River Water Circulation Model on the Natural Environment

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***Abstract*—**The existing of water is most important element for living human in natural environment. Then, water circulates Model on one river is discussed to one river system as natural environments. This model is constructed with many element models as rainfall model, steam model, evaporation model, and river flow model. On those model, the many simulation is developed with using a formula with the above elements in one area include one river. We simulated the flows trough the underground soil after the rainfall flow. The substantial parameters are from AMeDAS data and detected exactly river flows dates. They are compared with actual survey of the recorded dates to check its accuracy. To develop the simulation model, the System Dynamics was used. As a consequence, a connected rainfall model and river model was constructed as good result.

***Keywords*—**Water Circulate, Underground Water, Rainfall, Tank Model, Simulation, System Dynamics,

I. INTRODUCTION

THE Club of Rome model proposed by Meadows [1] was a point model, and the world was simulated with one model. However, in the case of this model, the simulation of a small range is disregarded, and so it lacks accuracy. To solve this problem, a shift from the point model to the face model is needed in the rainfall model.

In addition, the Club of Rome warned about the environmental problem, but scientific suggestions of how to solve it were not made concretely. Therefore, Yasuda [2] changed the Club of Rome model and created the concept of the Kyoto Club model. Such as a water cycle simulation created only water ground by Taki [3]. In this, the water cycle is not completed.

Therefore, the purpose of the present the purpose of the present study is to create a rainfall model for the Aizu area.

A portion of rainfall and snow fallen on the surface of the ground infiltrates under ground. Another portion flows to a river and a sea through the surface of the ground. It evaporates from the ground and the sea, become clouds in the sky and fall on the ground as rain. Thus, the water circulates continually. Since a river plays a major role in the water circulation, it is a very important element for the natural environment and humans. In order to manage the water circulation, the construction of a simulation model is required.

There are two earlier studies about water circulation in our laboratory. In 2006, we made a water circulation model for virtual river basins[9]. The model represents the appearance of a river flow which consists of rainfall, air temperature and evaporation. We were focused on the relationship between a river and paddy fields in 2007[10]. The model represents how much rice was produced per a certain amount of water consumption of the river in the paddy fields.

The present research focuses to water circulation phenomena around the Agano River in Aizu region. Precipitation is any product of the condensation of atmospheric water vapor that is pulled down by gravity and deposited on the Earth's surface. A portion of rainfall or snowfall on the surface of the ground infiltrates water ground. Another portion flows to river through the surface of the ground. The model is developed on the simulation software System Dynamics tools.

II. THE MODELING OF WATER CIRCULATION ON THE RIVER AREA

2.1 Agano river

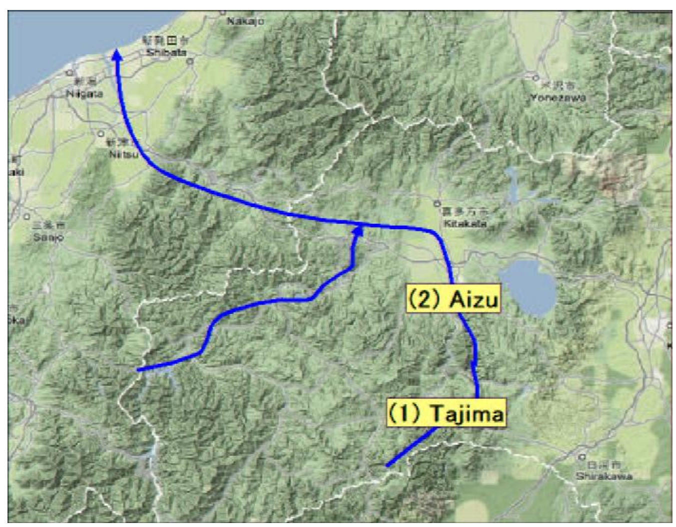

Figure 1, Agano Liver

The river investigated is the Agano River. It flows to the Japan Sea from Fukushima Prefecture via Niigata Prefecture. The length of this river is 210km, the 10th longest in Japan. The basin area is 7,710km2, the 8th widest in Japan. In order to compare the usability of the model, we measure o_ the Agano river area into 2 regions.

