# Challenges and opportunities of Earth observation for the prediction of water quality in inland waters

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Modelling Water Ecosystems + Aquatic Remote Sensing

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CSIRO

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Detect harmful algal blooms

monitor

predict

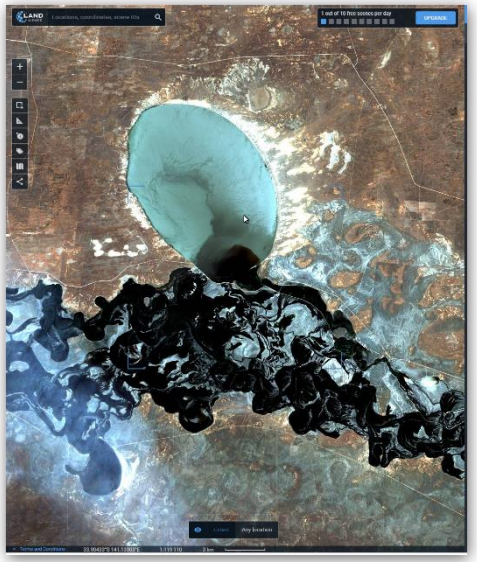
manage

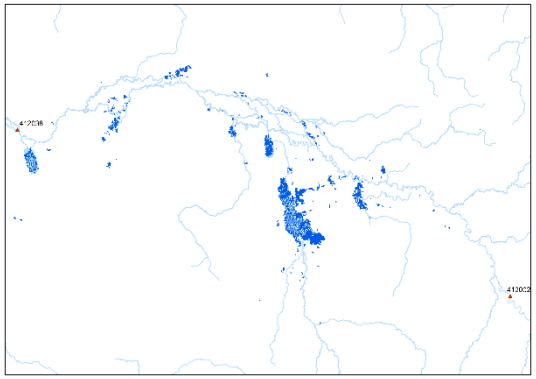
# Water Quality

via RS

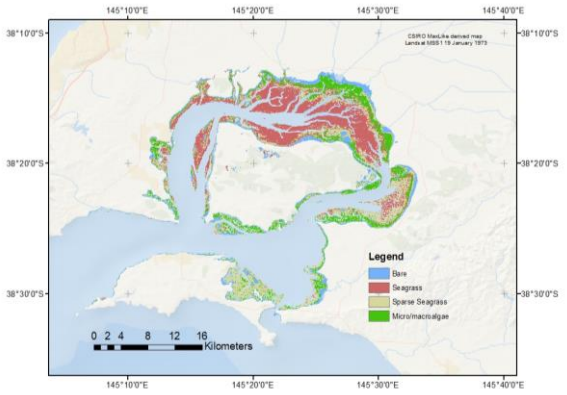
Area, Temperature, Turbidity Chlorophyll-a, cyanopigments, dissolved oxygen

Follow blackwater – hypoxia





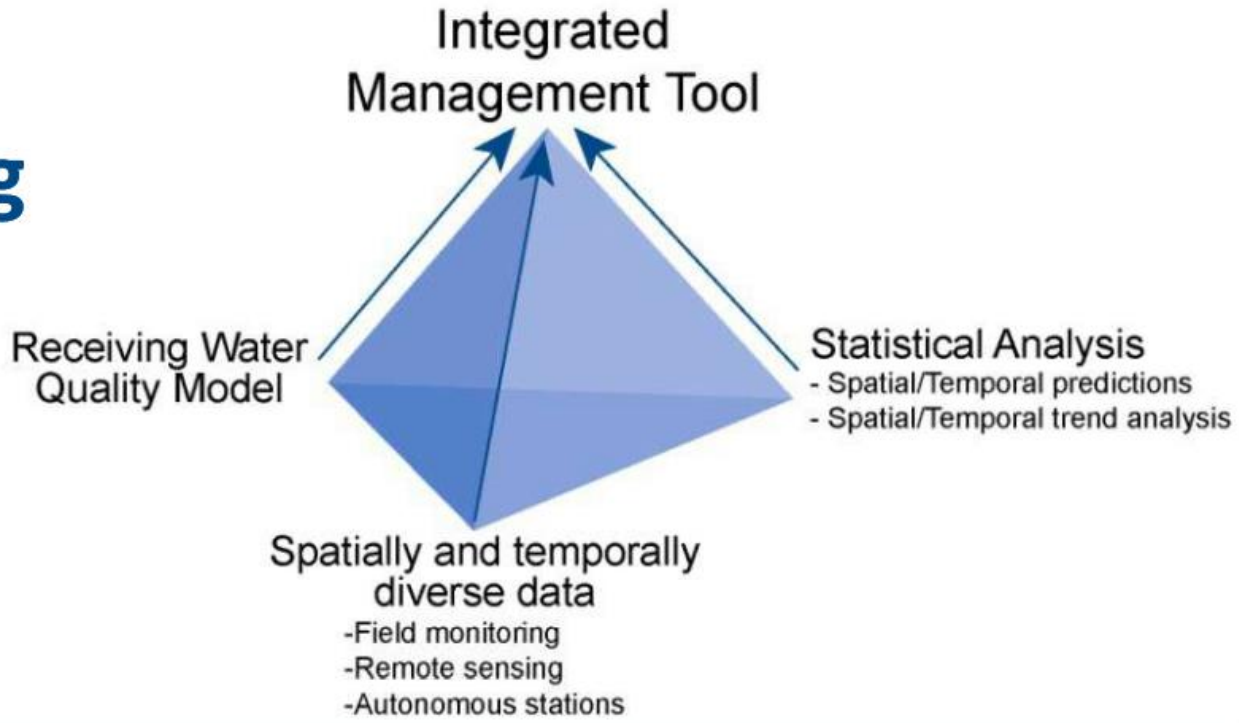
Quantify flood inundation and connectivity




Monitor seagrass decline

# The role of remote sensing

- Remote sensing imagery can provide accurate information on spatial extent and temporal patterns of water quality




- Satellite remote sensing imagery can estimate environmental variables (such as transparency, chlorophyll and turbidity concentrations) for input into biogeochemical models or integrated management tools.

- Point measurements cannot often be obtained as required after significant events (eg. Floods, land clearing etc) whereas satellite imagery can be obtained opportunistically.

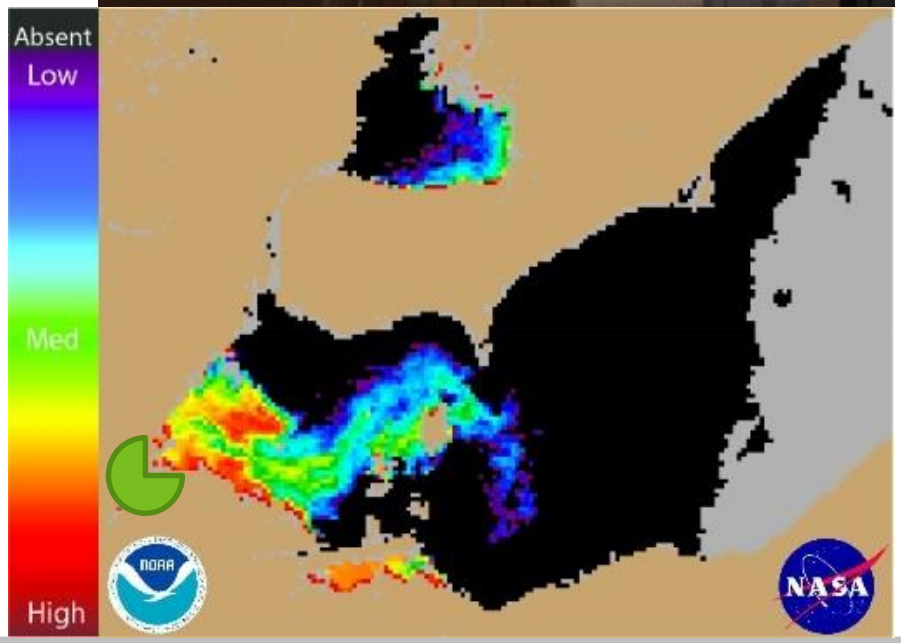
# Harmful algal blooms occur everywhere anytime

Lake Burley Griffin, Can

Mining lake in Germany
*Planktothrix rubescens* under ice

Red algal bloom at Bond

st, River Murray 2016


# Toledo, Ohio water crisis

## August 2014

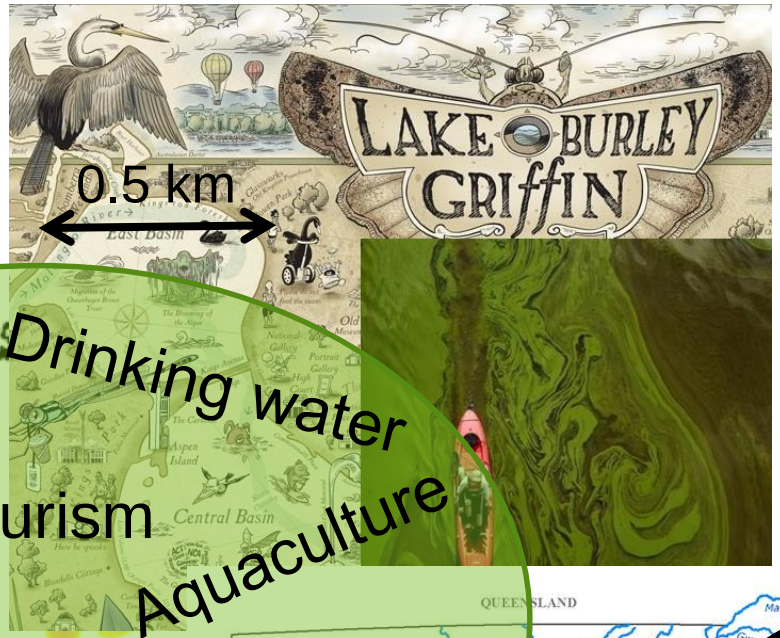
500000 water consumers were advised not to drink tap water for 3 days due to Microcystin content.

Triggered by a harmful algal bloom in Lake Erie.

Cause: inflow from farm fields (fertilizer, manure) and wastewater plants in the catchment.

