Fire Hazard Modeling in Colorado

By
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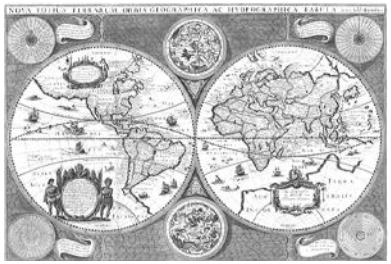
ERIA Consultants, LLC



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10/24/2014

Overview

- Wildfire is a natural event that has become a major issue in the western forests of the United States, particularly Colorado and Wyoming.
- The native mountain pine beetle (MPB) (*Dendroctonus ponderosae*) infestation coupled with other associated pest and pathogens have modified the wildfire hazard in many areas of Colorado.
- Long term forest management plans need to address and reduce the wildfire hazard in the western forests.
- A Geographic Information System (GIS) coupled with ancillary spatial data are key components for the construction of spatially explicit fire models.
- A vetting process was implemented to evaluate the model using a burn severity model derived for the "Four-Mile Canyon Fire", "Waldo Canyon Fire", and the "High Park Fire".

What We Are Going to Talk About

- We developed a series of ArcGIS® tool used to subset the data to create a wildfire severity model?
- We also used the Wildland Fire Assessment Tool (WFAT) to model the potential fire severity. http://www.fire.org
- We used three wildfire incidents as test sites.
  - Four Mile Canyon
  - Waldo Canyon
  - High Park
- We also compare these data to the Colorado Wildfire Risk (COWRAP) http://www.coloradowildfirerisk.com
- We also compare these data to Monitoring Trends in Burn Severity (MTBS)
  - http://www.mtbs.gov

What is Fire Severity?

- Fire Severity is defined as:
  - As a measure of the immediate and direct effects of fire on the environment.

- **From:** Robichaud, P. R., H. Rhee, et al. (2014). "A synthesis of post-fire Burned Area Reports from 1972 to 2009 for Western US Forest Service lands: trends in wildfire characteristics and post-fire stabilization treatments and expenditures." International Journal of Wildland Fire **23**(7).

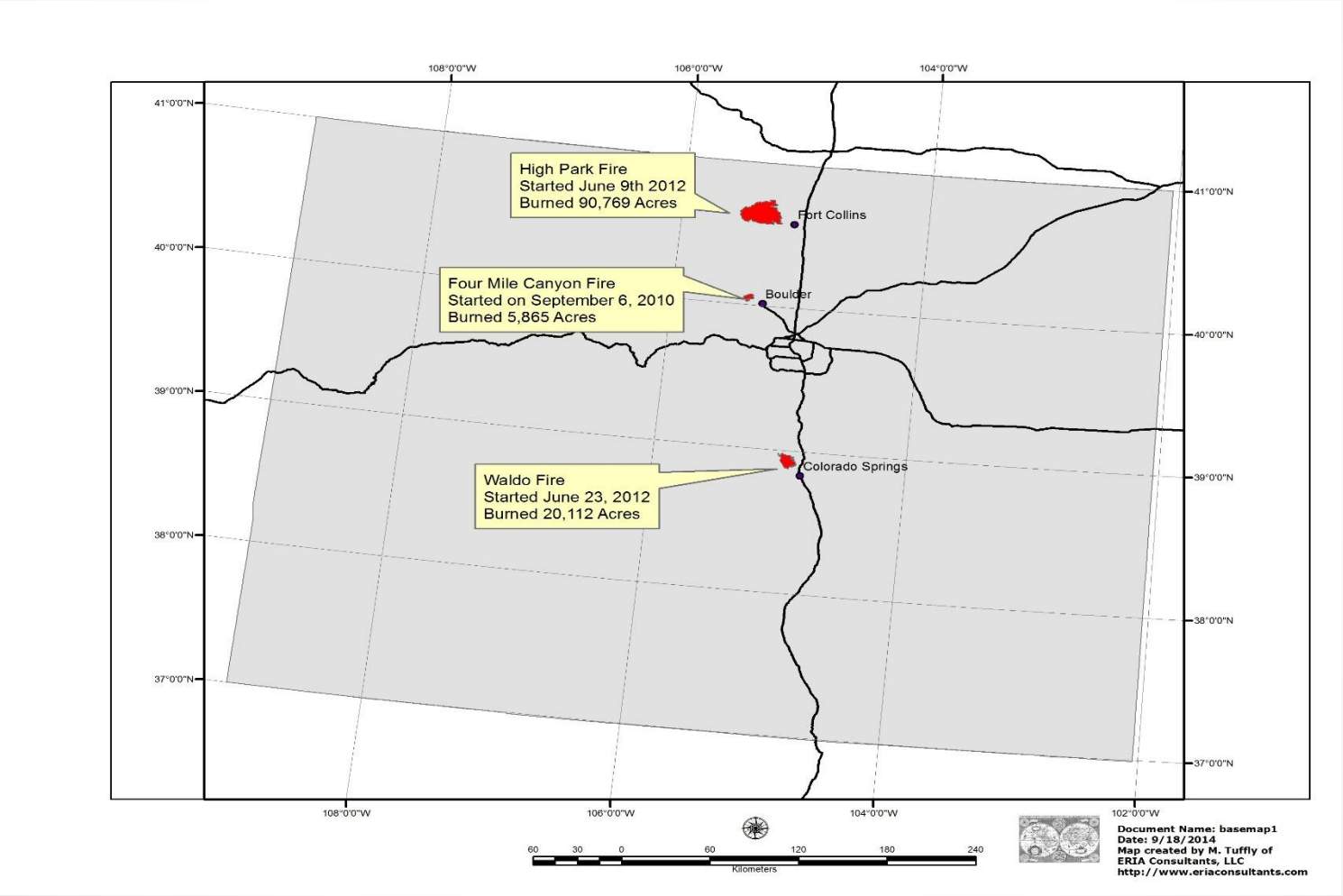
Who Cares About Wildland Fire Severity?

