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ORIGINAL ARTICLE

How to Analyze Climate Change Impact and Optimized Dam Operation

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Abstract: This study focuses on the impact of multi purpose dam volume reallocation as an adaptation policy of climate change. However there is a "trade-off" problem between water resource and water supply. We should evaluate this "trade-off " problem quantitatively. According to the analysis, the reallocation method is suitable for adaptation policy without significant cost.

Keywords: climate change, dam volume reallocation, adaptation policy

1. INTRODUCTION

1.1 Background

Climate change influences water resources and flood disasters. IPCC AR4 reports heavy rain will increase in mid-latitude regions. A Japanese policy report from the panel on infrastructure development in Ministry of Land, Infrastructure, Transport and Tourism (MLIT) indicated that the risk of flood and drought will increase. Thus, adapting climate change policies to river development is important.

However the MLIT white book has warned that the infrastructural investment budget will decrease because of financial difficulties and a dwindling population. Worse yet, renewal and maintenance costs will increase and exceeded the entire infrastructural investment budget, which indicates that new construction of infrastructure may become a challenge. Therefore, using existing stock is important for adaptation policy under climate change.

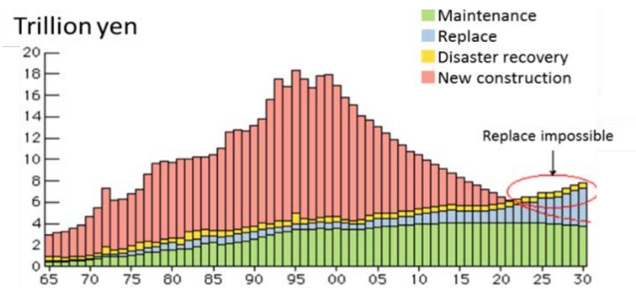

Figure.1 Infrastructure investment budget.

1.2 Objectives

The development of a multipurpose dam is important for water resource management and flood control. However there is a "trade-off" problem between water resource and water supply. But if small flood increases the dam water level and returns immediately. The risk of drought may decrease with less dam volume. We should evaluate this "trade-off " problem quantitatively. This paper focuses on how to evaluate the reallocation of multi purpose dam volume reallocation from water use to flood control and "trade-off " problem using global climate model (GCM) and hydrology model.

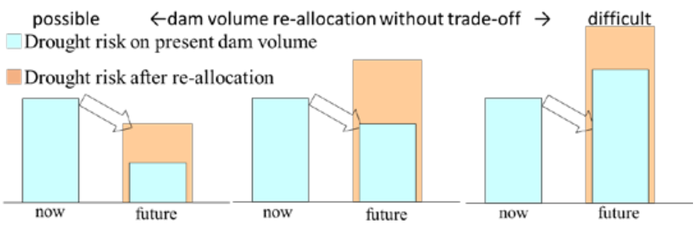

Figure. 2 Three patterns of conceptual figure of drought risk shift in future

1.3 The Global Circulation Model (GCM)

GCM is a numerical model of the atmosphere, ocean, cryosphere, and land surface. Presently GCM is used for weather forecasts and climate change projections under various scenarios.

However GCMs have some limitations, the most

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notable of which is uncertainty. Each GCM has uncertainty. There are two approaches for limitation. One is to perform an ensemble climate experiment, another is multi GCMs approach and the other is to apply a multi GCMs approach. A multi GCMs approach analyzes the common trend obtained from several GCMs, which is considered the probable projection.

The second problem facing GCMs is the temporal and spatial resolution. GCM resolution is insufficient for quantitative analysis of hydrological processes. Therefore, a downscaling (DS) process is necessary. The DS method has two types. One is dynamical DS using a fine resolution regional climate model (RCM). Another is the statistical DS (SDS), which aims to match observation data. Dynamical DS can simulate physical characteristics , however it requires significant computing resources. Moreover RCM contains its own uncertainty. On the other hand, SDS requires less computing resources, it was chosen in this multi GCM approach.

The third problem is the bias between the GCM output and observational data and thus a bias correction (BC) is necessary. However this study conducted the correction at the observed stations, thus, SDS can resolve these problems at the same time.

1.4. HYDROLOGICAL DISCHARGE MODEL

The hydrological discharge model can simulate river discharge and evapotranspiration from rainfall and weather data. This model is classified based on its purpose and on a temporal scale. The short term model can model flood discharge over days. The long term model can model low flow and water management over a few months or several years. Another classification is the model structure. Grid-based models can model flood discharge including the land use change and concentrated heavy rain. Physical-based models contain some components including land surface model and river channel model. WEB-DHM is selected in this study. This model was developed to model both the short and long terms simultaneously. This combined approach is important for multi purpose dam analyses. This structure is based on grid system and physical representation..

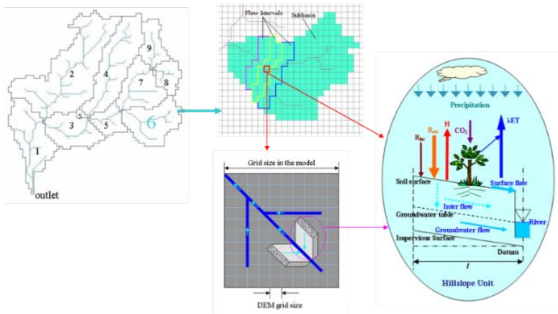

Figure.3 Concept of WEB-DHM

1.5 TARGET BASIN

The target basin is the Kino River located in the Wakayama and Nara Prefecture. This basin contains the Odaigahara plateau which is very famous because of heavy rain. In this basin, there are some multi-purpose dams based on the design of a comprehensive river development plan. In this basin, the flood risk is severe. Annual rainfall in Odaigahara reaches 4000 mm and daily rainfall reaches 1000 mm. The risk of drought is also severe too. Hence, the water supply system in here is complex. The water from the Kino-river is supplied to the Yamato plain outside of this basin, and for covering this loss, the Kino River receives water supplied from the Kumano River.

