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Technical Memorandum | Final

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Distribution:	**Distribution List**
From:	**Jim Pearce (Canyon) and Ben Harding (AMEC)**
Subject:	**CRWAS Phase I | Task 7.3 | Forest Change Literature Review/ Suggested Methods | Task 7.4 | Forest Change Assessment**
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Introduction

This Technical Memorandum summarizes information developed as part of Task 7 of the Colorado River Water Availability Study (CRWAS or Study).

One of the objectives of Task 7 is to:

Provide agency coordination, literature review, diagnostic analysis, data preparation, and model testing to generate projections for temperature, precipitation, weighted and scaled alternate hydrology, and water use relative to potential changes in forest and climate scenarios.

This memo covers CRWAS Task 7.3 (Forest Change Literature Review and Suggested Methods) and CRWAS Task 7.4 (Forest Change Assessment), pursuant to the task requirements to "….review methods and recommend an approach for addressing forest change to the CWCB." The memo reviews and summarizes information regarding the method and approach for addressing forest change in the Colorado Water Availability Study.

The following sections include: 1) the requirements of CRWAS; 2) a summary of the overall analytical framework regarding forest disturbance; 3) description of candidate methodologies, an evaluation of alternative approaches in the context of CRWAS requirements; 4) identification of a preferred technical approach; 5) conclusions and a recommendation for CRWAS; and 6) references; as well as an appendix that contains a bibliographic list of other relevant sources and detailed review of important publications.

Section 5 provides a recommendation to postpone detailed hydrologic analysis associated with Forest Change (originally contemplated for Task 7.4 – Forest Change Assessment) until additional data are developed and understood. The U.S. Forest Service (USFS), in conjunction with CWCB, is in the process of completing a multi-year study to collect information regarding forest change processes that most influence hydrology of disturbed forests within Colorado. As the USFS study progresses, corresponding information being developed is expected to better describe corresponding hydrologic processes, and to constrain assumptions, to be used in future hydrological models.

1) Requirements of CRWAS

The principal objective of Task 7 of CRWAS is to develop an alternate hydrology of climate change. CRWAS Tasks 7.3 and 7.4 describe a secondary objective to develop an alternate hydrology of forest change due to biotic factors (insect infestation) and fire events. This technical memorandum provides a review of alternative methods and recommends a corresponding approach for addressing forest change. The analysis of forest change involves a conceptual assessment of occurrence that includes initiation of change, intensity of change (area of infestations or fire), and time history of recovery.

As described in the contractual Scope of Work, CRWAS Task 7.4 was to be an assessment of the impact of forest change utilizing the hydrology model (Variable Infiltration Capacity model, VIC). The original intent of Sub-task 7.4 was to utilize information from CRWAS Task 7.3 to develop three forest change scenarios. The scenarios were to be developed into *as-if* hydrology regarding forest change relative to baseline (current) conditions. The *as-if* conditions were to represent forest change as though they had been fully developed at the start of the historical period and did not recover over the duration of the historical period. The analysis was to consider developing hydrology from the VIC model out to two planning horizons, 2040 and 2070.

2) Summary of Analytical Framework

The effects of forest disturbance on basin hydrology vary depending on the location, scale and timing of disturbance. The literature review described herein identifies biotic (insect infestation) and forest fire factors as the primary processes impacting forest disturbance.

<u>General Forest Disturbance:</u>

Forest management studies indicate that decreasing forest cover may result in increased stream flows (Megahan, 2000). Paired watershed studies in Colorado indicate that reductions in forest cover of approximately 20% in sub-alpine forests (elevations greater than approximately 8,500 feet) increases the volume of stream flow (MacDonald, 2003). Run-off volume increases because less precipitation is lost through the processes of evaporation and plant transpiration. In addition, forest disturbance can impact the timing and rate of snow pack and snow melt.

Forest disturbance below the sub-alpine zone has almost no effect on the quantity of run-off (MacDonald, 2003). At lower elevations, annual precipitation decreases, and there is sufficient evaporation, soil water storage, and plant transpiration processes such that there is practically no change in the volume of run-off[1].

[1] However, the water quality aspects associated with forest disturbance at lower elevations may be significant as shown by the Hayman Fire in the South Platte River Basin in 2002.

Insect Infestation:

Beetle kill of Colorado's mature lodgepole pine forests exemplify forest change on a large scale. Infestation primarily kills mature (>80 years old and >8 inches in diameter) lodgepole pine trees (Aguayo, 2006), with smaller trees also being infested and killed on a smaller scale. Although mature lodgepole pine currently appear to be the tree type impacted the greatest from beetle kill, it is understood (although not fully) that other tree types, such as ponderosa pine and limber pine, are also being impacted to a much less aerial extent. Forest health reports also indicate (although not fully understood) limited endemic aspen disturbance. For the purpose of this technical memorandum, focus is being placed on lodgepole pine due to available data.

Different types of beetles contribute to tree mortality depending on location and tree type. The Mountain Pine Beetle currently appears to be the most aggressive of the varied beetle types, feeding on the main trunk of a tree and leaving other parts of a tree for other beetle types. Other beetle types named as contributors to tree mortality include the Douglas-Fir Beetle, Spruce Beetle, and Western Balsam Bark Beetle, bark beetle, and twig beetle (a relatively newly-discovered type), the impact from which is just recently being understood for some of the beetle types. For the purpose of this technical memorandum, focus is being placed on the Mountain Pine Beetle due to available data.

Surveys of tree mortality and vegetative cover regarding Colorado's mountain pine beetle epidemic are readily available (US Forest Service Rocky Mountain Region, 2008). Forest officials report that the cumulative impacted area covers 1.9 million acres (US Forest Service and Colorado State Forest Service, 2009). Researchers predict that the epidemic may infect nearly every mature lodgepole pine forest in the State. Most of Colorado's lodgepole pine forests are comprised of mature and even-aged stands (Aguayo, 2006). Ponderosa pine stands are more varied, in terms of spacing and age, than lodgepole pine stands, making quantification of impacts much harder to predict.

Increases in water yield are expected from beetle kill in even-aged stands of lodgepole pine trees (Stednick, undated power point). No increase in water yield is expected from uneven aged stands of trees because of regeneration or release of the understory. Water yields increase because there is less vegetative cover intercepting, evaporating and transpiring available precipitation.

Forest Fire:

Forest fire may also affect watershed run-off volumes. Historically, Colorado's forests exhibit a wide range of fire severity and frequency (Graham, 2003). Generally, high-severity, infrequent fires typify sub-alpine forests. In the montane forests (less than approximately 8,500 feet elevation, similar to Hayman fire), the fire regime is characterized by low-severity, frequent fires. Mixed conifer forests indicate a wide range of fire regimes.

Graham (2003) reviewed and summarized fire and tree ring data from locations spanning from southern Wyoming to Southern Colorado. The analysis concluded that on a regional scale, synchrony of fire years suggest extreme weather-increase fire hazard over the area. Tree ring sampling indicated that major fires correspond with significant drought during the year and/or during the preceding year.

