ICHARM's Initiatives for Effective Flash Flood Forecasting and Management in Arid and Semi-arid Region

Yoichi Iwami*, Mohamed Rasmy

International Centre for Water Hazard and Risk Management (ICHARM), PWRI, Japan

*Corresponding author

Email: y-iwami@pwri.go.jp

Keywords: Rainfall-Runoff-Inundation (RRI) model, Evapotranspiration, Capacity Building, International Flood Initiative

Observation records indicate that frequency and intensity of floods are increasing around the world. Particularly, flash floods in the Wadi system in arid regions have occurred more frequently in recent years. Since the occurrences of flash floods in Wadi system are very rare compared with the occurrences in other climatic regions, there is lack of preparedness against these extreme events and thus lives and properties are under great danger in these regions. Therefore, it is very important to improve the forecasting capabilities and discuss the appropriate countermeasures against Wadi flash floods.

ICHARM which was established in 2006 aims of supporting to effectively manage water related hazard globally and is contributing to mitigate flood damages by providing scientific methodologies and hydrological analysis with capacity building in several countries. It has a lot of experiences for developing flood early warning systems in developing countries through the projects supported by local and international donors. One of the greater challenges for developing flood early warning systems is the poor observation network and inaccurate observations of rainfall and discharges.

To address these issues, ICHARM has developed and provided free flood simulation tools such as Integrated Flood Analysis System (IFAS) and Rainfall-Runoff-Inundation model (RRI), which allow users to easily develop and tune a model/system using available global data including global near-real-time satellite observations, so that the ICHARM's free tools can be applicable to poorly gauged regions with additional bias correction to satellite rainfall observation using few available ground gauges. In addition, ICHARM is also providing technical support and hands-on training on these free tools through the several international projects.

At this symposium, we will present ICHARM contributions to flood forecasting and management activities by presenting several applications using RRI model. On the other hand, physical runoff mechanism in Wadi system in arid and semi-arid region is quite unique compared with river basins in other regions (e.g. higher evapotranspiration and infiltration). We will also present our ongoing development of Water and Energy based Rainfall-Runoff-Inundation (WEB-RRI) model to incorporate detailed processes of evapotranspiration and infiltration to improve the simulation accuracy in arid and semi-arid regions. As ICHARM serves as the secretariat of International Flood Initiative (IFI), we are looking forward to further extant and enhance our contribution towards water related disasters risk reduction around the world through supporting the flood mitigation activities in arid and semi-arid regions.

ICHARM's initiatives for effective flash flood forecasting and management in arid and semi-arid region

at TUB, El Gouna campus, Egypt
October 25-27, 2016

Yoichi Iwami and Mohamed Rasmy
ICHARM under the auspices of UNESCO, Japan

Contents

1. What is ICHARM?
2. ICHARM models (IFAS/RRI)
3. Application in dry regions

2

ICHARM

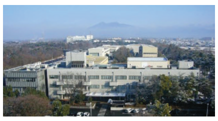
International Centre for Water Hazard and Risk Management

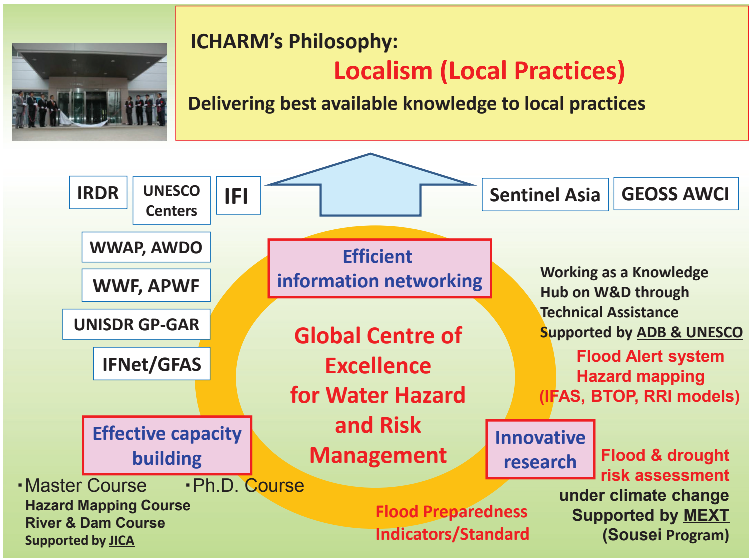
was established March 6, 2006 as a category 2 center of UNESCO

