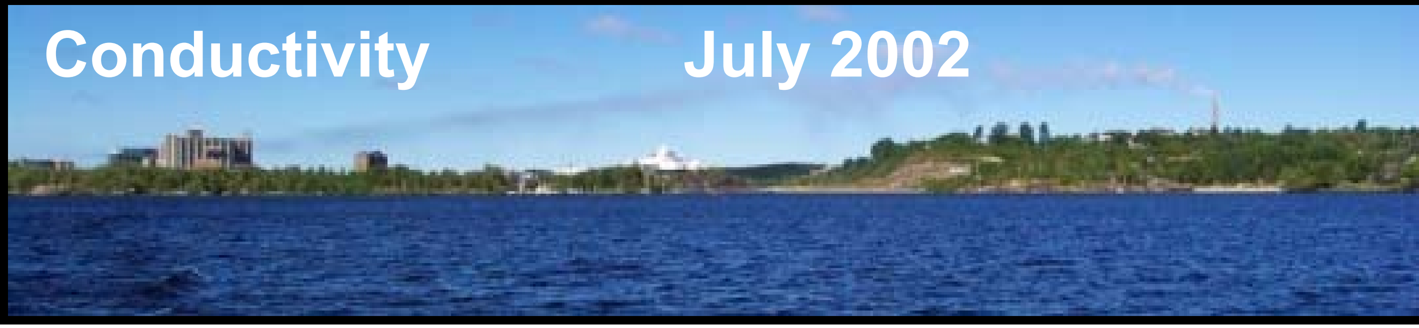
Mapping of Mineralized Groundwater Discharge into Lakes and Rivers

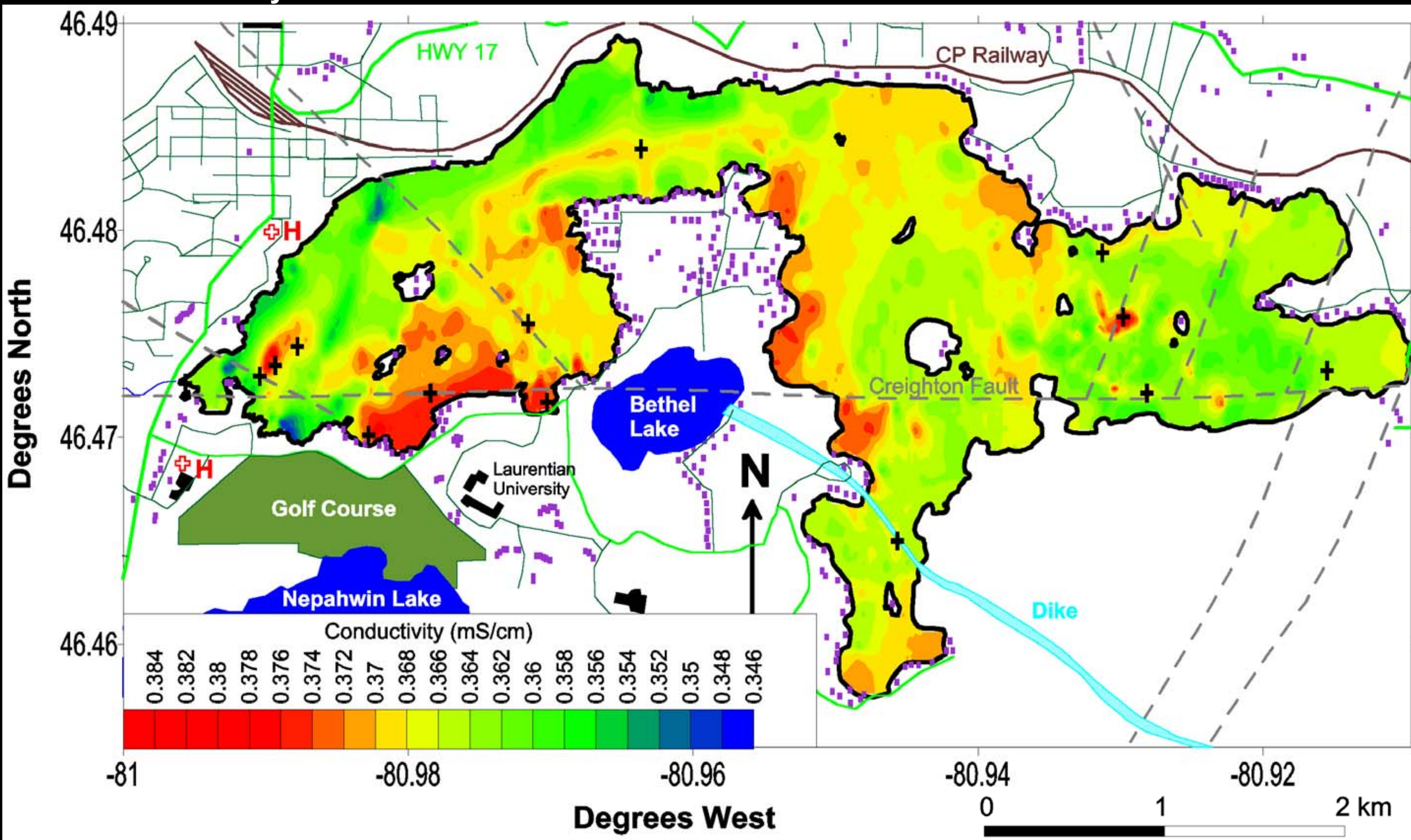
Blair Hostetler — Aquapath Pty Ltd
James Ray — Aquapath Pty Ltd
Richard Dyer — Ontario Geological Survey
Gary Grabowski — Ontario Geological Survey
David Guindon — Ontario Geological Survey
Ross Kelly — Ontario Geological Survey

Aquapath
CANADA ltd

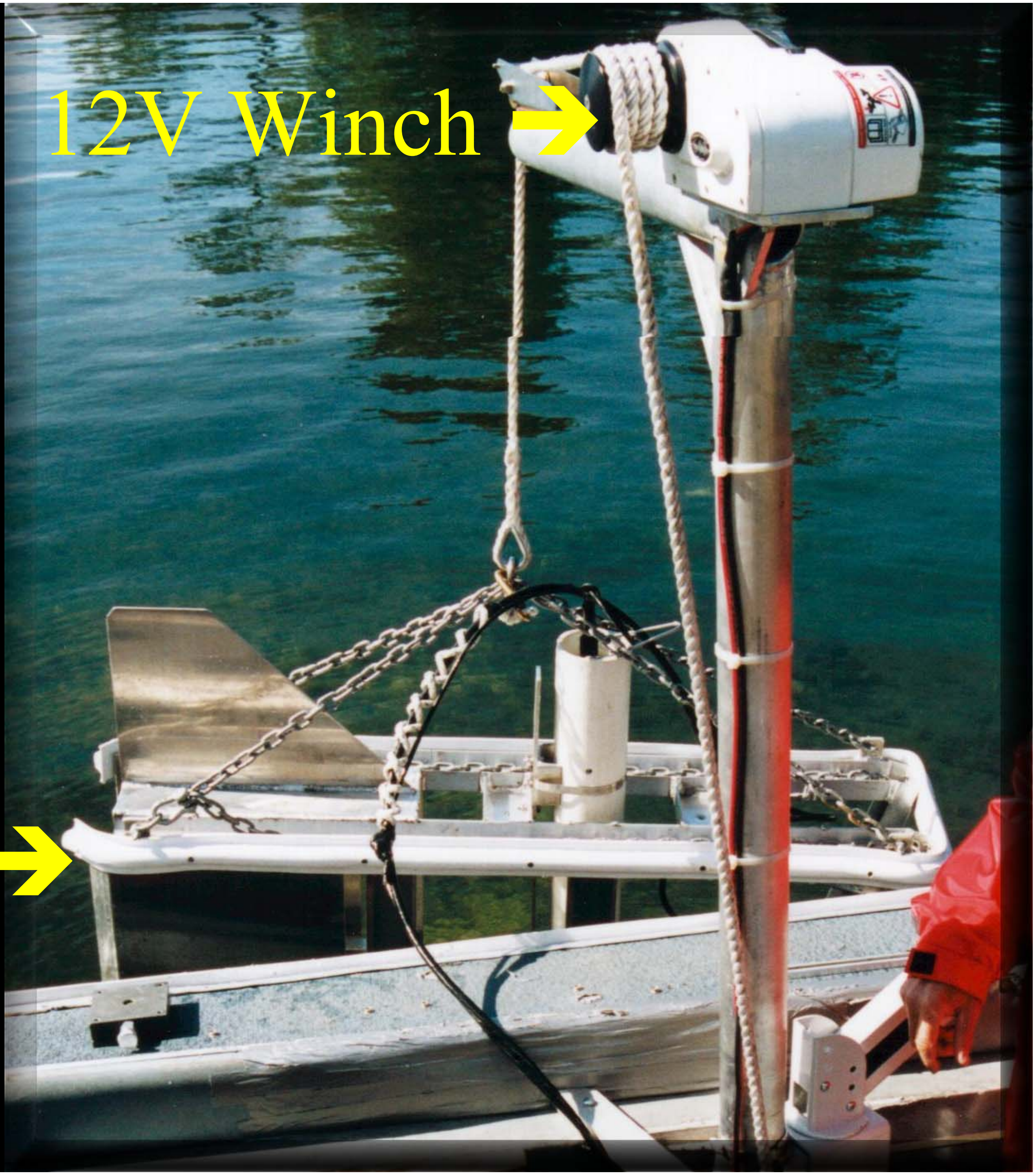
Ramsey Lake
Sudbury, Ontario

Sponsored by:
CEM,
Laurentian University





How do we map?



