Final Report to Wyoming Water Development Commission for the Project:
Impact of bark beetle outbreaks on forest water yield in southern Wyoming
(March 2010 – February 2013)
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Abstract
A Rocky Mountain Region outbreak of bark beetles and their associated fungi from British Columbia to New Mexico is having profound impacts on forest function and ecosystem services. These forests are key components of major river watersheds which could magnify any impacts on downstream users of water including those in Wyoming. Current and ongoing research is documenting the potential extent, causes and impacts on carbon exchange and evapotranspiration but less is known about how water yields will be impacted on short to long time scales. This project will enhance preliminary measurements of evapotranspiration and soil moisture from a mid-elevation lodgepole pine forest undergoing infestation by 1) reasonably closing stand water budgets to better quantify and thus predict water yield and 2) extending replicate measurements and analyses to post-infection management to facilitate future scaling to landscape water yield. New stands will be established in mid elevation former lodgepole pine that has been clearcut after infestation. We will provide complete water budgets that are closed on a stand basis by measuring 1) spatially explicit snow accumulation and loss, 2) detailed liquid canopy interception and stem flow, 3) appropriately scaled transpiration from living, dying and dead trees' water use (or lack thereof) through sap flow and leaf gas exchange, 4) soil hydraulic characteristics and modeling and runoff for water yield and 5) stable isotopes of soil, plant and atmospheric water as a further test of water budget component closure. Our proposed data collection and analysis will provide highly probable predictions of water yield during the first 5 to 10 years of the outbreak and provide the basis for first order predictions of the next 10 to 100 years of impact. The results of this project will be communicated with State and Federal agency personnel, providing data necessary for future water management decisions in all areas of Wyoming impacted by the bark beetle outbreak.

Objectives
1) Quantify how precipitation is partitioned into evapotranspiration, throughfall, stemflow, soil storage and water yield across forest types (including a clearcut) as trees die and the forests begin initial recovery from bark beetle-induced mortality

2) Determine errors and associated uncertainty in closing a water budget across forest types

Methodology
All major components of forest stand water budgets were measured at the lodgepole pine bark beetle sites with a select group of major components at the higher elevation spruce and fir bark beetle site. Some of the following measurements were also funded by a National Science Foundation Hydrologic Science and UW Agriculture Experiment Station grants. **Precipitation** was measured with multiple approaches to obtain incoming liquid and frozen preciptiation as well as throughfall and snowpack depth and density

prior to infiltrating or running off of soil. **Drainage** was estimated by combining soil physical properties with soil water storage measurements. Piezometers measured **streamflow** out of the forests at multiple spatial locations. **Evapotranspiration** was quantified through eddy covariance methods at the lodgepole pine, clear cut lodgpole pine and spruce and fir forests. **Tree transpiration** was measured in nearly 50 trees representing a range of bark beetle infestation and responses of trees to forest management such as thinning or clear cutting. Stable isotope measurements of water vapor fluxes were used to partition evapotranspiration into transpiration and **evaporation**. Measurements of leaf gas exchange and plant hydraulic conductance were made to test mechanisms of tree mortality in response to the bark beetle epidemic. A spatial grid of 144 plot level measurements of tree and understory characteristics was sampled to scale up plot level flux measurements to watersheds.

Principal Findings (Cited Papers are Publications Section)

We accomplished both objectives of the project; the outcomes of each objective are listed as the following specific findings. 1) Tree transpiration declines 50% within a month and is zero by the end of the first growing season in lodgepole pine while spruce takes two years (Edburg et al 2012). 2) Water fluxes to the atmosphere from the stands drop at the same rate as carbon fluxes resulting in a near constant water use efficiency until dead trees become a significant component of the stand (Reed et al In Review, Frank et al In Review). 3) Snowpack increases slightly in stands dominated by dead trees but sublimation is increased and snowmelt occurs earlier (Biederman et al 2012). 3) Liquid water interception is 25% lower in stands with high mortality. 5) Soil moisture increases with the decline in transpiration and evapotranspiration in all stands (Reed et al In Revision). 6) Energy balance closure is low (~50%) unless spatial heterogeneity and energy storage changes from mortality are included then closure is higher (~80%) (Reed et al In Revision). 7) Common sonic anemometers likely underestimate sensible and latent (i.e. evapotranspiration) heat fluxes (Frank et al 2013). 8) Increased soil moisture does not appear to increase streamflow likely due to a) earlier snow melt with declining canopy structure, b) increased evaporation and sublimation as indicated by stable isotopes of water and c) potential storage effects at the watershed scale (Somor et al In Review). Some of the key figures for these findings are included below.

