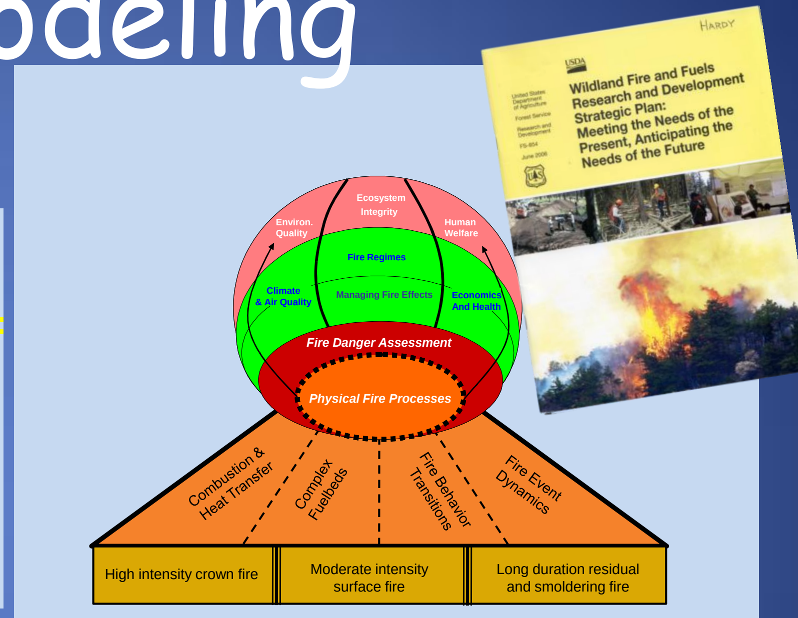
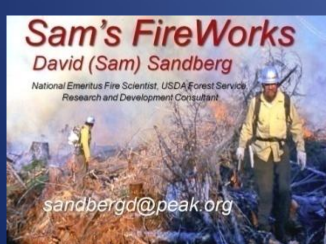
Management-Relevant Fire Spread Modeling



- David (Sam) Sandberg,
- Roger Ottmar (FS-PNW),
- Susan Pritchard (U.Wash.),

Advanced Combustion Engineering Research Center, February 26, 2010



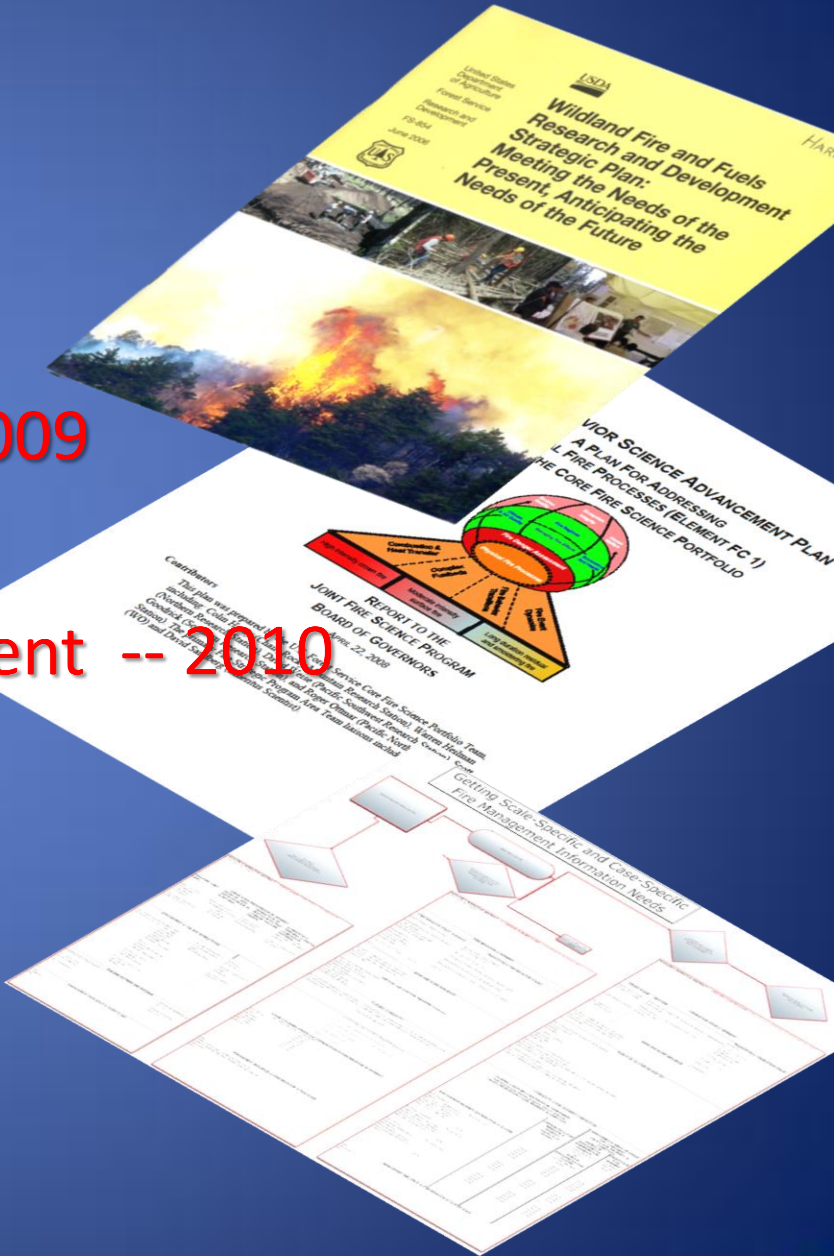
FERA
Fire and Environmental Research Applications

USDA FOREST SERVICE
Pacific Wildland Fire Sciences Lab
SEATTLE, WASHINGTON

NFP

Core Fire Sciences Advancement Plan

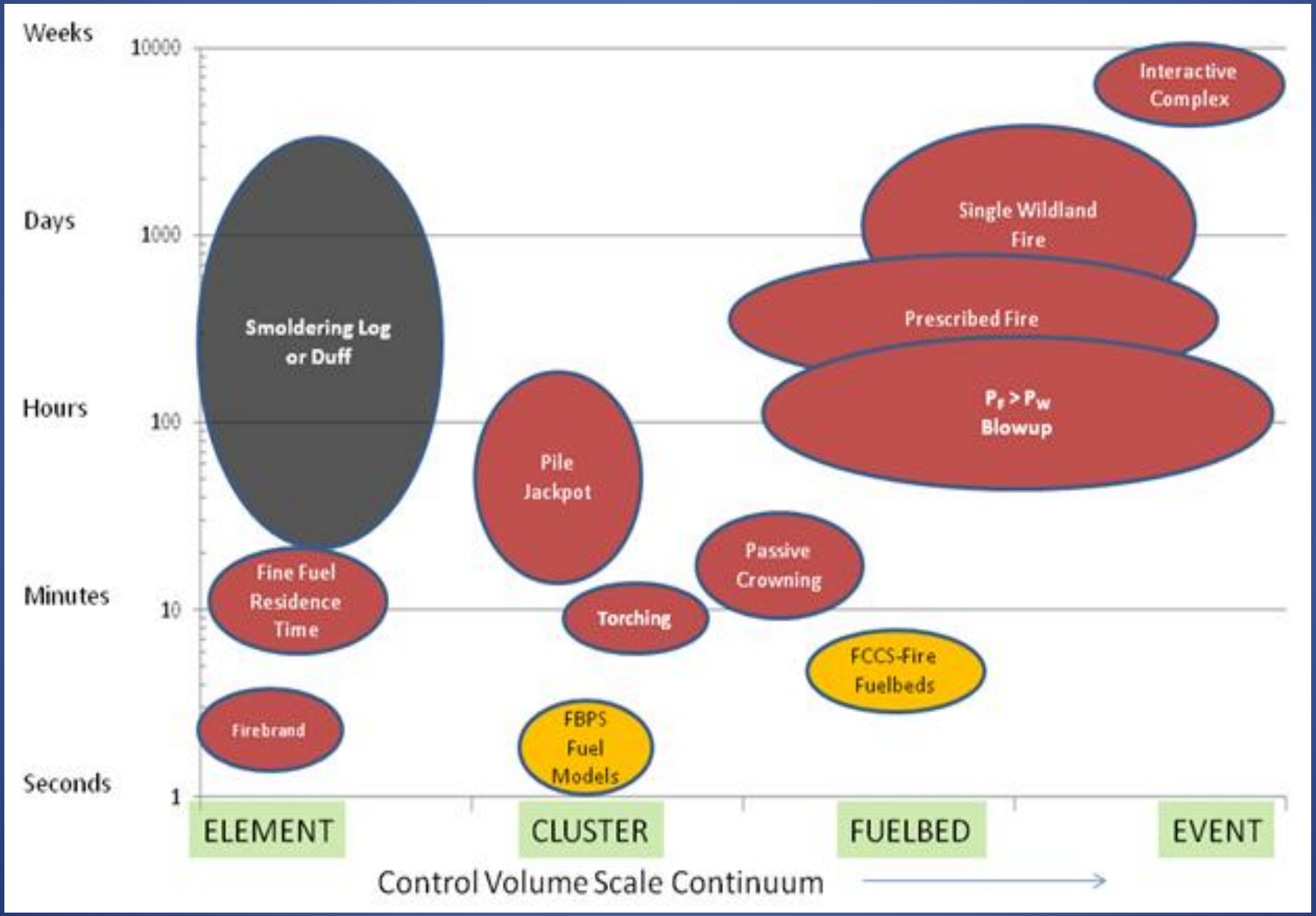
- CFS Caucus Advocacy -- 1999
- Strategic Problem Identification – 2003
- Clarity of Scope and Goals -- 2006
- Problem Analysis -- 2008
- **Combustion Schematics -- 2009**
- **Prioritization**
  - **By Relevance to Management -- 2010**
  - By Program Sufficiency
    - Realm, Scale, Quality



