The Future of Water Quality Monitoring by Remote Sensing

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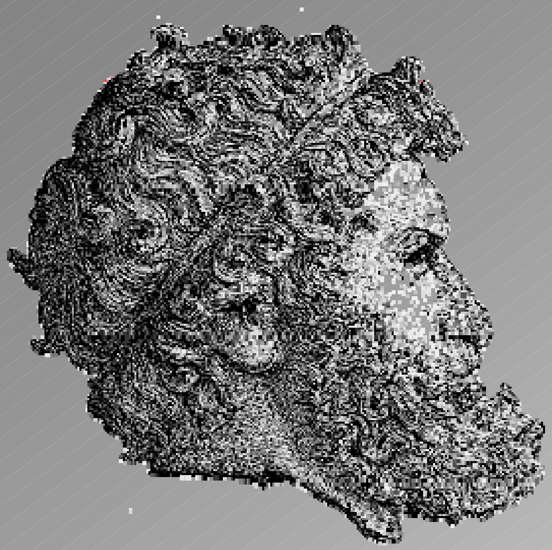
NATIONAL AERONAUTICS
AND SPACE ADMINISTRAT



The Heraclitus Problem

It is impossible to step into the same river twice, because water moves and flows; when you stick your toe back in the water, it is a different river.

Greek Philosopher Heraclitus 500 BC


Ontario
Quebec
Superior
Minnesota
Wisconsin
Michigan
Huron
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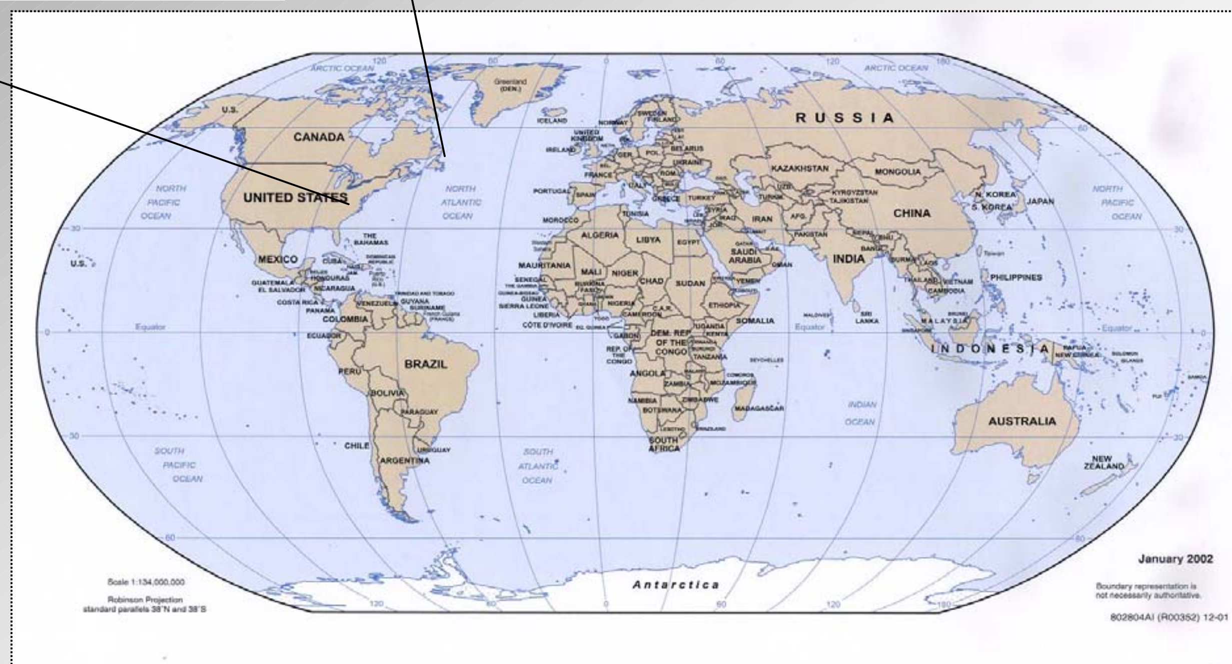
Ontario
New York
Erie
Pennsylvania
Illinois
Indiana
Ohio
Image © GLIN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UNITED STATES
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MONGOLIA
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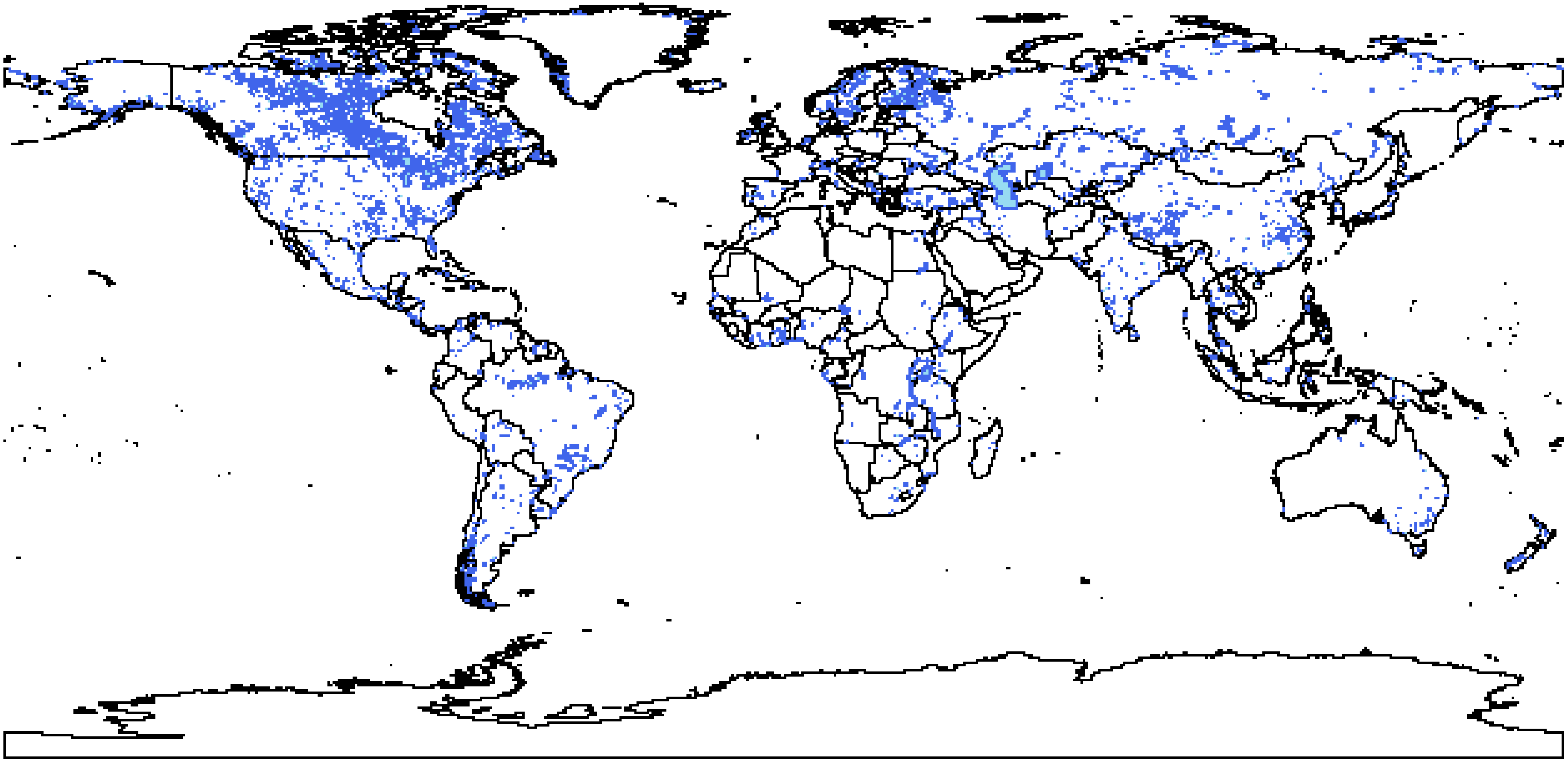
AUSTRALIA
Antarctica
January 2002