- Federal Agencies (initial responders)
  - United States Forest Service (USFS)
  - Bureau of Land Management (BLM)
  - National Park Service (NPS)
  - United States Geological Survey (USGS)
  - Natural Resource Conservation Service (NRCS)
  - Bureau of Indian Affairs (BIA)
- State Natural Resource Agencies
  - Colorado
  - Wyoming
- Local Watershed Groups
- Municipal Water Supply Agencies
  - Denver Water
- Private Land Owners
- General Public

What About Dynamically Predicting Wildland Fire Severity?

- Allows land managers and owners to assess and evaluate the potential fire severity over the landscape.
- Begin discussions with groups and agency's to address the potential fire severity.
- Create short and long term management plans to reduce the fire hazard due to predicted fire severity.
- Facilitate the construction and implementation of an initial response plan. (e.g. deploying suppression equipment)
- Evaluate over all forest health.

Where is the Area of Interest?



How Was This Project Done?

- First we created two tools in the Python Programming language that functions with ArcGIS ver 10.2.2.
  - These tools are design to:
    - Prepared the data for input into the WFAT (Wildland Fire Assessment Tool)*
    - Clean up the WFAT output and reclass the data
- Assemble a comprehensive and seamless data set for the States of Colorado and Wyoming
  - These comprehensive data sets are from **LandFire.
  - Also downloaded and assembled a 10 meter Digital Elevation Model (***DEM) from NRCS for the States of Colorado and Wyoming.
- Downloaded the potential fire severity from ***COWRAP for each of the three fire areas
- Downloaded the Difference Normalized Burn Ration (dNBR) from *****MTBS for the three fires.

- * http://www.fire.org
- ** http://www.landfire.gov
- *** http://datagateway.nrcs.usda.gov/
- **** http://www.coloradowildfirerisk.com/
- ***** http://www.mtbs.gov/

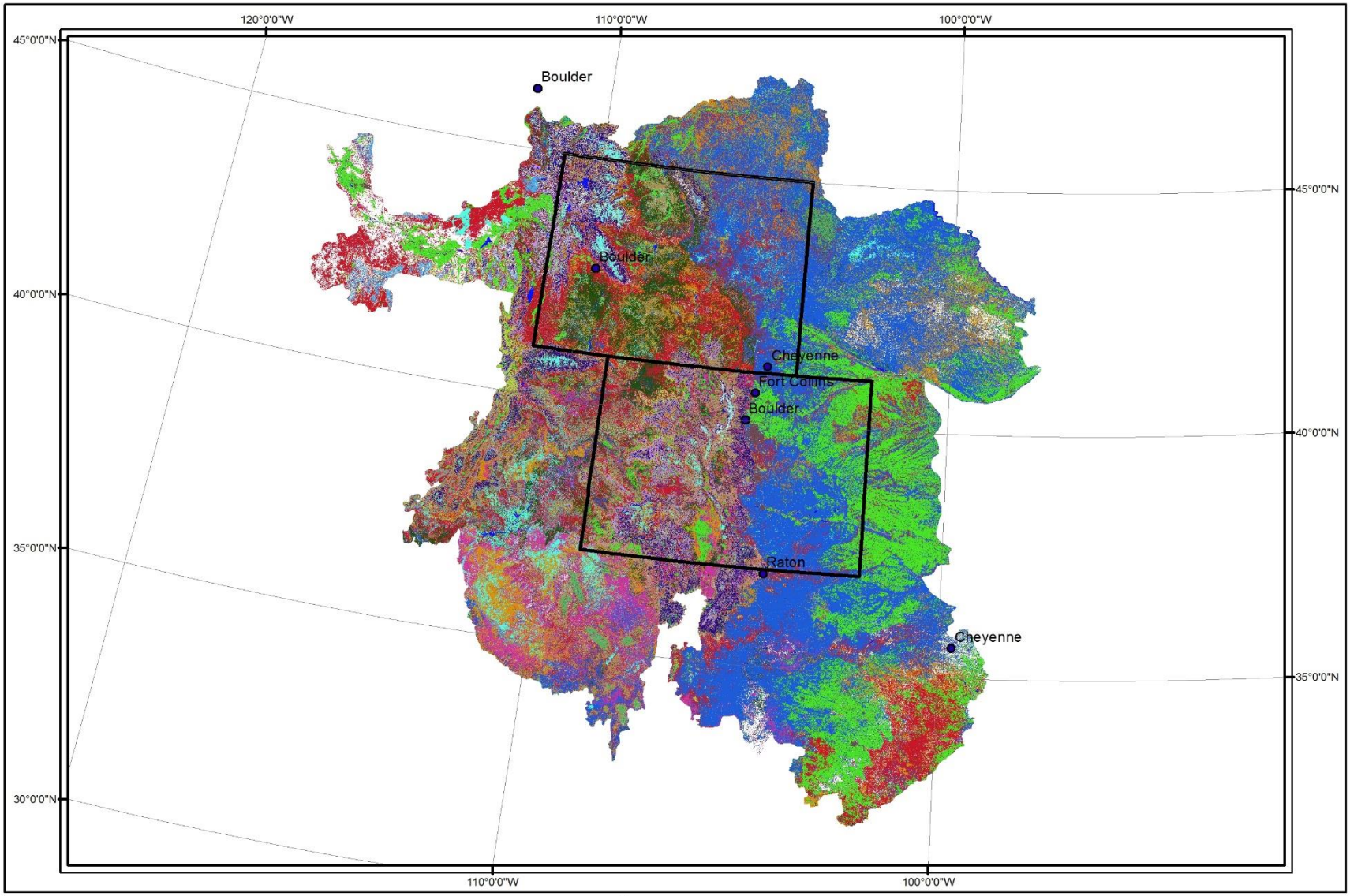
How Was This Project Complete?

- As with most projects data assembly was the most time consuming and this effort was no exception.
- The Landfire data had to be subsample from 30 meter cell size to 10 meter so that it matched the DEM cell size.
- The dNBR had to be partitioned into the needed 4 classes and subsample from 30 meter cell size to 10 meter to match the other data sets.
- The COWRAP data had to be partitioned into the same 4 classes subsample from 30 meter cell size to 10 meter to match the other data sets..
- Custom data preparation (python for ArcGIS) tools needed to be create.