FS Portfolio Team:
Mike Hilbruner
Colin Hardy
David Weise
Roger Ottmar
Warren Heilman
Scott Goodrick

Core Fire Science Caucus:
FS Portfolio Team
Rod Linn
Ruddy Mell
Kevin Heirs
……numerous others

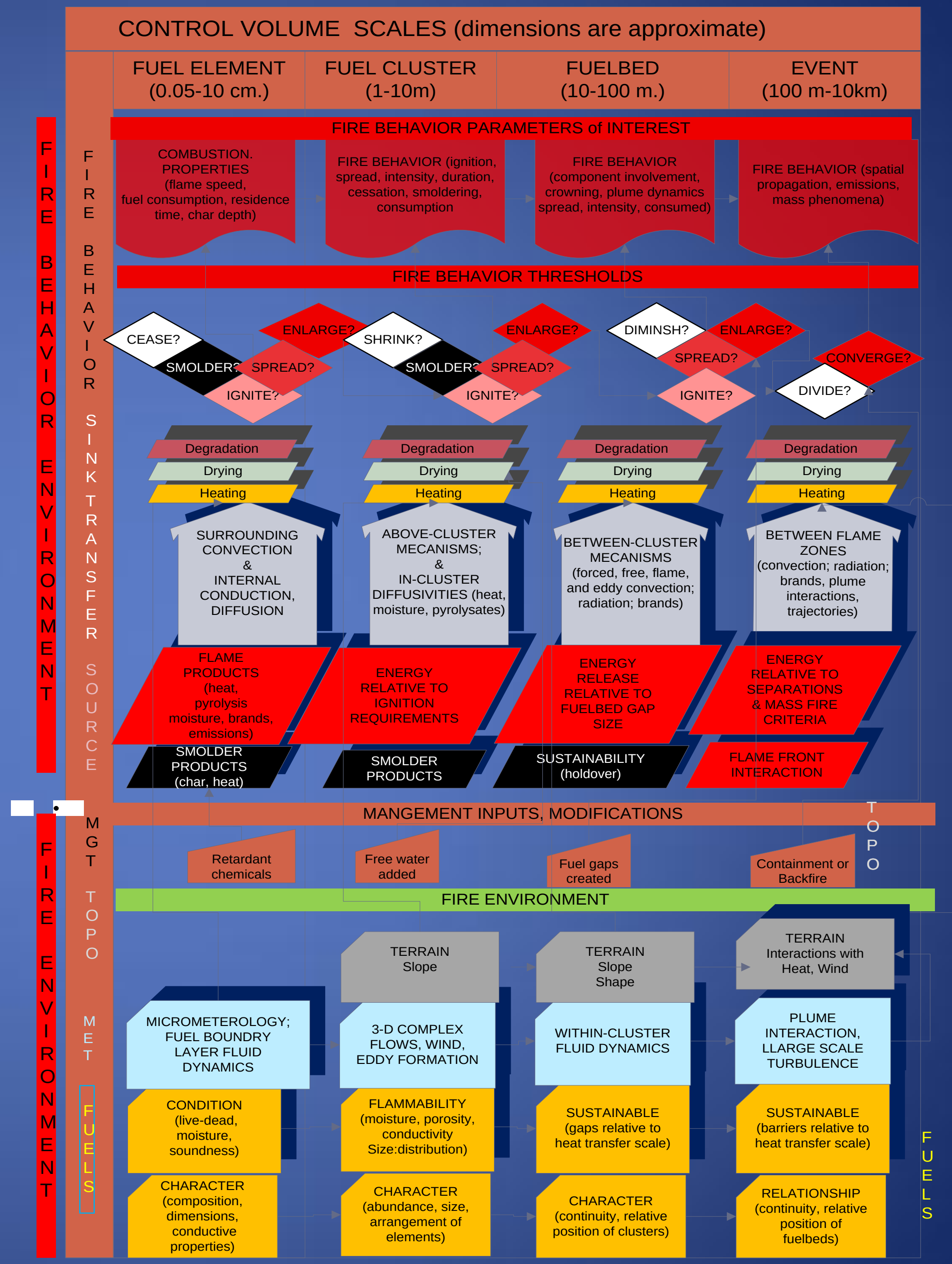
Combustion Environment "Scales"



