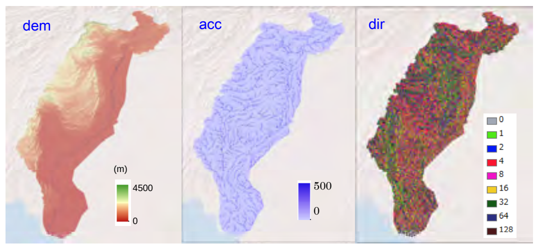
1. Input Topography

Digital Elevation Model | Flow Accumulation | Flow Direction



These three datasets can be obtained from HydroSHEDS
(SRTM based topography and flow direction dataset)

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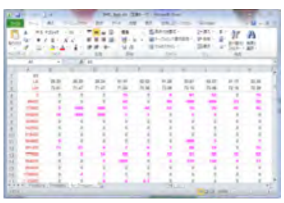
2. Input Rainfall

Rainfall Data (input) | Thiessen polygon (output)



Prepare rainfall data with time and location information (e.g. above excel file) and execute rainThiessen.exe program to create rainfall input file

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3. RRI Control File (RRI_Input.txt)

```
RRI_Input_Format_Ver1_4_1
./rain.txt
./adem.txt
./acc.txt
./adir.txt
0                    # utm(1) or latlon(0)
1                    # 4-direction (0), 8-direction(1)
2568                 # lasth
600                  # dt
60                   # dt_riv
104                  # outnum
66.0d0               # xllcorner_rain
23.0d0               # yllcorner_rain
0.1 0.1              # cellsize_rain
…
…
(continue)
```

Prepare RRI control file (RRI_Input.txt), which includes parameter settings, and execute 0_rri_1_4_1.exe to run RRI model

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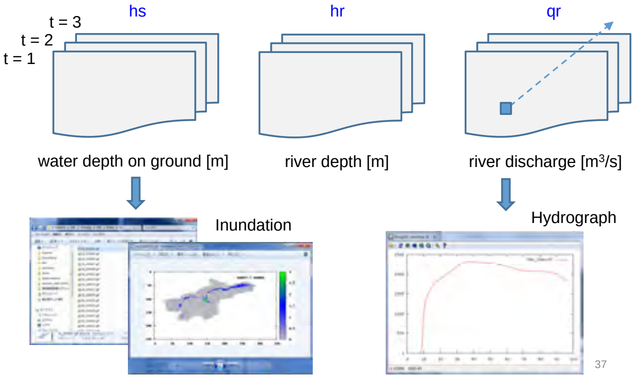
4. Visualizing Results



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Key Terms

- **State Variables**
  - A variable in the model that is part of the solution of the model equations and which varies with time during a simulation but which is not a flux or exchange of mass.
- **Boundary conditions**
  - Constraints and values of variables required to run a model for a particular flow domain and time period. May include input variables.
- **Initial conditions**
  - Values of storage or pressure variables to initialize a model at the start of a simulation period.

- **Calibration**
  - The process of adjusting parameter values of a model to obtain a better fit between observed and predicted variables.
- **Validation**
  - A process of evaluation of models to confirm that they are acceptable representations of a system.

From "Rainfall-Runoff-Modelling, The Primer" by Keith Beven 39

Types of Rainfall-Runoff Models

- Empirical R-R model (black box model)
  --- Empirical functions are derived from rainfall-runoff relationship
  --- Rational method, Unit hydrograph

- Conceptual R-R model
  --- Constructed with conceptual functions of rainfall-runoff processes
  --- Storage function model, Tank model

- Physically-based R-R model (process description model)
  --- Constructed with fundamental equations of water flow dynamics
  --- Kinematic wave model

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Lecture 4: Data Integration and Analysis System (DIAS) for water-related disasters

Akiyuki KAWASAKI (*Project Associate Professor, Graduate School of Engineering, The University of Tokyo*)

Abstract:

DIAS (Data Integration and Analysis System) was launched in 2006 as part of the Earth Observation and Ocean Exploration System, which is one of five National Key Technologies defined by the 3rd Basic Program for Science and Technology of Japan. The mission of DIAS is: 1) to coordinate the cutting-edge information science and technology and the various research fields including water-related disaster management; 2) to construct data infrastructure that can integrate earth observation data, numerical model outputs, and socio-economic data effectively; 3) to create knowledge enabling us to solve the global environment problems; and 4) to generate socio-economic benefits. DIAS is unique in the establishment of R&D community to support application and tool development on data infrastructure, in addition to the building of data infrastructure itself collaborating with ICT specialist. In the lecture the concept of DIAS from the viewpoint of three systems, namely infrastructure system, application development, and R&D community is firstly introduced. Then DIAS's principle on data sharing in terms of data access, metadata, and data policy is summarized. As a case study on DIAS's contribution to solving water-related disaster risk, we introduce flood management in Cambodia, Pakistan, and Philippines based on data analysis and integration on climate change projection data and local in-situ dataset. The lecture concludes with our thought on some of important directions in DIAS research and development toward the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030.

Data Integration and Analysis System (DIAS) for water-related disasters

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Agenda

1. **Introduction**
2. **Data system**: DIAS
3. **System for inter-linkage**: Water Cycle Integrator
4. **Opportunity**
5. **Summary**

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Agenda

1. **Introduction**
2. **Data system**: Data Integration and Analysis System (DIAS)
3. **System for inter-linkage**: Water Cycle Integrator
4. **Opportunity**
5. **Summary**

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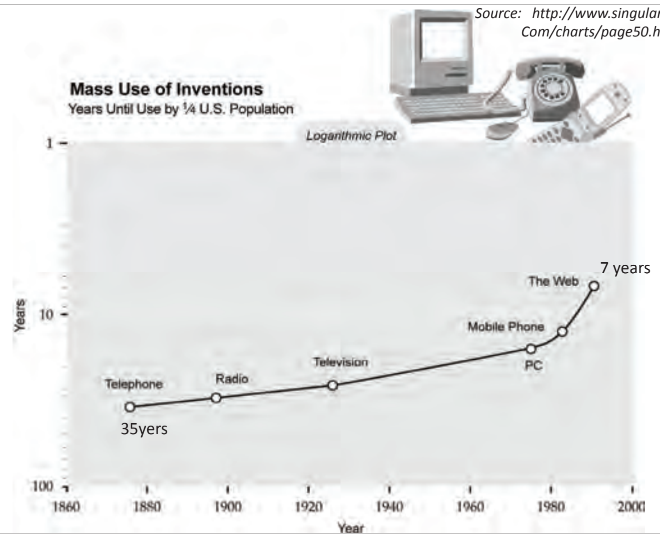
Source: http://www.singularity.Com/charts/page50.html



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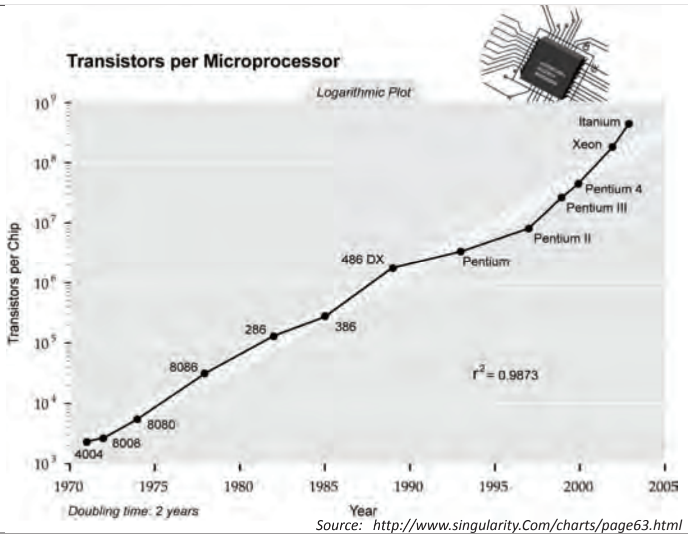
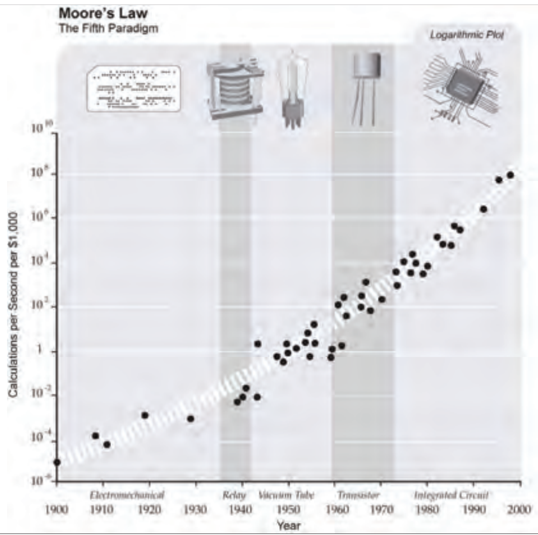


Source: http://www.singularity.Com/charts/page63.html 5



Source: http://www.singularity.Com/charts/page67.html

6

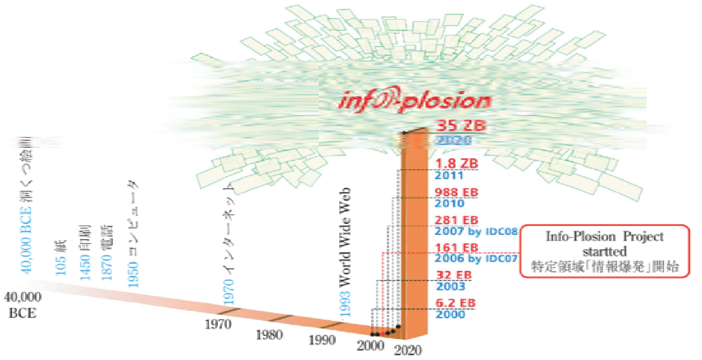


図1 情報爆発[10] （出典：Horison Information Strategies, cited from Storage New Game New Rules, p.34 (www.horison.com), IDC, The Diverse and Exploding Digital Universe 2020 (http://www.emc.com/collateral/demos/microstites/idc-digital-universe/iview.htm)）

Information explosion = excessive information ?

7

Agenda

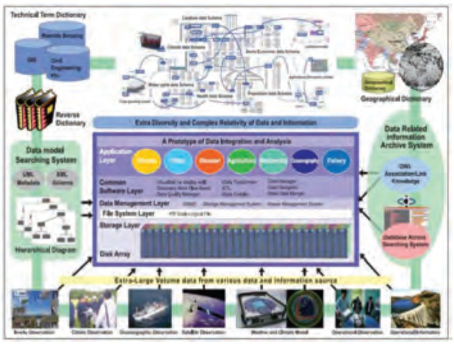
1. Introduction
2. **Data system**: Data Integration and Analysis System (DIAS)
3. **System for inter-linkage**: Water Cycle Integrator
4. **Opportunity**
5. **Summary**

8

Data Integration and Analysis System

a legacy for Japan's contributions to GEOSS

To create knowledge enabling us to solve the Earth environment problems and to generate socio-economic benefits,

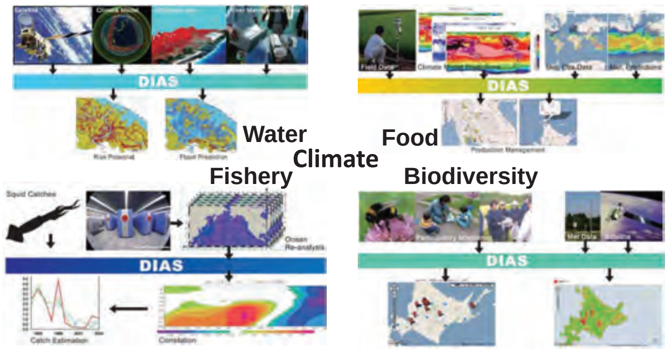


9

Data Integration and Analysis System

a legacy for Japan's contributions to GEOSS

enabling us to do integrated research and to realize inter-disciplinarity



10

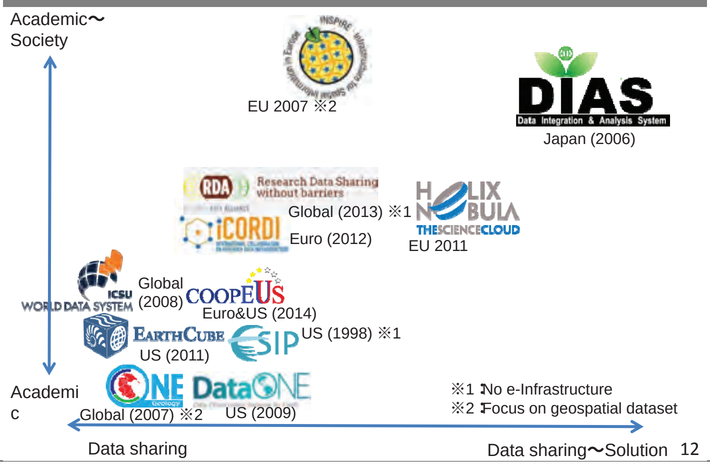
EDITORIA
THE UNIVERSITY OF TOKYO
Earth Observation Data Integration & Fusion Research Initiative
東京大学 地球観測データ統融合連携研究機構

- Basic platform development of the integration and fusion core system
  - **Institute of Industrial Science**
- Basic platform development of the ontology registry system
  - **Center for Spatial Information Science**
- Basic platform development of tools for the advanced application of technology to the task of statistically-driven information fusion
  - **School of Engineering**
  - **Graduate School of Agricultural and Life Sciences**
  - **Center for Climate System Research**
  - **Atmosphere and Ocean Research Institute**

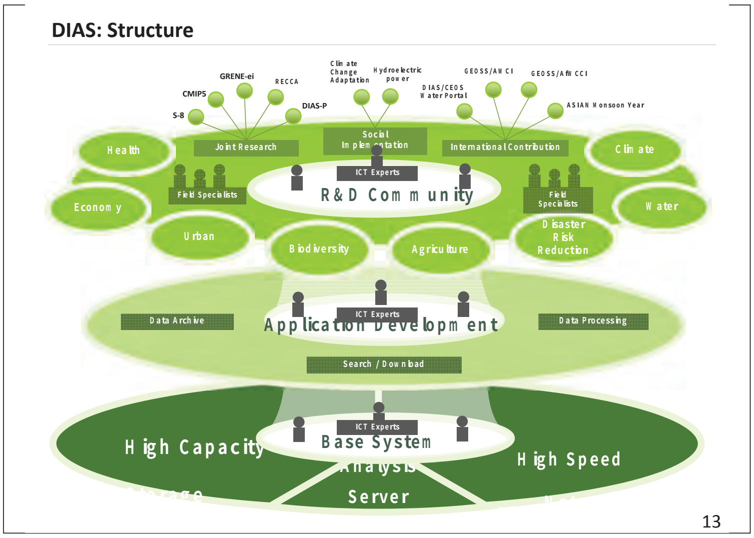
Kyoto University, Nagoya University, National Institute of Informatics
JAXA, JAMSTEC, National Institute for Environmental Studies
Hokkaido University, Kanazawa University, and Meteorological Institute

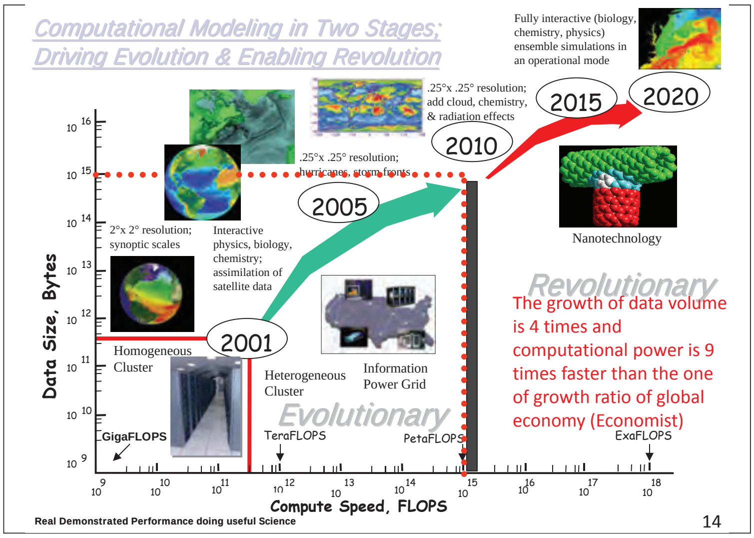
11

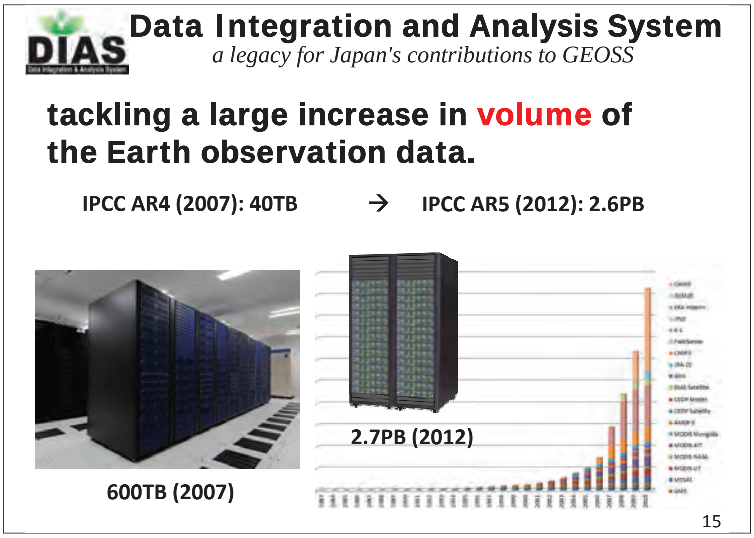
e-infrastructure mapping in the world

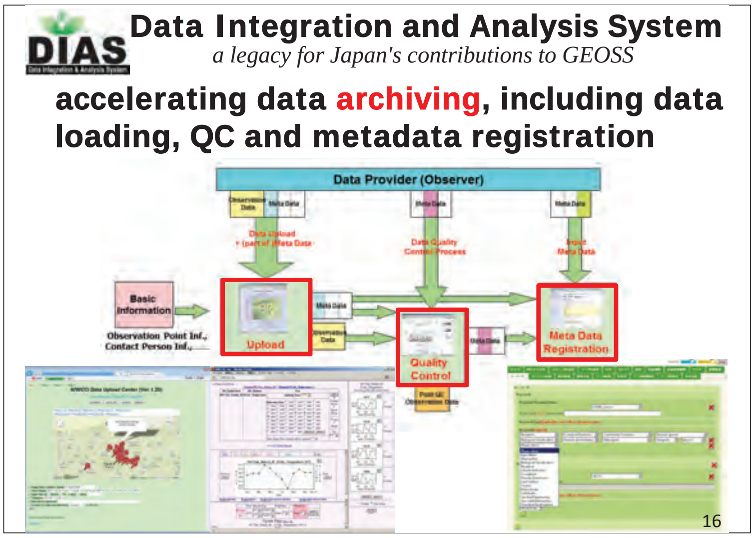


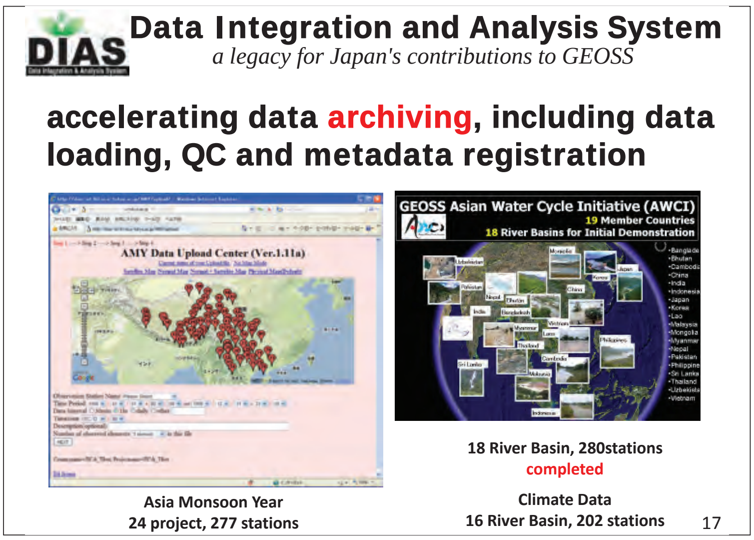
12

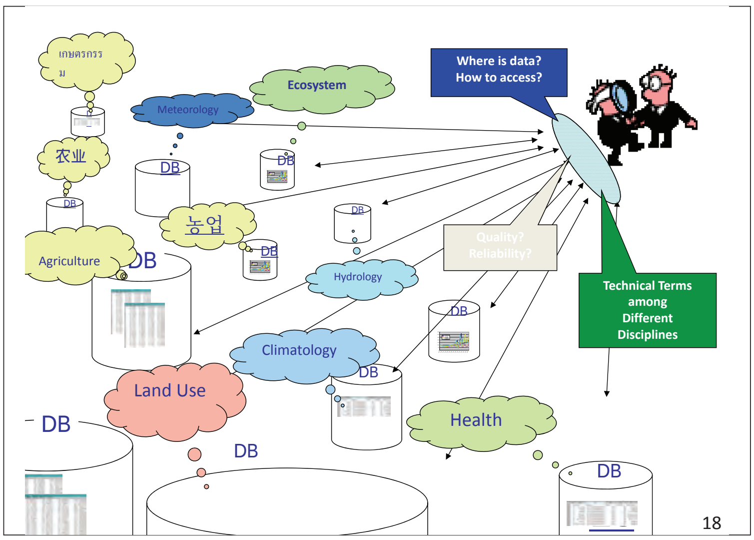

DIAS: Structure
GRENE-ei
CMIP5
S-8
RECCA
Climate Change Adaptation
Hydroelectric power
DIAS-P
DIAS/CEOS Water Portal
GEOSS/AWCI
GEOSS/AfWCCI
ASIAN Monsoon Year
Health
Joint Research
Social Implementation
International Contribution
Climate
Economy
Field Specialists
ICT Experts
R&D Community
Water
Urban
Biodiversity
Agriculture
Disaster Risk Reduction
Data Archive
Application Development
Data Processing
Search / Download
Base System
High Capacity
High Speed
Server
13

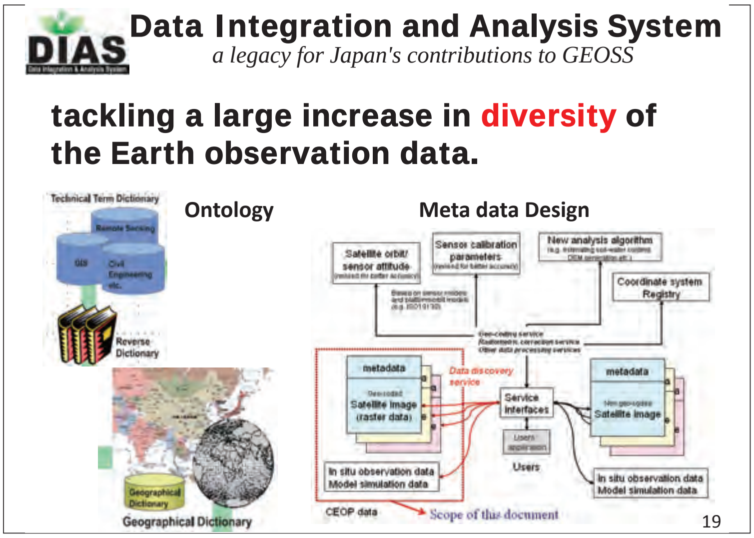

Computational Modeling in Two Stages;
Driving Evolution & Enabling Revolution
Fully interactive (biology, chemistry, physics) ensemble simulations in an operational mode
.25°x .25° resolution; add cloud, chemistry, & radiation effects
2015
2020
2010
.25°x .25° resolution; hurricanes, storm fronts
2005
Nanotechnology
2°x 2° resolution; synoptic scales
Interactive physics, biology, chemistry; assimilation of satellite data
Revolutionary
The growth of data volume is 4 times and computational power is 9 times faster than the one of growth ratio of global economy (Economist)
2001
Homogeneous Cluster
Heterogeneous Cluster
Information Power Grid
Evolutionary
GigaFLOPS
TeraFLOPS
PetaFLOPS
ExaFLOPS
Data Size, Bytes
Compute Speed, FLOPS
Real Demonstrated Performance doing useful Science
14

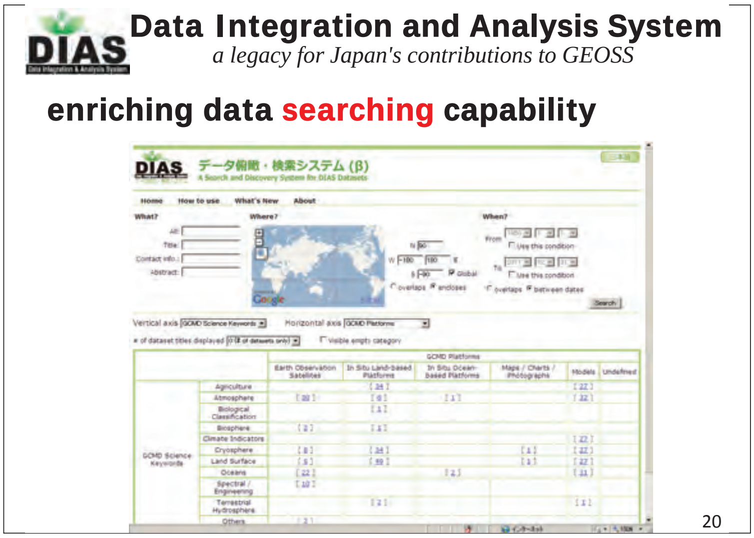

DIAS
Data Integration and Analysis System
a legacy for Japan's contributions to GEOSS
tackling a large increase in volume of the Earth observation data.
IPCC AR4 (2007): 40TB → IPCC AR5 (2012): 2.6PB
2.7PB (2012)
600TB (2007)
15

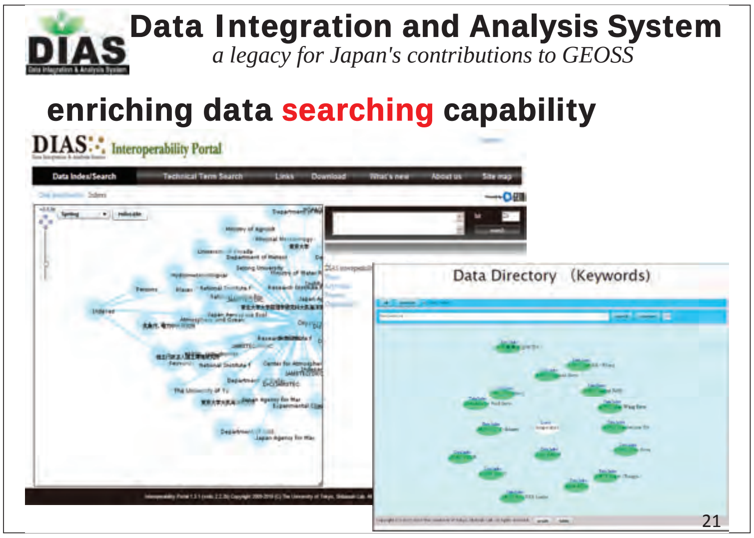

DIAS
Data Integration and Analysis System
a legacy for Japan's contributions to GEOSS
accelerating data archiving, including data loading, QC and metadata registration
Data Provider (Observer)
Basic Information
Observation Point Inf., Contact Person Inf.
Upload
Quality Control
Meta Data Registration
16

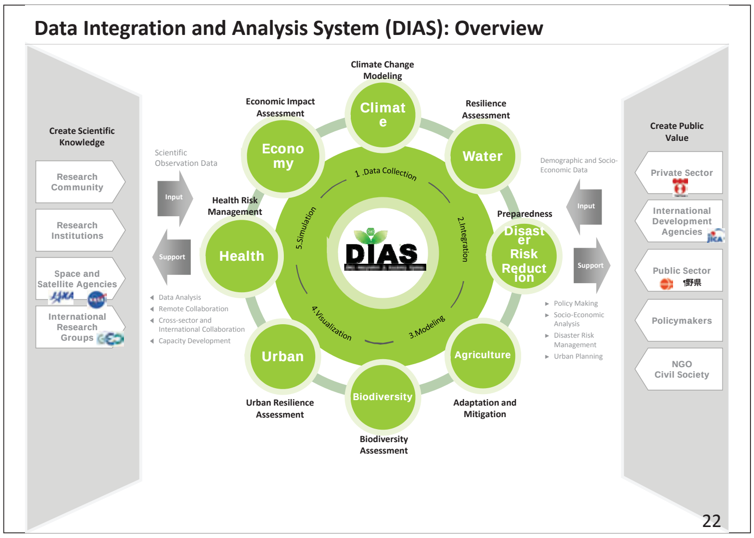

DIAS
Data Integration and Analysis System
a legacy for Japan's contributions to GEOSS
accelerating data archiving, including data loading, QC and metadata registration
AMY Data Upload Center (Ver.1.11a)
GEOSS Asian Water Cycle Initiative (AWCI)
19 Member Countries
18 River Basins for Initial Demonstration
Asia Monsoon Year
24 project, 277 stations
18 River Basin, 280stations
completed
Climate Data
16 River Basin, 202 stations
17

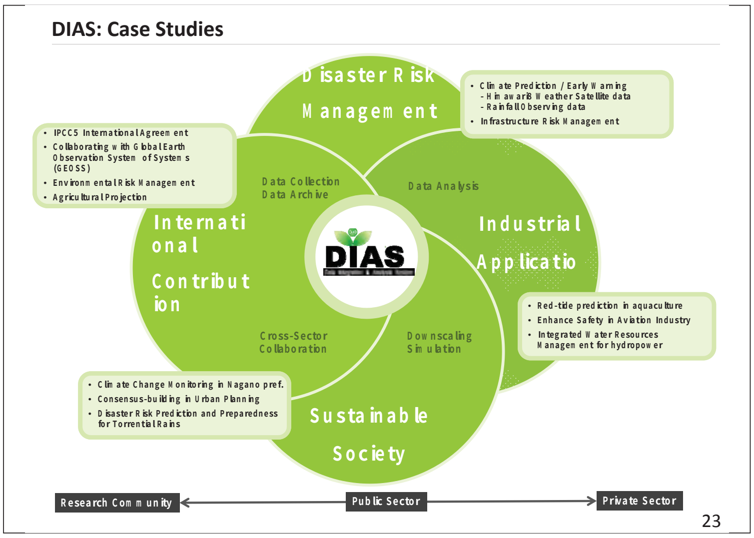

Where is data?
How to access?
Ecosystem
Meteorology
农业
DB
농업
Agriculture
Hydrology
Quality?
Reliability?
Technical Terms among Different Disciplines
Climatology
Land Use
Health
18

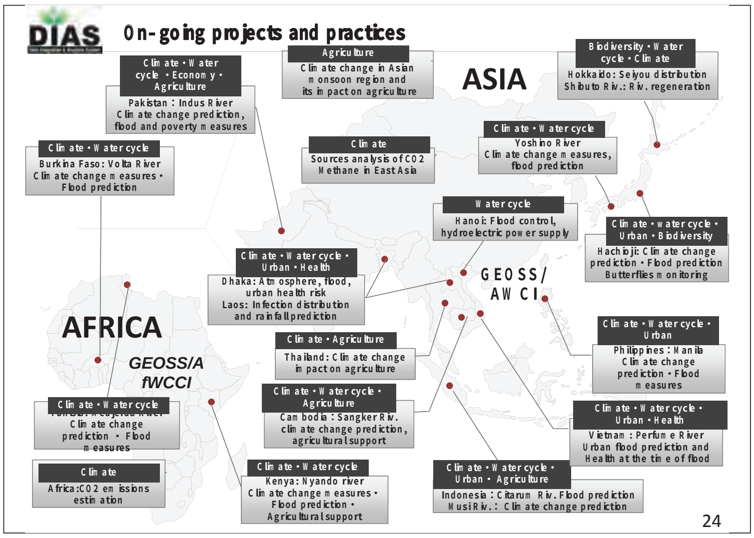

Data Integration and Analysis System
a legacy for Japan's contributions to GEOSS
tackling a large increase in diversity of the Earth observation data.
Technical Term Dictionary
Ontology
Meta data Design
Reverse Dictionary
Geographical Dictionary
Satellite orbit/ sensor attitude
Sensor calibration parameters
New analysis algorithm
Coordinate system Registry
metadata
Satellite image (raster data)
Data discovery service
Service interfaces
Users
In situ observation data
Model simulation data
CEOP data
Scope of this document
19


Data Integration and Analysis System
a legacy for Japan's contributions to GEOSS
enriching data searching capability
DIAS データ解析・検索システム (β)
What?
Where?
When?
GCMD Platforms
Earth Observation Satellites
In Situ Land-based Platforms
In Situ Ocean-based Platforms
Maps / Charts / Photographs
Models
Undefined
GCMD Science Keywords
Agriculture
Atmosphere
Biological Classification
Biosphere
Climate Indicators
Cryosphere
Land Surface
Oceans
Spectral / Engineering
Terrestrial Hydrosphere
Others
20


Data Integration and Analysis System
a legacy for Japan's contributions to GEOSS
enriching data searching capability
DIAS Interoperability Portal
Data Directory (Keywords)
21


Data Integration and Analysis System (DIAS): Overview
Create Scientific Knowledge
Research Community
Research Institutions
Space and Satellite Agencies
International Research Groups
Scientific Observation Data
Input
Support
Data Analysis
Remote Collaboration
Cross-sector and International Collaboration
Capacity Development
Climate Change Modeling
Climate
Economic Impact Assessment
Economy
Resilience Assessment
Water
Health Risk Management
Health
Preparedness
Disaster Risk Reduction
Urban
Urban Resilience Assessment
Biodiversity
Biodiversity Assessment
Agriculture
Adaptation and Mitigation
1. Data Collection
2. Integration
3. Modeling
4. Visualization
5. Simulation
DIAS
Demographic and Socio-Economic Data
Policy Making
Socio-Economic Analysis
Disaster Risk Management
Urban Planning
Create Public Value
Private Sector
International Development Agencies
Public Sector
Policymakers
NGO Civil Society
22


DIAS: Case Studies
Disaster Risk Management
Climate Prediction / Early Warning
- Himawari Weather Satellite data
- Rainfall Observing data
Infrastructure Risk Management
IPCC5 Intenational Agreement
Collaborating with Global Earth Observation System of Systems (GEOSS)
Environmental Risk Management
Agricultural Projection
International Contribution
Data Collection
Data Archive
Data Analysis
Industrial Application
Red-tide prediction in aquaculture
Enhance Safety in Aviation Industry
Integrated Water Resources Management for hydropower
Cross-Sector Collaboration
Downscaling Simulation
Sustainable Society
Climate Change Monitoring in Nagano pref.
Consensus-building in Urban Planning
Disaster Risk Prediction and Preparedness for Torrential Rains
Research Community
Public Sector
Private Sector
23


DIAS On-going projects and practices
ASIA
AFRICA
GEOSS/AWCI
GEOSS/AfWCCI
Climate・Water cycle・Economy・Agriculture
Pakistan: Indus River
Climate change prediction, flood and poverty measures
Agriculture
Climate change in Asian monsoon region and its impact on agriculture
Biodiversity・Water cycle・Climate
Hokkaido: Seiyou distribution
Shibuto Riv.: Riv. regeneration
Climate・Water cycle
Burkina Faso: Volta River
Climate change measures・Flood prediction
Climate
Sources analysis of CO2
Methane in East Asia
Climate・Water cycle
Yoshino River
Climate change measures, flood prediction
Water cycle
Hanoi: Flood control, hydroelectric power supply
Climate・water cycle・Urban・Biodiversity
Hachioji: Climate change prediction・Flood prediction
Butterflies monitoring
Climate・Water cycle・Urban・Health
Dhaka: Atmosphere, flood, urban health risk
Laos: Infection distribution and rainfall prediction
Climate・Agriculture
Thailand: Climate change impact on agriculture
Climate・Water cycle・Urban
Philippines: Manila
Climate change prediction・Flood measures
Climate・Water cycle
Climate change prediction・Flood measures
Climate・Water cycle・Agriculture
Cambodia: Sangker Riv.
climate change prediction, agricultural support
Climate・Water cycle・Urban・Health
Vietnam: Perfume River
Urban flood prediction and Health at the time of flood
Climate
Africa: CO2 emissions estimation
Climate・Water cycle
Kenya: Nyando river
Climate change measures・Flood prediction・Agricultural support
Climate・Water cycle・Urban・Agriculture
Indonesia: Citarum Riv. Flood prediction
Musi Riv.: Climate change prediction
24

DIAS Official website <http://www.diasjp.net>

25

35 tools and applications are now available!

< http://www.diasjp.net> 26

Data access portals

DIAS opens the data from 78 in-situ observations, 92 Satellite observations, and 49 numerical model outputs, and 11 Socio-economical data as of June 2015, and all these data has got individual meta data.

Data Search & Discovery

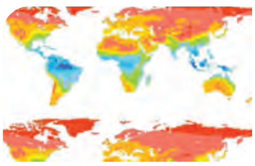
DIAS/CEOS Water Portal

Data Interoperability Portal

< http://www.diasjp.net> 27

Applications and tools

DIAS has established its own unique community where IT research group and Earth Science research group can discuss together to develop a new application to solve various global issues.



CMIP3/5 Analysis Tool

Meta Data Registration Tool

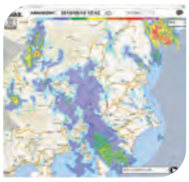
Crowdsourcing Tool

< http://www.diasjp.net> 28

Applications and tools

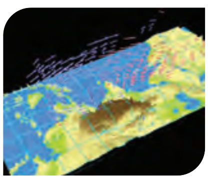
< http://www.diasjp.net>

Himawari 8 (GMS) Real-time Visualization Tool

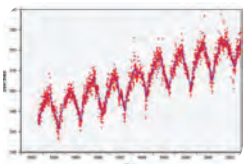


Radar Rain Real-time Visualization Tool

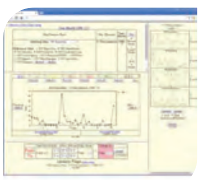
Simulation Model for RIce-Weather relations



3D Visualization Tool

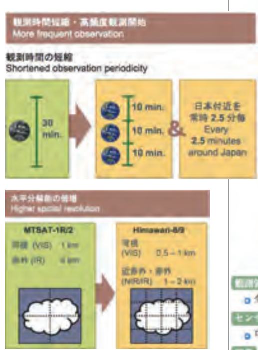


Earth Observation data Analysis Tool



In-situ data Quality Control Tool 29

Himawari 8 (GMS: geostationary meteorological satellites) Real-time Visualization Tool



(source: Japan Meteorological Agency)

< http://www.diasjp.net>

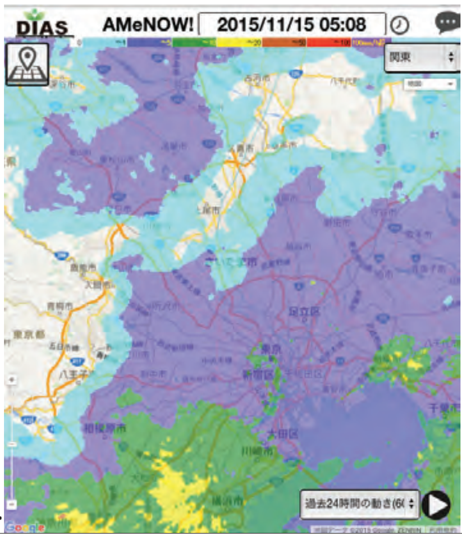
30

High-resolution Radar Rain* Real-time Visualization Tool

- 250 m grid
- Every 1 min.

* XRAIN (X-band polarimetric (multi parameter) RAdar Information Network) developed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan

< http://www.diasjp.net>

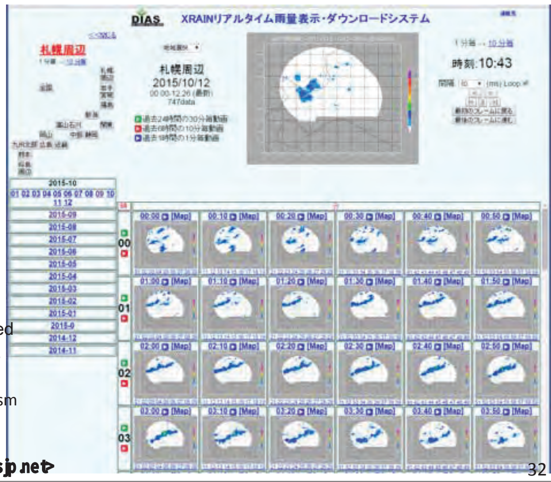


XRAIN high-resolution dataset download system

- 250 m grid
- Every 1 min.

