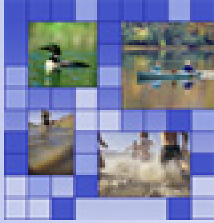

Using Critters, Clams and Fish to Define "Real" Ecological Risks at Orphaned & Abandoned Sites

The Lynn Lake case study

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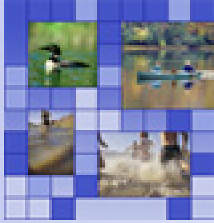
K.H. Mathers & D.E. Harron

MEND Manitoba Workshop

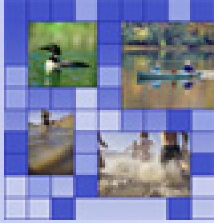
Challenges in Acidic Drainage for Operating, Closed or Abandoned Mines

June 4 2008



Presentation Outline

- Acknowledgements
- Acid-Mine Drainage
- East Tailings Management Area, Lynn Lake, MB
- Site Challenges
- Regulatory Considerations
- Choosing Practical Performance Targets
- Elements for Site-Management Plan
- Approach to Defining “Real” Ecological Risk
- River Mixing-Zone Modeling to Define Exposure Zones
- Caged Clams in Ecological Risk Assessment
- Exposure-Dose Relationship for Copper in Clam Tissue
- Environmental Risk Thresholds (ERTs)
- Compliance of Water Quality with Site-Specific ERTs
- Relationship between TEL-Based ERTs and PEL-Based ERTs
- ERTs and Modeling to drive Mitigation Engineering
- Fish & Invertebrate Studies to define “River Health”
- Conclusions



Acknowledgments

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  - Eric Blais, M.Sc.

Acid-Mine Drainage (AMD)

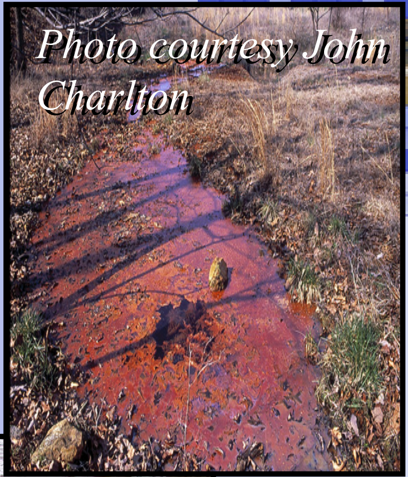


Photo courtesy John Charlton

- Acidic water generated by weathering of iron & sulphur-containing minerals that drains out of aboveground or underground coal & metal mines
- Impacts stream & river ecosystems by increasing acidity, depleting oxygen, & releasing heavy metals
- Can occur during mining operations or long after mine has been abandoned
- Over 135 AMD sites across Canada, with ~1.8 billion tonnes acidic tailings & 700 million tonnes acid waste rock raising serious concerns for water quality


Photo courtesy Don Harron

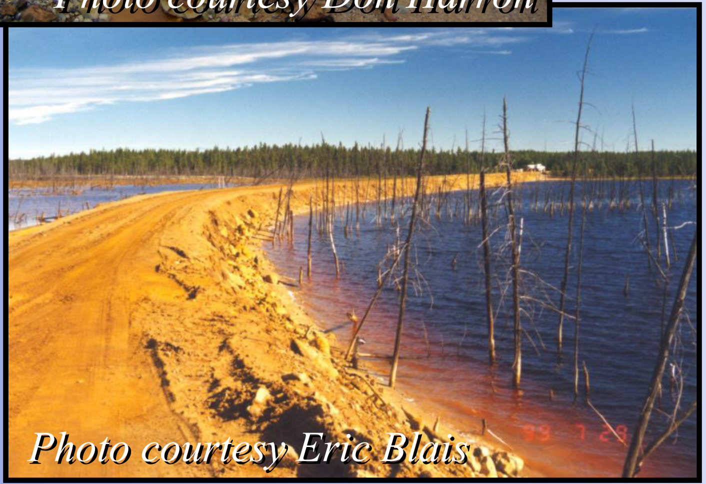


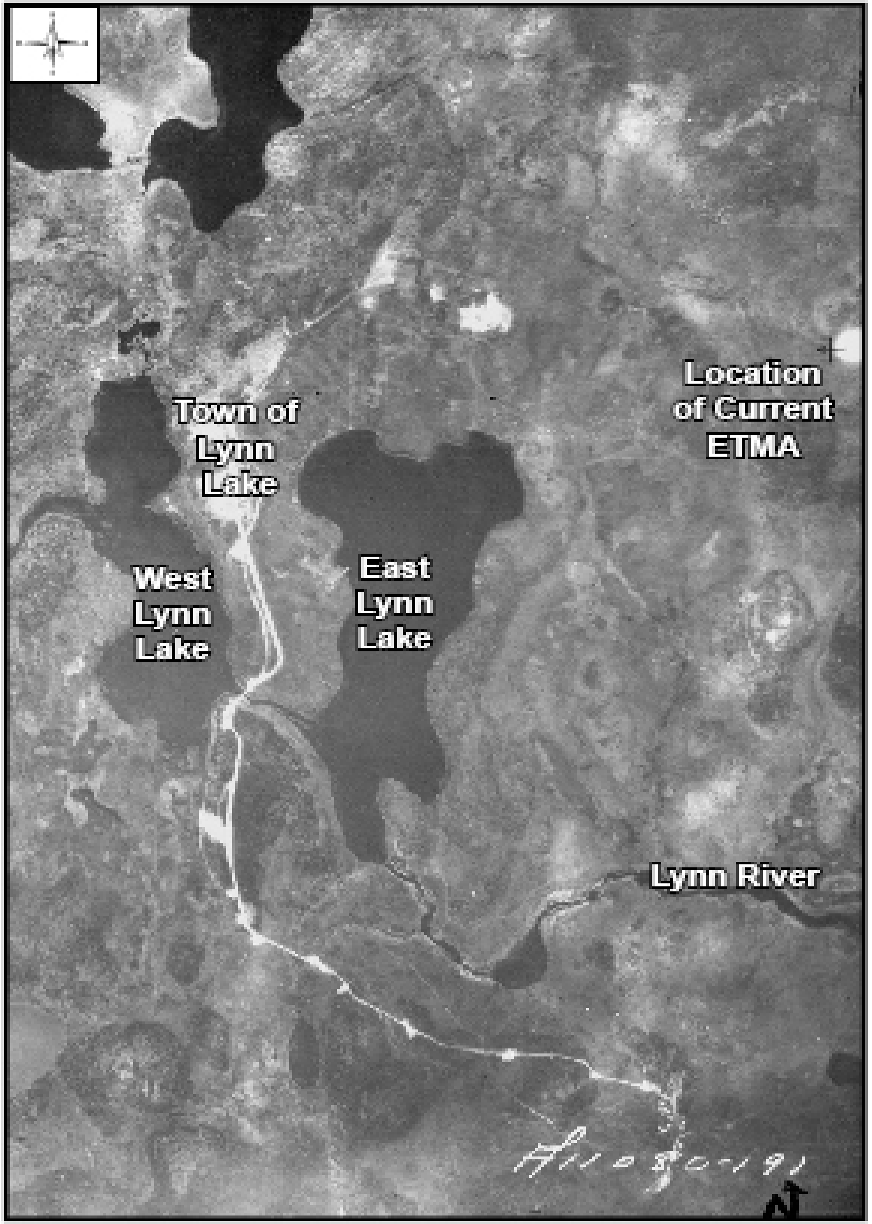
Photo courtesy Eric Blais

East Tailings Management Area (ETMA), Lynn Lake, MB

- Mining/milling operations from 1953 - 1976
- ~20 M tonnes of tailings deposited over 250 ha ETMA; content dominated by residual sulphide-bearing minerals“
- “End of the Road/dark side of the moon”


Aerial Photo of ETMA, looking SE

Solutions for a Sustainable Environment
TetrES CONSULTANTS INC.



