Evaluating the Feasibility of Systematic Inland Water Quality Monitoring with Satellite Remote Sensing

Arnold Dekker | Director Earth Observation & Informatics TCP CSIRO, Australia

12th November 2013 @ WorldBank: Water Partnership Program (WPP) and the Water Resources and Watershed Management Thematic Group (WRWSM TG)
OVERVIEW

The science (methods)

- Inland water information requirements
- Sensors, scales and coverage
- How to detect water quality from space
- Optical complexity & understanding variability

Overview international projects

Global approaches through GEO and CEOS

Limitations, thresholds, bottlenecks, institutional issues

Ideas & solutions
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Ideas & solutions
Declining trends and limited data

Aquatic ecosystem & biodiversity effects

- Brazil
- Canada
- UK
- Japan
- Australia
- Germany
- France
- Mexico
- United States

Declining ecosystem health over last decade
The challenge of *in situ* monitoring

- Declining surface networks?
- Poor data coverage
- Poor temporal continuity
- Inconsistent sampling
- Variation in data accessibility
- Limited understanding of the implications of extreme events on water quality
The Australian National Water Quality Management Strategy as an Example

**POLICY OBJECTIVE**

To achieve sustainable use of the nation’s water resources by protecting and enhancing their quality while maintaining economic and social development

**IMPLEMENTATION AT STATE, REGIONAL AND LOCAL LEVEL**

- National Water Quality Management Strategy
  - National Policies and Principles
  - National Guidelines

- Community desires for particular water bodies

- Designate the environmental values

- Evaluate the social, economic and environmental impacts

- Set State, regional and local objectives and develop action plans

**OUTCOME**

Sustainable Water Resources

- State water quality policies
- Current water quality

- Monitor and review the effects of action plan

Review

Impacts not acceptable

Impacts ok

Implement action plans

Review
Australian policy and program drivers: The National Water Quality Management Strategy Monitoring framework

- Setting monitoring program objectives
- Study design
- Field sampling program
- Laboratory analyses
- Data analysis and interpretation
- Reporting and information dissemination
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Ideas & solutions
## EO sensors suitable for water quality assessment with public access data policy

<table>
<thead>
<tr>
<th></th>
<th>Pixel Size (m)</th>
<th>Bands (400-900 nm)</th>
<th>Revisit cycle</th>
<th>CHL</th>
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<th>CDOM</th>
<th>SD</th>
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</table>

● Highly suited  ● Suited  ● Potential  ● Not suited

CHL=Chlorophyll; CYP=Cyanophycocyanin; TSM=Total Suspended Matter; CDOM=Coloured Dissolved Organic Matter; SD=Secchi Disk Transparency; Kd=Vertical Attenuation of Light
# EO sensors suitable for water quality assessment

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- **Highly suited**
- **Suited**
- **Potential**
- **Not suited**

HySpIRI decadal plan now beyond 2022; possible as Space Station Mission post 2017

CHL=Chlorophyll; CYP=Cyanophycocyanin; TSM=Total Suspended Matter; CDOM=Coloured Dissolved Organic Matter; SD=Secchi Disk Transparency; Kd=Vertical Attenuation of Light
Where are the water bodies and what type are they?
EO-resolvable water bodies in Australia

Continental Australia

Murray Darling Basin

Dekker & Hestir 2012, CSIRO
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Global approaches through GEO and CEOS

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Ideas & solutions
The conceptual physics-based model for optically deep waters
The Colours of Water

Daintree (Oct. 03)
The Colours of Water
The conceptual physics-based model for optically shallow waters (......optically deep on the right)
The Colours of Water
The Colours of Water
What do Managers Need from Optical Remote Sensing in Aquatic Ecosystems?

- **Status, Condition and Trend & Anomalies:**
  - **Status (survey, classify and map)**
    - what is where? (=99% of current remote sensing effort)
    - (is it absent when it should be present) or
    - (is it present when it should be absent?)
  - **Condition:**
    - is it healthy?, is it stable?
    - Is it stressed?
  - **Trend:**
    - Is it getting worse or is it improving?
      - Remote Sensing can do hind casting and now casting
      - Model data fusion needed for forecasting
  - **Anomalies:**
    - Normal (to be expected) or exceptional (indicating exceptional change from before? E.g. climate change indication?)
Variables that can be measured directly using RS (1)

- Water Column Properties:
  - Chlorophyll-a, Phaeophytin (all photosynthesizing orgs)
  - Cyanophycocyanin & CP-erythrin=>Cyanobacteria
  - Total Suspended Matter
  - Coloured Dissolved Organic Matter
  - Transparency/Turbidity/Vertical Attenuation of Light
- 3-D Information (if the bottom is visible)
  - Bathymetry (depth of substrate)
  - Bottom Relief (topography)
Variables that can be measured directly using RS (2) *(including object-based image analysis)*

