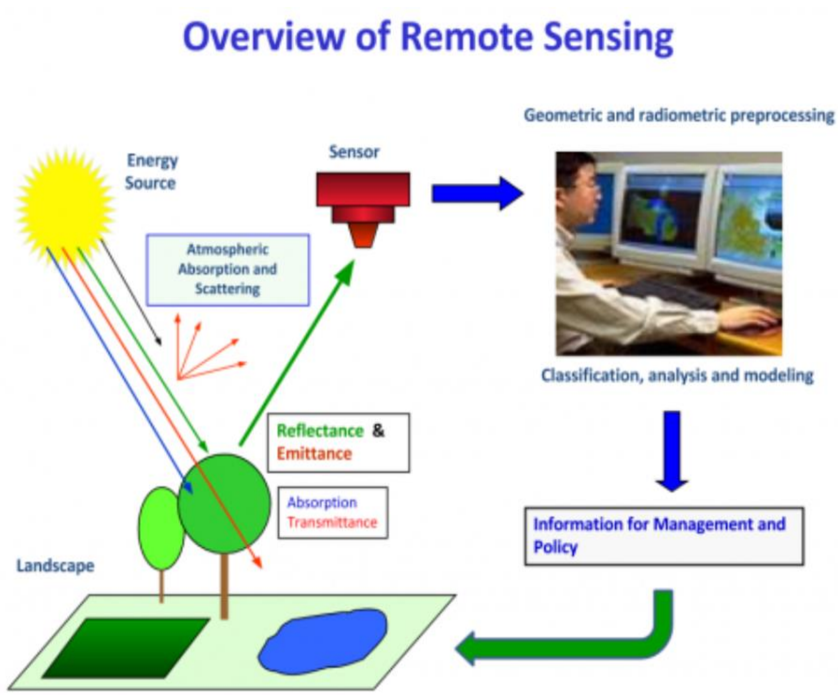
Historical Methods

Remote sensing is the science of obtaining information about an object or area through the analysis of measurements made at a distance from the object, i.e., not coming in contact with it.

The oldest form of remote sensing, in use since the 1920s, is aerial photography, where the sensor system is a camera and film. Over the past ~45 years, the field of remote sensing has grown to include various electronic-optical sensors that acquire multispectral digital images, which can be processed and analyzed by computers. Many of these sensors are on satellites that regularly orbit the Earth. There are numerous applications of satellite remote sensing for mapping and monitoring environmental and natural resources at local to global scales.



The quantity most frequently measured by these satellite sensors is the electro-magnetic energy reflected by the object. Such data are recorded in imagery for various wavelengths (spectral bands) within the visible, near infrared and thermal infrared regions of the spectrum. The source of the electromagnetic energy for most of these sensors is the sun, and the spectral reflectance properties of many Earth surface features, such as soil, vegetation and water, can be used to uniquely identify and characterize them.

Much research and monitoring of natural resources has been accomplished using multispectral sensors on the Landsat series of satellites (https://landsat.usgs.gov). Several features of these satellites make them particularly useful for assessment of inland lakes. Their geographic coverage (12,000 square miles per image) allows simultaneous assessment of thousands of lakes in lake-rich areas. Their spatial resolution (30 meters) is suitable for all lakes larger than

~10 acres and can be used to map in-lake variability. In addition, the imagery is available at no cost to users.

Strong relationships exist between the Landsat spectral responses in several visible bands and in-situ observations of water clarity as measured by Secchi depth, SD, which is a general measure of water quality. We have used such relationships to assess the clarity of water in more than 10,000 Minnesota lakes. Nine classifications at ~5-year intervals from 1975 to 2015 have provided an unprecedented assessment of these lakes.

The following section briefly describes the steps for extracting water clarity information from satellite imagery through text and a visual summary. More complete descriptions can be found in Chipman et al. (2009), Kloiber et al. (2002) and Olmanson et al. (2001).

Step 1: Collect ground samples

To extract useful information from satellite images about land features, we generally need to gather some information on the ground, commonly referred to as ground, reference, or field data. These data or samples provide information to verify what the satellite sensors detect. They should be collected close in time to when the satellite images are acquired.

Several ways can be used to gather ground samples depending on the water quality property being studied. For lake water clarity, we use Secchi depth data from the Minnesota the Pollution Control Agency and its Citizen Lake Monitoring Program, which regularly measures Secchi depth on about 900 lakes in Minnesota. In this case, collecting ground samples is simply a matter of obtaining the data from an MPCA web site.

Secchi disks are a water clarity measurement tool that indicates how clear lakes are by observing how deep an 8-inch, white disk can be lowered into a lake before it is not visible.

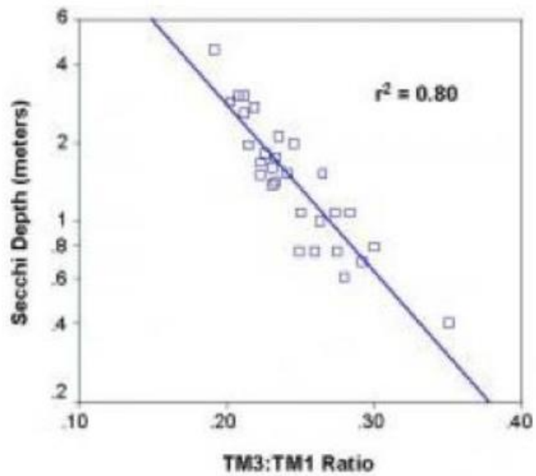
Step 2: Acquire satellite imagery

Satellite sensors vary in their spatial, spectral, radiometric, and temporal resolutions. Spatial resolution can vary from 0.6 meters (m) (e.g., QuickBird) to 1,000 m (MODIS). The Landsat sensors (Thematic Mapper, TM; Enhanced Thematic Mapper Plus, ETM+ and Operational Land Imager, OLI), the sensors used for most of our lake water clarity work, have medium resolution (30 meters) but cover relatively large areas with a swath width of 115 miles. MODIS, the sensor on the Terra and Aqua satellites, covers a much larger area with 1,400 miles swath width, but at coarse resolution (250-1000 m). Obtaining clear imagery is critical because haze, as well as clouds, can affect the results. If you would like to learn more about the science and technology behind satellite remote sensing, visit the **Classroom** section.

