NSERC Strategic Network
optimizing the forest bioeconomy

VCO
Value Chain Optimization

Rethinking the Strategic Model

Eldon Gunn, Andrew Martin, Evelyn Richards, Narges Sereshti
Department of Industrial Engineering
Dalhousie University

VCO Network members

NSERC
CRSNG

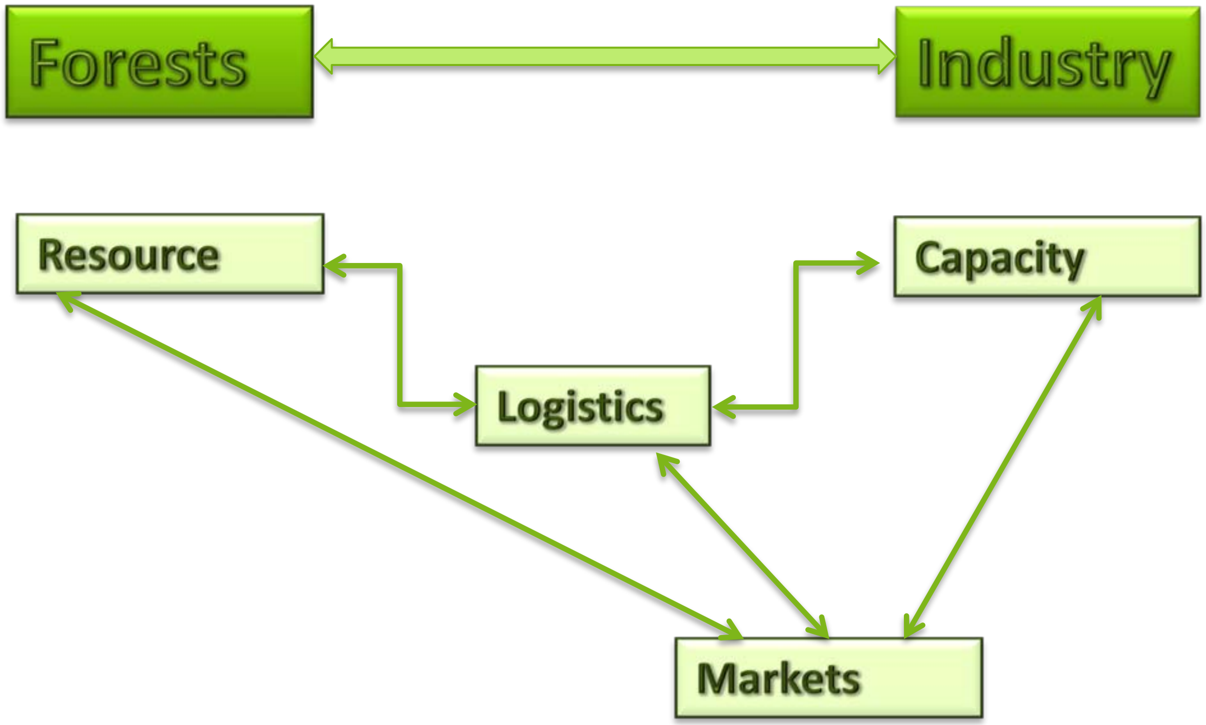
Abstract

If, in addition to its role in evaluating and planning landscape level ecosystem strategies, the strategic forest management modelling involves wood supply to the forest industry, then it seems obvious that it needs to include a reasonable representation of the industry capacity and how it might change over time. This paper discusses what this means for the mathematical structure for the model. We also raise questions about the appropriate time horizon for analysis. There are good reasons that this time horizon should be much shorter than it has been conventionally.

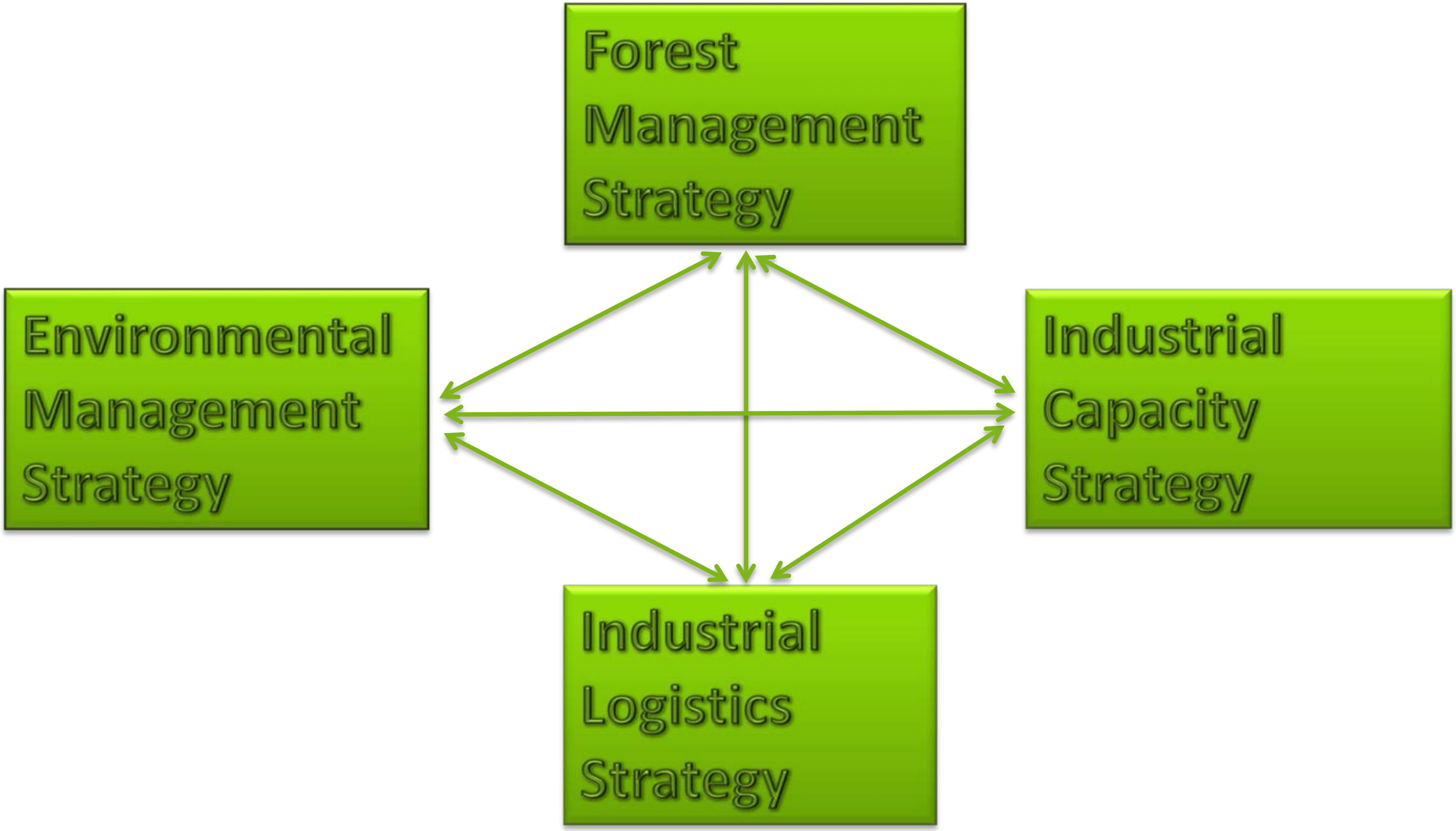
Organization

- Recent work looking at spatial content of strategic model
- Some comments on forest strategy

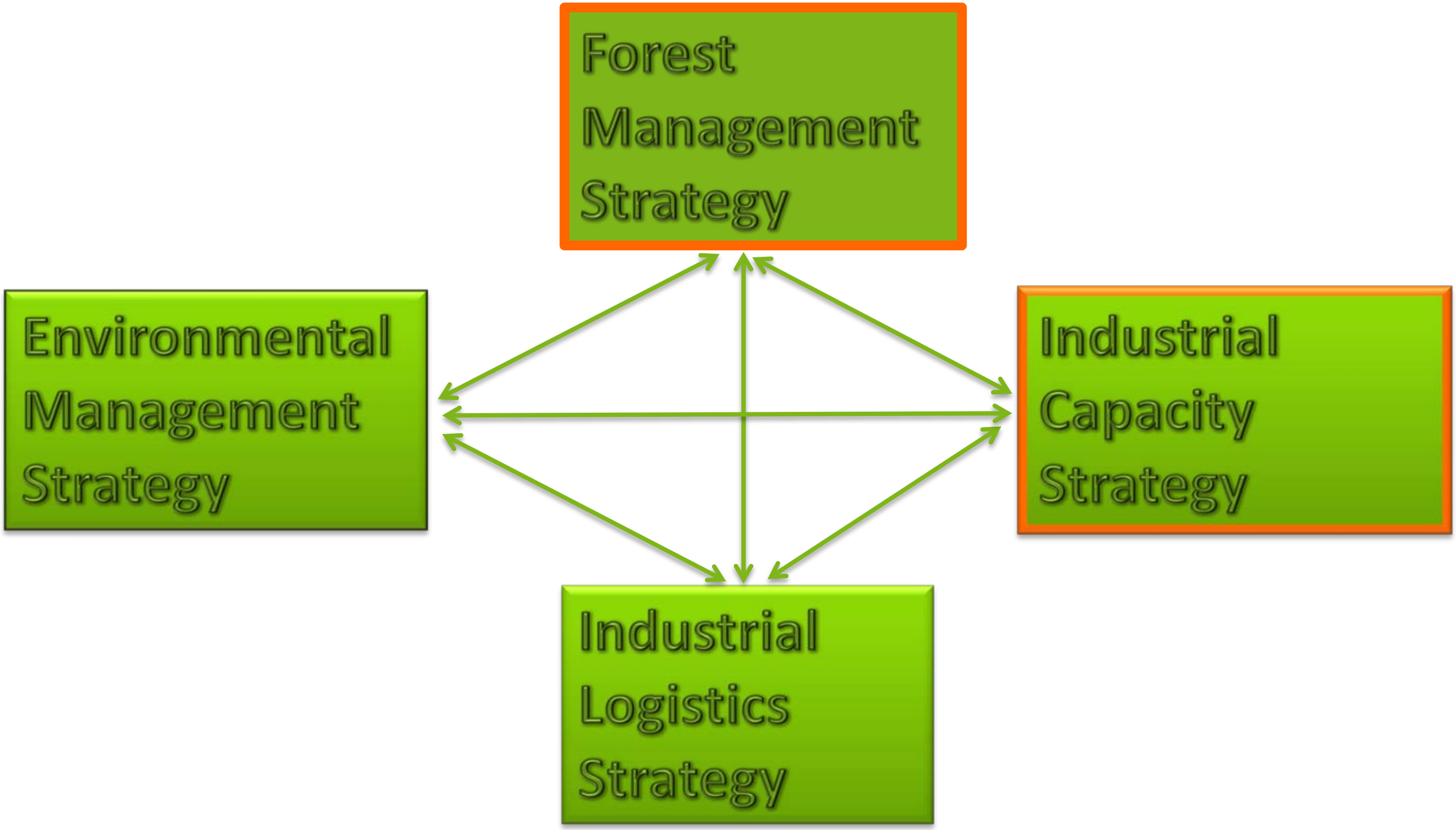
FOREST INDUSTRY



Strategy Areas



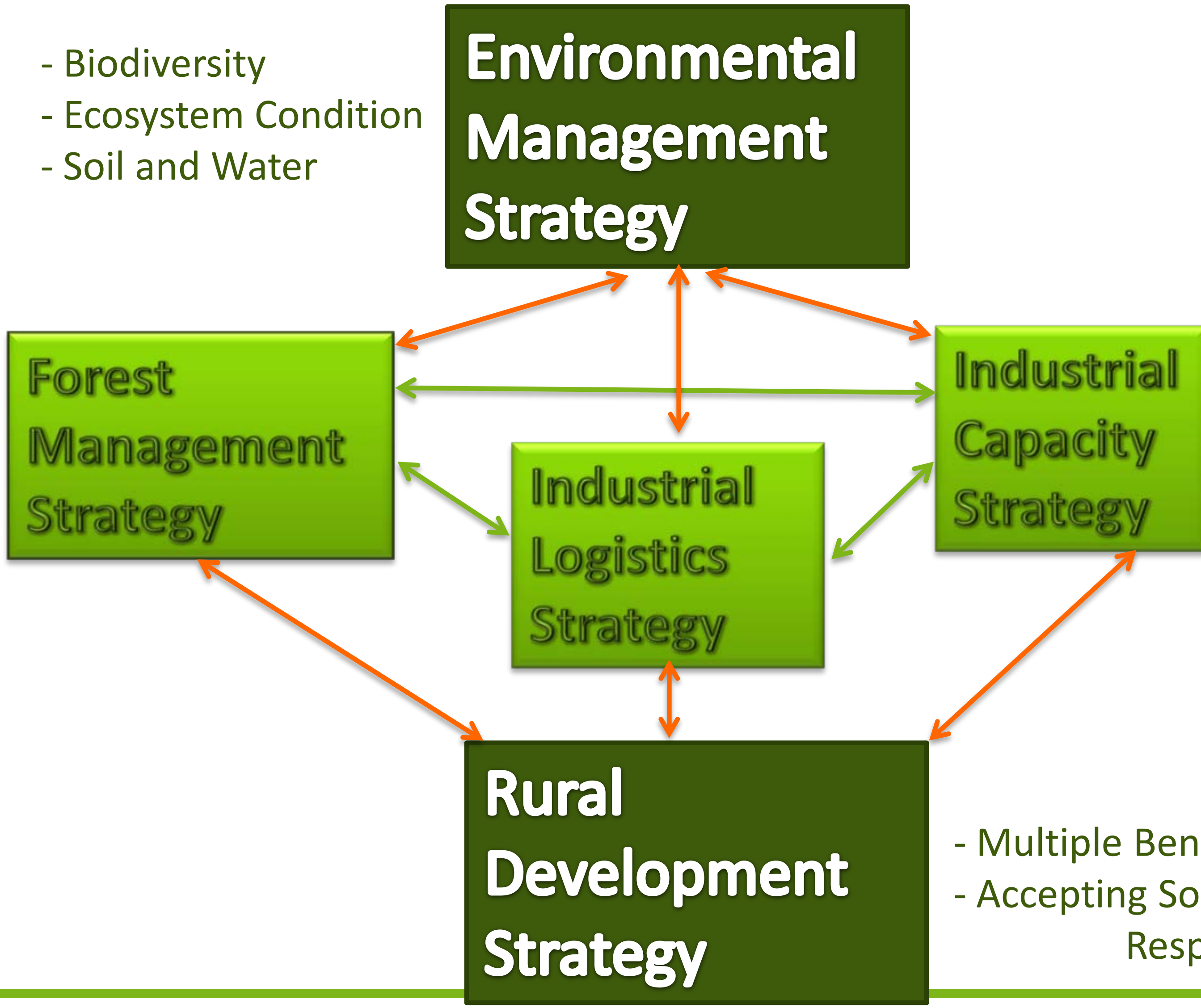
Strategy Areas



Public Policy Strategy Areas

- Global Cycles

- Biodiversity
- Ecosystem Condition
- Soil and Water

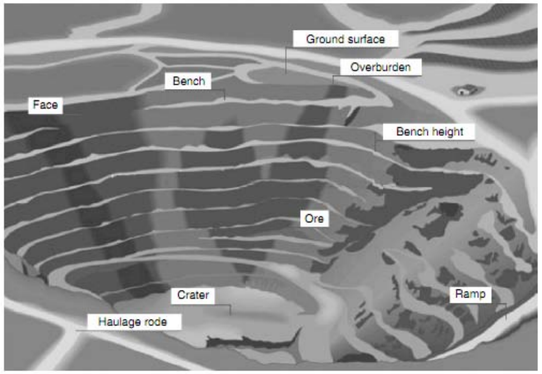


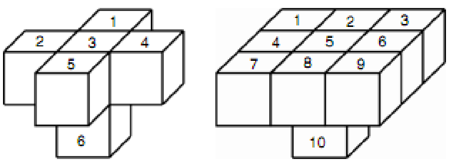
- Multiple Benefits
- Accepting Societies Responsibility