- **Benthic substratum**
  - **Coastal:** Seagrasses, macro-algae and associated substrates & freshwater: macrophytes and associated substrates
    - Extent
    - Main species differentiation: *if spectrally & spatially discriminable!*
    - Density of cover; biomass
- **Coral Reef and associated substrates**
  - Extent
  - Bleaching
  - Main substratum types (Live coral, dead coral, seagrasses, macro-algae)-main species: *if spectrally & spatially discriminable!*
Great Barrier Reef World Heritage Area subdivided into five management regions (left). Maximum CDOM absorption from regional parameterized ocean colour algorithm mapped for the period January to March 2008 (centre). Freshwater plume extent mapped by applying a CDOM threshold derived from linear regression of in-situ CDOM and salinity measurements.
Whole GBR: 2002/03-2009/10

Water quality: chlorophyll a and suspended solids

Chlorophyll a is used as an indicator of nutrient loads in the marine system. Data analysed from satellite imagery showed that inshore waters in the Wet Tropics and Burdekin regions had elevated concentrations of chlorophyll a over the monitoring period (Table 5.9).

The satellite data also showed that highest concentrations of suspended solids were recorded at inshore areas of the Cape York, Burdekin and Mackay Whitsunday regions. High concentrations of suspended solids were also recorded in midshelf and offshore waters in the Mackay Whitsunday region. It should be noted that the Cape York remote sensed water quality data requires further validation.

Table 5.9 – Summary of the exceedance of mean annual chlorophyll a and non-algal particulate matter as a measure of suspended solids using remote sensing data (retrieved from MODIS AQUA) for the inshore, midshelf and offshore waterbodies (1 May 2008–30 April 2009).

<table>
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<tr>
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<tr>
<td>Cape York</td>
<td>41</td>
<td>0</td>
<td>0</td>
<td>55</td>
<td>39</td>
<td>13</td>
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<tr>
<td>Wet Tropics</td>
<td>57</td>
<td>0</td>
<td>0</td>
<td>41</td>
<td>13</td>
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<td>Burdekin</td>
<td>54</td>
<td>1</td>
<td>0</td>
<td>65</td>
<td>5</td>
<td>3</td>
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<tr>
<td>Mackay Whitsunday</td>
<td>24</td>
<td>3</td>
<td>0</td>
<td>74</td>
<td>42</td>
<td>50</td>
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<td>Fitzroy</td>
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<td>0</td>
<td>35</td>
<td>2</td>
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<td>Burnett Mary</td>
<td>27</td>
<td>2</td>
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</table>
Implementing the guidelines

Table 5.9 – Summary of the exceedance of mean annual chlorophyll a and non-algal particulate matter as a measure of suspended solids using remote sensing data (retrieved from MODIS AQUA) for the inshore, midshelf and offshore waterbodies (1 May 2008–30 April 2009).

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Note: The table data represents the percentage of the waterbody area where the annual mean value exceeds the water quality guideline value.
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Ideas & solutions
Characterizing in situ optical complexity
Lake optical archetypes: *in situ*
Water quality signals in remote sensing reflectance

LDCM (Landsat 8) bands

- Suspended Solids
- Phycocyanins
- Chlorophyll
- Suspended Solids
- Colored dissolved organic matter

Reflectance (%)

Wavelength (nm)

380 455 530 605 680 755

Dekker & Hestir 2012, CSIRO
Water quality signals in remote sensing reflectance

**MERIS/OLCI bands**

- **Suspended Solids**
- **Phycocyanins**
- **Chlorophyll**
- **Suspended Solids**
- **Colored dissolved organic matter**

**Reflectance (%)**

- 0.1
- 0.08
- 0.06
- 0.04
- 0.02
- 0

**Wavelength (nm)**

- 380
- 455
- 530
- 605
- 680
- 755

Dekker & Hestir 2012, CSIRO
Water quality signals in remote sensing reflectance

![Graph showing reflectance (%), wavelength (nm), and bands of Worldview2 for Suspended Solids, Phycocyanins, Chlorophyll, and Colored dissolved organic matter.]