Instrumentation

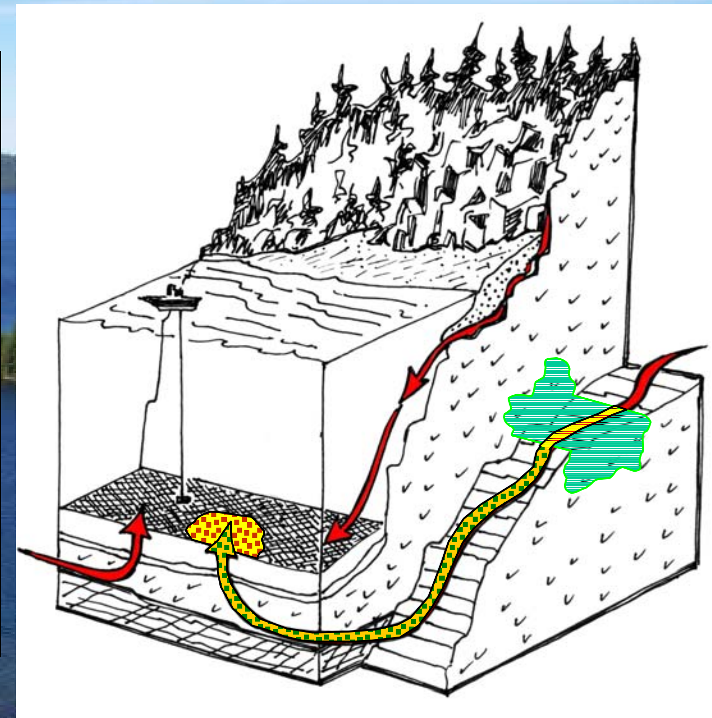
Hydrolab Datasonde

In-situ Mapping Parameters-

- pH, conductivity, dissolved oxygen, Eh, temperature, depth, chloride, turbidity

Why do we map?

- Detect groundwater springs entering lakes and rivers



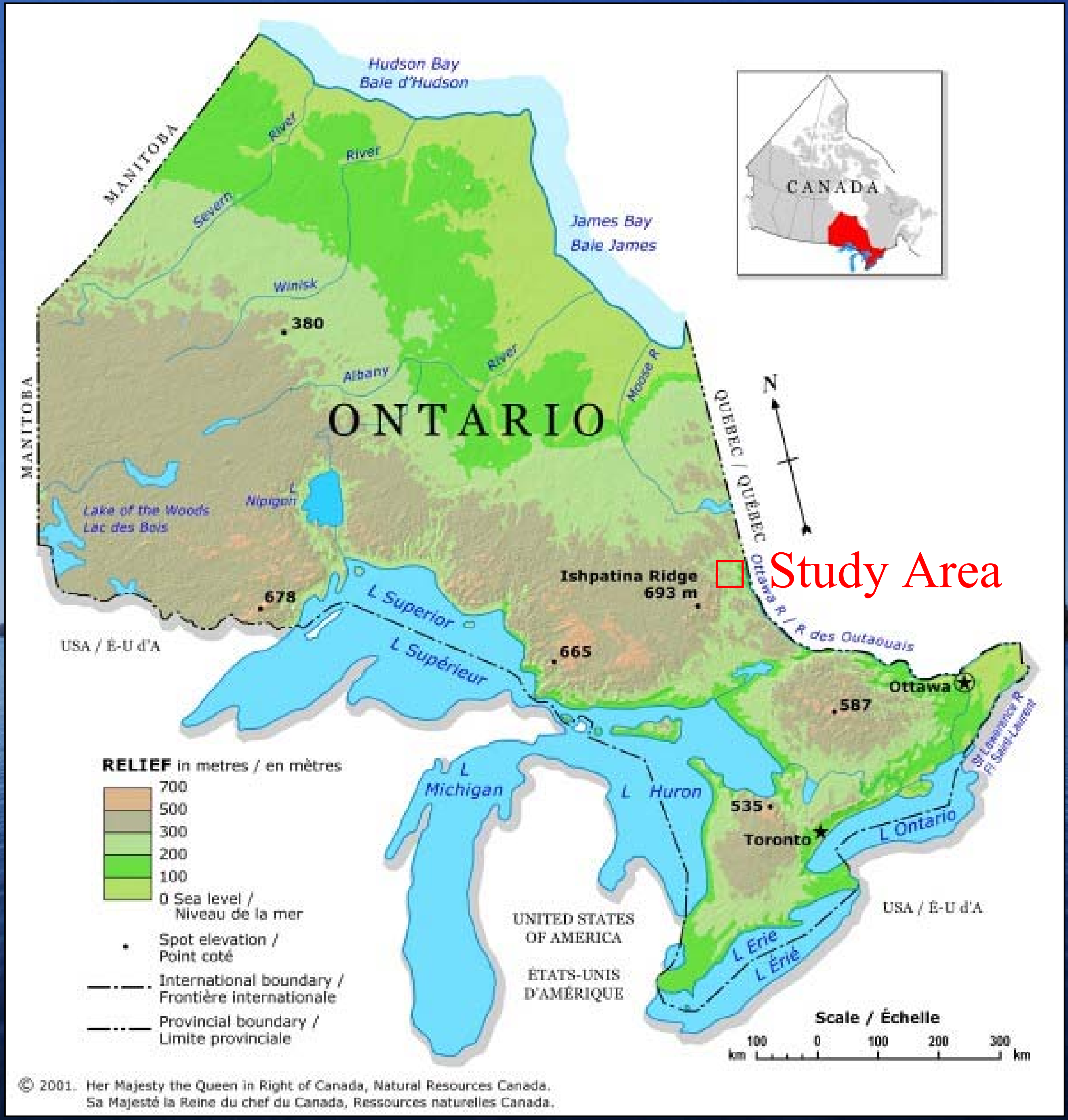
Groundwater Emergence Sites

- **Structural Control**
  - Faults *
  - Joints
  - Igneous contacts (dikes)
  - Stratigraphic boundaries
- **Glaciofluvial Conduits**

- Relate groundwater chemistry to the bedrock and mineralization with which it has been in contact

- Identify geochemical processes, such as precipitation of sulfides from the groundwater upwelling into surface water

