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Surface Runoff Modeling of Ephemeral Streams Considering Homogenization Theory in Arid Regions, Wadi Assiut in Egypt

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Abstract

It has been stated that the limitation of the development of arid zone hydrology is the lack of high quality observations. This paper introduces a distributed hydrological model of the Wadi system for flood control and water resources management considering the discontinuous occurrence of flow in both space and time. We provide a homogenization method of upscaling hydrologic parameters related to a distributed runoff model from macroscopic aspects up to megascopic ones. Discharge distribution of the Wadi system can be simulated. Transmission losses and their effects on surface and subsurface flow are evaluated. The conjunctive use of surface and subsurface water is recommended. It is concluded that this model is an applicable methodology for distributed discharge in the arid regions.

Keywords: Homogenization theory, transmission losses, Wadi system, Kinematic wave model.

1. Introduction

Understanding of hydrological processes of Wadi system in the arid regions is so important due to the importance of the water resources in such areas. In the arid areas, it is well known that there are many crucial problems, for instances, the shortage of water resources which affects the economic activity and human live and increasing the losses which represent in the evaporation, initial and transmission losses. Despite the critical importance of water in arid and semi-arid areas, hydrological data have historically been severely limited. Moreover, those countries of the arid areas are facing the problem of overpopulation, and consequently the demand of water resources for the agricultural and domestic purposes is needed to overcome this problem. For this reason we selected Egypt as arid region where most of the population is concentrating in the Nile Delta and Nile Valley, so we select it as case study to apply our hydrological model, especially in the Wadi catchments like Wadi Assiut in the eastern Desert. The modeling approach is a powerful tool to simulate the surface water process in the rainfall-runoff analysis.

This study proposes a homogenization method of upscaling hydrological parameters related to a distributed runoff model from microscopic aspects up to macroscopic ones. Homogenization is a mathematical method that allow us to upscale differential Equations (*i.e.* is a mathematical method which provides a means for upscaling of differential Equations). The essential idea of homogenization is to average inhomogeneous media in some way in order to capture global properties of the medium.

The relationship between Wadi flow transmission losses and groundwater recharge depend on the underlying geology. The alluvium underlying the Wadi bed is effective in minimizing evaporation loss through capillary rise (the coarse structure of alluvial deposits minimizes capillary effects). Wheater et al. (1997) and Telvari et al. (1998) stated that surface water and groundwater interactions depend strongly on the local characteristics of the underlying alluvium and the extent of their connection to, or isolation from, other aquifer systems.

Transmission losses in semiarid watersheds raise important distinctions about the spatial and temporal nature of surface water–groundwater interactions compared to humid basins. Because of transmission losses, the nature of surface water–groundwater interactions can be limited to brief periods during runoff events and to specific areas associated with the runoff production and downstream routing (Boughton and Stone, 1985). Walters (1990) and Jordan (1977) provided evidence that the rate of loss is linearly related to the volume of surface discharge.

Andersen et al. (1998) showed that losses are high when the alluvial aquifer is fully saturated, but are small once the water table drops below the surface. Sorman and Abdulrazzak (1993) provided an analysis of groundwater rise due to transmission loss for an experimental reach in Wadi Tabalah, S.W. Saudi Arabia and he stated that about average 75% of bed infiltration reaches the water table.

Much high quality research is needed, particularly to investigate processes such as spatial rainfall, and infiltration and groundwater recharge from ephemeral flows. New approaches to flood design and management are required which represent the extreme value characteristics of arid areas and recognize the severe problems of conventional rainfall-runoff analysis. One reason for the focus of this paper on the arid , semiarid regions to develop distributed hydrological model to overcome the prescribed struggles for water resources management and flood control purposes, in addition to evaluate the transmission loss and its effect on both surface and subsurface water.

Thus, our approach is an integrated numerical model based on sporadic precipitation and under conditions of data deficiency where we developed the watershed modeling by using GIS tool, surface runoff and stream routing modeling based on using the Kinematic wave approximation, the initial and transmission losses modeling estimated with applying SCS method (an empirical model for rainfall abstractions suggested by the U.S Soil conservation Service) and Walter's Equation (1990) respectively, and groundwater modeling based on the linear storage model.

2. The Target Watershed Basin

We aim to study the Wadi Assiut watershed (Fig. 1) which is located in the Eastern Desert of Egypt. Egypt is one of the most populous countries in Africa. The great majority of it estimated 80 million people live near the banks of the Nile River and in the Nile Delta, in an area of about 40,000 square kilometers, where the only arable agricultural land is found).

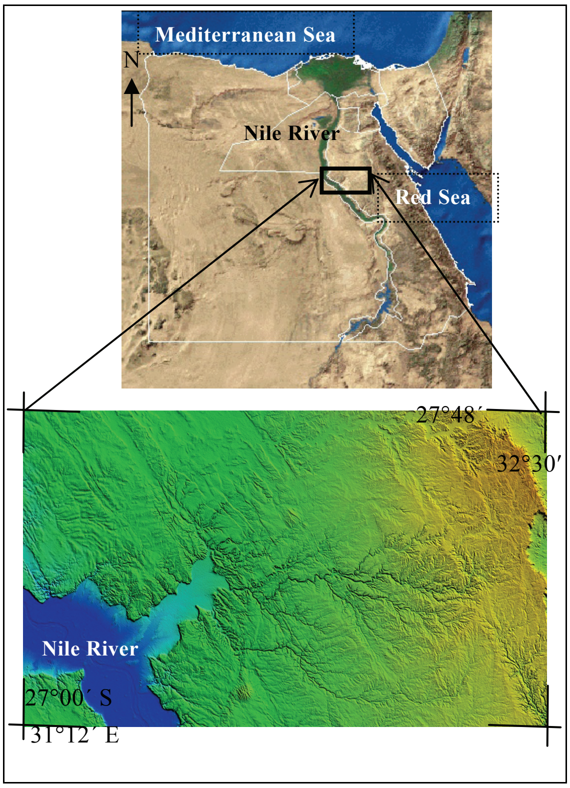


Fig.1 Location map of Wadi Assiut Watershed, Egypt

Wadi Assiut Watershed is located between Long: 32°30′ E & 31°12 W ′ and Lat: 27°48′ N & 27°00 S ′, and it is considered as sub-basin of the Nile River Basin. The total area of Wadi Assiut Catchment is 7293 km^2, the perimeter is 496.91 Km and the length of the main channel is 165.09 km.

