DETERMINATION OF IRRIGATED CROP CONSUMPTIVE WATER USE BY REMOTE SENSING AND GIS TECHNIQUES FOR RIVER BASINS

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ABSTRACT

This paper outlines a method for using remote sensed data from Landsat TM satellites and geographic information systems (GISes) to model the evapotranspiration requirements of irrigated cropland within the Cache la Poudre River basin, a tributary of the South Platte River. The flexibility of a GIS allows the model to evaluate specific crops or combinations of crops growing in any specified area or sub-area of the basin over any fraction of the growing season and to compute the spatially distributed crop evapotranspiration. Development of this model will allow modeling and evaluation of the South Platte Basin which contains a significant percentage of the irrigated lands of the Colorado Front Range. Progress on this project to date includes the classification of irrigated agricultural crops. Five major irrigated crops have been identified using Landsat TM multitemporal data sets and computer aided classification techniques. Crop species classification accuracies range from 65 to 94 percent. These crop maps comprise the crop map data layers for the evapotranspiration GIS model. Additional work to be accomplished in the first quarter of 1993 is the programming of the GIS model and the generation of weather and soils data layers and development of the basin water balance. The basin water balance will be used for checking the accuracy and precision of the evapotranspiration model.

INTRODUCTION

With the development of satellite platforms for remote sensing of vegetation, weather, and soil characteristics, and the development of Geographical Information Systems (GIS), the ability to acquire spatially distributed information about crops, weather, and the water resources is now available to the agricultural engineer and to managers of water resources.

This paper outlines a method for using remote sensed data from Landsat TM satellites and GISes to model the evapotranspiration requirements of irrigated cropland within the Cache la Poudre River basin. The flexibility of a GIS allows the model to evaluate specific crops or combinations of crops growing in any specified area or sub-area of the basin over any fraction of the growing season and to compute the spatially distributed crop evapotranspiration (E_t).

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Development of this model will allow modeling and evaluation of the South Platte Basin which contains a significant percentage of the irrigated lands of the Colorado Front Range. Accurate computation, prediction, and management of irrigation requirements in the South Platte River Basin would then allow more accurate allocation of Colorado water resources to the needs of an expanding urban population and industrial base within the State of Colorado and neighboring states.

DESCRIPTION OF STUDY AREA

The Cache La Poudre River basin is the major tributary of the South Platte River, located in north-central Colorado. The study area defined for the project contains the irrigated crop land of the Poudre basin. A small area of the Lone Tree Creek basin adjacent to Greeley, Colorado, contains contiguous irrigated crop land supplied by irrigation canals running through the Poudre basin. Excluding the Lone Tree basin cropland would detract from the GIS model integrity.

The area contains lakes and reservoirs used for irrigation of crops, rural subdivisions, farmsteads, irrigated crops, some rangeland, and river floodplains with wetlands and riverine ecosystems. Fort Collins (population 90,000) and Greeley (population 60,000) are located within the study area.

The Cache la Poudre River flows from west to east along the lower edge of study area. Major land cover classes within the riverine system include riparian vegetation, non-agricultural grasses, quarry-gravel extraction and rural subdivisions common to the river flood plain. The Poudre River is a meandering alluvial river overlaying an unconfined and connected aquifer which supports an extensive gravel extraction industry.

A bench land approximately 30 to 50 feet above the floodplain contains intensively irrigated cropland, rural subdivisions and feedlot operations. Drainage is from north to south with slightly rolling swales under cropping activity. Elevations range from 4650 feet above sea level at the southeast corner of the study area at the river surface to 5400 feet at the highest point in the northwest corner of the site.