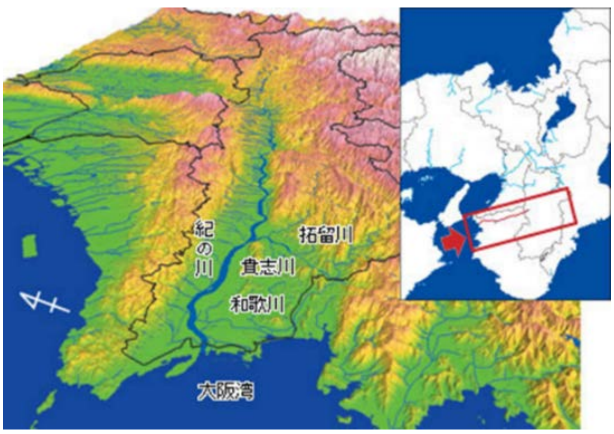

Figure. 4 Target basin

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2. GCM OUTPUT HANDLING

2.1 GCM selection

The first step of the selected GCMs contains the following outputs:

・Daily rainfall and weather data

・Past century representation in 40 years (20c)

・Emissions Scenarios A1B in 2050/2100

24 GCMs were selected and evaluated finally for their ability to model over a large area of East Asia. 11 GCMs is selected in this study.

Table.2 Selected GCMs

Country	Model	略称
Japan	MIROC3.2(hires)	miroc-h
Japan	MIROC3.2(medres)	miroc-m
Japan	MRI-CGCM2.3.2	mri
France	CNRM-CM3	cnrm
USA	GFDL-CM2.0	gfdl20
USA	GFDL-CM2.1	gfdl21
USA	GISS-AOM	giss-aom
Germany	ECHAM5/MPI-OM	mpi
Canada	CGCM3.1(T63)	cccma63
Canada	CGCM3.1(T47)	cccma31
Italy	INGV-SXG	ingv

2.2 Spatial SDS and BC

Figures 5 and 6 show the annual and daily rainfall, and number of rainfall days between in each observational data point and GCM past century output.

Based on the discharge analysis, all of the rainfall between heavy raining periods, which causes flooding, to small rainfall periods match the statistical parameters of the observation and GCM.

First, the GCM rainfall and observational rainfall were distinguished as “heavy rainfall” and “normal rainfall”, and the threshold is minimum value of annual maximum rainfall.

Figure. 7 shows the rate of “heavy rainfall” in each month. “Heavy rainfall” is centered in the Baiu season and typhoon season as shown in Fig. 8.

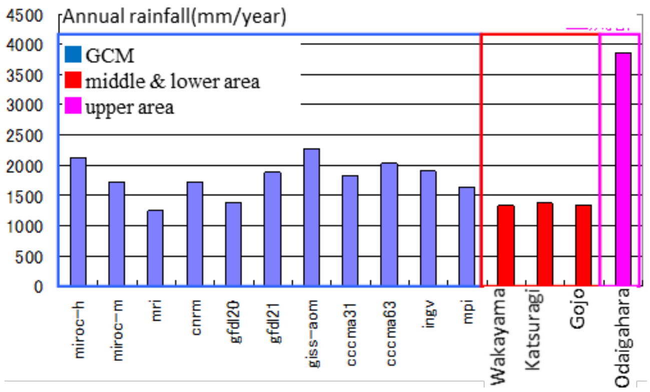

Figure.5 Annual rainfall

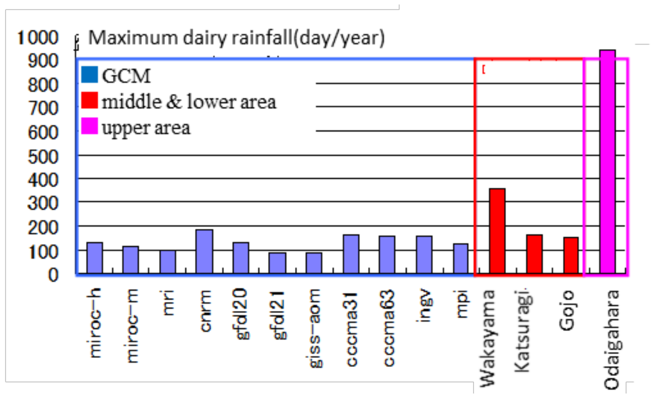

Figure.6 Maximum daily rainfall

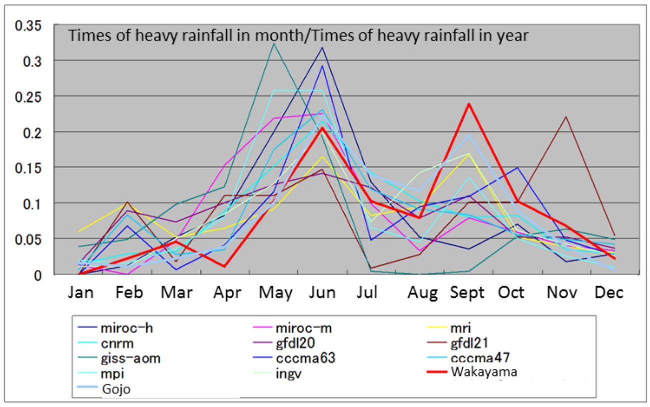

Figure.7 Rate of heavy rainfall frequency (month/year)

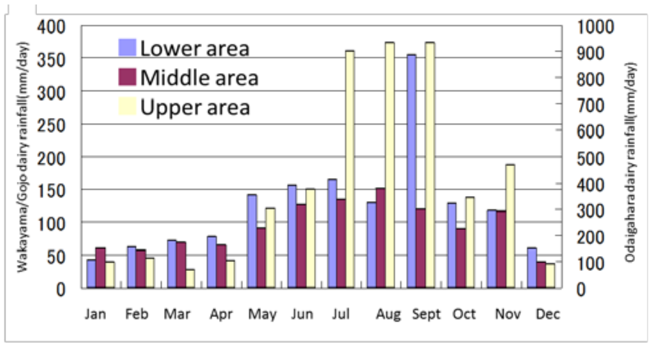

Figure.8 Maximum daily rainfall in each month

"The heavy rainfall", amounts are the same value of rainfall in the past century representation and future projection, The corrected value from GCM should be the same as observational data, and an increased value in the future projection should be converted according to the same relation. The method of Dettinger and Wood is suitable for the analysis the risk of drought, but in these studies, the rainfall data group is divided by each month. In this basin, typhoon and Baiu rain front are the keys for water management. This figure shows maximum daily rainfall in each month. The upper region near Odaigahara is divided into three groups. One is the typhoon season (July/August/September), followed by frontline rainfall and an extraordinary typhoon season (April/May/October/November), and the other months are non-flooding periods.