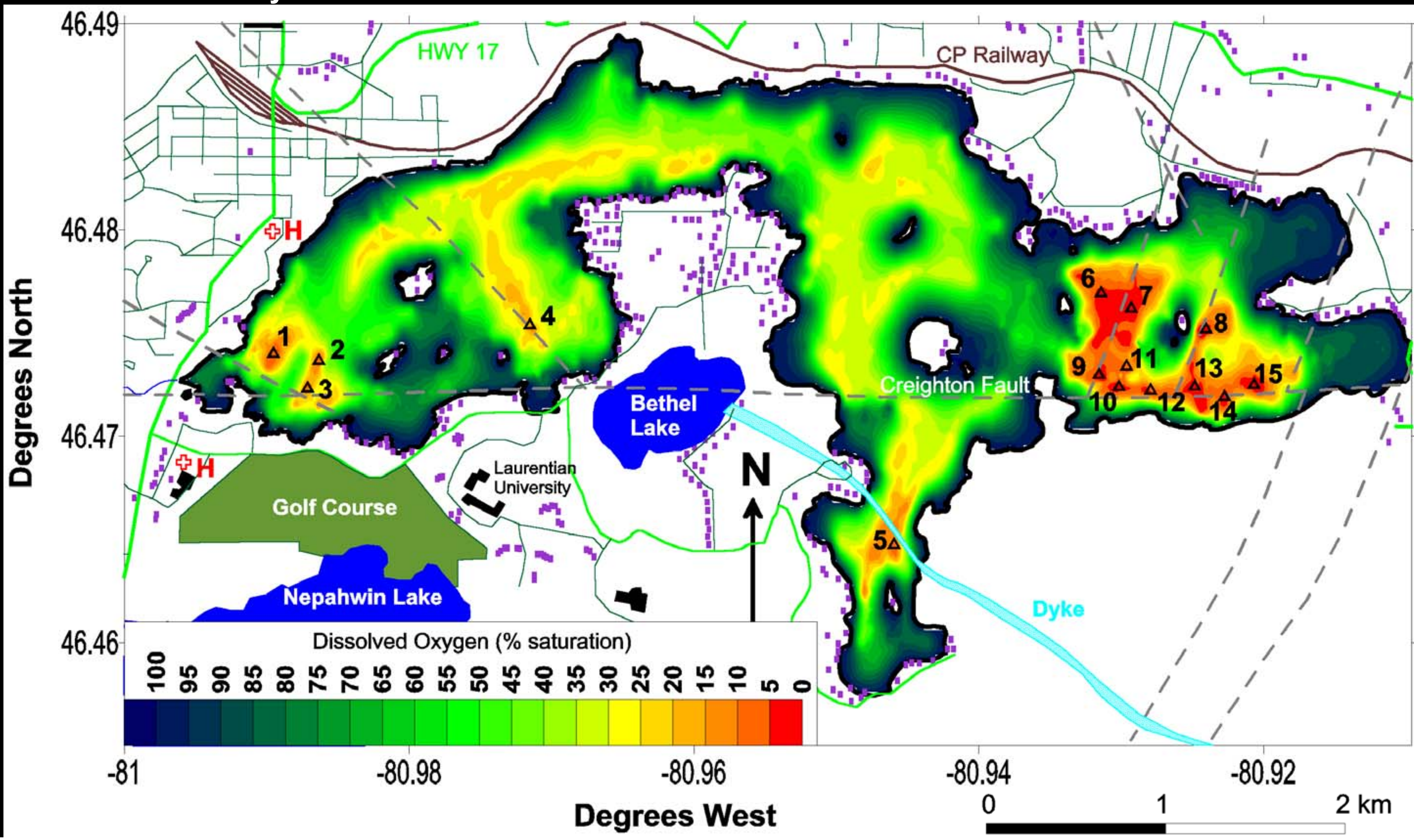
Study Area


Hudson Bay
Baie d'Hudson
James Bay
Baie James
MANITOBA
Severn
River
Winisk
Albany
Moose R
380
ONTARIO
QUEBEC / QUÉBEC
Lake of the Woods
Lac des Bois
L Nipigon
Ishpatina Ridge
693 m
Study Area
Ottawa R / R des Outaouais
678
L Superior
L Supérieur
665
USA / É-U d'A
Ottawa
587
St Lawrence R
Fl Saint-Laurent
L Michigan
L Huron
535
Toronto
L Ontario
UNITED STATES
OF AMERICA
ÉTATS-UNIS
D'AMÉRIQUE
L Erie
L Érié
CANADA
N
RELIEF in metres / en mètres
700
500
300
200
100
0 Sea level /
Niveau de la mer
Spot elevation /
Point coté
International boundary /
Frontière internationale
Provincial boundary /
Limite provinciale
Scale / Échelle
100 0 100 200 300
km
© 2001. Her Majesty the Queen in Right of Canada, Natural Resources Canada.
Sa Majesté la Reine du chef du Canada, Ressources naturelles Canada.

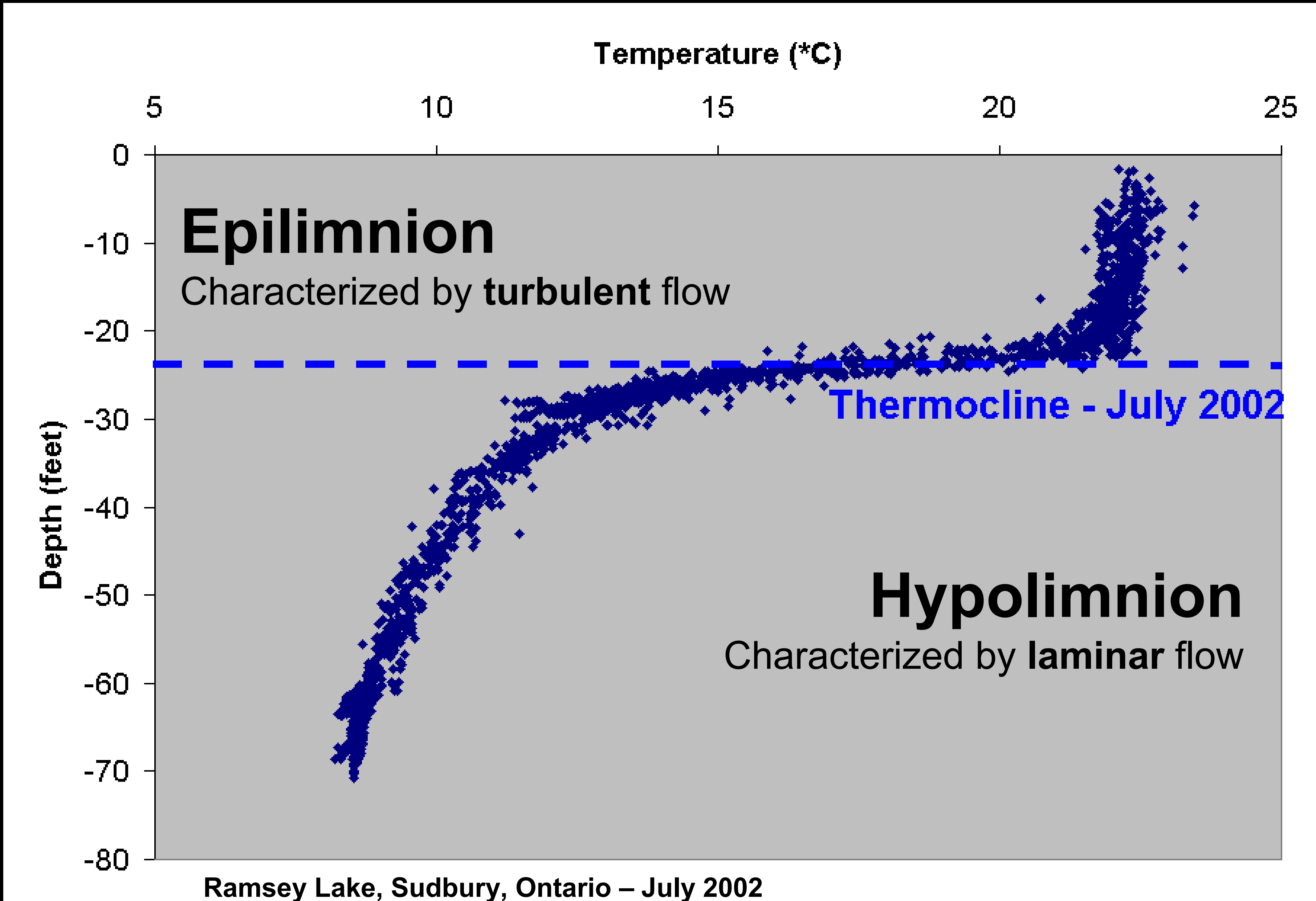
Ramsey Lake

Sudbury, Ontario

Sponsored by:
CEM,
Laurentian University



Where (and when) do we map?



Working Definitions

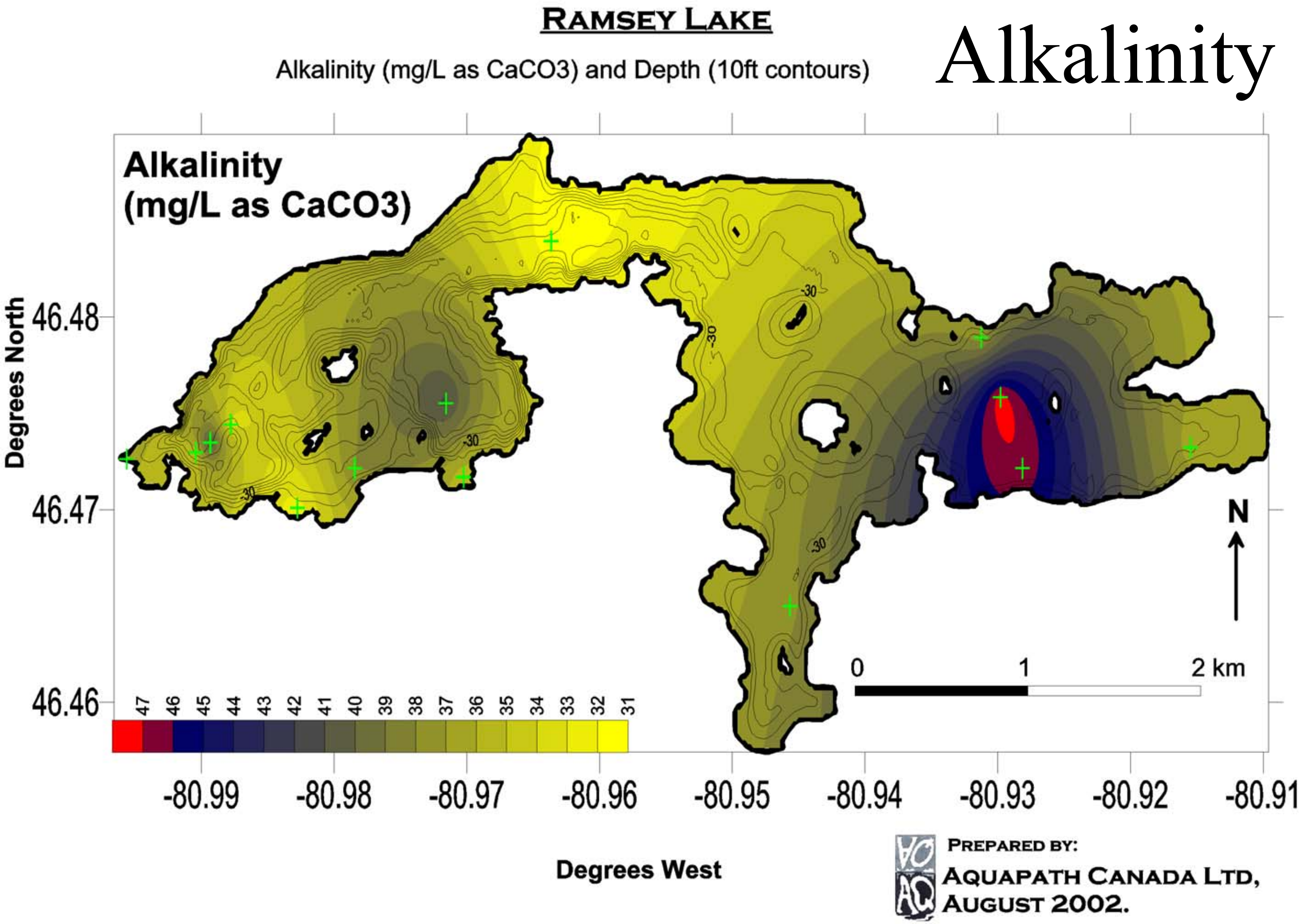
- **Oxic** = DO $\geq$ 15% saturation
- **Anoxic** = DO < 15% saturation ORP > 0 mV
- **Anaerobic** = DO < 10% saturation ORP < 0 mV

Redox potential controlled by anaerobic bacteria producing hydrogen sulfide and/or ammonia

