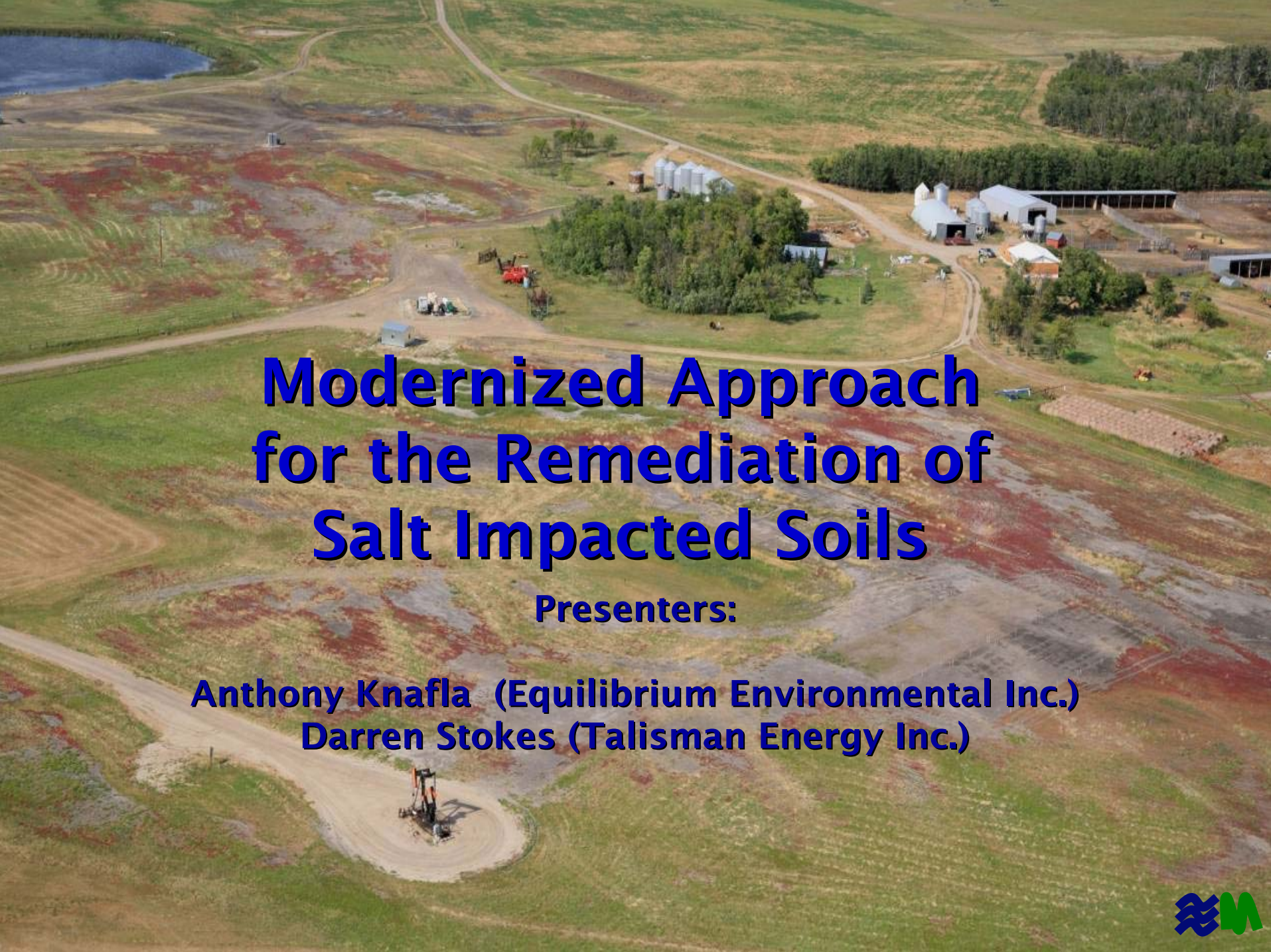


Modernized Approach for the Remediation of Salt Impacted Soils

Presenters:

Anthony Knafla (Equilibrium Environmental Inc.)
Darren Stokes (Talisman Energy Inc.)

Introduction

- **PURPOSE OF PRESENTATION**
  - **share knowledge gained from two years of study and resources dedicated towards:**
    - **understanding factors limiting the achievement of equivalent capability for a salt & boron impacted site**
    - **Evaluating the effectiveness of a longer-term remediation strategy**
  - **Knowledge gained may be of value to industry in dealing with other large produced water impacted sites**