In the order of upstream to downstream:

(1) Tajima region

(2) Aizu region

Tajima is a mountain region. Most of Tajima is covered in forests and high mountains. Aizu is a basin-shaped region. A lot of water flows down from surrounding mountains.

2.2 Aizu Area

The Aizu area is the west part of Fukushima prefecture, and the center of that is a basin called the Aizu Basin. The basin is of the largest grade in Japan, and it has a depth of more than 1,000 meters. The basin is oval shaped with a length of about 34 kilometers (north to south) and a width of about 13 kilometers (east to west).

In order to apply the tank model of water circulation, the following models which measured data is required:

(1) Rainfall model with including Snowfall,

(2) Underground water model,

for the Agano River, Those three models are considered in follows tank model.

2.3 Tank Model

The Tank model method is used to calculate the rainfall and underground water. It is widely utilized as an analysis of water cycle. Tank means imaginary water vessel tank.

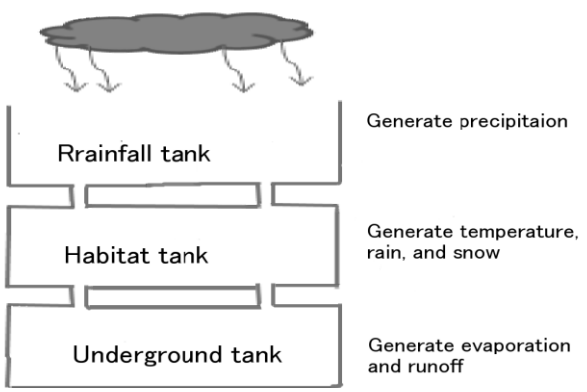

Figure 2, Tank Model

The tank model has to be set several parameters effectually to get accurate simulation model. It is a simple model, yet it has a reproducible method and has been used in a number of studies. Three series-connected tank models are used in this research, as Figure 2 shows, which consist of three vertically-connected tanks. First tank is rainfall tank. It generate precipitation phenomenon as atmospheric state peculiar to Aizu. Second tank is he appearance of a river flow which consists of rainfall, air temperature and evaporation.

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III. Rainfall Model

3.1 Method of Rainfall

The data of rainfall and Snowfall are provided by the Fukushima prefectural government and Niigata prefectural government. They are used as input to the tank model. The flow volume of the Agano River is provided by the Ministry of Land, Infrastructure, Transport and Tourism as shown in figure 3. It is used to compare to the calculation result. In order to apply the waterfall tank model, the following measured data is required:

(1) Temperature

(2) Rainfall

(3) Quantity of evapotranspiration

(4) Humidity

(5) Actual sunshine duration

Daily Temperature, Rainfall, Humidity, and Actual sunshine duration for 2009 are provided from Automated Meteorological Data Acquisition System (AMeDAS) [4] data. Quantity of evapotranspiration is calculated. Measured temperature and rainfall is used to compare to the model's calculated result.

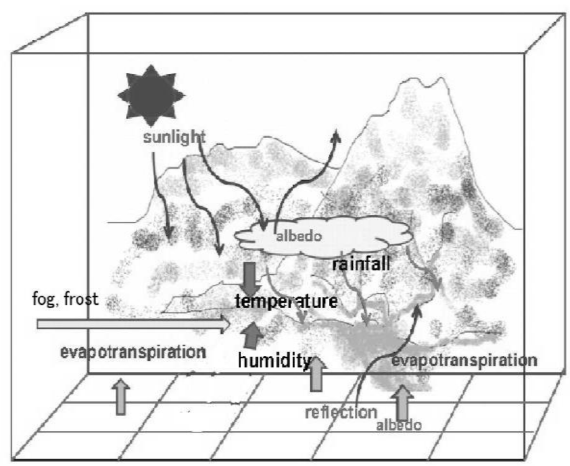

Figure 3, Habitat Tank

3.2 Additional Function

Two functions (temperature and irradiation) are added on the model for accurate rainfall model.