Mission of ICHARM

The mission of ICHARM is to serve as the **Global Centre of Excellence for Water Hazard and Risk Management** by, inter alia, observing and analyzing natural and social phenomena, developing methodologies and tools, building capacities, creating knowledge networks, and disseminating lessons and information in order to help governments and all stakeholders manage risks of water-related hazards at global, national, and community levels.

The hazards to be addressed include floods, droughts, landslides, debris flows, tsunamis, storm surges, water contamination, and snow and ice disasters.

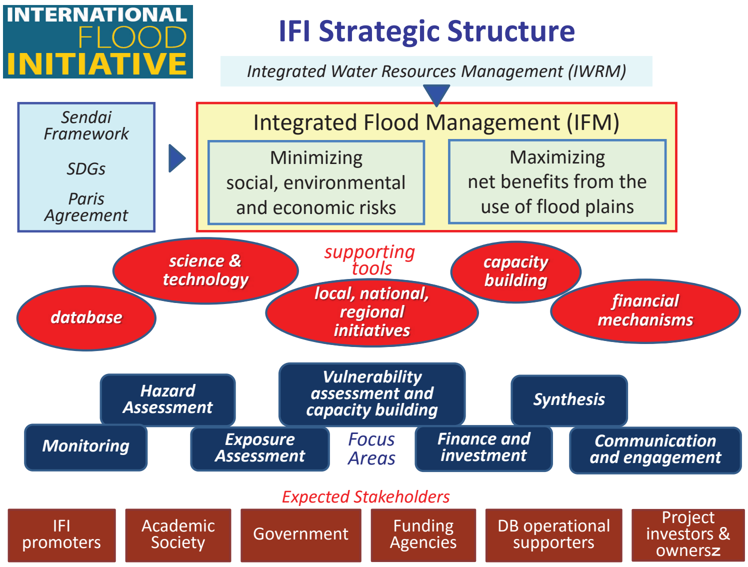
International Flood Initiative(IFI)

International Flood Initiative (IFI) is a joint initiative in collaboration with UNESCO (IHP), WMO, UN/ISDR, UNU, IAHS and IAHR.

IFI launched in Jan. 2005 at the World Conference on Disaster Reduction in Kobe, Japan.

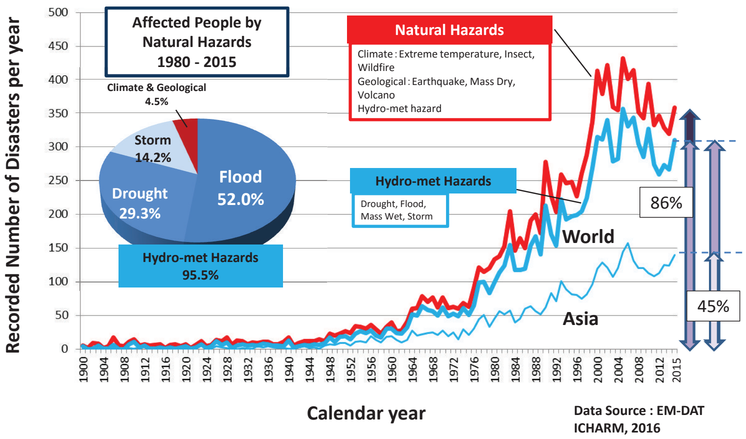
ICHARM is the secretariat of IFI.

