Final Report

Historical and Future Impacts of Vegetation Management and Natural Disturbance on Water Yield from Forest Service Lands in the South Platte River Basin

Submitted to

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Executive Summary

Historical and Future Impacts of Vegetation Management and Natural Disturbance on Water Yield from Forest Service Lands in the South Platte River Basin

C. A. Troendle, J. M. Nankervis, and A. Peavy

This report addresses the prediction, or modeling, of the historical range in variability of water yield and the consequence of present and future National Forest System (NFS) management activities and natural disturbance from fire and insects on water yield from the South Platte River Basin. The vegetation data, activity (management) data, and disturbance data needed for the simulations were provided by staff on the three national forests in the South Platte River Basin. Data acquisition was coordinated by the Forest Service Rocky Mountain Regional Office (R2).

Initially, the reference (1997) water yield was simulated using current or existing forest condition, other scenarios then were superimposed on current stand conditions and response in water yield was simulated to reflect the following:

a) *Historical stand conditions and attendant water yield simulations for 1860 to present*

b) Current forest stand conditions were projected into the future for three 20-year time cycles to evaluate the effect of a no human intervention and no natural disturbance scenario on future water yield

c) Current stands were projected into the future under a no human intervention scenario but allowing stand conditions to be altered to reflect the impact of natural disturbance on current vegetation.

d) The impact of management activities imposed on NFS land in the South Platte River Basin from 1997 to 2005.

The updated version of the WRENSS Hydrologic Model was used for the simulations.

For this assessment, each Forest provided similar polygon information for lands within the watershed boundary. The result was the development of a GIS database containing stand-level information characterizing specie composition, age class, aspect, elevation, monthly precipitation, and some post-1997 disturbance, or activity, data. Less than 1 percent of the NFS land in the South Platte River Basin is on the MBR National Forest while 53 percent is on the PSI National Forest and 47 percent is on the AR National Forest.

Simulated water yield from NFS land in the South Platte River Basin was greatest ca 1920 and has declined in proportion to the subsequent vegetation density increases that have occurred since then. The net reduction in water yield occurring from 1920 to 1997 is equivalent to about 1.8 area inches or 261,000 acre-feet from the 1.7 million acres of NFS land in the scenario that holds spruce-fir constant. The simulated decline in water yield was slightly greater at 2.1 area inches (about 300,000 acre-feet) with spruce-fir stands altered similarly to the other species. As was found for the North Platte River Basin, simulations also indicated that water yield from the South Platte River Basin will continue to decline assuming the natural succession of the current forest vegetation is not interrupted. As current stands continue to mature, water yield from NFS land can be expected to decline another 0.5 area inches, or an additional 72,000 acre-feet by the year 2060 if the current trend in vegetation density is not interrupted by management activity or catastrophic events such as fire or mortality resulting from insect infestation.

For the most part, the impacts of historic wildfires are reflected in the characterization of the current forest conditions provided by the three Forests. In 2002, however, the largest wildfire in recorded Colorado history occurred. Known as the Hayman Fire, about 110,000 acres within the fire boundary were consumed by fire. The simulated water yield from the burned area for the year 2020 is about 4.5 area inches and represents a 3.4-area inch or 30,600-acre-foot increase over the 1997 reference water yield from the same area. Simulations indicate that the water yield from the burned area will decline from 4.5 area inches in 2020 to 3.0 area inches in 2060, but still represent a 1.9-area inch (17,000 acre-foot) increase relative to the 1997 reference water yield.

Currently a major infestation of insects, bark beetles and defoliators, is affecting forest stands throughout Colorado, in nearby states, and in southwestern Canada. Although a variety of tree species are affected by the mountain pine beetle (ponderosa pine, lodgepole pine, and limber pine) or by the spruce beetle (Engelmann spruce), the lodgepole pine type seems to be impacted the most severely and extensively during this current epidemic. Of the 456,306 acres of lodgepole pine on NFS land in the South Platte River Basin, almost 95 percent are classified as pole or sawtimber stands and are subject to mountain pine beetle attack. Based on input from R2 staff, we simulated three scenarios in lodgepole pine. First, we simulated the hydrologic impact of a 50-percent kill in all lodgepole pine sawtimber and pole size stands. Second, we simulated the impact of a 90-percent kill throughout both the sawtimber and the pole stands. Third, based on the consensus of the R2 staff that a 50-percent kill in the pole size stands (4.9 to 9.0 inch DBH) and a 90-percent kill in the sawtimber stands was the most likely expectation of what may actually occur during the next few years, we simulated that impact. If 90 percent of the trees in the sawtimber stands are killed along with 50 percent of the trees in the pole size stands; the increased annual water yield from the impacted area in the lodgepole pine type will average nearly 3.6 area inches or 129,000 acre-feet.

Obviously, the simulated impacts of the beetle infestation are speculative and based on an assumed degree of mortality. For example, if the estimated beetle kill were reduced to 50-percent mortality on the 146,431 acres of sawtimber stands alone and impacts in the pole size stands were excluded; the increase in annual water yield would still be about 35,000 acre-feet. Increasing the estimate of mortality to 90 percent in the sawtimber stands alone

would result in a simulated increase in water yield in the South Platte River Basin of 65,000 acre-feet per year. Taking the simulation to extremes, 90-percent mortality in all the pole and sawtimber stands of lodgepole pine stands on NFS land in the South Platte River Basin would result in an increase in water yield of about 191,000 acre-feet per year.

