

Case studies of externality benefits of SRWCs in Florida: i) dendroremediation of reclaimed water, and ii) mined land reclamation

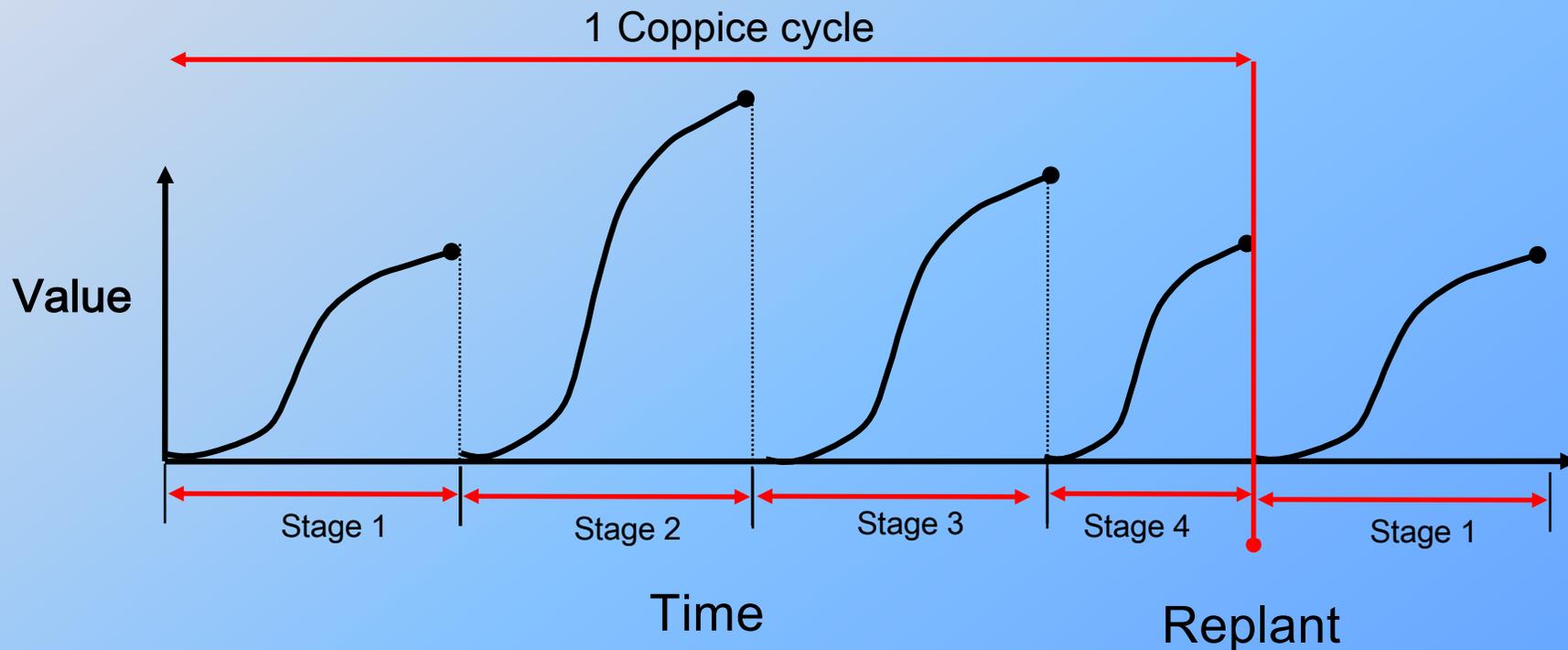
SRWCOWG October 12th , 2016

Matt Langholtz, ORNL

Model Explanation: Optimization of Coppice Plantations

Dual optimization:

1. Select optimum number of growth stages per cycle.
2. Select optimum length of each growth stage.

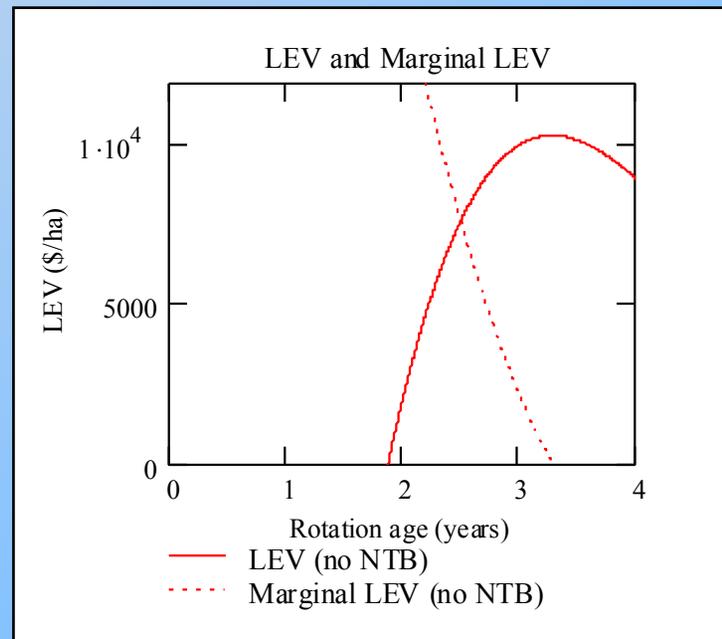


Model Explanation: Optimization of Coppice Plantations

Faustmann:

$$LEV(t) = \frac{V(t) * e^{-r \cdot t} - C}{1 - e^{-r * t}}$$

$$V'(t) = r * V(t) + r * LEV$$



Model Explanation: Optimization of Coppice Plantations

Faustmann:

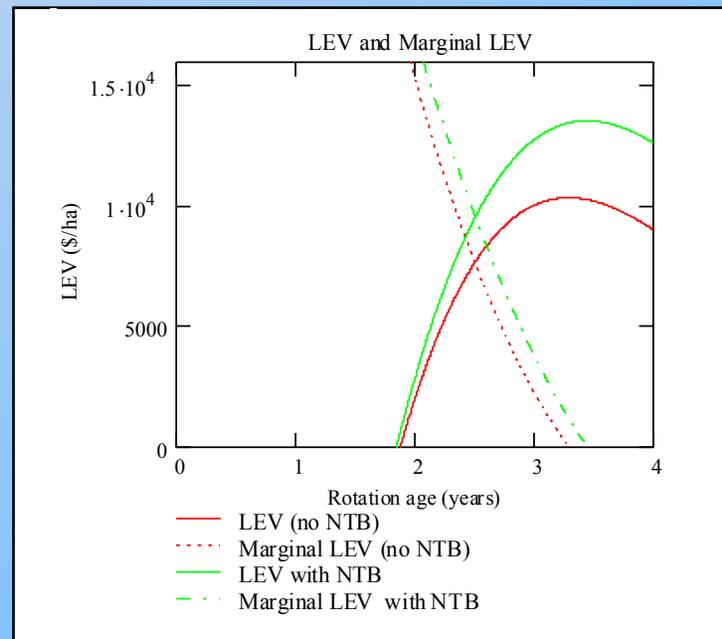
$$LEV(t) = \frac{V(t) * e^{-r*t} - C}{1 - e^{-r*t}}$$

$$V'(t) = r * V(t) + r * LEV$$

Hartman (1976):

$$LEV(t) = \frac{\int_0^t NTB(n) * e^{-r*n} dn + V(t) * e^{-r*t} - C}{1 - e^{-r*t}}$$

$$NTB(t) + V'(t) = r * V(t) + r * LEV$$



Model Explanation: Optimization of Coppice Plantations

Medema and Lyon (1985):

$$LEV(t) = \frac{\sum_{s=1}^n \left[V(t_s) * e^{(-r * \sum_{j=1}^s t_j)} - C_s * e^{(-r * \sum_{j=1}^s t_{j-1})} \right]}{1 - e^{(-r * \sum_{j=1}^n t_j)}}$$

Smart and Burgess (2000):

$$LEV(t) = \frac{\sum_{s=1}^n \left[V(t_s) * e^{(-r * \sum_{j=1}^s t_j)} + NTB_s^S * e^{(-r * \sum_{j=1}^s t_j)} - C_s * e^{(-r * \sum_{j=1}^s t_{j-1})} \right]}{1 - e^{(-r * \sum_{j=1}^n t_j)}}$$

Model Explanation: Optimization of Coppice Plantations

$$W_{fu3}(t) := \frac{\left[\left[g(t)_1 \cdot e^{(-i \cdot t_1)} + \int_0^{t_1} \left(\frac{d}{dt_1} \text{NTB}_1(t_1) \right) \cdot e^{(-i \cdot t_1)} dt_1 - CE_{pr} \cdot \text{NTB}_1(t_1) \cdot e^{(-i \cdot t_1)} \right] - (C_p + C_w) \right] \dots}{1 - e^{[-i \cdot (t_1+t_2+t_3)]}} + \left[\left[g(t)_2 \cdot e^{[-i \cdot (t_1+t_2)]} + \int_0^{t_2} \left(\frac{d}{dt_2} \text{NTB}_2(t_2) \right) \cdot e^{-i \cdot t_2} dt_2 \right] \cdot e^{-i \cdot (t_1)} - CE_{pr} \cdot \text{NTB}_2(t_2) \cdot e^{[-i \cdot (t_1+t_2)]} - [C_w \cdot e^{(-i \cdot t_1)}] \right] \dots + \left[\left[g(t)_3 \cdot e^{[-i \cdot (t_1+t_2+t_3)]} + \int_0^{t_3} \left(\frac{d}{dt_3} \text{NTB}_3(t_3) \right) \cdot e^{-i \cdot t_3} dt_3 \right] \cdot e^{-i \cdot (t_1+t_2)} - CE_{pr} \cdot \text{NTB}_3(t_3) \cdot e^{[-i \cdot (t_1+t_2+t_3)]} - [C_w \cdot e^{[-i \cdot (t_1+t_2)}] \right] \right]$$

$$W_{03}(t) := \frac{\left[\left[g(t)_1 \cdot e^{(-i \cdot t_1)} \right] - (C_p + C_w) \right] + \left[\left[g(t)_2 \cdot e^{[-i \cdot (t_1+t_2)]} \right] - [C_w \cdot e^{(-i \cdot t_1)}] \right] \dots}{1 - e^{[-i \cdot (t_1+t_2+t_3)]}} + \left[\left[g(t)_3 \cdot e^{[-i \cdot (t_1+t_2+t_3)]} \right] - [C_w \cdot e^{[-i \cdot (t_1+t_2)}] \right]$$

Model Explanation: Optimization of Coppice Plantations

Dual Optimization

LEV per hectare: (Interest= 6%, wood value=20\$ dry Mg⁻¹, value of N removal= \$1.00 kg⁻¹):