In Close Collaboration with:



Increasing & Evolving Disasters

Disaster trend from 1900 to 2015



Data Source : EM-DAT
ICHARM, 2016

Necessary activities

1. Think how to mitigate damages caused by water-related disasters which have been increasing and intensifying recently considering local issues (limitation of data and resources)
2. Use of advanced scientific technology for flood risk reduction considering operational systems in the target areas and climate change impact in the future
3. Support Local Practices with Capacity Building

8

2. ICHARM models (IFAS/RRI)

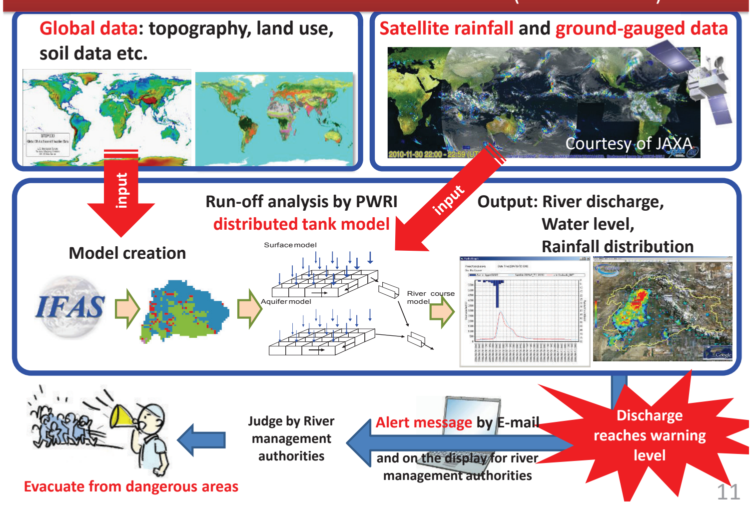
9

Background of IFAS development
Challenges in developing countries

	proposed solutions
1) Insufficient observed data (past and real time data) → Difficulty of flood forecasting, assessment of risk and future planning	Using Global data from satellite with in-situ data putting into distributed hydrological model (High computer performance)
2) Limitation of budget → Difficulty of developing infrastructures, establishing a flood forecasting system	Developing and providing free software
3) Need for capacity building → Difficulty of maintaining and operation of the system	Providing training to get necessary knowledge and skills for operation and upgrading the system

10

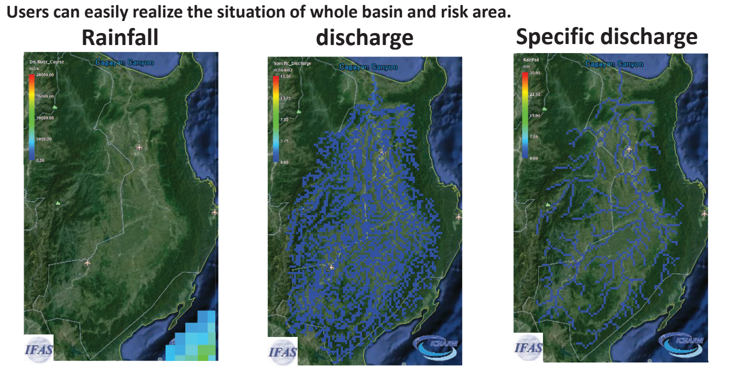
Integrated Flood Analysis System (IFAS)
Flood EWS for insufficient observed basin (free software)



11

IFAS Dynamic Map

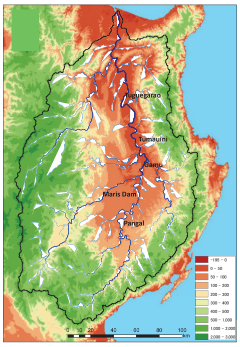
Specific discharge, discharge and rainfall can be displayed as a basin-wide animation.
Users can easily realize the situation of whole basin and risk area.



Critical level: 0.76
Alarm level: 0.39
Alert level: 0.23

Specific discharge ($m^3/s/km^2$) means the value of discharge divided by upper catchment area.