Mineral Resource Development - a digression

- To claim that a resource exists under NI-43-101 must demonstrate
  - How it will be accessed
  - How it will be processed
  - That it is profitable under a reasonable scenario of
    - Mineral prices
    - Exchange rates
    - Operating costs
    - Capital costs

Mine Resource Definition Model





$$V^k = C(Cap^k) + \frac{1}{(1+i)^{T^k}} RCst(Z)$$

$$+ \left(\begin{array}{l} Max \sum_{t=1,T^k} \sum_{b \in B} \frac{1}{(1+i)^t} \left[\left(v_t\left(g_b^k O_b\right) - m_t^k(O_b) - h_t^k(O_b) \right) Z_{bto} + \left(-m_t^k(O_b) - d_t^k(O_b) \right) Z_{btw} \right] \\ S.T. \quad \sum_{t=1,T^k} \sum_{a \in \{o,w\}} Z_{bta} \le 1 \quad b \in B \\ \qquad \sum_{a \in \{o,w\}} Z_{bta} \le \sum_{\tau \le t} Z_{\beta ta} \quad \beta \in P(b),\ b \in B,\ t = 2, T^k \\ \qquad \sum_{b \in B} \rho_t^k(O_b) Z_{bto} \le Cap_t^k \quad t = 1, T^k \end{array} \right)$$

O_b	amount of ore in block b
g_b^k	ore recovery rate under mill scenario k
$v_t(g_b^k O_b)$	value of the recovered ore, block b period t, mill scenario k
$m_t^k(O_b)$	mining costs, block b period t, mill scenario k
$h_t^k(O_b)$	handling/ processing costs, block b period t, mill scenario k
$d_t^k(O_b)$	disposal costs (waste), block b period t, scenario k

Z_{bta} action a is taken on block b in period t
actions o- ore and w- waste.

$C(Cap^k)$	capital cost
$RCst(Z)$	restoration cost

Features of Model

- Need to account for sequence of mine developments and cash flows over time
- Need to remove less valuable blocks to access more valuable blocks
- Need to account for capacity of processing facilities
- Need to account for land restoration costs after mining

- Many of these features have some commonality with forestry

What is the Case for Considering Demand When Setting Supply Levels

- Supply models have assumed that:
  - Certain stand types are harvested in order to achieve regeneration
  - Everything harvested in model is counted as “supply”
  - Access costs and timing of access don’t matter
  - Transport costs of supply to demand don’t matter
  - Variability in location, cost, wood quality don’t matter

- Demand depends on
  - Markets
  - Industrial capacity
    - Amount
    - Wood Species, Types, Quality
  - Location of Capacity
    - Relative to harvest
    - Relative to other mills
  - Cost of acquisition
    - Access, harvest, transportation
  - Collaboration of users

Short Message

- If forest management plans use unrealistic harvest scenarios that don't meet industrial needs,
- the plans won't come true

- If industrial harvests are inconsistent with the forest management plans,
- the plans won't come true

Complications:
Joint Economics :Who pays, Who benefits?

- Access roads
  - (first in?)
- Harvest
  - logs, stud, pulp, biomass, mixed species stands?
- Logistics
  - sorting, information and trucking?
- “Byproducts”
  - Biomass, chips, sawdust, shavings, bark

Complications: Now vs Future

Harvest Now

- Low cost stands
- Well located stands
- Pure stands
- High quality stands

Harvest later

- High cost stands
- Poorly located stands
- Mixed wood stands
- Low Quality Stands

Economics (NPV) work ⇔ Business model doesn't work

Forest Management Strategy Industrial Capacity Strategy — Some Issues !

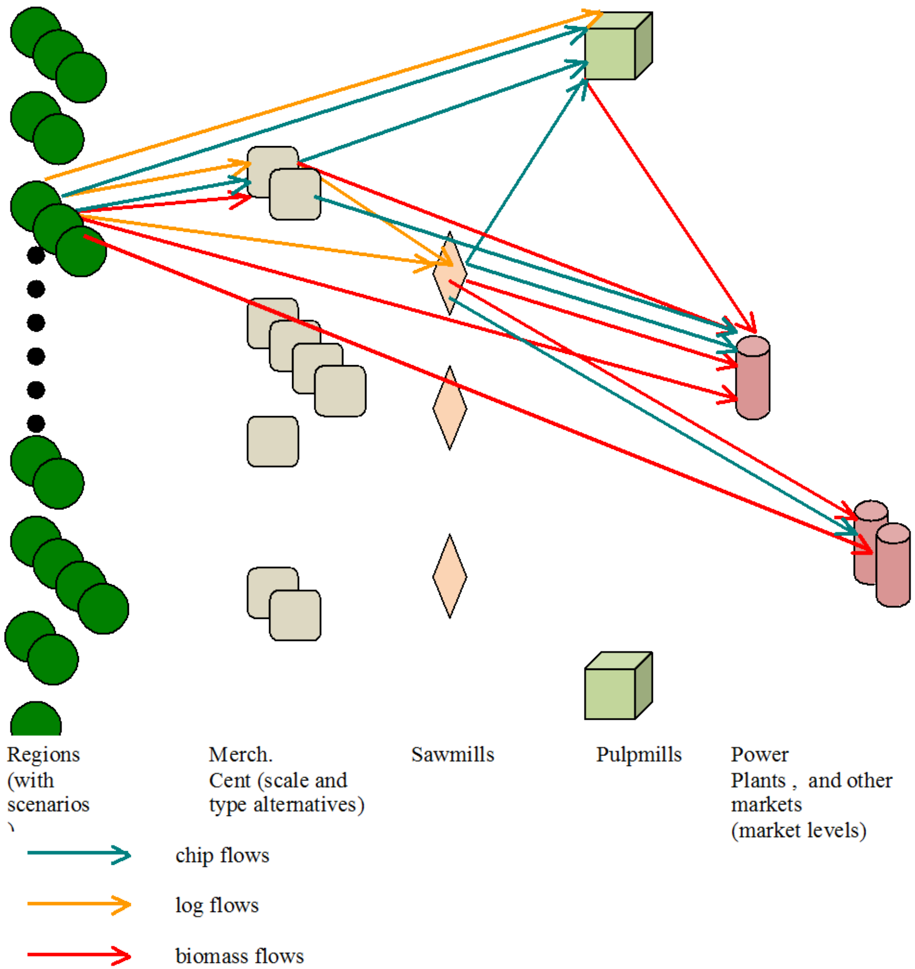
- **Forest Management Strategy**
  - AAC ⇔ Constant Yield
    - What is constant in life?
    - What should be?
  - What Can Be Highly Variable
    - Location of Harvest
      - Transportation cost
    - Composition of Harvest
      - Species mix
    - Quality of Harvest
      - Size and species

- **Industrial Capacity Strategy**
  - Current Mills
    - Small, old, inefficient
  - Location of Mills
    - Relative to forests
    - Relative to Markets
    - Relative to Each Other
  - Mix of Mills
    - Wood type requirements
  - Financial Structure
    - Liquidity challenges

Present Inconsistencies

- **Forest Management**
  - Wood volumes produced by species, dimension and quality
  - Silviculture needed for growth and regeneration
  - Location of harvest planned
  - Access to planned harvest
- **Industrial Capacity**
  - Wood volumes used by species dimension and quality
  - Silviculture achieved in harvest, thinnings and planting
  - Location of mill usage
  - Road building and logistics systems

The forest value chain is a flow network



- Starts in forest
- Logistics of flows through capacity
- Flows to markets and customers

(yes, there are other forest values)

Environmental Management Policy Documents


Water for Life:
NOVA SCOTIA'S WATER RESOURCE
MANAGEMENT STRATEGY
NOVA SCOTIA


NOVA SCOTIA CANADA

RESIDENTS | VISITORS | BUSINESSES | GOVERNMENT | NEWS | SEARCH

DNR › Forestry › Forestry Program Areas › Ecosystem Management

Natural Resources

DNR Home

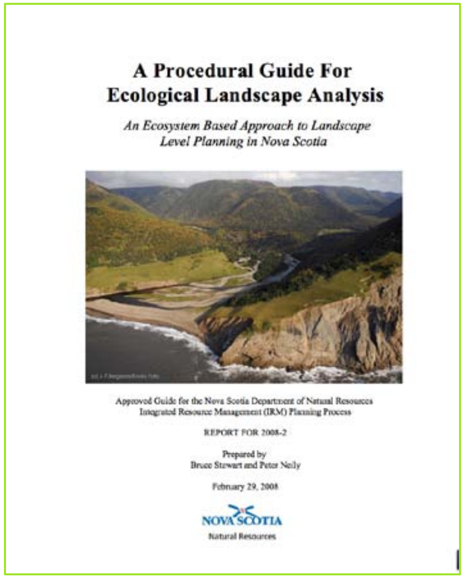
Forestry
- Community Forests
- Code of Forest Practice
- Forest Certification
- Forest Ecosystems
- Forest Program Areas
  - Forest Inventory
  - Timber Management
  - **Ecosystem Management**
  - GIS (Geographic Information Systems)
  - Forest Renewal/ Reforestation
  - Forest Resource Analysis
- Forest Vegetation Types
- Laws and Policies
- Maps and Forest Information
- Publications
- Registry of Buyers
- Related Links
- Selection Management
- Scaling
- Silviculture Assistance
- Tree Seedling Sales
- Contact Us

Ecosystem Management

The Nova Scotia Department of Natural Resources is developing an ecosystem based management planning system, as outlined below and organized in the linked web pages. A detailed overview is presented in the report "Implementing Ecosystem Based Integrated Resource Manangement in Nova Scotia"

Forest ecosystem based management provides a holistic way of managing resources with emphasis on the natural environment. In addition to producing traditional resources, forests are part of the provincial identity and supply great social and environmental wealth. These values are all produced by healthy functioning ecosystems. Ecosystems, with their focus on interconnectedness, describe the fundamental units of nature and provide a logical framework for understanding, planning, and managing natural resources. Ecosystem based planning takes its cues from nature, adopting a habitat based approach to conserve biodiversity and productivity by maintaining natural conditions and processes. True to ecosystem complexity, Forest Ecosystem Management (FEM) operates at multiple scales and incorporates components from several organizations and programs.

Ecosystem Management Resources
- Ecosystems
- Planning
- Old Growth
- Disturbance & Succession
- Soils - Waters
- Tools & Publications
- Contacts


A Procedural Guide For Ecological Landscape Analysis

An Ecosystem Based Approach to Landscape Level Planning in Nova Scotia

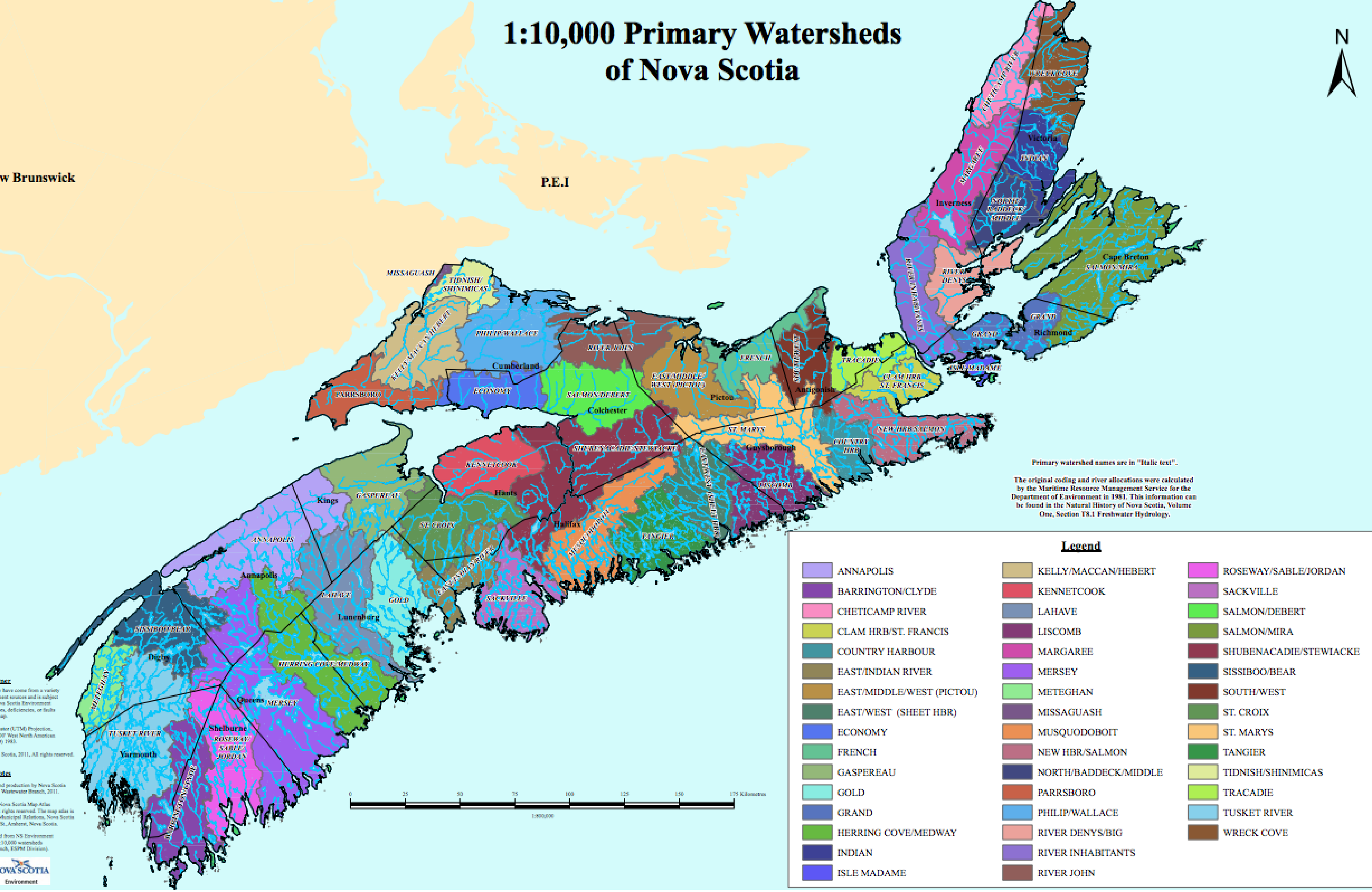
Approved Guide for the Nova Scotia Department of Natural Resources Integrated Resource Management (IRM) Planning Process