Most of its area is a desert except some part of urbanization, and very small areas of agricultures which are closed to Assiut city along the Nile River Basin. So studying this area is important due to the propagation of populations and consequently the need of water resources for agricultural, domestic and manufactory purposes.

Wadi Assiut catchment has undergone a number of improvements over the past centuries, where many of the past studies were applied and many of projects established there due to its importance. Furthermore, it is a good choice for application of the Wadi modeling simulation because its characteristics of the arid conditions for example its drainage system is ephemeral streams and the rainfall is very rare in space and time. Presently, the establishment of new town, which will be in the near future crowded by populations and consequently the importance of hydrological modeling for water resources management and flood threat control, is so crucial.

3. Purpose and Problem Statement

Ephemeral streams are characterized by much higher flow variability, extended periods of zero surface flow and the general absence of low flows except during the recession periods immediately after moderate to large high flow events (Knighton and Nanson, 1997). The scarcity of data and the lack of high quality observations as well as the potentially discontinuous occurrence of flow in both space and time are important characteristics of the ephemeral streams in the arid regions and consequently the difficulty of developing the powerful hydrological models. So, we propose distributed hydrological model showing the characteristics of Wadi system however the scarcity of data and the lack of high quality observations.

Our main purposes are flood control and the water resources management in the Wadi system due to the deficiency of the water resources and the dangerous of the flood threat, and studying the interaction between surface and subsurface water because the ground water considered the important water resources in the Wadi system. Moreover we aim to evaluate the transmission losses and its distribution to know its effect on both of the surface water flow and subsurface water.

4. Characteristics of Wadi System

The arid and semi-arid regions of the world are characterized by the expanding populations, increasing per capita water use, and limited water resources and so on. Rainfall is characterized by extremely high spatial and temporal variability. The most obvious characteristics in the ephemeral streams in the arid areas are the initial and transmission losses in addition to the discontinuous occurrence of flow in both space and time.

4.1 Initial and Transmission Losses

Initial losses occur in the sub-basins before runoff reaches the stream networks, whereas transmission losses occur as water is channeled through the valley network. Initial losses are related largely to infiltration, surface soil type, land use activities, evapotranspiration, interception, and surface depression storage.

Transmission losses are important not only with respect to their effect on stage flow reduction, but also to their effect as recharge to groundwater of underground alluvial aquifers. It was suggested that two sources of transmission loss could be occurring, direct losses to the bed, limited by available storage, and losses through the banks during flood events as shown in Fig. 2.

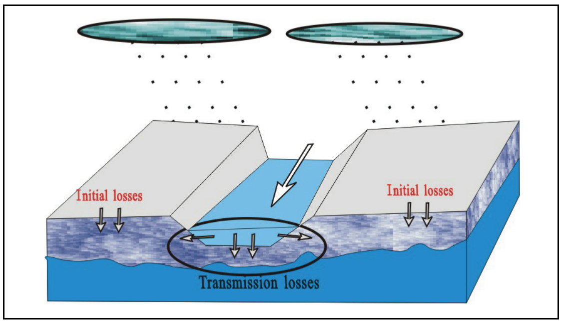


Fig.2 Conceptual model showing transmission and initial losses in the Wadi System

The rate of transmission loss from a river reach is a function of the characteristics of the channel alluvium, channel geometry, wetted perimeter, flow characteristics, and depth to groundwater.

In ephemeral streams, factors influencing transmission losses include antecedent moisture of the channel alluvium, duration of flow, storage capacity of the channel bed and bank, and the content and nature of sediment in the stream flow. The total effect of each of these factors on the magnitude of the transmission loss depends on the nature of the stream, river, irrigation canal or even rill being studied (Vivarelli and Perera, 2002).

It can be concluded that transmission loss is complex, that where deep unsaturated alluvial deposits exist the simple linear model as developed by Jordan (1977) and implicit in the results of Walters (1990) may be applicable, but that where alluvial storage is limited, this must be taken into account.

4.2 Surface and Subsurface Water Interactions

Thus Hellwig (1973) found that dropping the water table below 60cm in sand with a mean diameter of 0.53mm effectively prevented evaporation losses, and Sorey and Matlock (1969) reported that measured evaporation rates from streambed sand were lower than those reported for irrigated soils.

Surface water–groundwater interactions in semiarid drainages are controlled by transmission losses (recharge plus evapotranspiration). In contrast to humid basins, the coupling between stream channels and underlying aquifers in semiarid regions often promotes infiltration of water through the channel bed, i.e. channel transmission losses (Boughton and Stone, 1985; Stephens, 1996; Goodrich *et al*., 1997).

The balance between distributed infiltration from rainfall and Wadi bed infiltration is obviously dependant on local conditions, but soil moisture observations from S.W. Saudi Arabia imply that, at least for frequent events, distributed infiltration of catchment soils is limited, and that increased near surface soil moisture levels are subsequently depleted by evaporation. Hence Wadi bed infiltration may be the dominant process of groundwater recharge.

5. Methodology and Model components

Due to the severe problems in the Wadi system in the arid areas, it is recommended to develop the distributed hydrological models, including surface water/groundwater interactions in the active Wadi channel, sediment transport, evaporation processes and consumptive use of Wadi vegetation, and the wider issues of groundwater recharge. These are challenging studies, with particularly challenging logistical problems, and require the full range of advanced hydrological experimental methods and approaches to be applied.

A distributed hydrological model in the Wadi system is proposed. This model is based on the modification of Hydro-BEAM (Hydrological Basin Environmental Assessment Model) which has been chosen for simulation the surface runoff model and estimation of the transmission losses. Hydro-BEAM was first developed by Kojiri *et al*. (1998) as a tool to assist in simulating long-term fluctuations in water quantity and quality in rivers through an understanding of the hydrological processes that occur within a watershed. It has since been used in a pioneering work on comparative hydrology, where a methodology for assessing the similarity between watersheds was proposed (Park *et al*., 2000), to investigate sediment transport processes in the large watershed of the Yellow River, China (Tamura and Kojiri, 2002), and to investigate pesticide levels in rivers and their effects on hormone levels in fish (Tokai *et al*., 2002).

However, the problems of sporadic precipitation and data deficiency in Wadi Assiut, our approach is physically-based numerical model as shown in Fig. 3.