Step 3: Process satellite imagery

Once imagery is acquired, a series of steps are taken to prepare the imagery for analysis.

1. Following geometric rectification to match other maps, satellite imagery is pre-processed to remove cloud, haze and sun effects.



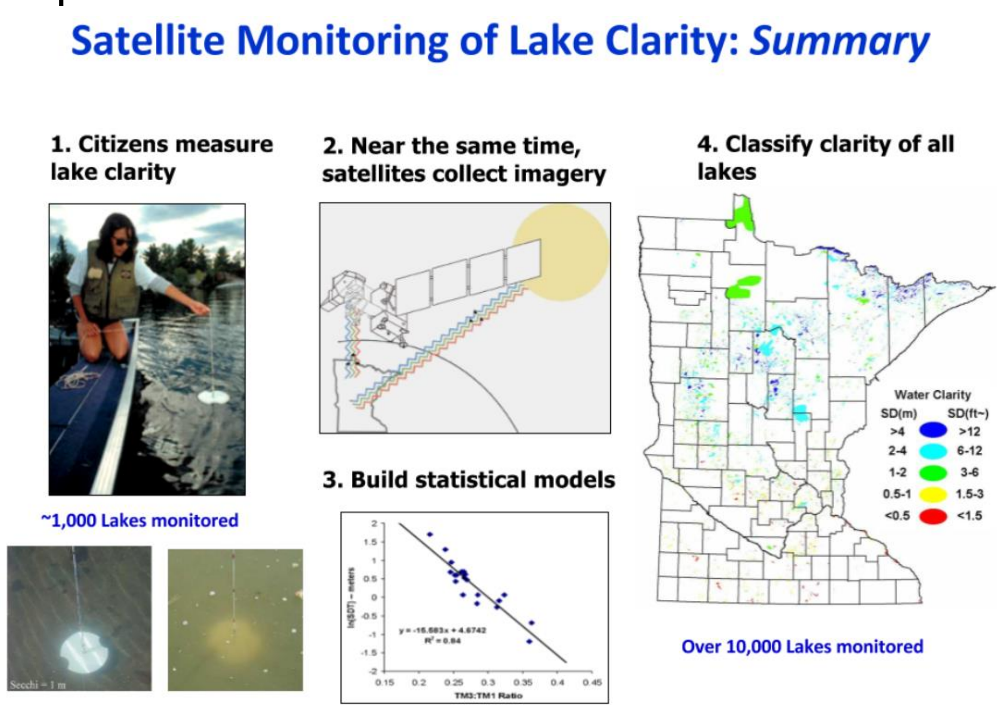
2. When mapping water features, non-water areas, such as agricultural land, urban land, and forests, are masked out of images.

3. After imagery has been pre-processed, the relationships between lake clarity and their spectral-radiometric responses (in the simplest sense, colors) are determined by regression modeling for a representative sample of each class. We have found strong relationships between lake water clarity and the responses in the blue and red spectral bands. It is important to note that in our historical approach, we calibrated each image to ground-based data. This approach eliminated the need to correct imagery for atmos-pheric effects (differing levels of aerosols and other factors the affect the amount of light reflected from ground/lake surfaces that reaches the satellite sensor). In our more recent studies, we have used atmospherically corrected imagery, which enables us to use calibration data across multiple images.

4. The regression model then is applied to all lakes in the image, providing a census of lake clarity.

Step 4: Create a map

Once the mathematical relationship between the satellite data and the field data has been developed and applied to all pixels, a map of water clarity is produced, and the pixels are grouped into discrete classes of clarity level and visually displayed, such as in the **Lake Browser**, or put into a Geographic Information System (GIS) for further analysis.



Similar relationships can be developed between reflectance data in various sensor bands and other important measures of water quality, including chlorophyll, a measure of the abundance of algae in waterbodies; colored dissolved organic matter (CDOM), a measure of total dissolved organic carbon that affects many aquatic ecosystem processes; phycocyanin, a measure of cyanobacteria (blue-green algae); and various measures of suspended particulate matter in natural waters. Compared with earlier Landsat satellites, the sensors on newer satellites, such as Landsat 8 and the European Sentinel-2 satellites, have greater numbers of spectral bands that are more narrowly focused and thus facilitate measurement of these constituents.

References

Chipman, J. W., L. G. Olmanson and A. A. Gitelson. 2009. Remote Sensing Methods for Lake Management: A guide for resource managers and decision-makers. Developed by the North American Lake Management Society in collaboration with Dartmouth College, University of Minnesota, and University of Nebraska for the United States Environmental Protection Agency. 126 p.

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Olmanson, L. G., S. M. Kloiber, M. E. Bauer, and P. L. Brezonik. 2001. Image processing protocol for regional assessments of lake water quality. Water Resources Center, Public Report Series #14, University of Minnesota, St. Paul, MN, 55108. 13 p.