Lynn Lake - 1948

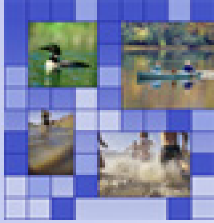
Lynn Lake - 1978

TetrES CONSULTANTS INC.

Aerial Photography of the Lynn Lake Area Illustrating Infilling of East Lynn Lake by WTMA Mining Activities

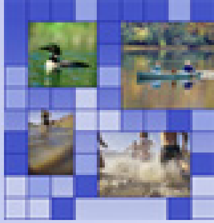
Site Challenges

- 1000+ years of heavy metal leachate predicted
- Runoff pH <4
- Immediate proximity to Lynn River
- Runoff copper & nickel in mg/L range
- Some groundwater nickel concentrations exceeding 1000 mg/L
- No mining revenues to offset remediation costs
- Sparse local financial, material & labour resources
  - Limited seasonal air access; rail services rare
  - No tax base
- Requirement to protect opportunities for future tailings reprocessing or new developments



Regulatory Considerations

- **The ETMA is no longer ‘Abandoned’**
  - Viridian & the Province of Manitoba have agreement to cost share site management/remediation
- **Notwithstanding absence of active mine, Viridian & MMB may bear exposure under *Fisheries Act* Metal Mining Effluent Regulation (“MMER”)**
- **Environment Canada increasingly concerned about historic provincial AMD sites**
  - Lack of proactivity can result in imposed solution
- **MMB notified formally about federal concern in 2002**
  - Joint Viridian/MMB actions since 2002 to mitigate historic AMD impacts



Choosing Practical Performance Targets

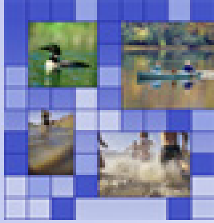
- **In a ‘dark side of the moon’ circumstance like Lynn Lake, choice is between:**
  - Attempting to consistently meet general water-quality guidelines (c/w ‘safety factors’)

    or
  - Seeking to meet intentions of *Fisheries Act* by reducing measured ecological risk

- **Viridian/MMB adopted strategic approach to site management intended to protect aquatic biota and habitats, to enhance current state of fisheries**
  - Adopted site-specific risk-based approach in 2002
  - Reflected in Site-Management Plan signed in 2007

Regulatory Considerations cont'd

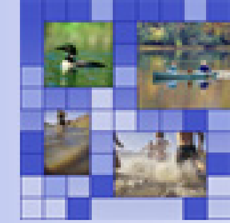
- **Tetr*ES* engaged since 2002 to:**
  - Identify aquatic biota at risk & general level of health of Lynn River
  - Identify extent of chemical exposure risk
  - Identify & evaluate extent of impacts to key biota
  - Determine thresholds for impacts on key biota
  - Determine site-specific performance targets for engineered mitigation works
- **Site-Management Plan is explicitly risk-based**
  - Seeks to promote healthy fishery by mitigating measurable risks to aquatic health



Elements of Site-Management Plan

- **Surface treatment**
  - Surface runoff & river-mixing simulations, & data on site-specific ecological impacts, identified best locations for capturing/treating contaminant loads
  - Simulations identified possible performance targets for site-specific surface-treatment options
- **Subsurface treatment**
  - Focused groundwater modeling supported runoff modeling, which simulated loads to receiving waters with & without subsurface-treatment options
  - Column trials used to guide siting trial Permeable Reactive Barrier(s) ("PRBs")

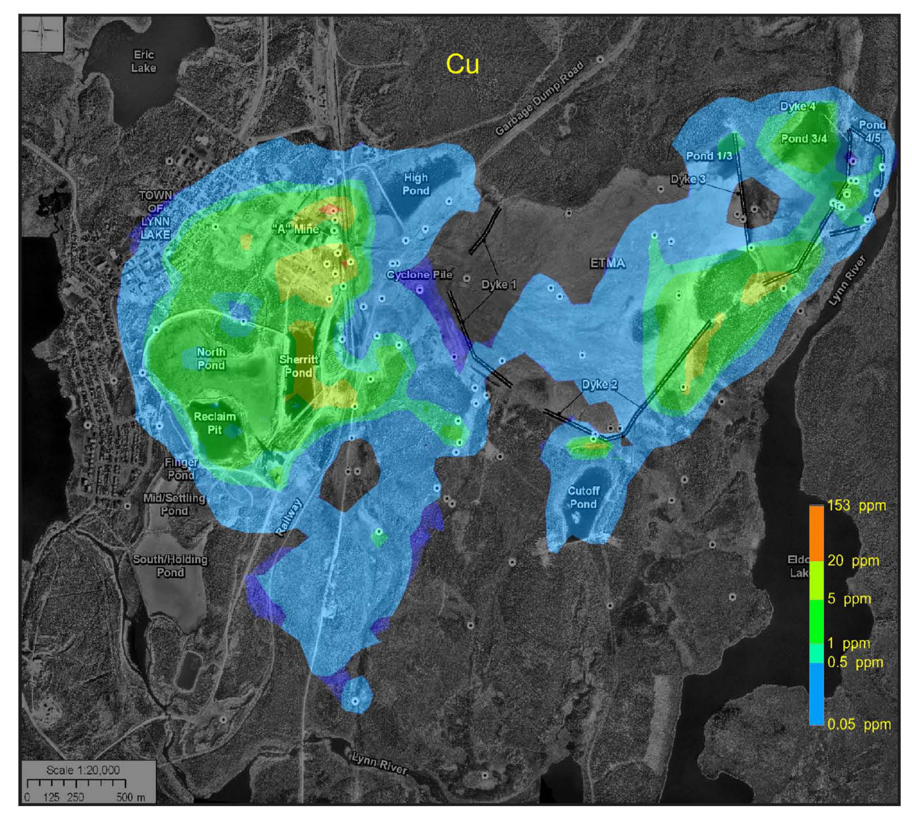
Approach to Defining "Real" Ecological Risk



