OptFuels: A decision support system to optimize spatial and temporal fuel treatments

Woodam Chung, Greg Jones, Janet Sullivan, and Pablo Aracena

Contents

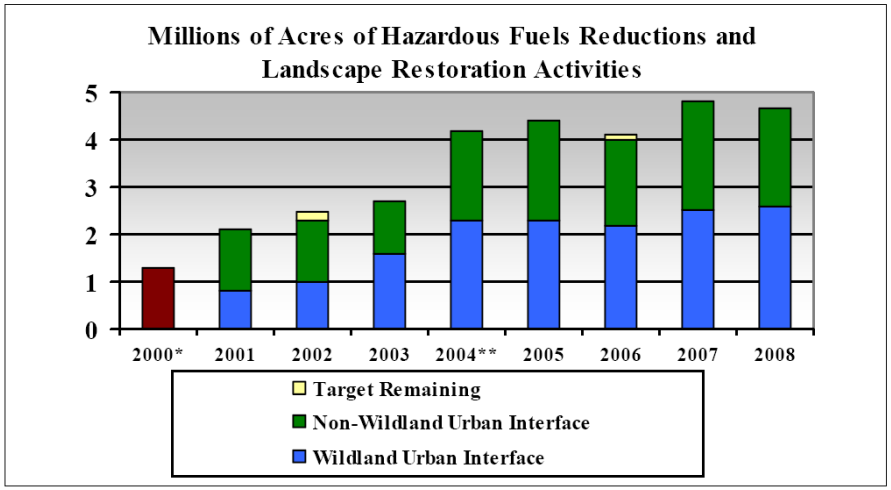
- Study Background and Objective
- System Components
- System Application (Preliminary results)
- Concluding Remarks

Background

- Over 8 million acres have burned every year between 2004 and 2007 (National Interagency Fire Center 2009)
- USDA Forest Service and DOI spent over $1.8 billion in each year on wildfire suppression in five of the past 8 years
- In 1991, the Forest Service spent 13% of its total budget on wildland fire management. In 2008, 45% of the agency's budget went to fighting fire

Background

- Fuel treatments have been used to alter fire behavior and reduce the potential fire intensity levels across a landscape
- From 2001 through 2008, FS and DOI have treated over 29 million acres of federal lands under the Healthy Forest Initiative (HFI) and the National Fire Plan.

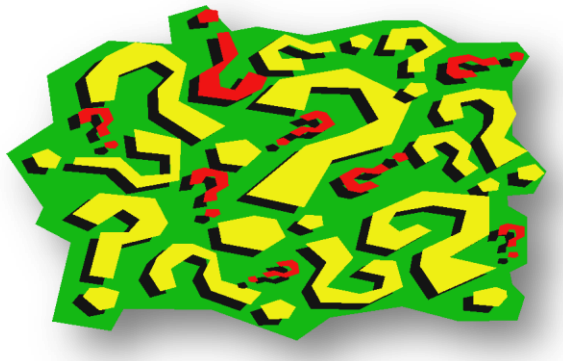


* FY 2000 is used as a baseline for reporting, as the NFP was implemented in FY 2001. Treatment location was not included in reporting prior to FY 2001.
** Acres treated under landscape restoration activities were not reported prior to FY 2004.

(from Healthy Forest Report for FY 2008 written by Healthy Forests and Rangelands)

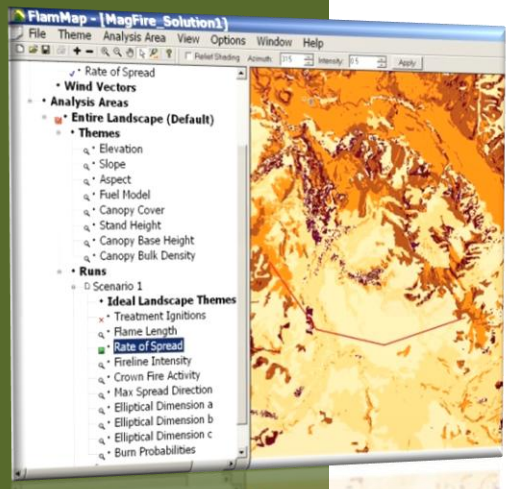
Background

- No tools exist to help land managers establish priorities for **where, when, and how** to apply new and **maintenance** fuel treatments



Background

- No tools exist to help land managers establish priorities for where, when, and how to apply new and maintenance fuel treatments
- Tools available for land managers
  - FARSITE (Finney 1998) and FlamMap (Finney 2006)



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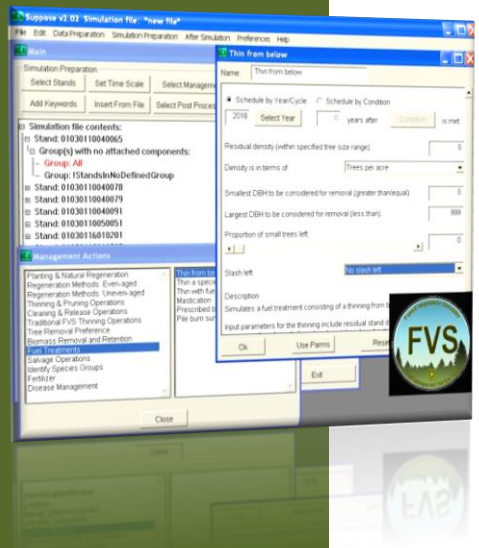
  - FVS-FFE (Reinhardt and Crookston 2003)



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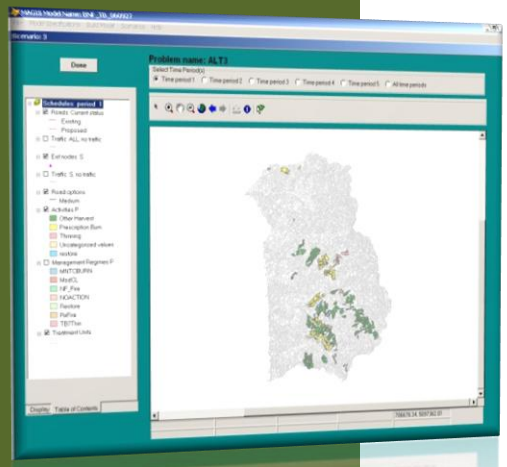
- Tools available for land managers
  - FARSITE (Finney 1998) and FlamMap (Finney 2006)
  - FVS-FFE (Reinhardt and Crrokston 2003)
  - MAGIS (Zuuring et al. 1995, Chung et al. 2005)



Background

- Treatment Optimization Model (Finney 2007)

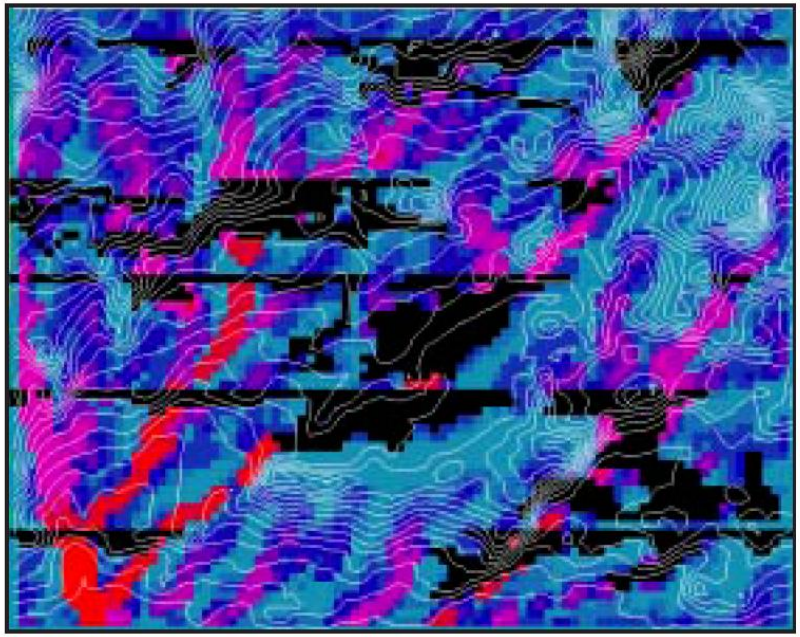
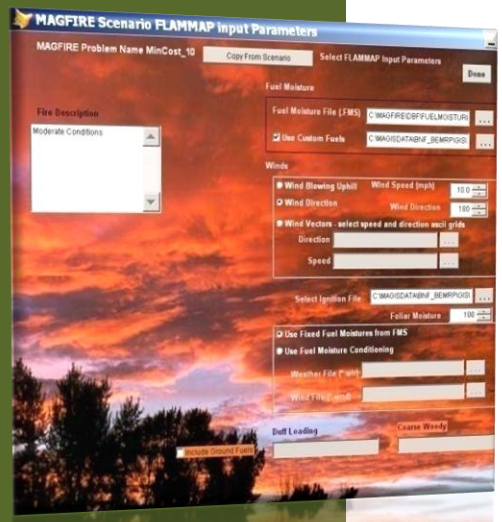


Figure 2—Routes resulting in the most burned area can be identified using graph theory (Finney 2002). These routes reflect the greatest opportunities for disrupting the simulated fire growth using fuel management. Red indicates high influence and blue little or none. Heuristic algorithms can then optimize fuel treatment locations (shown in black) that result in efficient reductions in fire spread rate per unit area treated. The treatments shown in black reduce fire spread rate by 40% with less than 16% of the area treated because treatments are located to block the fastest and most influential routes.