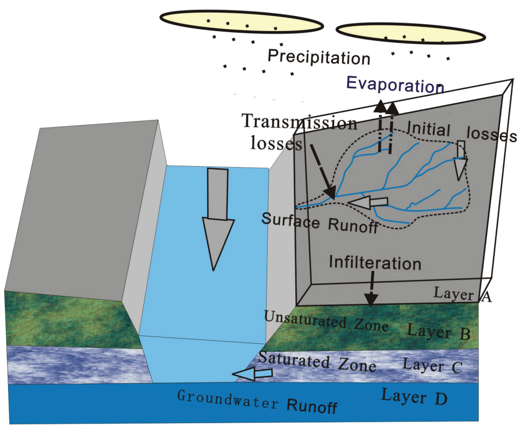


Fig. 3 Schematic conceptual model of Wadi system

The watershed modeling using GIS technique is achieved, surface runoff and stream routing modeling based on using the Kinematic wave approximation is applied, the initial and transmission losses modeling is estimated by using SCS (1985) method (an empirical model for rainfall abstractions suggested by the U.S Soil conservation Service) and Walter's equation (1990) respectively, Groundwater modeling based on the linear storage model is used.

We provide a homogenization method of upscaling hydrologic parameters related to a distributed runoff model from macroscopic aspects up to megascopic ones. A surface flow direction prescribed through a flow routing map is significant to replace the discontinuous flow in the lumped model cell to the homogenized equivalent flow for the simplicity of calculations in the complicated Wadi system based on the conservation of water balance. Where the homogenized parameters (equivalent roughness coefficient n^* and equivalent hydraulic conductivity k^*) are equivalently derived from the mathematically formulated descriptions based on the conservation of surface and subsurface water quantities.

These parameters are relied on Darcy's law and Manning's law with assumption that the calculation of the equivalent hydrological parameters is processed with the flow direction in each model cell as depicted in Figs. 4 and 5. The obtained Equations of the equivalent parameters are different considering the cell conditions, for instances, when we have a regular grid with even longitude and transverse intervals (i.e. the length and the breadth of the cells are the same), we noted that the parameters are depending only on number of cells and independent of the length and breadth of cells as given in equation 1 of equivalent roughness coefficient n^* and equation 2 of equivalent hydraulic conductivity k^*.

$$n^* = \frac{1}{\sum_{j=1}^{\mu} \frac{1}{\sum_{p=1}^{\mu} n_{jp}}} \tag{1}$$

$$k^* = \sum_{j=1}^{\mu} \frac{1}{\sum_{p=1}^{\mu} \frac{1}{k_{jp}}} \tag{2}$$

On the other hand, if we have uneven longitude and transverse intervals, the parameters are depending on them as given in equation 3 of equivalent roughness coefficient n^* and equation 4 of equivalent hydraulic conductivity k^*.

$$n^* = \frac{\gamma}{\beta} \frac{1}{\sum_{j=1}^{\beta} \frac{1}{\sum_{p=1}^{\gamma} n_{jp}}} \tag{3}$$

$$k^* = \frac{\gamma}{\beta} \sum_{j=1}^{\beta} \frac{1}{\sum_{p=1}^{\gamma} \frac{1}{k_{jp}}} \tag{4}$$

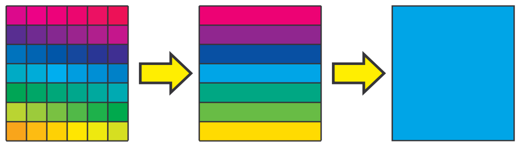


Fig. 4 Schematic diagram showing the homogenization method based on the flow direction

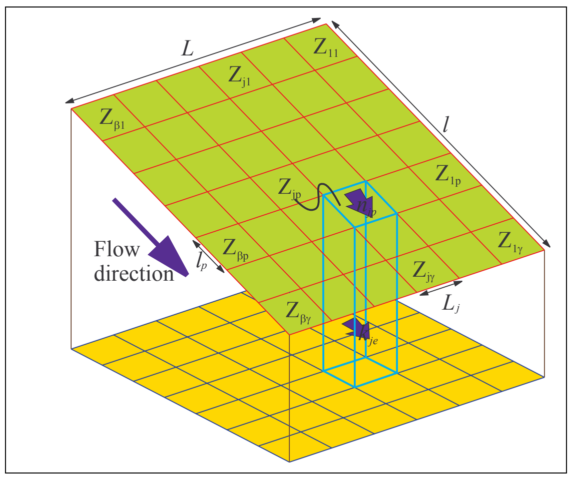


Fig. 5 Schematic diagram showing the homogenization method Fig. 5 Schematic diagram showing distribution of the slope direction cells and the transverse cells (as two dimensional domain), where slope direction: γ, vertical direction: β, slope length: l(m), slope width: L(m), cell Z_{jp}, Size : L_j(m)×lp (m), coefficient of roughness: n_{jp}($m^{-1/3}$.s), and coefficient of permeability: k_{jp}(m/s) (Hamaguchi *et. al.*, 2007).

5.1 Model Components

Rainfall-runoff modeling is the process of transforming a rainfall hyetograph into a runoff hydrograph. This can be achieved through the use of data-driven or statistical mathematical techniques, through developing physical descriptions of the rainfall-runoff process, or through various combinations of these approaches.

Hydro-BEAM has been chosen for simulation the surface runoff in the arid area due to its flexibility of application to accomplish many purposes of hydrological simulation. The most important merit of Hydro-BEAM is that its ability for simulation of the monthly, daily and hourly discharge at every mesh.

Hydro-BEAM is one of the distributed runoff models developed by Kojiri's Laboratory. The watershed is modeled as a uniform array of multi-layered mesh cells, each mesh containing information regarding surface land use characteristics, ground surface slope direction, runoff, and the presence/absence of a channel. The original Hydro-BEAM model as depicted in Fig. 6 that uses for the humid conditions can be adopted for simulation in the arid area in Wadi system as described in the following sections. Initial and transmission losses are evaluated as subroutine model in Hydro-BEAM in this study, as crucial resource for the subsurface water in such areas.

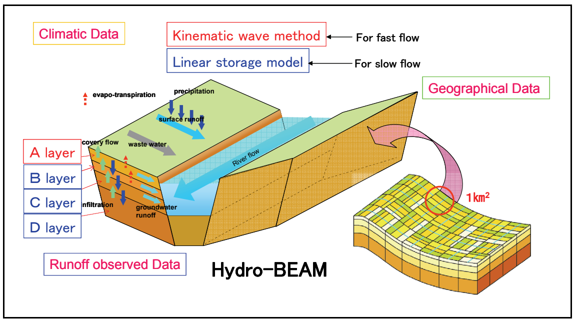


Fig. 6 Conceptual model of Hydro-BEAM

The watershed to be investigated is divided into an array of unit mesh cells. A mesh cell can be arranged as a combination of a surface layer and several subsurface layers. The following description considers Hydro-BEAM calibrated with four subsurface layers, labeled A, B, C and D. A-Layer is calibrated using Kinematic wave model for the overland flow evaluation and the other C-D layers (subsurface layers) are calculated by the linear storage model.