In contrast to the extensive area affected by fire and insect mortality, forest management activities on the three Forests appear relatively minor since 1997. The activities implemented consist mostly of partial stand removal practices primarily intended to reduce fuels, foster tree release, or to improve stand condition. About 38,000 acres of the 1.7 millions acres of NFS land has been treated in recent years. Of that, almost 24,000 acres were treated using a natural fuels broadcast or understory burn with the objective of impacting 20 to 40 percent of the residual basal area of the stand. Data indicate that 78 percent of the activity occurred on the PSI National Forest with the balance occurring on the AR National Forest. The potential increase in water yield resulting from the net effect of recent and current management activities will increase water yield by about 5,000 acre-feet per year. If the current level of activity is projected into the future, the net increase would average 10,000 to 20,000 acre-feet per year over time.

Two significant conclusions were drawn from the assessment of the historical trends in water yield from NFS land in the South Platte River Basin. First, as was the case in the North Platte study, simulations suggest that a significant decline in water yield occurred from NFS land as a result of increases in forest density. In both basins, the data also indicated that the process is cyclical. As stands mature naturally, water yield declines; as stand regenerate, water yield increases. Without human intervention, this natural process is largely propagated by fire and insects. The second conclusion is that although water yield is expected to increase after catastrophic fires, such as the Hayman Fire, the potential effect of the current insect infestation, particularly in the lodgepole pine type, is a far more extensive and may be a more significant factor in effecting water yield in the future. Mortality from the current mountain pine beetle infestation may recapture much of the decline in water yield caused by growth or re-growth of forest stands over the past 80 or 90 years. Hydrologic impacts that may result from insect infestations are also occurring to some extent in other forest types and on other public and private land that is not considered in this study so the impact of the infestations on water yield from the entire Platte River basin might be quite significant.

Final Report

Historical and Future Impacts of Vegetation Management and Natural Disturbance on Water Yield from Forest Service Lands in the South Platte River Basin

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Introduction

Troendle and Nankervis (2000) reviewed the current knowledge on the regional effects of forest disturbance or vegetation change on water yield as part of an analysis evaluating changes in water yield that may have resulted from management of National Forest System (NFS) lands in the North Platte River Basin.

Numerous studies worldwide have found that changes in forest density cause changes in water yield. Hibbert (1967), Troendle and Leaf (1980), Bosch and Hewlett (1982), and Stednick (1996) summarized findings from these studies. As Hibbert (1967) observed, reducing forest cover increases water yield, establishing (or increasing) forest cover on sparsely vegetated land decreases water yield, and response to treatment is highly variable and unpredictable. The first two of these conclusions –changes in forest density decreases water yield and reducing forest cover generally increases water yield--are well documented and universally accepted.

However, the hydrologic response to changes in forest cover, although variable, is more predictable than Hibbert (1967) initially concluded (Troendle and Leaf 1980; Bosch and Hewlett 1982; and Stednick 1996). This change in thinking about predictability is a result of increased number of observations over time as well as an improved understanding of factors influencing streamflow response. Streamflow response to a change in forest cover is strongly related to climate, species composition, and the percentage change in vegetation density (Figure 1, Bosch and Hewlett 1982). Data from 95 watershed experiments conducted throughout the United States shows that, on average, streamflow increases by nearly 0.1 inch for each 1 percent of watershed area harvested (Stednick 1996). Because annual streamflow varies greatly, the general conclusion was that about 20 percent of the basal area of the vegetation, above the point of streamflow measurement, must be removed before a statistically significant change in flow can be detected (Hibbert 1967; Bosch and Hewlett 1982; and Stednick 1996). However, as Bosch and Hewlett (1982) suggest, reducing forest cover by less than 20 percent may well produce statistically non-significant responses that presumably approach zero increase at zero change in forest cover.

A significant body of hydrologic research is specifically appropriate for assessing the effects of vegetation changes on water yield. Yet, the universal relationships depicted in

Figure 1 adequately reflect the nature and range of expected hydrologic changes in the South Platte River Basin resulting from changes in forest density, regardless of whether the changes reflect (1) an increase in forest density due to in-growth or (2) a reduction in density resulting from timber harvest, fire, or mortality due to insect attack.

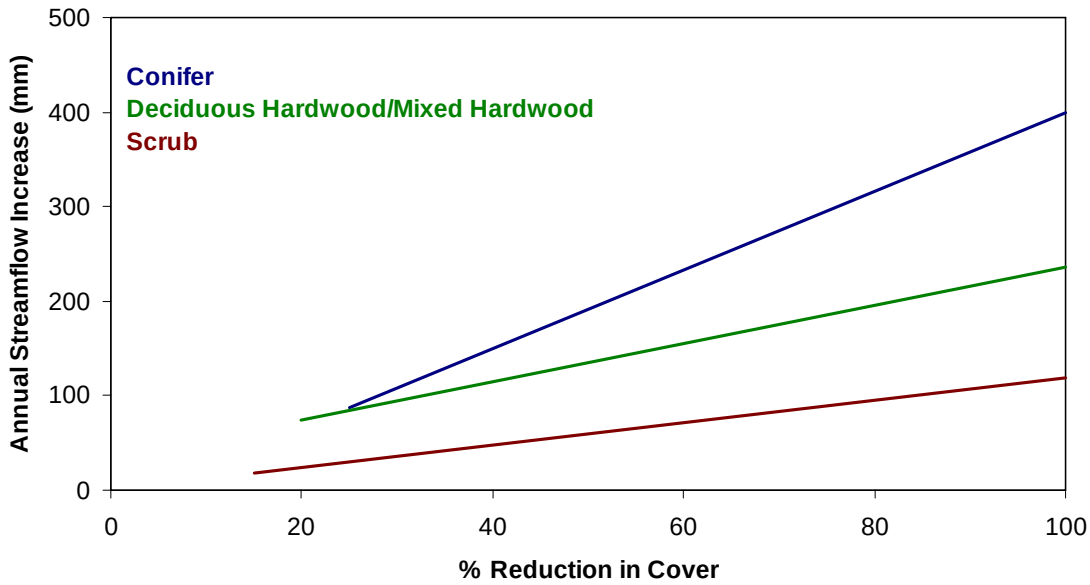

Figure 1. The relationship between reduction in vegetation cover and increased streamflow for three vegetation types (redrawn from Bosch and Hewlett 1982).