3.2.1 Temperature

As AMeDAS provides data of rain and snow, precipitation needs to be divided into rain and snow to compare with measured data for checking whether the rainfall model output is correct. For the comparison, temperature model is required. The formula for the temperature (T) can be calculated as below [6].

$$T = \sqrt[4]{\frac{I_{00}(1-A)}{22.68*10^{-8}}} \times \sqrt[4]{\frac{1}{1-\alpha}}$$

$$A: albedo, \alpha: 0.054 + steam\ \ pressure$$

$$I_{00} = 1365$$

The albedo is set to 0.1. However, the albedo change from 0.1 to 0.2 in winter because snow albedo is high. The result of the formula is shown as pink line in Figure4. Comparing with measured data, the result is approximation of it.

The temperature model based on the formula is utilized

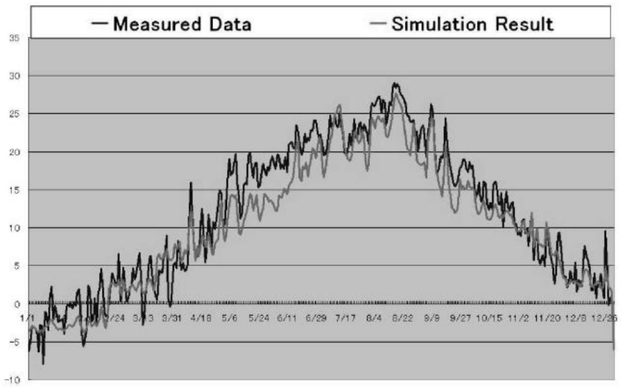

Figure 4, Comparison of the measured temperature data with simulation result in Aizu area into the rainfall model.

3.2.2 Global Solar Radiation

Generally, irradiation is dependence index of steam, and steam is dependence index of temperature. Actual sunshine duration (*N*) are observed at the AMeDAS observatory of all parts of Japan. An average of global solar radiation is estimated using *N* [7]. The global solar radiation in Aizu is calculated as below figure 5. However, data of global solar radiation itself is not found and accuracy can not be checked. Therefore, the rainfall model employs measured data of steam.

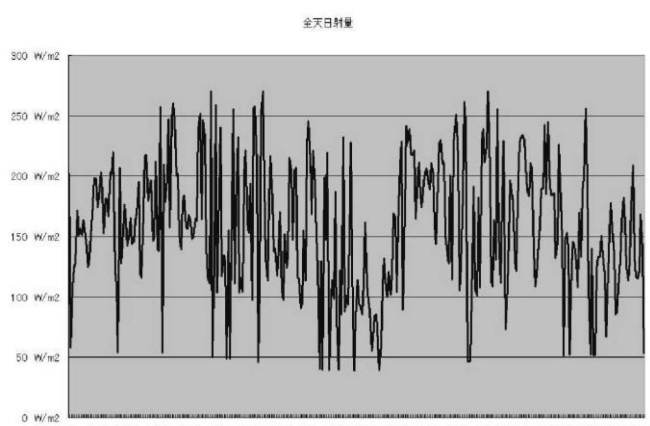

Figure 5, Global solar radiation in Aizu area

3.3 Rainfall Model

Based on temperature model in previous section and Takanashi model [8], The rainfall model is proposed.

According to Takanashi model, the standard deviation (SD) is below.

$$sd = d \times \max(e \times \sin(\frac{2\pi}{8(month)} day + f(month))$$

$$-g, -h \times \sin(\frac{2\pi}{8(month)} day + 3(month))$$

$$*0.8\sin(\frac{2\pi}{g(month)} day)^3 + 0.2,$$

$$\text{d, e, f, g, h, i : environment parameters}$$

The temporary rainfall (TR) is:

$$TR = \max(0, normal(ave, ave*SD)) - 5.4$$

$$\text{ave = (averagera in f all)mm/day}$$

In the current model, ave is set as 5.