(1) Watershed Modeling

The data of digital elevation model (DEM, (SRTM (Shuttle Radar Topography Mission) from USGS internet site is obtained. The resolution of mesh size is (100 m). By processing the DEM using Global Mapper Program and Golden Surfer software to be input data of Arcview GIS tool, the watershed basin, sub-basin watersheds and stream network determination can be delineated as shown in Fig. 7, in addition to obtaining some geomorphologic information such as watershed area, perimeter, and main channel length, etc. We considered some points in the watershed modeling as follow: i) Determination of the watershed boundary location, ii) Division of the watershed into a regular grid of mesh cells (2 km), iii) Determination of a flow routing network based on mesh cell elevation as given by a DEM and checked against a printed map.

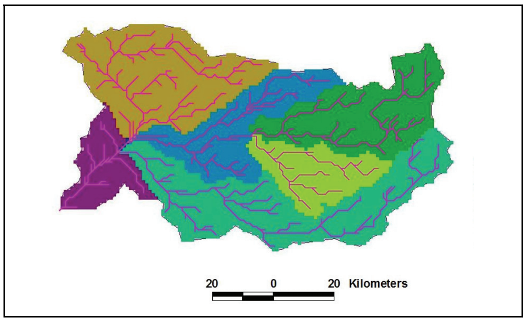


Fig. 7 Watershed delineation and stream network determination of Wadi Assiut

(a) Flow Routing Map

As well known, there are two types of flow routing system; 4 directions and 8 directions to determine drainage of flow water direction of drainage basin. Hydro-BEAM was originally developed to use a 4-direction flow routing map. The function of a flow routing map is to define a downstream destination for the discharge resulting from every cell in the watershed, with the exception of the furthest downstream mesh cell located at the watershed mouth. Flow direction from any given mesh cell can be estimated using the DEM elevations of the corners of each mesh cell as declared in Fig. 8.

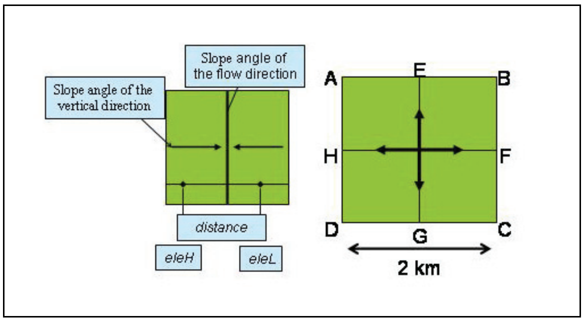


Fig. 8 Schematic diagram of the flow direction determination

Where the flow path of each mesh is decided based on the elevation values of each corner. On the other hand, the perpendicular direction of slope of the two half of the mesh is estimated based on dividing of each mesh into 20 parts. So, the flow direction in each mesh depend on the direction of its slope, then manually the opposite and paradox flow directions can be corrected based on the elevation map or the printed topographic map.

(b) Land Use Classification

Land use information is used to specify the structure of each mesh, its infiltration and runoff characteristics. Hydro-BEAM is set to use five categories of land use types as given in table 1, where they are grouped and represented as a percentage land cover of the total area of the mesh cell.

The land use distribution data of the world, GLCC (Global Land Cover Characterization) are available in USGS internet site as given in table 2. Land use data of GLCC is divided into 24 land use type. For the reason of hydro-BEAM is set to use five land use categories, we reclassified those types 24 into 5 types only to be available to input in Hydro-BEAM, The five categories of land use types are; mountains and forests, paddy field (rice field).

Table 1 Land use types of modified Hydro-BEAM

Category	Description
Mountains	Densely-vegetated regions (forest)
Field+ Paddy field	Agricultural regions including farms and orchards
Desert	Most of the Wadi areas are desert in the arid areas
Urban area	Paved or otherwise impervious urban regions
Water body	Bodies of water including inland waters

(2) Climatic Model

The metrological data are needed for each mesh in hydro-BEAM as input data for the climatic model to calculate evapotranspiration. So, we used climatic data of NCDC (National Climatic Data Center), Global Hourly and Monthly data as shown in table 2.

Due to the lacking of many kind of data, we adopted Thornthwaite method to calculate daily mean potential evapotranspiration (potential evapotranspiration) as given in equations 5, 6, 7, and 8. The mean air temperature and duration of possible sunshine of each mesh are needed as meteorological data for our model.

$$E_p = 0.553 D_0 \left(\frac{10 T_i}{J} \right)^a \quad (5)$$

$$a = 0.000000675 J^3 - 0.0000771 J^2 + 0.01792 J + 0.049293 \quad (6)$$

$$J = \sum_{i=1}^{12} \left(\frac{T_i}{5} \right)^{1.514} \quad (7)$$

$$E_a = M \times E_p \quad (8)$$

Where, E_a, E_p *(mm/d)* are the actual and the potential evapotranspiration; *Ti* (^0C) is the monthly average temperature, J: Heat index, D_0 *(h/12h)* is the potential day length and M is the reduction coefficient, vapor effective parameter.

Table 2 Types of input data and its resources

Type of data	Source of the data
DEM Data; SRTM (Shuttle Radar Topography Mission)	CGIAR-CSI (Consortium for Spatial Information)
Land use; GLCC (Global Land Cover	USGS (U.S. Geological Survey)

Characterization）	
Climatic Data; Surface Data,　Hourly Global data	NCDC（National Climatic Data Center）
Daily Climatic quality Data; GHCN（Global Historical Climate Network Ver.2）	NCDC（National Climatic Data Center）

(3)　Kinematic Wave Model

The kinematic wave equations as given in eq. 9 are derived from the St. Venant equations by preserving conservation of mass and approximately satisfying conservation of momentum. The momentum of the flow can be approximated with a uniform flow assumption as described by Manning's and Chezy's equations as shown in eq. 10. In this study, Kinematic wave model is applied for surface runoff and stream routing modeling based on using the Kinematic wave approximation with the assumption of the river channel cross section is supposed as a triangle shape. A finite difference approximation of the kinematic wave model can be used to model watershed runoff on the surface and layer A　in Hydro-BEAM. The various features of the irregular surface geometry of the basin are generally approximated by either of two types of basic flow elements: an overland flow element, or a stream- or channel- flow element. In the modeling process, overland flow elements are combined with channel-flow elements to represent a subbasin. The entire basin is modeled by linking the various subbasins together.