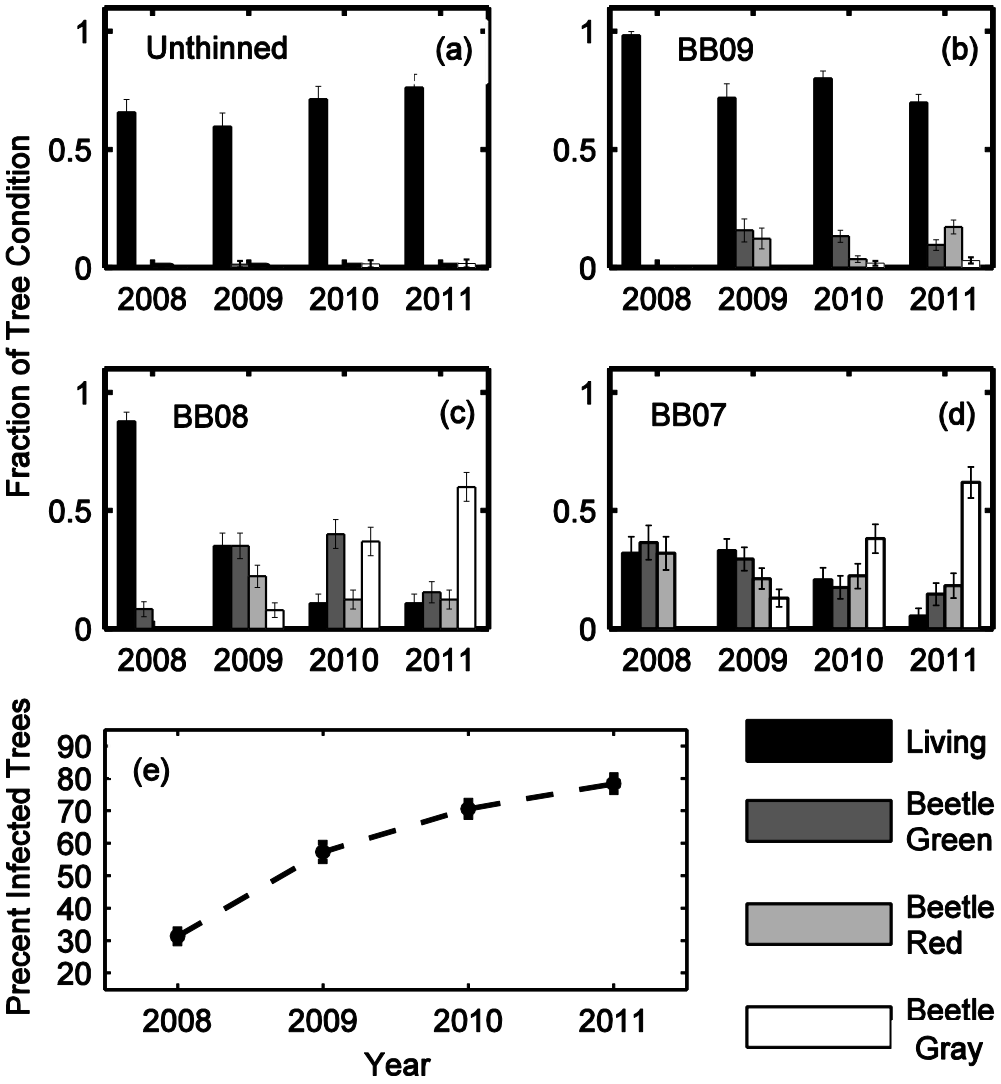
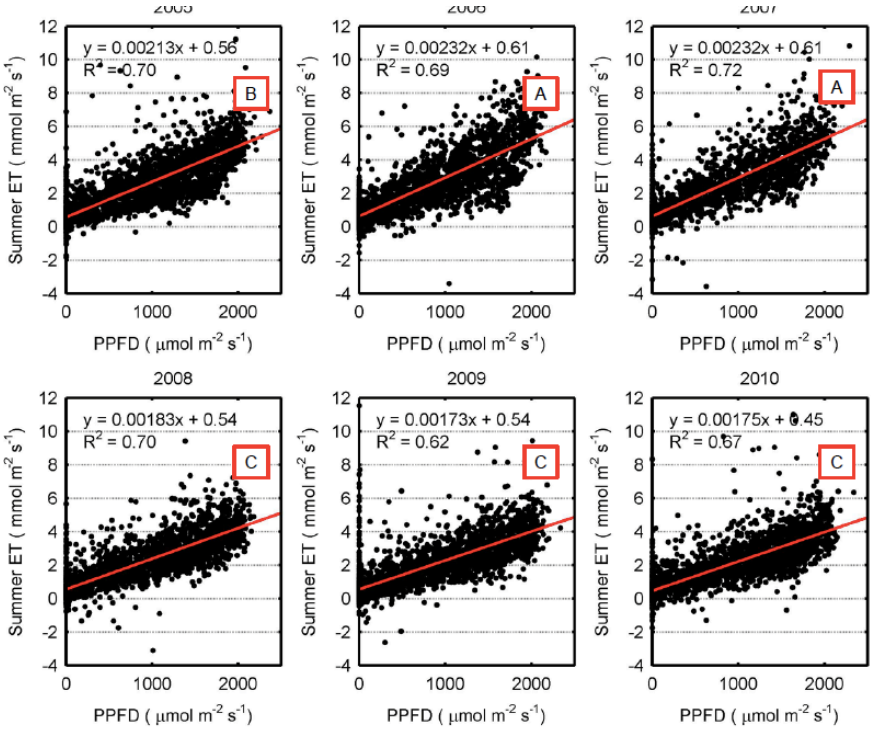


Figure 1 Mortality progresses quickly in lodgepole pine forests because the trees die in one growing season from fungal occlusion of the xylem. The process takes two years in spruce trees but the results are largely the same, dramatic decreases in tree transpiration. (Reed et al. In Revision).



Evapotranspiration (ET) response to radiation that drives photosynthesis (PPFD). Letters indicate significant differences in the response; before the beetles (2005 – 2007) have higher ET values at the same radiation.

Figure 2 Because of the drop in tree transpiration, all of the post-beetle epidemic years have evapotranspiration rates that are at least 20% lower. (Frank et al In Review).