Inland Water Quality

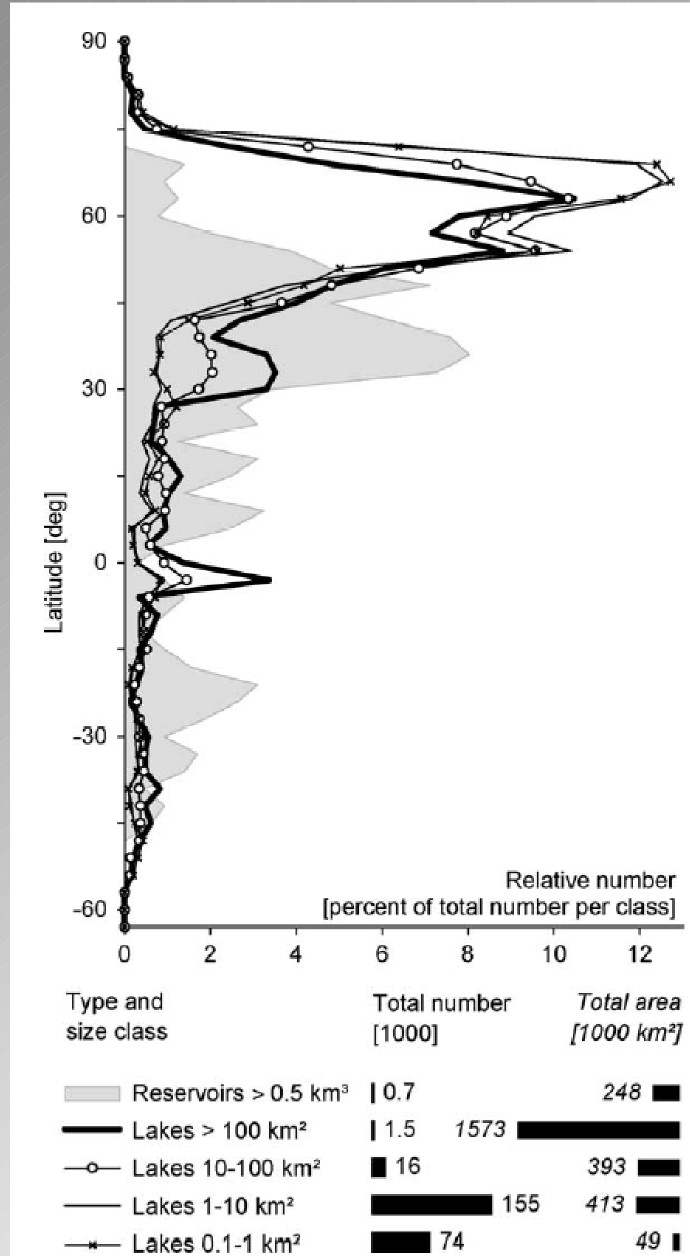
- Essential for life
- Only 3% of global water is fresh, <0.01 available
- Half of water appropriated
- Demands
  - Drinking water
  - Sanitation
  - Irrigation
  - Recreation
  - Industrial process water
- Dwindling supplies
  - Munic.&indust. Discharges
  - Nonpoint sources

Implications of Poor Water Quality

- Impacts- Human
  - One fifth of population inadequate drinking water
  - One half of population inadequate sanitation
  - Two billion water borne illnesses annually
- Impacts- Ecosystem
  - Half major rivers and lakes degraded
  - Accelerated algal blooms, D.O. depletion
  - Over fishing
  - Toxicity



From: Lehner, B. and P. Döll (2004): Development and validation of a global database of lakes, reservoirs and wetlands. Journal of Hydrology 296/1-4: 1-22.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Lakes > 100 km²
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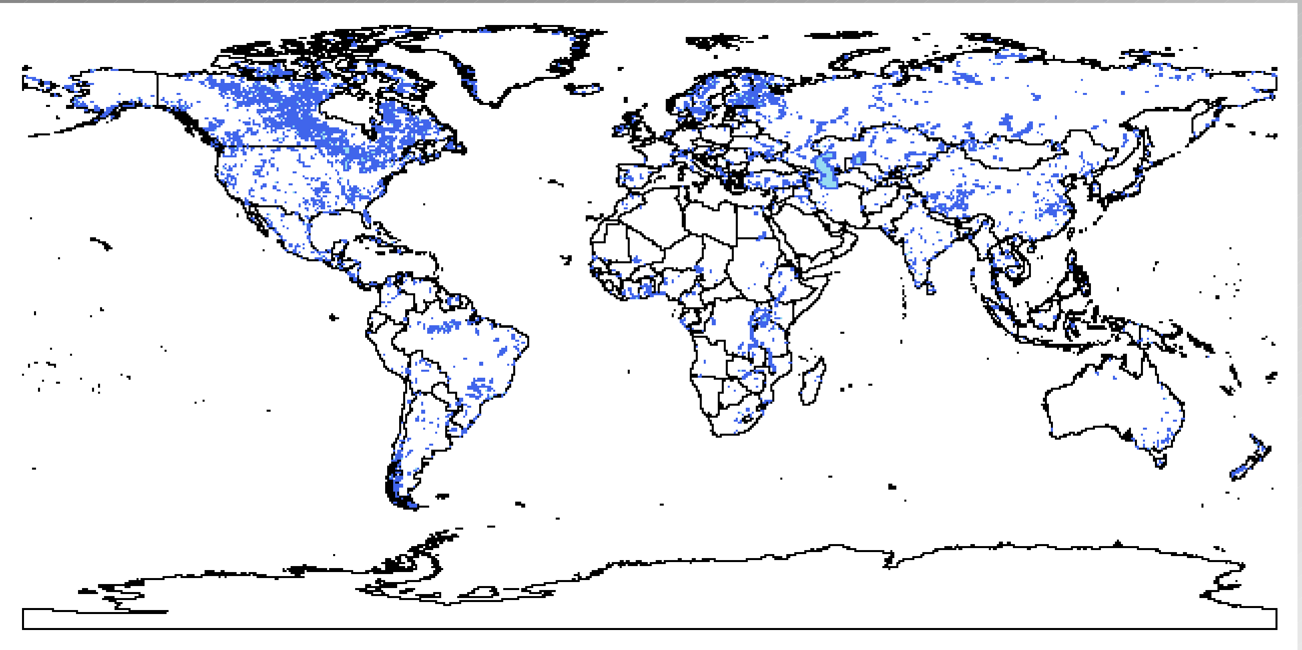
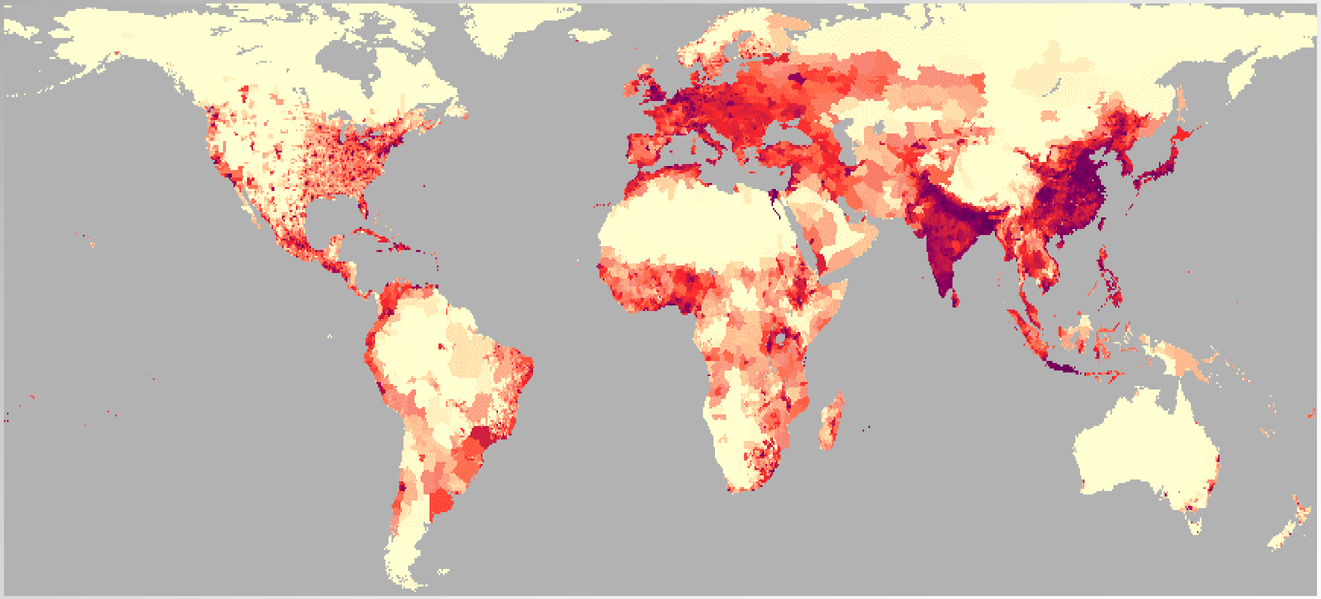
Lakes 1-10 km²
155
413
Lakes 0.1-1 km²
74
49