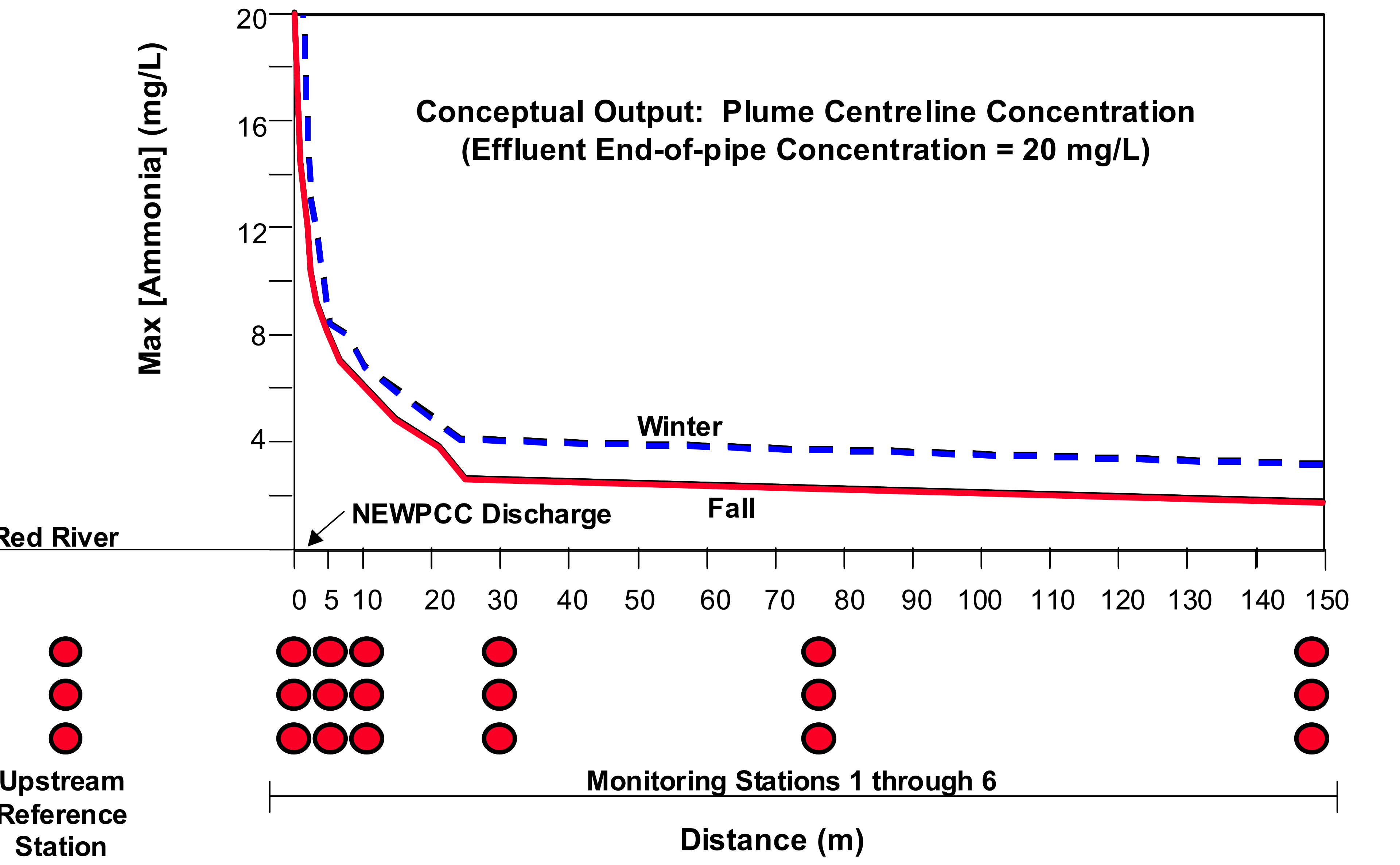
- **Define "exposure zones" & areas of potential impacts in receiving water course(s)**
  - Implement method that defines type, spatial & temporal distribution of ecological impacts
- **Prioritize range of impact types identified & their distributions (i.e., define which impacts matter most to eliminate or to significantly reduce)**
- **Define extent of "biological health" in local reach Lynn River**

River Mixing-Zone Modeling to Define Exposure Zones

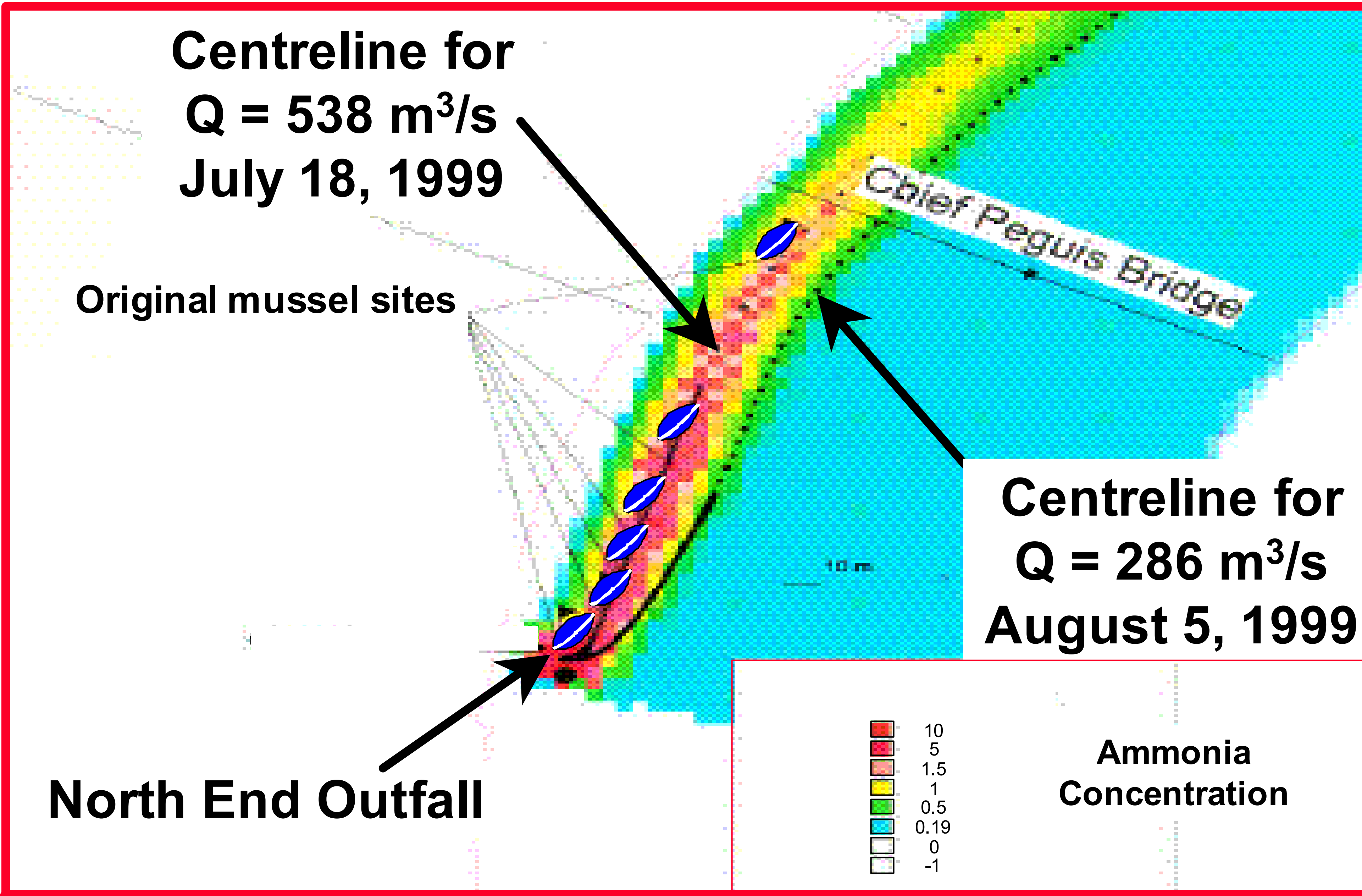
- **Mixing-zone model linked to groundwater model; used to estimate dispersal of pollutant loads from specific locations**
  - Contaminant-transport groundwater model output provides "source" terms to mixing-zone modeling
- **Mixing-zone modeling helped identify locations for *in situ* bioassays to define "real" ecological impacts**