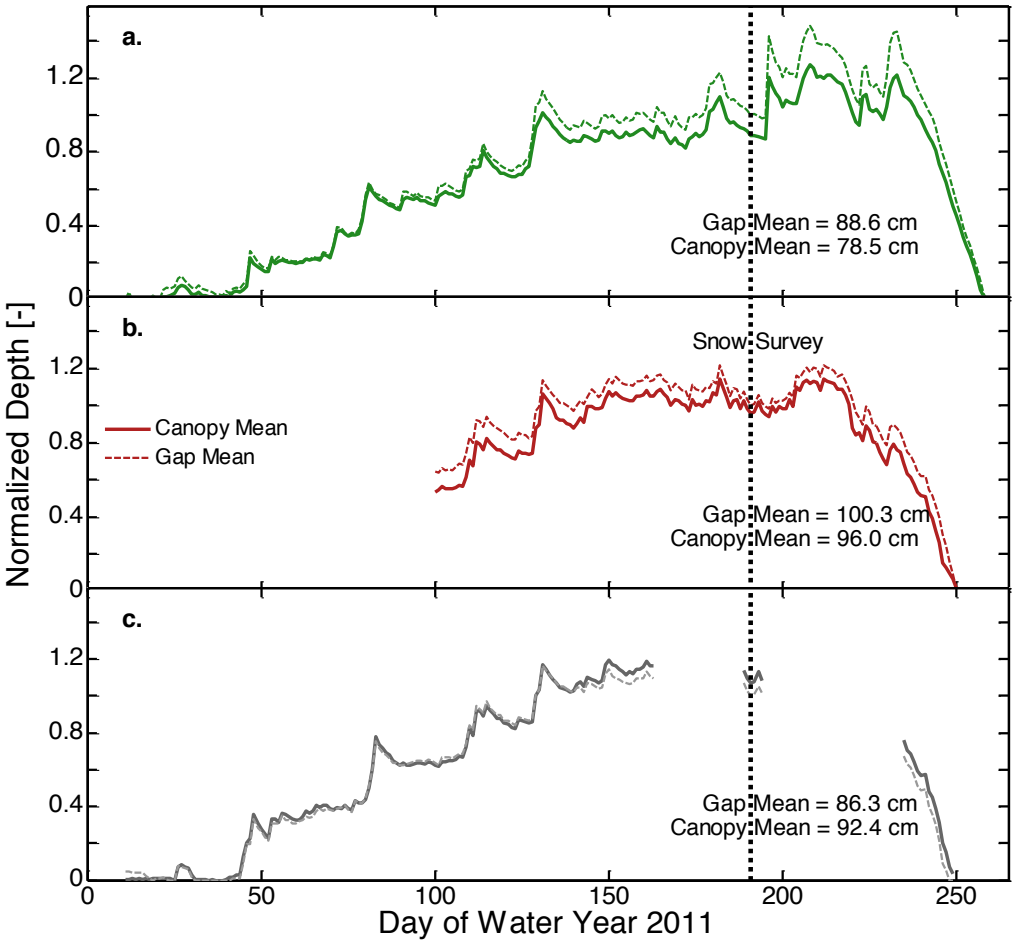


Figure 3 Snow pack depths are greater in beetle red and gray stands (used as line colors above). However, the snow pack is reduced faster due to increased sublimation and melt occuring 1-2 weeks faster due to darker albedos and more radiation and turbulence in dying and dead stands. (Biederman et al 2012).

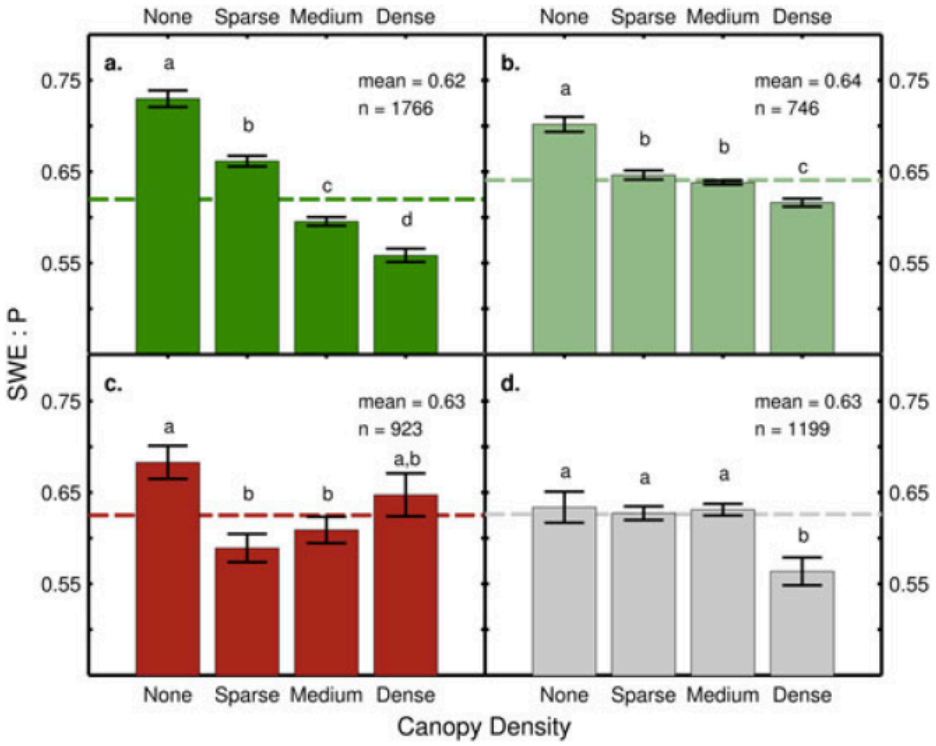


Figure 4 The ratio of soil water equivalent to precipitation (SWE:P) normalizes for precipitation differences. There was no difference in the mean value of the ratio across living (a), green but infested (b), red (c) or gray stage (d) stands. The difference between no tree and dense trees also became less as the epidemic progressed. (Biederman et al 2012).