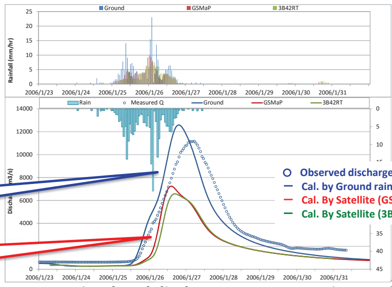
IFAS calculation in Cagayan river basins in the Philippines (ADB project)



Cagayan River

27,280km^2
5 rainfall stations
5 water level stations

Gamu station



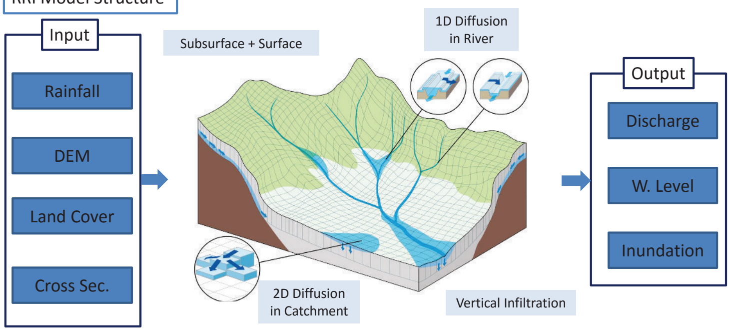
Ground rain gauges input results in good accuracy

Satellite observed precipitation input needs bias correction by ground rain gauges.

IFAS simulated discharge at Gamu station

13

RRI (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

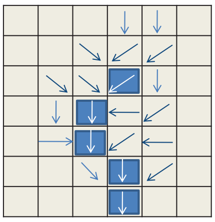
Sayama, T. et al.: Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, *Hydrological Sciences Journal*, 57(2), pp. 298-312, 2012.

14

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

Distributed R-R Model

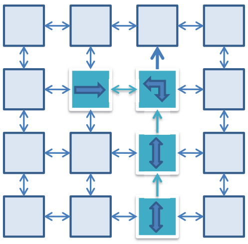
Flow directions are fixed based on topography



1D Kinematic (or similar)

RRI Model

Flow directions change based on water levels



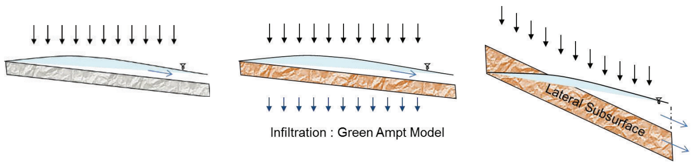
2D Diffusive

15

Three Conditions of Surface / Subsurface Flow

Surface / subsurface flow conditions

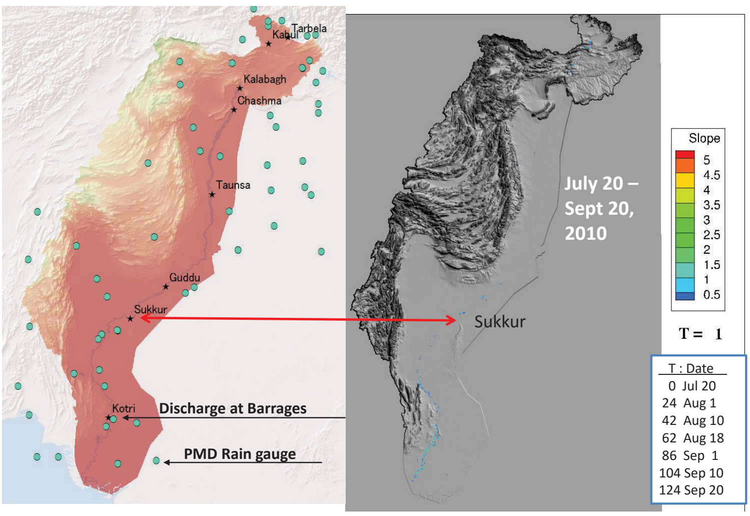
- (A) Only overland flow (no infiltration loss, no subsurface flow)
- (B) Vertical infiltration + Infiltration excess overland flow
- (C) Saturated subsurface + Saturation excess overland flow



