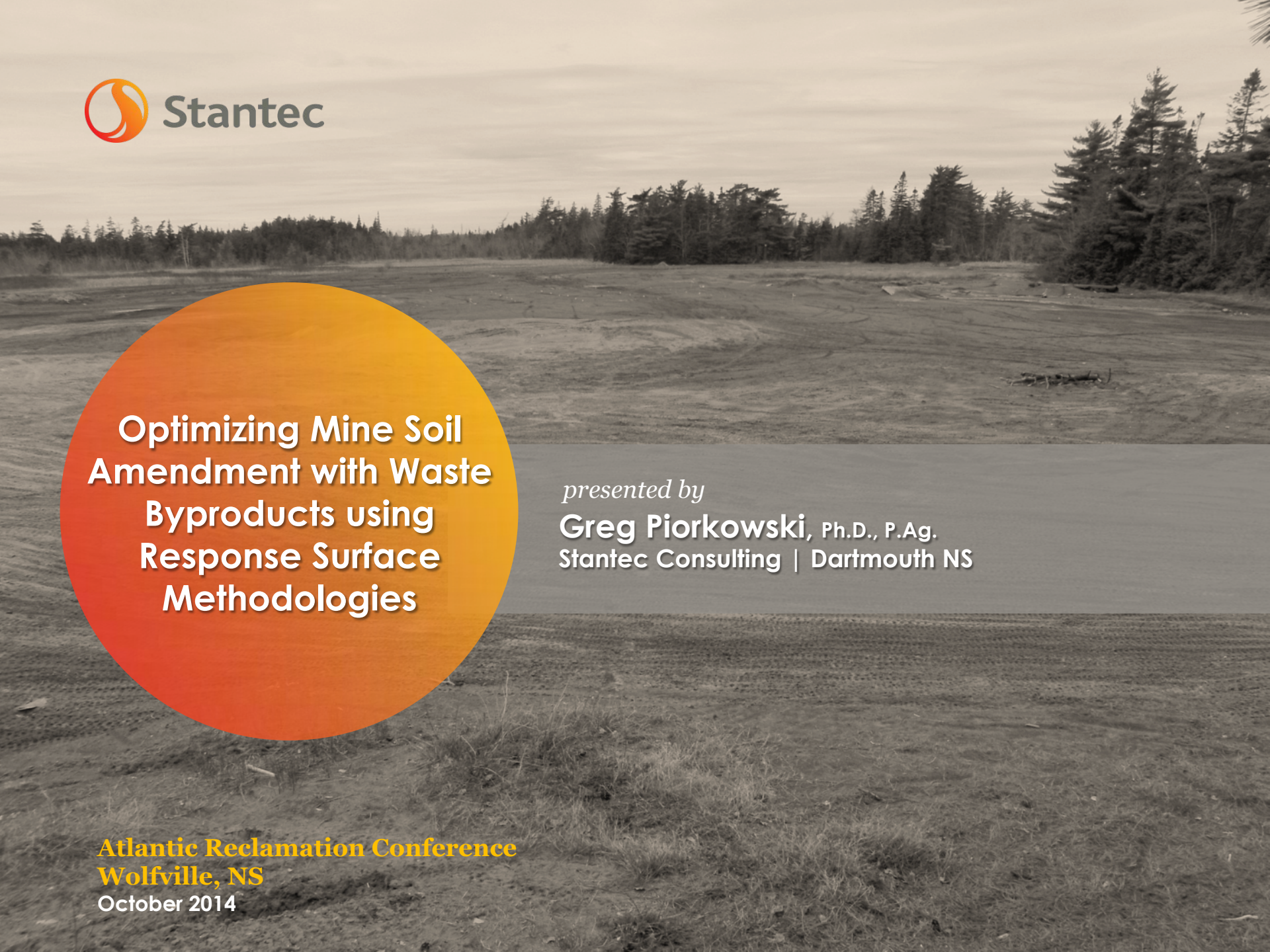

Optimizing Mine Soil Amendment with Waste Byproducts using Response Surface Methodologies

presented by
Greg Piorkowski, Ph.D., P.Ag.
Stantec Consulting | Dartmouth NS

Atlantic Reclamation Conference
Wolfville, NS
October 2014

Road Map

1. Waste byproducts as amendments
2. Overview of response surface methodologies
3. Applying RSM: Optimizing waste byproduct amendments for revegetating gold mine tailings and quarry substrates

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Mine Soil Constraints

Infertility

Add nutrients:
Organic amendment
Fertilizer

Physical Constraints

Break-up soil (tillage)
Promote aggregation (organic matter)

Toxicity

Increase pH (lime)
Add complexing agents:
Organics (compost)
Inorganic sorbent (iron oxides)

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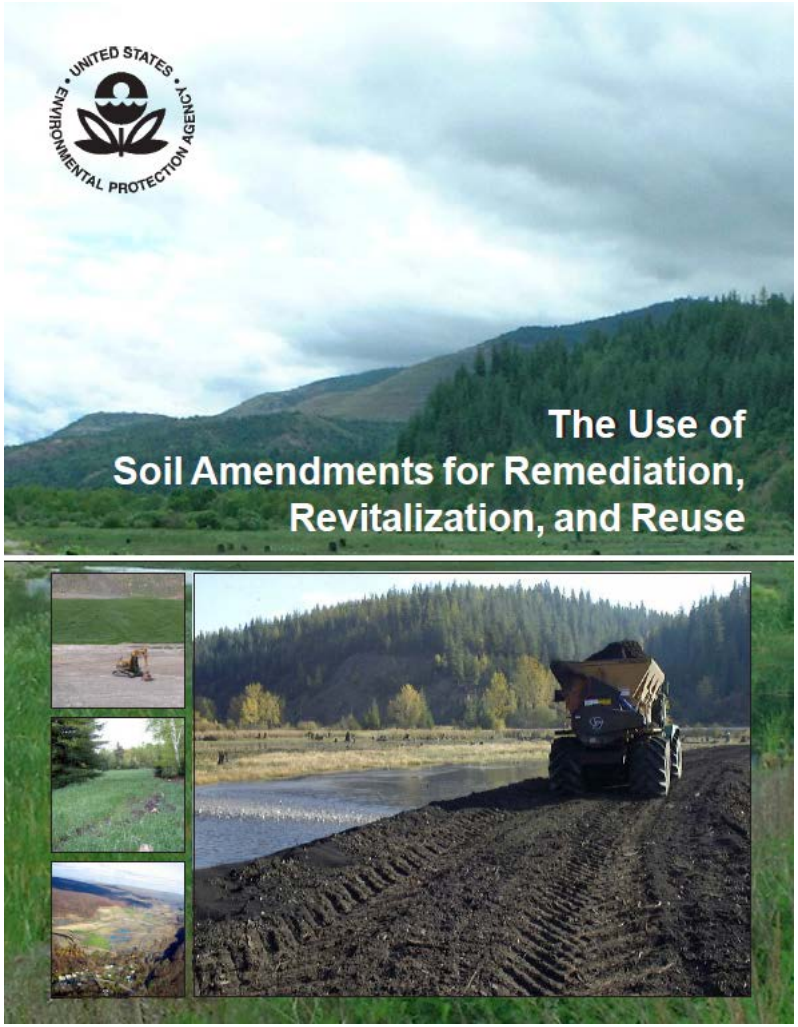
Organic and Liming Amendments