- **ACKNOWLEDGEMENTS**

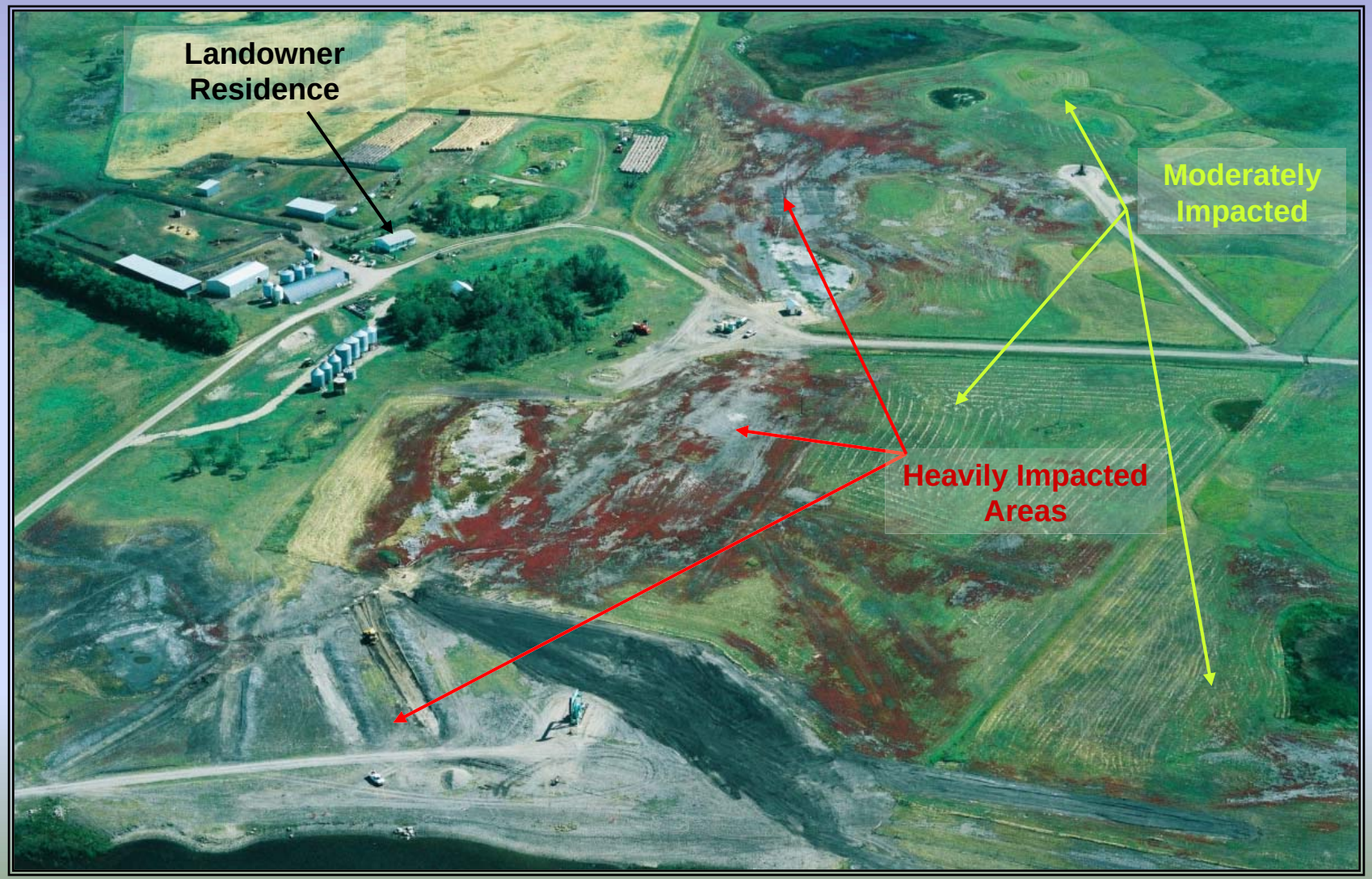
  - **NAL Oil and Gas Trust (Cost Sharing Partner)**
  - **Matrix Solutions Inc. (Groundwater, pumping tests)**
  - **Strata Environmental (Weed Control, Contractor Management, Soil Investigations)**
  - **Odyssey Environmental (Species Identification)**

Brief Site History

- Two spill events in the late 1960's that released an unknown large quantity of produced fluids
- Salt water flowed into low lying areas – these areas are now unable to sustain cereal or forage crops
- Numerous historical attempts at remediation using conventional methods were unsuccessful (e.g., gypsum amendments)
- large stands of foxtail barley developed in heavily and moderately impacted areas - hindrance to livestock pasturing
- Impact represents a significant source of environmental liability in the millions using a dig and dump approach
- As a consequence, the problem must be studied to establish the most cost effective approach to reducing environmental liability

Air Photo of Impacted Area

- Close proximity to landowner residence
- Greater than 100 acres of impact; 30 acres of heavy impact
- Depth of impact frequently extends to 4 m



Problem Formulation

- **Large area**
  - **Evaluate effectiveness of longer term remediation and interim risk management**
- **Multiple toxic stressors**
  - **Salt ions (electrical conductivity values <50 dS/m)**
  - **Surface soil SAR values of up to 20**
  - **Boron (concentrations < 20 mg/kg)**
- **Close proximity of landowner residence**
  - **Chloride impacts in a well not use as potable water**
- **Weed control required in moderately impacted areas**
- **Shallow groundwater table (discharge area)**
- **Limited excavation is not feasible since resalinization of backfilled soils will occur due to shallow groundwater and soil texture**

End Goals

- **Stabilize plume to prevent the spreading of impacts**
- **No unacceptable risks to the health of humans and environment**
  - **Human Health and Ecological Risk Assessment**
- **Achieve Equivalent Land Capability**
  - **Defined using risk assessment**
    - **<20% reduction in seed germination for >50% of cultivar and hay/pasture species typical to the area compared to background**
    - **< 50% reduction in plant yield for >50% of species**
  - **Site-Specific definition accepted by SIR (Sept 6, 2003)**
  - **Quantitative endpoints**
    - **establishing plant growth to the above targets**
    - **Estimated that these plant endpoints are equivalent to soil salinity EC values of 4 dS/m (topsoil) and 10 dS/m (shallow subsoil) – relative to background EC values**