It's important to note that when this method is expanded to a new target basin, grouping is the most important factor.

The middle and lower basin, whole data was treated as one group. Quantile mapping was used. for heavy rainfall regions. Heavy rainfall values are distributed in "a long tail" descending order curve. Thus, heavy rainfall periods produced by the GCM output and observational data were converted to log-normal values, and averages and variance of each rainfall value were calculated.

"Normal rainfall" periods in GCM output are converted based on the descending order of their rank. If you find 20 mm/day in the GCM output, at first change this value to the rank in the entire GCM output data, like as " e.g., rank 360 in 40 years × 365 days.". Next search the 30 mm/day relatively same rank such as "rank 270 in 30 years × 365 days" in observational data. Following this correction, the corrected GCM annual rainfall rate and the number of days of rainfall will match the one of the observed data.

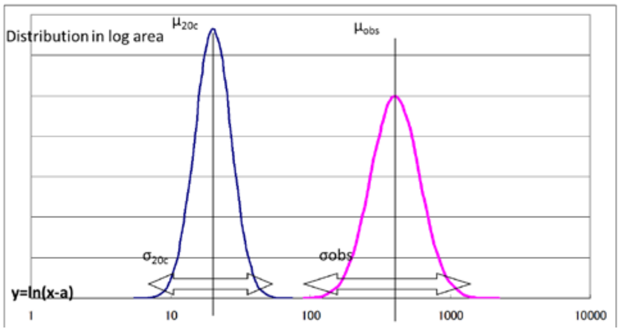

Figure.9 Annual maximum rainfall distribution

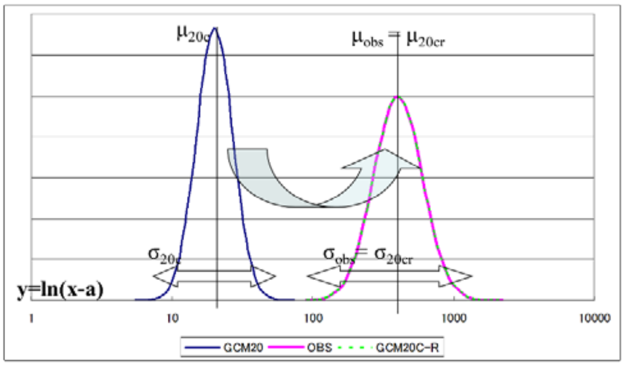

Figure.10 Annual maximum rainfall distribution and of the observation and corrected GCM in 20c

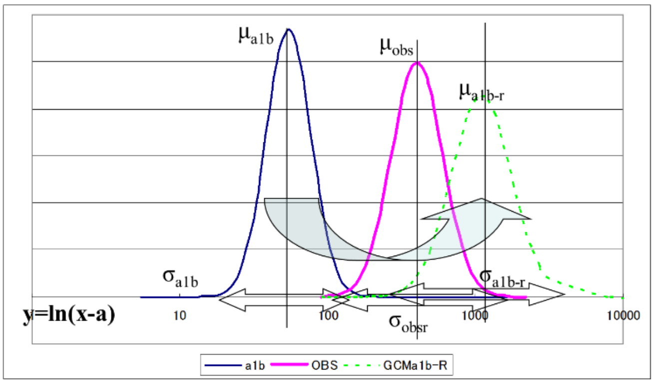

Figure.11 Annual maximum rainfall distribution and of the observation and corrected GCM in the future.

2.3 Temporal SDS

The GCM output is daily. However, this is not sufficient for hydrological analysis of flood risk.

Thus, the corrected GCM output data should be changed from daily data to hourly data. For this purpose an autoregressive model is useful.

At first, hourly rainfall in each day was divided by daily rainfall value 10 classes in each observation point. In each class, some parameter was tallied. Additionally, daily GCM data was converted to hourly rainfall data according to the parameters of the same rank of observed data.

In this basin, each point of the observation exhibits a different rainfall amount. Thus, middle and lower area, hourly rainfall were independently generated in random numbers. For maximum rank of the upper area, hourly rainfall was generated from expanded Isewan-typhoon rainfall pattern.

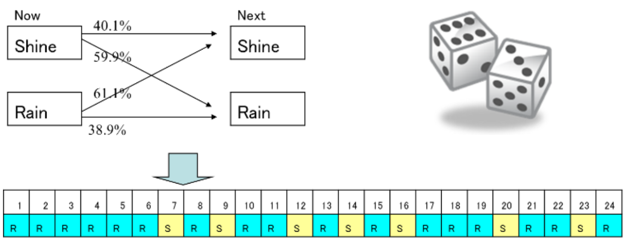

Figure.12 Generation of shine/rainfall pattern

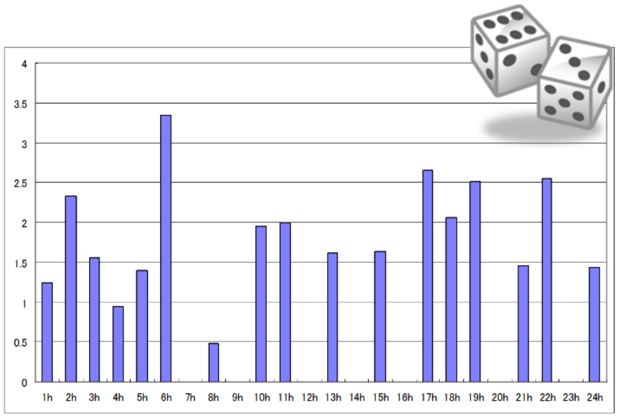

Figure.13 Hourly rainfall generation.