Dekker & Hestir 2012, CSIRO
Water quality variables from remote sensing

- Chlorophyll
- Colored dissolved organic matter
- Cyanopigments
- Total suspended matter

Water column optically active components

- Vertical attenuation of light
- Secchi depth
- Bathymetry
- Vegetation

Estimated from water column properties
OVERVIEW

The Big Data Challenge
Use input point data instead of grids or averages

Single pass at national or regional scale: no tiling

Data cubes, data arrays instead of multiple flies

Analyse for longer time periods or use shorter time intervals

Based on European Climate Computing Environments, Bryan Lawrence (http://home.badc.rl.ac.uk/lawrence/blog/2010/08/02)
The Advanced ICT Tetrahedron in balance

Content (Data, Information, Knowledge)

High Performance Computing

Bandwidth

Tools
The Advanced ICT Tetrahedron in 2012

- **High Performance Computing**
- **Bandwidth**
- **Tools, Codes**
- **Content: Data, Information, Knowledge**
Australia’s EOS vision (NEOS-IP)

Value layer

- APS 200 and FOI reform
- Climate and weather
- Carbon accounting
- Water
- Emergency management
- Private sector

National framework datasets:
- Authoritative Base Image and Landcover of Australia

Data acquisition and preparation layer

- Image generation
- Geometric correction
- Observation corrections
- Analysis of biophysical dynamics (Green/brown/water/soil fraction and indices)
- Generation of landcover map

Data acquisition
- Public good data (Landsat, MODIS, GMES Sentinels)
- Commercial data (DMCii, SPOT, WV2, Geoeye, aerial)
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Ideas & solutions
Investigate the state of lakes & their response to environmental change drivers:

- Near real time processing satellite based observatory
- Processing archived data for up to 20-year time series
- Including:
  - (i) LSWT; (ii) TSM; (iii) CDOM; (iv) Chl a; (v) PC
- Detect spatial & temporal trends & attribute causes of change for 1000 lakes worldwide (1/3 of inland water, 2/3 of all inland water > 1km$^2$)
- Forecast lake sensitivity to environmental change
- Apply findings into lake management
Currently, we have a population of 1,811 target lakes under consideration globally.
Global Lakes Sentinel Services

Prepare for use of Sentinel data in the context of lakes and reservoirs

Case studies

Use case 1: Shallow lakes with high eutrophication, potentially toxic algae: lake IJsselmeer (NL) and Lake Peipsi (EE)

Use case 2: Deep, clear, lakes with increasing eutrophication: Lake Garda (IT)

Use case 3: Small lakes with high CDOM concentration: Lake Pääjärvi (FI)

Use case 4: Shallow lakes with low transparency due to sediment resuspension: Lake Markermeer: (NL)

Use case 5: Mine tailing ponds

Www.glass-project.eu, info@glass-project.eu, @GlaSS_Project, glassfp7project
EO Information Services in support of Zambezi River Basin Mapping - Some Results -

Steef Peters & Katrhin Poser WI
2.a) Lake Malawi Water Quality:
Chlorophyll-a concentration 2010-09-20

Chlorophyll-a concentration 2010-10-09

Chlorophyll-a concentration 2011-03-13

Chlorophyll-a plumes
Warmer plumes caused by riverine influx.
Lake Malawi Chlorophyll-a (Jan 2010 - Aug 2011) estimated from MERIS FR images & WISP algorithm

Storm

Nutrient upwelling at end of trade wind season

Lake Malawi SST (Jan 2010 - Aug 2011) estimated from AATSR
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(https://earthobservations.org/index.shtml) & (http://www.ceos.org/)

Limitations, thresholds, bottlenecks, institutional issues

Ideas & solutions
GEO Inland and Coastal Water Quality Working Group
A component of
WA-01: Water Task Work Plan

- C1 Integrated Water-cycle Products and Services
- C2 Information Systems for Hydro-meteorological Extremes (incl. Floods and Droughts)
- C3 Information Service for Cold Regions
- C4 Global Water Quality Products and Services
- C5 Information System Development and Capacity Building

C4 Task leads
Steven R. Greb  Wisconsin Department of Natural Resources
Arnold Dekker  CSIRO
Tiit Kutser  Estonian Marine Institute, University of Tartu
The goal of this component is to develop an international operational water quality information systems based on Earth observation.

This component will integrate water quality data from multiple sources in a timely manner and through data assimilation of Earth observations with other sources of data such as water quantity, hydrodynamics, biogeochemical modelling, generate higher level information products such as trends and anomalies and additional “value-added” products such as fluxes and flows.

This component encompasses both the collation and development of in-situ water quality databases and remote-sensed data, particularly space-borne data.

The component addresses both flowing and static water bodies, recognizes differing approaches to assessing their water quality and the linkages/interface between them.
C4 Global Water Quality Products and Services

Develop 2012-15 Work Plan

<table>
<thead>
<tr>
<th>Component</th>
<th>Suggested Remote Sensing Team Leader(s)</th>
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<tr>
<td>Data</td>
<td>Arnold Dekker, Tiit Kutser, Menghua Wang</td>
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<td>Products/Indicators</td>
<td>Paul DiGiacomo, Stewart Bernard, Mark Dowell</td>
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<tr>
<td>Information</td>
<td>Gordon Campbell, Hans van der Woerd</td>
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<td>Knowledge/ Decision Making tools</td>
<td>Chris Mannerts, Suhyb Salama</td>
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<td>End-to-end application</td>
<td>Steve Groom</td>
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<td>Coordination</td>
<td>Steven Greb, Arnold Dekker</td>
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Current and New Initiatives for 2013-2014

• Webinar Series
  Six global WQ projects presented in 2013

• COST Proposal (submitted)
  Standardization of optical in-situ methodologies

• IOCCG working group proposal
  Provide a strategic plan for incorporation of current and future EO information into national and international near-coastal and inland water quality monitoring efforts.