Combustion Schematics--2009

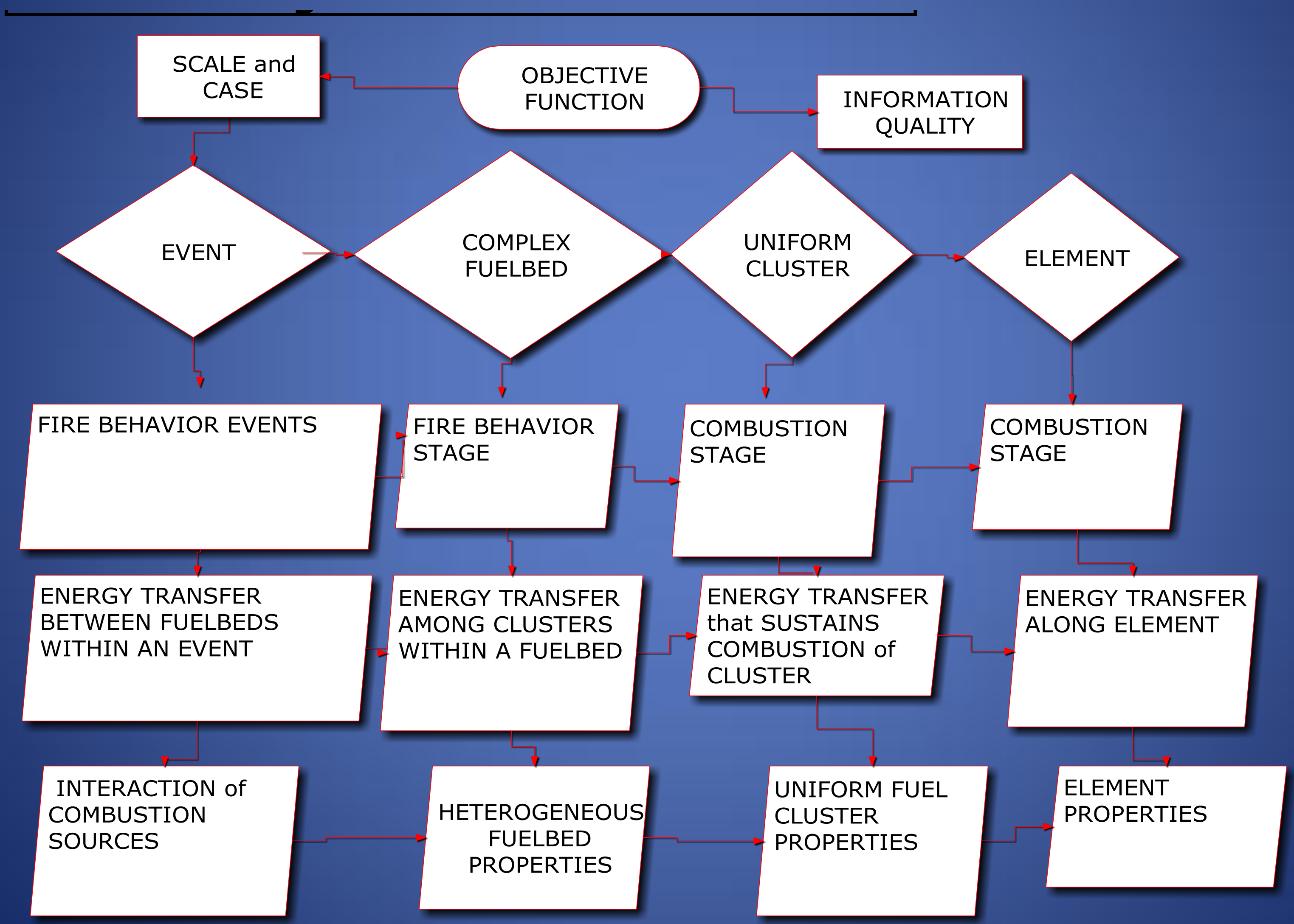
Washington Institute

FS Portfolio Team

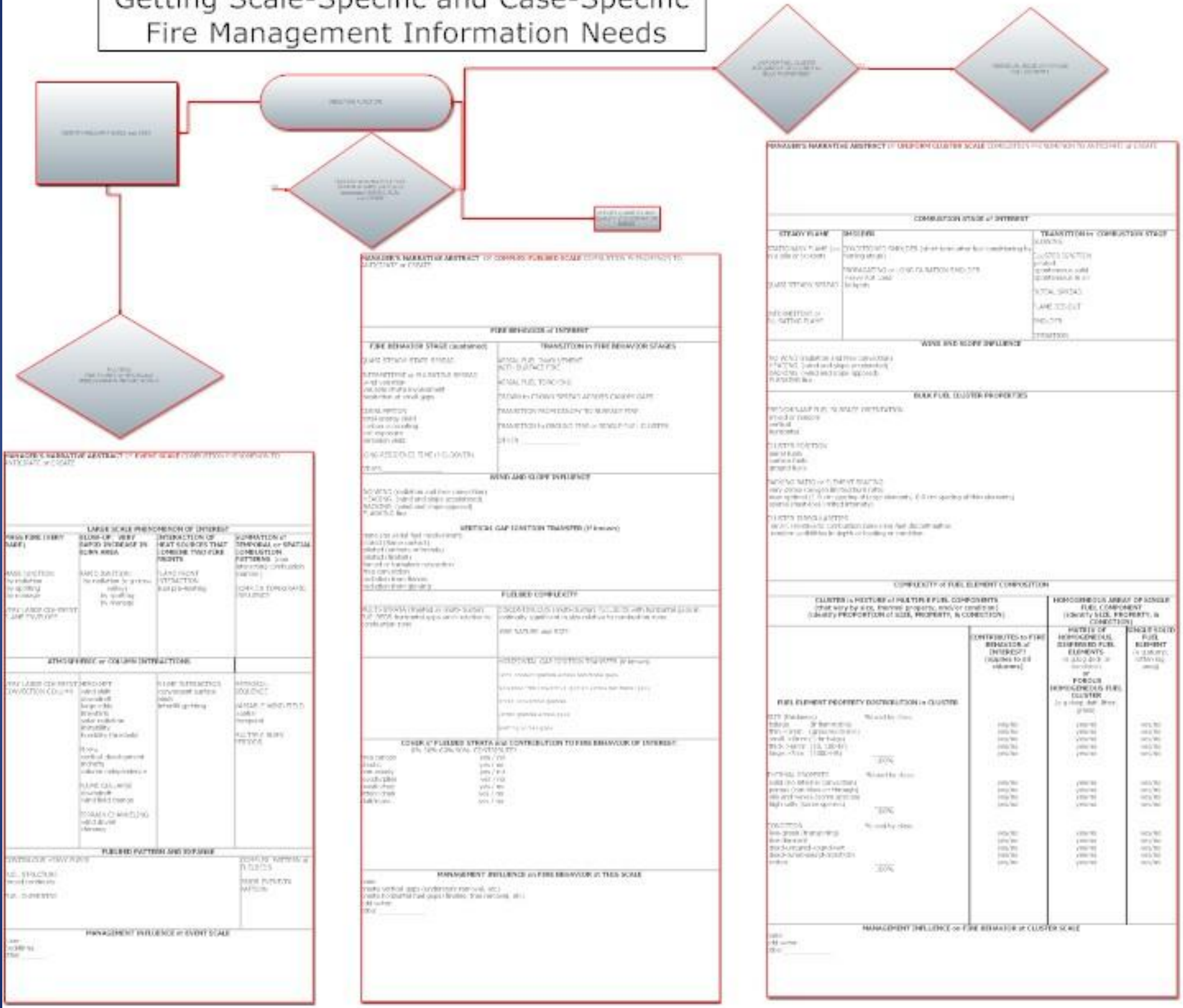


“SPATIAL SCALES”
“FIRE. ENVIRONMENT”
“COMB. STAGE”

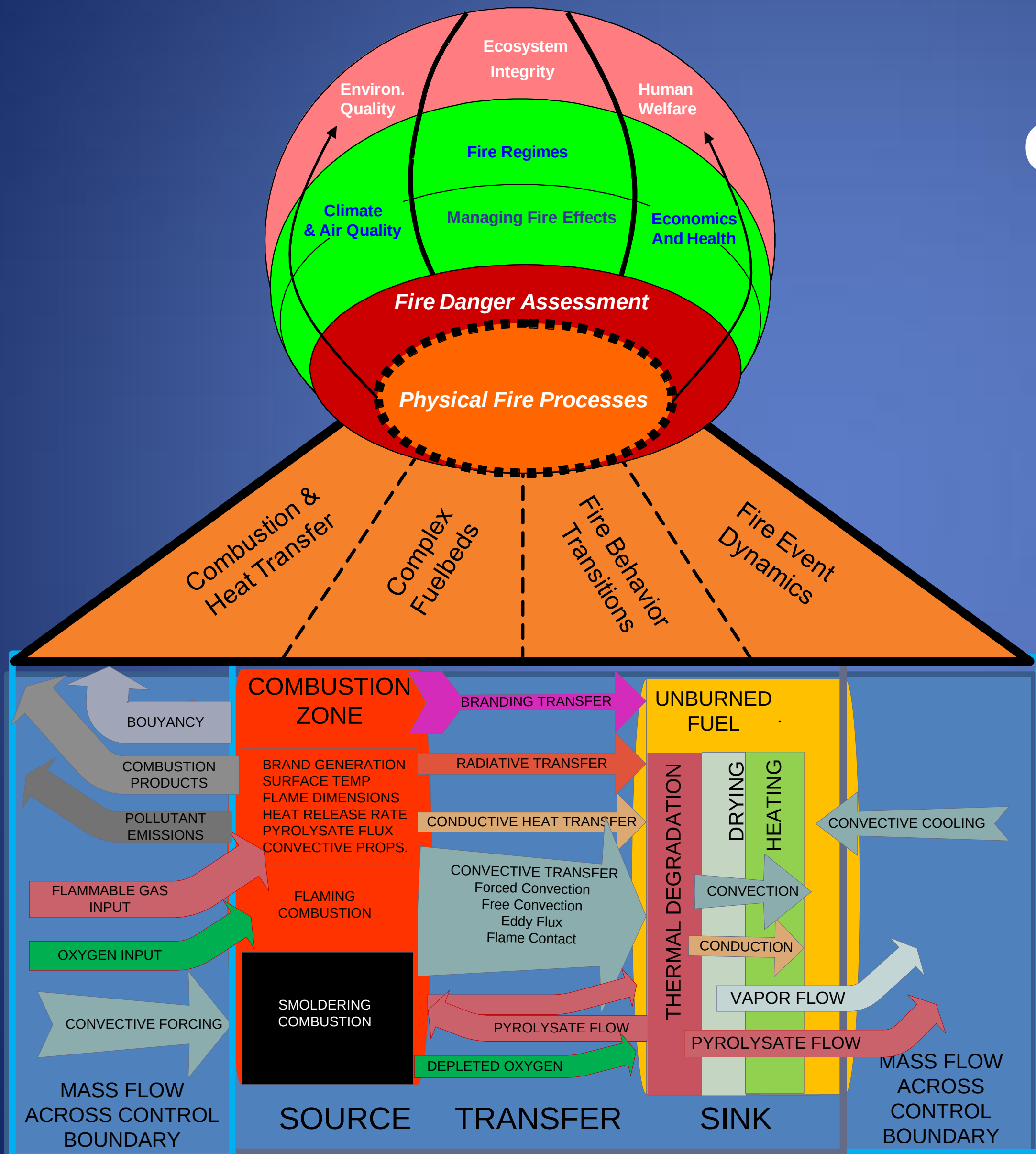
Getting Case Specific to Assess RELEVANCE



Getting Scale-Specific and Case-Specific Fire Management Information Needs



Prioritize and Sequence Research-2010



Objective Functions

Relevance, Measured by Common Language

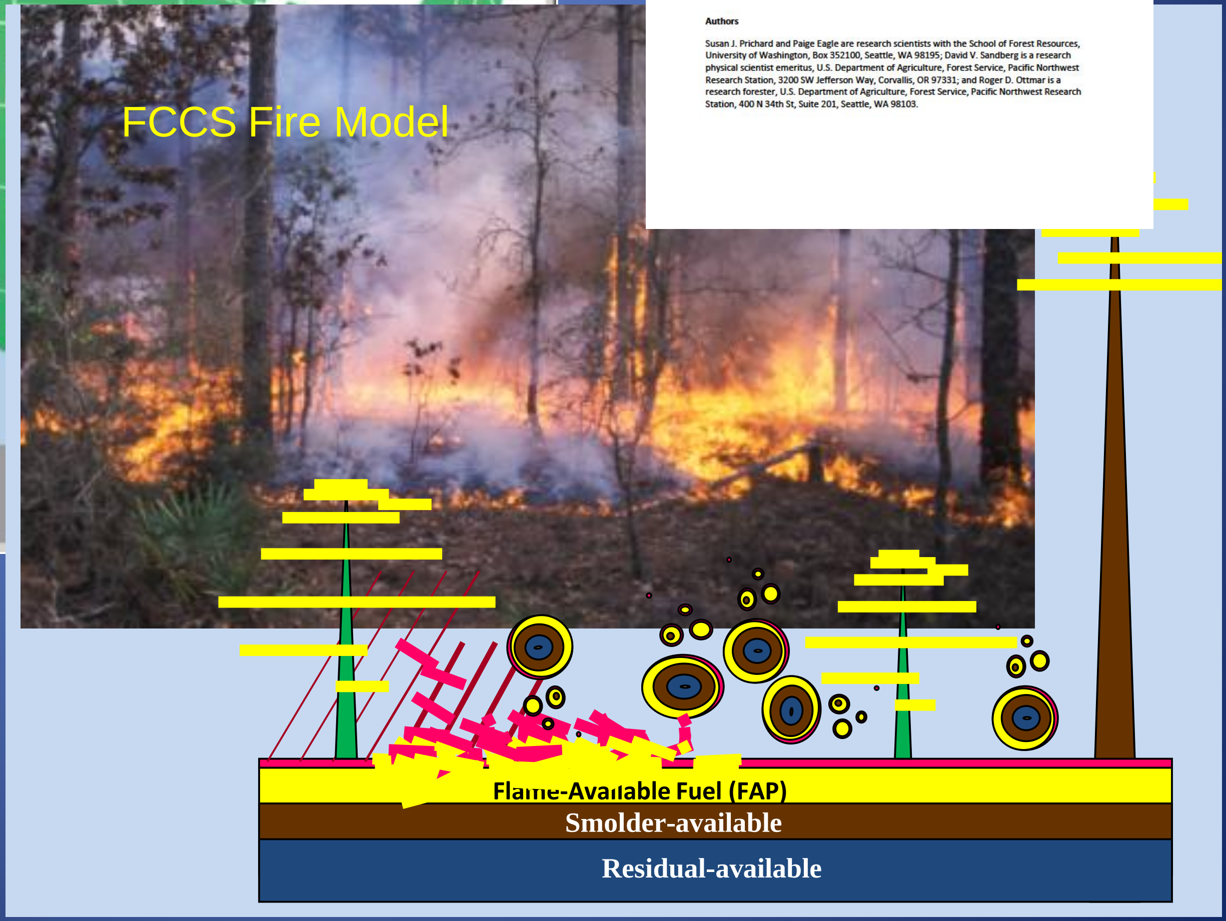
Research Design

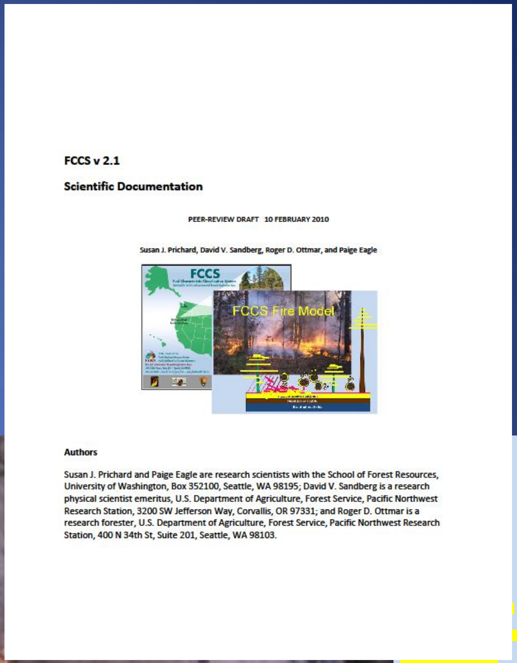
Core Fire Sciences Advancement Plan

- CFS Caucus Advocacy -- 1999
- Strategic Problem Identification – 2003
- Clarity of Scope and Goals -- 2006
- Problem Analysis -- 2008
- Universal Schematics -- 2009
- Prioritization
  - By Relevance to Management -- 2010