# HAB scale of occurrence

Local scale




Drinking water

Irrigation

Tourism

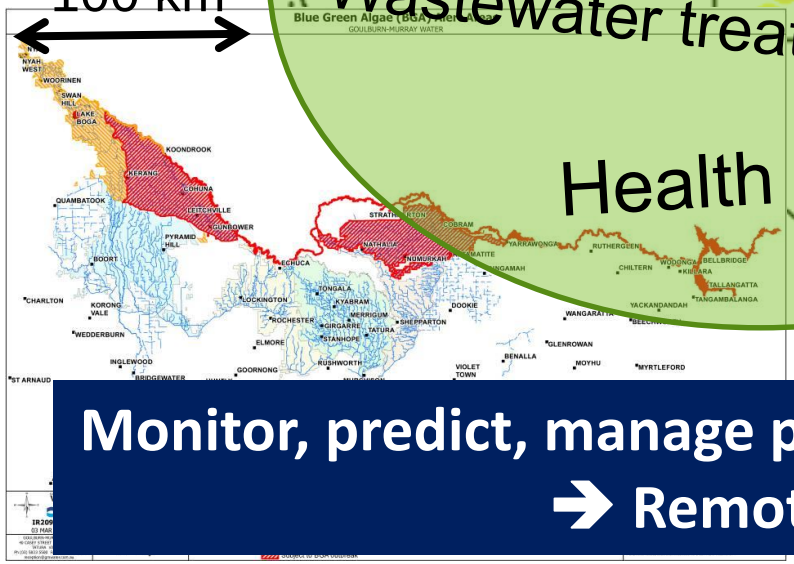
Aquaculture

Wastewater treatment plants

Health

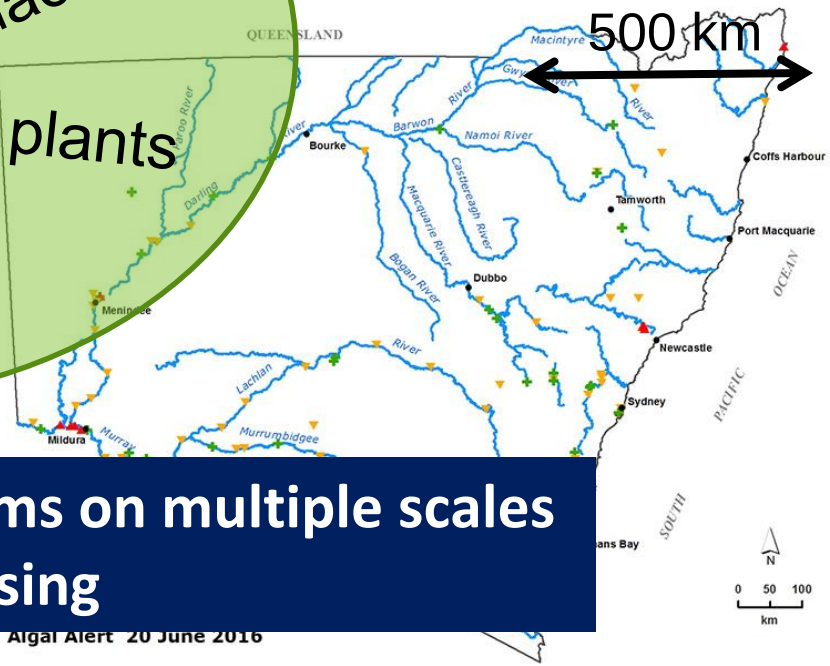
River scale

100 km




Basin scale

500 km

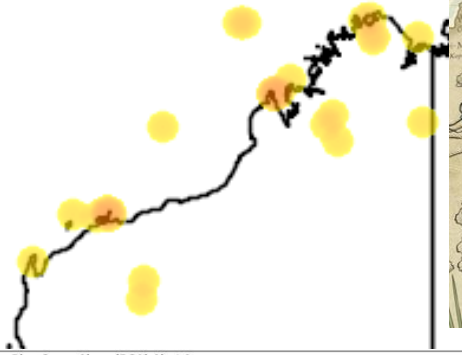



**Monitor, predict, manage problems on multiple scales**

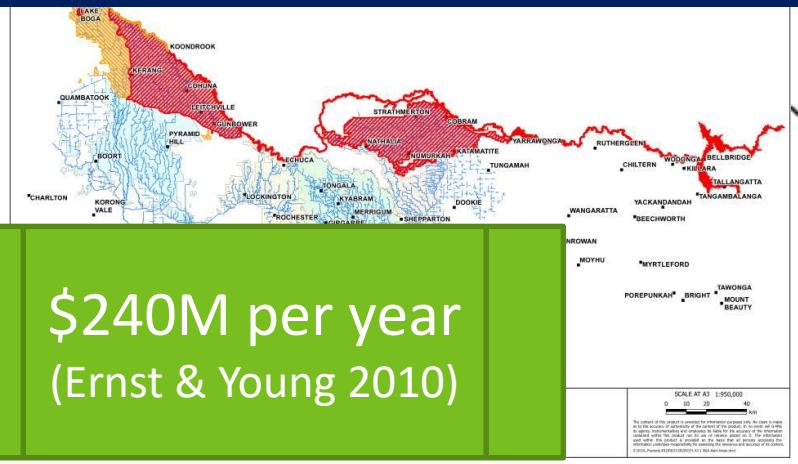
**➔ Remote Sensing**

# HAB scale of occurrence

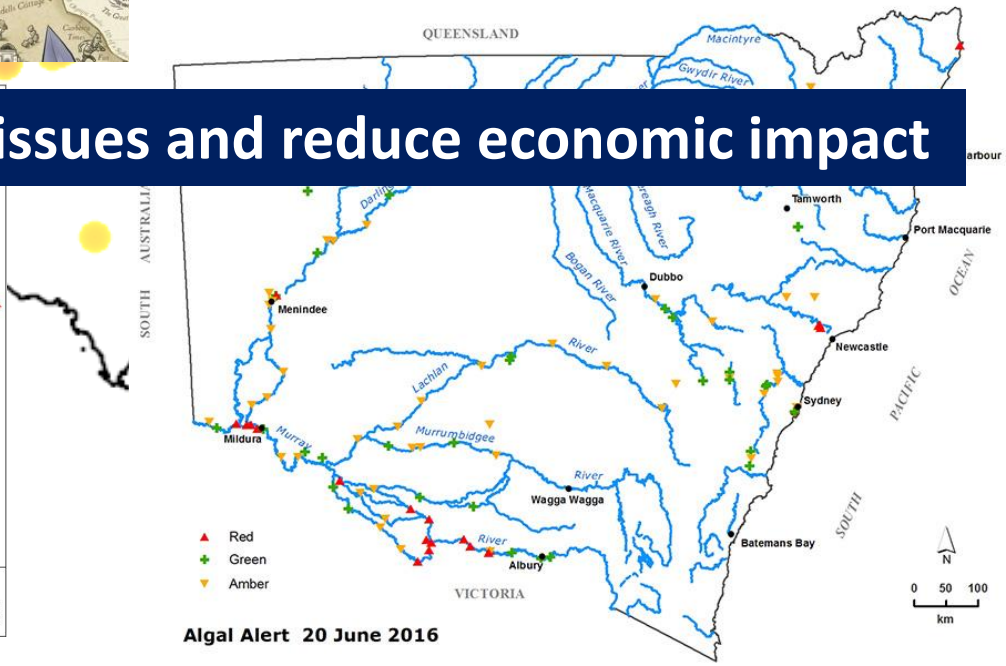

$25M per year
(Lawrence 2012)



**…to solve ecosystem and health issues and reduce economic impact**



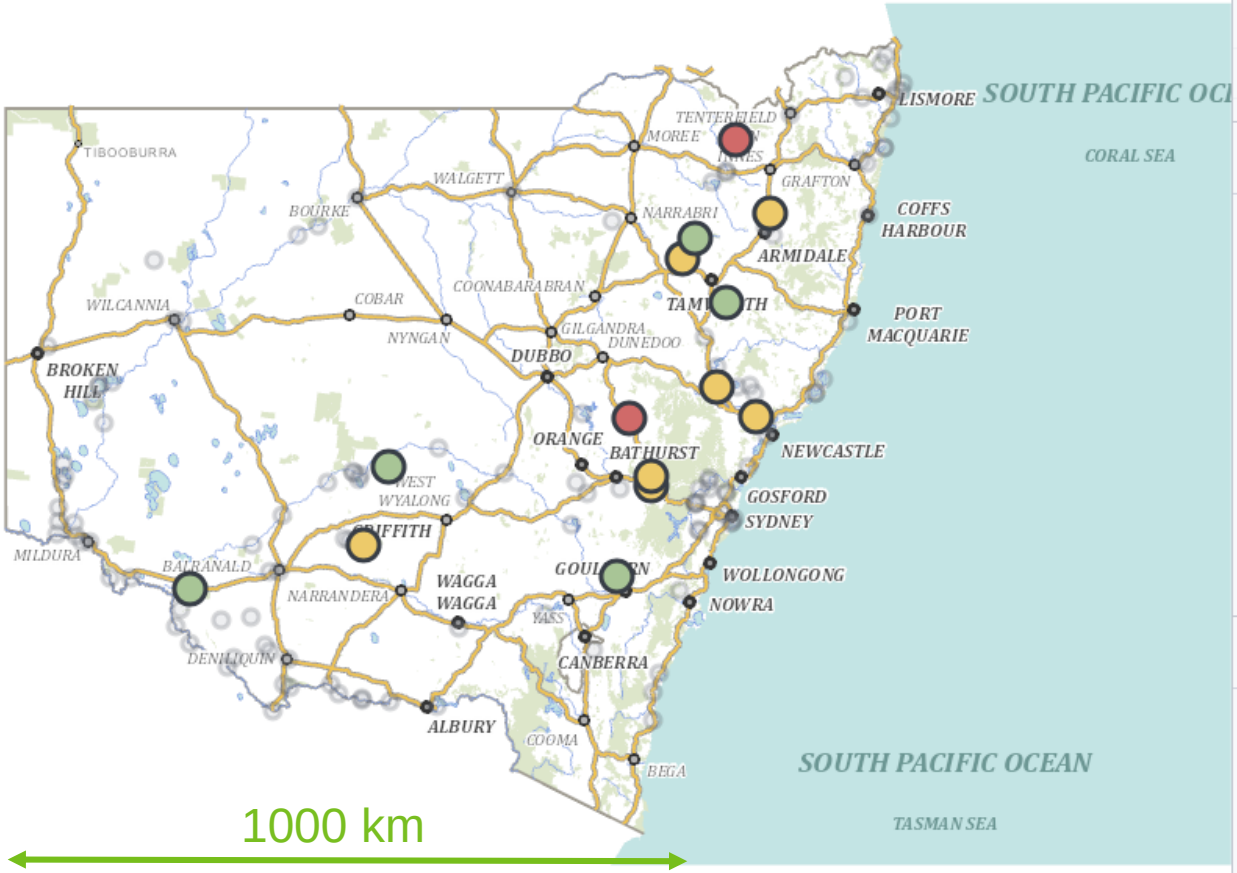

$240M per year
(Ernst & Young 2010)



# NSW Algal alert project

## HAB Early warning from remote sensing

(NSW = New South Wales)




Algae Flags

Timespan: 2014

Location: e.g. Windamere Reserv

| Date | Location | Flag |
|---|---|---|
| 2014-12-27 | Yanga Lake | green |
| 2014-12-27 | Walka Waterworks Lagoon, Maitland | amber |
| 2014-12-27 | Split Rock Reservoir | green |
| 2014-12-27 | Malpas Reservoir | amber |

New South Wales

Settings

Map: Streets Satellite Test Overlay (Windamere)

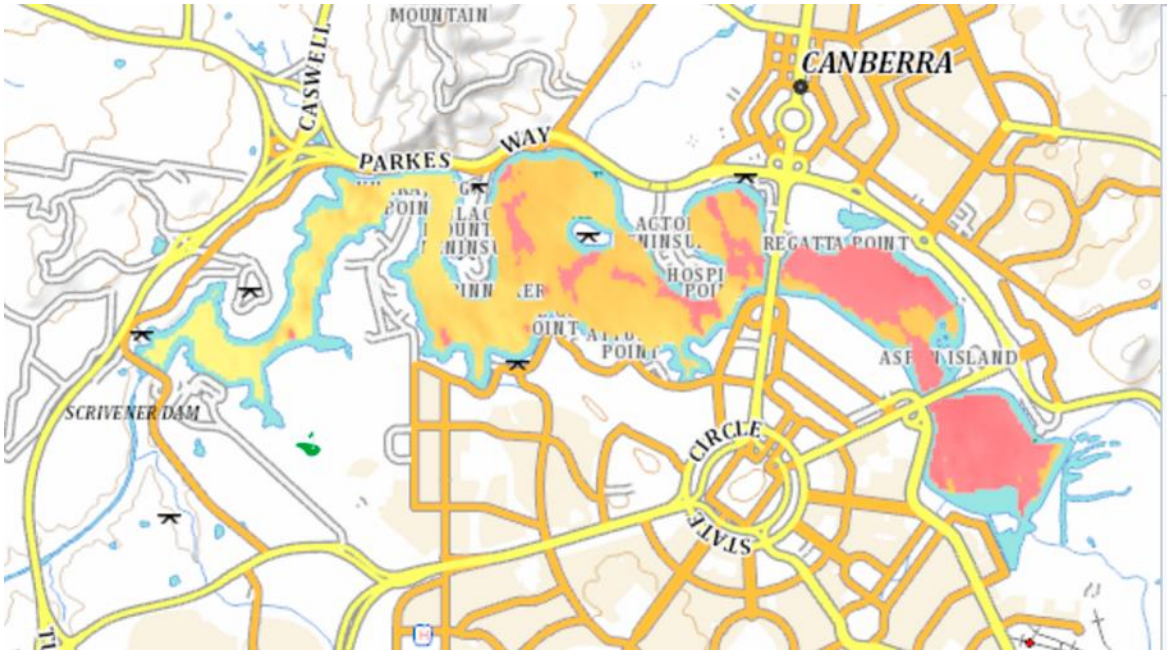
# NSW Algal Alert project

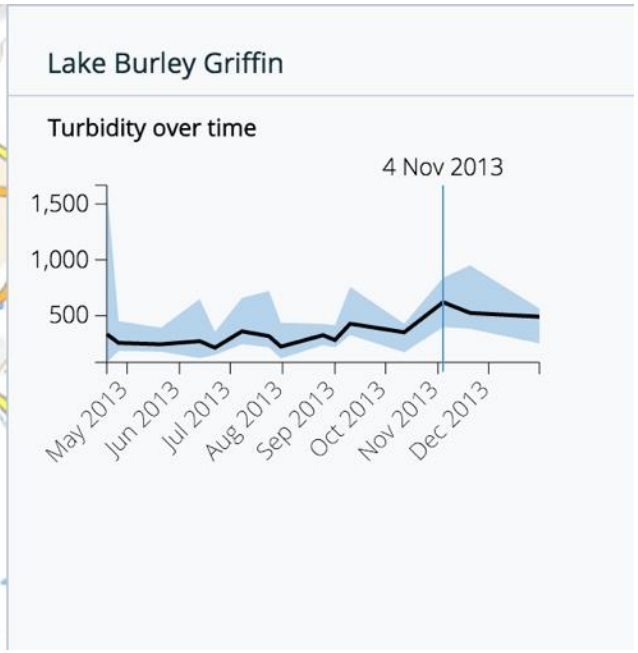
## Problems with previous bloom alerts now resolved

- Blooms are immediately identified
  → Public Health risk decreased
- Spatial extent adequately defined
  → Public Health Risk decreased
- Bloom detection no longer dependent on time consuming sampling
  → Economic impact

