CHAPTER 7 APPLICATION OF REMOTE SENSING IN THE MANAGEMENT OF HYDROLOGY AND WATER RESOURCES

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7.1 INTRODUCTION

Remote sensing has been defined as the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by sensor that is not in direct contact with the target of investigation. During the period of year 2003 to 2006, the remote sensing technique and its application is rapidly developed in both the world and China. More and more sensors with higher spatial and temporal resolution were developed and put in optional use or research works in various fields. In China, Meteorology Satellite FY/1D and FY/2C were respectively lunched in May of 2002 and in October of 2004. The Earth Resources Satellite CBERS/02 was successfully lunched in October of 2003. The Ocean Satellite HY-1 was successfully lunched in May of 2002. Miniature Satellite BJ-1 was successfully lunched in October of 2005, and put in operation in June of 2006. These satellites have provided rich information for almost all of the departments allover the country. Also, the remotely sensed data pay very important roles in the field of water resources. Compared to conventional hydrological measurements, remote sensing has certain significant advantages, but also some disadvantages. In this chapter, remote sensing application to hydrologic monitoring and modeling, as well as water management in recent years are discussed with emphases on water cycle research, flood and drought hazard monitoring and evaluation, irrigation and drainage management, monitoring of ecologic environment related to water resources development and utilization.

7.2 REMOTE SENSING APPLICATION TO HYDROLOGIC MONITORING AND MODELING

7.2.1 Remote Sensing in Hydrologic Modeling

For hydrologic modeling, the time series of runoff and possibly precipitation, and a climatological estimate of monthly evapo-transpiration are very important, which may be obtained by the station-based observation system. The model development based on surface station for a large river basin is almost impossible due to the scarcity of land surface observations and difficulties in representing hydrological processes at large scales. Remote sensing may provide the required data, such as information on land surface/cover, soil texture, initial soil moisture and topography, for hydrological modeling at regional to global scales. For modeling land-atmospheric hydrologic interactions, remote sensing provides both model parameters and meteorological data, like surface air temperature, humidity, precipitation and radiation.

Liu S.C. and Zhang W.C. (2004) gave a review of application of remote sensing to retrieval of precipitation, land use/ cover classification, leaf area index, albedo, land surface heat flux and some indirect parameters in distributed hydrological model, and proposed a framework for developing a distributed hydrological model by integrating GIS and remote sensing. Wu J.F. and Liu C.M. (2002) considered that the data obtained from remote sensing is still hard to use in hydrological model directly, and the hydrological scale problem is the important aspect for hydrological modeling using remote sensing. Li D.F. et al. (2005) developed a physical-based distributed hydrological model to simulate the watershed runoff response process under climate and land-cover changes in the head area of Yellow River by using remote sensing and GIS. Liu C.M. et al. (2004) developed distributed hydrological model for Yellow River basin, which is a part of National Key Project "Yellow River Water Resources Evolution Law and Renewability Maintaining Mechanism". The area precipitation data obtained from meteorology satellite image was treated as an input for the model.

7.2.2 Remote Sensing in Water Cycle

Remote sensing pays important roles in water cycle research especially for regional scale or watershed scale, and the hydrological cycle components may involve precipitation, evapotranspiration, soil moisture, surface water as well as groundwater.

Precipitation is of primary importance in hydrology. It shows large and frequent spatial and rapid temporal variations. The scales over which precipitation occurs are so large that methods of measurement are wide ranging and usually complementary. Point measurements are insufficiently representative of catchment scales. So remote sensing becomes a very powerful tool for obtain the precipitation information for water cycle research. Currently, the emphases are put on the application of radar, ground-based or space-borne radar, as well as passive microwave data. The approaches based on visible and infrared satellite data were also developed. Two basic approaches namely the "life-history" and the "cloud-indexing" are widely used. Wang J.H. (2003) developed the area precipitation model according to the regression relationship between cloud and point precipitation by using GMS image and surface rain gage. The model prediction precision reached to 90% in Yellow River Basin. Huang Y. (2006) developed the Flood-Causing Torrential Rain Forecasting and Warning System for Huaihe River. Rainfall was estimated by using of satellite and CIN RAD-radar data. Furthermore, form GMS-5 multi-channel data, the empirical formula of rainfall measurement was developed by using statistic method in Huaihe River field. The model was tested verified by the application of flood season in year 2003.