Need to check for semi-arid regions: soil moisture accounting and crusted soil

16

RRI simulation for UNESCO-Pakistan project

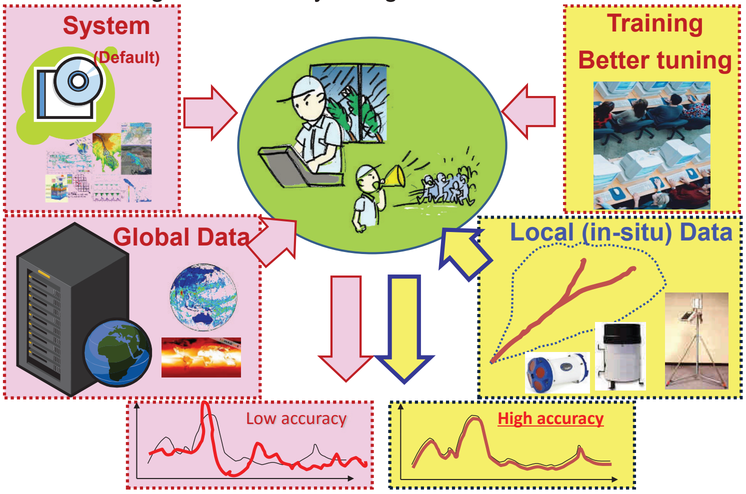


Hydrological observation

1. **Precipitation**
   - ・Ground gauges (manual / telemetry system)
   - ・Radar system (need calibration)
   - ・Satellite (need calibration)
2. **Water level (stage) gauge** (manual / telemetry system)
3. **Discharge**
   - a) Multiply velocity by cross section
     - Velocity observation:
       - ・propeller current meter
       - ・radio wave current meter
       - ・float observation
       - ・acoustic Doppler current profiler(aDcp)
       - ・digital image analysis
   - b) Convert from WL into discharge by using rating curve
4. **Flood marks**
   - ・WL (remained floating wreckage, etc)
   - ・inundation area (manual recording, airplane-shot, UAV)

18

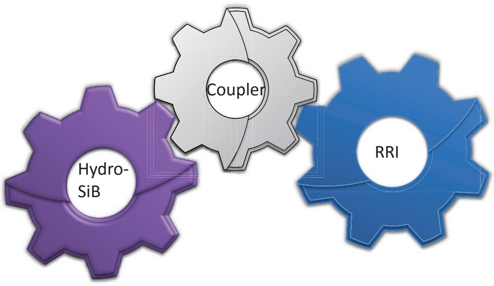
Importance to enhance Local Ownership of flood forecasts and to strengthen in-situ hydrological observation network



IFAS Training for Arab countries in Cairo, 2015
organized by UNESCO Cairo office

20

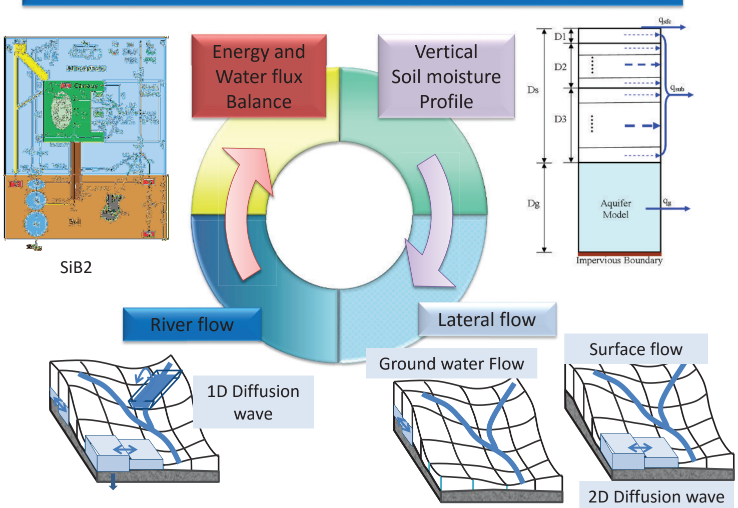
Water and Energy based Rainfall-Runoff-Inundation (WEB-RRI) Model



