Optimizing Water Allocation in Arid Regions Using Advanced Hydrological Models

1st Dilshad A.H. Alhadrawi

Department of Building & Construction Techniques, College of Technical Engineering

The Islamic University
54001 Najaf, Iraq

dilshadeng61@iunajaf.edu.iq

ABSTRACT

In dry areas, water is considered a scarce commodity. A great deal of research has gone into developing hydrological models for these areas. By analyzing several research on GIS and RS, as well as the data and applications they have been used in, this study investigates how these technologies enhance hydrological modeling in dry locations. A number of important aspects of hydrological models were the focus of the review article. These aspects included data on rainfall, land use/cover, soil, digital elevation model, hydrological and watershed models, KINEROS2, IHACRES, The RCN method, and HEC-HMS. A greater emphasis on dry regions by researchers is necessary to address the difficulties of hydrological modeling.

A BRIEVE OVERVIEW.

Allocating water resources means distributing them in a way that takes into account the various demands of a community. There is a marked difference in the water needs of urban areas, farms, fisheries, factories, and animals. Consideration of several factors, including water source and acquisition methods, is required for water resource distribution. Also taken into account is the budget for the water treatment and delivery systems.

Hydrological models are essential for many different fields and uses, including flood prediction and design, water resource planning and development, and climate, hydro-ecology, and water quality modeling. Unfortunately, owing to a lack of resources and an inadequate array of measuring methods, there is a dearth of spatial-temporal data. Therefore, it is necessary to extrapolate data from existing spatial and temporal observations and assess the potential hydrological effects of future system responses, such as those resulting from changes in land management and climate. Due to the increased demand for water resources and the accompanying environmental problems that are occurring now and will occur in the future, there are worries about the capacity to forecast and comprehend the natural course of this scenario. The occurrence of streamflow and precipitation are only two of the numerous characteristics of the hydrological system that have been the source of inspiration for a multitude of models (Beven, 2001).

HYDROLOGICAL MODELS AND THEIR APPLICATIONS.

A thorough, transparent, and unified consideration of all kinds of mistakes is essential for reducing bias and uncertainty in the final forecast. Ignoring certain sources of uncertainty (such as structural, parameter, or data mistakes) could lead to inaccurate estimates of uncertainty in the model's output. There has been some progress in improving scientific understanding via the presentation of frameworks such as BATEA, IBUNE, and FUSE, which assess the impact of data and model structural uncertainty on streamflow simulations. Obtaining more insightful and high-quality data in space and time, improving our understanding of physical processes and how they are represented in hydrological models, and creating methods for using the model identification and prediction procedures to extract

and incorporate information from the available data are three methods that Liu and Gupta (2007) suggest could be used to decrease uncertainty in hydrological predictions.

Constraints on Hydrological Modeling.

The use of hydrological models based on computers dates back almost thirty years. As Klemes (1988) points out in his assessment of hydrology's (lack of) scientific legacy, technical instruments like the Sacramento model and other classic deterministic hydrological models of lumped conceptual type cannot be reasonably claimed to be scientifically sound. Klemes (1988) cast doubt on the reliability of these models' forecasts. Another study that found minimal predictive usefulness in hydrological models was Abbott's (1972). An initial description of the needs and concept for a physically-based dispersed catchment model was provided by Freeze and Harlan (1969). In 1976, three European organizations started working on the System Hydrologique European (SHE), and Freeze's groundbreaking work was a major reason why. Since then, a plethora of other distributed models have been created. There has been significant progress in modeling over the last twenty years, yet distributed hydrological models are still underutilized in practice

Information accessibility,

To get the most out of the distributed physically-based models, you need a ton of data. This includes precise geospatial information on things like geology, soil, and vegetation, as well as things like water abstraction, farming methods, and pollution discharge.