Evapotranspiration plays an important role in earth-atmosphere interaction process, and has attracted a rather considerable amount of attention and research work. The researches are related to the use of thermal infrared observations and the land surface heat balance, as well as spectrum of multi-spectral measurements by space- and airborne instruments to estimate potential evaporation and crop water requirements for the purpose of water management especially in irrigation regions. Wang J.M. (2003), Guo X.Y. (2004) and Sun M.Z. (2005) et.al. gave a review of advances in the monitoring approaches of evapo-transpiration with remote sensing data and its application in water resources management. Sun M.Z. (2005) et al. developed SEBAL model by using spectral radiances recorded by satellite-based sensors, plus ordinary meteorological data, to solve the energy balance at the earth's surface, and to evaluate evapo-transpiration in the Haihe River Basin. Hu M.G. (2006) considered ET technique of remote sensing monitoring to realize the sustainable management of agricultural water supply in Beijing City. Pang Z.G. et. al. (2004) developed the evapo-transpiration estimation model based on energy balance by using remote sensing, and the approaches were demonstrated in Heilongjiang province.

Soil moisture is the interface between the solid earth surface and the atmosphere, and is very important to understand the hydrological cycle process in both smaller and larger scales. However, soil moisture is a very difficult variable to measure, not at a point in time, but at a consistent and spatially comprehensive basis. It has been shown the soil moisture can be measured to some extent by a variety of the electromagnetic spectrum. Successful measurement of soil moisture by remote sensing depends on the type of reflected or emitted electromagnetic radiation, and only the microwave region of the spectrum can provide a quantitative approach to estimate soil moisture under a variety of topographic and vegetation cover condition (E.T. Engman, 2000). Zhang H.M. and Sha J.M. (2005), Zhang C.L. (2006) summarized the theories and methods of soil moisture monitoring by remote sensing, including microwave remote sensing monitoring, thermal inertia, the composite index of crop vegetation and brightness index, as well as hot infrared monitoring. Bao Y.S. et al. (2005) discussed the estimation approaches of soil water content and wheat coverage with ASAR image. The authors concluded backscattering, which was greatly affected by land surface roughness and soil texture, is a key problem which must be considered in the retrieval of soil water content, and the vertical polarization backscattering coefficient is significantly correlated to soil water content while the horizontal polarization backscattering coefficient is significantly correlated to both soil water content and wheat cover.

Surface water may occur as lakes, reservoirs, rivers as well as snow and ice. Remote sensing can be used to estimate the area extent and water content of these surface water-bodies, as well as the changes in water regimes. One of the main obscuration to remote sensing application is the limitation of relatively cloud-free and daylight condition. Microwave satellites offer the potential all-weather application and the synergistic application of combined SAR and optical remote sensing for surface water estimates needs to be examined more closely (G. Kite and A. Pietroniro, 2000). Yang G.D. et al. (2003) presented a method for analyzing the surface water system in plain areas with the help of GIS, DEM and remote sensing. Hong Z.G. et al. (2006) utilized the various sources of remote sensing images combined with DEM and DOM data to analyze the characteristics of surface water system including springs, lakes, water resources of head regions in Tsinghai and Tibet plateau. Wang Y.J. and Zhang Y. (2005) developed a momentum BP neural network model to retrieve the water depth information for the South Channel of the Yangtze River Estuary using the relationship between reflectance derived from Landsat ETM+ satellite data and water depth.

Groundwater is essentially a subsurface phenomenon, so the common current remote sensing, mainly recording features on the surface, can only provide information to indirectly help qualitative or semi-quantitative analysis of groundwater system with simple geological condition and shallow groundwater table. The application of remote sensing involves two aspects, i.e. the conceptualization of the hydrogeology and water budget (Allard M.J. Meijerink, 2000). Abduwasit and Qin Q.M. (2004) presented a review of the development and progress of remote sensing application research on groundwater exploration, as well as the methods of regional groundwater monitoring, delineation and detection. Tashpolat Tiyip et al. (2005) developed a quantitative model for deriving groundwater level in oasis-desert ectone in arid area by using LandSat-7 ETM+ data.