Water Distribution



Population Density



Recent Global Attention

1992 Earth Summit

1996 World Water Council- WWF

2002 World Summit on Sustainable Development
Resolutions#27,28

27. Support developing countries and countries with economies in transition in their efforts to monitor and assess the quantity and quality of water resources, including through the establishment and/or further development of national monitoring networks and water resources databases and the development of relevant national indicators.
28. Improve water resource management and scientific understanding of the water cycle through cooperation in joint observation and research, and for this purpose encourage and promote knowledge-sharing and provide capacity-building and the transfer of technology, as mutually agreed, including remote-sensing and satellite technologies, particularly to developing countries and countries with economies in transition.

2003 Third Water Forum, Koyoto “Year of the Freshwater”

The collection, analysis, dissemination, and utilization of water data and information around the world requires greater investment, especially in information-poor areas in the developing world where poverty, water scarcity, floods, droughts, pollution and disease have devastating impacts.

2005 GEOSS Implementation Plan 4.1.5

Improving Water Resources Management…………water quality

Impetus for Increased RM

- Lack of financial, institutional, technical resources for monitoring, insufficient coverage
- Continuity of historical records/ political instability
- Slow dissemination/sharing of data/transboundary issues

Remote Sensing of Freshwater

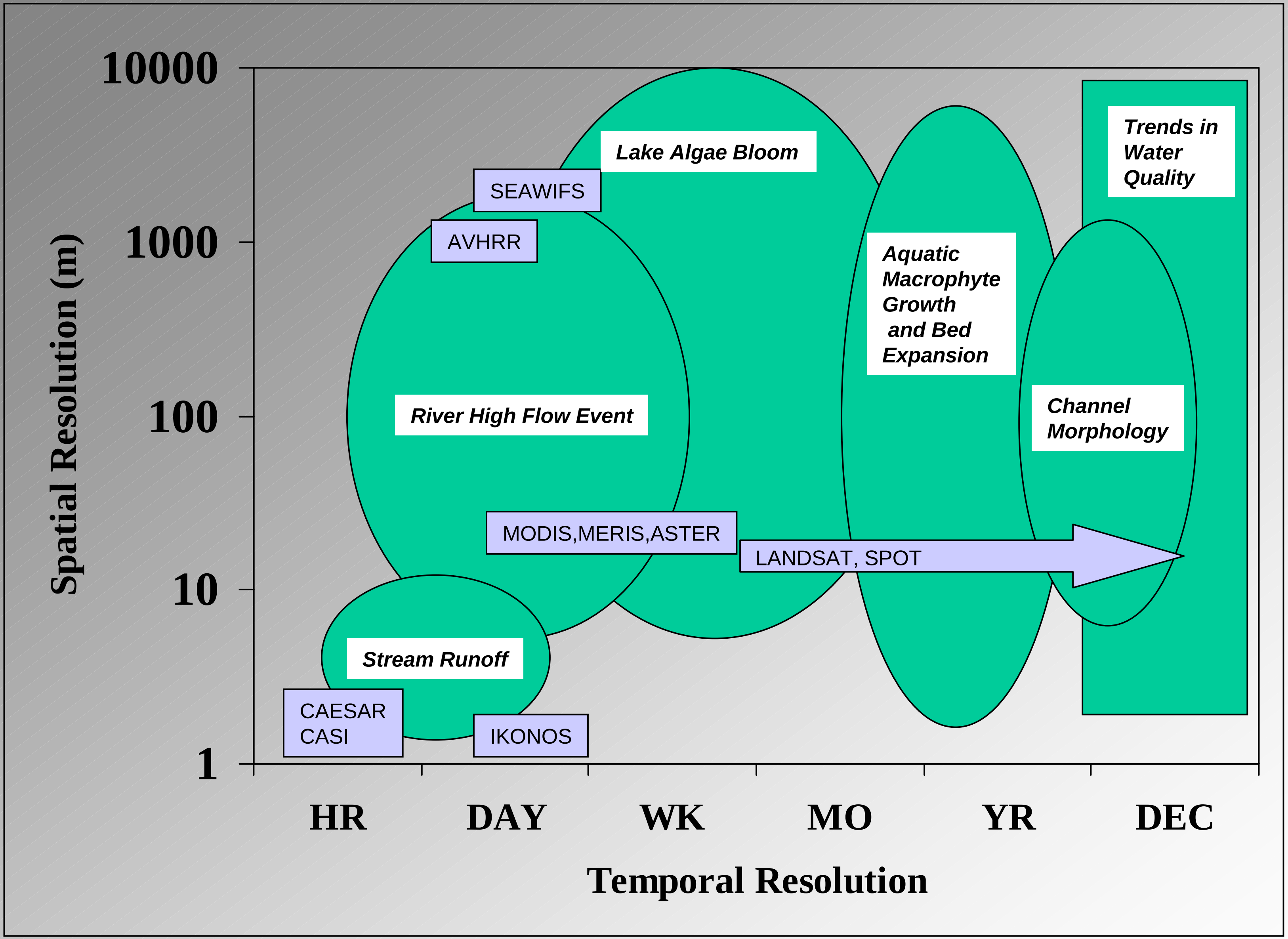
- Emergent flux of photons
- Physical, chemical, and biological properties modify spectral signature
- Generally use visible spectra (390um to 740um)
- WQ parameters via remote sensing
    - Temperature
    - Turbidity/ Suspended Solids
    - Color
    - Salinity
    - Oil Slick
    - Secchi Depth
    - Algae, Chlorophyll- distribution, speciation, productivity
    - Surrogates- Nitrogen, phosphorus, bacteria, metals
    - Macrophyte Surveys
    - Fish Counts

Water Related Diseases and Remote Sensing Potential

Factor	Disease	Mapping Opportunity
Flooding	Malaria	Mosquito Habitat
	Rift Valley Fever	Breeding Habitat
	Schistosomiasis	Snail Habitat
	St Louis Encephalitis	Habitat creation
Permanent Water	Filariasis	Breeding habitat
	Malaria	“
	Onchocerciasis	Simulium larval habitat
	Schistosomiasis	Snail habitat
Wetlands	Cholera	Vibrio cholerae
	Encephalitis	Mosquito habitat
	Malaria	“
	Schistosomiasis	Snail Habitat

Water Quality/ Remote Sensing Challenges

1. Freshwater (CaseII) complex mixture, CPA’s- algae, particulate,color
2. RS measure surface conditions, bottom visible in shallow
3. Dynamic water quality changes
4. Relatively small water body sizes
5. Cloud cover over inland areas
6. Can’t monitor all parameters


10000
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1
Spatial Resolution (m)
Lake Algae Bloom
SEAWIFS
AVHRR
River High Flow Event
Trends in Water Quality
Aquatic Macrophyte Growth and Bed Expansion
Channel Morphology
MODIS,MERIS,ASTER
LANDSAT, SPOT
Stream Runoff
CAESAR CASI
IKONOS
HR
DAY
WK
MO
YR
DEC
Temporal Resolution

Temperature

•Important physical parameter

Control gas solubility

Water density

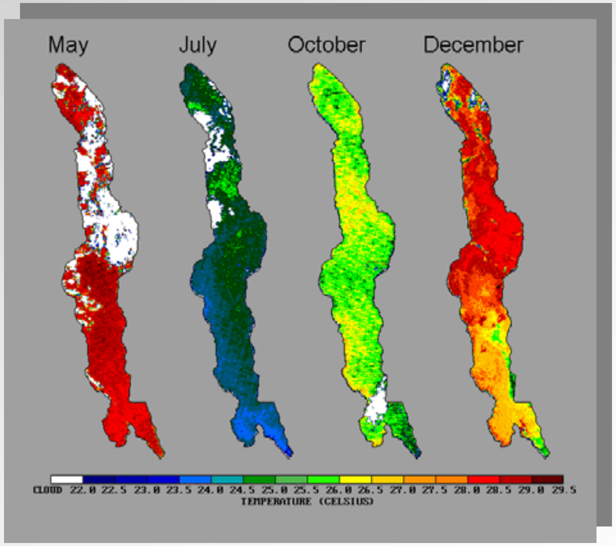
Biological growth rates

•Remote Sensing used to map surface “skin” (100nm)

>AVHRR- Assist marine fisheries in ocean surface temps.