Objectives

The purpose of the project being reported was to conduct an analysis in the South Platte River Basin that parallels the May 2003 report on the North Platte River Basin entitled: "Impact of Forest Service Activities on the Stream Flow Regime in the Platte River" (Troendle, Nankervis, and Porth 2003). Like its predecessor, this report addresses the prediction, or modeling, of the historical range in variability of water yield and the consequence of present and future Forest Service management activities and natural disturbance from fire and insects on water yield from the South Platte River Basin.

Vegetation data, activity (management) data, and disturbance data were provided by staff on the three national forests in the South Platte River Basin. Data acquisition was coordinated by the Forest Service Rocky Mountain Regional Office (R2). The data are assumed to represent the best characterization of current vegetative conditions on NFS land in the South Platte River Basin.

Initially, the reference (1997) water yield was simulated using current or existing forest condition. After reference, or baseline, conditions were defined and the hydrologic response was simulated, other scenarios were superimposed on current stand conditions and responses in water yield were simulated to reflect the following:

a) *Historical stand conditions and attendant water yield simulations for 1860 to present:* Stand projections for this and the other tasks followed the simplistic

approach of moving stands into and out of various age classes over time as was done by Troendle and Nankervis (2000) and Troendle et al. (2003) in the assessment of the North Platte River Basin.

b) *Current forest stand conditions were projected into the future for three 20-year time cycles to evaluate the effect of a no human intervention or no natural disturbance scenario on future water yield*: In concept, this scenario simulates the progression of all forest land to a state of complete hydrologic utilization with mature stands remaining mature and young stands moving toward maturity.

c) *Current stands were projected into the future under a no human intervention scenario but allowing stand conditions to be altered to reflect the impact of natural disturbance on current vegetation*: Examples of natural disturbance include the 2002 Hayman Fire and the current mountain pine bark beetle infestation in lodgepole pine.

d) *The impact of management activities imposed on NFS land in the South Platte River Basin from 1997 to 2005.*

The updated version of the WRENSS Hydrologic Model (Troendle and Leaf 1980; Troendle et al. 2003; Swanson 2004) was used for the simulations. Changes made to the original WRENSS Hydrologic Model were reported in an earlier report on the North Platte River Basin (Troendle et al. 2003). As noted in *a* through *d* above, the primary objective of this assessment was to document *changes* in water yield that may have occurred because of various changes in vegetation density or forest cover over time in the South Platte River Basin. The WRENSS Hydrologic Model (Troendle and Leaf 1980) was developed to focus on predicting *change* in water yield, or water available for streamflow, annually. Less emphasis is placed on the accurate simulation of total water yield as this is more complex, requires calibration, and errors in the simulation process can make change detection more difficult (U.S. Environmental Protection Agency 1980). For that reason, although this and the earlier reports do simulate total water yield from forest lands, emphasize is on the potential changes in water yield that may have, or might, occur as the result of past or proposed activities that alter vegetation composition or density. Grassland areas, water bodies, and other non-forested surfaces are not included in the simulations simply because they do not contribute to the estimate of change. Emphasis is placed on simulating potential changes in water yield that may result from changes in forest vegetation.

Historical Range of Variability in Water Yield

Forest Characterization

In the first analysis of the historical impacts of forest management activities on water yield from the North Platte River Basin, the data for the stand polygons for the respective national forests were aggregated based on similarities in aspect, elevation, species, and so forth. This process reduced the 23,000-polygon database to a manageable number of aggregates (Troendle and Nankervis 2000). For the later analysis of the North Platte River Basin (Troendle et al. 2003), data were assembled on a geographic information system (GIS) platform by Andrew Peavy (GIS analyst, Forest Service Ecosystem Management Unit, Fort Collins, CO). Stand polygon layers provided by each forest were merged into a composite for all NFS land in the North Platte River Basin. The individual stand polygons were then intersected with Oregon State climatic maps for either Colorado or Wyoming to obtain an estimate of the average monthly precipitation for each of the individual forest stand polygons. For this assessment of the South Platte River Basin, each Forest provided similar polygon information for lands within the watershed boundary. Data compilation was done similarly to the earlier analyses. As part of this effort, Steve Johnson (Renewable Resources Staff, R2, Lakewood, CO) served as the liaison with the Pike-San Isabel (PSI), Arapaho-Roosevelt (AR), and the Medicine Bow-Routt (MBR) National Forests to obtain the vegetation descriptions and disturbance data. The result was the development of a GIS database containing stand-level information characterizing specie composition, age class, aspect, elevation, monthly precipitation, and some post-1997 disturbance activity. The relative location of NFS lands within the North and South Platte River Basins is depicted on Figure 2. Less than 1 percent of the NFS land in the South Platte River Basin is on the MBR National Forest while 53 percent is on the PSI National Forest and 47 percent is on the AR National Forest.

