B−23 **Sensitivity of The River Basin Runoff to Climate Variability**

Urban Engineering Dept., University of Tokyo H. HASSAN
RCAST ,University of Tokyo K. HANAKI
Urban Engineering Dept., University of Tokyo T. MATSUO

1. INTRODUCTION

Global climate change due to greenhouse gases is now a well agreed phenomenon. The earth's climate is not static any long due to the rapid increase of anthropogenic activities. The assessment of the climate change impact on water resources attempts to portray the range of possible physical changes in temperature and precipitation. These changes are likely to affect a wide range of water uses, thus indirectly affecting the socio-economic structure of society. Direct effects of these impacts will introduce a change in the runoff quantity of river basins. This paper presents an approach of developing hydrological models which can utilize climate change scenarios to estimate the percentage changes in runoff. In this study, two hydrological models (annual, monthly) were developed and were applied to several basins, however, simulation results of runoff for both historical and climate change data of Vistula River Basin, Poland, are only presented here. In the application of the annual model, hypothetical scenarios of uniform change in temperature and precipitation changes were formulated and be applied for the annual runoff estimates. On the other hand, the monthly climate change scenarios of GISS and GFDL, based on doubling CO2, were obtained from General Circulation Models, GCM.

2. MODELS DESCRIPTION

2.1 Annual Approach

In long term water balance simulation of a large catchment, an appropriate assumption is that the change in annual basin storage can be neglected and only the effect of temperature, or evapotranspiration, and precipitation on estimating annual runoff can be considered. Accordingly, an annual hydrological model with one calibration parameter was developed. The structure of the model is based on Truc, 1991, relationships. The annual runoff can be estimated as follows;

$$Q_a = P_a\left[1 - \frac{L_a}{\sqrt{cL_a^2 + P_a}}\right]$$

$$L_a = 300 + 25T_a + 0.05T_a^2$$

Q_a = *The annual flow, mm/year*
L_a = *Regression coefficient of runoff to temperature*
P_a = *Annual precipitation, mm/year*
T_a = *Maen annual temperature,* ^oC

where; c is the model calibration parameter. The sensitivity of the estimated runoff to changes in temperature and precipitation are then expressed as partial derivatives;

$$dQ_a = \frac{\partial Q_a}{\partial T_a}dT_a + \frac{\partial Q_a}{\partial P_a}dP_a$$

2.2 Monthly Approach

A lumped integral-conceptual model was developed to incorporate a simple mass balance in conjunction with a temperature-index snowmelt. This is a monthly water balance model which uses multi-annual monthly mean values of precipitation, temperature, potential evapotranspiration, and runoff. It uses previous month storage to compute snow accumualtion, infiltration, actual evapotranspiration and runoff. The monthly basin storage can be expressed as follows;

$$S_{i-1} = Pe_i - S_i - Ev_i - R_i$$

Effective precipitation, snow accumulation, evapotranspiration, and runoff can be expressed as the following set of equations, in i month, mm;

$$Pe_i = \alpha_i(A_{i-1} + P_i)$$
$$A_i = (1-\alpha_i)(A_{i-1} + P_i)$$
$$Ev_i = PET_i(1 - \exp^{-K_e S_{i-1}})$$

$$R_i = \begin{cases} K_g S_{i-1} & \text{for } P_i \le I_i \\ K_g S_{i-1} + \dfrac{(P_i - I_i)^2}{P_i - 4I_i} & \text{for } P_i > I_i \end{cases}$$

$$\alpha_i = \begin{cases} 0 & \text{for } T_i \le T_s \\ 1 & \text{for } T_i \ge T_l \\ \dfrac{(T_i - T_s)}{(T_l - T_s)} & \text{for } T_s < T_i < T_l \end{cases}$$

where; I, infiltration rate can be expressed as;

$$I_i = \left\{ 0.2\left(\frac{1}{K_s} - S_{i-1}\right) \right. \quad \text{for } \frac{1}{K_s} > S_{i-1}$$

Model input data and state variable

Pe_i = effective precepitation at month i, mm

P_i = measured precipitation, mm

PET_i = potential evapotranspiration, mm

S_i = active basin storage, mm

R_i = Basin runoff, mm

Ai = snow accumulation, mm

α_i = accumulation index, ($0 \le \alpha_i \le 1$)

T_i = Air temperature, °C

Model Parameters are:

K_e = Evapotranspiration parameter

K_g = Active basin storage parameter

K_w = Winter basin runoff parameter

K_s = Inverse of the maximum capacity

The model contains six parameters, with two of them being the upper and lower temperature bounds on the freezing and snow melt process, Ts and Tl. "Pattern-Search" optimization technique was modified and applied to estimate the model parameters by minimizing the residual error between the observed and computed runoff.

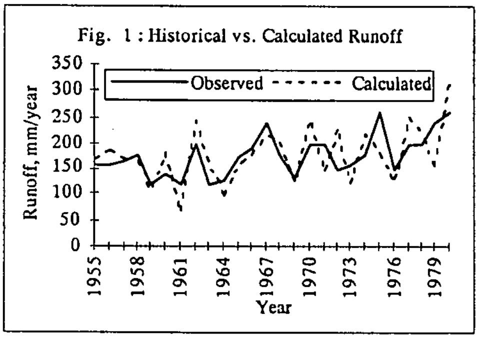
4. CATCHMENT DESCRIPTION

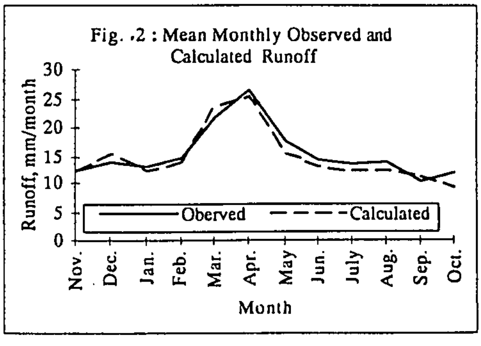
The two developed models were applied to Vistula river basin in Poland (Lat. 52 °N, Long 20° E). The catchment covers an area of 197,376, km^2. The area can be divided into main water sheds; with a mountainous area in the southern portion and numerous lakes in the northern portion. Annual precipitation ranging from 500 to 600 mm, mean annual air temperature 7.5 ° C, and runoff coefficient of 0.3. Historical records were available through 4 flow stations and 14 temperature and precipitation climatological stations. Matching the available records with the data obtained from GCM's scenarios have been taken due to *Ozga M. Zielinska*, 1994, in which one set of data was developed for the whole basin for both historical and climate change data.