THE STUDY PROBLEM

The use of a raster based GIS with a 28.5x28.5 meter pixel (picture element) size allows the variability of vegetation biomass (derived from remote sensed crop data) and associated vegetation transpiration and soil evaporation to more accurately predict the spatial variability of evapotranspiration over the land cover of a river basin. With the ability to correctly assess evapotranspiration over tributary basins or major river basins, basin-wide water management is enhanced. The accurate estimation of evapotranspiration forms the basis of control of almost every use of water in the Western United States. The ability to correctly assess the evapotranspiration of water through vegetation, primarily rigated cropland, wetlands and urban irrigation affects the following water ıanagement areas:

Trans-basin transfer of water controlled by historic consumptive use of the water rights holders,

maintenance of in-stream flows for the preservation of endangered species (Meyer, 1990),

maintenance of riparian ecosystems,

reduction of nutrients in river aquifers,

change of water from agricultural to municipal use, and

the determination of irrigation water demands and distribution and scheduling of water diversion to headgates at the appropriate time and in the correct amount.

Since evapotranspiration studies traditionally use lysimeter data for either lfalfa or grass reference E_t (a point value), when crop E_t rates are computed, iscrepancies arise due to the nonhomogeniety of the crops within a field. Vhen study areas as large as a river basin are considered, the assumptions for omogenous crop or vegetation coverage do not hold. The need for ground ruth or ground reference data to verify the evapotranspiration model for large reas is costly. Recent work (Seevers,1990; Seevers et al, 1990) substitutes egetation indices in the evapotranspiration computation method as a surrogate or the crop coefficient. Sufficient research has been done to verify the ffectiveness of using vegetation indices to eliminate costly development of field eference data by relating the vegetation indices to changes in biomass and leaf rea. This study will evaluate the use of vegetation indices and the potential ccuracy of that computation method, as compared to the use of crop oefficients in the Penman-Montieth evapotranspiration computation.

pecific objectives

To determine the acceptable levels of accuracy and precision for identifying the types and spatial distribution of agricultural crops at a river basin level and to determine the accuracy and precision measurement parameters.

To determine the magnitude and type of scale-up factors derived from using ET point estimates based on lysimeter evapotranspiration reference data and single station weather data as the basis for spatially distributed GIS-based evapotranspiration models extending over river basins or other large areas.

To determine the difference in precision and accuracy of computation of large area evapotranspiration using crop species based crop coefficients and surrogate vegetation indices derived from Landsat TM satellite imagery.

METHODOLOGIES

The project was developed in two phases; the generation of crop maps as a GIS data layer by remote sensed data from Landsat TM satellite imagery, and the development of a geographic information system model for computing the spatially distributed evapotranspiration.

Phase 1: Remote Sensing And Development of Crop Maps

a. Assembly of existing digitized data base materials. This digitized map information contains land use, political and geographic information, elevation data for land surfaces as well as water table elevations, and soils information at the county level. Weather data for the study area is obtained from the Northern Colorado Water Conservancy District's (NCWCD) weather net for the basin.

b. USGS supplied 9-track Landsat TM satellite imagery for May, July and September, 1991, was downloaded to ERDAS Remote sensing/GIS software. Imagery has been previously georectified by the USGS.

c. The portion of the Landsat scene for the Poudre River hydrologic basin was extracted from the data set.

d. Using grid sampling techniques, test sites were randomly selected that approximated the proportional amounts of vegetation types within the Poudre River Basin. These test areas were not used for generating training statistics for the classification operation.

e. The May, July and September images were combined into a multitemporal image

f. Unsupervised classification techniques were used to develop training statistics for vegetation classification within the study area scene.

g. The May, July and September non-enhanced 7 band satellite spectral images were classified to Level III of the U.S.Geologic Survey Land Use and Land Cover Classification System (Anderson et al., 1976) using maximum likelihood classification algorithms.

h. Using image preprocessing techniques, the May, July, September, and combined multitemporal images were enhanced to develop a select number of vegetation indices and image transforms for classification using the same classification techniques described above. The goal for this step was to select indices and transforms which have previously been shown to correlate to biomass, leaf area and evapotranspiration characteristics of irrigated crops. These indices and transforms will be used to determine the effectiveness of classifying transformed images into biomass, leaf area or other surrogate land cover maps (GIS data layers) that will provide equivalent or better accuracy in modeling evapotranspiration characteristics of the irrigated agricultural crops.

