Remote Sensing of Lakes, Streams, Wetlands and Impervious Surfaces

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1905 International Falls (before dam) from Wilson Family
International Falls Settlement 1870's
Wilson Family
From Photo Foreground Shopping Mall
Overview of Remote Sensing

Image

Atmospheric Absorption and Scattering

Landscape

Energy Source

Sensor

Reflectance

Absorption Transmittance

Interpretation and Analysis

Information – maps and statistics – for Applications
Physical Basis of Remote Sensing

The distinctive character of electromagnetic radiation reflected or emitted from natural and human-made objects and scenes

Spectral Reflectance of Basic Cover Types

- Green Vegetation
- Light Soil
- Dark Soil
- Turbid Water
- Clear Water
Advantages of Remote Sensing

1. Improved vantage point, synoptic view
2. Broadened spectral sensitivity
3. Increased spatial resolution
4. 3-D perspective
5. Capability to stop action
6. Historical record
7. Comparability of data
8. Rapid data collection
9. Ability to extend ground observations
10. Quantitative analysis
11. Cost savings
Lake Clarity Monitoring

Summary: what we do

1. Citizens measure lake clarity
2. Near the same time, satellites collect imagery
3. Build statistical models
4. Clarity of all lakes is classified

~850 Lakes monitored

Over 10,000 Lakes monitored

\[ y = -15.583x + 4.6742 \]
\[ R^2 = 0.84 \]

Lake Water Clarity Inferred from Early 1990's Landsat Images

Water Resources Center & Remote Sensing Laboratory
University of Minnesota
Landsat Imagery and Results

Two of the Landsat paths used for ~2000 water clarity assessment and agreement between in-situ measurements and Landsat estimates.
Census of Minnesota Lake Water Clarity

- All lakes 20 acres or larger are included
- Over 10,000 lakes classified

~1985, ~1995 data currently being processed
Minnesota Water Clarity Change by Ecoregion from 1990 to 2000

- 10,062 lakes classified in ~1990 and ~2000
- 1249 lakes (12.4%) changed >10 TSI units
  - 659 Lakes (6.5%) clarity increased >10 TSI units
  - 590 Lakes (5.9%) clarity decreased >10 TSI units
Lake Water Clarity
Lake of the Woods

Inferred from an August 30, 1990 Landsat Image
by Leif Olmanson
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Water Resources Center & Remote Sensing Laboratory
University of Minnesota

TSI(SDT) SDT(m)

- 30  8
- 40  4
- 50  2
- 60  1
- 70  0.5
- 80  0.25
- 90  0.125
Dissemination of Information
water.umn.edu and LakeBrowser
Using Landsat to aid monitoring program design: MPCA examples

- **Example - 1** – Develop a study to examine interrelationships among water quality, lake morphometry, rooted plant growth, and other factors in shallow lakes (Part of an EPA-funded study for purpose of developing nutrient criteria);
- Needed a range in trophic status to aid in defining these relationships;
- Had minimal data on shallow lakes as few had been previously sampled by MPCA, MDNR or by volunteers;
- Used satellite imagery to identify potential lakes, linked to MDNR and MPCA web sites for further information & identified a subset for further monitoring in 2003.
Satellite-estimated TSI

• Start at county or regional level, identify potential lakes for study,
• link to MDNR & MPCA web sites for details on lake

East Solomon Lake
• 706 acres, 13 foot max. depth;
• Lake level data available;
• MDNR plant survey data
• Include in 2003 study

2003 Shallow lake study
Resulting distribution of study lakes for 2003.
Northern MN lakes in 2004

Example 2: Long-term - seek to monitor all lakes greater than 500 acres in size, prioritize sampling based on TMDL thresholds;

• Focused on north-central MN in 2004 – wanted to identify “outliers” – lakes that may be above TMDL threshold for NLF ecoregion lakes;

• Used satellite image to identify candidate lakes (i.e., higher TSI than norm for region);
Lake monitoring 2004: North-central MN: Cass, Crow Wing & Aitkin Counties

- NLF ecoregion – lakes are predominately oligo-mesotrophic;

- Seek eutrophic (green ~ eutrophic in terms of clarity) lakes near TMDL threshold for further study:

- Seek other lakes with limited data in same “area” (cluster sampling for efficiency);

Sugar & Vermilion Lakes:

- Lower clarity as compared to norm for region;

- Little or no existing water quality data;

- Included in 2004 sample effort;
NALMS Remote Sensing Project

NALMS to receive a grant to further remote sensing in Region V states – building on success of RESAC effort in MN, WI, and MI;

1) Will develop a guidance manual that compares various remote sensing platforms (preferred application, costs, pros and cons) over a range of scale (e.g.):
   • MODIS (500-1,000 m) – low spatial resolution, high spatial coverage;
   • Landsat (30 m) – moderate spatial resolution, moderate spatial coverage;
   • Proximal sensing (in-situ) – very high spatial resolution, low spatial coverage;

2) Develop prototype (Landsat-based) water clarity assessment for each participating state - anticipate: OH, IL, and IN;

3) Develop a workshop to share information on above with all interested states;
Monitoring Rivers and Streams

from September 5, 2003 Landsat TM imagery
River Airborne Remote Sensing Project
Confluence of the St. Croix River with the Mississippi River