---- Application May-July

--- Publication Nov-December





FCCS v 2.1

Scientific Documentation

PEER-REVIEW DRAFT 10 FEBRUARY 2010

Susan J. Prichard, David V. Sandberg, Roger D. Ottmar, and Paige Eagle

Authors

Susan J. Prichard and Paige Eagle are research scientists with the School of Forest Resources, University of Washington, Box 352100, Seattle, WA 98195; David V. Sandberg is a research physical scientist emeritus, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331; and Roger D. Ottmar is a research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 400 N 34th St, Suite 201, Seattle, WA 98103.

Variables Important to Surface Fire Behavior:

- Shrub layer (primary, secondary)
  - Percent cover
  - Percent live
  - Live foliar moisture content (check)
  - Species and rel cov
  - Needle drape
- Nonwoody layer (primary, secondary)
  - Percent cover
  - Percent live
  - Live foliar moisture content (check)
- Loading
- Species and rel cov
- Woody fuels
  - All woody
    - Total percent cover
    - Depth
  - Sound wood by size class
    - Loading
    - Species and relative cover
  - Rotten wood by size class
    - Loading
    - Species and relative cover
- LLM (Litter, Lichen and Moss layers)
  - Litter arrangement, type, relative cover (affects loading)
  - Moss type
- Depth
- Percent Cover

Surface Fire Behavior Prediction

Summary: Difference between FCCS and Rothermel

revisions since 2007 publication

FCCS Fire Behavior

1. No change;
2. Significant changes in
   heat sink (shell thickness) at ignition
   live fuel moisture influence
   reaction velocity computation
3. Adjusted (constricted) wind and slope coefficient algorithms, with **alternatives**
4. Re-formulation that evaluates heat source and sink by fuel category
   litter layer separation; variability
   shrub layer segregation; variability
5. Use of realistic (measured, managed) fuelbed characteristics as inputs.
   Improved multi-strata interactions

Rothermel Fire Behavior

1. Conceptual modeling framework; empirical measurements
2. Equations for rate of spread under no-wind, no-slope conditions;
3. Multiplication factors for the effect of wind speed and slope
4. Formulation of a fire behavior model that homogenizes fuelbeds
5. Application to the field, using stylized uniform and homogeneous fuel models as inputs.

Surface Fire Behavior Prediction

Conceptual Similarity of FCCS to Rothermel

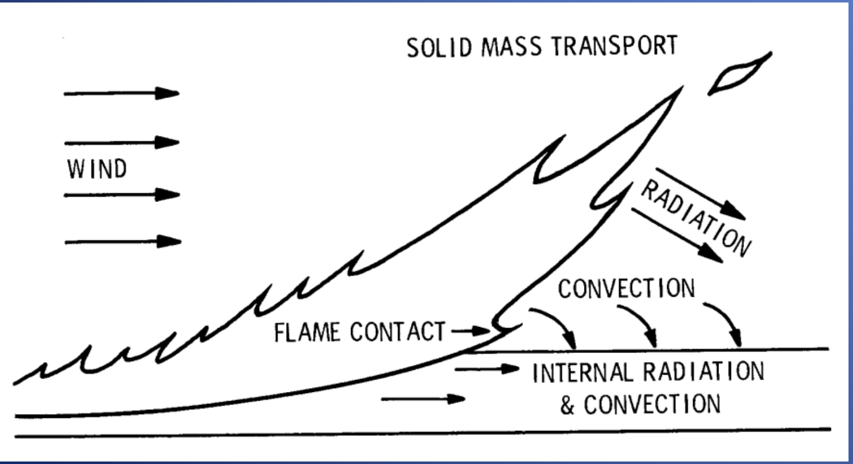
so, only an interim, incremental solution

$$R = \frac{I_R \xi (1 + \phi_W + \phi_S)}{\rho_b \varepsilon_{Frandsen} Q_{ig}}$$

Heat Source

Heat Transfer

Heat Sink



1. **conceptual modeling framework**;

- Quasi steady state
- Series of successive ignitions
- (Heat Source) x (Flux Ratio) / (Heat Sink)
- Evaluate @ no wind/slope; modify empirically
- **Evaluate @ uniform fuels, Formulate model for heterogeneous fuelbeds**

Reformulated surface fire behavior equations calculates heat sink and source by shrub, grass, small woody, and litter components allowing the use of real fuels!!

Differences between FCCS and Rothermel

5. both reduce complex fuelbed to bulk properties, but to a different degree of simplification.

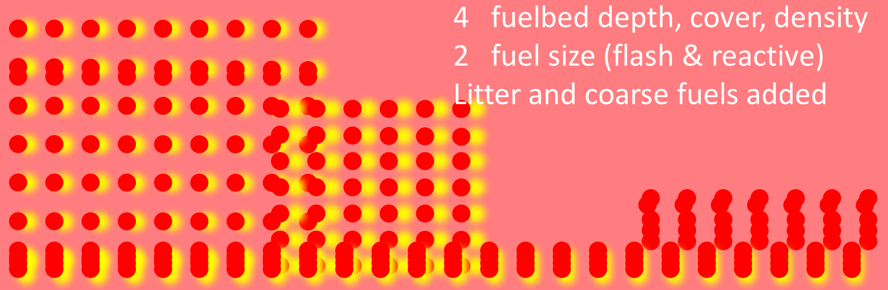
FCCS Fuelbed Inventory

56 fuelbed category (in 4 strata)
4+ fuelbed depth (measured)
4+ fuel sizes (flash, reactive, smolder, residual)
Litter and coarse fuels included

FCCS Fire Behavior math

$$R_{FCCS} = \frac{I_R\ \xi\ (1+\varphi_{W.FCCS}+\varphi_S)}{\left[FAI\ \varsigma_I \rho_P\ Q_{ig}/\delta\right]_{woody} + \left[\theta\ \rho_b\ Q_{ig}\right]_{nonwoody} + \left[\theta\ \rho_b\ Q_{ig}\right]_{shrub} + \left[\theta\ \eta_{\Delta'}\ \rho_b\ Q_{ig}\right]_{llm}}$$

4+ fuelbed category heterogeneity
4 fuelbed depth, cover, density
2 fuel size (flash & reactive)
Litter and coarse fuels added



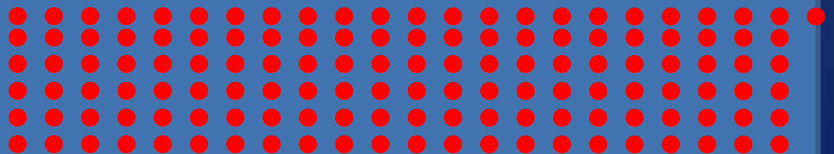
BEHAVE Fuel Model Description

3 fuelbed category (dead, herb, live)
1 fuelbed depth (artificial)
1 fuel size (flash fuel) per category
No litter or coarse fuels