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=r(x,t) \qquad (9)$$

$$q=\alpha h^{m} \qquad (10)$$

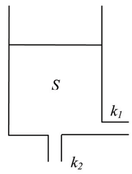
Where, h: water depth m, q: is discharge per unit length of flow [m3/m.s],　r is rainfall intensity [m/s], t is time [s], x is distance from the upstream edge, and α, m is constant concerning friction

(4)　Linear Storage Model

We used linear storage model as given in equations　11 and 12 for modeling of groundwater in layers B, C, and D layers in each mesh of the catchment area, thus the ground water storage can be evaluated in our model in Hydro-BEAM.

$$\frac{dS}{dt}=I-O \qquad (11)$$

$$O=(k_1+k_2)\cdot S \qquad (12)$$



Where S: is storage amount [m], I: is inflow [ms^{-1}], O: is outflow [ms^{-1}], k_1, k_2: are coefficient of permeability

(5)　Initial and Transmission Losses Model

Due to the importance of the losses in the arid areas, we added one subroutine to Hydro-BEAM to calculate the initial and transmission loesses in each mesh.

(a)　Initial losses

Initial losses occur in the sub-basins before runoff reaches the stream networks. It is related largely to infiltration, surface soil type, land use activities, evapotranspiration, interception, and surface depression storage. We adopted the NRCS method to calculate initial losses in the Wadi Assiut catchment. The method is suited for humid, arid and semiarid conditions (SCS. 1985) and it has been successfully applied to ephemeral watersheds in SW US, which resemble the eastern desert in Egypt in climate, topographical and land use (Osterkamp et al. 1994). Runoff in sub basins occurs after rainfall exceeds an initial abstraction (Ia) value. Rainfall excess, Q, in NRCS method is related to the effective potential retention value, S, as given in equation 13.

$$P_e=\frac{(P-I_a)^2}{P-I_a+S} \qquad (13)$$

The initial abstraction is suggested by NRCS to be approximately 20 % of the maximum potential retention value. The initial abstraction consists mainly of interception, infiltration prior to runoff, and surface storage, and is related to potential maximum retention (Empirical relationship of I_a and S)　as given in equation 14

$$I_a = 0.2S \quad (14)$$

S (mm) is the maximum retention parameter and given as in equation 15.

$$S = \frac{25400 - 254CN}{CN} \quad (15)$$

Where, P_e = Accumulated precipitation excess at time t (mm), P = Accumulated rainfall depth at time t (mm), I_a = the initial loss (mm), S = potential maximum retention (mm)

The catchment's capability for rainfall abstraction is inversely proportional to the runoff curve number. For CN = 100, no abstraction is possible, with runoff being equal to total rainfall. On the other hand, for CN = 1 practically all rainfall would be abstracted, with runoff being reduced to zero. The curve number CN value depends on hydrologic soil group and land use cover complex. The hydrologic soil group as defined by SCS soil scientists are A, B, C, and D are classified based o the soil type and infiltration rate. So, based on the land use, soil type and infiltration rate, the curve number of the land use in the studied area can be estimated as given in table 3.

Table 3 Curve number values of the land use type

Land use	Soil group	Curve number
Mountains	A	45
Field	B	71
Desert	A	63
Urban	B	86

(b) Transmission Losses

Transmission loss is important not only in its obvious effect on flow reduction, but also as a source of ground water recharge to underlying alluvial aquifers. The variables that are considered useful in estimating the variation in the transmission loss included; 1-the flow volume at the upstream end of the reach, 2-channel antecedent condition, 3-chaneel slope, 4- channel bed material, the duration of the flow, 5- channel width. Walter's (1990) developed equation to calculate the transmission losses as given in Eq. 10.

$$V_1 = 0.0006225W^{1.216}V_A^{\ 0.507} \quad (3)$$

Where V_1 =transmission loss for the first mile (acre-ft), V_A = upstream flow volume (acre-ft), w=active channel width.

We used this equation to estimate transmission losses in the Wadi system, what is new in our paper is calculation of distributed transmission losses.

6. Results and Application

Hydro-BEAM is a multilayer hydrological model, four layers (A-D); A-Layer is composed of the surface and soil surface layer. kinematic wave model and Manning equation are used to estimate the surface runoff and roughness coefficient in each mesh of the watershed basin. B-D-Layers are subsurface layers, which are evaluated using linear storage model, with the assumption of that the flow in each of B and C layers toward the river, but D-layer is considered as groundwater storage. It makes the ground-water zone which does not exert influence in river flow. When storage water content reaches to thickness and becomes saturated state, water content flows into the upper layer of model as returns style.

Modeling processes and programming are declared in Fig. 9, where Hydro-BEAM consists mainly of three main modeling parts; climatic modeling, watershed modeling and the main program modeling. The simulation period is from 1994 to 1995 based on geographical and climatic data where Egypt subjected to a big rainfall event on November 1994. The watershed modeling of Wadi Assiut is achieved based on DEM data by using GIS.