<i>Number of stages/cycle</i>	<i>Optimum stage length (years)</i>	<i>LEV (\$/ha)</i>	<i>Marginal LEV (\$/ha)</i>
1	2.4	\$ -1,072.00	-
1	2.3	\$ +26.00	\$ 1,098.00
2	2.3		
1	2.3	* \$ +72.00	\$ 46.00
2	2.3		
3	2.2		
1	2.4	\$ -369.00	\$ -44.00
2	2.3		
3	2.3		
4	2.0		

Background Scenario 1: Dendroremediation at Water Conserv II - Winter Garden



- 40% to RIBs
- 72 RIBs
- 1,500 Ha (3,725 acres)
- 14 million gal day⁻¹
- 7 ppm nitrate nitrogen;
- 1 ppm total phosphorus

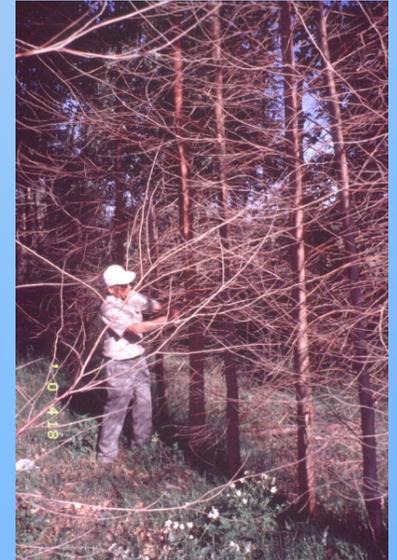
Background 1

Matt Langholtz, ORNL, Jan 21st,
2010

Background Scenario 1: Dendroremediation at Water Conserv II - Winter Garden

E. grandis at WCII:

- ~15 dry Mg ha⁻¹ yr⁻¹ @ 9,500 trees ha⁻¹
- Potential to mitigate nitrates and phosphates.



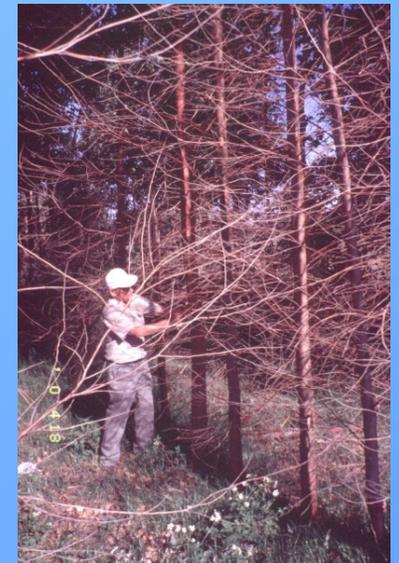
Background Scenario 1: Dendroremediation at Water Conserv II - Winter Garden

Objective:

Assess the impact of incentives for dendroremediation on profitability and management of SRWC culture irrigated with reclaimed water.

E. grandis at WCII:

- ~15 dry Mg ha⁻¹ yr⁻¹ @ 9,500 trees ha⁻¹
- Potential to mitigate nitrates and phosphates.



Model Application: Dendroremediation

NTB functions:

Stock Benefit:
$$NTB_s^S = NTB_s(t)$$

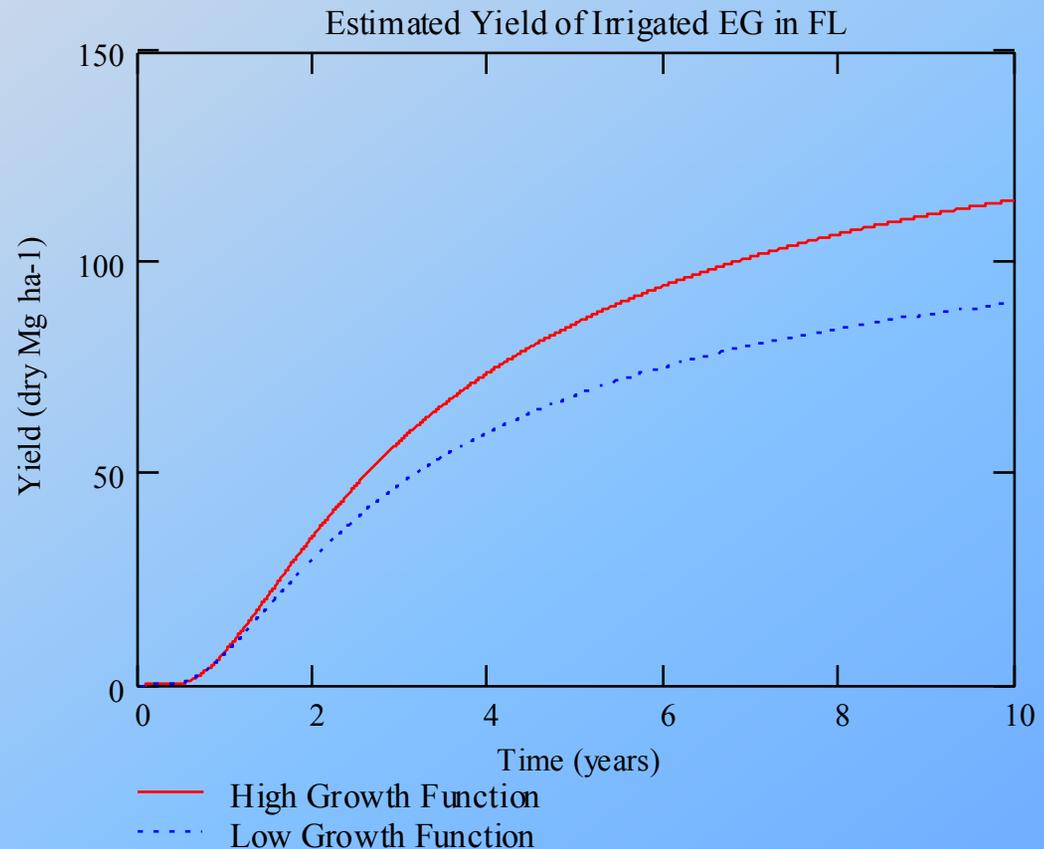
Flow Benefit :
$$NTB_s^F = \left[\int_0^t \left(\frac{d}{dt} (NTB_s(t)) * e^{(-r*t)} \right) dt \right]$$

Model Application: Water Conserv II Scenario

Model components: G&Y

G&Y Function:

- 2nd stage: 80%,
- 3rd state: 65%
- 4th stage 30%



G&Y
Functions

Background 1

Background 2

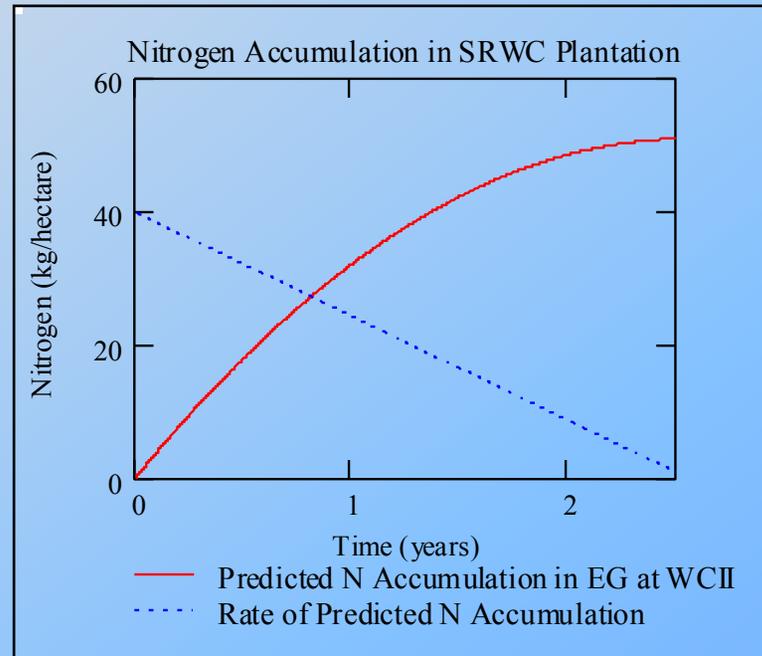
Model
Explanation

Model
Application

Model Application: Water Conserv II Scenario

Model components: Nitrogen Accumulation:

<i>Tree Component</i>	<i>Nitrate Concentration</i>
Stemwood	0.092%
Stem Bark	0.280%
Branches	0.272%
Leaves	1.390%



G&Y
Functions

Externalities

Model
Application

Model Application: Water Conserv II Scenario

Value of Nitrogen Removal

Valuation of N removal (City of Orlando Wastewater Treatment):

Total treatment costs: \$0.88/1,000 gal

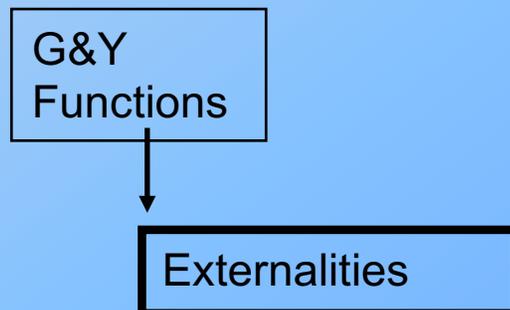
18ppm N removed=68g/1,000 gal

@ 5% of \$0.88/1,000 = ~ \$0.65 kg⁻¹ N

@ 10% of \$0.88/1,000 = ~ \$1.29 kg⁻¹ N

Increasing price of removing scarce N?

Decreasing willing to pay to remove additional N?