Groundwater Characteristics

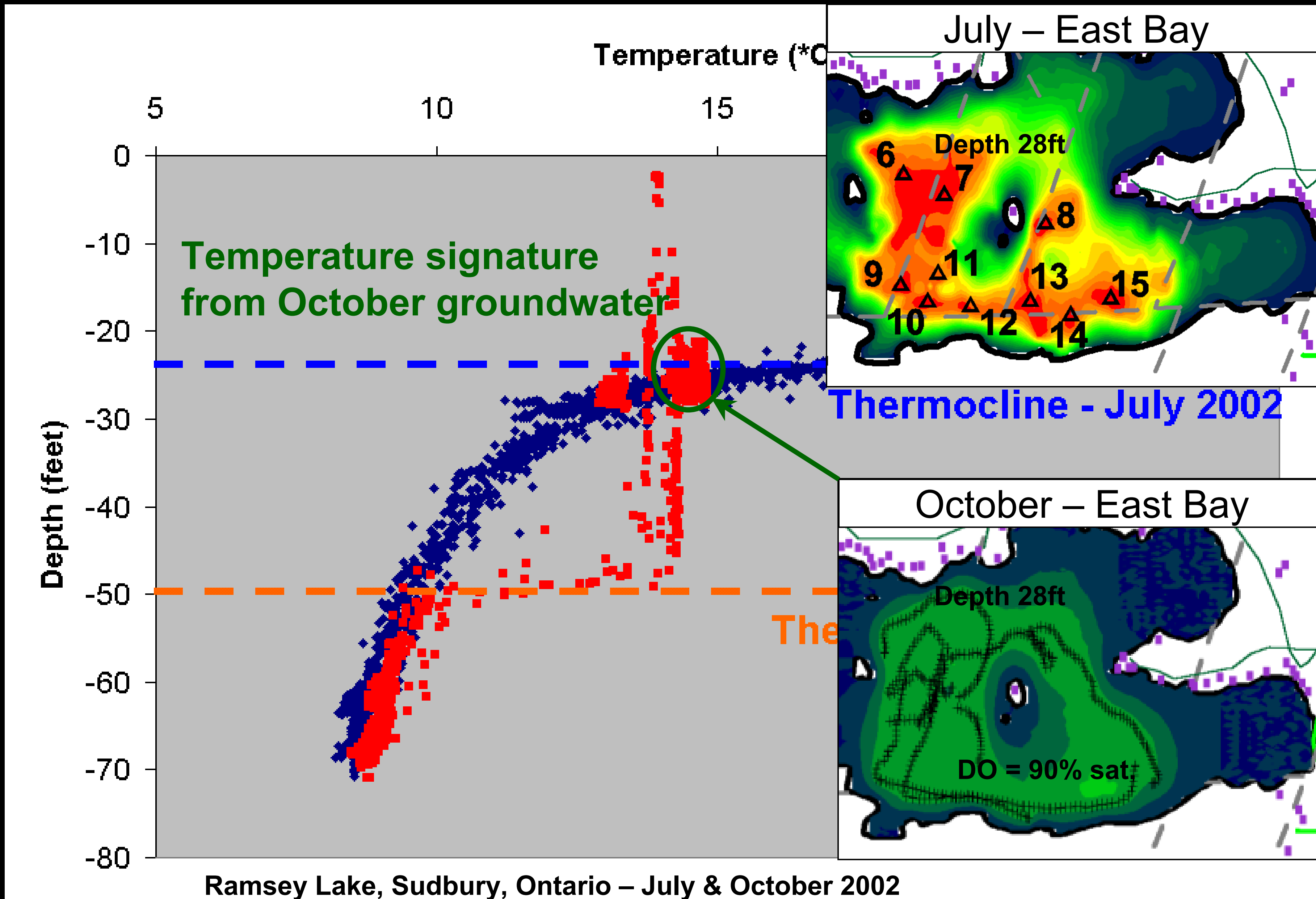
- Zero % dissolved oxygen
- Higher concentration of TDS than lake / river water (usually)
- Silica concentration $\geq$ quartz saturation
- Higher alkalinity (usually)

Alkalinity



RAMSEY LAKE
Alkalinity (mg/L as CaCO3) and Depth (10ft contours)
Alkalinity
(mg/L as CaCO3)
Degrees North
46.48
46.47
46.46
-30
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
0
1
2 km
N
-80.99
-80.98
-80.97
-80.96
-80.95
-80.94
-80.93
-80.92
-80.91
Degrees West
PREPARED BY:
AQUAPATH CANADA LTD,
AUGUST 2002.

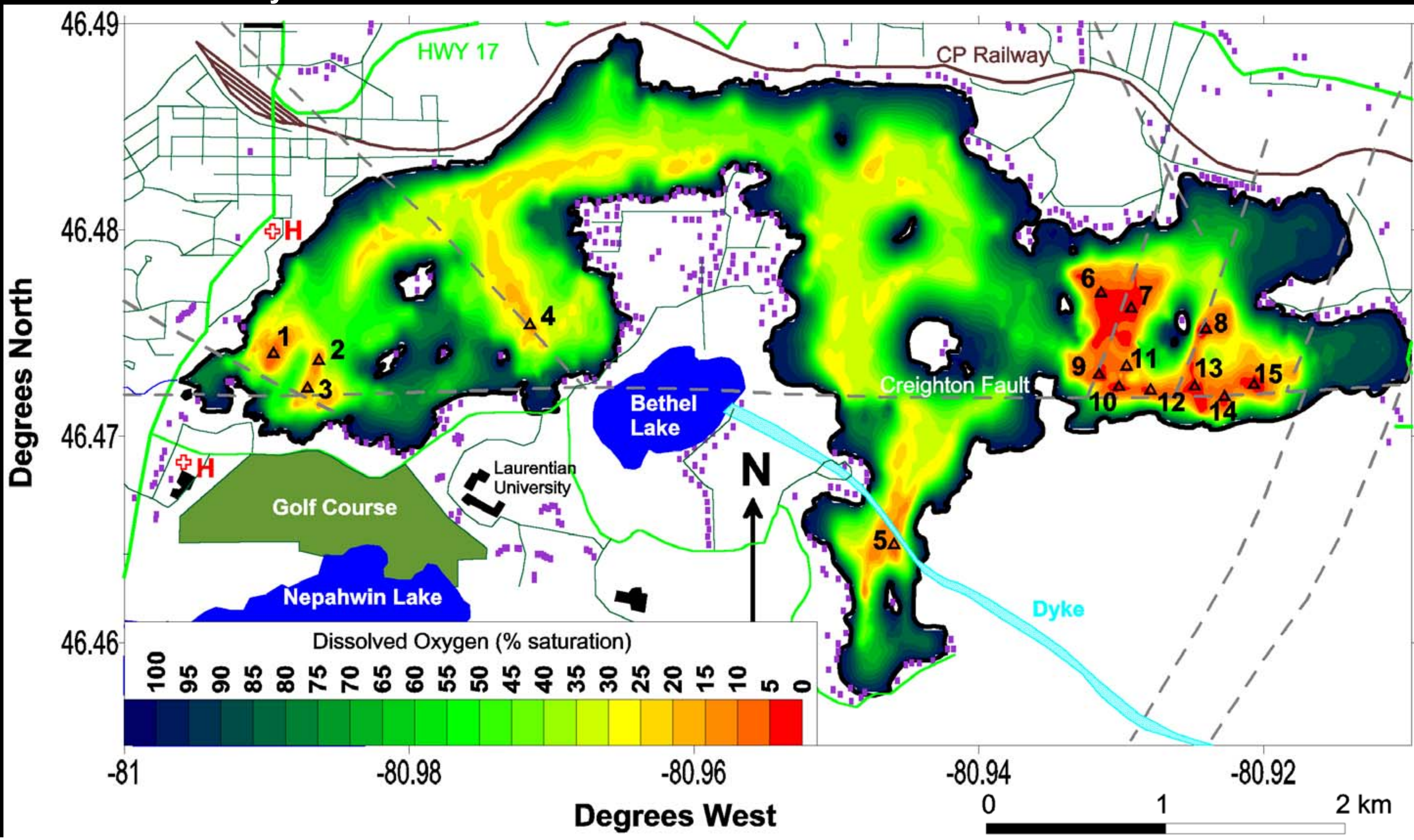
Where (and when) do we map?



