TECHNOLOGY COOPERATION IN WATER RESOURCES ENGINEERING

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ABSTRACT

A theme of water resources engineering is discussed and approaches for technology cooperation with countries in the process of recovering from devastation due to war or natural disasters are presented. The development of area-wide estimates of soil moisture in the top one meter of soil is of paramount importance for the judicious operational use of water resources for irrigated agriculture, for increased crop yield, and for the planning of agricultural development in a region. Modern advances in the aforementioned area are discussed in this paper through an example of application in the United States, and methodologies for implementation are offered. Efficient systems may be developed at present based on typical operational data networks, readily available climate information, and modern day atmospheric, hydrologic and decision support models.

Key words: water engineering, water resources, operational data networks

INTRODUCTION

Water availability in acceptable quantity and quality, and judicious and efficient use of available water supply for economic development are of great importance to many nations of the World. Amidst devastations from war 1 and a changing climate 2 many nations are seeking to develop or improve their means of water use at the dawn of the 21 st Century. This paper outlines recent research and development work concerning the design and implementation of operational systems for soil moisture estimation and forecasting over large areas for agricultural use. The work was performed by the Hydrologic Research Center (HRC). HRC is a non profit research and technology-cooperation organization in San Diego, California, with a mission to advance the science and engineering of Hydrology through research and technology cooperation activities with Universities, Government Agencies and various User Groups in the US and Abroad. Information on HRC and its activities may be found in http://www.hrc-web.org. The discussion that follows is drawn from recent publications [3,4,5] .

It is long recognized that soil moisture regulates land-surface energy and moisture exchanges with the atmosphere and has a key role in flood and drought genesis and maintenance. Soil moisture deficit plays a significant role in regulating plant transpiration and, consequently, constitutes a diagnostic variable for irrigation. High extremes of soil moisture are associated with high potential for flooding and hazardous conditions. Although the importance of soil moisture for hydrologic science and applications cannot be overemphasized, there are few long-term and large-scale measurement programs for soil moisture that provide in-situ profile data suitable for hydroclimatic analysis and design in the US and abroad. Active and passive microwave data from polar orbiting satellites or reconnaissance airplanes do provide estimates of surface soil moisture with continuous spatial coverage. They are limited in that they only measure soil moisture within the first few centimeters from the soil surface, and are reliable when vegetation cover is sparse or absent. As a consequence of the lack of suitable observations, most of the continental-scale studies in hydroclimatology and those pertaining to water resources engineering and agricultural studies, use estimates of soil moisture produced by a variety of models ranging from the land-surface components of global climate models to conceptual hydrologic models. Modern digital spatial databases of soils, land use and land cover exist for most of the world and may be advantageously used together with available precipitation and temperature data to provide large-area monthly estimates and forecasts of soil moisture in an operational environment for a variety of uses.

The soil moisture model assigns a characteristic soil moisture content over areas of order 10 3 km 3 on the basis of its dominant soil and plant cover characteristics. The state of the model is the soil moisture content θ (m^3/m^3). characterizing the soil column within the analysis area during a certain month. The forcing variables are the precipitation plus snowmelt rate, r (mm/mo), and the atmosphere's potential rate for evaporation, e_0 (mm/mo). The latter is modified to reflect plant ground cover. Water availability in the soil column then determines the actual evapotranspiration rate e from the soil. Surface runoff, q (mm/mo), is generated as a result of soil water availability and difference in average rates between infiltration and precipitation over a month. Baseflow, b (mm/mo), and deep groundwater leakage, g (mm/mo), are produced throughout the soil column to accommodate infiltrated rates, large-scale catchment geometry and stream topology.

The equation for the conservation of soil water volume in a soil column characterizing a model division is:

$$Z_r\,(\theta(t) - \theta_w)/dt = r(t) - e\,(t) - q(t) - b(t) - g(t) \tag{1}$$

where Z_T (m) is the modeled soil depth, and $\theta(t)$ is the soil moisture content of the soil at time t. The wilting-point soil-moisture content θ_w is defined as the residual moisture that the soil retains at a –1.5 MPa matric potential. Moisture contents less or equal to this moisture content are not available for evapotranspiration. Together with the saturation soil moisture content, θ_s, and the field capacity moisture content, θ_f, the wilting point defines the range of soil moisture, which is available for use by plants and for the generation of gravity flow in the soil. Equation (1) is a statement of the natural conservation of water, and to obtain estimates of $\theta(t)$, expressions for the various flow rates through and over the soils are needed. In developing such expressions (or parameterizations), one should consider the available databases, both spatial digital databases and hydrometeorological databases. Parameterizations commonly used presume availability of the following digital spatial databases: soils and land-use/land-cover digital databases; monthly (or shorter period) data of precipitation and temperature; and limited monthly (or shorter period) natural streamflow data. Given, an initial soil moisture estimate, the models that are based on Equation (1) may be used with observed surface meteorological data to simulate soil moisture over large areas, and, in conjunction with numerical meteorological models or climate outlooks, to forecast soil moisture availability in large areas with forecast lead times of days or even months. When forced with global climate model information, the model can also be used in planning agricultural development in a variable and changing climate.