# NSW Algal Alert project

## Visualizing individual waterbodies (spatial heterogeneity)



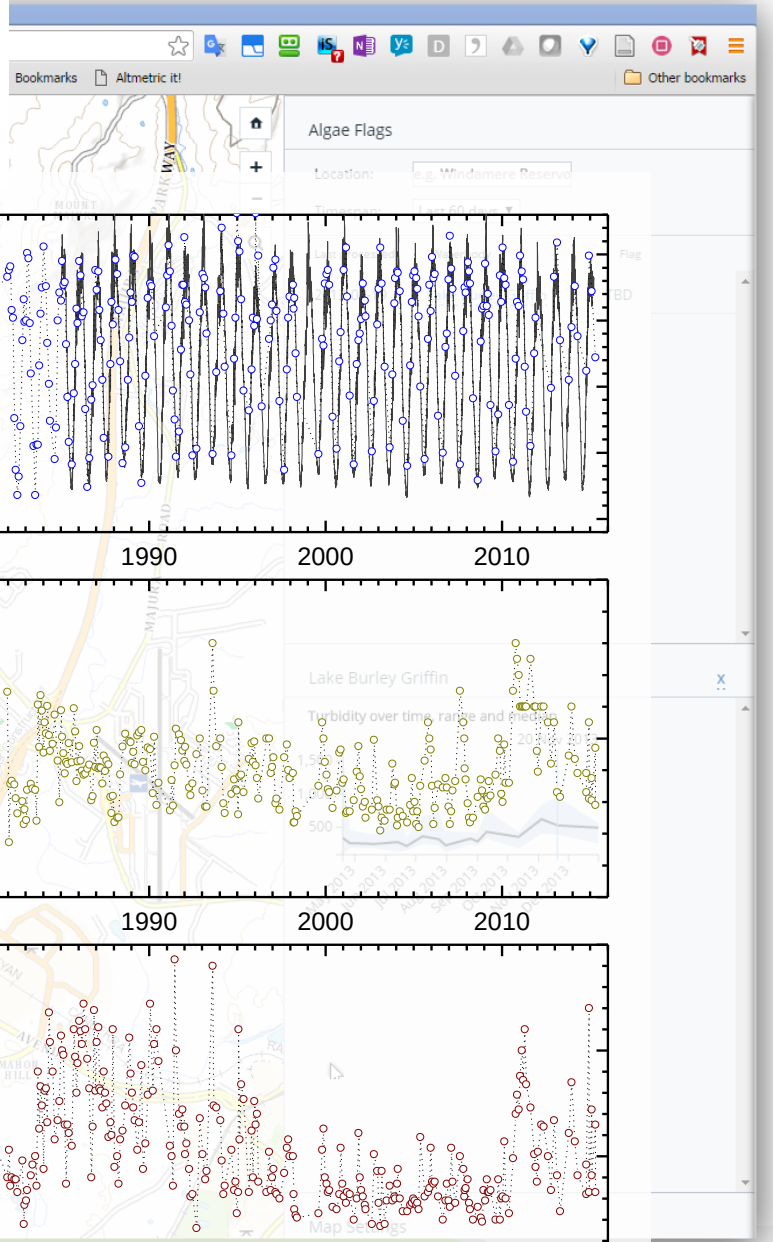



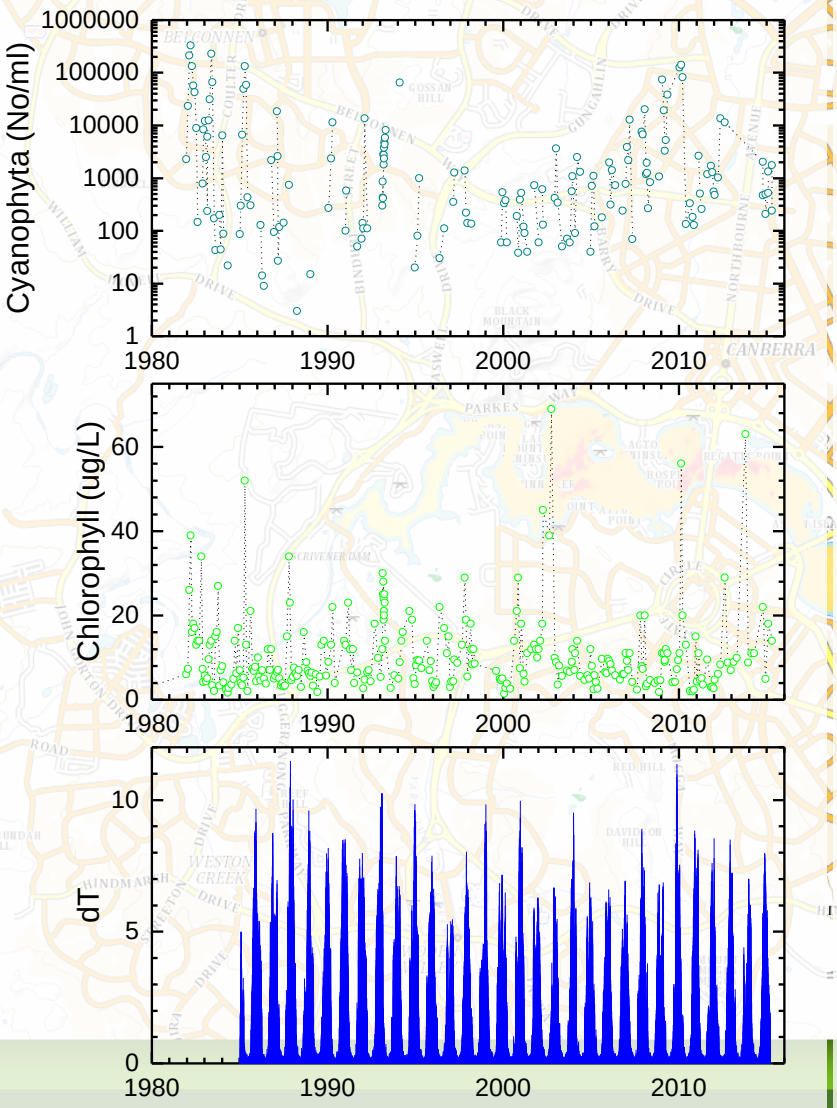
# NSW Algal Alert project

## Visualization of remote sensing data

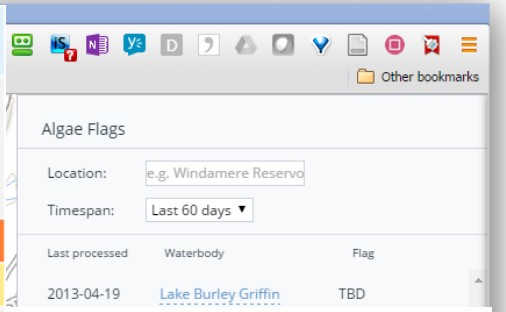
- Covers large areas
- Shows heterogeneities in water bodies
- Is a momentary snapshot
- Needs in-situ data to calibrate
- Not continuously available … ← modelling

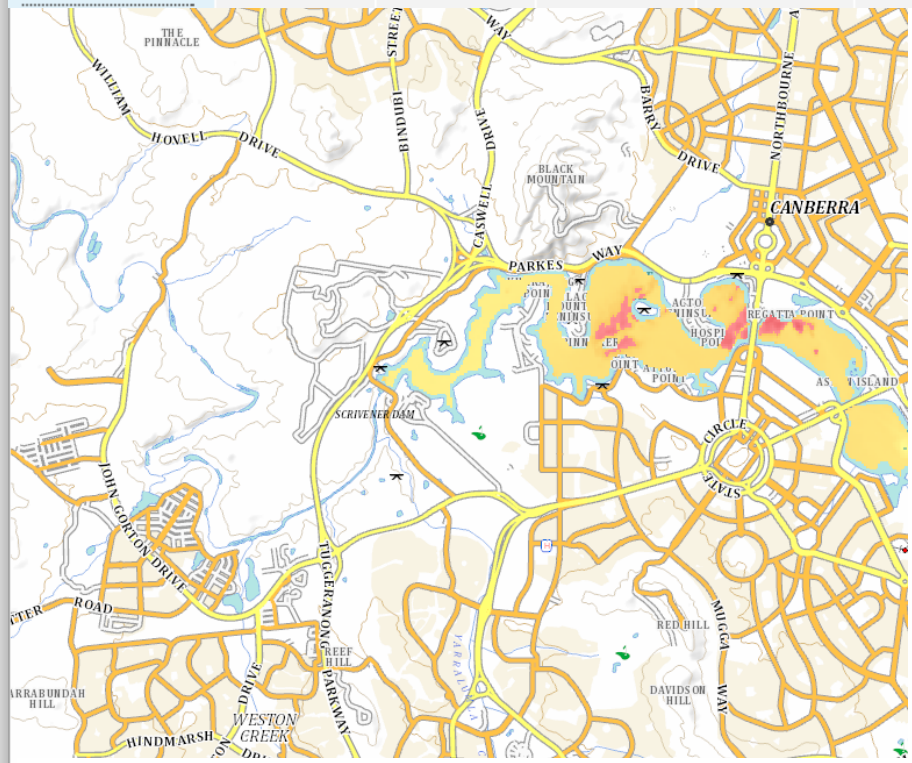
# In future:
# From existing observations

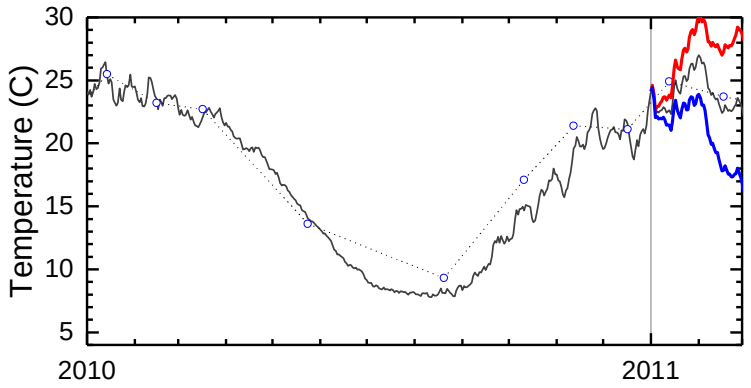


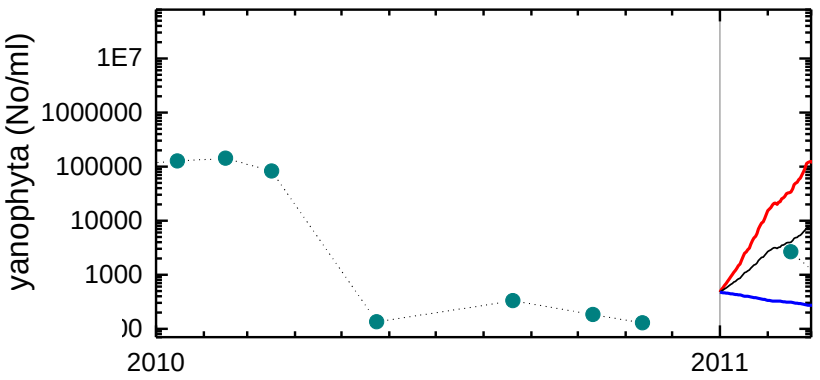



| | Wed Jun 22 | Thu Jun 23 | Fri Jun 24 | Sat Jun 25 | Sun Jun 26 | Mon Jun 27 | Tue Jun 28 |
|---|---|---|---|---|---|---|---|
| Summary | Sunny | Sunny | Sunny | Sunny | Sunny | Sunny | Sunny |
| Maximum | 30°C | 29°C | 31°C | 30°C | 31°C | 31°C | 32°C |
| Minimum | 18°C | 19°C | 19°C | 19°C | 18°C | 18°C | 19°C |
| Chance of Rain | 5% | 5% | 5% | 5% | 5% | 5% | 20% |




# … to meaningful predictions

# Lake Hume harmful algal bloom modelling and management

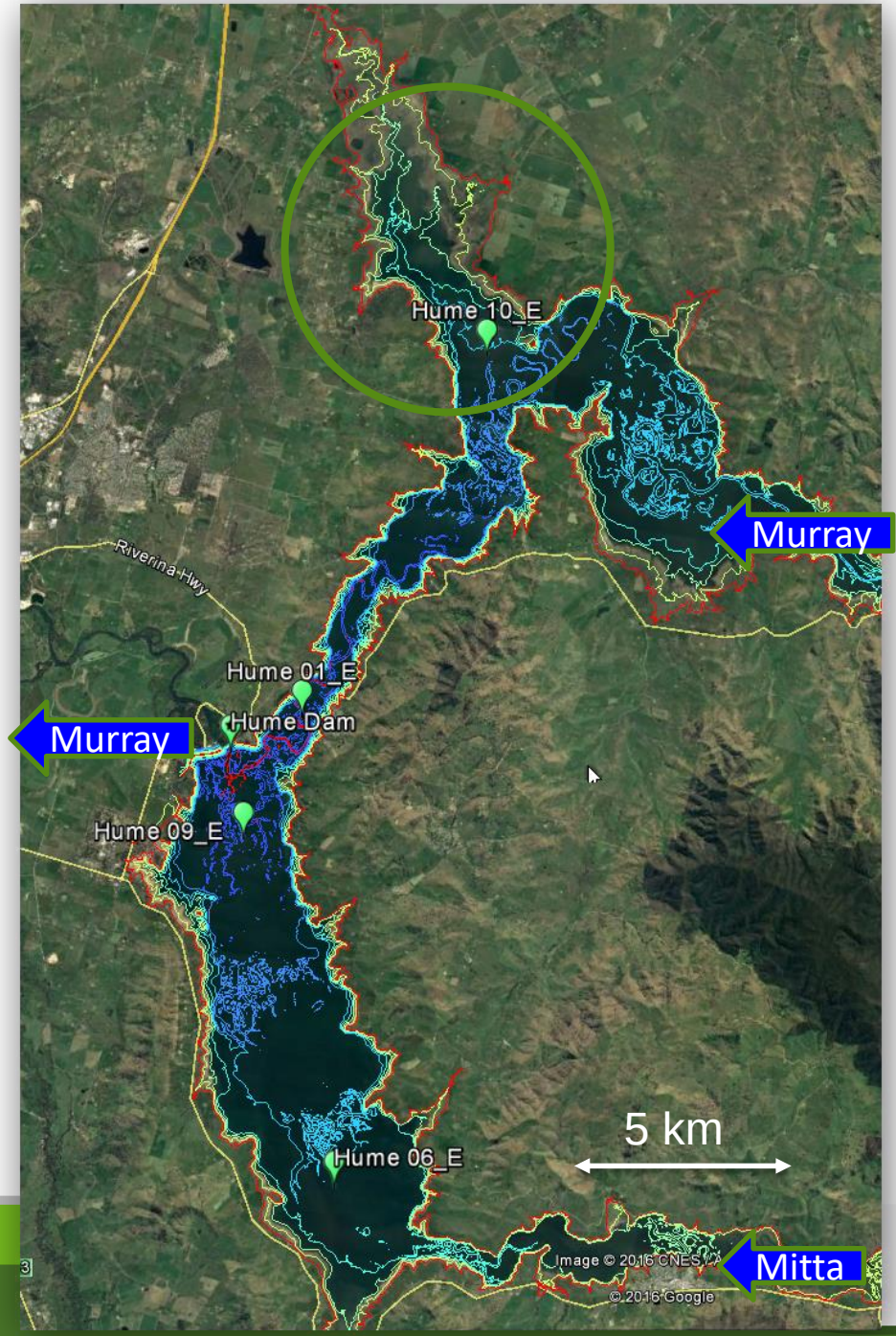
Monitoring (5 stations)