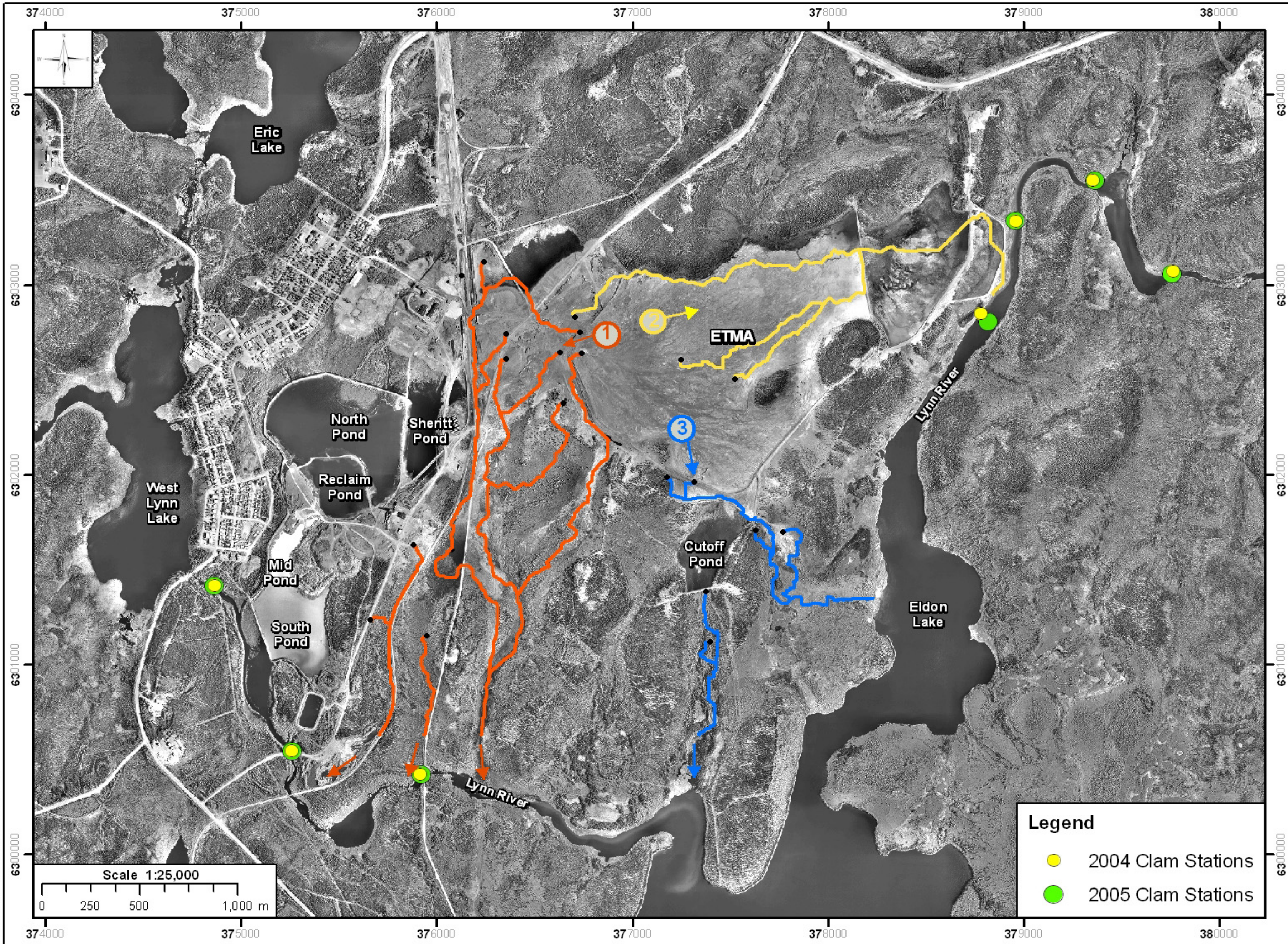


Tetr*ES* modeling identified caged mussel positions along a decreasing gradient of ammonia concentrations



Tetr*ES* modeling facilitated interpretation of exposure & effects data to account for temporal & spatial variability

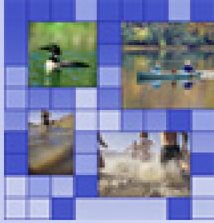


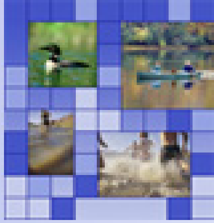


G:\GIS\0495\10\Surface_Runoff_Clams.mxd

Caged Clams in Ecological Risk Assessment

- **Key tool is caged-mussel study**
  - True measure of exposure
  - Sensitive measurement of effects
  - Accepted by ASTM, USEPA, EC (e.g., EEM)
- **Caged-mussel studies are "data-rich"; substantial statistical power creates results credible to regulators**
  - Both lethal (acute) & sublethal (chronic) effects can be identified; allows range of performance targets to be credibly identified
- **Two deployment campaigns in 2004 ("normal" year) & 2005 (record "wet" year) conditions**