- **Organics**
  - Adds nutrients and organic matter
  - Biosolids, composts, agronomic waste, manures, papermill sludges, wood chips, etc.
- **Soil Acidity/pH Amendments**
  - Increased pH reduces metal bioavailability and improves nutrient retention
  - Fly ash, wood ash, FGD sludge, etc. (20 – 80% CCE)
  - Used in conjunction with lime

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Mineral Soil Conditioners

- **Foundry sand**
  - Modify soil texture
- **Steel slag**
  - Combined alkaline soil amendment, sorbent and micronutrient source
- **Dredged materials**
  - Modify soil texture or form soil profile
- **Phosphogypsum**
  - Enhance soil aggregation, offset sodicity and aluminum toxicity
- **Water Treatment residuals**
  - Modify soil texture and sorb trace metals

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Application Rates

- **Organic Amendments**
  - Meet plant N requirements
  - Increase soil organic matter content (2 – 5%)
  - **But**, wastes can have imbalanced nutrients or high moisture content (⇧ transport costs)
- **Acidity/pH Amendment**
  - Balance acidity using calcium carbonate equivalents (CCE)
  - **But**, wastes can have soluble salts, boron, heavy metals
- **Mineral Soil Conditioners**
  - Site and objective specific, but usually up to 100 Mg/ha
  - **But**, wastes can have soluble salts and trace metals

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Response Surface Methods

Purpose:

Predict operating conditions that yield an optimum response in one or more response factors

Benefits:

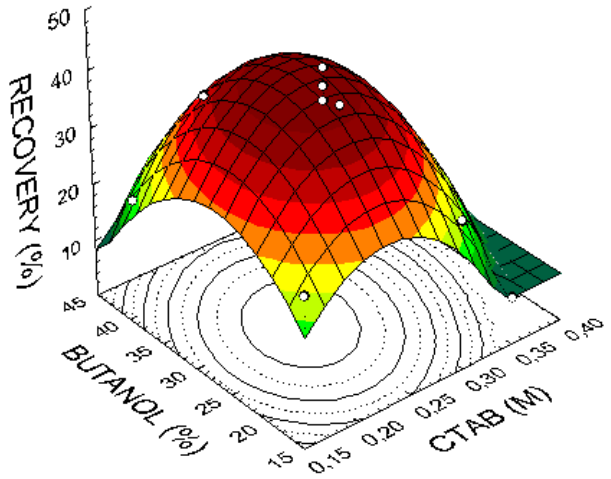
Optimization-specific experiments

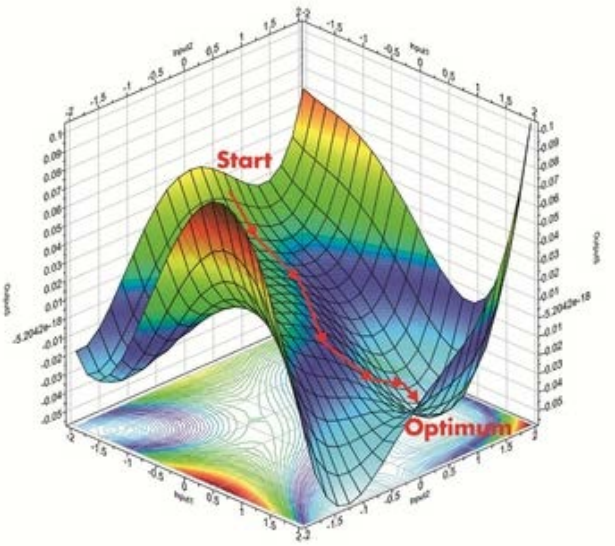
Fewer experimental units and lower cost than factorial designs

Drawbacks:

Assumes all factors are important (i.e. no treatment comparison)

Requires advanced software for design and analysis





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Research Objectives:

Verify response surface methodologies can be used for optimizing soil amendments

- **Greenhouse experimentation**
- **Two case studies:**
  - ***Abandoned gold mine tailings (metal-contaminated)***
  - ***Quarry overburden (infertile)***

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Response: Vegetation Performance

Aboveground Biomass (Shoots)

- Maximize

Belowground biomass (Roots)

- Maximize

Root : Shoot ratio

- Balanced (~1.0)

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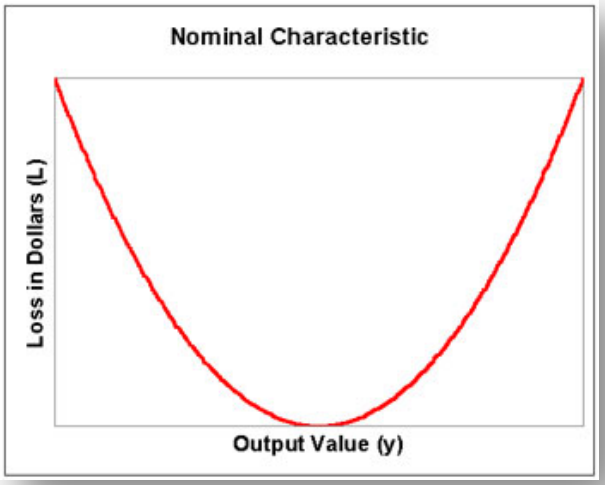
Response: Cost

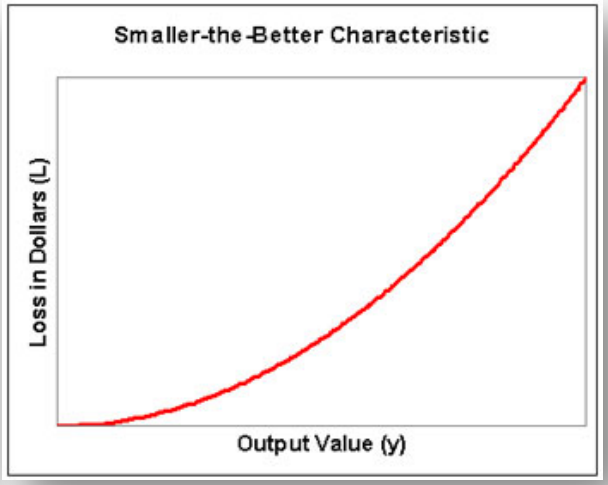
Total Cost = *Materials* + *Quality Loss*

Materials = Purchase + Transport

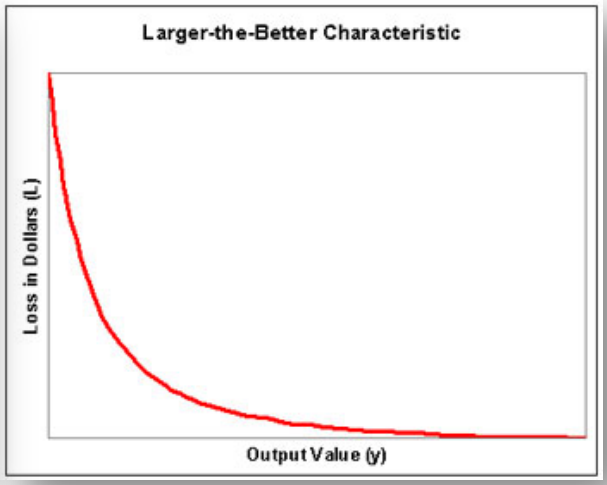
Quality Loss = Monetization of performance using Taguchi quality loss function