The classified maps were evaluated using information obtained from the NCWCD's Irrigation Management Program, to determine the classification accuracy and precision.

hase 2: Development of the GIS Model

he general steps used in developing the GIS model are as follows:

. Basic and derived data layers needed for the GIS model are as follows:

1. Temperature
2. Wind Speed
3. Solar Radiation
4. Relative Humidity
5. Crop Coefficients or surrogate vegetation indices
6. Vegetation maps (more generally land cover maps)
7. Summary daily evapotranspiration
8. Cumulative growing season evapotranspiration
9. Kriging coefficients for distributing weather data
10. Weather station location
11. Rainfall
12. Soils
13. Districts (for definition of sub-areas)
14. Irrigation water requirements
15. Growing degree days

. Process weather data into appropriate data layers. An external data base of weather station data will be used with a weather generation model to preprocess weather data into a spatial data base that will include data layers appropriate for the model run. For example, if daily E_t is desired, the weather generation model will provide a data layer for computing E_t from daily weather characteristics. The weather generation model will probably take the form of a separate GIS.

. Using GIS algebra, the GIS is programmed with command functions for developing data layers which can be used to compute reference evaporation. Data layers are wind speed, rainfall, temperature, relative humidity, solar radiation.

. Data layers are developed containing crop coefficients for crops identified within the study area. Depending on the evaluation of the effectiveness of surrogate vegetation indices, data layers containing these indices are included.

d. Data layers containing vegetation classes, reference ET and crop coefficients are used to compute ET for selected NCWCD IMS sites for selected time periods.

Verification of the Model

The model is verified both on a field scale and a basin-wide scale. NCWCD evapotranspiration values for individual fields can be used to verify the model for differing time periods throughout the irrigation season as NCWCD has accurate data for crop types and both reference ET and crop ET values for individual fields throughout the 1991 irrigation season. This time period corresponds to the satellite imagery dates used to develop the model.

a. With crop data provided from NCWCD, the accuracy of the remote sensed satellite processed vegetation classification is compared to ground verified crop types for specific field sites.

b. The model output is compared with irrigation ET's computed and used by the NCWCD during the 1991 irrigation season for NCWCD IMS sites.

c. The seasonal river basin ET is computed for all irrigated lands and for urban irrigated lands. A water balance is computed for the river basin for an irrigation season. The difference between river basin inputs and outputs and change in aquifer storage will approximate the consumptive use in the basin.

d. If satisfactory simulations are achieved indicating conformance to the NCWCD field E_t estimates +/- 10 percent, and conformance to +/- 15 percent of the Poudre River hydrologic basin water balance, the software template is finalized and a demonstration of the model to interested agencies is scheduled.

RESULTS TO DATE

The land cover classification was completed using six data sets containing Landsat 5 TM data for May, July and September, 1991. The data sets included both TM spectral data bands and transformed spectral data in the form of normalized difference vegetation (NDVI) indices and Tasseled Cap transformations. Both multitemporal and unitemporal data sets were evaluated with one, two and three date unitemporal and multitemporal combinations used. Initial clustering with ISODATA clustering algorithms yielded a minimum of 12 land cover categories that effectively represented the land cover category actually found within the study site.

Considering only agricultural crops species, the 15 TM spectral band data set identified most of the predominate crops in the study area at accuracies greater than 86 percent. Lesser prevalent crops such as onions were identified at about 60 percent. The Tasseled Cap transformation identified the four predominate crops at accuracies above 94 percent and the NDVI vegetation ıdex data set ranked third, identifying the four predominate crops at :curacies greater than 79 percent. The 10 TM spectral band data set for July-ɜptember yielded the lowest accuracy in identifying crop species at 40 percent ɔr pinto beans but with alfalfa, corn and sugar beets at accuracies above 78 ercent.

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