Methods

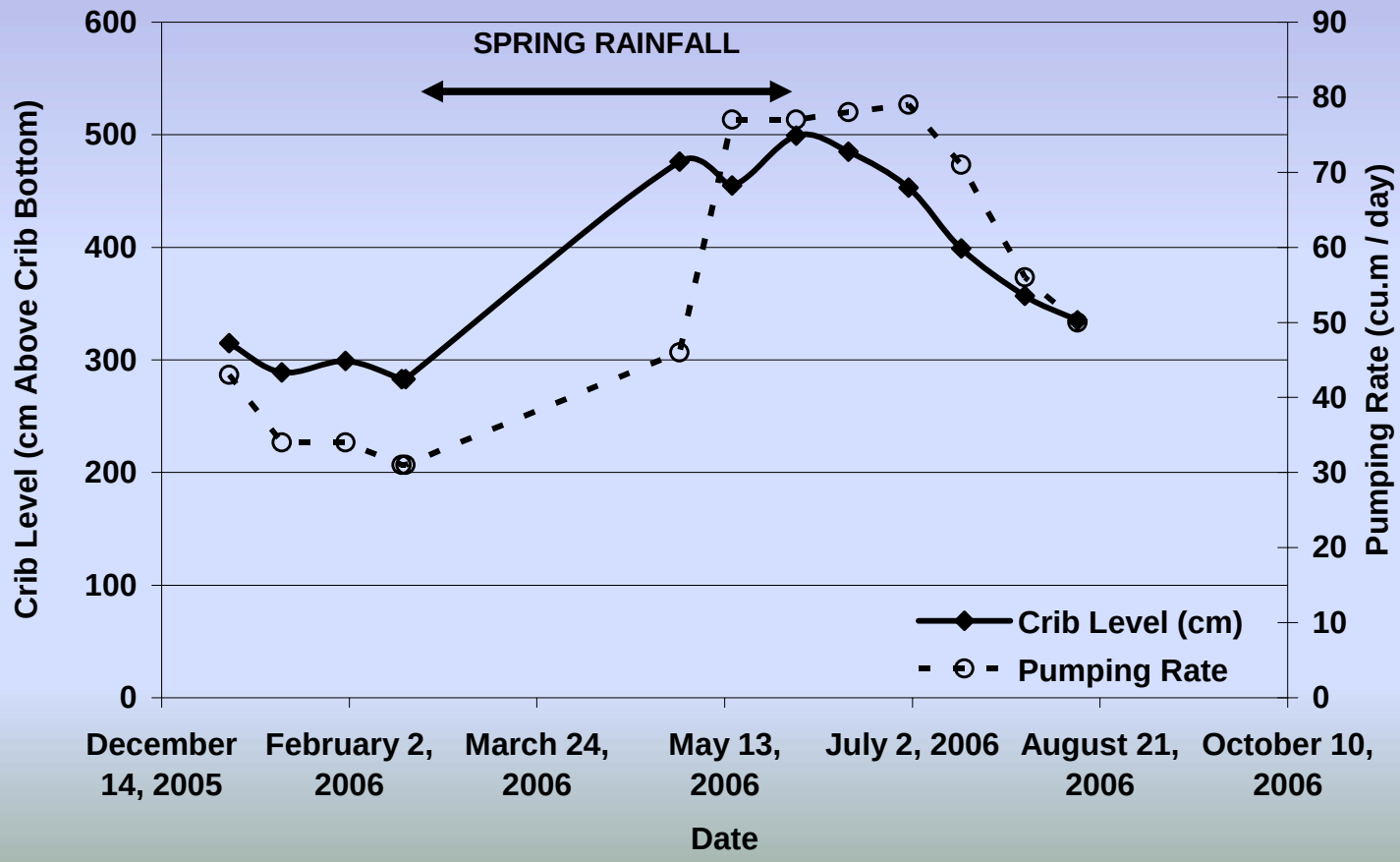
- **Interim Risk Management**
  - Fence area to prevent cattle foraging in the impacted area
  - Notify landowner of impacts and potential risks
- **Tile Remediation System**
  - Extensive - 5 km of tile
  - Disposal pipeline to nearby battery
  - Automated control of leachate water pumping
- **Pilot Distillation Unit**
  - Test effectiveness at processing leachate water into irrigation quality water and concentrating waste stream
- **Research Study to gauge soil remediation**
  - Boron and salt removal through leaching and plant uptake

Tile Remediation System
(Automated Pumping System)

- Purpose – to marginalize groundwater fluctuations
- Pressure transducers measuring culvert water levels
- Variable speed pumps linked to water levels
- Flow meters linked to chemical dosing pump