Target Objective



Minimum objective



Maximum objective

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Case Study 1:

Phytostabilization of abandoned gold mine tailings

- Municipal solid waste compost (OM & Nutrients)
- Wood chips (C:N adjustment)
- Steel slag (As adsorbent & Alkalinity)

Case Study 2:

Quarry substrate revegetation

- Municipal solid waste compost (OM & Nutrients)
- Alkaline stabilized biosolids (Nutrients & Alkalinity)
- Wood chips (C:N adjustment)

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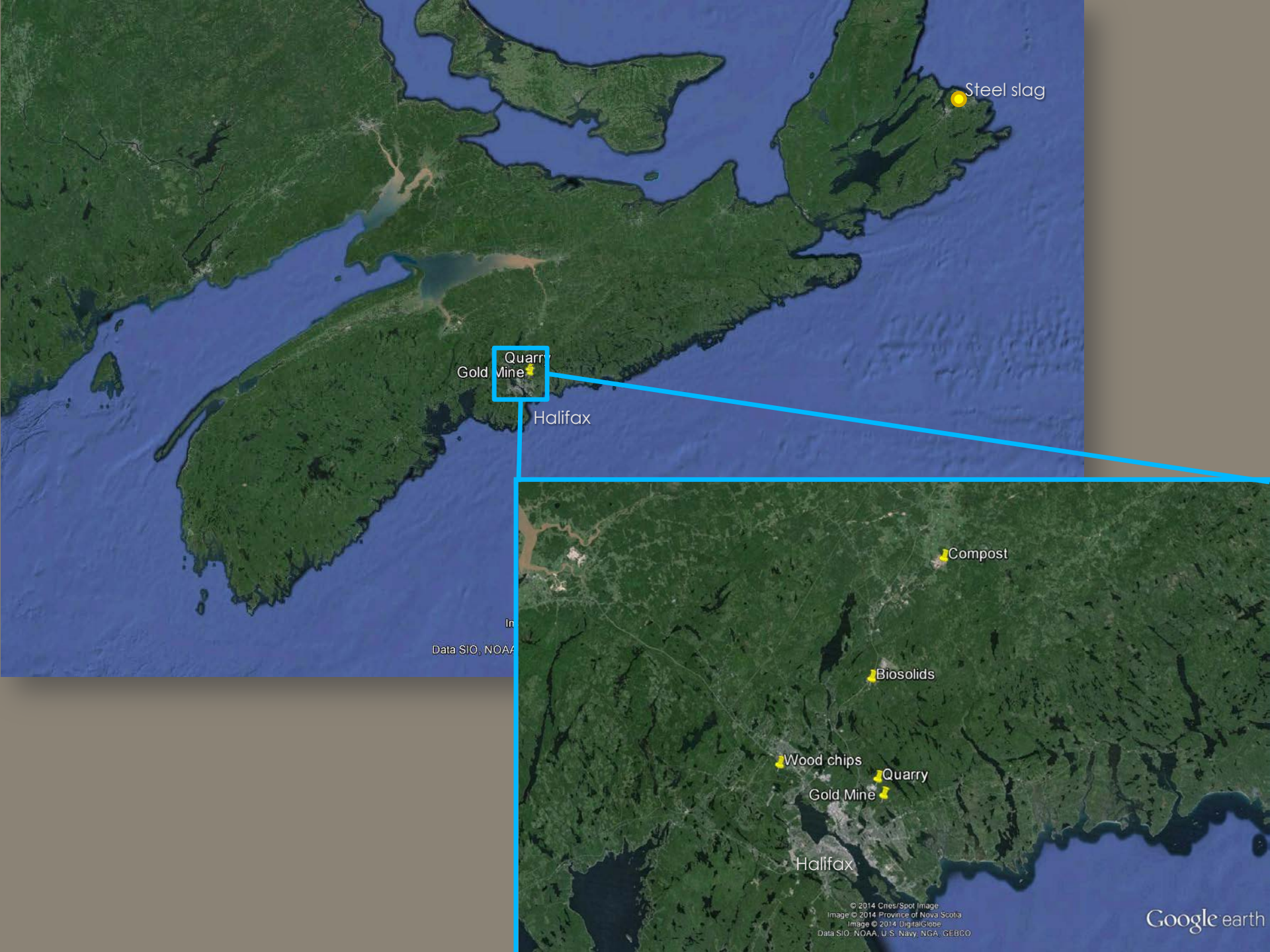
Steel slag
Quarry
Gold Mine
Halifax
Data SIO, NOAA
Compost
Biosolids
Wood chips
Quarry
Gold Mine
Halifax
© 2014 Cnes/Spot Image
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

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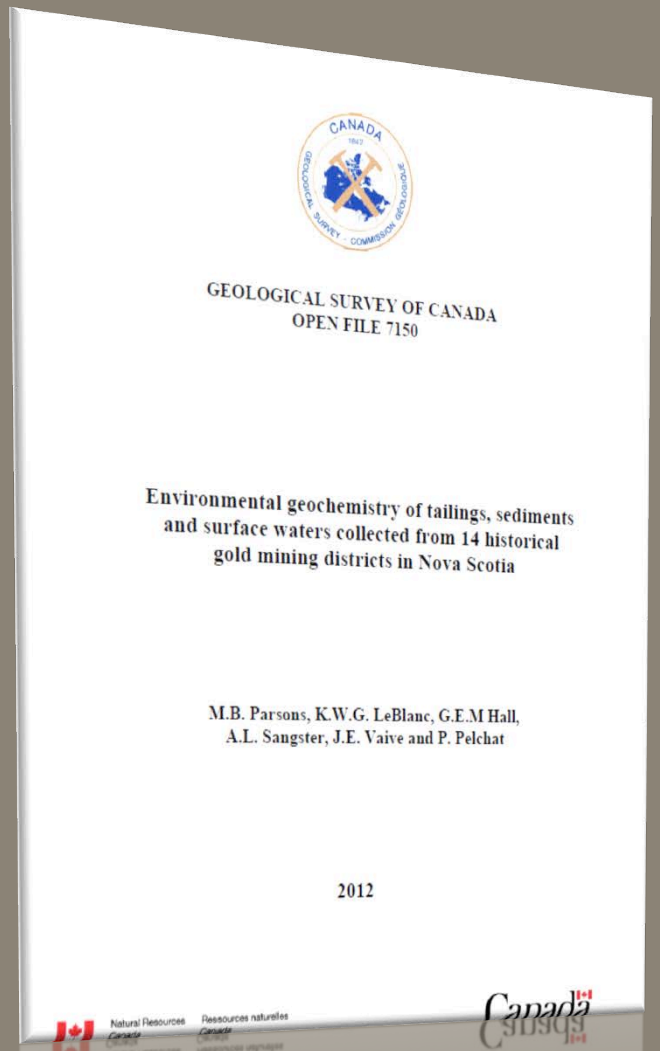
Case Study 1:
Phytostabilization of
Abandoned Gold
Mine Tailings