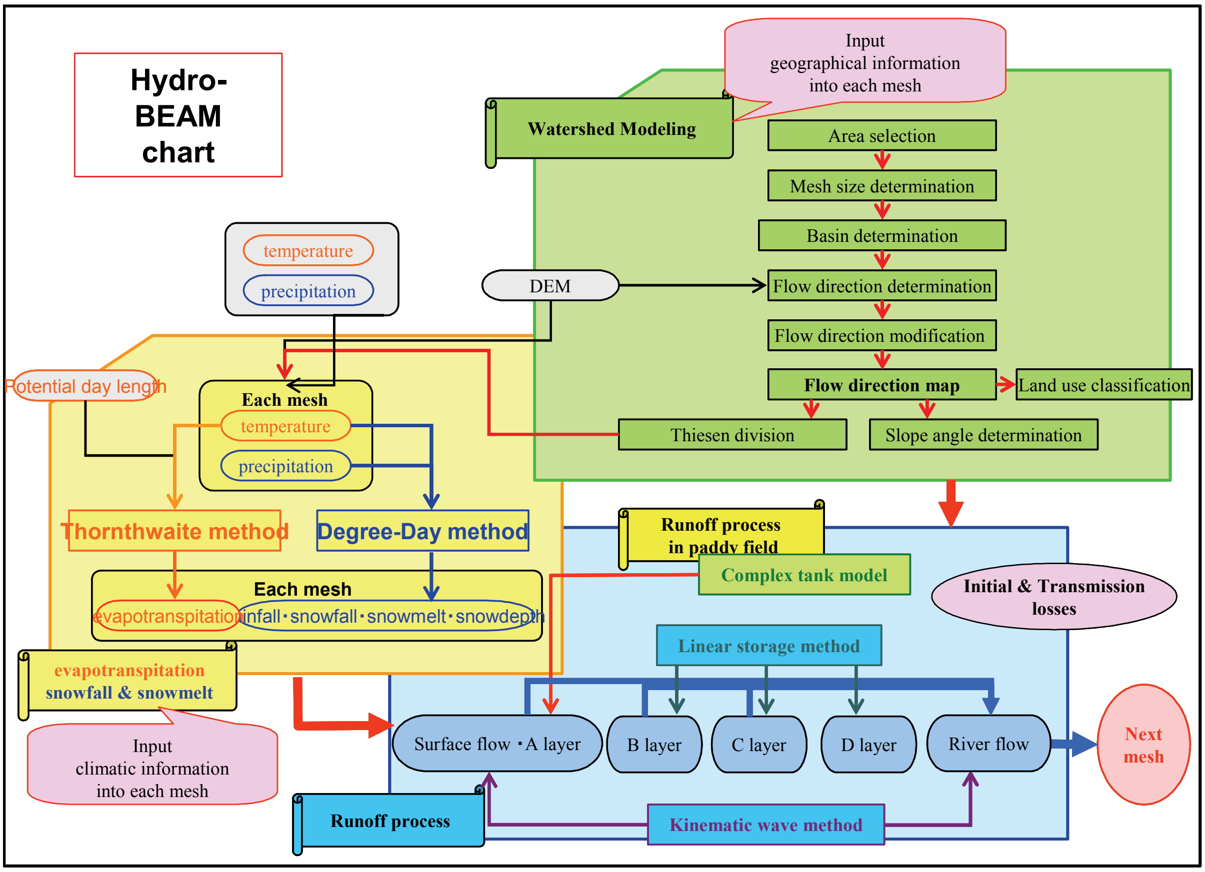


Fig. 9 Hydro-BEAM flow chart

The digital topological map of Wadi Assiut is demonstrated as shown in fig. 10. It is clear that the maximum elevation on the NE corner and the minimum elevation at the outlet point of Wadi Assiut that means the general slope from Northeastern to Southwestern direction.

Land use types can be reclassified and distributed using GLCC data which are classified into 24 types. Hydro-BEAM is setting to five land use categories; we classified land use in Wadi Assiut into five categories of land use types as follow; mountains and forests, paddy field (rice field) and field, desert, city or urban areas and Water. The model result of land use distribution in Wadi Assiut can be depicted as mountains, field, desert, city, and water as demonstrated in Figs. 11, 12, 13, 14, and 15 respectively. From the distribution maps of land use, it was found that the mountainous and forest land use type are limited as given in Fig. 11, and the field land use type is concentrated at the Southwestern part and small distribution in the central part of Wadi Assiut as declared in Fig. 12. Most of Wadi Assiut is desert areas as shown in fig.13.

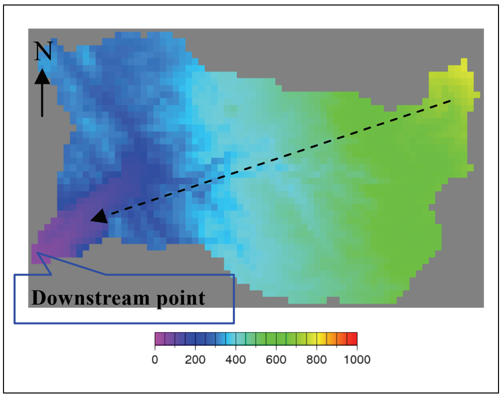


Fig. 10 Modeled topographical map of Wadi Assiut watershed

The distribution of urban land use type is limited as depicted in fig. 14 and also the water distribution is limited and it is located only at the downstream part of Wadi Assiut in the south western side.