3) Candidate Methodologies

Temporal Considerations:

Post-event forest change effects on hydrology differ between insect infestation and forest fire, in the short-term, and become more similar in the longer-term. For example, the nature of impacts from beetle infestation require analysis on long-term temporal scales, whereas hydrology of an area impacted by a fire event is largely primarily impacted in the period immediately after the fire event due to effects of fire on the soil surface characteristics. After a few years, the effect of forest fire on soil surfaces diminishes, where changes in snow dynamics and evapotranspiration become predominant hydrologic factors. It is at this point where conditions in a burn area become more similar to conditions in an area affected by insect infestation. Due to the long-term planning nature of study, CRWAS is primarily concerned with long-term forest change impacts that may occur from insect infestation and forest fire.

Spatial Considerations:

Spatial characteristics of an infestation area and a burn area also differ. Insect infestation results in essentially-complete elimination of lodgepole pine in Colorado's even-aged and mature stands, whereas fire may extend across different ecological zones. Significance of this difference on hydrologic impacts is not fully known, but expected to be relatively small.

Research indicates that at least a 20 to 30 percent reduction in forest basal area is necessary before any increase in annual water yield can be detected (Douglass and Swank 1972, Bosch and Hewlett 1982, Hornbeck et al 1997). Sub-alpine zone forests are known to contribute most of the run-off (MacDonald, 2006). At the scale of a small or moderately sized basin, a fire devastating 30% or more of the trees is conceivable. However, disturbance from fires large enough to affect the basin model are not expected. Consequently, the analysis of fire disturbance is not recommended as a component of the hydrologic runoff modeling regarding forest disturbance mechanisms.

Acreage that will be affected at the peak of current insect infestation will be much larger than average acreage impacted by a forest fire event, and that larger area will still be relatively small compared to the size of the major sub-basins within Colorado. Nonetheless, the approach for forest change should utilize a basin-wide perspective.

Event Probability Considerations:

The general nature of the probability of insect infestation and forest fire events also differ. Evidence indicates that insect infestation follows a generally predictable course leading to a nearly-complete elimination of lodgepole pine in Colorado; whereas the occurrence of forest fire includes a significant random component, so the occurrence of fire at any particular site within Colorado can best be described by probability or expected value. Thus, a basin-wide analysis of insect infestation could provide useful, site-specific information on forest impacts, while forest impacts from forest fire in a particular basin are primarily limited to the expected value of the fraction of the basin that will be impacted by fire at any point in time.

Candidate Methodologies:

There are two candidate methodologies for analyzing hydrologic and water supply effects of forest change for CRWAS. Some form of modeling (extrapolation being a type of model) will be required in either case.

- The first method would employ results from empirical studies of forest disturbance on run-off (watershed scale) to adjust existing natural flows for a watershed. Employing results from published literature provides the advantage of simplicity. The principal disadvantage of this approach is that there is little guidance for extrapolating impacts from the particular conditions in an experimental watershed to another area.

- The second method would utilize a hydrology model to estimate the incremental change in run-off due to forest change. This would involve modifying land surface model parameters to represent the post-fire / infestation condition and then running the hydrology model using the modified land surface parameters to obtain the post-fire / infestation streamflow. Using a hydrology model to represent the changed vegetative cover provides the advantage of incorporating specific vegetative, physical, and hydrologic characteristics of the study watershed. The disadvantage of this approach includes quantification of impact that relies on a model of the land surface and vegetation rather than actual field measurements.

4) Preferred Technical Approach

Based on the nature of forest impacts from fire and infestation, available scientific information, and the advantages and disadvantages of the available methods, the preferred technical approach to represent the impact of forest disturbance is use of hydrology modeling (the Variable Infiltration Model, VIC - to be consistent with other CRWAS hydrology modeling). The model area would include the Colorado River Basin within Colorado. To understand hydrologic impacts within local areas, hydrology derived from VIC modeling can be evaluated at sub-basin and watershed scales.

The scale of forest disturbance / impact from insect infestation would be the area occupied by lodgepole pine, since foresters predict that insect infestation will reach practically every mature lodgepole pine forest. Although mature lodgepole pine forests appear to be impacted the greatest from beetle kill, it is understood (although not fully) that other tree types, such as ponderosa pine and limber pine, are also being impacted to a much less aerial extent. Forest health reports also indicate (although not fully understood) limited endemic aspen disturbance. Forest fire disturbance would not be included in modeling activities because theorized size of disturbed areas is expected to be relatively small in relation to CRWAS model extents.

This approach would include adjusting vegetation parameters within VIC cells to reflect forest change due to insect infestation. The change in run-off predicted by the model can be compared to empirical ranges described by MacDonald (2003).

The method would rely on vegetation cover data as available from State Forest mapping and databases (Colorado Vegetation Classification Project, 2009). The mapping and database describes vegetation classifications statewide. Depending on the sufficiency of the land cover data, land cover classifications associated with areas of lodgepole pine forests (and other impacted tree species) would be identified. The total area of potentially-impacted tree types in each VIC grid cell as a fraction of the total coniferous forest would be determined for the Colorado River Basin in Colorado. The vegetation parameters in VIC would then be adjusted to reflect tree mortality on an area basis by reducing the coniferous forest fraction in the VIC vegetation parameter input to reflect elimination of potentially-impacted tree types. The percentage of grass would be increased to reflect replacement of potentially-impacted tree types by grass.

The State has also mapped the extent of the recent beetle infestations as indicated by tree mortality. In 2007 (the most recent snapshot), the mapping shows approximately 2,100 square miles of lodgepole pine killed in the Colorado River Basin in Colorado. The current impact to other tree types is not yet fully understood. The recommended approach would assume 100% lodgepole pine mortality with substantial regrowth at 2040 and complete re-growth at 2070.

5) Conclusions and Recommendation

<u>Addressing Forest Change Due to Fire:</u>

Impact of fire is localized and relatively small, and the incidence of fire has a substantial random component, so predictions of impact would have to be made on the average areas expected to be affected, and these average values would be very small in any given locale. Accordingly, the value of an analysis of fire impacts on basin-wide hydrology used for CRWAS would have little utility. **Therefore it is recommended that analysis of fire disturbance not be used as a component of the VIC modeling regarding forest disturbance mechanisms.**

<u>Addressing Forest Change Due to Insect Infestation:</u>

Although the approach identified in Section 4 above is technically feasible, due to data availability, current understanding of forest recovery timeframes, and water supply impact detection thresholds (all described below), **it is recommend that at this time the CWCB postpone analysis originally scoped for CRWAS Task 7.4 (Forest Change Assessment) corresponding to forest change due to insect infestation**. The basis for this recommendation includes multiple reasons.

Data Availability:
Existing data on the extent of lodgepole pine and other tree types (e.g., ponderosa pine, limber pine, and aspen) and the extent and type of beetles impacting trees have limitations that would reduce the reliability of the resulting analysis and increase its cost and risk. The United States Forest Service is currently conducting extensive site-specific studies regarding the pine beetle epidemic in the North Platte Basin. The CWCB and North Platte River Basin Roundtable have contributed funding to the USFS effort. The investigations will develop new data regarding the processes that most influence the hydrology of disturbed forest areas. Inclusion of the new data being developed would be possible if the Task 7.4 analysis is postponed. The initial reports are due in 2010.