Probability of rainfall (PR) is a flag, and if the value is 1, it is rainy, and if the value is 0, it is sunny. Probability of rainfall is :

$$PR = (SD + 2) > 1.8?1:0$$

Rainfall is: $3*(TR > 0?TR:0)*PR$ mm a day

Whether it snow or rain (Figure 6) is judged by the following formula based on steam pressure and temperature[7].

$$Tc = 11.01?1.5*\text{steam pressure}$$

$$\text{Temperature} \le Tc : \text{snows}$$

$$\text{Temperature} > Tc : \text{rains}$$

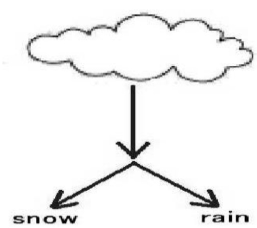

Figure 6, Precipitation

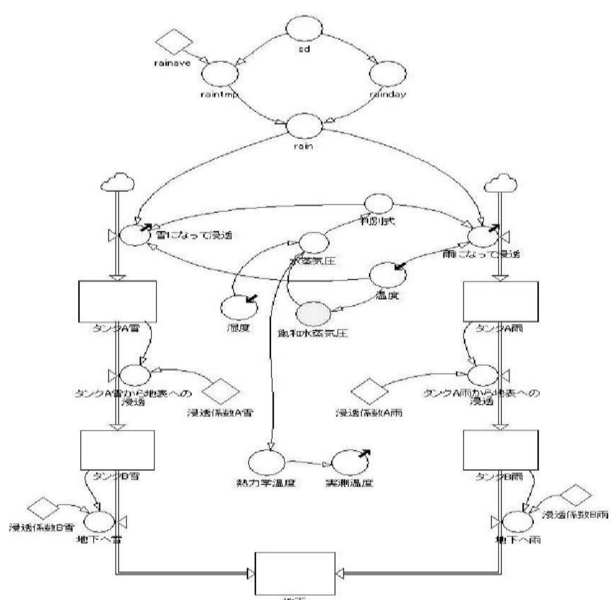

Figure 7, Rainfall Model

Figure 7 shows three series-connected tank models. First tank is rainfall tank, second tank is habitat tank for the Aizu area, and third tank is connection to underground of tank as shown after section. The rainfall infiltrates the tank below from the bottom holes. If it is decided that it snow, rainfall is poured into the left second tank. If it is decided that it rain, rainfall is poured into the right second tank.

3.4 Environmental Parameters in Aizu Area

In the model, suitable parameters which differ depending on regions are need to be applied. Running the simulation model and comparing the measured data in Aizu repeatedly, Beyond the process, the results of rain and snow are shown as in Figure 8 and Figure 9.

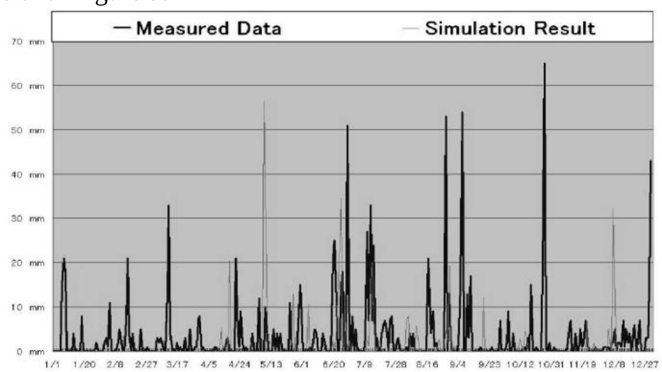

Figure 8, Rainfall simulation result in Aizu area

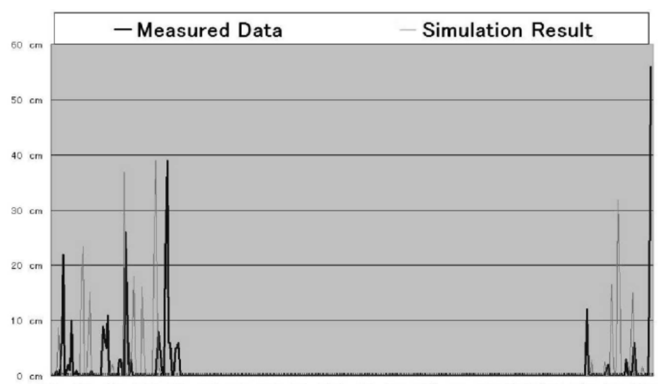

Figure 9, Simulation result of Snow in Aizu area.

Comparison of the measured rain and snow data with simulation result in Aize area have been a good.