Model Application: Water Conserv II Scenario

Assumptions:

Dendroremediation Incentives from \$0-\$3.50 kg⁻¹ N

Planting cost (with planting stock): \$500 Ha⁻¹

Price of mulchwood: \$20 dry Mg⁻¹

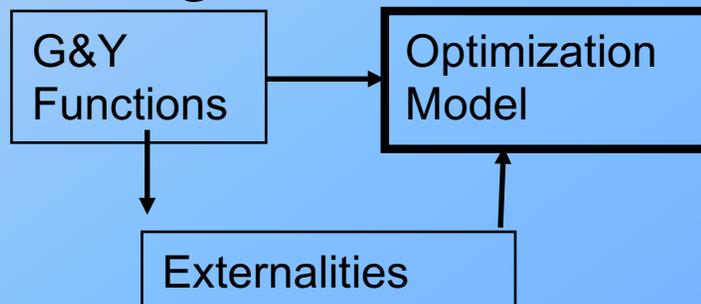
Irrigation Installment: \$2,471 and \$3,707 Ha⁻¹

Interest rate: 4 and 6%

Weed Control at coppice harvest: \$120 Ha⁻¹

Annual Maintenance: \$50 Ha⁻¹

Low and High Estimated Growth Functions



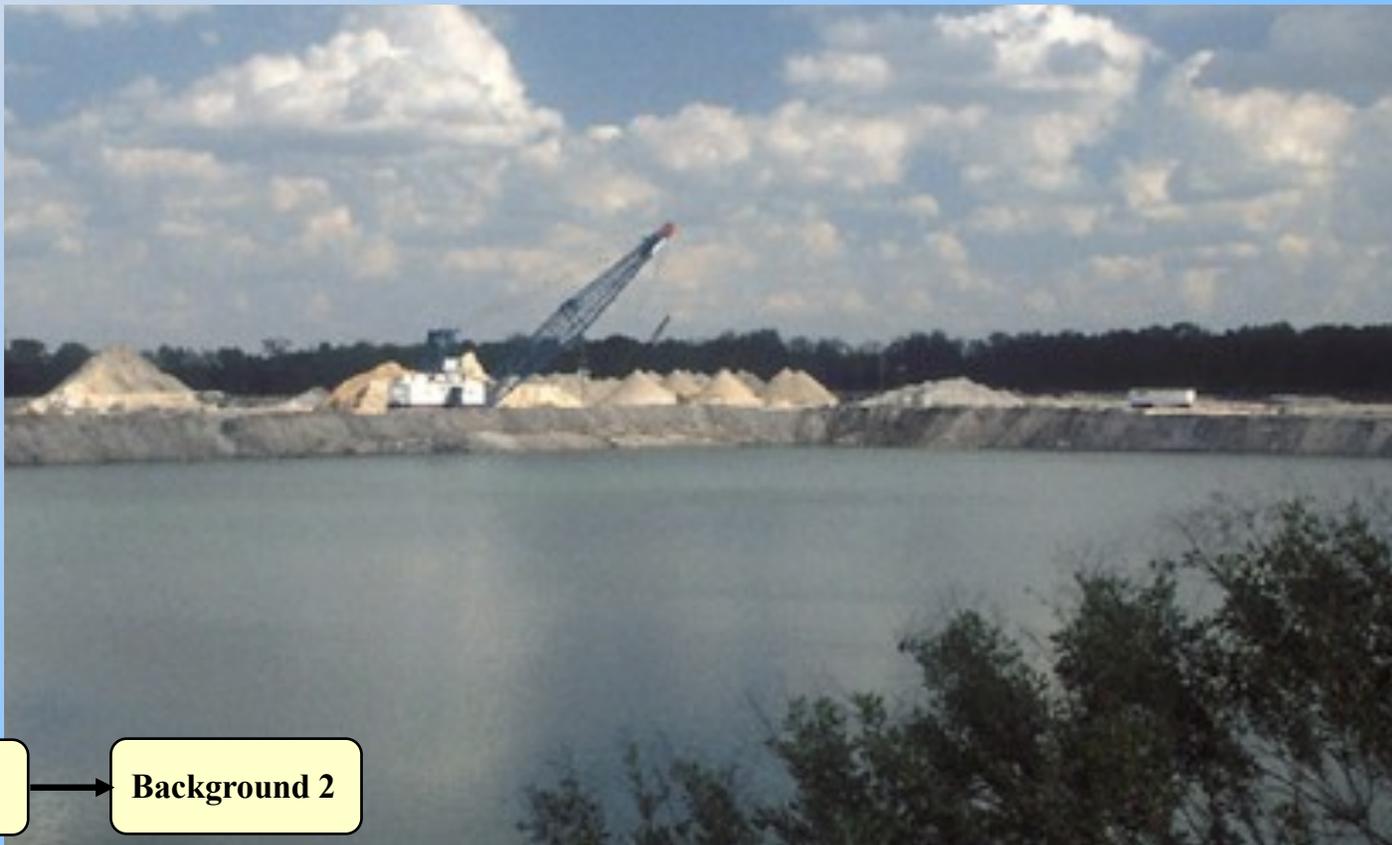
Dendroremediation Scenario: Results

- Every of \$1 kg⁻¹ of N dendroremediation incentive increases LEV by \$206 to \$246 Ha⁻¹ if treated as a stock benefit, or \$246 to \$287 Ha⁻¹ if treated as a flow benefit.
- The LEV of the *Eucalyptus grandis* SRWC system is likely to be negative without compensation for N dendroremediation, depending largely on irrigation costs and productivity.

Langholtz, M., D. R. Carter, et al. (2005). "Effect of dendroremediation incentives on the profitability of short-rotation woody cropping of *Eucalyptus grandis*." Forest Policy and Economics 7(5): 806-817.

Background Scenario 2: Mined land reclamation and CO₂ mitigation using SRWCs

- 162,000 ha (400,000 ac) of phosphate-mined lands in Florida.
- 75% of the nation's and 25% of the world's phosphate supply (IMC Phosphates, 2002).



Background 1

Background 2

Background Scenario 2: CO₂ mitigation on CSAs using SRWCs

>40,000 ha (100,000 acres) of CSA lands in Central Florida.



Background 1

Background 2

Background Scenario 2: CO₂ mitigation on CSAs using SRWCs

Objective:

Assess the impact of incentives for CO₂ mitigation on profitability and management of SRWC culture on CSAs.