• Develop linkages and new initiatives with GEO HEALTH SBA
  Participated in GEO/WHO/NOAA workshop July 2013, Wash.DC

• GEOSS Water Strategy report: From Observations to Decisions
  Wrote Water Quality Chapter. Key recommendation: Increase availability and use of data, information, and indicators of the quality of inland and near-coastal waters to support an operational water quality decision-making system.
OVERVIEW

The science (methods)

- Inland water information requirements
- Sensors, scales and coverage
- How to detect water quality from space
- Optical complexity & understanding variability

Overview international projects

Global approaches through GEO and CEOS

Limitations, thresholds, bottlenecks, institutional issues

Ideas & solutions
Barriers to adopting satellites for management in USA (By Blake Schaeffer – US EPA)

- Cost
  - Satellite imagery only obtained with financial commitment
  - Personnel and resources required to process the data
- Product Accuracy
  - Concern of accuracy and error estimates
  - Less concern regarding the error with standard *in situ* measurements
- Data Continuity
  - Mission continuity was relevant to investment
- Programmatic support
  - Buy-in and support from organizational management was important.

Sources: Schaeffer et al. IJRS (2013)
Fragmented approaches- coordination is increasing

• Pre-2007 fragmented locally active R&D in EO of WQ
• 2007 :GEO connected disparate research groups- 1st Workshop Geneva ; report with excellent summary of the potential for EO of WQ globally and generic description on steps forward
• 2009: GEO organised follow up workshop with specific activities identified and leaders and teams designated
• 2009-2011 ...............little action........no funding....goodwill is not sufficient
• 2012 ++ more and more continental or cross country projects with higher level of aggregation of R&D groups
• 2013  GEO (Water Task) and CEOS (Water Portal) have potential for global approach - are coordinating bodies
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Ideas & solutions
Ideas & Solutions:

Needed are End-User requirements: e.g.

• Are time series needed (e.g. back to 1984?)
• Are Near Real Time products needed?
• Is it most important to prepare for future sensors?

Or:
• Is EO derived WQ information needed before or during the start of a project?
• Is it needed to determine the effectiveness of a management action into the future (or in hindsight mode)
Ideas & Solutions:

• Needed: global drivers and related consistent funding: e.g. poverty reduction (access to drinking water, other domestic uses; industrial uses) or aquatic ecosystem health & resilience, aquatic biodiversity etc.

• An international coordinated approach with support from WB(?); ADB(?), FAO(?), UNEP(?) etc. which will:
  1. Empower the global R&D community to focus on applications
  2. Create effectiveness and efficiencies
     1. Develop approaches for Countries/continents with capacity for uptake an implementation that is:
        1. High: Local training and implementation
        2. Medium: Global processing of EO data and distribution of information products to local institutes
        3. Low Global Processing and Information Product- accessible via ? Internet?
     2. Embrace technology accelerators such as smart phones and apps
Ideas & Solutions:

Or:

• Phased approach:
  
  • Demonstrator projects for different use applications e.g.
    
    – Focus on hotspots (e.g. algal blooms or waterborne diseases)
    
    – Large lakes & rivers (as the EO of large lakes & rivers is ripest technologically and EO data is free)
    
    – As part of larger integrated water management projects to understand how to interface.

Or: One large global (or continental) approach with multiple spin-off projects for countries/areas with varying levels of uptake and implementation capability
National Space and Earth Observation Policy Development
“..certainty and strategic direction for satellite technology users”

“..better domestic co-ordination and focused international engagement”

Australia’s Satellite Utilisation Policy

“...giving priority to Earth observations from space..”

“CSIRO is Australia’s lead R&D Agency”

Draft NEOS-IP Plan

National Earth Observations from Space Infrastructure Plan
Prepared by Geoscience Australia and the Bureau of Meteorology

AUSTRALIA’S FUTURE: THE EOS IMPERATIVE
Arnold Dekker & CSIRO Team

Director Earth Observation & Informatics Transformational Capability Platform

CSIRO Land & Water

E Arnold.dekker@csiro.au T +61 2 6246 5821 M +61 (0)419411338
GPOBOX 1666, Canberra, ACT, 2601, Australia www.csiro.au
Adjunct-Professor University of Queensland