REMOTE SENSING AS A TOOL FOR WATER RESOURCE ENGINEERS

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INTRODUCTION

The technology of remote sensing offers a unique method of data collection and analysis for water resource managers and engineers. This technology, like all others, has its capabilities and limitations. Herein, we examine the North American state-of-the-art of remote sensing for water resource applications from a practical point of view.

Once the technical feasibility of a remote sensing application has been established, “practicality” can be re-defined as “cost-effectiveness”. With this in mind, it can be easily recognized that the least expensive of competing information sources and methods is preferable. Thus, much research in this field has focused on satellite data applications in contrast to airborne methods. The costs of satellite data are shared jointly by all users of the system while airborne imaging projects are most often customized for the individual user and therefore, more expensive. Of course, airborne data collection is much more flexible to the client’s demands, and is therefore favoured by the researcher. When a methodology for a particular remote sensing application approaches “operational” status, it behooves researchers to attempt to transfer their methods to the more economical satellite data sources. If successful, that would make their techniques cost-efficient too.

For this reason, primarily satellite data applications are considered here with only some reference to airborne methods of data collection.

DATA CHARACTERISTICS

Remotely sensed data, especially from sensors on satellite platforms, offer the dramatic advantage of total areal coverage. Compared to in-situ sampling, it means that interpolation or extrapolation of discrete point samples is not necessary. Also, anomalous or unique areas of a water body will be as easily sampled as any other area, and without prior knowledge.

Since satellites repeat their orbits every sixteen days or so (depending on the specific satellite) multi-temporal coverage is achieved without any effort on the part of the user. Thus, time sequence studies may be conveniently made for analysis of seasonal variation, yearly change or environmental impact before/after construction. The earliest satellite coverage, on a regular basis, was collected in 1972 (Landsat-1). Therefore, archives of satellite imagery extending back approximately 15 years may be regarded as a historical resource of environmental conditions. Methods exist (see: Alföldi, 1980) for extracting quantitative water quality (and other) information from these historical images without the benefit of simultaneously-acquired in-situ data for corroboration.

Because satellite imagery is originally digital in nature, it means that it is, first of all, objective and quantitative. Secondly, it is reducible by computer, which is an absolute necessity, since there is so much data to handle.

Raw remotely sensed images harbour distortions of the true geometric and radiometric character of the scene they depict. The data must be “pre-processed” to remove these distortions so that the image gives a representation of reality as best it can. Most often, the pre-processing is a service offered by the agency which records and distributes the satellite images.

ANALYSIS METHODS

Since imagery acquired by remote sensing can be made into photographs or shown on television screens, therefore, they may be visually interpreted. Interpretation by eye is usually for those applications involving texture, pattern, shapes and context, and gives subjective results. An example might be the analysis of circulation patterns in a water body.

Computer analysis is most applicable to those problems requiring the manipulation of brightness and colour or large areas or multiple images. Examples might be the identification of seaweed types or the measure of suspended sediment concentration.

Often, a mix of man and machine is best for a particular analysis objective. For example, a computer (digital image analysis system) is used to correct and enhance an image so that a human interpreter can analyze the subtleties of a scene which otherwise may have been missed. Conversely, the automated classification of an image into its environmental components may be initiated, and later guided, by the knowledge of a human interpreter.

Image analysis is most often done for the purpose of mapping some environmental feature(s). In the realm of water resources, however, there is a much greater tendency to monitor changes to the (water) environment. This is, no doubt, because of its dynamic nature. Satellite remote sensing is ideally suited to this purpose, with its repetitive, large area coverage. In many cases, it is not even necessary to depend on the images for the positive identification of a target or phenomenon. It is simply very useful to recognize that something has changed, and to pinpoint the timing and location of that change. Then, field crews can be sent to the location(s) to make accurate identification of the phenomenon.

WATER RESOURCES APPLICATIONS

Water resource managers are interested in two broad categories of information which remote sensing can address. Watershed hydrology parameters which refer to the geographic and dynamic characteristics of a watershed are conveniently mapped and monitored through remote sensing means. These parameters include: land use/cover; surface water, snow and ice distribution; and geomorphological features (floodplains, drainage patterns, etc.). The other category is water quality. The parameters here include: turbidity, suspended sediment concentration, chlorophyll concentration, temperature, trophic state and pollutants. Sometimes water circulation and bathymetry is added to this second category.

Watershed Hydrology

The success with which remote sensing can collect useful information about watershed hydrology is very high. This is due to the fact that the targets of interest are on the earth’s surface and therefore technically simple to sense. Further, these targets/parameters influence light directly, and so a direct relationship may be established between the optical properties of the light being sensed/recorded and the environmental features of the watershed.

One of the clearest examples of this is the mapping of surface water areas. At wavelengths in the near infrared, there is a very large contrast between the high reflectivity of terrain and the low reflectivity (high absorption) of water. This permits surface water mapping at 98% or more accuracy. Other watershed features such as land cover, snow cover and ice distribution also enjoy very high (>95%) mapping accuracy. Those which require interpretation in context (floodplains, land use, irrigated land) typically produce accuracies at 90% or better.

Middleton and Munday (1980) stated that most of these watershed hydrology features could be mapped at full- or quasi-operational level. Several states (in the USA) were at that time already using Landsat satellite data for routine watershed and water quality management planning.