Background 1

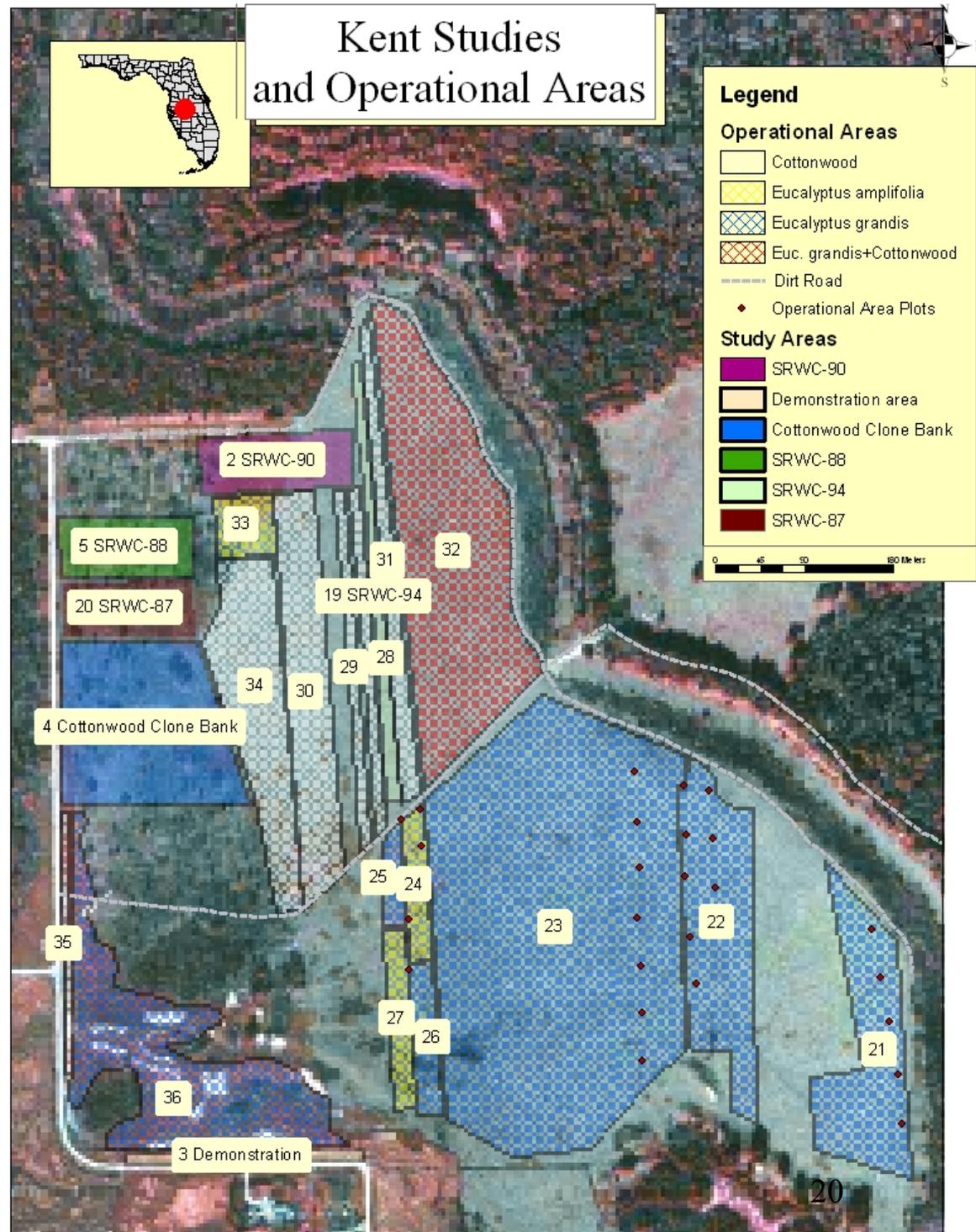
Background 2

Model Application: CO₂ mitigation on CSAs using SRWCs

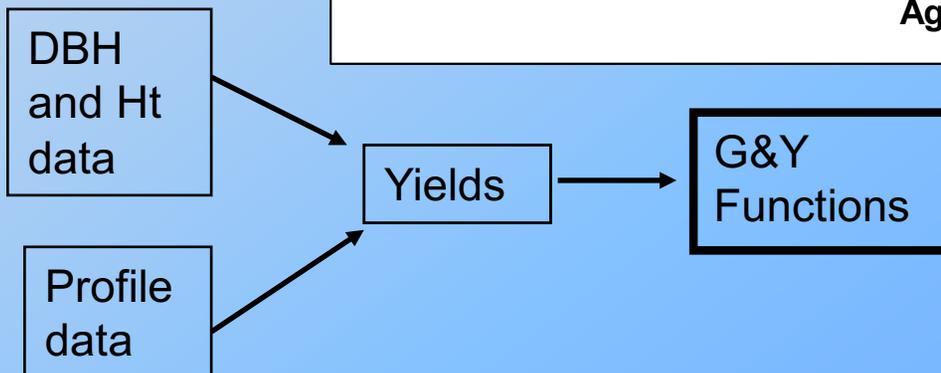
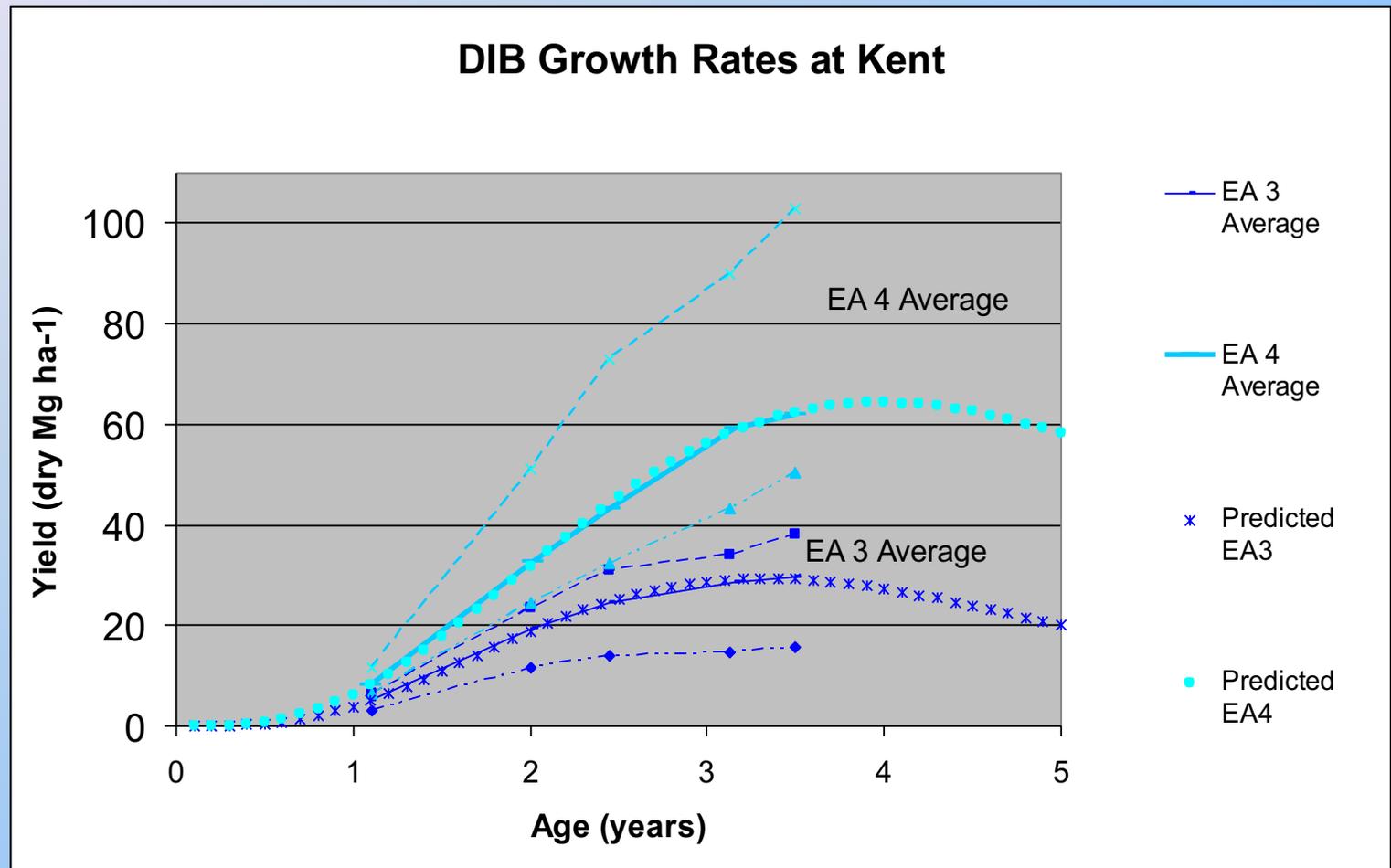
- SRWC-90, EG, EA; June 2001
- Area 22: EG, June 2002
- Area 23: EG, June 2001
- Demonstration area, EG, EA, and CW, April 2001

DBH
and Ht
data

Model
Application



Model Application: CO₂ mitigation on CSAs using SRWCs



Model Application: CO₂ mitigation on CSAs using SRWCs

C Sequestration

(mulch):

$$NTB_s^M = \left[\int_0^t \left(\frac{d}{dt} (C_{b_s}(t)) * e^{(-r*t)} \right) dt \right] - \left[\frac{C_{b_s}(t)}{5} * \left(\frac{1 - e^{(-r*5)}}{r} \right) \right] * e^{(-r*t)}$$

C Sequestration

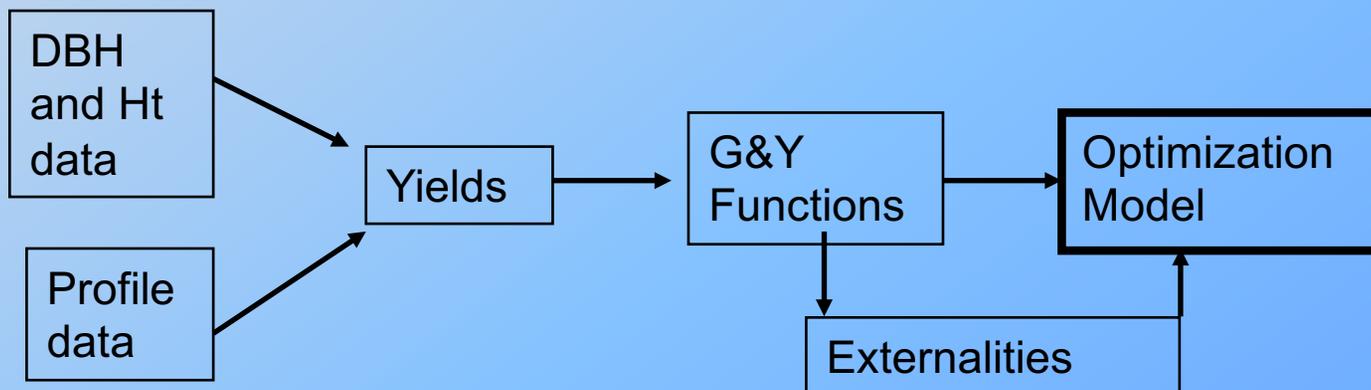
(biofuels):

$$NTB_s^{BF} = \left[\int_0^t \left(\frac{d}{dt} (C_{b_s}(t)) * e^{(-r*t)} \right) dt \right] - \left[(0.1 * C_{b_s}(t)) \right] * e^{(-r*t)}$$

Model Application: CO₂ mitigation on CSAs using SRWCs

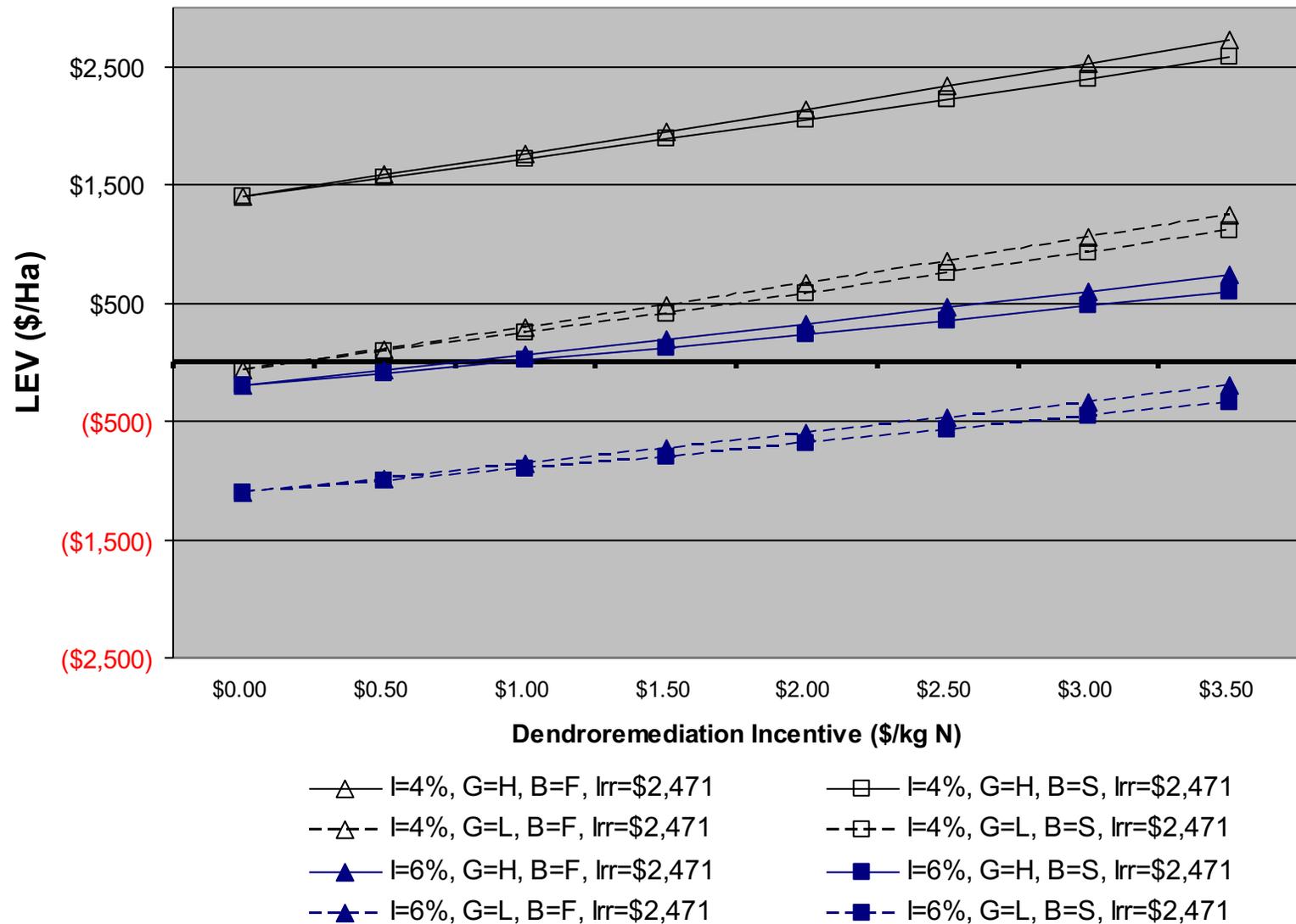
Assumptions:

- Stumpage prices: \$10, \$20, and \$30 dry Mg⁻¹.
- Site Preparation: \$900 and \$1,800 ha⁻¹.
- Planting cost: \$600 and \$1,200 ha⁻¹.
- Weed control: \$0 and \$200 ha⁻¹ stage⁻¹.
- Growth and Yield: Low (EA 3) and High (EA 4).
- Scenarios: No NTB, NTB (Mulch), and NTB (Biofuels)
- C Price: \$0, \$5, and \$10 Mg⁻¹ C