Modelling (1D and 3D)

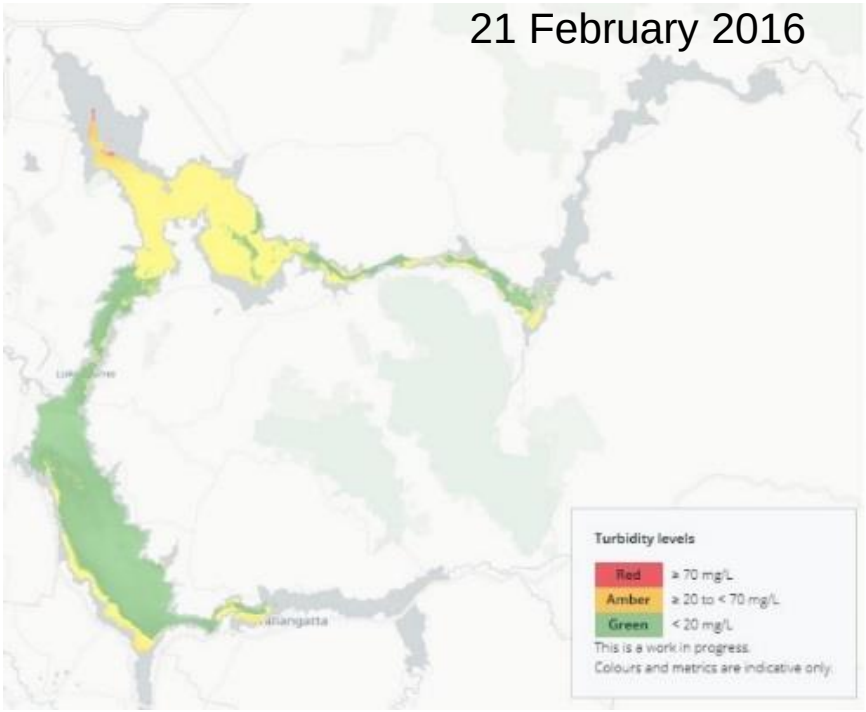
Remote sensing

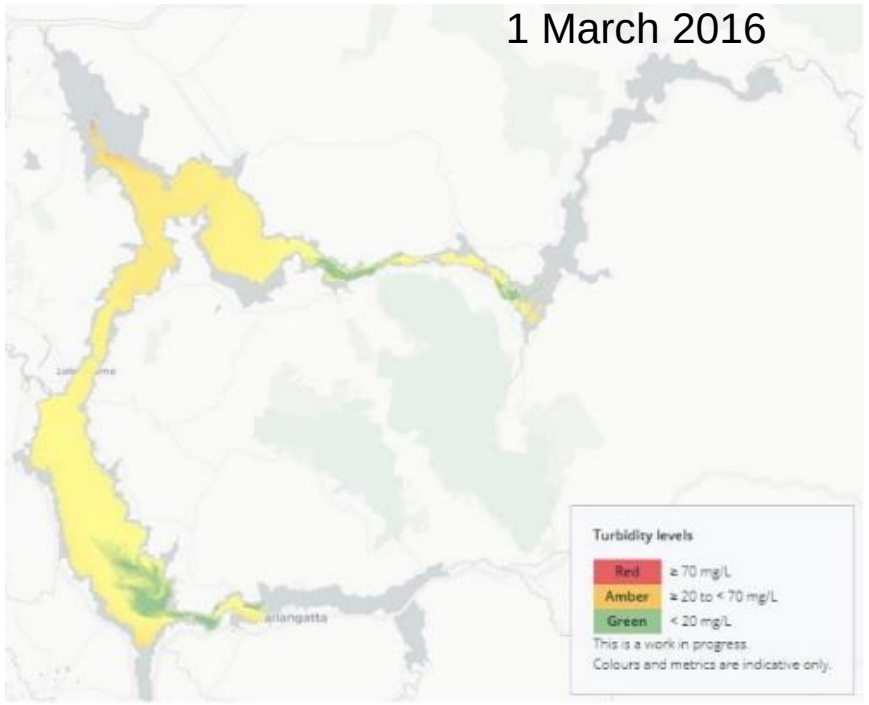
→ test scenarios of cold water inflow for future management of cyanobacteria blooms

→ See also next talk



# Satellite data



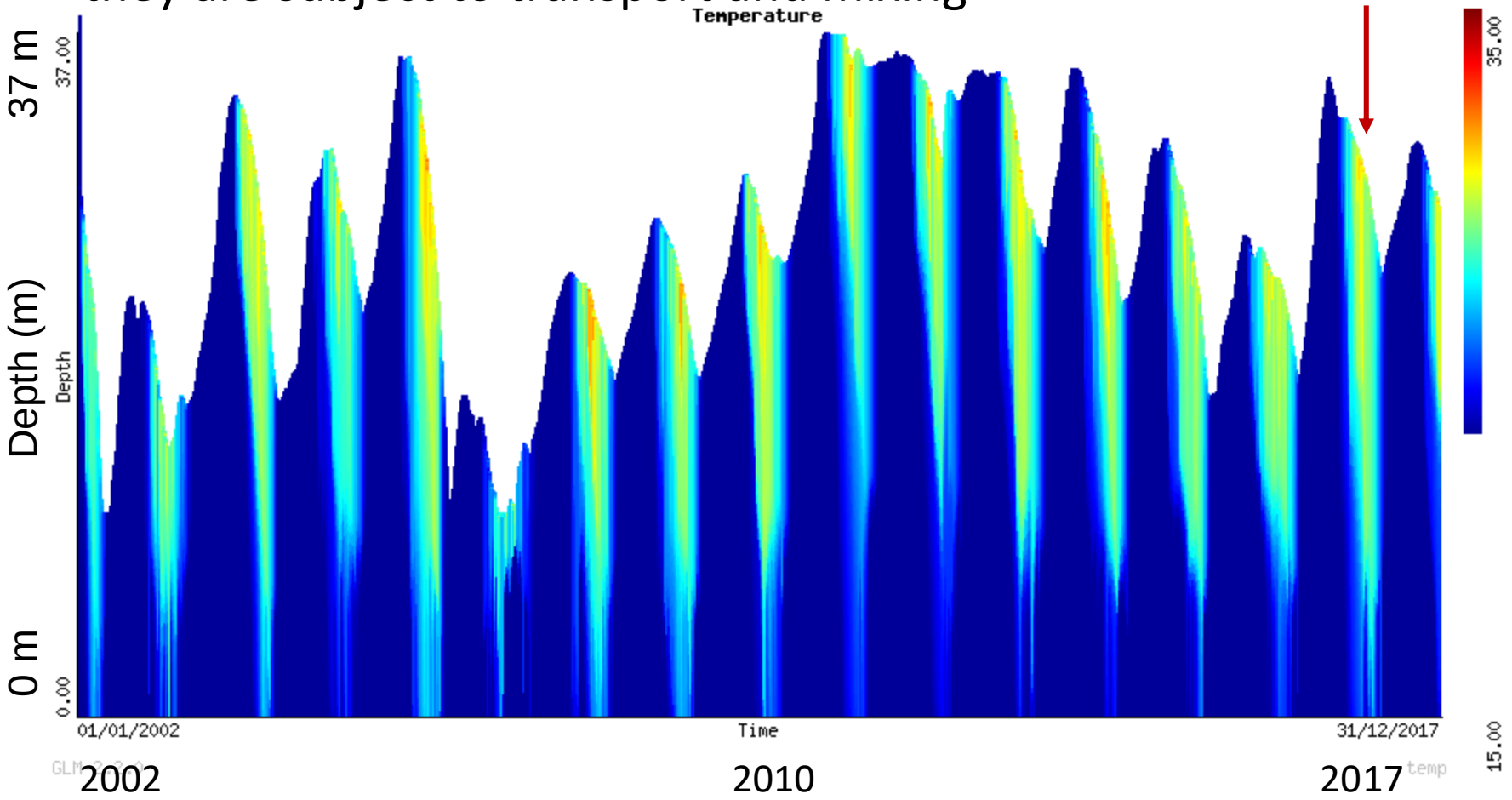




# Turbidity as proxy for cyanobacteria biomass

Malthus, T.J., Botha, E., and Anstee, J. (2018) Early warning system for harmful algal blooms: Report on Workpackage 5 – Satellite sensing - refining algorithms for water quality. CSIRO, Australia.

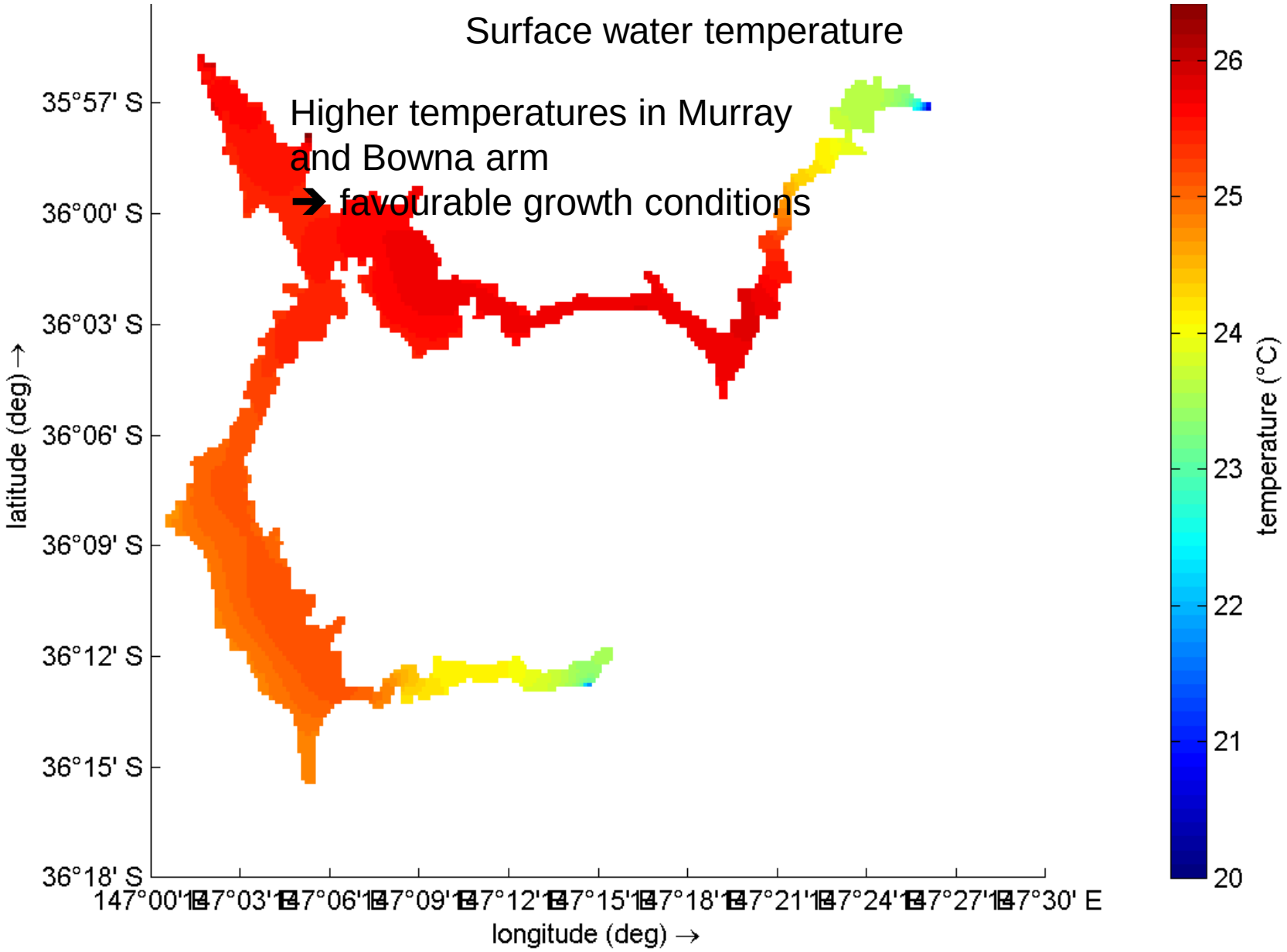
# What remote sensing cannot take into account

Cyanobacteria live in a 3 D environment (horizontal and vertical), they are subject to transport and mixing