>Air borne FLIR- US Pacific NW, map river temp. for salmonid habitat

> Landsat-7 Define thermal bars in Great Lakes

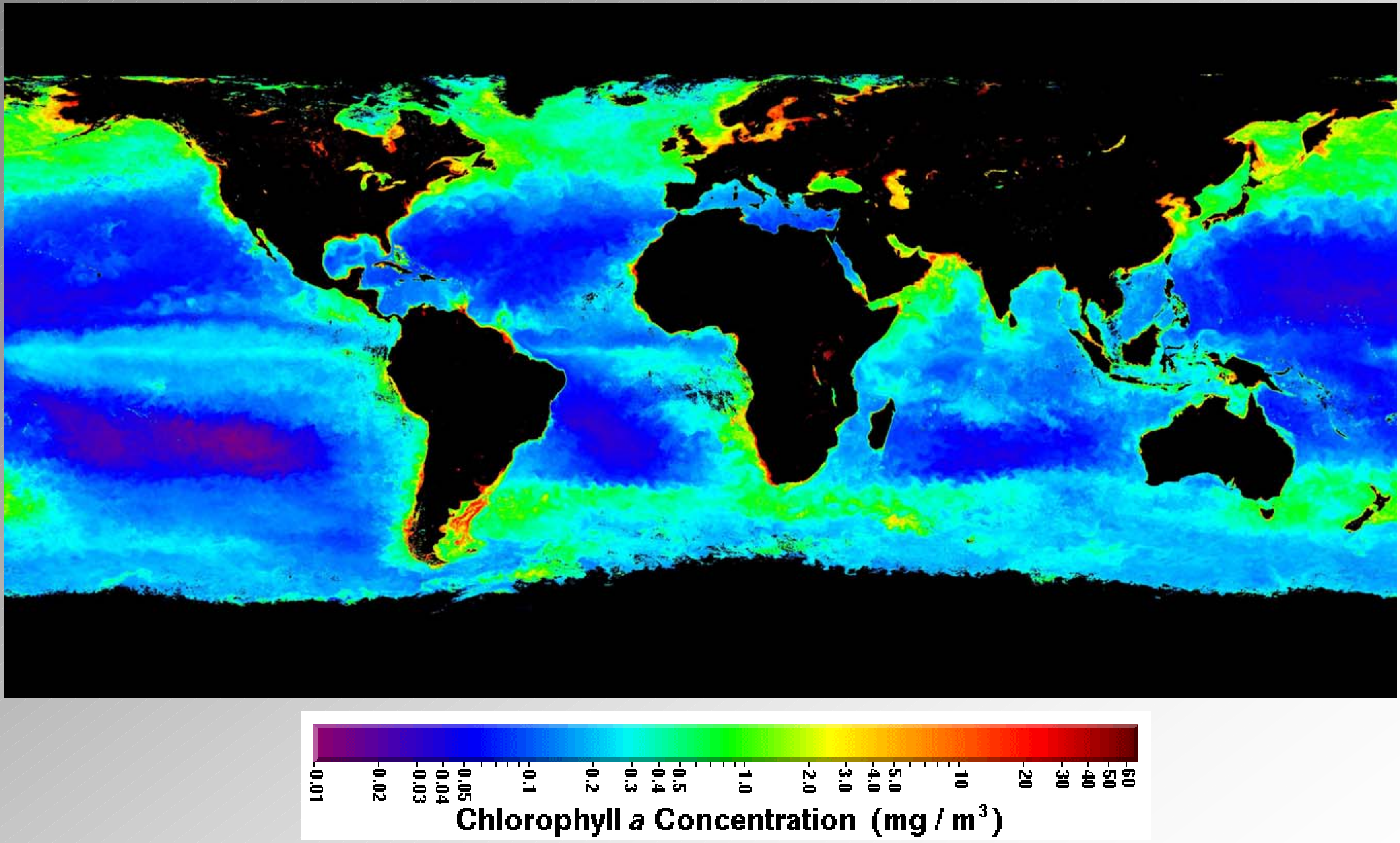


Example of lake surface temperature maps from Africa’s Lake Malawi in 1993
Woolster et al. 1994

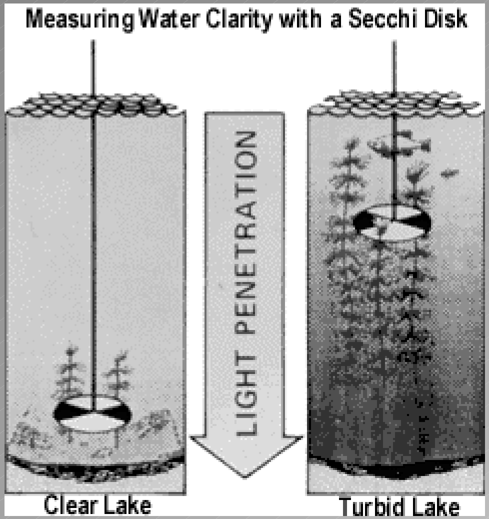
Chlorophyll and Trophic Status Index

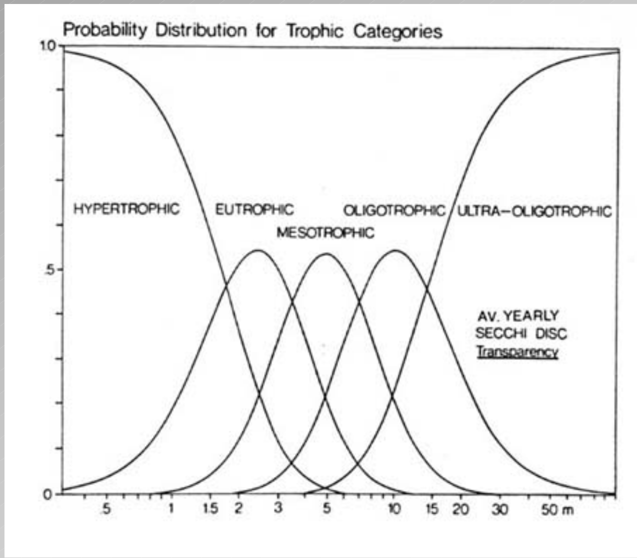
- Generally defines productivity of water
- Nutrient enrichment-eutrophication
- Largest emphasis w/ respect to remote sensing
- Approaches range from empirical >semi empirical>analytical
- Generally use reflectance bans in the red/infrared regions
- Spectral ratios commonly used
- Mathematical approaches include regression,peak integration, derivative analysis, neural networks

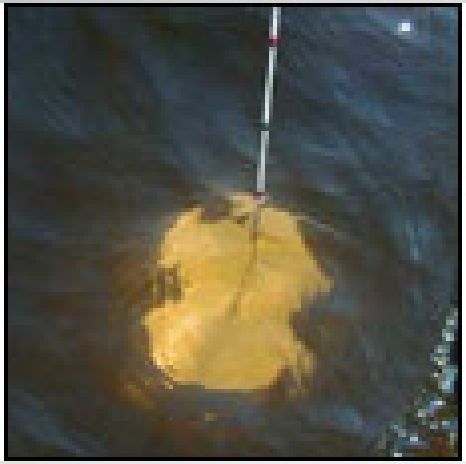
Aqua-MODIS and SeaWiFS ocean chlorophyll products