(Source: Finney 2003. Landscape Planning. USDA Forest Service Proceedings RMRS-P-29)

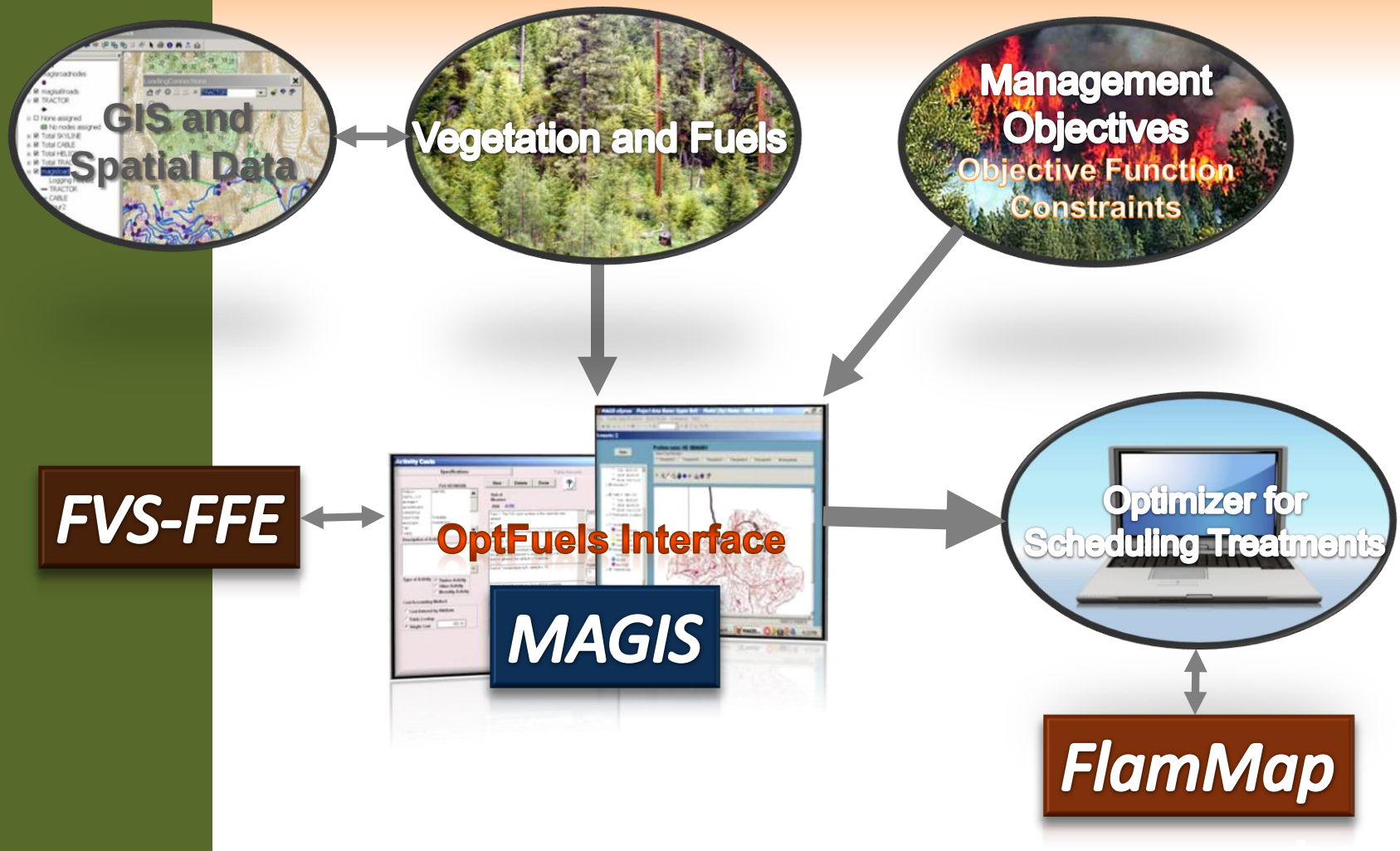
Objective

- Integrate existing fire behavior (FlamMap), vegetation simulation (FVS-FFE), and land management planning (MAGIS) tools into one decision support system that supports long-term fuel management decisions in order to
  - optimize **spatial and temporal** location of fuel treatments in a way that landscape-level fuel management effects are maximized and maintained over time,
  - while satisfying given budget and operational constraints.

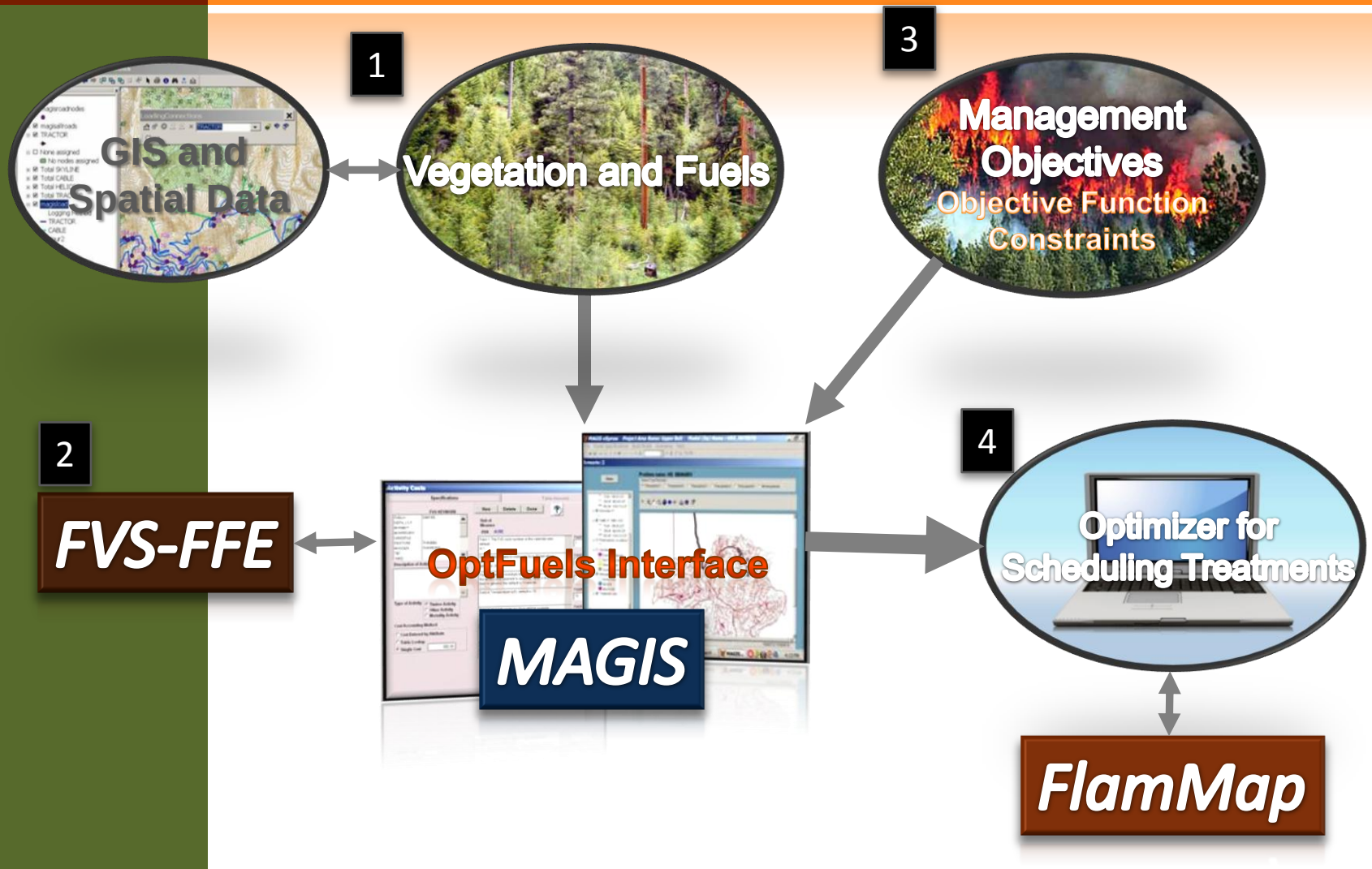


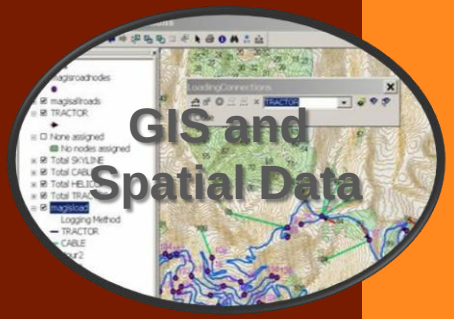
OptFuels

System Components



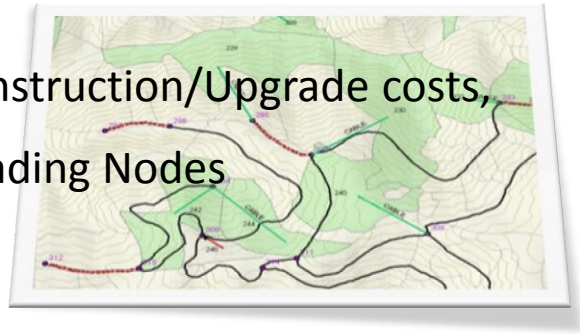
System Components





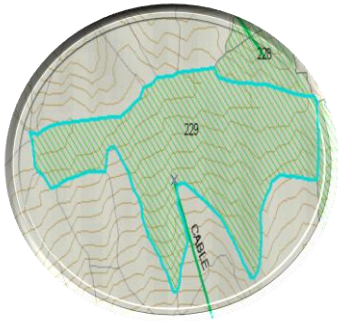
Spatial Data

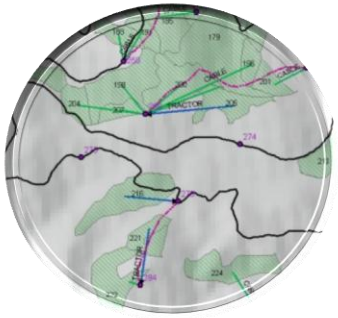
- Polygon Input Layers - Vegetation GIS Data
  - Wall-to-Wall stand polygons, FVS-Ready data crosswalked to polygons, Management Zones, etc.
- Rasters (for fire behavior)
  - Elevation, Slope, Aspect
- Road Input Layer - Optional
  - Existing & Proposed links, Construction/Upgrade costs, Variable Costs (haul cost), Loading Nodes