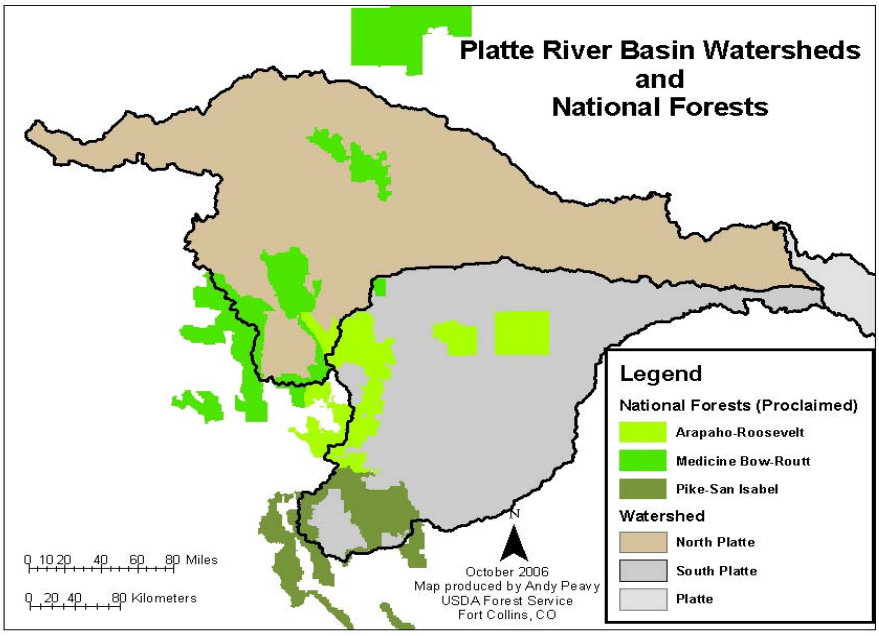

Figure 2. Schematic of the North and South Platte River Basins showing the location of NFS land.

In total, 12 tree species are present on the 1,733,866 acres of forested NFS land in the South Platte watershed (Table 1). Of those 12, 6 species (aspen, bristlecone pine, Douglas fir, lodgepole pine, ponderosa pine, and spruce-fir) occupy 95 percent of the forested area and account for at least that proportion of the streamflow from NFS land. Lodgepole pine is the most dominant specie on the AR National Forest, occupying about 45 percent of the forested area. Ponderosa pine and spruce-fir occupy 22 and 21 percent of the area, respectively. In contrast, ponderosa pine is the predominant species on the PSI National Forest and occupies 33 percent of the forested area. Douglas fir and spruce-fir are the next two most prevalent species occupying 19 and 14 percent of the area, respectively. Lack of specie specific evapotranspiration relationships for the 6 less frequent species, lumped as other species in Table 1, required that they be combined hydrologically with the dominant species for simulation purposes. It is unlikely that this necessity altered the outcome of the analysis. Precipitation estimates for each forested polygon were calculated by intersecting the individual stand polygon with the Oregon State Climatic map for either Colorado or Wyoming. Although there was some aggregation of similar polygons for simulation purposes, this was not done until after all polygon attributes, including seasonal precipitation, were determined and polygons with identical characteristics could be identified.

Table 1. Aerial extent (in acres) of all tree species on NFS lands in the South Platte River Basin. The total area of 1,733,866 acres does not include non-forested NFS lands (alpine, water, meadows, and so forth). Although 12 species are present, only the area for the 6 dominant species is presented with the balance of species represented as "other species".

Species	Arapaho-Roosevelt NF (acres)	Medicine Bow-Routt NF (acres)	Pike-San Isabel NF (acres)	Total (acres)
Aspen	12,147	3,421	127,583	143,152
Bristlecone pine	16,322	0	65,582	81,903
Douglas fir	6,379	1,387	175,413	183,178
Lodgepole pine	362,826	3,930	89,550	456,306
Ponderosa pine	179,113	2,702	304,032	485,847
Spruce-fir	168,973	45	130,707	299,725
Other species	63,411	0	20,344	83,755
Total	**809,171**	**11,486**	**913,209**	**1,733,866**

Similar to the earlier analyses, the first step was to characterize each polygon based on current forest stand conditions (species, basal area, aspect, and precipitation) and then project current stand condition backward in time, using 20-year increments, to the year 1860. This step consisted primarily of identifying specie composition and defining the size class for each polygon. Five size classes were used to describe the forest cover for earlier studies on the North Platte River Basin. However, because of limited data for the PSI National Forest, only three size classes were used for this South Platte River Basin

effort. All non-stocked, seedling, and sapling stands were combined into the youngest age group, and this grouping consisted of all stands with vegetation less than 4.9 inches in diameter at breast height (DBH). The second size class was poles and consisted of stands where the average DBH ranged from 4.9 to 9.0 inches. The third size class consisted of sawtimber stands with an average DBH greater than 9 inches.

The GIS was used to overlay each original stand polygon with topographic aspect and precipitation. This overlay procedure created a new, composite, GIS map depicting all the logical combinations of stand polygons, aspect, and precipitation. The definition of aspect consisted of assigning one of the four cardinal directions to each resulting polygon. In a later lumping process, polygons with either an east- or west-aspect designation were considered similar in the modeling process. Monthly precipitation was determined using the Oregon State climatic maps for either Colorado or Wyoming. This process caused the number of unique polygons to increase dramatically. Once done, however, like polygons (identical species, basal area, aspect, and seasonal precipitation) were then aggregated, by Forest, to reduce sample size and simplify or expedite various aspects of the modeling process.