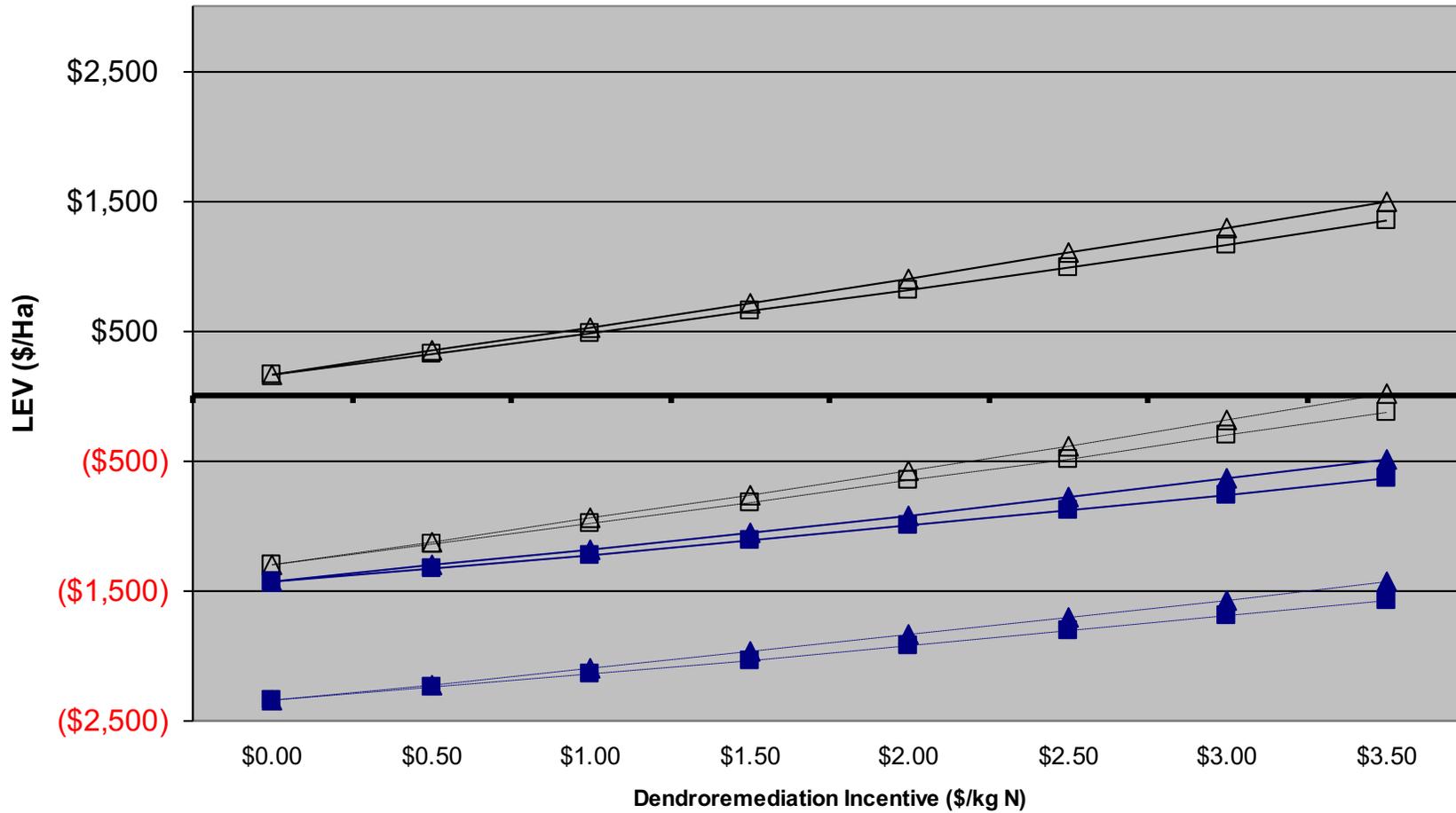
Model Application: Water Conserv II Scenario

LEVs (\$/ha) as a function of Dendroremediation Incentive



Model Application: Water Conserv II Scenario

LEVs (\$/ha) as a function of Dendroremediation Incentive



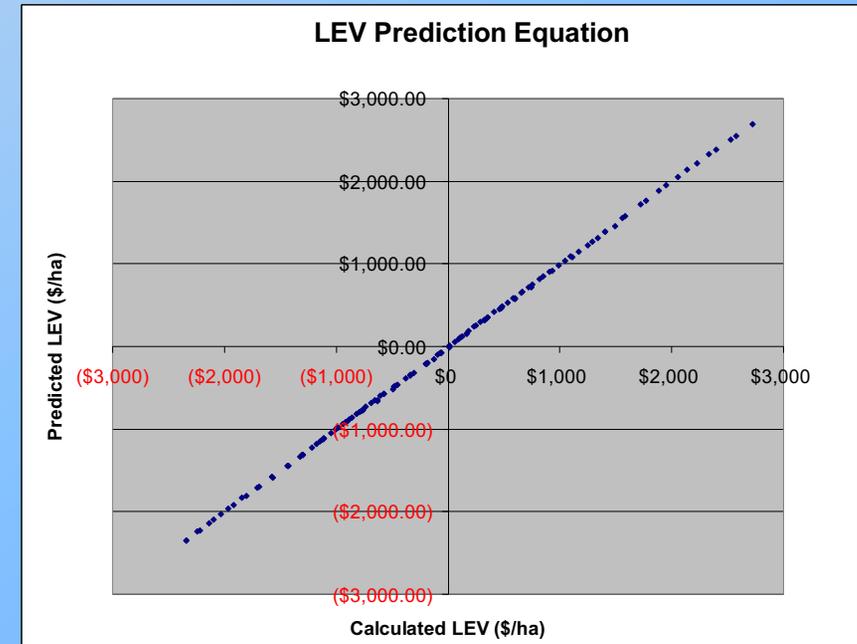
- △— I=4%, G=H, B=F, Irr=\$3,707
- △— I=4%, G=L, B=F, Irr=\$3,707
- ▲— I=6%, G=H, B=F, Irr=\$3,707
- ▲— I=6%, G=L, B=F, Irr=\$3,707
- I=4%, G=H, B=S, Irr=\$3,707
- I=4%, G=L, B=S, Irr=\$3,707
- I=6%, G=H, B=S, Irr=\$3,707
- I=6%, G=L, B=S, Irr=\$3,707

Model Application: Water Conserv II Scenario

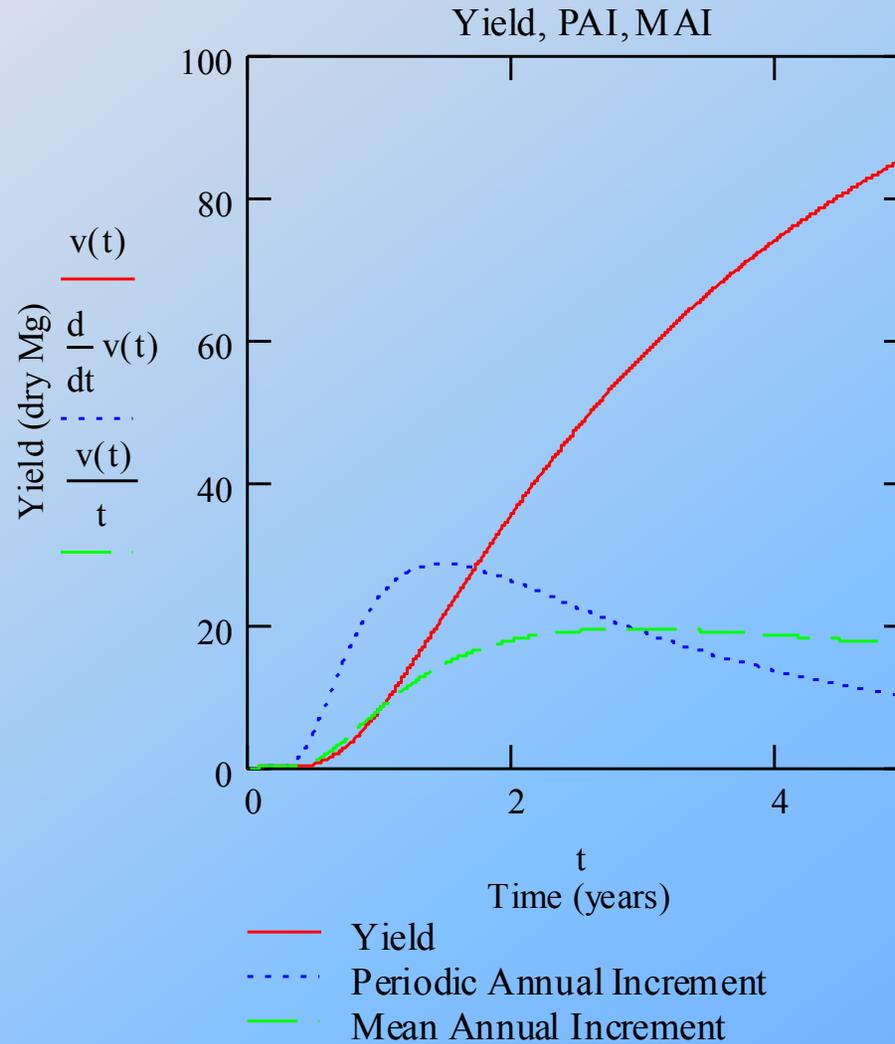
Condensed Prediction Equation

$$LEV(I, g, Y, v, N) = \left(\beta_0 * e^{-\beta_1 * I} + g * \beta_2 * e^{-\beta_3 * I} - Y \right) + \left(\beta_4 * e^{-\beta_5 * I} + \beta_6 * v + g * \beta_7 * e^{\beta_8 * I} \right) * N + \varepsilon$$

Variable	Value
I	Real interest rate.
g	Growth model, $-1 \leq g \leq 1$, where -1 and 1 represent the low and high growth, respectively, as represented in Figure 1.
Y	Price of irrigation establishment, $\$ \text{ ha}^{-1}$
v	0=stock benefit calculation, 1=flow benefit calculation
N	Value of N dendroremediation benefit, $\$ \text{ kg}^{-1}$.