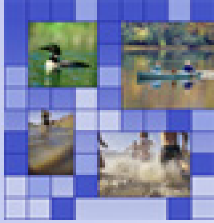




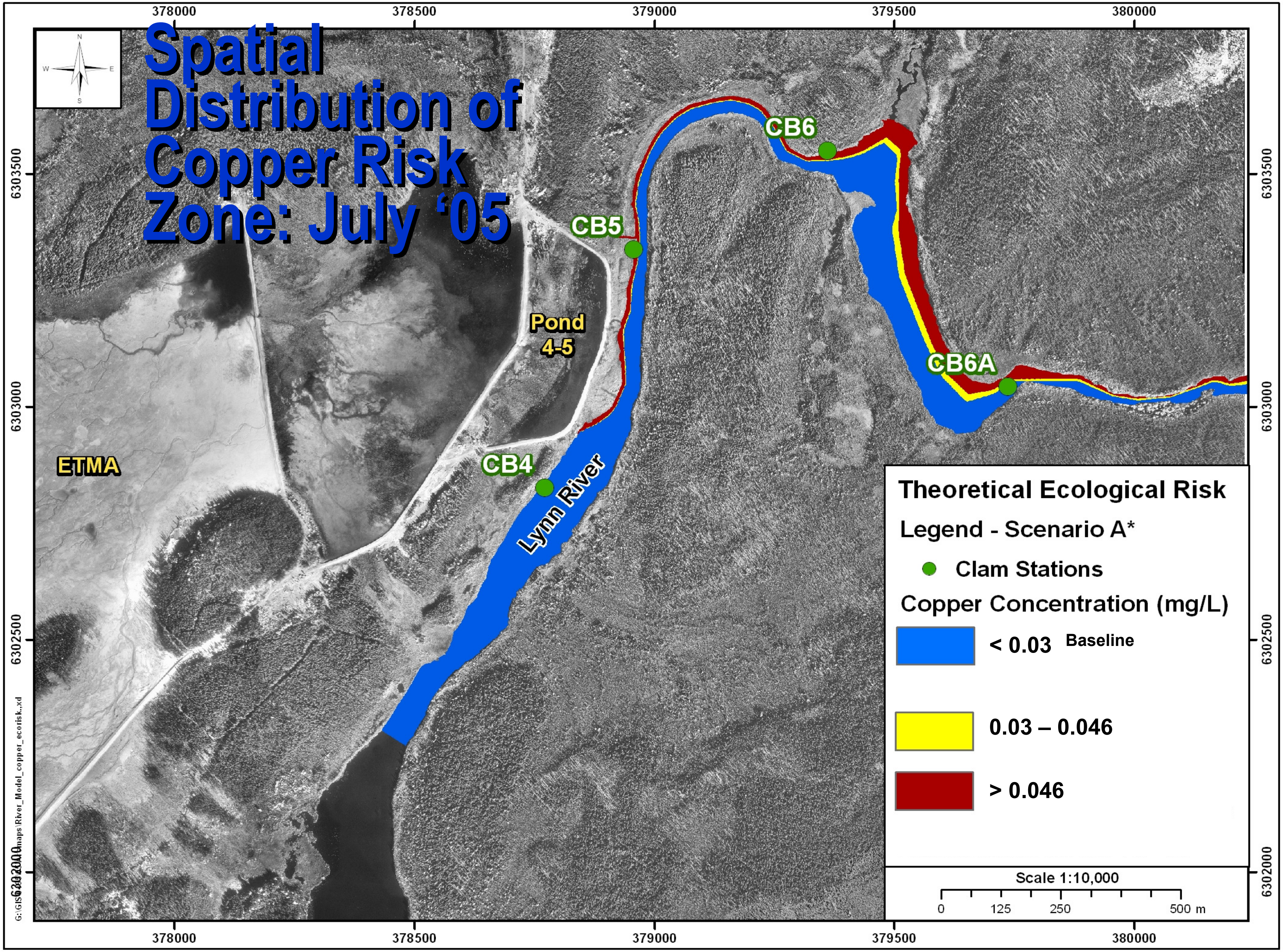
Why Caged Clams??

- **Best combination of longevity, complexity, immobility, & ability to concentrate chemicals in their tissues; e.g.**
  - Don’t move (fish do)
  - Longer-lived than most fish
  - Accumulate metals from filtering water
  - Most cost-effective type of individual end-point measurement (more bang for buck)
  - Meaningful ecological niche
  - Only biological exposure system that is practical, fully replicated & statistically robust

Key Findings from *in-situ* Bioassays

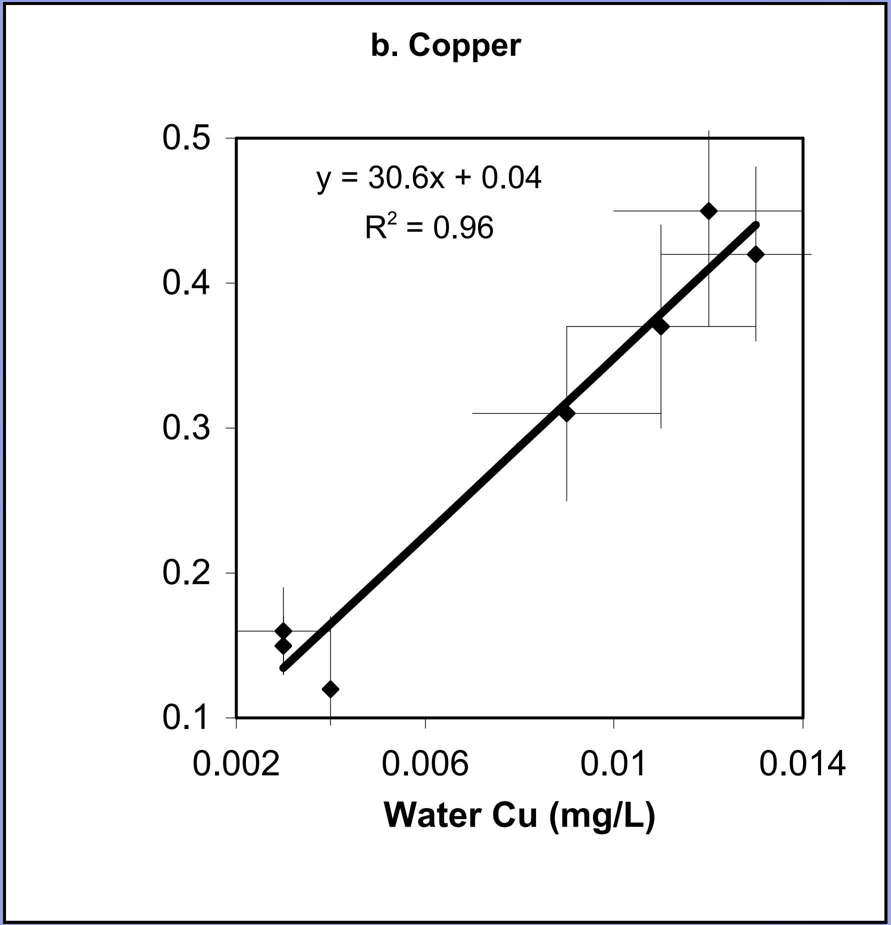


- **Impacts confined almost exclusively to sublethal endpoints**
  - Almost no lethality
  - No measurable inhibition of growth
- **Impacts confined to area downstream of ETMA**
- **Metal whose river concentrations are closest to reported injury thresholds was copper (but no dose-response data for Ni, Zn or Al in mussels)**
- **Combination of mixing-zone modeling, caged-clam exposures, tissue-chemistry analyses & determination of free-ion ratios resulted in ability to calculate "Environmental Risk Thresholds"**
  - Derivation of values for nickel, zinc & aluminum based on calculation for copper using Biotic Ligand Model