Study Site: Montague Gold Mine



ca. 1865 – 1940

Arsenopyrite Deposit
Mercury Amalgamation

As (mg/kg): 2,600 – 43,000

Hg (mg/kg): 650 – 6,700

pH ~ 4.5 - 5.5

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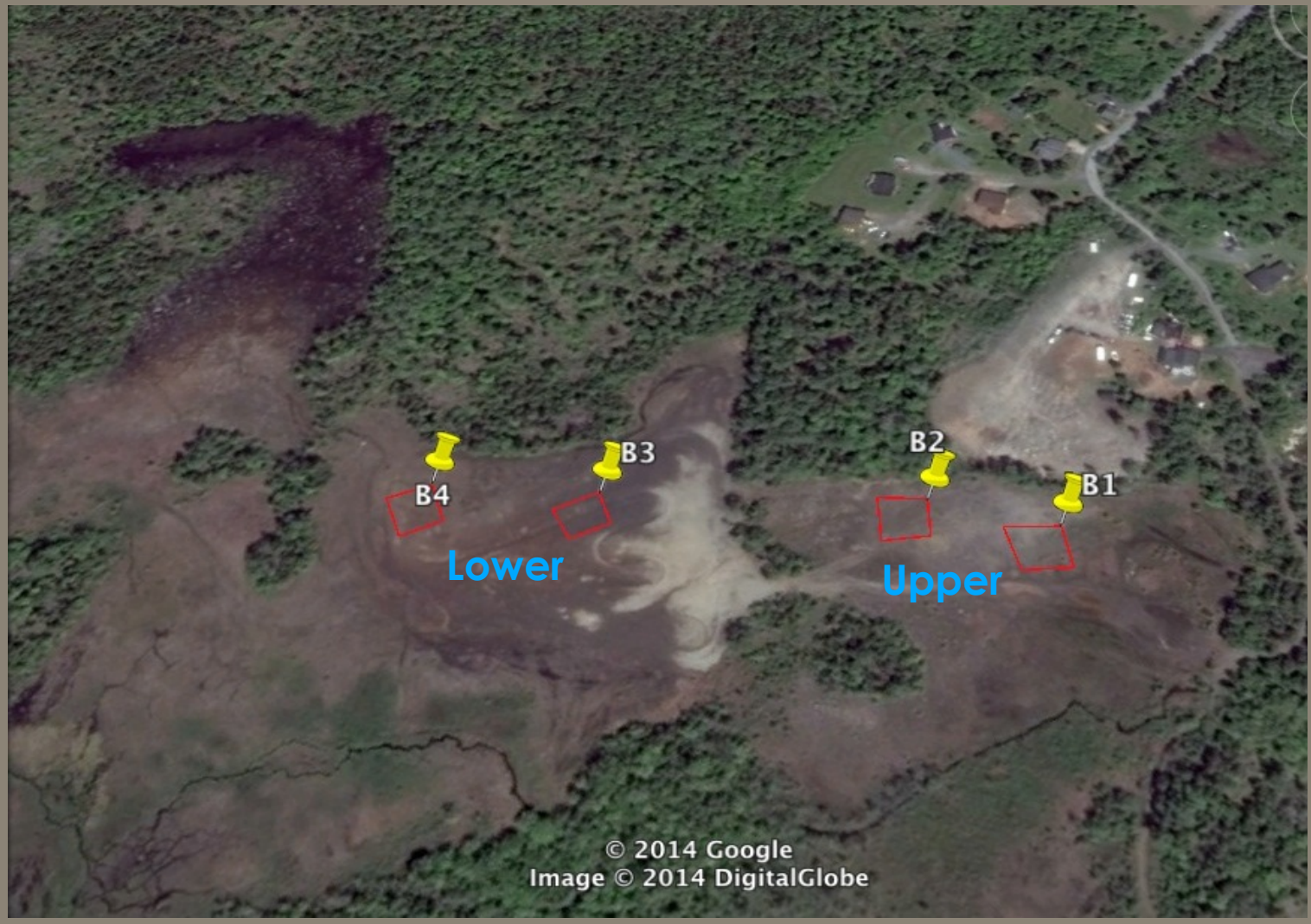
Sample Collection Areas



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Montague Tailings

Amend

Oxidized
As available

Reduced
As bound

Component-Amount Design

MSW Compost
30 – 100 Mg/ha

Wood chips
0 – 10 Mg/ha

Steel slag
0 – 35 Mg/ha

Amendments varied independently

- Main effects
- Interactions

Logistics:

- Transport
- Application
- Incorporation

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Greenhouse Experiment

- Seeded with tufted hairgrass (*Deschampsia cespitosa*)
- Incubated 50 days post-germination
- Measured above- and below-ground biomass
- Analyzing tissue and soil heavy metals

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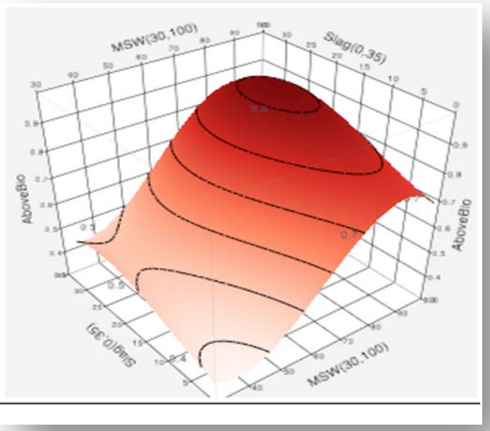
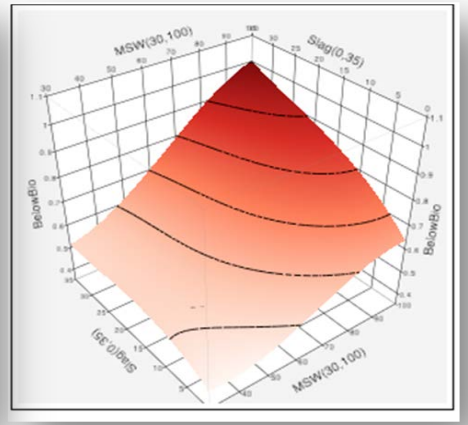
Response Surface Model

Shoot Biomass



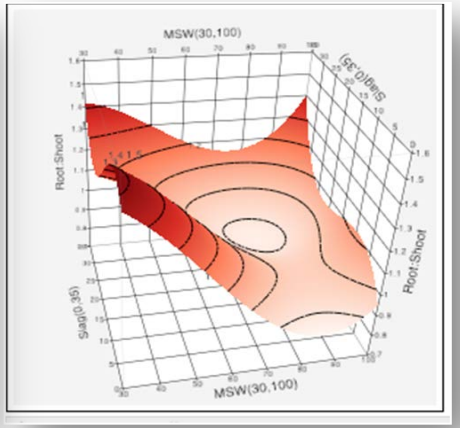
Maximum desired
Peak observed

Root Biomass



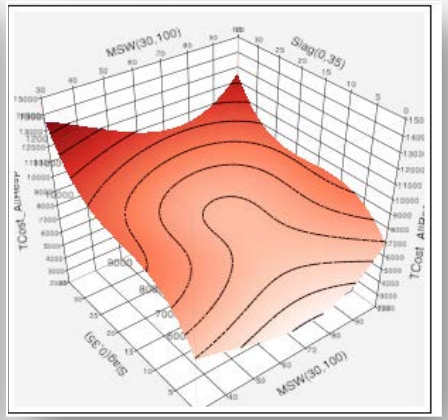
Maximum desired
Peak not observed

Root:Shoot Ratio



~1.0 desired
Trough observed

Total Cost



Minimum desired
"Plateau" observed

Optimum:

85 Mg/ha MSW compost, 24 Mg/ha steel slag and **2 Mg/ha wood chips**

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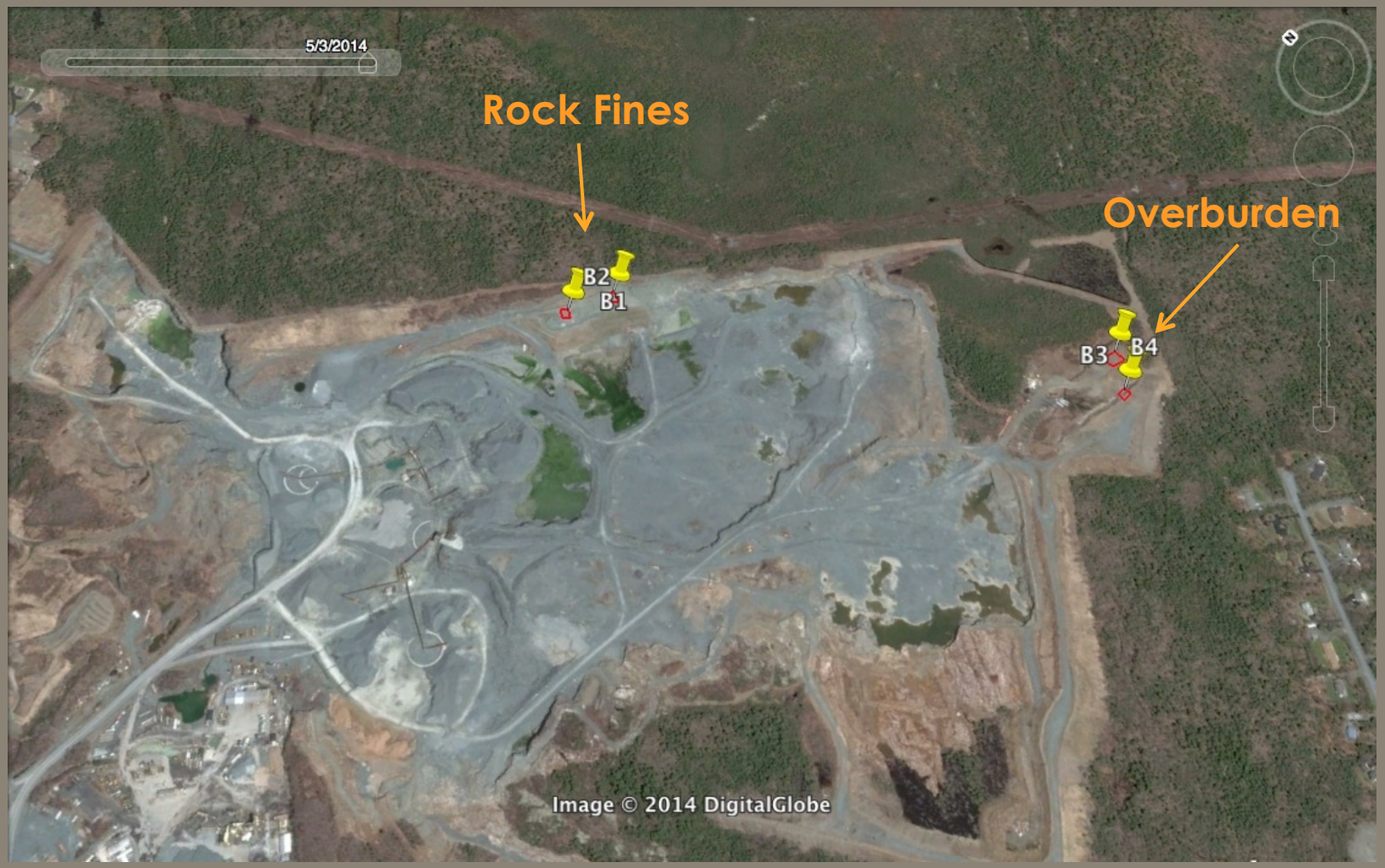
Case Study 2: Optimizing Organic Amendment Mixes for Quarry Soil Reclamation

Sample Collection Areas



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Quarry Soils

Compact
Infertile: <0.5% OM

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Mixture-Amount Design

Blended Amendment

Amount:
30 – 100 Mg/ha

Mixture:
0 – 100% MSW Compost
0 – 100% Biosolids
0 – 10% Wood chips

Assess blending behavior and influence of total application

Why? Logistics:

- **Storage**
- **Availability**
- **Incorporation**

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Greenhouse Experiment

100 Mg/ha
100% MSW Compost

Seeded with Nova Scotia Highway Mix:
40% red fescue | 20% timothy | 15% tall fescue | 15% perennial ryegrass | 15% kentucky bluegrass

Biomass harvested 50 days following germination

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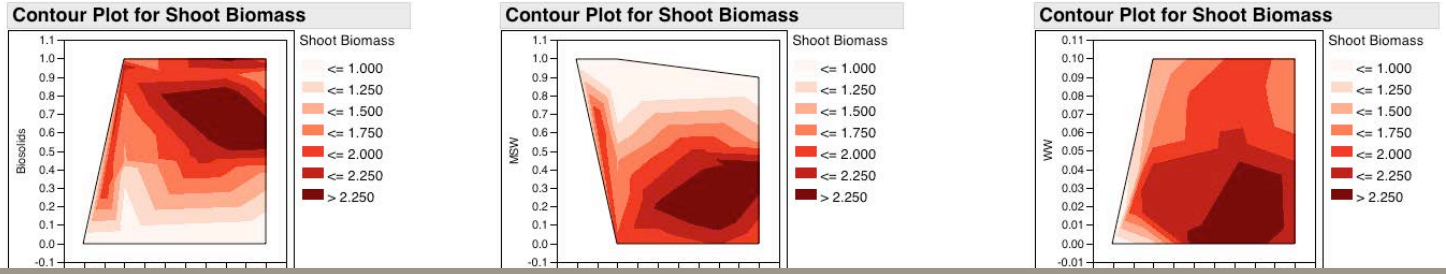
Biosolids | MSW Compost | Wood

