High Resolution Analysis[1]/

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The purpose of this statement is to explain in general the possibilities for the use of high resolution analysis in the field of hydrology and water resources. High resolution analysis is considered here to mean high spectral resolution, not high spatial resolution.

The current state of knowledge of high spectral resolution analysis in hydrology is meager. Spectrocopy for the identification and measurement of the concentration of constituents in water is highly developed for laboratory use and is capable of measuring the concentration of many substances in water at levels of micrograms and nanograms per liter. Remote measurement of the quality of water has, to date, involved only measurement of sediment concentration by reflected light, measurement of chlorophyll and phaeopigments (Nimbus CZCS), and the measurement of fluoresence with the Fraunhofer Line Discriminator (FLD). The FLD can detect fluorescing substances in water at levels of less than one part per billion of Rhodamine WT equivalents but is not diagnostic of chemical species.

I have not considered here the use or development of high spectral resolution methods in other disciplines such as geology (rock discrimination), agricultural or natural vegetation, soils, or cultural features. Identification and discrimination of such features by high resolution analysis can be done, and improved upon, and inferences on the hydrologic characteristics can then be made. High resolution spectral analysis in those fields does not give direct hydrologic information.

[1]/ This is an informal statement of problems and recommendations prepared for the Hydrology Workshop of the Multispectral Imaging Science Working Group, April 26, 1982.

Critical gaps in scientific knowledge that need to be filled before new technology can be evaluated involve the spectral response of water, substances dissolved and suspended in water, and substances floating on water. A major example is the sensing of oil on water. Mapping and monitoring of oil slicks has been done in the visible, near infrared, thermal infrared, and ultraviolet regions of the spectrum, and it is clear that the most complete mapping can be done in the ultraviolet region. Ultraviolet sensing has been done only from aircraft at altitudes of 1000 meters or less because of the attenuation of ultraviolet radiation in the atmosphere which severely limits its sensing at higher altitudes and precludes its use from satellite altitudes. Is there a way around this problem? Is there a way of measuring the ultraviolet reflection at the surface from satellite altitudes? This gap in knowledge may well be worth filling.

Witzig and Whitehurst (1980) have reviewed the use of Landsat MSS data for the trophic classification of lakes. A copy of their paper is attached. This excellent review points out that there is a serious lack of sensors that can measure the fundamental reflectance of water. It seems likely that the use of high spectral resolution sensors in a reasonable number of narrow bands may be able to sense reflectance or emission characteristics of water and its contained materials that will be correlatable with the commonly used water-quality variables. It seems unlikely that remote sensing instruments can be built that have detection sensitivities for dissolved constituents in water that are as low as those that are now achieved with laboratory instruments. Nevertheless, the ability of remote sensors in airborne or spaceborne platforms to survey large areas rapidly and synoptically may outweigh the lack of sensitivity to individual constituents.

Candidate remote sensing experiments should be conducted both empirically and on the basis of testing of hypotheses. An example of an empirical experiment would be the use of the Thematic Mapper (or the airborne TM simulator) to view water bodies in various trophic states to determine if the previously unavailable bands are useful in characterizing trophic state.

Experiments to test hypotheses might involve such hypotheses as "the backscattering of light from sediment particles in water is dependent upon the composition, size, and concentration of the particles."

Experiments should also be made in an empirical way to determine if the fluorescence characteristics of substances in water are diagnostic of the type and concentration of the substances.

The technological alternatives available to experiment with problems of sensing water quality are (1) to use existing remote sensing instrumentation in an empirical mode and (2) to develop new instruments to either test hypotheses or to conduct empirical experiments. Goldberg and Weiner (1977) in their paper "Feasibility and technology for making remote measurements of solutes in water" (copy attached) recommend construction of a Raman spectrometer which could ". . . rapidly map the concentration of many water solutes, even in water bodies that are difficult to access by ground." This suggestion should be evaluated in light of developments in the 5 years since their paper was published.

Goldberg has informed me recently that the advances in optical multichannel analyzers and in Fourier and Hadamard transform methods in spectroscopy may now make it possible to build a remote reflectance spectrometer with equivalent of several hundred narrow bands which could be used for empirical experiments in remote measurement of water quality. Attached is a paper by Marshall and Comisarow (1975), "Fourier and Hadamard transform methods in spectroscopy" which outlines the advantages of these techniques over the commonly used spectrometric (or multiband remote sensing) techniques.

The technological developments required are involved in the use of available methods and instruments developed for other purposes (such as optical multichannel detectors) for water-quality sensing. Consideration should be given to utilizing such instruments initially in the laboratory and later in the field for empirical studies of water-quality characteristics.

No specific information extraction research is proposed for the extraction of information from multispectral data. Developments in Fourier transform spectroscopy should be investigated for their applicability.

Drainage Basins/Soil Moisture Uses for Visible Infrared Data

Some form of visible infrared data is essential to the use of remote sensing for appraisal of watershed drainage areas and for the estimation of soil moisture. It is, however, difficult to conceive of significant advantages in either area of application that will result from improved spatial resolution of these data. Improved spectral resolution, on the other hand, may provide better mapping of the characteristics that we need for drainage areas and for agricultural areas where soil moisture is estimated.