Spatial Data

- WFAT needs nine data sets as input
  - LandFire Data come in 30 meter by 30 meter cell size
    - Canopy Closure (CC) (subsampled to 10 meters, Nearest Neighbor)
    - Canopy Bulk Density (CBD) (subsampled to 10 meters, Cubic Convolute)
    - Canopy Height (CH) (subsampled to 10 meters, Nearest Neighbor)
    - Canopy Base Height (CBH) (subsampled to 10 meters, Cubic Convolute)
    - Spatial Fuel Model (Scott and Burgan (2005)) (subsampled to 10 meters, Nearest Neighbor)
    - Fuel Loading Model (subsampled to 10 meters, Nearest Neighbor)
    - From the DEM (native format 10 meter)
      - Slope
      - Aspect
      - Elevation
  - The WFAT also needs the data to be spatially homogeneous
    - Standard pixel size
    - Standard spatial extent
    - Exact number of rows and columns
    - Data should also be aligned (Snapped) to a common data set.
  - Mosaicked the data sets together (by Map Zone) to produce a comprehensive data set by theme for the States of Colorado and Wyoming.
  - The nine large GRIDs needed to be stored in a file-geodatabase.

Fuel Model for Colorado and Wyoming



250 125 0 250 500 750 1,000

Kilometers

Document Name: wfat_base1
Date: 9/19/2014
Map created by M. Tuffly of
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Fire Model

- Wildland Fire Assessment Tool (WFAT)
  - Created by Systems for Environmental Management (http://www.fire.org)
- What is WFAT?
  - WFAT is an add-on tool for ArcGIS ver 10.2.2 used to model wildfire
  - WFAT is designed to be used with LandFire data (http://www.landfire.gov)
  - WFAT produces standard fire output (ESRI GRIDs)
  - WFAT is free software

  - The output used from the WFAT was "flame length"
    - Flame length units are in meters
    - Data were converted into feet and partitioned into 4 classes to match the dNBR classes (custom tool)
    - < 2' (Unburned)
    - > 2' and < 6' (Low Burned)
    - > 6' and < 12' (Moderate Burned)
    - > 12' (High Burn)

dNBR

- Difference Normalized Burn Ratio
- dNBR = (NBR(pre fire) – NBR(post fire))

- *NBR (Normalized Burn Index) =
  - LandSat 7 or 5 [(band4 – band7) / (band4 + band7)] * 1000
  - LandSat 8 [(band5 – band7) / (band5+ band7)] * 1000 (needs to be converted from 16 bit to 8 bit pixel depth) when combining with LandSat 5 or LandSat 7.

  - NBR values range from -1 to 1 (-1000 to 1000)
  - dNBR may range from -2000 to 2000

  - MTBS published threshold values to partition the data. Threshold are unique to each fire. The dNBR are partition into four classes: Unburned, Low Burn, Moderate Burn, and High Burn.

  - **When implementing the dNBR it is best to acquire the imagery as close to the same month as possible and no less than one year apart and no more than two years apart.

  - *Key, C. and N. Benson (2006). "USDA Forest Service General Technical Report RMRX-GTR-164-CD-2006." Landsape Assessment (LA) Sampling and Analyisis Methods. Retrieved 7/26/2014, 2014, from http://www.fs.fed.us/rm/pubs/rmrs_gtr164/rmrs_gtr164_13_land_assess.pdf.

  - ** Chen, X., Z. Zhu., et al. (2008). Use of Multiple Spectral Indices to Estimate Burn Severity in the Black Hills of South Dakota. Pecora 17. Denver, Colorado, American Society for Photogrammetry and Remote Sensing.

COWRAP

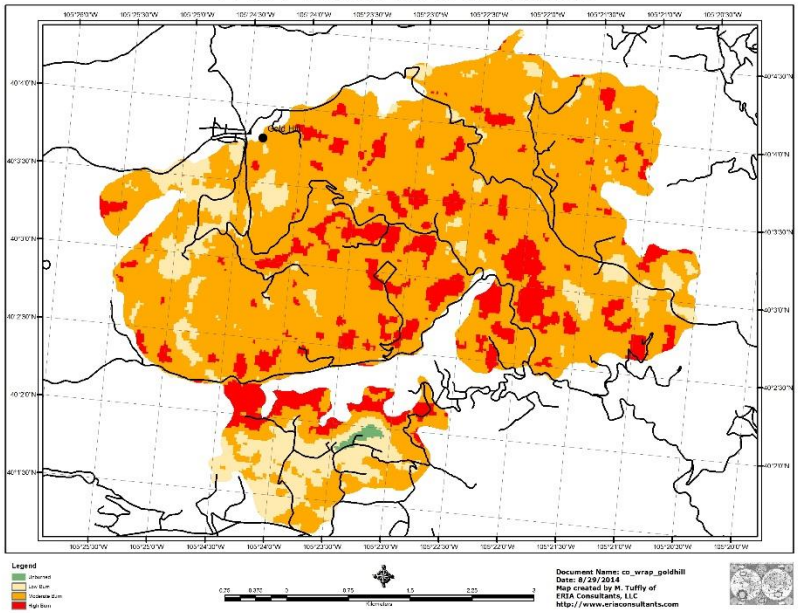
- Data resolution is 30 by 30 meter cells
- Output data used was flame length
- Flame length data are in feet
  - And partitioned into six classes
    - < 2'
    - > 2' and < 4'
    - > 4' and < 6'
    - > 6" and < 8"
    - >8' and < 12'
    - > 12'

  - Data had to be compressed into 4 classes to be compatible with dNBR data
    - < 2'
    - > 2' and < 6'
    - > 6' and < 12'
    - > 12'