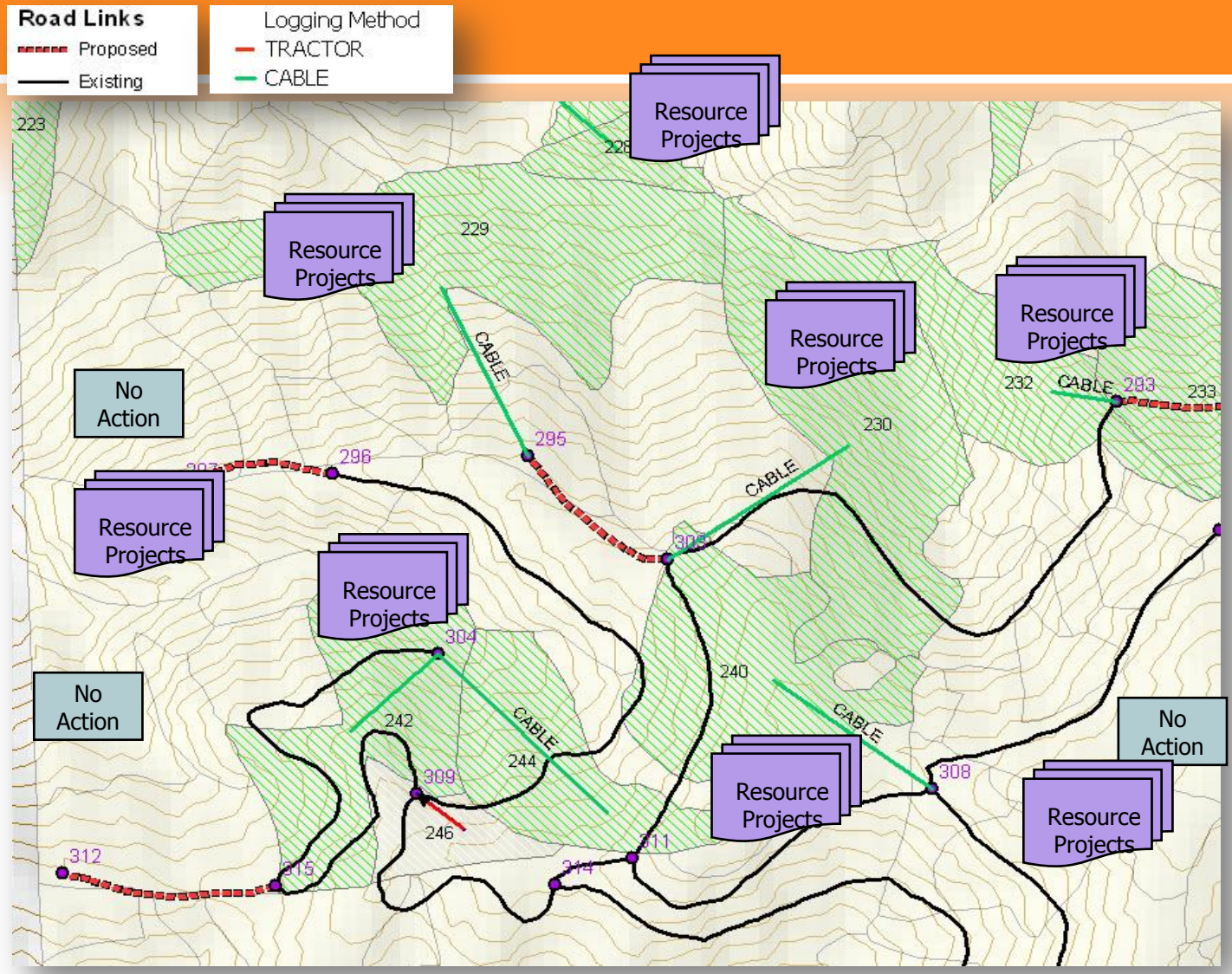
Vegetation and Fuels Component

- Building Alternative Treatments
  - Treatment units
  - Treatment options
  - Harvesting methods and costs
  - Loading nodes and accessibility
  - Starting period



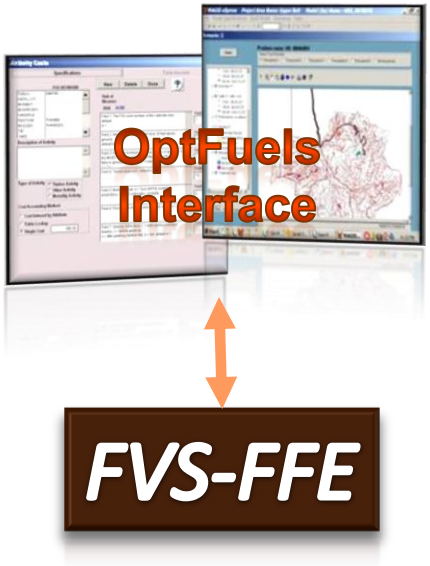


Vegetation and Fuels Component



Vegetation and Fuels Component

- Run FVS-FFE for No Action
  - FFE Fuels for no action
- Run FVS on Resource Projects
  - Prescribed Fire, Mechanical Treatments, Commercial Harvest
  - Calculate post-treatment FFE fuels
  - Calculate outputs (timber, biomass)



Management Objectives Component

- Objective for driving treatment placement and scheduling
  - Minimize expected loss to wildland fire over time

$$Minimize \sum_{t \in T} \sum_{c \in C} \sum_{f \in F} Loss_{f,c,t} \times Y_{f,c,t} \times P_{c,t}$$

Where

f is an index of flame length category,
c is an index of grid cells,
t is a time period,
$\boldsymbol{Loss_{f,c,t}}$ is an expected loss value of grid cell *c* at flame length category ***f*** in time period ***t***,
$\boldsymbol{Y_{f,c,t}}$ is a binary variable indicating the flame length category of cell ***c*** in period ***t***, and
$\boldsymbol{P_{c,t}}$ is a probability of cell c being burn by given fire scenarios (fire ignition locations and durations) in time period ***t***.

Management Objectives Component

- OptFuels Objective Function

$$Minimize \sum_{t \in T} \sum_{c \in C} \sum_{f \in F} Loss_{f,c,t} \times Y_{f,c,t} \times P_{c,t}$$

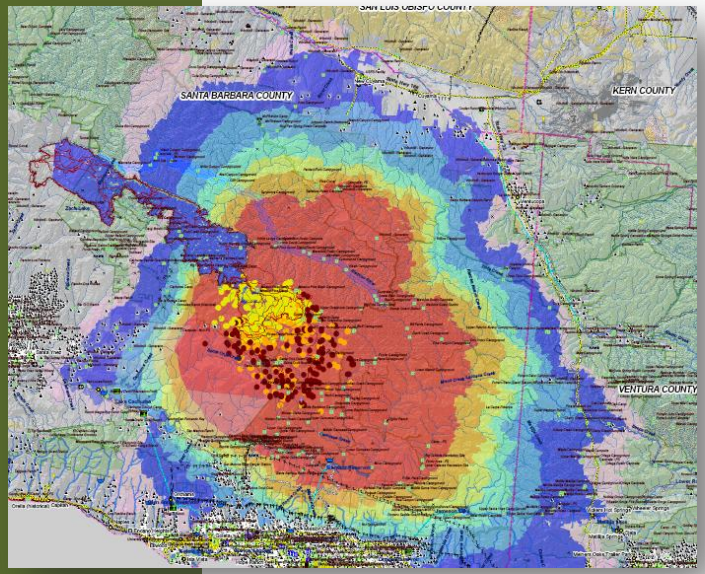
Relative Expected Loss ($Loss_{f,c,t}$)

	Low	Med.	High	Very High
FS, roadless	0	10	20	30
FS, accessible	0	60	70	80
FS, WUI	50	150	250	480
Right-of-way	0	0	800	800
State and Private	10	30	50	80

Management Objectives Component

- OptFuels Objective Function

$$Minimize \sum_{t \in T} \sum_{c \in C} \sum_{f \in F} Loss_{f,c,t} \times Y_{f,c,t} \times P_{c,t}$$



Burn Probability ($P_{c,t}$)

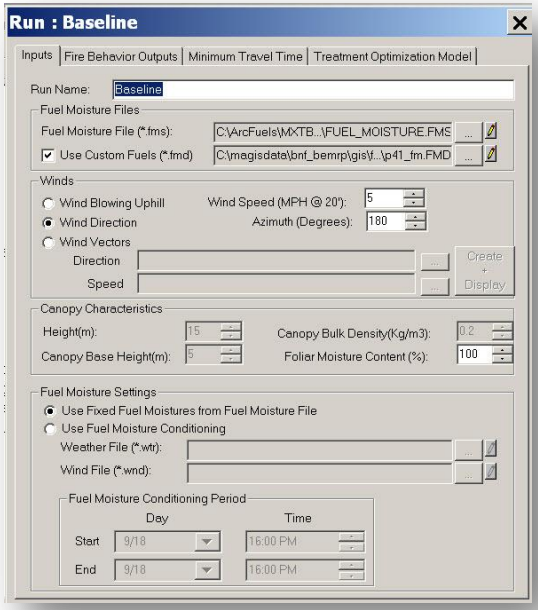
Time step	Probability
1 day	0.9
2 days	0.7
3 days	0.5
4 days	0.3
5 days	0.2
6 days	0.1
7 days	0.1
8 days	0.0
9 days	0.0
10 days	0.0

Management Objectives Component

- Potential Constraints
  - Budget constraints
  - Estimate quantity and value of products produced by treatments
  - Limit treatment options and acres by zones (treatment exclusion, treatment priority, treatment type)
  - Require road access for treatments that remove product
  - Schedule road construction, upgrades, etc.

Management Objectives Component

- Fire Scenarios
  - Ignition points (shapefile)
  - Wind speed and direction
  - Fuel moisture file
  - Custom fuel model



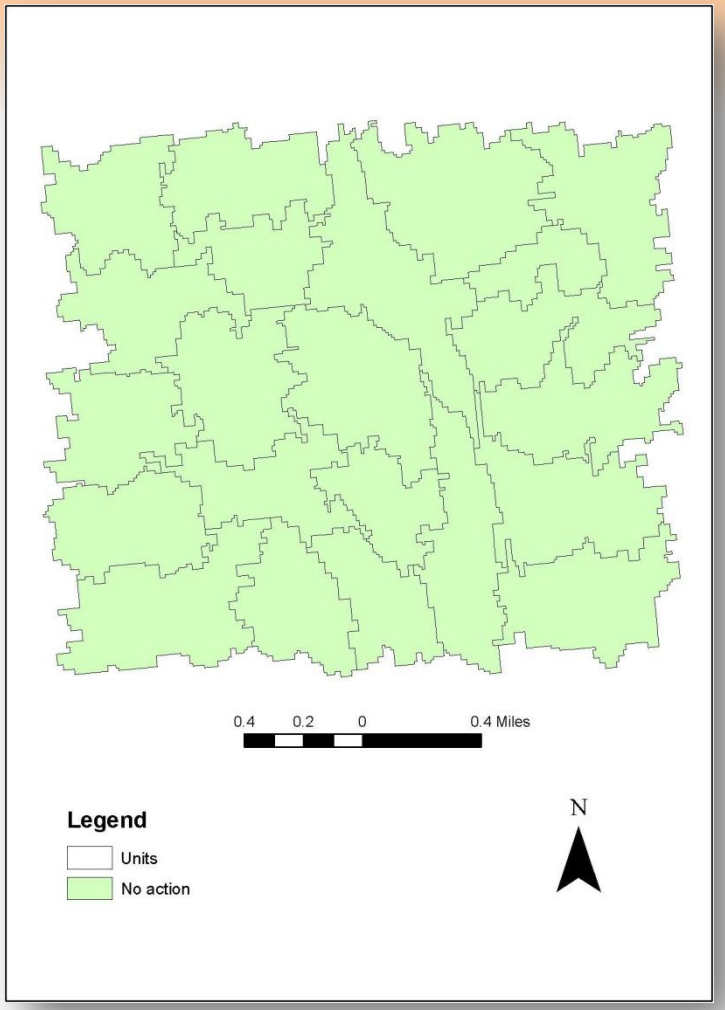
Heuristic Solver

- Heuristic solver in OptFuels employs a simulated annealing and a heuristic network algorithm to efficiently produce near-optimal solutions
  - uses an iterative method to generate a large number of alternative solutions (i.e., fuels treatment schedules)
  - evaluates the alternatives based on given objective function and constraints, and
  - selects the best solution among alternatives