* XRAIN (X-band polarimetric (multi parameter) RAdar Information Network) developed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan

< http://www.diasjp.net>



Agenda

1. Introduction
2. **Data system**: Data Integration and Analysis System (DIAS)
3. **System for inter-linkage**: Water Cycle Integrator
4. Opportunity
5. Summary

DIAS Data Integration & Analysis System

東京大学 THE UNIVERSITY OF TOKYO

3. System for inter-linkage:

Water Cycle Integrator

3-1. **Coupled A-L Das (CALDAS)**

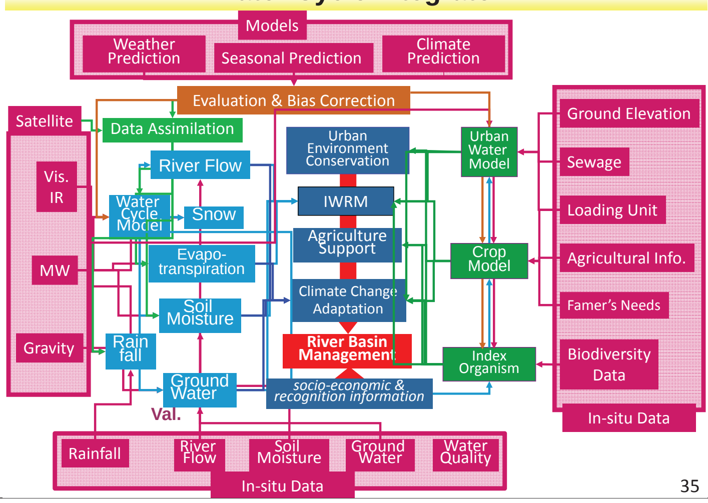
3-2. **Real-time flood forecast system:** Upper Tone Basin and Red River, Vietnam

3-3. **Seamless integrated river-sewerage-coastal hydraulic model:** Tsurumi River

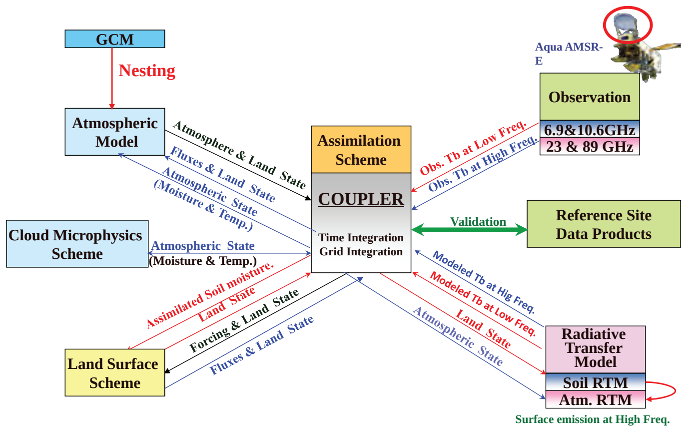
3-4. **River-sewage-public health**: Hue, Vietnam

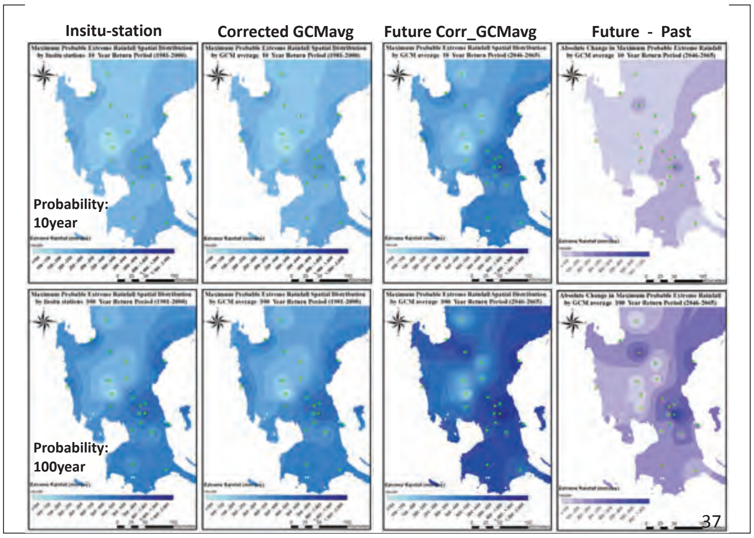
3-5. **Water-climate-agriculture workbench:** Cambodia

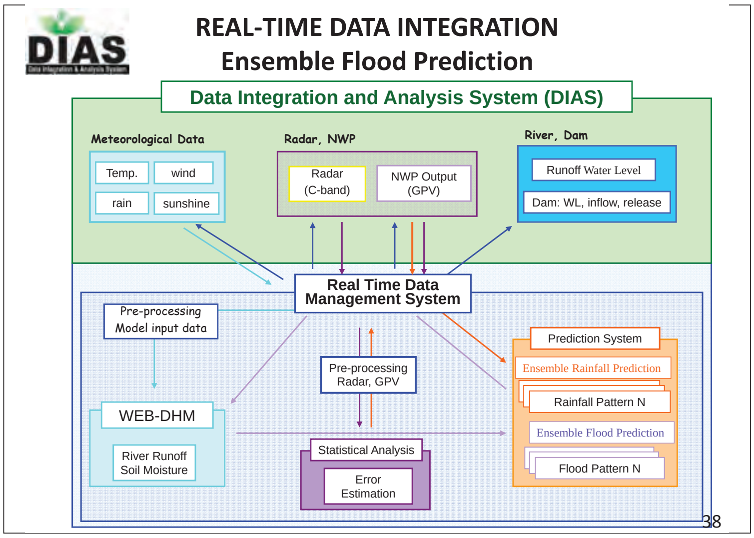
Water Cycle Integrator

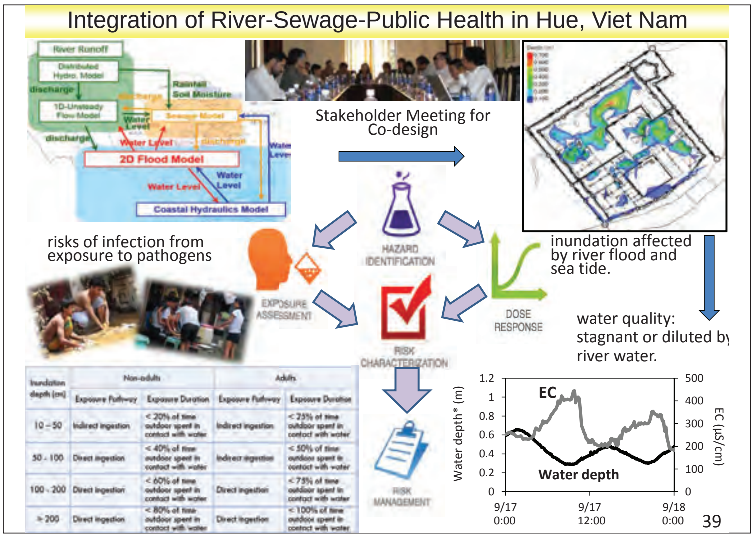


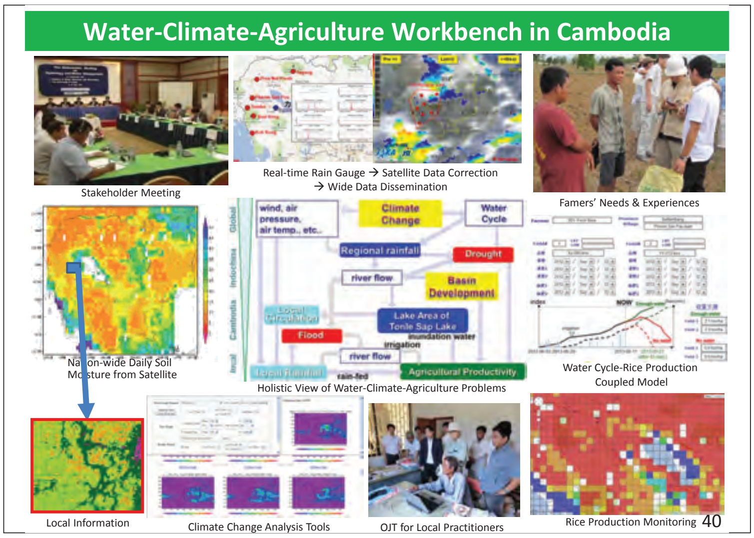
Coupled A-L DAS (CALDAS)-COUPLER











Agenda

1. Introduction
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5. Summary

41

GEO and GEOSS

- **GEO (Group on Earth Observations) is an Intergovernmental Initiative**
  - 60 Nations
  - European Commission
  - 43 Participating Organizations
- **With a Single Objective: GEOSS**
  - To establish a global, coordinated, comprehensive and sustained system of Earth observing systems

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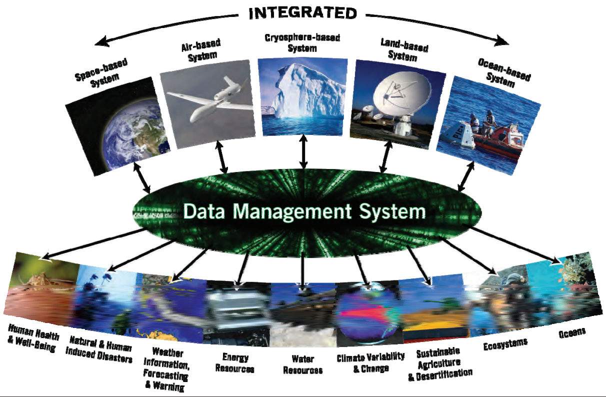
Global Earth Observation System of Systems（GEOSS）



43

Plan of Implementation
Project Design Matrix (PDM) Proposal

GEOSS Africa Water Cycle Coordination Initiative (AfWCCI)

1. Kenya: Tana River ---------- 1
2. Morocco: Ou Er Rbia Basin ---------- 5
3. Tunisia: Medjerda River Basin ---------- 9
4. Niger River Basin ----------14
5. Volta River Basin ----------16
6. Lake Chad Basin ----------19

GEOSS Asia Water Cycle Initiative (AWCI)

1. Bangladesh ----------21
2. Cambodia: Sangker River Basin ----------24
3. India ----------27
4. Indonesia: Citarum River Basin ----------31
5. Lao PDR: Xe Bangfai and Xe Banghieng River Basins ----------35
6. Malaysia ----------39
7. Mongolia ----------43
8. Myanmar: Ayeyarwady and Chindwin River Basins ----------48
9. Nepal: Bagmati River Basin ----------50
10. Pakistan ----------54
11. Sri Lanka: Kelani River Basin ----------59
12. Thailand: Ping River Basin ----------62
13. Uzbekistan: Chirchiq - Akhangaran River Basins ----------67
14. Vietnam: Thai Binh River Basin ----------

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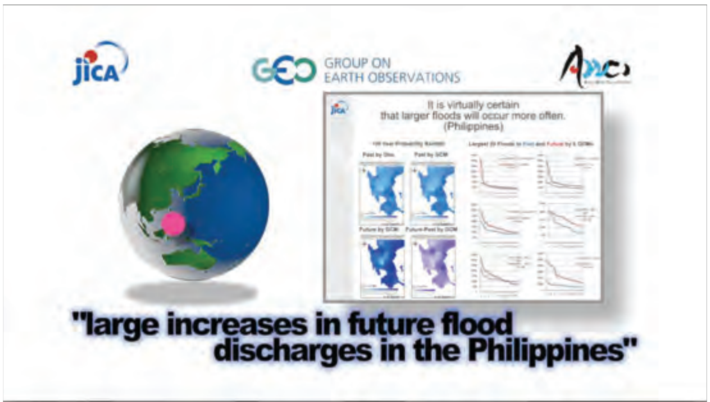
GEOSS Asian Water Cycle Initiative (AWCI)

movie presentation (4:27)



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Agenda

1. **Introduction**
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DIAS Data Integration & Analysis System

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Lecture 5: Fundamentals in Flood Frequency Analysis
Exercise 4: Flood Frequency Analysis

Shigenobu TANAKA (WRRC, DPRI, KYoto University)

In the risk management or the risk assessment of water-related disasters, the relationship between the frequency of hazard and its consequence is indispensable. The probability of rare events is important. The aim of this lecture is to introduce fundamental knowledge of flood frequency analysis. There are, in general, two ways of preparing sample for flood frequency analysis based on Extreme Value Theory, that is, Annual Maximum Series(AMS) and Peaks Over Threshold(POT). The method using AMS is popular for flood frequency analysis. Generalized Extreme Value distribution(GEV) including Gumbel distribution as its special case is used corresponding to the analysis of AMS. It is easy to understand that larger hazards cause disasters. Since AMS consists of larger events in the regions where many independent flood events occur in a year, AMS is useful. But there are different regions where very small floods or no flood occur in some years such as semi-arid area. In this case, AMS is no longer applicable and POT is useful. Generalized Pareto distribution(GP or GPD) including Exponential distribution as its special case is corresponding to POT. Further, when both AMS and POT extracted from a time series are available, it is interesting whether the result of each analysis almost coincides or not.

This lecture provides sampling method and corresponding analyses for both sampling method, AMS and POT. When we use POT, we have to extract independent peaks and then there is an issue of selecting threshold. A selection method of threshold based on Exponential distribution is introduced.

Through this lecture, it is introduced that AMS, POT, probability density function(PDF), cumulative distribution function(CDF), return period, return level, Gumbel distribution, Generalized Extreme Value distribution(GEV), Exponential distribution, Generalized Pareto distribution(GP), method of moment, L-moment, probability paper, plotting positions. After this lecture, you will exercise how to do in practice.

Flood Frequency Analysis

Shigenobu Tanaka

Chapter 1

Frequency Analysis of Extremes

In order to plan or design the disaster countermeasures, future extreme is one of the important issues. When the maximum record or smaller event is used for design, we don't need frequency analysis. However, if we use extrapolated extreme for design of infrastructure, we need frequency analysis of extremes. Generally, when the asset in the flood prone area become large, we need more insurance or safety. Countermeasures against such extreme event should be implemented before the occurrence.

Chao Phraya River Flood, Thailand
Rangsit Canal on 12 Nov 2011

Shigenobu Tanaka
Water Resources Research Center, DPRI, KU

SECTION 1

Explanatory Hazard Variable for Flood Damages

What is the key variable for representing flood magnitude?

REPRESENTATIVE HAZARD

- With which variable can we express flood frequency or flood magnitude?
- In Japan, since one of the most probable cause of dike breech is overtopping of flood water, peak water level is important but the level is easily affected by river morphological change. Peak discharge is an alternative but the observation period is very short. Then, rainfall during design rainfall duration is used as the variable for flood frequency analysis.
- In the earlier stage of modernization of Japan, the floods once in several years or ten years were used for design of flood control facilities such as embankments.
- Later, the maximum flood record was used for the design.
- After the World War II, the way of using the maximum flood has been switched to probabilistic flood and further, not only flood control but also water resources development by reservoir became popular, which needs hydrograph of discharge.
- Nowadays, assessment of flood risk through planning of flood control facilities have been carried out with rainfall data.
- Because rivers without sufficient embankment such as the Chao Phraya will cause inundation with moderate flood, inundation volume is appropriate to the representative hazard variable for flood damages. It is found that the inundation volume of the Chao Phraya can be estimated by 5-month rainfall depth of the basin.

Flood frequency shows relationship between the magnitude of flood and how often the flood occurs. The magnitude of flood generally depends on rainfall characteristics. In a steep river basin, peak discharge is the most important. On the contrary, in a very flat flood plain, flood inundation water volume is the most important. The former depends on mostly rainfall intensity and its pattern in time and space but the latter on total rainfall in some period. Further, like in Japan, most rivers are installed with continuous embankments on both sides. Once embankment breach occurs, flood water spreads to the flood plain. Because soil embankment is very vulnerable for over topping, whether overtopping occur or not is critical. Water level can be determined by the peak discharge. Then, peak discharge can be one of the most important factors. So, the peak discharge is used for assessing flood magnitude in practice. However, discharge observation period is usually not so long and discharge and/or water level at a station has been influenced by upstream flooding condition. On the other hand, rainfall observation has been carried out for rather long period compared to discharge observation and not affected by alteration of upstream basin and river channel. Furthermore, the conventional hydrological frequency analysis is based on stationary condition.

Concurrently with the application of probabilistic flood and quick development of urbanization, water resources in many river basins had become short and flood control by dam had become necessary to protect existing urbanized area in flood plain. In this context, the peak discharge of hydrograph and catchment averaged rainfall in design rainfall duration have been key variables for the flood risk assessment in Japan.

If there exists no sufficient embankment along the river channel such as Chao Phraya river in Thailand, even moderate floods cause inundation and then flood damage. Generally, flood damage depends on water depth and inundation extent. The water depth and inundation extent can be explained by the inundation volume. In such case, the inundation volume should be used for assessing flood frequency. It is investigated that the total amount of five month rainfall

explains the inundation volume in the Chao Phraya river basin well.

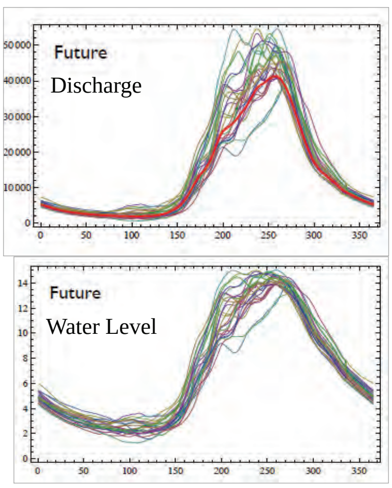
Explanatory hazard variable depends on dominant factors of flood damage in considering flood plain. Once we know the relationship between frequency of explanatory hazard and flood damage in money, we can know expected annual flood damage.

Flood frequency can be expressed in terms of

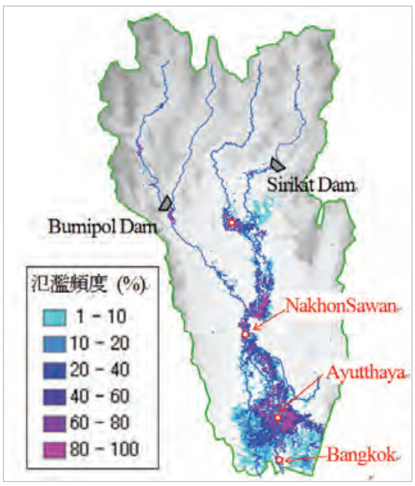
- Peak discharge
- Catchment average rainfall during design rainfall duration
- Inundation volume

⟷ Good relationship ⟷ **Flood Damage $**

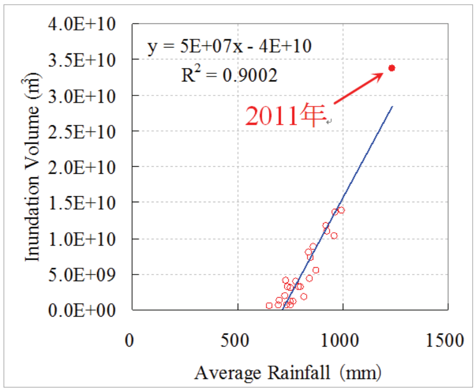
Expected Annual Flood Damage



Discharge and water level in Campong Cham, in Cambodia.



Inundation frequency in Chao Phraya basin



Relationship between Annual Maximum 5 months rainfall and calculated Inundation volume in Chao Phraya basin

SECTION 2

Relationship between how much rainfall and how often

TERMINOLOGY

- Histogram
- Random variable : usually expressed by X, lower case x a possible value of X
- PDF : Probability Density Function, usually expressed $f(x)$
- CDF : Cumulative Distribution Function, usually expressed by $F(x)$
- Non-exceedance probability : usually expressed by F or p
- Exceedance probability : 1-F
- Quantile : x_p is expressed inverse form of $F(x_p)=p$

When you have a set of observations $(X_1, X_2, \ldots, X_i, \ldots, X_n)$, select arbitrary bin width, for example, 20 mm in the following example and count the number of X_i which falls in each bin such as 6 for from 40 to 60 mm and 30 for 60-80 mm. Histogram plots these numbers against bin specifications. Histogram shows relative frequencies of variables. Total of the number of each bin is equal to sample size n. It is seen that the frequency of big rainfall becomes small, that is, extreme event occurs seldom.

Next, if we consider total area of the histogram as 1, the height of each bin will be relative frequency(height of each bin divided by sample size) divided bin width. So, the dimension of y axes will be 1/(dimension of variables). In this sample, there are no data between 280-360 mm. It is expected when the sample size become very big and the width of bin become very small, the envelope will be rather smooth.

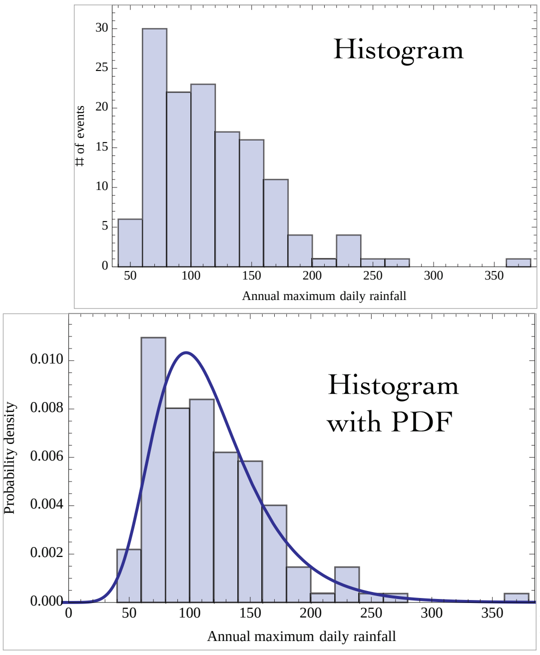


Fig. 2.1 Histogram and PDF fitting

- Return period :

$$T = \frac{1}{1-p}$$

- Mean of a random variable X

$$\mu_x = E[X]$$

- Variance : Var(X) or σ_x^2

$$\sigma_x^2 = \mathrm{Var}(X) = E\left[\left(X-\mu_x\right)^2\right]$$

- Sample : a set of observations $(X_1, X_2, \ldots, X_i, \ldots, X_n)$
- Sample size : n
- Sample estimators

$$\hat{\mu}_x = \overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

$$\hat{\sigma}_x^2 = S^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2$$

(unbiased estimator)

Here, we'd like to see several important definitions. **PDF**(probability density function) is defined as derivative of **CDF**(cumulative distribution function).

When we take annual maximum series as variate, **Return Period** T is defined as 1/(1-p), the reciprocal of the **exceedance probability**. When p=0.95, 1-p=0.05, for example, then T=20. Confirm the relationship between PDF and CDF in the pictures below.

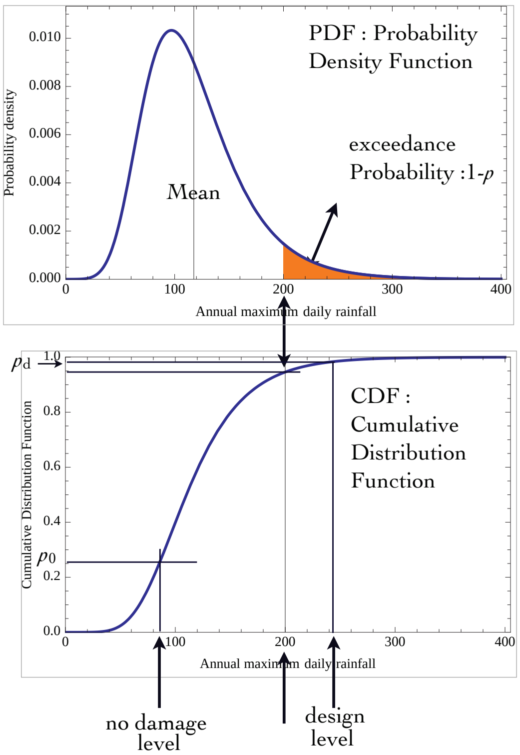


Fig. 2.2 PDF and CDF

SECTION 3

Extremes and Extreme Value Theory

EXTREME VALUE THEORY

- Block Maximum : Annual Maximum Series(AMS)

Generalized Extreme Value(GEV) distribution

$$F[x] = \exp\left[-\left\{1-\kappa\left(\frac{x-\xi}{\alpha}\right)\right\}^{1/\kappa}\right]$$

Gumbel distribution

$$F[x] = \exp\left[-\exp\left\{-\frac{x-\xi}{\alpha}\right\}\right]$$

We know from experience that the severer natural hazard is, the more infrequent. And also, larger hazard causes extensive damage. Since usual hazard event does not cause significant disaster, our concern is that how large (or small) event will occur how frequent, that is, probability of such unusual event. The extreme value theory deal with this problem.

AMS(Annual Maximum Series) and POT(Peaks Over Threshold)

In this process, mean value such as the mean of the daily precipitations in a year is not useful. Such rainfall does not cause disaster. Our concern is big events which cause disaster. There are several definition of "big events".The "**block maximum**" is usually used to investigate the behavior of extreme value. Annual maximum daily precipitation, annual maximum temperature, annual maximum peak discharge, annual maximum inundation area and so on are the examples of block maxima. In this theory, the probability distribution of block maxima is discussed not probability of whole data. This means you don't need to collect whole data but just annual maximum series(**AMS**). The other popular definition of "big events" is peaks over threshold(POT). In this course, distributions for analyzing AMS and POT will be explained, respectively.

Generalized Extreme Value Distribution(GEV)

It has been proved that there are just three types of extreme value distribution, that is, Gumbel-type distribution, Fréchet-type distribution and Weibull-type distribution. These three types of extreme value distribution can be combined into a single form

POT

- Peaks Over Threshold

Generalized Pareto (GP) distribution

$$G(x) = 1-\left(1-k\frac{x-\xi}{\alpha}\right)^{1/k}$$

Exponential distribution

$$G(x) = 1-\exp\left\{-\frac{x-\xi}{\alpha}\right\}$$

$$F[x] = \exp\left[-\left\{1-\kappa\left(\frac{x-\xi}{\alpha}\right)\right\}^{1/\kappa}\right] \quad (3\text{-}1)$$

which is called Generalized Extreme Value(**GEV**) distribution, and where ξ:location parameter, α: scale parameter, κ : shape parameter. When $\kappa < 0$, GEV is Fréchet-type distribution and has a finite lower bound $x > \xi + \alpha/\kappa$, on the other hand, when $\kappa > 0$, GEV is Weibull-type distribution and has a finite upper bound $x < \xi + \alpha/\kappa$.Please note there are two forms of definition of **GEV** with different sign of shape parameter. *Handbook of Hydrology* uses the form of Eq.(3-1).

In the special case κ=0, this equation becomes **Gumbel** distribution.

$$F[x] = \exp\left[-\exp\left\{-\frac{x-\xi}{\alpha}\right\}\right] \quad (3\text{-}2)$$

where $-\infty < x < \infty$.

In order to estimate the risk of large disaster, the probability $F(x)$ is indispensable. The risk is generally defined as expected annual flood damage and in order to estimate it, we need the probability distribution function $F(x)$ of concerning hazard and damages as its consequence.

Generalized Pareto distribution(GP)

In hydrological frequency analysis, AMS is widely used. However, there are cases that they don't record every year's maximum event but all events that they operate their barrages for the flood mitigation and no record in dry years. Every flood with barrage operation is significantly large and usually independent and we can regard them as **POT**. In this case, we cannot apply **GEV** distribution including Gumbel distribution any more. Generalized Pareto distribution(**GP** or GPD) including **Exponential** distribution is used for denoting probability of **POT**.

Eq.(3-3) shows the CDF of GP.

$$G(x) = 1 - \left(1 - k\frac{x-\xi}{\alpha}\right)^{1/k} \qquad (3\text{-}3)$$

where ξ:location parameter, α: scale parameter, κ : shape parameter. Please note there are two forms of definition of **GP** with different sign of shape parameter. *Handbook of Hydrology* uses the form of Eq.(3-3).

In the special case κ=0, this equation becomes **Exponential** distribution. The CDF and PDF of Exponential distribution(Exp) are shown by Eq.(3-4) and (3-5).

$$G(x) = 1 - \exp\left\{-\frac{x-\xi}{\alpha}\right\} \qquad (3\text{-}4)$$

$$g(x) = \frac{\exp\left\{-\frac{x-\xi}{\alpha}\right\}}{\alpha} \qquad (3\text{-}5)$$

The mean of the PDF of Exp becomes α in case of ξ=0. Using this characteristics, we can select effective threshold(see sample mean excess function(SMEF)).

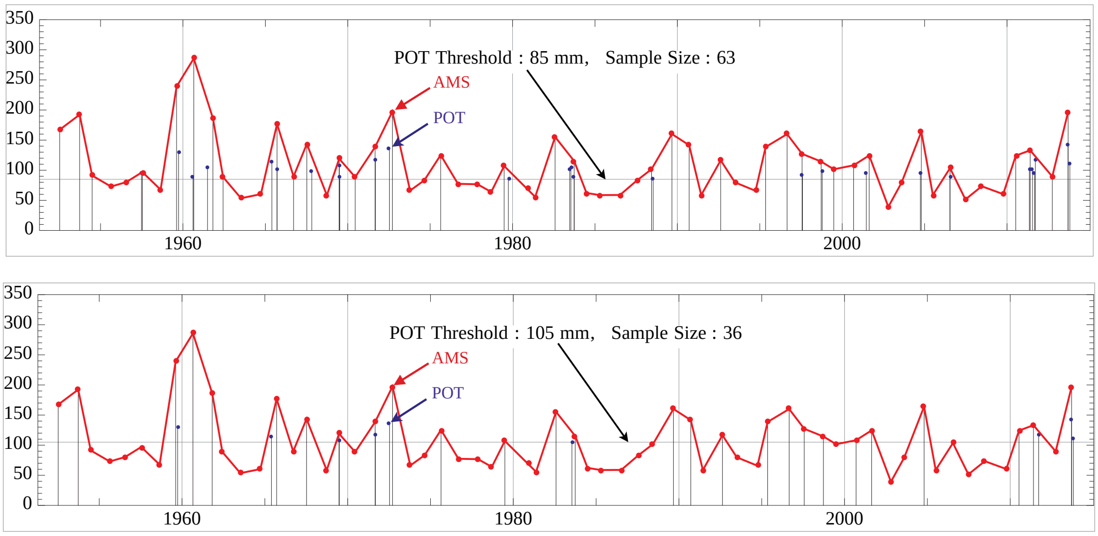


Fig. 3.1 Example of AMS and POT

Figure 3.1 shows an example of time series of two day rainfall in 62 years and includes AMS and POT. Red points connected with red lines are AMS and blue points with vertical fine lines are POT. The threshold of POT is 85mm in the top figure and 105mm in the botom one. Histograms of AMS and POT are shown in Fig. 3.2 with fitting curves. AMS is fitted with Gumbel distribution and POT with Exponential distribution.

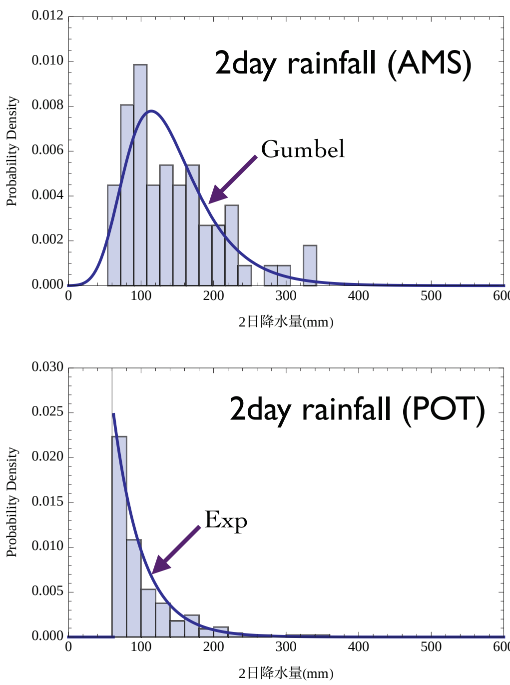


Fig. 3.2 Histogram of AMS and POT

There is an equation (3-6) which connects AMS and POT.

$$F(x) = \exp\left\{-\lambda\left(1 - G(x)\right)\right\} \qquad (3\text{-}6)$$

where $F(x)$:distribution function corresponding AMS which shows the probability that the annual maximum in a year will not exceed x, $G(x)$:distribution function of **POT** which shows the probability of less than x, λ:arrival rate of POT. Eq.(3-6) can be also useful in probability plot of AMS samples with POT's.

Selection of Threshold

As mentioned previously, an interesting characteristics of Exp is used in selecting threshold. Sample mean excess function(SMEF) shown Eq.(3-7) calculate the mean of variable x more than u.

$$e_n(u) = \frac{\sum_{i=1}^{n}(x_i - u)I(u < x_i)}{\sum_{i=1}^{n} I(u < x_i)} \qquad (3\text{-}7)$$

where, $I(u < x)$: 1, if $u < x$ and 0 otherwise. When x more than c are data from Exponential distribution, then Eq.(3-7) is constant in the range u>c. An example of SMEF is shown in Fig. 3.3(bottom right).

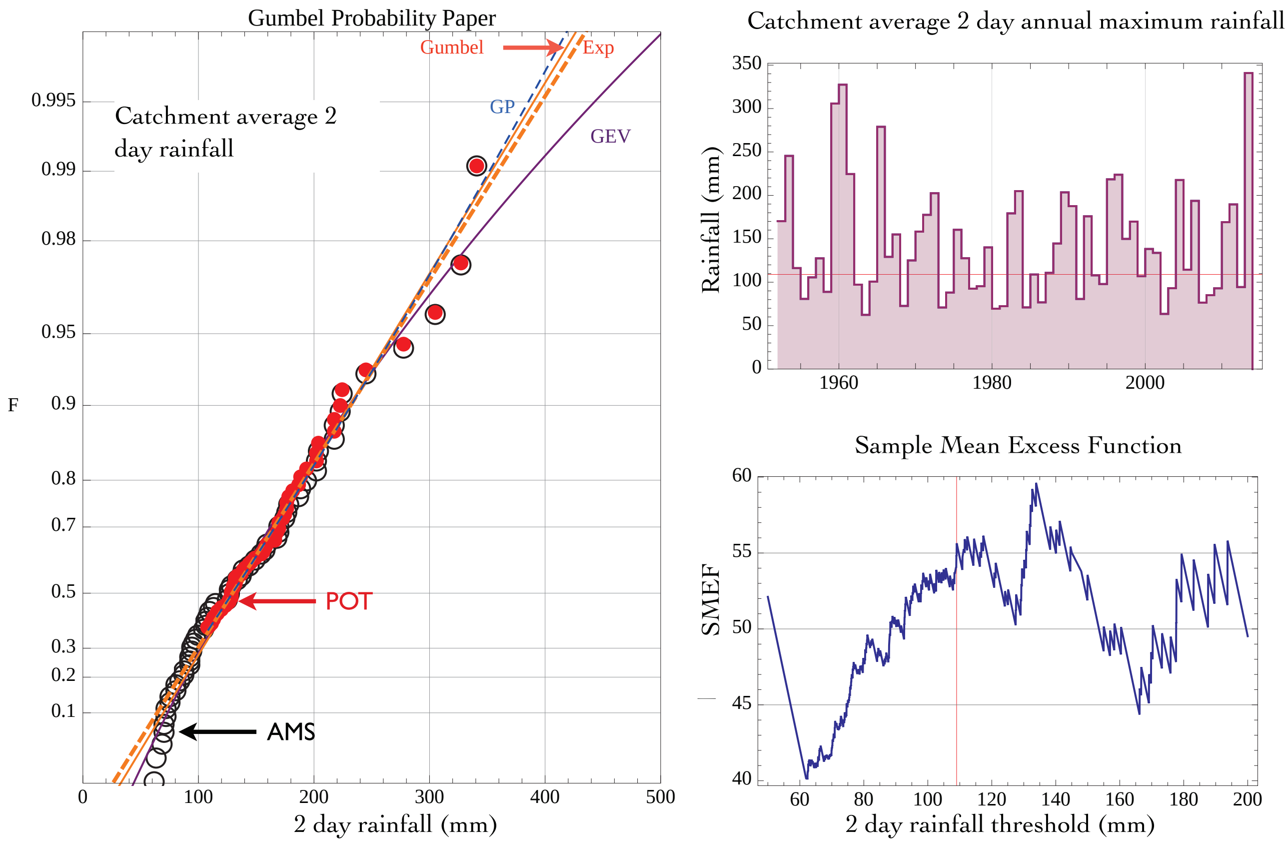


Fig. 3.3 Example of AMS and POT comparison with time series and SMEF

SECTION 4

Product Moment and L-Moment

PRODUCT MOMENT

- Mean μ

$$\mu = \int_{-\infty}^{\infty} x f(x)\, dx$$

- Variance σ^2

$$\sigma^2 = \int_{-\infty}^{\infty} (x-\mu)^2 f(x)\, dx$$

- Gumbel Distribution's mean μ and variance σ^2

$$\mu = 0.5772\,\alpha + \xi$$

$$\sigma^2 = \frac{\pi^2\alpha^2}{6}$$

Product Moment

When PDF of variable x is denoted as $f(x)$, Mean μ and Variance σ^2 of x are expressed as,

$$\mu = \int_{-\infty}^{\infty} x f(x)\, dx \tag{4-1}$$

$$\sigma^2 = \int_{-\infty}^{\infty} (x-\mu)^2 f(x)\, dx \tag{4-2}$$

These values are called Product Moments. $f(x)$ of two parameter distribution includes parameters such as location and scale parameter. **GEV** is a three parameter distribution and has additional parameter, shape parameter.

In practice, nobody knows the population characteristics such as the parameters of $f(x)$. In order to fit a distribution to given sample, theoretical moments should be same as unbiased sample moments. From this relation, parameters are determined. For example, in Gumbel distribution's case, $f(x)$ is expressed as follows.

$$f(x) = \frac{\exp\left\{-\frac{x-\xi}{\alpha}\right\}}{\alpha} \exp\left[-\exp\left\{-\frac{x-\xi}{\alpha}\right\}\right] \tag{4-3}$$

Then, by substituting Eq.(4-3) into Eq.(4-1) and (4-2) and conducting integration, we can obtain μ and σ^2 for **Gumbel** distribution as follows.

$$\mu = 0.5772\,\alpha + \xi \tag{4-4}$$

$$\sigma^2 = \frac{\pi^2\alpha^2}{6} \tag{4-5}$$

PWM & L-MOMENT

- Basic idea is integration in probability space.

$$E(X) = \int_0^1 x(u)\,du$$

- Order Statistics

$$X = \left\{X_{(1)} \geq \cdots \geq X_{(n)}\right\}$$

- Unbiased PWM Estimators (4-11)

$$b_0 = \overline{X}$$

$$b_1 = \sum_{j=1}^{n-1} \frac{(n-j)X_{(j)}}{n(n-1)}$$

$$b_2 = \sum_{j=1}^{n-2} \frac{(n-j)(n-j-1)X_{(j)}}{n(n-1)(n-2)}$$

$$b_3 = \sum_{j=1}^{n-3} \frac{(n-j)(n-j-1)(n-j-2)X_{(j)}}{n(n-1)(n-2)(n-3)}$$

general formula (4-12)

$$b_r = \frac{1}{n}\sum_{j=1}^{n-r} \frac{\binom{n-j}{r}X_{(j)}}{\binom{n-1}{r}}$$

When we replace product moments μ and σ^2 with sample estimators μ_x and $\sigma_x{}^2$, respectively, we get the simultaneous equations for two parameters, α and ξ.

$$\frac{\sum_{i=1}^{n} X_i}{n} = 0.5772\,\alpha + \xi \tag{4-6}$$

$$\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n-1} = \frac{\pi^2\alpha^2}{6} \tag{4-7}$$

For the other distributions, the solutions are shown in Table 18.2.1 of *Handbook of Hydrology*(David Maidment, 1993).

PWM and L-Moment

There may be cases that a sample includes outliers. The product moment method is known to be affected by the outliers excessively since r-th order **product moment** includes x^r. In order to improve this situation, PWM(Probability Weighted Moment) or L-moment method were developed.

The *expectation* of the random variable X is defined as follows.

$$E(X) = \int_{-\infty}^{\infty} x\,dF(x) = \int_{-\infty}^{\infty} xf(x)\,dx \tag{4-8}$$

With the transformation of $u = F(x)$, then, $du/dx = f(x)$, we can write as follows.

$$E(X) = \int_0^1 x(u)\,du \tag{4-9}$$

For higher r-th order moment,

$$b_r = \int_0^1 x(u)u^r\,du \tag{4-10}$$

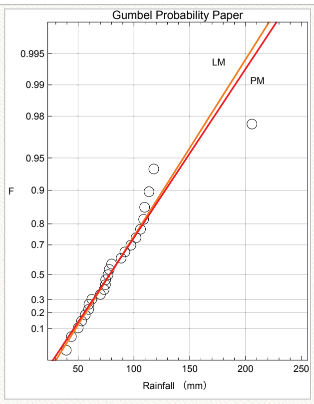


Fig. Outlier and its effect

L-MOMENT

- L-Moment (4-13)

$$\lambda_1 = b_0$$

$$\lambda_2 = 2b_1 - b_0$$

$$\lambda_3 = 6b_2 - 6b_1 + b_0$$

$$\lambda_4 = 20b_3 - 30b_2 + 12b_1 - b_0$$

L-skewness $\tau_3 = \lambda_3/\lambda_2$

L-kurtosis $\tau_4 = \lambda_4/\lambda_2$

and it includes just first order x. This difference is the advantage of PWM or **L-Moment** against Product Moment. The r-th order **PWM**s are shown in Eq.(4-11).

$$b_0 = \overline{X}$$
$$b_1 = \sum_{j=1}^{n-1} \frac{(n-j)X_{(j)}}{n(n-1)}$$
$$b_2 = \sum_{j=1}^{n-2} \frac{(n-j)(n-j-1)X_{(j)}}{n(n-1)(n-2)} \tag{4-11}$$
$$b_3 = \sum_{j=1}^{n-3} \frac{(n-j)(n-j-1)(n-j-2)X_{(j)}}{n(n-1)(n-2)(n-3)}$$

And Eq.(4-12) is the general formula of Eq.(4-11).

$$b_r = \frac{1}{n}\sum_{j=1}^{n-r} \frac{\binom{n-j}{r}X_{(j)}}{\binom{n-1}{r}} \tag{4-12}$$

The r-th order L-moments are shown in Eq.(4-13) using PWM in Eq.(4-11). The solution of L-moment is shown in Table 18.1.2 in *Handbook of Hydrology*. For more detailed information of L-moments, see *Regional Frequency Analysis*(Hosking and Wallis, 1997)

$$\lambda_1 = b_0$$
$$\lambda_2 = 2b_1 - b_0$$
$$\lambda_3 = 6b_2 - 6b_1 + b_0 \tag{4-13}$$
$$\lambda_4 = 20b_3 - 30b_2 + 12b_1 - b_0$$
$$\tau_3 = \lambda_3/\lambda_2, \qquad \tau_4 = \lambda_4/\lambda_2$$

PARAMETER ESTIMATION BY L-MOMENT FOR AMS

- Gumbel Distribution

$\lambda_1 = 0.5772\,\alpha + \xi$

$\lambda_2 = \alpha \ \ln\ 2$

- GEV Distribution

$c = \frac{2}{3+\tau_3} - \frac{\ln 2}{\ln 3} = \frac{2\lambda_2}{3\lambda_2+\lambda_3} - \frac{\ln 2}{\ln 3}$

$k \ \approx 7.859c + 2.9554c^2$

$\xi = \lambda_1 - \alpha\left\{1 - \Gamma(1+k)\right\}/k$

$\alpha = \frac{\lambda_2 k}{(1-2^{-k})\Gamma(1+k)}$

•Quantile Estimator

•Gumbel Distribution

$x = \xi - \alpha \ \ln(-\ln F)$

•GEV Distribution

$x = \xi + \frac{\alpha}{k}\left\{1 - (-\ln F)^k\right\} \quad (k \neq 0)$

Parameter Estimation by L-Moment for AMS

For **Gumbel** distribution, the parameters can be given by the combination of L-moment as shown below.

$$\begin{cases} \lambda_1 = 0.5772\,\alpha + \xi \\ \lambda_2 = \alpha \ \ln\ 2 \end{cases} \qquad (4\text{-}14)$$

The **quantile** x of Gumble distribution is obtained by following equation,

$$x = \xi - \alpha \ \ln(-\ln F) \qquad (4\text{-}15)$$

where F is non-exceedance probability.

For GEV distribution, the relationship between three parameters and L-moment estimators is expressed as below.

$$\begin{cases} \lambda_1 = \xi + \alpha\left\{1 - \Gamma(1+k)\right\}/k \\ \lambda_2 = \alpha(1-2^{-k})\Gamma(1+k)/k \\ \tau_3 = 2(1-3^{-k})/(1-2^{-k}) - 3 \end{cases} \qquad (4\text{-}16)$$

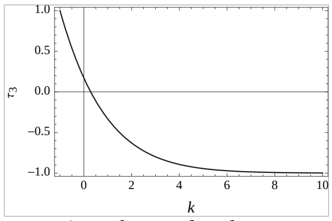


Fig. 4.1 relationship between κ and τ_3

The relationship between τ_3 and κ is not easy to solve but is in simple decreasing function as Fig. 4.1. By defining c with τ_3 as Eq.(4-17), we can get the approximation of shape parameter κ.

$$c = \frac{2}{3+\tau_3} - \frac{\ln 2}{\ln 3} = \frac{2\lambda_2}{3\lambda_2+\lambda_3} - \frac{\ln 2}{\ln 3} \quad ,$$

$$k \ \approx 7.859c + 2.9554c^2 \qquad (4\text{-}17)$$

After obtaining κ, we can easily get scale and location parameters α and ξ by Eq.(4-16).

PARAMETER ESTIMATION BY L-MOMENT FOR POT(1)

- Exponential Distribution

$\lambda_1 = \xi + \alpha, \quad \lambda_2 = \frac{1}{2}\alpha$

- GP Distribution

when ξ is known

$k = \frac{(\lambda_1 - \xi)}{\lambda_2} - 2$

$\alpha = (1+k)(\lambda_1 - \xi)$

when ξ is unknown

$k = \frac{1-3\tau_3}{1+\tau_3}$

$\alpha = (1+k)(2+k)\lambda_2$

$\xi = \lambda_1 - (2+k)\lambda_2$

$$\alpha = \frac{\lambda_2 k}{(1-2^{-k})\Gamma(1+k)}, \quad \xi = \lambda_1 - \alpha\left\{1 - \Gamma(1+k)\right\}/k \qquad (4\text{-}18)$$

Note that Eq.18.2.22c in *Handbook of Hydrology* is not correct and above Eq.(4-18) is correct.

The **quantile** x of GEV distribution is obtained by following equation,

$$x = \xi + \frac{\alpha}{k}\left\{1 - (-\ln F)^k\right\} \qquad (k \neq 0) \qquad (4\text{-}19)$$

where F is non-exceedance probability.

[Note]:approximation of gamma function

$\Gamma(w+1) = w\Gamma(w)$

$$\Gamma(1+\delta) = 1 + \sum_{i=1}^{5} a_i \delta^i + \epsilon$$

where $a_1 = -0.574\ 8646$
$a_2 = 0.951\ 2363$
$a_3 = -0.699\ 8588$
$a_4 = 0.424\ 5549$
$a_5 = -0.101\ 0678$

Parameter Estimation by L-Moment for POT

In the process of POT, we must realize that $G(x)$ is different from $F(x)$. After parameter estimation of $G(x)$, in order to know annual exceedance probability, it is necessary to transform $G(x)$ to $F(x)$ by Eq.(3-6) with arrival rate λ which is equal to number of events per observation period. Exponential distribution and Generalized Pareto(GP) distribution are generally used for $G(x)$, and parameter estimation by L-Moment is as follows. For **Exponential** distribution,

$$\lambda_1 = \xi + \alpha \qquad (4\text{-}20)$$

$$\lambda_2 = \frac{1}{2}\alpha \qquad (4\text{-}21)$$

and for **GP** distribution, we need following three equations,

PARAMETER ESTIMATION BY L-MOMENT FOR POT(2)

- Quantile Estimator
- GP Distribution

$x = \xi + \alpha\left\{1 - (1-G)^k\right\}/k$

- Exponential Distribution

$x = \xi - \alpha \ln(1-G)$

- POT to AMS transformation

$F(x) = \exp\left\{-\lambda(1 - G(x))\right\}$

- AMS to POT transformation

$G(x) = 1 + \frac{\ln F(x)}{\lambda}$

$$\lambda_1 = \xi + \alpha/(1+k) \quad (4\text{-}22)$$

$$\lambda_2 = \frac{\alpha}{(1+k)(2+k)} \quad (4\text{-}23)$$

$$\tau_3 = \frac{1-k}{3+k} \quad (4\text{-}24)$$

The solution of L-Moment for κ is, when ξ is known,

$$k = \frac{(\lambda_1 - \xi)}{\lambda_2} - 2, \quad \alpha = (1+k)(\lambda_1 - \xi) \quad (4\text{-}25)$$

when ξ is unknown,

$$k = \frac{1 - 3\tau_3}{1 + \tau_3}, \quad \alpha = (1+k)(2+k)\lambda_2, \quad \xi = \lambda_1 - (2+k)\lambda_2 \quad (4\text{-}26)$$

Quantile estimator for GP and Exponential distribution are as Eq.(4-17) and (4-18), respectively;

GP

$$x = \xi + \alpha\left\{1 - (1-G)^k\right\}/k \quad (4\text{-}27)$$

Exponential Distribution

$$x = \xi - \alpha \ln(1-G) \quad (4\text{-}28)$$

In order to obtain **return level**, it is necessary to get G corresponding F using inverse form of Eq.(3-3).

$$G = 1 + \frac{\ln F}{\lambda} \quad (4\text{-}29)$$

16

SECTION 5

How to use a probability paper

PROBABILITY PAPER & PLOTTING POSITION

- AMS :Gumbel probability paper

$y_i = -\ln\left[-\ln(1 - q_i)\right]$

- Plotting Position (exceedance probability)

$q_i = \frac{i - a}{n + 1 - 2a}$

where n : sample size, i : order of the order statistics, α : plotting-position parameter

- Cunnane Plot : α=0.40
- Weibull Plot : α=0
- Gringorten Plot : α=0.44
- Hazen Plot : α=0.50

In practice, there used to be a probability paper. Normal Probability Paper and Log-Normal Probability Paper are popular. Concerning to annual extreme value, i.e. **AMS**, **Gumbel probability paper** is recommendable. On Gumbel probability paper, the data of **exceedance** probability q_i is plotted at y_i in probability axis. And also Gumbel distribution function $F(x)$ is expressed in a straight line.

$$y_i = -\ln\left[-\ln(1 - q_i)\right] \quad (5\text{-}1)$$

In Japan, generally, probability paper has variable on horizontal axis and cumulative probability

Table 5.1 Plotting Positions

Name	Formula	a	T_1	Motivation
Weibull	$i/(n+1)$	0	n+1	Unbiased exceedance probabilites for all distributions
Median	(i-0.3175)/(n+0.365)	0.3175	1.47n+0.5	Median exceedance probabilities for all distributions
APL	(i-0.35)/n	~0.35	1.54n	Used with PWMs
Blom	(i-3/8)/(n+1/4)	0.375	1.60n+0.4	Unbiased normal quantiles
Cunnane	(i-0.40)/(n+0.2)	0.40	1.67n+0.3	Approximately quantile-unbiased
Gringorten	(i-0.44)/(n+0.12)	0.44	1.79n+0.2	Optimized for Gumbel Distribution
Hazen	(i-0.5)/n	0.5	2n	A traditional choice

T_1 is the return period each plotting position assings to the largest observation in a sample of size n.