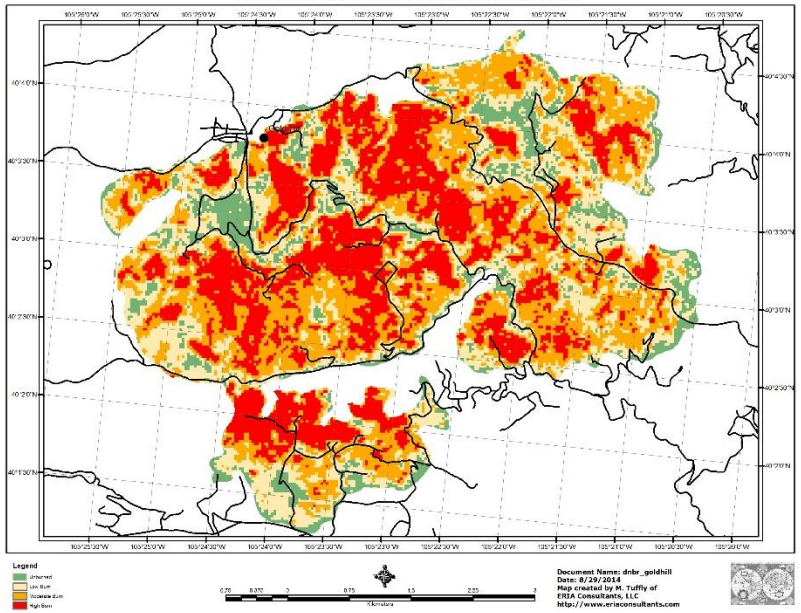
Four Mile Canyon Fire

Fire charges down the hill to Gold Hill at about 5:30 p.m. Monday September 6th 2010 in a photo taken by photographer Greg Cortopassi, whose Web site is cortoimages.com. Photos Greg Cortopassi http://cortoimages.com (Photos Greg Cortopassi, cortoimages.com)

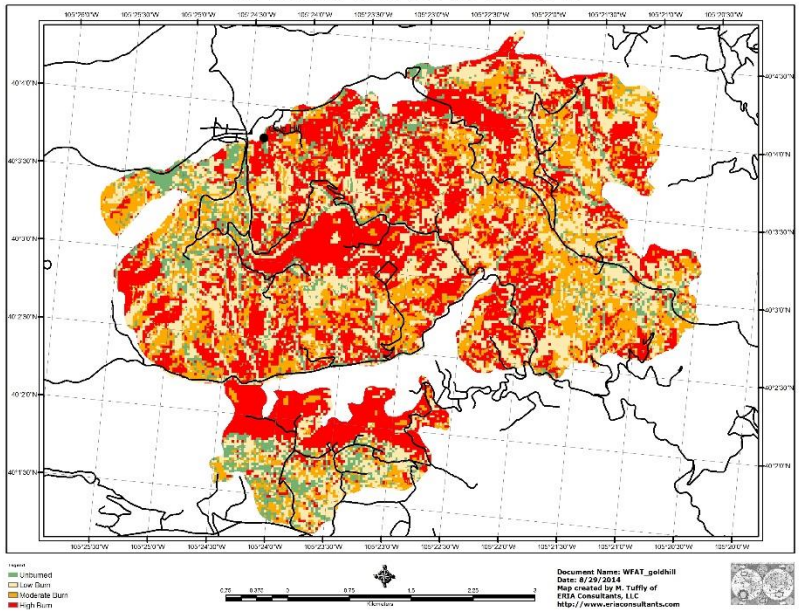
COWRAP Severity for the Four Mile Canyon Fire



dNBR Severity for the Four Mile Canyon Fire



WFAT Severity for the Four Mile Canyon Fire



WFAT input Parameters

Wind speed = 25 MPH
Wind Direction = Uphill
Foliar Moisture = 100%
Crown Fire Calculation = Scott & Reinhardt (2001)
Fuel Moisture = “default40”

		dNBR							
		1	2	3	4	Total	Omission Error (%)	Commission Error (%)	Accuracy(%)
WFAT	1	0	7,820	6,514	4,232	18,566	---	----	---
	2	0	20,561	24,473	19,270	64,304	68.03	67.41	31.97
	3	0	17,098	21,399	8,982	47,479	54.93	73.57	45.07
	4	0	17,610	28,586	34,450	80,646	57.28	48.53	42.72
	Total	0	63,089	80,972	66,934	210,995			36.21

		dNBR							
		1	2	3	4	Total	Omission Error (%)	Commission Error (%)	Accuracy(%)
COWRAP	1	0	189	385	107	681	---	---	---
	2	0	12,212	9,117	4,523	25,852	52.76	80.64	47.24
	3	0	45,498	59,880	50,581	155,959	61.61	26.05	38.39
	4	0	5,190	11,588	11,723	28,501	58.87	82.49	41.13
	Total	0	63,089	80,970	66,934	210,993			39.72

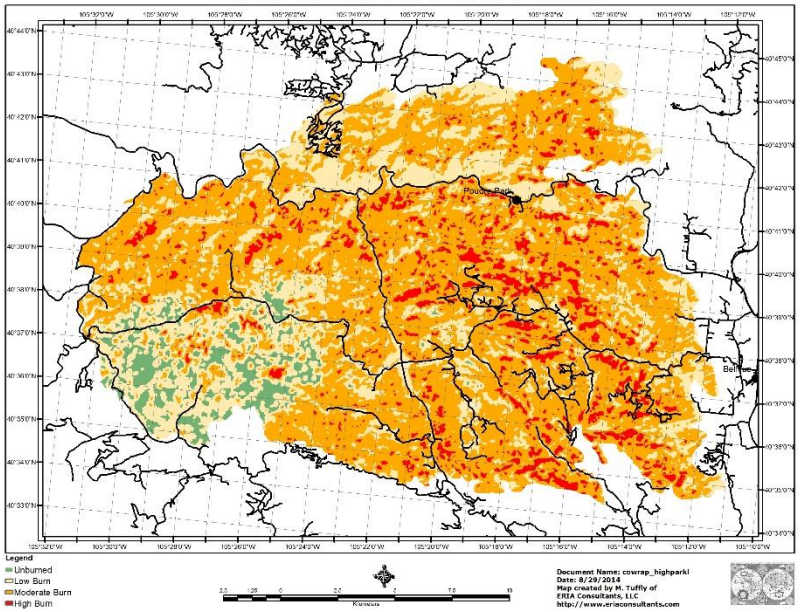
		WFAT							
		1	2	3	4	Total	Omission Error (%)	Commission Error (%)	Accuracy(%)
COWRAP	1	100	208	40	333	681	85.32	99.56	14.68
	2	9,021	13,377	6,030	3,735	32,163	58.41	81.70	41.59
	3	13,241	56,562	41,942	62,416	174,161	75.92	22.70	24.08
	4	352	2,964	6,248	20,741	30,305	31.56	76.22	68.44
	Total	22,714	73,111	54,260	87,225	237,310			32.09