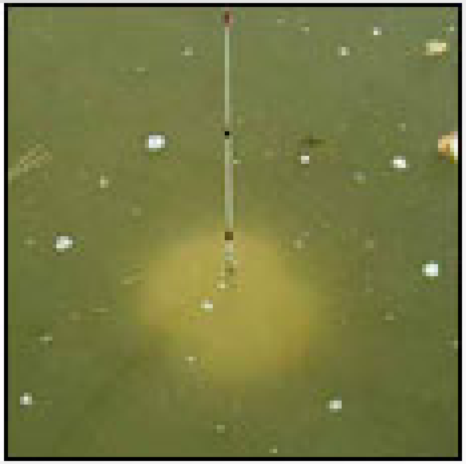


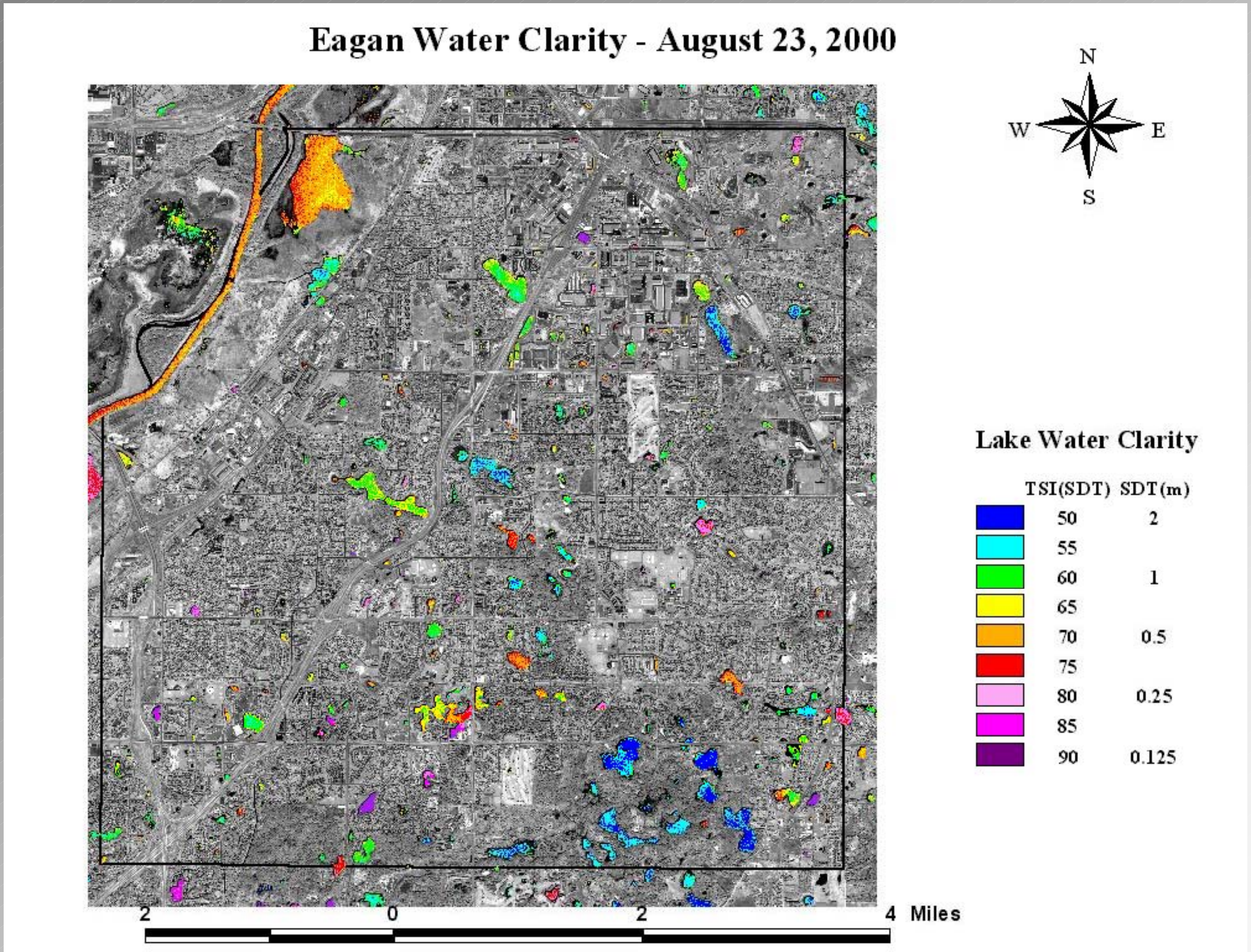
Secchi Disk- A Simple but Important Tool











Trophic status index map of water bodies near Eagan, Minnesota, generated from IKONOS data. Note the fine resolution provides trophic status information about a small river in the image's upper left corner (U. Minnesota, Regional Earth Science Applications Center)

Suspended Solids

•Aggregate parameter (0.45 µm)

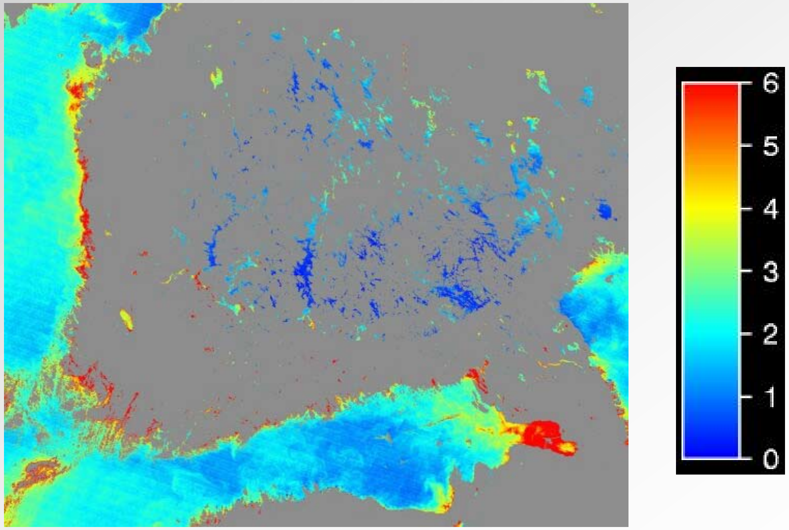
•Comprised of silt (eroded particles), detritus, sewage waste

•Detrimental- blocks sunlight, clogs filtration plants, fish gills
blanket benthic organisms, fills reservoirs

•Increases radiance with concentration

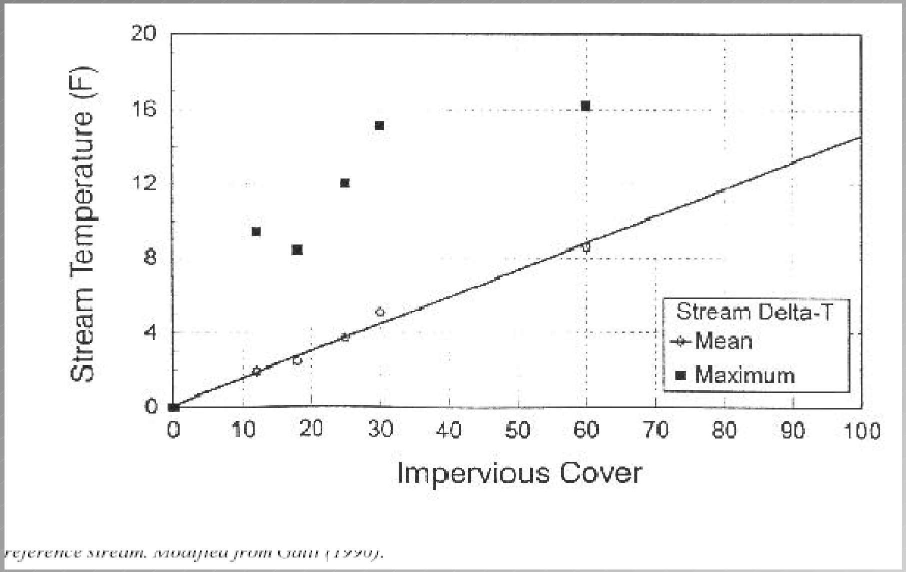
•Successfully measured via remote sensing-
Landsat, SPOT, AVHRR

•Vary w/ particle size, mineralogy,
color and conc.