Optimizer for Scheduling Treatments

Heuristic Solver

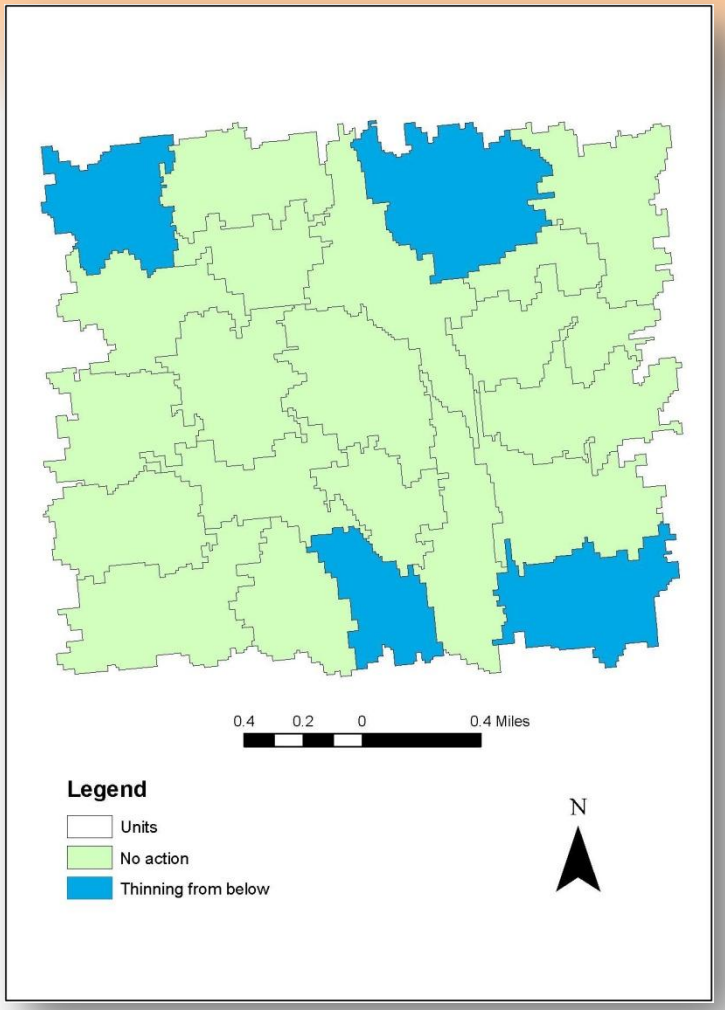
- Generating alternative solutions



Optimizer for Scheduling Treatments

Heuristic Solver

- Generating alternative solutions



Optimizer for Scheduling Treatments

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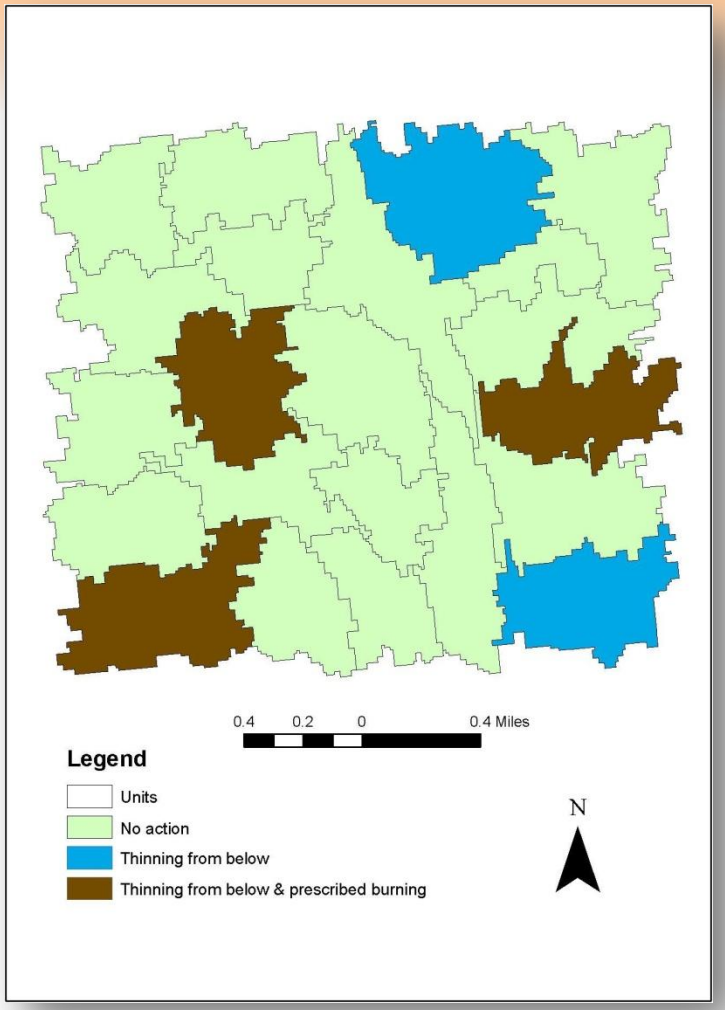

Optimizer for Scheduling Treatments

Heuristic Solver

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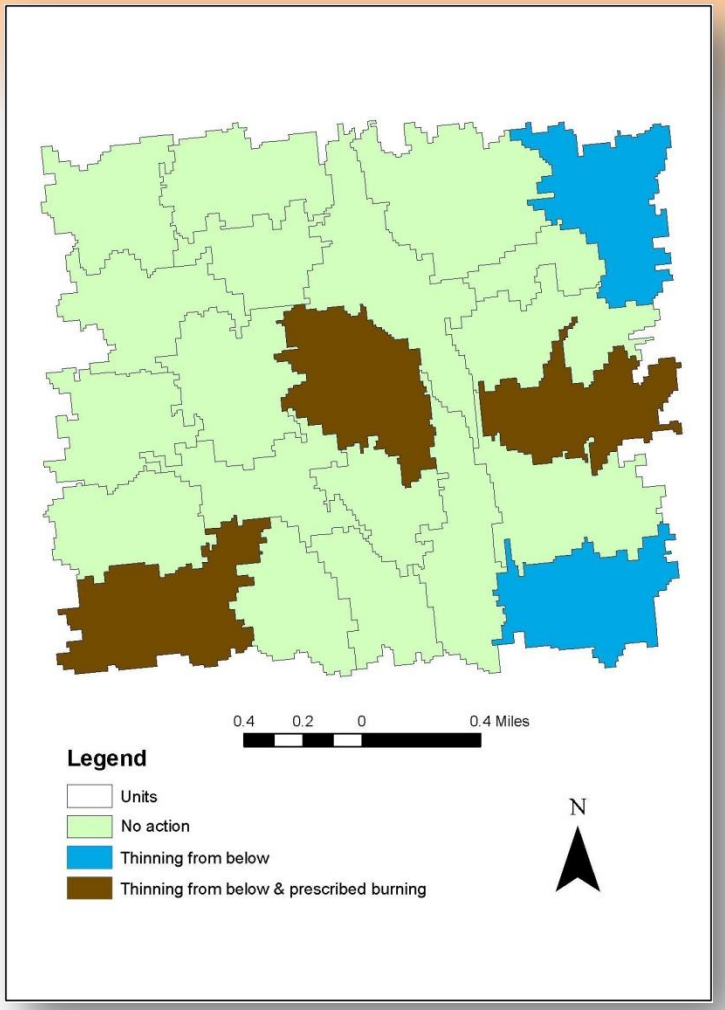