Four Mile Canyon

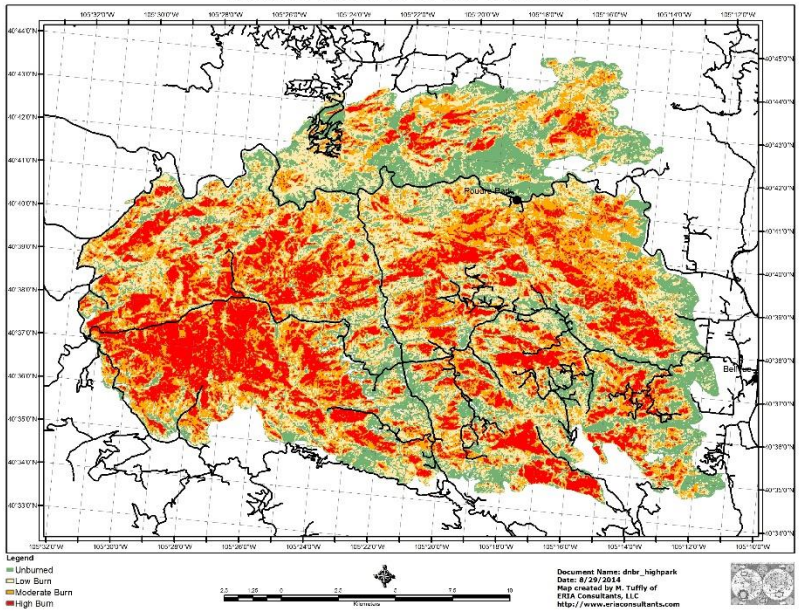
High Park Fire

Photo from Denver Post; Aaron Oniveroz

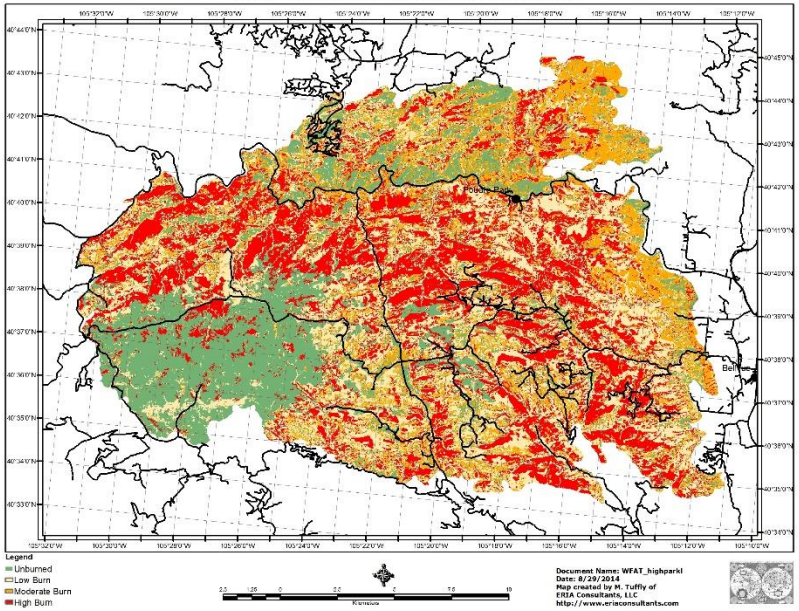
COWRAP Fire Severity for the High Park Incident



dNBR Fire Severity for the High Park Incident



WFAT Fire Severity for the High Park Incident



WFAT input Parameters

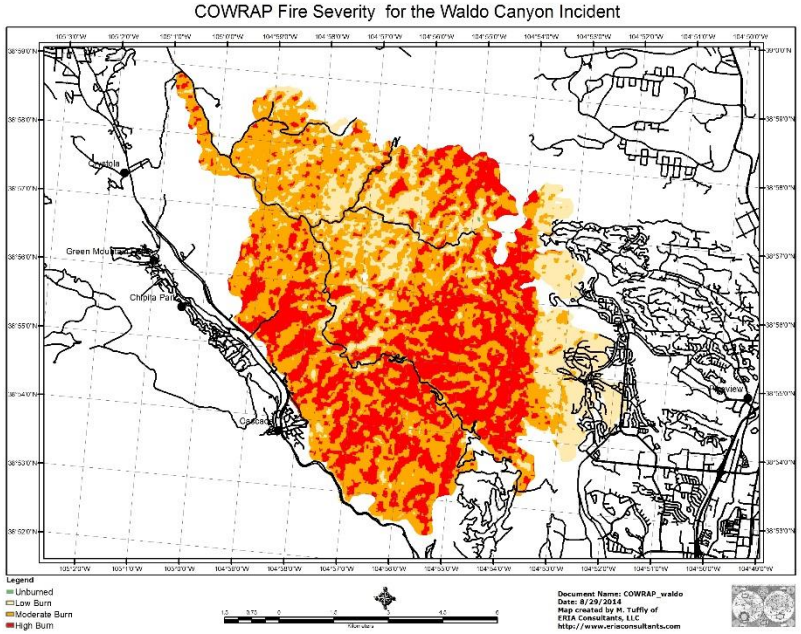
Wind speed = 23 MPH
Wind Direction = Uphill
Foliar Moisture = 100%
Crown Fire Calculation = Scott & Reinhardt (2001)
Fuel Moisture = “default40”