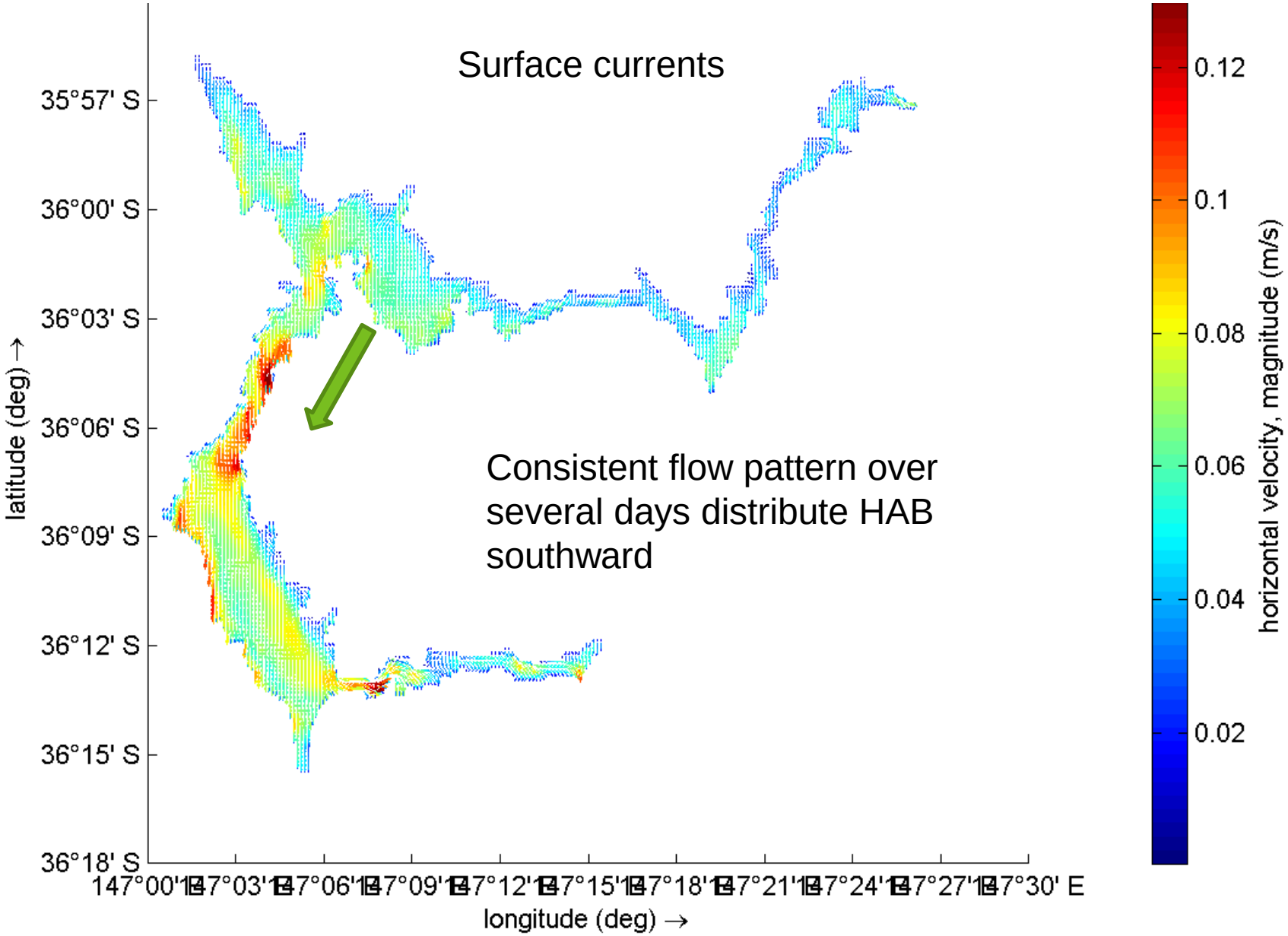



1D vertical model: Temperature stratification (blue 12 °C – orange 25 °C)

# Match RS observations with 3D hydrodynamic model



# Match RS observations with 3D hydrodynamic model



# Cyanobacteria at water treatment plants

Cyanobacteria blooms can challenge the capability of

- drinking water
- irrigation water
- wastewater treatment works

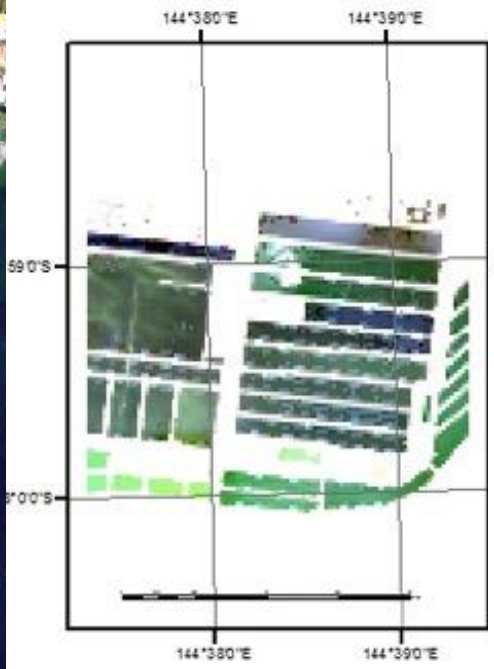
Toxins and taste and odour compounds (T&O)

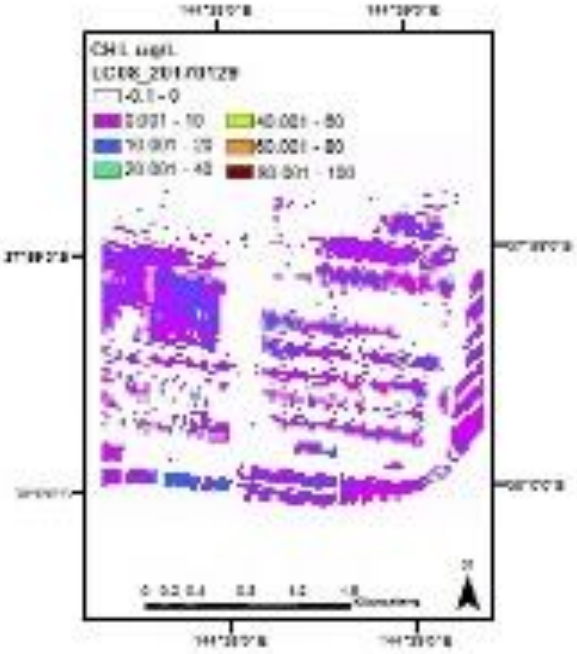
## Prediction can reduce costs of treatment

Pictures: Rita Henderson UNSW

# Cyanobacteria at water treatment plants

Remote sensing of cyanobacteria blooms in a lagoon type water treatment plant → see also next talk

# Cyanobacteria at water treatment plants

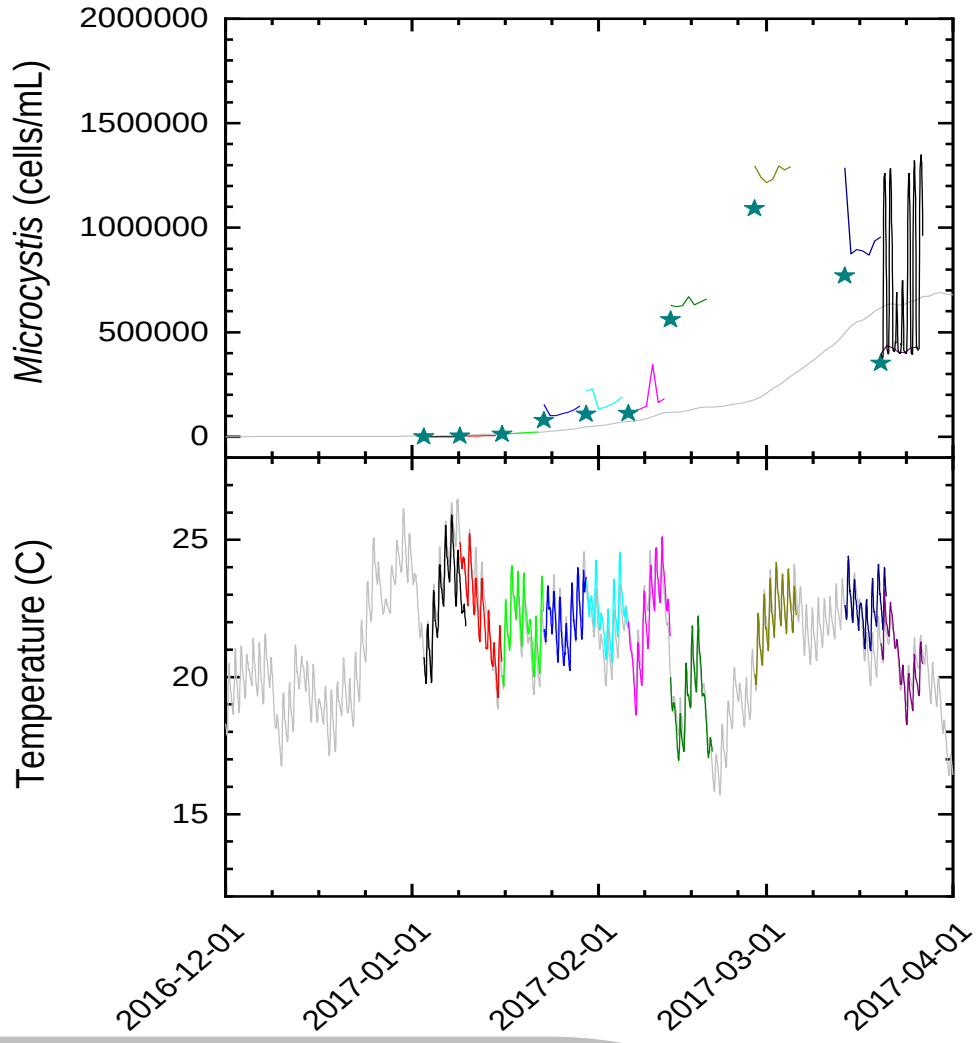
## 1D hydrodynamic + population dynamic model

7-day ahead prediction of water temperatures and cyanobacteria cell counts starting at weekly sampling dates (predictions in colour, continuous model in grey).

Using continuous cell counts from hyperspectral RS will improve these predictions significantly

→

Operational management tool

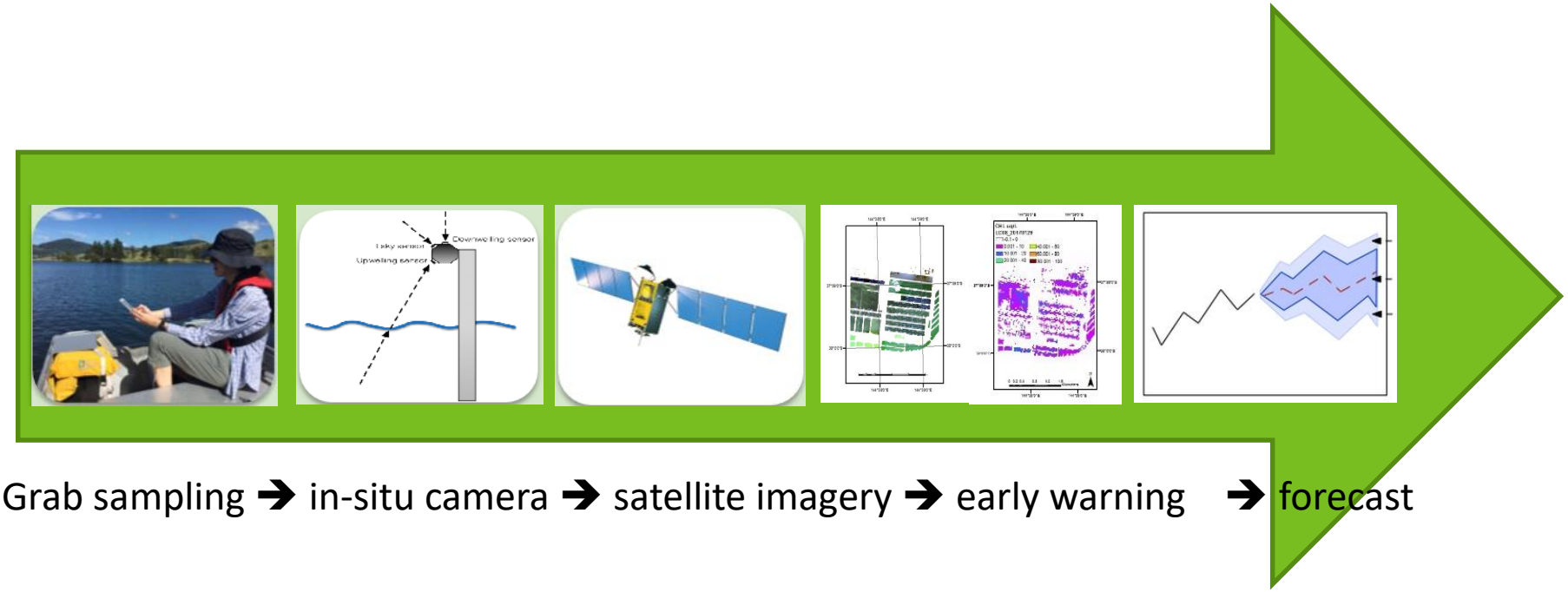


# Lake Hume harmful algal bloom modelling and Cyanobacteria in Water treatment plants

- Hydrodynamic modelling in combination with RS reveals spread of blooms
- Hydrodynamic model allows resolution of “hidden” vertical dimension
- Use of hyperspectral RS to resolve cyanobacteria species

- → RS used for Early Warning
- → HM used for scenario modelling and lake management
- → RS + HM for short term prediction

Combining remote sensing and hydrodynamic modelling will allow a continuous forecast of harmful algal growth, similar to common weather forecast