17

on vertical axis(Fig. 5.1). In U.S., probability lies on horizontal axis.

When you plot a sample on a probability paper, you have to know the exceedance or non-exceedance probability for each data of the sample. Plotting position shows them. Several **plotting position** formulas(Table 5.1) have been proposed to show exceedance probability q_i and they are expressed in an equation with different α.

$$q_i = \frac{\mathrm{i} - a}{n + 1 - 2a} \qquad (5\text{-}2)$$

You have to decide which plotting position you use. **Cunnane plotting position** is recommended for wide range of distribution. After plotting your sample data, you can overlay fitted probability distribution function on it. If you do so, you can easily find any return level corresponding return period and vice versa. And you can also check the goodness of fit and reason of less performance(Fig. 5.1).

Table 5.2 shows plotting positions for sample size 30 with Cunnane plot(a:0.40). Figure 5.2 shows example plots of sample size 30 using Cunnane plot. It is seen the maximum data is plotted about return period 50 years. Generally, a sample including outliers is fitted by GEV with negative shape parameter κ in case of the definition as Eq.(3-1).

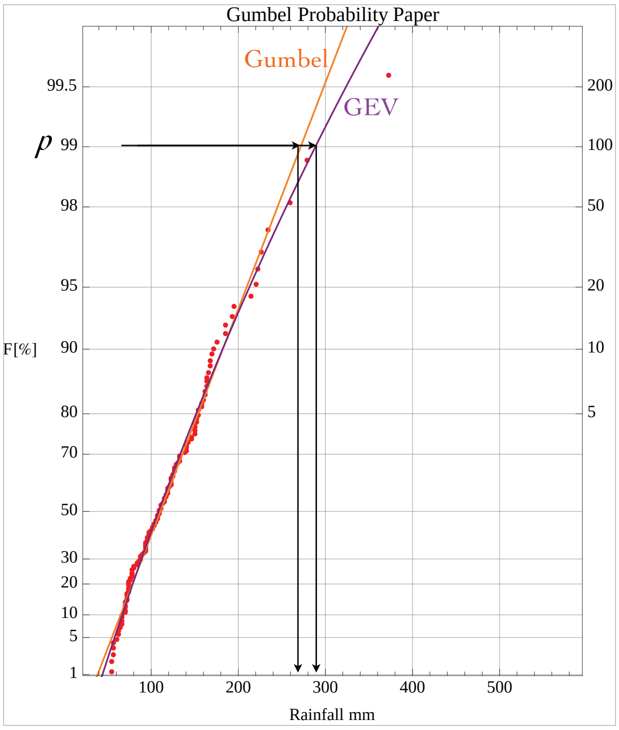


Fig. 5.1 Probability Paper in Japan

Table 5.2 Plotting Positions for sample size 30 (Cunnane plot)

order	q	F
1	0.02	0.98
2	0.053	0.947
3	0.086	0.914
4	0.119	0.881
5	0.152	0.848
6	0.185	0.815
7	0.219	0.781
8	0.252	0.748
9	0.285	0.715
10	0.318	0.682
11	0.351	0.649
12	0.384	0.616
13	0.417	0.583
14	0.45	0.55
15	0.483	0.517
16	0.517	0.483
17	0.55	0.45
18	0.583	0.417
19	0.616	0.384
20	0.649	0.351
21	0.682	0.318
22	0.715	0.285
23	0.748	0.252
24	0.781	0.219
25	0.815	0.185
26	0.848	0.152
27	0.881	0.119
28	0.914	0.086
29	0.947	0.053
30	0.98	0.02

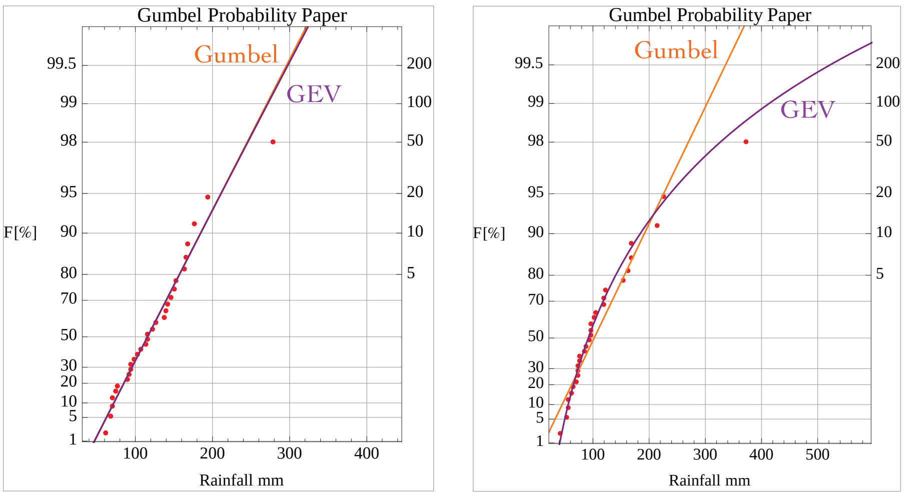


Fig. 5.2 Examples of Probability Plot and Gumbel/GEV fitting on Gumbel Probability Paper

SECTION 6

Frequency Analysis Procedure of a Time Series

TIPS FOR FREQ. ANAL.

- Examine extremes in both AMS and POT
- While similar results are expected, different results come out in general.
- Let's have an experience
- Probability paper is useful for checking the goodness of fit of distributions
- Do not directly compare AMS and POT, use Eq.(3-3)
- The maximum of AMS and that of POT from a time series should show almost identical exceedance probabilities.
- GEV is apt to have long tail than GP in hydrological frequency analysis.

The followings are general procedure of frequency analysis for a time series.

1) Checking trend

2) Pick up extremes AMS and POT

3) assess with AMS

    1) probability plot on a Gumbel probability paper using plotting position

    2) estimate parameters of distributions

    3) plot the distributions onto 1)

    4) estimate quantile

4) assess with POT

    1) probability plot on a Gumbel probability paper

    2) plot sample mean excess function and determine the suitable threshold

    3) re-select POT more than the threshold

    4) estimate parameters of distributions, if necessary, probability plot

    5) plot the distributions onto 4-1)

    6) estimate quantile

5) compare results of AMS with that of POT

6) judge

SECTION 6

Exercise

EXERCISE (AMS)

- Draw Histgram
- Draw Probability Plot
    - Obtain Plotting Position q_i
- Fit Gumbel and GEV to the sample
    - Obtain L-moments estimator
    - Obtain Gumbel & GEV distribution parameters
    - Draw both lines onto the Probability Plot
- Obtain 1/30, 1/50 and 1/100 Quantiles by Gumbel and GEV, respectively
- Obtain return periods for the record maximum, 1.1 and 2.0 times of it.

	Group1	Group2	Group3	Group4	Group5	Group6
1	56.3	56.9	62.3	55.3	43.	54.
2	56.9	62.3	67.	60.	54.	56.
3	64.5	66.3	69.9	61.9	55.3	65.5
4	66.3	69.9	70.5	70.1	56.	66.
5	72.2	73.2	74.8	70.6	61.9	70.
6	73.2	74.	77.6	71.5	65.5	73.
7	74.	74.1	88.8	74.8	70.1	74.5
8	76.2	80.5	92.9	77.2	73.	93.5
9	77.8	88.8	93.6	77.6	73.	94.
10	78.9	89.2	94.2	83.9	74.5	96.
11	79.9	96.	97.9	92.2	75.5	97.5
12	80.5	97.9	101.7	93.6	77.2	98.5
13	84.5	106.8	107.6	103.5	83.9	104.5
14	86.4	107.6	113.8	106.2	87.5	107.5
15	99.8	110.1	115.7	116.1	93.	115.
16	106.8	111.7	116.1	118.	96.	119.
17	109.	113.8	122.2	118.5	96.5	122.5
18	109.7	115.7	126.2	119.	97.5	123.5
19	110.1	126.1	138.2	126.2	103.	130.5
20	116.7	129.2	139.7	139.7	104.5	141.
21	123.8	133.5	141.5	141.	118.	151.
22	125.6	138.2	147.	147.	119.	167.5
23	126.1	141.5	150.4	151.3	122.5	185.
24	132.8	146.6	152.8	152.8	154.5	186.
25	133.	158.7	163.6	154.5	161.2	195.
26	149.5	159.4	164.7	157.5	167.5	215.
27	150.9	164.8	168.5	161.2	169.5	220.5
28	159.4	165.9	175.9	164.7	215.	222.5
29	162.	171.5	193.7	278.3	225.5	234.5
30	164.8	193.7	278.3	371.9	371.9	259.5

L-moments estimators

	Group1	Group2	Group3	Group4	Group5	Group6
λ_1	103.587	114.13	123.57	123.87	112.183	131.283
λ_2	19.1547	21.6617	25.3174	32.0489	32.8746	33.573
λ_3	2.31475	1.66655	4.3902	9.74123	12.9197	6.14245
λ_4	0.153344	0.723629	3.436	7.59988	8.65103	1.68383
λ_2/λ_1	0.184915	0.189799	0.204883	0.25873	0.293044	0.255729
λ_3/λ_2	0.120845	0.0769353	0.173407	0.303949	0.393001	0.182958
λ_4/λ_2	0.00800556	0.0334059	0.135717	0.237134	0.263153	0.0501542

Gumbel distribution

parameters:

	Group1	Group2	Group3	Group4	Group5	Group6
α	27.6344	31.2513	36.5252	46.2367	47.428	48.4356
ξ	87.6361	96.0918	102.488	97.1822	84.8079	103.326

quantiles:

	Group1	Group2	Group3	Group4	Group5	Group6
1/30	181	202	226	254	245	267
1/50	195	218	245	278	270	292
1/100	215	240	271	310	303	326

GEV distribution

parameters:

	Group1	Group2	Group3	Group4	Group5	Group6
α	29.559	35.2881	36.3413	37.0641	31.7826	47.5198
κ	0.078271	0.150927	-0.00543864	-0.199204	-0.320914	-0.0202833
ξ	88.6616	98.4029	102.397	93.4794	79.2591	102.883

quantiles:

	Group1	Group2	Group3	Group4	Group5	Group6
1/30	177	192	227	273	274	269
1/50	188	202	246	312	327	296
1/100	203	215	272	373	414	332

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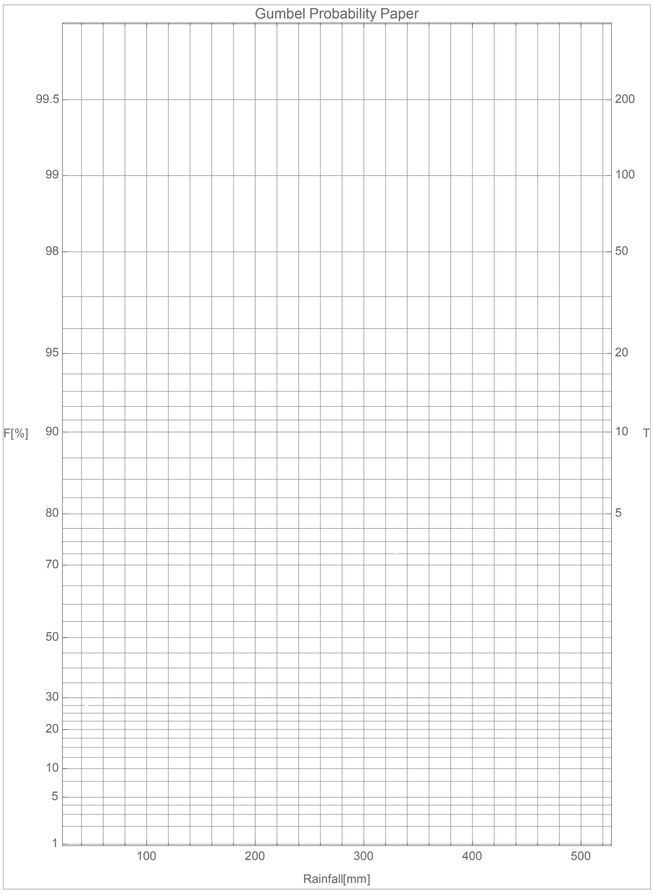
Hosking, J.R.M. and J.R. Wallis : *Regional Frequency Analysis –An Approach Based on L-Moments–*, Cambridge Univ. Press., p.207, 1997.

Stedinger, J.R., R.M. Vogel, and E. Foufoula-Georgiou: Frequency Analysis of Extreme Events, Chap. 18, *Handbook of Hydrology*, (Ed.) D. R. Maidment, McGraw-Hill, New York, pp.18.1-18.66, 1993.



Lecture 6: Efforts to develop disaster statistics in the world

Yuichi ONO, (*Assistant Director and Professor, International Research Institute of Disaster Science (IRIDeS) at Tohoku University*)

Abstract:

The lecture consists of three components. First, we will take an overview about the current situation of disaster loss and damage database (global/national) in the world and consider what are lacking in the existing database.

Secondly, we will take a look in to the international process related to disaster risk reduction focused on disaster statistics. Especially focusing on the targets established under two international framework which is an important driver to develop disaster statistics in the world, Sustainable Development Goals (SDGs) and Sendai Framework on Disaster Risk Reduction (SFDRR). Targets to reduce the number on death, people affected and direct economic loss caused by disaster was included in these frameworks and development of disaster loss database have become a "Must thing" for countries to monitor and report the situation. The lecture will also include on-going discussion of how to monitor these targets such as indicators and terminologies.

Thirdly, as one of the specific activities to support development of disaster statistics in the world "Global Centre for Disaster Statistics" will be introduced. The centre was established in April 2015 based on the cooperation between UNDP and International Research Institute of Disaster Science (IRIDeS), Tohoku University. The centre plan to (1) develop a comprehensive global database on disaster loss and damage; (2) analyze the disaster loss data; (3) make incites to the international process on disaster risk reduction and development agendas. In the lecture, distinctive points of the Centre's activities and its strategy will be introduced.

Overall, the lecture provide a good chance to (1) know the situation and future strategy to develop disaster statistics in the world, in other words to support development of national database in countries and to gather those data into one global database; (2) know the international process of disaster risk reduction including the contents of targets in SDGs and SFDRR and present discussion on monitoring (indicator and terminology) method of the targets.

Lecture6:
Efforts to develop disaster statistics in the world

Yuichi Ono, Ph.D.

Assistant Director and Professor, International Research Institute of Disaster Science (IRIDeS) at Tohoku University

Visiting Professor, Disaster Prevention Research Institute (DPRI) at Kyoto University

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Data – Analysis - Insight

Contents of the lecture

1. Current situations overview
   - Existing international database on disaster loss data
   - Situations in regions
   - What are the lacking points of the existing database?
   - DesInventar platform
2. Drivers for enhancing database development
   - World Conference on Disaster Risk Reduction
   - Sendai Framework on Disaster Risk Reduction
   - Sustainable Development Goals
   - Monitoring Process of the Targets and Indicators
3. Global Centre for Disaster Statistics
   - Outlines
   - Activities
   - Five Distinctive Points
4. Conclusions

Current Situations Overview

Existing international databases on disaster losses

	EM-DAT database	NatCatSERVICE	DesInventar format
Ownership	CRED: Centre for Research on the Epidemiology if Disaster	Munich Reinsurance	Mostly Governments Some by NGO, Research Institute etc.
Scope of the database	126 countries	Not Identified ※mainly developed countries	Over 82 countries
	21,468 events	21,700 events	Over 490,000 events
	1990-Present	1980-Present	Depends on the country (Oldest record)
Disaster Collected	Disasters which meet a certain criteria	Disasters with Human or Economic loss	All Disasters
Data Source	Multiple Source (UN agencies, Countries, Red Cross, Red Crescent, World Bank, Reinsurance, Media)	Insurance Company based (Munich Reinsurance offices and clients, International Insurance association)	Authorized by the Government

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Current Situations Overview

Situations in Regions

- Latin America

  27 databases depending on the DesInventar Format.
  DesInventar based on the similar methodology developed by groups of researchers and institutional actors in Latin America called LA RED.

- Europe and the European Commission

  Joint Research Centre of the European Commission is preparing guidelines for standardizing European Union Loss database (Groeve et al. 2013).
  4 databases based on the DesInventar Format.

Current Situations Overview

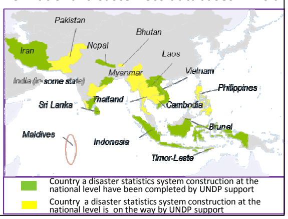
Situations in Regions

- Asia and the Pacific
  - ESCAP (UN Economic and Social Commission for Asia and the Pacific), Committee on Disaster Risk Reduction playing an important roll in promoting development of disaster loss database in the region
  - UNDP assisted countries and 18 databases based on the DesInventar format
- Africa

  18 database based on the DesInventar format

  Some other databases exist
  - Global Information and Early Warning System (not focused on disaster loss)
  - Natural Disaster Database for Central Africa (data gathered from existing databases)

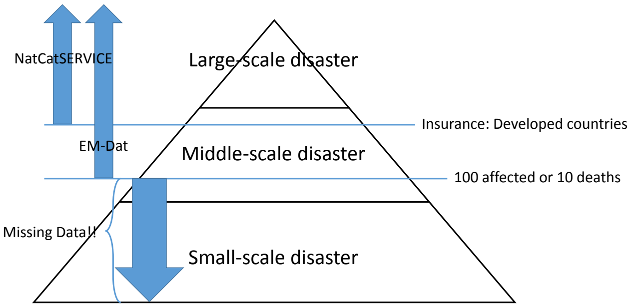
Figure: Current situations of the development of national disaster loss databases in Asia



Current Situation Overview

What is missing in the existing databases?

- Large-scale disaster are well reported while smaller scale ones are not



Current Situation Overview

What is missing in the existing database?

- Not many countries collect and own disaster loss data authorized by their governments
- Data collection methodology installed in 82 countries

  But the problem is
  - Some database stopped updating
  - Not collected from all local regions of the country
  - Methodology and Standard is some how different between countries

  ※Especially with countries not in the DesInventar format

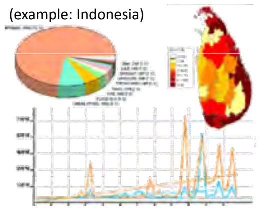
http://www.desinventar.net/index_www.html

Current Situation Overview

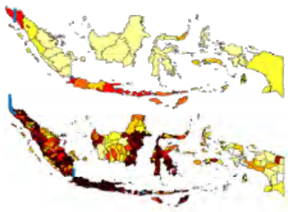
DesInventar platform

- Based on inputs from the local officials
- Web-based platform to provide outputs on simple visual images, including graphs and maps
- Some country has adapted the DesInventar and has its own one

(example: Indonesia)



Sample of Database in Sri Lanka (DesInventar platform)



Sample of Database in Indonesia (modified DesInventar platform)

Drivers for enhancing database development

World Conference on Disaster Risk Reduction

- Disaster risk is a potential risk
- WCDRR is a UN conference to develop an international strategy to reduce disaster risks (c.f. disaster management)

  ※Disaster: Disaster caused by natural hazards
- Major update in the 3rd Conference was to set "7 Global Targets"

1994 — 1st Conference at Yokohama
Yokohama Strategy
"5 Plan for action"

2005 — 2nd Conference at Kobe
Hyogo Framework for Action
"3 Strategic goals"
"5 Priorities for Action"

2015 — 3rd Conference Sendai
Sendai Framework for Disaster Risk Reduction
"7 Global Targets"
"4 Priorities for Action"

Drivers for enhancing database development

Sendai Framework on Disaster Risk Reduction

- 4 "Priorities for action" adopted in the conference

Priority 1: Understanding disaster risk.
Priority 2: Strengthening disaster risk governance to manage disaster risk.
Priority 3: Investing in disaster risk reduction for resilience.
Priority 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

Drivers for enhancing database development

Sendai Framework on Disaster Risk Reduction

- Adopted 7 "Global targets"

(a) Substantially reduce global disaster mortality by 2030, aiming to lower the average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005– 2015;
(b) Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015
(c) Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030
(d) Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030
(e) Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020;
(f) Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of the present Framework by 2030
(g) Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030

Sendai Framework on Disaster Risk Reduction

- 7 "Global targets" adopted in the conference

(a) Substantially reduce global disaster mortality by 2030, aiming to lower the average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005– 2015;
(b) Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015
(c) Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030

- With these 3 outcome targets, development of disaster loss database have become a "Must thing" for countries.

Sustainable Development Goals

- A new set of goals and targets developed after the Millennium Development Goals adopted at the UN Sustainable Development Summit in September 2015
- 17 Goals and 169 Targets were adopted
- Disaster Risk issues was also included as one of the targets
- Target 11.5 and 11.b is closely liked with SFDRR

Sustainable Development Goals

- Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
  - 11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
  - 11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels

Monitoring Process of the Targets

- Indicators and Methodology
  - In monitoring the targets, indicators (Definition of words included in the target, Method of calculation, and Level of disaggregation etc.) need to be developed
  - Open-ended intergovernmental expert working group on indicator and terminology relating to disaster risk reduction had its first meeting in Geneva in June 2015
  - First open-ended intergovernmental meeting in Geneva, September 2015
  - Second one to be held in Geneva around February 2016
  - Expected to be completed by the end of 2016 in the form of the UN Resolution

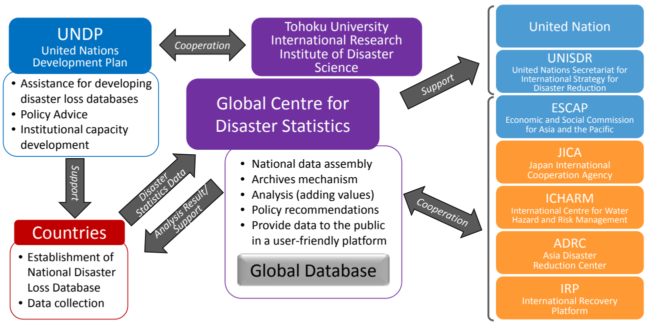
Key negotiation points: Definitions, international cooperation

Outlines

- Situations of the global framework and the basic idea
  - Development of disaster loss database has become a "Must thing" for countries
  - How can countries have good disaster management strategy without knowing what is happening in their country?
- UNDP
  - Has been supporting development of disaster loss database in more then 30 countries
  - Country-based support is available with strong relationship between government and related agencies in developing countries
- IRIDeS
  - Experts in more than 37 academic disciplines and capable to carry out analysis based on disaster data
  - Strong relationship between related organization/agencies/research institute in Japan

Outlines

- Relationship among the centre and associated organizations/agencies



Five distinctive points of the Centre

Point1:
Scope and coverage
- Including extensive disaster data

Point2:
Data Source from National/Local Governments in collaboration with UNDP
- Disaster data from official sources
- Provide incentives to data entry efforts

Point3:
Supporting the Monitoring process of the SFDRR
- A new global database can serve as a platform for UN to monitor SFDRR and SDGs
- The data will be archived in a standardized format and application

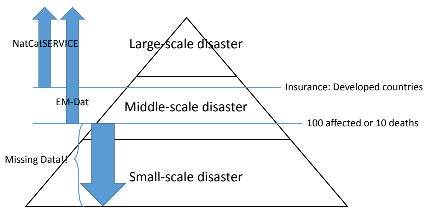
Five distinctive points of the Centre

Point4:
Analysis based on collected disaster loss data
- Macro-economic analysis
- Analysis based on disaggregated data
- Provide inputs to advocacy material on disaster risk reduction

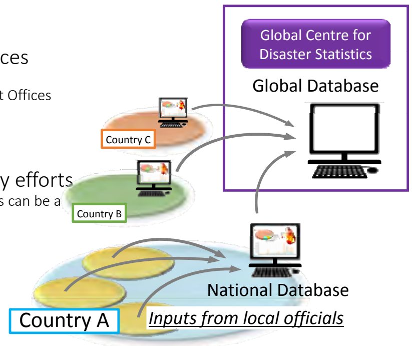
Point5:
Supporting National/Local Governments
- Empowering technical and institutional capacity
- Supporting disaster data reporting for policy making

Five distinctive points of the centre

Point1:
Scope and coverage
- Including extensive disasters data
  *Capture small-scale disaster data (the missing data)
  *Data disaggregated by demographic, social, and economic characteristics
- Meta data (nature and source of data is known)



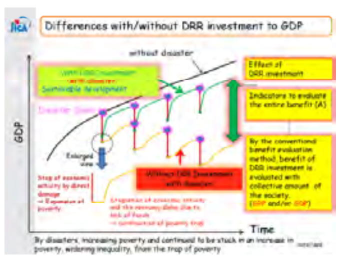
Point2:
Data Source from National/Local Governments in collaboration with UNDP
- Disaster data from official sources
  (utilizing DesInventar methodology)
  *Provided by National Disaster Management Offices
  *Reporting from local officials
  *UNDP's country-based support
- Provide incentives to data entry efforts
  *See impacts of entering data by themselves can be a good incentive



Point3:
Supporting Monitoring of progress in the SFDRR
- A new database developed under the centre can serve as a platform for international data sharing
- The data will be archived in a standardized format and application
  *Contribute in monitoring the target bellow
  *Support countries based on Indicators and standards to be agreed (ongoing process led by UNISDR)

(a) Substantially reduce global disaster mortality by 2030, aiming to lower the average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005– 2015;
(b) Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015
(c) Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030
(d) Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030
※Partly possible to monitor

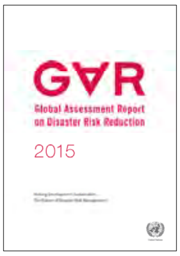
Point4:
Analysis based on collected disaster loss data
- Macro-economic analysis
  *One example of the analysis to evaluate the effect of pre-disaster investment
- Analysis based on disaggregated data
  *Data disaggregated by social, demographic, and economic characteristics



DR²AD model, developed by JICA, to quantitatively estimate the effect of pre-disaster investment to economic development

Point4:
Analysis based on collected disaster loss data

- Provide inputs to advocacy material on disaster risk reduction
  *Supporting UNISDR by providing materials to the Global Assessment Report (GAR)



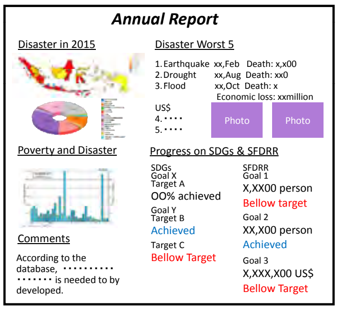
Point5:
Supporting National/Local Governments

- Empowering technical and institutional capacity
  *Trainings for disaster damage data collection
  *Technical advisory on disaster statistics analysis

- Supporting disaster data reporting for policy making
  *Develop a system to output a Annual Report
  *Semi-automatically, officers could complete local/national White Book on Disaster Risk Reduction
  *which motivates local officials to collect disaster damage data
  *Such Reports would generate effective policy on DRR

Point5:
Supporting National/Local Governments

[Image of the Annual Report]



Contents of the Report

- Trend of the Disasters
  - *Map, Chart, Graph etc.*
- Details of disasters
  - *Information of disasters*
  - *Photo Reports*
- Analysis Results
  - *Correlational Analysis of Disaster Statistics and Other Statistics such as Census*
    Ex. Relation between poverty and number of deaths caused by disaster
- Achieve situation report of disaster-related global targets
  - *Sustainable Development Goals (SDGs)*
  - *Sendai Framework on Disaster Risk Reduction (SFDRR)*

Conclusions

- The existing database is not enough for capturing the whole situations of the disaster risk in countries
- SFDRR and SDGs are important drivers for advancing the development of disaster statistics
- The monitoring process has been discussed at the UN
- IRIDeS and UNDP jointly developed the new centre (Global Centre for Disaster Statistics)
- The concept of the new centre is to support countries to monitor the progress in SFDRR and to enhance the capacity of governance in disaster risk reduction for countries
- These supports are essential for promoting the efforts to develop disaster statistics in the world

Data – Analysis - Insight

Lecture 7: Fundamentals in river basin modelling

Yoshinobu SATO (Faculty of Agriculture, Ehime University)

The aim of this lecture is to provide fundamental knowledge about river basin modelling for distributed hydrological simulations. River basin is the entire geographical land area drained by a river and its tributaries or an area characterized by all runoff being conveyed to the same outlet. Generally, river basin have typical futures, these include:

Tributaries: smaller rivers flowing into a larger river.

A watershed: an area or ridge of land that separates waters flowing to different rivers.

A confluence: where a river joins another river.

Source: the start of a river.

Mouth: where a river meets a lake, the sea or an ocean.

In many regions of the world, digital elevation/ terrain maps (DEM/DTM) are becoming available at a resolution fine enough to represent the form of hillslopes. In this lecture, a DEM with a fixed grid size (raster data) is used for the analysis. However, in fact, most raster DEMs have been built by interpolating from digitized counters and as a result may be, in places, cause to significant error, particularly where, in flat topography there are few counters, or where there are short steep slopes. Therefore, in this lecture, the procedure of how to delete depressed area in a flat zone and how to create flow direction map in the specific river basin will be introduced. Physically, waters does have tendency to flow downhill, at least for shallow river systems, so that obtaining information about the form of topography should have some utility in hydrological modelling. Distributed hydrological model often uses this type of topological data directory. But, a coarse-resolution DEM will not able to provide an adequate description of hillslope flow pathways. For the better hydrological simulation, all the topological information in a fine resolution are required. Variables derived from topographic data, calibrated parameter values, and the result of model simulations by a distributed models will based on the grid resolution of the DEMs. In the case of Japan, 50m DEM created by the GSI (Geophysical Survey Institute of Japan) are available and in the case of global scale, the SRTM30 which have horizontal spacing of 30 arc-second (Approx. 1km) generated by NASA, Shuttle Radar Topography Mission (http://www2.jpl.nasa.gov/srtm) are available. River basin boundary and channel network information will be obtained from GDBD (Global Drainage Basin Database), consist of six GIS (Geographical Information System) data: 1. Drainage basin boundary data, 2. River network data, 3. Discharge gauging station data, 4. Natural lake data, 5. Dam lake data, and 6. Flow direction data, developed by CCGR-NIES (Center for Global Environment Research, National Institute for Environmental Studies: http://www.cger.nies.go.jp/db/gdbd/gdbd_index_e.html). Each data can be extracted by ArcGIS software. For the interpolation, IDW (Inverse Distance Weighting) method is used. For each grid cell, there are four/eight possible flow directions assuming that the river channels run through the lowest part of each grid mesh and flow to the adjacent mesh with the steepest slope. If a depression sink occurs before the river mouth is reached, the elevation of mesh is modified to allow flow down to the nearest lowest mesh among four/eight directions. The detailed procedure for the river basin modelling such as the definition of grid cell coding (coordination system), calculation order, elevation data preparation, hillslope and river channel slope preparation, flow direction map, channel network, river channel order etc. will be explained in this lecture.

Lecture 7
Fundamentals in river basin modelling

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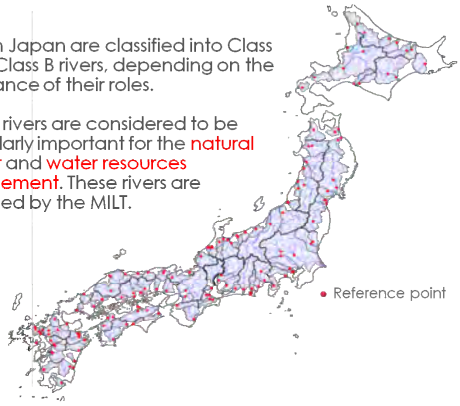
EHIME UNIVERSITY

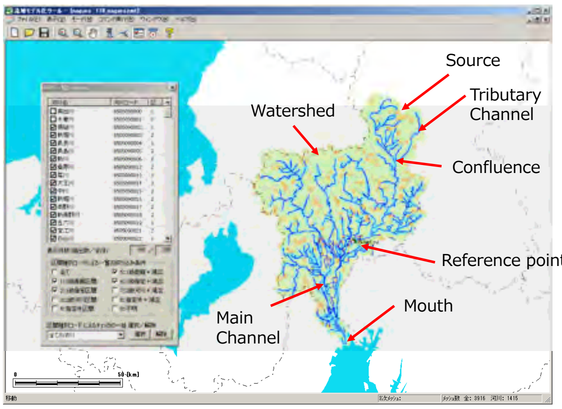
Class A river basin in Japan

Rivers in Japan are classified into Class A and Class B rivers, depending on the importance of their roles.

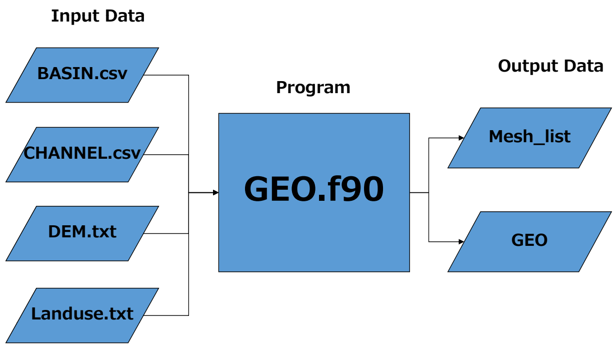
Class A rivers are considered to be particularly important for the natural disaster and water resources management. These rivers are managed by the MILT.



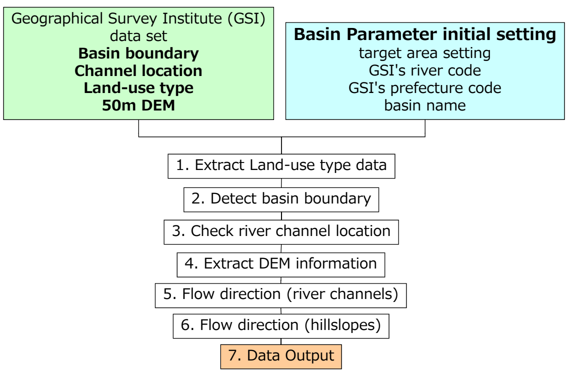
River basin modelling



River basin modelling tool

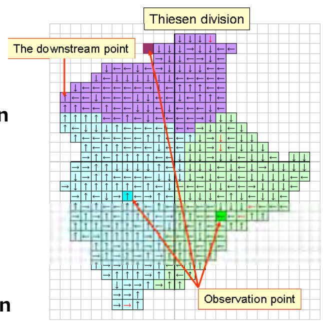


Flow of the modelling

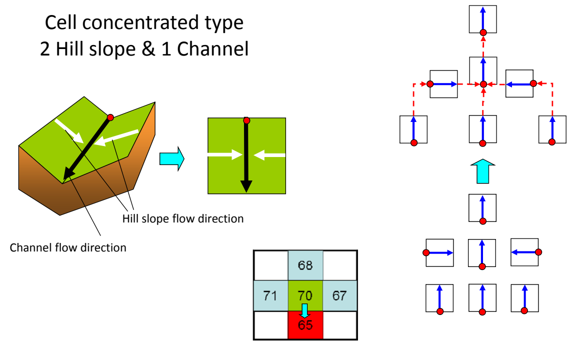


Flow of the modelling

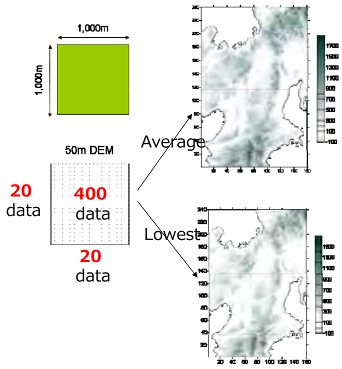
1. Total area selection
↓
2. Basin area determination
↓
3. Flow direction determination
↓
4. Flow direction modification
↓
5. Flow direction map
↓
6. a) Land use classification
   b) Slope angle determination



Flow routing

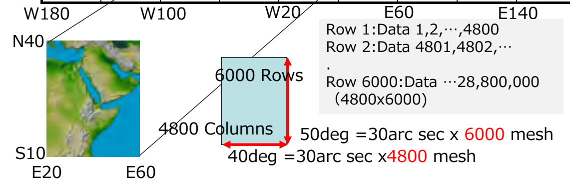


Elevation data



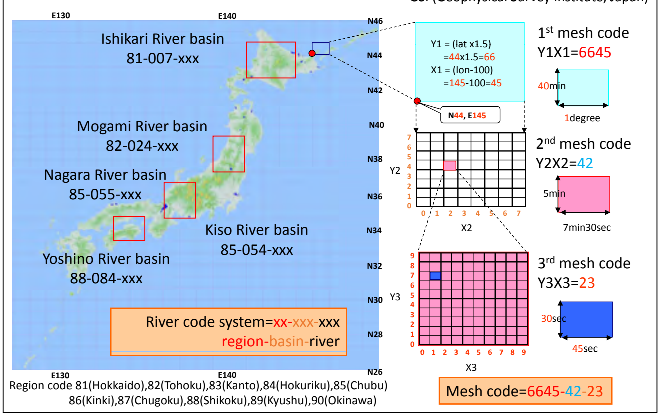
Elevation data (SRTM30)

	W140		W60		E20		E100	
W180 N90	W140 N90	W100 N90	W060 N90	W020 N90	E020 N90	E060 N90	E100 N90	E140 N90
W180 N40	W140 N40	W100 N40	W060 N40	W020 N40	E020 N40	E060 N40	E100 N40	E140 N40
W180 S10	W140 S10	W100 S10	W060 S10	W020 S10	E020 S10	E060 S10	E100 S10	E140 S10

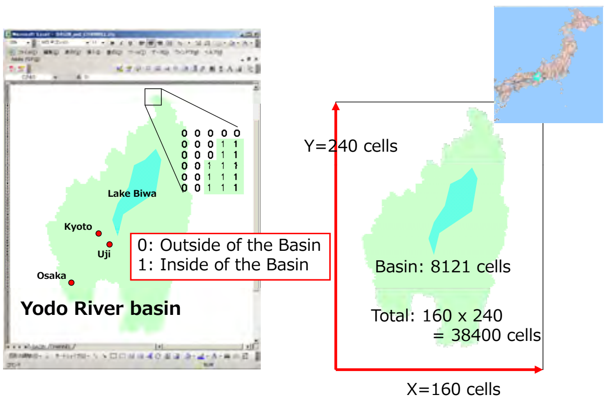


GSI's mesh code system

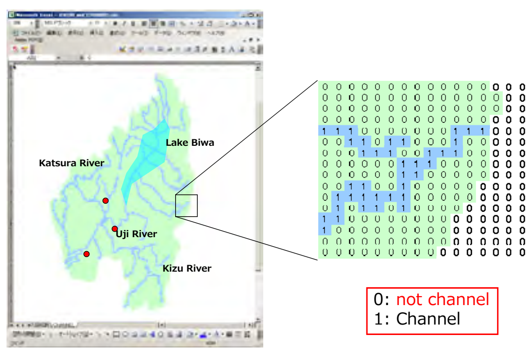
GSI (Geophysical Survey Institute, Japan)



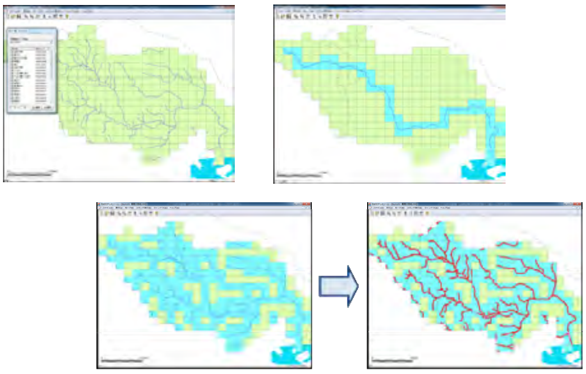
Basin boundary



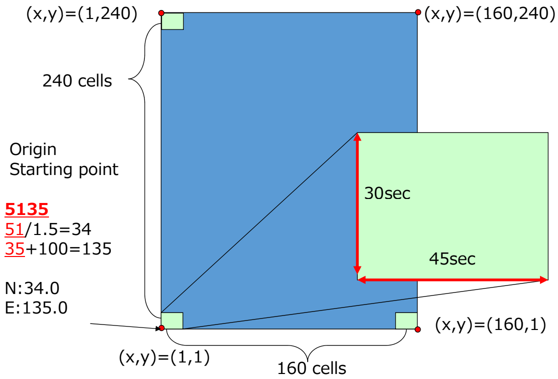
River channels



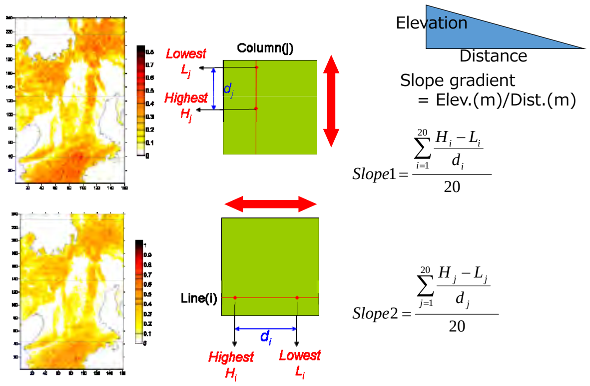
Basin modelling tool



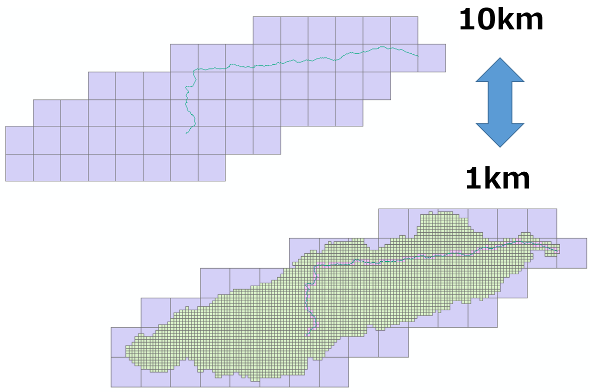
Coordination system



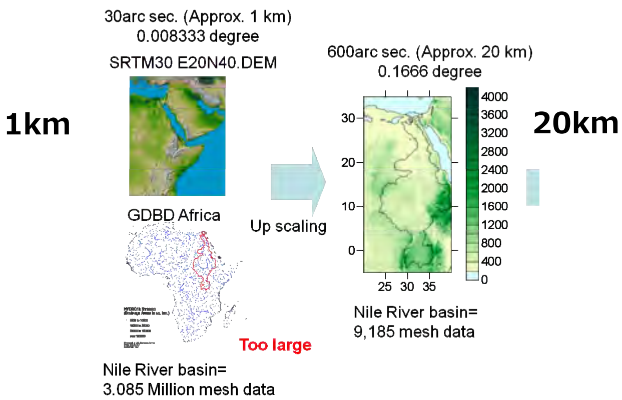
Slope data



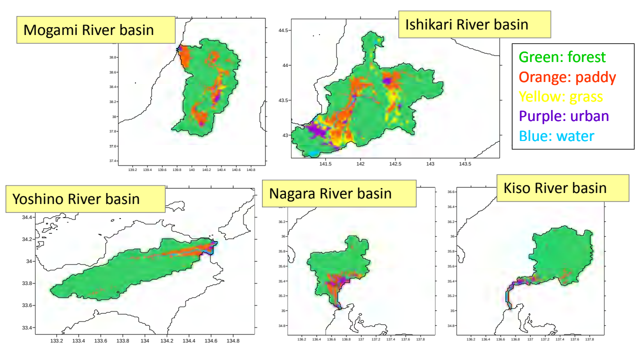
Resolution



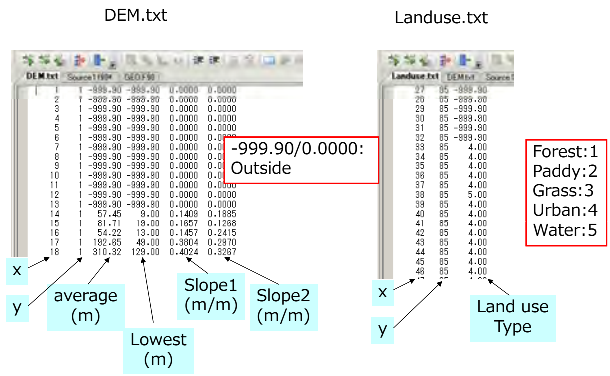
Resolution



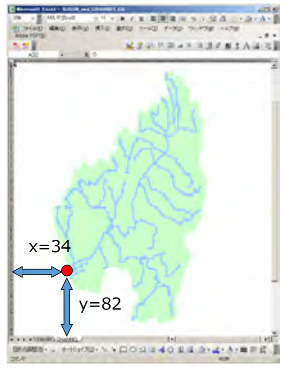
Land use classification



Data format



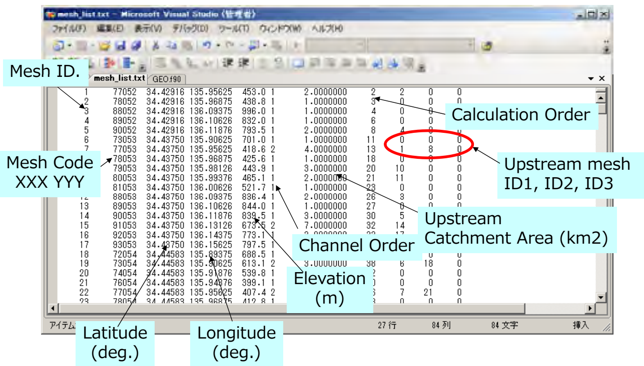
River mouth



In the case of Yodo River basin, the river mouth position is (x,y) = (34,82)

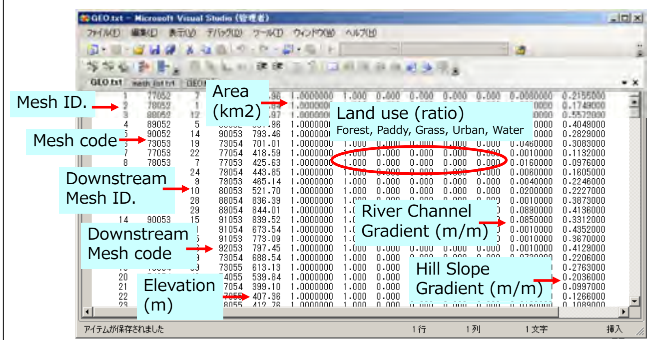
Output data

mesh_list.txt

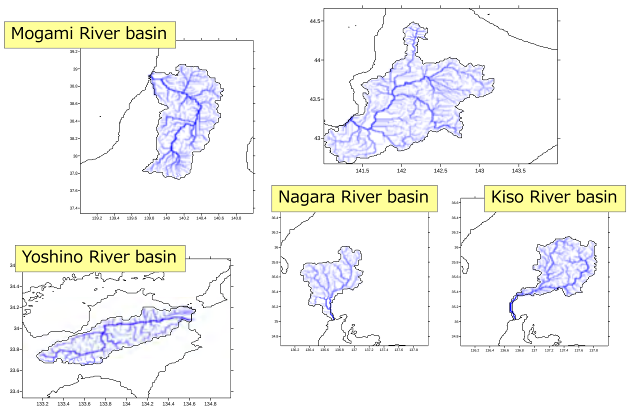


Output data

GEO.txt



Channel network



Summary
(River basin modelling)

- River channel runs through the **mesh lowest elevation**
- direction type: **4/8 direction**
- flow direction: **Steepest slope**

- Follow the actual river channel position

- Depression is corrected automatically by changing mesh elevation

Lecture 8: Fundamentals in Optimum Operation of Reservoir Systems

Tomoharu HORI
(*Water Resources Research Center, Disaster Prevention Research Institute, 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

Modeling of the Interaction between Water Resources and Socio-economic systems

Tomoharu HORI, Professor
Water Resources Research Center,
Disaster Prevention Research Institute,
Kyoto University

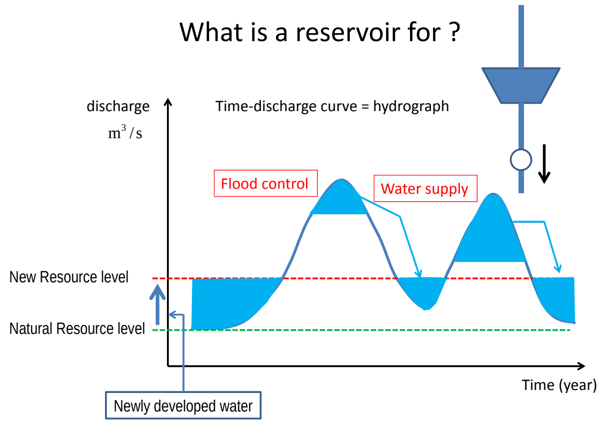
Recent Research Interest

- Modeling of the Interaction Between Water Resources and Socio-economic Systems
- Optimal Reservoir Operation scheme using Global Information
- Modeling of Human Response to Flood Emergency and Quantitative Performance Evaluation of Non-facility-based Countermeasures
- Optimal Design Framework of a Flood Control System Including In-floodplain Countermeasures Based on Distributed Risk Assessment

contents

1. Functions of Reservoirs
2. Multi-purpose reservoir - an example –
3. Mathematical expression of reservoir operation
4. Optimal operation by deterministic dynamic programming
5. Optimal operation by stochastic dynamic programming

What is a reservoir for ?