7.2.3 Soil Erosion

Soil erosion, as a natural process caused by water, wind, and ice, has been accelerated by human activities. The consequence from soil erosion on loss of productivity, land degradation, and off-site, downstream damages from eroded soil particles on water quality become major concerns around the world. Soil erosion is characterized by spatially and temporally distribution on the landscape, it is difficult, time consuming, and expensive to use the classical soil erosion measurement techniques. The remote sensing techniques that measure the spectral properties of landscape are most commonly applied to soil erosion management and research. The data sources of remote sensing involve optical sensors like LandSat/TM, SPOT, IRS, AVHRR, ground-based and airborne laser system, as well as Synthetic Aperture Radar (SAR) for evaluating large-scale soil erosion patterns and rates. The application of remote sensing techniques to study and monitor soil erosion may include the following general approaches: photointerpretation /photogrammetry, model/GIS input, spectral properties, and topographic measurements. Xue L.H. and Yang L.Z. (2004) Zhou W.F. et al. (2005) gave a brief introduction to the theory, technique and methods of soil erosion with remote sensing, and discussed the future development trends and prospect of soil erosion with remote sensing. Bu Z.H. et al. (200) introduced the advance of quantitative remote sensing for monitoring annual soil erosion and its application in Taihu Lake basin. Tan B.X. et al. (2005) presented a method for extracting vegetation coverage and estimating soil erosion by remote sensing data combined with surface investigation information and DEM, and applied in Guishuihe river basin of Beijing City. Jiang H. et al. (2005) utilized remote sensing to establish the Universal Soil Loss Equation (USLE) for the dynamic monitoring of soil erosion in Changding County of Fujian province.

7.2.4 Water Quality

Monitoring and assessing the quality of waters in rivers, lakes, reservoirs, estuaries, and oceans are critical for managing and improving water resources and environment. Classical techniques for measuring indicators of water, in situ measures or laboratory analysis, are time consuming and expensive, although they can give accurate measurements. Remote sensing of indicators of water quality offers the potential of relatively inexpensive, frequent, and synoptic measurements. The indicators like suspended sediments (turbidity), chlorophylls, dissolved organic matter, thermal release and oils produce visible and/or thermal changes in surface waters that can change the energy spectra of reflected solar and/or emitted thermal radiation from surface waters. This fact is the basis for using remote sensing to estimate water quality of an individual water body or multiple water bodies across the landscape. Most chemicals do not directly affect or change the spectral or thermal properties of surface waters. Measuring water properties affected by chemicals can only be inferred indirectly from remotely sensed measurement of other water quality parameters affected by these chemicals (J.C.Ritchie and F.R.Schiebe 2000). With the coming availability of hyper spectral data, more parameters can be quantified using remote sensing technique. Yang Y. P. et al. (2004) Zhou Y. et al. (2004) Liu C.D.et al. (2005) presented a review of the current situation of application of remote sensing techniques to inland water quality monitoring and its development process, and explored the principles and methods of applying different kinds of remote sensed images. Lu H. et al. (2005) discussed three common methods of water quality inversion algorithm including empirical model, bio-optical model and artificial neural network model and their application limitation. The authors also discussed the main factors determining water quality retrieve accuracy, and pointed out the atmosphere correction models need to be developed for water quality remote sensing. Lei K. et al. (2004) proposed the models for the estimation of concentration of chlorophyll and total nitrogen in Taihu Lake based on the regression analysis between the CBERS-1 CCD data and semi-synchronous ground referenced data, with the consideration of the spectral characteristics of water components. He L.H. and Yang J.G. (2005) utilized NOAA/AVHRR images to measure hue, temperature, and transparency, in order to discern the different pollution level of water bodies in Yangtze River delta region by remote sensing. Yin Q. et.al.(2005) developed the optimal channel combination models for retrieving chlorophyll and suspended sediment concentration from remote sensing data of FY-01C multi-channel scanning radiometer, Landsat TM, SeaWiFS of Seasat and a supposed set of remote sensing channels. The models were used to estimate the eutrophic degree, its spatial distribution and its variation with time in Taihu Lake and Dianchi Lake. Wan Y. (2003) studied the possibility of using hyper spectral remote sensing to detect the degree of pollution. The water spectra can not only reflect the relative pollution degree but also determine the types and characteristics of water pollution.