In Canada, remote sensing technology transfer between the federal and provincial/territorial governments is under the Technology Enhancement Program (TEP). To date, each individual program under the TEP has included evaluation or demonstration projects for watershed analysis, land use mapping or other watershed hydrology – related applications (CACRS, 1986). Following the completion of each (2-3 year) technology transfer program, it has been found that these remote sensing/monitoring activities are either done routinely by a provincial government agency, or offered as a service by a commercial source.

Water Quality

Measures of water quality parameters are more difficult than those of surface features because of the nebulous link between the parameters sought and their optical properties. Many researchers concentrate on establishing the correlation between some water quality parameter and the appearance (brightness/colour) of the water body to a remote sensor. Needless to say, the results are varied.

Johnson, et al (1980) report that Landsat (Multispectral Scanner) was capable of measuring total suspended sediment at concentrations above 5 mg/l with an accuracy of ±5 mg/l. They also identify Landsat's ability to measure chlorophyll blooms above 10 mg/m^3 and to measure surface temperature between 260 – 340^0K with an accuracy of $\pm 1.5^0$K. Munday, et al (1979) show high correlation (R>96%) between Landsat-measured colour and total suspended sediment for concentrations between 1 and 1000 mg/l. Middleton and Munday (1980) indicate that Landsat-based measures of turbidity, Secchi disk depth and suspended sediment concentration are operational techniques, but not the measurement of chlorophyll concentration.

It is apparent in the literature that the measure of total suspended solids or inorganic suspended solids is much more successful than that of chlorophyll because of several factors. First, chlorophyll is a much darker target than inorganic sediment, resulting in a greater error of measurement of its reflected light. In turn, that results in less accurate estimates of concentration for the darker target. Second, chlorophyll concentration is typically more (spatially) heterogeneous than inorganics, making its representation in a picture element of (say) 50 x 50 metres, more error prone.

Chlorophyll in the form of aquatic vegetation, however, is high enough in concentration and temporally stable, so as to permit detection and mapping. Using airborne methods at first, Mouchot et al (1986) showed that not only detection was possible, but even separation and identification of various species of marine plants.

Other problems exist with water quality measurement from satellite. The measure of temperature is limited to the water surface, leaving investigators to ponder the relationship between surface and sub-surface temperature. Suspended sediment can be measured in the photic depth only, which may be quite shallow in turbid waters, leaving speculation open as to the turbidity conditions at greater depths. Suspended sediment appears the same (in the visible wavelengths commonly used to measure this parameter) as sediment which has settled to the bottom. Thus the question arises in clear/shallow conditions: is the phenomenon depicted in a satellite image, a bathymetric feature or a turbidity condition?

Probably the most vexing problem for measuring any water quality parameter by satellite deals with atmospheric interference. The light being measured by satellite sensors (in the visible wavelengths), are influenced by the ever changing atmospheric conditions. When a satellite image is “calibrated” by the data acquired in-situ, simultaneously to the overpass of the satellite, that relationship (between surface and satellite data) is valid only for that single image (or perhaps part of that image). Because the atmospheric conditions will dramatically alter from that occasion to the next acquisition of a satellite image, the correlation established for the first image will not be applicable for the next. This necessitates acquiring in-situ data for each satellite image to be used. Considering the cost and complexity of collecting in-situ data, it becomes unfeasible to do this on a regular basis.

Some researchers have been trying to find a way to extend (extrapolate) the utility of one correlation (surface versus satellite data) to other images which did not have the benefit of coincident in-situ measurements. A common feature of several different approaches has been the use of standard reflectors or constant targets found within a satellite image to remove the atmospheric component of the signals recorded by the satellite. These may be oligotrophic lakes (Ahern et al, 1977), airport runways (Scarpace et al, 1978), phosphate mines (Welby et al, 1977), or sediment plumes (Alföldi et al, 1978). Success in using these targets for atmospheric correction varies, and for the potential user, depends significantly on whether the targets are commonly found in his region.

CONCLUSIONS/DISCUSSION

In North America, those agencies with the mandate for water resources management have found many and diverse uses for remotely sensed data in their operational activities. Two certain indicators of the maturity of remote sensing technology are the concern with cost-effectiveness by users and the existence of commercial services for remote sensing data analysis. This signals that potential users have a technically valid and cost-effective tool at hand.

While the literature shows the abundant applicability of this technology to water resources applications, individual users should only rely on their own evaluations. There is sufficient geographic variability and difference in user needs to warrant at least a feasibility study or pilot project for those interested in incorporating remote sensing methods into their operational management and planning activities.

SOURCES OF FURTHER INFORMATION

There exists a wealth (even a glut) of information on the application of remote sensing to water resources management. For those interested in the technical aspects, a comprehensive bibliography has been prepared by NASA (see Middleton and Marcell, 1983), wherein the scientific papers have been broken into categories and sub-categories of water quality topics. Besides the variety of university level textbooks on remote sensing available, the American Society of Photogrammetry and Remote Sensing offers a two-volume manual (ASPRS 1983) that has extensive references to water resource science and applications.

One of the most comprehensive sources of information on all aspects of remote sensing is the Technical Information Service (TIS) of the Canada Centre for Remote Sensing. In addition to full library services, the TIS offers a computerized data base (RESORS) on remote sensing bibliographic references which is free and rapid. Through the use of keywords, RESORS searches may be customized for general or very specific topics of interest. Address inquiries to The Library, CCRS, 2464 Sheffield Rd., Ottawa, Canada K1S 0Y7. (author's note: this is no longer available)

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