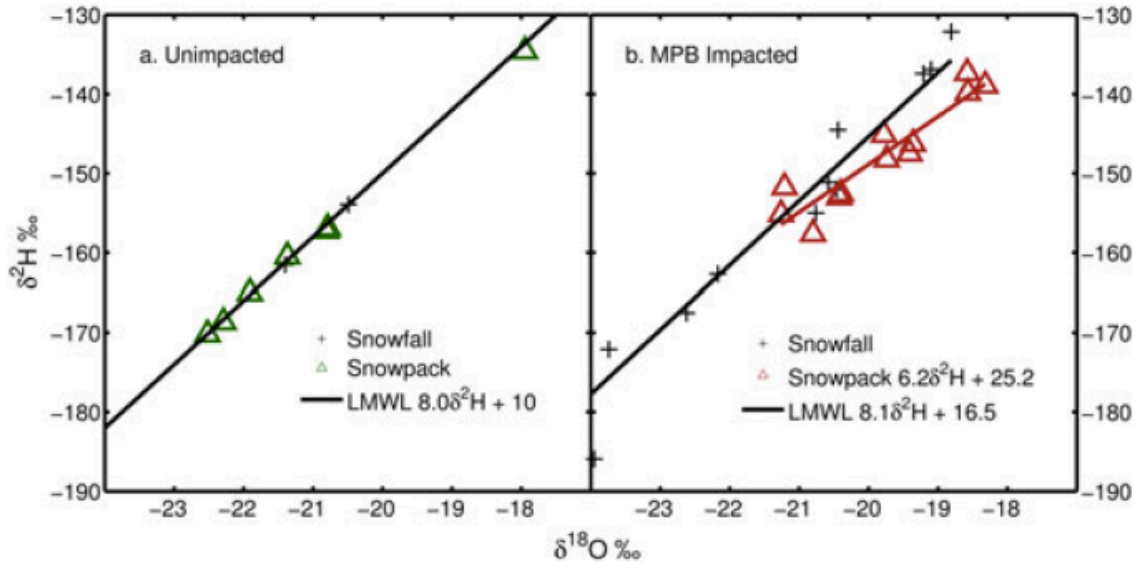
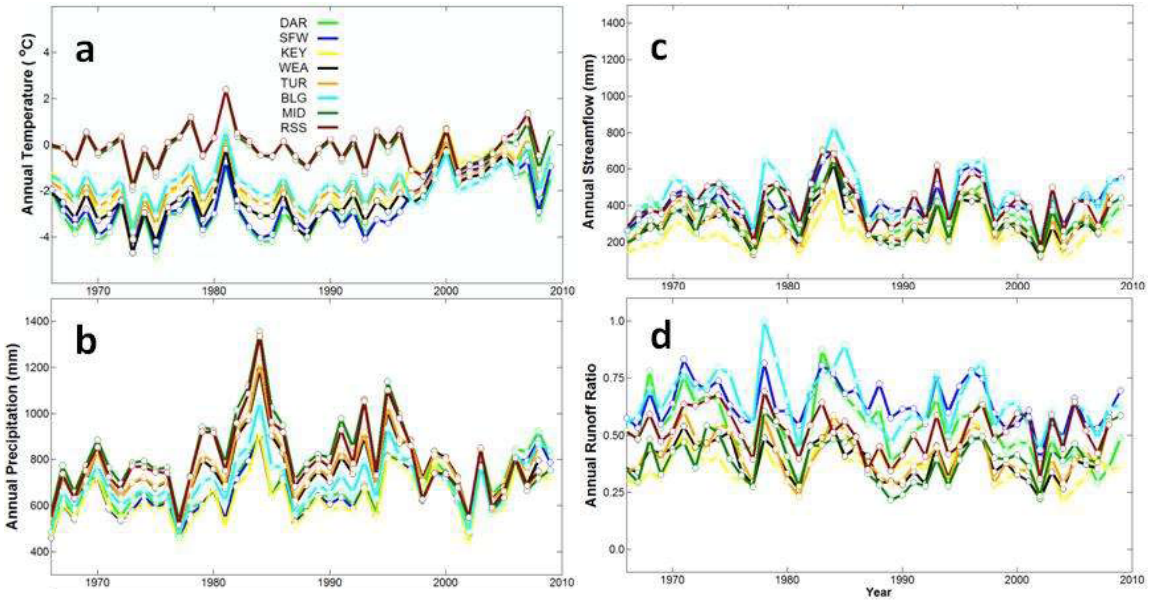


Figure 5 Unimpacted stands show little isotopic enrichment in the snowpack compared to new snowfall (a) while MPB impacted stands show enrichment suggesting increased sublimation due to increased turbulence and radiation drivers. (Biederman et al 2012).



Somor et al In Review

Eight watersheds from northern Colorado that were hit by bark beetles from 2003-2007. Neither streamflow nor runoff ratio (runoff/ precipitation) responded to the beetle outbreak. Temperatures were consistently high during the beetle outbreaks.

Figure 6 Stand level data from evapotranspiration, transpiration and soil moisture suggests that more water should leave infested stands while snow data suggests less water is available. The resulting streamflow from eight infested stands in Colorado (infestation began in 2002) does not show an increase in streamflow (Somor et al In Revision).