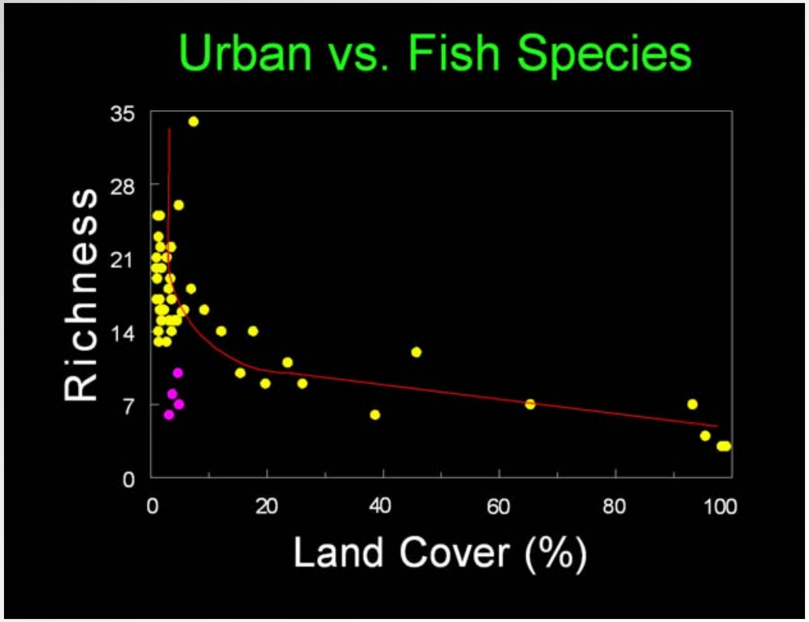


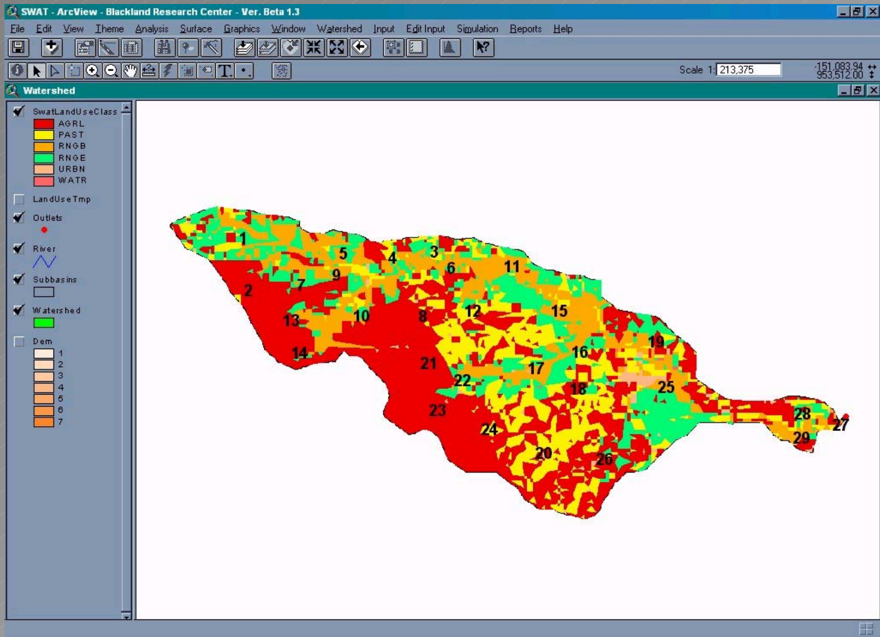
Turbidity (FTU) of lakes of southern Finland and northern Baltic sea as measured by space-borne MODIS spectrometer on 27 August 2000. *courtesy of Helsinki University of Technology, Laboratory of Space Technology.*

Land Use -Water Quality Relationships



Human Impacts >>>Biophysical Responses

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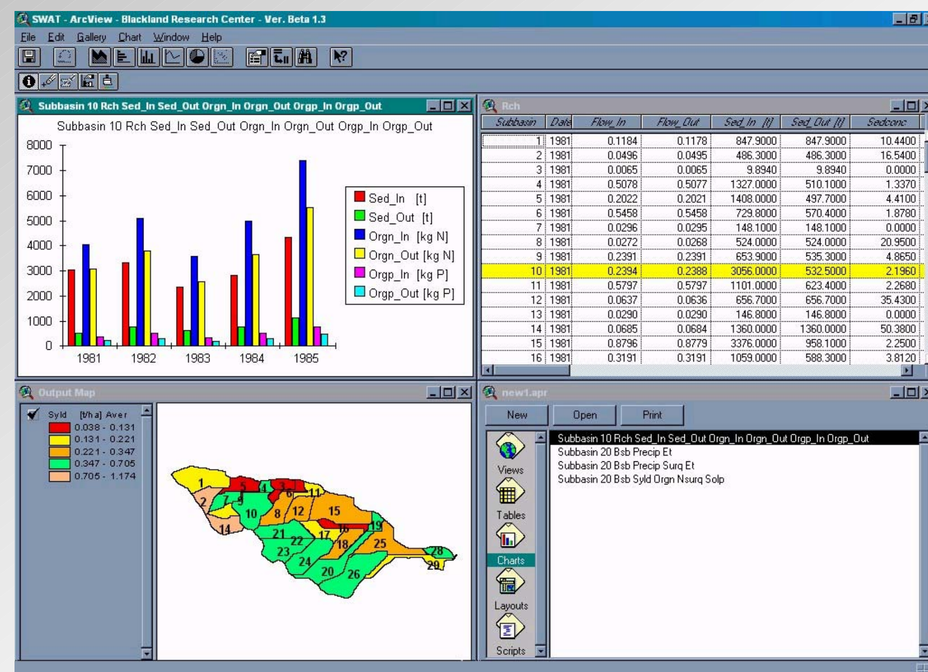
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2 1981 0.0496 0.0495 486.3000 486.3000 16.5400
3 1981 0.0065 0.0065 9.8940 9.8940 0.0000
4 1981 0.5078 0.5077 1327.0000 510.1000 1.3370
5 1981 0.2022 0.2021 1408.0000 497.7000 4.4100
6 1981 0.5458 0.5458 729.8000 570.4000 1.8780
7 1981 0.0296 0.0295 148.1000 148.1000 0.0000
8 1981 0.0272 0.0268 524.0000 524.0000 20.9500
9 1981 0.2391 0.2391 653.9000 535.3000 4.8650
10 1981 0.2394 0.2388 3056.0000 532.5000 2.1960
11 1981 0.5797 0.5797 1101.0000 623.4000 2.2680
12 1981 0.0637 0.0636 656.7000 656.7000 35.4300
13 1981 0.0290 0.0290 146.8000 146.8000 0.0000
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15 1981 0.8796 0.8779 3376.0000 958.1000 2.2500
16 1981 0.3191 0.3191 1059.0000 588.3000 3.8120
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Ground-based Efforts in Support of Remote Sensing