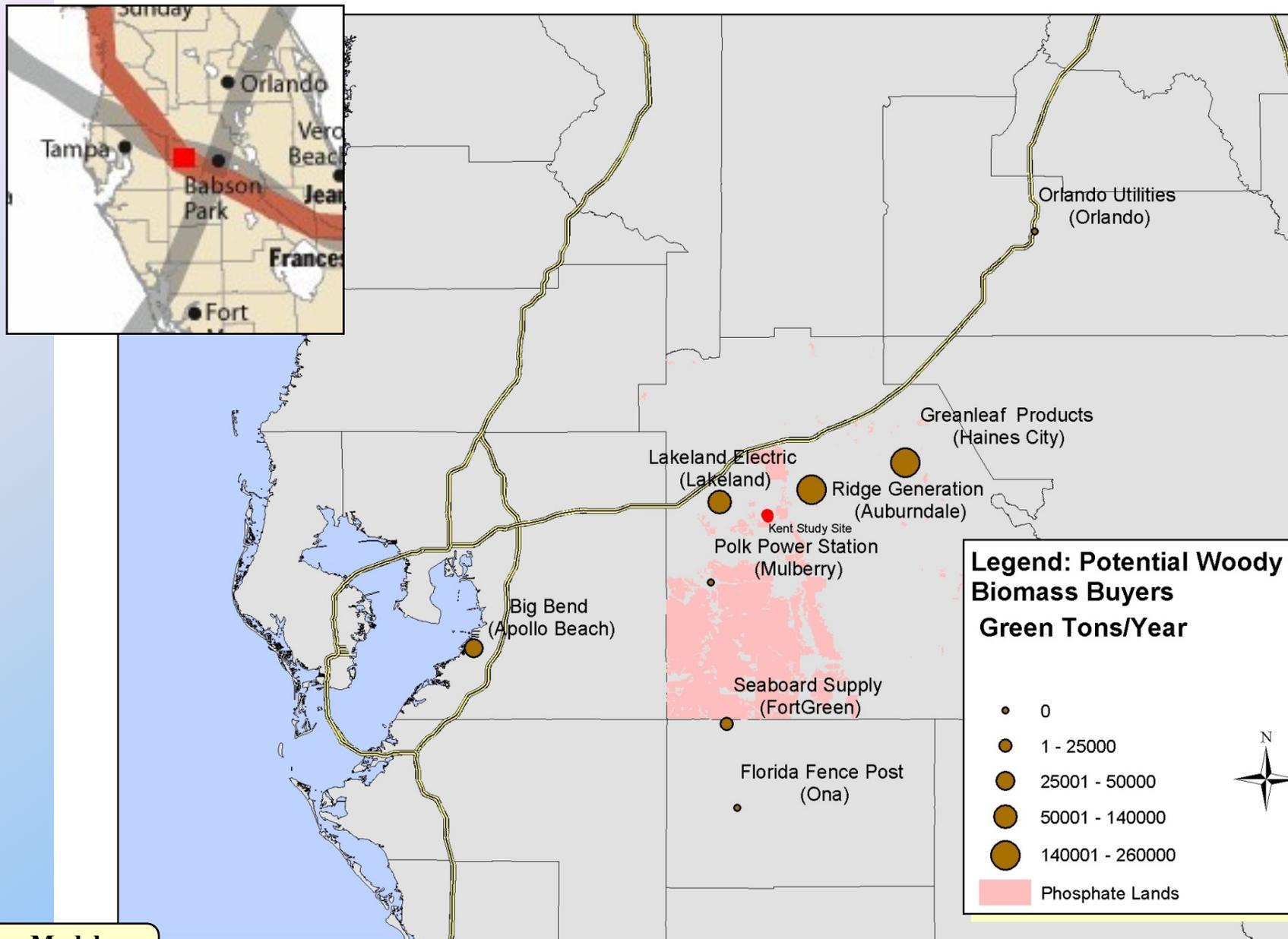


Model Application: Water Conserv II Scenario



$$V_{\max} = 2.9$$

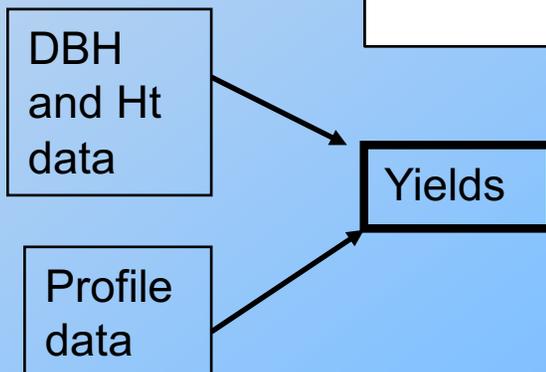
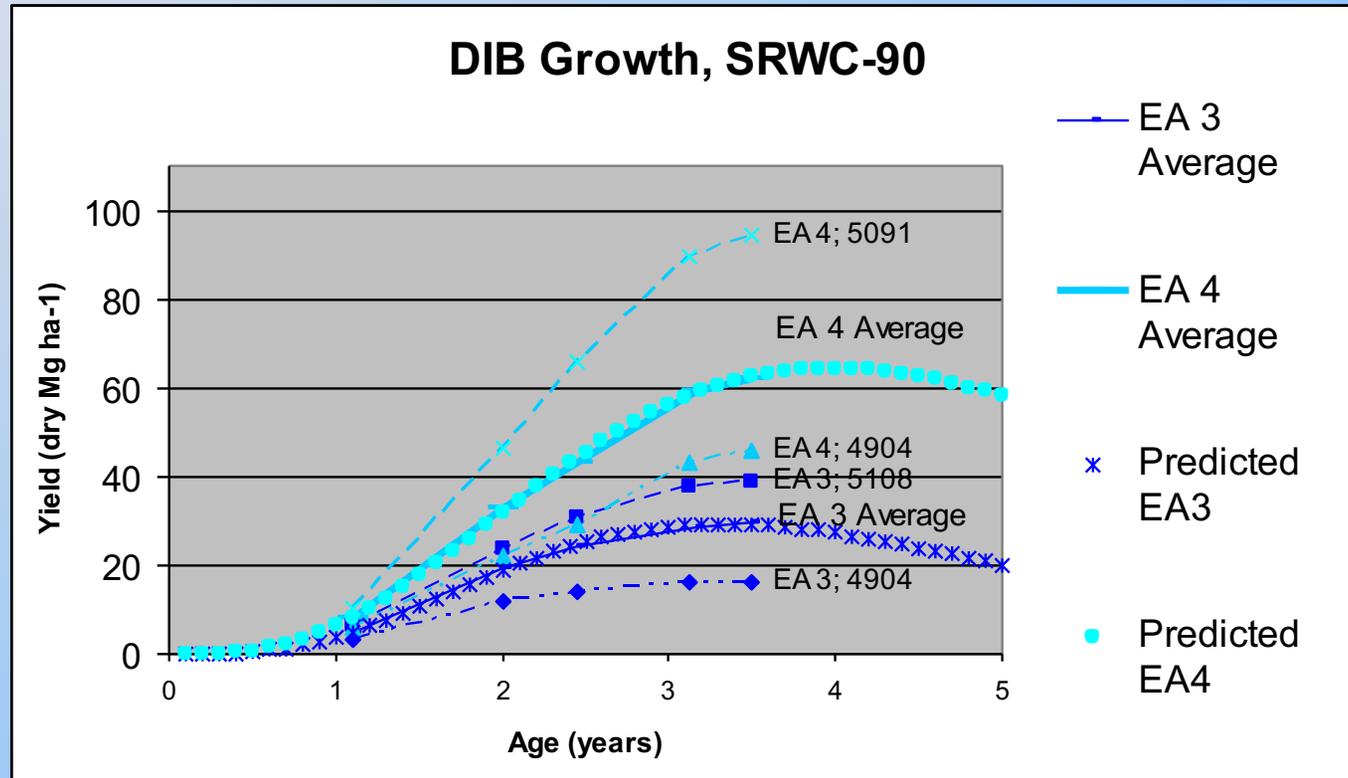
Model Application: CO₂ mitigation on CSAs using SRWCs



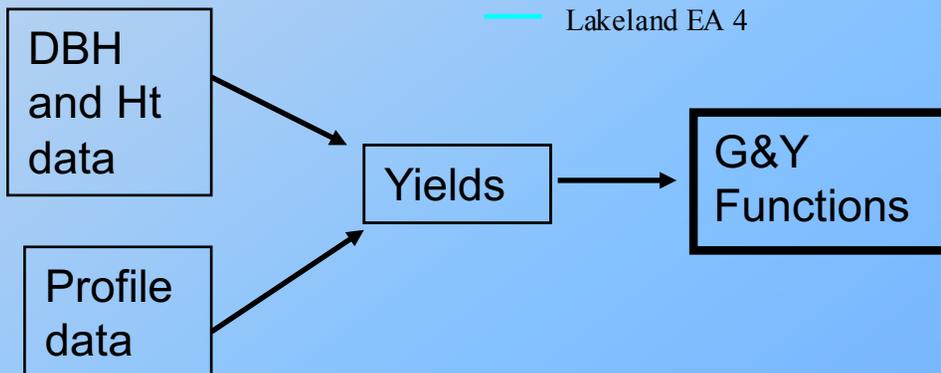
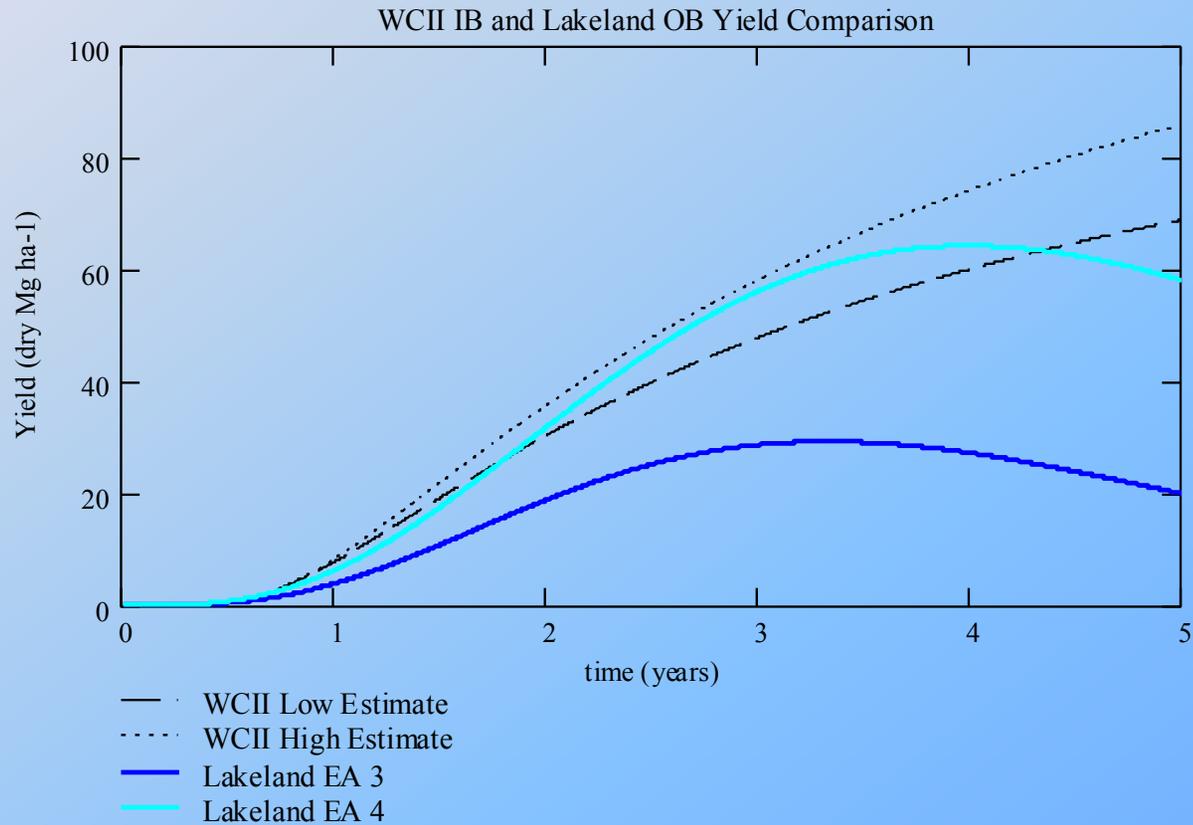
Model Application