Rothermel Fire Behavior math

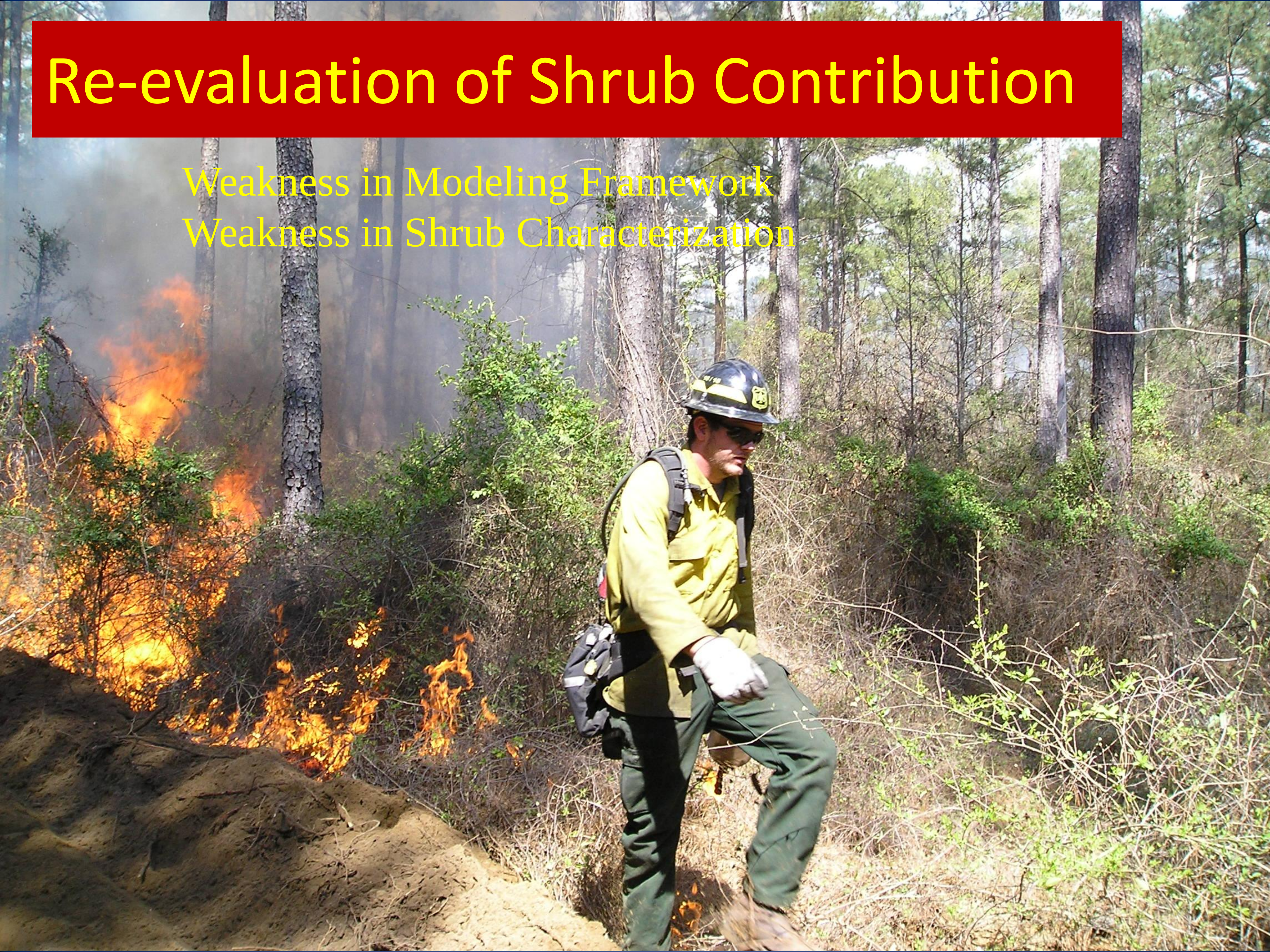
$$R = \frac{I_R \xi (1+\phi_W+\phi_S)}{\rho_b \varepsilon_{Frandsen} Q_{ig}}$$

Homogeneous fuelbed
1 fuelbed depth (artificial)
1 fuel size (flash fuel) per category
No litter or coarse fuels



Re-evaluation of Shrub Contribution

Weakness in Modeling Framework
Weakness in Shrub Characterization



Rothermel Fire Behavior

$$R=\frac{\Gamma'_{\max}\,\eta_{\Delta'}\eta_M\eta_S\,\xi(1+\phi_W+\phi_S)}{\rho_b\,\varepsilon_{Frandsen}\,Q_{ig}}$$

FCCS Fire Behavior v 1.1

$$\mathrm{R_{FCCS}}=\frac{\left[\sum_{i=1}^{4}(\Gamma'_{\max})_i\,(\eta_{\Delta'}\eta_M\eta_s)_i\right]\ \xi\ (1+\varphi_{W.FCCS}+\varphi_S)}{\left[(\mathrm{FAI}\ \varsigma_I\rho_P/\delta)\ Q_{ig}\right]_{woody}+\left[\theta\ \rho_b\ Q_{ig}\right]_{nonwoody}+\left[\theta\ \rho_b\ Q_{ig}\right]_{shrub}+\left[\theta\ \eta_{\Delta'}\ \rho_b\ Q_{ig}\right]_{llm}}$$

FCCS Fire Behavior v 2.0

New Optimum Reaction Velocity

$$\mathrm{R_{FCCS}}=\max\left\{\begin{array}{l}\left[\dfrac{\left[\sum_{i=1}^{4}(\Gamma'_{\max})_i\,(\eta_{\Delta'}\eta_M\eta_s)_i\,(\xi_i)(fl_i)\right](1+\varphi_{W.FCCS}+\varphi_S)_{surf}}{\left[\eta_{\Delta'}(\mathrm{FAI}\ \varsigma_I\rho_P/\delta)\ Q_{ig}\right]_{woody}+\left[\eta_{\Delta'}(w_n/\theta\delta)Q_{ig}\right]_{nonwoody}+\left[\eta_{\Delta'}(w_n/\theta\delta\eta_{\Delta'})Q_{ig}\right]_{shrub}+\left[\eta_{\Delta'}(w_n/\theta\delta)Q_{ig}\right]_{llm}}\right]\\ \left[(\Gamma'_{\max}\,\eta_{\Delta'}\eta_M\eta_s\xi)_i\,(1+\varphi_{W.FCCS}+\varphi_S)/\left[\eta_{\Delta'}(w_n/\theta\delta)Q_{ig}\right]\right]_{llm}\end{array}\right\}$$

LLM Wind Speed

Surface Fire Behavior Prediction

Difference FCCS v 1.1 and v2.0

4. Formulation of a Fire Spread Model

FCCS Fire Behavior v 1.1

New Optimum Reaction Velocity

$$R_{FCCS} = \frac{\left[\sum_{i=1}^{4} (\Gamma'_{max})_i (\eta_{\Delta'} \eta_M \eta_s)_i\right] \; \xi \; (1 + \varphi_{W.FCCS} + \varphi_S)}{\left[(FAI\, \varsigma_I \rho_P / \delta)\, Q_{ig}\right]_{woody} + \left[\theta\, \rho_b\, Q_{ig}\right]_{nonwoody} + \left[\theta\, \rho_b\, Q_{ig}\right]_{shrub} + \left[\theta\, \eta_{\Delta'}\, \rho_b\, Q_{ig}\right]_{llm}}$$

FCCS Fire Behavior v 2.0

LLM Wind Speed

$$R_{FCCS} = \frac{\left[\sum_{i=1}^{3} (\Gamma'_{max})_i (\eta_{\Delta} \eta_M \eta_s)_i (\xi_i)(fl_i)\right] (1 + \varphi_{W.FCCS} + \varphi_S)_{surf} + \left[(\Gamma'_{max}\, \eta_{\Delta} \eta_M \eta_s \xi)_i (1 + \varphi_{W.FCCS} + \varphi_S)\right]_{llm}}{\left[\eta_{\Delta'} (FAI\, \varsigma_I \rho_P / \delta)\, Q_{ig}\right]_{woody} + \left[\eta_{\Delta'} (w_n / \theta\delta) Q_{ig}\right]_{nonwoody} + \left[\eta_{\Delta'} (w_n / \theta\delta\eta_{\Delta'}) Q_{ig}\right]_{shrub} + \left[\eta_{\Delta'} (w_n / \theta\delta) Q_{ig}\right]_{llm}}$$

Effective Stratum Depth

Reaction Efficiency (LLM stratum)

Stratum Fuel Load

Shrub species flammability

FCCS Fire Behavior v 2.0

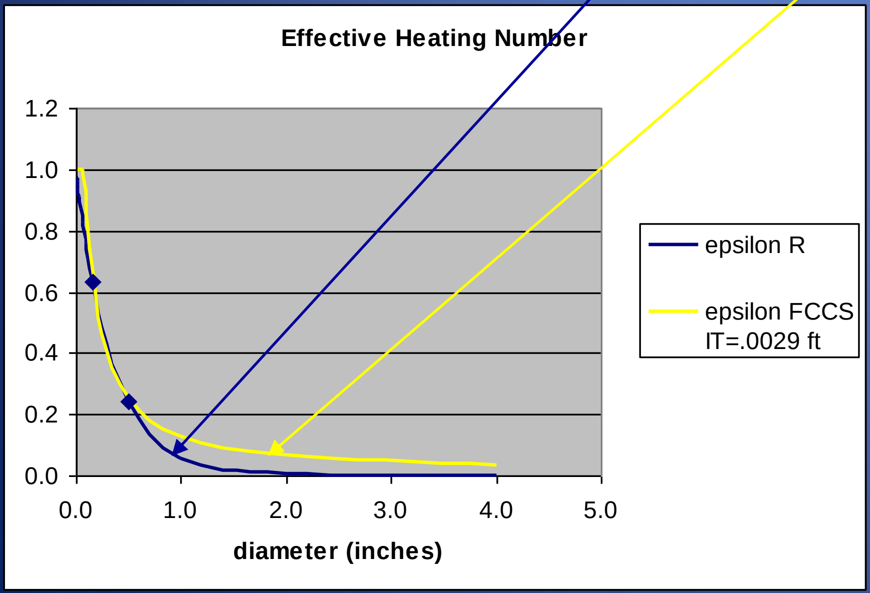
$$R_{FCCS} = \max\left\{\begin{array}{l}\left[\dfrac{\left[\sum_{i=1}^{4}\left(\Gamma'_{\max}\right)_i\left(\eta_{\Delta'}\eta_M\eta_s\right)_i\left(\xi_i\right)\left(fl_i\right)\right]\left(1+\varphi_{W.FCCS}+\varphi_S\right)_{surf}}{\left[\eta_{\Delta'}\left(\mathrm{FAI}\,\varsigma_{\mathrm{I}}\rho_{\mathrm{P}}/\delta\right)\mathrm{Q}_{\mathrm{ig}}\right]_{\mathrm{woody}}+\left[\eta_{\Delta'}\left(\mathrm{w}_n/\theta\delta\right)\mathrm{Q}_{\mathrm{ig}}\right]_{\mathrm{nonwoody}}+\left[\eta_{\Delta'}\left(\mathrm{w}_n/\theta\delta\eta_{\Delta'}\right)\mathrm{Q}_{\mathrm{ig}}\right]_{\mathrm{shrub}}+\left[\eta_{\Delta'}\left(\mathrm{w}_n/\theta\delta\right)\mathrm{Q}_{\mathrm{ig}}\right]_{llm}}\right] \\ \left[\left(\Gamma'_{\max}\eta_{\Delta'}\eta_M\eta_s\xi\right)_i\left(1+\varphi_{W.FCCS}+\varphi_S\right)/\left[\eta_{\Delta'}\left(\mathrm{w}_n/\theta\delta\right)\mathrm{Q}_{\mathrm{ig}}\right]\right]_{llm}\end{array}\right\}$$