Forest Recovery Timeframe:
Vegetation recovery from forest clearing due to insect infestation begins immediately after the event has occurred. The reduction in evapotranspiration from the death of trees will

likely be offset quickly by the development of full cover vegetation of grass and shrubs. Less evaporation resulting from changes in snow dynamics will be offset by regrowth of trees, and this will take longer (full recovery to baseline conditions may take as long as 60 years). But, even if the recovery process is linear, substantial recovery and re-establishment of forests will have occurred at the earliest planning horizon for this study (2040). The extent that recovery has occurred by that time will further reduce the scale of watersheds that will demonstrate a significant change in flow. Because of the relatively low sensitivity of flow to clearing, and the possibility that substantial recovery will occur over a period of a few decades, results of this analysis will have limited value for the two planning horizons (2040 and 2070) adopted for CRWAS. Virtually full recovery of current insect infestations will certainly have occurred by 2070 and substantial recovery would be expected by 2040, further supporting the stance that related analysis has limited value.

Water Supply Impact Detection Threshold:
Evidence from research indicates that between 20 and 30 percent of a watershed must be cleared of trees before change in flow can be detected (Douglass and Swank 1972, Bosch and Hewlett 1982, Hornbeck et al 1997). Available mapping of lodgepole pine appear to indicate that only in the smaller watersheds would clearing from complete tree mortality reach this detection threshold. Most of the annual flow volume comes from the sub-alpine forest (elevations >8,000 feet). Forest disturbance in lower elevation areas, even if sever, does not change the flow volume significantly. Larger percentages of clearing, perhaps much larger, presumably would be required before the change in flow became significant to water supply. The impact on stream flows from forest disturbance is much smaller than impacts on stream flow from projected changes in climate. The USFS studies forthcoming will provide useful empirical data and analysis to better understand the watershed management activities best suited for further analysis. The magnitude of changes in streamflow that can reasonably be expected in all but the smaller watersheds is expected to be much smaller than impacts on streamflow from projected climate changes.

<u>Summary:</u>

The study of Forest Change includes dynamic processes that are just recently being understood, including extent and types of trees impacted from beetle infestation and extent and types of beetles responsible for the impacts. Experts indicate that the progression of beetle kill is expected to change and that the changes are currently difficult to quantify. Data availability, current understanding of forest recovery timeframes, and water supply impact detection thresholds limit the value for CRWAS of analyzing forest change.

The U.S. Forest Service (USFS), in conjunction with CWCB, is in the process of completing a multi-year study to collect information regarding forest change processes that most influence hydrology of disturbed forests within Colorado. As the USFS study progresses, corresponding information being developed is expected to better describe corresponding hydrologic processes, and to constrain assumptions, to be used in future hydrological models, perhaps in Phase II of this study.

It is, therefore, recommended that detailed hydrologic analysis associated with Forest Change (originally contemplated for Task 7.4 – Forest Change Assessment) be postponed until additional data are developed and better understood.

6) References

Aguayo, Ingrid. " Bark Beetle Situation in Colorado," Testimony before the Committee on Resources, United States House of Representatives. Hearing on the GAO Report on Invasive Forest Pest. June 21, 2006.
http://republicans.resourcescommittee.house.gov/archives/ii00/archives/109/testimony/2006/ingridaguayo.htm

Bosch and Hewlett 1982. "A Review of Paired Catchment Studies for Determining Changes in Water Yield Resulting from Alterations in Vegetation". Journal of Hydrology, Volume 310, Issues 1-4.

Colorado Vegetation Classification Project. Accessed February 28, 2009.
http://ndis.nrel.colostate.edu/coveg/

Douglass, J. E., and W. T. Swank. 1972. "Streamflow Modification through Management of Eastern Forests. USDA Forest Service, Southeast. Forest Experiment Station Res. Pap. SE-9M-, 15 pp.

Graham, Russell T., Technical Editor. 2003. " Hayman Fire Case Study." Gen. Tech. Rep.MRS-GTR-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 396 p. Accessed March 3, 2009.

Hornbeck et al. 1997. Summary of Water Yield Experiments at Hubbard Brook Experimental Forest, New Hampshire. Canadian Journal of Forest Research, 27, 2043-2052.

MacDonald, Lee H. and Stednick, John D. "Forests and Water: A State of the Art Review for Colorado." CWRRI Completion Report No. 196. Colorado Water Resources Research Institute. 2003.
http://welcome.warnercnr.colostate.edu/~leemac/publications/ForestandWater.pdf

Megahan, W.F. and Hornbeck, J. " Lessons Learned in Watershed Management," USDA Forest Service Proceedings RMRS–P–13. 2000. Accessed January 5, 2009.
http://www.fs.fed.us/rm/pubs/rmrs_p013/rmrs_p013_177_188.pdf

Stednick, John, undated Power Point presentation. " Effects of pine beetle infestations on water yield and water quality at the watershed scale in Northern Colorado," Posted on the Colorado Water Congress web page links. Accessed March 3, 2009.
Microsoft PowerPoint - John Stednick - Effects of Pine Beetle ...

US Forest Service and Colorado State Forest Service Release Results of the Annual Forest Health Aerial Survey. The Mountain Pine Beetle, Spruce Beetle and Aspen Decline are Conditions of Concern DENVER, Jan. 16, 2009.
http://csfs.colostate.edu/pages/documents/nr_COforesthealth_1-16-09_final.pdf

Appendix – Interviews and Literature Review

Individuals interviewed in this review:

- Ingrid Aguayo, State Forest Entomologist, Fort Collins, Colorado
- Greg Bevenger, USFS Hydrologist, Cody, Wyoming.
- Andrea Holland-Sears, USFS White River Forest, Glenwood Springs, Colorado
- Lee MacDonald, Colorado State University, Fort Collins, Colorado
- Kelly Elder, USFS

References included in this review:

A Communicators Guide. Wildland Fires. Condition Class Attributes: Defining Fire Regimes. Accessed November 15, 2008.
www.nifc.gov/preved/comm_guide/wildfire/fire_5.html

A forest wildfire management communication guide developed by the National Interagency Fire Center (NIFC). NIFC and the National Wildfire Coordinating Group (NWCG) provide the United States comprehensive wildland fire management. The guide provides several excellent overviews on wildfire processes and resources. In particular:
http://www.nifc.gov/preved/comm_guide/wildfire/fire_4.html discusses the science of wildfire and describes the basic processes.
http://www.nifc.gov/preved/comm_guide/wildfire/fire_28.html provides many links to other resources regarding wildfire in the United States.

Aguayo, Ingrid. " Bark Beetle Situation in Colorado," Testimony before the Committee on Resources, United States House of Representatives. Hearing on the GAO Report on Invasive Forest Pest. June 21, 2006.
http://republicans.resourcescommittee.house.gov/archives/ii00/archives/109/testimony/2006/ingridaguayo.htm

"The primary factors causing susceptible conditions for an epidemic in a stand of trees are stand density, extensive areas of mature and over mature forests (>80 years), average diameter (> 8 in), and a triggering event. In Northern Colorado, the triggering event for mountain pine beetles appears to be the recent drought, given rise to stressed trees that are not able to resist bark beetle attack; and warm winters that allow a higher percentage of larvae to survive."