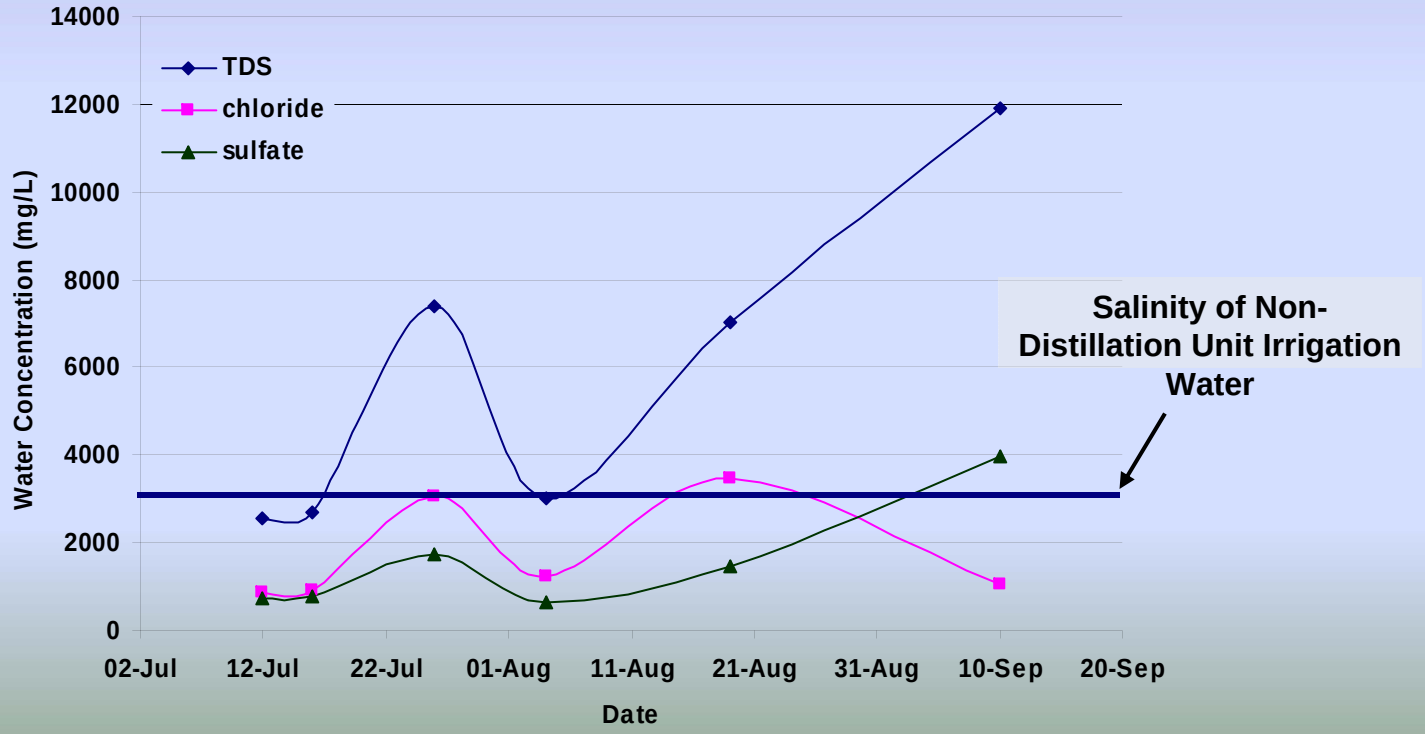
Tile Remediation System
(Automated Pumping System)

- **Results**
  - **Pumping system increased disposal rates of leachate water and marginalized culvert (and groundwater) levels after heavy rainfalls**



Tile Remediation System
(Automated Pumping System)

- **Results and Implications for 2007 Work**
  - Seasonal change to salinity levels in culvert
  - Suggests the possibility of collection during spring months and re-use as irrigation water in hot dry summer months
    - More environmentally responsible approach
    - Required a very controlled situation
  - Use of lower salinity water (< 3,000 ppm TDS) approved by SIR
  - Can be implemented as part of the automatic system



Pilot Distillation Unit

- Vacuum distillation
- Mobile – trailer mounted and suitable for remote areas
- “silent” genset – initial rented unit had significant noise issues
- Satellite communication system for contractor notification
- Automated (chemical dosing, descaling cycles)
- Heat recovery systems – 60% of waste heat recaptured
- Trucked water when production lost due to scale formation
- Security cameras required to offset vandalism activity
- Can produce between 150 and 5,000 gal/day

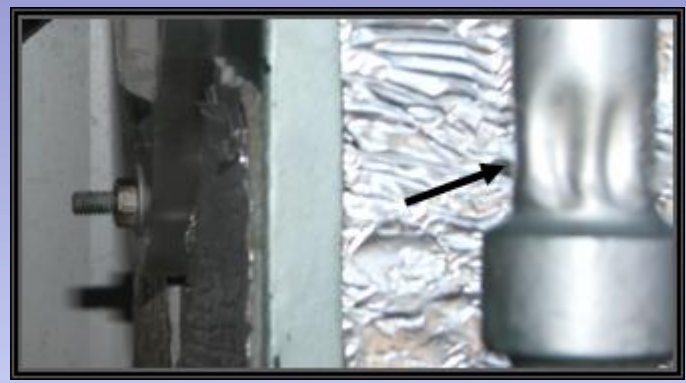
Scale Control

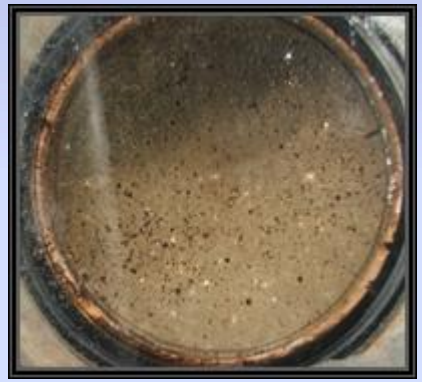
- Net continues water production was < 30% of capacity and maximum capacity was 50%
  - Due to time for sulfate descaling – carbonate scale easily removed