Shoots

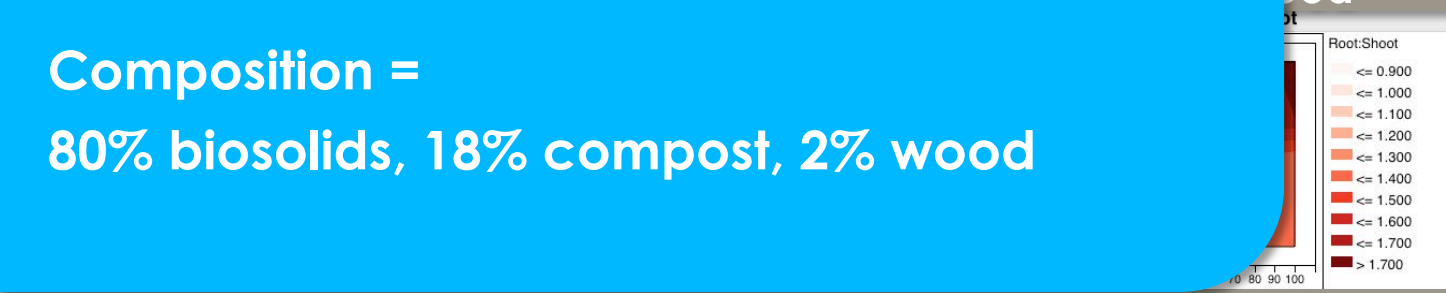


50 – 90 Mg/ha: High proportion biosolids, lower proportions MSW and Wood

Roots

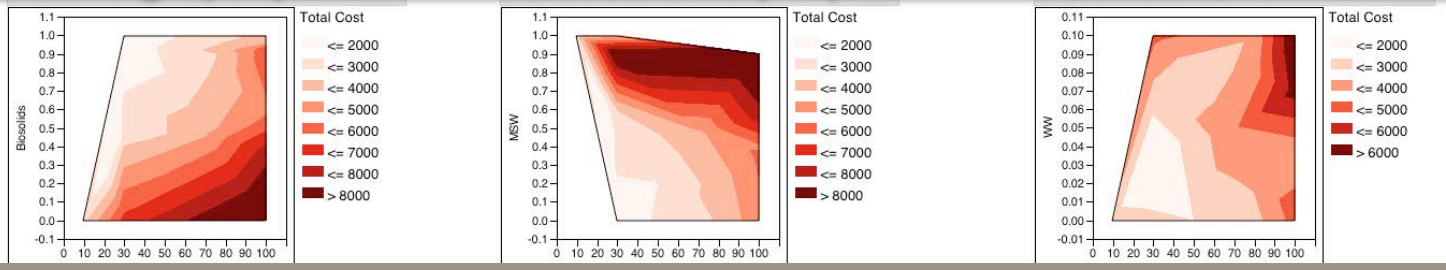
70 – 100 M … od

Root: Shoot



30 – 70 Mg/ha: High proportion biosolids, lower proportions MSW and Wood

Total Cost



<80 Mg/ha: High proportion biosolids, lower proportions MSW and Wood

Optimized Amendment:

Rate = 60 Mg/ha

Composition =
80% biosolids, 18% compost, 2% wood

Summary

1. **Response surface methods (RSM) worked well for amendment optimization in greenhouse**

2. **RSM-based optimization can improve project performance and economics**
   - *Avoid under/over-application and potential toxicity*

3. **Field validation is required and ongoing**
   - *Quarry: RSM design in field – compare against greenhouse*
   - *Tailings: Temporal stability ± mycorrhizal fungi*

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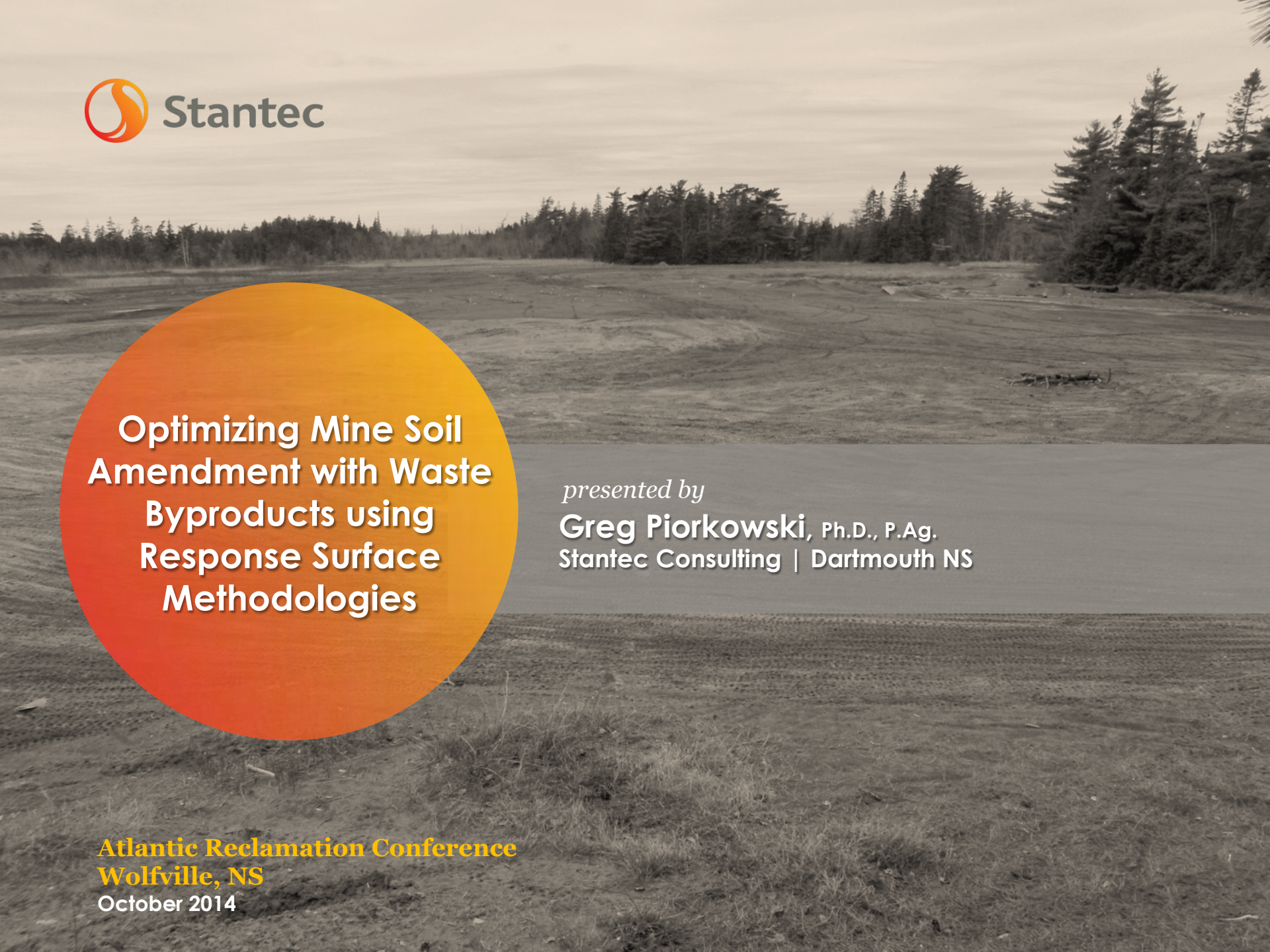
Acknowledgements

Carol Jones, Victoria, B.C.
Natalie Tashe, Victoria, B.C.
Denis Rushton, Dartmouth, N.S.
Elizabeth, Kennedy, Dartmouth, N.S.