When such relevant data does exist, it is sometimes not easily accessible due to a lack of adequate electronic databases. On the other hand, there is often no such data at all. The fact that these models can use and require data from a variety of other sources, such as agricultural, soil science, and geological studies, in addition to the traditional hydro meteorological data, presents an administrative problem that further complicates matters in this context.

Missing knowledge in scientific and hydrological aspects

Both the small-scale and large-scale mechanisms of flow, transport, and water quality remain poorly understood. Concurrent research in process descriptions and the advent of a new paradigm for modeling have both contributed to the emergence of these gaps. On the one hand, these scientific gaps have restricted distributed hydrological models' usefulness in the real world, but on the other, studying these problems via these models has improved our knowledge of hydrology as a whole.

Historical foundation in water resource engineering and hydrology,

To fully leverage the potential of distributed physically-based codes to an economic point where it is justified, it is frequently necessary to bring in both specialized and generalist personnel. However, few companies possess both sets of skills. It is common for specialists in fields such as hydrogeology, soil physics, and plant physiology to have a limited perspective on the whole system.

limitations in technology,

According to hydraulic engineering experience, in order to reach a substantial section of the professional community with modeling technology, so-called fourth generation modeling systems are required. Also, in order for modeling technologies to be as useful as possible, fifth generation systems are believed to be essential.

A hypothetical hydrological model for arid regions.

These factors make it difficult for hydrologists to make accurate predictions within these regions. They come to the conclusion that disrupted models are unable to provide a realistic picture of reality, which is also referred to as the "fully developed image of existence." This is a further conclusion that they reach. that hydrologists are unable to apply hydrological models effectively in dry regions owing to the harsh weather conditions and the absence of high-quality data. As a further conclusion, they arrive to the conclusion that disrupted models are unable of delivering an accurate portrayal of reality, sometimes known as the "fully developed image of existence."

Extreme weather and a dearth of reliable data in dry areas may become even more pressing issues as a result of this. For example, flash flood flow forecasting is difficult for several reasons, such as extreme physical and climatic dryness. because there are not many natural control sections that are suited for streams that have movable beds, because artificial control is expensive, because there is restricted access during wet seasons, and because there is a possibility that boulders and silt loads might harm instruments

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There have only been a few of distributed models that have been upgraded or built for use in dry areas.

Hydrological modeling data for arid regions.

1. **data on land usage and land cover,**

What we call "land cover" is really just the earth's natural surface, which includes things like water, soil, and plant. Includes both natural features and man-made features, such as crops and livestock. According to Fresco (1994), land use encompasses all human activities that take place on land, including settlement, environmental modification, and changes to land cover.

Land use and cover statistics may be found, in part, in surveys and census records. Environmental researchers may get land use statistics from countries and international organizations. Remote sensing (RS) technology provides further information on land cover and usage. A variety of land-use categories are generated from the digital pictures acquired by remote sensing by using supervised and unsupervised classification methods (Gunduz, 2003). Hydrological models use information on land usage and cover to determine the ground's resistance, or roughness, which affects the flow of water. Using land-use data, one may measure the quantity of rainwater that infiltrates a surface. In addition, the soil properties of a given surface, as well as data on land use. The ASCE (1999) provides a method for determining percolation and water storage capacity values.

2. Soil data,

Soil data is crucial for hydrologic modeling. The bulk of hydrologic cycles need specific soil characteristics such as soil type, hydraulic conductivity, porosity, and other relevant factors. To identify the types of soil, it is necessary to analyze the data obtained from soil survey maps or remote sensing pictures using either supervised or unsupervised algorithms.

3. Stats on precipitation,

Theoretically, hydrological modeling relies heavily on rainfall data. Rainfall and runoff statistics must be precise in order to calibrate and validate hydrological models. For hydrologic modeling purposes, rain gauge data is the most reliable and easily accessible data format.

Implementation of Hydrological Models on Arid Regions.