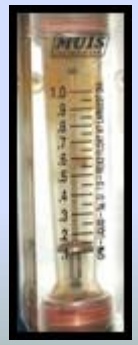
- Various scale control measures examined:
  - Chemicals – more than 10 O&G products tested from Canada, USA, UK
    - Scale Inhibitors
      - » Ineffective alone
    - Gypsum Scale Removers
      - » High doses required and often caused other problems
    - Carbonate Scale Removers
      - » Easiest to control for the water chemistry processed
      - » Caused significant corrosion (acid-based)
  - Coatings
    - Teflon based to heating bundle
      - » Reduced rate of descaling compared to bare alloy metal surface
      - » Significantly reduced corrosion rate
  - Water softening salts
    - decreased the activity coefficients for sulfate- and carbonate-based scale
    - custom soft water mixture
  - Various combinations thereof were tested at variable doses

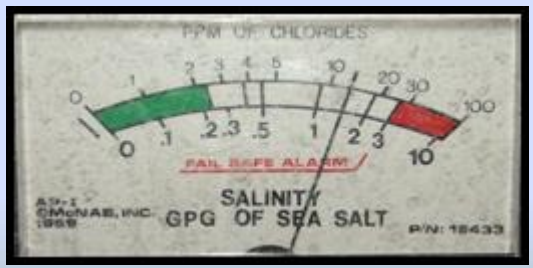
Scale Control

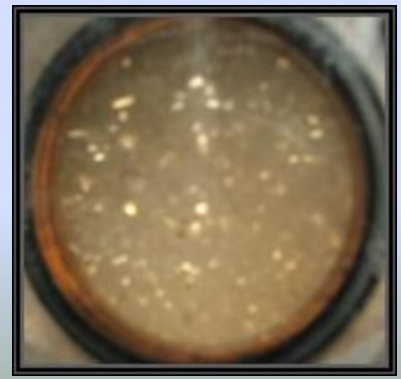
- **Chemically-Related Problems**
  - Pipe corrosion
  - Foam buildup and carryover
  - Orifice compromised
  - Odours (xylenes-related)