Gordon Price, Waste Management

Anne Naeth, Land Reclamation

Mike Parsons, Geochemistry



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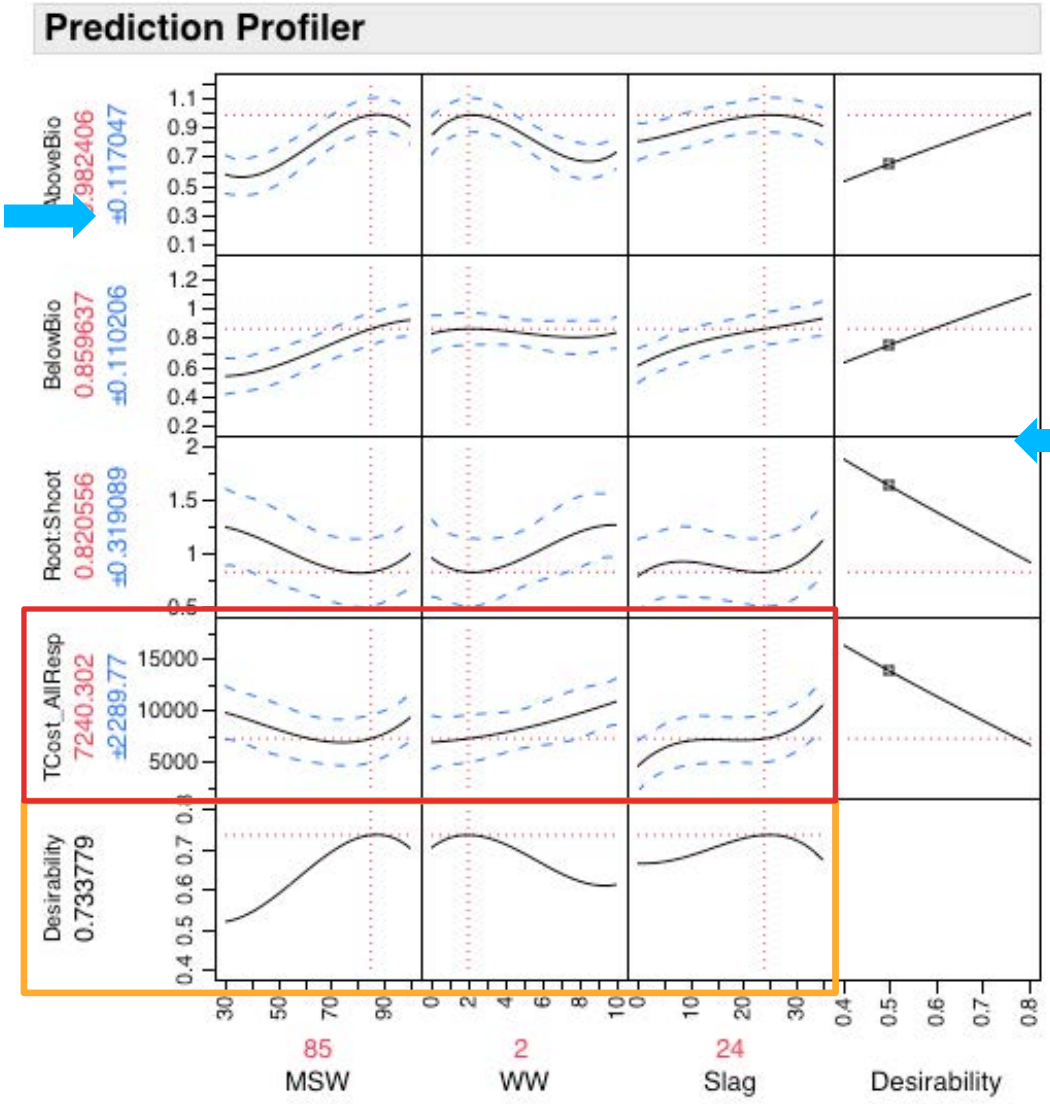
1. Fit statistical model for each response



2. Fit individual desirability functions

3. Maximize overall desirability

Optimum: 85 Mg/ha MSW compost, 24 Mg/ha steel slag and 2 Mg/ha wood chips

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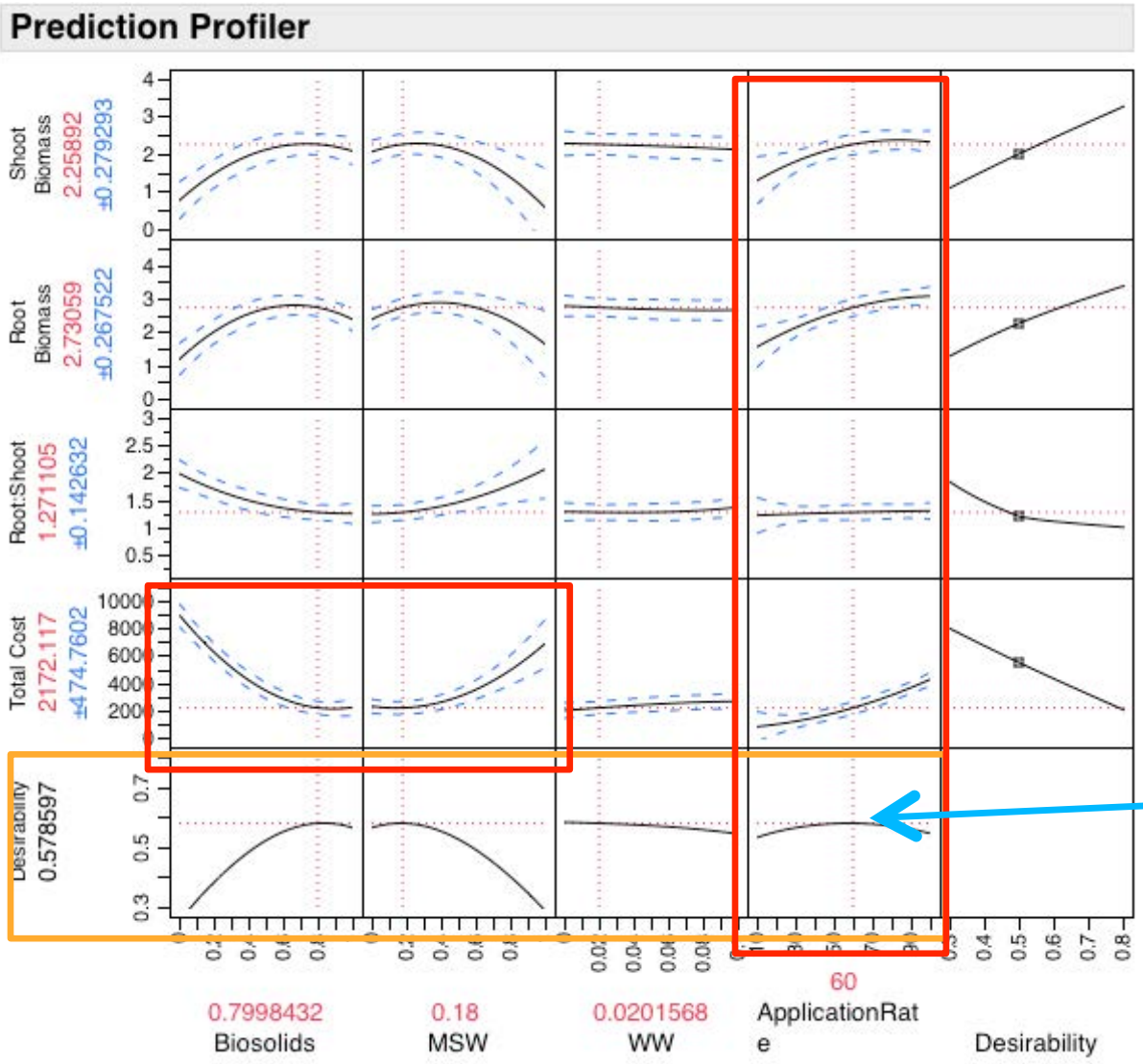

Rate: Compromise between performance and cost

Optimum: 60 Mg/ha amendment composed of **80% biosolids, 18% MSW compost** and **2% wood chips**

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Experimental Designs

E.g. B = biosolids (Mg/ha); F = fly ash (Mg/ha)

ANOVA-based:

Main Effects

Interaction

$$Y = X_0 + aB + bF + cBF + \varepsilon$$

Error

Most common!
Most appropriate?