5. MODELS APPLICATION

5.1 Historical Results

Fig. (1) and Fig. (2) present the annual and monthly models results , respectively, in which the observed flow was plotted against the modeled values. Both models show that the simulated and observed flow match reasonably well.





For the calibration process, the data was split into two sets, in which the first 13 years were used for calibration process and the next 13 years for validation process. The correlation coefficient for the annual and monthly models were 0.87 and 0.91. The annual average error was 4.9 mm/month and average monthly error value was -7 mm/month.

5.2 Climate Change Assessment

Fig. (3) and Fig.(4) present the sensitivity simulation of the runoff for both models in which, 25 hypothetical scenarios of uniform annual change in temperature, ΔT (0,1,2,3,4), %P (-20, -10,0,+10,+20). were applied for the annual model, and two GCM's models, GISS-GFDL, scenarios were applied for monthly estimates. The annual model presents a linear reduction in the percentage of annual runoff as the temperature increases for all the precipitation change trends. The maximum-minimum percentage of the monthly model outputs are summarized in Table (1);

% Change	GISS	GFDL
Max +R	22.75 - Feb	20.92 - Feb
Max - R	47.88 - April	52.56 - April
Max - Storage	13.98 - Jan	18.65 - April
Max + E.T	30.38 - Feb.	45.60 - Nov.
Max - Snow	83.90 - Jan.	88.03 - Jan

Table (1): Sensitivity analysis results due to GCM's models, ex; 52.56 % reduction in runoff on April can be estimated due to GFDL scenario, and 83.90 % reduction in snow accumulation on January was estimated due to GISS scenario.

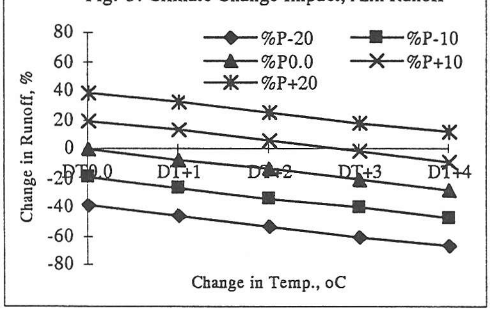


Fig. 3: Climate Change Impact, Ann Runoff

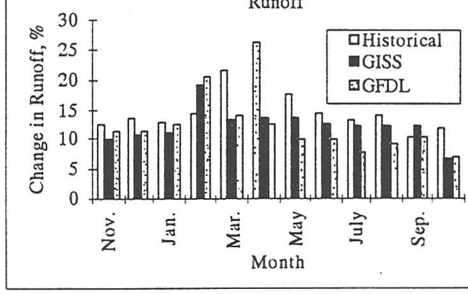


Fig. 4 : Climate Change impact, Monthly Runoff

Impact of climate change due to GCM's scenarios, for monthly model, shows that the simulated values of runoff will be higher than the historical values on two months, Jan and Feb., and lower for almost the rest of year. Results of both scenarios, GISS and GFDL, show that there will be no snow accumulation all over the year except for Jan., (8.78 and 6.53 mm, respectively). An increase of evapotranspiration simulated all over the year, in which a significant increase can be noticed in the summer season, (May - Sep.). On the other hand, a significant decrease in the basin storage will occur from May till September.

6. DISCUSSION AND CONCLUSIONS

There have been a considerable number of efforts to find tools that properly model the impact of climate change on river basin runoff. This work has been an attempt to develop a hydrological model in which the estimation of monthly or annual runoff of basin area can be obtained . Regarding the data characteristics and its availability, two separately models for each time scale have been considered. Results obtained from climate change assessment for the annual simulation, introduced a percentage of change in runoff values ranges between, -66.97 % (ΔT+4, %P-20) and +39.21 % (ΔT0, %P+20). GCM's scenarios were applied for the monthly basis model, in which -20.92 % in the average annual flow can be predicted due to GISS, (Max +22.75 % and Max-47.88 %) . Due to GFDL scenario, -25.21 % average annual flow can be predicted, (Max +20.92 % and Max -52.56 %) . The models results using the 2XCO2 scenarios based assumption should be viewed as a sensitivity analysis rather than a prediction of future water balance. Based on the simulated results obtained from this analysis, an alarm of the distribution and utilization of the fresh water carried upon this basin will have a dramatical effects .

7. REFERENCES

True, Dooge, J.I (1991), *Models and climate change Hydrologic*, J. of Geophysical Research, 97 (D3: 2677 - 2686)

D. Yates, M. Zielinska (1994),*Meso-Scale Hydrologic Modeling for Climate Impact Assessment*, CP-94-14

K. Hanaki (1994), *Towards an Urban Area With Less Emission of Greenhouse Gases*, International Environmental Planning Center, INTEP, The University of Tokyo.

K. Hanaki (1995), *Climate Change and Management of Water Environment*, Journal of Korean Society of Environmental Engineers, J. of KSEE. Vol. 17, No. 8, pp. 713 - 721.