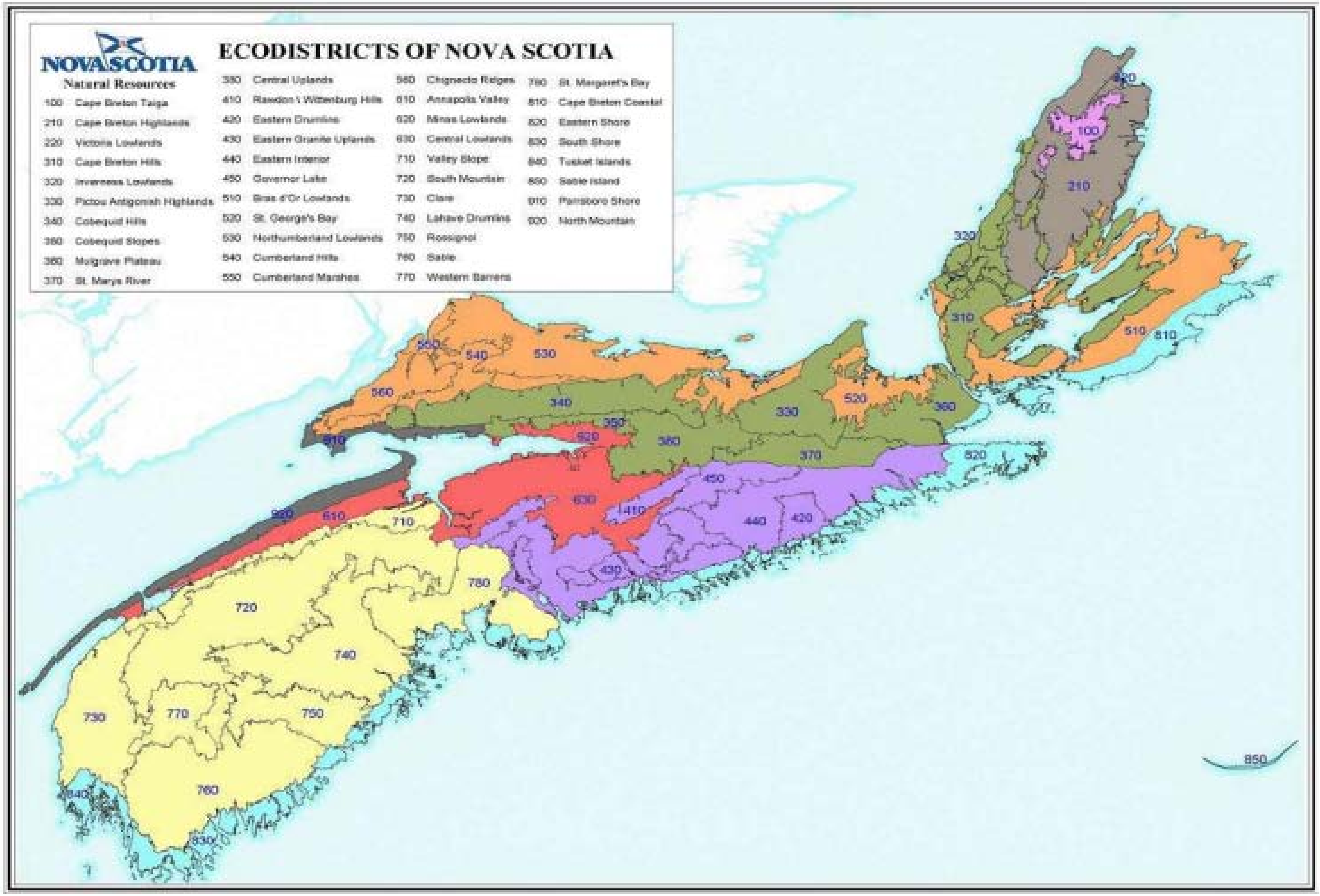
REPORT FOR 2008-2

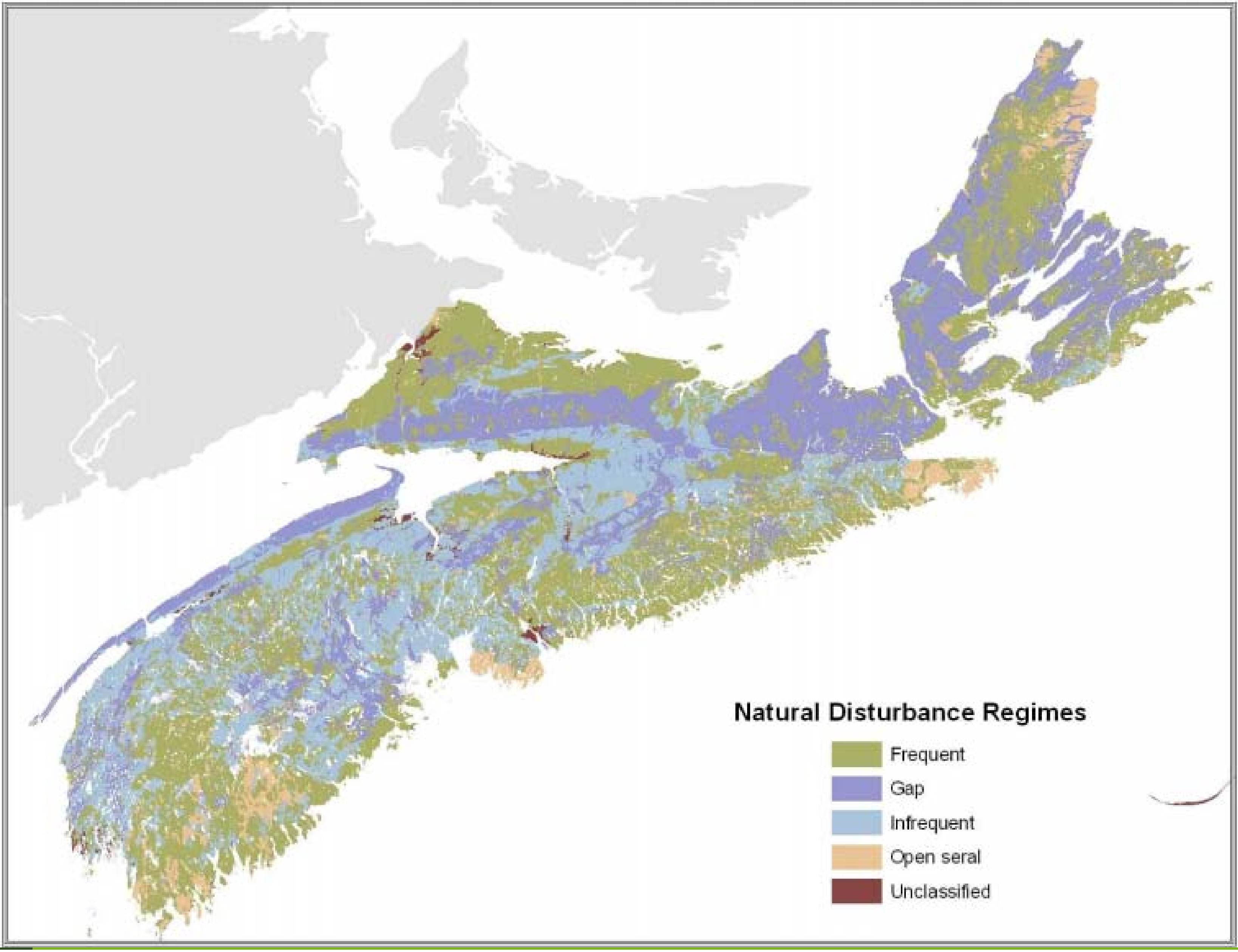
Prepared by
Bruce Stewart and Peter Neily

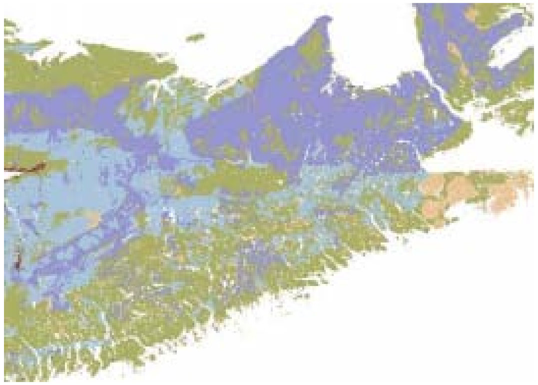
February 29, 2008

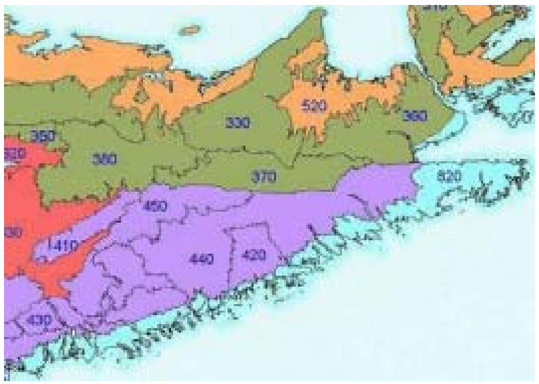
NOVA SCOTIA
Natural Resources

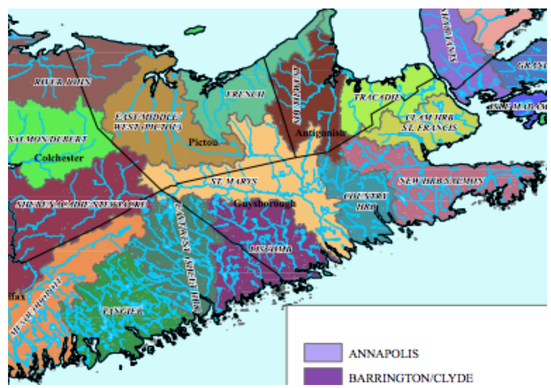

1:10,000 Primary Watersheds
of Nova Scotia
N
P.E.I
Primary watershed names are in "Italic text".
The original coding and river allocations were calculated by the Maritime Resource Management Service for the Department of Environment in 1981. This information can be found in the Natural History of Nova Scotia, Volume One, Section T8.1 Freshwater Hydrology.
Legend
ANNAPOLIS
BARRINGTON/CLYDE
CHETICAMP RIVER
CLAM HRB/ST. FRANCIS
COUNTRY HARBOUR
EAST/INDIAN RIVER
EAST/MIDDLE/WEST (PICTOU)
EAST/WEST (SHEET HBR)
ECONOMY
FRENCH
GASPEREAU
GOLD
GRAND
HERRING COVE/MEDWAY
INDIAN
ISLE MADAME
KELLY/MACCAN/HEBERT
KENNETCOOK
LAHAVE
LISCOMB
MARGAREE
MERSEY
METEGHAN
MISSAGUASH
MUSQUODOBOIT
NEW HBR/SALMON
NORTH/BADDECK/MIDDLE
PARRSBORO
PHILIP/WALLACE
RIVER DENYS/BIG
RIVER INHABITANTS
RIVER JOHN
ROSEWAY/SABLE/JORDAN
SACKVILLE
SALMON/DEBERT
SALMON/MIRA
SHUBENACADIE/STEWIACKE
SISSIBOO/BEAR
SOUTH/WEST
ST. CROIX
ST. MARYS
TANGIER
TIDNISH/SHINIMICAS
TRACADIE
TUSKET RIVER
WRECK COVE


NOVA SCOTIA
Natural Resources
ECODISTRICTS OF NOVA SCOTIA
100 Cape Breton Taiga
210 Cape Breton Highlands
220 Victoria Lowlands
310 Cape Breton Hills
320 Inverness Lowlands
330 Pictou Antigonish Highlands
340 Cobequid Hills
350 Cobequid Slopes
360 Mulgrave Plateau
370 St. Marys River
380 Central Uplands
410 Rawdon \ Wittenburg Hills
420 Eastern Drumlins
430 Eastern Granite Uplands
440 Eastern Interior
450 Governor Lake
510 Bras d'Or Lowlands
520 St. George's Bay
530 Northumberland Lowlands
540 Cumberland Hills
550 Cumberland Marshes
560 Chignecto Ridges
610 Annapolis Valley
620 Minas Lowlands
630 Central Lowlands
710 Valley Slope
720 South Mountain
730 Clare
740 Lahave Drumlins
750 Rossignol
760 Sable
770 Western Barrens
780 St. Margaret's Bay
810 Cape Breton Coastal
820 Eastern Shore
830 South Shore
840 Tusket Islands
850 Sable Island
910 Parrsboro Shore
920 North Mountain


Natural Disturbance Regimes
Frequent
Gap
Infrequent
Open seral
Unclassified







Fundamental spatial entities

- 20 counties
- 46 watersheds
- 38 ecodistricts
- 4 NDR

20*46*38*4= 13,984

Other Management Attributes

- 3 ownerships
- 12 cover types
- 5 site classes

13,984*3*12*5=2517120

Not Quite that Bad

- St Mary's River
  - 3NDR, 3 counties, 5 ecodistricts => 45 combinations
- East/West/Middle Pictou
  - 3 NDR, 1 county, 5 ecodistricts => 15 combinations
- Lahave River
  - 3 NDR, 3 counties, 2 ecodistricts => 18 combinations
- Overall
  - 46 watersheds, 15-20 combinations per wshd

    => 700 – 900

Basic Forest Management Attributes

```
*THEME {9 - SITE CLASSES}
 3 _INDEX(lc=3,si=11.85,siNPG=11.85,siIND=11.85,siOTH=11.85);SW LC = 1-3 & HW LC = 1
 4 _INDEX(lc=4,si=13.60,siNPG=11.85,siIND=13.60,siOTH=11.85);SW LC = 4-4 & HW LC = 1
 5 _INDEX(lc=5,si=15.38,siNPG=11.85,siIND=15.38,siOTH=13.60);SW LC = 5-5 & HW LC = 2
 6 _INDEX(lc=6,si=17.06,siNPG=13.60,siIND=17.06,siOTH=15.38);SW LC = 6-6 & HW LC = 2
 7 _INDEX(lc=7,si=18.65,siNPG=15.38,siIND=18.65,siOTH=17.06);SW LC = > 6 & HW LC = > 2
```