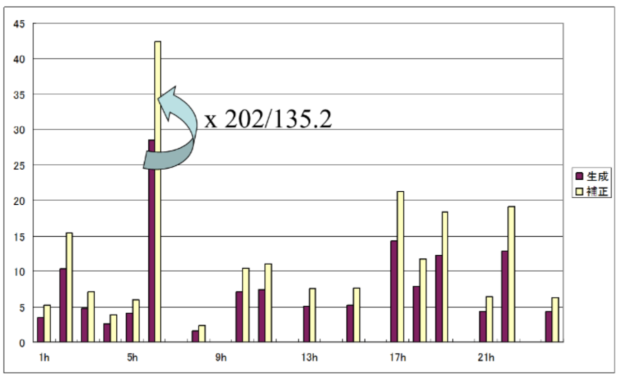

Figure.14 Correction of hourly rainfall

2.4 Results of SDS and BC

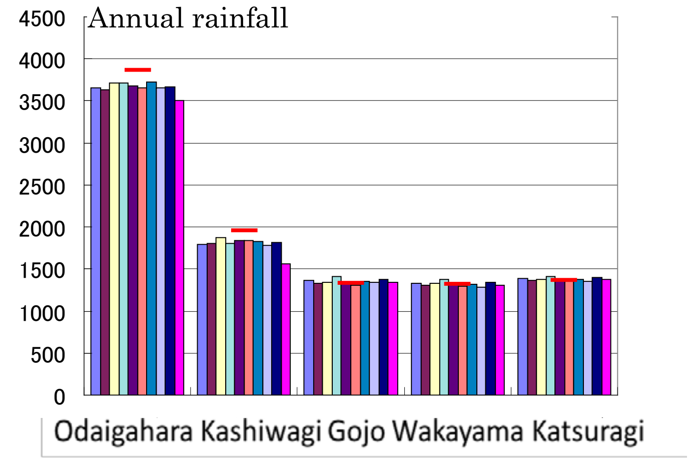

Figure.15 Annual rainfall of corrected GCMs and observations.

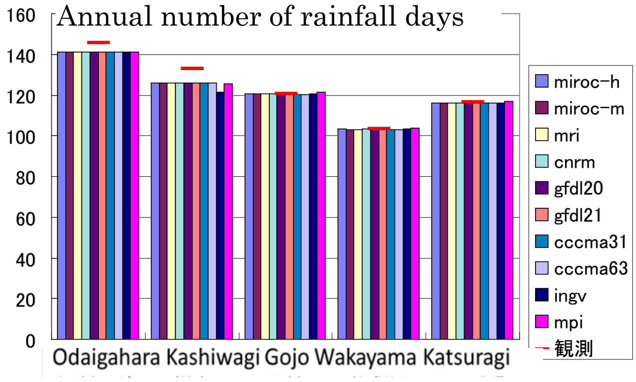

Figure.16 Annual days of corrected GCMs and observation

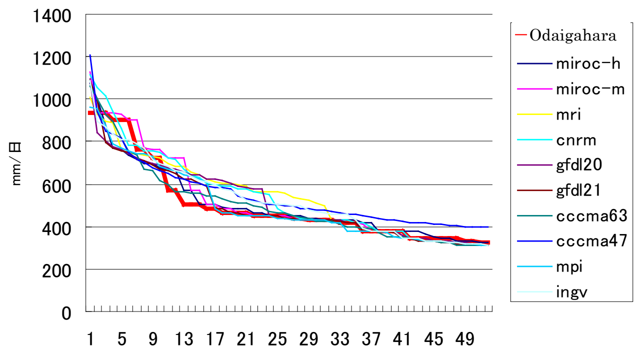

Figure.17 Daily GCM rainfall and observations in Odaihgahara.

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3. DISCHARGE　MODEL CONSTRUCTION

3.1 Grid size

Grid size has a problem with tradeoffs. While the resolution mode has good representation, but fine resolution model can accurately represent the observations, it requires significant computing resources time. The rough resolution model requires less computing resource and time, but it may not able to model the concentrated heavy rainfall and river network structure.

In this study, the grid size was set to 500 m according to the original digital elevation model (50 m) and radar rainfall data resolution (5 km).

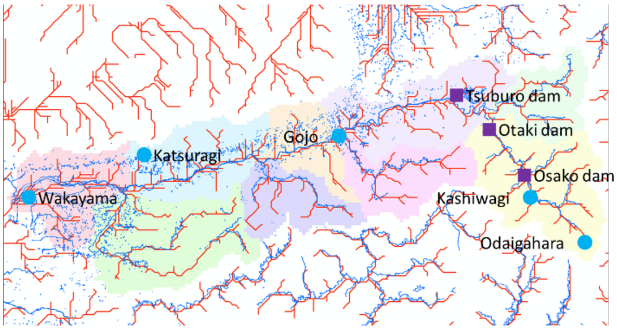

Figure. 18　Model of basin (—generated stream line —actual river ■dam)

3.2 Input data

Weather data is generated from the AMeDAS observational points.

Rainfall data generated two types. One is generated from an observation station. In this basin, there two groups of rainfall observation stations, the JMA AMeDAS station and the river manager's station. The former is uniformly-distributed and selected for middle and lower regions. The latter is concentrated near dam area and selected in upper regions.

3.3 Calibration result for past flood

Next 2 figures show the result of past flood representation in the point located near river mouth. Figure.20 shows the result of representation in flood at 1990. Figure.21 shows the result of representation in flood of Isewan Typhoon which is the largest flood in this basin.