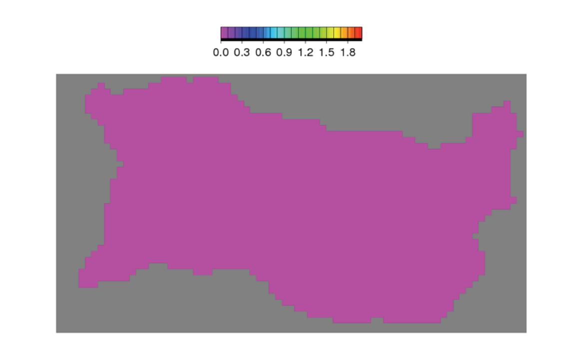


Fig. 11 Distribution map of mountains

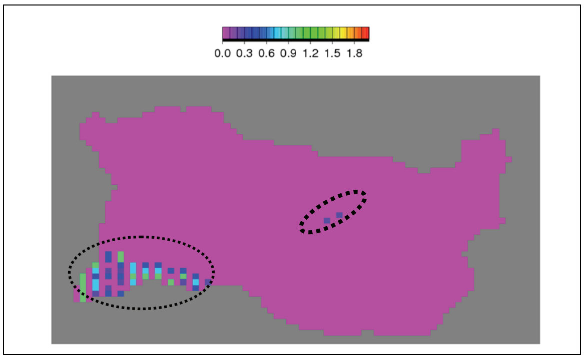


Fig. 12 Distribution map of filed and paddy field

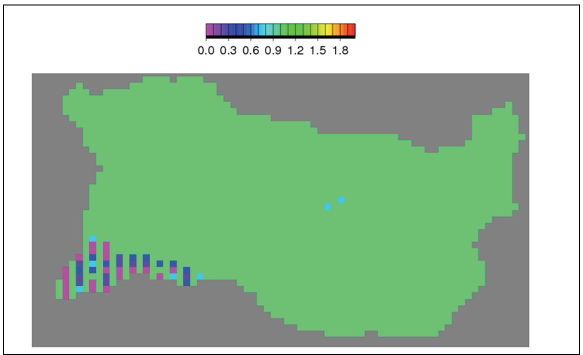


Fig. 13 Distribution map of desert

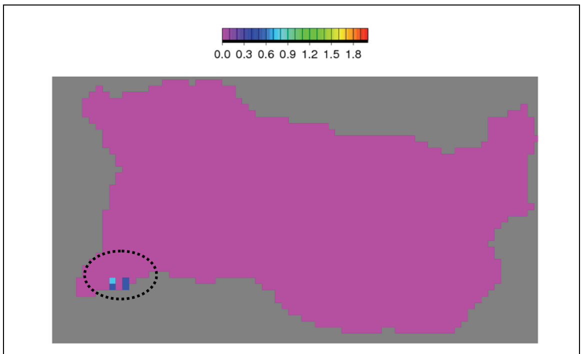


Fig. 14 Distribution map of city

The surface flow discharge can be demonstrated in Wadi Assiut watershed using the climatic data of the two years (1994-1995) for our simulation, where the daily and hourly output results can be obtained using Hydro-BEAM.

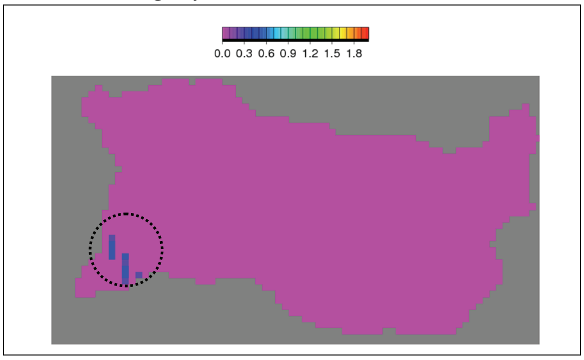


Fig. 15 Distribution map of water

However the lack of observed data, the simulated result is considered satisfied due to good agreement between discharge hydrograph and rainfall hytograph as shown in Fig. 16. The maximum peak of the runoff in Wadi assiut is 85m^3/s and the rainfall maximum peak is about 12.7mm/hr as shown in Fig. 2.

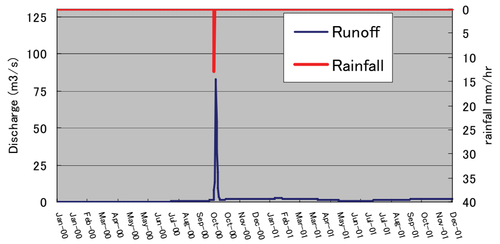


Fig.16 Daily discharge simulation hydrograph and rainfall hyetograph.

The simulation of hourly discharge also is accomplished as the maximum peak of is 49 m^3/s as shown in fig. 17, and it is clear that the result of daily and hourly simulations (simulation period is November 2-5, 1995) are completely coincide in their curve shape that means that behavior of the Wadi system can be declared using our model. From the distribution map of surface runoff in the Wadi system, we noticed that the discontinuous flow is perfectly depicted as shown in Fig.18, so the most import characteristics (the discontinuous surface flow) in the ephemeral streams is successfully evaluated by using our approach.

The merit of our model is evaluation the interaction between surface and subsurface water due to its importance in the arid regions. So, based on the linear storage model, the equivalent ground water storage can be investigated.

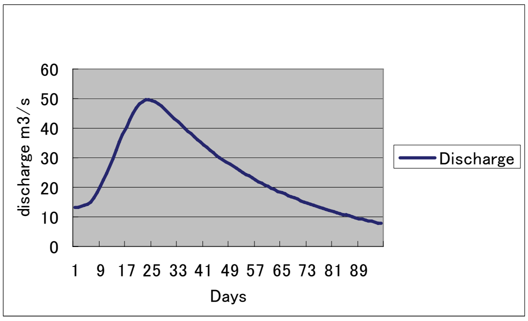


Fig. 17 Hydrograph of hourly discharge simulation

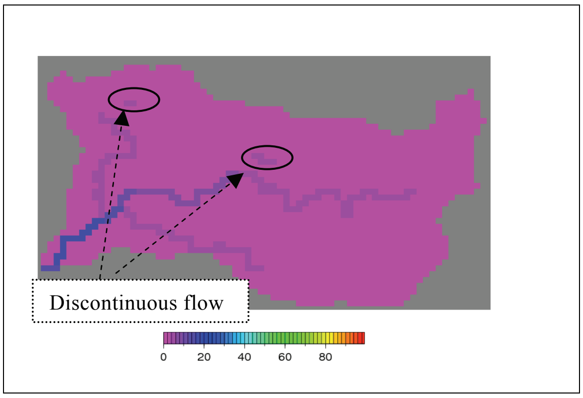


Fig. 18 Distributed map showing the discontinuously surface flow

It is declared that the subsurface water storage is affected by the flood effect where the curve showed that the subsurface storage increased during flood event and then gradually decreased during the recession of the flood as depicted in Fig.19.

Quantification of transmission loss is important, but it raises a number of difficulties. Walters (1990) provided evidence that the rate of loss is linearly related to the volume of surface discharge. Transmission losses are very important as the main resource of ground water recharge in the arid regions.

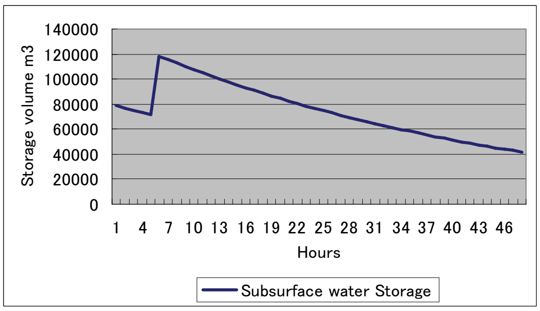


Fig. 19 Subsurface equivalent storage

It is evaluated in this study by using Walter's equation and the balance method (the difference between inflow and out flow in each mesh). A good agreement between the results of transmission losses using the two methods is found as shown in Fig. 20. The maximum peak of transmission losses is $13m^3/s$ by using Walter's method and $15m^3/s$ by using balance method.

It is deduced that the transmission losses contribute to the ground water as the main recharge for the subsurface water in the Wadi system, also with comparing the two curves of discharge and transmission losses, we noticed that the linear relationship between them, in other words the transmission losses affected positively with increasing the discharge that means that the maximum losses is in the time of the maximum flood peak as shown in Fig. 21, Moreover, you can see that the transmission losses curve at the recession of the flood is approximately equal to runoff.