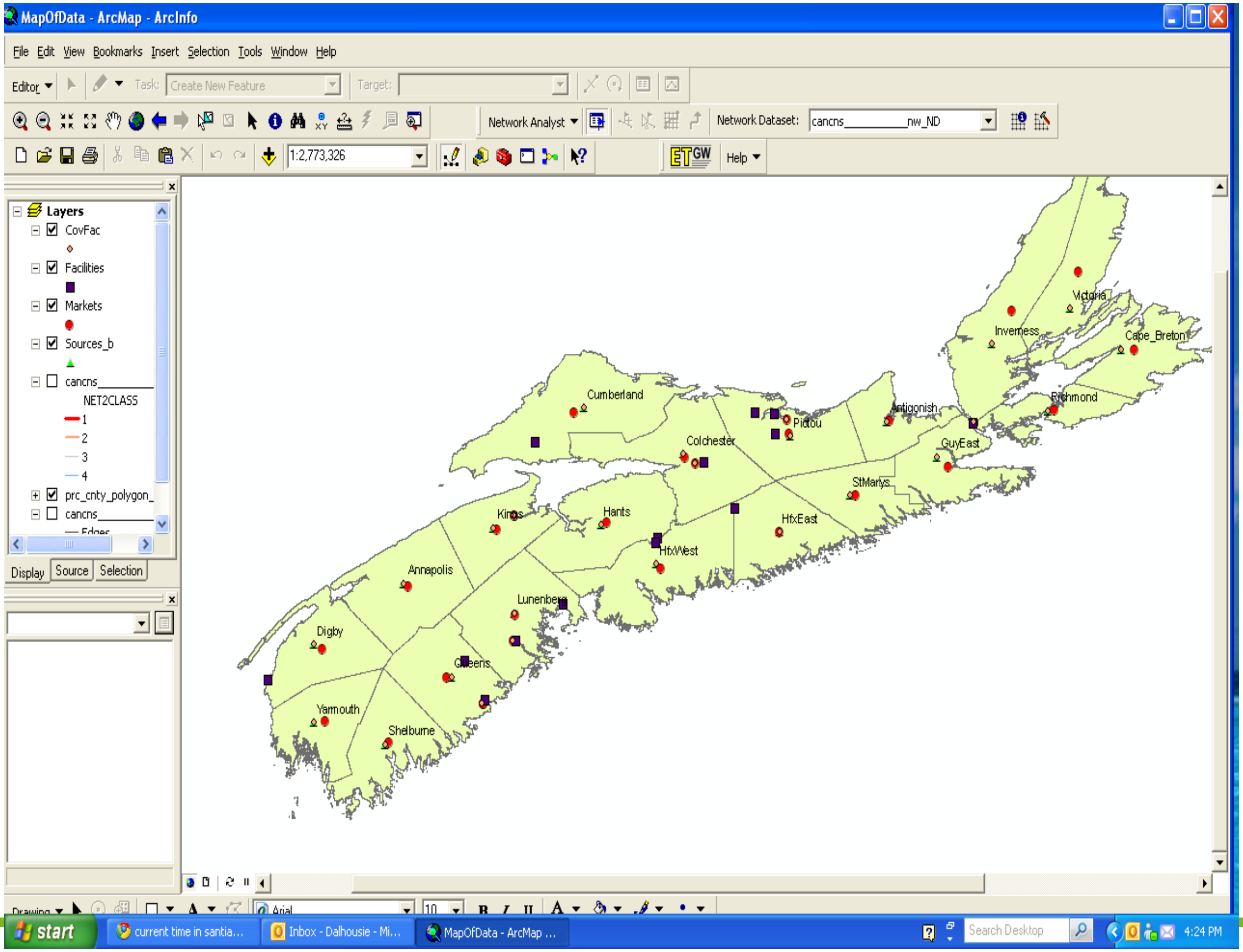
```
*THEME {7 - FOREST COMMUNITIES}
 ;Forest Communities
 ;-------------------
  ;Hardwood
   HIHw      _INDEX(fc=101) ;Intolerant Hardwood
   HITHw     _INDEX(fc=102) ;Mixed Intolerant/Tolarant Hardwood
   HTHw      _INDEX(fc=103) ;Tolerant Hardwood
  ;Mixedwood
   MIHwHS    _INDEX(fc=201) ;Intolerant Hardwood - Hardwood Leading
   MIHwSH    _INDEX(fc=202) ;Intolerant Hardwood - Softwood Leading
   MTHw      _INDEX(fc=203) ;Tolerant Hardwood
  ;Softwood
   SrSbSDom  _INDEX(fc=301) ;Red/Black Spruce Dominant
   SwSDom    _INDEX(fc=302) ;White/Other Spruce Dominant
   SbFDom    _INDEX(fc=303) ;Balsam Fir Dominant
   SSpbFDom  _INDEX(fc=304) ;Spruce/Fir Dominant
   SPiDom    _INDEX(fc=305) ;Pine Dominant
   SMHePiSp  _INDEX(fc=306) ;Mixed Spruce/Pine/Hemlock

 ;Managed Stand Types
 ;------------------------
   SrSPL     _INDEX(fc=401)   ;Softwood Plantation: Native Red Spruce
   SbSPL     _INDEX(fc=402)   ;Softwood Plantation: Native Black Spruce
   SPiPL     _INDEX(fc=403)   ;Softwood Plantation: Native Pine
   SwSPL     _INDEX(fc=404)   ;Softwood Plantation: White Spruce
   SExPL     _INDEX(fc=405)   ;Softwood Plantation: Exotic Species - Norway Spruce / xLarch
```

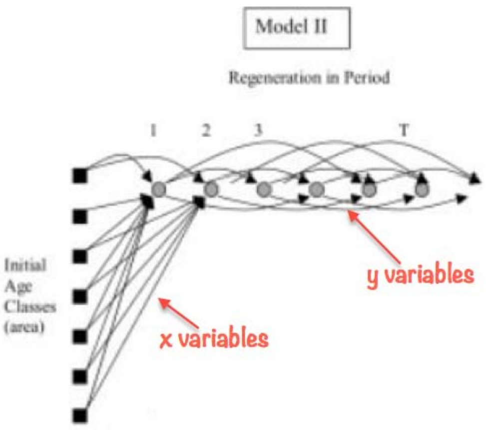
```
*THEME {10 - FOREST STATE INDICATOR}
 NAE     _INDEX(fs=10) ;NATURAL UNMANAGED STAND - EVENAGED
 NAU     _INDEX(fs=20) ;NATURAL UNMANAGED STAND - UNEVENAGED
 NRG     _INDEX(fs=30) ;2ND ROTATION UNMANAGED
 PLT     _INDEX(fs=40) ;MANAGED STAND - PLANTATION
 PCT     _INDEX(fs=50) ;MANAGED STAND - PRECOMMERCIAL THINNING
 CTH     _INDEX(fs=61) ;MANAGED STAND - COMMERCIAL THINNING IN NATURAL STANDS (NAE OR NRG)
 CTCTH   _INDEX(fs=62) ;MANAGED STAND - COMMERCIAL THINNING IN COMMERCIALLY THINNED NATURAL STANDS
 CTPCT   _INDEX(fs=63) ;MANAGED STAND - COMMERCIAL THINNING IN PRECOMMERCIALLY THINNED STANDS
 CTCTPCT _INDEX(fs=64) ;MANAGED STAND - COMMERCIAL THINNING IN PREVOOUSLY COMMERCIALLY THINNED AND
           PRECOMMERCIALLY THINNED STANDS
 CTPLT   _INDEX(fs=65) ;MANAGED STAND - COMMERCIAL THINNING IN PLANTATIONS
 CTCTPLT _INDEX(fs=66) ;MANAGED STAND - COMMERCIAL THINNING IN PREVIOUSLY COMERCIALLY THINNED
           PLANTATIONS
 SELNE   _INDEX(fs=71) ;MANAGED STAND - SELECTION HARVESTING IN NATURAL EVENADED STANDS (NAE OR NRG)
 SELNP   _INDEX(fs=72) ;MANAGED STAND - SELECTION HARVESTING IN NATURAL EVENADED PCT'd STANDS (PCT)
 SELNU   _INDEX(fs=73) ;MANAGED STAND - SELECTION HARVESTING IN NATURAL UNEVENAGED STANDS (NAU)
 ESC     _INDEX(fs=0) ;TRACK MANAGED STANDS THAT ESCAPE NORMAL WINDOW
 SHL     _INDEX(fs=80) ;  Shelterwood Harvest 1st pass removes 40% SOURCE TM
```

Transportation

perhaps the biggest spatial issue



Model II



$$\max \sum_{\substack{i\in I, a\in T\\ k\in K}} c_{iak} x_{iak} + \sum_{\substack{a\in T, b\in T\\ k\in K}} d_{abk} y_{abk}$$

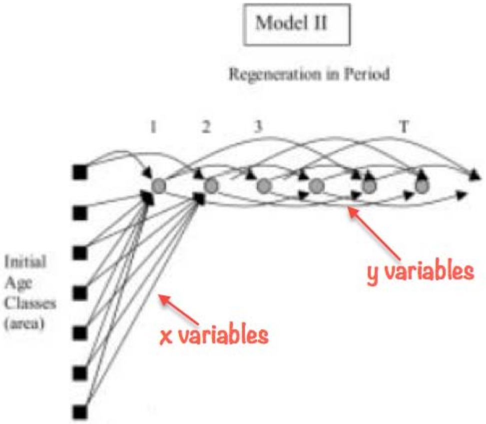
$$\sum_{b\in T, k\in K} y_{abk} = \sum_{i\in I, k\in K} x_{iak} \qquad a\in T, a<b$$

$$\sum_{a\in T, k\in K} y_{abk} = \sum_{f\in T, k\in K} y_{bfk} \qquad b\in T$$

$$\sum_{a\in T, k\in K} x_{iak} = area_i \qquad i\in I$$

+ side constraints on entire region

Model II spatial



$$\max \sum_{\substack{i\in I,a\in T\\k\in K,w\in S}} c_{iakw}x_{iakw} + \sum_{\substack{a\in T,b\in T\\k\in K,w\in S}} d_{abkw}y_{abkw}$$

$$\sum_{b\in T,k\in K} y_{abkw} = \sum_{i\in I,k\in K} x_{iakw} \qquad a\in T, a<b, w\in S$$

$$\sum_{a\in T,k\in K} y_{abkw} = \sum_{f\in T,k\in K} y_{bfkw} \qquad b\in T, w\in S$$

$$\sum_{a\in T,k\in K} x_{iakw} = area_i \qquad i\in I(w), w\in S$$

+ side constraints on entire region
+ side constraints on each w

Illustration of Growth Problem

Scenario	Constraints	Spatial Resolution
1	none	none
2	4.4, 4.5, 4.6	Ownership
3	run 2 and 4.8, 4.9	Ownership and Ecodistrict
4	run 3 and 4.11	Ownership, Ecodistrict and Watershed

Table 4.1: Model One and Model Two Comparison Desc

The Crown Central forest covers 379,000 ha, divided among, 3 ownerships, 22 Ecodistricts, 24 watersheds, and covers 5 counties: Halifax, Hants, Colchester, Cumberland, Pictou.

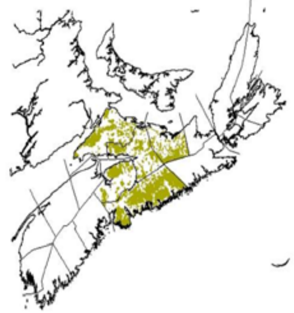


Figure 4.1: The Crown Central

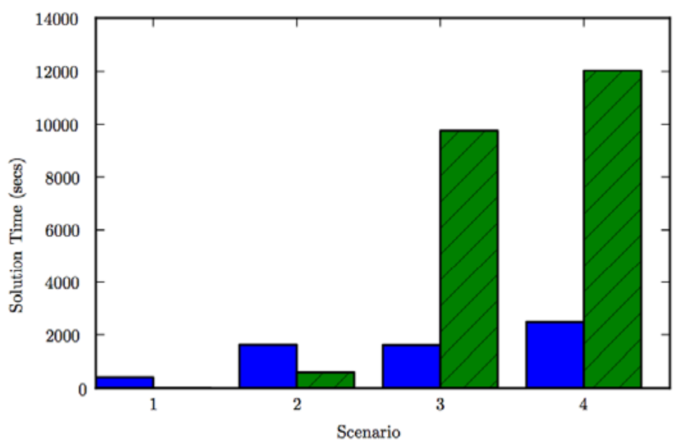


Figure 4.7: Model One (solid) and Model Two (hatched) Phase 1 Solution Times

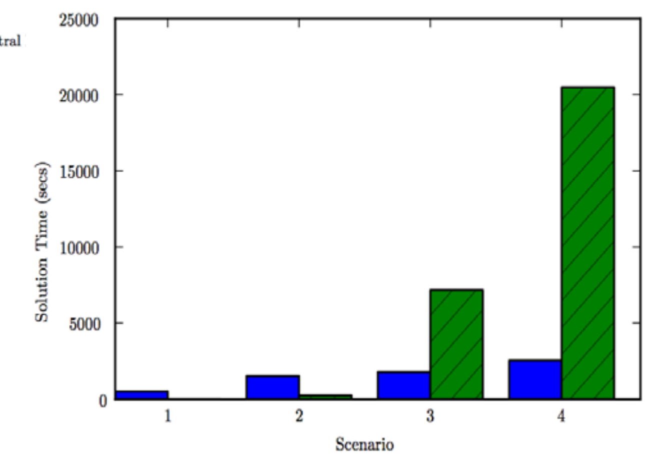


Figure 4.8: Model One (solid) and Model Two (hatched) Phase 2 Solution Times

	M1		M2	
Scenario	Solution Time (secs)	Objective (10^7)	Solution Time (secs)	Objective (10^7)
1	417.81	4.715	4.41	4.790
2	1623.81	3.788	603.44	3.869
3	1615.75	3.574	9754.32	3.744
4	2488.03	3.573	12,032.67	3.744

Table 4.2: Phase 1 Model One, Model Two Comparison Results

	M1		M2	
Scenario	Solution Time (secs)	Objective (10^7)	Solution Time (secs)	Objective (10^7)
1	512.14	5.296	5.27	5.380
2	1528.38	4.294	269.44	4.191
3	1798.42	4.126	7170.34	4.119
4	2541.74	4.126	20,480.18	4.119

VCO Value Chain Optimization

Illustration of Growth Problem

	Model One			Model Two		
Scenario	Rows	Columns	Non-Zeroes	Rows	Columns	Non-Zeroes
1	100,679	665,381	60,435,407	260,296	787,506	1,700,820
2	100,910	665,381	60,435,959	262,723	788,952	8,927,070
3	106,190	665,381	60,446,519	511,513	1,360,729	60,268,649
4	106,790	665,381	60,447,119	722,002	1,823,163	100,002,631

Table 4.4: Phase 1: Model One and Model Two Matrix Sizes

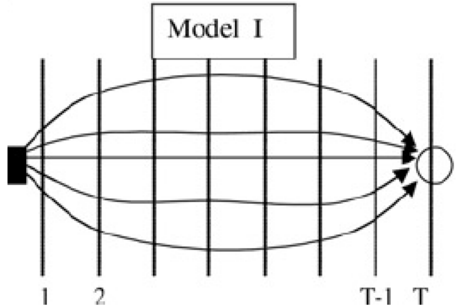
	Model One			Model Two		
Scenario	Rows	Columns	Non-Zeroes	Rows	Columns	Non-Zeroes
1	100,679	768,427	71,227,495	322,852	821,549	1,646,491
2	100,910	768,427	71,228,047	325,279	822,995	6,999,298
3	106,190	768,427	71,238,607	738,450	1,855,004	59,330,090
4	106,790	768,427	71,239,207	1,156,015	2,900,105	120,417,153

Table 4.5: Phase 2: Model One and Model Two Matrix Sizes

Problems with Model II

- Model growth as spatial issues are added
  - Need to add more spatial entities to deal with transport/logistics
- Model II is a puzzle solver, not a prescription generator
  - Many of the potential action sequences do not correspond to prescriptions a forester would assign to a stand.