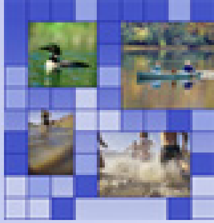
Spatial Distribution of Copper Risk Zone: July '05
378000
378500
379000
379500
380000
6303500
6303000
6302500
6302000
N
S
W
E
CB6
CB5
CB6A
CB4
Pond 4-5
ETMA
Lynn River
Theoretical Ecological Risk
Legend - Scenario A*
Clam Stations
Copper Concentration (mg/L)
< 0.03 Baseline
0.03 – 0.046
> 0.046
Scale 1:10,000
0
125
250
500 m

Exposure-Dose Relationship for Copper in Clam Tissue



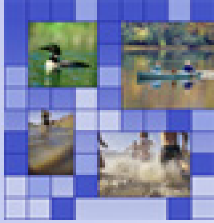
- **Significant linear relationship between environmental exposure (4-yr dataset) & dose (combined 2-yr dataset)**
- **Threshold Effect Level (TEL) for internal copper (~30 mg/kg dw) reached at river-dissolved concentration of 0.014 mg/L**
  - ERT of 14 ug/L is ~50% more stringent than 0.03 mg/L value calculated from 1-yr dataset
- **Copper ERT (14 ug/L) yields a free-ion Cu concentration of 0.85 ug/L**

Calculated Environmental Risk Thresholds (ERTs)



Metal	Log Kgill[1]	Relative Toxicity[2]	Free ion ratio[3]	Environmental Risk Threshold[4]	Toxic	Site-Specific MWQSOG (mg/L diss.)
Cu	7.4-8.0	1	0.06	**0.014**	Y/N	0.001 to 0.008
Al	5.9-6.5	10-70	0.0002	30-300	N	0.005 to 0.100
Ni	4.0-5.0	100-3000	0.7	0.2-4	Y/N	0.009 to 0.049
Zn	5.3-5.6	40-200	0.6	0.05-0.3	Y/N	0.019 to 0.111
Cd	7.0-8.6	0.1-10	0.7	0.0001-0.009	N	

- **Site-specific copper ERT calculated directly from dose-response dataset**
- **Log Kgill based on biotic ligand model relationships for standard test-fish species**
- **Relative toxicity calculated from LogKgill linear relationship to toxicity**
- **Site-specific ERT for aluminum, nickel & zinc calculated as; [Cu_{free}] x Relative Toxicity/Free Ion Ratio**
  - No MWQSOG calculated for Cd, as generally < detection limit



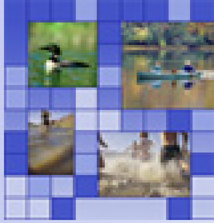
Calculated ERTs cont'd

Ratio between ERT and MWQ based on TEL and PEL for Clams

Metal	TEL*	PEL*
Copper (Cu)	2 to 14	4 to 40
Aluminium (Al)	300 to 6×10^4	750 to 2×10^5
Aluminium (Al) pH 5.0	2 to 400	5 to 1200
Nickel (Ni)	4 to 400	10 to 1300
Zinc (Zn)	0.5 to 16	1 to 50

*TEL refers to toxicity estimates that are based on the Threshold Effects Level for clams. PEL refers to toxicity estimates that are based on the Probable Effects Level for clams.

- **Relationship of ERTs to MWQSOGs generally >1 (i.e., regulatory values not appropriate for guiding practical remediation at this site; overprotective)**
- **Exception to this pattern is lower ERT limit for Zn (which is slightly < than upper MWQSOG)**

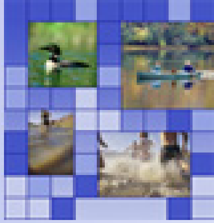


Compliance of Water Quality with Site-Specific ERTs

Metal	ERT	Mean	Median	75%	High Value
Al*	30	+	+	+	+
	300	+	+	+	+
Cu	0.014	+	+	+	-
Ni	0.2	-	+	+	-
	4	+	+	+	+
Zn	0.05	-	-	-	-
	3	+	+	+	+

- **Aluminum values uncertain due to considerable extrapolation required for calculation**
- **Copper concentrations exceeded the ERT at the highest values observed**
- **Nickel concentrations were intermittently above the lower limit ERT, but not the upper limit**
- **Zinc concentrations were consistently above the lower ERT, but did not exceed the upper ERT limit**

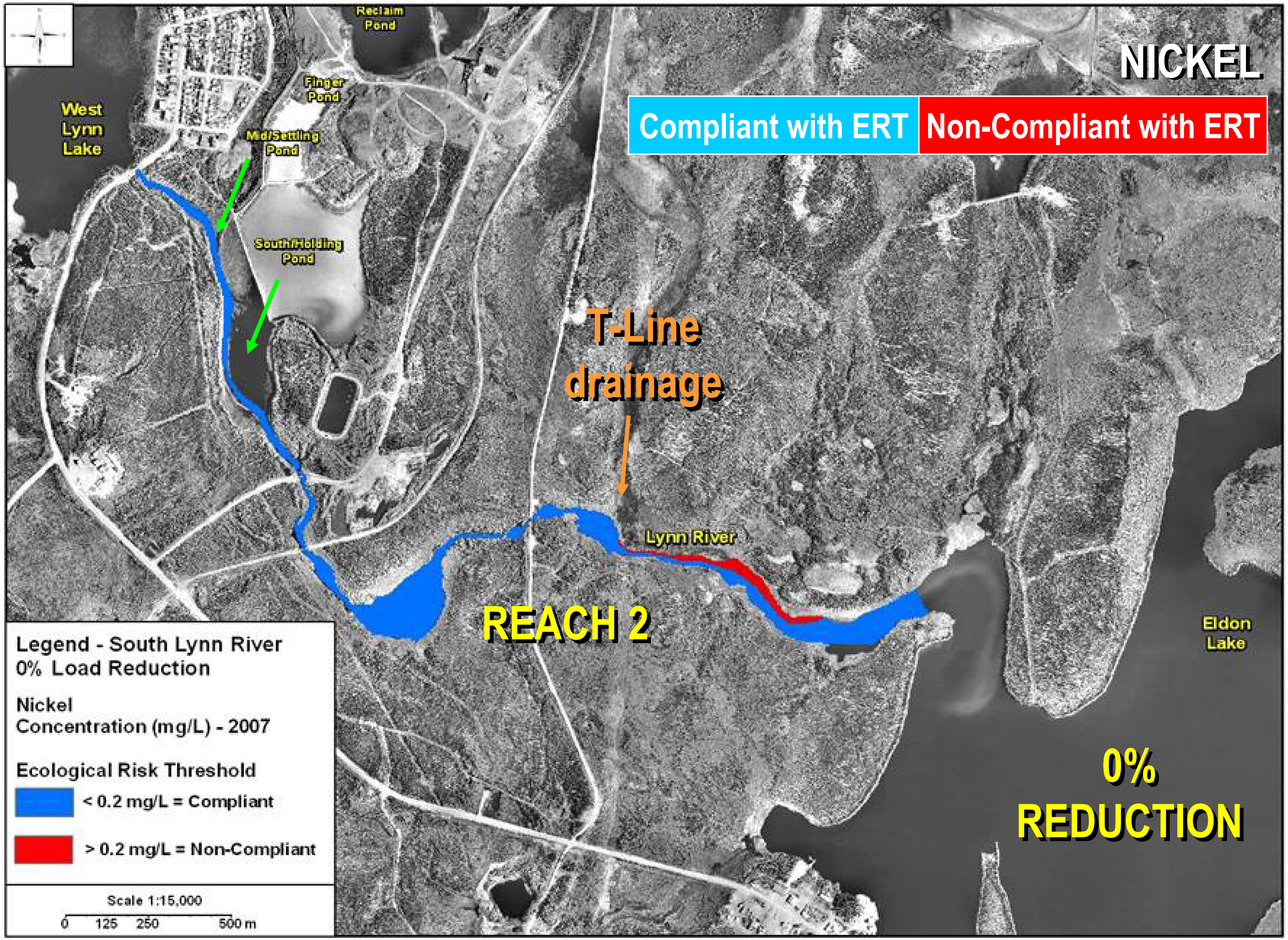
RELATIONSHIP BETWEEN TEL-BASED ERTs & PEL-BASED ERTs