Repositories of WQ Data

•GIWA- Global assessment of 66 transboundary waters areas

Identify priorities for remedial, mitigation, future scenarios

•GEMS- 101 countries, 100 parameters

High quality data base-QA/QC

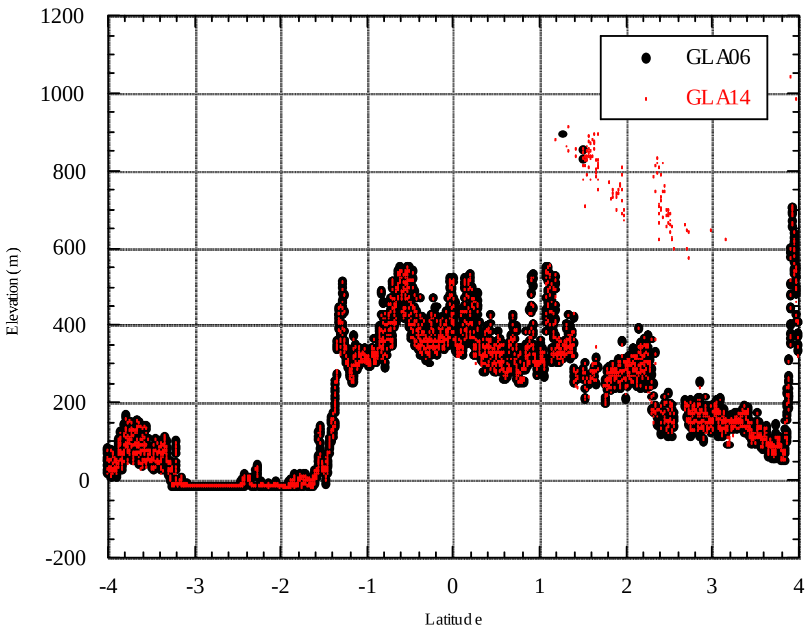
Remote In-*situ* Monitoring

Numerous combination sensor/data loggers

MOBY

Chesapeake Bay, Long Island Sound, Kansas river networks

2003 September 29 Track



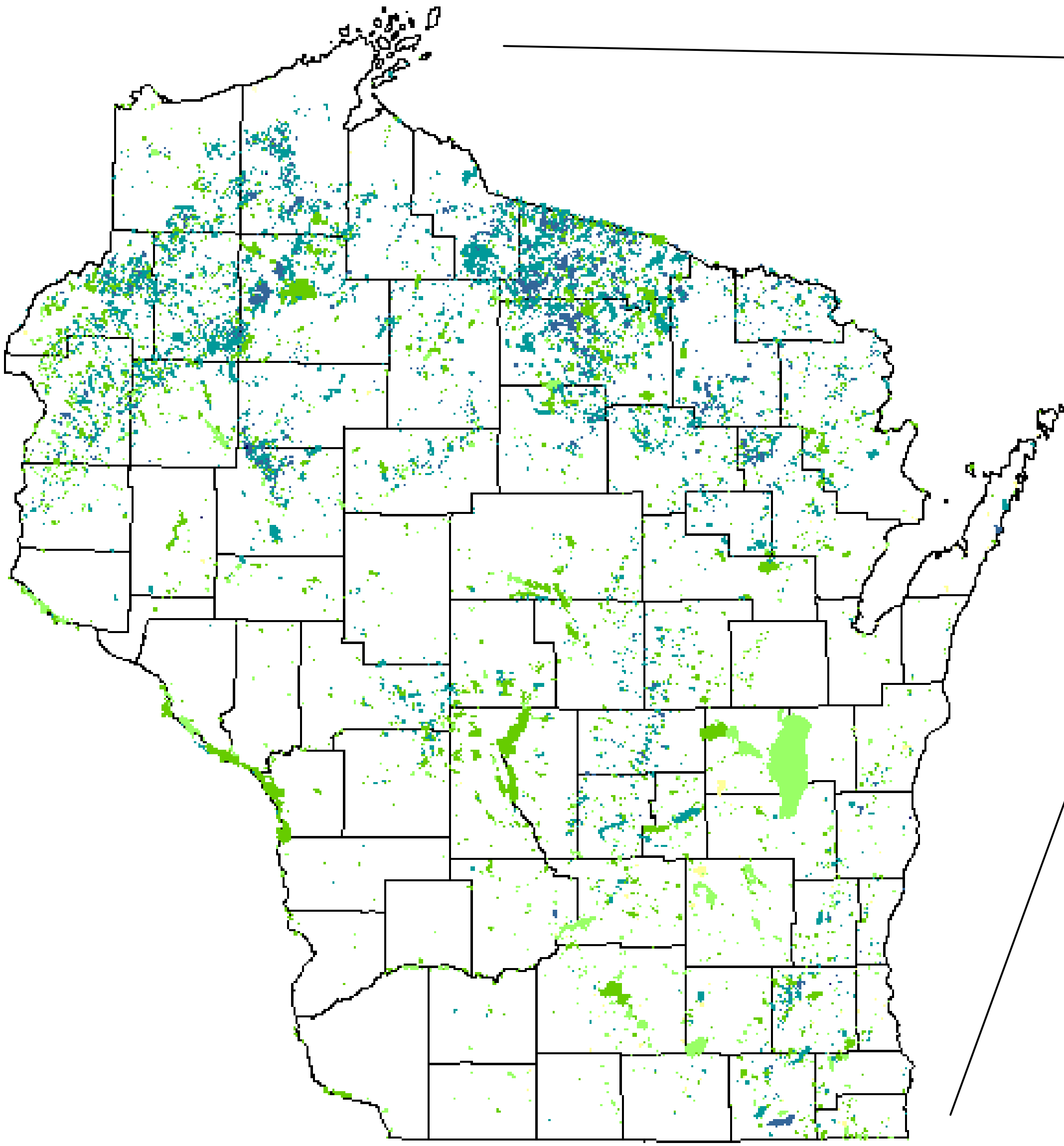
Prepared by Tim Urban, CSR

Landsat image showing confluence of Rio Tapajos with Amazon

Current Operational Programs

- Netherlands- Bi-monthly water quality atlas for North Sea (POWERS)
- Finland- Semi-operative methods developed for regional lakes
- Minnesota-Water clarity for 500 state lakes
- Upper Midwest- Currently in R&D phase regional maps.
- Global - MODIS & SeaWiFS- 8-day and monthly ocean chlorophyll

Wisconsin Lake Trophic State Index



Trophic State Index	Estimated Secchi Depth
> 80	< 0.25 m (< 0.8 ft)
70 to 80	0.25 - 0.5 m (0.8 - 1.6 ft)
60 to 70	0.5 - 1 m (1.6 - 3.3 ft)
50 to 60	1 - 2 m (3.3 - 6.6 ft)
40 to 50	2 - 4 m (6.6 - 13.1 ft)
30 to 40	4 - 8 m (13.1 - 26.2 ft)
< 30	> 8 m (> 26.2 ft)

Environmental Remote Sensing Center, University of Wisconsin

Perceived "Disinterest" in Operational RS/WQ products

1.Technology is inadequate. Sensors, software
2. Science is inadequate
3. Communications need to be improved
4. No official standards
5. Costs too high.
6. Institutional barriers
7. Freshwater users not organized like ocean folks. Scale mismatch of end-users w/ producers

Dekker et al.(2002) and others

Suggested Goals of an Operational Global Freshwater Remote Sensing Water Quality Program

- Monitor near-real time water quality constituents including transparency, suspended solids, chlorophyll, temperature and color

- Produce a freely accessible water quality data base, statistics and images in a timely fashion.

- Provide support to local/national water quality personnel.

- Support other global interdisciplinary programs such as those found in WHO, WMO, and UNESCO

Selected Activities of a Global Freshwater RS/WQ Program

- Define end-user needs/requirements
- Further characterization of spectral signatures, create library or clearinghouse for data base
- Coordination with local field efforts
- Deployment of in-situ monitoring equipment
- Continued analytical model development
- Calibration and validation
- Coordination with hydrologic programs
- Development of data integration and dissemination tools

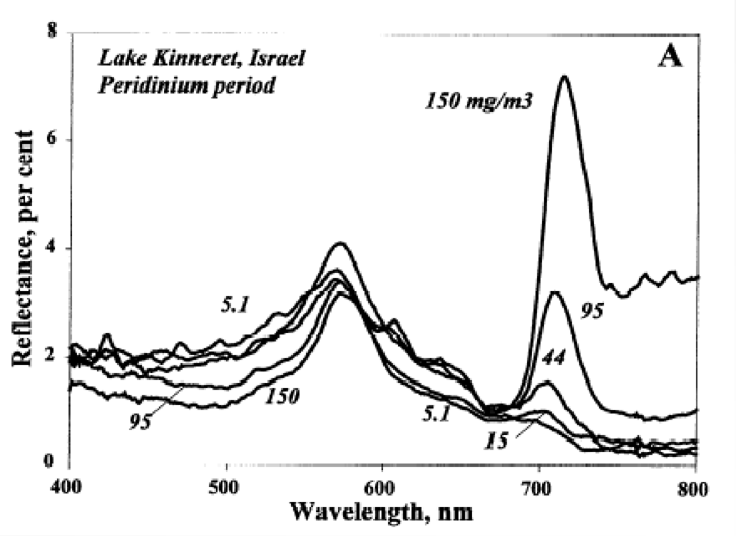
“*Hints of universal algorithms*”

Chl-a NIR/Red ratio (trough of max absorbance at 670)

- *Midwest USA, Israel, Mediterranean- Gitelson et al. 2000 (*700µm/670µm)
- *Swedish Lakes -Philipson et al. 2003 (*705µm/664µm)
- *Lake Inbanuma, Japan Iwashita et al. 2003 (*720µm/675µm)
- *Lake Kinneret Gitelson 1995 (*760-900µm/630-670µm)

Water Clarity Green/ Red ratio (TM1/ TM3)

- *Minnesota Lakes Kloiber et al. 2002*
- *Wisconsin Lakes Chipman et al. 2004*
- *Wyoming Lakes Lathrop 1992*
- *Perth Bay, Australia Lavery et al. 1993*
- *Carolina Reservoirs Cox et al. 1998*