IV. The Underground Water Model

4.1 Underground Tank Model

The Tank model method is used to calculate the amount of water infiltrates in the soil and flows out to the river from the soil. The Underground Tank model calculates the amount of the water by regarding the river basin as combination of the tanks. It is developed by M.Sugawara, National Research Institute for Earth Science and Disaster Prevention in 1972. It is a simple model yet a reproducible method and has been used in a number of studies. series-connected tank model is used in this research, as figure 10 shows, which consist of 4 vertically-connected tanks.

Because there is no general method to define the constant numbers, they are obtained by comparison between the actual measured values and the results of repeated calculation by the model. As Figure 10 below shows, the water, rainfall and snowfall, is poured at the top of 4 series-connected tanks.

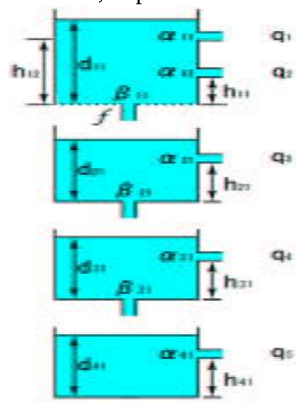

Figure 10, The Underground Tank Model

Water gradually infiltrates the tank below from the bottom holes or runoff from the side holes of the tanks over time. A summation of the runoff from the side holes means runoff to the river at the time. Unless water level reaches the height of the side holes, it does not flow out to the river and water infiltrates tank below.

The formula of the underground tank model is:

$$S_1(t+\Delta t) = \beta_1 \Delta t \cdot S_1(t) - q_1(t) \cdot \Delta t + R$$

$$S_2(t+\Delta t) = \beta_2 \Delta t \cdot S_2(t) - q_2(t) \cdot \Delta t + \beta_1 \cdot S1(t) \cdot \Delta t$$

$$S_3(t+\Delta t) = \beta_3 \Delta t \cdot S_3(t) - q_3(t) \cdot \Delta t + \beta_1 \cdot S_2(t) \cdot \Delta t$$

$$S_4(t+\Delta t) = \beta_4 \Delta t \cdot S_4(t) - q_4(t) \cdot \Delta t + \beta_1 \cdot S_3(t) \cdot \Delta t$$

$S_1; S_2; S_3; S_4$: Water level of each tanks.

$\beta_1; \beta_2; \beta_3, \beta_4$; Infiltration value of infiltration hole at the bottom of each tanks.

$q_1; q_2; q_3; q_4$: Flow out volume from side holes of each tanks.

R : Input of rainfall and snowfall.

Generally, river flow volume increase as it goes to the downstream because a portion of rain and snow infiltrates into underground and runoff to the river gradually. Increased river flow volume in the zone between two measurement points was calculated by subtracting river flow volume at the upstream from downstream.

Next, we applied the tank model method (more details are given in section 4.2) for 2 regions to calculate the runoff volume by using the data simulated with rainfall and snowfall tank model shown Figure 7. We compared the simulation results with measured river flow volume. The run off volume was related to the subtraction of the river flow volume. To examine the effect of forest on the run off, we added 2 functions on the tank model which are the evaporation from plants and ground, and absorption by the plant roots.

4.2 Additional Function

Source of the river is rain and snow fallen on the river basin. Of those sources, water does not run off can be considered as evaporation and absorption. It is considered that the higher the forest area is, the higher the evaporation and the absorption become. We added 2 functions on the tank model. One is the evaporation from plants and ground, and another one is absorption by the plant roots. The evaporation rate is determined by referring to the data about forest area in each region. The rate of absorption from the 2nd tank, which has a role of mid-layer of the earth, is determined constant through a year. If water evaporates and absorbed from the tanks, it effects on the run off volume. With these function, the relation between forest area and run off volume will be shown.