After characterization of current stand conditions was completed and all unique polygons were identified, the current stand condition (size class) was altered using inventory derived age/basal area relationships to reflect how the stand may have evolved, or developed, over time. Inventory data provided by the Forests were used to develop age/basal area relationships for each primary tree species. The age/basal area inventory data provided for the AR and MBR National Forests are the same as those used in the earlier analyses (Troendle and Nankervis 2000; Troendle et al. 2003) and included some data representative of the Route National Forest. Age/basal area data for stands on the PSI National Forest were added to the original data set, and the equations used in the earlier analyses were re-calculated. As was determined in the earlier analyses, a single equation for each species best represented the age/basal area relationships for stands on all NFS land in the South Platte River Basin. Virtually no change occurred in either the slope or the intercept of the equations derived earlier when the data for the PSI National Forest was added to the data set and the models re-fit (see Figures 3–7). Using the age/basal area relationships, the relative age and basal area of all current stands (ca year 2000, the surrogate for the reference year 1997) was then calculated. Using the same relationships, it was possible to go forward or backward in 20-year increments, and estimate a new basal area and size class appropriate to the adjusted age for each stand, or polygon. As the stands were moved forward or backward in time and new age and basal area were determined, the size class may also have changed as the stands passed through the midpoint between the average age of the differing size classes (see Figures 3-7).

The estimated average ages, and therefore basal areas, for the three size classes (particularly sawtimber) tended to be lower on the PSI National Forest than for other Forests although the age/basal area data were consistent across Forests (see for example Figures 3-7). This created a slight problem in the hydrologic simulations because a lower age and basal area for sawtimber stands at “complete hydrologic utilization” (see Troendle and Leaf 1980) had to be defined for the PSI National Forest than was used for the other Forests. Because hydrologically mature stands were generally younger and less dense on the PSI National Forest, the temporal cycle from non-stocked to sawtimber

occurred on a shorter rotation on the PSI National Forest than for the other two Forests. This did not seem to be a problem because the basic age/basal area data representative of the PSI National Forest meshed so well with data for the other Forests; however, it does imply that what are considered fully stocked, hydrologically mature stands on the PSI National Forest are generally younger and less dense than on the other two Forests. Since energy is greater and precipitation is less on the PSI National Forest than on the other two Forests, the conclusion that younger, less dense, stands utilize all the precipitation (complete hydrologic utilization) appears reasonable. Of greater significance is the fact that the difference between the average age, and therefore basal area, of pole stands (stands averaging between 4.9 and 9.0 inches DBH) and sawtimber stands (stands averaging over 9.0 inches DBH) is quite small relative to the other two Forests—only about 10 years. Using a 20–year increment resulted in many stands on the PSI National Forest to initiate in the sawtimber class and not be classed as sawtimber again during the 1860 to 1997 period. This is an artifact of using a 20-year increment rather than a 5- or 10-year increment. The basal area estimates calculated for each time increment are the actual metric used to drive the hydrologic model, and the basal area estimates are continuous and do not reflect this bias.

As observed in earlier analyses, more monitoring data are needed to improve definition of the relationship between size class, stand age, and basal area and to characterize current forest conditions more robustly. Along with improved GIS capability, the capability to type map specie composition, size class, and other individual or unique vegetation characteristics is improving rapidly. However, the development of adequate inventory data, or the necessary ground truthing, that is critical to characterizing what is contained on the individual mapped polygons has not kept pace with technology. This linkage is still inadequate. The ability to characterize current (or mapped) forest conditions is critical to studies like this as well as any landscape assessment. That said, the inventory data used in developing the age/basal area prediction equations appear to be quite consistent across all Forests and represents the best information available.

Additional age/basal area data were provided using the newer Forest Inventory and Assessment (FIA) database, where available. Unfortunately, no apparent relationship between age and basal area seemed to exist in the FIA data. Also, basal area estimates derived from the FIA data, particularly for older stands, were quite low relative to any of the R2 VEG data; so combining data to increase sample size was not possible. FIA data were not used because a different protocol was used and the data were inconsistent with those used in this study. We strongly recommend that the disparity between the two data sets be evaluated further. Specie specific age/basal area relationships were developed for bristlecone pine, aspen (cottonwood was aggregated with aspen), Douglas fir, limber pine, lodgepole pine, ponderosa pine, Rocky Mountain juniper, and spruce-fir.

As in earlier efforts (Troendle and Nankervis 2000; Troendle et al. 2003), the initial size class designation was used to estimate the reference water yield (1997) and average basal area of all stands using the age/basal area relationship. For each 20-year interval from 2000 (ca 1997) to 1860, 20 was subtracted from what was the current age of the stand and the age/basal area relationship was used to calculate the basal area for that stand 20-years earlier. The process was reiterated in 20-year increments back to 1860. If the calculated age of an existing stand was discounted to age zero or non-stocked during that 140-year

period, it was assumed to have been fully forested for the prior 20-year increment. This process allowed forest cover to be redefined for each 20-year increment from the year 1860 to 1997. In a similar, but reversed, procedure the current conditions were extrapolated in 20-year increments forward to 2060. A summary of the estimated size class distribution by species for 1860 to 2060 is presented in Table 2. Because the stand description data used in this analysis were collected over several years beginning in the 1990s; what is considered to be the current or existing condition (ca 2000) is also considered to synonymous with the reference year 1997.

As was the case in the two previous efforts on the North Platte River Basin, basal area projections were done in two ways for the spruce-fir type. As presented in Table 2 changes in spruce-fir may be projected using the same procedure as other species. A preferred approach, however, is to hold the current spruce-fir component constant for the entire time. The logic is that since the spruce-fir type is a climax complex, little actual change in those stands may have occurred during the past 140 or so years. The hydrologic consequences of both alternatives are presented.