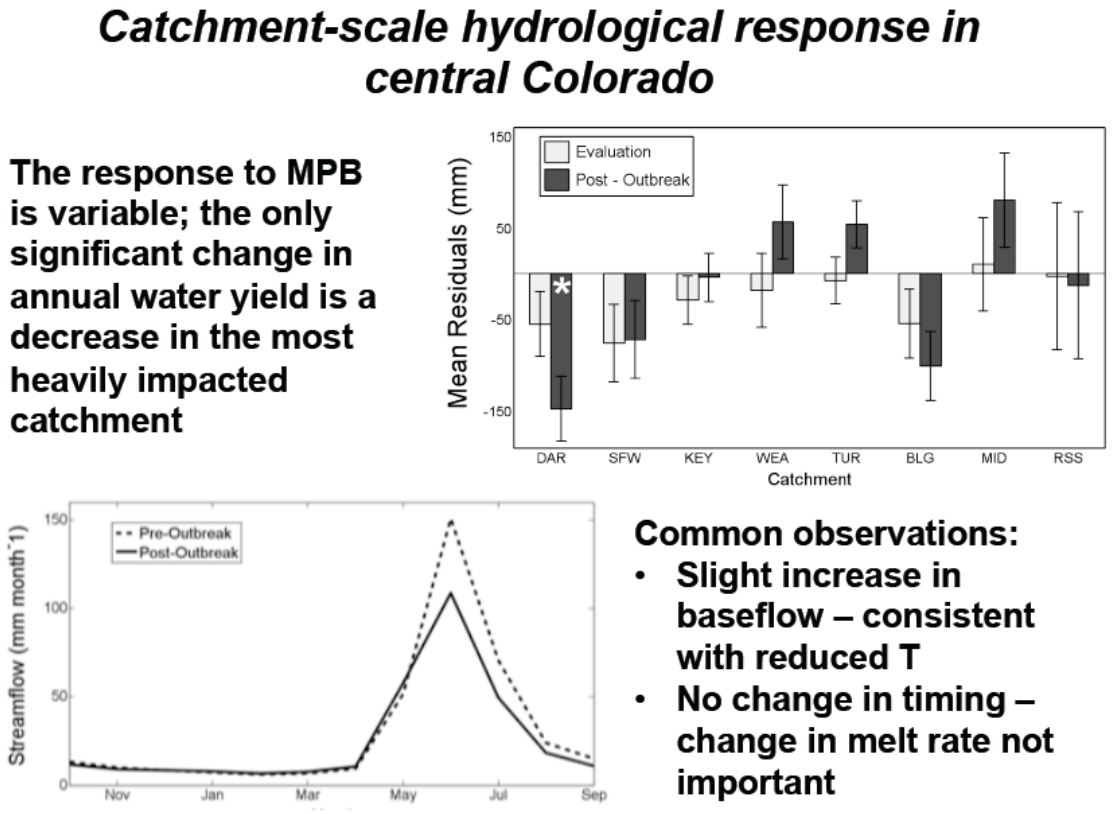


Figure 7. Analysis of data from Figure 6 showing that there was no increase in streamflow once climate variability between years was incorporated with empirical models.

Significance

This work provided measurements and analysis of stand-level water balance that are critical to developing and testing forecasting tools for determining the impact of bark beetles on streamflows from primary streams to major river systems. We found very clear and compelling direct impacts of mortality on precipitation partitioning at the stand scale as expected. However, the mechanistic impact of bark beetles on streamflow is unresolved. Empirical data shows that soil moisture increases do not lead directly to streamflow increase. Thus, the scaling of bark beetle-induced water budget changes from stands to watersheds is the most uncertain result of this project.

Our work from this project has lead to the following significant impacts. First, Wyoming State and regional water managers cannot assume that the reduction in evapotranspiration from forests with high bark beetle mortality will lead directly to increased streamflow. The PI of this project has given many talks around the state and region with this message which has led to heated, ongoing policy debates. Second, our results suggest a clear research path. Models of bark beetle impacts on streamflow must be able to replicate the stand-scale changes in water budgets; our new funding from this agency will test a model at this scale and then use the resulting parameterization to explore the watershed consequences. The same model will also be used to examine how long the stand scale

consequences of bark beetle mortality will last. This research effort will additionally require resources to investigate sublimation more thoroughly as well as alternative sources of error in watershed scaling including storage by geological substrates. The results of this project were used as a major, scientific justification for the largest NSF Award to U.W (see leveraged support below). Third, many undergraduate and graduate students as well as a post-doc were partially supported on this project. Several of these students will continue to work in the state and region resulting in ongoing benefits to the state.

Students/Post-Docs Supported

Julia Angstmann, PhD student, helped establish research sites, graduated before project began. Currently employed at Indiana University.

Tim Aston- ongoing PhD student, helped set up sap flux measurements, no direct support from project beyond logistics.

Bujidma Borkhuu-ongoing PhD student, main responsibilities are soil measurements and assistance with atmospheric measurements. Received partial support from project.

John Frank- ongoing PhD student, main responsibilities are all of the flux measurements from the spruce and fir bark beetle site (note: John Frank is a full time employee of the USFS RM Exp St in Ft. Collins, and does not receive any salary support from this project). Support from this project is used for field visits and site maintenance through a USFS subcontract.

David Reed-ongoing PhD Student, main responsibilities are the atmospheric and streamflow measurements. Received partial support from project.

Faith Whitehouse-MS Student, main responsibilities were the tree physiology measurements. Faith decided to leave graduate school and become a full time photographer; she is currently operating her own photography business in Laramie. Received partial support from project.

Claire Hudson-Undergraduate Student, main responsibilities were assisting with soil trace gas measurements and lab processing and vegetation measurements. Now a graduate student at UW working on an MS regarding Alaskan Forests and Climate Change. Received partial support from project.

Margo Hamann-Undergraduate Student, main responsibilities are assisting with tree physiology field measurements and lab processing. Received partial support from project.

Holly Barnand-Post-doc, main responsibilities were isotopic measurements for ET partitioning. Holly is now an Assistant Professor at CU-Boulder. Received partial support from project.