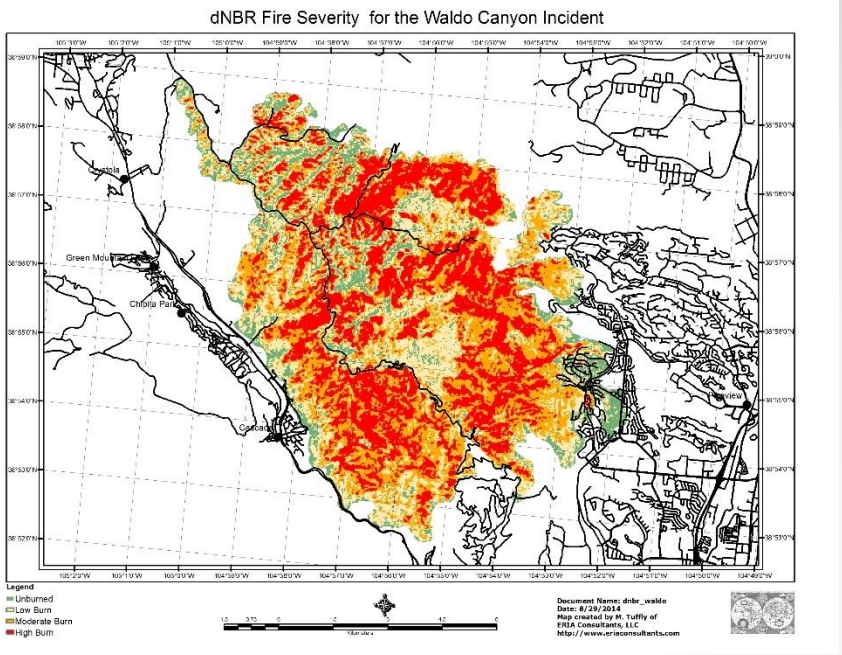
		dNBR							
		1	2	3	4	Total	Omission Error (%)	Commission Error (%)	Accuracy(%)
	1	0	162,831	182,497	241,762	587,090	----	---	----
WFAT	2	0	392,761	307,367	216,800	916,928	57.17	63.85	42.83
	3	0	272,445	160,791	38,629	471,865	65.92	83.69	34.08
	4	0	258,356	335,295	312,762	906,413	65.49	61.39	34.51
	Total	0	1,086,393	985,950	809,953	2,882,296			30.06

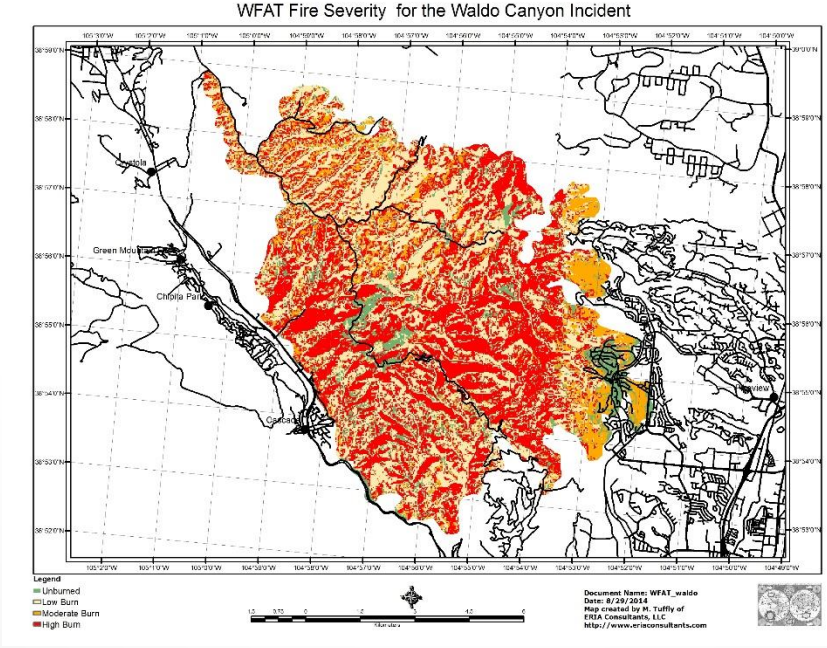
		dNBR							
		1	2	3	4	Total	Omission Error (%)	Commission Error (%)	Accuracy(%)
	1	0	16,873	47,413	62,404	126,690	----	----	---
COWRAP	2	0	266,757	180,517	214,292	661,566	59.68	75.44	40.32
	3	0	738,486	671,878	426,639	1,837,003	63.43	31.85	36.57
	4	0	63,826	86,094	106,614	256,534	58.44	86.84	41.56
	Total	0	1,085,942	985,902	809,949	2,881,793			36.27

		WFAT							
		1	2	3	4	Total	Omission Error (%)	Commission Error (%)	Accuracy(%)
	1	125,611	1,782	207	1,661	129,261	2.82	84.75	97.18
COWRAP	2	526,532	315,822	181,080	42,775	1,066,209	70.38	72.61	29.62
	3	164,855	815,827	477,420	743,329	2,201,431	78.31	31.57	21.69
	4	6,886	19,675	38,944	208,631	274,136	23.90	79.06	76.10
	Total	823,884	1,153,106	697,651	996,396	3,671,037			30.71