Model I



$$\sum_{j \in P_i} x_{ij} = area_i \qquad i \in I$$

- MaxMillion, FORPLAN (original), SPECTRUM
- HEUREKA (Sweden) , JLP (Finland)

- Basic Model does not grow with spatial detail
  - Side constraints do

- Main problem
  - Potentially lots of prescriptions
    - Combinatorics over horizon
    - Initial conditions don't fit prescriptions
  - Solution – prescription generator/simulator
    - Heureka (part of system)
    - SIMO (Finland - input to JLP)

- Spatial detail
  - Combinations of spatial zones
  - Explicit within Heureka

- Model Compression
  - Stands that share all growth attributes and all spatial attributes can be combined

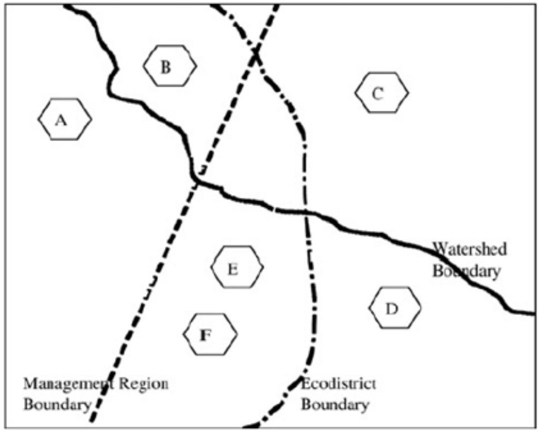
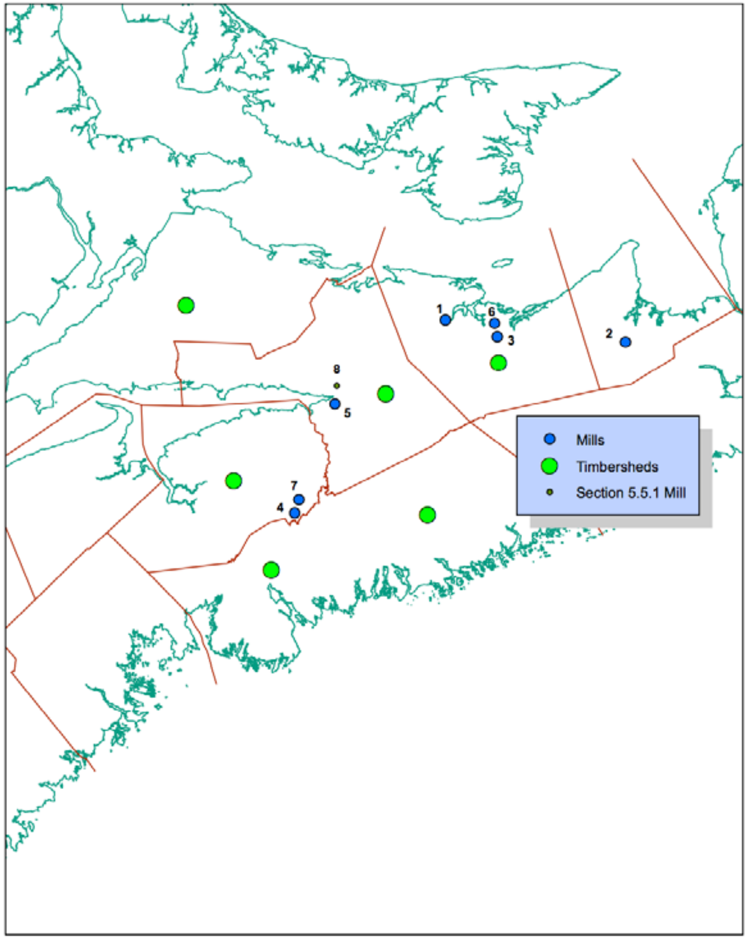


Figure 6. Illustration of when stands can be combined

Does harvest location matter



- Crown central stands as before
  - 8 mills
  - 6 timbersheds

Species	Log Value ($\$/m^3$)	Pulp Value ($\$/m^3$)
Sugar-Maple/Yellow Birch	35.00	10.00
Intolerant Hardwood/Red Oak/Beech	10.00	10.00
Spruce-Fir	35.00	15.00
Pine/Eastern Hemlock/Tamarack Larch	20.00	15.00

Mill	Accepts
1	all softwood sawlogs
2	all softwood pulp
3	valuable hardwood sawlogs
4	all softwood sawlogs
5	all softwood sawlogs
6	all softwood pulp
7	low-value softwood and all hardwood
8	all softwood sawlogs

A Model I Framework

Objective

$$\max \sum_{\substack{m\in M\\ t\in T_v}} 0.95^t \cdot PROF_{mt} - 3000 \cdot \sum_{\substack{d\in D,e\in E\\ n\in N,t\in T}} J_{d,e,n,t} - 3000 \cdot \sum_{\substack{c\in C,e\in E\\ n\in N,t\in T}} G_{c,e,n,t} \qquad (5.1)$$

Constraints

$$\sum_{j\in P_i} x_{ij} = area_i \qquad i\in I \qquad (5.2)$$

Timber Constraints

$$SPBF_{ut} \le SPBF_{u,t+1} \qquad u\in U, t\in T \qquad (5.3)$$

$$OTHER_{ut} \le 0.25TOT_{ut} \qquad u\in U, t\in T \qquad (5.4)$$

$$SPBFINV_{ut} \le SPBFINV_{u,t+1} \qquad u\in U, t\ge 12 \qquad (5.5)$$

$$\sum_{\substack{i\in I(n,e)\\ j\in P_i}} y_{ijkt}\cdot x_{ij} = DEVCLS_{dent} \qquad d\in D, e\in E, n\in N, t\in T \qquad (5.6)$$

Ecosystem Constraints

$$DEVCLS_{dent} + J_{dent} \ge A_{dent} area_{en} \qquad d\in D, e\in E, n\in N, t\ge 11 \qquad (5.7)$$

$$SERALCLS_{cent} + G_{cent} \ge B_{cent} area_{en} \qquad c\in C, e\in E, n\in N, t\ge 11 \qquad (5.8)$$

Environmental Policy Variables are computed as follows:

$$COVER_{wt} = \sum_{i\in I(w)} y_{ijkt}\cdot x_{ij} \qquad w\in W, t\in T \qquad (5.9)$$

$$CLEARCUT_{et} = \sum_{\substack{i\in I(e)\\ j\in P(cc)_t}} x_{ij} \qquad e\in E, t\in T \qquad (5.10)$$

$$SHELTHARV_{et} = \sum_{\substack{i\in I(e)\\ j\in P(shelt)_t}} x_{ij} \qquad ee\in E, t\in T \qquad (5.11)$$

Environmental Policy Constraints

$$COVER_{wt} \ge 0.6area_w \qquad w\in W, t\ge 5 \qquad (5.12)$$

$$CLEARCUT_{et} \le 0.5area_e \qquad e\in E, t\in T \qquad (5.13)$$

$$SHELTHARV_{et} \le 0.15area_e \qquad e\in E, t\in T \qquad (5.14)$$

Figure 5.3: Integrated Industry Model Formulation: Objective and Constraints

Shipping Network

$$\sum_{m\in M} z_{urmkt} = \sum_{\substack{i\in I(ur)\\ j\in P_i}} y_{ijkt}\cdot x_{ij} \qquad u\in U, r\in R, k\in Y_w, t\in T_v \qquad (5.15)$$

$$\sum_{n\in M} p_{umnkt} \le 0.5\cdot \sum_{r\in R} z_{urmkt} \qquad u\in U, m\in M, k\in Y_w, t\in T_v \qquad (5.16)$$

$$\sum_{\substack{u\in U\\ r\in R\\ y\in Y_w}} dc_{mk}\cdot z_{urmkt} + \sum_{\substack{n\in M\\ u\in U\\ k\in Y_w}} dc_{mk}\cdot p_{unmkt} = d_{mt} \qquad m\in M, t\in T_v \qquad (5.17)$$

$$\sum_{\substack{u\in S\\ r\in R\\ y\in Y_w}} z_{urmkt} + \sum_{\substack{n\in M\\ u\in U\\ k\in Y_w}} p_{unmkt} \le cap_m \qquad m\in M, t\in T_v \qquad (5.18)$$

$$d_{mt} \ge dem_m \qquad m\in M, t\in T_v \qquad (5.19)$$

In constraint 5.20 y is low-value species volume and k is total volume

$$\sum_{\substack{u\in U\\ r\in R}} (z_{urmyt} - 0.1z_{urmkt}) + \sum_{\substack{u\in U\\ n\in M_s}} (p_{unmyt} - 0.1p_{unmkt}) \le 0 \qquad m\in M, t\in T_v \qquad (5.20)$$

$$TRANS_{mt} = \sum_{\substack{u\in U\\ r\in R\\ y\in Y_w}} sc_{rm}\cdot z_{urmyt} + \sum_{\substack{u\in U\\ n\in M_s\\ y\in Y_w}} sc_{nm}\cdot p_{unmyt} \qquad m\in M, t\in T_v \qquad (5.21)$$

$$REV_{mt} = d_{mt} + \sum_{\substack{u\in U\\ n\in M_p\\ y\in Y_w}} 20p_{umnyt} \qquad m\in M, t\in T_v \qquad (5.22)$$

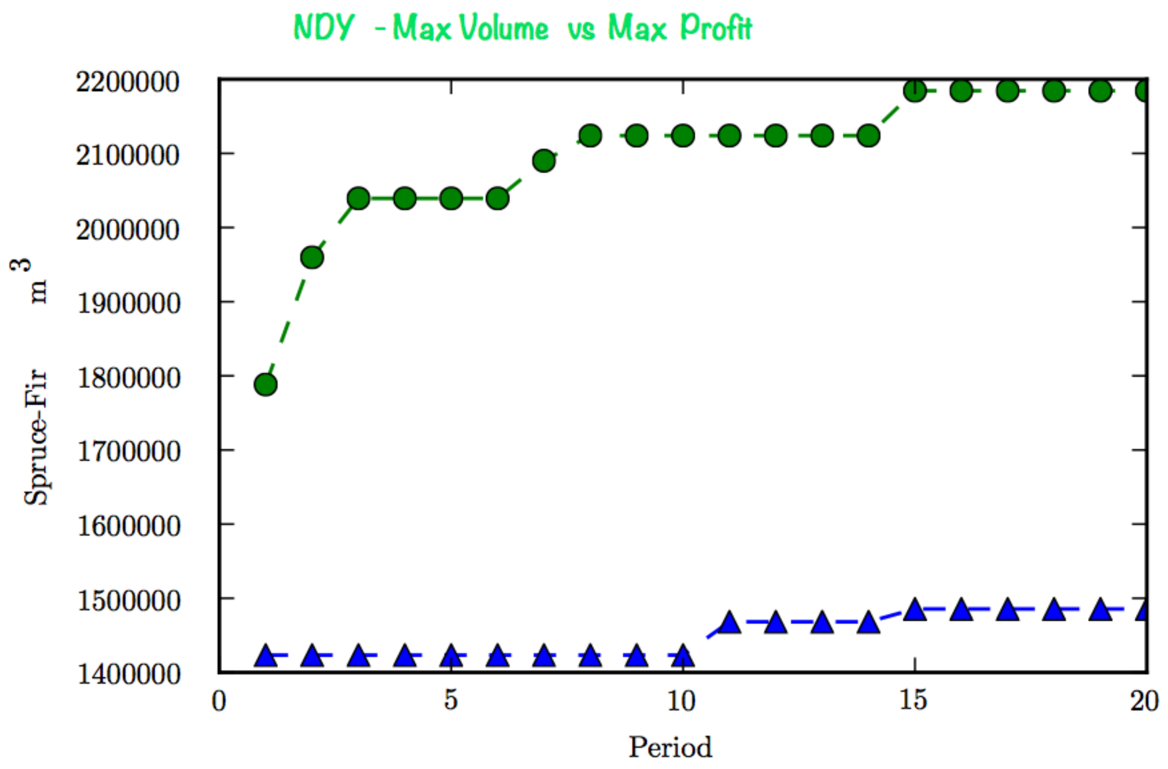
$$PROF_{mt} = REV_{mt} - TRANS_{mt} \qquad m\in M, t\in T_v \qquad (5.23)$$

Figure 5.4: Integrated Industry Model Formulation: Shipping Network

DALHOUSIE UNIVERSITY *Inspiring Minds*

NSERC CRSNG

Some Results
Max Volume vs Max Profits



Some Results
Clearcut and Shelterwood Restrictions

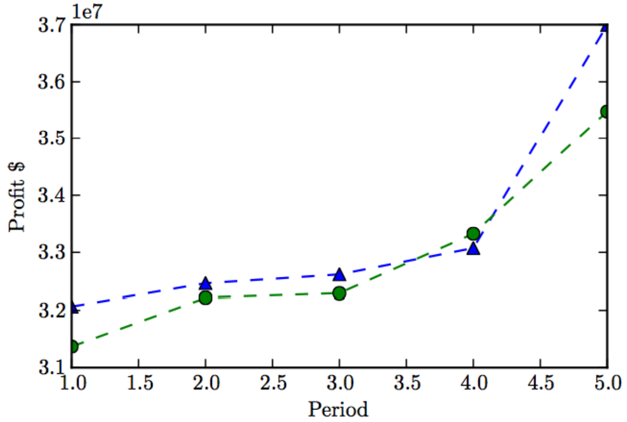


Figure 5.9: Clearcut and Shelterwood Restriction: Profit - Base (triangles), Shelterw stricted (circles)

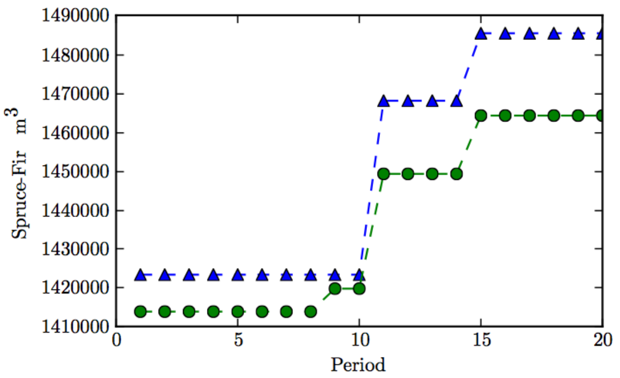


Figure 5.10: Clearcut Restriction: Spruce-Fir Harvests - Base (triangles), Shelterwood Restricted (circles)

Some Results

Watershed Management (doesn't matter - at 60%)

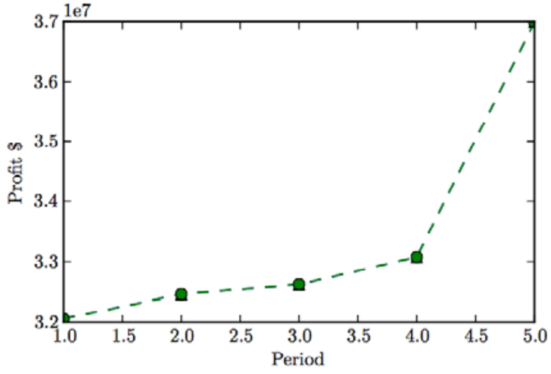


Figure 5.11: Watershed Management: Profit- Base (triangles), 60% Cover Condition (circles)