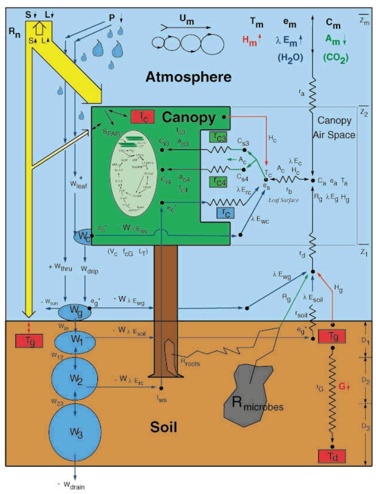
WEB-RRI coupling model

- ✓ Water and Energy Budget-based Distributed Hydrological Model (WEB-DHM) (Wang et al., 2009)
  →Simple Biosphere Model-2 (SiB2) with a hydrological model
  - ✓ Semi-distributed and kinematic wave model and thus not capable of simulating runoff-inundation processes.
- ✓ Rainfall-Runoff-Inundation (RRI) model (Sayama et al., 2010)
  → Rainfall-runoff-inundation simultaneously (2D diff. wave eq.) RRI is lacking in estimating the energy-water related processes (e.g. soil moisture, canopy interception, evapotranspiration, and heat fluxes)
- ✓ WEB-RRI (SiB2 + RRI) was developed improve the estimation of water and energy budget processes and initial soil storages
  - ✓ to enhance the RRI model for flood forecasting and early warning applications
  - ✓ long-term simulations for climate change scenarios without any estimated BC .

WEB-RRI: 4-Components Model Structure



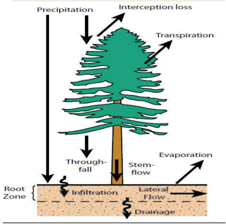
1. Energy and Water flux Balance (SiB2)



Forcing data
1. Precipitation
2. Downward solar radiations
3. Downward long wave radiation
4. Air temperature
5. Humidity
6. Wind speed
7. Cloud cover

1. Energy and Water flux Balance (SiB2)

Canopy Interception

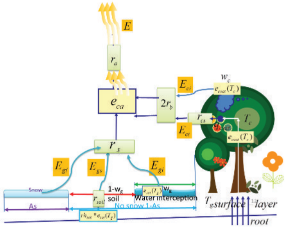


$$\frac{\partial M_{cw,s}}{\partial t} = P - (D_d + D_c) - E_{ci}/\rho_w$$

$M_{cw,s}$ Water or snow interception(m)
D_d Canopy throughfall rate(m/s)
D_c Canopy drainage rate(m/s)
P:Total rainfall rate(m/s)
E_{ci}: Evaporation from canopy

Max interception =depends on land use type

Evapotranspiration



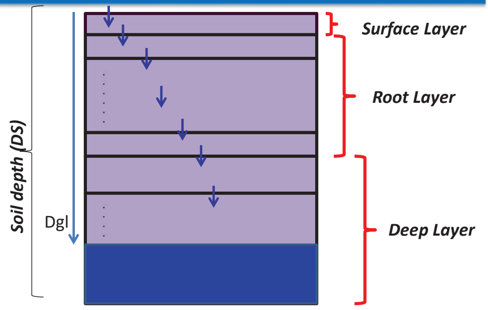
$$E = E_{gi} + E_{gs} + E_{ci} + E_{ct}$$

E_{gs} soil evaporation
E_{gi} Evaporation from ground interception
E_{ci} Evaporation from Canopy interception
E_{ct} Canopy transpiration

2. Vertical Moisture distribution

Sib2 adopts 3 layer soil model to calculate

- *Infiltration and percolation*
- *Soil moisture changes*



Each Sib2 layer further divided to several layers

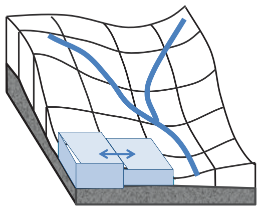
$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K + D\frac{\partial \theta}{\partial z}\right]$$