1. **The SWAT model is a comprehensive tool used for assessing soil and water conditions.**

The inception and enhancement of the SWAT began three decades ago. Wlliams et al. (1984), the model for Chemicals, Runoff, and Erosion from Agricultural Management Systems (Knisel, 1980), and the Groundwater Loading Effects on Agricultural Management Systems (Leonard et al., 1987) are some of the models that have been included into SWAT by the USDA-ARS Agricultural Research Service. The SWAT model is said to have arisen from the Simulator for Water Resources in Rural Basins. The SWAT model utilizes a physically-based, continuous-time, semi-distributed methodology to replicate the techniques used in watershed management. The model incorporates several components such as agricultural management, crop growth, meteorological conditions, sedimentation, soil temperature, nutrient levels, and hydrology. When attempting to anticipate the influence that land-use practices will have on water, agricultural crops, and sediment, SWAT is used in watersheds that are comprehensive and intricate. An alternative method for generating weather data or completing missing data is to integrate the WXGEN weather generator model with the SWAT model (Sharpley and Williams, 1990). The revised universal soil loss equation may be used to calculate the sediment yield for each sub-basin. By simulating the temperature of each layer of soil, it is possible to accurately mimic the growth of crops.
It is possible to simulate irrigation and system withdrawals after water diversions.

2. **Model for Kinematic Runoff and Erosion.**

Kineros2 (K2) is a rainfall-runoff model that is event-based, physically-based, and distributed. Primarily used in regions characterized by semi-arid and desert watersheds. This model delineates the mechanisms of erosion, surface runoff, interception, and dynamic infiltration in small watersheds, where overland flow is the predominant mode of flow. This model partitions the catchment into many one-dimensional overland flow channels and planes, using topography data as the basis for division. Distinct parameters are assigned to both overland flow and each canal.

The kinematic wave equation is solved implicitly by the use of a finite difference technique to effectively direct the flow of runoff (AlQurashi et al., 2008). The K2 model simulation approach should start with the upslope/upstream sections and go downstream to guarantee the inclusion of upper boundary conditions (Semmens et al., 2008). The model's geographically scattered characteristics, together with higher-resolution rainfall data and a reduced number

of time phases, enable accurate prediction of the rainfall-runoff process in small basins (Schaffner et al., 2010). Wheater (1981) used an outdated iteration of Kineros, with a time step of 15 minutes, to investigate storms in Wadi Aday, Oman. The Kineros model yielded superior results in comparison to those obtained using the time-area method. The results were enhanced due to the use of a physically-based model, which effectively accounted for the non-linear effects of channel and overland flow.
Mott Macdonald (1992) performed a hydrological investigation on the Wadi Ahin in Oman, specifically focusing on groundwater recharge analysis using the Kineros model. The findings indicated that doing several calibrations across 16 instances resulted in a much wider spectrum of volume inaccuracies. As a result, the study suggests transferring the calibrated parameters from Wadi Ahin to nearby ungauged catchments. In order to assess the effectiveness of K2 in forecasting flash floods and determine the main factors contributing to uncertainty, Yatheendradas et al. (2008) used this method in analyzing eight specific events inside the Walnut Gulch 6.4-km2 subcatchment as part of a separate study. The investigation determined that the primary factor contributing to uncertainty was inconsistencies in the documented radar precipitation.

The overall amount of precipitation for a certain incident varied between 15 mm and 35 mm, depending on the estimation technique used.

Forecasting an occurrence using an attribute sets obtained by examining prior occurrences also comes with a noticeable amount of uncertainty, as pointed out by the authors. Michaud and Sorooshian (1994b) published an additional research that used the Kineros model. They used Walnut Gulch, a 150 km2 catchment region. This research used 24-hour rainfall data with a 2-minute precision for validation and six-hour rainfall events for calibration. Due to the model's execution, the study's findings were insufficient. As an example, suppose there are four peaks.