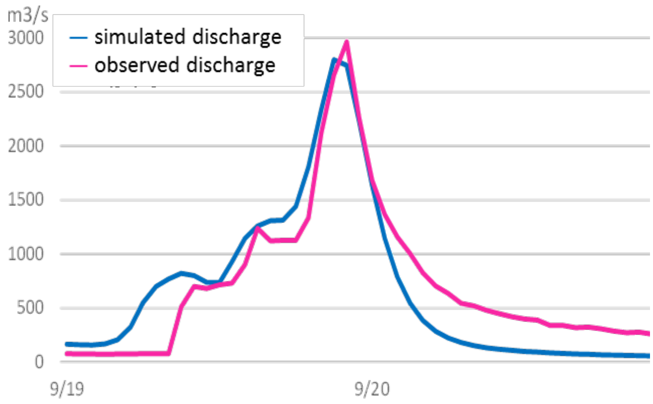

Figure. 19　Representation of flood discharge at 1990.

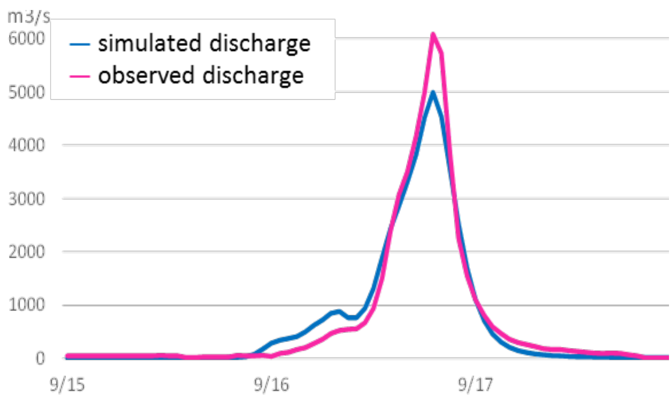

Figure. 20　Representation of flood discharge of

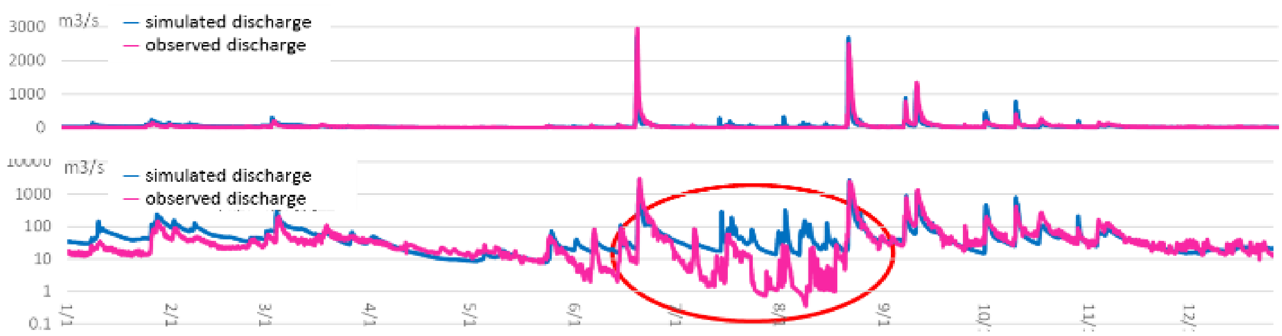

Figure.21 Representation of long-term discharge at 2001.

Isewan Typhoon.

And next figure shows the result of long term discharge in 2001.Lower figure shows logarithmic discharge for emphasis of low flow. The difference of simulated discharge and calculated discharge in summer season is caused by water use for irrigation and city water. Figure. 21

3.4 Verification of corrected GCM data

Next figure shows the verification of descending order curve about daily average river discharge calculated from corrected GCM rainfall and observed rainfall using WEB-DHM.

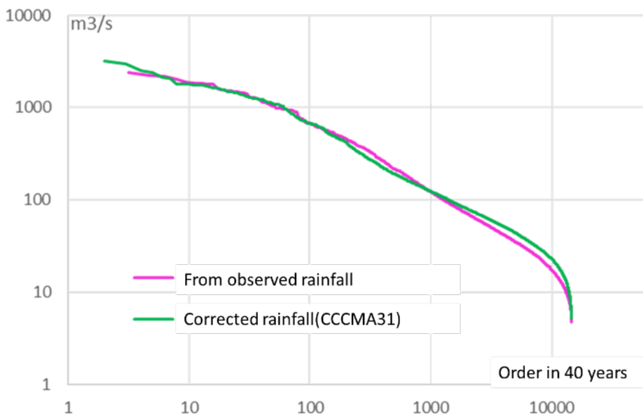

Figure. 22 Descending order curve of daily discharge.

4. DAM OPERATION ANALYSIS

4.1 Flood risk and drought risk

In most GCMs, the flood frequency increase. Regarding the risk of drought, the target period is from June to September according to the water use system. Some indexes of drought level is available. One is “droughty water-discharge” which means the 119 rank of 122 days. However there are no common trends.

Another drought index is the number of days when the discharge was shorted due to the demand. The threshold is 30 m3/s in the Funato station. In most GCMs, the number of days of drought decreases.

This difference means that in the future heavy drought will come and discharge will become stable in non-drought periods.

4.2 Significance of dam operation analysis

The analysis in the previous chapter focused on the risk of flood and drought separately. If the discharge falls below the demand, the multipurpose dam seizes the flood and supply water. If a flood occurs following a severe drought , the dam water level recovers to the standard. Thus, a separate analysis is inefficient for this problem.

4.3 Dam operation analysis

In this analysis, input data is used to simulate discharge in the Funato station. The parameters are flood and water demand threshold, flood control dam volume, and water use dam volume.

The dam volume is at a set level at the beginning of the simulation. The set level refers to the water use volume.

If the discharge exceeds the flood threshold (6,000 m^3/s), flood water is stored in the dam volume. After flooding, water level recovers to the initial water level.

If the discharge falls below the water demand threshold of 30 m3/s, the dam supply pooling water in the water use volume of dams to the river. In this water supply operation, water level becomes lower than given level. If rainfall comes when water becomes lower than the initial level, water level recovers to the initial level.