Publications (*Students and Post-Docs are italicized*)

Reed D, BE Ewers, E Pendall, R Kelley. In Revision. Bark Beetle Mortality Increases Energy Imbalance in Eddy Covariance Measurements Due to Canopy Heterogeneity. Agriculture and Forest Meteorology.

Frank JM, Ewers BE, Massman MJ, Hackaby, LS, Negron, JF. In Review. Bark beetles cause predictable declines in ecosystem carbon and water fluxes. Ecology.

Reed D, BE Ewers, E Pendall. In Review. Impact of mountain pine beetle induced mortality on forest carbon and water fluxes. Environmental Research Letters.

Biederman, JA, PD Brooks, AA Harpold, DJ Gochis, E Gutmann, ***DE Reed***, E Pendall, BE Ewers. 2013. Multi-scale observations of snow accumulation and peak snowpack following widespread, insect-induced lodgepole pine mortality. Ecohydrology. DOI *10.1002/eco.1342*.

Frank, JM, WJ Massman, BE Ewers. 2013. Underestimates of sensible heat flux due to vertical velocity measurements in non-orthogonal sonic anemometers. Agricultural and Forest Meteorology. 171-172:72-81.

Edburg, SL, JA Hicke, PD Brooks, EG Pendall, BE Ewers, U Norton, D Gochis, and E Gutmann. 2012. Cascading Impacts of Bark Beetle-Caused Tree Mortality to Coupled Biogeophysical and Biogeochemical Processes. Frontiers in Ecology and Environment. 10:416-424.

-----Following manuscript was cited in Principle Findings none of the authors were funded by this project.
Somor et al. In Review. Mountain pine beetle mortality does not lead to increased streamflow. Water Resources Research.

Presentations (*Students and Post-Docs are bolded*)

(Invited) Ewers BE. Hydraulic Limitations Help Explain the Behavior of Plants: from clocks to mortality to ghosts. Department of Biology, U. of New Mexico, February, 2013

(Invited) Ewers BE. Hydraulic Limitations Help Explain the Behavior of Plants: from clocks to mortality to ghosts. Department of Biology, Los Alamos National Labs, February, 2013

(Invited) Ewers BE. Impact of Fire and Insect Disturbance on Water Cycling in Ecosystems. Land Managers of the Laramie District of the Medicine Bow National Forest. February 2013

(Invited) Ewers BE. Surprising effects of bark beetle-induced mortality on snowpacks and water yield. Wyoming Weather Modification Technical Advisory Team Meeting, Cheyenne, WY January, 2013.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Wyoming Association of Conservation Districts. Casper, WY, December, 2012.

P.D. Brooks; A.A. Harpold; J.A. Biederman; M.E. Litvak; P.D.Broxton; D. Gochis; N.P. Molotch; P.A. Troch; B.E. Ewers. Insects, firests, and climate change: implications for snow cover, water resources and ecosystem recovery in Western North America. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

Ewers, BE, DS Mackay, C Guadagno, **SD Peckham**, E Pendall, B Borkhuu, **T Aston**, **JM Frank**, WJ Massman, **DE Reed**, Y Yarkhunova, C Weinig. Nonstructural carbon dynamics are best predicted by the combination of photosynthesis and plant hydraulics during both bark beetle induced mortality and herbaceous plant response to drought. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

King A, BE Ewers, R Sivanpillai, E Pendall. Testing remote sensing estimates of bark beetle induced mortality in lodgepole pine and Engelmann spruce with ground data. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

Peckham, SD, BE Ewers, DS Mackay**, JM Frank**, WJ Massman, MG Ryan, H Scott, E Pendall. Modeling net ecosystem exchange of carbon dioxide in a beetle-attacked subalpine forest using a data-constrained ecosystem model. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

Mackay, DS, BE Ewers, **DE Reed**, E Pendall, NG McDowell. Plant hydraulic controls over ecosystem responses to climate-enhanced disturbances. American Geophysical Union Meeting, San Francisco, CA, Dec. 2012.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Wyoming Water Development Commission. Cheyenne, WY, November, 2012.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Joint meeting of the Wyoming Water Development Commission and the Select Water Subcommittee of the Wyoming Legislature. Casper, WY, November, 2012.

(Invited) Ewers BE. Impact of bark beetle outbreaks on forest water yield. Wyoming Water Association Annual Meeting. Lander, WY, October, 2012.

Reed, DE, BE Ewers, E Pendall, RD Kelly, U Norton, **FN Whitehouse**. Mountain pine beetle epidemic changes ecosystem flux controls of lodgepole pine. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Brooks, PD, HR Barnard, J Biederman, B Borkhuu, SL Edburd, BE Ewers, D Gochis, E Gutmann, AA Harpold, JA Hicke, DJP Moore, E Pendall, **D Reed**, A Somor, PA Troch. Multi-scale observation of hydrologic partitioning following insect-induced tree mortality: Implications for ecosystem water and biogeochemical cycles. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Frank, JM, WJ Massman, BE Ewers. Linking bark beetle caused hydraulic failure to declining ecosystem fluxes in a high elevation Rock Mountain (Wyoming, USA) forest. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Ewers BE, DS Mackay, E Pendall, J**M Frank, DE Reed,** WJ Massman, **TL Aston**, **JL Angstmann, K Nathani, B** Mitra. Use of plant hydraulic theory to predict plant controls over mass and energy fluxes in response to changes in soils, elevation and mortality. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Barnard, HR, A Byers, A Harpold, BE Ewers, D Gochis, P Brooks. Examining the response of lodgepole transpiration to snow melt and summer rainfall in subalpine Colorado, USA. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Brown, NR, U Norton, E Pendall, BE Ewers, **B Borkhuu**. High levels of soil and litter nitrogen contents after bark beetle-induced lodgepole pine mortality. Ecological Society of America Annual Meeting, Portland, OR, August 2012.