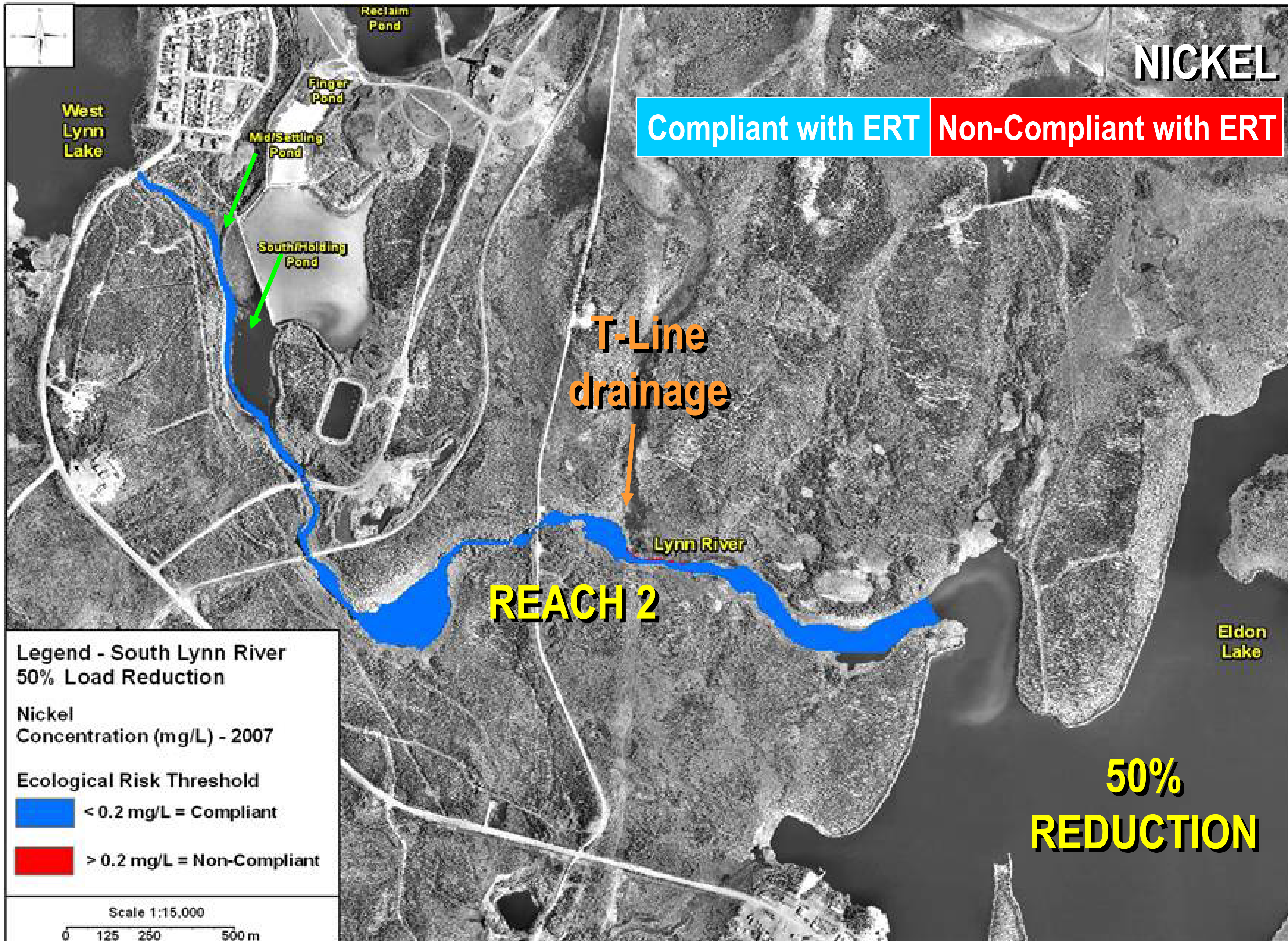


- TEL is level of copper tissue burden at which effects <u>begin</u> to be expressed
- Literature suggests that Probable Effects Level (PEL) for copper 3x higher than TEL
- Basing calculation of ERTs on TELs, rather than PELs, is very conservative (comparable to using LOEC instead of EC50)
- Using TEL-based ERTs as input to engineering design means that engineered mitigations could be over-designed (i.e. highly protective of river biota)

USING RIVER MODELING & ERTs TO SUPPORT MITIGATION ENGINEERING

- ERTs defined ‘performance targets’ for engineering solutions
- Mixing-zone modeling able to simulate different degrees of performance needed to mitigate real ecological impacts
- Extent of necessary reduction in river ‘impact zones’ now known
- TEL-based ERTs, and impact-zone-reduction targets, now key input to engineering design processes able to protect river biota


NICKEL
Compliant with ERT
Non-Compliant with ERT
Reclaim Pond
Finger Pond
West Lynn Lake
Mid/Settling Pond
South/Holding Pond
T-Line drainage
Lynn River
REACH 2
Eldon Lake
0% REDUCTION
Legend - South Lynn River
0% Load Reduction
Nickel
Concentration (mg/L) - 2007
Ecological Risk Threshold
< 0.2 mg/L = Compliant
> 0.2 mg/L = Non-Compliant
Scale 1:15,000
0 125 250 500 m