Richard's Eq. to estimate moisture changes in each layer

$$rech. = K\left(\frac{\psi_g - \psi_n}{\Delta z_{g,n}} + 1\right)$$

Darcy's Eq. for recharge

3. Lateral water flow: 2D Diffusive Wave Model



Under the diffusion wave approximation, momentum eq. are

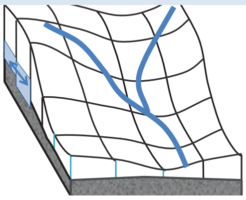
$$q_x = -\frac{1}{n}h^{5/3}\sqrt{\left|\frac{\partial H}{\partial x}\right|}\,sgn\left(\frac{\partial H}{\partial x}\right) \qquad q_y = -\frac{1}{n}h^{5/3}\sqrt{\left|\frac{\partial H}{\partial y}\right|}\,sgn\left(\frac{\partial H}{\partial y}\right)$$

The RRI model spatially discretizes mass balance eq. as

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

where ${q_x}^{i,j}, {q_y}^{i,j}$ are x and y direction discharges from a grid cell at (i,j).

Ground water Flow



Dgl is measured from surface, so H → -Hs

$$q_x = -khs\left(\frac{\partial Hs}{\partial x}\right) \qquad q_y = -khs\left(\frac{\partial Hs}{\partial y}\right)$$

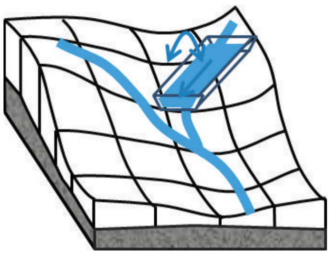
$$\frac{dhs^{i,j}}{dt} + \frac{{q_x}^{i,j-1} - {q_x}^{i,j}}{\Delta x} + \frac{{q_y}^{i,j-1} - {q_y}^{i,j}}{\Delta y} = rech.^{i,j}$$

where ${q_x}^{i,j}, {q_y}^{i,j}$ are x and y direction discharges from a grid cell at (i,j).

Sayama et al., (2010).

4. River Routing : 1D Diffusive Wave Model

River Routing

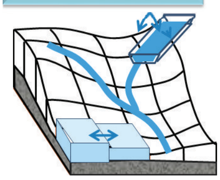


$$q = -\frac{1}{n}h^{5/3}\sqrt{\left|\frac{\partial H}{\partial x}\right|}\,sgn\left(\frac{\partial H}{\partial x}\right)$$

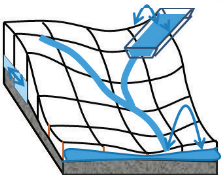
where
q - discharge at a river cell (i,j),
$sgn\left(\frac{\partial H}{\partial x}\right)$ - direction of flow based on water level

Interactions

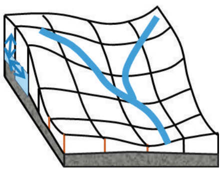
Surface flow-River Interaction



Ground Water-River Interaction



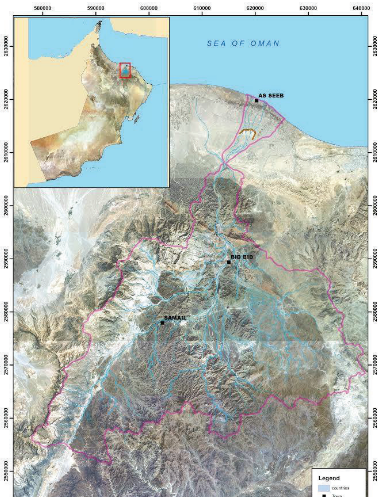
Ground Water-Soil Moisture Interaction



31

3. Application in dry regions

Application of WEB-RRI to Wadi Samail in Oman

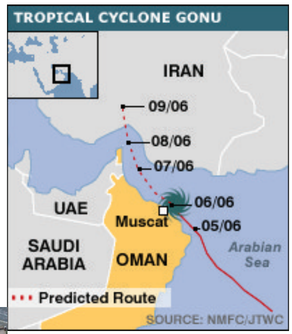


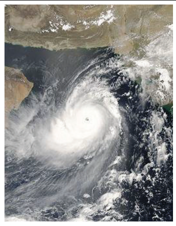
Cyclone Gonu hits Gulf state of Oman

A powerful cyclone was passing near the Gulf state of Oman, brought heavy rains to the capital, Muscat.