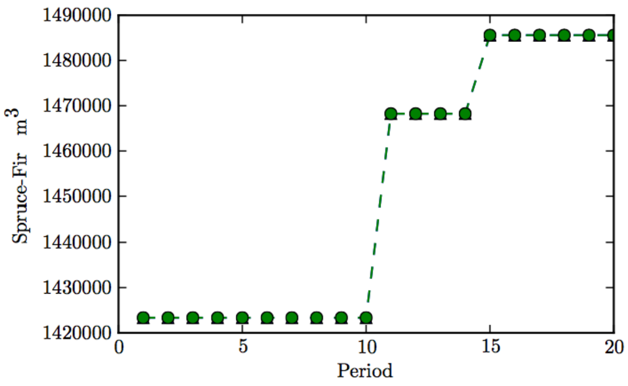


Figure 5.12: Watershed Management: Spruce-Fir Harvests - Base (triangles), 60% Cover Condition (circles)

Some Results

New Mill Capacity Added (In right location)

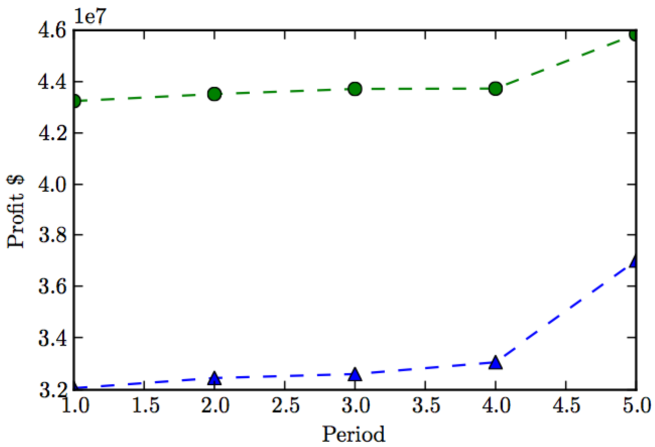


Figure 5.13: Industrial Expansion: Profit - Base (triangles), Expanded Industry (circles)

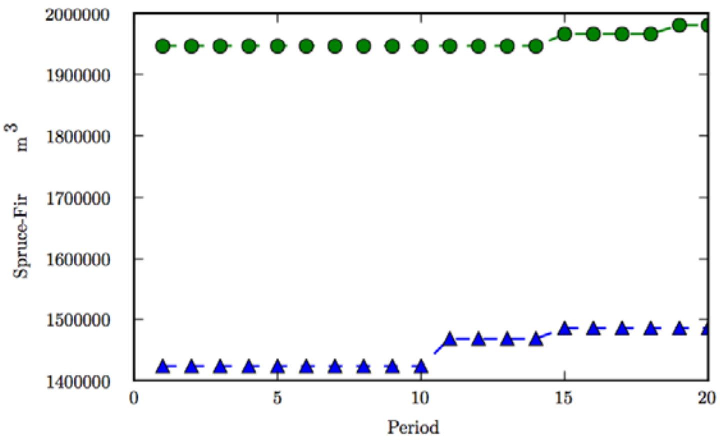


Figure 5.14: Industrial Expansion: Spruce-Fir Harvests - Base (triangles), Expanded Industry (circles)

Some Results
Alternative Regulation Strategies

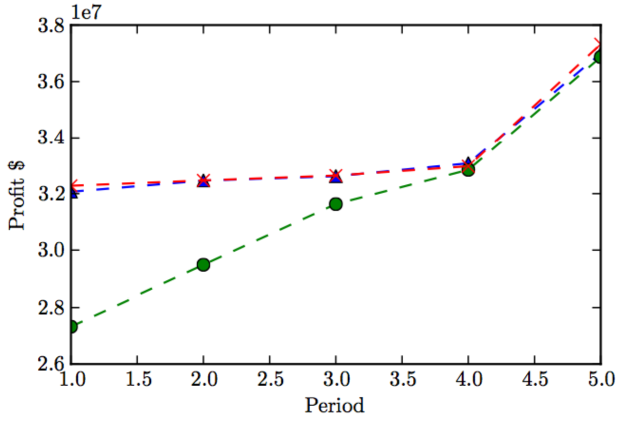


Figure 5.15: Alternate Regulation Strategies to Non-Declining Yield: Profit - NDY (triangles) Mill Regulation (circles), Mean Regulation (x)

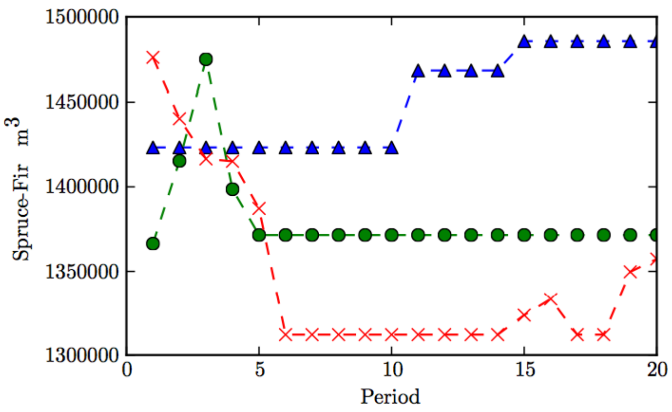


Figure 5.16: Alternate Regulation Strategies to Non-Declining Yield: Spruce-Fir Harvests - NDY (triangles), Mill Regulation (circles), Mean Regulation (x)

Some Results
Alternative Regulation Strategies

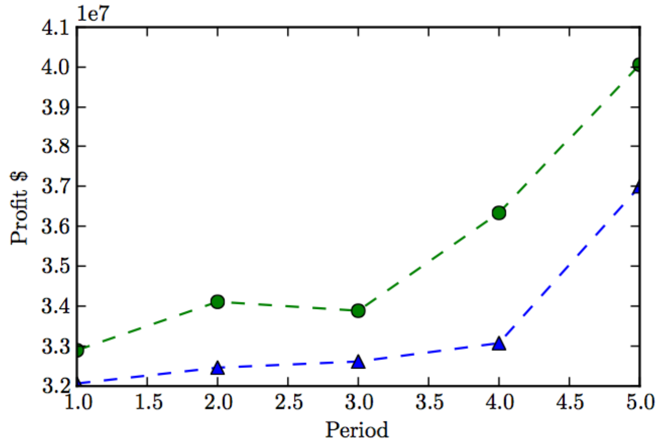


Figure 5.17: Leaving Wood in the Forest: Profit - Ship Everything (triangles), Ship Selectively (circles)

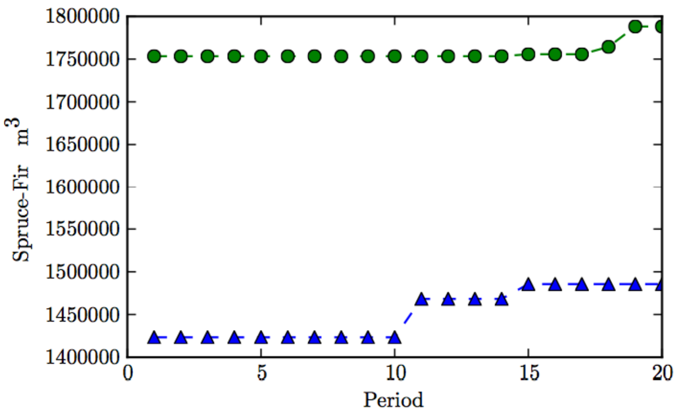


Figure 5.18: Leaving Wood in the Forest: Spruce-Fir Harvests - Ship Everything (triangles), Ship Selectively (circles)

Some notes

- Although model is “big”, can do a lot of analysis quite quickly
- Model Generation - AMPL (GMPL)
- Model Solution – GUROBI
  - Python routines permit modifying model constraints and re-running without leaving GUROBI

```
mm=read('Model1.lp)'
mm.optimize()
...
    interactive Python routines
...
mm.optimize()
```

- Key to eventual strategic planning usage
  - Encourage playing with strategy

Technical issues
- solving big Model I models

- How big (NS provincial)
  - 6 million polygons in GIS
  - Disolvable to about 1 million stands
  - Stand compression (within spatial combinations) about 3=>1 => 300-400,000 "stands"
  - 10-20 prescriptions per stand

  - 3-4 million variables
  - 300-400,000 GUB (area) constraints
  - 30-50,000 side constraints

- Key issue is exploiting the GUB's
  - JLP based on this

What should be in the strategic model

- All the strategic spatial issues
  - Biodiversity
  - Ecosystem condition and productivity
  - Soil and Water
  - Multiple Economic benefits
    - Markets
    - Transportation
  - Accepting responsibility
    - Obey the law
    - First Nations
- Good forestry
  - Alternative prescriptions that meet the forest conditions
    - Species associations
    - Site
    - Current stocking
    - Current stand quality
- Good Economics
  - Scale and location of mills
  - Cash flow requirements
  - Harvest, Transport costs
  - Product markets
    - Local, export
- Good infrastructure and logistics
  - Merchandizing yards
  - Multi-modes
    - Forest, highway trucking
    - Rail, seaborn

Comments on Strategy

- Strategic decisions are made now!
  - Stakeholders
  - Landowners (65+20=85?)
  - Governments (4 years)
  - Companies ($.90^{20}$= 0.15)
  - Forests
    - Every tree to be harvested in the next 30 years is growing now

- Planning for long term (100 years) is a myth
  - Economy
    - Wood Products: markets, prices
    - Fuel, energy, biochemicals
  - Technologies
    - Harvesting, transport
    - Solid wood processing and products
    - Fibre processin
    - Thermochemical and biochemical processes
  - Workforce
    - Population, skills, education
  - Large scale Natural Disturbance

Planning for the Immediate Does Not Mean Ignoring the Future

- Investing in Plants changes:
  - future capital/labour costs
  - Product Mix
  - Logistics cost structure
  - Material utilization
- Investing in logistics
  - Reduces future acquisition costs
  - Improves future supply chain possibilities
- Harvesting, silviculture:
  - Creates the young forest
  - removes decadent, poorly stocked stands
  - Changes species, age, spacing distriibitions
  - Changes harvest productivity
  - Determines habitat for biodersity
  - Determines ecosystem measures measures
  - Determines watershed cover

Nature of the Strategic Model

- Relatively short term
  - 20-30 year
- Highly focussed on good forestry prescriptions
- Highly focussed on short spatial issues
- Highly focussed on economics:
  - Harvesting
  - Logistics
  - Markets

- Strong focus on end conditions
  - Specifications of DFC
  - Models of future value
    - Ecosystem productivity
    - Forest growth proodoctivity
    - Forest harvesting productivity
    - Industrial labour productivity
    - Industrial Capital Productivity

Need to think a lot more about what goes into the Strategic Model

A Sandbox to Play in

- Ability to generate a fairly broad variety of forests
- Ability to look at various capacity cost structures
- Ability to include logistics:
  - Forest to mills
  - By-products at mills
  - Mill to Mill transport
- Examine effects of NDY
- Examine role of discount factors
- Multiple regulation modes
  - System wide periodic revenues
  - Effects of Sharing Revenues

The Forestry

- Many “stands”
- Multiple Cover Types
- Multiple Site Types
- Variable Stocking

- Stands have “locations”

StandGen

	A	B	C	D	E	F	G	H	I	J
1	Number of stands		3000		Mean area	1000	(expone ntial)			Write File
2										
3	Age Class Distribution									
4	Age	Cum Pct	Site	CumPct	Cover	CumPct	Stock	Cum Pct	Region	CumPct
5	0	5	3	10	Soft	60	30	15	1	6
6	20	25	4	40	Mixed	80	40	35	2	14
7	40	45	5	70	Hard	100	50	65	3	20
8	60	70	6	90			60	85	4	26
9	80	90	7	100			70	95	5	31
10	100	95	8	100			80	100	6	38
11	120	100							7	45
12	200	100							8	52
13									9	59
14									10	65
15									11	72
16									12	79
17									13	85
18									14	92
19									15	100

GenArea | Genages | Gensite | GenCover | GenStock | GenRegion

	A	B	C	D	E	F	G
27		2931676.56					
28							
29	Stand	Area	Age	Site	Cover	Stock	Region
30	1	348.781165	50	5	1	30	14
31	2	628.438637	45	6	1	30	6
32	3	545.557492	30	4	2	30	6
33	4	1239.38424	45	5	1	40	11
34	5	1197.50043	35	4	1	50	8
35	6	255.227661	55	3	2	30	5
36	7	4267.43863	50	6	1	50	12

Value Chain Optimization

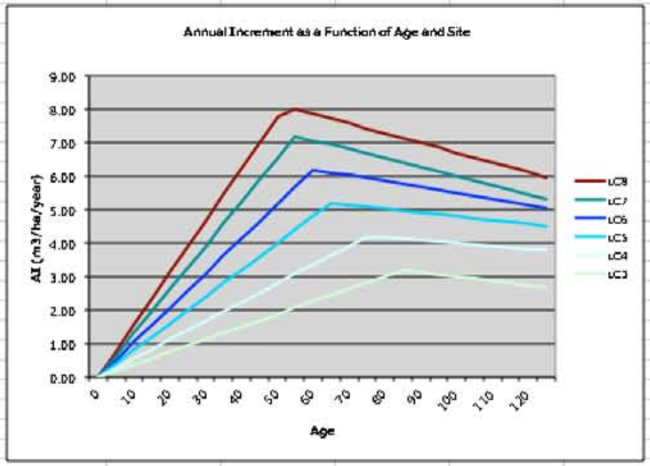
MAI Ylds

A	B	C	D	E	F	G	H	I	J	K	L	M
LC	12	11	10	9	8	7	6	5	4	3	2	1
MaxMai	11.75	10.8	9.9	9.1	8.1	7.2	6.2	5.2	4.2	3.2	2.2	0.8
Year	40	40	45	50	52	55	60	65	75	85	90	99
100MAI	8.7	8.4	7.7	7.3	6.7	6	5.5	4.8	4	3	2	0.8
age ontime	40	40	45	50	55	55	60	65	75	85	90	95
	470	432	445.5	455	440.6875	396	372	338	315	272	198	72.92929
age early	35	35	40	45	50	50	55	55	65	75	80	85
	359.8438	330.75	352	368.55	389.4231	327.2727	312.5833	242	236.6	211.7647	156.4444	58.38384
age late	50	50	55	60	65	65	70	70	80	90	95	100
	562.0833	520	522.5	524.4	501.8542	450.6667	421.75	360	332.8	282	199.5	80