3. The Hydrologic Modeling System Model (HEC-HMS) developed by the Hydrologic Engineering Center.

Verma et al. (2010) state that the system has the ability to replicate various geographical regions, spanning from extensive river catchments to compact urban or natural watersheds. According to Abushandi (2011), the model is often used to predict and simulate stream flow in tropical, subtropical, desert, and humid watersheds. The four primary constituents consist of: an advanced visual depiction of the hydrologic system and its constituents; computational models capable of determining overflow and channel routing; a system for storing and managing data; and a tool for presenting and exhibiting information (Moghadas, 2009). Al-Abed et al. (2005) used the HEC-HMS and another model in the AL-Zaraqa basin of Jordan to determine the benefits of using hydrological models based on GIS as instruments for water management. Their study demonstrated that the HEC-HMS model exhibited superior accuracy compared to the alternative model. Yener et al. (2006) used intensity duration frequency curves in the HEC-HMS model to analyze the Yuvacik Basin in Turkey and simulate various runoff scenarios. Another study conducted by Nasri et al. (2011) used the HEC-HMS model to forecast the rainfall-runoff patterns specific to the Sheikh Bahaei Dam basin in Iran. The study's findings demonstrated the accuracy of the HEC-HMS model in identifying the primary factors contributing to flood formation. In their study, Dastorani et al. (2011) assessed the predictive capacity of the HECHMS model in forecasting floods in the Toroq watershed of Iran via the simulation of rainfall-runoff dynamics. Their research demonstrated the superiority of the HEC-HMS model over other approaches in simulating

rainfall and runoff in ungauged catchments. However, the results were mostly affected by the starting loss and the curve number (CN). These factors need to be appropriately approximated during calibration to get the most precise outcomes.

The three primary features of the HEC-HMS model—water control structures, channel routing, and runoff—and their respective benefits. In terms of data management—including input, organization, access, and visualization—the model uses a simple method.

4. Runoff Curve (RNC) Number Method

The Root Cause Network (RCN) is a reliable method for forecasting the amount of water runoff from a specific site during rainfall. The Soil Conservation Service (SCS), a division of the United States Department of Agriculture's Natural Resources Conservation Service, devised the technique in 1954. The Rationalized Convolution Number (RCN), sometimes referred to as the Soil Conservation Service (SCS), is a method used by hydrologists to quantitatively assess the amount of water infiltration and surface runoff resulting from. Ritzema (1994) explained the use of the RCN (Runoff Curve Number) in drainage basins. This approach predicts the depth of direct runoff based on the amount of rainfall, and it generates an index that represents the properties of the runoff response.

The RCN is affected by several elements, such as the initial soil moisture levels in the drainage basin, the hydrologic status of the area, land use, treatment, and hydrologic group (Ritzema, 1994; Ponce et al., 1996). The RCN is governed by two variables: initial abstraction and actual retention. An abstraction starts with the auditory perception of rainfall. The pre-runoff indicators include invasion, depression storage, and interception. Additional precipitation is lost by infiltration after runoff has started, and effective retention occurs thereafter. The SCS-CN technique relies on the fundamental mathematical assumption that, when runoff starts, the proportion of actual soil retention to the maximum potential retention is equivalent to the ratio of direct runoff to the maximum potential runoff. The given mathematical equation describes the relationships that come before, after some algebraic manipulation and a simplifying assumption.

The formula for Q is expressed as the square of (P minus 0.2S) divided by P plus 0.8S.

Where is it located?

The runoff factor is represented by the variable Q.

The sign P represents precipitation.

Following the onset of runoff, S represents the upper limit of precipitation that the soil can store.

The rapid advancement of technology has enabled the ArcGIS program to precisely calculate the CN in the RCN technique. Zhan and Huang (2004) provided a comprehensive account of the creation and use of the ArcCN runoff tool. Utilize the ArcCN runoff tool to calculate storm-related runoff or infiltration, as well as Curve Numbers (CNs), within a specified watershed.