Towards a global remote sensing/ water quality monitoring program

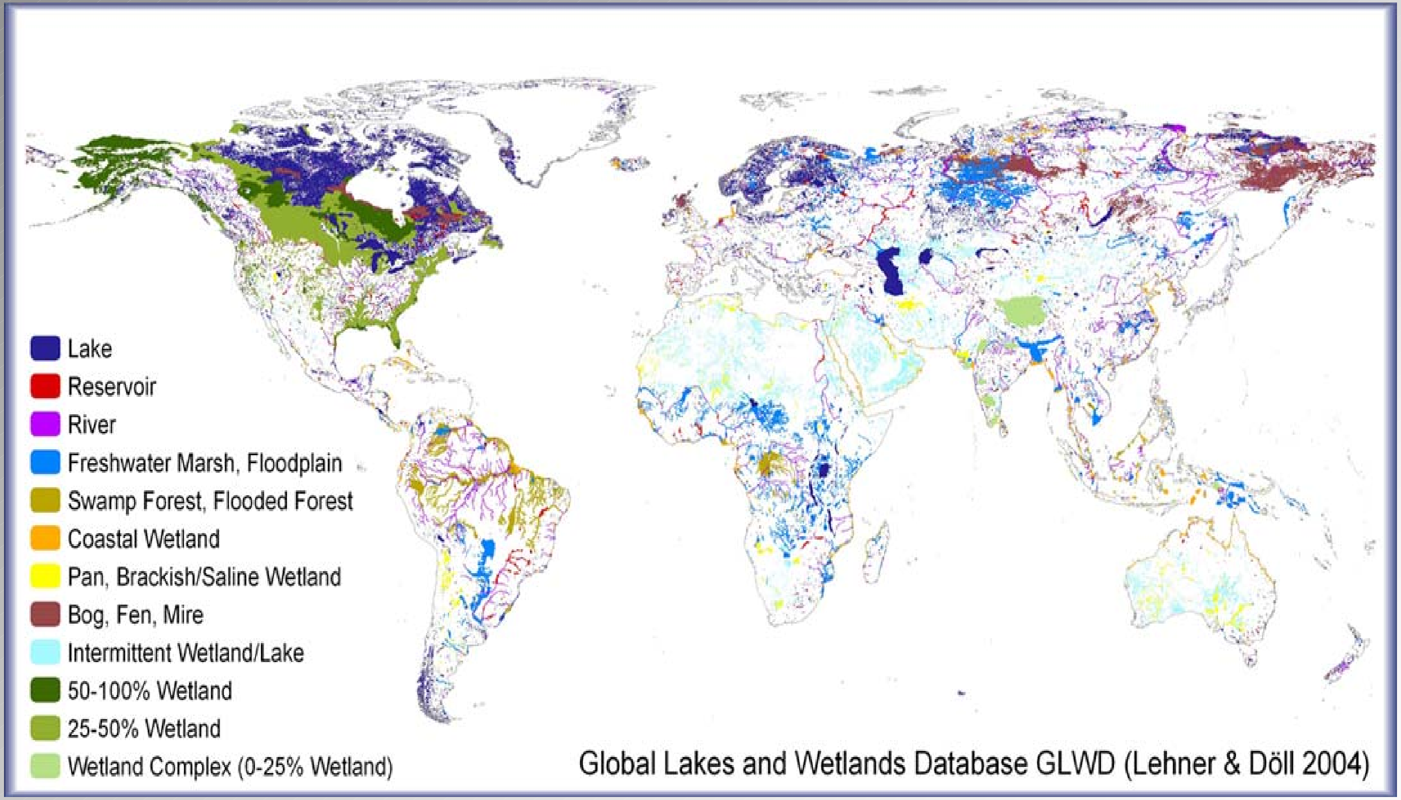
-A project proposal -

1. Spatial data and image synthesis

a. GLWD mapping database

Global Lakes and Wetlands Database- **GLWD**

Data layer	Subject	Resolution	Size	File Format
Level 1	3067 lakes +654 reservoirs	area > 50 km2	16.4 MB	Arcview polygon shapefile
Level 2	250,000 lakes	area > 0.1 km2	96.5 MB	Arcview polygon shapefile
Level 3	wetland+lakes+reservoirs	30 x 30 sec.	26.9 MB	Grid in Arcview



Lehner, B. and P. Döll (2004): Development and validation of a global database of lakes, reservoirs and wetlands. Journal of Hydrology 296/1-4: 1-22.

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a. GLWD mapping database

b. GEMS WQ data

GEMS Water

- More than 100 countries
- Two million data entries
- High QC database
- 1977-present

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b. GEMS WQ data

c. Satellite images e.g. MODIS, MERIS, LANDSAT

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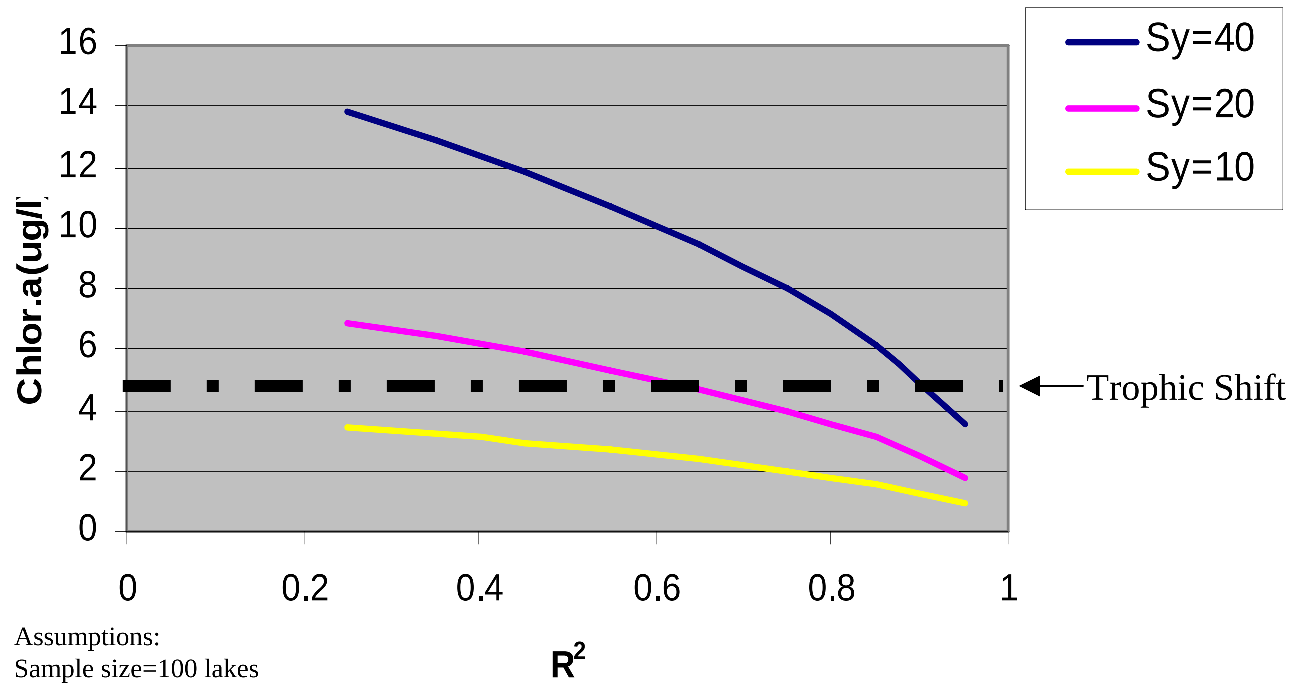
Algorithm(s) development and application

How much change in mean Chlor. *a* concentration is required to detect a significant difference?

Regression Estimator

$Var(\bar{y}) = S_y^2(1-R^2)/n\,[\,1+(n'-n)/n * p/(n-p-2)] + R^2S_y^2/n' - S_y^2/N'$

from: *Sampling Techniques* 3rd Ed. by W.G.Cochran



Assumptions:
Sample size=100 lakes
Population=3700 lakes

Lake Classification System	Oligotrophic	Mesotrophic	Eutrophic
Mean Chlor.	1.7	4.7	14.3
Range Chlor.	0.3-4.5	3-11	3-78

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1. Spatial data and image synthesis

- a. GLWD mapping database
- b. GEMS WQ data
- c. Satellite images e.g. MODIS, MERIS, LANDSAT

2. Algorithm development and application

3. Statistics and Trends Analysis