A recently published example application over the US is discussed next [3,4] . The purpose of the model application was to estimate historical monthly soil moisture variability using the available record of monthly surface precipitation and temperature for each one of the climate divisions that tile the conterminous US, and to estimate future variability of soil moisture under a potential climatic change. The US climate divisions are large areas (344 divisions cover the conterminous US), each encompassing regions of similar precipitation and temperature climatologies. The model soil moisture estimates were used with a crop yield model to arrive at assessments of crop yield variability and trends in the US under the present and a potentially changing climate. Decile differences for standardized soil moisture anomalies present one of the results of analysis for the historical record and for the entire conterminous US. The difference between the upper and lower decile soil moisture standardized anomalies (monthly soil moisture estimate minus long-term monthly mean divided by long-term monthly standard deviation) is analised for the period 1931-1998. It is apparent that the central regions of the US with thick soils and agricultural land use show the greatest variability over the historical record, with standardized anomaly differences that exceed 2.5. This result has implications for irrigation requirements and the variability of crop yields in the region, assuming factors other than soil moisture remain the same. Model application with precipitation and temperature data from global climate models (GCMs) was also performed for planning irrigation requirements and crop yield. The future GCM data corresponded to a control run simulating present conditions for greenhouse gases and sulfate aerosols, and a greenhouse gas increase run with a 1% increase per year of greenhouse gas emissions through year 2030. The GCM data were preprocessed to adjust for scale effects and for GCM-model biases. Other analysis is analogous, but for a projected greenhouse gas increase of 1% per annum. It gives results for the case of a future greenhouse gas increase. It is shown that in a future scenario of increased greenhouse gas emissions, the soil moisture variability of the various regions of the US is likely to significantly change. Increased variability in soil moisture is likely throughout the US with serious implications for planning irrigation requirements and crop yield for the semi arid and arid regions.

Lastly, a class of soil moisture models based on Equation (1) developed jointly by HRC and the Climate Prediction Center (CPC) of the National Oceanic and Atmospheric Administration (NOAA) are used for the routine production of monthly soil moisture estimates and seasonal soil moisture outlooks (http://www.cpc.ncep.noaa.gov/soilmst/cas_text.html and http://www.cpc.ncep.noaa.gov/soilmst/cas_verif.html) for the conterminous US. These estimates are available through the internet and find many uses in agriculture and energy-demand estimation and planning. The latter use is based on the finding that, in summer and for several regions of the continental US, soil moisture is a good predictor of monthly surface temperature for the next month 5 .

TECHNOLOGY COOPERATION

The theory and products of the discussed developments in large-scale soil moisture modeling have beneficial applications for several world regions, especially when soil

moisture is a limiting factor for agriculture. It is through technology cooperation between organizations such as HRC and government and private agencies that these developments may lead to useful applications in regions different from those of their original development. The following are a few essential steps for a successful cooperation as derived from HRC's experience with technology cooperation projects in the US and abroad.
Step 1 – Design of products with participation of users or user agencies (e.g., maps of soil moisture estimates of a given duration and area extent, updated over given intervals, with a given format and available via a given medium to the users).
Step 2 – Formation of a development group consisting of research and technology cooperation organizations such as HRC and of regional development organizations from the target region such as Universities or/and government labs. Regional incentives may be required for the establishment of these partnerships.
Step 3 – Reciprocal knowledge transfer between developers and users on science issues and region-specific issues (for instance, what are the limitations of the soil moisture theory used and what are the scale applicability limitations versus the regional knowledge on past soil moisture and surrogate-variable behavior as affects the designed products).
Step 4 – Assessment of available technology and data required to produce desired products (for example, is the data availability commensurate with theory, and chosen temporal and spatial scales of soil moisture products).
Step 5 – During development, HRC hosts staff of the partner regional development agency for effective on-the-development technology cooperation.
Step 6 – Short course development for users of soil moisture products.
Step 7 – Identification of a regional implementation organization with commitment for supporting and maintaining the developed models and products. Typically, this organization participates in the development of the soil moisture products as a regional developer.
Step 8 – Establishment of performance criteria by mutual agreement of developers and users and evaluation of system performance after implementation.
Step 9 – Establishment of mechanisms for monitoring the operation of the developed system for soil moisture products.
Step 10 – Establishment of mechanisms for future enhancement of products either regionally or with assistance by organizations such as HRC.

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