tt Langholtz, September 2004

Model Application: CO₂ mitigation on CSAs using SRWCs



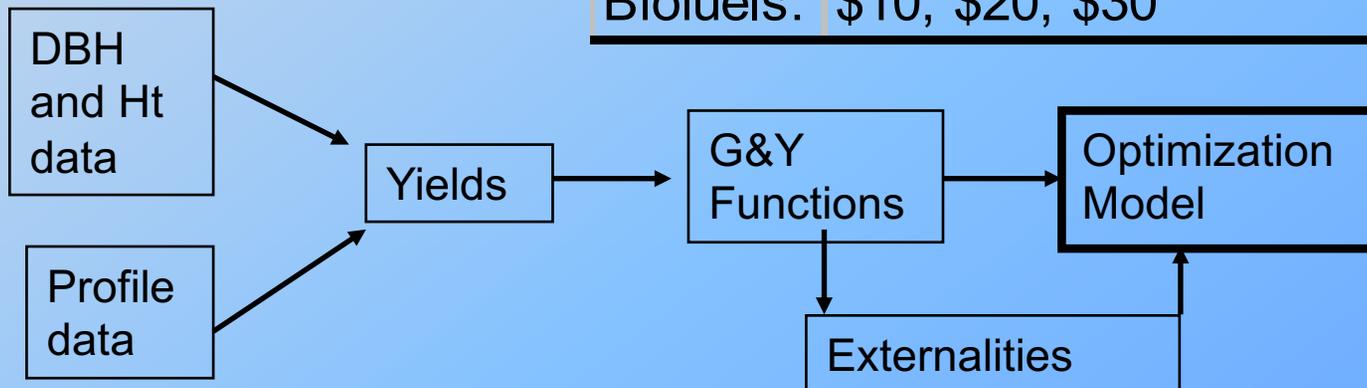
Model Application: CO₂ mitigation on CSAs using SRWCs



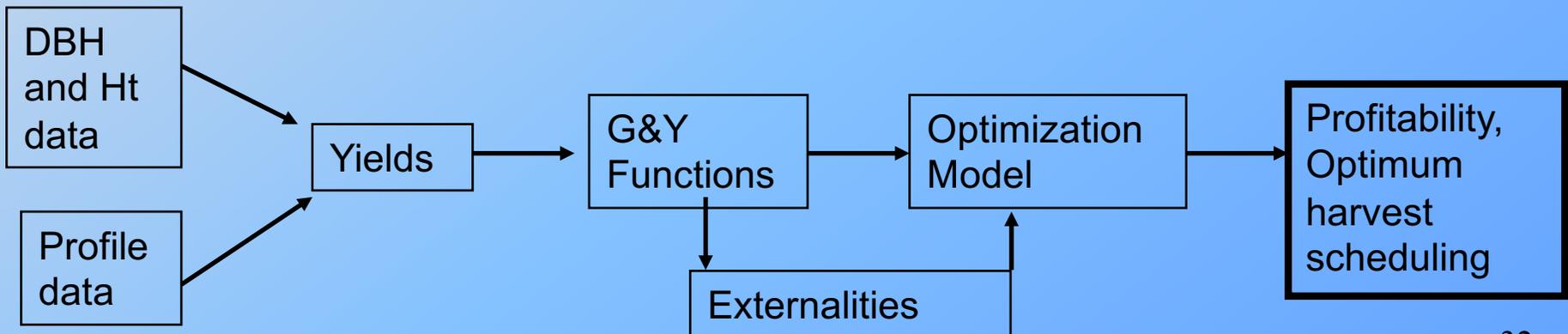
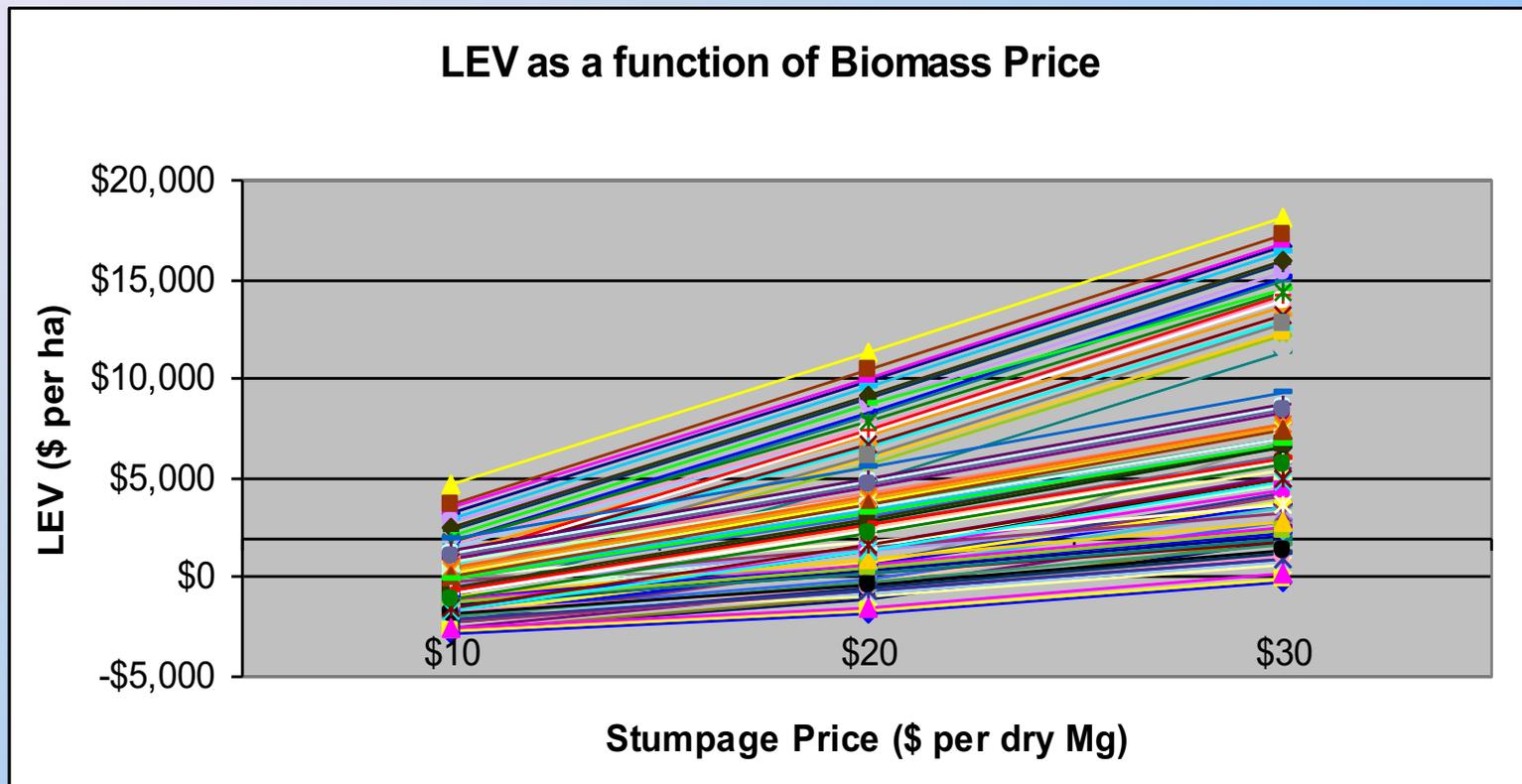
Model Application: CO₂ mitigation on CSAs using SRWCs

<i>Product</i>	<i>¢/kWh</i>	<i>\$/green ton</i>	<i>\$/dry Mg</i>
Mulch (low)		\$8	\$18
Mulch (high)		\$16	\$35
Biofuels (delivered, coal equivalent)		\$15	\$34
Biofuels (stumpage, coal equivalent)		\$0	\$0
Renewable Energy Marketing (delivered)	2.5 ¢	\$18	\$41
REPI (delivered)	1.76 ¢	\$13	\$29
Section 45 (delivered)	2.75 ¢	\$20	\$45
High Biofuels (delivered, renewable+Sec 45)		\$39	\$85

	<i>\$/dry Mg, Stumpage</i>
Mulch:	\$10 and \$20
Biofuels:	\$10, \$20, \$30

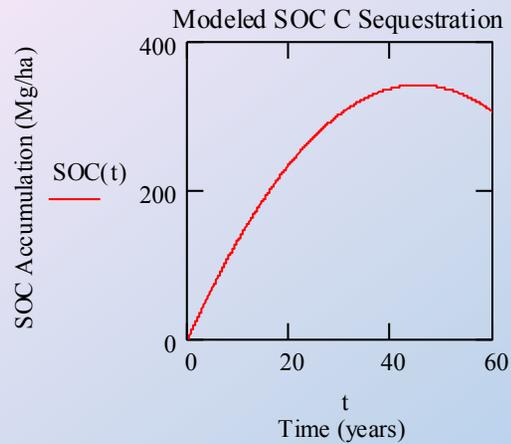


Model Application: CO₂ mitigation on CSAs using SRWCs



Model Application

SOC



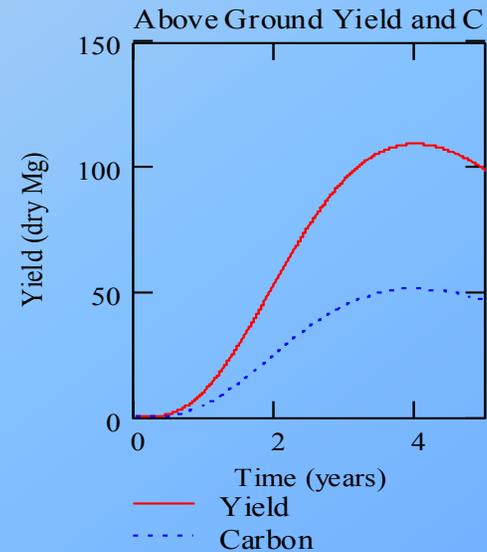
$$SOC_{max} = 45$$

$$SOC(SOC_{max}) = 341$$

$$\frac{SOC(SOC_{max})}{SOC_{max}} = 7.5$$

C Sequestration vs. C Mitigation:

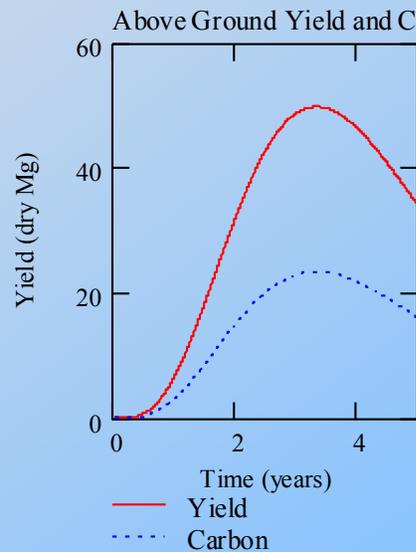
Above ground (high growth)



$$C_m(3.2) = 47$$

$$\frac{C_m(3.2)}{3.2} = 14.8$$

Above ground (low growth)



$$C_m(2.9) = 23$$

$$\frac{C_m(2.9)}{2.9} = 7.8$$

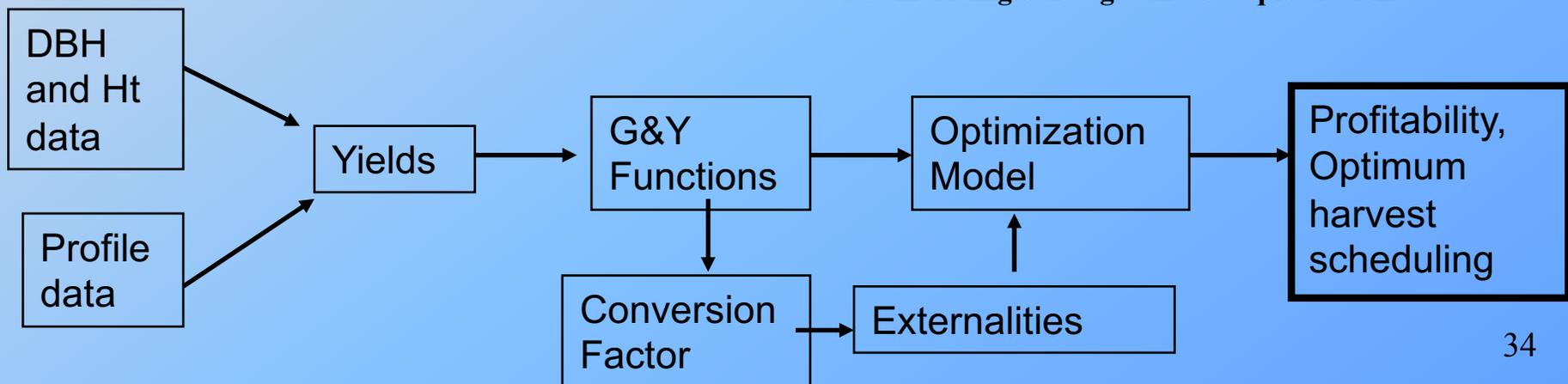
Model Application

Model Application: CO₂ mitigation on CSAs using SRWCs

Interest 4%, Site prep \$1,800 ha⁻¹, Planting \$1,200 ha⁻¹, C \$5 Mg⁻¹

NTB	Growth	\$10/dry Mg		\$20/dry Mg		\$30/dry Mg	
		LEV (\$/ha)	Harvest age (years)	LEV (\$/ha)	Harvest age (years)	LEV (\$/ha)	Harvest age (years)
None	Low	-1,967	3.1, 3.1, 3.2, 3.3, 3.4	674	2.9, 2.9, 2.8, 2.6	3,722	2.8, 2.8, 2.6
C(M)	Low	-1,883	3.1, 3.1, 3.2, 3.2, 3.3	771	2.9, 2.9, 2.8, 2.6	3,828	2.8, 2.8, 2.6
C(B)	Low	-1,424	3.0, 3.1, 3.1, 3.1, 2.9	1,320	2.9, 2.9, 2.8, 2.6	4,448	2.8, 2.8, 2.6
None	High	619	3.4, 3.4, 3.3, 3.0	6,507	3.2, 3.1, 2.9	12,960	3.2, 3.0
C(M)	High	810	3.4, 3.4, 3.3, 3.0	6,715	3.2, 3.1, 2.9	13,140	3.2, 3.0
C(B)	High	1,832	3.4, 3.4, 3.3, 2.9	7,869	3.2, 3.1, 2.9	14,419	3.1, 3.0

* Not including below ground C sequestration.



Response to Changes in C Price

Stumpage price \$20 dry Mg⁻¹, Interest 4%, Site prep \$1,800 ha⁻¹, Planting \$1,200 ha⁻¹

Mulch scenario:				
\$/Mg C	LEV (\$/ha)	Optimum Stage Lengths (years)	Marginal Benefit (LEV increment per \$ Incentive)	Below Ground (\$/ha)
0	6,507	3.2, 3.1, 2.9		n/a
5	6,715	3.2, 3.1, 2.9	42	1,163
15	7,131	3.3, 3.1, 2.9	42	3,492
25	7,548	3.3, 3.2, 2.9	42	5,819
35	7,965	3.3, 3.2, 2.9	42	8,097

Biofuels scenario:				
\$/Mg C	LEV (\$/ha)	Optimum Stage Lengths (years)	Marginal Benefit (LEV increment per \$ Incentive)	Below Ground (\$/ha)
0	6,507	3.2, 3.1, 2.9		n/a
5	7,869	3.2, 3.1, 2.9	272	1,163
15	10,598	3.2, 3.1, 2.8	273	3,492
25	13,505	3.1, 3.0	291	5,819
35	16,422	3.1, 3.0	292	8,097

Sensitivity Analysis:

- CO₂ Mitigation: 1\$ increase Mg⁻¹ C incentive increases LEV by \$17-\$42 (mulch) or \$109-\$292 (biofuels), +~\$249 for below ground sequestration (\$ ha⁻¹).
- Stumpage Price: 1\$ increase dry Mg⁻¹ \$284-\$629 ha⁻¹.
- Growth and Yield: High growth increases LEV by \$2,586-\$9,971 ha⁻¹.
- Interest rate: 1% increase decreases LEV by \$142-\$2,581 ha⁻¹
- Planting Cost: \$100 cost increase decreases LEV by \$289-\$467 ha⁻¹.
- Decreased harvest costs=~increased stumpage value.

Results: SRWC on CSAs

- SRWC production likely profitable ($LEV > 0$) assuming stumpage value \$20 dry Mg^{-1} .
- LEVs ranging from \$762 to \$6,507 ha^{-1} assuming discount rates of 10% and 4%, respectively.

Langholtz, M., D. R. Carter, et al. (2007). "The economic feasibility of reclaiming phosphate mined lands with short-rotation woody crops in Florida." Journal of Forest Economics 12(4): 237-249.

Results: CO₂ mitigation on CSAs using SRWCs

- CO₂ mitigation incentives of \$5 Mg⁻¹ C increase LEVs \$84-191 ha⁻¹ for mulch and \$543-1,459 ha⁻¹ for biofuels.
- At C prices up to \$15 Mg⁻¹ C, influence of CO₂ mitigation incentives on optimum coppice stage lengths is not operationally significant.

Langholtz, M., D. Carter, et al. (2009). "The Influence of CO₂ Mitigation Incentives on Profitability of Eucalyptus Production on Clay Settling Areas in Florida." Biomass and Bioenergy 33(5): 785-792.

Where do we go?

- Related interests: BETO gulf hypoxia workshop
- CBW water quality-bridge the gap between WTP and WTA?
- USDA environmental markets
- Local governments?

SRWC DSS

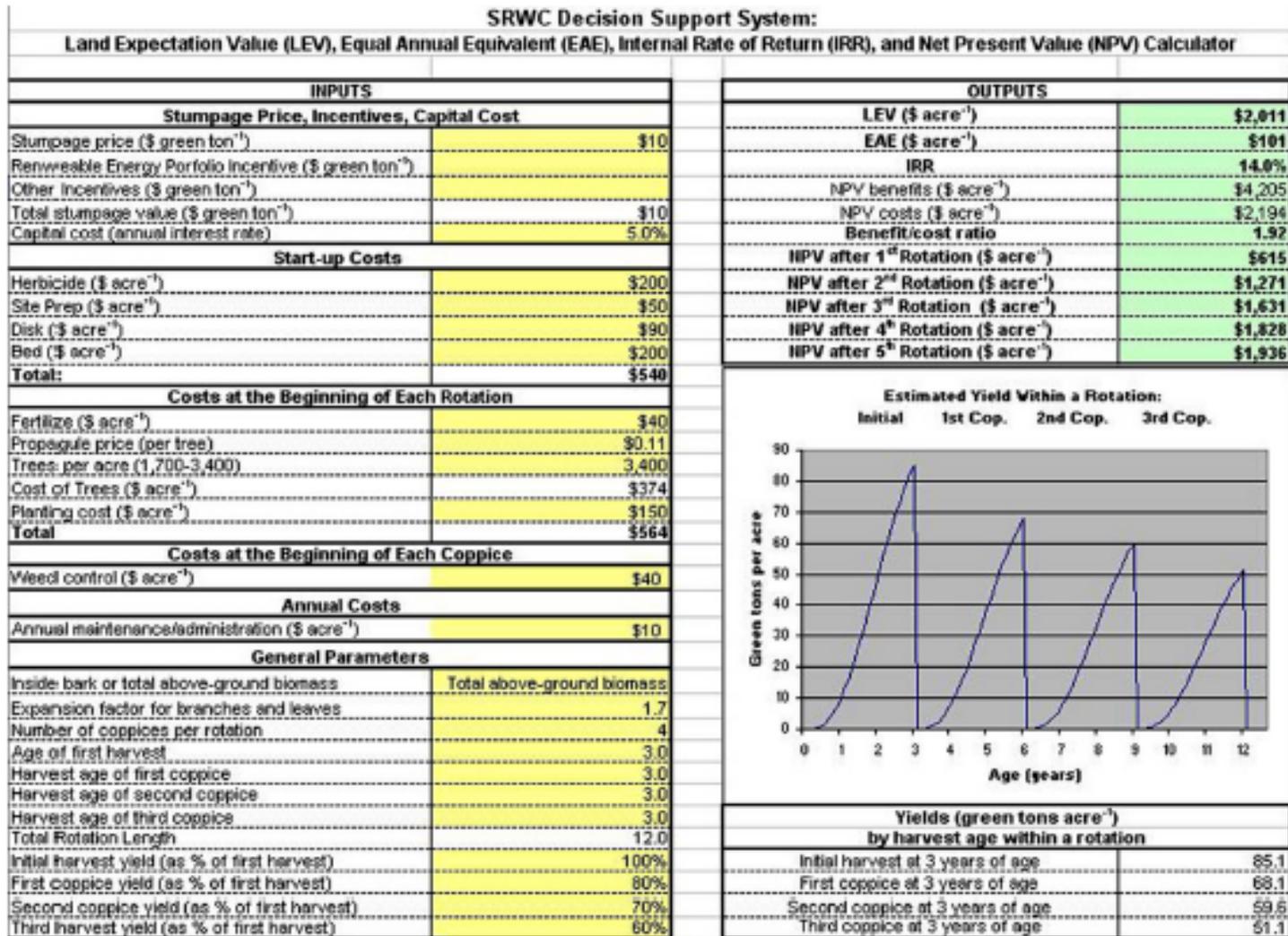


Figure 1. The SRWC Decision Support System spreadsheet.



Questions?

Matt Langholtz, ORNL, Jan 21st,
2010