Fixed: categorical (treatments)
Random: continuous (linear)

Response surface methods (RSM):

$$Y = X_0 + aB + bF + cB^2 + dF^2 + eBF + \varepsilon$$

Error

Main Effects

Polynomial

Interaction

All Continuous! (Required for optimization)

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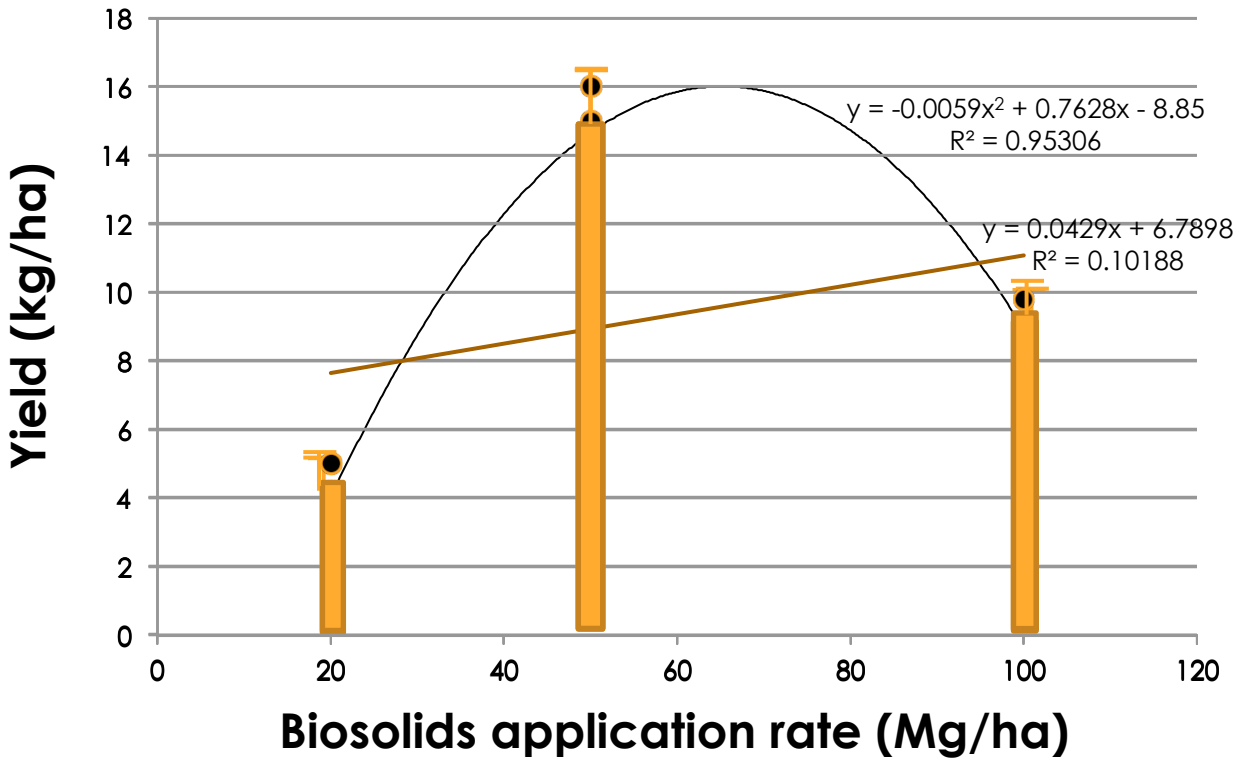
Model Comparison



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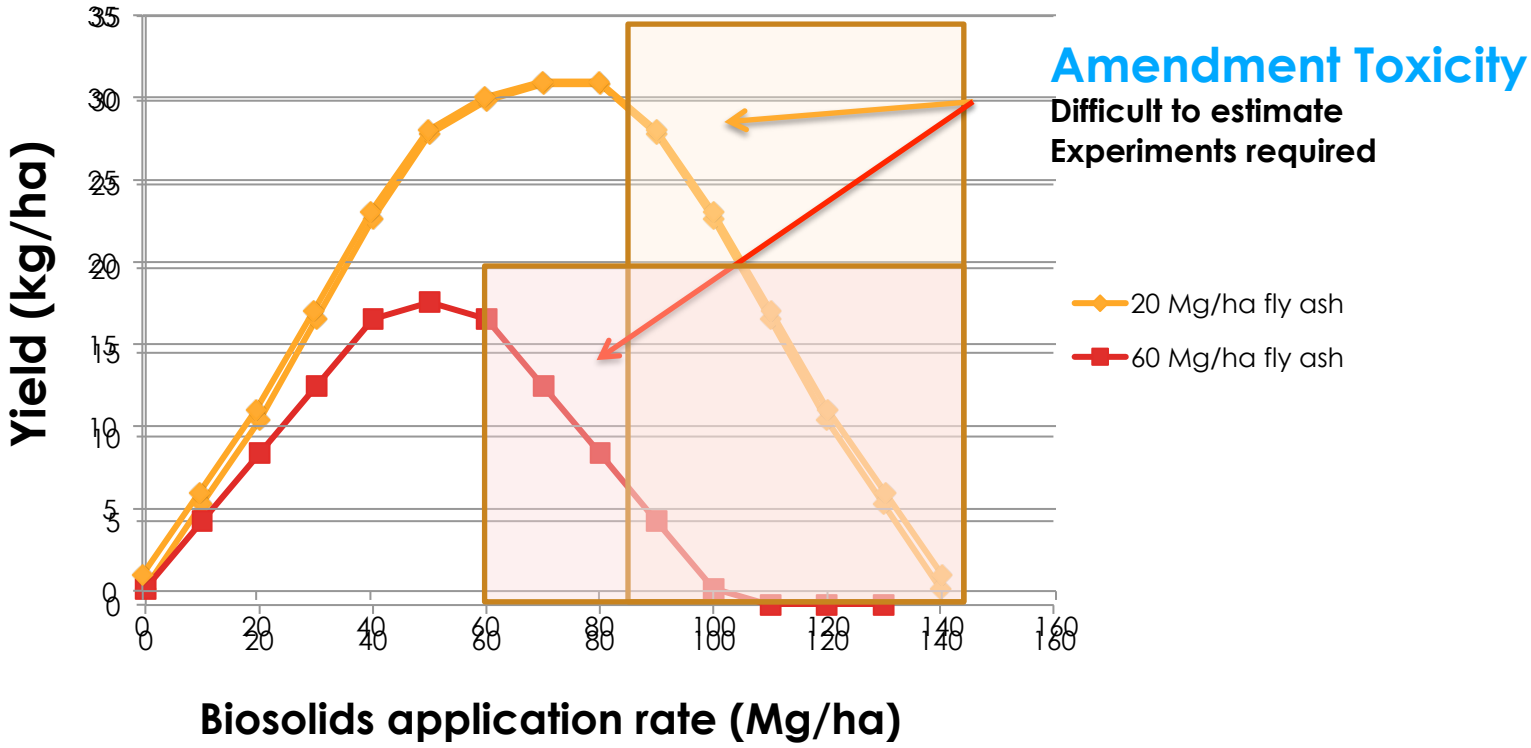
Example: Plant Response to Biosolids



Polynomial Effect: "Curvature" in response due to phytotoxic compounds

Interaction Effect: Different response at different rates of additional factor

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