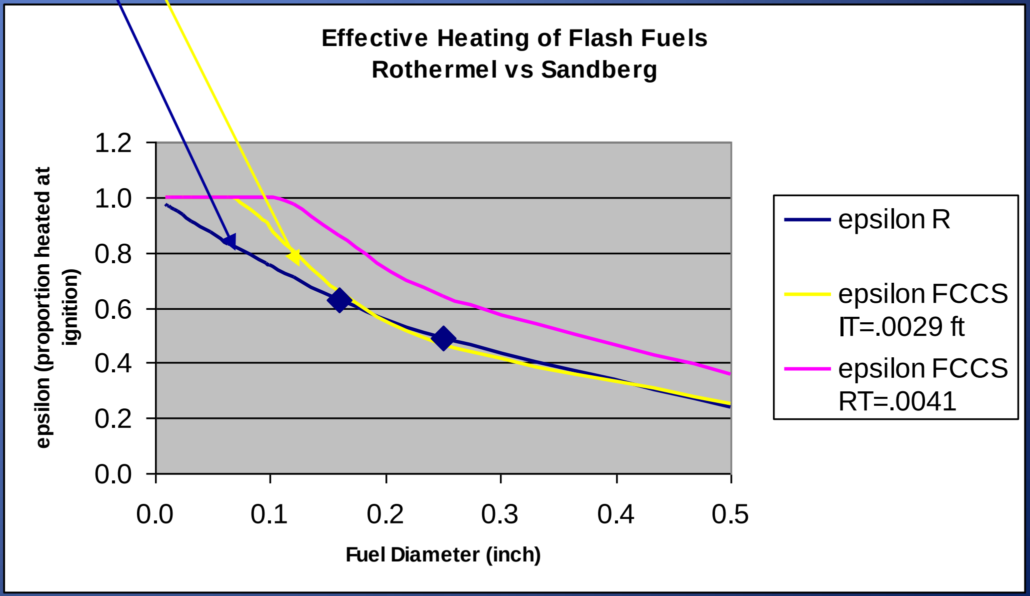
FCCS Fire Behavior v 2.x

$$R_{FCCS} = \begin{array}{lllll}
\left(1/\tau_{\max}\right)_{sh}\left(\eta_{\Delta'}\eta_M\eta_s\right)_{sh}\left(fl_{sh}\right) & \Rightarrow & \left(\xi_{sh}\right) & \Rightarrow 1/ & \left[\eta_{\Delta'}\left(\mathrm{w}_n/\theta\delta\eta_{\Delta'}\right)\mathrm{Q}_{\mathrm{ig}}\right]_{\mathrm{shrub}} \\
\left(1/\tau_{\max}\right)_{nw}\left(\eta_{\Delta'}\eta_M\eta_s\right)_{nw}\left(fl_{nw}\right) & \Rightarrow & \left(\xi_{nw}\right) & \Rightarrow 1/ & \left[\eta_{\Delta'}\left(\mathrm{w}_n/\theta\delta\right)\mathrm{Q}_{\mathrm{ig}}\right]_{\mathrm{nonwoody}} \\
\left(1/\tau_{\max}\right)_{w}\left(\eta_{\Delta'}\eta_M\eta_s\right)_{w}\left(fl_{w}\right) & \Rightarrow & \left(\xi_{w}\right) & \Rightarrow 1/ & \left[\eta_{\Delta'}\left(\mathrm{FAI}\,\varsigma_{\mathrm{I}}\rho_{\mathrm{P}}/\delta\right)\mathrm{Q}_{\mathrm{ig}}\right]_{\mathrm{woody}} \\
\left(1/\tau_{\max}\right)_{llm}\left(\eta_{\Delta'}\eta_M\eta_s\right)_{llm}\left(fl_{llm}\right) & \Rightarrow & \left(\xi_{llm}\right) & \Rightarrow 1/ & \left[\eta_{\Delta'}\left(\mathrm{w}_n/\theta\delta\right)\mathrm{Q}_{\mathrm{ig}}\right]_{llm} \\
\left(1/\tau_{\max}\right)_{v2.0}\left(\eta_{\Delta'}\eta_M\eta_s\right)_{v2.0}\left(fl_{v2.0}\right) & & \left(\xi_{v2.0}\right) & 1/ & FCCSv2.0heatsnk
\end{array}$$

FCCS Surface Fire Behavior Potentials

Change in Effective Heating Number, epsilon





Surface Fire Behavior Prediction

Difference FCCS from Rothermel

2. Basic homogeneous spread equations

FCCS Fire Behavior

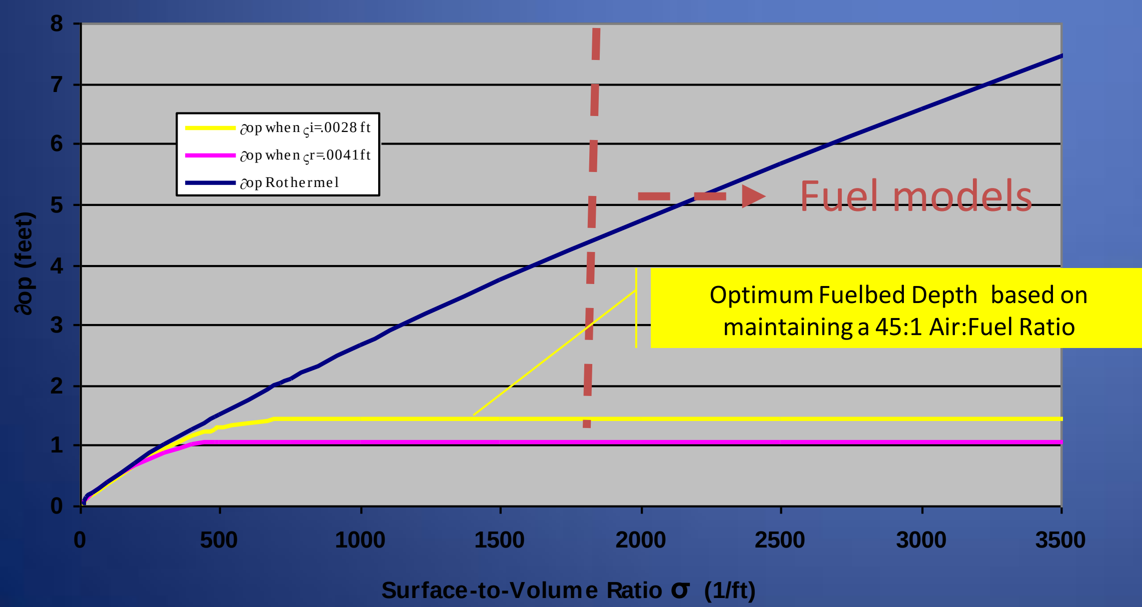
2. Significant changes in
   heat sink (shell thickness) at ignition
   measured fuelbed depths

Rothermel Fire Behavior

2. **equations for rate of spread under no-wind, no-slope conditions;**

   must assign depths to tune outputs

4b Optimum Fuelbed Depth ∂op / Fuel Load (ft / lb/ft2)



Substitutes Air:Fuel Ratio for packing ratio

Optimum depth calculated in FCCS is about 1/5 of that calculated by Rothermel

Result: Measured fuelbed depth is valid input to FCCS

Surface Fire Behavior Prediction

Difference FCCS v 1.1 and v2.0

2b. Basic homogeneous spread equations (FCCS v 2.0)