Grab sampling ➔ in-situ camera ➔ satellite imagery ➔ early warning ➔ forecast

# Flood inundation and connectivity mapping

## Detecting habitat conditions for fish

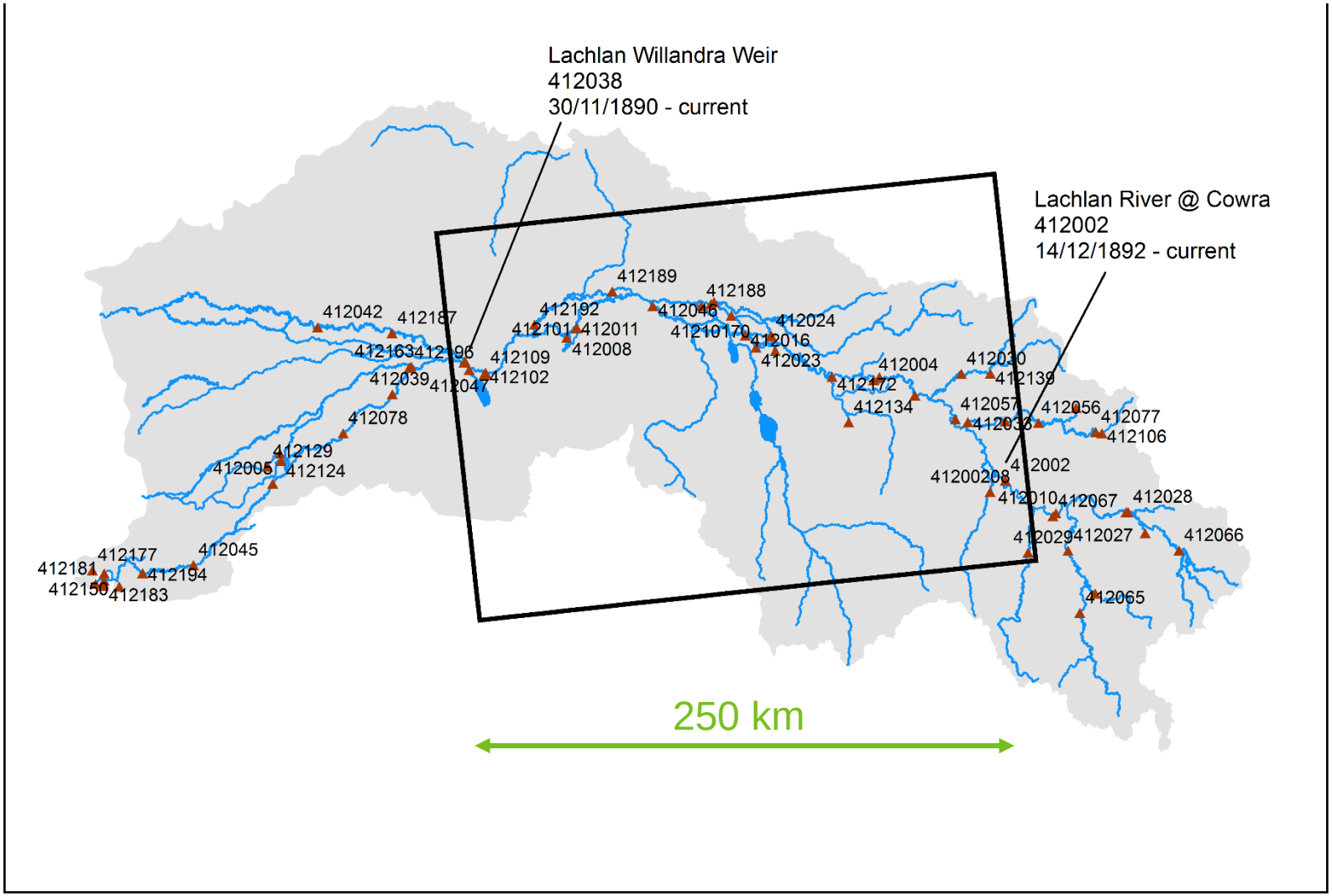
(National carp control plan – eradicating European carp using carp-specific herpesvirus)

- **MODIS time-series imagery** (Terra product “MOD09A1”) from February 2000 to February 2016
- **8-day composite** data at a **500 m resolution**
- Open Water Likelihood (OWL) index (Ticehurst et al., 2014)

**Results ➔ Inundation maps**

- Probability of the existence of standing water (0 to 100%)
- No inundation within the pixel area (OWL = 0) to inundation occurrence over the entire pixel area (OWL = 100%)

# Inundation and connectivity mapping to derive fish spawning grounds (European carp)



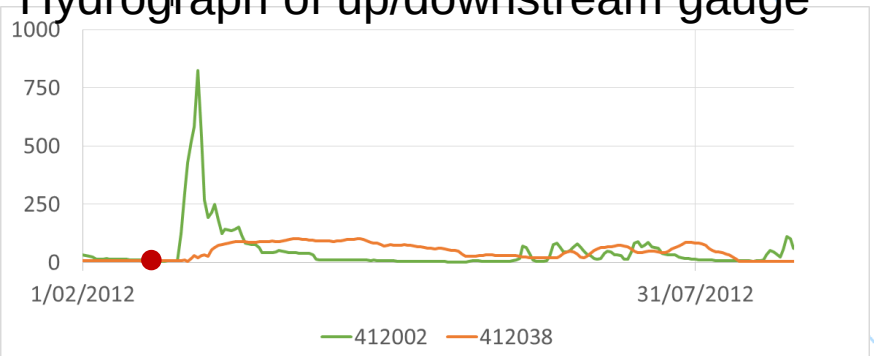
18 February 2012

412038

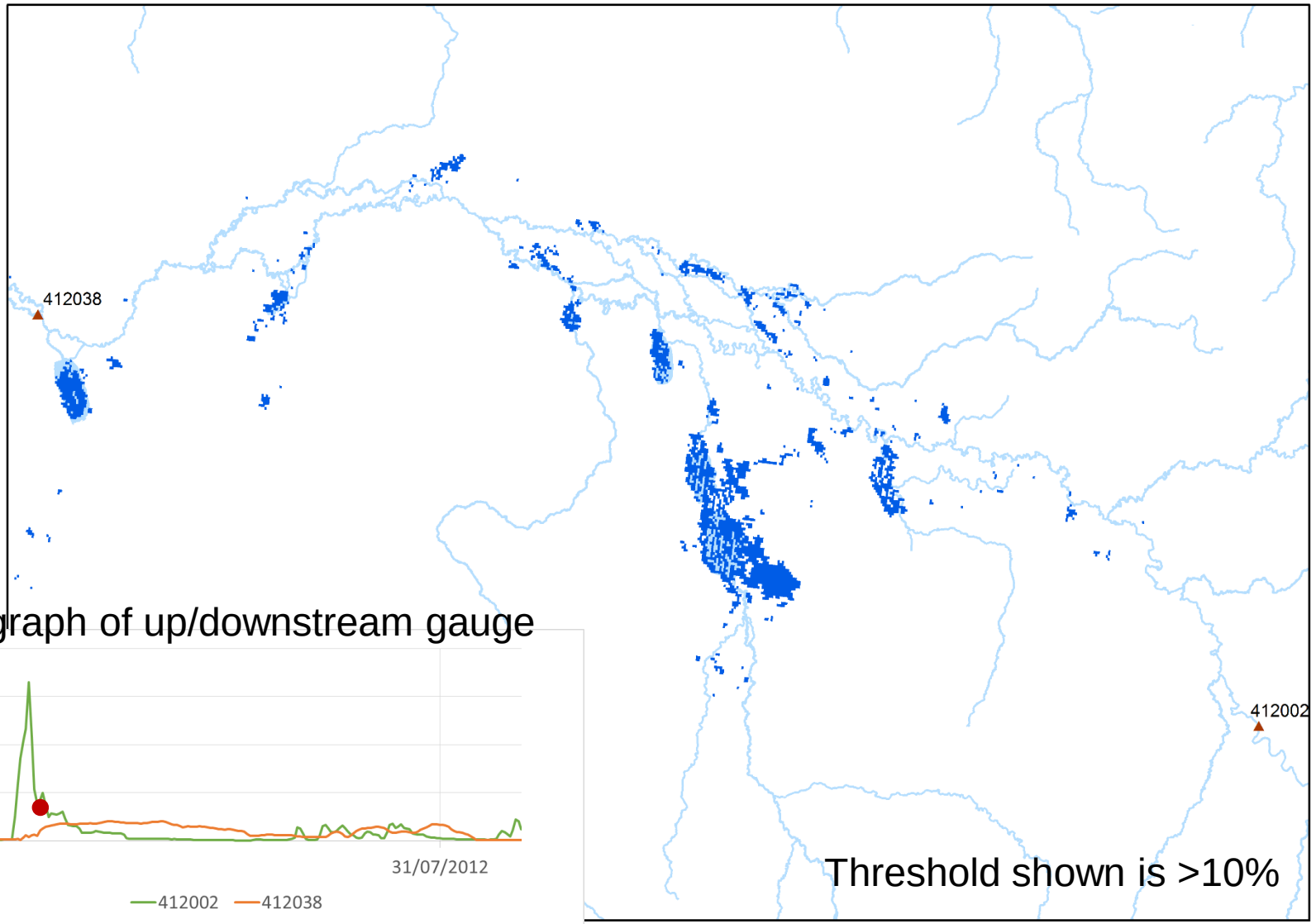
412002

Threshold shown is >10%

Hydrograph of up/downstream gauge



13 March 2012




Hydrograph of up/downstream gauge

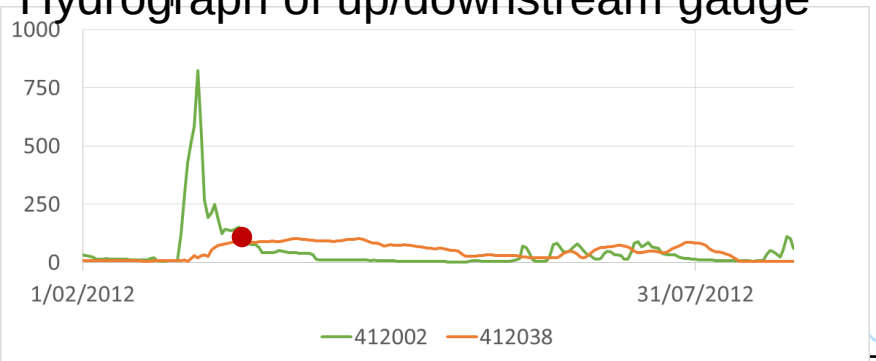
# 21 March 2012

412038

412002

Threshold shown is >10%

Hydrograph of up/downstream gauge



# Inundation and connectivity mapping to derive fish spawning grounds (European carp)

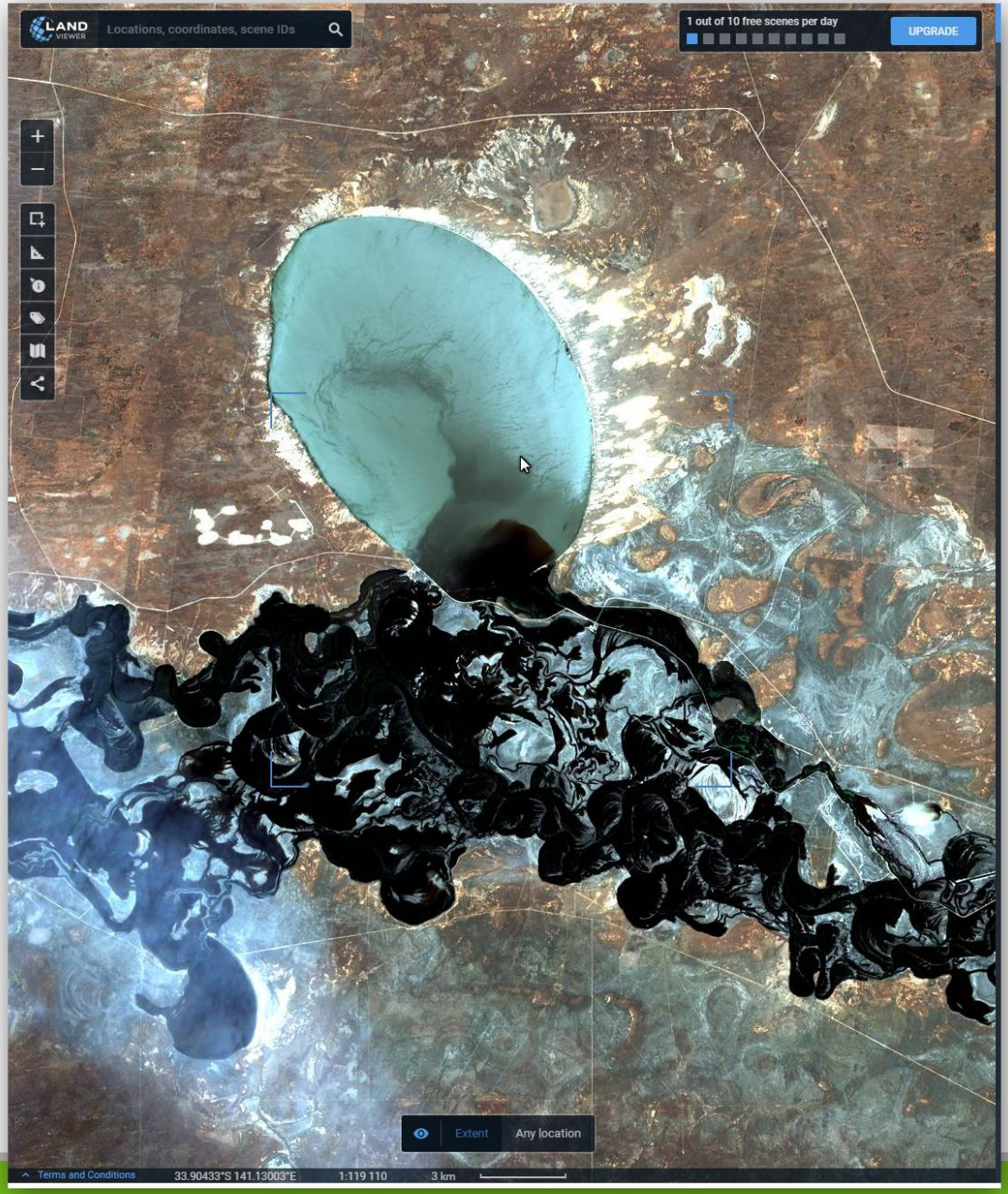
RS in combination with hydrological modelling – flow and water temperature – is used to drive a demographic fish model and an epidemiological model for spread of carp specific herpesvirus to eradicate an invasive species (European carp)