Ewers BE et al. Use of plant hydraulic theory to predict plant controls over mass and energy fluxes in response to changes in species, soils and mortality. American Society of Plant Biology Annual Meeting, Austin, TX, July, 2012.

(Invited) Ewers BE. Simulation modeling of bark beetle effects on stand water budgets. Wyoming Weather Modification Technical Advisory Team Meeting. Saratoga, WY July 2012.

(Invited) Ewers BE. Temporal and Spatial Scaling of Evapotranspiration Using Plant Hydraulic Theory. Penn State. Critical Zone Observatory Distinguished Speaker Series. Mar. 23, 2012

Ewers BE. Impact of Bark Beetle Outbreaks on Precipitation Processing by Forests. Wyoming Weather Modification Technical Advisory Team, Meeting, Cheyenne, WY Jan. 18, 2012.

Frank, J, B Massman, B Ewers. Errors in measured sensible heat flux due to vertical velocity measurements in non-orthogonal sonic anemometers. Front Range Student Ecology Symposium, CSU, Ft. Collins, CO Feb. 22, 2012.

Frank, J, B Massman, BE Ewers. Net ecosystem exchange of carbon dioxide and evapotranspiration response of a high elevation Rocky Mountain (Wyoming, USA) forest to a bark beetle epidemic. UW Program in Ecology Symposium, Feb. 17, 2012.

DE Reed, BE Ewers, E Pendall, RD Kelly. Mountain Pine Beetle epidemic effects on the carbon, water, and energy fluxes of lodgepole pine ecosystems. UW Program in Ecology Symposium, Feb. 17, 2012.

Mackay, DS, BE Ewers, DE Roberts, NG McDowell, E Pendall, **JM Frank, DE Reed**, WJ Massman, B Mitra. A coupled carbon and plant hydraulic model to predict ecosystem carbon and water flux responses to disturbance and environmental change. American Geophysical Union Meeting, San Francisco, CA, Dec. 2011.

Brooks, PD, HR Barnards, JA Biederman, **B Borkhuu**, SL Edburg, BE Ewers, DJ Gochis, ED Gutmann, AA Harpold, JA Hicke, E Pendall, **DE Reed**, AJ Somor, PA Troch. Water, Carbon, and Nutrient Cycling Following Insect-Induced Tree Mortality: How well do plot-scale observations predict ecosystem-scale repsonse. American Geophysical Union Meeting, San Francisco, CA, Dec. 2011.

(Invited) Ewers, BE, E Pendall, D Reed, H Barnard, F Whitehouse, J Frank, W Massman, P Brooks, J Biederman, K Nathan, B Mitra, DS Mackay. Use of plant hydraulic theory to predict ecosystem fluxes across mountainous gradients in environmental controls and insect disturbance. American Geophysical Union Meeting, San Francisco, CA, Dec. 2011.

Frank, JM, WJ Massman, BE Ewers. Net ecosystem exchange of carbon dioxide and evapotranspiration response of a high elevation Rocky Mountain (Wyoming, USA) forest to a bark beetle epidemic. American Geophysical Union Meeting, San Francisco, CA, Dec. 2011.

Norton, U, E Pendall, BE Ewers, **B Borkhuu**. Trace gas emissions from a chronosequence of bark beetle-infested lodgepole pine (Pinus contorta) forest stands. American Geophysical Union Meeting, San Francisco, CA, Dec. 2011.

DE Reed, BE Ewers, E Pendall, RD Kelly. Mountain Pine Beetle epidemic effects on the carbon, water, and energy fluxes of lodgepole pine ecosystems. American Geophysical Union Meeting, San Francisco, CA, Dec. 2011.

Gochis, DJ, ED Gutmann, PD Brooks, DE Reed, BE Ewers, E Pendall, JA Biedermann, AA Harpold, HR Barnard, J Hu. Diagnosing the influence of model structure on the simulation of water, energy and carbon fluxes on bark beetle infested forests. American Geophysical Union Meeting, San Francisco, CA, Dec. 2011.

(Invited) Ewers, BE. Plant Hydraulic Theory and Mountains. Mountain Research Institute, Berkeley, CA, Dec. 2011.

(Invited) Ewers, BE, E Pendall, H Barnard, D Williams, U Norton, **D Reed**, P Brooks, D Gochis, A Harpold, **J Frank**, W Massman, F Whitehouse, **B Borkhuu, J Angstmann.** Impact of Bark Beetle Outbreaks on Forest Ecosystem Processes. Wyoming Environment and Natural Resources Speaker Series, Jackson, WY, Dec. 2011.

(Invited) Ewers, BE, E Pendall, H Barnard, D Williams, U Norton**, D Reed**, P Brooks, D Gochis, A Harpold**, J Frank**, W Massman, **F Whitehouse, B Borkhuu, J Angstmann .** Impact of Bark Beetle Outbreaks on Forest Water Yield. Wyoming Water Development Commission. Cheyenne, WY, Nov. 2011.

(Invited) Ewers, BE, E Pendall, H Barnard, D Williams, U Norton, **D Reed,** P Brooks, D Gochis, A Harpold, **J Frank**, W Massman, **F Whitehouse, B Borkhuu, J Angstmann** . Impact of Bark Beetle Outbreaks on Forest Water Yield. Joint Agriculture Committee of the Wyoming Legislature. Afton, WY, Oct. 2011.