7.2.5 Snow and Ice

Ice and snow, storing most of the Earth's freshwater, are important components of the hydrological cycle. The ice and snow cover, also called as cryosphere, carry information on the other system components like climate system. Moreover, about one billion people depend on water resources originating from snowmelt runoff. Melt-water runoff is extensively used for hydropower generation, irrigation or freshwater supply. The positive aspects of ice and snow, particularly as freshwater, go in hand with a large number of natural hazards like floods (the outburst of subglacial lakes), slushflows, ice fall and so on. The investigation and monitoring of ice and snow cover is essentially important. However, the presence of ice and snow is confined to cold climates either at high altitudes or high latitude (or a combination of both). In many cases, ground-based observations of ice and snow properties are difficult to obtain in the respective regions due to lacking infrastructure and complex topography, harsh climates. Remote sensing has received increasing significance over last two decades, since it is the only feasible way for acquisition of ice and snow information. The EOS Science Plan (NASA, 1999) comprehensively describes the current sate of knowledge, the unsolved problems and new possibilities and strategies of ice and snow research by remote sensing system. The recent researches focus on radiative transfer models suitable to correct high-resolution VNIR and SWIR images for topographic adjancy and bi-directional reflectance distribution function (BRDF) effects, accurate retrieval of ice and snow properties from remote sensing data in particular snow water equivalent at high spatial and temporal resolution to develop the snowmelt runoff model, as well as the subpixel analysis algorithms such as the retrieval of snow properties in forested areas or detection of cloud contaminated pixels. Huang X.Y. (2004) presented a review of the application of microwave remote sensing in monitoring the snow and ice and its future directions. Che T. et al. (2004) used the SSM/I brightness temperature data to estimate the snow water equivalent (SWE) in Tibetan Plateau. The authors established an improved algorithm to retrieve the snow depth from the difference of 19 and 37 GHz brightness temperatures in horizontal polarization, and developed a statistical algorithm to estimate the snow water equivalent from the differences of 19 and 37 GHz in vertical polarization. Zhang Z.J. et.al.(2004) put forward an effective method of distinguishing snowpack, probability combined with threshold, by using NOAA-16/AVHRR3 and FY-1D/MVIRS, and established the operational system of snow cover monitoring. The features of winder snow cover distribution in China, from 1996 to 2003 were discussed. Liu Y.J. et al. (2003) calculated the percent of snow cover in west of China by the multi-spectral analysis of AVHRR data.