What is a reservoir for ?

1. to protect flood disasters

   Keep reservoir empty during non-flood period

2. to supply water, to generate power

   Keep reservoir full during non-drought period

A sample of multi-purpose dam reservoir - Hiyoshi dam – (1)

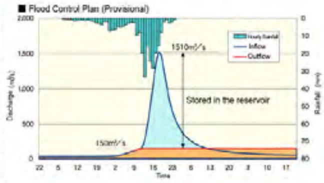
(Japan water agency)

A sample of multi-purpose dam reservoir - Hiyoshi dam – (2)

Purpose (1): Flood Control

By temporarily storing water in the dam reservoir during floods and by discharging water at a safe rate for the downstream areas, Hiyoshi Dam can reduce the damage caused by floods.

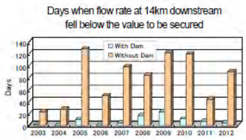
Hiyoshi Dam was constructed under a plan to control the 100-year floods. However, since river improvements in the lower reaches of the Katsura River are still in progress, flood-control operation with discharges of up to 150 m^3 has been provisionally carried out for controlling the 20-year floods. This operation is designed to maximize the effectiveness of flood control by the dam.



(Japan water agency)

A sample of multi-purpose dam reservoir - Hiyoshi dam – (3)

Purpose (2): Maintenance of Normal Function of River



Hiyoshi Dam can discharge supplemental water for the vested water rights along the Katsura River and environmental preservation to maintain the normal functions of the river water. This supply has greatly reduced downstream water shortages.

However, the capacity of the dam is limited. If the dam were to continue discharging supplemental water for a long time without rainfall, the water level of the reservoir would decrease and the desirable flow rate downstream could not be secured. Therefore, the amount of supply is coordinated among the related members.

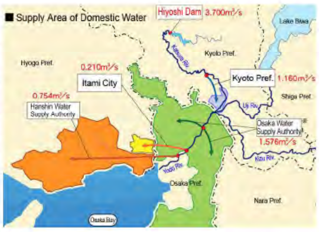
(Japan water agency)

A sample of multi-purpose dam reservoir - Hiyoshi dam – (3)

Purpose (3): Development of Water Use

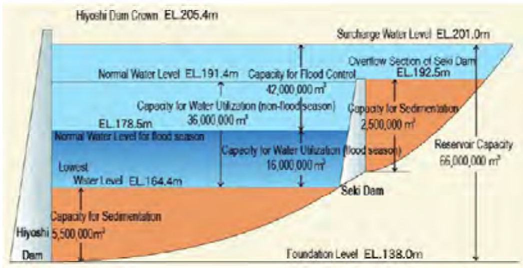
Hiyoshi Dam has created additional water use of 3.7 m^3/s (sufficient for approx. 1 million people). It can supply domestic water to Kyoto Prefecture (Otokuni District: Muko City, Nagaokakyo City, and Oyamazaki Town), Osaka Prefecture (Osaka Water Supply Authority), and Hyogo Prefecture (Itami City; and Hanshin Water Supply Authority: Amagasaki City, Nishinomiya City, Ashiya City, and Kobe City).

*Osaka Water Supply Authority supplies domestic water to the whole of Osaka Prefecture except Osaka City.

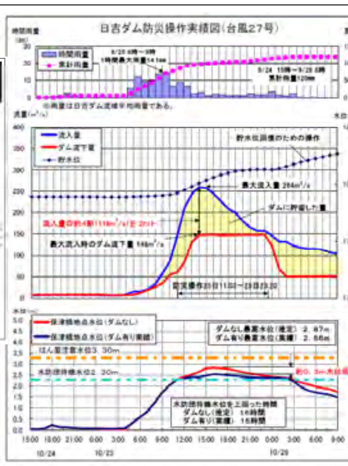


(Japan water agency)

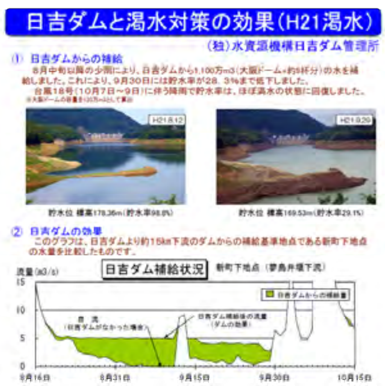
Capacity allocation of multi-purpose dam reservoir



(Japan water agency)

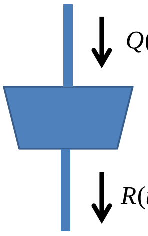


(Japan water agency)



(Japan water agency)

Key variables to describe state of a reservoir



$Q(t)$: Inflow discharge at time t

$S(t)$: Storage volume at time t

$R(t)$: Release discharge 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

Analyticaly 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

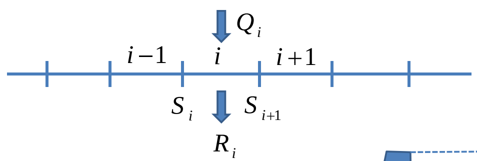
Unknown in future from the current time

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)

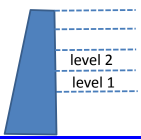
Discretization in time and volume

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

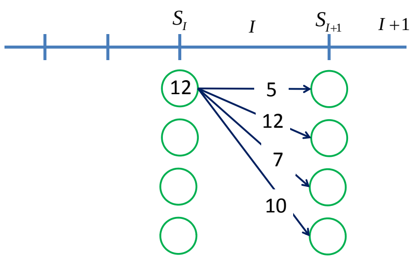
$J(\bullet,\bullet)$: assessment function

R_{max} :upper limit of release, S_{min} and S_{max} : lower and upper limit of storage.

Deterministic DP operation

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

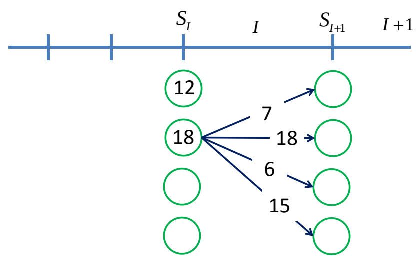
$$= \max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$



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

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$

$$= \max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + \max_{\substack{R_I \\ \text{for given } S_I}} \left[J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right] \right]$$

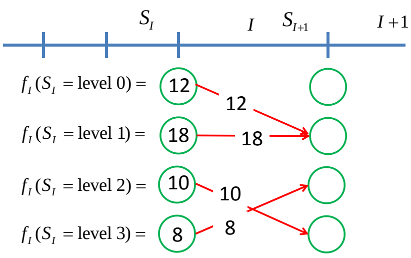
$$= \max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I-1} J(R_i, \frac{S_i + S_{i+1}}{2}) + f_I(S_I) \right]$$

where

$$f_I(S_I) = \max_{\substack{R_I \\ \text{for given } S_I}} \left[J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$

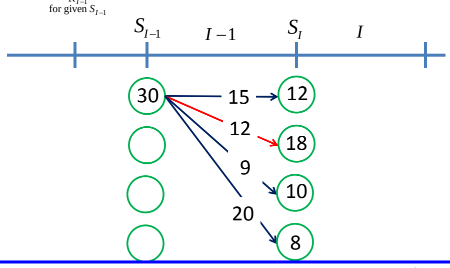
Deterministic DP operation

$$f_I(S_I) = \max_{\substack{R_I \\ \text{for given } S_I}} \left[J(R_I, S_I + \frac{Q_I - R_{I+1}}{2}) \right]$$



$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

$$= \max_{\substack{R_i \\ i=1,\cdots,I-2}} \left[\sum_{i=1}^{I-2} J(R_i, \frac{S_i + S_{i+1}}{2}) + \max_{\substack{R_{I-1} \\ \text{for given } S_{I-1}}} \left\{ J(R_{I-1}, S_{I-1} + \frac{Q_{I-1} - R_{I-1}}{2}) + f_I(S_{I-1} + Q_{I-1} - R_{I-1}) \right\} \right]$$



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

$$\max_{\substack{R_i \\ i=1,\cdots,I}} \left[\sum_{i=1}^{I} J(R_i, \frac{S_i + S_{i+1}}{2}) \right]$$

$$= \max_{\substack{R_i \\ i=1,\cdots,I-3}} \left[\sum_{i=1}^{I-3} J(R_i, \frac{S_i + S_{i+1}}{2}) + \max_{\substack{R_{I-2} \\ \text{for given } S_{I-2}}} \left\{ J(R_{I-2}, S_{I-2} + \frac{Q_{I-2} - R_{I-2}}{2}) + f_{I-1}(S_{I-2} + Q_{I-2} - R_{I-2}) \right\} \right].$$

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}.

$$\Pr[\,Q_i \mid Q_{i-1}]$$

$$= \begin{pmatrix} \Pr[Q_i = 1 \mid Q_{i-1} = 1] & \Pr[Q_i = 2 \mid Q_{i-1} = 1] & \Pr[Q_i = 3 \mid Q_{i-1} = 1] \\ \Pr[Q_i = 1 \mid Q_{i-1} = 2] & \Pr[Q_i = 2 \mid Q_{i-1} = 2] & \Pr[Q_i = 3 \mid Q_{i-1} = 2] \\ \Pr[Q_i = 1 \mid Q_{i-1} = 3] & \Pr[Q_i = 2 \mid Q_{i-1} = 3] & \Pr[Q_i = 3 \mid Q_{i-1} = 3] \end{pmatrix}$$

$$= \begin{pmatrix} 0.6 & 0.3 & 0.1 \\ 0.3 & 0.5 & 0.2 \\ 0.3 & 0.3 & 0.4 \end{pmatrix}$$

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 $\Pr[\,Q_{i-1}] = \begin{pmatrix} 0.3 \\ 0.5 \\ 0.2 \end{pmatrix}^T$

you can get the probability distribution of Q_i as follows

$$\Pr[Q_i] = \Pr[Q_i \mid Q_{i-1}] \cdot \Pr[Q_i] = (0.3 \quad 0.5 \quad 0.2) \cdot \begin{pmatrix} 0.6 & 0.3 & 0.1 \\ 0.3 & 0.5 & 0.2 \\ 0.3 & 0.3 & 0.4 \end{pmatrix}$$

$$= \begin{pmatrix} 0.3 \times 0.6 + 0.5 \times 0.3 + 0.2 \times 0.3 \\ 0.3 \times 0.3 + 0.5 \times 0.5 + 0.2 \times 0.3 \\ 0.3 \times 0.1 + 0.5 \times 0.2 + 0.2 \times 0.4 \end{pmatrix}^T$$

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:

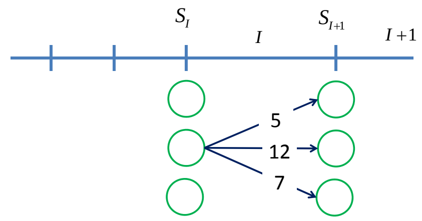
$\Pr[Q_{i-1} \mid Q_{i-1} = \text{level 1}] = (0.3 \quad 0.5 \quad 0.2)$.

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:

$$\Pr[S_{i+1}] = \begin{pmatrix} 0.3 & (\text{for} \quad S_{i+1} = 2+1-2=1) \\ 0.5 & (\text{for} \quad S_{i+1} = 2+2-2=2) \\ 0.2 & (\text{for} \quad S_{i+1} = 2+3-2=3) \end{pmatrix}$$

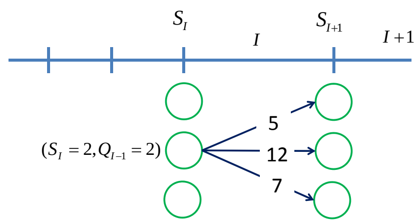
Stochastic Dynamic Programming

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
$5\times0.3+12\times0.5+7\times0.2=8.9$.



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
$5\times0.3+12\times0.5+7\times0.2=8.9$.



Stochastic Dynamic Programming

$$f_{I-i}(S_{I-i}, Q_{I-i-1}) = \max_{\substack{R_{I-i} \\ \text{for given } S_{I-i},\, Q_{I-i-1}}} \left\{ \sum_{Q_{I-i}=1}^{K} \Pr[Q_{I-i} \mid Q_{I-i-1}] \cdot \left(J\left(R_{I-i}, S_{I-i} + \frac{Q_{I-i}-R_{I-i}}{2}\right) + f_{I-i+1}(S_{I-i}+Q_{I-i}-R_{I-i}) \right) \right\}$$

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.

Lecture 9: *Wadi* Flash Floods Risk Management under Changing Climate in the Arid Regions

Sameh Ahmed KANTOUSH

(*Water Resources Research Center, Disaster Prevention Research Institute, Kyoto University*)

1. Definition of *Wadi* System:

The water resources availability in the arid regions is questionable over time due to a number of factors such as climate change and associated impacts such as uneven rainfall patterns, frequent extreme events in the last ten years (flash floods and droughts) and high evaporation rates. *Wadi* in Figure 1 is a dry river in the arid regions that can discharge large water volumes after heavy rainfall either to coastal or desert plateau. *Wadi* Flash Floods (*WFF*) occurs with little warning, causing deaths, roads, houses and properties damages. The main cause of *WFF* is not limited to weather or *wadi* conditions, but also the distribution of human populations near water. The rapid increase of population, urbanization and economic developments have pushed people for building in high disaster risk zones such as on *wadi* flood plains. *WFF* are known from other types of urban and river flooding by the short duration and the small spatial scales inside the *wadi* in which flooding occurs.

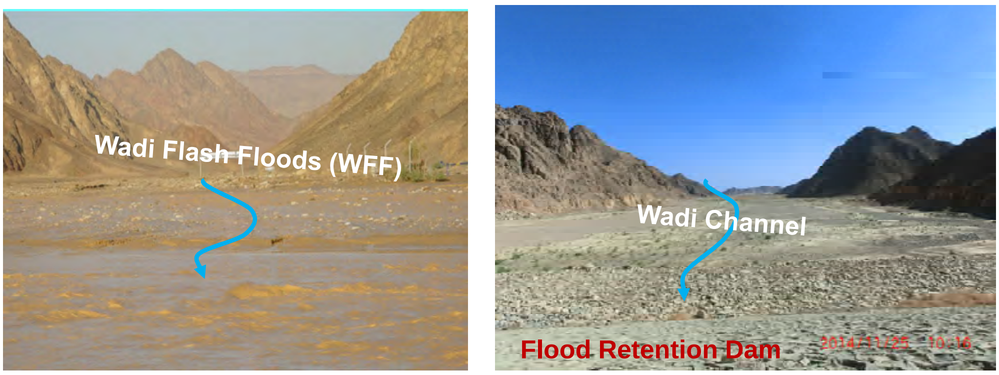


Figure 1: Main channel of Wadi system with and without flash flood

2. Key Questions and Challenges of *Wadi* Flash Floods (*WFF*):

The associated social and environmental risks after *WFF* of drylands receive little attention due to the relative infrequent occurrence of runoff events and the society awareness is very weak as *WFF* not considered as a disaster until it occurs. Figure 2 shows *WFF* challenges and management options. In such drylands, the law enforcement is absent and random settlement of the immigrants is common inside *wadi*. What is measured, is managed *WFF* as the data is discontinuous and never enough due to the lack of rainfall and runoff continuous monitoring. Therefore, the hydrological modelling for these ungauged catchments is neither calibrated nor verified and the consequent hydrological analyses are fraught with great deal of uncertainty. Decision makers have no tools to assist them in the planning against *WFF* risks. Furthermore, *wadi* local people and nearby urban area are not entirely involved in the planning of the flash flood mitigation strategies. Flood protection structures are not common and is done on individual level no integrated grouping of Wadi

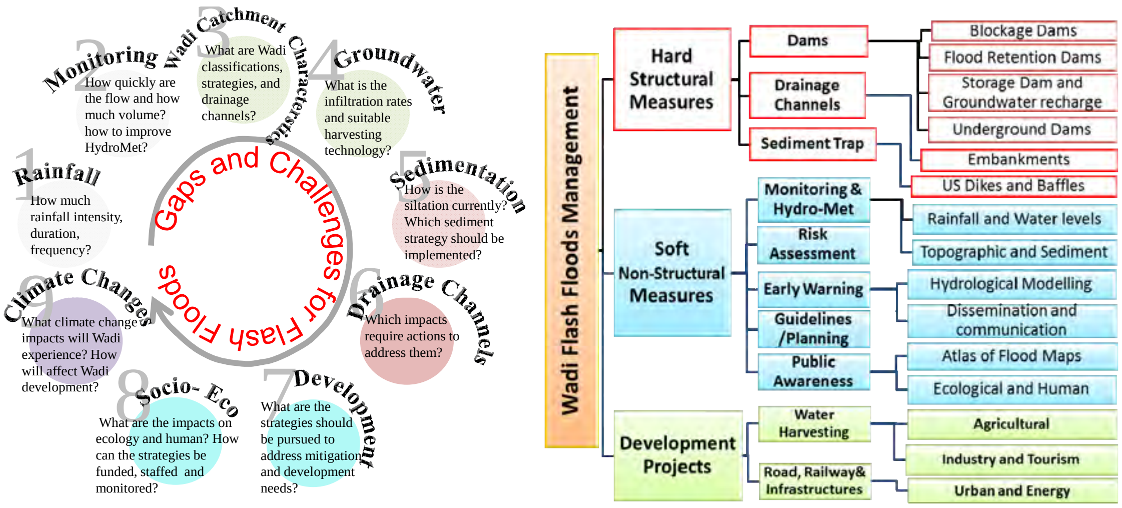


Figure 2: Key questions, challenges and strategies for Wadi Flash Floods in the arid regions

3. Hydrological Modelling and Early Warning System:

To face data limitation on arid environment, a physical-based distributed hydrological model and remote sensing data as well as GIS technique have been integrated to simulate flash floods of target *wadi* in the arid regions. Hydro-BEAM (Hydrological River Basin Environmental Assessment Model) which was first developed by Kojiri, et al. 2002, and it was also adopted as Hydro-BEAM-WaS (Hydrological River Basin Environmental Assessment Model Incorporating Wadi System) by Saber et al. 2010, to be applicable at Wadi system in arid regions.

4. Integrated Strategies of *WFF* in the Arid Regions: Mitigation and Harvesting

There are several flash flood mitigation measures in the arid *wadi's* as storage dams, recharging dams, artificial lakes and embankments, although soft mitigation measures as early warning systems still very rare. Not all flash floods are destructives and harvest of floodwater and rainfall runoff for human, livestock usage and agricultural developments, should be considered in the management by construction underground dams, artificial lakes, recharge dams and off-stream structures. Until today, no comprehensive proper strategy, mitigation and water resources management for *wadi* systems in the arid regions. There is an urgent need to establish a guideline and integrated method for assessment and mitigation of potential *wadi's* for future developments projects mitigate and utilize floodwater as a new supply to sustain a minimum water resources base in rural desert areas. Important research challenges include, understanding the processes that drive the extreme rainfall events, determining how frequent such events occurred, defining proper mitigation measures, and developing reliable hazard maps and warning system.

International Hydrological Programme (IHP)

Risk Management of Water-related Disasters under Changing Climate

The Twenty-fifth IHP Training Course (30 November - 11 December, 2015, Kyoto, Japan)

Lecture 9: Wadi Flash Floods Risk Management Under Changing Climate in the Arid Regions

Sameh Kantoush

Water Resources Research Center
Disaster Prevention Research Institute
Kyoto University

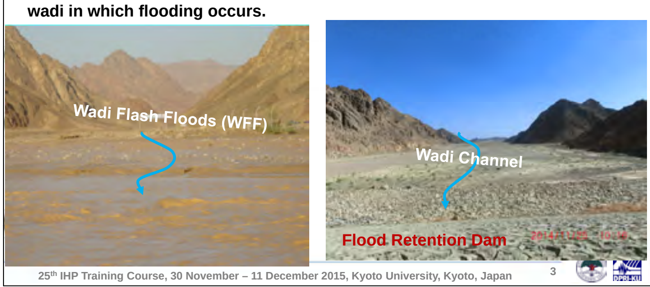
Email: kantoush.samehahmed.2n@Kyoto-u.ac.jp

Wadi Background and Problematic

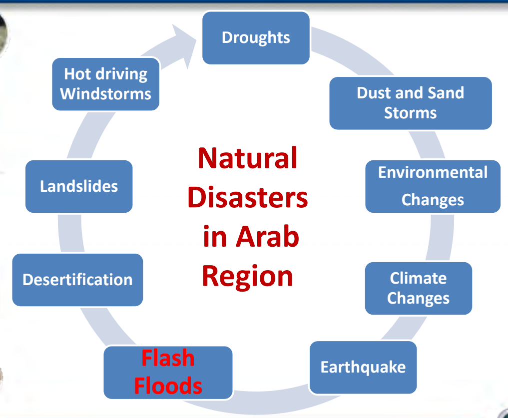
- The availability of water resources in the arid regions are under increasing pressure due to climate change impacts as droughts and floods.
- Rapid increase of population and urbanization has pushed people to high disaster risk zones such as Wadi flood plain.
- The frequency of WFF between 2009 and 2015, has increased markedly in the Arab regions, as has the estimated economic damage they cause.
- Huge efforts by governments of the Arab countries to enhance flash floods monitoring, modelling, install mitigation structures and early warning systems
- WFF risk assessment should be incorporated in development projects for disaster risk reduction and develop integrated management strategies.
- Until today, no comprehensive proper strategy, mitigation and water resources management for wadi systems in the Arabian region.
- There is an urgent need to establish a guideline for assessment and mitigation and utilize floodwater as a new supply.
- Important research challenges include, improved data collection techniques, defining flash flood types and the reasons for their occurrences, spatial and temporal distribution, forecasting, warning systems and mitigation measures, sedimentation, wadi ecosystem, water reuse and harvesting techniques.

Wadi Definition of Wadi Flash Floods (WFF)

- Wadi is a dry riverbed that can discharge large water volumes after heavy rainfall either to the coastal or to the desert plateau.
- WFF occurs with little warning, causing deaths, roads, and properties damages.
- The main cause of WFF is not limited to weather or wadi conditions, but also the distribution of human populations near water.
- WFF are known by the short duration and the small spatial scales inside the wadi in which flooding occurs.



Wadi Types of Disaster Risk in the Arab Region



Wadi

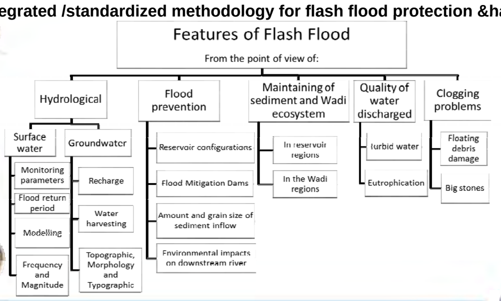
Wadi Objectives

We would like to stress on the existing gaps for integrated strategy and guideline for country affected by flash floods, to provide suggestions on:

- How to improve community understanding of the effects of flash floods,
- How to upgrade the current design guidelines, protection measures, and implementation strategies,
- Steps that can be taken to establish a detailed code for decision makers and to ensure that communities and local government are aware of the hazards associated with flash floods and are prepared to deal with them through appropriate mitigation strategies.

Wadi Flash Flood Governing Parameters

- Several factors contribute strongly to wadi Flash Floods among them are the high permeability of the desert, high recharge of ground surfaces, and steep slopes.
- A majority of flash-flood-related deaths occur in motor vehicles as people seek shelter and/or try to escape from rising waters.
- No integrated /standardized methodology for flash flood protection &harvesting.

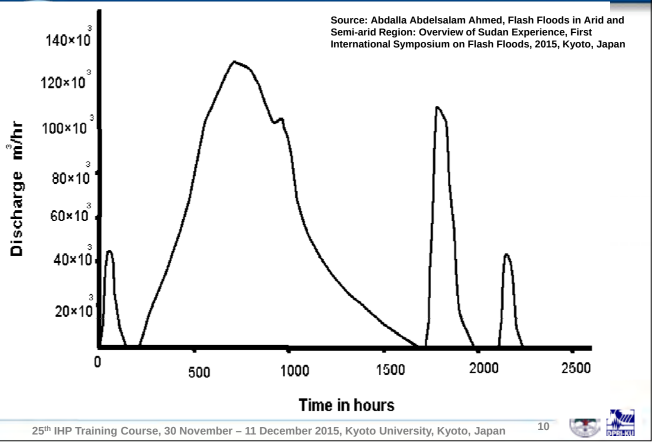


Wadi Characteristics of Arid Regions

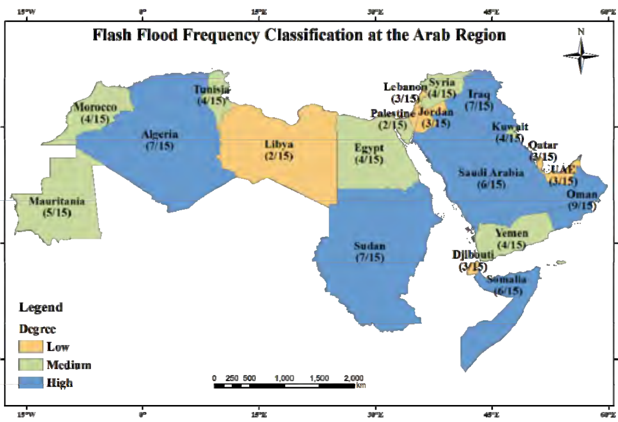
- The hydrology of arid areas is very different from that of humid areas and much less well understood
- Data capture is problematic - events are infrequent and damaging, networks are sparse and record lengths limited (Experimental networks are limited)
- Rainfall events in arid areas are hard to forecast, uneven patterns, highly variable in space and time.
- and time and often highly localized.
- Wadi Flash floods cause severe damages and difficult to quantify.
- Absence of base flow.
- Sparsity of plant cover.
- High transmission losses.
- High potential evaporation and evapotranspiration.
- Water harvesting and groundwater recharge near *Wadi* channel is unreliable.
- Most of Wadi's have high infiltration rates in the sandy areas and low infiltration rates in the rocky areas.

Wadi Africa is suffering from recent Drought – Kenya 06

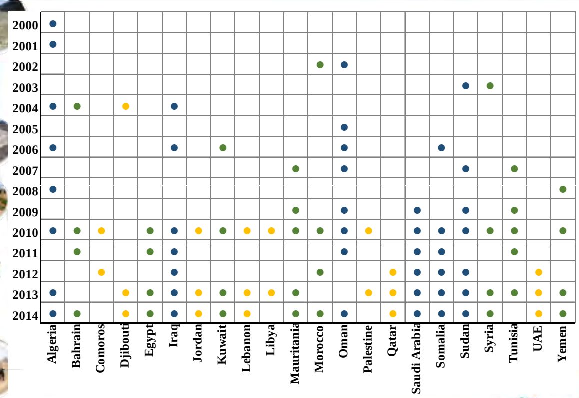
Wadi Typical Wadis Hydrograph (Wadi Abu Hamra – Western Sudan)

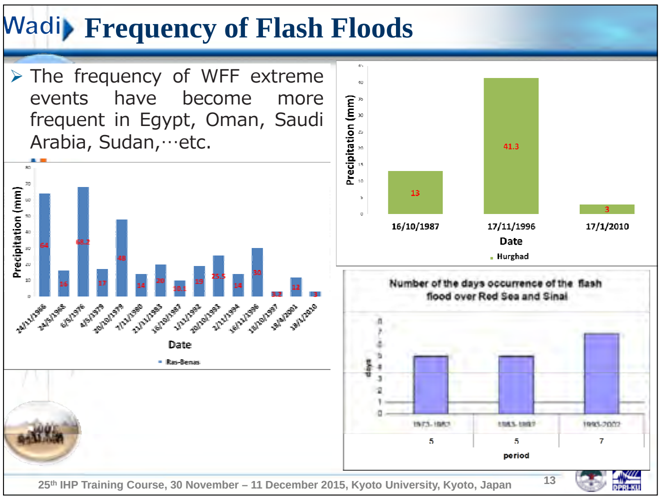


Wadi Arab Region Between Drought and Flash Floods



Wadi Flash Floods Under Changing Climate




Wadi
Frequency of Flash Floods
The frequency of WFF extreme events have become more frequent in Egypt, Oman, Saudi Arabia, Sudan,…etc.
Precipitation (mm)
Date
Ras-Benas
16/10/1987
17/11/1996
17/1/2010
Hurghad
Number of the days occurrence of the flash flood over Red Sea and Sinai
days
period
25th IHP Training Course, 30 November – 11 December 2015, Kyoto University, Kyoto, Japan
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Wadi
Flash Flood Damages in 2010 Saudi Arabia & Egypt
Saudi Arabia
Egypt
Sinai Egypt
Source of pictures from Prof. Gamal Koteb, NWRC, MWRI, Egypt
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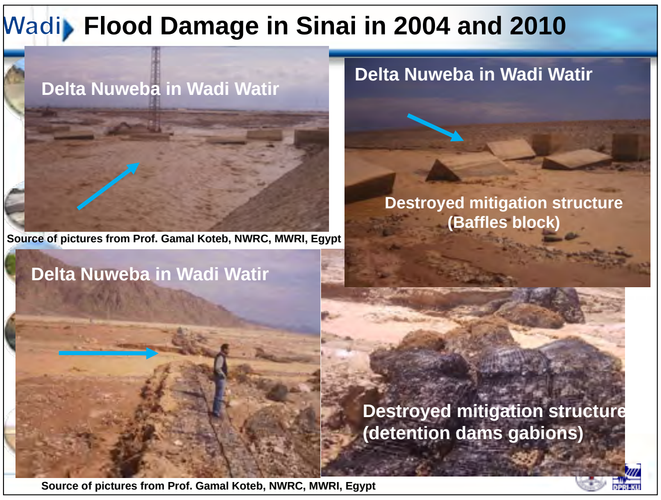
Wadi
Flood Damage in Sinai in 2004 and 2010
Delta Nuweba in Wadi Watir
Delta Nuweba in Wadi Watir
Destroyed mitigation structure (Baffles block)
Source of pictures from Prof. Gamal Koteb, NWRC, MWRI, Egypt
Delta Nuweba in Wadi Watir
Destroyed mitigation structure (detention dams gabions)
Source of pictures from Prof. Gamal Koteb, NWRC, MWRI, Egypt


Flood Damage in Sinai
Wadi ElArish
Source of pictures from Prof. Gamal Koteb, NWRC, MWRI, Egypt
Road Damages and undercutting
Source of pictures from Prof. Gamal Koteb, NWRC, MWRI, Egypt
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Wadi
Examples of Flash Flood Damages
Flash flood in Morocco's, 2014
Spillway of El-Rawafaa Dam during flash flood in 2010, in Sinai
Source: Breaking news.ie
Source of pictures from Prof. Gamal Koteb, NWRC, MWRI, Egypt
Flash flood in Saudi Arabia, 2013
Source: riyadhconnect.com


Wadi
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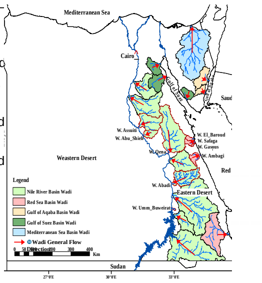
Wadi History of Flash Floods in Saudi Arabia

Date	Affected Area	Fatalities	Damages
Nov. 2009	Jeddah	122 killed and more than 350 were missing	270 million USD, at least 3000 vehicles were swept away or damaged
Jan. 2011	Jeddah	10 people died, 18 000 people displaced	
May 2012		20 people died	
April and May, 2013	Riyadh, Baha Taiif, and Hail	24 deaths, 4 missed people	4544 evacuated peoples, hundreds cars damage, Tabalah dam collapse (capacity 68 million m^3)
Nov. 2013	Riyadh, Arar and AlBaha	11 deaths, 4 missed people	
Jan. 2014	Mekkah		
Mar. 2014	Hail and Riyadh	4 deaths	
Mar. 2015	Meccah, Asir, Najran and Riyadh	11 deaths	over 400 vehicles have been trapped in flood water

Almazroui, 2011

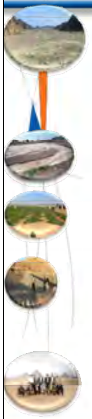
Wadi Historical Records of Flash Floods in Egypt

Date	Area	Damages and Ref.
21 February 2015	Sinai, Red Sea region	
March 2014	Sohag, Aswan, Kom Ombo	Dam failure Sohag, Road damages in Kom-Ombo, Aswan
January 2010	Along the Red Sea	Heavy rainfall associated with thunderstorms.
May 1997	Safaga and El Qusier	Heavy rainfall associated with thunderstorms.
November 1996	Hurghada and Marsa Alam	Destroy roods, 200 death, damage of vehicles
November 1994	Sohage, Qena, Red Sea (Safaga and El Qusier)	
August 1991	Marsa Alam	- Reports of Red Sea Governorate, 1994.
20 October 1990	Wadi El Gemal between Marsa Alam and Shalateen	- Red Sea Environmental Profile 2008
October 1979	Marsa Alam and El Qusier	
October 1987	South Sinai	
1975	Wadi El-Arish	20 death / Road roblems

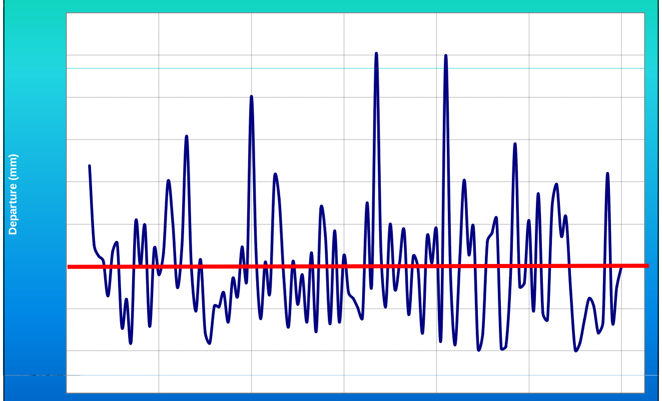


Eastern Deseret& Sinai Peninsula main wadis showing different wadi systems based on the downstream feature (wadis in red outline were visited at the field investigation)

Wadi Historical Records of Flash Floods in Oman



MUSCAT 5-YEAR RAINFALL 1895-2010
DEPARTURE FROM MEAN (98 mm)



Source: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan

Wadi Flash Floods Caused by Thunder Storms

Thunder storms are common in Oman and when associated with heavy rains they cause flash floods

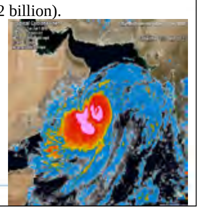
- On Dec. 1995 - 283 mm recorded in Musandam for the month. It rained for 11 days, floods washed roads, 100 leave their homes.
- November 1997 –very heavy rainfall causing floods most part of the country. 83 mm of rainfall was recorded in 1hr causing flash floods.
- 6-7 March, 1999 - Heavy rainfall causing flash floods especially in Sur. Gauging station recorded 1250 m^3/sec. The village of Sur was covered with more than 1 meter flooding.
- On the 14th April 2003 a line of thunderstorms. Rainfall of 82 mm was recorded in Bahla within less than 12 hours. Drowning of around 20 people, Swept cars, uprooted trees, destroyed roads, and damaged electricity and telephone cables

Sources: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan

Wadi Flash Floods Caused by Cyclones

- On the 5th June 2007 Tropical Cyclone (Gonu) approached the coast of Sharqiya Region.
- The most disastrous Tropical cyclone ever recorded in the history of Oman TC record
- T C Gonu was associated with Heavy Thunder storms, strong winds, high sea and flooding
- Surface wind reached to Category 4 : 211-250 km/h.
- 49 people left died, and estimated loss of 1.5 billion R.O ($4 billion).
- On the 4th June 2010 Tropical Cyclone (Phet) approached the coast of Oman near Qalhat and proceeded to Sharqiya and Batinah region.
- The 2nd most disastrous Tropical cyclone ever recorded in the history of Oman TC record
- Phet was associated with Heavy Thunder storms, strong winds, high sea and flooding. Surface wind reached to Category 4 : 211-250 km/h at sea.
- 6 people reported dead, and estimated loss of R.O 780 million ($2 billion).

Sources: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan

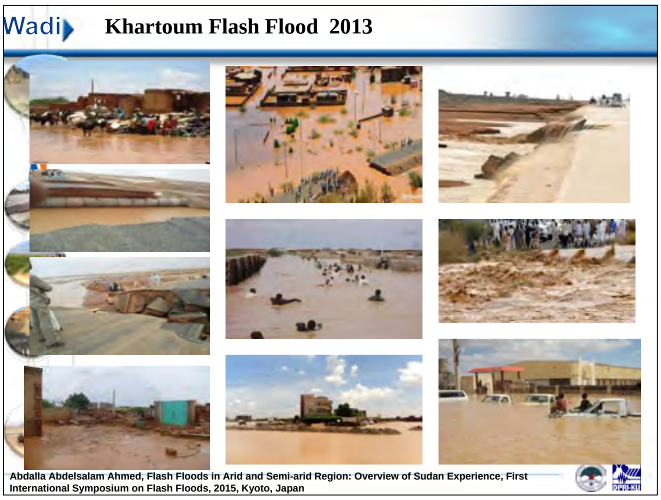



Wadi
Flood Damages in Oman
Source: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan

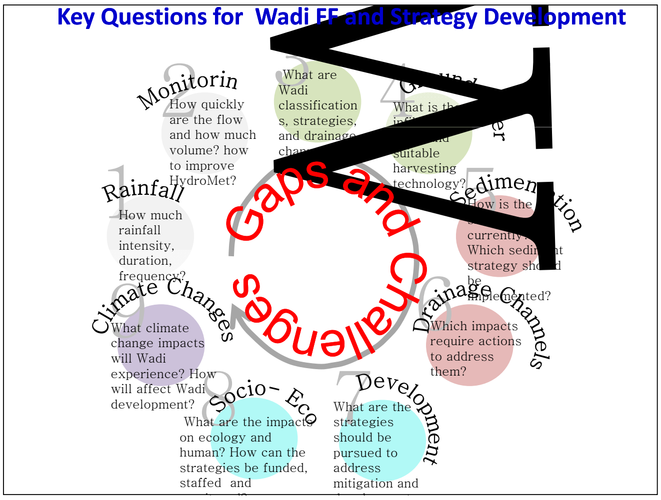

Sources: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan

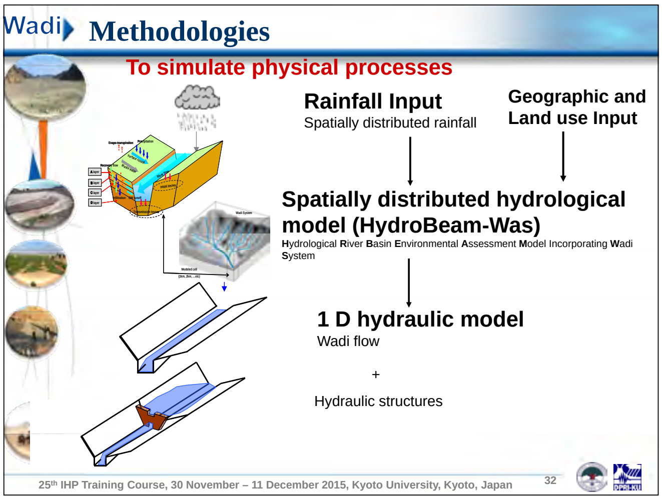

Source: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan


Source: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan


Wadi
Khartoum Flash Flood 2013
Abdalla Abdelsalam Ahmed, Flash Floods in Arid and Semi-arid Region: Overview of Sudan Experience, First International Symposium on Flash Floods, 2015, Kyoto, Japan


Wadi
Flash Floods Season 2013 – Khartoum State
Khartoum, Sudan, 2014
Abdalla Abdelsalam Ahmed, Flash Floods in Arid and Semi-arid Region: Overview of Sudan Experience, First International Symposium on Flash Floods, 2015, Kyoto, Japan


Key Questions for Wadi FF and Strategy Development
Gaps and Challenges
1 Rainfall
How much rainfall intensity, duration, frequency?
2 Monitoring
How quickly are the flow and how much volume? how to improve HydroMet?
3 What are Wadi classifications, strategies, and drainage channels?
4 What is the suitable harvesting technology?
5 Sedimentation
How is the currently? Which sediment strategy should be implemented?
6 Drainage Channels
Which impacts require actions to address them?
7 Development
What are the strategies should be pursued to address mitigation and
8 Socio-Eco
What are the impacts on ecology and human? How can the strategies be funded, staffed and
9 Climate Changes
What climate change impacts will Wadi experience? How will affect Wadi development?