Visible-infrared data in the past have been used both in a qualitative and quantitative sense to make preliminary assessment of watershed characteristics. Quantitative evaluation of drainage area, aerial extent of snow cover, topography or slopes, stream channel numbers and land use have been common tools for practicing hydrologists for years. Some of these characteristics are more readily quantified with digital data and modern processing techniques. With the exception of the extent of snow cover these watershed characteristics are all relatively stable with time.

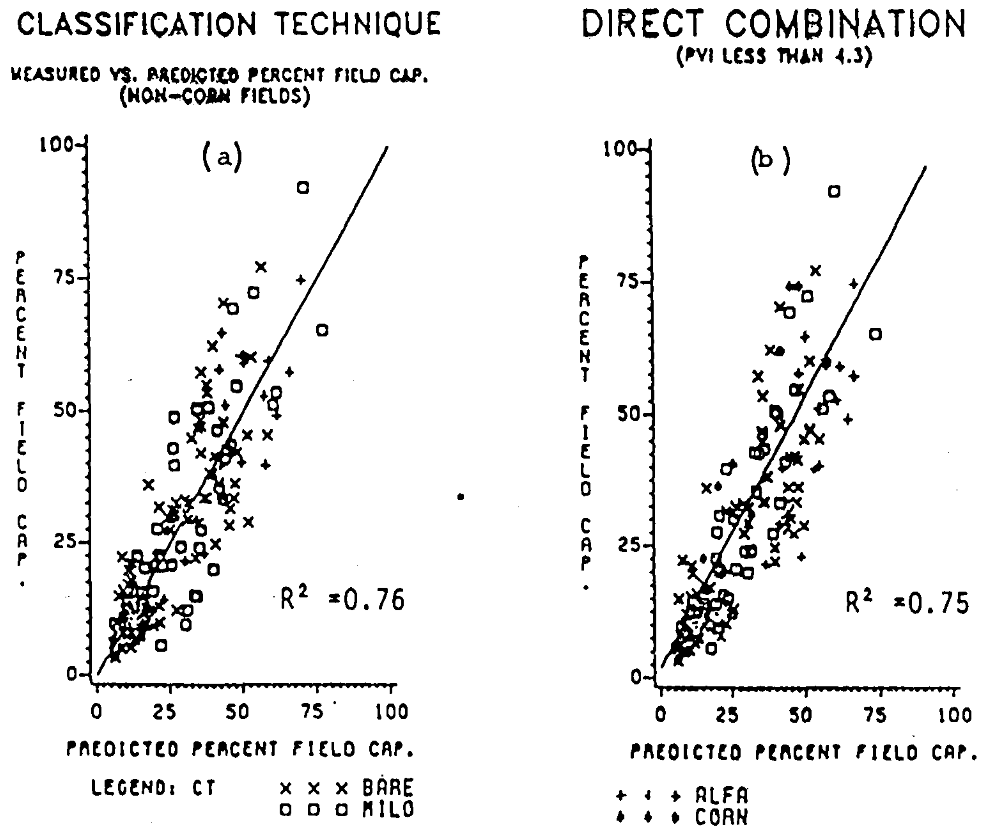
Three major characteristics of much greater importance to watershed hydrologists are: 1. Mapping of the hydrologic character of surface soils, i.e. infiltration rate, hydraulic conductivity or storage capacity; 2. Mapping soil moisture; and 3. Mapping of water content of snow. Mapping any one of these will require the use of microwave systems, however, none of these can be adequately mapped by microwave over significant areas of the land without supplemental visible-infrared data.

An attempt has been made to modify or adjust microwave data over vegetated areas by use of classification or a biomass estimation to provide improved estimates of soil moisture, Figure 1 from a recent study by S. Theis. A simple biomass estimator, the perpendicular vegetation index (PVI), was found more useful overall than a 100% correct classification of five vegetation types. The biomass estimation is used in this study as a surrogate measure of the water content of the vegetation--the actual parameter that is adding confusion to the microwave energy from the surface soil water mix. We show this figure to illustrate that the visible-infrared information required to make this estimation is an absolute requirement.

When acceptable soil moisture measurement can be made in a time series, the remote sensing classification of soils becomes a possibility. Using information from two models, one for soil moisture profile definition [Hillel] and one for passive microwave emission [Schmugge], it can be shown that time series changes in emissivity can be used to indicate the hydraulic character of soils, Figure 2. To accomplish this classification a precise and reasonably accurate estimate of soil moisture is required, therefore, we must have the visible-infrared data available if significant portions of the land surface are to be classified as to soil type.

Both the soil moisture and soil classification will most likely be limited to cells greater than 5 x 5 km in size. There is, therefore, little likelihood that improved spatial resolution would improve the results. In the Theis study, the thematic mapper simulator from JSC was used to calculate the biomass. In addition, data from the 11 channel scanner on the C-130 and data from Landsat were available for a portion of the study. There was some indication that better spectral resolution improved the estimate of biomass.