Ewers, BE, E Pendall, U Norton, **D Reed, J Frank, B Borkhuu**, **F Whitehouse, N Brown,** H Barnard, P Brooks, **T Aston, J Angstmann,** W Massman, D Williams, A Harpold, J Biederman, S Edburg, A Meddens, D Gochis, J Hicke. Cascading effects of bark beetles and blue stain fungi on coupled water, C and N cycles. UW Dept. Botany. Sept. 2011.

(Invited) Ewers, BE, E Pendall, H Barnard, D Williams, U Norton, **D King, D Reed**, P Brooks, D Gochis, A Harpold, **J Frank**, W Massman, **F Whitehouse, B Borkhuu**, J Angstmann. The challenge of predicting the interacting effects of weather modification and bark beetles on forest water yield. Wyoming Weather Modification Technical Advertisory Team Meeting. Lander, WY, July 2011.

Borkhuu, B, E Pendall, U Norton, BE Ewers. Effects of mountain pine bark beetle infestation on soil CO2 efflux in lodgepole forests in Southeastern Wyoming. Soil Science Society Western Meeting, Laramie, WY. June 2011.

(Invited) Ewers, BE. Testimony on bark beetle impacts on forest hydrology. Joint meeting of the Select Water Committee of the Wyoming Legislature and the Wyoming Water Development Commission. Cheyenne, WY, June 2011.

Ewers, BE, E Pendall, H Barndard, **F Whitehouse**, **D Reed, J Frank**, P Fornwalt, T Aston, J Angstmann, U Norton, A Harpold, P Brooks. Sap flux measurements quantify the timing of transpiration loss due to fungal xylem occlusion following bark beetle attack and subsequent ecosystem consequences. VIII International Sap Flow Meeting, Volterra, IT, May, 2011.

(Invited) Ewers, BE, E Pendall, H Barnard, D Williams, U Norton, **D Reed,** P Brooks, D Gochis, A Harpold, **J Frank**, W Massman, F Whitehouse, **B Borkhuu,** J Angstmann. Impact of Bark Beetle Outbreaks on Forest Water Yield. Wyoming Water and Environmental Law Conference, Cheyenne, WY, Apr. 2011.

Frank, J, WJ Massman, BE Ewers. Evapotranspiration response of a high elevation Rocky Mountain (Wyoming, USA) forest to a bark beetle epidemic. Bark Beetle-Water Symposium, Boulder, CO 2011.

Harpold, AA, PD Brooks, JA Biederman, A Somor, P Troch, D Gochis, E Gutmann, H Barnard, **D Reed,** E Pendall, BE Ewers. Quantifying the effects of tree dieoff from mountain pine beetles on hydrologic partitioning at the catchment-scale. Bark Beetle-Water Symposium, Boulder, CO 2011.

Gochis, D, E Gutmann, AA Harpold, PD Brooks, JA Biederman, H Barnard, **D Reed**, E Pendall, BE Ewers. Multi-model assessment and verification of bark beetle impacts on land surface-atmosphere energy and water exchanges. Bark Beetle-Water Symposium, Boulder, CO 2011.

Frank J, W Massman, BE Ewers. Response of high elevation rock mountain forest evapotranspiration to a bark beetle epidemic. CSU Hydrology Days, Ft. Collins CO. Feb. 2011.

Reed D, Kelly R, Ewers B, Pendall E. Energy Closure of a Heterogeneous Forest Canopy. Ameriflux Annual Meeting, Feb. 2011

Frank J, W Massman, BE Ewers. Response of high elevation rocky mountain (Wyoming, USA) forest carbon dioxide and water vapor fluxes to a bark beetle epidemic. Ameriflux Annual Meeting, Feb. 2011.

BE Ewers, E Pendall, U Norton, **D Reed, J Franks, T Aston, F Whitehouse**, HR Barnard, PD Brooks, J Angstmann, WJ Massman, DG Williams, AA Harpold, J Biederman, SL Edburg, AJ Meddens, DJ Gochis, JA Hicke. The Rocky Mountain epidemic of bark beetles and blue stain fungi cause cascading effects of coupled water, C and N cycles. AGU, San Francisco, CA, Dec, 2010.

DE Reed, RD Kelly, BE Ewers, E Pendall. The mountain pine beetle epidemic contributes to increased spatial and temporal variablity and decoupling of carbon and water fluxes from lodgepole pine. AGU, San Francisco, CA, Dec, 2010.

DJ Gochis, PD Brooks, AA Harpold, BE Ewers, E Pendall, HR Barnard, **D Reed**, PC Harley, J Hu, J Biederman. Measuring and modeling changes in land-atmosphere exchanges and hydrologic response in forests undergoing insect-driven mortality. AGU, San Francisco, CA, Dec, 2010.

PD Brooks, AA Harpold, AJ Somor, PA Troch, DJ Gochis, BE Ewers, E Pendall, JA Biederman, **D Reed, HR Barnard, F Whitehouse, T Aston, B Borkhuu**. Quantifying the effects of mountain pine beetle infestation on water and biogeochemical cycles at multiple spatial and temporal scales. AGU, San Francisco, CA, Dec, 2010.

BE Ewers (invited) E Pendall, **D Reed, F Whitehouse, J Frank, T Aston, J Angstmann,** D Williams, H Barnard, WJ Massman, U Norton. Impacts of a bark beetle epidemic on forest hydrology. Wyoming Water Forum, Cheyenne, WY, Nov. 2010.

BE Ewers E Pendall, U Norton, **B Borkhu, T Aston, D Reed, J Frank, J Anstmann**, WJ Massman, PD Brooks, DJ Gochis, HR Barnard, D Williams. First and higher order impacts of bark beetles on ecosystem processes of Rocky Mountain Forests. Ecological Society of America Meeting, Pittsburgh, PA, Aug. 2010.