Wadi
Methodologies
To simulate physical processes
Rainfall Input
Spatially distributed rainfall
Geographic and Land use Input
Spatially distributed hydrological model (HydroBeam-Was)
Hydrological River Basin Environmental Assessment Model Incorporating Wadi System
1 D hydraulic model
Wadi flow
+
Hydraulic structures
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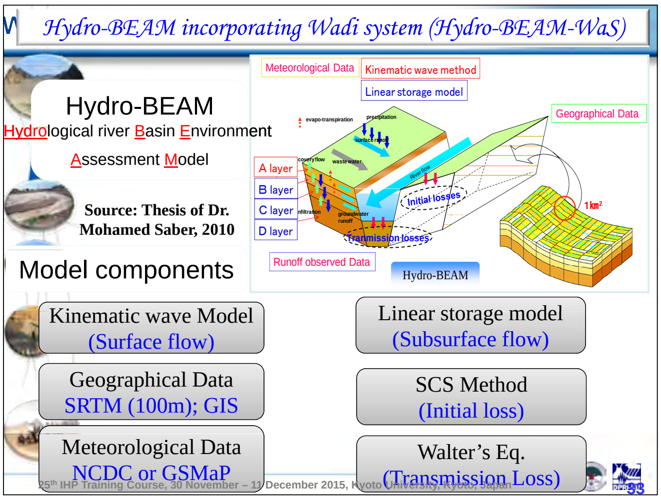
Hydro-BEAM incorporating Wadi system (Hydro-BEAM-WaS)
Hydro-BEAM
Hydrological river Basin Environment Assessment Model
Source: Thesis of Dr. Mohamed Saber, 2010
Meteorological Data
Kinematic wave method
Linear storage model
Geographical Data
A layer
B layer
C layer
D layer
Initial losses
Transmission losses
1km²
Runoff observed Data
Hydro-BEAM
Model components
Kinematic wave Model (Surface flow)
Linear storage model (Subsurface flow)
Geographical Data SRTM (100m); GIS
SCS Method (Initial loss)
Meteorological Data NCDC or GSMaP
Walter's Eq. (Transmission Loss)
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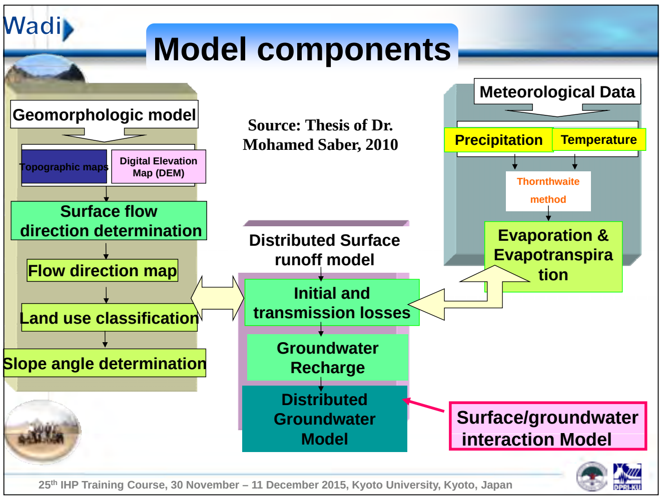
Wadi
Model components
Source: Thesis of Dr. Mohamed Saber, 2010
Geomorphologic model
Topographic maps
Digital Elevation Map (DEM)
Surface flow direction determination
Flow direction map
Land use classification
Slope angle determination
Meteorological Data
Precipitation
Temperature
Thornthwaite method
Evaporation & Evapotranspiration
Distributed Surface runoff model
Initial and transmission losses
Groundwater Recharge
Distributed Groundwater Model
Surface/groundwater interaction Model
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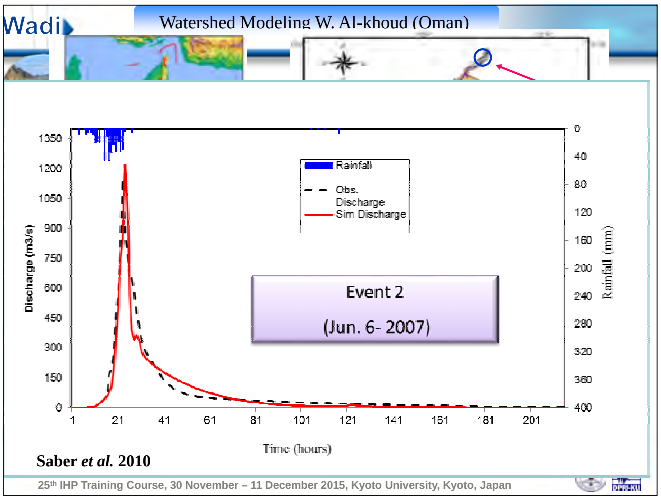
Wadi
Watershed Modeling W. Al-khoud (Oman)
Rainfall
Obs. Discharge
Sim Discharge
Event 2
(Jun. 6- 2007)
Discharge (m3/s)
Rainfall (mm)
Time (hours)
Saber et al. 2010
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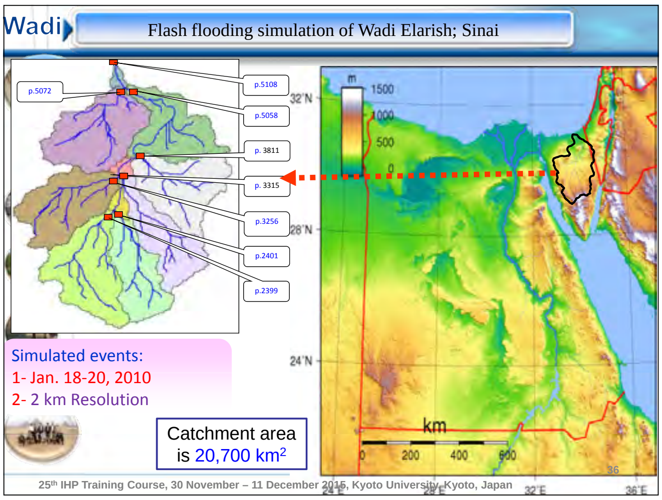
Wadi
Flash flooding simulation of Wadi Elarish; Sinai
Simulated events:
1- Jan. 18-20, 2010
2- 2 km Resolution
Catchment area is 20,700 km²
km
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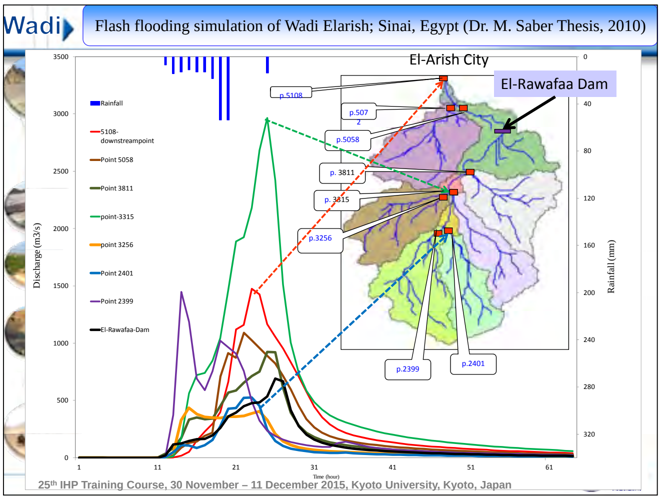
Wadi
Flash flooding simulation of Wadi Elarish; Sinai, Egypt (Dr. M. Saber Thesis, 2010)
El-Arish City
El-Rawafaa Dam
Discharge (m3/s)
Rainfall (mm)
Rainfall
Point 5058
Point 3811
point 3315
point 3256
Point 2401
Point 2399
El-Rawafaa-Dam
p.5108
p.5058
p. 3811
p.3256
p.2399
p.2401
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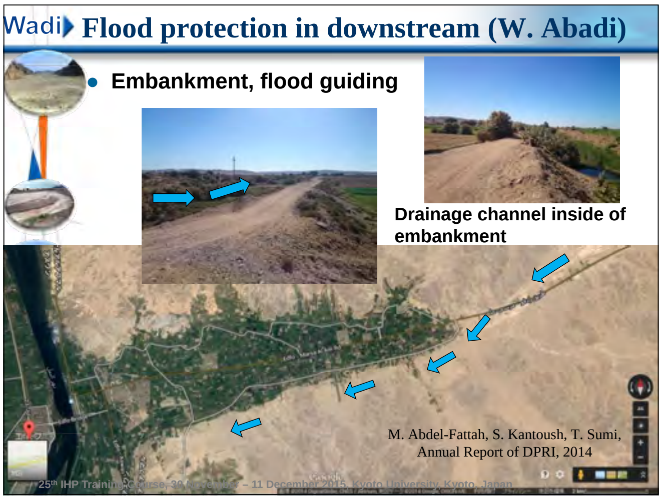
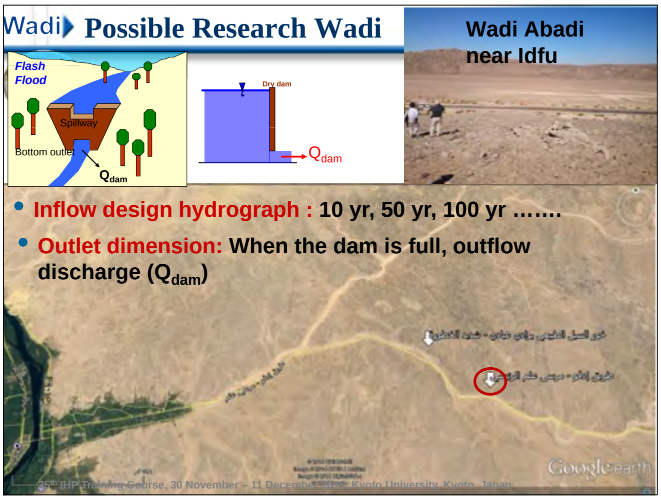

Wadi
Flood protection in downstream (W. Abadi)
Embankment, flood guiding
Drainage channel inside of embankment
M. Abdel-Fattah, S. Kantoush, T. Sumi, Annual Report of DPRI, 2014
25th IHP Training Course, 30 November – 11 December 2015, Kyoto University, Kyoto, Japan


Wadi
Possible Research Wadi
Wadi Abadi near Idfu
Flash Flood
Spillway
Bottom outlet
Qdam
Dry dam
Qdam
Inflow design hydrograph : 10 yr, 50 yr, 100 yr ....
Outlet dimension: When the dam is full, outflow discharge (Qdam)
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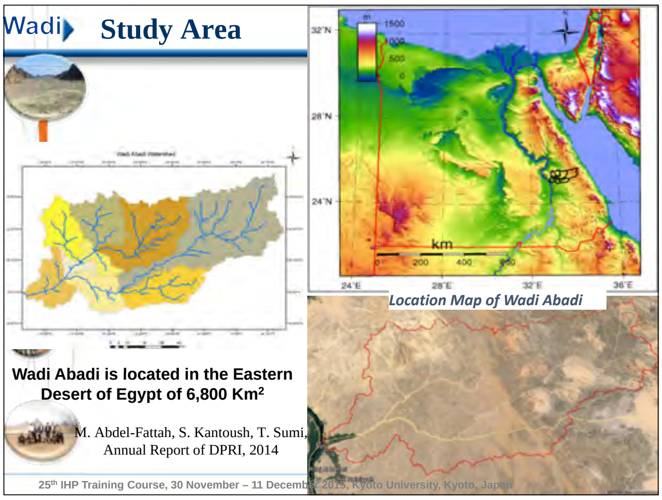
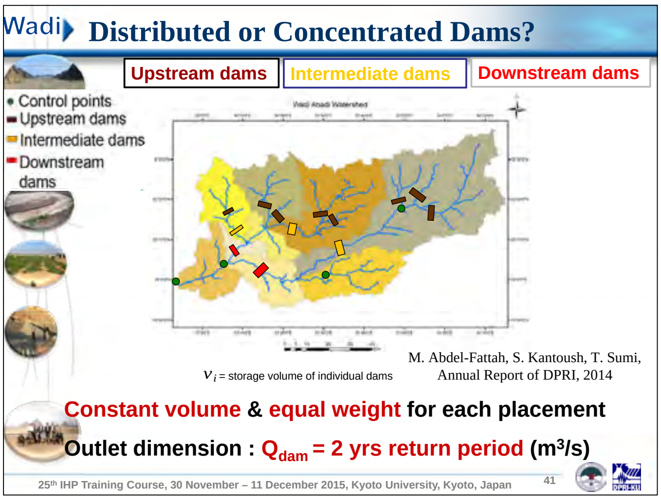

Wadi
Study Area
Location Map of Wadi Abadi
Wadi Abadi is located in the Eastern Desert of Egypt of 6,800 Km2
M. Abdel-Fattah, S. Kantoush, T. Sumi, Annual Report of DPRI, 2014
25th IHP Training Course, 30 November – 11 December 2015, Kyoto University, Kyoto, Japan


Wadi
Distributed or Concentrated Dams?
Upstream dams
Intermediate dams
Downstream dams
Control points
Upstream dams
Intermediate dams
Downstream dams
Wadi Abadi Watershed
M. Abdel-Fattah, S. Kantoush, T. Sumi, Annual Report of DPRI, 2014
Vi = storage volume of individual dams
Constant volume & equal weight for each placement
Outlet dimension : Qdam = 2 yrs return period (m3/s)
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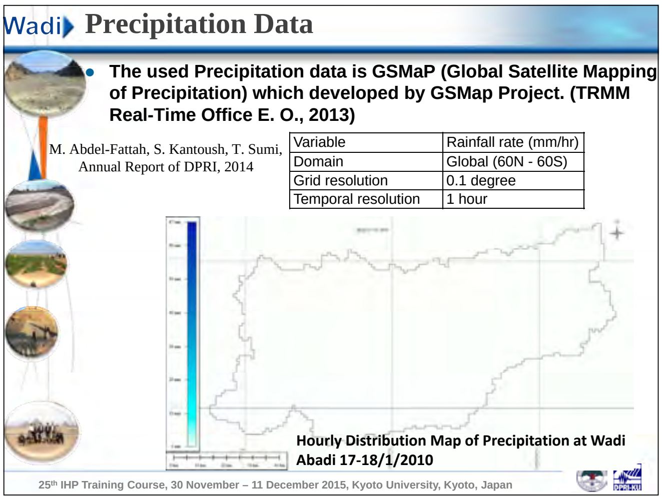
Wadi
Precipitation Data
The used Precipitation data is GSMaP (Global Satellite Mapping of Precipitation) which developed by GSMap Project. (TRMM Real-Time Office E. O., 2013)
M. Abdel-Fattah, S. Kantoush, T. Sumi, Annual Report of DPRI, 2014
Variable | Rainfall rate (mm/hr)
Domain | Global (60N - 60S)
Grid resolution | 0.1 degree
Temporal resolution | 1 hour
Hourly Distribution Map of Precipitation at Wadi Abadi 17-18/1/2010
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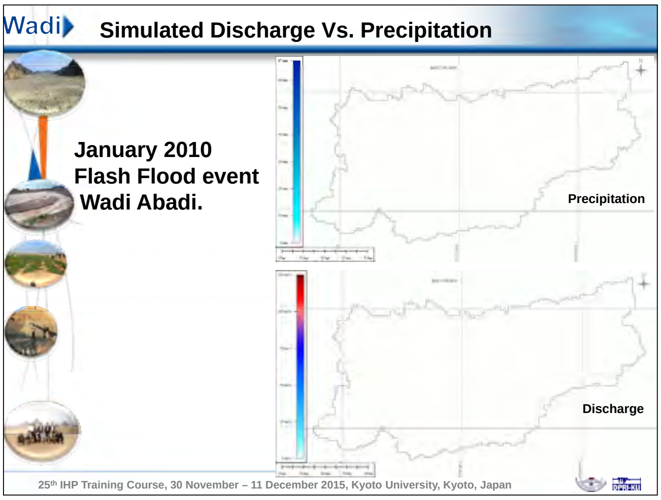
Wadi
Simulated Discharge Vs. Precipitation
January 2010
Flash Flood event
Wadi Abadi.
Precipitation
Discharge
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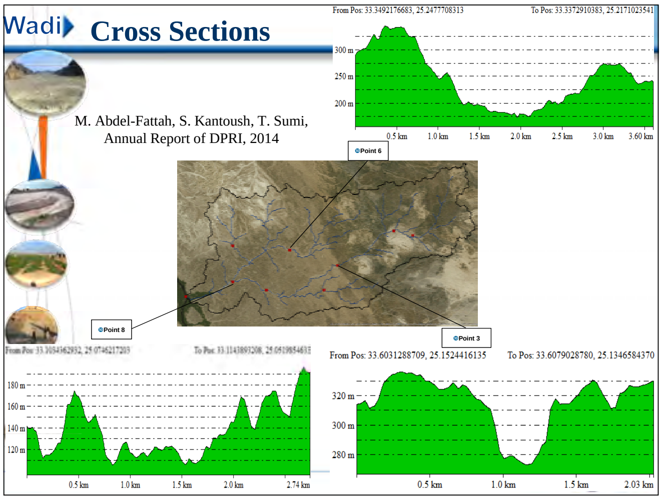
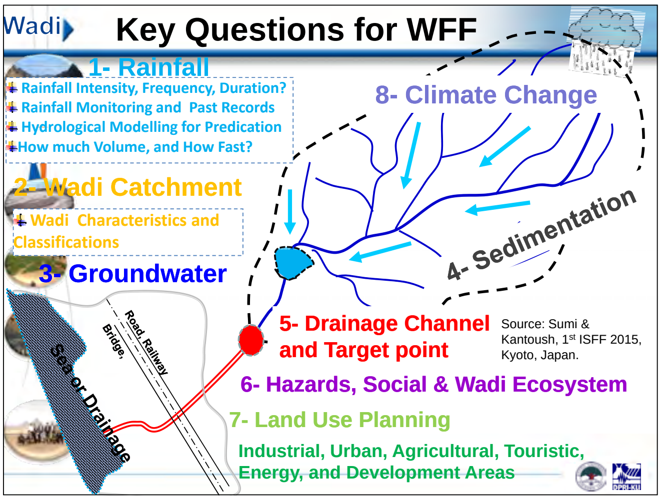
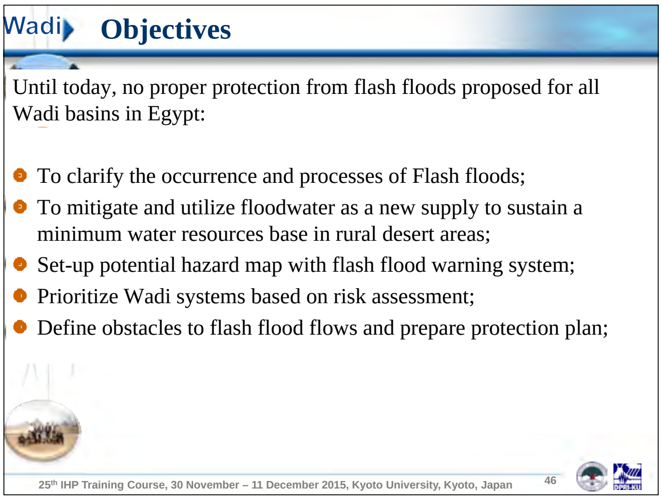

Wadi
Cross Sections
M. Abdel-Fattah, S. Kantoush, T. Sumi,
Annual Report of DPRI, 2014
300 m
250 m
200 m
0.5 km
1.0 km
1.5 km
2.0 km
2.5 km
3.0 km
3.60 km
Point 6
Point 8
Point 3
180 m
160 m
140 m
120 m
2.74 km
From Pos: 33.6031288709, 25.1524416135
To Pos: 33.6079028780, 25.1346584370
320 m
300 m
280 m
2.03 km


Wadi
Key Questions for WFF
1- Rainfall
Rainfall Intensity, Frequency, Duration?
Rainfall Monitoring and Past Records
Hydrological Modelling for Predication
How much Volume, and How Fast?
2- Wadi Catchment
Wadi Characteristics and Classifications
3- Groundwater
8- Climate Change
4- Sedimentation
5- Drainage Channel and Target point
Source: Sumi & Kantoush, 1st ISFF 2015, Kyoto, Japan.
Road, Railway
Bridge,
Sea or Drainage
6- Hazards, Social & Wadi Ecosystem
7- Land Use Planning
Industrial, Urban, Agricultural, Touristic, Energy, and Development Areas


Wadi
Objectives
Until today, no proper protection from flash floods proposed for all Wadi basins in Egypt:
To clarify the occurrence and processes of Flash floods;
To mitigate and utilize floodwater as a new supply to sustain a minimum water resources base in rural desert areas;
Set-up potential hazard map with flash flood warning system;
Prioritize Wadi systems based on risk assessment;
Define obstacles to flash flood flows and prepare protection plan;
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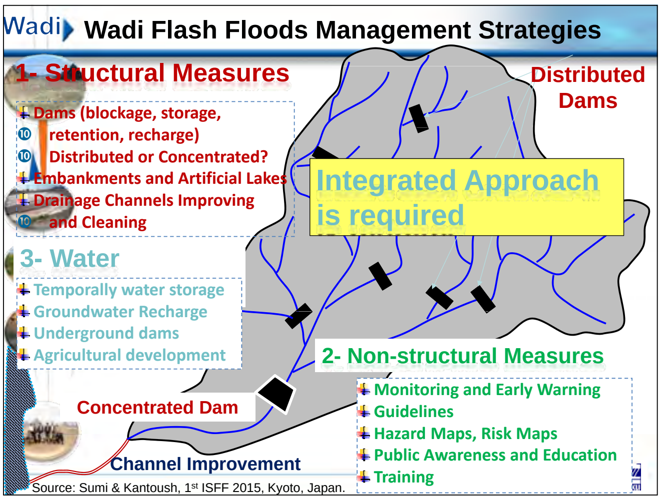
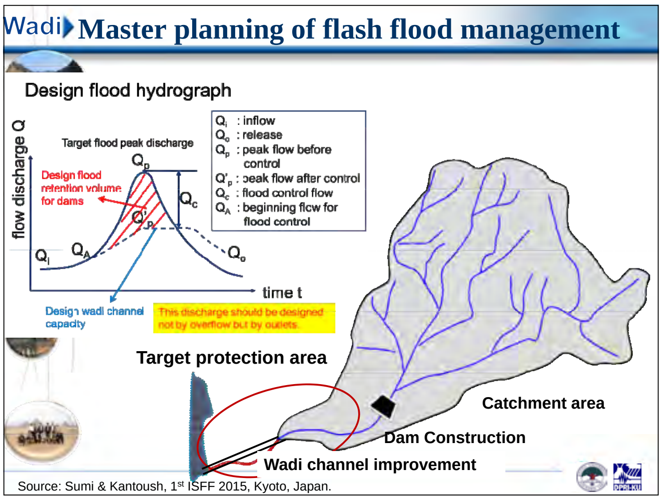
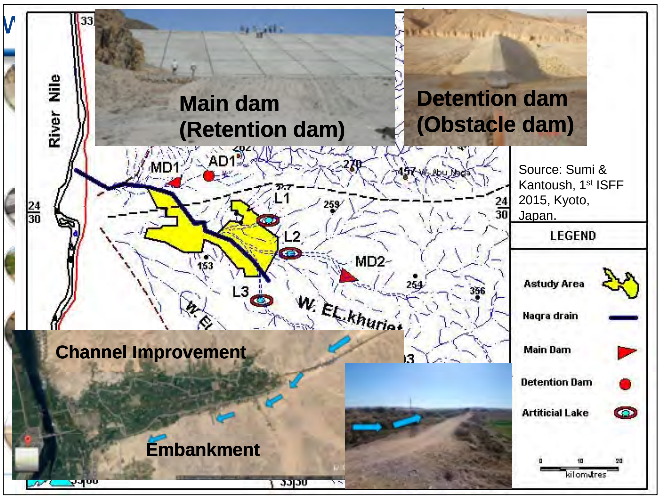
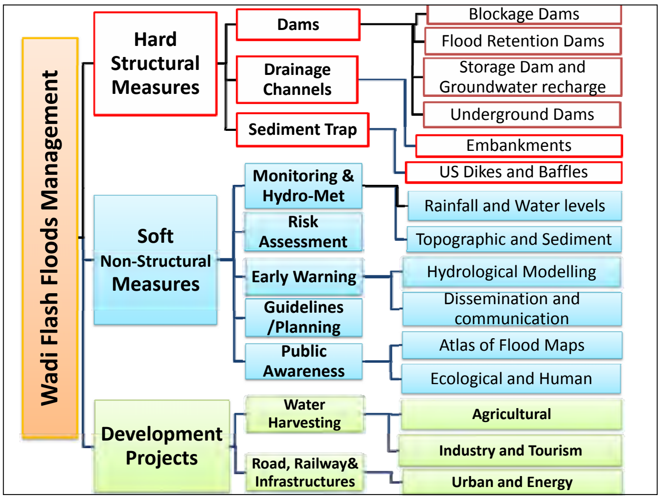
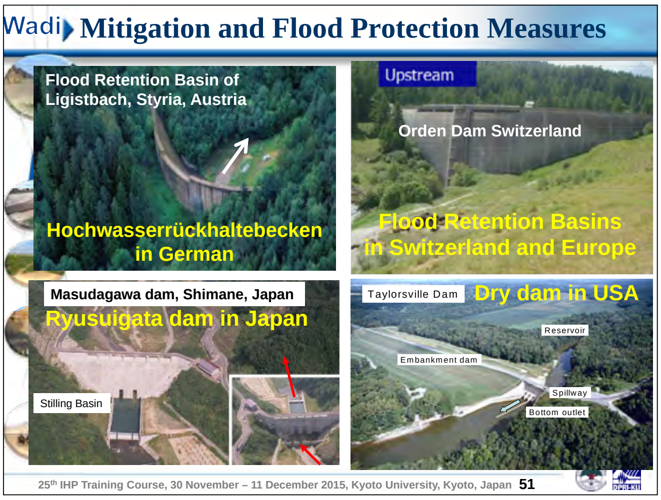

Wadi
Wadi Flash Floods Management Strategies
1- Structural Measures
Dams (blockage, storage, retention, recharge)
Distributed or Concentrated?
Embankments and Artificial Lakes
Drainage Channels Improving and Cleaning
Distributed Dams
Integrated Approach is required
3- Water
Temporally water storage
Groundwater Recharge
Underground dams
Agricultural development
2- Non-structural Measures
Monitoring and Early Warning
Guidelines
Hazard Maps, Risk Maps
Public Awareness and Education
Training
Concentrated Dam
Channel Improvement
Source: Sumi & Kantoush, 1st ISFF 2015, Kyoto, Japan.


Wadi
Master planning of flash flood management
Design flood hydrograph
flow discharge Q
Target flood peak discharge
Design flood retention volume for dams
time t
Design wadi channel capacity
This discharge should be designed not by overflow but by outlets
Qi : inflow
Qo : release
Qp : peak flow before control
Q'p : peak flow after control
Qc : flood control flow
QA : beginning flow for flood control
Target protection area
Catchment area
Dam Construction
Wadi channel improvement
Source: Sumi & Kantoush, 1st ISFF 2015, Kyoto, Japan.


Main dam
(Retention dam)
Detention dam
(Obstacle dam)
River Nile
Source: Sumi & Kantoush, 1st ISFF 2015, Kyoto, Japan.
LEGEND
Astudy Area
Naqra drain
Main Dam
Detention Dam
Artificial Lake
MD1
AD1
L1
L2
MD2
L3
W. EL.khuriet
Channel Improvement
Embankment


Wadi Flash Floods Management
Hard Structural Measures
Dams
Drainage Channels
Sediment Trap
Blockage Dams
Flood Retention Dams
Storage Dam and Groundwater recharge
Underground Dams
Embankments
US Dikes and Baffles
Soft Non-Structural Measures
Monitoring & Hydro-Met
Risk Assessment
Early Warning
Guidelines /Planning
Public Awareness
Rainfall and Water levels
Topographic and Sediment
Hydrological Modelling
Dissemination and communication
Atlas of Flood Maps
Ecological and Human
Development Projects
Water Harvesting
Road, Railway& Infrastructures
Agricultural
Industry and Tourism
Urban and Energy


Wadi
Mitigation and Flood Protection Measures
Flood Retention Basin of Ligistbach, Styria, Austria
Hochwasserrückhaltebecken in German
Upstream
Orden Dam Switzerland
Flood Retention Basins in Switzerland and Europe
Masudagawa dam, Shimane, Japan
Ryusuigata dam in Japan
Stilling Basin
Taylorsville Dam
Dry dam in USA
Reservoir
Embankment dam
Spillway
Bottom outlet
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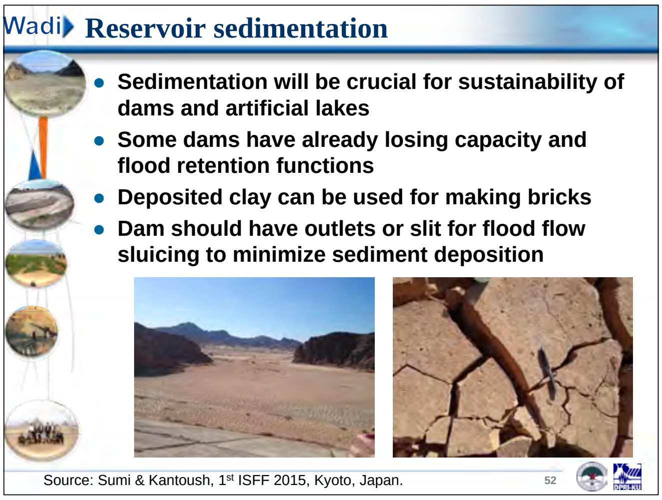
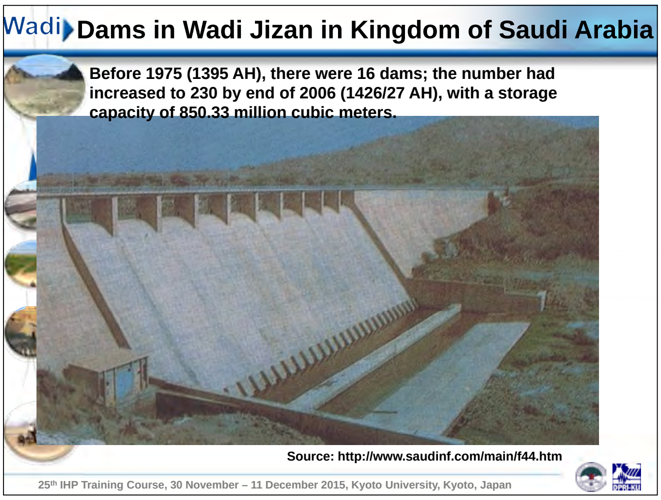

Wadi
Reservoir sedimentation
• Sedimentation will be crucial for sustainability of dams and artificial lakes
• Some dams have already losing capacity and flood retention functions
• Deposited clay can be used for making bricks
• Dam should have outlets or slit for flood flow sluicing to minimize sediment deposition
Source: Sumi & Kantoush, 1st ISFF 2015, Kyoto, Japan.
52


Wadi
Dams in Wadi Jizan in Kingdom of Saudi Arabia
Before 1975 (1395 AH), there were 16 dams; the number had increased to 230 by end of 2006 (1426/27 AH), with a storage capacity of 850.33 million cubic meters.
Source: http://www.saudinf.com/main/f44.htm
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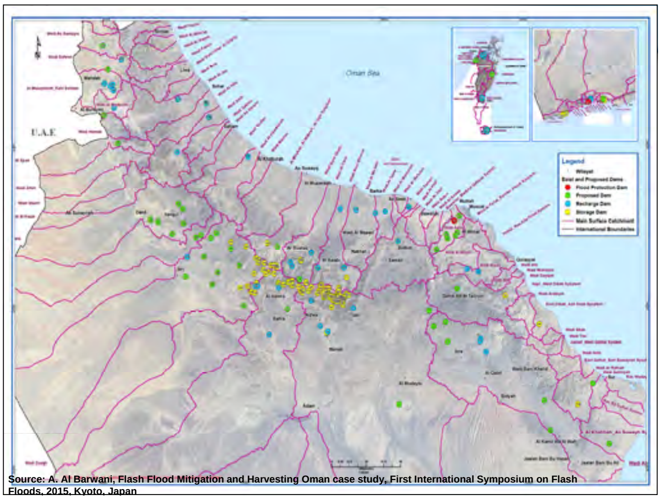
Najran Dam
Source: http://www.saudinf.com/main/f44.htm

Wadi ▸ Flood Mitigation Dams in Oman

- Fourteen flood mitigation dams, 44 groundwater recharge dams and more than 97 storage dams in various region and governorates of the Sultanate.
- Reservoir capacity of 1928 MCM where 57% of this water recharged the groundwater aquifers.

Source: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan



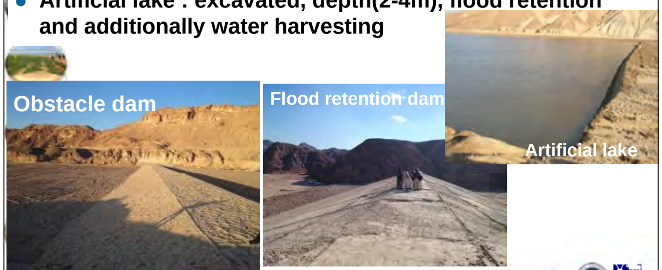
Source: A. Al Barwani, Flash Flood Mitigation and Harvesting Oman case study, First International Symposium on Flash Floods, 2015, Kyoto, Japan

Wadi ▸ Improvement of Drainage Systems

- The drainage system in many cities of the country are either poor managed or not available.
- Actions have been taken to clean the available drainage and open the wadi channels.
- The Muscat Municipality has just completed a master plan on drainage for the greater Muscat area.

Wadi ▸ Flood Mitigation and Harvesting in Egypt

- Obstacle dam : low dam(less than 4-6m), only for reducing flood impact(velocity reduction)
- Flood retention dam : middle height dam (around 10m), flood retention and additionally water harvesting
- Artificial lake : excavated, depth(2-4m), flood retention and additionally water harvesting

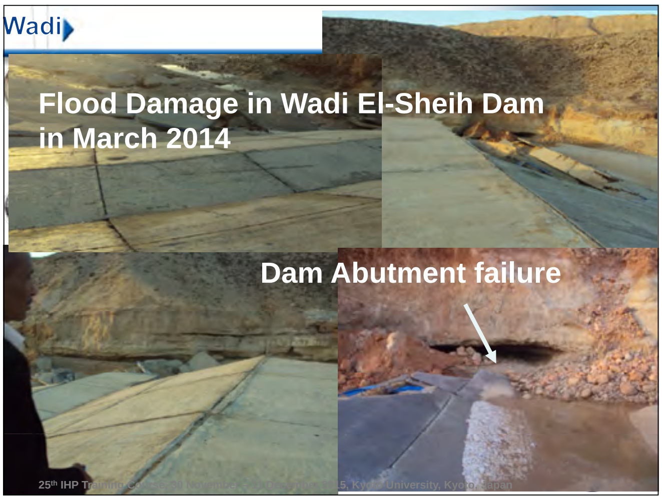


Wadi ▸ Development Projects

Agriculture in upper wadi system (W. Qena)

- Drip irrigation for watermelon by groundwater pumping

Wadi ▸



Wadi Design Guidelines

① Grouping Wadi based on Rainfall events patterns and Regional Importance

② Classify Importance of Wadi System based on Wadi Class

③ Select Design Return Period

④ Assess Past Records of Rainfall patterns

⑤ Maximum Extension Rate

⑥ Design Necessary by Using the Planned Rainfall

⑦ Simulated Hydrograph

⑧ Target Design Necessary Hydrograph

⑨ Propose Wadi Discharge Scenarios

Wadi Integrated Flash Floods Management "PARADIGM SHIFT"

Mitigation: Risk Reduction / Prevention
- Structural Measures (Dry dams, artificial lake, storage dams, blockage dams
- Environmental Management
- Comprehensive Land Use Plan
- No-structural measures
- Risk proofing
- Financial tools
- Hazard identification &
- Vulnerability Analysis
- Capacity Analysis

Socio-Economic and Funds
- Economic analysis
- Cost- Benefit analysis
- Public awareness
- Public commitment
- Community actions
- Education & Training
- Alternative development

Field Investigations
- Topographic
- Hydrological
- Geomorphological
- Society education for water harvesting and infrastructure maintenance

Global Warning System
- GIS and Remote sensing data
- Hazard map
- Hydrological modelling
- Set-up an early warning system
- Education and training: Society flood education
- community training about disaster and for evacuation

Comprehensive Vision for Wadi Flash Floods in Arab Region

Risk Assessment:
- Flood hazard map;
- Early warning system

Mitigation Strategies
- Design guideline;
- Hard measures;
- Implementation

Wadi Development and Water Resources Management
- Water harvesting;
- Road and industrial construction

Socio-Economic
- Training, meeting and workshop;
- Capacity building

Wadi Conclusions

- Wadi region's new residents and investors generally lack direct experience with Wadi flooding and its potential hazards, and many road constructions, power plants, tourist developments and solid waste dumps have been sited in wadis to take advantage of flat, easily-worked ground.
- Optimal development patterns would cluster development facilities around Wadi's and avoid building in wadis channel.
- Geomorphic features, precipitation and runoff analysis, digitized terrain data and hydrologic models can inform land-use suitability maps at scales appropriate to guide future development.
- There are few stations for monitoring and for some W. no data.
- Mitigation structural and no-structural measures with harvesting

Future Challenges

- Combinations of several mitigation measure as detention, storage artificial lake, and harvesting techniques;
- The key question is small distributed dams or medium size of large dams concept is better?
- Also for water harvesting by recharging groundwater, construction underground tank, and off-stream structures;
- Upgrading the current design guidelines, protection measures and construction methods;
- Establish detailed code for decision makers
- There is a need to enhance the knowledge of the local engineers, and decision makers by training, workshop, FF code and Atlas.
- Upgrading the design guidelines and construction method with natural materials and inexpensive efficient techniques;
- Warning system by hydrological modeling, monitoring, rainfall and meteorological stations covering Wadi's in target area;
- Finally the target project will be guideline for Wadi basin protection work, in Egypt, Saudi Arabia, Oman…arid region.

Lecture 10: Flood Risk Assessment toward Flood Risk Management

Hirokazu TATANO (*Disaster Prevention Research Institute, Kyoto University*)

In this class, basic procedure for flood risk management will be explained. Firstly, three components of flood risk are illustrated, i.e., hazard, exposure and vulnerability. To assess flood risk, not only hazard analysis but also exposure and vulnerability assessment are needed. Hazard analysis is conducted to relate frequency and magnitude. The magnitude can be enumerated as heights of water, flow volumes and/or velocity in the focused river or/and floodplain. To estimate flood damage, the magnitude of flood should be transformed to loss(es). To do this, we need to know population and assets distribution over the space. The procedure to estimate spatial distribution of the population and assets which threatened by floods are called exposure analysis. Simultaneously, we need to assess the vulnerability of the exposures. In the narrow sense, Vulnerability of exposure is defined as probability of occurrence of loss conditional on the magnitude of a flood. A typical representation of vulnerability is a loss function which relates water depth to loss ratio of property. Finally, by combing with the analyses of hazard, exposure and vulnerability, we can obtain flood risk distribution over the space, i.e., the relationship between flood frequency and loss(es), which can be represented as exceedance probability of economic loss caused by floods.

After explaining the procedure, students will be asked to design a flood risk assessment procedure for their own country, and develop questionnaire survey after a flood event to develop data needed for the flood risk assessment. At the end of class, group discussion will be conducted to find the way to improve flood risk assessment to be utilized for effective flood risk management for their own countries.

Lecture 11: Integrated sediment and floating debris management

Tetsuya SUMI (*Professor, Disaster Prevention Research Institute, Kyoto University*)

Abstract:

Reservoir sedimentation is one of the most crucial issues for reservoir sustainability in the world. In many countries, various countermeasures have been implemented to decrease sediment accumulation and loss of storage capacity. They are (i) reduce sediment inflow, (ii) route sediments and (iii) sediment removal. In order to select suitable sediment management methodologies, combination of flow and sediment release should be appropriately designed to meet demands of various functions based on data of hydrology, water quality, river morphology and ecosystem, etc. Furthermore, the integrated sediment management approach should be considered in a sediment routing system which covers not only a river basin but also coastal areas. Among several updated methodologies, effective and ecofriendly sediment flushing, bypassing and replenishment techniques have been intensively developing in Japan. Even though target volume of sediment is very much different between these approaches, positive influences should be addressed from both point of views of reservoir sustainability and downstream environmental improvement.

Not only sediment, we should consider intensive yield and management of floating woody debris from upstream catchment. In recent years, localized heavy rain tends to increase. These rainfall events have caused an increase in deep landslides and severe riverbank erosions associated with the increase of large amount of floating debris which flows into the downstream dam reservoirs. They are causing adverse effects such as increasing the removal cost and causing many troubles for dam operation safely. On the other hand, floating debris captured by the dam can be pointed out that they are prevented the risk of expanding the flood risk by clogging at the bridges downstream river. Recently, positive effects on river environment have been addressed. Floating woody debris has a set of ecological roles such as trophic sources in the riparian and coastal ecosystems, and provision of habitats for various aquatic organisms. In consideration with the ecological functions, some amount of woody debris should be allowed to retain on the riverbed in river management.

Nowadays, it is required to consider comprehensive management both on sediment and floating debris in a river basin.

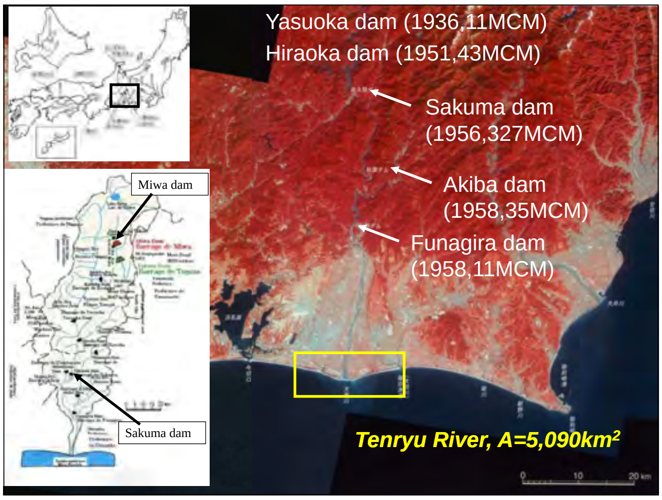
The 25th UNESCO - IHP Training Course on
Risk Management of Water-related Disasters under
Changing Climate, Nov.30-Dec.11, 2015.