Battles, J. et al. "Climate Change Impact on Forest Resources." California Climate Change Center. CEC-500-20050193-SF. March 2006. Accessed at:
http://www.energy.ca.gov/2005publications/CEC-500-2005-193/CEC-500-2005-193-SF.PDF

This study evaluated the climate change impacts on the productivity, health, and value of a forest for a specific region in California—the Sierran mixed conifer timberbelt. The research team forecasted 30-year tree growth and timber yields for forest stands in El Dorado County under a changing climate. The model projections were constrained by structural and demographic data from the Blodgett Forest Research Station in El Dorado County in order to represent a realistic range of legal management regimes employed on private and governmental forests in the region.

Bethlahmy, N. 1974. More streamflow after bark beetle epidemic. Journal of Hydrology 23:185-189

A beetle epidemic near the Continental Divide in Colorado destroyed the timber in two large drainages but bypassed a third drainage. Long-term streamflow records were available for the three drainages for the periods before and after the onset of the epidemic. Analysis of these records reveals that a major increase in streamflow occurred after the epidemic.

Provides a description of the correlative method used to determine significance of change in run-off. Bethlahmy reports that the smallest increases in run-off occurred in the first 5-years (as the epidemic got started) and were the most pronounced 15 year later (approximately 7 years after the beetles has run their course. Tabulates increase in run-off for 5-year periods from 1945 – 1965. Estimated Yampa increased run-off of 23.6 mm for 25 year period, 1941 – 1965. Estimated 31.8 mm increases in run-off the White River.

Breshears, David, et al. "Regional Vegetation die-off in Response to Global Climate Change." PNAS, October 18, 2005, vol. 102, no. 42.

Drought from global warming may lead to increased vegetative die-off.

Brown, P. and Shepperd, W. "Fire History and Fire Climatology Along a 5 degree Gradient in Latitude in Colorado and Wyoming," Palaeobotanist, 50 (2001 : 133-140). Accessed January 9, 2009 at: http://www.rmtrr.org/data/Brown&Shepperd_2001.pdf

This report documents fire scar chronologies for the Front Range Rocky Mountains in Colorado and Wyoming. The work compares reconstructed fire frequencies to assess fire climate relations and latitude. The report concludes that fires were more frequent during dry periods and in the more southern sites.

In the article's Introduction Brown summarizes previous authors findings, "…fires were important forest disturbances prior to the twentieth century (Swetnam, 1993)." The Introduction continues, "fire is an important factor in forest ecology and health."

Characterizing Forest Change with Satellite Imagery and FIA Data. USFS, Research and Development, RMRS. Accessed January 5, 2009. http://www.fs.fed.us/rmrs/research/highlights/forest-satellite-imagery/

Biennial Landsat satellite imagery from 1984 to 2002 has been acquired for 30 areas (each 185 by 185 km). Change detection algorithms have been developed that use FIA plot data to identify disturbances and estimate their effects on forest structure. Re-growth trajectories will also be produced for each disturbance, enabling study of factors that affect forest recovery.

Colorado Forest Health Reports. Accessed March 3, 2009.
http://csfs.colostate.edu/pages/pub-csfs2.html
http://csfs.colostate.edu/pages/documents/2008_FHR_Executive_Summary.pdf

Colorado Vegetation Classification Project. Accessed February 28, 2009. http://ndis.nrel.colostate.edu/coveg/

GIS datasets for vegetation classification and land cover in Colorado. Participants in the cooperative effort include the Colorado Department of Wildlife, USFS, and BLM.

Donnegan, J.A. and Rebertes, A. J. "Rates and mechanisms of subalpine forest succession along an environmental gradient," Ecology, June, 1999. Accessed January 5, 2009. http://findarticles.com/p/articles/mi_m2120/is_/ai_54994065

The main objective of this study was to quantify rates of secondary succession and to determine how they vary both spatially, along an environmental gradient, and temporally, from early- to late-seral communities.

"This paper examines how rates and mechanisms of succession vary spatially and temporally in xeric, subalpine forests in Colorado, United States. We reconstructed 300 years of succession from limber pine (*Pinus flexilis*) to Engelmann spruce (*Picea engelmanii*) and subalpine fir (*Abies lasiocarpa*) in two watersheds recovering from the same fire. More than 1850 live and dead trees were cored and mapped in 25 plots systematically spaced along a topographic gradient. We used tree ring analysis to reconstruct dates of tree establishment and death. Relative species abundances and basal areas were charted at 20-yr intervals, and three measures of ecological similarity were also used to capture different elements of change: simple Euclidean distance, Euclidean distance in ordination space, and Horn's C_H similarity index.

"Successional rates for mesic lower slopes and north aspects were roughly twice those on south-facing side slopes. Rates were positively correlated with soil P, N, Fe, organic matter, and Parker's topographic moisture index, and negatively correlated with solar radiation and surface rock cover. Higher rates on mesic plots were primarily the result of heavy overstory mortality of pioneer limber pines ~200 yr postfire, coupled with higher recruitment of spruce and fir 200–300 yr postfire. On mesic sites, successional rates peaked during this thinning phase of limber pine, but rates were stable or slowly increasing 300 yr postfire on xeric sites. Previous studies have shown that Clark's Nutcracker catalyzes early succession by caching limber pine seeds in extensive burns, many of which germinate to form multitrunk pines. Limber pines, in turn, may act as nurse trees for spruce and fir. However, we reconstructed past spatial patterns of trees and found that limber pine mortality in midsuccession was strongly related to its clumped pattern of establishment and tendency to attract spruce and fir. Solitary pines with no spruce and fir neighbors within a 2 m radius had a >80% chance of survival, 1893–1993. In contrast, pines within clumps of six or more trees and surrounded by many spruce and fir trees had only 10–20% chance of survival, 1893–1993. The multitrunk growth form of limber pines may be selectively advantageous on harsh sites, including early postfire environments, but our results suggest that this same growth form may be disadvantageous on mesic sites with heavy spruce and fir competition during mid- to late-successional stages. We confirmed the equilibrium prediction that succession is more rapid on mesic sites, but even in this very simple system, demographic mechanisms of succession were relatively complex.

Graham, Russell T., Technical Editor. 2003. " Hayman Fire Case Study." Gen. Tech. Rep.MRS-GTR-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 396 p. Accessed March 3, 2009.

The Hayman Fire burned 138,000 acres near Cheeseman Reservoir in the South Platte Basin of Colorado in 2002. The following table from the report lists the types of vegetation and areas burn in the fire.

Table 18—Acres by vegetation type

Vegetation type	Acres	Percent of total
Ponderosa Pine	72,862	52.76
Douglas-fir	50,235	36.38
Shrubland	484	0.35
Grassland	718	0.52
Spruce/Fir	1,029	0.74
Aspen	2,019	1.46
Barren / Rock	333	0.24
Limber Pine	171	0.12
Water	836	0.61
Bristle Cone Pine	153	0.11
Unknown (Private)	8,839	6.40
Lodgepole Pine	416	0.30
Total	138,095	100.00

Note that the acreage total does not correspond to the official final fire size because data are absent from non-National Forest land on the periphery of the burned area.