7.3 WATER MANAGEMENT WITH THE AID OF REMOTE SENSING TECHNOLOGY

7.3.1 Flood Hazard Monitoring and Assessment

Flood severely affects the life and environment at different places over the country each year. It causes considerable damage to buildings, roads, villages, towns and agriculture. Often floods cause also a high loss of human or animal life. Heavy rains, snow smelts or typhoons are reasons for the generation of floods. Rapid identification and response to flooded areas can help to safe life and to protect some important areas. Real-time flood monitoring with high resolution images in the optical wavelength range are desirable but usually not possible because of the cloudy and rainy weather conditions at this time. Because of their independency of weather and light conditions, Synthetic Aperture Radar data are used for these purposes. After the floods a precise assessment of the damaged areas can help local authorities in planning and organizing the reconstruction and future protection measures. Data from optical instruments in different spectral channels of satellites like SPOT or LandSat are very helpful in precise assessment of the situation and damages. Liu Y.L. et al. (2003) put forward the concept of normal water extent (NWE) to define the minimal values for the assessment of flood losses, referring to some special areas around the river, lake, reservoir and dyke and to the land use etc., which are easy to suffer the flood during the rain season. The basic data for NWE are TM or NOAA/AVHRR images. The authors set up the NWE database for seven large river basins of China, which were used to monitor and assess the floods in China since 1999. Yi Y.H. et al. (2005) put forward an algorithm to calculate the depth distribution within the inundated region extracted from the satellite imagery, which can be applied in the flood monitoring and loss evaluation. The algorithm combines the flood region with DEM and acquires a smooth elevation distribution in the flood borderlines after efficient error control due to inadequate precision in the satellite imagery processing. Li D.K. (2005) used MODIS data to identify the flood areas with high bedload content in Weihe river flood of 2003 and concluded that the method of vegetation and the false color composition of channel 2, 5 and 6 were effective to pick up the areas of a flood with high bedload content. Yu T.S. et al. (2003) discussed the monitoring and prediction approaches of drought and flood disasters using meteorological satellite, numerical prediction and field data in Changjiang and Huaihe river basins.

7.3.2 Drought Hazard Monitoring and Evaluation

Droughts, both natural or meteorological droughts and human-induced or agricultural droughts are frequent hazards which cause considerable economic loss in China. The monitoring and assessment of drought are essentially important for hazard alleviation and agriculture management. Remote sensing technique has superiority in drought monitoring compared with conventional means like ground-based measurement. The approaches by VIS/NIR/FIR bands of remote sensing include the methods based on soil thermal inertia, calculation of regional evapo-transpiration, vegetative cover index and temperature, and feature of soil water contents spectrum and so on. For regional drought monitoring and assessment, the polar orbit meteorology satellite like NOAA or FY, as well as Earth Observation System (EOS/MODIS) are the feasible sources because of the appropriate spatial and temporal resolution. Sun L. et al. (2004) Xia H. et.al. (2005) presented a review of the approaches of remote sensing based drought hazard monitoring and their applications. Zhang S.Y. et al. (2006) established the regional drought monitoring model, i.e. the thermal inertia model and vegetation supply water index（VSWI） model, using MODIS data and the work flow to process the remote sensing data, and the severe spring drought in Shaanxi province was successfully monitored in 2005. Mo W.H. et al. (2006) discussed the application of the vegetation supply water index（VSWI）, the ratio of normalized difference vegetation index to land surface temperature, in the assessment of farmland drought with the NOAA satellite data from 1995 to 2000 and the digital information of land use in Guigang City of Guangxi Province. Qin Z.H. et al. (2005) described the methodology to retrieve land surface temperature from MODIS data for agricultural drought monitoring in China, and concluded that the band 31 and 32, of the 8 thermal bands, could be especially suitable for land surface temperature estimation. Zhang J.Y. et al. (2005) introduced the principles of the surface energy balance system (SEBS) and an arithmetic for quantitative survey of surface drought characters based on SEBS using NOAA satellite images and weather observations, discussed the application of the arithmetic, including the data processing, model parameter initialization, result evaluation and error analysis, on drought monitoring at large scale in China.

7.3.3 Irrigation and Drainage Management

The complexity of sustainable land and water management leads to a need for improved monitoring, understanding and modeling of spatial processes related to irrigation and drainage. The remote sensing technique pays a significant role for this purpose. The applications may include the high resolution mapping of irrigated lands, crop water requirement, crop water stress, detection of saline areas, catchment hydrology, and irrigation management. Liu X.L. et al. (2005) discussed the approach to assistant extraction of winter wheat cropping area using the time series of MODIS vegetation indicator. Bao Y.S. (2006) described the method for retrieving soil water content and winter wheat planted field from ENVISAT ASAR, by analyzing the relationship between winter wheat field's backscattering coefficient and soil water content or wheat coverage. Kang Q.et al. (2005) Fu Q.H. et al. (2005) presented a review of current major methods for soil salinazation monitoring by remote sensing and its prospective. Kang Q.et al. (2005) discussed the remote sensing application in studying soil salinization in arid areas based on ASTER images. A remote sensing dataset comprised of 9-band multi-spectral images of ASTER was used, and the accuracy of the method reached to 79.1%. Pan S.B.et al. (2004) discussed the impact of water resources development on the environment system in Shule River basin located in Hexi Corridor, Gansu province of China. The numerical groundwater simulation models for three irrigation commands was developed with the aid of remote sensing and GIS in order to analyze the ecological environment changes after the implementing of the agriculture development project.