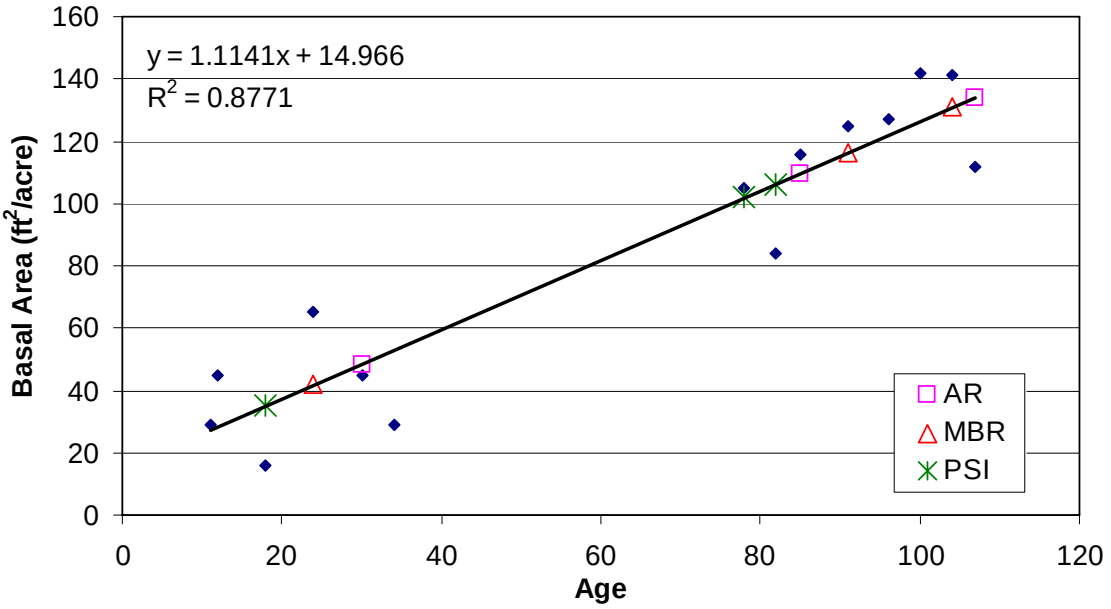

Figure 3. Basal area/age relationship for aspen. The keyed symbols represent the average age and basal area of seedling-saplings (youngest), poles (mid-point), and sawtimber (oldest), by Forest. Small symbols represent inventory data used to derive the line. The age and basal area of poles and sawtimber on the PSI are younger and less dense than on the other forests.

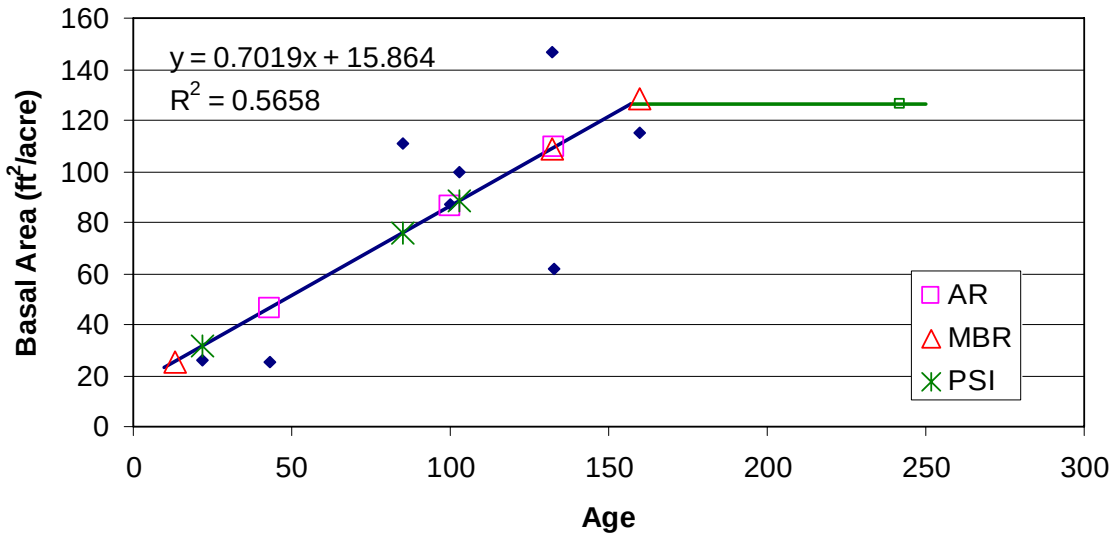

Figure 4. Basal area/age relationship for Douglas fir. The keyed symbols represent the average age and basal area of seedling-saplings (youngest), poles (mid-point), and sawtimber (oldest), by forest. Small symbols represent inventory data used to derive the line. The age and basal area of poles and sawtimber on the PSI are younger and less dense than on the other forests.