- High spatial resolution needed
  ← carp can even bridge non wet areas
- Large scale, basin wide application

# Blackwater – hypoxia

- Inundation of areas covered with organic material leads to leaching of dissolved organic carbon (DOC)
  → water appears black
- Microbial degradation decreases dissolve oxygen concentration
  → hypoxic
- Below a certain threshold this is
  → lethal for fish and other aquatic organisms

- Remote sensing can be used to follow the extend and spread of blackwater, and possibly
- Quantify dissolved oxygen via duration of high DOC content
  ← combining RS with process dynamics

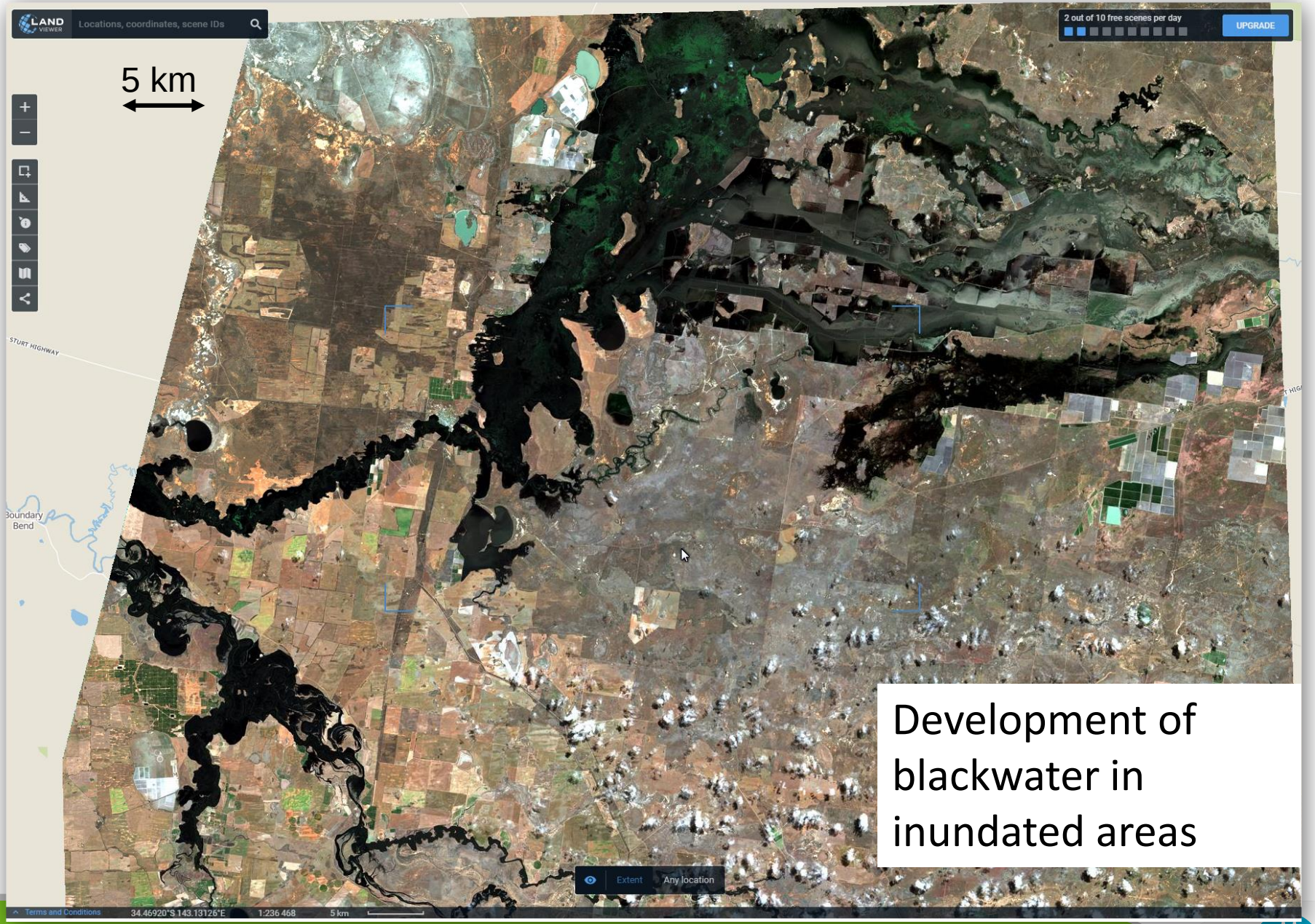



# Inflow of blackwater into Lake Victoria

3 km



https://eos.com/landviewer/?lat=-34.04896&lng=141.37896&z=12&s=Sentinel2&id=S2A_tile_20161128_54HWH_0&b=Red,Green,Blue&anti

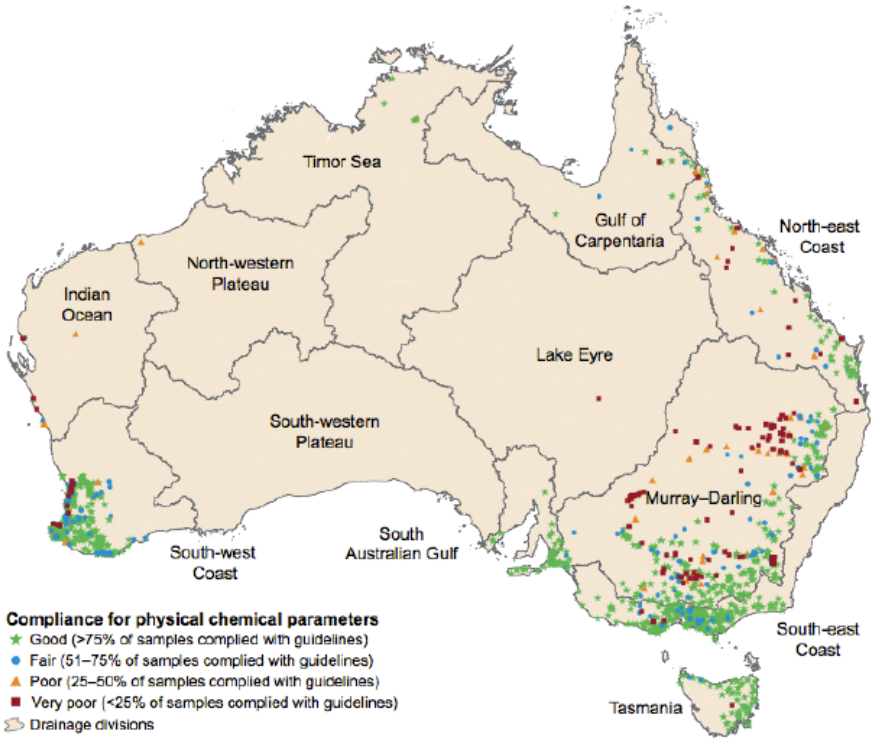



Development of blackwater in inundated areas



https://eos.com/landviewer/?lat=-34.66766&lng=143.91694&z=11&s=Sentinel2&id=S2A_tile_20161102_54HYG_0&b=Red,Green,Blue&anti

# The challenge of *in situ* monitoring



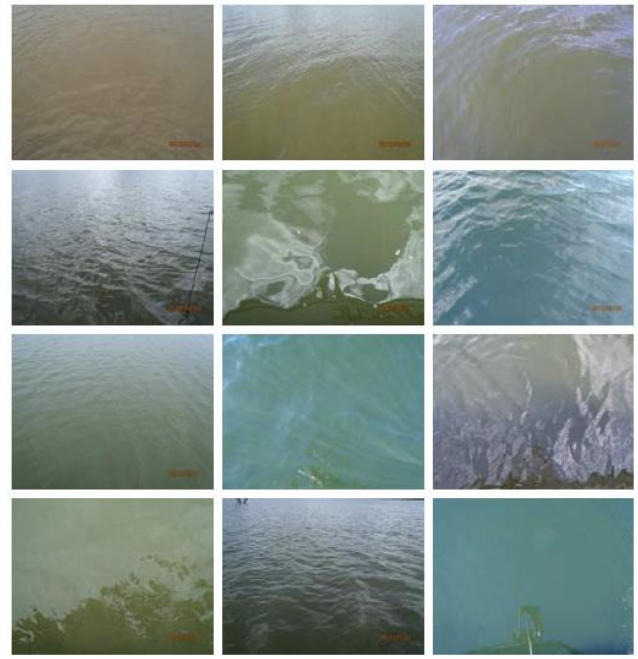

*National Water Quality Audit 2011*

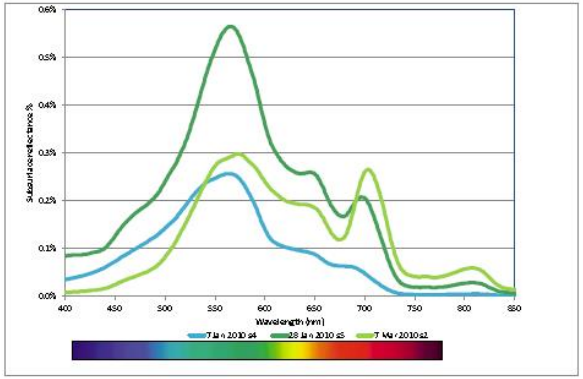
# Remote sensing to support monitoring

- Systematic, repeatable
- Supra-regional assessments
- Complements existing *in situ* programs and sensor networks
- Opportunities for time series analyses
- Continental, free data

# Challenges

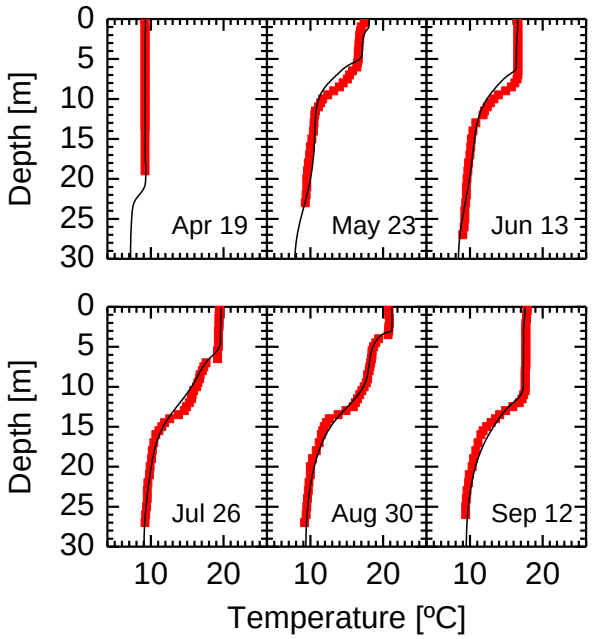
- Optical complexity of inland waters
- Need to parameterize water quality algorithms
- Lack of *in situ* knowledge
- Validation data





# Challenges

- Water bodies have a depth dimension – stratification and mixing
- Need for higher resolution
  spectral
  → classification of cyanobacteria species
  time
  → follow fast changes in ecosystems
  space
  → observe smaller lakes and narrow rivers
- Integration of data from citizen science, in situ sensor and satellite to allow users to obtain ‘continuous’ information about the state of water bodies across a wide region
- Use of calibrated/validated hydrodynamic and biogeochemical models for prediction

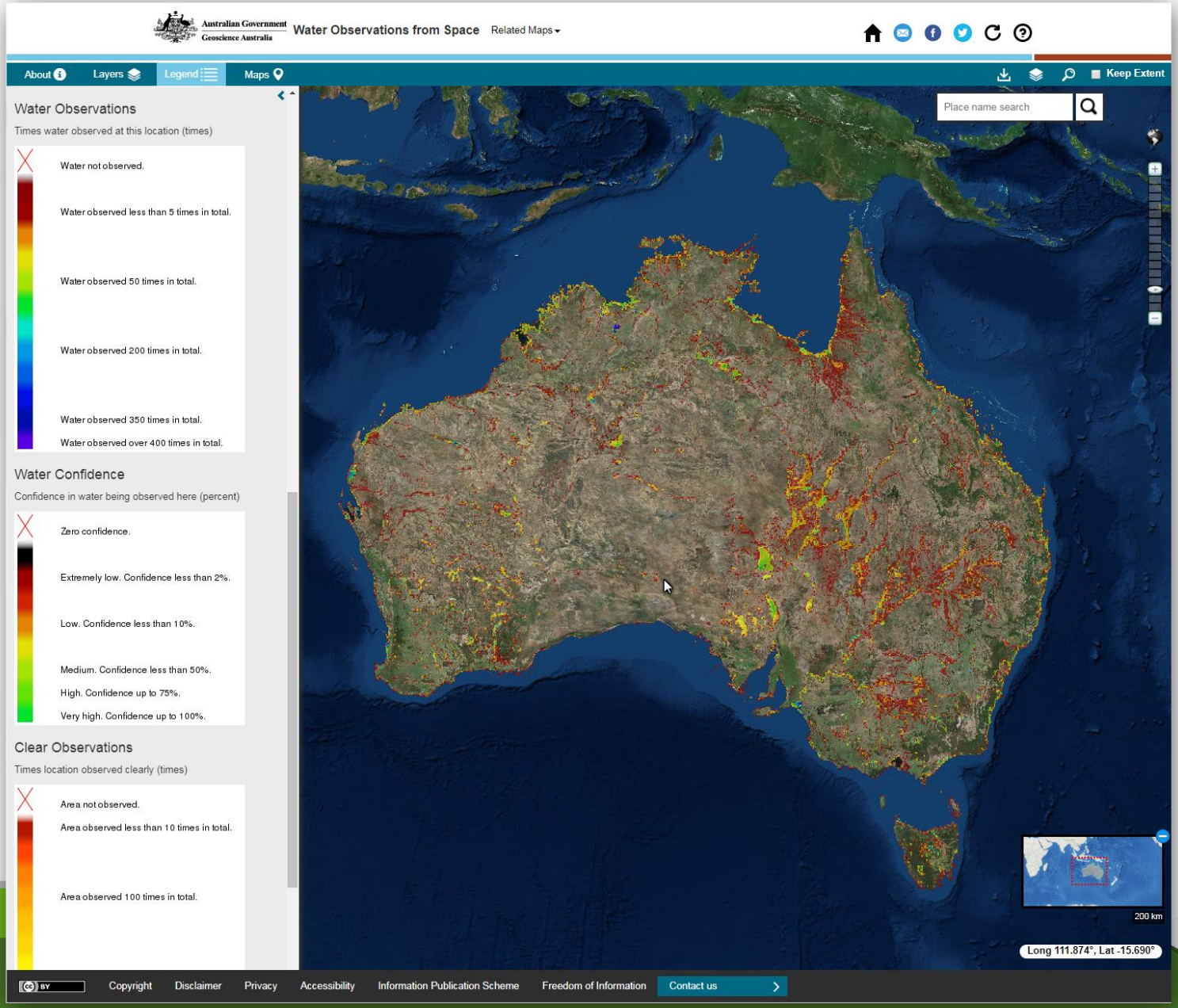


# Continental scale model

System for
short-term prediction – 'Early warning system' – of
cyanobacteria blooms in inland waters and
long-term scenario modelling
of lakes and reservoirs
in continental Australia