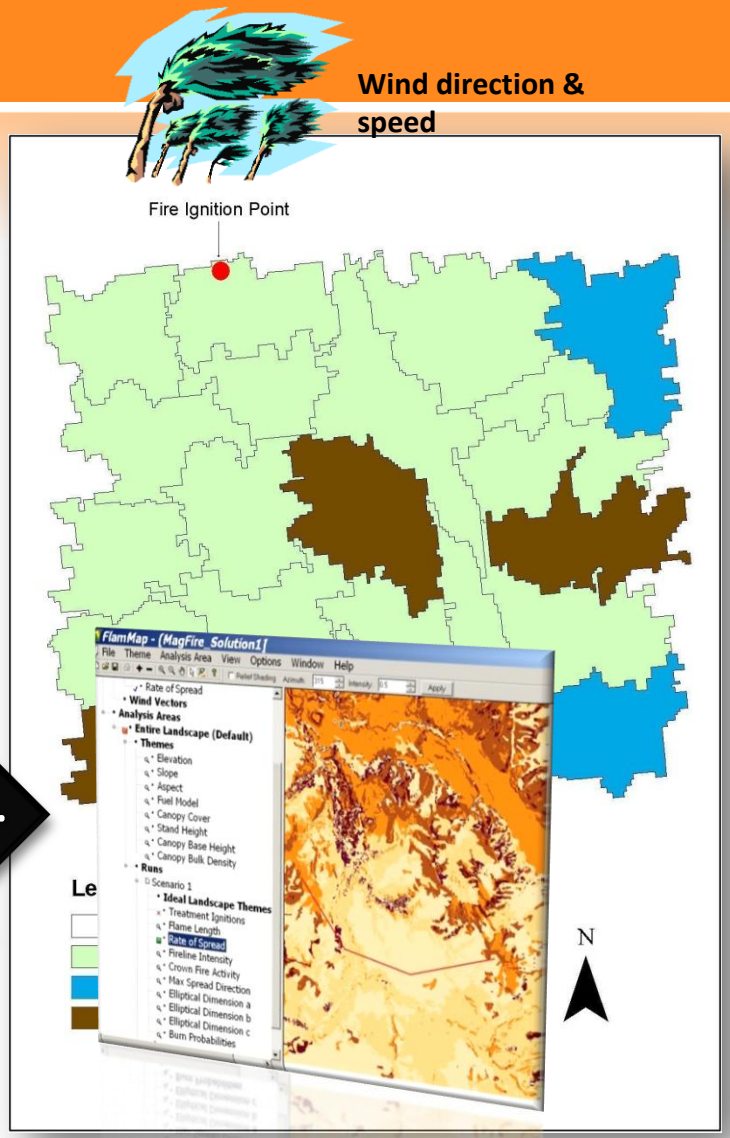
Optimizer for Scheduling Treatments

Heuristic Solver

- Evaluating each candidate solution

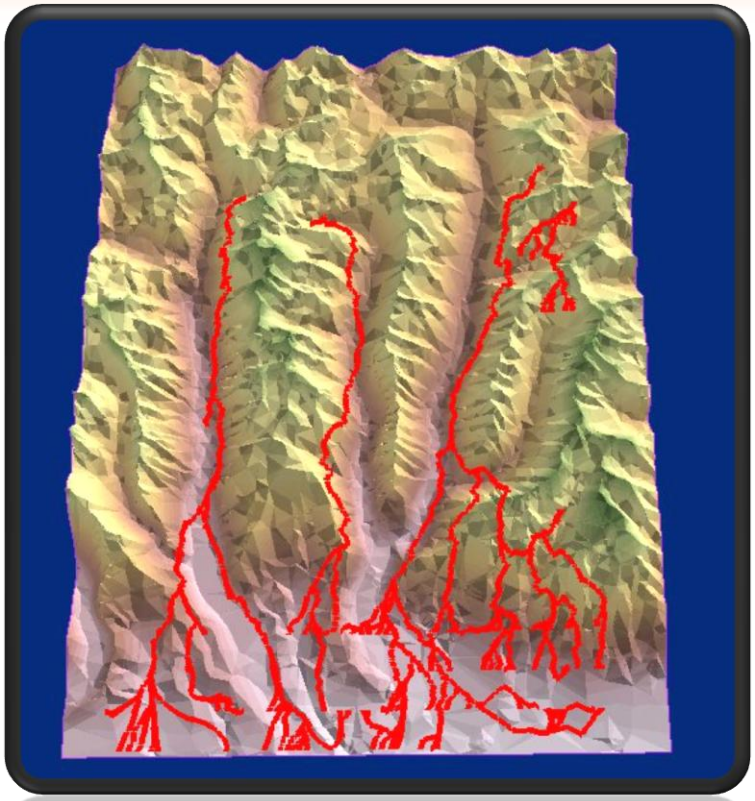
LCP file generator
mf_ffe_mgt.txt,
mf_ffe_noaction.txt,
mf_objectivevalues.txt,
aspect.txt, elev.txt,
slope.txt, etc.

FlamMap-MTT DLL



Heuristic Solver

- MTT (Minimum Travel Time) algorithm (Finney 2002) calculates least-time path of large fire movement under specified target conditions based upon relative conductivity of fuels



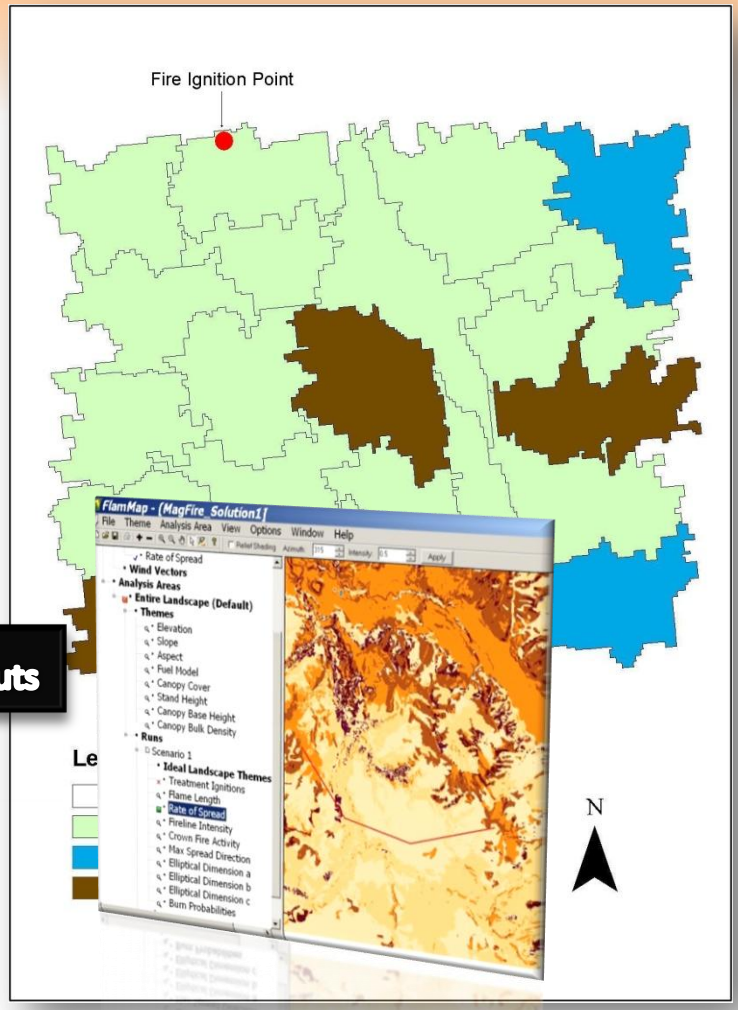
Optimizer for Scheduling Treatments

Heuristic Solver

- Evaluating each candidate solution

Fire behavior characteristics
- Fire travel time
- Flame length
- Rate of spread
- Max. spread direction
- Ellipse dimensions

FlamMap Outputs



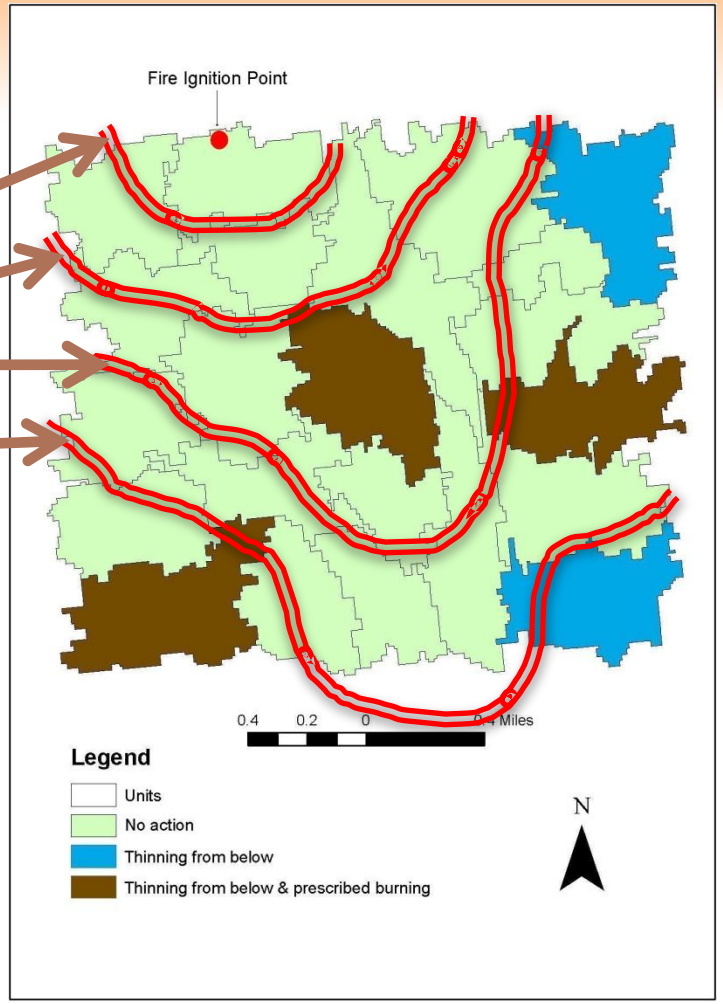
Heuristic Solver

1 day (95%)

3 days (70%)

5 days (50%)

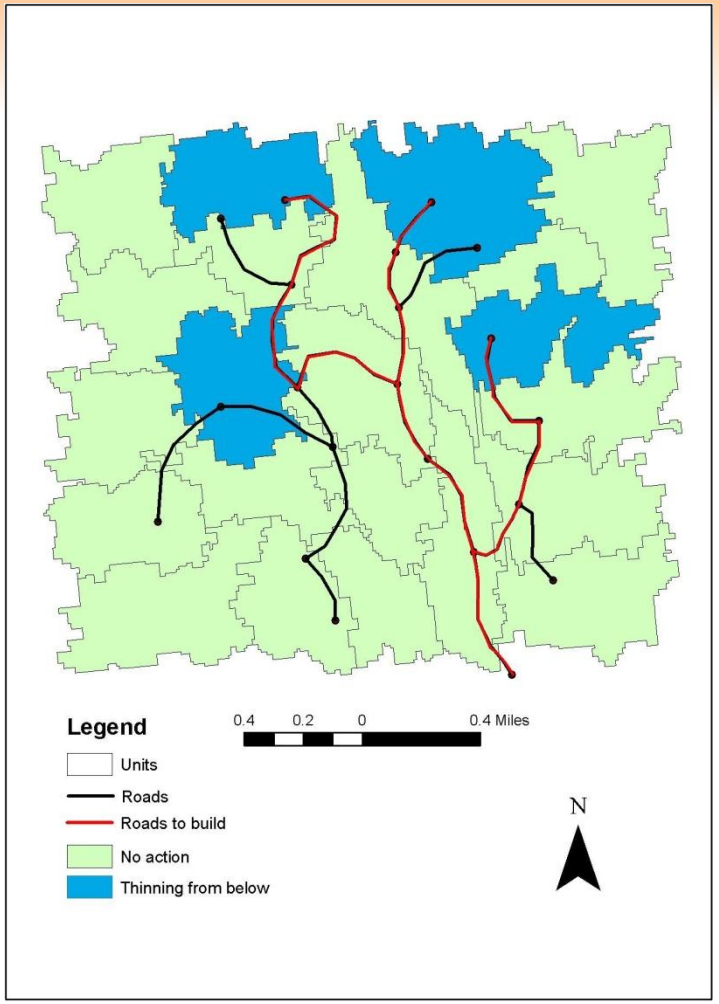
10 days (10%)



$$\textit{Minimize} \sum_{t \in T} \sum_{c \in C} \sum_{f \in F} Loss_{f,c,t} \times Y_{f,c,t} \times P_{c,t}$$