7.3.4 Land Cover Changes and Water Resources Development

The production and use of information on land cover and land use has dramatically increased during the last 50 years in relation with the development of spatial planning policies on one hand and of remote sensing and GIS techniques on the other hand. Land cover i.e. the cover of the earth's surface with soil, water, vegetation, cities etc. depends on natural factors and human activities. The anthropogenic influence on land cover is related to land use and for agriculture, forestry and urbanization. Changes in land cover include changes in the hydrological cycle and in most of the mass and energy fluxes that sustain the biosphere and geosphere. As a result the amount of runoff, the soil moisture and groundwater recharge are strongly affected by land use changes. On the other hand, unreasonable water resources development, especially in arid or semi-arid regions, may also cause the land cover changes such as the degradation of vegetation and desertification. Chen H.L. et al. (2005) presented a review of remote sensing application in land use/cover change (LUCC) monitoring and assessment with emphasis on the composite application of multi-source data and numerical experiment. Yan Z.L. and Tang G.A. (2004) employed remote sensing to investigate the variation of vegetation after emergent water transferring in Tarim River basin in year 2000. Cui W.G. and Mu G.J. (2004) introduced the evaluation of Manas oasis, and the method using RS technology and the theory of physiognomy and geology to study oasis spatial and temporal change process. Wang Y.Y. and Li J. (2004) described new methods aiming at improving the conventional computer classifiers, such as statistic based classification, artificial neural network classification, knowledge based, support vector machine classification. Cao Yu, et al (2006) discussed the landscape ecological classification using vegetation indices based on remote sensing data, and demonstrated the method for natural oasis landscape analysis at Ejina of Inner Mongolia of China.

7.4 CONCLUSIONS AND FUTURE PERSPECTIVE

7.4.1 Conclusions

Remote sensing, particularly from various satellites in various spectral bands, can provide information on watershed characteristics for the spatial estimation of regional parameters for hydrological research and water resources management at various scales. Another important facet of remote sensing is the fact, that such data can be acquired in remote areas or under very difficult circumstances.

Many of the advances in the application of remote sensing technique in hydrology and water resources management have come from various fields including flood and drought hazard monitoring and evaluation, irrigation and drainage management, monitoring of ecologic environment, as well as water cycle research in catchment, watershed and global scale. The advantages of using remote sensing are as followings (E.T. Engman and G.A.Schultz 2000):

-- The ability to provide spatial data, rather than point data,

-- The potential to provide measurements of hydrological variables, such as soil moisture and snow water content, which are not available through traditional techniques.

-- The ability, through satellite sensors, to provide long-term, global-wide data, even for remote and generally inaccessible regions of the earth.

7.4.2 Future Perspective

The future development of remote sensing application in hydrology and water resources is likely to be great for several reasons such as:

-- The convergence of data acquisition and data visualization technologies,

-- The integration and fusion of data from all available sources and the development of models related to hydrology and water resources, as well as disaster and environment.

-- The possibility, to acquire data for large areas with a high resolution in space and time at one spot and in real-time, which may serve as basis for water management decisions in real-time.

In China, the Miniature Environmental Disaster Satellite Constellation, which is composed of four optical satellites and four radar satellites, is planned to be lunched in recent years. The CBERS -03/04, the succession of CBERS- 01/02, are also planned to be lunched before 2010. The spatial resolution and the quality of image of the satellites will be considerably improved.

FY-3 and FY-4, respectively the polar orbit and geostationary orbit of the second generation of meteorology satellites, are also put in planning. The applications of remote sensing in hydrology and water resources management could be expected to be greatly developed with more and more sources of satellites.

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