Dam volume is divided into flood control volume and water use volume. On the surface, there is trade-off problem, however there is the hypothesis that frequent floods quickly recover the water level and water use becomes stable.

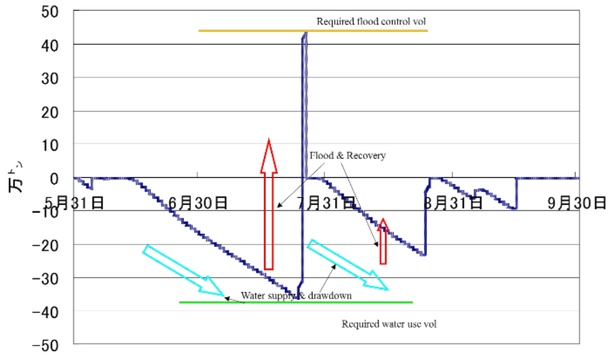

Figure.23 Dam storage water curve

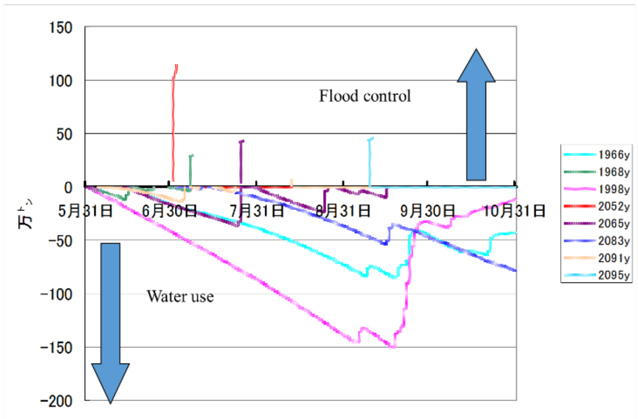

Figure.24 Change in the dam storage water over time.

4.4 Dam volume

In this basin, there are three large dams. The Otaki dam is a multipurpose dam, and the Osako and Tsuburo dams are irrigation dams.

The Otaki dam operation and dam volume allocation has 3 patterns, a non-flooding period, No1 flood period, and No2 flood period. The Otaki and Osako dam volumes can change their purpose from water use to flood control.

Table.2 Dam volume distribution

	non−flood		No1−flood	
10^5m3	flood	water use	flood	water use
Osako	27	−	27	−
Tsuburo	25	−	25	−
Otaki	71	0	31	45
sum	123	0	83	45
	No2−flood		max reallocation	
	flood	water use	flood	water use
Osako	27	−	0	27
Tsuburo	25	−	25	−
Otaki	15	61	0	76
sum	67	61	25	103

4.5 Flood hazard mitigation effect analysis

If the flood control volume is filled, the dam loses its ability to control floods . At this point, the dam becomes a “zerocut operation,” which means the dam releases the water at the same rate it is supplied.

Dam volume reallocation effect can be evaluated based on the number of times the dam can avoid the “zero-cut operation”.

Figure.21 shows the number of times the flood control operation became a “zerocut operation” at the present flood control volume and re-allocated volume.

In some GCMs, “zero-cut operation” can be avoided with flood control priority volume allocation.

Moreover, even if the dam becomes a “zero-cut operation” in the re-allocated dam volume, the “zero cut operation” becomes delayed, and the peak flow decreases. Figure.22 shows the flood in MPI 2082. The dam volume re-allocation delays the zero-cut operation by four hours, and peak flows are decreased by 2000 $m^3 s^{-1}$.

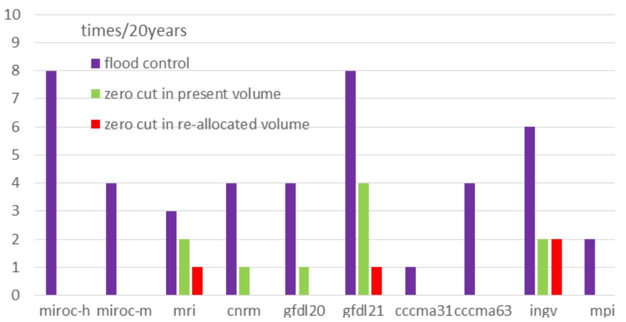

Figure.25 Flood control frequency in 2050

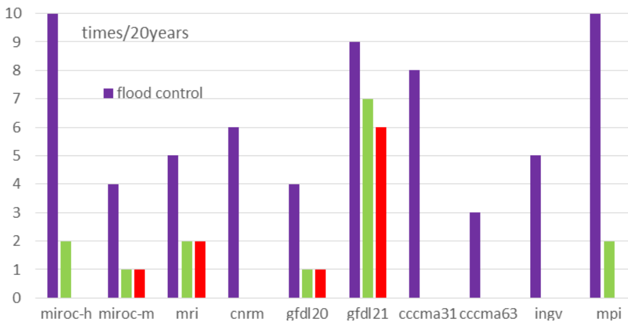

Figure.26 Flood control frequency in 2100.

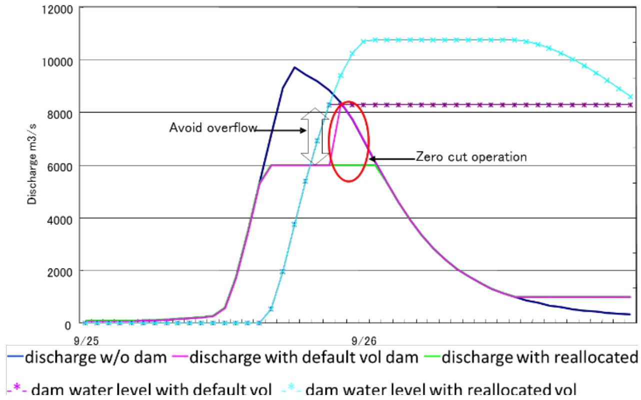

Figure.27 Concept of zero cut operation and its deferment effect.