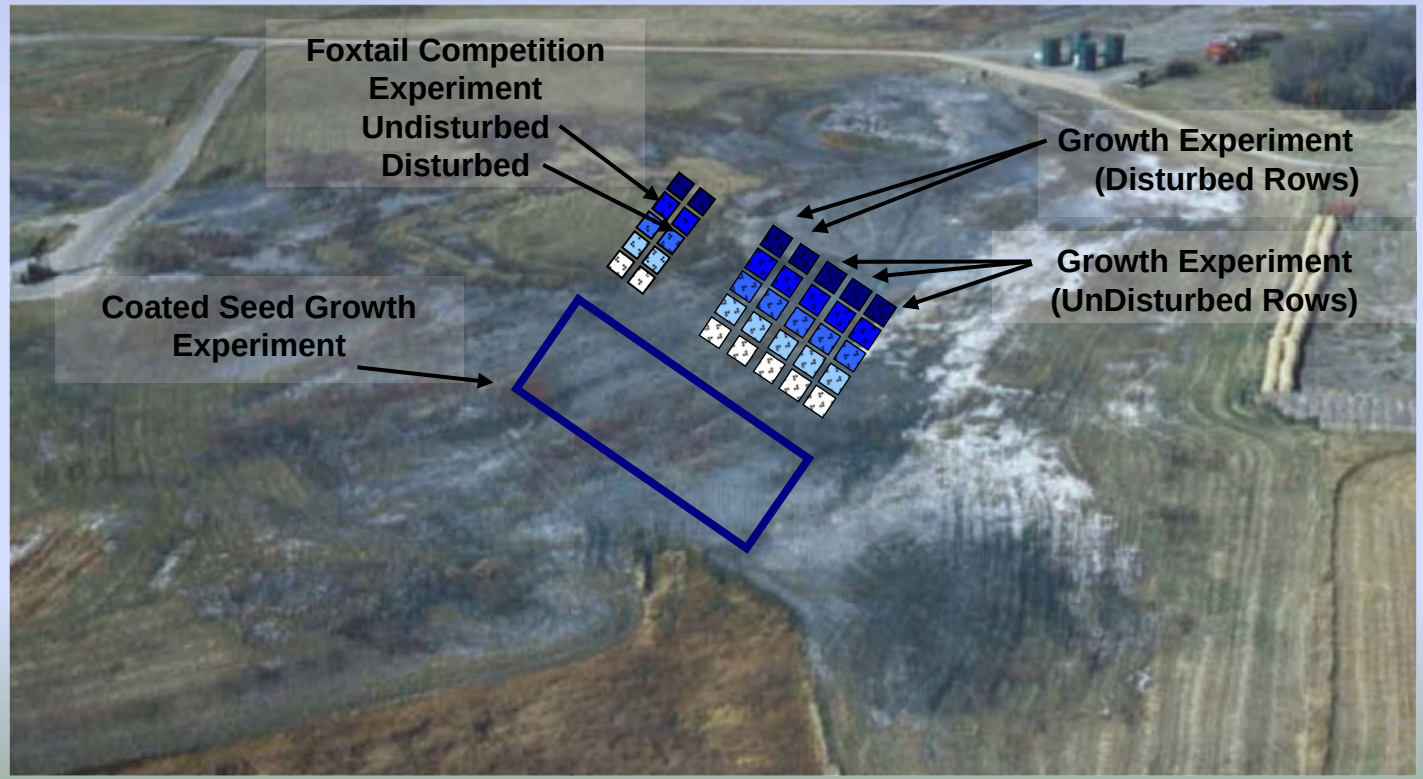
Scale Control

- **Heating Blundle**
  - **Scaled and corroded**

  - **Descaled and uncorroded**

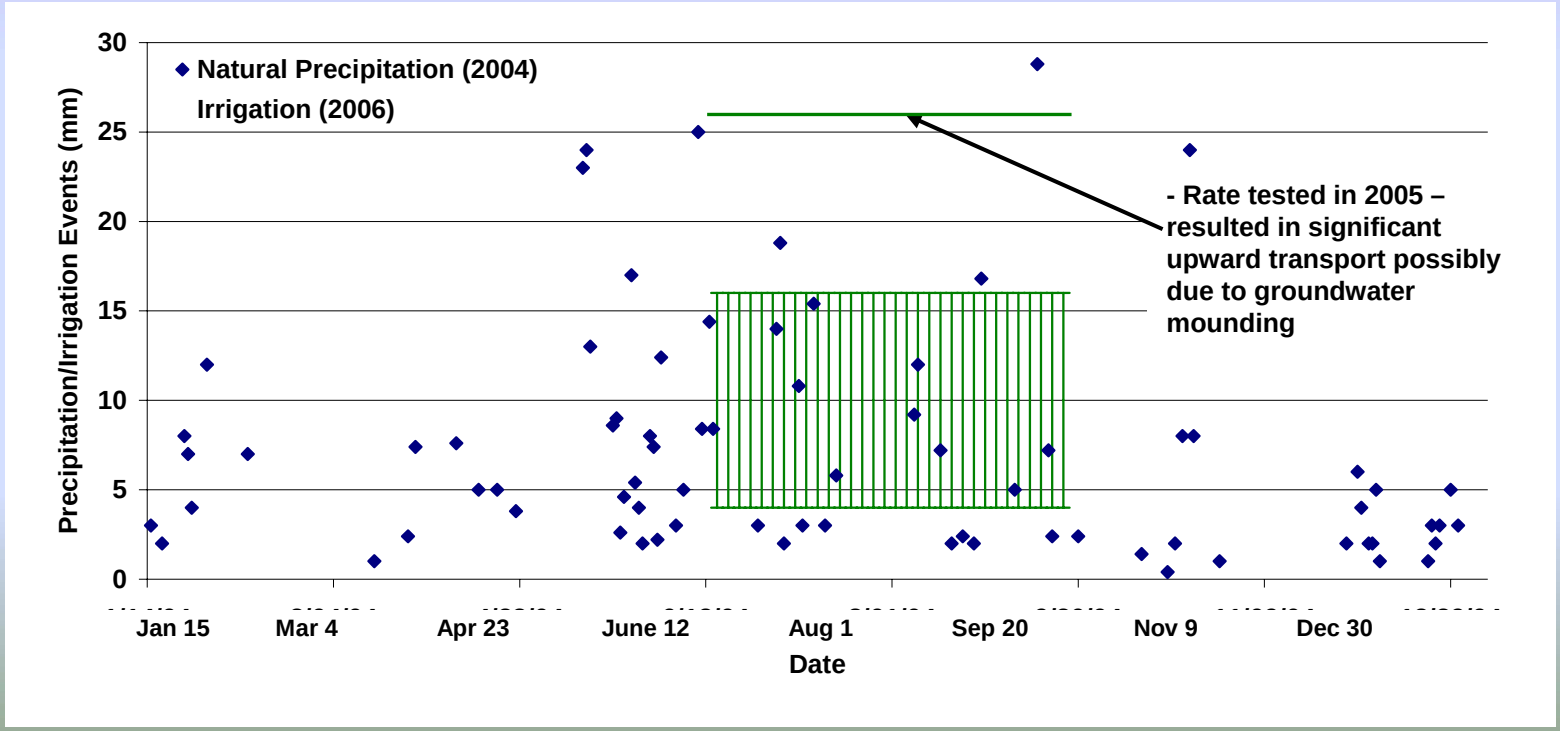
Research Test Plots

- Three Experiments (test rows composed of 5 x 20'x20' plots)
  - Growth establishment (plots built in 2004 – resalinized for 2005)
  - Foxtail competition experiment and boron phytoremediation
  - Dr. Greenburg's generic treated seeds
- Distillation unit – 500 GPD unit
  - 100% production provides water to irrigate test rows every 3rd day