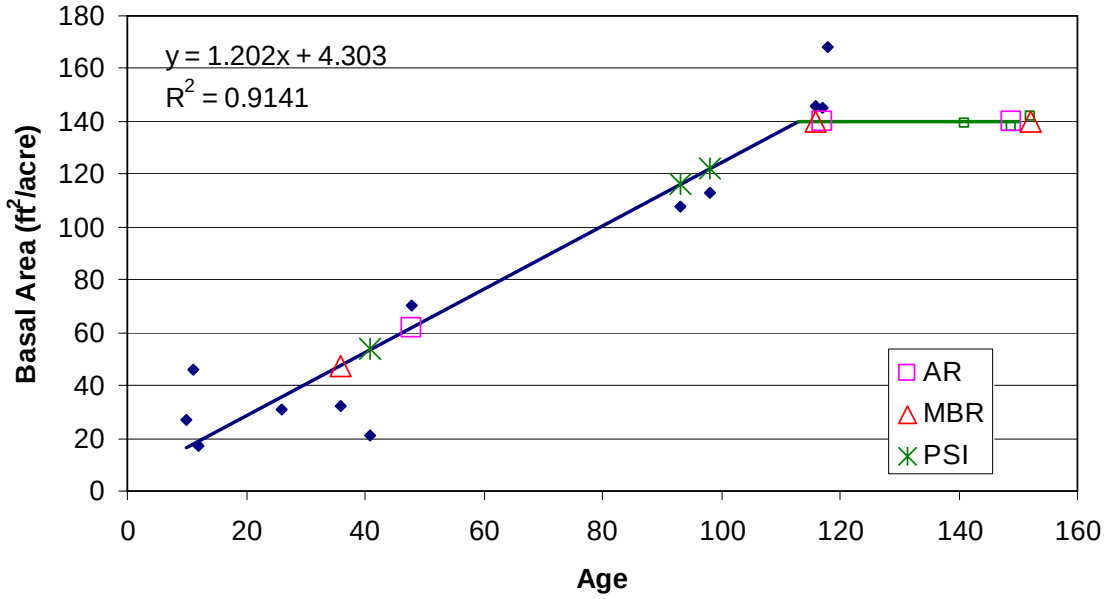

Figure 5. Basal area/age relationship for lodgepole pine. The keyed symbols represent the average age and basal area of seedling-saplings (youngest), poles (mid-point), and sawtimber (oldest), by forest. Small symbols represent inventory data used to derive the line. The age and basal area of poles and sawtimber on the PSI are younger and less dense than on the other forests.

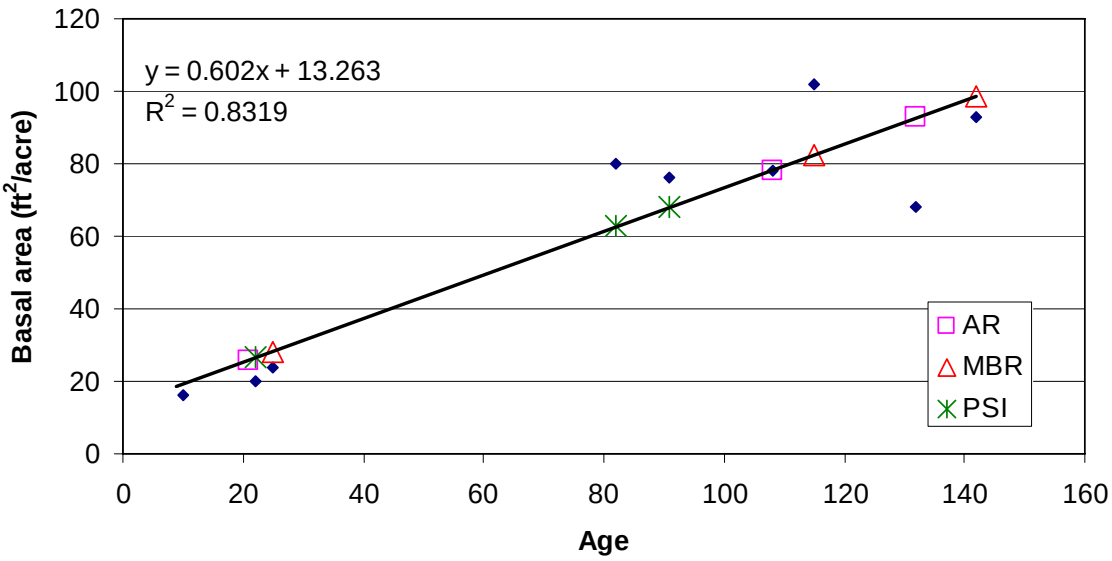

Figure 6. Basal area/age relationship for ponderosa pine. The keyed symbols represent the average age and basal area of seedling-saplings (youngest), poles (mid-point), and sawtimber (oldest), by forest. Small symbols represent inventory data used to derive the line. The age and basal area of poles and sawtimber on the PSI are younger and less dense than on the other forests.

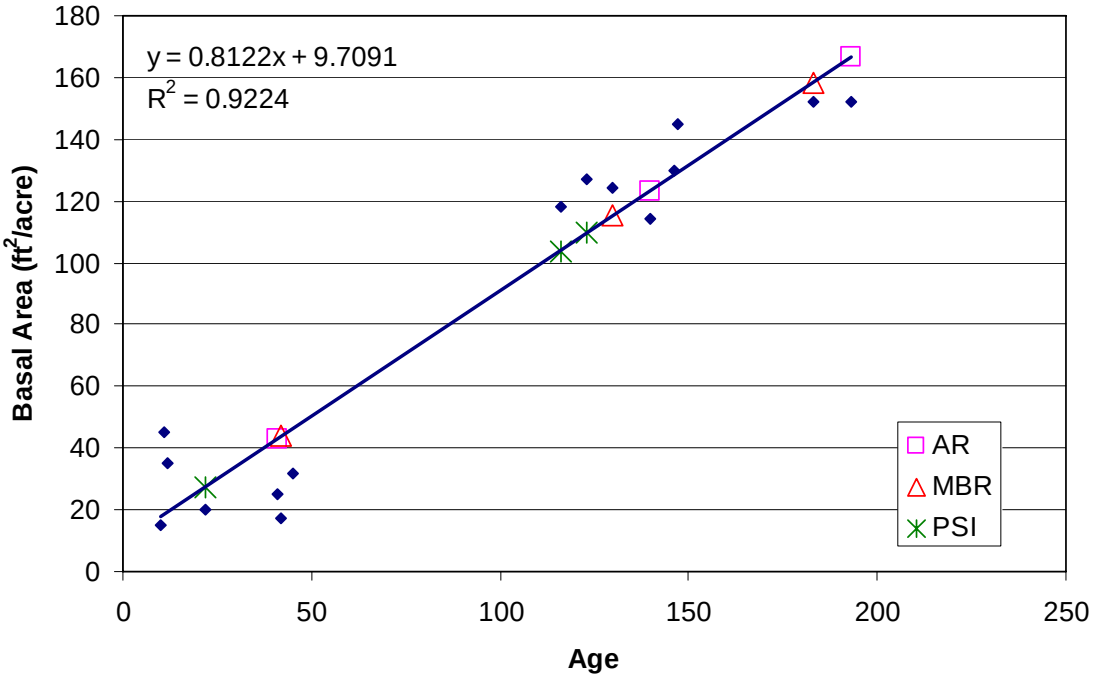

Figure 7. Basal area/age relationship for spruce-fir. The keyed symbols represent the average age and basal area of seedling-saplings (youngest), poles (mid-point), and sawtimber (oldest), by forest. Small symbols represent inventory data used to derive the line. The age and basal area of poles and sawtimber on the PSI are younger and less dense than on the other forests.