The report details almost every aspect of the fire and the fight to contain the blaze. The section "Ecological Effects of the Hayman fire" describes the historical and current fire regime, the historical and current forest landscape, succession, aquatic systems and changes in aquatic systems, and soil properties erosion and rehabilitation. The Ecological Effects are explained in a general context, so that the nature of the Hayman fire is placed in context with respect to other forest types, the conditions leading up to the fire, the role of human fire suppression, and other factors.

"Throughout this report, we compare ecological conditions in the aftermath of the Hayman Fire not only to conditions that existed just prior to the fire, but also to the natural range of conditions that characterized this ecosystem for hundreds of years prior to the arrival of Euro-American settlers. It becomes apparent that not all conditions just prior to the fire were "natural" or even desirable from an ecological standpoint."

A "fire regime" is a summary description of the salient characteristics of fire occurrence and effects within a specified area. The following descriptions summarize the fire regimes as used in the Hayman Fire Case Study:

"Infrequent High-Severity Fire Regimes – Continuous canopy fuels of dense Engelmann spruce, subalpine fir, and lodgepole pine forests, growing in cool, moist environments, permit widespread stand replacing crown fires or severe surface fires – but only during conditions of low fuel moisture, low relative humidity, high temperatures, and winds. These kinds of weather conditions occur only a few times in several decades in the subalpine zone, and consequently most ignitions extinguish naturally without spreading. Low decomposition rates in the sub alpine zone cause accumulation of fuels during the long intervals between fires and, therefore, intense fire behavior when extremely dry weather conditions eventually coincide with ignition (Clagg 1975; Romme and Knight 1981). Thus, subalpine forests generally are characterized by infrequent, high-severity fires."

"Frequent Low-Severity Fire Regimes – Fires in open ponderosa pine woodlands of the lower montane zone, where grass and other herbaceous fuel types are well developed, tend to be surface fires of relatively low intensity and high frequency. Weather conditions that dry fuels sufficiently for fire spread are more common at lower elevations and result in widespread fires during dry years (Veblen and others 2000). Thus, lower montane ponderosa pine forests generally were characterized by frequent, low-severity fires prior to the mid-1800s (table 3). This historical fire regime along the lower forest ecotone in the Colorado Front Range is similar in some respects to the historical fire regime of Southwestern ponderosa pine forests, for example, in northern Arizona (Covington and Moore 1994; Fuler and others 1997; Veblen and others 2000; Brown and Shepperd 2001)."

"Mixed-severity fire regimes - in forests of ponderosa pine and Douglas-fir in the Colorado Front Range can be characterized as follows (from Brown and others 1999; Kaufmann and others 2000a,b, 2001; Veblen and others 2000; Ehle and Baker in press): Fires recurred at highly variable intervals, ranging from a decade to a century, and varied in size from very small (less than 1 ha) to very large (tens of thousands of hectares). Within the perimeter of any individual fire were areas where all of the canopy trees were killed, areas where many but not all of the trees were killed, areas with little or no canopy mortality, and unburned patches. These mortality patterns were produced by a mix of active crown fire, passive crown fire, severe surface fire that scorched tree crowns, and low-intensity underburning that did not scorch tree crowns. Proportions of total burned area in each of these categories of fire severity varied greatly among individual fire events. The largest, most severe fires tended to occur in extremely dry years, especially dry years following one to three wet years. Some large fires burned over a period of several months, dying down during moist days but flaring up again on dry windy days. However, not every watershed necessarily burned in every dry year, because of random variation in locations of ignitions as well as local variation in weather, disturbance history, and fuels characteristics."

The Case Study summarizes previous research on fires in the area from Southern Wyoming to Southern Colorado. The analysis concluded that on a regional scale, synchrony of fire years suggests extreme weather increases fire hazard over the area. Tree ring sampling indicated that major fires correspond with significant drought during the year and/or during the preceding year. There were several large fires in 2002, the tree-ring record of drought and fire occurrence indicates that over the past several hundred years, fire years of similar extent to the year 2002 have occurred numerous times.

The Case Study discusses the importance of 20th century fire exclusion in altering fuel conditions and fire severity.

"Fire severity becomes progressively less with increasing elevation, because natural fire intervals generally increase with elevation. Twentieth-century fire exclusion generally has had the least impact in subalpine forests dominated by spruce, fir, lodgepole pine, and limber pine. In mid-elevation forests with a large component of ponderosa pine (including forests co-dominated by Douglas-fir), the reduction in fire frequency also is more pronounced at lower elevations than at higher elevations (Veblen and others 2000). Consequently, changes in fuels conditions as a result of fire exclusion are likely to be greatest at the lowest elevations, where historical fire regimes were dominated by frequent low-severity fires, and least at the highest elevations, within infrequent high-severity fire regimes."

"Fire severity in subalpine forests also does not appear to have been altered significantly by 20th century fire exclusion because these forests are naturally characterized by infrequent but high-severity, stand-replacing fires occurring under severe fire weather conditions. For example, the severe fires that occurred in 2002 in spruce-fir forests in the Park Range, on the White River Plateau, and in the San Juan Mountains of Colorado probably were well within the historical range of variability for fire severity and fire size in these ecosystems. Indeed, it is important to stress that severe and widespread fires are a natural feature of lodgepole pine and spruce-fir forests of the Colorado Front Range and elsewhere in the Southern Rocky Mountains. Thus, the premise that fire exclusion has created unnatural fuel buildup in spruce-fir forests of the Front Range is not supported."

Hodanash, S. and Wolyn, P. Lightning Climatology for the State of Colorado. NOAA/NWS Pueblo, Colorado. Accessed January 4, 2009. http://www.crh.noaa.gov/Image/pub/ltg2/CO_ltg_climo_5sep.pdf

This paper documents cloud to ground (CG) lightning activity over the state of Colorado for a 16 year period; 1989 – 2005, excluding 2000. All data is from the National Lightning Detection Network (NLDN) collected by Vaisala. In this study, no attempt has been made to account for year to year changes in the detection efficiency of the NLDN. The primary goal in this analysis is to show hourly spatial trends in the data.

Logan, J.A., et al. Assessing the Impacts of Global Warming on Forest Pest Dynamics. Frontiers and Ecology and Environment. Accesses August 29, 2009. http://www.for.gov.bc.ca/hfd/library/MPB/Logan_2003_assessing.pdf

Forest insects and pathogens are the most pervasive and important agents of disturbance in North American forests, affecting an area almost 50 times larger than fire. The same attributes that result in an insect herbivore being termed a "pest" predispose it to disruption by climate change. This paper considers the data and models that are necessary to evaluate the impacts of climate change and pests and the assessments that have been made to date. The results indicate that all aspects if insect outbreak behavior will intensify as the climate warms.

This paper includes a good general description of the modeling techniques, data requirements, and an excellent reference list.

Love, L.D. 1955. The effect on stream flow of the killing of spruce and pine by the Engelmann spruce beetle. Transactions of the American Geophysical Union 36:113-118.

One of the most referenced articles on this subject as it is one of the earliest studies using paired water shed and statistical methods.