Ramsey Lake
Sudbury, Ontario

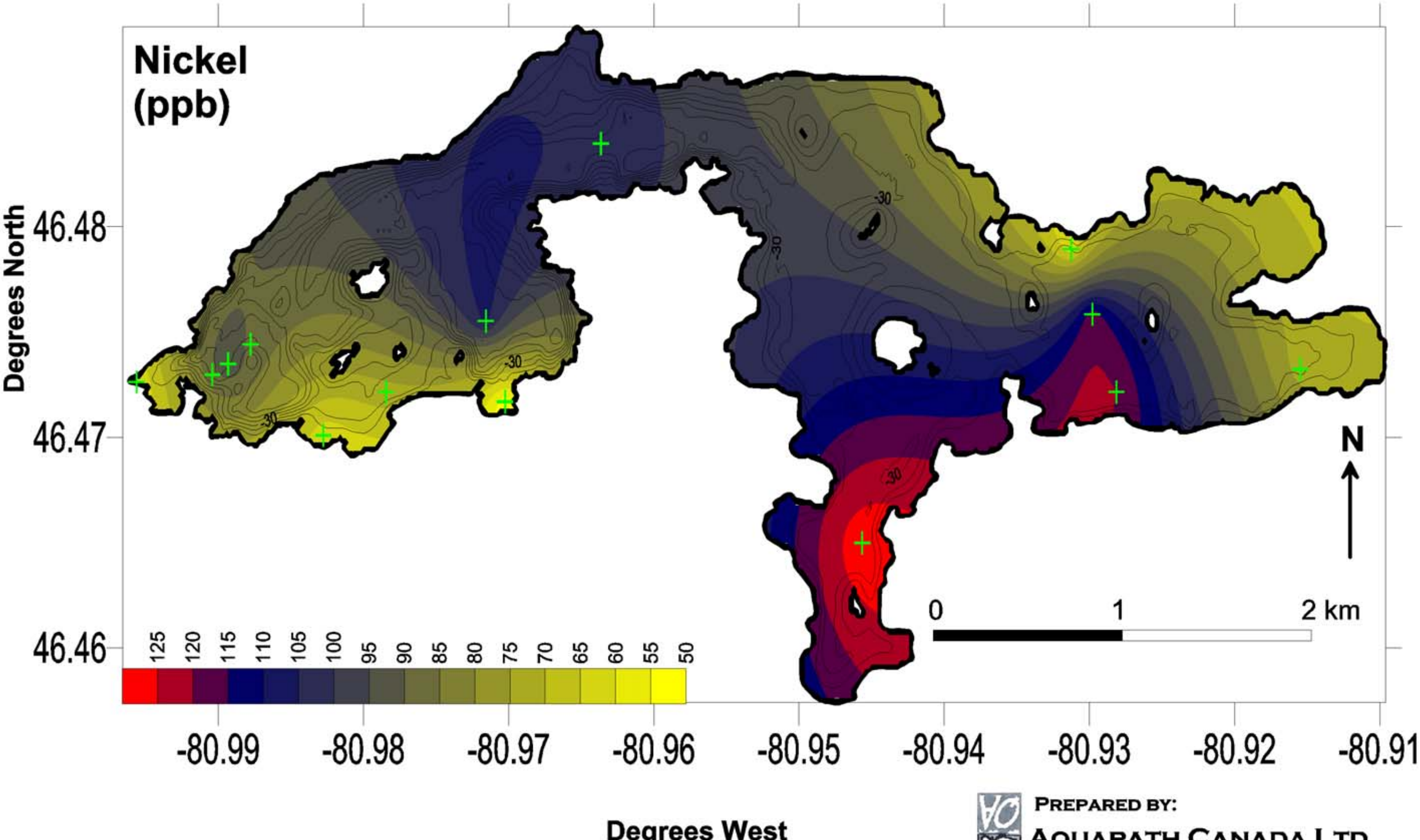
Sponsored by:
CEM,
Laurentian University

Dissolved Oxygen July 2002



Ramsey Lake

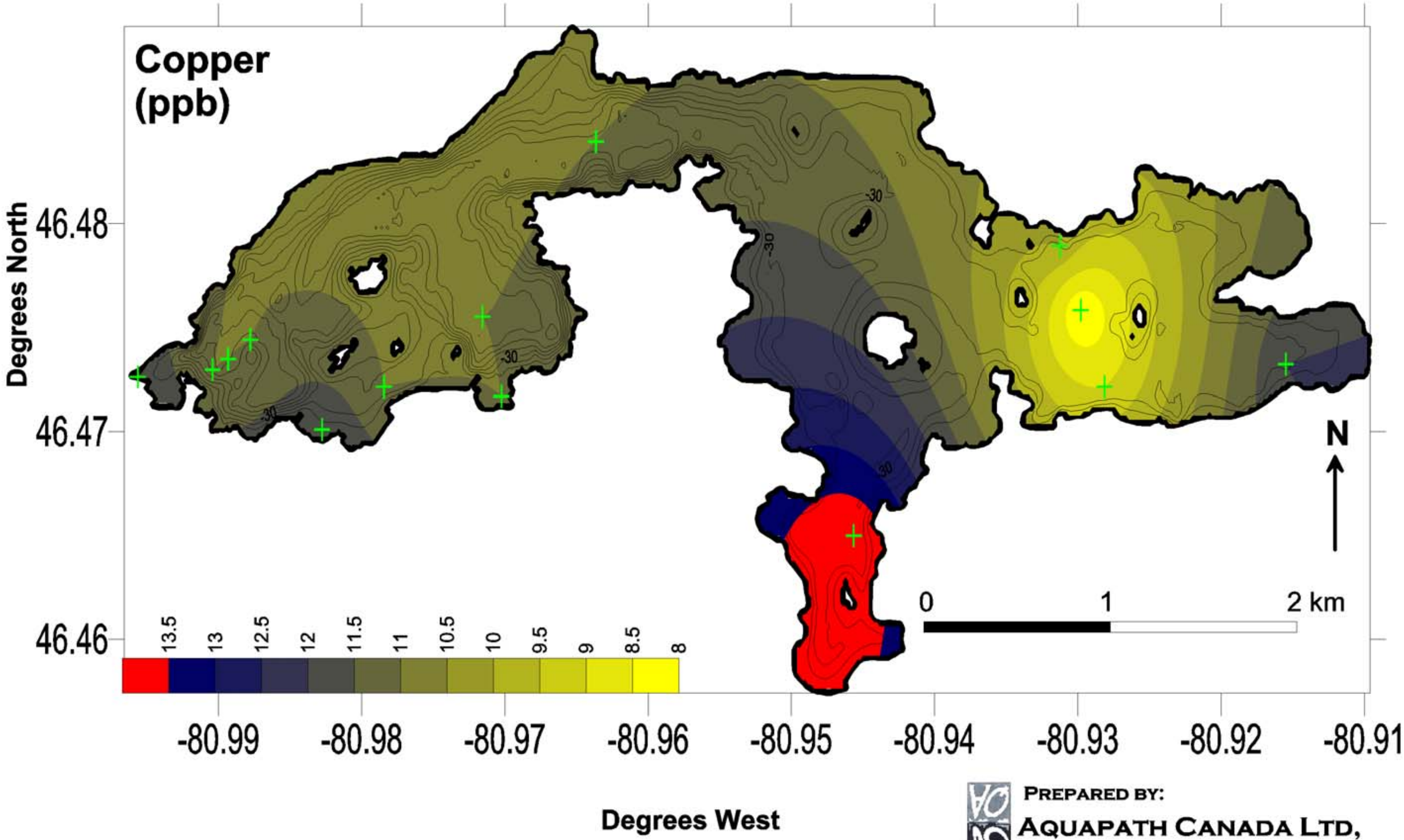
Nickel (ppb) and Depth (10ft contours)



Prepared by:
Aquapath Canada Ltd,
August 2002.

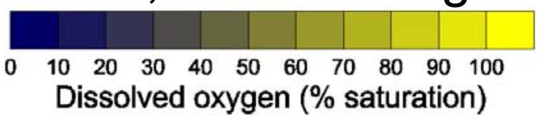
Ramsey Lake

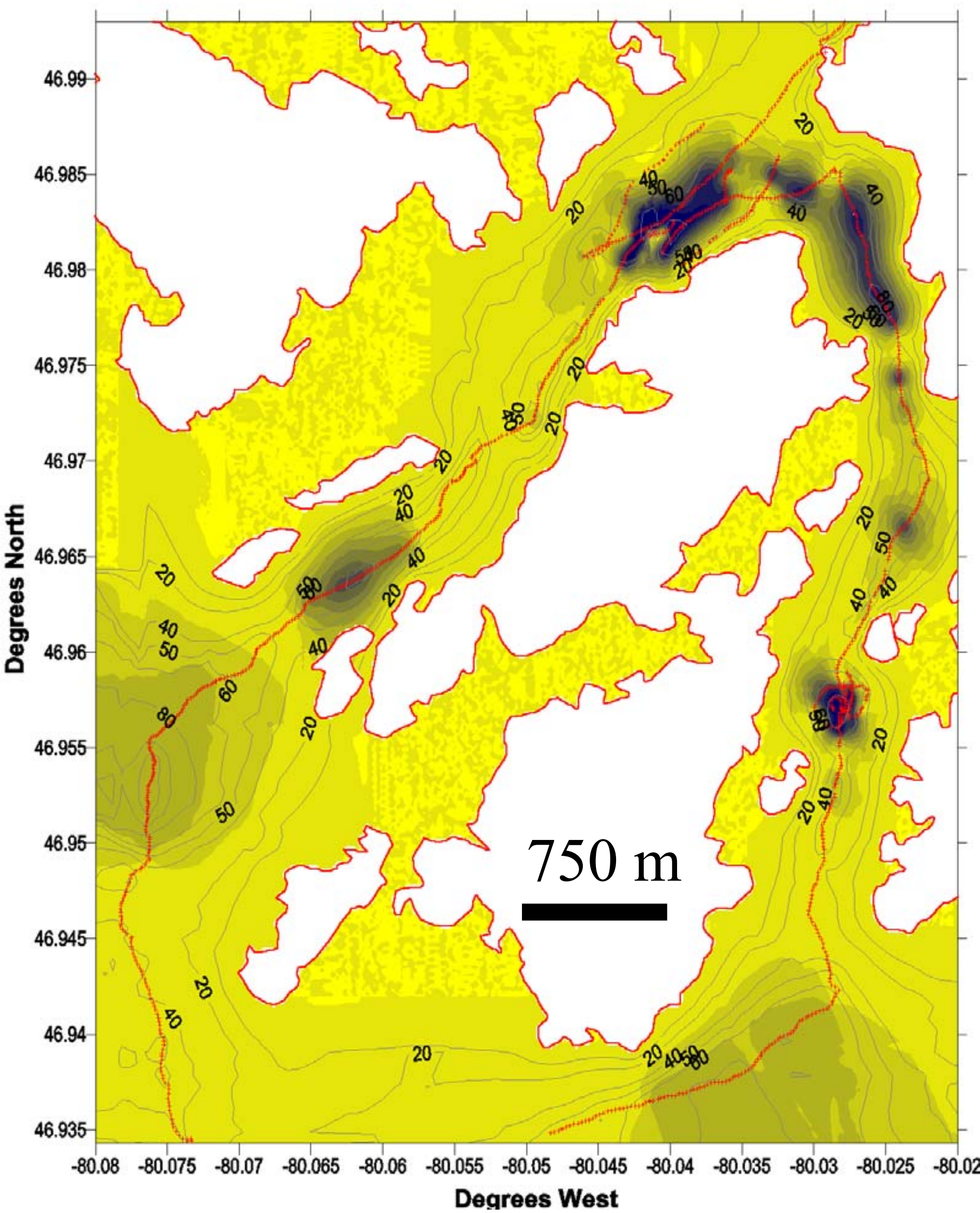
Copper (ppb) and Depth (10ft contours)