Heuristic Solver

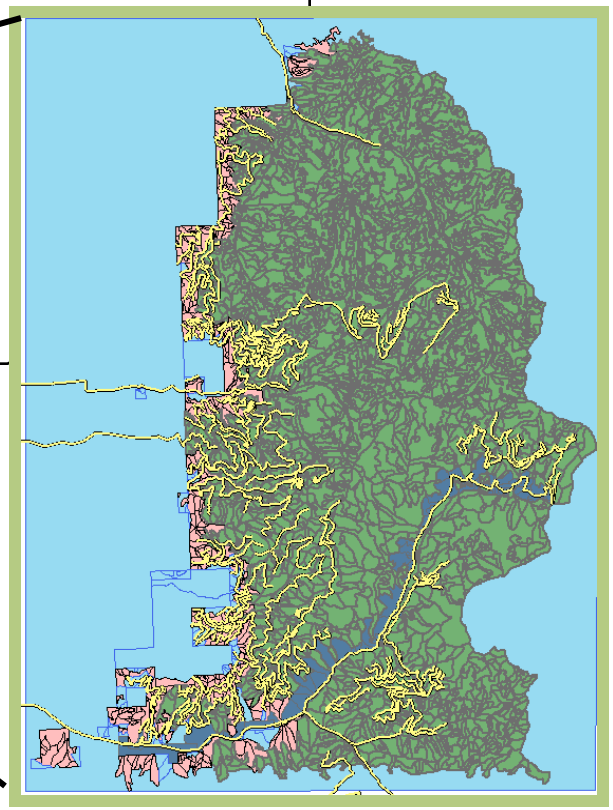
- Evaluating each candidate solution



Application

Montana

Bitterroot National Forest



Willow-Gird analysis area

Application

Study area

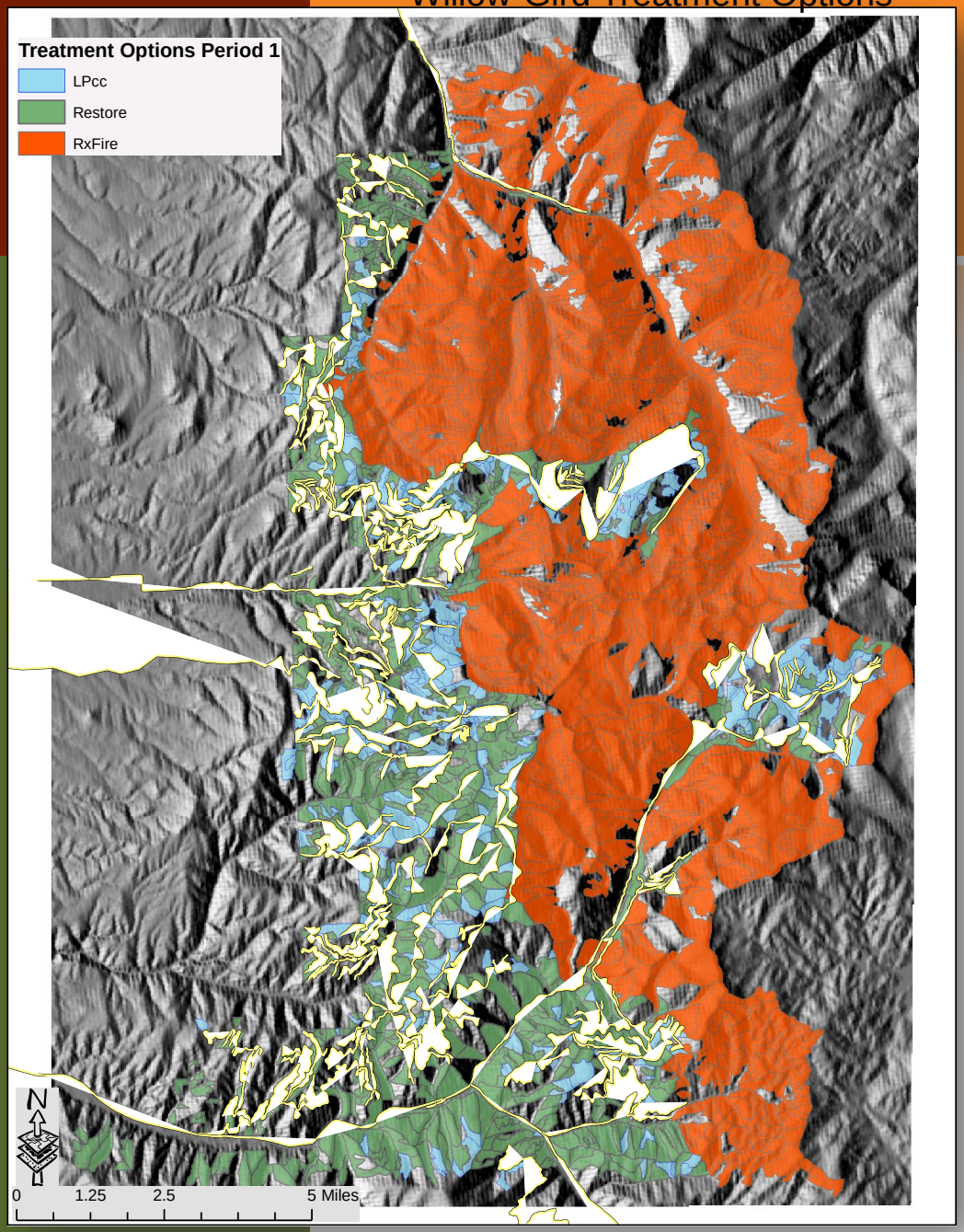
Types	Acres
FS, roadless	52,744
FS, accessible	30,939
FS, WUI	9,817
Right-of-way	3,830
State & Private	6,358
TOTAL	103,688

Relative Expected Loss ($Loss_{f,c,t}$)

	Low	Med.	High	Very High
FS, roadless	0	10	20	30
FS, accessible	0	60	70	80
FS, WUI	50	150	250	480
Right-of-way	0	0	800	800
State and Private	10	30	50	80

Application

Willow-Gird Treatment Options



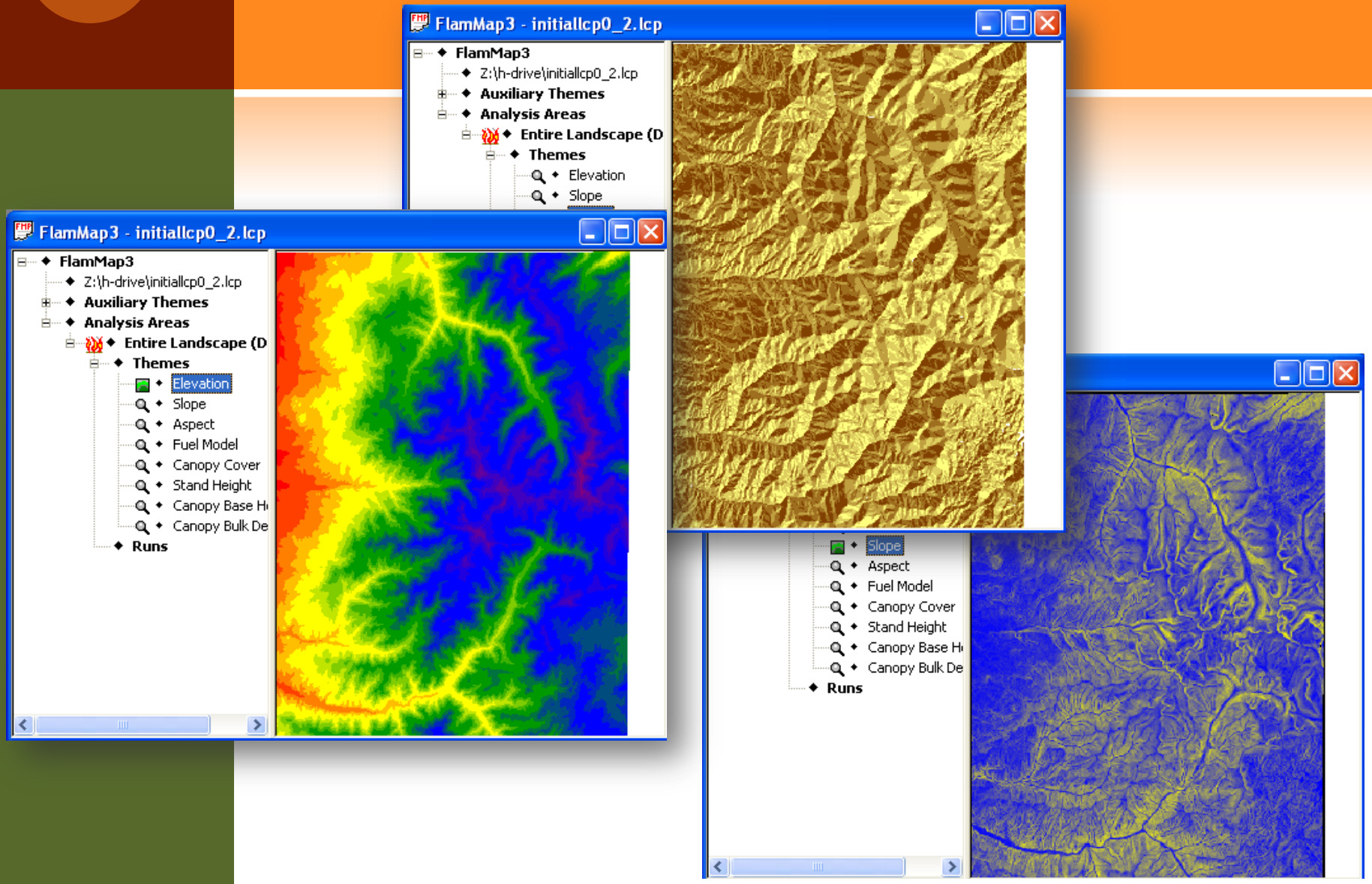
Treatments

Types	Polygons
LP Clear Cut	309
PP, DF Restoration	807
Prescribed Fire	1319
No action only	775
TOTAL	3,210

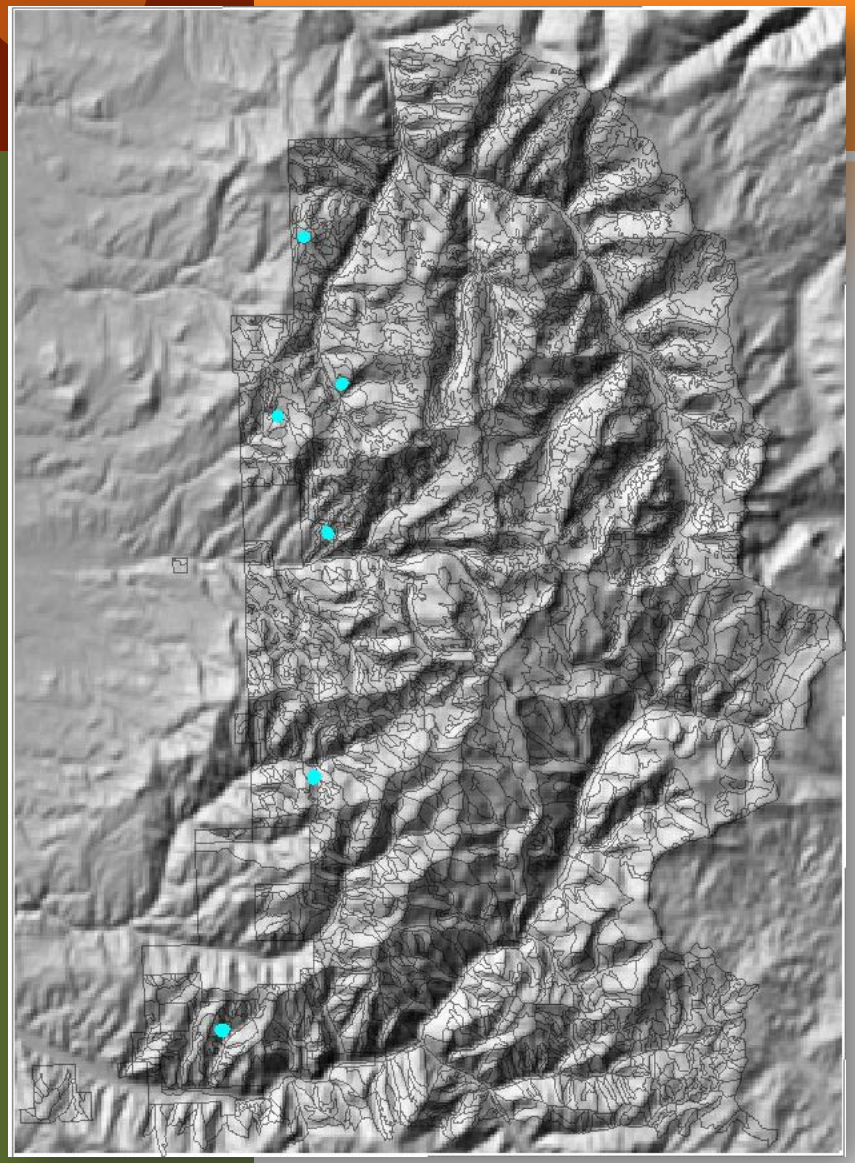
Two time periods with a 10 year interval