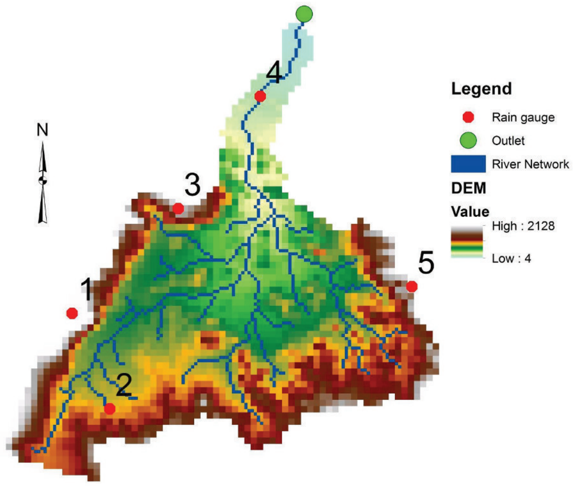
Reports said that Cyclone Gonu (Category Five hurricane) is the strongest to hit the Arabian Peninsula since records started in 1945.
http://news.bbc.co.uk/2/hi/middle_east/6722749.stm

The cyclone caused 50 deaths and about $4.2 billion in damage (2007 USD) in Oman, where the cyclone was considered the nation's worst natural disaster.

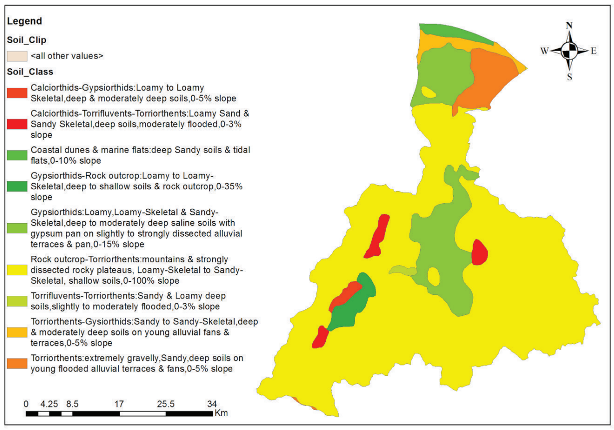




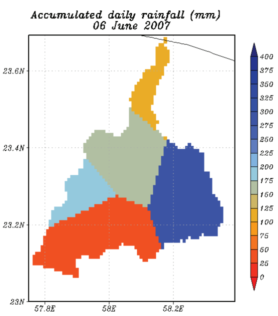
Wadi Samail and its rain gauges in Oman

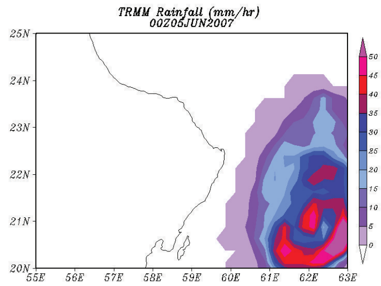


Soil type of Wadi Samail in Oman

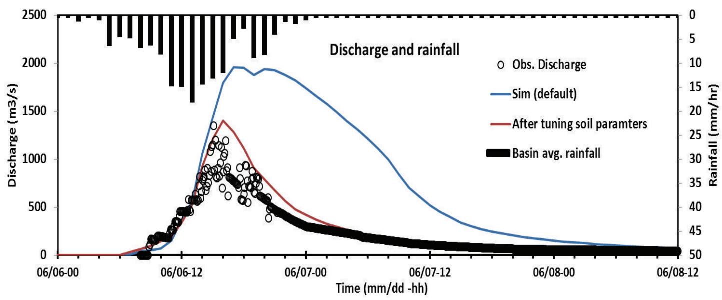


Rainfall data in Wadi Samail





A simulation case of the 2007 flood in Wadi Samail in Oman by WEB-RRI model



Setting soil depth
Tuning parameters especially for infiltration (hydraulic conductivity)


Thank you for your attention
Miyazaki, Japan