Waldo Canyon Fire







WFAT input Parameters

Wind speed = 30 MPH
Wind Direction = Uphill
Foliar Moisture = 100%
Crown Fire Calculation = Scott & Reinhardt (2001)
Fuel Moisture = “default40”

		dNBR							
		1	2	3	4	Total	Omission Error (%)	Commision Error (%)	Accuracy(%)
WFAT	1	0	17,717	20,205	14,253	52,175	--	---	---
	2	0	79,361	100,465	91,802	271,628	70.78	61.77	29.22
	3	0	33,050	28,974	12,778	74,802	61.27	88.66	38.73
	4	0	77,445	105,755	127,181	310,381	59.02	48.30	40.98
	Total	0	207,573	255,399	246,014	708,986			33.22

		dNBR							
		1	2	3	4	Total	Omission Error (%)	Commision Error (%)	Accuracy(%)
COWRAP	1	0	39	28	16	83	--		---
	2	0	43,859	38,338	42,243	124,440	64.75	78.79	35.25
	3	0	111,790	133,512	92,182	337,484	60.44	47.63	39.56
	4	0	51,125	83,078	111,529	245,732	54.61	54.66	45.39
	Total	0	206,813	254,956	245,970	707,739			40.82

		WFAT							
		1	2	3	4	Total	Omission Error (%)	Commision Error (%)	Accuracy(%)
COWRAP	1	88	0	0	0	88	0.00	99.87	100.00
	2	31,319	75,022	38,955	17,331	162,627	53.87	75.49	46.13
	3	29,757	179,803	49,741	130,572	389,873	87.24	50.38	12.76
	4	8,884	51,286	11,548	186,519	258,237	27.77	44.23	72.23
	Total	70,048	306,111	100,244	334,422	810,825			38.40

Waldo Canyon Fire

Fire Temporal Effects

- *First-order effects are the direct effects and are usually observed less than one year after the fire. These effects include:
  - Fuel consumption
  - Canopy scorching
  - Heating of the soil
  - Immediate Tree Mortality

- *Second-order effects are the indirect effects and are usually observed two or more years after a fire. These effects include:
  - Vegetation Succession (post fire)
  - Delayed Tree mortality
    - Often increases in tree mortality are observed >= 2 years post fire.
  - Observations of secondary casual agents (insects and diseases)
  - Landscape Changes

* Chen, X., Z. Zhu., et al. (2008). Use of Multiple Spectral Indices to Estimate Burn Severity in the Black Hills of South Dakota. Pecora 17. Denver, Colorado, American Society for Photogrammetry and Remote Sensing.

Issues (dNBR)

- Waldo Canyon Fire used LandSat5 for pre(NBR) in 2010 and LandSat8 for post NBR in 2013.
  - Data were three years apart (Second-Order Effects)
  - Fire started on June 23, 2012
  - Imagery was collected on Sept 18th, 2010 and Sept 26, 2013 pre and post NBR, respectively.
  - Post growing season.
  - Differences may occur when using to difference satellites.
  - LandSat 8 data had to be converted from 16bit to 8bit pixels.

- Fourmile Canyon Fire used LandSat 5 for both pre(NBR) (2010) and post(NBR) (2011) (First-Order Effects)
  - Fire started on Sept 10th 2010.
    - Imagery was collected June, 21, 2010 and June, 24, 2011 pre and post NBR, respectively.
    - Data were only one year apart (First-Order Effects)

- High Park Fire used LandSat5 for pre(NBR) in 2011 and LandSat8 for post NBR in 2013.
  - Data were collect two years apart (Second-Order Effects).
  - Fire started on June 9th 2012.
  - Imagery was collected Sept 12th 2011 and Sept 1, 2013 pre and post NBR, respectively.
  - Post growing season.
  - Differences may occur when using to difference satellites.
  - LandSat 8 data had to be converted from 16bit to 8bit pixels.

Additional Issues with (dNBR)

- dNBR does not measure flame length directly
  - Indirect flame length is assigned a value via Low, Medium, and High burn
    - As describe by the MTBS data (NBR) description
    - e.g. High numbers indicate high flame length and low numbers indicate good regrowth.
- Only usefully for post fire assessment
  - 1 Year post fire for first-order effects
  - 2 Years post fire for second-order effects.
- Burn Categories
  - May be influenced by suppression efforts
    - Other techniques (e.g. COWRAP or WFAT) may classify the region as high
    - Suppression efforts could have reduce the severity to low.
    - Unburned categories we not considered.
      - It is unknown why regions did not burn.
- Can be difficult to acquire imagery that is cloud free for the time periods of interest.

Issues with COWRAP

- Data are 30 meter by 30 meter resolution
  - Does not included the 10 meter DEM
- Flame Length output is in a ridged 6 class category
  - < 2'
  - >2' to < 4'
  - >4' to < 6'
  - >6' to < 8'
  - > 8' to < 12'
  - > 12'
- Only includes historic weather conditions and unable to include current or local conditions (e.g. wind speed or fuel moisture)
- Difficult to update data
  - Currently the schedule data update is every 5 years
- Does not address urban areas
- Extremely expensive to create
- Unlikely to be precise

WFAT Issues

- Wind Speed is constant for the entire study area
- Foliar Moisture is constant for entire study area
- Vegetation Cover-Type information is not uses
  - Only vegetation structure elements are used as inputs
- Flame Length output is in meters
  - May produce misclassifications when compared to COWRAP data
    - COWRAP flame length output is in feet, partitioned into 6 classes.

dNBR Benefits

- Cost effective
- Can be completed rapidly
  - After the imagery is acquired for the time period of interest.
- Output is precise
- Other fires can be compared to each other
- dNBR can be used to update the LandFire data sets.

COWRAP Benefits

- Quick to access data
- Uses an array of data sets
- Comprehensive for entire State
- Standardized for most of the western state?
- Adopted by many state and federal agencies
  - Wildfire Insurance and Forest Health Task Force
    http://www.colorado.gov/cs/Satellite/GovHickenlooper/CBON/1251639076858
  - http://www.dora.state.co.us/taskforce/

WFAT Benefits

- Can be customized for any area of interest
  - Currently only for Colorado and Wyoming
  - Wind Speed can be input for current site conditions
  - Fuel Moisture can be modified for current site conditions
- Uses 10 meter DEM
- Precise output
- Output data are rapidly created (less than 10 minutes)
  - When using the custom python tools created by ERIA Consultants, LLC
- Different fire scenarios containing different wind speeds and fuel moisture values can be rapidly generate and evaluated.
- Minimal cost

COWRAP and WFAT Comparison

- Both of these data output can be used for planning purposed to address both pre-fire and post-fire efforts
- In addition both of these data outputs can be deployed in the event of a wildfire and used for initial attack planning and resource deployment efforts.
- WFAT is dynamic (adjust wind speed and fuel moisture), easily updated, minimal cost, and precise.
- COWRAP inflexible, difficult to update, expensive to generate, may not be precise.