OutPut Yields

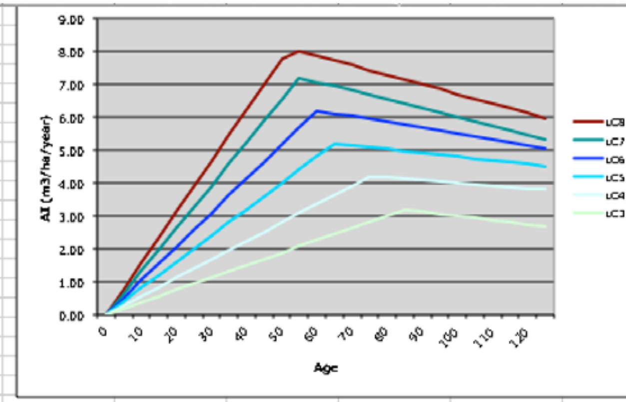
OutYields

	12	11	10	9	8	7	6	5	4	3	2	1
MAI	LC12	LC11	LC10	LC9	LC8	LC7	LC6	LC5	LC4	LC3	LC2	LC1
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.47	1.35	1.10	0.91	0.78	0.65	0.52	0.40	0.28	0.19	0.12	0.04
10	2.94	2.70	2.20	1.82	1.56	1.31	1.03	0.80	0.56	0.38	0.24	0.08
15	4.41	4.05	3.30	2.73	2.34	1.96	1.55	1.20	0.84	0.56	0.37	0.12
20	5.88	5.40	4.40	3.64	3.12	2.62	2.07	1.60	1.12	0.75	0.49	0.16
25	7.34	6.75	5.50	4.55	3.89	3.27	2.58	2.00	1.40	0.94	0.61	0.20
30	8.81	8.10	6.60	5.46	4.67	3.93	3.10	2.40	1.68	1.13	0.73	0.24
35	10.28	9.45	7.70	6.37	5.45	4.58	3.62	2.80	1.96	1.32	0.86	0.28
40	11.75	10.80	8.80	7.28	6.23	5.24	4.13	3.20	2.24	1.51	0.98	0.32
45	11.50	10.60	9.90	8.19	7.01	5.89	4.65	3.60	2.52	1.69	1.10	0.36
50	11.24	10.40	9.70	9.10	7.79	6.55	5.17	4.00	2.80	1.88	1.22	0.40
55	10.99	10.20	9.50	8.92	8.01	7.20	5.68	4.40	3.08	2.07	1.34	0.44
60	10.73	10.00	9.30	8.74	7.87	7.07	6.20	4.80	3.36	2.26	1.47	0.48
65	10.48	9.80	9.10	8.56	7.72	6.93	6.11	5.20	3.64	2.45	1.59	0.53
70	10.23	9.60	8.90	8.38	7.58	6.80	6.03	5.14	3.92	2.64	1.71	0.57
75	9.97	9.40	8.70	8.20	7.43	6.67	5.94	5.09	4.20	2.82	1.83	0.61
80	9.72	9.20	8.50	8.02	7.28	6.53	5.85	5.03	4.16	3.01	1.96	0.65
85	9.46	9.00	8.30	7.84	7.14	6.40	5.76	4.97	4.12	3.20	2.08	0.69
90	9.21	8.80	8.10	7.66	6.99	6.27	5.68	4.91	4.08	3.13	2.20	0.73
95	8.95	8.60	7.90	7.48	6.85	6.13	5.59	4.86	4.04	3.07	2.10	0.77
100	8.70	8.40	7.70	7.30	6.70	6.00	5.50	4.80	4.00	3.00	2.00	0.80
105	8.45	8.20	7.50	7.12	6.55	5.87	5.41	4.74	3.96	2.93	1.90	0.80

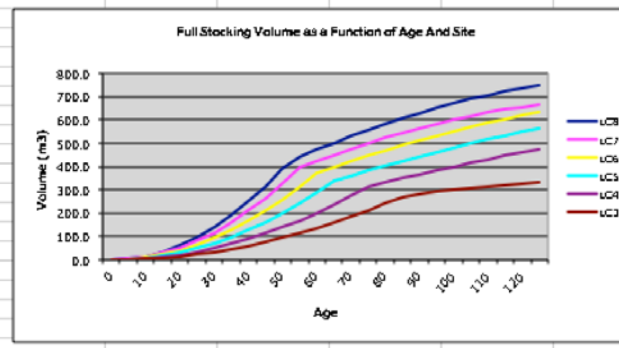


MAI Ylds (vol)

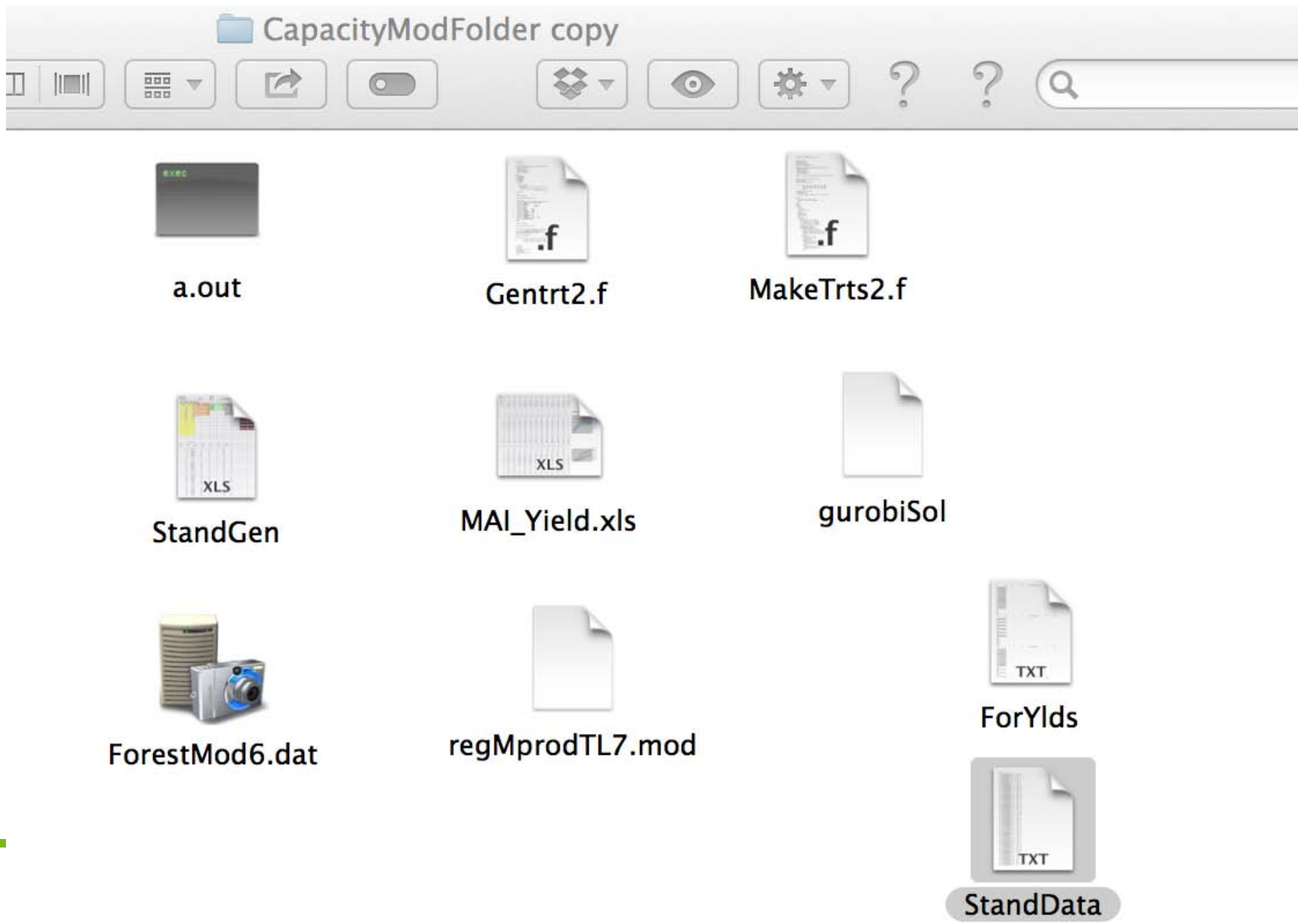
MAI	LC12	LC11	LC10	LC9	LC8	LC7	LC6	LC5	LC4	LC3	LC2	LC1
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.47	1.35	1.10	0.91	0.78	0.65	0.52	0.40	0.28	0.19	0.12	0.04
10	2.94	2.70	2.20	1.82	1.56	1.31	1.03	0.80	0.56	0.38	0.24	0.08
15	4.41	4.05	3.30	2.73	2.34	1.96	1.55	1.20	0.84	0.56	0.37	0.12
20	5.88	5.40	4.40	3.64	3.12	2.62	2.07	1.60	1.12	0.75	0.49	0.16
25	7.34	6.75	5.50	4.55	3.89	3.27	2.58	2.00	1.40	0.94	0.61	0.20
30	8.81	8.10	6.60	5.46	4.67	3.93	3.10	2.40	1.68	1.13	0.73	0.24
35	10.28	9.45	7.70	6.37	5.45	4.58	3.62	2.80	1.96	1.32	0.86	0.28
40	11.75	10.80	8.80	7.28	6.23	5.24	4.13	3.20	2.24	1.51	0.98	0.32
45	11.50	10.60	9.90	8.19	7.01	5.89	4.65	3.60	2.52	1.69	1.10	0.36
50	11.24	10.40	9.70	9.10	7.79	6.55	5.17	4.00	2.80	1.88	1.22	0.40
55	10.99	10.20	9.50	8.92	8.01	7.20	5.68	4.40	3.08	2.07	1.34	0.44
60	10.73	10.00	9.30	8.74	7.87	7.07	6.20	4.80	3.36	2.26	1.47	0.48
65	10.48	9.80	9.10	8.56	7.72	6.93	6.11	5.20	3.64	2.45	1.59	0.53
70	10.23	9.60	8.90	8.38	7.58	6.80	6.03	5.14	3.92	2.64	1.71	0.57
75	9.97	9.40	8.70	8.20	7.43	6.67	5.94	5.09	4.20	2.82	1.83	0.61
80	9.72	9.20	8.50	8.02	7.28	6.53	5.85	5.03	4.16	3.01	1.96	0.65
85	9.46	9.00	8.30	7.84	7.14	6.40	5.76	4.97	4.12	3.20	2.08	0.69
90	9.21	8.80	8.10	7.66	6.99	6.27	5.68	4.91	4.08	3.13	2.20	0.73
95	8.95	8.60	7.90	7.48	6.85	6.13	5.59	4.86	4.04	3.07	2.10	0.77
100	8.70	8.40	7.70	7.30	6.70	6.00	5.50	4.80	4.00	3.00	2.00	0.80
105	8.45	8.20	7.50	7.12	6.55	5.87	5.41	4.74	3.96	2.93	1.90	0.80
110	8.19	8.00	7.30	6.94	6.41	5.73	5.33	4.69	3.92	2.87	1.80	0.80
115	7.94	7.80	7.10	6.76	6.26	5.60	5.24	4.63	3.88	2.80	1.70	0.80
120	7.68	7.60	6.90	6.58	6.12	5.47	5.15	4.57	3.84	2.73	1.60	0.80
125	7.43	7.40	6.70	6.40	5.97	5.33	5.06	4.51	3.80	2.67	1.50	0.80



Volume	LC12	LC11	LC10	LC9	LC8	LC7	LC6	LC5	LC4	LC3	LC2	LC1
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	7.3	6.8	5.5	4.6	3.9	3.3	2.6	2.0	1.4	0.9	0.6	0.2
10	29.4	27.0	22.0	18.2	15.6	13.1	10.3	8.0	5.6	3.8	2.4	0.8
15	66.1	60.8	49.5	41.0	35.0	29.5	23.3	18.0	12.6	8.5	5.5	1.8
20	117.5	108.0	88.0	72.8	62.3	52.4	41.3	32.0	22.4	15.1	9.8	3.2
25	183.6	168.8	137.5	113.8	97.4	81.8	64.6	50.0	35.0	23.5	15.3	5.1
30	264.4	243.0	198.0	163.8	140.2	117.8	93.0	72.0	50.4	33.9	22.0	7.3
35	359.8	330.8	269.5	223.0	190.8	160.4	126.6	98.0	68.6	46.1	29.9	9.9
40	470.0	432.0	352.0	291.2	249.2	209.5	165.3	128.0	89.6	60.2	39.1	12.9
45	517.3	477.0	445.5	368.6	315.4	265.1	209.3	162.0	113.4	76.2	49.5	16.4
50	562.1	520.0	485.0	455.0	389.4	327.3	258.3	200.0	140.0	94.1	61.1	20.2
55	604.3	561.0	522.5	490.6	440.7	396.0	312.6	242.0	169.4	113.9	73.9	24.4
60	644.0	600.0	558.0	524.4	472.0	424.0	372.0	288.0	201.6	135.5	88.0	29.1
65	681.1	637.0	591.5	556.4	501.9	450.7	397.3	338.0	236.6	159.1	103.3	34.1
70	715.8	672.0	623.0	586.6	530.3	476.0	421.8	360.0	274.4	184.5	119.8	39.6
75	747.8	705.0	652.5	615.0	557.2	500.0	445.3	381.4	315.0	211.8	137.5	45.5
80	777.3	736.0	680.0	641.6	582.7	522.7	468.0	402.3	332.8	240.9	156.4	51.7



Stand Data Ready To Go



Capacity

- Multiple Capacity Types
  - Softwood Stud
  - Softwood Saw
  - Softwood Pulp
  - Hardwood Saw
  - Hardwood Pulp
  - Bioenergy
- Capacity have locations
  - Euclidian distances
    - Keep it simple

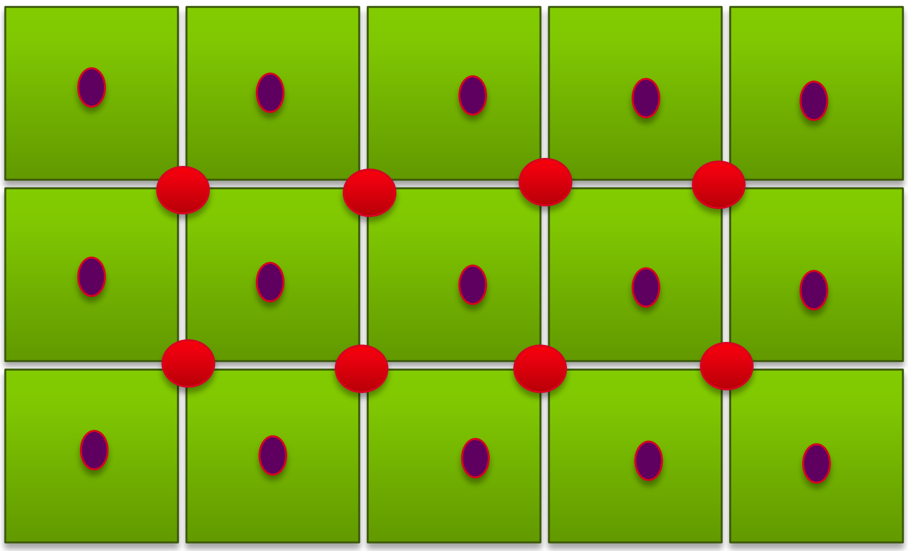
- Economies of Scale
- $C_j(x_j) = k_j \, x_j^{alpha}$
- Modelled as piecewise linear

Simple Situation

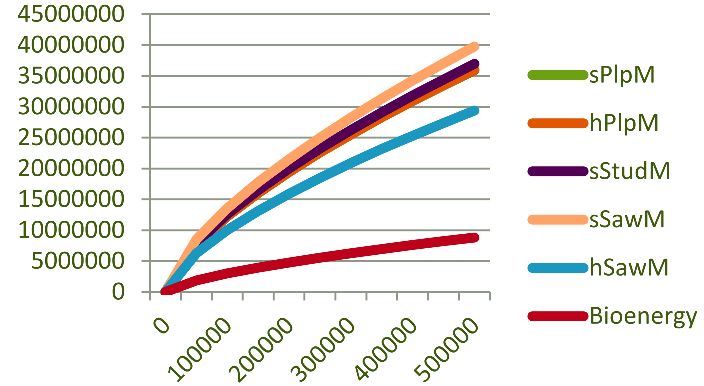
15 Regions 50x50 km

8 Mill Sites

Regional Centroids
(15 for Transport Calcs.