Integrated sediment and floating debris management

Tetsuya SUMI
Disaster Prevention Research Institute, Kyoto University

Flushing, Dashidaira dam

Sediment Replenishment, Nunome dam



Reservoir sedimentation in Sakuma dam

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

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

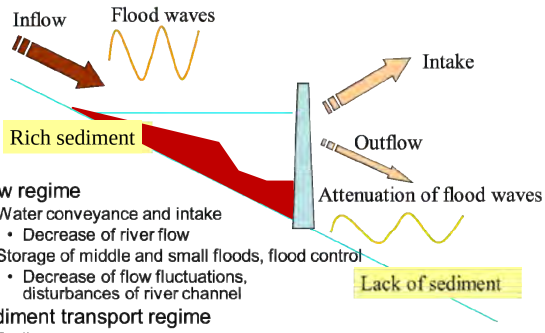
Sedimentation in reservoir
- Reduction of storage capacity

Downstream geomorphology
- Bed armouring and degradation

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

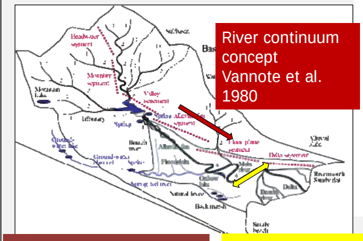
Downstream ecosystem
- Reduced ecosystem health (Biodiversity, Quality and quantity of food resources, Water quality)

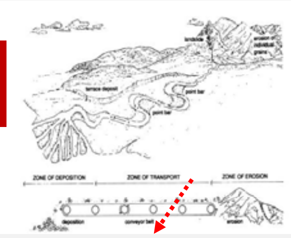
Change of flow and sediment transport regimes



- 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)





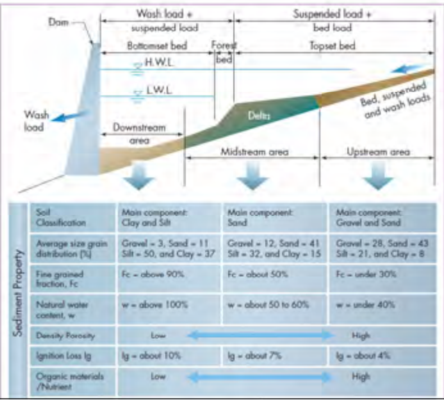
Natural flow regime
Poff et al. 1997

Flood pulse concept
Junk et al. 1989

River channel as conveyor belt for sediment (Kondolf 1994)

Fluvial river systems composed of 6 segments (Takemon 2010)

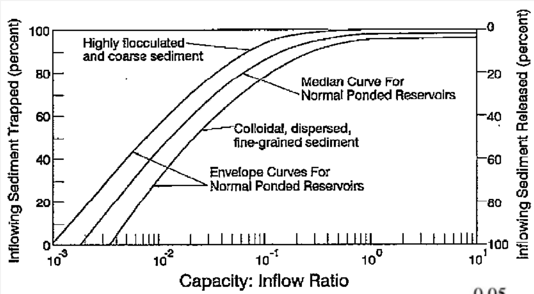
Quality of sediment in reservoirs



Soil Classification	Main component: Clay and Silt	Main component: Sand	Main component: Gravel and Sand
Average size grain distribution (%)	Gravel = 3, Sand = 11 Silt = 50, and Clay = 37	Gravel = 12, Sand = 41 Silt = 32, and Clay = 15	Gravel = 28, Sand = 43 Silt = 21, and Clay = 8
Fine grained fraction, Fc	Fc = above 90%	Fc = about 50%	Fc = under 30%
Natural water content, w	w = above 100%	w = about 50 to 60%	w = under 40%
Density Porosity	Low	↔	High
Ignition Loss Ig	Ig = about 10%	Ig = about 7%	Ig = about 4%
Organic materials /Nutrient	Low	↔	High

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

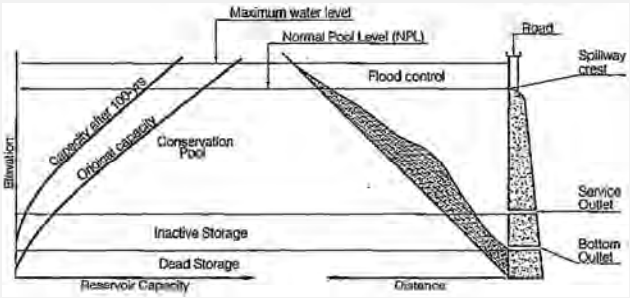
Brune curve (1953) Sediment trapping efficiency of reservoirs



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

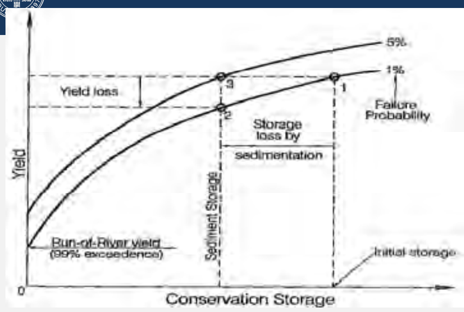
Source: Reservoir Sedimentation handbook, Morris and Fan(1996)

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



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

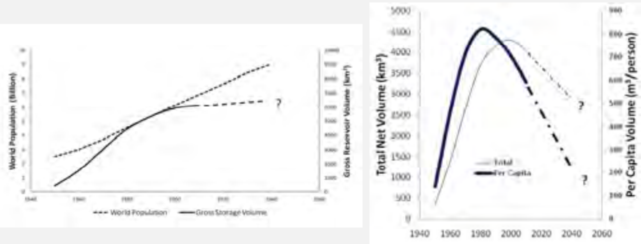
Reservoir Yield change by reservoir sedimentation



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

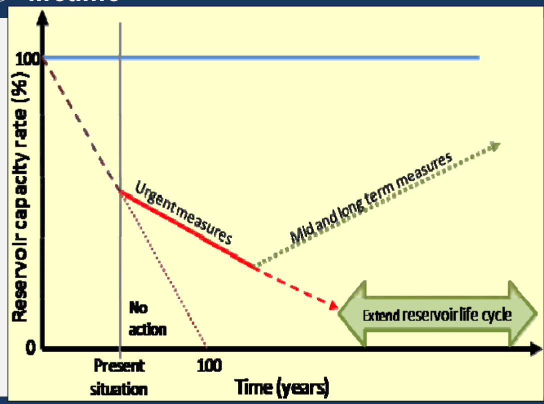
General shape of a reservoir storage-yield curve, in which yield asymptotically approaches the mean watershed yield, less evaporative and seepage losses, as storage becomes very large. Two yield curves are shown for different levels of service. The impact of sediment accumulation in the conservation 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

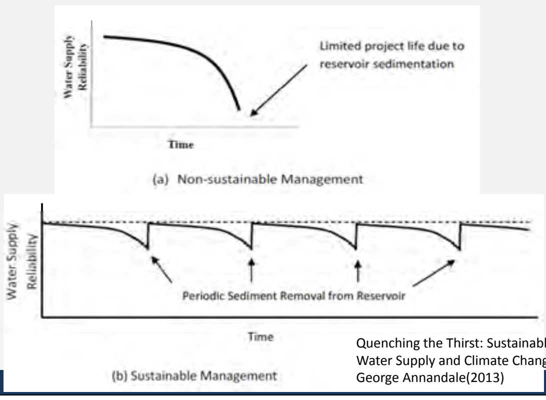


Source: T.Sumi and S.A. Kantoush, ICOLD Annual Meeting, Luzern 2011

Conventional design life approach and Life cycle management approach

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

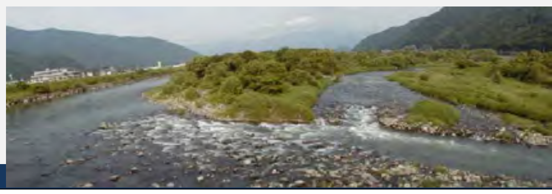
Water supply reliability based on (a) the design life approach and (b) the life cycle management approach

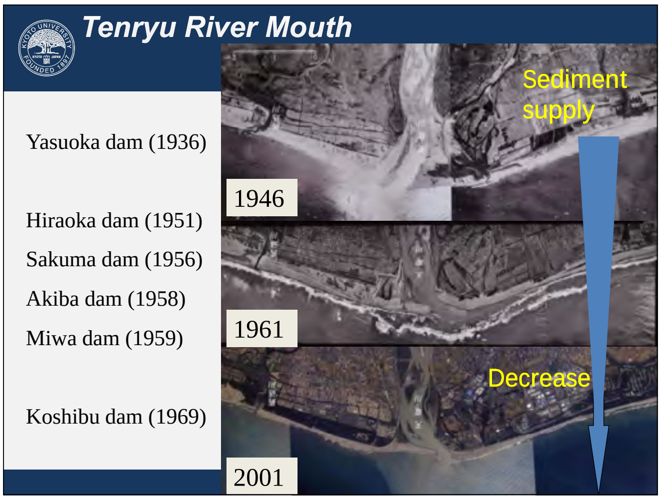


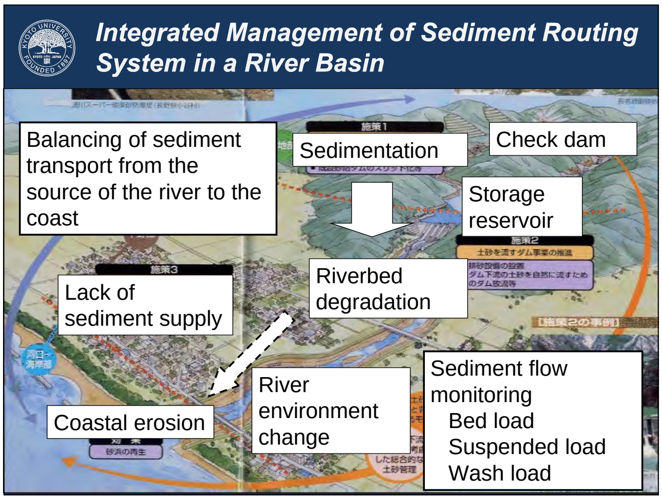
Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

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**

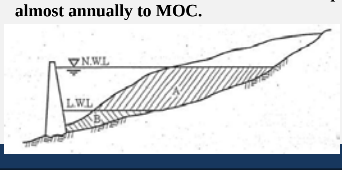






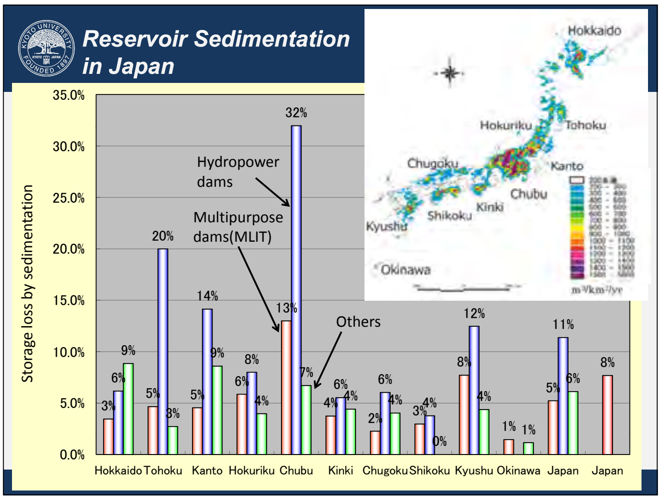
History of guidelines on reservoir sedimentation design in Japan

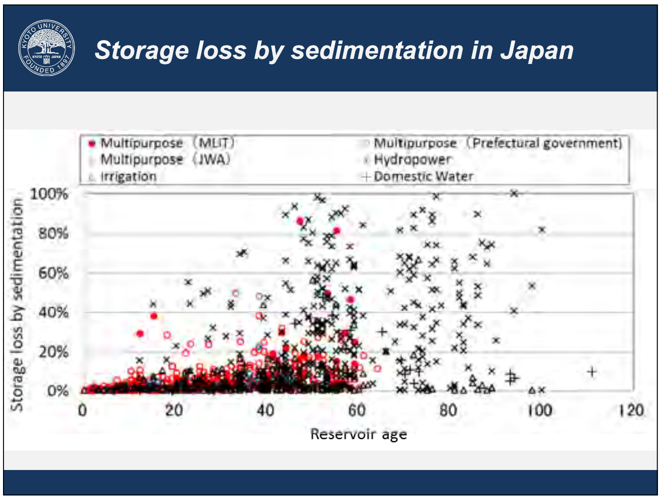
- **1958, Technical Criteria for River Works, Ministry of Construction**
  - Necessary volume for reservoir sedimentation is 100 years
- **1966, Reservoir sedimentation database guideline, MOC**
  - To check riverbed aggradation in order to prevent flooding risks upstream of reservoirs caused by sedimentation
- **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.

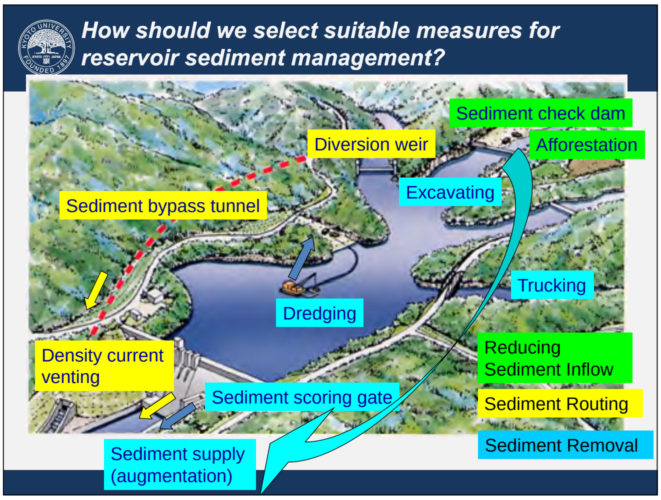


In Japan, 2730 dams (>15m high) with 23 BCM capacity.

Target dams : 971 dams of 18.2 BCM capacity



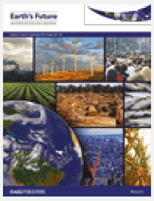




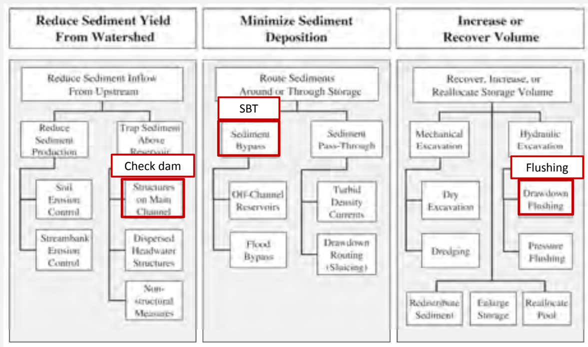
Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents

Earth's Future, Volume 2, Issue 5, pages 256–280, May 2014

- **G. Mathias Kondolf, Yongxuan Gao, George W. Annandale, Gregory L. Morris, Enhui Jiang, Junhua Zhang, Yongtao Cao, Paul Carlin, Kaidao Fu, Qingchao Guo, Rollin Hotchkiss, Christophe Peteuil, Tetsuya Sumi, Hsiao-WenWang, ZhongmeiWang, ZhilinWei, Baosheng Wu, CaipingWu, and Chih Ted Yang**



Reservoir Sedimentation Management Options



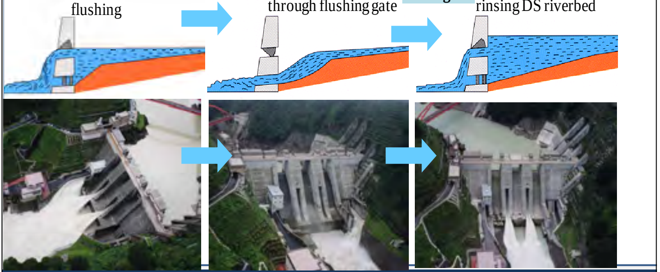
Kondolf et al. 2014

Sediment Flushing in the Kurobe River

Draw down Stage Reduction of water level, to gradual and rapid emptying of the reservoir, to initiate flushing

Erosion flushing Stage The riverine flow formed with high velocities scour fine sediment and transport through flushing gate

Refill and restore water Stage Closing the bottom outlet to refill the reservoir. During specific period incoming water is discharged for rinsing DS riverbed

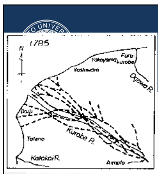


Sediment flushing dams in the World

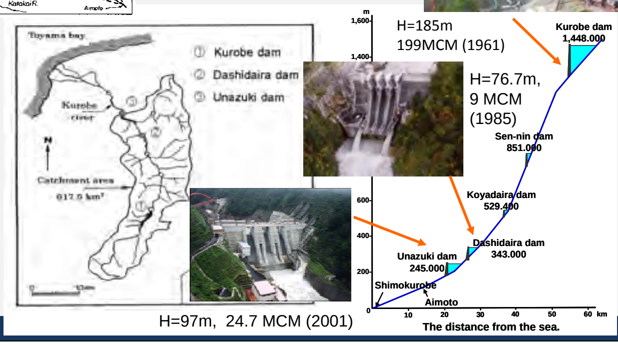
Name of Dam	Country	Dam completed	Dam Height (m)	Initial Storage Capacity (CAP) (million m^3)	Mean Annual Sediment Inflow (MAS) (million m^3)[1)]	1／(Mean Annual Runoff) (=CAP/MAR)	Reservoir Life (=CAP/MAS)	Average Flushing Discharge (m3/s)	Flushing Duration (hrs)	Flushing Frequency (1/ yr)
Dashidaira	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

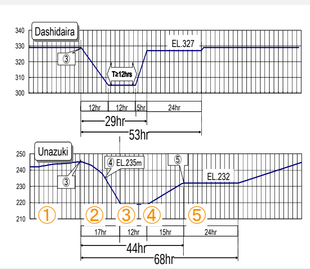
Kurobe River Basin

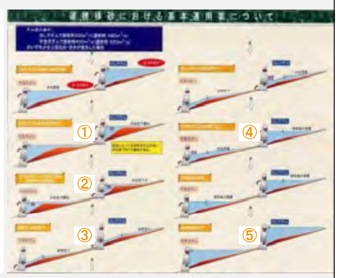


Catchment area= 682 km^2,
River length= 85 km



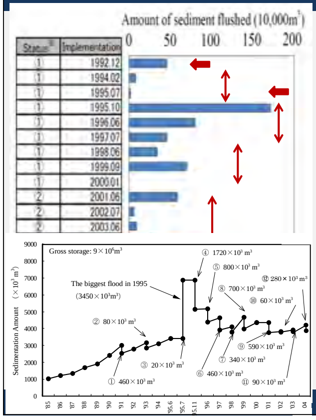
Coordinated sediment flushing in the Kurobe river





Coordinated water and sediment management is very much important. Rainy season, June-July, and natural flood timing is suitable for flushing.

History of sediment flushing in the Kurobe River

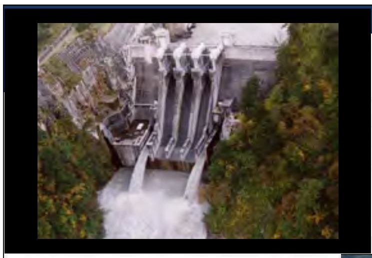


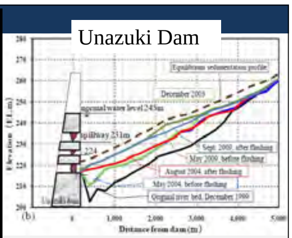
- Dashidaira dam 1985
- First flushing in Dec. 1991
  Severe water quality problem
- Tentatively stopped
- Sediment Flushing Evaluation Committee 1992
- Extreme Flood 1995
- Restart of flushing 1995, 96, 97
- After 1998, general flushing operation started
- Unazuki dam 2001
- Coordinated flushing started 2001

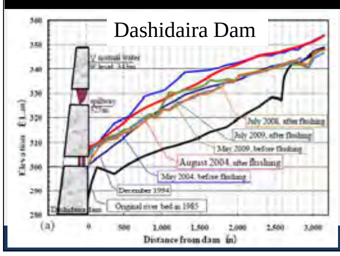
History Operation rules of sediment flushing in the Kurobe river

- **Sediment flushing operation rule from 2001.**

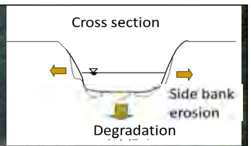
Item	Sediment flushing		Sediment sluicing	
	Dashidaira dam	Unazuki dam	Dashidaira dam	Unazuki dam
(1) Period	･The first flood whenever either of Dashidaira or Unazuki exceed the flood levels of 300m³/s or 400m³/s from June to August.		･Whenever either of Dashidaira or Unazuki exceed the flood levels of 480m³/s or 650m³/s from June to August after implementing the sediment flushing.	
(2) Amount of sediment flushed	･The exceed sediment for keeping the stable longitudinal profile.		･Transporting the incoming sediment from upstream to downstream under the flood flow.	
(3) Measure	･Gravity flow		the same as on the left	
(4) Hour	･The hour required for flushing the exceed sediment for keeping the stable longitudinal profile.		･Within implementing gravity flow at Unazuki.	･Within 12 hours after the gravity flow.
(5) Post-treatment after flushing & sluicing operation	･The withdrawal for power generation is stopped for 24 hours after sediment flushing: discharge the entire flow entering the dam downstream.	･Entire flow is discharged from the dam and Unazuki power station for 24 hours after sediment flushing.	･Flush at the dams and the power station located on the downstream for 12 hours after sediment sluicing.	







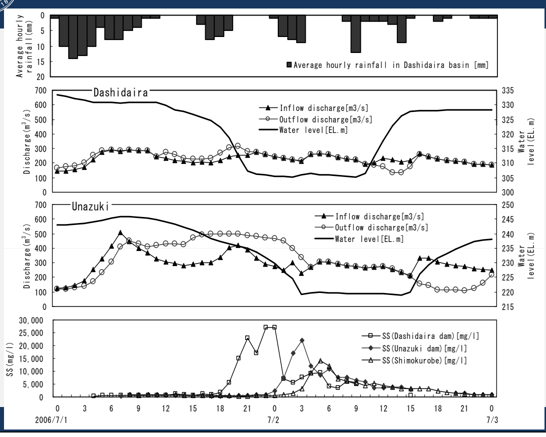
Challenges of sediment flushing



- **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.

Coordinated sediment flushing operation in 2006



Actual sediment flushing and sluicing operations at the Dashidaira Dam

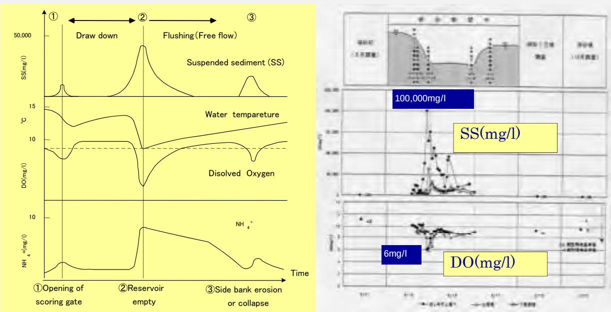
	Maximum Discharge Inflow (m^3/s)	Average Discharge Inflow (m^3/s)	Flushing Volume (10^3 m^3)	Maximum SS (mg/l)	Average SS (mg/l)
2001 Flushing	333	277	590	90,000	15,000
2001 Sluicing	491	273		29,000	6,700
2002 Flushing	362	215	60	22,000	4,500
2003 Flushing	777	217	90	69,000	7,100
2004 Flushing	356	229	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

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 rising and DO dropping
    - Establish minimizing measures（ex. Sediment Discharge Rule）
  - **Re-deposition of fine sediment on the river and the coastal areas and those impacts on the aquatic ecosystem**
    - Estimate the influences of fine sediment on river channel, mouth and coastal areas
    - Establish minimizing measures（ex. Rinsing Flow Operation）
- **Evaluate positive impacts correctly**
  - **Contribution to the comprehensive management of the Sediment Routing System**
  - **Restoration of supplying nutrients and other materials to the river channel and the sea**

SS and DO change during sediment flushing in 2000 (Dashidaira dam)



Measurement values of DO and SS during flushing

Sediment flushing		Amount of Dashidaira sediment flushing	DO（mg/l）（Minimum value）			SS（mg/l）（Maximum value）		
Year	Event		Dashidaira	Unazuki	Shimo-kurobe	Dashidaira	Unazuki	Shimo-kurobe
Jul-95	Flood	–	–	11.3	10.5	–	3,700	1,800
Oct-95	Flushing	1.72MCM	8.8	9.7	8.9	103,500	29,400	26,000
Jun-96	Flushing	0.8MCM	10.7	10.3	9.8	56,800	9,470	6,770
Jul-97	Flushing	0.46MCM	9.8	9.2	9.3	93,200	28,900	4,330
Jun-98	Flushing	0.34MCM	8.2	7.0	7.3	44,700	9,400	6,750
Jul-98	Flood	–	–	10.5	9.5	–	6,090	5,260
Sep-99	Flushing	0.7MCM	6.0	5.8	6.5	161,000	52,100	25,700
Jun-01	Coordinated flushing	0.59MCM	7.2	11.4	10.2	90,000	2,500	1,500
Jul-01	Coordinated sluicing	–	11.1	10.6	9.6	29,000	3,700	2,200
Jul-02	Coordinated flushing	0.06MCM	9.5	10.5	9.5	22,000	5,400	2,800
Jun-03	Coordinated flushing	0.09MCM	11.8	11.3	9.6	69,000	17,000	10,000
Jul-04	Coordinated flushing	0.28MCM	9.3	10.2	9.8	42,000	6,800	11,000
Jul-04	Flood	–	10.8	11.2	10.3	30,000	12,000	14,000
Jul-04	Coordinated sluicing	–	10.6	11.2	9.6	16,000	17,000	21,000

⇒ Manual sampling in every one hour
Continuous monitoring method for DO and SS is necessary

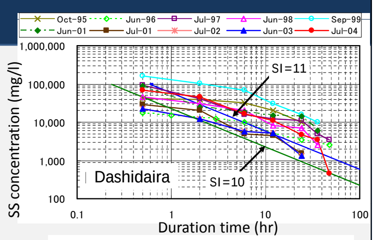
'Ayu (鮎)', (Sweet fish, 香魚, 銀魚: Plecoglossus altivelis) Typical fish in Japanese rivers

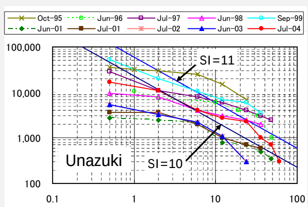
Ca. 20cm

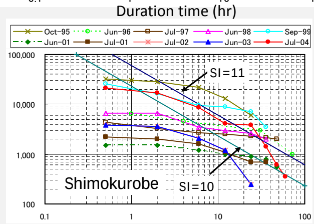
SS-Duration curve of flushing

Stress Index (Newcombe and MacDonald 1991; Newcombe and Jensen 1996)

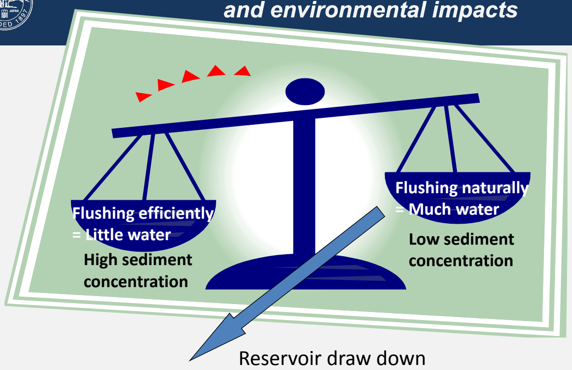
SI＝log e（SS concentration (mg/l) × Duration time (hr)）







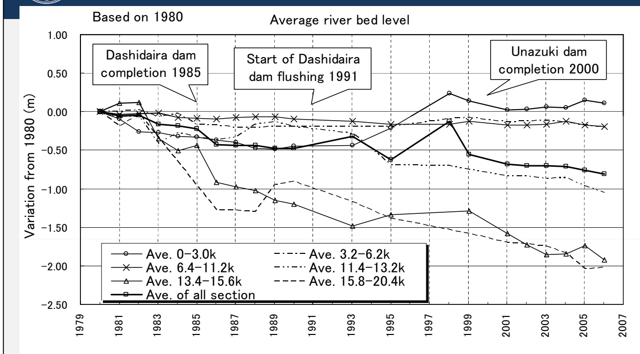
Balancing of Flushing efficiency and environmental impacts



Water use

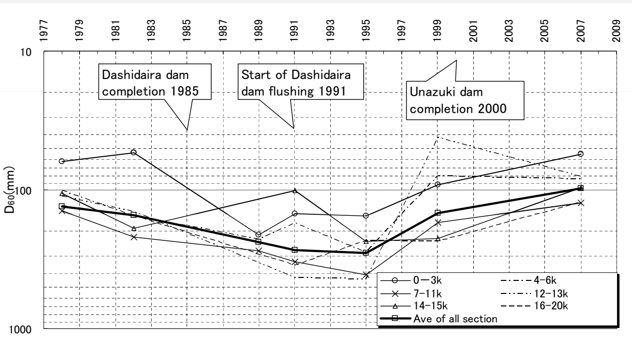
Reservoir draw down
Enough flushing discharge water
Rinsing discharge after flushing, etc.

Riverbed elevation change from 1980



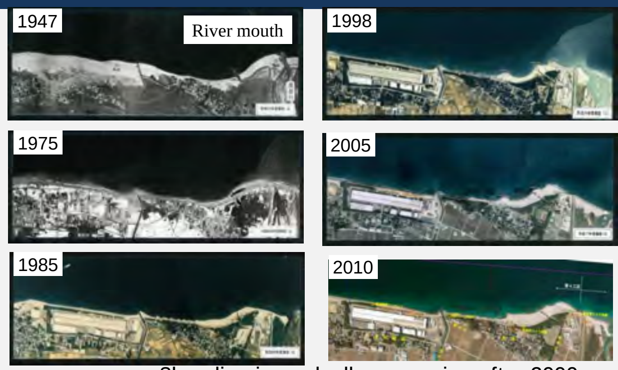
River channel bed is gradually recovering in the river mouth area.

Grain size distribution change from 1980



Downstream river bed is receiving mainly sandy materials.

Shoreline change of the Kurobe river mouth area



Shoreline is gradually recovering after 2000.

Source: MLIT

Lessons learned in the Kurobe River

1) Periodical sediment flushing is important.

In the Kurobe River, both sediment flushing and sluicing are performed approximately once a year. It reduces flushing sediment volume in one time.

2) Selecting suitable timing can reduce is important.

Appropriate sediment flushing seasons (June to August), and times when the natural water flow rate exceeds a certain level, 300 (250 in some special case) m³/s or more for sediment flushing, and 480 m³/s or more for sediment sluicing.

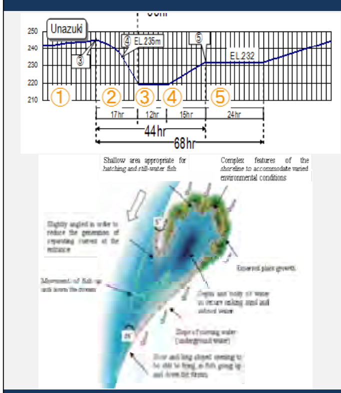
3) Flushing efficiency at Dashidaira Dam is about 0.01 to 0.03.

4) Discharged SS at the Dashidaira Dam during a sediment flushing operation was 8,000 mg/l on average and 40,000 mg/l on the peak.

5) Dashidaira Dam is currently at an equilibrium state by passing of approximately 1 MCM sediment annually.

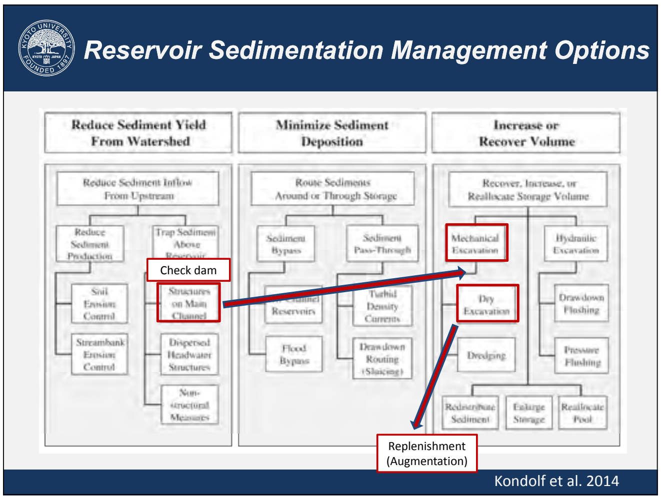
6) By suppling sediment, downstream riverbed aggradation and bed armoring as well as coastal erosion have been recovered gradually.

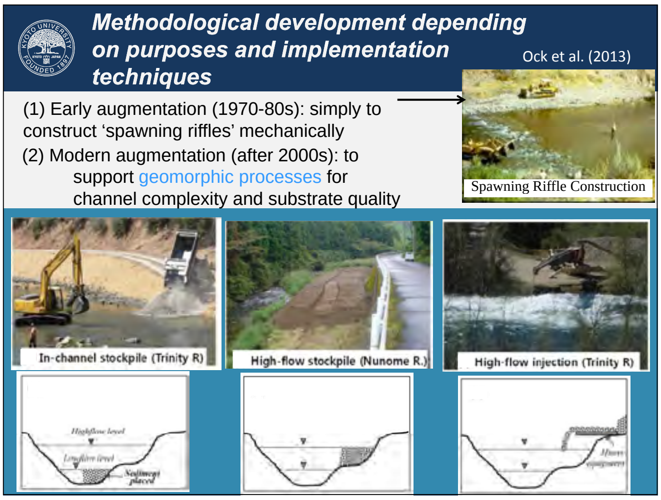
Methodologies to reducing risks in downstream river channel



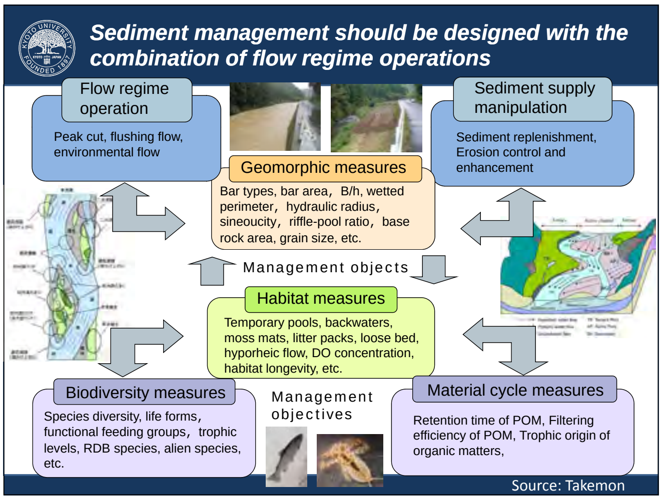
7) In order to prevent accumulation of fine sediment on the downstream gravel bars, the rinsing discharge from both dams is performed after recovering reservoir water revel.

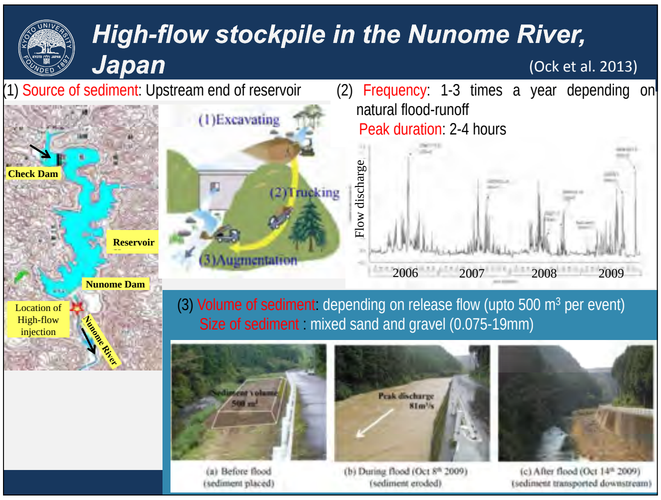
8) Evacuation channels have been prepared as shelters for many species of fish, such as Ayu, during high turbidity in the main stem due to sediment flushing.

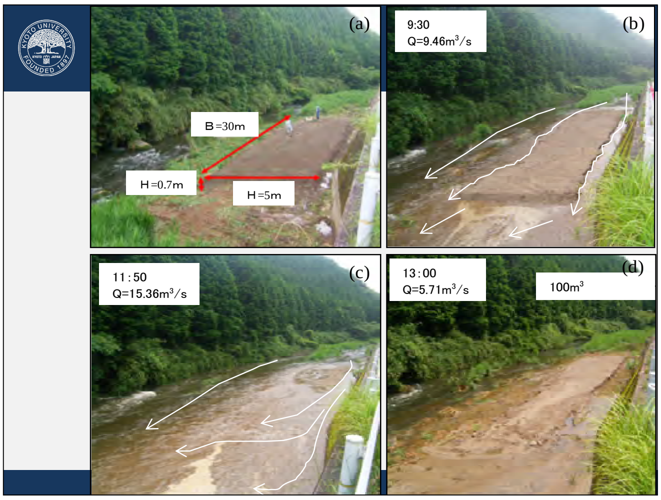

Reservoir Sedimentation Management Options
Reduce Sediment Yield From Watershed
Minimize Sediment Deposition
Increase or Recover Volume
Reduce Sediment Inflow From Upstream
Route Sediments Around or Through Storage
Recover, Increase, or Reallocate Storage Volume
Reduce Sediment Production
Trap Sediment Above Reservoir
Sediment Bypass
Sediment Pass-Through
Mechanical Excavation
Hydraulic Excavation
Check dam
Soil Erosion Control
Structures on Main Channel
Offchannel Reservoirs
Turbid Density Currents
Dry Excavation
Drawdown Flushing
Streambank Erosion Control
Dispersed Headwater Structures
Flood Bypass
Drawdown Routing (Sluicing)
Dredging
Pressure Flushing
Non-structural Measures
Redistribute Sediment
Enlarge Storage
Reallocate Pool
Replenishment (Augmentation)
Kondolf et al. 2014


Methodological development depending on purposes and implementation techniques
Ock et al. (2013)
(1) Early augmentation (1970-80s): simply to construct 'spawning riffles' mechanically
(2) Modern augmentation (after 2000s): to support geomorphic processes for channel complexity and substrate quality
Spawning Riffle Construction
In-channel stockpile (Trinity R)
High-flow stockpile (Nunome R.)
High-flow injection (Trinity R)
Highflow level
Lowflow level
Sediment placed


Sediment replenishment (augmentation) dams in Japan
Futase Dam
Miharu Dam
Koshibu Dam
Nagayasuguchi Dam
Nibutani
Aimata
Miharu
Agigawa
Tedorigawa
Managawa
Nunome
Hitokura
Murou
Haji
Yasaka
Kawamata
Kawaji
Shimokubo
Urayama
Futase
Sagami
Miyagase
Miho
Koshibu
Hinachi
Hachisu
Nagayasuguchi
Tomisato
Nagashima
Akiha
Yahagi
Sakurai et al. (2013)


Sediment management should be designed with the combination of flow regime operations
Flow regime operation
Peak cut, flushing flow, environmental flow
Sediment supply manipulation
Sediment replenishment, Erosion control and enhancement
Geomorphic measures
Bar types, bar area, B/h, wetted perimeter, hydraulic radius, sineoucity, riffle-pool ratio, base rock area, grain size, etc.
Management objects
Habitat measures
Temporary pools, backwaters, moss mats, litter packs, loose bed, hyporheic flow, DO concentration, habitat longevity, etc.
Biodiversity measures
Species diversity, life forms, functional feeding groups, trophic levels, RDB species, alien species, etc.
Management objectives
Material cycle measures
Retention time of POM, Filtering efficiency of POM, Trophic origin of organic matters,
Source: Takemon


High-flow stockpile in the Nunome River, Japan
(Ock et al. 2013)
(1) Source of sediment: Upstream end of reservoir
(2) Frequency: 1-3 times a year depending on natural flood-runoff
Peak duration: 2-4 hours
Check Dam
Reservoir
Nunome Dam
Location of High-flow injection
Nunome River
(1)Excavating
(2)Trucking
(3)Augmentation
Flow discharge
2006
2007
2008
2009
(3) Volume of sediment: depending on release flow (upto 500 m³ per event)
Size of sediment : mixed sand and gravel (0.075-19mm)
(a) Before flood (sediment placed)
(b) During flood (Oct 8th 2009) (sediment eroded)
(c) After flood (Oct 14th 2009) (sediment transported downstream)

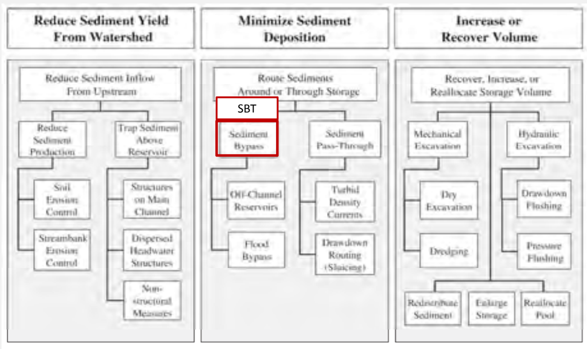

(a)
B=30m
H=0.7m
H=5m
9:30
Q=9.46m³/s
(b)
11:50
Q=15.36m³/s
(c)
13:00
Q=5.71m³/s
100m³
(d)

Summary of sediment replenishment (or augmentation) in Japan

1) In order to reduce sediment inflow, mainly coarse bed load sediment is trapped by a low check dam constructed at the end of reservoir and regularly excavated mechanically. Recently, sediment replenishment has been carried out more than 20 dams in Japan.
2) Percentages of sediment replenishment are very limited, ranging between 0.1 to 10 % of annual reservoir sedimentation since these projects are still in trial stage.
3) Sediment replenishment volume and grain size are recognized as key factors for a successful management in the river basin to create and maintain physical habitats, aquatic and riparian ecosystems.
4) Creating new habitats for spawning and other fish life stages are new challenging topics in Japan. Long riffles supplemented by high-flow stockpile could function as an important natural filter for removing reservoir plankton, subsequently contributed to macroinvertebrates' richness and functional feeding group.

55

Reservoir Sedimentation Management Options

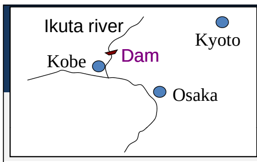


Kondolf et al. 2014

Characteristics of successful sediment bypass tunnels in Japan and Switzerland

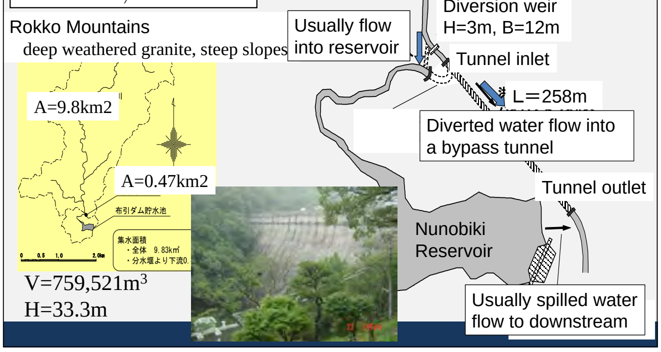
Name	Country	Completion	Cross section	Diameter B×H(m)	Length (m)	Slope (%)	Design Discharge	Design Flood Velocity (m/s)	Design Sediment Size (mm) d_m/d_{90}	Operation (Day／yr)
Nunobiki Gohonmatsu	Japan	1908	Hood	2.9×2.9	258	1.3	39	7		
Asahi	Japan	1998	Hood	3.8×3.8	2,350	2.9	140	12	50/300	13
Miwa	Japan	2004	Horse shoe	2r = 7.8	4,300	1	300	10	WL only	2～3
Matsukawa	Japan	UC	Hood	5.2×5.2	1,417	4	200	15		-
Koshibu	Japan	UC	Horse shoe	2r = 7.9	3,982	2	370	9	(5/30)	-
Pfaffensprung	Swiss	1922	Horse shoe	A =21.0m²	280	3	220	14	250/2700	ca.200
Runcahez	Swiss	1961	Horse shoe	3.8×4.5	572	1.4	110	9	230/500	4
Palagnedra	Swiss	1974	Horse shoe	2r = 6.2	1,800	2	110	13	74/160	2～5
Egschi	Swiss	1976	Circle	r = 2.8	360	2.6	74	10	100/300	10
Rempen	Swiss	1983	Horse shoe	3.5×3.3	450	4	80	12	60/200	1～5
Solis	Swiss	2012	Horse shoe	4.4×4.68	973	1.8	170	11	60/150	1～10

Outline of Nunobiki Dam

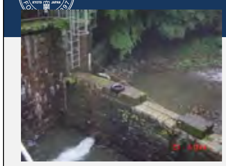


Purpose:
Drinking water supply

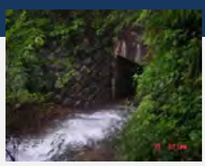
Dam: 1900
Bypass Tunnel: 1908



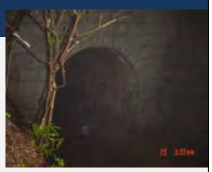
Sediment Bypass Tunnel of Nunobiki dam



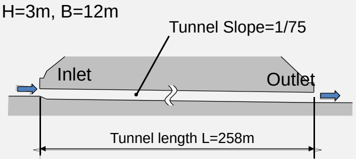
Diversion weir
H=3m, B=12m



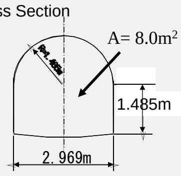
Inlet



Outlet



Tunnel discharge：Q＝1.11～39m3/s



※ Inlet and Outlet sections are covered with natural granite stones, while other sections have no lining materials.

Evaluation of sediment bypass effects

- Daily sediment inflow in ca.100 yrs can be calculated by (Ashida and Okumura 1977).