The objective of creating the ArcCN runoff tool was to address the issue of runoff estimates that do not take into account the detailed geographical variations within the watershed. The ArcCN tool has the capability to use polygons of diverse forms to maintain uneven boundaries, and it also has an integrated database that aids in determining CN by using soil and land use data.
The program's skills may be advantageous in the fields of project management and design, hydraulic modeling of watershed reactions to urbanization, and discharge forecasting.

Zhan and Huang (2004) proposed numerous improvements for the ArcCN tool's predictions, including the incorporation of a rainfall time series and the consideration of elements such as wet and dry antecedent moisture conditions for the CN parameters. Braun et al. (2003) developed a method for assessing groundwater recharge zones that is linked to Geographic Information Systems (GIS). His methodology was used to investigate the sites where recharging occurs in Waukesha County, Wisconsin. The technique used data on precipitation, soil, and land cover to construct maps depicting root-zone water capacity, surface runoff, percolation, and temperature. The integration of soil and land use data facilitated the accurate detection of variations in surface runoff potential. In this methodology, rather of allocating a solitary curve number (CN) to a catchment, the CN values were apportioned to several regions according to their distinct soil and land cover characteristics. The CN rankings were used to generate maps illustrating the surface runoff potential. The areas exhibiting little surface runoff were identified by a high rating, whereas those with high rankings showed low surface runoff. Subsequently, we compiled and organized the maps of root-zone water capacity, percolation, and surface runoff based on the potential for recharging in various places.

In the Makkah metropolitan area in southwest Saudi Arabia, Dawod et al. (2011) performed a supplementary study utilizing a Geographic Information System (GIS) technology and the CN method. The main aim of the study was to develop a technique for cartographically representing and assessing indicators related to flood evaluation using a Geographic Information System (GIS). A GIS system was developed using the CN flood modeling technique to integrate various data related to geography, meteorology, geology, and land use. The study demonstrates that several variables influence the overall flood volume. The factors to consider are the region from which water is collected, the distance of the stream that forms the basin, and the highest rate of water flow. The study demonstrated that flooding and runoff threats increased in correlation with higher CN levels.

5. The IHACRES Model's Unit Hydrograph and Component Flows derived from Rainfall, Evaporation, and Streamflow.

The IHACRES model integrates both conceptual and metric components. It combines the attributes of robustness in conceptual and metric models. Utilizing the simplicity of metric models is necessary in order to minimize ambiguity about the important parameters of hydrological models. This model adheres to metric standards and tries to provide a comprehensive set of internal process information simultaneously (Croke et al., 2008). Jakeman et al. (1990) first developed the IHACRES model for use in temperate catchments. Scheider et al. (1995) and Ye et al. (1995, 1997, 1996) modified the model by include characteristics that are pertinent to temporary streams. The IHACRES model serves the primary objective of describing hydrological behavior at the catchment scale by using a restricted set of parameters, as stated by Littlewood (2003). Hence, the model becomes valuable in dry places without adequate hydrological data. In recent years, the IHACRES

model has undergone refinement and enhancement to provide a more precise depiction of ephemeral streams in arid regions. The model consists of two components: a non-linear loss module that transforms actual rainfall into effective rainfall, and a linear module that transfers effective rainfall to stream flow. This structure was described by Croke et al. (2008). The IHACRES model was first constructed using an exponentially decaying soil moisture index to transform rainfall into effective rainfall.

Ye et al. (1997) created an enhanced version of the model to enhance its performance in transitory catchments. The formula that determines this version is encoded into IHACRES v2.0.

The equation is as follows: uk = [c(ϕk-I)]prk.

The effective rainfall is represented by the symbol "uk."

Precipitation in the form of rain was seen and recorded as "rk".

Within this particular framework, the variable c symbolizes the equilibrium of mass, the variable I represent the threshold for soil moisture index, and the variable P signifies the non-linear components of the response.