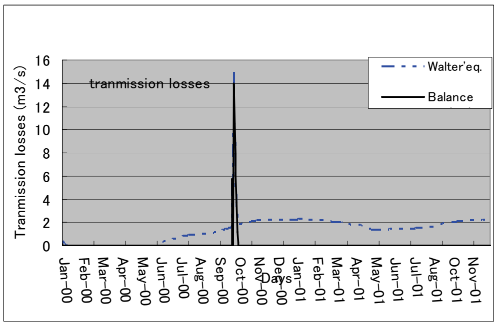


Fig.20 Transmission losses simulation (Walter's Equation and Balance method)

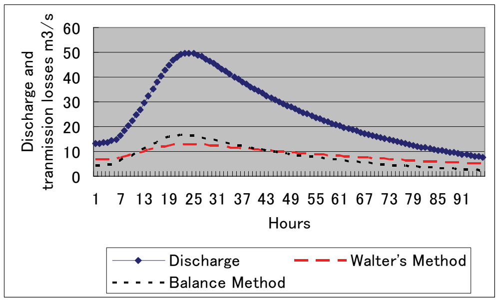


Fig.21 Comparing of discharge and transmission losses (Walter's Equation and Balance method)

One of the advantages of our research is that the transmission losses can be evaluated as distribution value is not from one point to another one as the previous researches as depicted in fig. 22. It is obvious that the transmission losses are mainly concentrating on the stream channels of Wadi Assiut.

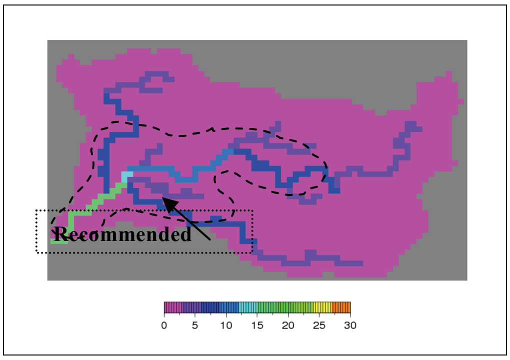


Fig. 22 Distribution map of transmission losses

Because of our main purposes in this research is water resources management and flood control, the conjunctive use of surface and subsurface water can be used for the real application. A lot of surface water infiltrated as the main resource of recharge to the subsurface due to the transmission losses. This subsurface water can be utilized for domestic and agriculture use. Constructing the pumping wells in the middle and western parts of Wadi Assiut is recommended as declared in Fig. 22. The surface water during the flood event or the rainy season can be used for the agriculture purposes.

We propose for the flood control and water resources management to establish two dams along the main channel of Wadi Assiut due to the maximum discharge during the flood at the two locations as shown in Fig. 23.

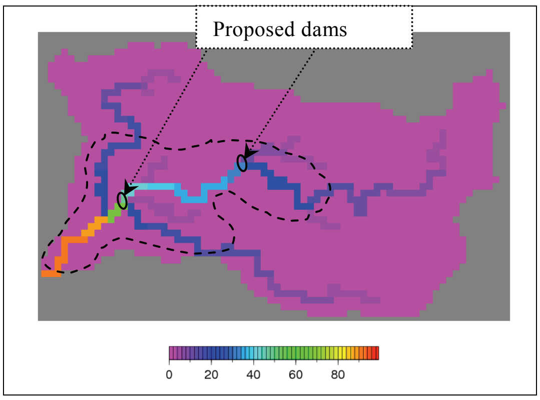


Fig. 23 Distributed map showing the maximum surface runoff.

They will be useful for protection the people from any flood threat and to increase the recharge to the subsurface water which can be used for the long term for people needs.

7. Conclusion

Hydro-BEAM has been chosen as distributed model for the Wadi System modeling. Modifications of Hydro-BEAM have been made to simulate the surface runoff in the ephemeral streams and to estimate the transmission losses as the main source of the recharge to subsurface water.

The runoff simulation is successfully achieved using Hydro-BEAM in the Wadi system. The maximum peak of the runoff in Wadi Assiut is $85m^3/s$ for the simulation period from (1994-1995). The rainfall maximum peak is about 12.7mm/hr. The simulation of hourly discharge also is accomplished. The maximum peak of discharge is 49 m^3/s, the simulation period is November 2-5, 1995, and it is clear that the result of daily and hourly simulations are completely coincide in their curve shape that means that behavior of the Wadi system can be declared using the proposed model.

The novelty of this research is that the proposed model shows the discontinuously surface flow of the Wadi system, in addition to the distribution of the equivalent subsurface water storage. The conjunctive use of surface and subsurface water can be used in the real application for the flood control and water resources management in Wadi Assiut. It is recommended that the western and the middle parts of Wadi Assiut can be utilized for pumping of subsurface water and establishment the dams to protect the people from the flood thread and increase the water resources to overcome the problem of the water shortage.

The transmission loss can be evaluated using two methods; Walter's equation and the balance method and the result is reasonable due to its agreement. It is concluded that transmission losses participate as the main source of recharge to the subsurface. It is noticed that it is affected by the volume of surface runoff as evidence that the rate of losses is linearly related to the volume of surface discharge.

It is concluded that the proposed model is considered an applicable methodology in larger areas and consequently, a vital contribution to estimate the distributed surface and subsurface runoff regionally not only in Wadi Assiut, Egypt but also in the other arid regions. Much more researches is recommended for the Wadi system modeling based on the observed data and the regional application of the Wadi system model is our future target.

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エジプト・ワジアシュート流域における 均質化理論を考慮した乾燥地断流河川の表面流出モデリング

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要　旨

高精度の観測値があまりない乾燥地のワジ機構の特徴として，表面流出で見る限りでは時空間的な不連続現象となる。本稿は，時空間的な断流河川の不連続現象を考慮しながら治水や水資源管理のためにワジ機構の分布型水文モデルを導出する。まず分布型水文モデルのパラメータをマクロスケールからメガスケールまでアップスケールする均質化手法を示す。この結果を用いてワジ機構の流出分布をシミュレーションを実行し，河道での移動損失が表面流や中間流・地下水流からその効果の評価を示した。この手法を使って表流水・地下水の有機的利用は大いに活用されるべきである。本モデルは乾燥地の分布型流出に関連する諸問題に応用可能であると言える。

キーワード:均質化，移動損失，ワジ機構，キネマティック・ウェーブ法