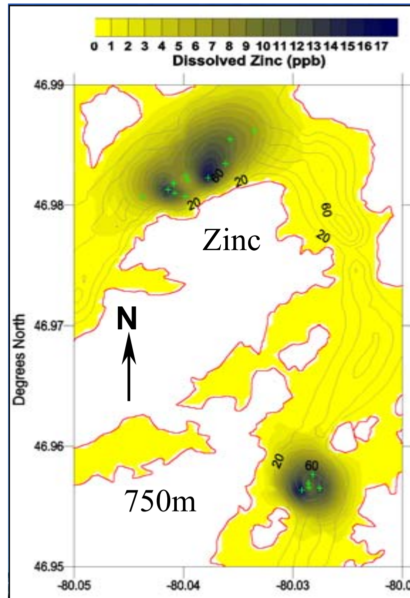


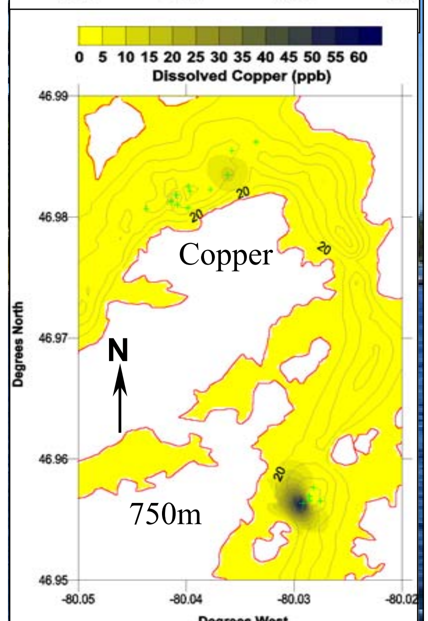
PREPARED BY:
AQUAPATH CANADA LTD,
AUGUST 2002.

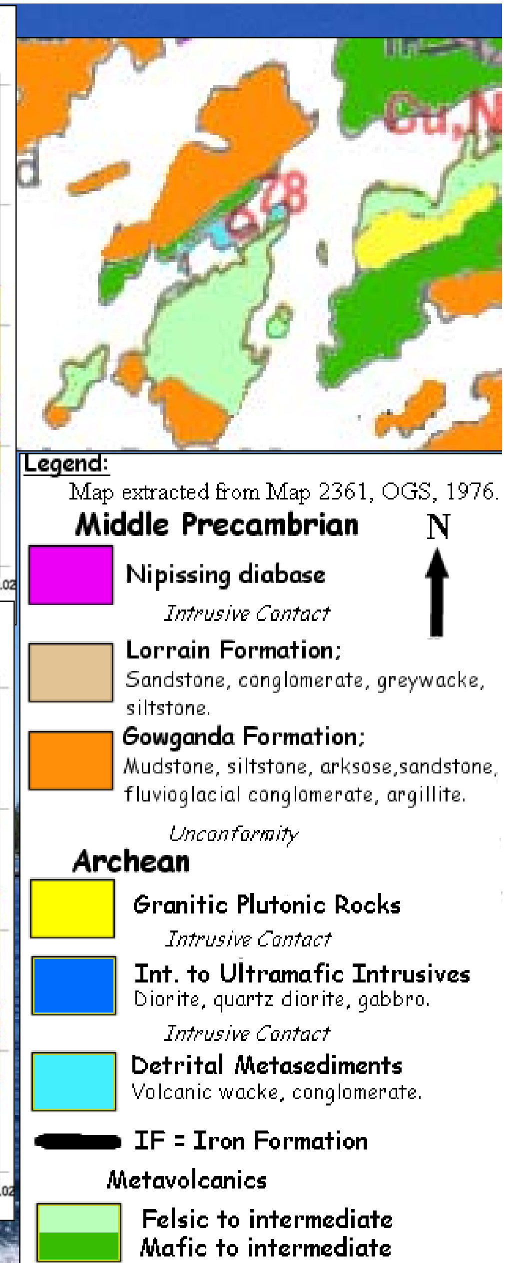
Temagami Island, Lake Temagami, Ontario





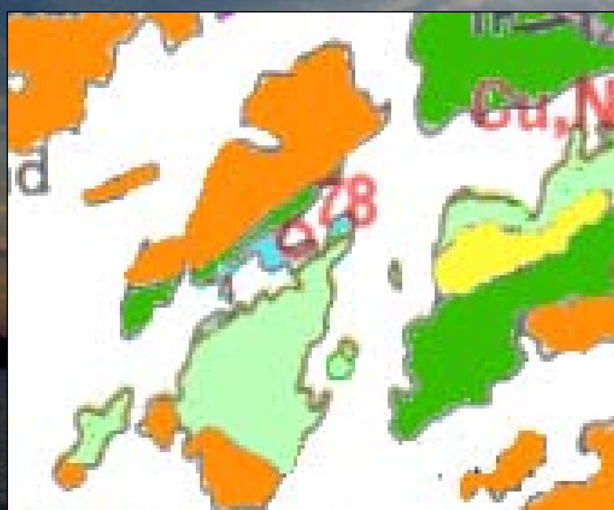




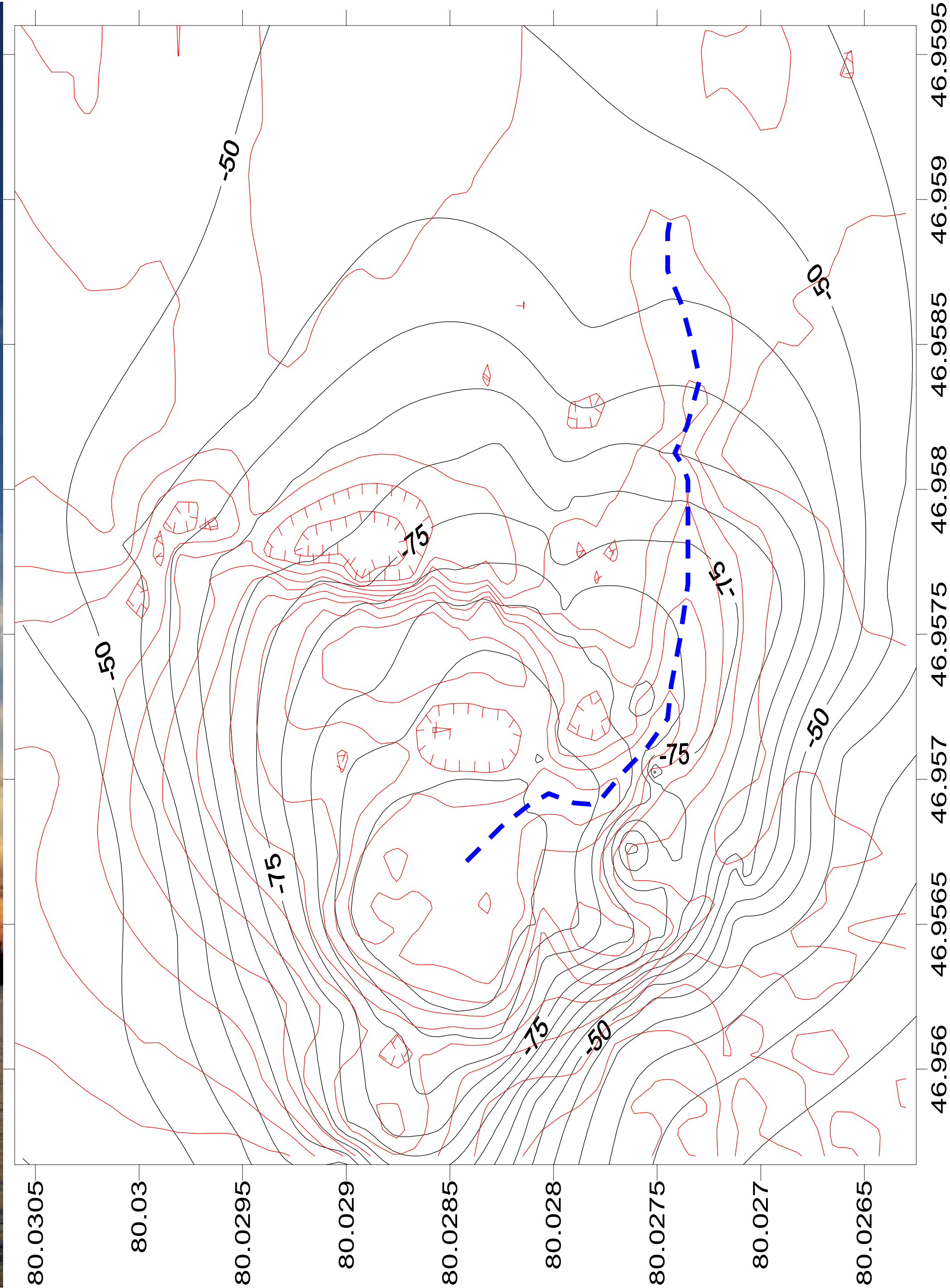


Mapping from Chloride Contours

Strike 082º
Dip 4º S



250 feet



Working Definitions

- **Oxic** = DO $\geq$ 15% saturation
- **Anoxic** = DO < 15% saturation ORP > 0 mV
- **Anaerobic** = DO < 10% saturation ORP < 0 mV