MacDonald, Lee H. and Stednick, John D. "Forests and Water: A State of the Art Review for Colorado." CWRRI Completion Report No. 196. Colorado Water Resources Research Institute. 2003.
http://welcome.warnercnr.colostate.edu/~leemac/publications/ForestandWater.pdf

MacDonald and Stednick's report provides a comprehensive review regarding forest management and how it affects water quantity and quality and identifies key gaps in knowledge. MacDonald takes a "process based" approach stating that understanding the affects of forest change requires a systematic analysis of the underlying processes. He cautions regarding extrapolations of forest change data: "Generalizations and extrapolations can be misleading unless there is a clear linkage to, and understanding of, the underlying processes."

The authors point out the importance of forest change in relation to Colorado's water supply, "most of the runoff in Colorado comes from forest and alpine areas above approximately 9000 ft (2730 m) in elevation. The dominant role of high-elevation areas is due to the increase in precipitation with increasing elevation, the decrease in potential evapotranspiration with increasing elevation, and the concentration of snowmelt in a relatively short period of time. In lower elevation forests the amount of runoff per unit area is greatly reduced because the rainfall and snowmelt inputs are much smaller relative to potential evapotranspiration".

Many of MacDonald and Stednick's conclusions and recommendations are relevant to the Water Availability Study. The flowing excerpts from "Forests and Water" highlight their findings:

"Annual water yields in the higher elevation spruce-fir and lodgepole pine forests are inversely proportional to the amount of forest canopy as indexed by basal area. Complete removal of the forest canopy in the sub-alpine zone can increase annual water yields by as much as 8 inches (20 cm) of water per unit area. This increase in water yield is due to the reduction in winter interception losses and summer evapotranspiration. Nearly all of this additional runoff comes on the rising limb of the snowmelt hydrograph (i. e., early May to mid-June), and the increases in runoff are several times larger in wet years than dry years."

"A reduction in the amount of forest canopy will increase the rate of spring snowmelt, and complete removal of the forest canopy will increase the size of the annual maximum peak flows by approximately 40-50%. Paired-watershed studies have shown that removal of the forest canopy has no significant effect on summer low flows, as the water "saved" by reducing summer evapotranspiration is simply carried over to the following spring."

"Reducing forest density has a progressively smaller effect on annual water yields with decreasing annual precipitation. Both paired-watershed studies and plot-scale research show that reducing forest density has no detectable effect on water yields when annual precipitation is less than 18-19 inches or approximately 460 mm. Paired watershed studies also indicate that at least 15% of the forest canopy within a watershed must be removed in order to obtain a measurable increase in annual water yields from small research watersheds. The detection of change becomes much more difficult in larger watersheds when discharge is being measured with standard techniques in natural channels."

“The increase in water yield that results from timber harvest or other disturbances will decrease as the forest regrows. Paired watershed studies suggest that it will take approximately 60 years until annual water yields return to their pre-disturbance levels in the higher-elevation spruce-fir and lodge pole pine forests. Hydrologic recovery is substantially faster in aspen forests due to faster regrowth and in drier forest types.”

The report also reviews information on the effects of fires on run-off:

“In summary, high-severity fires in forested areas can greatly increase runoff rates. The effect of low-severity fires on runoff generally is consistent with the effects of forest harvest on runoff, as low-severity fires do not substantially alter the runoff processes and pathways. Detailed, process-based studies need to be implemented immediately after severe fires in order to better document the magnitude and causes of changes in runoff, and better predict the risk to downstream areas. The observed increase in peak flows after the South Canyon, Buffalo Creek, and Bobcat fires confirm that high-severity wildfires can greatly alter the basic rainfall-runoff response, and there is a need to determine whether similar changes can be expected in other areas of Colorado.”

“The magnitude of the water yield increase that might result from large, high-intensity wildfires in the lodgepole and ponderosa pine forests in southern Wyoming and north-central Colorado were recently modeled by Troendle and Nankervis (2000). The modeled fire was assumed to reduce the basal area by 90% on 26,000 acres of lodgepole pine and 4,000 acres of ponderosa pine within the North Platte River basin. Model predictions were based on the change in cover, and did not account for any possible change in runoff processes, so the values were effectively identical to the values that would be expected from a comparable timber harvest. They predicted that the first-year increase in water yield from the lodgepole pine area would be 15,700 acre-feet or 7.2 inches per unit burned area, while the predicted water yield increase from the ponderosa pine stands was only 1,500 acre-feet or 4.4 inches per unit burned area. The smaller water yield increase from the ponderosa pine stand is due to the fact that water is more limited in this vegetation type, so evaporation and the residual vegetation use much of the water that was formerly being transpired by the ponderosa pines (Troendle and Nankervis 2000). We know of no other effort to model the change in water yield that might be induced by wildfires.”

“Threshold of response how much of a basin must be treated in order to detect a change in runoff – is relatively well known. A 1982 review of paired catchment experiments concluded that at least 15-20% of a forested basin must be treated within a short time period in order to detect a change in runoff (Bosch and Hewlett, 1982).”

“Troendle and Leaf (1980) noted that 20-30% of a watershed must be treated to detect a statistically significant change in flow, and this value has been supported by the magnitude of flow changes observed in paired watershed experiments in the Rocky Mountains.”

“At Coon Creek in south-central Wyoming there was a detectable change in annual water yield as a result of harvest and road-building on 24% of the watershed (Troendle et al., 2001). Small increases in annual water yields were observed by removing 31-33% of the trees in two small watersheds in northern Arizona (Baker, 1986).”

Mann, L.K., D.W. Johnson, D.C. West, D.W. Cole, J.W. Hornbeck, C.W. Martin, H. Riekerk, C.T. Smith, W.T. Swank, L.M. Tritton, and D.H. Van Lear. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. Forest Science 43:412-428. Accessed August 28, 2009 at: http://cwt33.ecology.uga.edu/publications/pubs_oct10/700.pdf

Nutrient removal by saw log or pulp wood harvest and whole tree harvest was determined for 11 forest stands located throughout the United States. Limited data from harvested stands show greater re-growth in saw log than with whole tree harvest in some areas. In the 11 harvested stands, hydrologic losses of N, K, and Ca generally increased immediately after harvest, but returned to levels comparable to control areas within 3 years. Because of the short duration of elevated nutrient losses, the hydrologic losses are considered minor relative to harvest removals. Ca and K are possible exceptions.

Megahan, W.F. and Hornbeck, J. " Lessons Learned in Watershed Management," USDA Forest Service Proceedings RMRS–P–13. 2000. Accessed January 5, 2009. http://www.fs.fed.us/rm/pubs/rmrs_p013/rmrs_p013_177_188.pdf

The summary document provides comments and background information regarding forest watershed management. The authors discuss research selected to represent a variety of geographic locations, forest types, topography and climate. These studies have shown the effects of forests and forest disturbances on water yield, peak and flood flows, snow accumulation and melt, soil erosion, and water quality including sedimentation and turbidity, chemicals and temperature. This paper reviews some important lessons learned from watershed management research across the nation and includes an extensive reference list.

"Hibbert (1967) summarized the results from 39 such experiments involving treated watersheds and developed three generalizations.