FCCS Fire Behavior

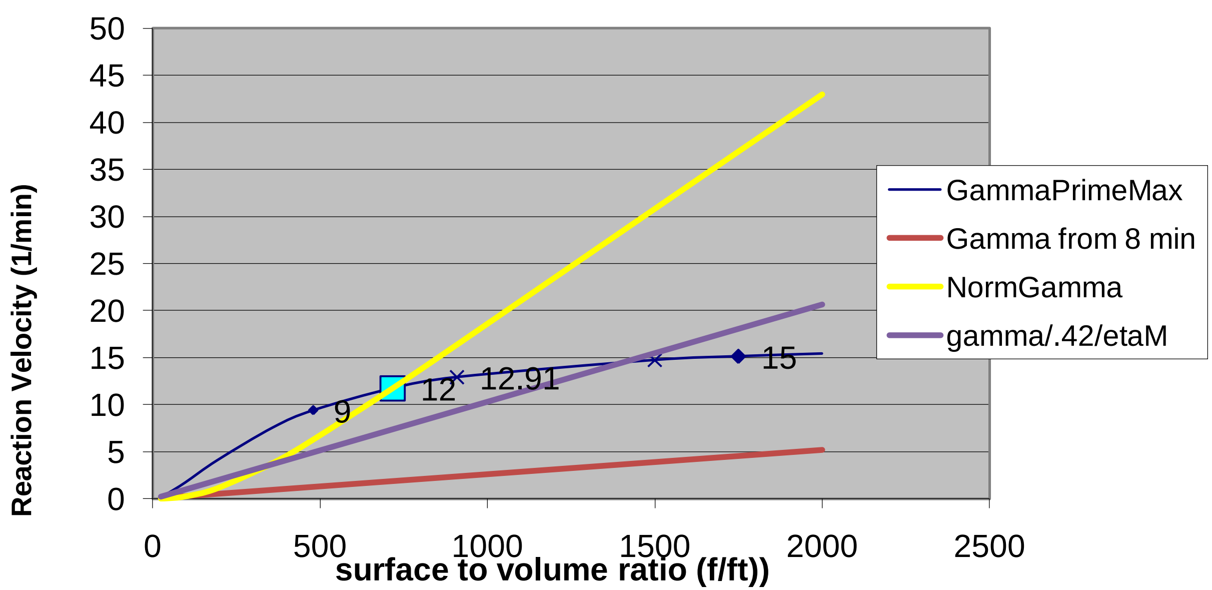
2. Significant changes in

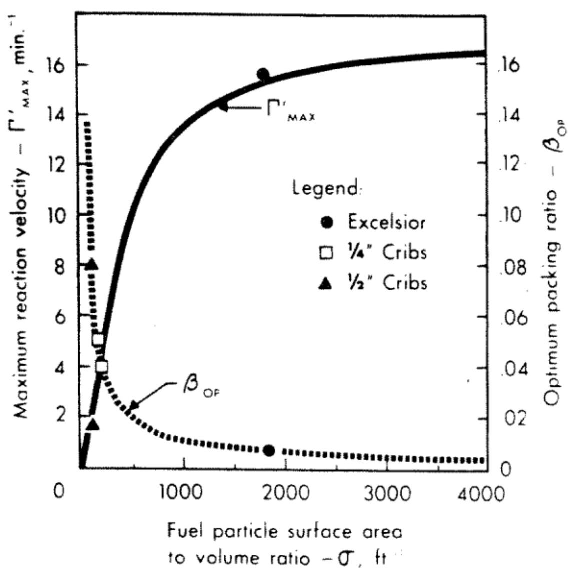
Reaction Velocity (min-¹)

(proportional to sigma)

Rothermel Fire Behavior

2. Maximum Reaction Velocity = 16/min





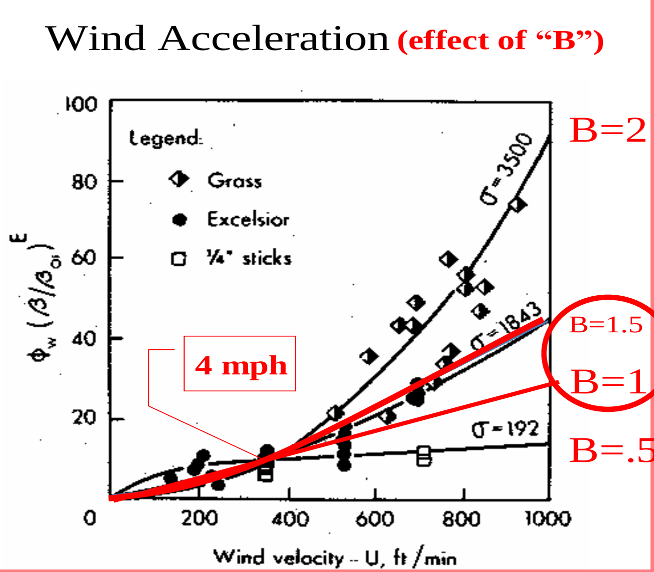
Surface Fire Behavior Prediction

Difference FCCS from Rothermel

3b. multiplication factors for the effect of wind speed and slope

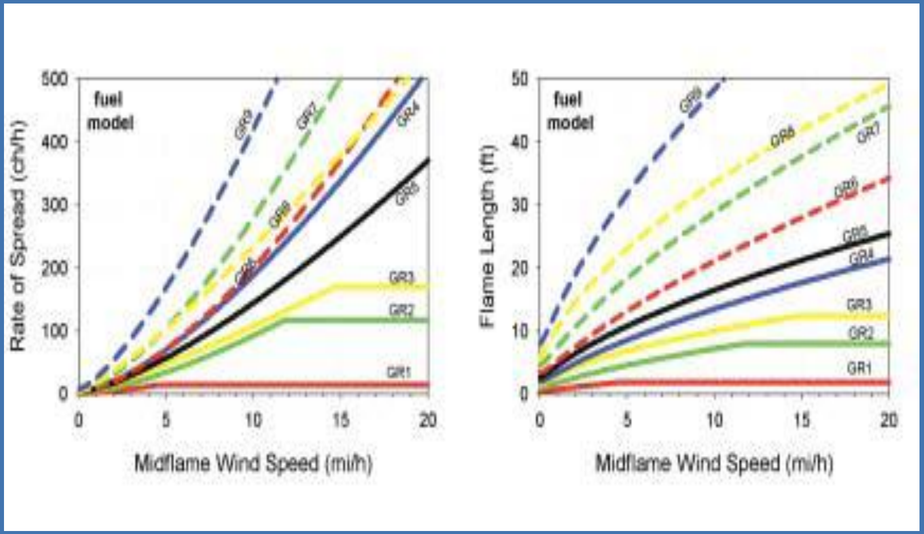
FCCS Fire Behavior

3. Adjusted **(constricted) wind** and slope coefficient algorithms, with alternatives



Rothermel Fire Behavior

BEHAVE uses 0 MPH as wind speed benchmark and varies B between 0.5 to 2.0



Surface Fire Behavior Prediction

Difference FCCS from Rothermel

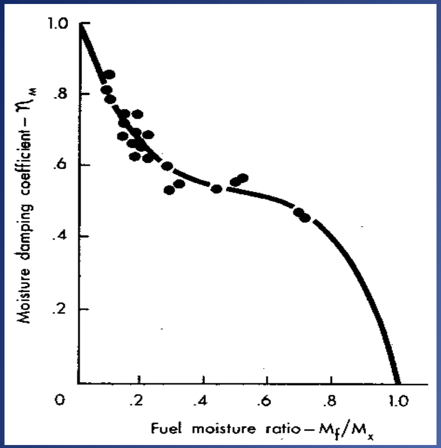
3. FCCS Offers Options for Dead and Live Fuel Moisture Effect

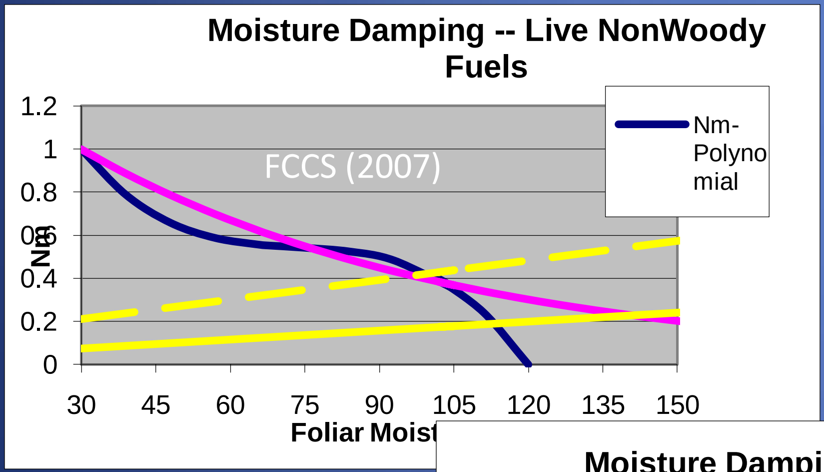
Default: FCCS uses Frandsen(1973) dead fuel damping equation

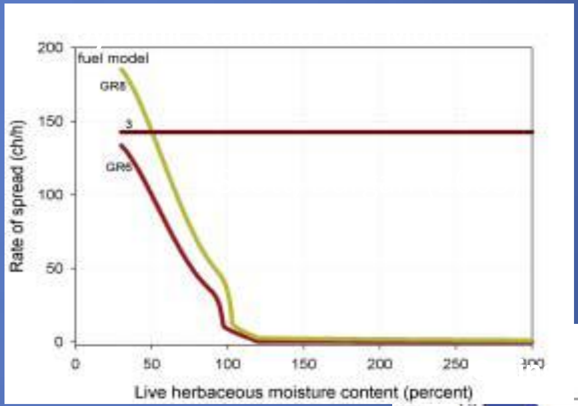
Other (e.g. Wilson (1990), Beer (1993)…

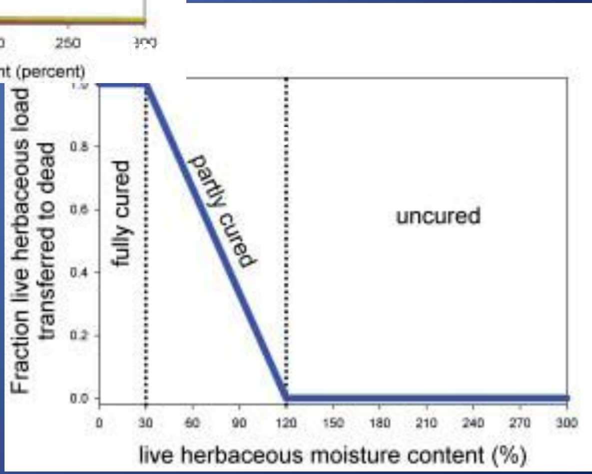
Many choices for live fuel are available, including original …..