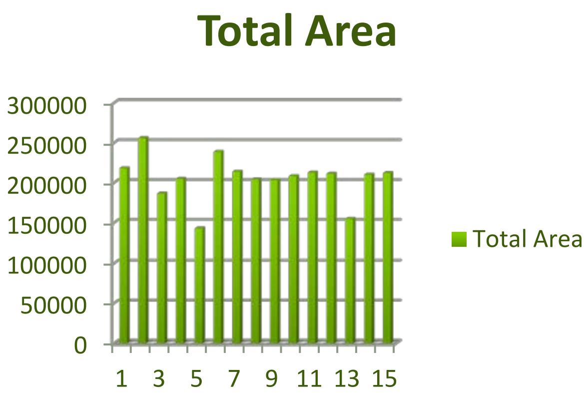


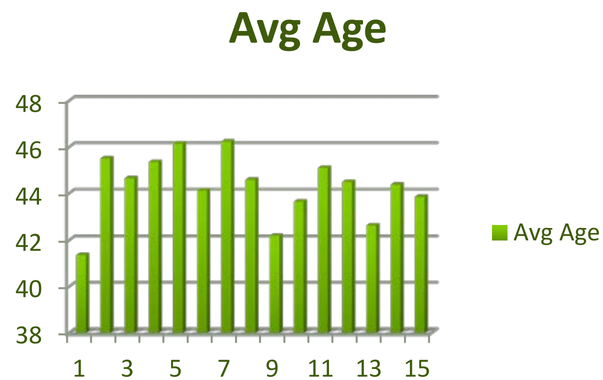
6 Mill Types

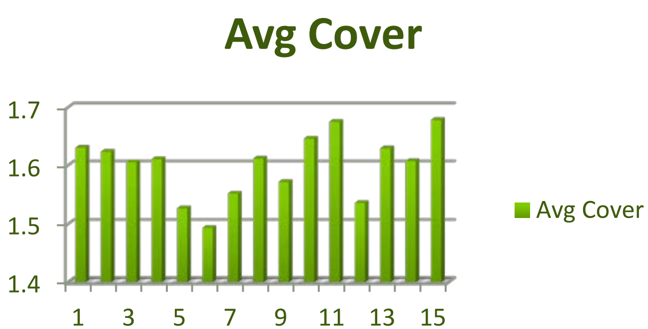


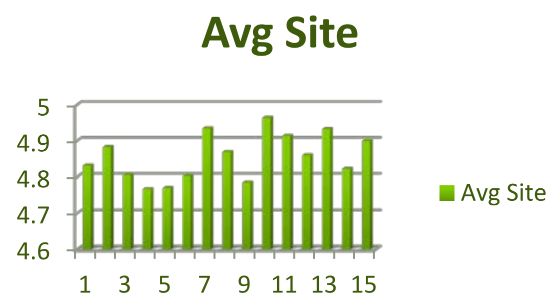
Capacity Cost Functions
$C(x)=Kx^{\alpha}$

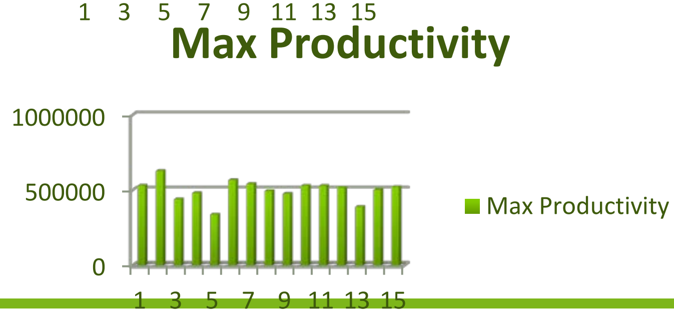
Simulated Regional Characteristics





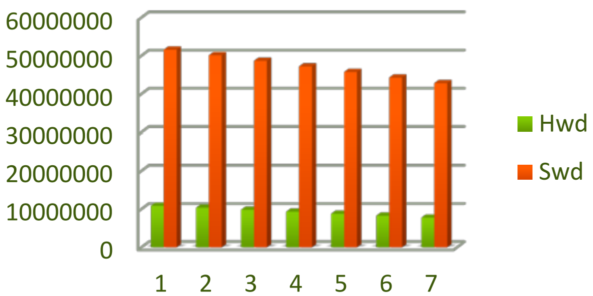




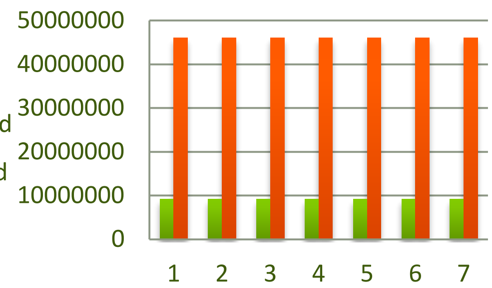


Total Harvest Effects

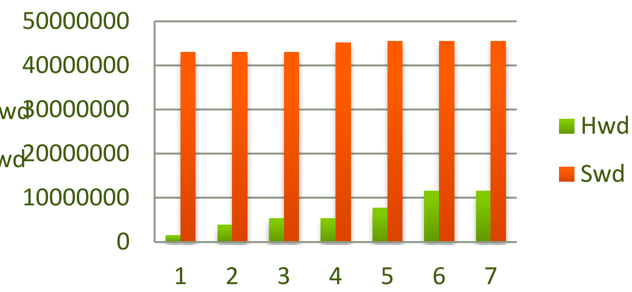
No NDY - No Costs



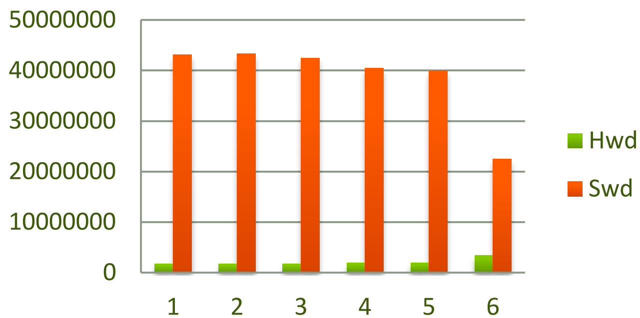
NDY - No Costs



NDY - with Costs, No Cap

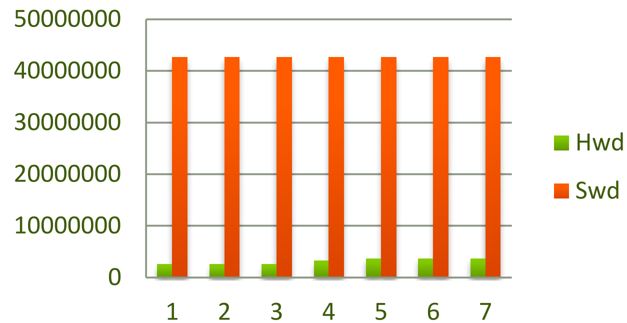


No NDY - with Capacity



$410.8 Million (NPV)

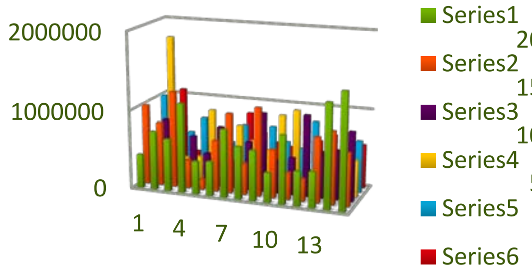
NDY with Capacity



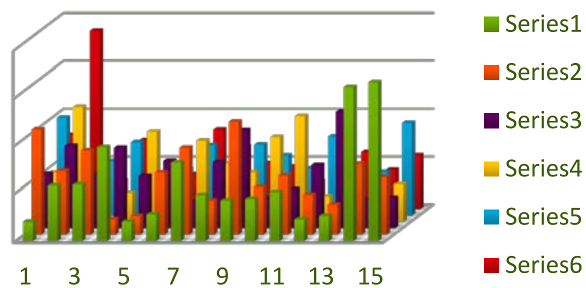
$395.6 Million (NPV)

Regional Harvests

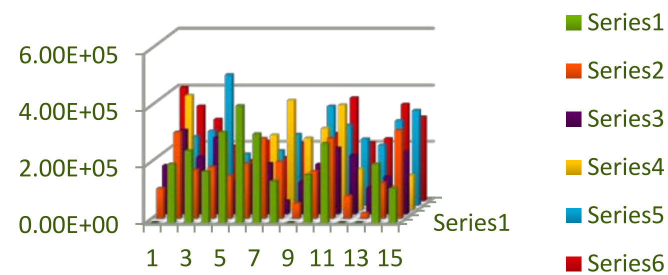
Regional -HWD



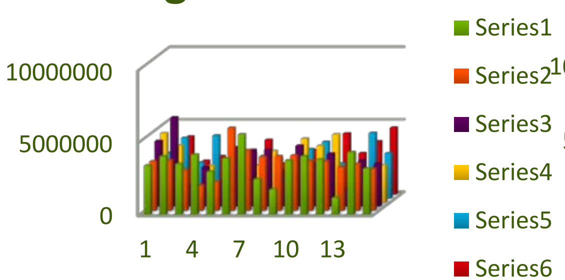
Regional -Hwd



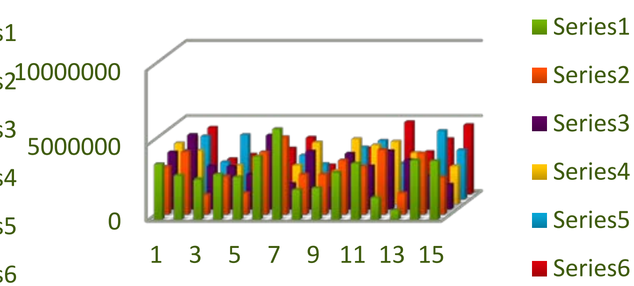
Regional - Hwd



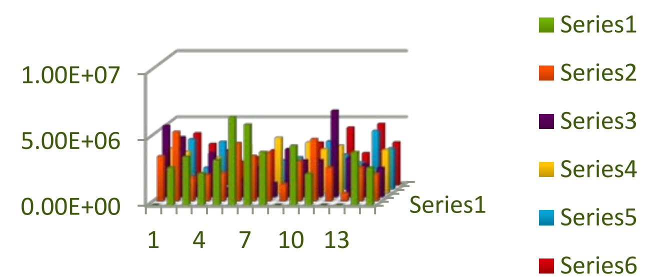
Regional -Swd



Regional -Swd



Regional - Swd

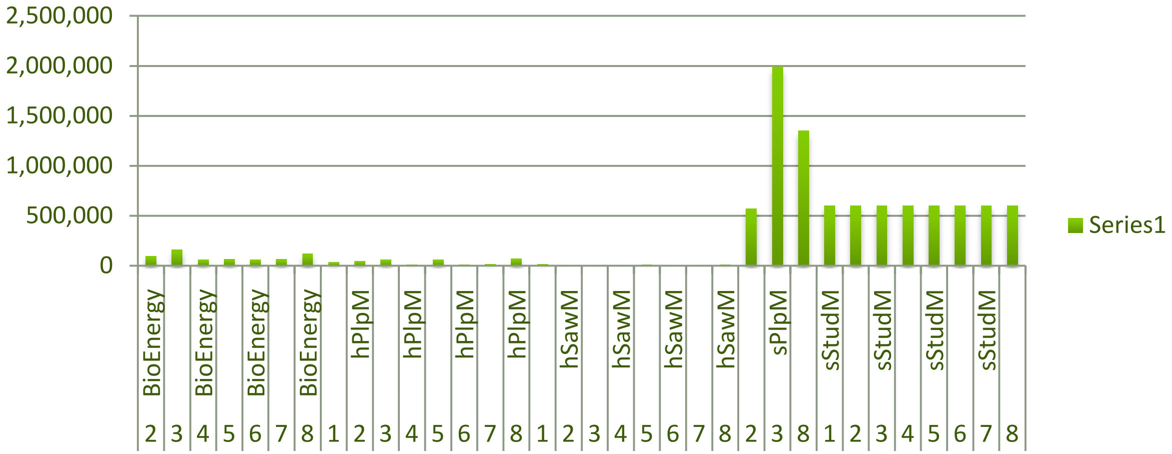


Base – No NDY,No Costs

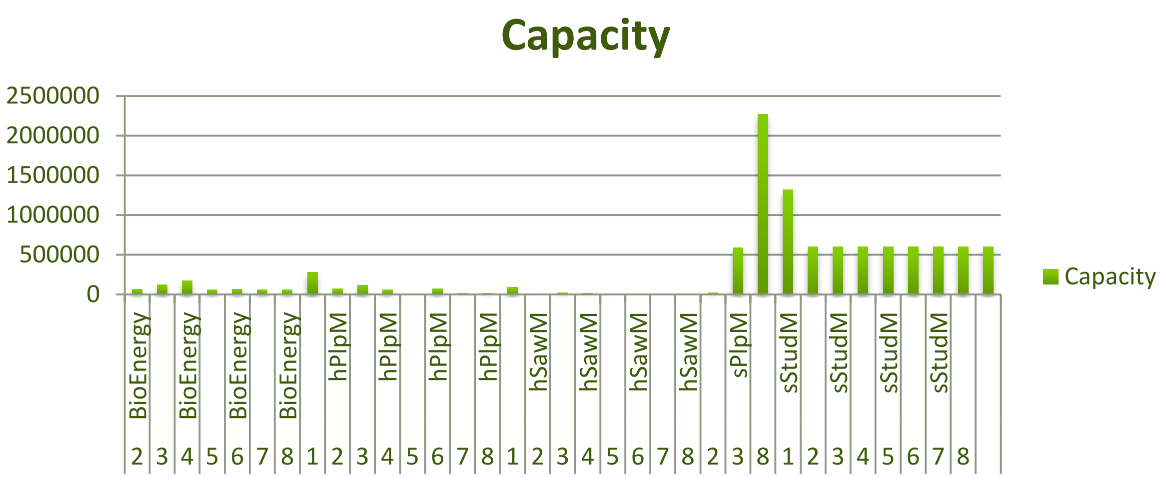
NDY – No Cost, No Cap

NDY With Capacity

Installed Capacity



No NDY



NDY

Some Ways of Getting at Long Term Sustainability

- Model 1 Prescriptions
  - Good prescriptions are inherently sustainable at the stand level
- Milestone Years
  - Non-declining standing volumes (t=50, 100, etc)
    - not harvest
    - By species
    - By watershed, ecodistrict, etc
    - By harvest region ??
  - Improving Harvest Productivity
    - At same height

      Productivity ~ D^2
    - Silviculture does not change height much but changes D

- Can we get aggregate long term measures of environment and productivity just like NPV in economics
  - Not so clear that NPV in Economics is that great an idea
- Can we tradeoff long term measures of environment, and productivity and short term economics
  - Mathematically ?
  - Organizationally
- Can we develop End- State Models for short (20-30 years) strategic models

Models Matter in Strategy

- Do not give answers
- Allow examination of tradeoffs if they are constructed properly
  - Model Generation Times can be long
  - Use python within Gurobi to run tradeoffs without regenerating model
- Substantial problems of “who benefits”
  - Even more of who benefits “ when”

That’s It
Thanks for Listening

- Questions
- Comments