COWRAP and WFAT Comparison

- Think of baking a cake
  - COWRAP bakes a single cake for all consumers
  - WFAT bakes as many unique cakes as the consumer requests

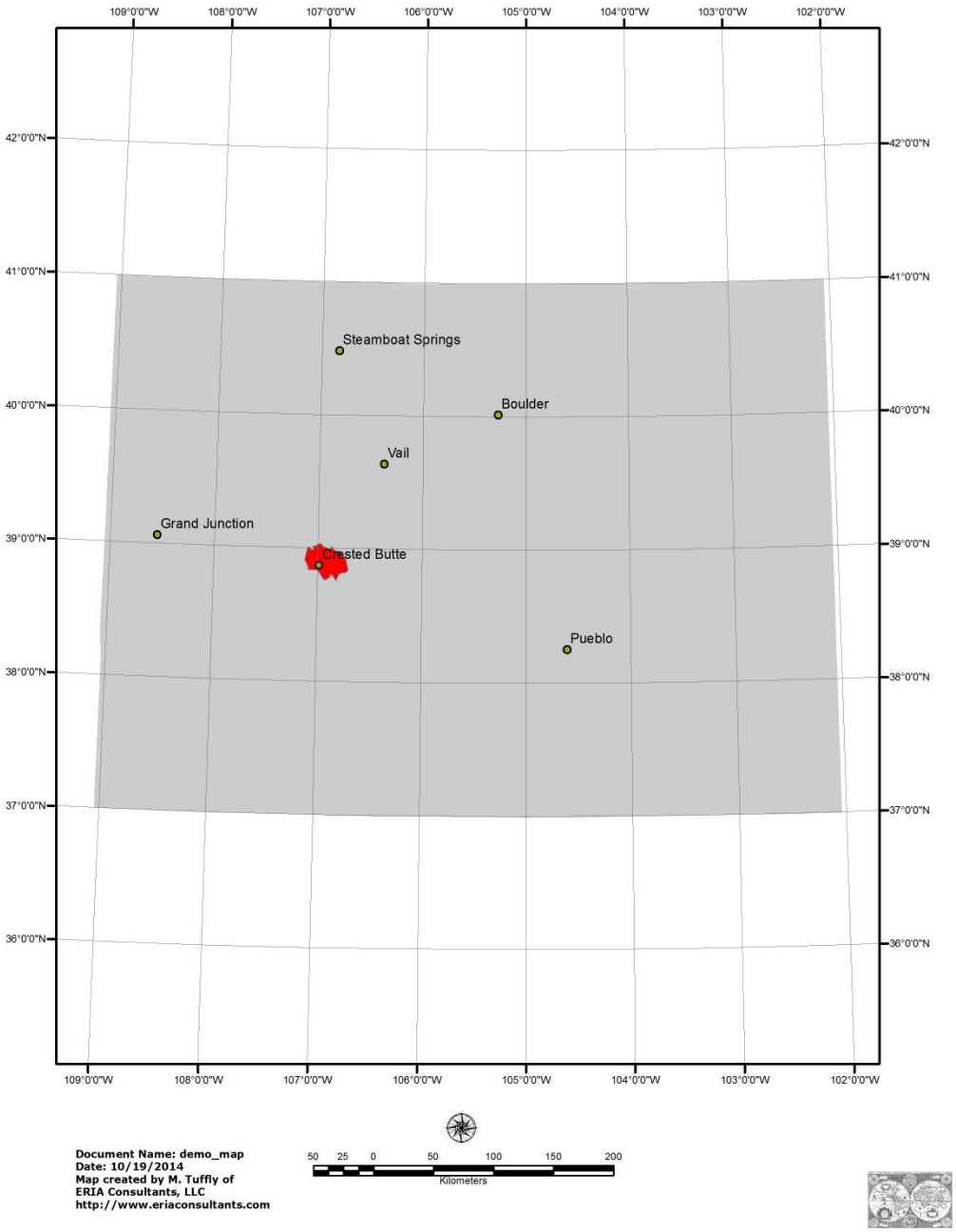
  - COWRAP bakes cakes using all the same ingredients
  - COWRAP cakes remain on the shelf for many years and may become stale

  - WFAT bakes cakes using new and updated and fresher ingredients
  - WFAT cakes do not linger on the shelf; hence, maintain freshness

  - WFAT allows cake consumers to sample and compare different cake flavors (e.g. wind-speed, fuel moisture).

Demo

- Use of the ERIA tool for data preparation for input into WFAT
- Use of WFAT
- Use of the ERIA tool to clean up output from WFAT
- Examine the output
  - Study Area is located in and around the town of Crested Butte, CO.
  - Study area is 17,000 Acres
  - Estimate time is 6 minutes



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Future Ideas

- dNBR
  - May have more utility since the launch of LandSat 8
    - LandSat 8 went into service on May 30th 2013
    - LandSat 8 image bands may produce more accurate output
      - LandSat 8 has a narrow band width and greater pixel depth when compared to LandSat7.

        - LandSat 8
          - Band 5 = 0.85 to 0.88 micrometers
          - Band 7 = 2.11 to 2.29 micrometers
          - Band 5 and 7 are 16 bit (pixel depth)

        - LandSat 7
          - Band 4 = 0.75 to 0.90 micrometers
          - Band 7 = 2.09 to 2.35 micrometers
          - All data from Landsat 7 is 8 bit (pixel depth)
        - LandSat 5
          - Decommissioned in December of 2012

  - The dNBR categorical breaks can be modified by field data
  - Classification and Regression Tree (CART) techniques coupled with field data show promising results in the development of dNBR categorical breaks.

Questions?

- Thank you for your time.

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