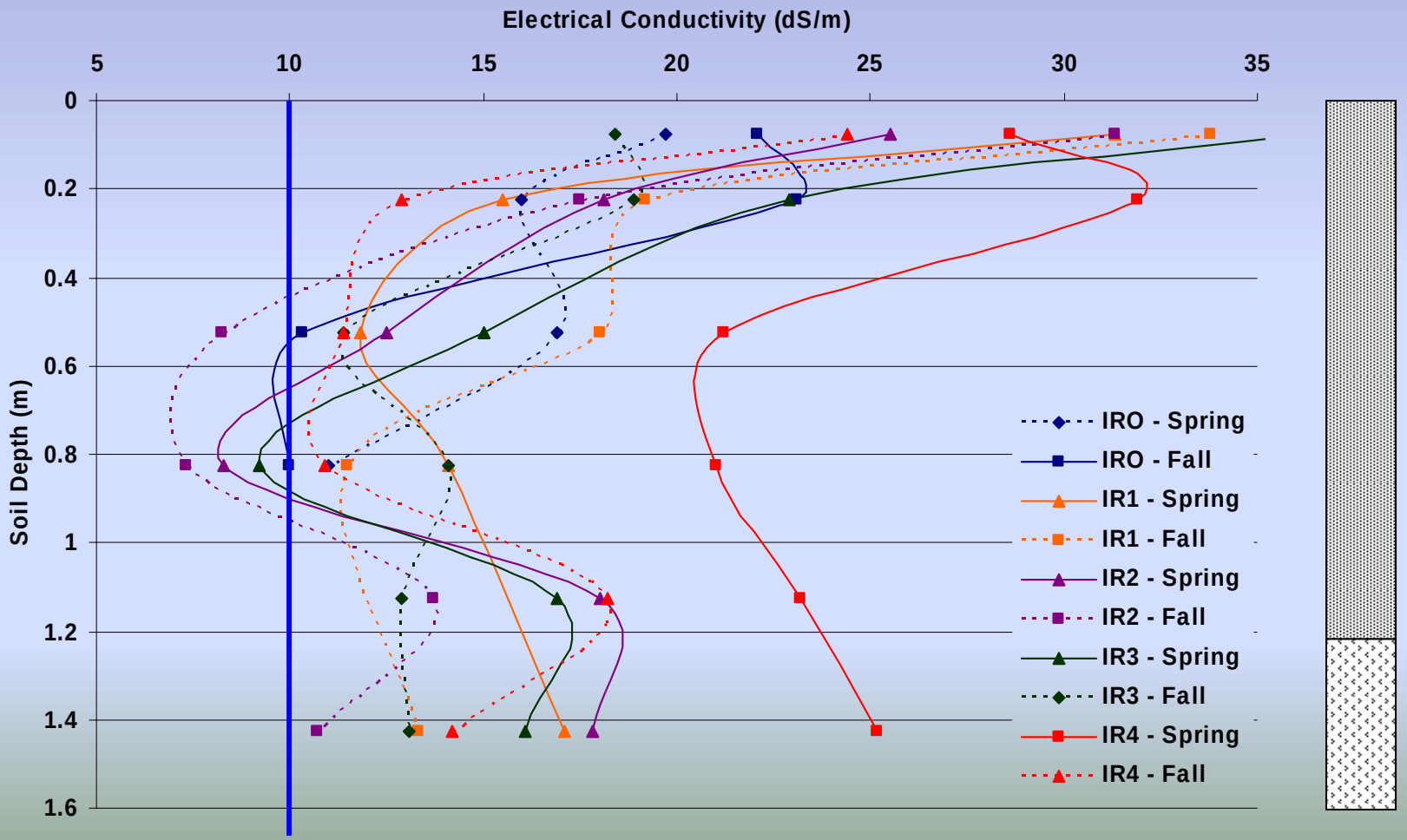
Research Test Plots - Irrigation

Irrigation Rate Label	Irrigation (mm/ event)	Total # of Irrigation Events	Equivalent Water Usage	Equivalent Precipitation Event Based on Historical Carlyle Norms (1971 to 2000)
IR0	0	0	0%	No rainfall
IR1	4	28	6%	Light spring shower
IR2	8	28	13%	Moderate spring shower
IR1 + IR2	- -	28	19%	Light plus moderate (26 events/year)
IR3	16	28	39%	Moderately large (10 events/year)
IR4	14	28	33%	Moderately large (10 events/year)