NICKEL
Compliant with ERT
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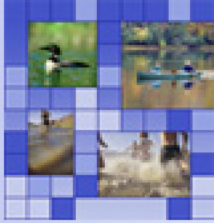
Finger Pond
West Lynn Lake
Mid/Settling Pond
South/Holding Pond
T-Line drainage
Lynn River
REACH 2
Eldon Lake
50% REDUCTION
Legend - South Lynn River
50% Load Reduction
Nickel
Concentration (mg/L) - 2007
Ecological Risk Threshold
< 0.2 mg/L = Compliant
> 0.2 mg/L = Non-Compliant
Scale 1:15,000
0 125 250 500 m

Load-Reduction Estimates calculated from ERTs & Mixing-Zone Modeling

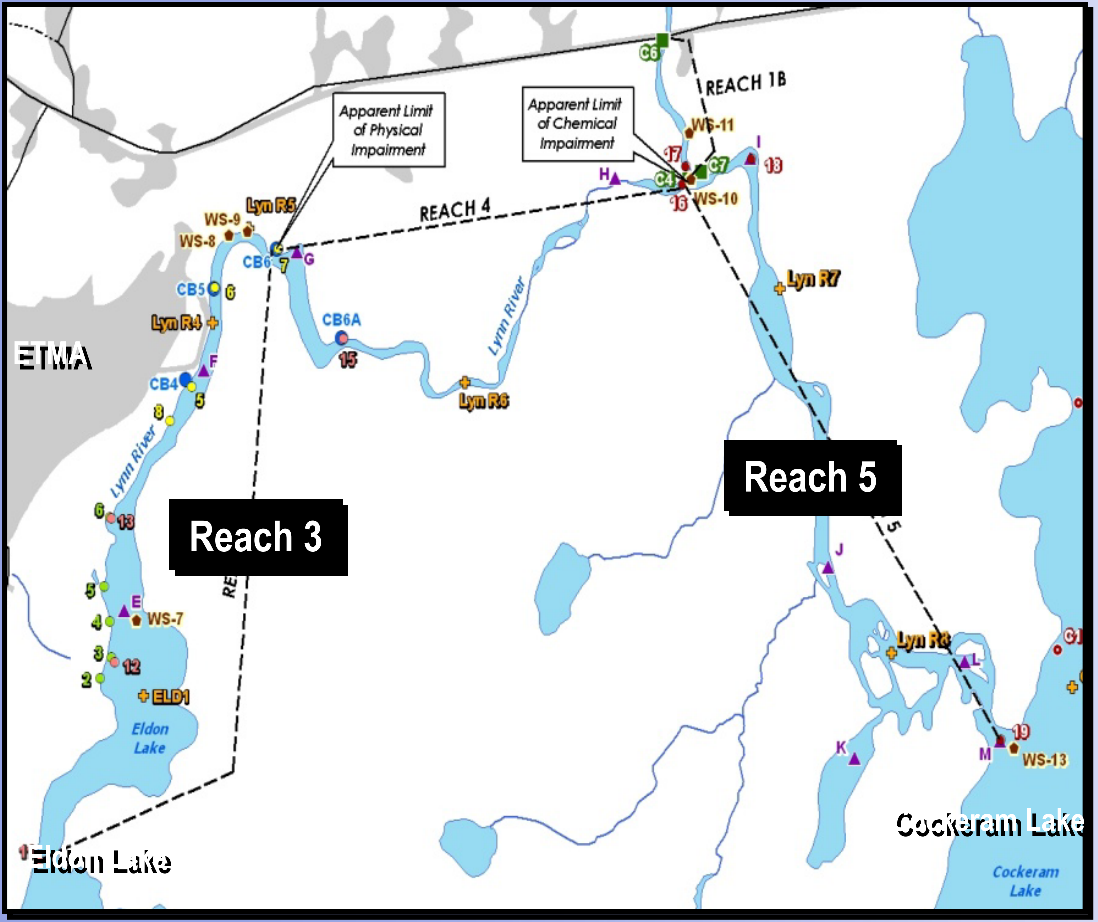
2005, 2006, 2007 Load Reduction Estimates Using 2007 ERT Limits

METAL	REACH	2005	2006	2007
Aluminum	Reach 2	0%	0%	0%
	Reach 3	0%	0%	0%
Copper	Reach 2	0%	30%	0%
	Reach 3	0%	0%	0%
Nickel	Reach 2	0%	75%	50%
	Reach 3	0%	0%	0%
Zinc	Reach 2	50% or 55%	85%	60%
	Reach 3	45% or 0%	0%	0%



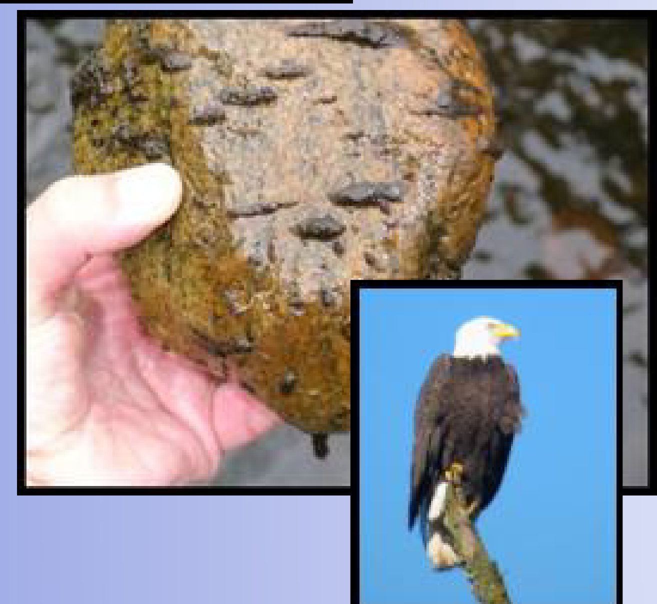
State of River Health

- Studies begun in 2007 examined species composition, species richness & other indicators of ecological health in local reaches of Lynn River



State of River Health (Cont'd)

- Fish netted near ETMA were healthy, “typicaL’ for area, with Condition Factors unchanged since last studies 30 yrs ago
- Invertebrates displayed abundance, composition and richness unaffected by metal exposures
- Piscivorous birds present, healthy



Conclusions

- **Caged-clam bioassays critical to creating site-specific environmental risk threshold values**
  - Key benefit of using mussels was availability of TEL (“dose”) data for copper
- **ERTs critical to defining minimum acceptable water chemistry (“performance targets”at edge of (provincial) mixing zones for effluent from final tailings pond**
- **ERTs are key input to design-engineering processes focussing on surface (& subsurface) treatment of contamination along major flow paths**
- **TEL-based ERTs & related engineering solutions should greatly minimize risks to aquatic biota**
- **Fish and invert studies demonstrated study area river and lakes to be surprisingly healthy**
- **Time is available to fashion locally appropriate engineering solutions targeted on reducing measurable ecological risk**


QUESTIONS?