4.3 The Simulation of Underground Tank Model

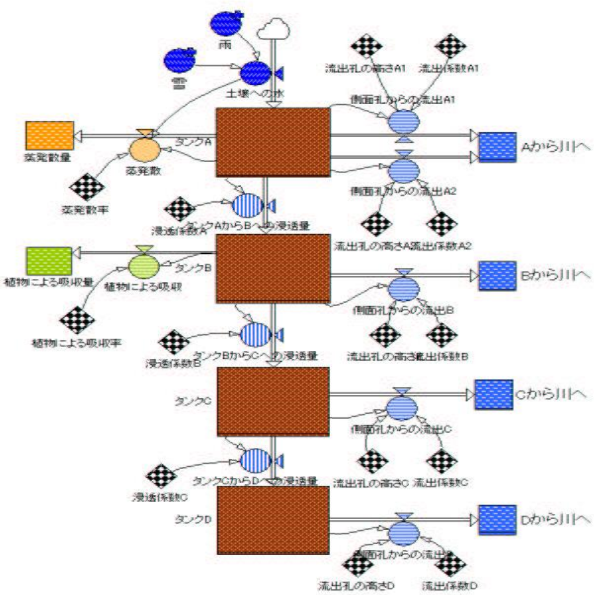

Figure 11, The underground tank model

The underground tank model is constructed 4 series-connected tank model represented with Figure11. Water, rainfall and snowfall, was poured at the top of the tanks. The water infiltrates the tank below from the bottom holes or runs off from side holes and gathered in the river. The thin line connecting icons indicate that they have a mathematical link.

The bold line represents water flow, which goes in the direction of the arrow. The diamond-shaped icon symbolizes constant value. Infiltration rate and the height of the holes belong to this because they do not change through the simulation. The round icons represent parameters of rainfall and flow rate belong to this because they change hourly. The box-shaped icons indicate tanks, and they keep the level of water that flows in constant, and they flow water to the next tank controlled by parameter.

The flow from the 1st tank to the left represents evaporation from forest and ground. The evaporation volume is controlled by the parameter which changes according to the weather. If it rains or snows, evaporation rate becomes low. And if is fine, the rate becomes high. The flow from the 2nd tank to the left represents absorption by plant roots.

We divided the snowmelt process into 2 parts. 50 percent of the snowfall melt into water in a moment and poured into the top tank. Other 50 percent melt one month after.

4.4 The Parameters for Simulation

These parameters are determined by a lot of trial and error approach. The approach is as follows:

(1)Input the tank model parameters used on the Meteorological Office's website as default. It is used to flood alert at river side in Japan. Since they uses the same parameters anywhere in Japan, it is need to be adjusted to accurate the model.

(2) The initial parameter of evaporation is set to 0.3, and absorption is set to 0.05.

(3) Run the simulation and compare the result with measured data.

(4) On the line chart of the tank model, the acute part of the chart is related to the 1st and 2nd tank. The smooth part of the chart is related to the 3rd and 4th tank. Change the parameters of the tanks to reduce the errors between the result and measured data.

(5) Since the parameter of evaporation is considered as related to the forest area, change the parameter referring to the data about forest area.

Figure 12 and 13 shows the parameters of model in Tajima and Aizu. In Tajima, the runoff parameters of 1st and 2nd tank were higher than that of Aizu. It means the time between rainfall and the start of runoff is fast. In Aizu, the parameters of 3rd and 4th tank were higher than that of Tajima. It means Aizu region retains much water in underground.

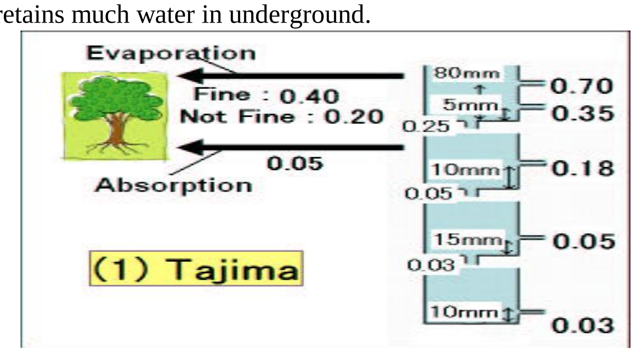

Figure 12, The parameters of the model in Tajima

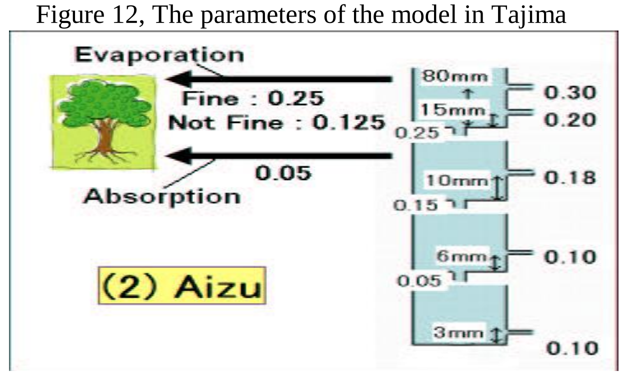

Figure 13, The parameters of the model in Aizu

4.5 Results of the simulation

Figure 14 and 15 shows the Comparison of the measured data with simulation results in Tajima and Aizu.