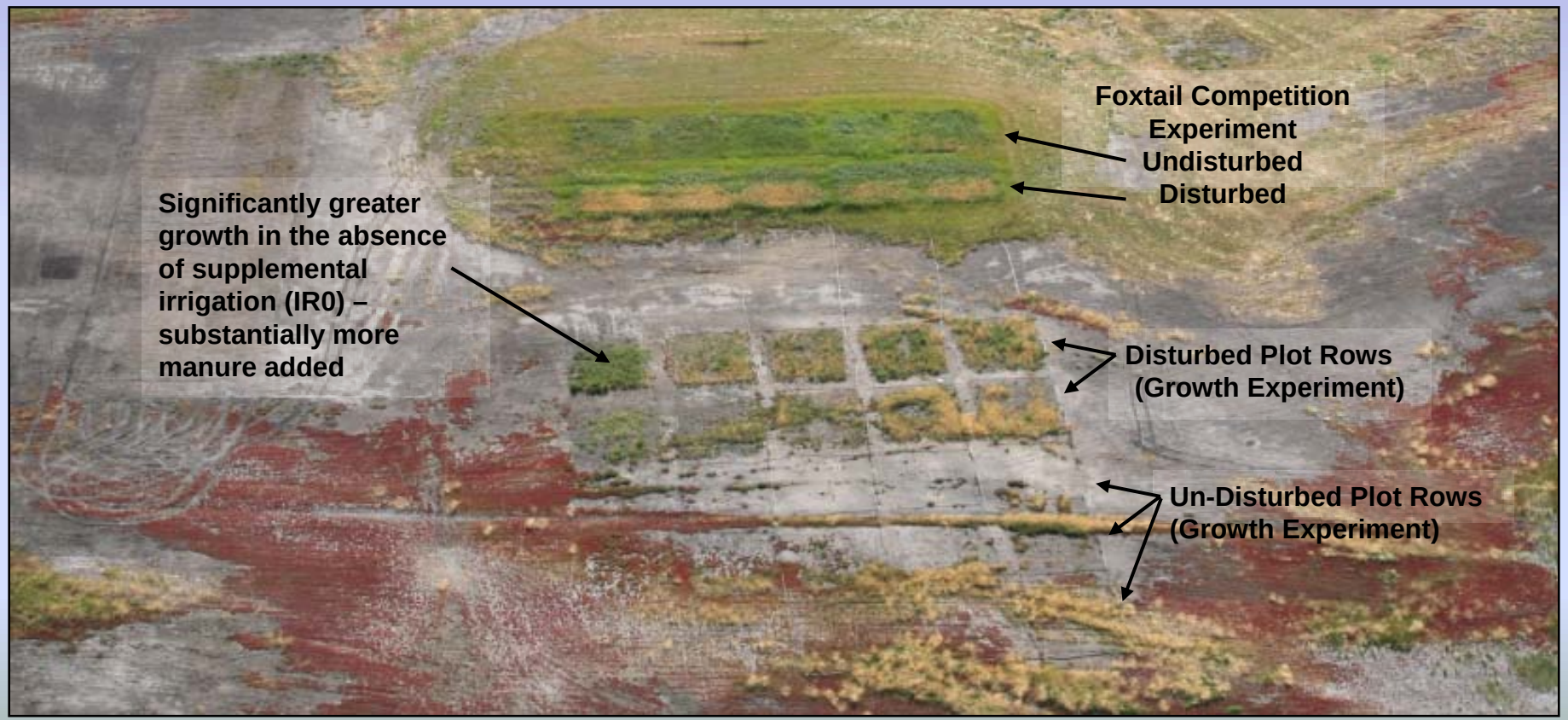
Research Test Plots – Soil Salinity

- Lower irrigation rates associated with upward transport
- Higher irrigation rates associated with downward leaching
- Undisturbed plots showed significantly less leaching (not shown)
- end goals reached in 1 year (< 10 dS/m) for certain disturbed heavy irrigation test plots (not shown - initial EC values of 20 dS/m)



Research Test Plots – Plants

- Growth established in areas where no species have emerged (with exception of foxtail and red samphire) over a 40 year period
- Out-competed foxtail barley growth in areas where historical plant growth has been observed



Research Test Plots – Plant Growth

- **Two mixes – native and forage**
- **Seeding rate – 600 lbs/acre**
- **Concept of toxicology – no two seeds are alike!**
- **Increases the probability that natural genetic salt tolerance variations will establish**

Native Seed Bed	Species in Mix A*	Species in Mix B*
Foxtail barley	Nuttall's alkali grass	Forage barley
Red samphire	Slender wheatgrass	Annual ryegrass
Sea milkwort	Tall wheatgrass	NewHy wheatgrass
Seaside arrowgrass	Tall fescue	Orchard grass
		Alfalfa

Research Plots – Growth Experiment

Before

After

Control Versus Treated

Barley "Yellowing"

Research Plots

Foxtail Control and Boron Phytoremediation

Research Plots

Foxtail Control and Boron Phytoremediation

- Estimates of root length for identifying soil depth interval for the calculation of uptake factors
- Viable seed production – seeds also analyzed for uptake rates

Root Length
Approx. 15 cm

Research Plots - Boron Phytoremediation

- Boron soil concentrations ranged from 2 to 9.2 mg/kg (HWS)
- No clear trends between boron concentrations in soil and plants
  - Significant difference in uptake between barley plant parts
  - Significant difference in uptake between barley and alfalfa
  - Duplicate plant sample concentrations varied by < 25%

	Average Boron Plant Concentration (mg/kg dw)	% StDev on Mean	Average Boron BCF	% StDev on Mean
Barley Stem	5.7	31%	1.0	33%
Barley Seed	1.2	53%	0.2	46%
Alfalfa	109	15%	19.9	17%

- Photoremediation Mass Removal Estimate
  - Based on a root depth of 30 cm (boron exceedence range), dry yield for alfalfa of 0.73 kg/m^2, average boron HWS conc. of 5.5 mg/kg, and average BCF of 19.9, estimated 3.2% of HWS boron removed per crop yield
  - Literature data suggests greater proportional uptake at lower HWS boron soil concentrations (*e.g.*, BCF values of > 100)
  - Estimated 10 years to phytoremediate (two crops per year)
  - Irrigation may substantially increase yield and uptake

- No unacceptable livestock risks predicted up to HWS boron of 9 mg/kg
- No risks for humans consuming barley seeds or other plants tested

Conclusions

- **Tile Pumping System**
  - Effective at reducing groundwater levels
  - Still issues with spring rainfall (9 inches)
  - Potential use of low leachate water for irrigation
- **Pilot Distillation Unit**
  - Failed to meet production goals
  - For now, application will be restricted to low background EC sites (low sulfate) where high production rates can be obtained
- **Research Plots**
  - Some disturbed and amended plots reached regulatory objectives and other plots appear to be able to reach objectives in under five years
  - Irrigation increases the rate of salt leaching
  - Foxtail barley growth can be inhibited competitively by the growth of other species in disturbed and amended plots
  - High seeding rate is more effective
  - Boron phytoremediation potential exists – should evaluate uptake rate simultaneously with single species plots and yield measurements for a more accurate estimate