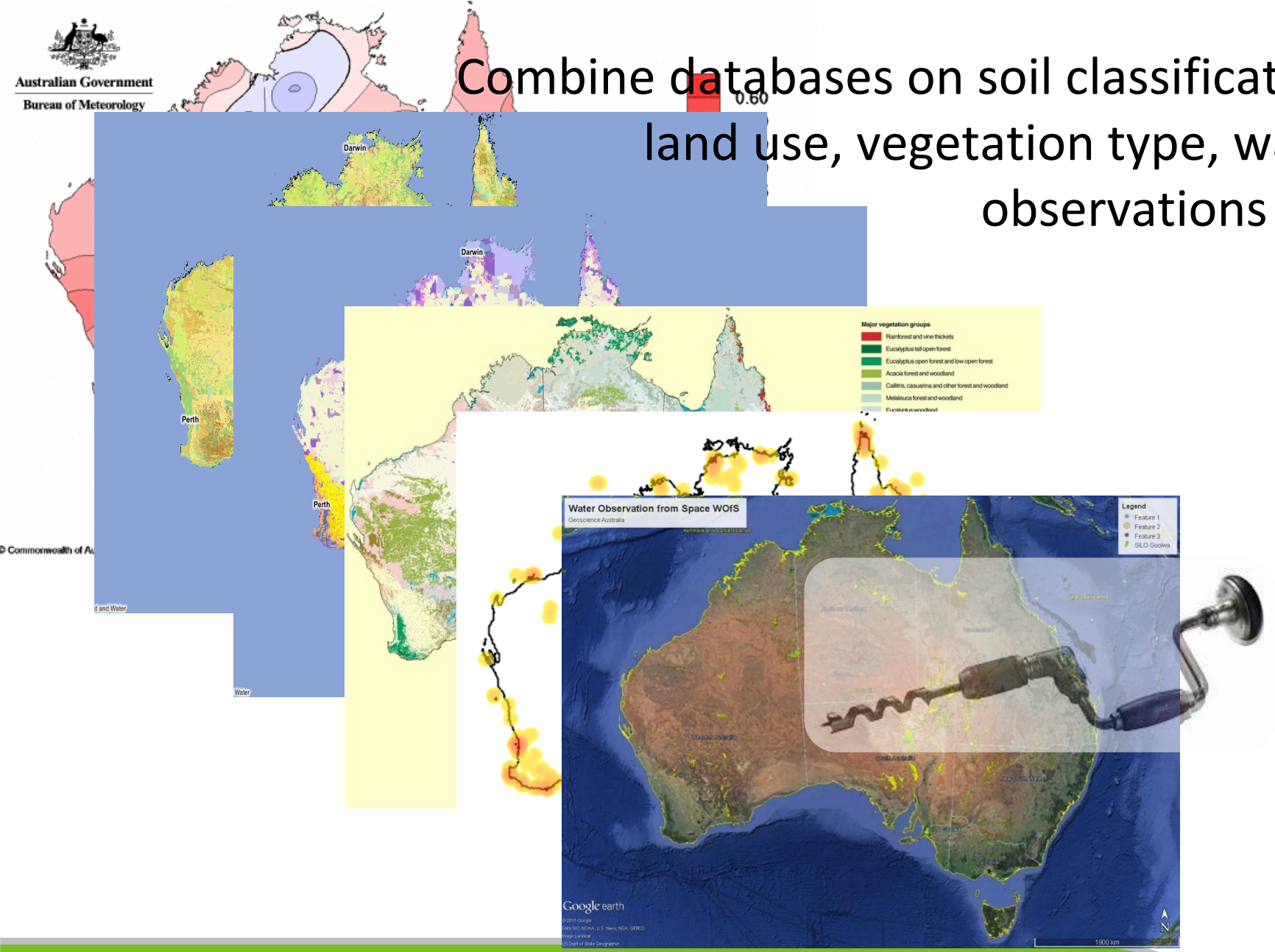
- Large-scale simulation model for algal blooms in inland waters (rivers, lakes, reservoirs, wetlands)
- Driven by gridded meteorological, streamflow, etc data
- Based on mapped information on nutrient, land use, etc data
- Drawing from a database on algal physiology, distribution, processes
- Linked to in-situ data on algal biomass, species composition,
- Assimilating remote sensing data (surface temperature, Chl-a,…)

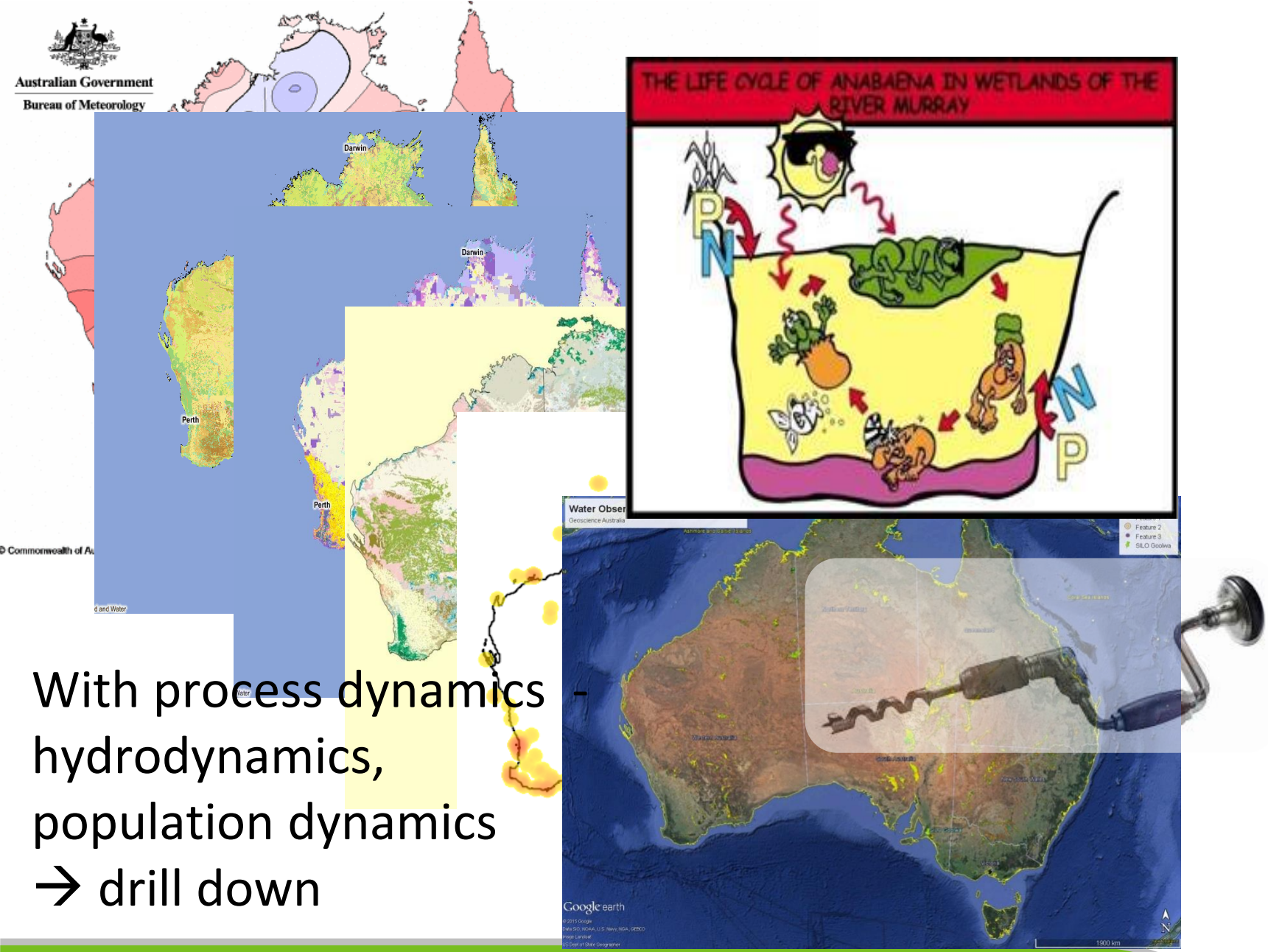
# Continental scale model – Water Observation from Space



Australian Government
Bureau of Meteorology

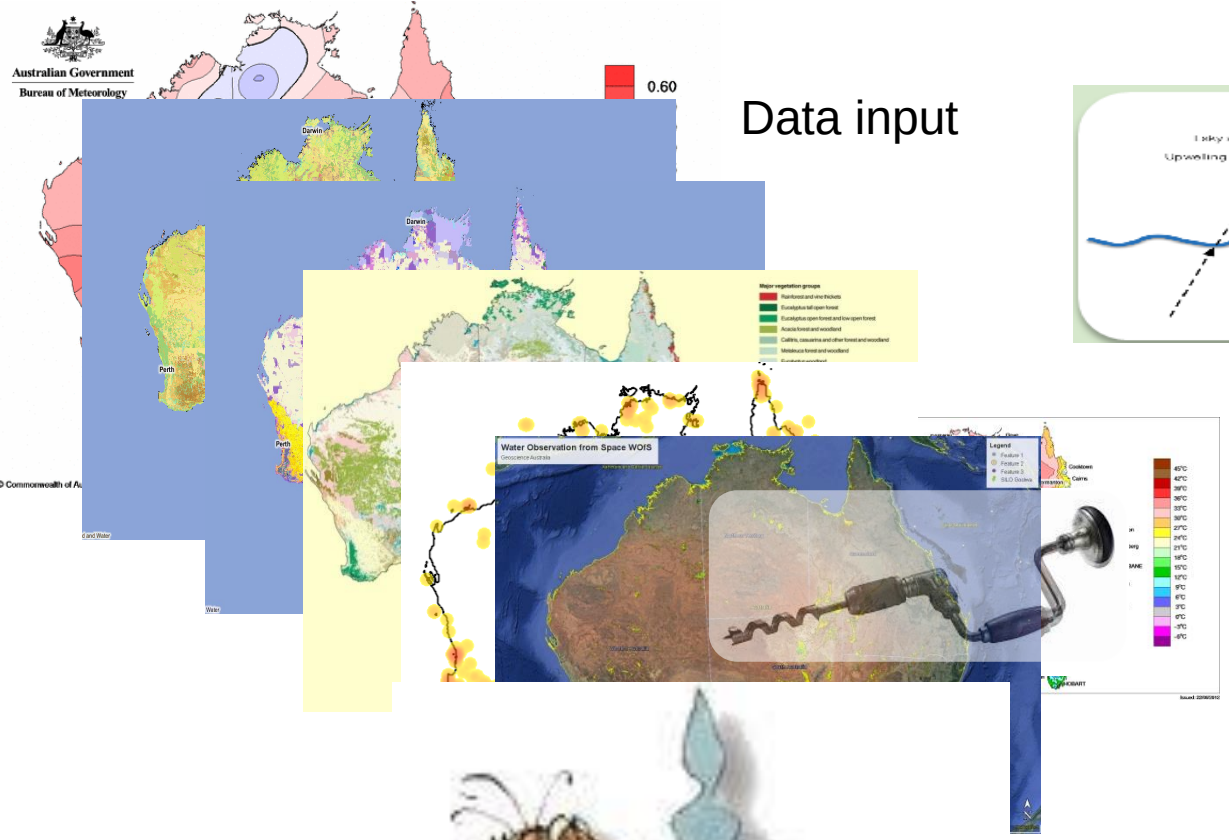
# Combine databases on soil classification, land use, vegetation type, water observations etc.

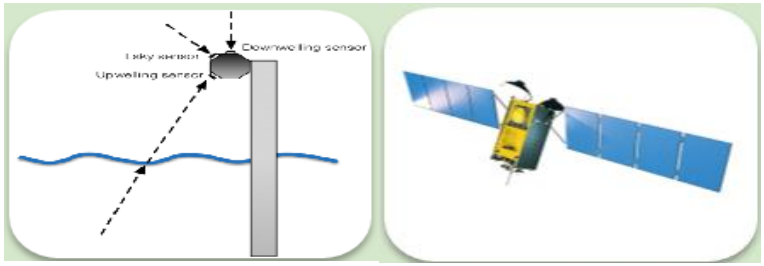





With process dynamics - hydrodynamics, population dynamics → drill down

Data input




Assimilate remote sensing data for prediction of water quality at each location

Expert knowledge

Model

Model output