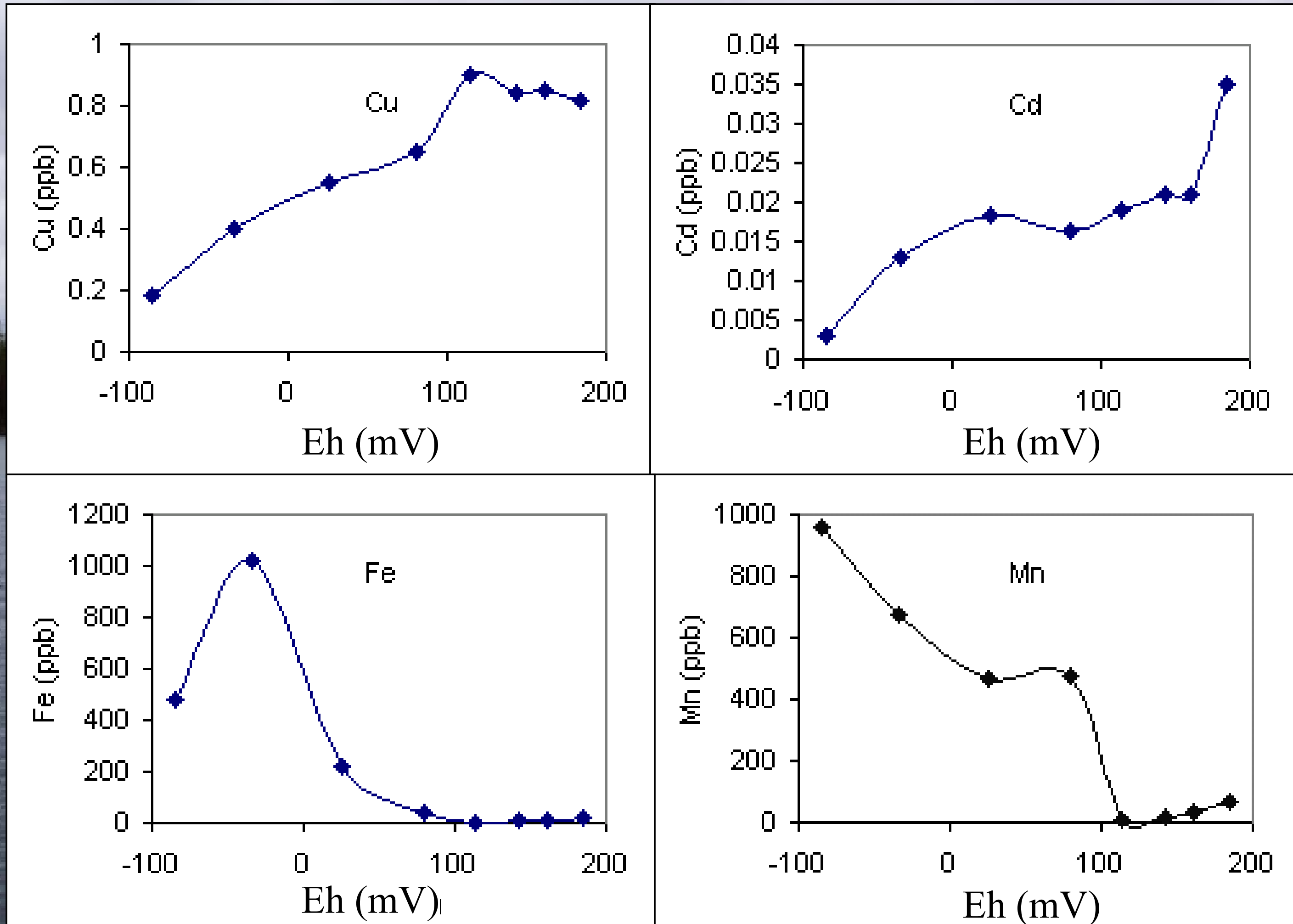
Redox potential controlled by anaerobic bacteria producing hydrogen sulfide and/or ammonia

Groundwater Characteristics

- Zero % dissolved oxygen
- Higher concentration of TDS than lake / river water (usually)
- Silica concentration $\geq$ quartz saturation
- Higher alkalinity (usually)

Distribution of metals under varying Eh conditions

Precipitation of trace metal sulfides such as copper, cadmium & zinc, in some cases depleting soluble levels of these metals below ICP-MS detection limits



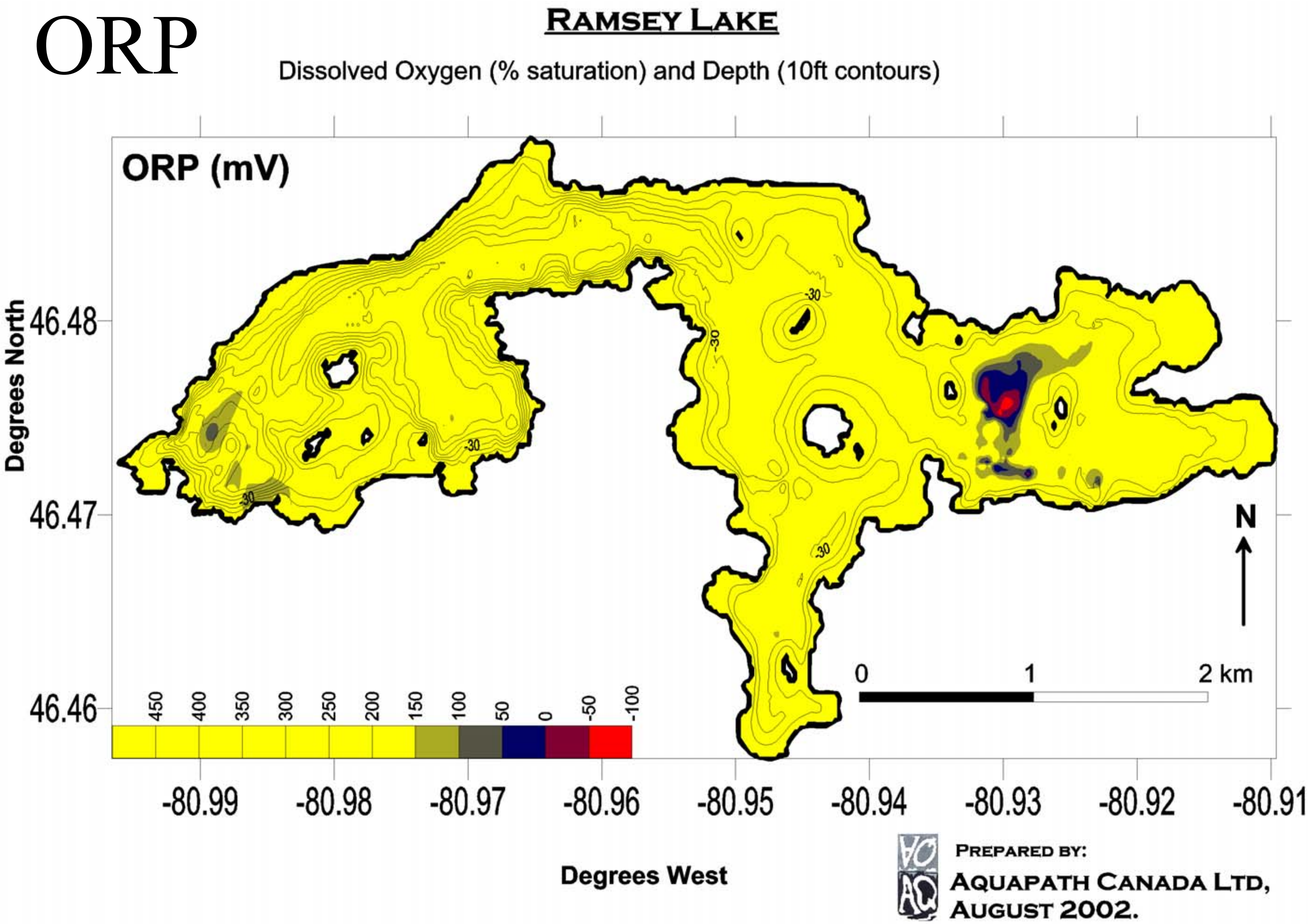
Ray (2002)
236 water samples from 1998

Eh	n
< -50	14
-50 - 0	14
0 - 59	14
60 - 100	24
101 - 130	35
131-150	47
151-170	52
> 170	36