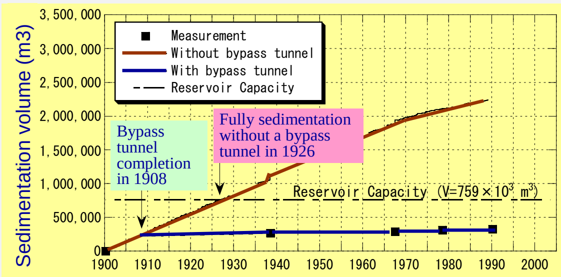
$$D = \alpha (A \cdot R \cdot I)^{\beta}$$

where, D : sediment yield during a flood event(m3), A : catchment area(km2), R : daily rainfall(mm), I : average riverbed slope in 200 m upstream from the calculating point, α , β : constants.

- A_1=9.83km² : before a sediment bypass , A_2 = 0.47km² : after a bypass
- R : actual record 1900-2000, I = 0.044 by the geographical survey
- β is usually fixed as 2.0 (Ashida and Okumura 1977), α is estimated as 6.0 by real accumulated sediment volumes.

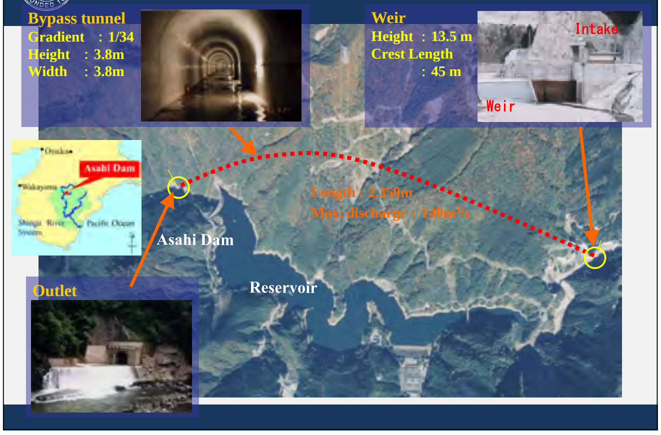
	Before a bypass completion	After a bypass completion
Mean annual sediment inflow	30,000 m3/yr	1,500 m3/yr
Reservoir life	ca.30 yrs	ca.500 yrs

Comparison of sedimentation progress with and without a bypass tunnel

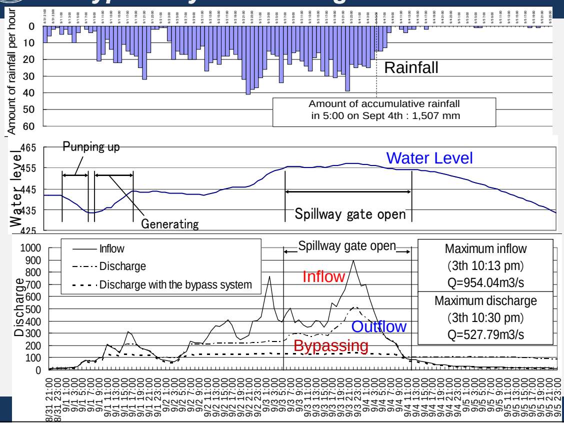


	Before a bypass completion	After a bypass completion
Mean annual sediment inflow	30,000 m3/yr	1,500 m3/yr
Reservoir life	ca.30 yrs	ca.500 yrs

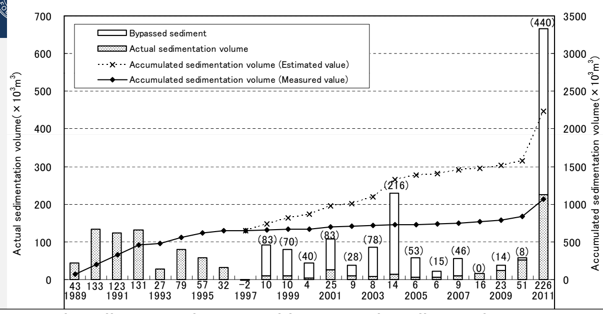
Sediment bypass system at Asahi Dam



Operational Results of Asahi Dam & Bypass System during the Flood

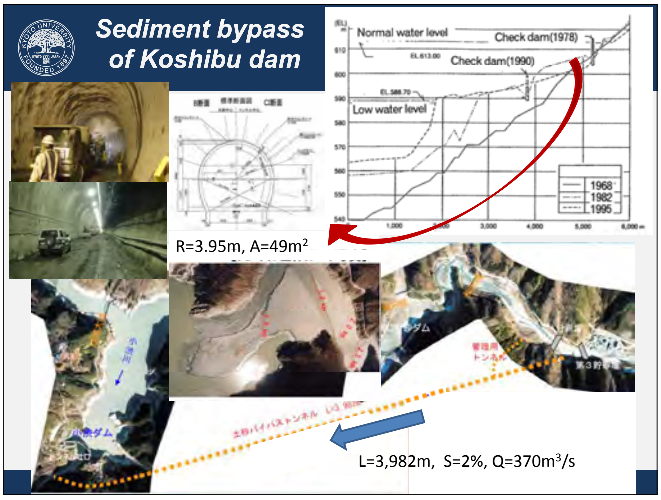


Reduction of Sediment Volume in Reservoir

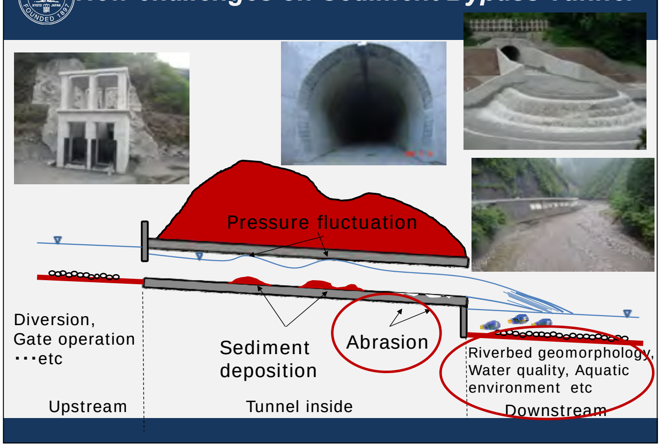


- Annual sediment volume and bypassed sediment in 2011 were the largest volume since the start of the bypass operation.
- Without bypass system, about 74% of sediment volume would have been accumulated in the reservoir. This sediment have now positive effects on downstream river environment.

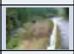
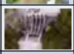
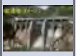
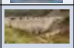
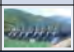
Sediment bypass of Koshibu dam



New challenges on Sediment Bypass Tunnel

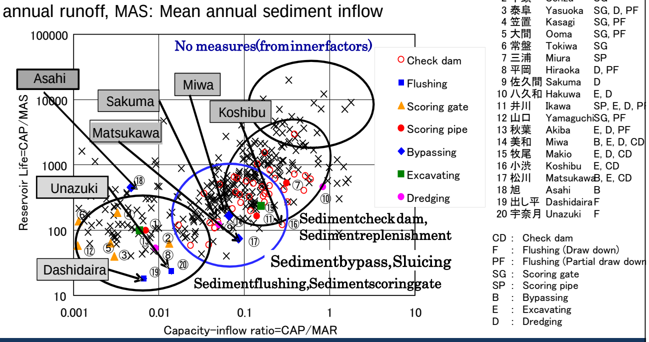


Sediment management options and sediment passing functions

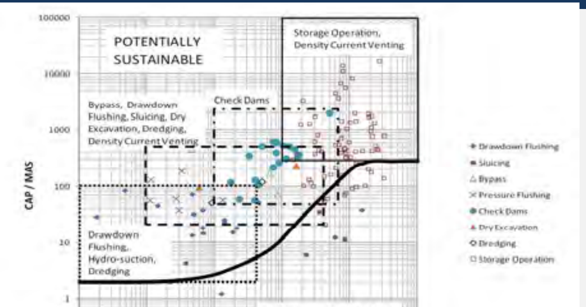
Classification of options		Normal Impound-ment	Draw down level	Frequency	Sediment passing	
					Coarse	Fine
Normal Impoundment		○	None	None	None	Small
Sediment Augmentation		○	None	Several times/year	Partially (Concentrated)	Partially (Concentrated)
Sediment Flushing		○	All (Empty)	Once/yr	All (Concentrated)	All (Concentrated)
Sediment Sluicing		○	Half	Several times/yr	Almost all (Partially concentrated)	All (Distributed)
Sediment Bypassing		○	None	Several times/yr	Almost all (Distributed)	Partially (Distributed)
Dry dam		None	All (Empty)	―	Almost all (Naturally)	All (Naturally)
Decommiss-ioning		None	―	―	All	All

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



Reservoir sedimentation management approaches (Basson, 2009 and Sumi, 2003)

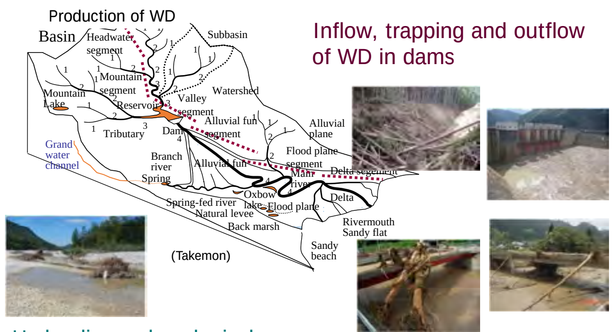


Quenching the Thirst: Sustainable Water Supply and Climate Change, George Annandale(2013)

Conclusions

- **Sediment management is important both for reservoir and river basin sustainability.**
- **Sediment supply downstream will be beneficial to improve river geomorphology by creating suitable habitat, and maintaining biodiversity and suitable material cycles.**
- **Flushing, sluicing, bypassing and replenishment (augmentation) are attractive options for reservoir sediment management.**
- **These options should be appropriately selected based on reservoir size(CAP) vs annual sediment(MAS) and water inflows(MAR).**
- **In order to maximize the benefit, incorporating with flushing flows (magnitude, frequency and timing), determining quantity (amount added) and quality (grain size and source materials) of coarse sediment are key factors.**

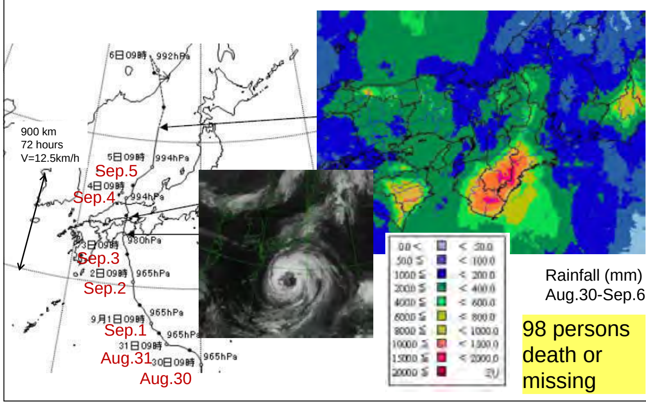
Comprehensive management of floating woody debris in a river basin



Hydraulics and ecological functions of WD in river channels

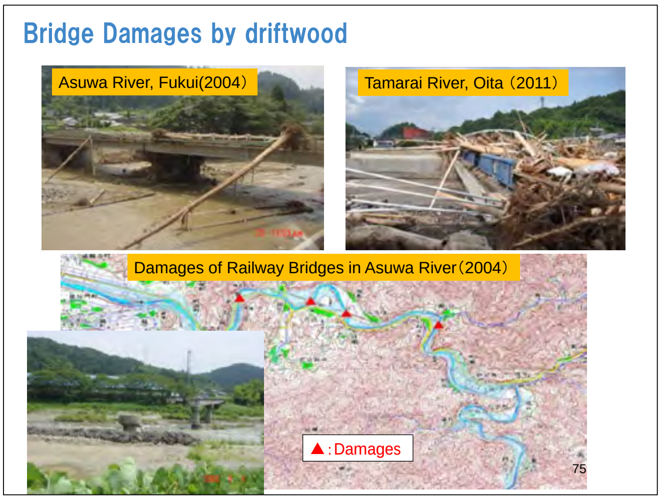
Transport and depositing mechanism of WD in river channels

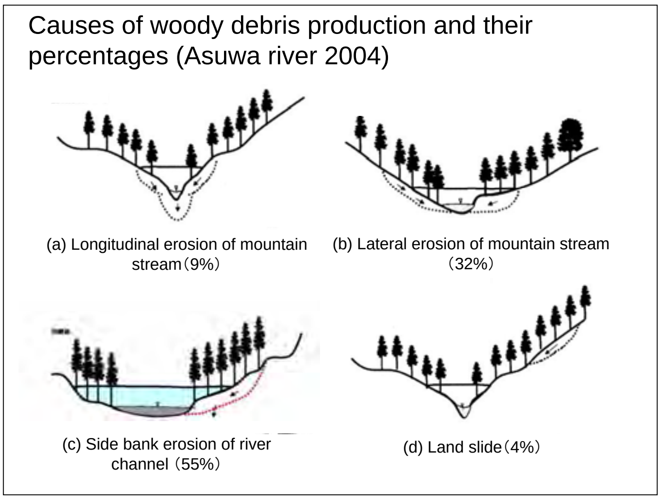
Tropical typhoon Talas, 2011

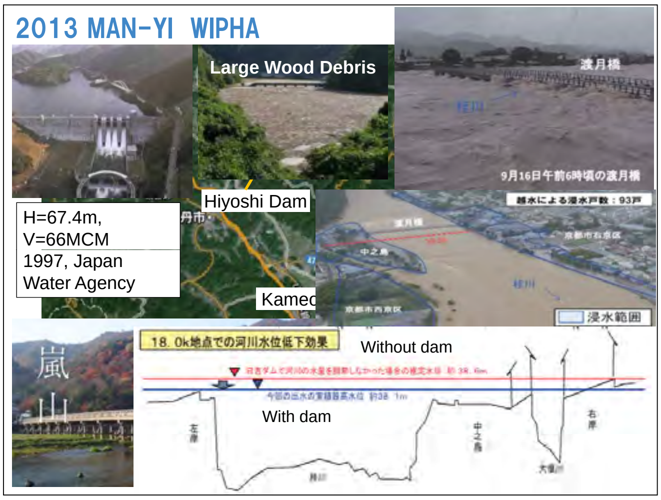


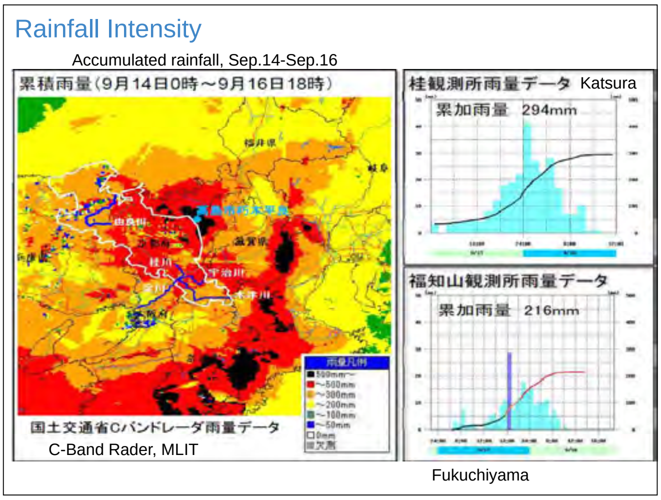

Upstream regions
MLIT
Kazaya Dam
Land slide dam
Debris flow


Downstream regions
MLIT
Japan Railway bridge

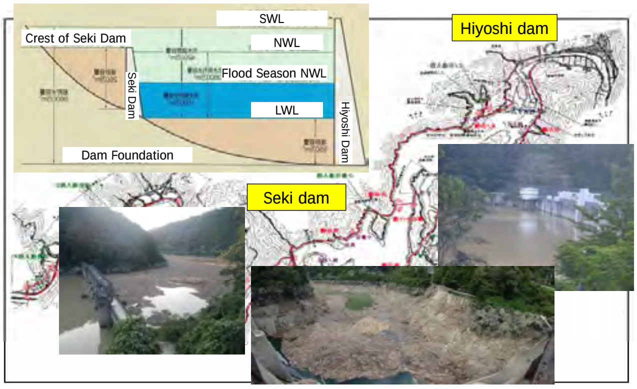

Bridge Damages by driftwood
Asuwa River, Fukui(2004)
Tamarai River, Oita (2011)
Damages of Railway Bridges in Asuwa River(2004)
▲:Damages
75


Causes of woody debris production and their percentages (Asuwa river 2004)
(a) Longitudinal erosion of mountain stream(9%)
(b) Lateral erosion of mountain stream (32%)
(c) Side bank erosion of river channel (55%)
(d) Land slide(4%)

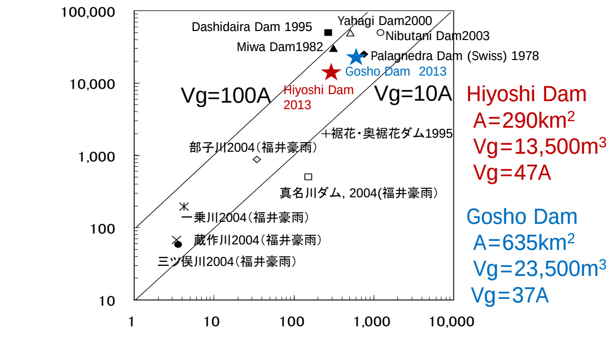

2013 MAN-YI WIPHA
Large Wood Debris
渡月橋
Hiyoshi Dam
H=67.4m,
V=66MCM
1997, Japan
Water Agency
Kameo
浸水範囲
嵐山
Without dam
With dam


Rainfall Intensity
Accumulated rainfall, Sep.14-Sep.16
累積雨量（9月14日0時～9月16日18時）
桂観測所雨量データ Katsura
累加雨量 294mm
福知山観測所雨量データ
累加雨量 216mm
国土交通省Cバンドレーダ雨量データ
C-Band Rader, MLIT
Fukuchiyama

Woody debris trapping at the Hiyoshi dam upstream of the Katsura River at Typhoon Man-yi, 2013



Catchment area and woody debris volume

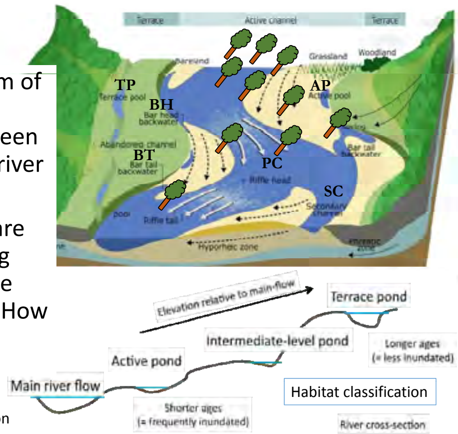


Three questions for floating woody debris management

- WD trapping ratio would change depending on the dam types ?
  (Flood control/water use only, with/without of log boom etc.)
  Is it possible to WD countermeasures in case of drawdown sediment
  flushing or sediment sluicing ?
- How WD trapping is reducing flood risks below dams?
- Is flood control itself also reducing WD additional production?
- Discharge and deposition of WD are only functioning negatively in the river channel or the coastal area?

Concept of woody debris management in the river channel

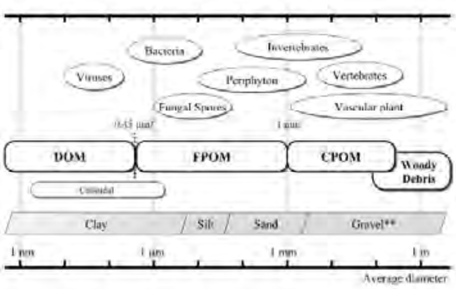
- How mechanism of woody debris transport has been studied in the river channel ?
- Woody debris are only functioning negatively in the river channel? How about creating habitats ?



After Terada and Takemon

Classification of organic matter

Woody debris（WD）is the largest POM in river ecosystems



After Yoshimura et al. (2006)

Ecological roles of woody debris

1. Trophic sources in river and coastal ecosystems
2. Provision of habitats for aquatic organisms as their substrates and/or refuges
3. Creation of pool habitats for aquatic organisms
4. Conditioning of habitats by trapping organic matter such as CPOM and FPOM

Woody debris is required to be installed in rivers under human impacts

Subjects to be investigated

Location of woody debris suitable for promoting ecological functions

After Terada and Takemon

Exercise 2: Fundamentals of Data Processing

Toshio HAMAGUCHI (*Disaster Prevention Research Institute, Kyoto University*)

This lecture aims that you get the fundamental knowledge of data processing using the FORTRAN language. The FORTRAN language is a useful and powerful tool for scientifically numerical calculations. First, this lecture starts with the introduction of digital data and historical transition of the interpreters of the machine language (the computer mother language). Second, the installation process of a certain public domain software of FORTRAN compiling system in Windows 7/8/8.1 is visually shown. Third, some practical exercises are conducted via a output command, a looping operation one, a conditional one, a dimension one and a data arrangement. Fourth and last, some assignment exercises and their suggested answers are given. Through this lecture, the preparation for subsequent exercise lecturesis completed. In other words, a GCM/historical data analysis, a flood frequency analysis, a flood simulation with rainfall-runoff-inundation model, reservoir operation's optimization are applicable based on this lecture's knowledge. It can be helpfully performed in any computational cases.

UNESCO IHP Training Course
Exercise 2
Fundamentals of Data Processing

Toshio Hamaguchi

Disaster Prevention Research Institute, Kyoto University

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

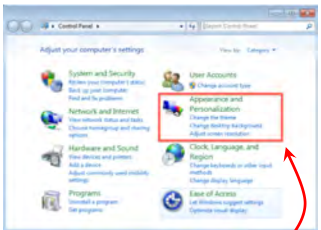
→FORTRAN2008→?

We use it herein! (FORTRAN90) **Fundamentals** (FORTRAN77)

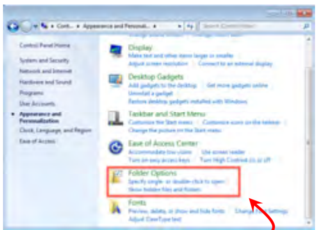
Preliminary work before FORTRAN installation

Change the filename view setting because you'll get confused execution file with execution one after compiling FORTRAN source codes if you cannot view filename

In case of Windows7

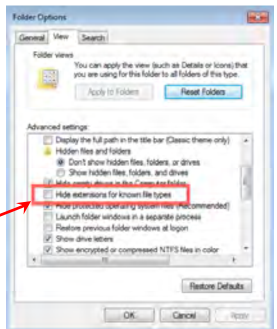


Click "Appearance and Personalization" in Control Panel.



Click "Folder Options."

Preliminary work before FORTRAN installation (Cont.)

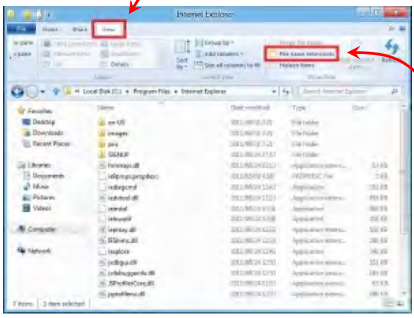


Click the box of "Hide extension for known file types" to take off the check mark.

Preliminary work before FORTRAN installation (Cont.)

In case of Windows8/8.1

Run Explorer in a certain folder and click “view” Tab.



Click the box of “File name extensions” to check the mark in it.

How to install gfortran system (1)

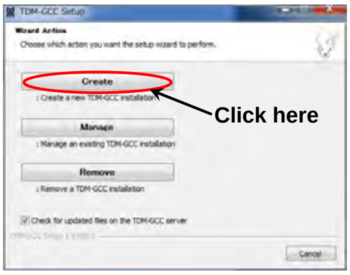
Please browse the following webpage :
http://tdm-gcc.tdragon.net
and download the installation package of TDM-GCC.

for 32bit OS

for 64bit OS

How to install gfortran system (2)

Run the downloaded execution file,
and click the [Create] button in the following window.



Click here

How to install gfortran system (3)

Choose and click the radio button according your OS,
and click the [Next] button in the bottom.

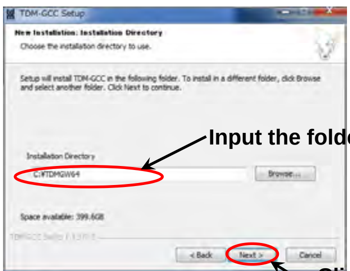
for 32bit OS

for 64bit OS

Click here after the above choice.

How to install gfortran system (4)

Ex. in case of 64bit OS, input the folder name to be installed.

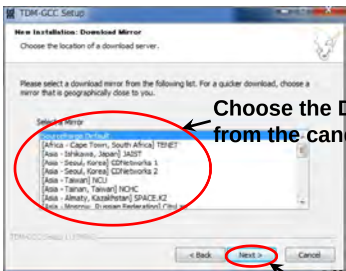


Input the folder name.

Click here after the above input.

How to install gfortran system (5)

Choose the download site.
(Default one would be better.)

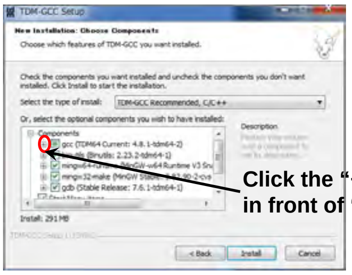


Choose the DL site from the candidates.

Click here after the above choice.

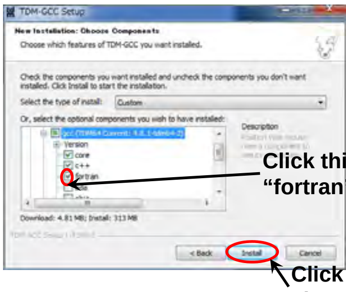
How to install gfortran system (6)

Click the plus mark in front of “gcc” to select the compiling languages to be installed.



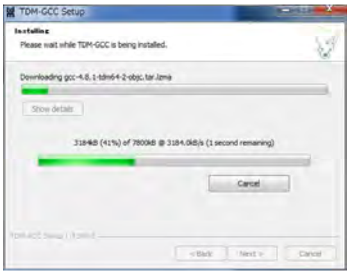
How to install gfortran system (7)

Additionally click the mark in the box of “fortran.”
(Preferred languages can be installed at the same time.)



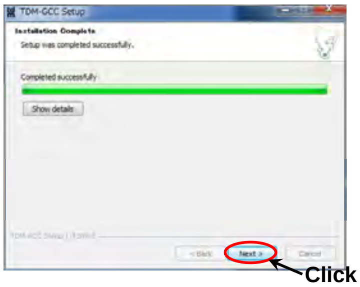
How to install gfortran system (8)

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.”

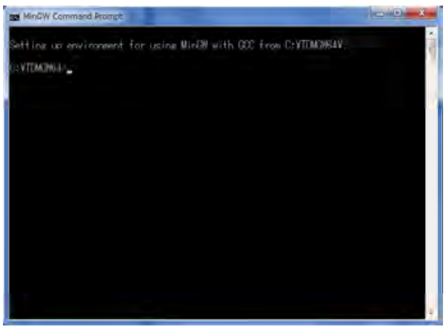


How to install gfortran system (10)

This is the last window of installation.

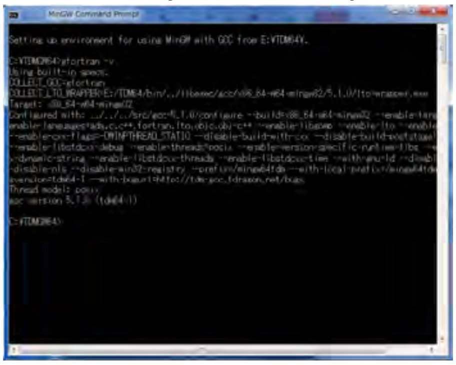
How to examine the feasibility of gfortran system (1)

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 “Notepad.”
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 3: Data Analysis of GCM and 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.

There are many river basins in the world where historical meteorological data are not enough or very limited. So, the information of global precipitation dataset such as GPCC(Global Precipitation Climatology Center) and GSMaP (Global Satellite Mapping of Precipitation) is introduced.

25th IHP Training Course(2015/12/4)

Data analysis of GCM and historical Data

Kenji Tanaka
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tanaka.kenji.6u@kyoto-u.ac.jp

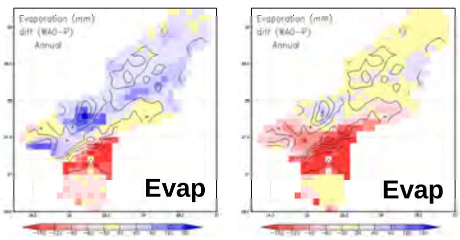
Back ground

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.

Effect of bias correction on the climate change impact assessment (from ICCAP)



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

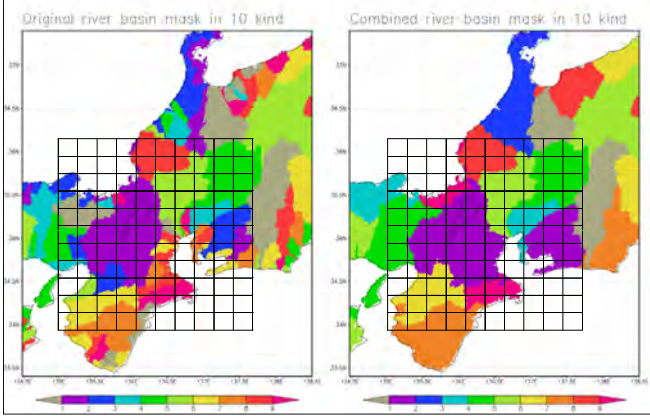
Providing bias information of GCM/RCM output

- 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

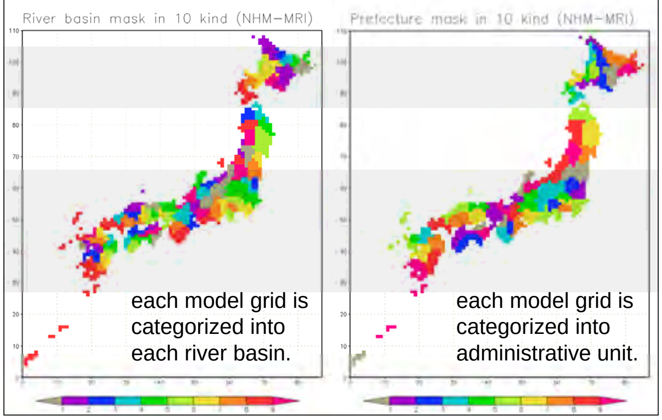
Procedure of bias correction

1. Creation of river basin mask and administration mask (basmask1.f)
2. Finding corresponding grid for each observation station (stnmatch3.f)
3. Re-ordering model output (readmodel.f)
4. Detection of model mean bias, calculating frequency distribution (biaspdfvar3.f)
5. Bias correction considering frequency distribution

Original Watershed code / Combined Watershed



River basin mask and prefecture mask expressed by MRI-NHM grids



Procedure of bias correction

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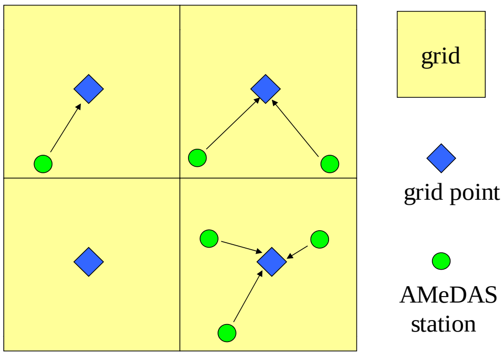
4. Detection of model mean bias, calculating frequency distribution (biaspdfvar3.f)
5. Bias correction considering frequency distribution

Finding corresponding grid

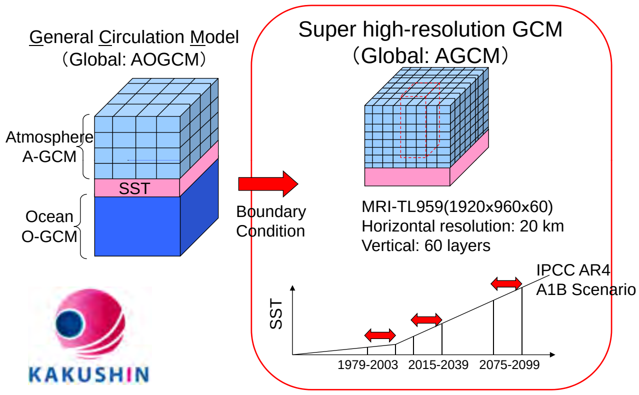


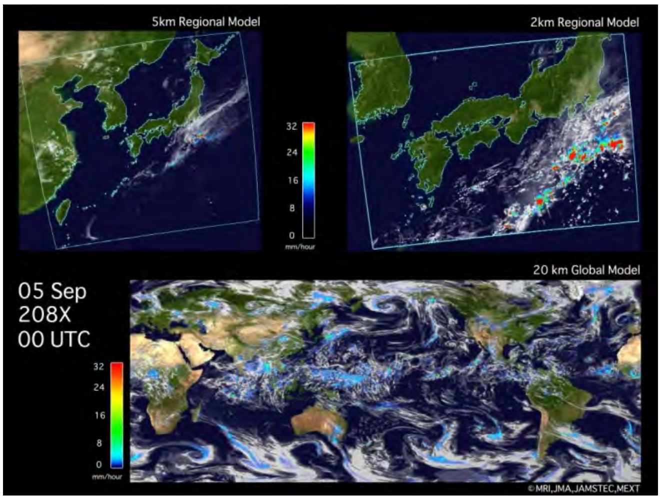
Available 20km model output

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)

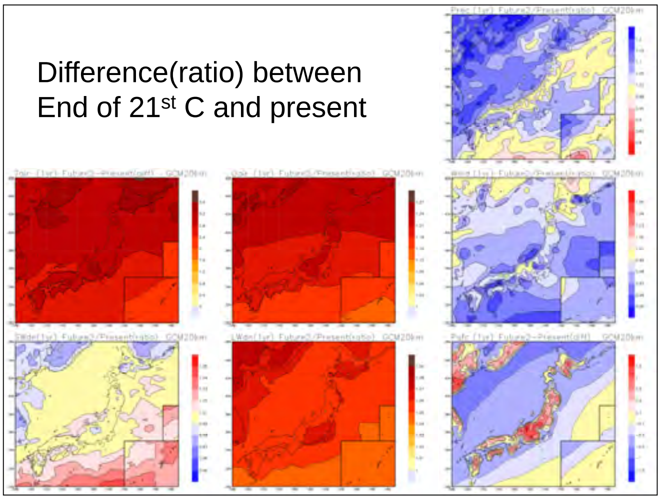
name	mx	my	mr	mp	im	iamax
NHMMRI1	105	115	60	60	54	1076
NHMMRI2	131	121	61	60	49	1047
RAMSDP0	130	140	62	60	57	1094
RAMSDP1	128	144	62	60	57	1094
RAMSTU0	130	140	62	60	57	1094
RAMSTU1	130	140	62	60	57	1094
WRF−TU1	129	139	56	60	47	958
GCM20km	163	162	67	60	69	1275

Detecting hydrological impact using super-high resolution GCM



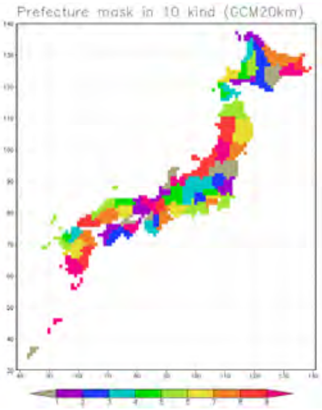


Difference(ratio) between
End of 21st C and present



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

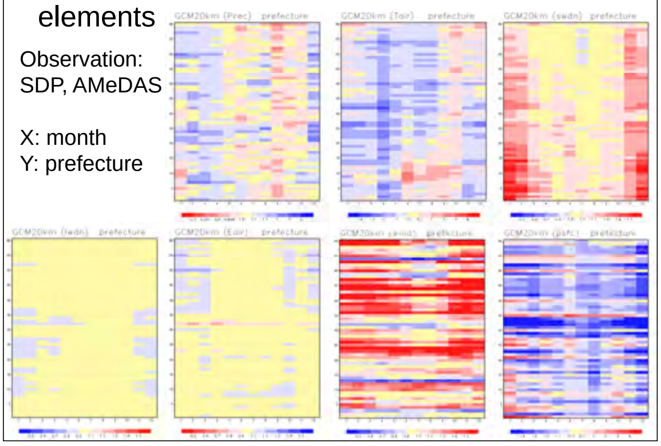


Bias correction system was developed
in S-5-3 project (MOE fund)

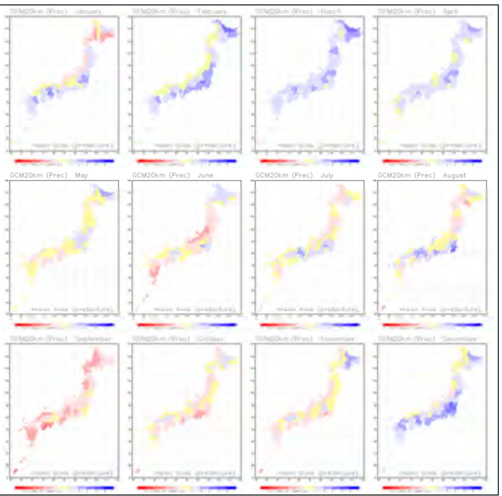
Model bias of 7 surface meteorological elements

Observation:
SDP, AMeDAS

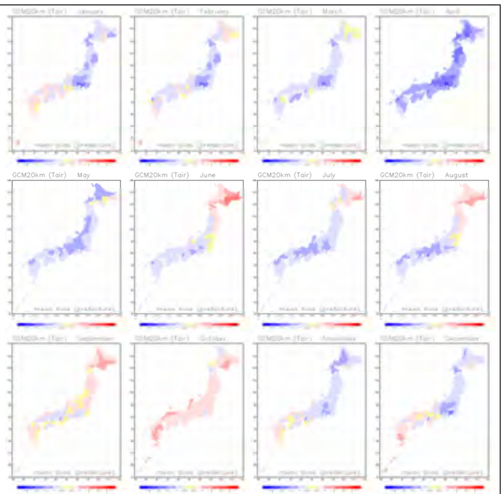
X: month
Y: prefecture

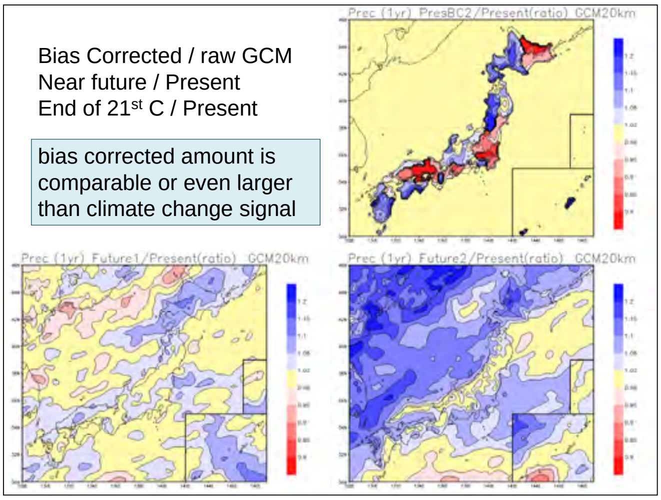


Prec



Tair





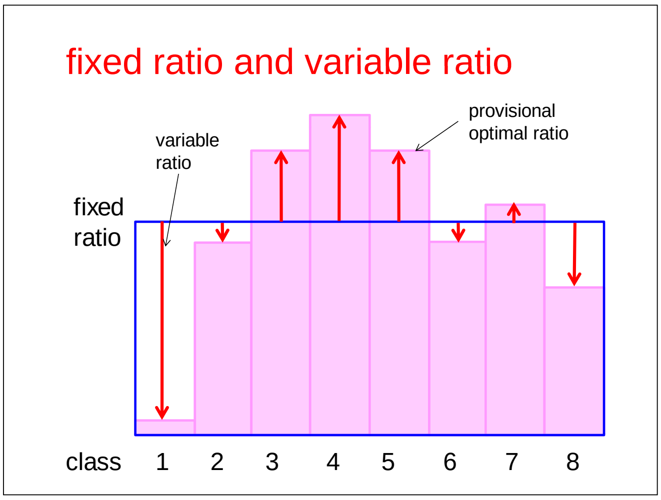
New algorithm for adjustment of frequency distribution

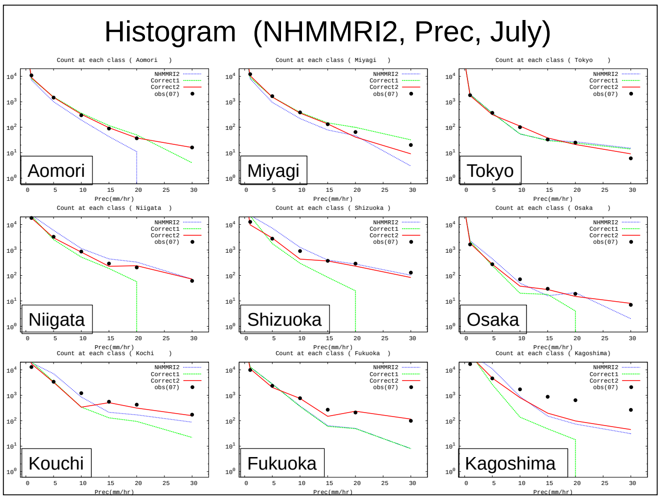
- every 1hr data are classified for each month
  8 class (Prec) / 10 class (Tair)
- 2 steps correction

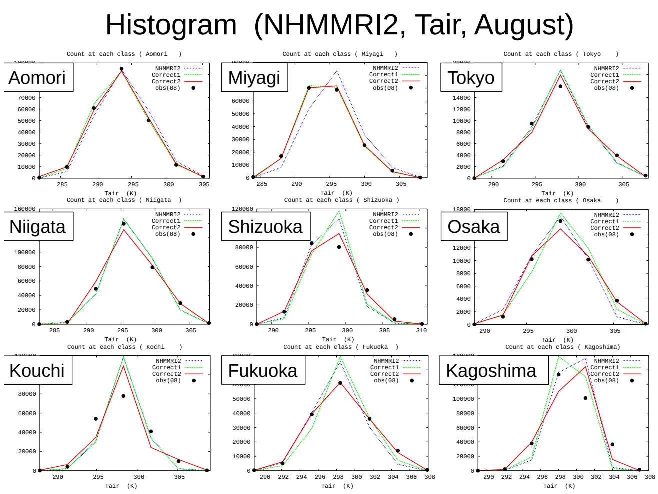
Temporal correction with fixed ratio — Monthly mean value

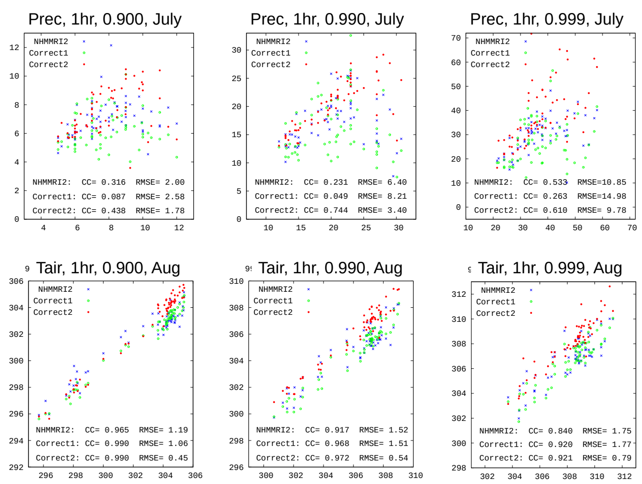
↓

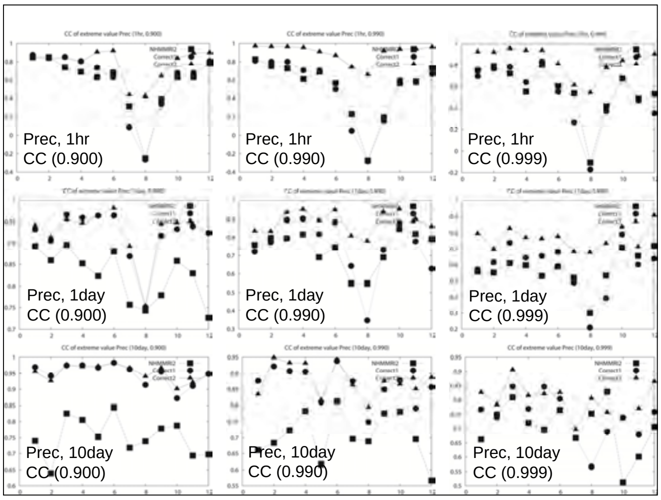
Adjustment of correction factor for each class — Frequency distribution