- Reduction of forest cover increases water yield.
- Establishment of forest cover on sparsely vegetated land decreases water yield.
- Response to treatment is highly variable and, for the most part, unpredictable.

The magnitude of the increases alluded to in the first generalization was highly variable. First-year responses to complete forest reduction ranged from 34 mm to >450 mm of increased streamflow, thus giving rise to Hibbert's third generalization."

"Under similar precipitation regimes, increases in water yield are roughly proportional to percentage reduction in stand basal area, with at least a 20-30% reduction being necessary to generate detectable increases in annual water yield (Douglass and Swank 1972, Bosch and Hewlett 1982, Hornbeck et al 1997). Coniferous forests have greater influences on water yield than deciduous forests, and species conversions from softwoods to hardwoods or grass will usually increase water yields. A number of studies have shown that water yield increases following partial cuttings are related to the configuration and/or location of the cuttings in relation to source areas for streamflow (Hornbeck et al 1993; Troendle 1986)."

"Given the widely documented increases in annual water yield from forest cutting, it is clear that streamflow increases following timber harvest; the question remains as to how the flow changes are distributed. "

"Troendle et al. (1998) studied effects of timber harvest on the Coon Creek watershed in the snow zone of Wyoming. They found that the highest flows in this 1.7 km2 basin were not significantly increased although the duration of the higher, near bankfull discharges as extended. The authors report that findings at Coon Creek support and are comparable with documented observations on smaller, experimental watershed studies elsewhere in the snow zone."

Mountain Pine Beetle Publications. British Columbia Ministry Library. http://www.for.gov.bc.ca/hfd/library/lib_MPB.htm

This site provides an extensive reference list and links to pine beetle research.

Potts, D.F. 1984. "Hydrologic Impacts of a Large-Scale Mountain Pine Beetle (Dentrocdonus Ponderosea) Epidemic," Water Resources Bulliton, AWRA, Vol. 20, No.3

Hydrologic analysis pre- and post-beetle mortality in 35% of the timber in a 52-square-mile drainage in Montana suggests a 15% increase in annual water yield, a two-to three week advance in the annual hydrograph and 10% increase in low flows.

Pyne, S., Andrews, P.L. & Laven, R.D. 1996. "Introduction to Wildland Fire," John Wiley & Sons, New York-Chichester-Brisbane-Toronto-Singapore. 769 p.

This text presents the fundamentals of wildfire science. Forest fire ignition is largely determined by weather. The primary factors are fuel moisture content, wind, lightning, and human activities.

Romme, W.H. et al. "Recent Forest Insect Outbreaks and Fire Risk in Colorado Forests: A Brief Synthesis of Relevant Research," Colorado State University. Accessed February 27, 2009. http://www.cfri.colostate.edu/docs/cfri_insect.pdf

A question and answer "primer" regarding insect outbreaks in Colorado.

Recent bark beetle outbreaks in Colorado are a result of four interacting factors:

- long-term drought, which stresses trees and makes them more vulnerable to insects,
- warm summers, which further stress the trees and may accelerate growth of the insects,
- warm winters, which enhance survival of insect larvae, and
- abundant food (trees) for the insects in Colorado's extensive and often dense forests.

Bark beetles (including mountain pine beetles, spruce beetles, and pinon ips beetles) and defoliators are killing trees in Colorado. The mountain pine beetle feeds on ponderosa , lodgepole, and limber pine. Adult bark beetles bore through a tree trunk and lay eggs within the inner bark. The eggs hatch and the beetle larvae eat the inner bark, killing the tree. After the larvae mature, the new adults fly to new trees, bore through the bark, and continue the cycle.

Defoliators are a group of insects having a life cycle very different from the bark beetles. The adult defoliators are tiny moths that lay their eggs in the buds of trees. The eggs hatch into caterpillars that feed on the emerging new leaves in spring and early summer. When numerous, the caterpillars may eliminate essentially all of a tree’s annual production of leaves or needles.

These insects are usually present in a forest in very low numbers, killing only the occasional weak tree. Such low numbers are referred to as "endemic" populations. Periodically, however, insect populations grow rapidly and kill large numbers of trees over large areas. This is referred to as an "outbreak" or "epidemic" population. Outbreaks of all of the insect species described above have occurred recently, and have caused extensive mortality events in their respective tree hosts.

The article reports on the severity of the current insect outbreak in Colorado.

“The outbreaks now taking place in Colorado are similar in intensity and ecological effects to previously documented outbreaks in the Rocky Mountains. For example, mountain pine beetle outbreaks killed millions of lodgepole pine trees over thousands of square miles in the Cascade and Rocky Mountains during the 1960s, 1970s, and early 1980s (Lynch 2006; chapter 4); and a spruce beetle outbreak in the 1940s killed spruce trees over much of the White River Plateau in western Colorado. Historic photos and tree-ring evidence also document extensive insect outbreaks prior to the 20th century (Baker and Veblen 1990, Veblen et al. 1991, Veblen et al. 1994, Swetnam and Lynch 1998, Eisenhart and Veblen 2000, Veblen and Donnegan 2006). Thus, insect outbreaks are a natural occurrence in almost all of the different kinds of forests in Colorado.”

Return periods.

“Given the naturally long intervals between recurrent bark beetle outbreaks in Rocky Mountain forests, there is nothing unusual about a hundred-year period of low activity followed by an extensive outbreak.”

Potential relationship of Insect outbreaks to the risk of severe wildfires.

“Although it is widely believed that insect outbreaks set the stage for severe forest fires, the few scientific studies that support this idea report a very small effect, and other studies have found no relationship between insect outbreaks and subsequent fire activity. Theoretical considerations suggest that bark beetle outbreaks actually may reduce fire risk in some lodgepole pine forests once the dead needles fall from the trees...Based on current knowledge, the assumed link between insect outbreaks and subsequent forest fire is not well supported, and may in fact be incorrect or so small an effect as to be inconsequential for many or most of the forests in Colorado.”

Rorig, M.L. and Ferguson, S.A. "Characteristics of Lightning and WildfireIgnition in the Pacific Northwest," <u>Journal of Applied Meteorology</u>. Volume 38, November 1999.
http://www.fs.fed.us/pnw/pubs/journals/ferguson_amslightning.pdf

Fire is an important disturbance mechanism in forest ecosystems, and lightning is the primary cause of wildland fires in the western United States.

Because of the potential importance of dry fuels to fire ignition, this study distinguished days on which lightning occurred without precipitation that reached the ground from days when significant rainfall accumulated simultaneously with lightning.

Shafer, S. et al. Potential Changes in Distributions of Western North America Tree and Shrub Taxa Under Future Climate Scenarios. <u>Ecosystems</u>, 4: 200 – 215. Springer and Verlag. 2001. Accessed at
http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/Ecosystems4%20Shafer.pdf

Increases in atmospheric greenhouse gases are driving significant changes in global climate. To project potential vegetation response to future climate change, this study uses response surfaces to describe the relationship between bioclimatic variables and the distribution of tree and shrub taxa in western North America. The response surfaces illustrate the probability of the occurrence of a taxon at particular points in climate space. Climate space was defined using three bioclimatic variables: mean temperature of the coldest month, growing degree days, and a moisture index. Species distributions were simulated under present climate using observed data (1951–80, 30-year mean) and under future climate (2090–99, 10-year mean) using scenarios generated by three general circulation models— HADCM2, CGCM1, and CSIRO.