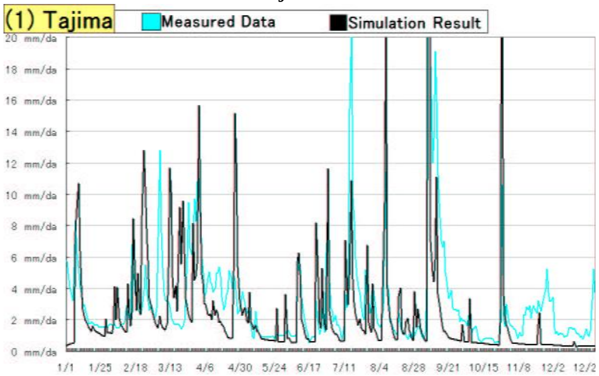

Figure14. The Comparison of the measured data with simulation results in Tajima

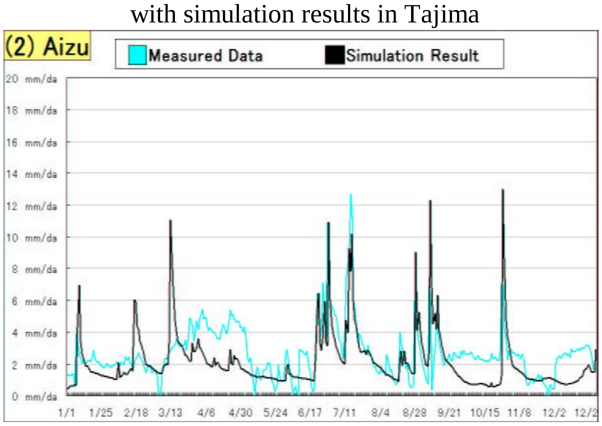

Figure 15. The Comparison of the measured data with simulation results in Aizu

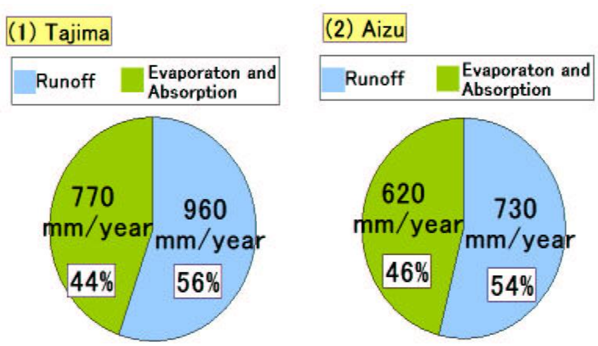

Figure 16. The percentages of water flow from the tanks.

Figure 16 shows percentages of the runoff volume and evaporation and absorption from the tanks. Tajima has 87 percent of forest area. Aizu has 65percent. Comparing Tajima with Aizu.

V. Conclusion

Good results for the rain data, snow data based on the temperature data are gained. Even though some errors occur between the result and measured data, almost values are proximate. These need to be set parameters to complete habitat tank. In addition, this model is expanded into other areas if parameters change. It is useful for weather forecast. To forecast weather, it is necessary that one more tank is set of the rainfall tank and, air mass and the monsoon are simulated. The runoff volume from each tank of underground tank model is succeeding.

The water circulation river model is created with connecting a rainfall tank model and an underground tank model as shown in this discussion.

As Future work, this model has to add frost, fog, and humidity in habitat tank. And it has to apply to other areas. There are several models which have already developed. It is essential to connect them to the water circulation river model for scientific suggestions of environmental problem solutions. Moreover, if the model is extended from System Dynamics into programming language such as C# or JAVA, the model's flexibility will be improved.

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