4.6 Drought risk analysis

At first, Figure.24 shows the required water use volume to hold an equivalent volume lost to drought with present climate and present water use volume. If the required water use volume decreases, the decreased volume can be used to re-allocate flood control volume without the trade-off problem. As a result, 5 GCMs are available in 2050, and 6 GCMs are available in 2100 without trade-offs. The result of 2 GCMs (miroc-m and ingv in 2050) shows that the number of drought days will decrease without the dam, but the required dam volume will increase. This means drought will decrease most of the time, but more severe drought is likely. Thus, an adaptation scenario should be considered for this aspect(α in Table.3)

From a different perspective, the maximum dam volume re-allocation is a fixing condition because the flood risks outweigh the short-term risks of drought. Figure 26 shows the number of drought days

.

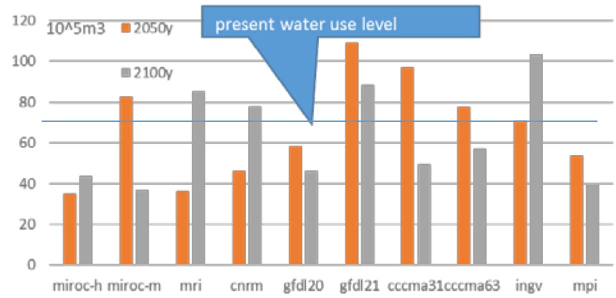

Figure.28 Required dam volume for water use

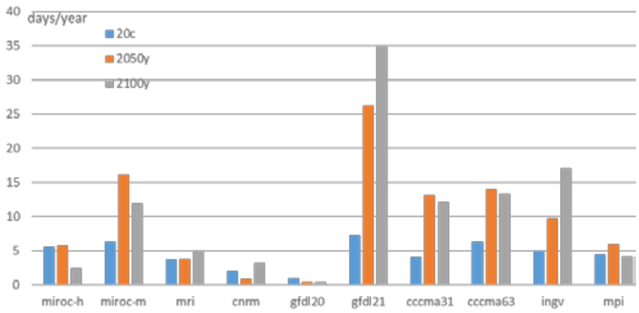

Figure. 29 Number of drought days with minimum water use volume

Table.3 Evaluation in each GCM

	2050y	2100y
miroc-h	O	O
miroc-m	α	O
mri	O	β
cnrm	O	β
gfdl20	O	O
gfdl21	×	×
cccma31	Δ	O
cccma63	Δ	O
ingv	α	×
mpi	O	O

- Drought risk will decrease→little trade-off O
- Only flood risk will increase→ simple trade-off Δ
- Drought and flood risk will increase→ ×
- We should think alternative approach for both risk.

- Drought risk will decrease in most year,but sometimes heavy drought will come.: α
- With reallocated small water use volume trade-off problem will decrease.: β

5. Conclusion and recommendations

5.1 Dam volume re-allocation in response to adaptation policy

The GCM output contains uncertainty. Thus, the results of analysis for future projection may be incorrect. In some GCMs, there are large differences between the projection in 2050 and that in 2100. If the river manager constructs facilities used for only water use or flood control, these facilities lose their utility value. However, dam volume re-allocation does not have this problem.

According to climate and socio-economic conditions, the dam volume can be changed.

However, sometimes dam volume re-allocation needs dam renovation. For example, Tsuruda dam located in Kyushu island is now under construction to add a new spillway tunnel near the bottom. This cost is lower than the cost for new construction, but there are many difficulties and special approaches needed to modify existing dams.

5.2 Dam operation analysis for social management

In many countries, dams play important roles in power generation, flood control, water supply, and irrigation.

Large dams are costly in terms of construction and maintenance. Thus, the government and dam operators should make an effort for sustainable maintenance and management.

Also, climate and the condition of the dam will change following the planning period. Even the social environment will change with economic development. Additionally, water needs will change.

The demand for irrigation water has decreased rapidly in Japan as well as the demand for industrial water and city water. Hydropower, especially pumped water, plays a greater role in power generation, than non-pumped water.

As a result, some multipurpose dam plans were terminated and thus flood control can be achieved only by river channel development. In this regard, the dam volume re-allocation has an advantage.

Conversely, water needs in developing countries will increase, and urban development changes land use, so the flood risk will increase. As a result, the problem of trade-offs worsens. Thus, this dam operation analysis is growing in importance.

5.3 Model modification and update for social management

For analysis this dam reallocation policy, accuracy damage analysis for both of drought and flood is necessary. 1D unsteady model with discharge rate from WEB-DHM and river channel cross-section shape can calculate the water level at any time step and point.

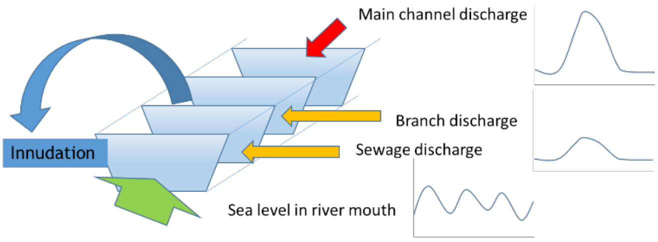

Figure.30 Concept of 1D unsteady model

Additionally, the 2D inundation model can calculate water depth and velocity of inundated flood water in a city region with fine resolution digital elevation map (DEM), and the water level in a dike break point.

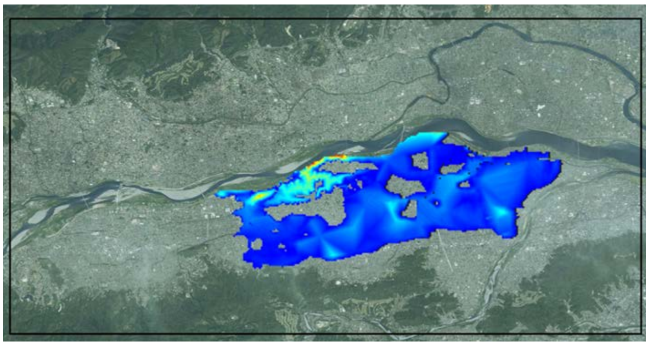

Figure.31 Image of 2D inundation model output

Water depth of output of 2D inundation model can be used to predict the loss of life and property. For example the LIFEsim model developed by the United States Army Corps of Engineers can analyze the loss of life in a flood. This model has been validated in Hurricane Katrina.