Upper limit in treated acreas: 8,500 acres per period

Application



Application



- Fire Scenario
  - Wind speed: 15 MPH
  - Wind direction: 270°

Burn Probability ($P_{c,t}$)

Time step	Probability
1 day	0.9
2 days	0.7
3 days	0.5
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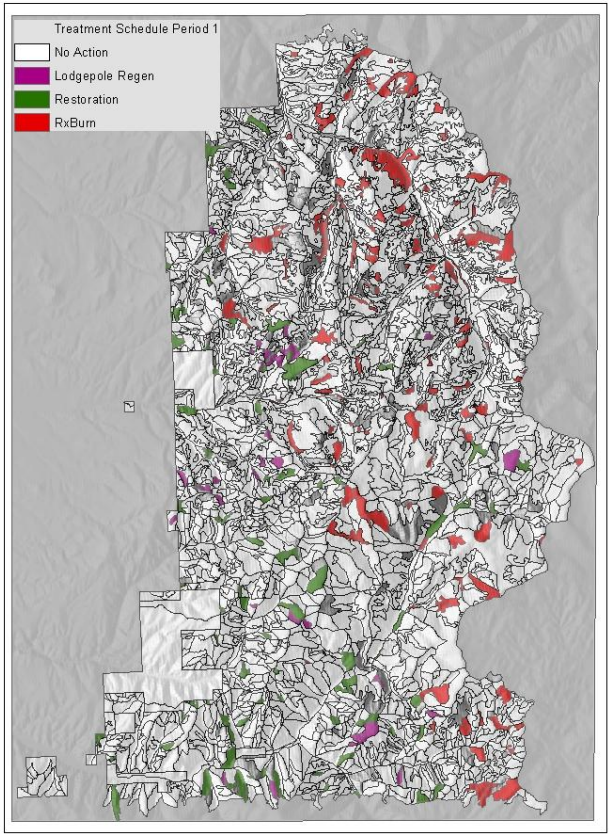
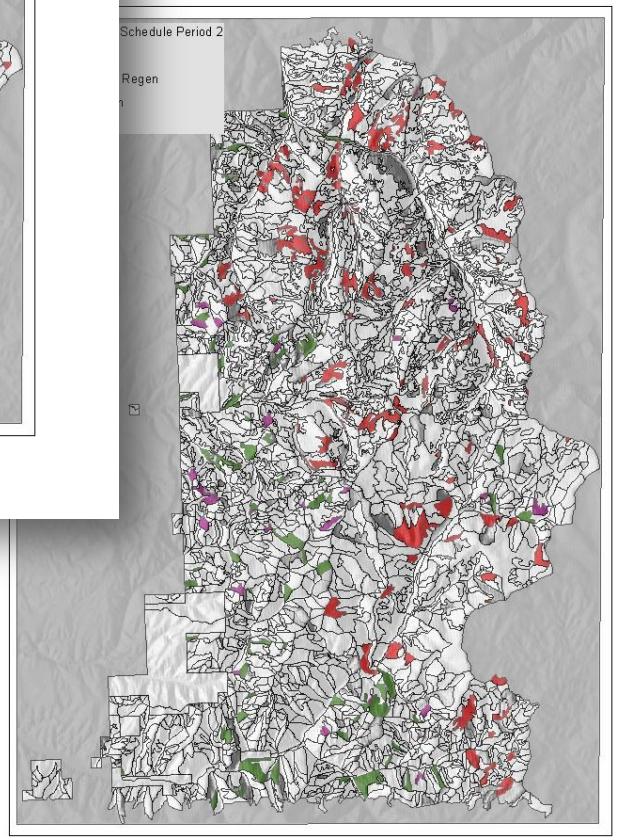
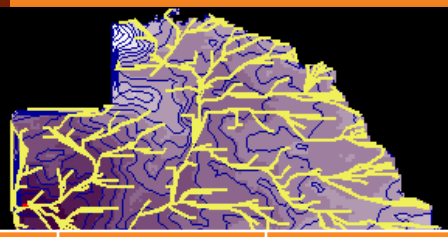
Application



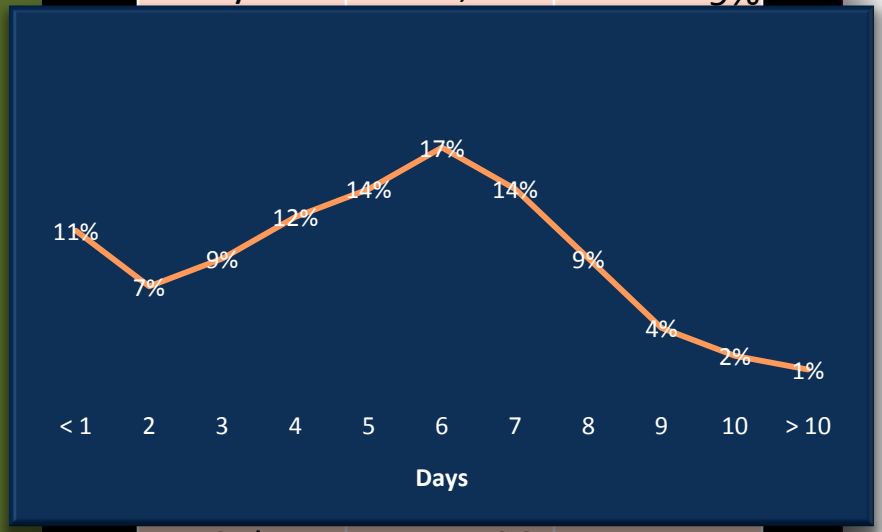


A total of 16,060 acres to be treated (15% of total project area)

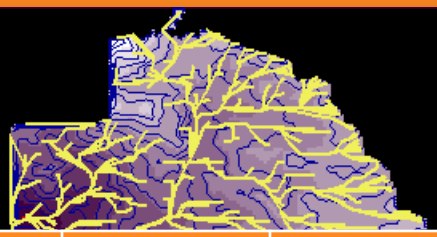
No action - 1st period



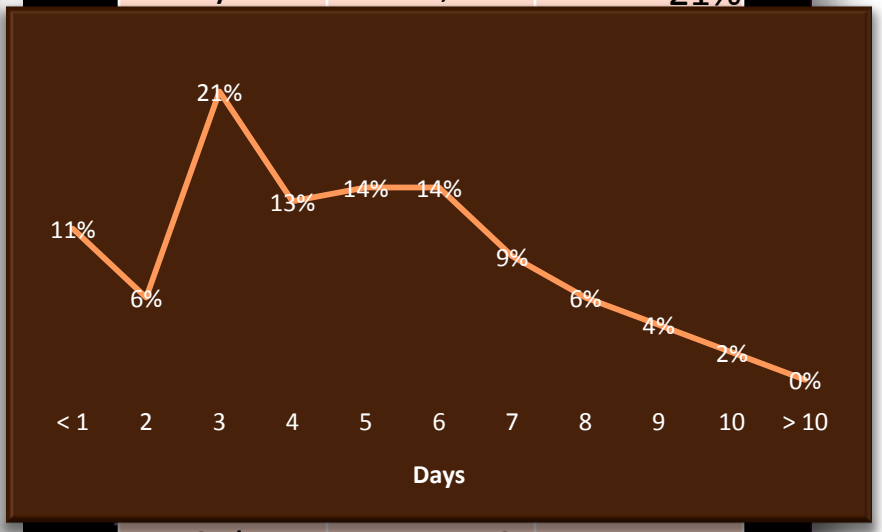
Time	# of cells	% area
< 1 day	6,009	11%
2 days	3,835	7%
3 days	4,694	9%
> 10 days	796	1%



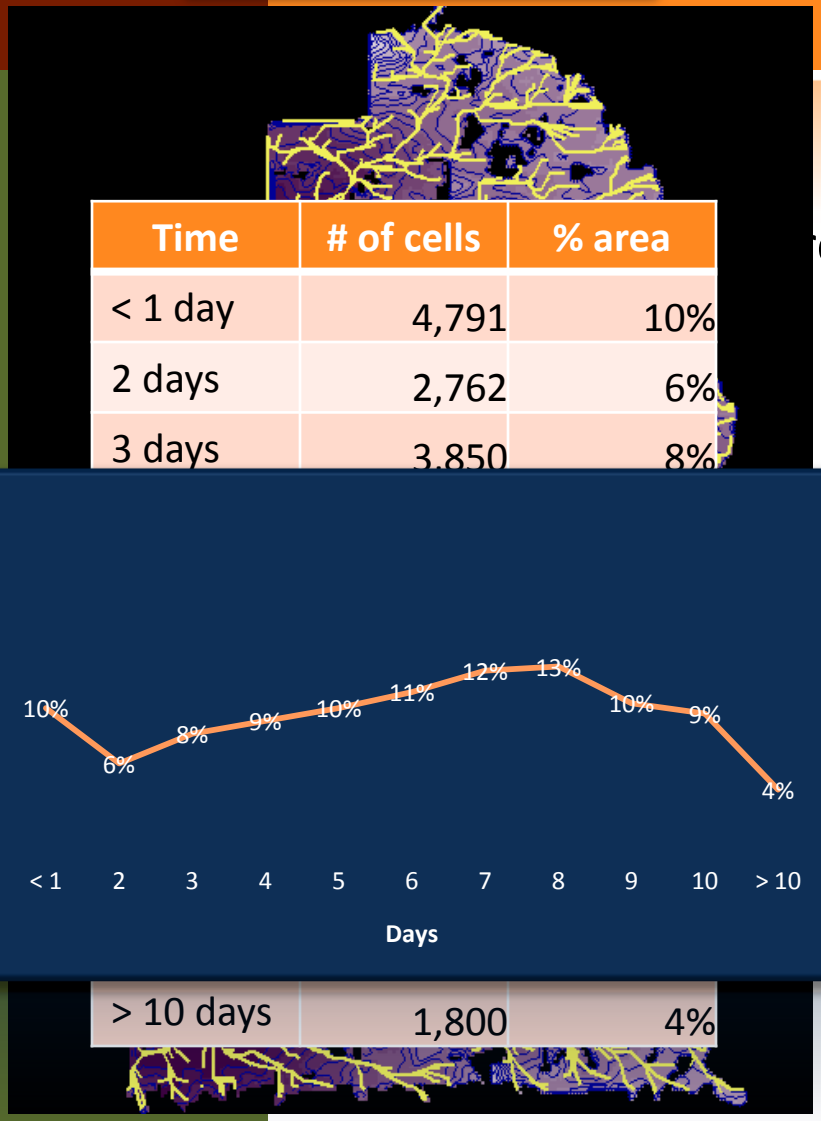
No action - 2nd period



Time	# of cells	% area
< 1 day	5,804	11%
2 days	3,208	6%
3 days	11,162	21%
> 10 days	0	0%