The soil-moisture index is denoted by the symbol ϕk.
Several regions in Africa, Australia, Jordan, and Oman exemplify semi-arid and dry catchments that have achieved favorable outcomes by using the IHACRES rainfall-runoff model. IHACRES has been employed in several studies, including those that forecast streamflow in ungauged catchments and analyze dynamic response characteristics (Kokkonen et al., 2003; Croke and Jakeman, 2004; Kokkonen et al., 2001), as well as those that investigate physical catchment patterns (Sefton and Howarth, 1998). Ye et al. (1997) used the IHACRES model in three underproductive catchments in Australia, using continuous-time simulation and daily time-steps. The research investigated three conceptual models, namely LASCAM, GSFB, and IHACRES, with varying parameter values. While the scientists acknowledged the satisfactory performance of IHACRES, they found that the 22-parameter LASCAM system outperformed it in terms of validation and calibration.

Croke et al. (2006) conducted a distinct study in New South Wales, Australia, where they used IHACRES in a semi-distributed model throughout an extensive watershed. The objective of their study was to provide substantiation for a more thorough assessment of water distribution networks. The partitioning of the watershed into sixteen subcatchments was based on the hydrological responses and climatic spatial variability. Researchers used IHACRES to successfully reproduce flow peaks and volumes in the Omani Wadi Ahin watershed during 2009. However, the analysis revealed that the model's accuracy was insufficient for two subcatchments owing to inadequate rain gauge coverage. Their primary responsibility was to use an experimental methodology to assess the efficacy of different IHACRES versions. By doing a sensitivity analysis, we reduced the number of parameters in IHACRES from nine (as stated by Ye et al., 1997) to five, four, and three. Subsequently, we evaluated the predicted accuracy of each version. The findings revealed that the four-parameter version was most effective in predicting flow peaks, but the three-parameter version was most effective in estimating volume. Consequently, all the basic iterations of the IHACRES model performed as anticipated. However, the forecasts were very unpredictable since the effective parameter values underwent significant changes throughout the events.

Maximizing Hydrological Model Quality

Solving issues pertaining to water using mathematical optimization methods such as linear programming, integer programming, dynamic programming, or quadratic programming is known as hydrological optimization. These problems can be associated with surface water, groundwater, or both. Experts in operations research, hydrology, civil engineering, and environmental engineering may all contribute to the project.

The foundation of optimization models consists of three parts:

1. An aim, such as "Minimize cost"

2. Decision variables that are compatible with the alternatives available to management

3. Limitations, which are the physical or technological restrictions imposed on the available choices

Hydrological optimization relies on the discovery of optimization constraint coefficients via simulation. Next, a manager or engineer may input the costs and benefits of several options into the optimization model to determine the optimal course of action.

For problems that hydrological optimization was able to fix,

1.Remediating polluted aquifers. The choice dilemma is to reduce expenditures while stopping the spread of pollution by choosing the pumping rate and well site.

2. Allotting resources to improve wetland areas. Managing invasive plants and distributing water are two ways that this optimization model recommends improving wetland quality. Here are some examples of problems that hydrological optimization has tackled in the habitats of priority bird species. Hydraulic infrastructure capacity, geographical connectedness, water availability, vegetation responses, and available funds are some of the constraints that impact these proposals.

3.We aim to quantify the influence of each user's water usage on other users and the environment as accurately as possible. Then, we optimize well abstraction within the constraints of ambient flow. Currently, there are realistic solutions accessible.

Using a simple optimization model, we can determine the cost-minimizing combination of optimal management methods to reduce the surplus nutrients in a watershed, which directly impacts water quality. 5.At the moment, there are suggestions to apply hydrological optimization to water-related smart markets.

6.Optimizing pipeline networks using genetic algorithms.

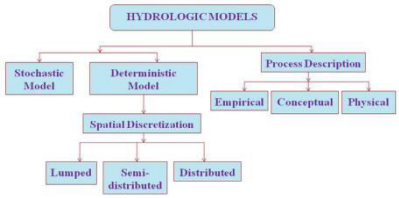


Figure 1: Hydrological Models Categorized

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