The third significant need for remote sensing of watersheds, the estimation of snow water content, requires a different array of microwave sensors and most likely will require different visible and infrared data. It is evident



The ability of the L-band radiometer to predict percent field capacity when used a) with classification technique (no corn), and b) with direct combination technique (excluding fields with PVI greater than 4.3).

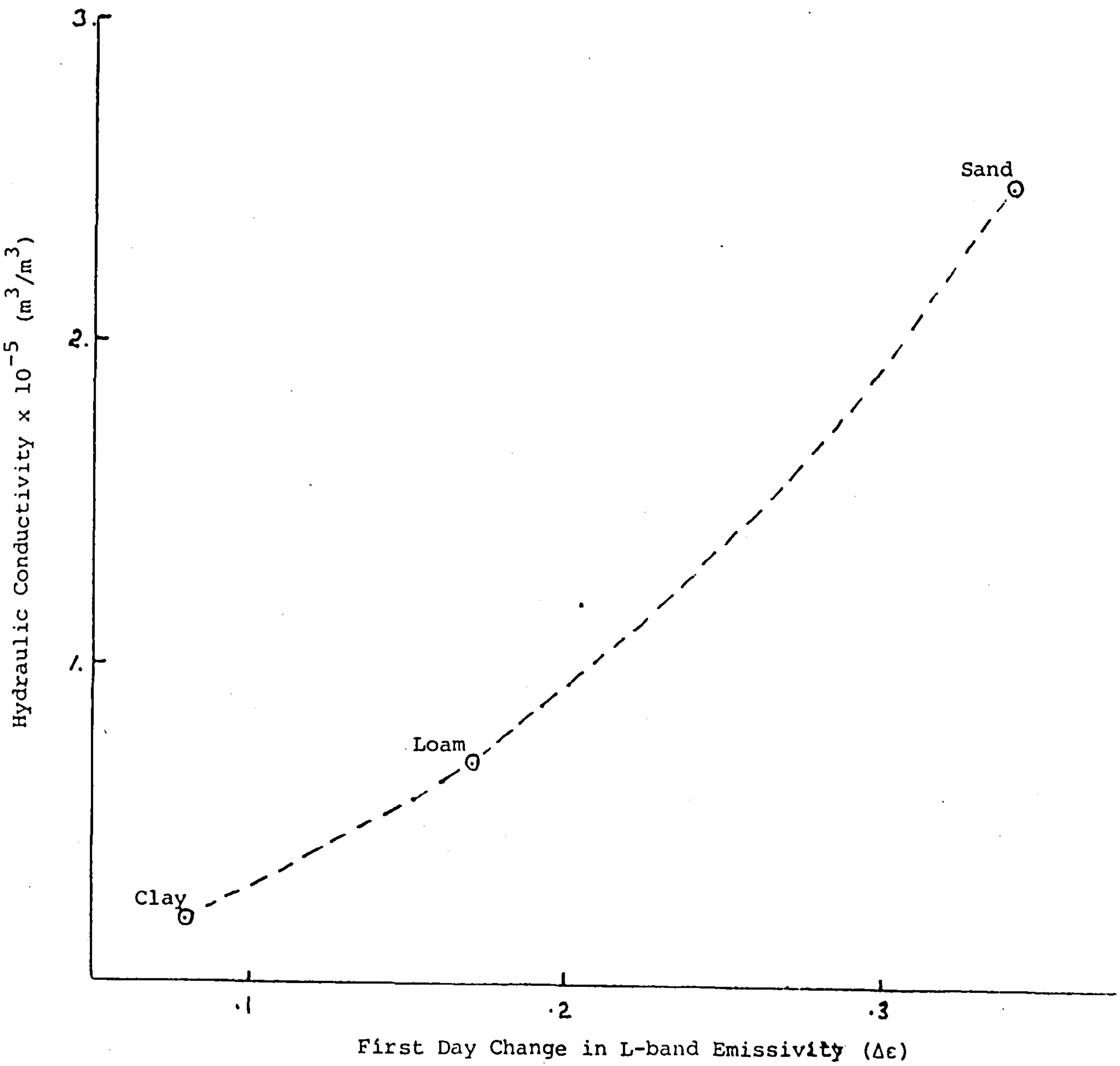


Figure 2. The relation between the change in L-band passive microwave return and hydraulic properties of the surface soils. (Data from Hillel and Van Bavel.)

that extension of the range in the near infrared provided in the thematic mapper will provide the opportunity to separate clouds and snow cover. It is not, however, evident that any significant improvement in snow area estimation will come from improved spatial resolution.

Improved spatial resolution will provide the hydrologist with improved data on very small watersheds (1 km^2, or less). This may aid some small area research efforts of an academic nature but the results from hydrologic studies of small areas cannot necessarily be extrapolated to larger areas.

Generally, it would appear that improved spatial resolution will not be of value to the watershed hydrologist while better spectral resolution at selected frequencies may improve estimates needed in this work. It is evident from the Theis study that there are several options for selection of bands from the Thematic Mapper to provide an acceptable biomass estimate. These could be selected to also be of value to snow mapping and water quality requirements thus minimizing the total data volume needed.