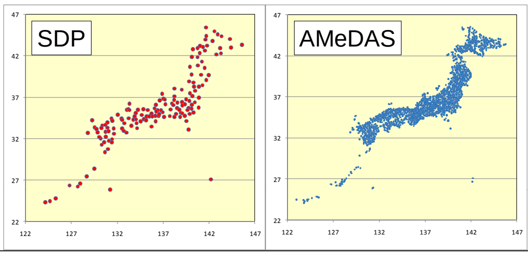
Program and Data list

```
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



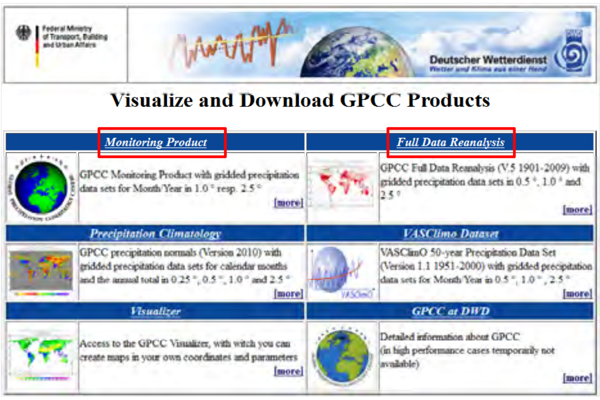
In-situ measurement is not enough?

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

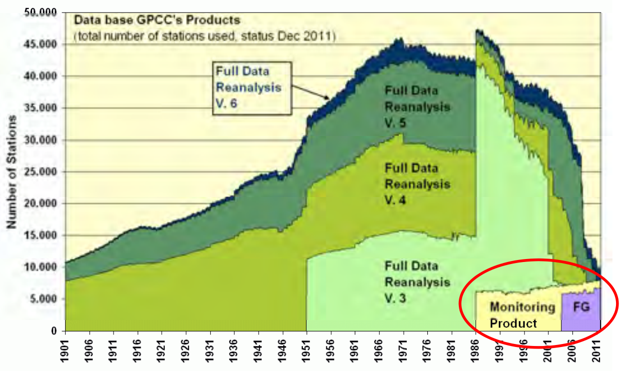


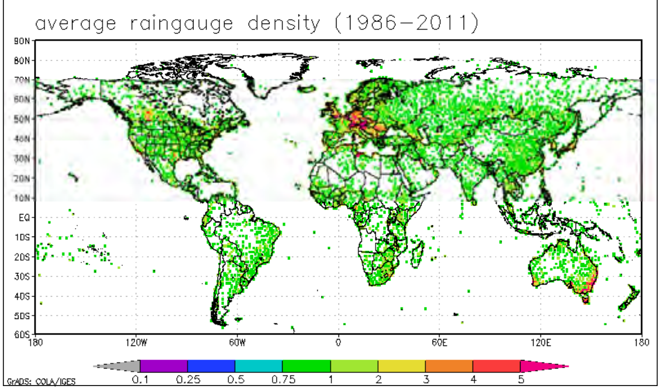
Download page for Monitoring Product

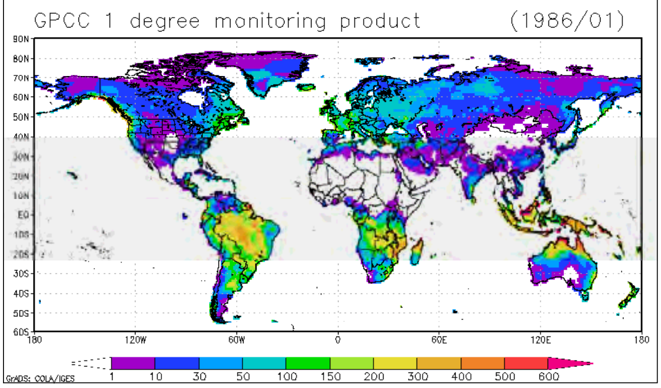
Monitoring Product for Month/Year	1.0 ° (.zip)	2.5 ° (.zip)
01-12 1986 (archive)	download	download
01-12 1987 (archive)	download	download
01-12 1988 (archive)	download	download
01-12 1989 (archive)	download	download
01-12 1990 (archive)	download	download
01-12 1991 (archive)	download	download
01-12 1992 (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







(http://sharaku.eorc.jaxa.jp/GSMaP/)

We offer hourly global rainfall maps in near real time (about four hours after observation) using the combined MW-IR algorithm with GPM-Core GMI, TRMM TMI, GCOM-W AMSR2, DMSP series SSMIS, NOAA series AMSU, MetOp series AMSU and Geostationary IR data. Background cloud images are globally merged IR data produced by NOAA Climate Prediction Center (CPC), using IR data observed by JMA's MTSAT satellite, NOAA's GOES satellites and EUMETSAT's Meteosat satellites.

User Registartion for Near-Real-Time Data

To use data, user registration is needed. Since September 3, 2014, near-real-time products and images will be replaced by reanalysis version about 3 days later. Reanalysis data in latest version (GSMaP_MVK Ver.6.000) currently available period after September 1, 2014, but past period data will be released sequentially after processing. Reanalysis data in old version (GSMaP_MVK ver.5.222) are available for the period from Mar. 2000 to Nov. 2010, and will be removed from the server when new version data is available.

User Registration

You can access to the GSMaP products after registration.

Procedure of data analysis

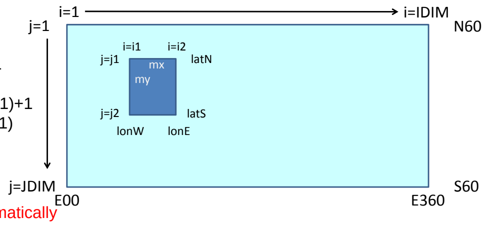
Step0: unpack the data (gzipped file)
Step1: select the region for analysis (GSMaP)
(GSMAP/daily/cutgsmap.f)
Step2: select the region for analysis (GPCC)
(GSMAP/daily/cutgpcc.f)
Step3: calculate climatological value and correction factor
(GSMAP/daily/climanal.f)
Step4: select the region for analysis (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



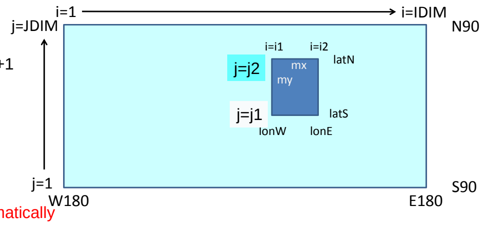
do iy=2000,2010 loop for year
write(cy,'(i4.4)') iy write the year information in cy
open(22,file='NILE/GSMAP-Nile-1mon'//cy//'.gad'
,form='unformatted',access='direct',recl=mx*my*4)
Use cy (year information) in file name automatically

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

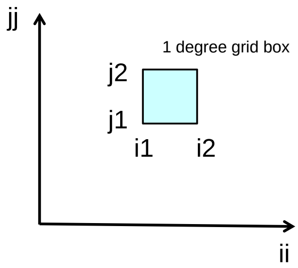
Size of target area
Is calculated automatically



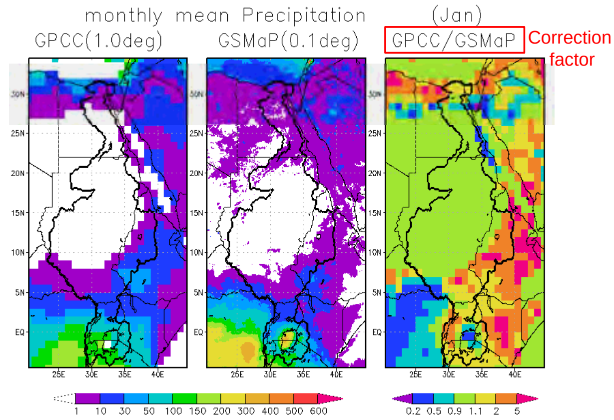
do iy=1986,2011 loop for year
write(cy,'(i4.4)') iy write the year information in cy
open(22,file='NILE/GPCC-Nile-1mon'//cy//'.gad'
,form='unformatted',access='direct',recl=mx*my*4)
Use cy (year information) in file name automatically

Step3: calculate climatological value and correction factor (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)



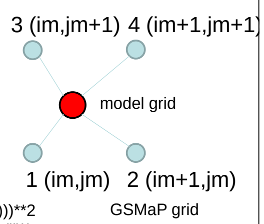
Comparison of monthly mean precipitation



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

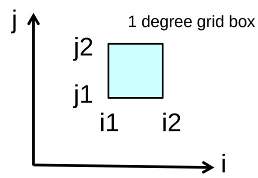


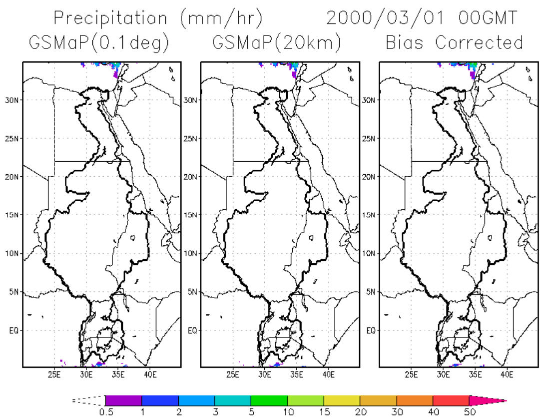
dis1=(xlon2(ii)-xlon1(im(ii)))**2+(xlat2(jj)-xlat1(jm(jj)))**2
dis2=(xlon2(ii)-xlon1(im(ii)+1))**2+(xlat2(jj)-xlat1(jm(jj)))**2 distance x distance
dis3=(xlon2(ii)-xlon1(im(ii)))**2+(xlat2(jj)-xlat1(jm(jj)+1))**2
dis4=(xlon2(ii)-xlon1(im(ii)+1))**2+(xlat2(jj)-
xlat1(jm(jj)+1))**2
www=1./dis1+1./dis2+1./dis3+1./dis4
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





GrADS

- The Grid Analysis and Display System (GrADS)
  - Free Software to display 2 Dimensional data
- Install
  - *Activate* :grads-2.0.2.oga.2-win32_superpack.exe

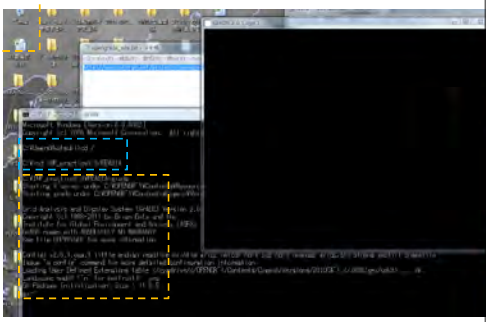
    This installer is included in USB flash memory (GSMAP/grads/)

  - Source : http://sourceforge.net/projects/opengrads/files/

    grads2: OpenGrADS Bundle Distribution (Windows/Mac/Linux/Unix)

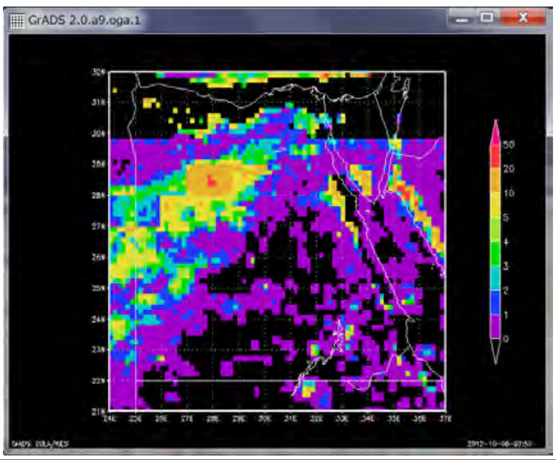
How to use "Grads" ?

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
```



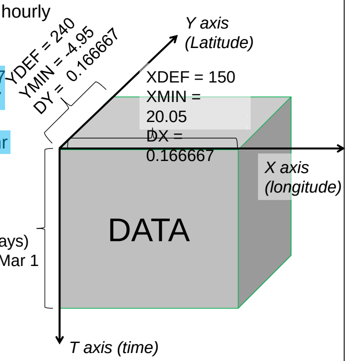
Data description file (ctl file)

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 6: Optimization of Reservoir Operation

Daisuke NOHARA

(*Water Resources Research Center, Disaster Prevention Research Institute, Kyoto University*)

Abstract:

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

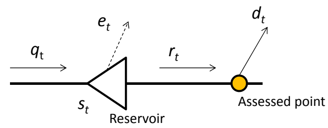
INTRODUCTION

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)

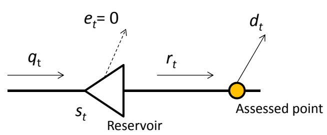
Physical constraints of the reservoir:

- $S_{min} = 0$, $S_{max} = 40$
- $R_{min} = 0$, $R_{max} = 40$

Matrix for Inflow / Target release (MCM):

	t=1	t=2	t=3
q_t	10	10	10
d_t	20	30	30

SIMPLE EXAMPLE



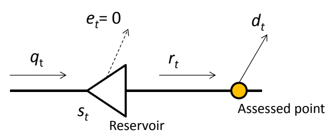
Assumptions to simplify the problem:

- 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:

$$\min_{r_t} \sum_{t=1}^{3} H(r_t)$$

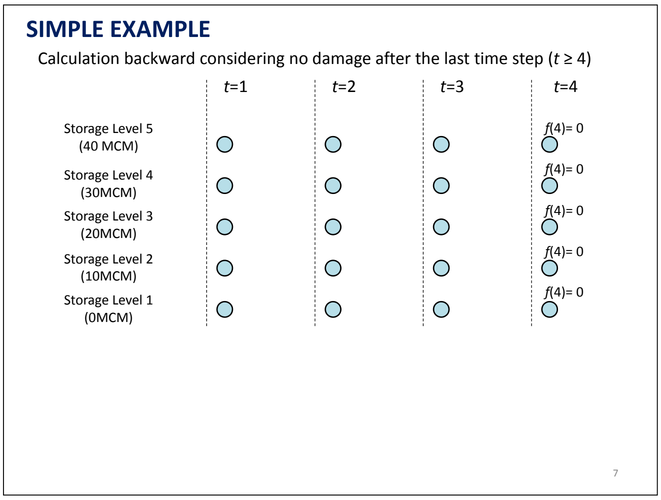
subject to:

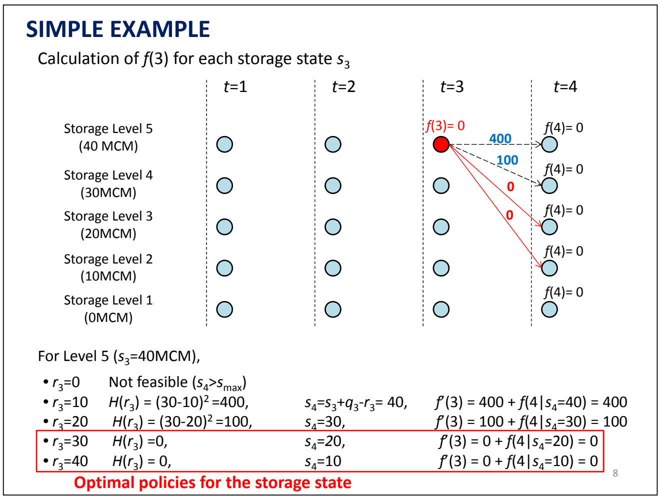
- $S_{min} = 0$, $S_{max} = 40$, $S_{min} \le s_t \le S_{max}$
- $R_{min} = 0$, $R_{max} = 40$, $R_{min} \le r_t \le R_{max}$
- $s_{t+1} = s_t + q_t - r_t - e_t$

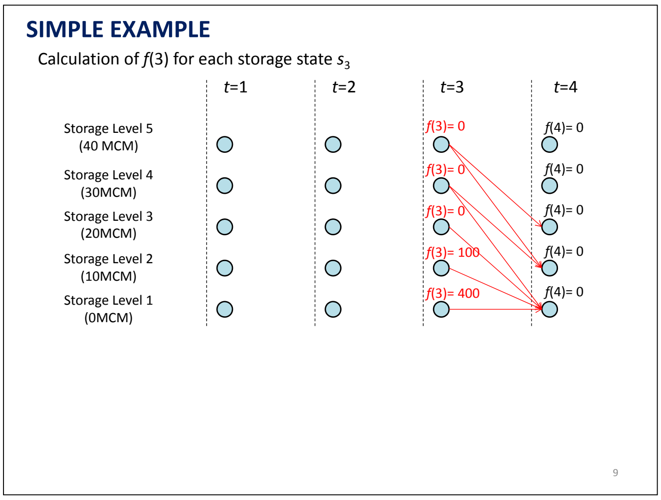
Recursive equation:

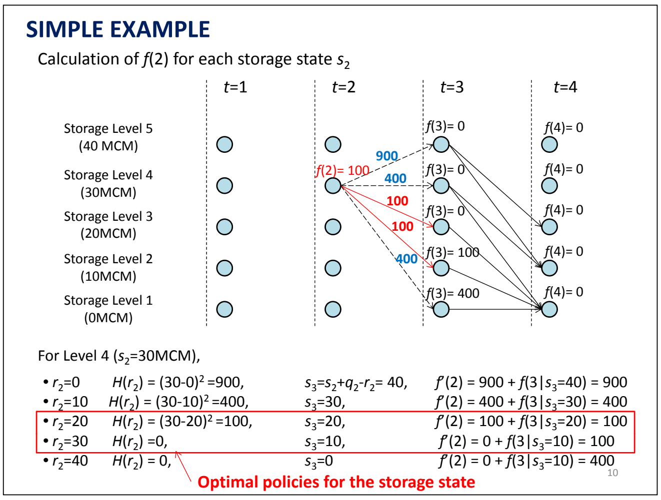
$$f(s_t) = \min_{r(t)} \left[H(r_t) + f(s_{t+1}) \right]$$

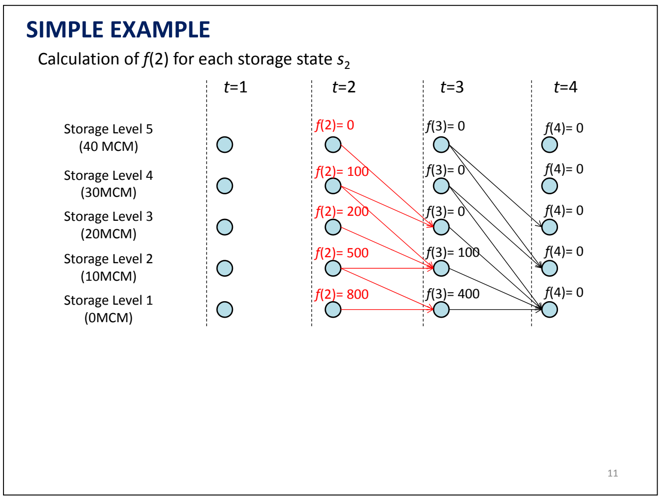
$f(\cdot)$: Future damage function

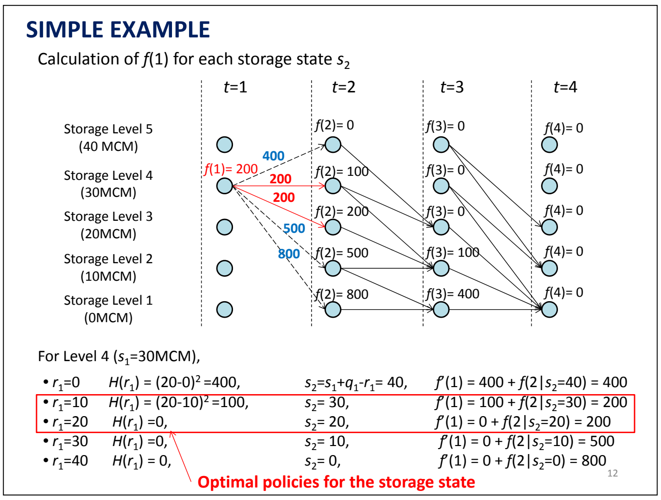

SIMPLE EXAMPLE
Calculation backward considering no damage after the last time step (t ≥ 4)
t=1 t=2 t=3 t=4
Storage Level 5 (40 MCM)
Storage Level 4 (30MCM)
Storage Level 3 (20MCM)
Storage Level 2 (10MCM)
Storage Level 1 (0MCM)
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
7


SIMPLE EXAMPLE
Calculation of f(3) for each storage state s_3
t=1 t=2 t=3 t=4
Storage Level 5 (40 MCM)
Storage Level 4 (30MCM)
Storage Level 3 (20MCM)
Storage Level 2 (10MCM)
Storage Level 1 (0MCM)
f(3)= 0
400
100
0
0
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
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
8


SIMPLE EXAMPLE
Calculation of f(3) for each storage state s_3
t=1 t=2 t=3 t=4
Storage Level 5 (40 MCM)
Storage Level 4 (30MCM)
Storage Level 3 (20MCM)
Storage Level 2 (10MCM)
Storage Level 1 (0MCM)
f(3)= 0
f(3)= 0
f(3)= 0
f(3)= 100
f(3)= 400
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
9

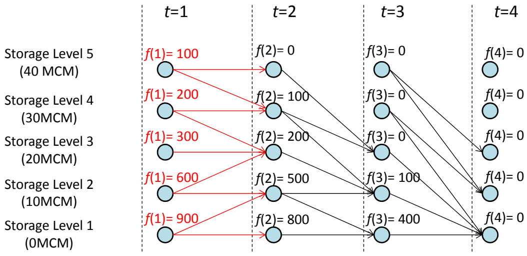

SIMPLE EXAMPLE
Calculation of f(2) for each storage state s_2
t=1 t=2 t=3 t=4
Storage Level 5 (40 MCM)
Storage Level 4 (30MCM)
Storage Level 3 (20MCM)
Storage Level 2 (10MCM)
Storage Level 1 (0MCM)
f(2)= 100
900
400
100
100
400
f(3)= 0
f(3)= 0
f(3)= 0
f(3)= 100
f(3)= 400
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
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
10


SIMPLE EXAMPLE
Calculation of f(2) for each storage state s_2
t=1 t=2 t=3 t=4
Storage Level 5 (40 MCM)
Storage Level 4 (30MCM)
Storage Level 3 (20MCM)
Storage Level 2 (10MCM)
Storage Level 1 (0MCM)
f(2)= 0
f(2)= 100
f(2)= 200
f(2)= 500
f(2)= 800
f(3)= 0
f(3)= 0
f(3)= 0
f(3)= 100
f(3)= 400
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
11


SIMPLE EXAMPLE
Calculation of f(1) for each storage state s_2
t=1 t=2 t=3 t=4
Storage Level 5 (40 MCM)
Storage Level 4 (30MCM)
Storage Level 3 (20MCM)
Storage Level 2 (10MCM)
Storage Level 1 (0MCM)
f(1)= 200
400
200
200
500
800
f(2)= 0
f(2)= 100
f(2)= 200
f(2)= 500
f(2)= 800
f(3)= 0
f(3)= 0
f(3)= 0
f(3)= 100
f(3)= 400
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
f(4)= 0
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
12

SIMPLE EXAMPLE

Calculation of $f(1)$ for each storage state s_2



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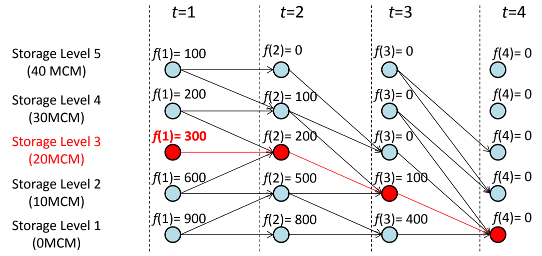
SIMPLE EXAMPLE

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…



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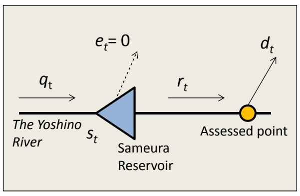
EXERCISES

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

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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

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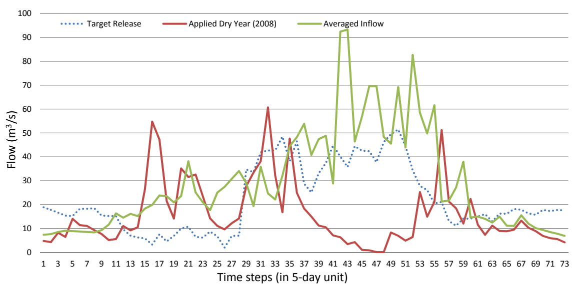
FLOW REGIME AND TARGET RELEASE

Flow regime in the applied dry year (2008) and assumed water demand just downstream Sameura Reservoir (assumed target release of Sameura Reservoir)



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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):

$$H(r_t) = \begin{cases} (d_t - r_t)^2 / d_t & (r_t < d_t) \\ 0 & (r_t \geq d_t) \end{cases}$$

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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)

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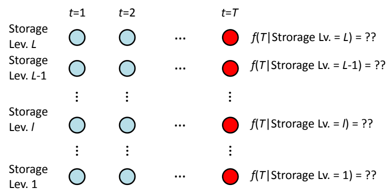
SETTING PARAMETERS FOR SOLVING DP

Future damage function at the last time step of optimization
Necessary to define for backward calculation of *f*()



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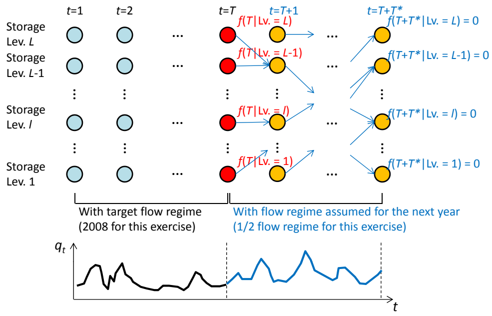
SETTING PARAMETERS FOR SOLVING DP

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



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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

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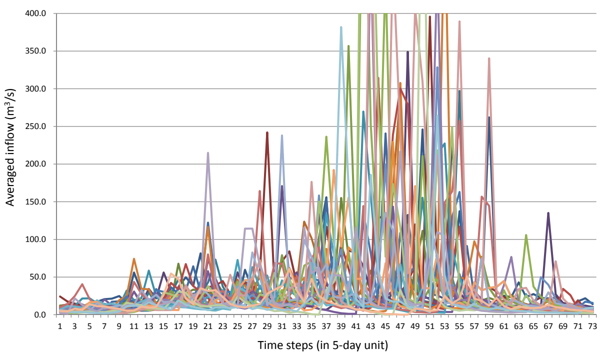
HISTORICAL HYDROLOGICAL DATA

Inflow sequences observed for 30 years (1979-2008)



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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:

$$H(r_t) = \begin{cases} (d_t - r_t)^2 / d_t & (r_t < d_t) \\ 0 & (r_t \ge d_t) \end{cases}$$

24

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.

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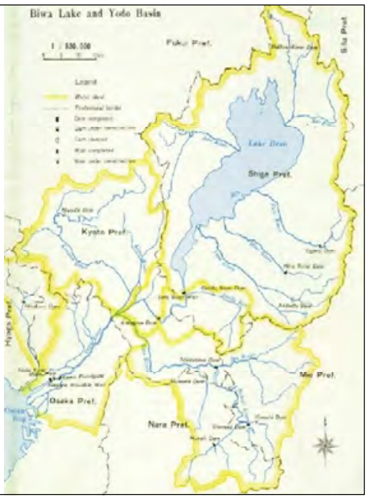
Brief Guide of the Lake Biwa and the Uji River for Technical excursion of IHP Training Course on Dec 5 (Sat) 2015

Edited by
Yasuhiro TAKEMON
(DPRI, Kyoto Univ)



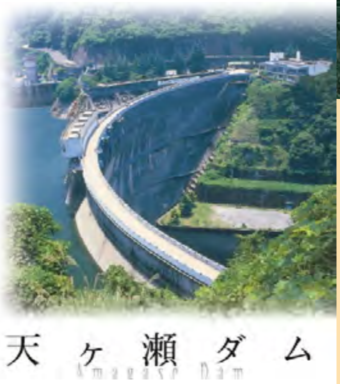
Time Schedule

Meeting place: Hybrid Space of Obaku Plaza

- 9:20 Meeting time
- 9:30 Departure: Travel via local road (two cars)
- 10:00 Amagase Dam:
  walking on the dam
- 10:20 Departure: Travel via highway
- 11:00 Seta Barrage
- 11:30 Departure: Travel via local road
- 12:10 Biwa Lake Museum:
  Lunch at Cafeteria of the Museum
- 13:00 Free time inside
- 15:20 Departure: Travel via highway
- 16:15 DPRI Open Laboratory
  Watching the riverbed degradation in the Uji River
- 16:30 Departure: Travel via local road
- 17:10 Obaku Plaza Breakup

Hybrid Space (Meeting place)

Amagase Dam



天ヶ瀬ダム本体及び貯水池諸元

河川名	淀川水系淀川（宇治川）
位置	【左岸】宇治市槙島町六石 【右岸】宇治市槙島町槙尾山
流域面積	[illegible]
型式	ドーム型アーチ式コンクリートダム
堤頂長及び堤高	堤頂長254m、堤高73m
体積	[illegible]
地質	砂岩、粘板岩
コンジットゲート	3門、放流量1,100m³/S（最大）、840m³/S（計画最大放流量）
クレストゲート	[illegible]
湛水面積	1.88km²
[illegible]	O.P.78.5m
[illegible]	O.P.78.5m
[illegible]	O.P.72.0m（6月16日〜10月15日）
[illegible]	O.P.58.0m
[illegible]	[illegible]
利用水深	20.5m
総貯水容量	26,280,000m³ [illegible]
有効貯水容量	20,000,000m³

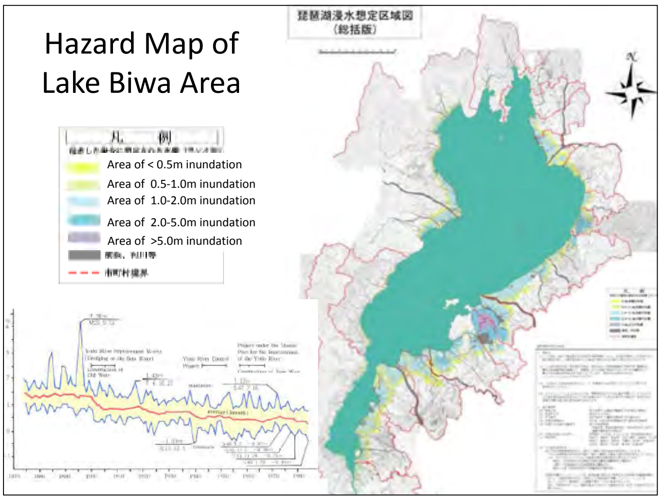
Lake Biwa

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

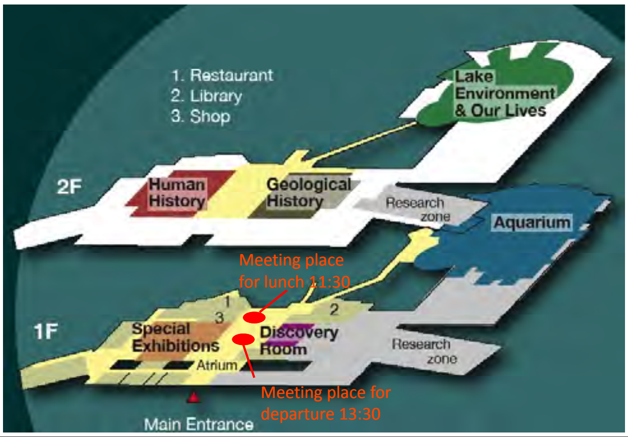
- Size: 674 square km
- Volume: Total 27.5 cubic km
  - North Basin 27.3 cubic km
  - South Basin 0.2 cubic km
- Max depth:
  - North Basin 104 m
  - South Basin 8 m
- Mean depth:
  - North Basin 44 m
  - South Basin 3.5 m
- Length of shoreline: 235 km
- Catchment area: 3,174 square km
- No. of inflowing 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



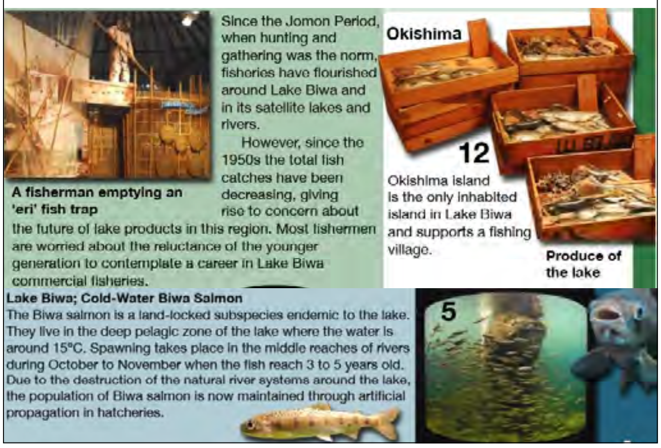
Setagawa weir (Nango-Araizeki)

Visit of the Lake Biwa Museum

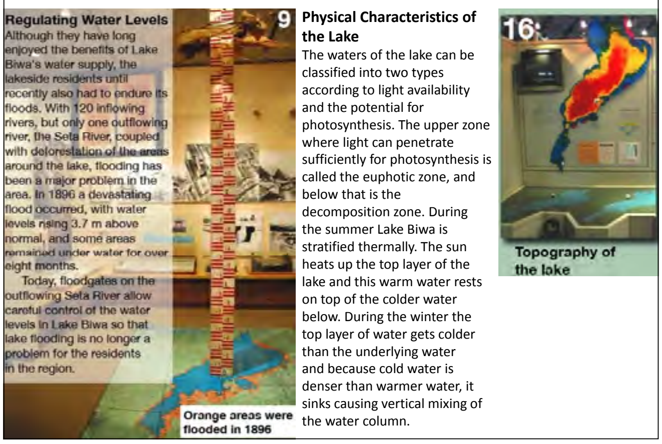


Natural Resources Exploitation in Lake Biwa

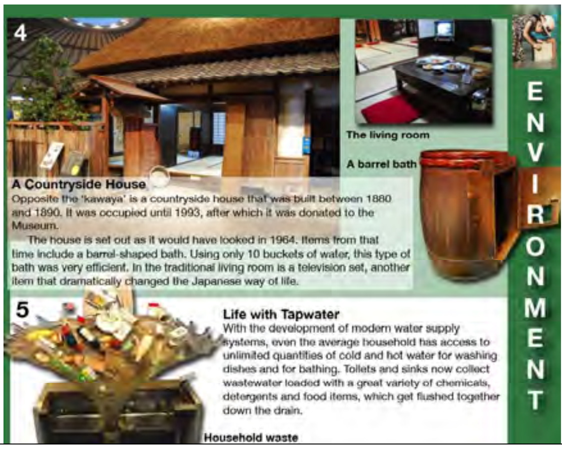
Fisherman's life in Lake Biwa



History of flood control in Lake Biwa



Environmental problems in Lake Biwa



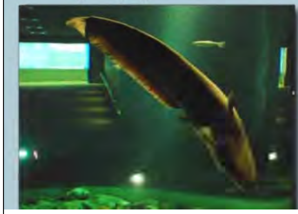
You can observe living planktons

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



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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.

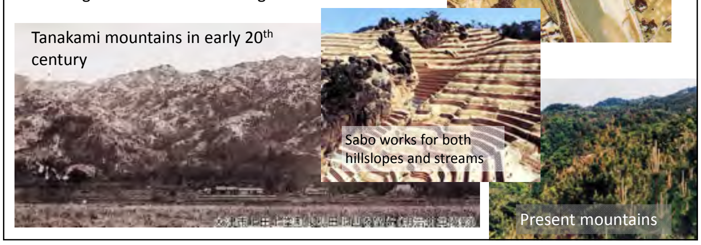
Sedimentation of Amagase-dam

1. Upstream watershed and sediment yield

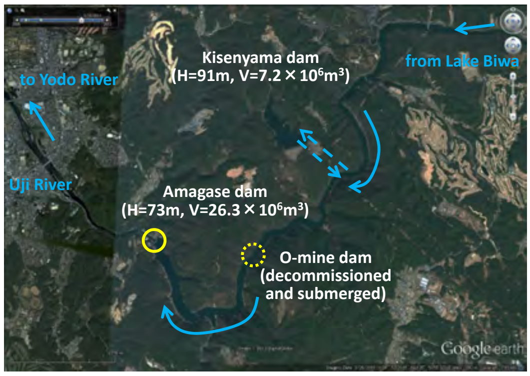
Seta River is the outlet of **Lake Biwa**. The name changes to **Uji River** from the border of Kyoto Prefecture. **Amagase dam** is located in the upstream reach of Uji River. **Daido River** is the largest tributary of Seta/Uji River and **the largest source of sediment** because little sediment supply 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.

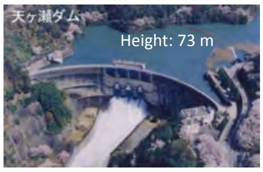


2. Construction and operation of dams in Uji River

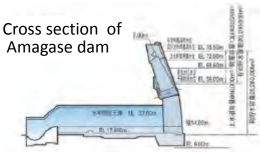


O-mine dam (constructed in 1923)

Amagase dam (constructed in 1964)

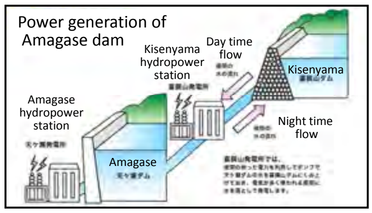


Cross section of Amagase dam

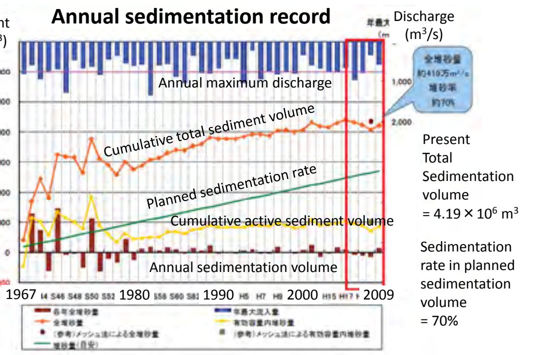


O-mine dam was constructed for hydro-power after an increase of energy demand of Kansai area. It was **the first concrete-gravity dam** in Japan. The **dam was decommissioned** (submerged) by the Amagase dam construction.

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.



3. Reservoir sedimentation in Amagase dam

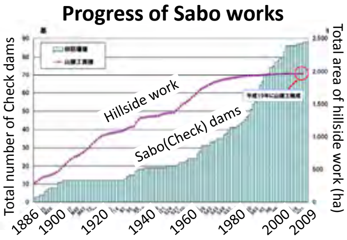


Planned Total Sedimentation volume = 6×10⁶ m³

Present Total Sedimentation volume = 4.19×10⁶ m³

Sedimentation rate in planned sedimentation volume = 70%

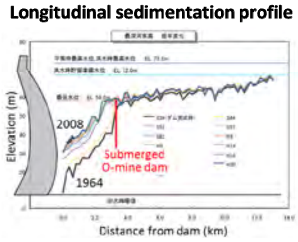
Progress of Sabo works



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.

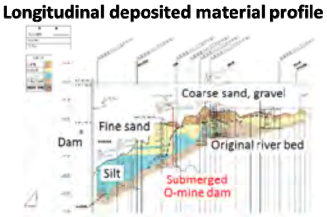
Almost 70% of planned sedimentation volume has been already filled. Capacity loss of total storage is 16%.

Longitudinal sedimentation profile



Most sediment deposit can be observed in the downstream of submerged O-mine dam, where deposit depth is almost 20 m.

Longitudinal deposited material profile

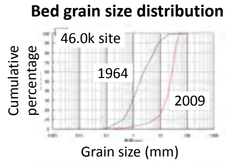


Deposited materials change at submerged O-mine dam, coarse sediment in the upstream, while fine one in the downstream.

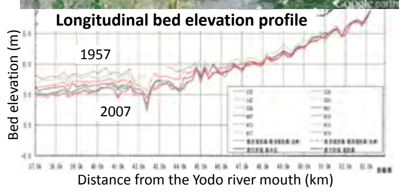
4. Dam and environmental issues in Uji River

Downstream area of Amagase dam

Bed grain size distribution

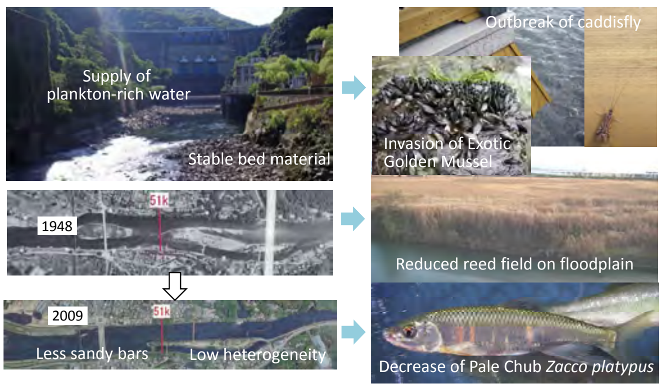


Longitudinal bed elevation profile



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.

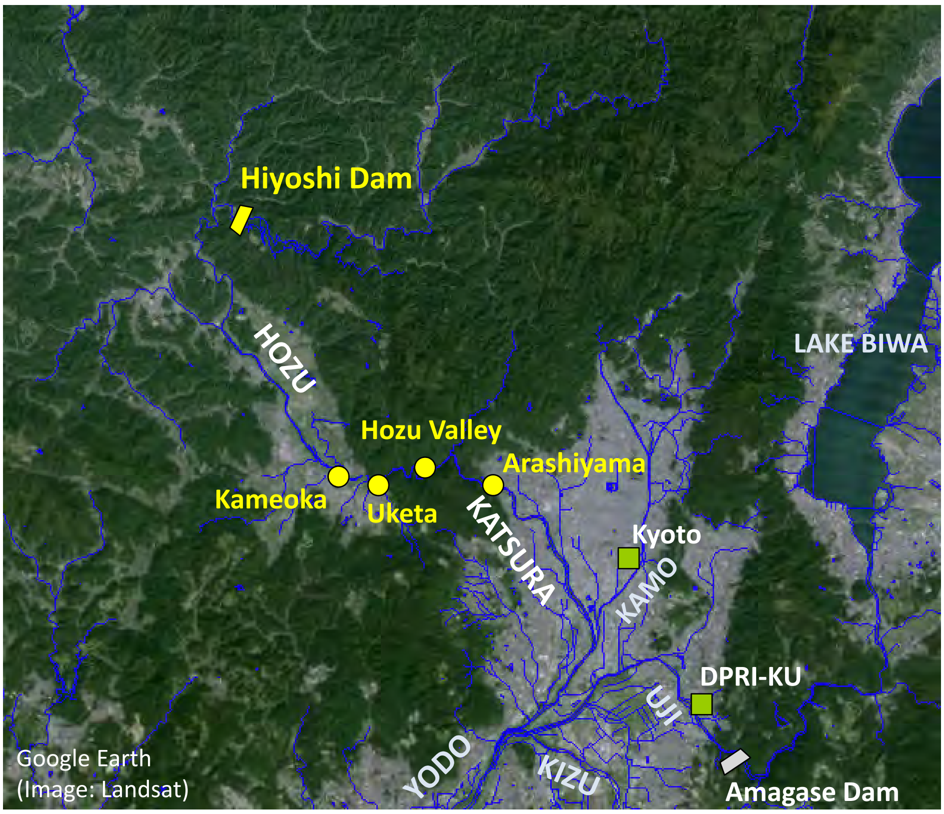
Overview of the Field Workshop at the Hiyoshi Dam and the Katsura (Hozu) River

9 December, 2015
The 25th UNESCO-IHP Training Course

Daisuke NOHARA
Water Resources Research Centre
Disaster Prevention Research Institute
Kyoto University

KATSURA RIVER BASIN

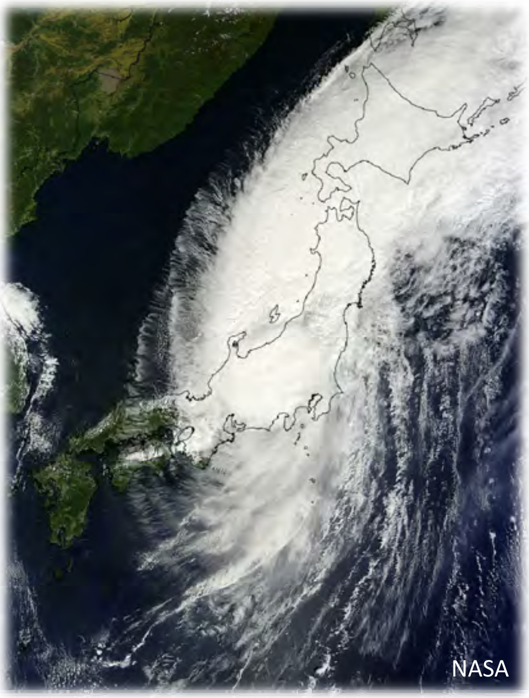
One of the main tributaries of the Yodo River System



2

RECENT FLOOD EVENT

Flood caused by Typhoon Man-yi in September in 2013



LIST OF ACTIVITIES

- **Meeting up at Hybrid Space of Obaku Plaza (at 8:40 AM)**
- Visit and workshop at Hiyoshi Dam
- Field exercises at the Hozu/Katsura River:
  - ◆ Visiting the inundated areas by the flood due to Typhoon Man-yi in 2013
  - ◆ Measuring river width

  at several locations including Kameoka, Uketa, Hozu Valley and Arashiyama
- **Breakup at Arashiyama (at 5:00PM)**

4