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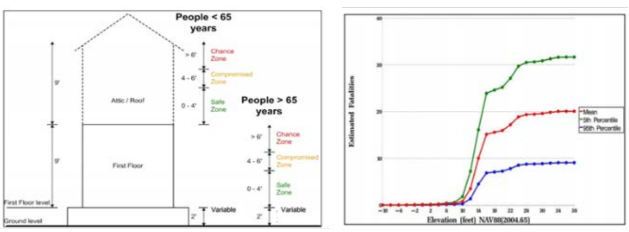

Figure.32 Concept of LIFEsim

To analyze the economic losses from a drought, the KUT group uses an inter-industry relations table. This method can also be used to estimate the economic impacts of flooding. Presently, the economic impacts of flooding are calculated based on the direct property and building damage, and their operating losses. However, this method represents a broad category of economic loss, for example, blocking of supply chain.

5.4 Requirement of dam operation analysis

Many factors are necessary for the analysis of dam operations. One is discussion about the rule and policy of dam operation and water user. Presently the rule is fixed from the era of planning with the consensus of stakeholder, so the discussion and new consensus about dam operation when dam operation rule is changed.

Another requirement is the threshold, and the definition of flood and drought. These questions include when and where will the flood occur if the discharge exceeds the threshold? What defines the severity of drought? Duration? Frequency? Season of occurrence?

Accuracy and the richness of hydrological data are basic for the analysis.

REFERENCES

IPCC,2007:*IPCC Fourth Assessment Report*

Panel on Infrastructure Development of Ministry of Land, Infrastructure, Transport and Tourism 2008: *Climate Change Adaptation Strategies to Cope with Water-related Disasters due to Global Warming*

Ministry of Land, Infrastructure, Transport and Tourism 2005 : *WHITE PAPER ON LAND, INFRASTRUCTURE AND TRANSPORT IN JAPAN*

RL Wilby, SP Charles, E Zorita, B Timbal, P Whetton, LO Mearns 2004 : *Guidelines for Use of Climate Scenarios Developed from Statistical Downscaling Methods*.,IPCC

PCMDI 2008 : *CMIP3 Climate Model Documentation*, References, and Links,http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php,(Last date accessed: 2012/4/23)

Dettinger, M.D./ Cayan, D.R., Meyer, M.K., and Jeton,A.E. 2004 : Simulated hydrologic responses to climate variations and change in the Merced, Carson,and American River basins, Sierra Nevada, California,1900-2099, *Climatic Change*, 62,10.1175/1520-0442

Wood, A.W., Leung, L.R., Sridhar, V. and Lettenmaier,D.P. 2004 : Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs, *Climatic Change*,62,10.1029/2008JD010800

Sellers, P.J, Randall, D.A, Collatz, G.J, Berry, J.A, Field, C.B,Dazlich, D.A, Zhang, C, Collelo, G.D. and Bounoua, L. 1996 :A Revised Land Surface Parameterization (SiB2) for Atmospheric GCMS.Part I: Model Formulation, *Journal of Climate*,114,10.1016 /j.jhydrol.2009.08.005

Yang, D. 1998 :Development of a geomorphology-based hydrological model for large catchments,*Journal of Hydroscience and Hydraulic Engineering*,337

Wang, L, Koike, T, Yang, K, Jackson, T, Bindlish, R. and Yang,D. 2009 :Development of a distributed biosphere hydrological model and its evaluation with the Southern Great Plains Experiments (SGP97 and SGP99), *JOURNAL OF GEOPHYSICAL RESEARCH*,,

Wang, L., T. Koike, K. Yang, and P. Yeh 2009 :Assessment of a distributed biosphere hydrological model against streamflows and MODIS land surface temperature in the upper Tone River Basin,*Journal of Hydrology*

Kohei Yoshimura,Toshio Koike 2015 :DAM VOLUME REALLOCATION BETWEEN FLOOD CONTROL AND WATER USE AS AN ADAPTING POLICY UNDER CLIMATE CHANGE IN KINO RIVER BASIN,*Journal of Hydroscience and Hydraulic Engineering*,59

Ministry of Land, Infrastructure, Transport and Tourism 2012 :*The outline of Tsuruda Dam redevelopment*,http://www.qsr.mlit.go.jp/sendai/tsuruta-damu/pdf/tdr.pdf,(Last date accessed: 2015/10/25)

Kohei Yoshimura,Yoshimitsu Tajima,Hiroshi Sanuki,Yoshihiro Shibuo,Shuji Sato,Toshio Koike 2014 :DEVELOPMENT OF REALTIME FLOOD SIMULATION MODEL IN URBAN LOW-LYING RIVER BASIN,*Journal of Hydroscience and Hydraulic Engineering*,70(4)

Yoshimura,Kouhei;Tajima,Yoshimitsu;Sanuki,Hiroshi;Shibuo,Yoshihiro;Sato,Shinji;Lee,SungAe;Furumai,Hiroaki;Koike,Toshio 2014 :Development of river flood model in lower reach of urbanized river basin,*EGU General Assembly 2014,* held 27 April - 2 May, 2014 in Vienna, Austria

Maged Aboelataand David S. Bowles 2008 :LIFESim: *A Tool for Estimating and Reducing Life-Loss Resulting from Dam and Levee Failures,In Proceedings of the Association of State Dam Safety Officials* “Dam Safety 2008” Conference, Indian Wells, CA.

Pongsak SUTTINON, Seigo NASU 2013 : REGIONAL VIRTUAL WATER OF THE SHIKOKU ISLAND: INTER-REGIONAL INPUT-OUTPUT TABLE,*SSMS*,SMS12-9627

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