Precipitation of iron and manganese oxides in oxic environments

MACQUARIE UNIVERSITY—SYDNEY

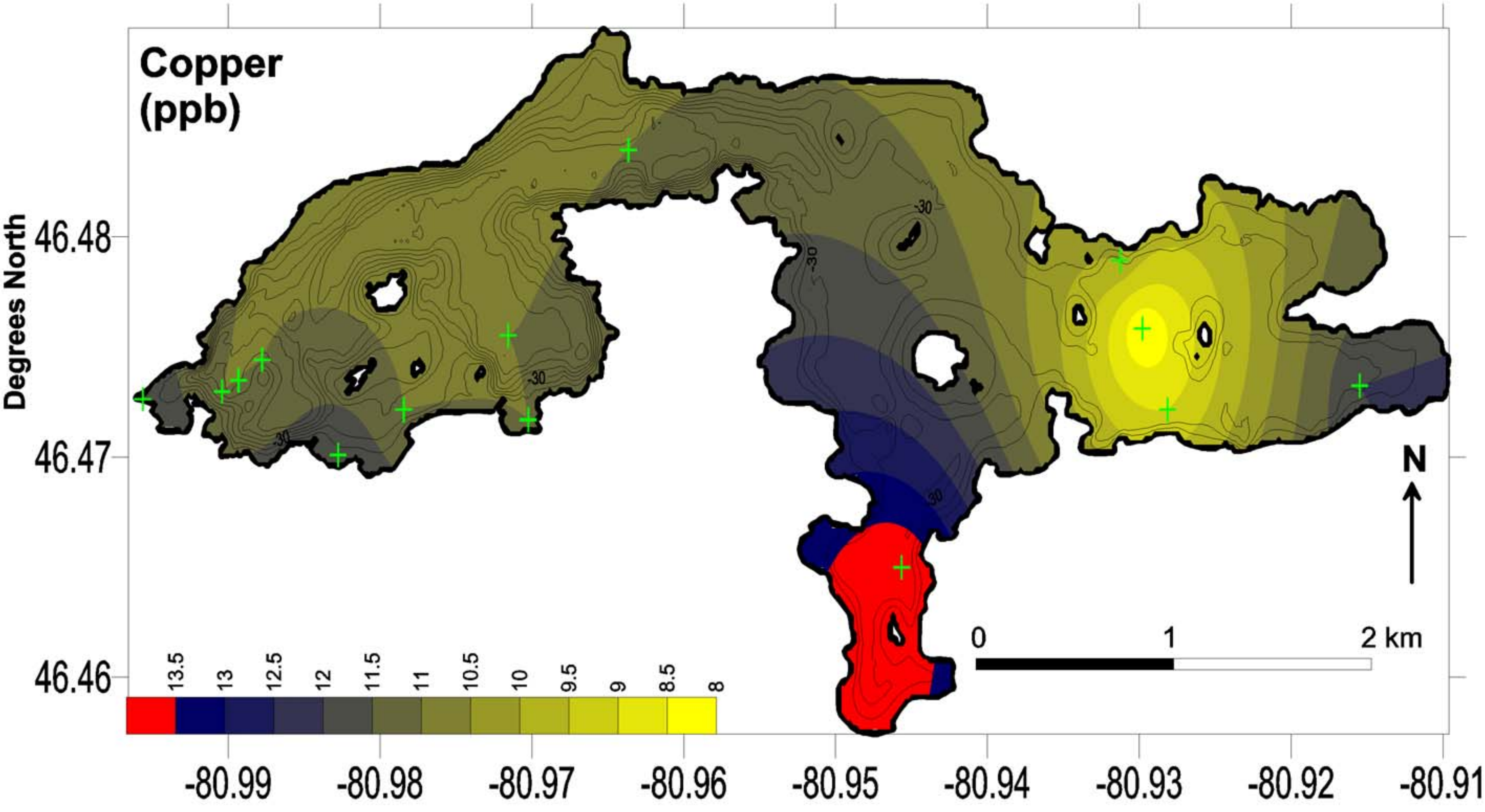
ORP



Ramsey Lake
Dissolved Oxygen (% saturation) and Depth (10ft contours)
ORP (mV)
-30
Degrees North
46.48
46.47
46.46
450
400
350
300
250
200
150
100
50
0
-50
-100
0
1
2 km
N
-80.99
-80.98
-80.97
-80.96
-80.95
-80.94
-80.93
-80.92
-80.91
Degrees West
Prepared by:
Aquapath Canada Ltd,
August 2002.

Ramsey Lake

Copper (ppb) and Depth (10ft contours)



Prepared by:
Aquapath Canada Ltd,
August 2002.

Rates of Groundwater Flow into Lower Circulation Cell

Determinations:

- Volumes of lower & upper circulation cells
- Time since homogenization
- Mean concentration of upper & lower cells
- Mean concentration of incoming groundwater

Calculations:

- Mean lake water concentration at the time of homogenization
(intermediate between present concentration of upper cell and weighted mean of both cells)
- Mass of constituent required to reach concentration in lower cell
- Litres of groundwater/second to reach this concentration

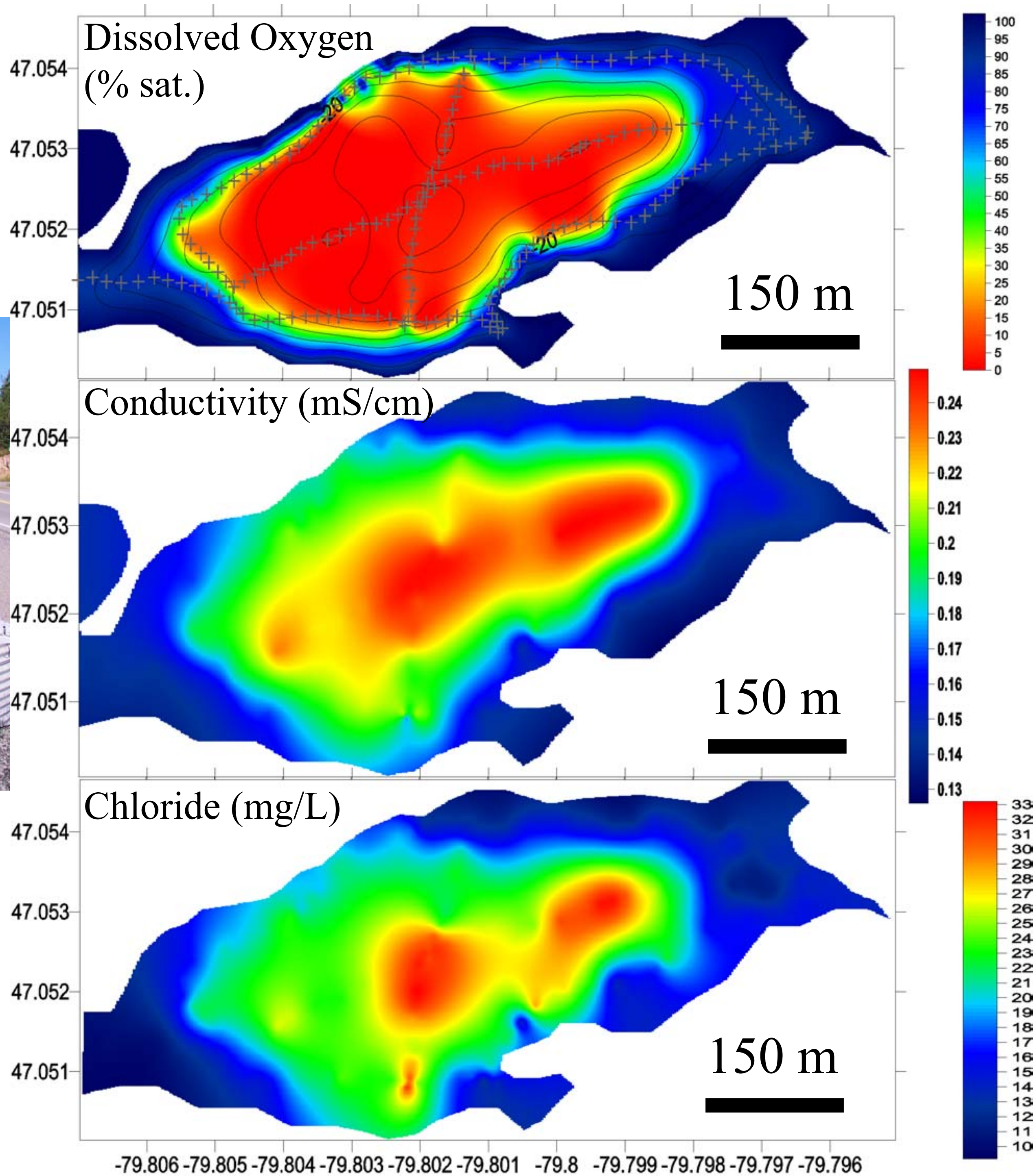
Estimation of Groundwater Flow Rate

Constituent (nearly conservative)	Groundwater Flow Rate (L/s)
Nitrate	600
Nickel	580
Fluorine	480
Phosphorus	385
TOC	270

Removal of Constituents from the Lower Circulation Cell

Constituent	% remaining since homogenization
Nitrate	100
Nickel	96
Fluorine	80
Phosphorus	64
Manganese	57
Zinc	49
TOC	45
Arsenic	14
Iron	4

Inlet Bay –
Lake Temagami



Summary

1. Aquapath methodology to prepare contour maps of lake and river bottom water in terms of specific sensor variables, such as dissolved oxygen or TDS
2. Detect, measure and sample sites of groundwater emergence
3. Use groundwater geochemistry to point to source rocks or source material
4. Use structural control or glaciofluvial conduit control to point to source material
5. Within a lake, or isolated lake basin below the thermocline, determine groundwater input flow rates and removal rates for specific constituents / contaminants

Acknowledgements

- Aquapath staff
- CEM staff – Laurentian University
- OMET and OMET Partners
    - OGS – Sudbury
    - OGS – Kirkland Lake
    - Activation Laboratories