Water Clarity (cm) T-tube

- 80
- 55
- 33
- 28
- 23
- 18
- 13
- 3

Field Sample Point

[Map and graph showing water clarity and wavelength data]

2 0 2 4 6 Miles
Monitoring Rivers and Streams

• Similar relationships for rivers and streams as for lakes
• However, it’s a more challenging problem
  – Rivers are more dynamic
  – Resolution of Landsat (30 meters) is not sufficient for narrower streams
  – And, if we want more than clarity, we really need a better set of spectral bands than the Landsat bands

• Solution = aerial hyperspectral data
  – High spatial resolution (1-3 meters) and 35 narrow, contiguous bands
Hyperspectral Data Acquisition
August 19-20, 2004

Field data for calibration and analysis of remote sensing data acquired by MPCA and Metropolitan Council for 37 sampling sites:

Chl, TSS, VSS, Turbidity,
River Airborne Hyperspectral Remote Sensing -- preliminary results

Confluence of Minnesota and Mississippi Rivers

Water Clarity (cm) T-tube
- 33
- 28
- 23
- 18
- 13

Field Sample Point
Summary – River Monitoring

• Image preprocessing and calibration is well along
• Statistical analysis to identify key spectral bands for assessing water parameters initiated
• Next step will be to map key water quality variables from the imagery
• Develop methods and recommend imagery for future river assessments
Wetland Condition and Aquatic Vegetation Surveys using High Resolution Imagery
Spectral Signature Collection

Airborne Imaging Spectrometer
Aquatic Plant Reflectance

![Graph showing reflectance of various aquatic plants across different wavelengths.](image)

**Spectral Bands**
- 1-m Hyperspectral
- 2-m
- Landsat TM

- Waterlily & water
- Waterlily leaves
- Waterlily leaf Poor Condition
- Floating leaf pondweed
- Lesser duckweed and water meal
- Lesser/greater duckweed & watermeal
- Cattail
- Arrowhead
- Submerged plants
Example 3-band Color Composite Image
Preliminary Classification of Wetlands
Summary – Wetland Condition Mapping

• Collected detailed plant and community observations, along with reflectance data of wetlands, in support of analysis of remote sensing imagery
• Establishing spectral separability of different plant species and developing a library of spectral signatures for aquatic plant species or groups
• Determine ability to map aquatic plants with hyperspectral image data
• Determine data needs to accurately classify wetlands and wetland health
Impervious Surface Mapping and Change Monitoring using Landsat Remote Sensing

Minneapolis

St. Paul
Greenness is sensitive to amount of green vegetation and inversely related to amount of impervious surface.
Overall accuracy: 92.1%
Kappa: 90.2%
Determination of % impervious for model development and accuracy assessment
Model Relationship of Landsat Greenness and Percent Impervious Surface Area

\[ Y = 48.35 - 1.156 G - 0.00055 G^2 \]

\[ R^2 = 0.91 \]

\[ \text{Std. Error} = 10.6 \]

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<th>Year</th>
<th>N</th>
<th>( R^2 )</th>
<th>Std. Error</th>
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<td>0.90</td>
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<td>53</td>
<td>0.86</td>
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<td>1998</td>
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<tr>
<td>2002</td>
<td>59</td>
<td>0.91</td>
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Results

Landsat Classification of Impervious Surface Area

- **Agriculture**
- **Forest**
- **Shrub & Herbaceous**
- **Water**
- **0 % Impervious**
- **Urban/Developed**
- **100 % Impervious**
Change in Percent Impervious Surface Area
1986 – 2002, by County

Anoka  Carver  Dakota  Hennipin  Ramsey  Scott  Washington  Total:

Impervious Area (%)
0  5  10  15  20  25  30  35

Types of Impervious Area:
- 1986
- 1991
- 1998
- 2002
Woodbury, 1986

Impervious Area
1,949 acres
8.5 %
Woodbury, 1991

Impervious Area
2,573 acres
11.2 %
Woodbury, 1998

Impervious Area
4,169 acres
18.2 %
Woodbury, 2002

Impervious Area
4,438 acres
19.4 %
Summary – Impervious Mapping

- Strong relationship between impervious area and Landsat greenness enables mapping percent impervious surface area at the pixel level.
- We are in the middle of statewide classifications, but believe that Landsat classifications provide GIS-ready, accurate and consistent maps and estimates at 30-meter resolution over city to county to regional size areas.
  - Like lake clarity monitoring, this too is working.
The Future

• Lake clarity monitoring
  – Transfer to MPCA for routine/operational use

• River and stream water quality
  – The data acquired this summer is a promising start, but will need further development and testing if it is to become operational
    • Will also need means to economically acquire data

• Refine and continue impervious surface mapping

• Near shore impacts to lakes
  – Next logical step from current work
  – Will require relatively high resolution imagery
Aerial Remote Sensing System for Minnesota

- High spatial resolution needed for narrow rivers and lake shore areas
- Control/flexibility of timing of data acquisition
- Hyperspectral sensor recommended
- These requirements are not met by satellite sensors
  - And, contracting to out of state vendor is likely not economical
- Will have many applications by multiple agencies, including DNR, Metropolitan Council, as well PCA
- We should initiate discussions and planning with agencies aimed at acquiring this capability