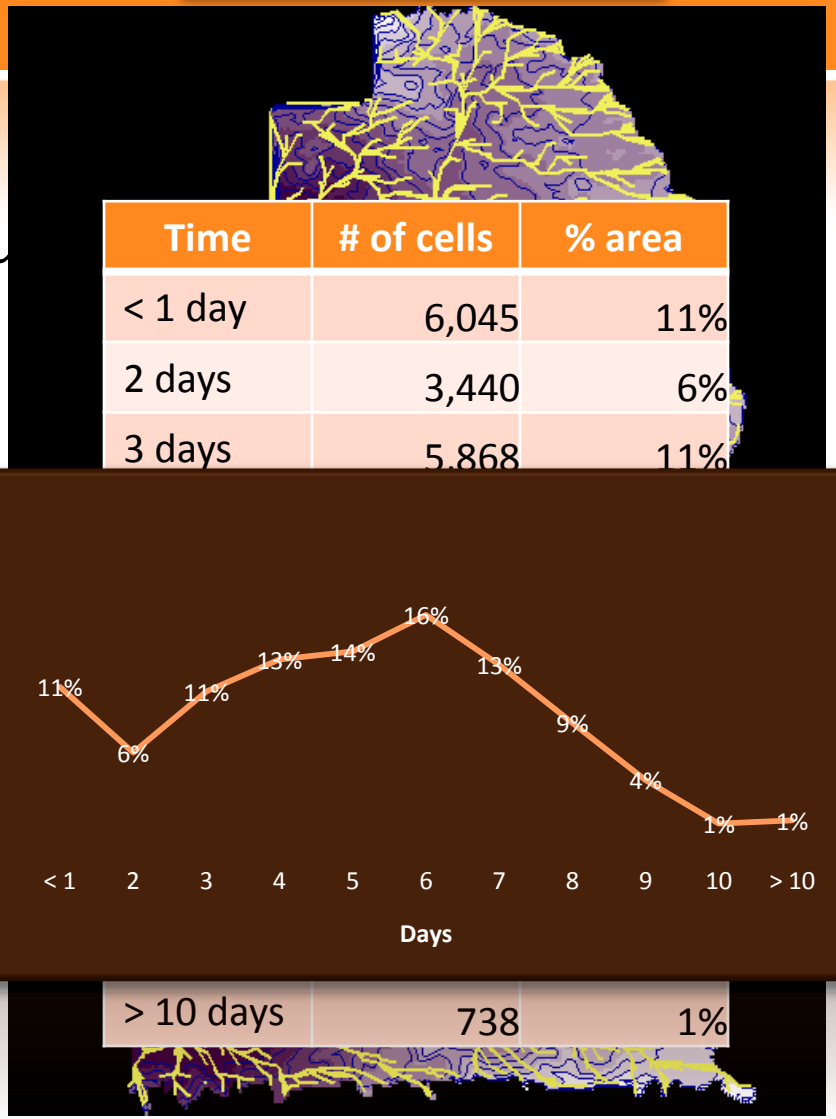


Treatment - 1st period



Time	# of cells	% area
< 1 day	4,791	10%
2 days	2,762	6%
3 days	3,850	8%
> 10 days	1,800	4%

Treatment - 2nd period

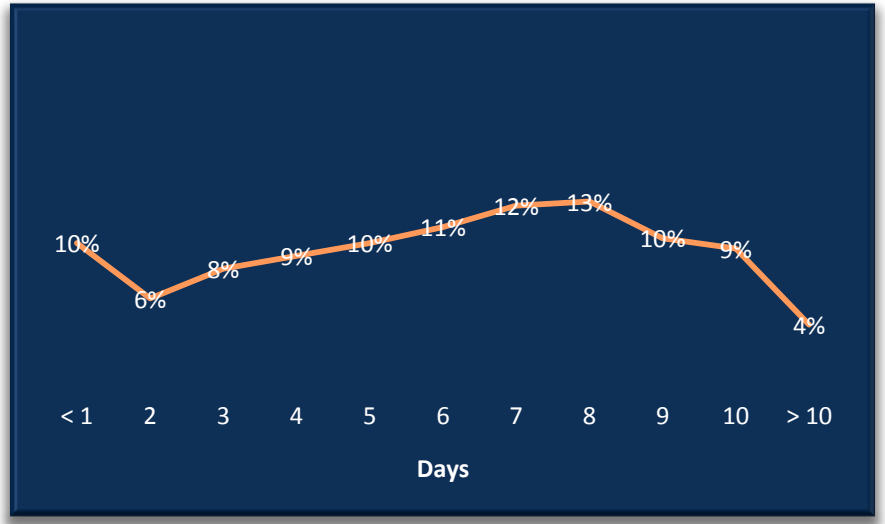


Time	# of cells	% area
< 1 day	6,045	11%
2 days	3,440	6%
3 days	5,868	11%
> 10 days	738	1%

Application

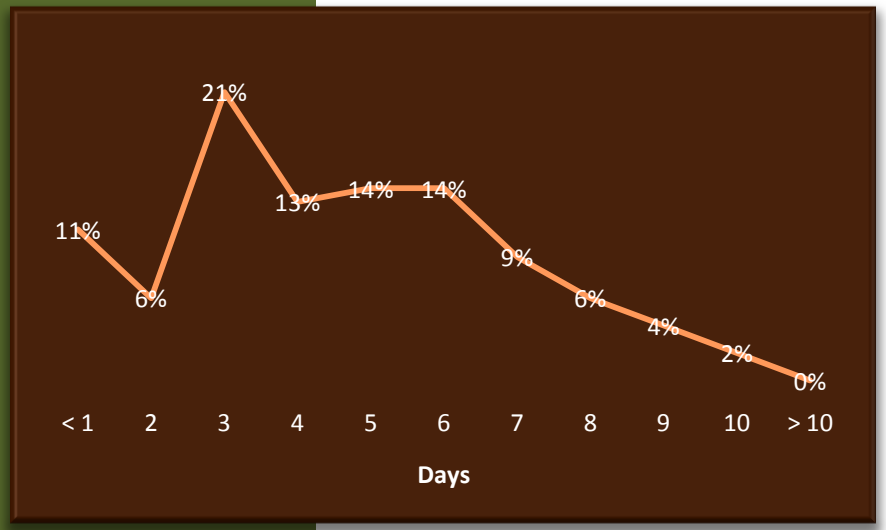
No action - 1st period

Treatment - 1st period

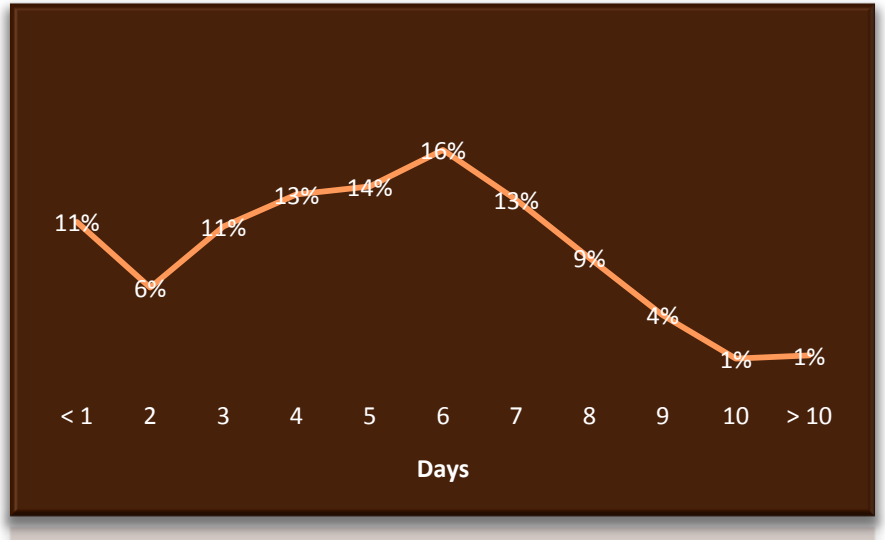


Application

No action - 2nd period



Treatment - 2nd period



Concluding Remarks

- Development of data transfer interfaces among the MAGIS, FlamMap, FVS-FFE models and the heuristic solver for OptFuels has been completed.
- Extensive testing of the system and applications development will be carried out.

Concluding Remarks

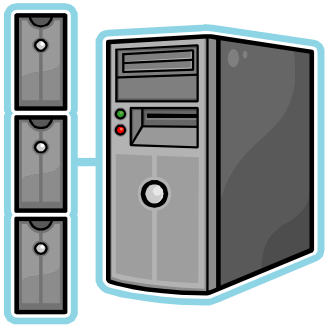
- Highlights of OptFuels
  - Management Objective: Minimize Expected Loss Value across a Landscape
  - Temporal – FVS-FFE
  - Spatial – GIS
  - Constraints – Budget, Treatment Zones, Access
  - Work with Management Units

Concluding Remarks

- Upon completion of the system, OptFuels can be useful for developing fuel treatment schedules that are cost-efficient and practically feasible

Concluding Remarks

- Challenges
  - Lack of spatial data for individual polygons
  - Considerable computation time required
    - Parallel programming techniques
    - Multiple processor computers
    - Genetic Algorithm



Thank you!