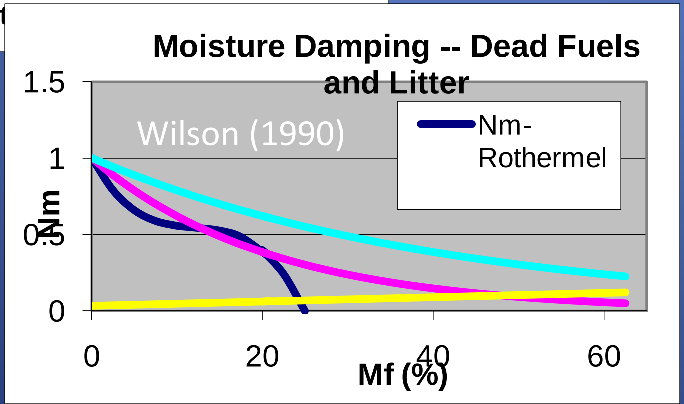
No physics-based model for live moisture contribution exists





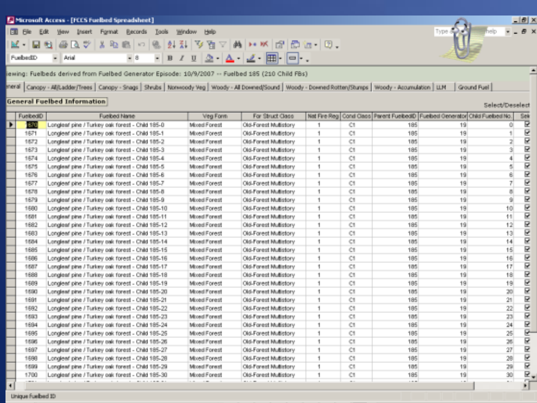


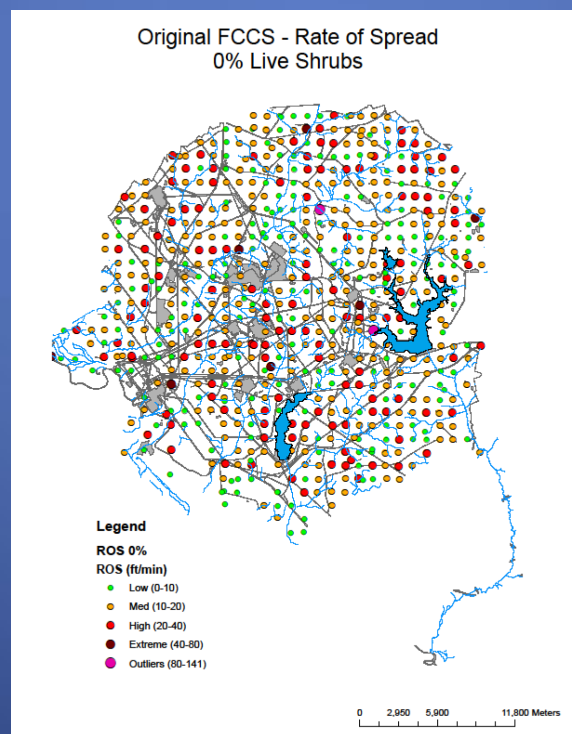


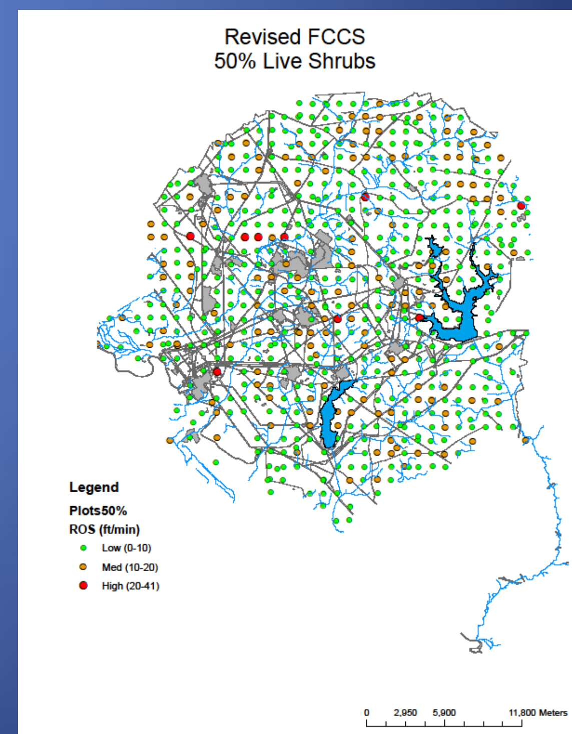


Acid Test of FCCS at Savannah River

– Independent field data
  - SRS – Savannah River enhanced FIA data
– FCCS Validation and FBPS Comparison
– Systematic data synthesis
  - Stepwise increase/decrease in each input (load, depth, cover….)
  - Simulates all possible fuelbed modifications







Motivation: Changing Information Needs for Management

SYSTEM	FCCS (2007a,b,c,d,e,f)	"ROTHERMEL" (1972) BEHAVE(2006), FARSITE
OBJECTIVE	Compare fire behavior between fuelbed characteristics under benchmark weather conditions	Support fire management operations in standard fuels in changing weather conditions
FUEL CHARACTERIZATION		
FUEL "MODEL"	Measured/ possible realistic FUELBED characteristics	Numerical inputs to Rothermel Spread Model.
PRECISION	Infinitely-expandable database of local/regional fuelbeds	3 discrete fuel model sets Customizable by Experts
REPEATABLE	Physical Model, Repeatable Measurement-based	Physical Model + Subjective Adjustment to measurements
CROSSWALK?	One-way Crosswalk from Fuelbeds To Fuel Models	Can't add information to go one-to-many
FIRE BEHAVIOR		
FIRE MODEL	Surface and Crown Fire Model Formulation for any realistic fuelbed. Relative or Explicit Output	"Standard" semi-empirical fire spread model for stylized fuel models
FLEXIBILITY	"Fixes" Fire model reliance on fuel models	Foundation for NFDRS, BEHAVE/FARSITE/FLAMMAP
ADAPATABILITY	Adaptable framework to incorporate new knowledge (e.g. Live fuel moisture)	Mature and consistent formulation Centralized
PEER-REVIEW?	Extensively Peer Reviewed, Refereed Application-tested	Extensively Used, Endorsed, Implemented

Conclusions

- Management –Relevant Fire Behavior Modeling
  - Value of fire research accrues to fire management success
  - Support depends on improved “ “
- Core Fire Science Advancement Plan
  - Clear Communication of Relevant Combustion Environment
  - Information need ←→ Research Investigation
- FCCS Fire Behavior Model(s)
  - Interim, Inadequate, but necessary analytical improvements
  - Flexible platform for incremental improvements, sensitivity
  - Adaptive communication vehicle
- Dead Ends (missing theory or evidence)

  -- Complex winds, Live fuel moisture, Discontinuous fuelbeds, Resolution of heat transfer, Event-scale physics………

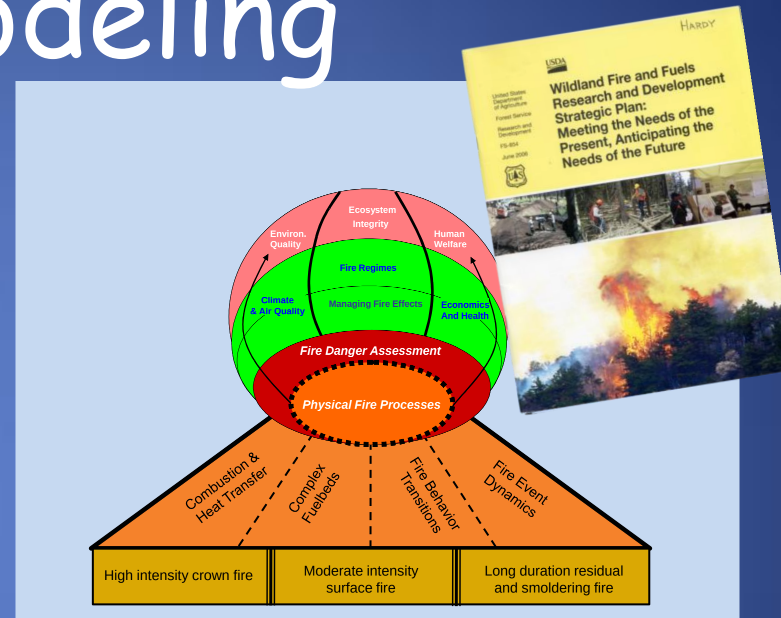
Dead Ends (missing theory or evidence)

-- Complex winds, Live fuel moisture, Discontinuous fuelbeds, Resolution of heat transfer, Event-scale physics………

Friday, February 26th

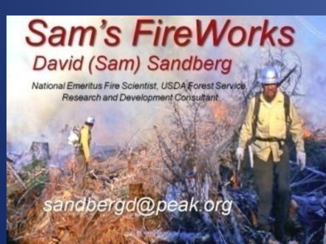
08:00-08:30 AM- Continental Breakfast
08:30-08:40 AM- Opening Remarks
08:40-09:10 AM- DV (Sam) Sandberg, *U.S. Fire Service,* "Management-relevant Fire Spread Modeling..."
09:10-09:35 AM- David Lignell, *BYU, "*Using ODT to Model Flame Propagation..."
09:35-09:55 AM- Discussion
10:00-10:10 AM- Break
10:10-10:35 AM- Anay Luketa, *Sandia,* "Evaluation of the Wildland/Urban Defensible Space..."
10:35-11:00 AM- Mary Ann Jenkins, *York University,* "The Importance of Wind in the Fire Environment"
11:00-11:25 AM- Adam Kochanski, *U of U,* "Wind Forecasting in the Fire Environment"
11:25-11:45 AM- Discussion
11:45-01:00 PM- Lunch
01:00-01:25 PM- David Weise, *Forest Service,* "Observations of Shrub Orientation on Flame Spread..."
01:25-01:50 PM- Jesse Lozano, *U of CA- Riverside,* "An Investigation of Laboratory Scale Crown Fire..."
01:50-02:10 PM- Discussion
02:10-02:20 PM- Break
02:20-02:45 PM- McKaye Dennis, *BYU,* "Effects of Wind on Flame Characteristics of Leaves ..."
02:45-03:10 PM- Thomas H. Fletcher, *BYU,* "Observations of Burning Bush Behavior..."
03:10-03:45 PM- Brandon Andersen, *BYU,* "Modeling a Burning Bush with and without..."
03:45-04:00 PM- Discussion

Management-Relevant Fire Spread Modeling



- David (Sam) Sandberg,
- Roger Ottmar (FS-PNW),
- Susan Pritchard (U.Wash.),

Advanced Combustion Engineering Research Center,
February 26, 2010



NFP