Stednick, John, undated Power Point presentation. " Effects of pine beetle infestations on water yield and water quality at the watershed scale in Northern Colorado," Posted on the Colorado Water Congress web page links. Accessed March 3, 2009.
Microsoft PowerPoint - John Stednick - Effects of Pine Beetle ...

Increased run-off from beetle kill in even aged stands [of lodgepole pine]. No increase in run-off from uneven aged stands, regeneration or release of understory.

Sugart, H., Sedjo, R., and Sohngen, R. <u>Forests and Global Climate Change, Potential Impacts on U.S. Forest Resources.</u> Pew Center on Global Climate Change. Accessed February 2003: http://www.pewclimate.org/docUploads/forestry.pdf

This report analyzes the current state of knowledge about the ecological and economic effects of climate change on U.S. forestry.

- Climate change is virtually certain to drive the migration of tree species, resulting in changes in the geographic distribution of forest types and new combinations of species within forests. Generally, tree species are expected to shift northward or to higher altitudes.

- Increased temperatures could increase fire risk in areas that experience increased aridity, and climate change could promote the proliferation of diseases and pests that attack tree species.

- Existing projections for future changes in temperature and precipitation span a broad range, making it difficult to predict the future climate that forests will experience, particularly at the regional level. The ecological models used to relate forest distribution and productivity to changes in climate introduce additional uncertainty. Thus, current projections could fail to accurately predict the actual long-term impacts of climate change on the forestry sector.

Swetnam, T.W., Baisan, C.H. "Historical Fire Regime p\Patterns in the Southwestern United States since AD 1700. In: C.D. Allen, ed., Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium. USDA," 1996. Forest Service General Technical Report RM- 286: 11-32.

This report documents fire scar chronologies from 63 sites in the Southwestern United States. Comparison of fire scar network and documentary records of areas burned in all Southwestern Regional National Forests (1928 – 1978) with Palmer Drought Severity Index clearly shows the association with severe drought and large fires, and wet periods with small fires.

The goal of this ongoing research is to document the natural range of variability of fire regimes across multiple temporal and spatial scales and use the knowledge to support ecosystem management programs.

Touchan, Ramzi, Allen, C.D., and Swetman, T.W., "History and climatic patterns in Ponderosa pine and mixed-conifer forests of the Jemez mountains, northern New Mexico: in, Fire Effects in Southwestern Forests; Proceedings of the Second La Mesa Fire Symposium, United States Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, 1996. General Technical Report RM-GTR-286, pp. 33-46. Accessed January 6, 2009. http://www.ltrr.arizona.edu/~tswetnam/tws-pdf/TouchanEtAl1996.pdf

Major fires years tended to be drier than normal.

Table 2 and Figure 2 provide summaries of fire scar data in the study area beginning in the 1500's. Low severity and frequent fires were the historical pattern up through circa 1880.

Troendle, C. A., and J. E. Nanverkis. 2000. Estimating additional water yield from changes in management of National Forests in the North Platte Basin. Report Submitted to the U.S. Bureau of Reclamation, Lakewood, Colorado. Abstract accessed August 28, 2009 at: http://www.fs.fed.us/r2/resources/water/platte_2003_sum.pdf

Simulated water yield changes from increasing vegetative density and from forest management activities. Troendle reports that increasing vegetative density accounts for decreases in run-off from 1860 – 1997 in the North Platte River Basin. The amount of the decreases in run-off is thought to be greater than slight increases due to forest management practices in the basin.

US Forest Service and Colorado State Forest Service Release Results of the Annual Forest Health Aerial Survey. The Mountain Pine Beetle, Spruce Beetle and Aspen Decline are Conditions of Concern DENVER, Jan. 16, 2009. http://csfs.colostate.edu/pages/documents/nr_COforesthealth_1-16-09_final.pdf

The spread of the mountain pine beetle in Colorado from 2007- 2008 affected 400,000 new acres, bringing the total number of acres impacted to nearly 2 million since the outbreak was first detected in 1996.

USFS Pacific Northwest Research Station. Mapped Atmosphere-Plant-Soil System Study. November 16, 2008. Accessed at: http://www.fs.fed.us/pnw/mdr/mapss/index.shtml

The Research Station is developing a vegetation distribution model that simulates the potential biosphere impacts and biosphere-atmosphere feedbacks from climatic change. MAPSS was originally a steady-state biogeography model, able to simulate a map of potential natural vegetation under a long-term average climate. Emerging technology couples the biogeographical rule base of MAPSS with two different ecosystem nutrient cycling models and a process-based fire model in order to simulate the spatially explicit dynamics of vegetation at landscape to global scales under both stable and changing climates.

US Forest Service Rocky Mountain Region. Forest Insect & Disease Aerial Survey Data Download. November 15, 2008. http://www.fs.fed.us/r2/resources/fhm/aerialsurvey/download/

Geographical Information System coverage showing progression of the pine beetle epidemic, annual time slices from 1994 to 2007. http://www.fs.fed.us/r2/news/2008/01/nr_barkbeetle_pressconf_1-14-08.pdf

USFS Wildland Fire Assessment System. USFS Missoula Fire Sciences Lab. November 15, 2008. http://www.wfas.net/component/option,com_frontpage/Itemid,1/

This research section is developing models that link fuels, weather, topography and ignition potential to depict fire danger in the United States.

The Lab publishes Firemodles.org, http://www.firemodels.org/component/option,com_frontpage/Itemid,1/

The link provides public domain fire behavior and fire danger models. Fire behavior systems produce specific elements of a fire (spread rate, perimeter, flame length, scorch height, etc.) whereas fire danger systems produce indices.

Whitaker, Younes, and Decker. "Evaluating peak flow sensitivity to clear-cutting in different elevation bands of a snowmelt-dominated mountainous catchment." Water Resources Research, Vol. 38, No.9, 1172, doi:10.1029/2001WR000514, 2002.

Hydrologic model of a mountainous snow-melt dominated catchment in British Columbia. The modeling focused on peak flow and effects of logging at different elevation bands on run-off. Generally, the simulations showed that clear-cutting in the lower elevation bands had less effect on peak flows than clear cutting at the higher elevation bands.

The simulations suggest that peak flow increases may be caused by greater snow accumulation and snow melt in clear-cut areas. Clear-cutting at 'lower" elevations appeared not to influence peak flows because of timing of snowmelt (early and not coincident with peak).

Wilcox, B.P. Transformative Landscape Change in the West: Implications for Watershed Management. At website Southwest Hydrology. Accessed March 31, 2009 at http://www.swhydro.arizona.edu/archive/V8_N2/feature1.pdf

Wilcox states that "managing watersheds for increased yield is not a viable strategy." The conclusion is based on the observations that 1) the yields are small and not sustainable, 2) water quality can be diminished, 3) little return is available in dry periods, and 4) the size of the area requiring treatment is prohibitively large.