Currently, about 54 percent of the 1.7 million acres of NFS land in the South Platte River Basin is occupied by sawtimber while only 14 percent is non-stocked or occupied by seedlings and saplings (Table 2). The reverse appears to be true in the year 1900, for example, when only 14 percent of the area was occupied by sawtimber and the majority (62 percent) either non-stocked or occupied by seedlings and saplings. Intuitively, one would expect a larger sawtimber component in 1900 than was estimated using the procedure in this analysis to characterize historic stand condition. One factor that limits the area calculated to be sawtimber is a consequence of the fact the difference in age between poles and sawtimber is so short on the PSI National Forest that the 20-year increment exceeds the duration of that size class on the age/basal area relationship and to some extent, excludes it from selection. Although all stands are grouped into one of three discrete size classes, the actual basal areas associated with the stands represented in Table 2 have a much more uniform distribution over time and it is the estimate of basal area that is used in the hydrologic simulations.

Table 2. Summary of acreages on NFS land in the South Platte River Basin in the size classes S (non-stocked forest area and seedlings and saplings less than 4.9 inches DBH), M (pole stands 4.9 to 9.0 inches DBH), and L (sawtimber stands greater than 9.0 inches DBH) for each 20-year increment from 1860 to the reference year (1997) and forward to 2060.

Year	Size Class Acreages			Total
	S	M	L	
1860	824,033	695,586	214,247	**1,733,866**
1880	672,861	773,564	287,441	**1,733,866**
1900	1,079,915	566,954	86,998	**1,733,866**
1920	1,440,700	243,457	49,709	**1,733,866**
1940	1,111,910	544,704	77,252	**1,733,866**
1960	737,707	942,554	53,605	**1,733,866**
1980	138,212	1,422,498	173,156	**1,733,866**
2000	235,380	563,481	935,005	**1,733,866**
2020	323,443	57,910	1,352,513	**1,733,866**
2040	163,021	173,996	1,396,850	**1,733,866**
2060	14,959	299,437	1,419,470	**1,733,866**

After the vegetation polygons were characterized, the WRENSS Hydrologic Model was used to simulate average hydrologic response, by forest type, for the stand conditions characterized on each polygon for each time interval. Aspect and precipitation for each polygon was held constant for each time interval, only basal area was altered in the hydrologic simulation process. For hydrologic simulation purposes, all like polygons (similar species, basal area (size class), aspect, and precipitation) were lumped to reduce the number of calculations and shorten simulation run time.

Historical Water Yield

The WRENSS Hydrologic Model (Troendle and Leaf 1980; Troendle and Nankervis 2000; Troendle et al. 2003; and Swanson 2004) was used to simulate water available for streamflow, or water yield, from the South Platte River Basin. As was determined for the North Platte River Basin (Troendle and Nankervis 2000; Troendle et al. 2003), water yield from NFS lands in the South Platte River Basin has steadily declined since the early 1900s (Table 3). As noted earlier, two scenarios for spruce-fir were simulated for each of the 20-year intervals from 1860 to 1997, and a single scenario was used to extrapolate current conditions without disturbance from 1997 to 2060. In the first simulation scenario, the current spruce-fir stands were adjusted to reflect change over time in the same manner as for the other species. In the second scenario, the spruce-fir stands were maintained at their current condition throughout 1860 to 1997. Simulated results for both scenarios are presented (Table 3). The consensus of the R2 Silviculture and Ecology staff was that the current spruce-fir stands were most likely, on average, to be present on the same sites during the entire time from 1860 to 1997 because spruce-fir is a climax tree species. This does not imply the stands were static but it does assume the stands were not "reset" during that period. Given that spruce-fir is less likely to replace itself in a stand-replacing scenario and is more likely to sustain itself over time, the decision to simulate the no-change scenario seemed reasonable. Similar assumptions are less likely to be the case for the balance of species present.

Simulated water yield from NFS land in the South Platte River Basin was greatest ca 1920 (Table 3) and has declined in proportion to the subsequent vegetation density increases (see Table 2). The net reduction in water yield occurring from 1920 to 1997 is equivalent to about 1.8 area inches or 261,000 acre-feet from the 1.7 million acres of NFS land in the scenario that holds spruce-fir constant (Table 3). The simulated decline in water yield was slightly greater at 2.1 area inches (about 300,000 acre-feet) with spruce-fir stands altered similarly to the other species. Decreases in water yield from NFS land in the North Platte River Basin were estimated to be 3.4 area inches from 1860 to 1997 (Troendle et al. 2003). Average precipitation and streamflow are much lower in the South Platte River Basin than in the North Platte River Basin, so changes in flow resulting from either increases or decreases in vegetation are expected to be smaller.

Numerous uncertainties, or risks, are inherent in the hydrologic simulations. Some uncertainties are more or less constant for each simulation while others vary. Uncertainties associated with the application of the hydrologic model probably do not vary from application to application. The strength of the WRENSS Hydrologic Model is in the assessment of changes in water yield. Prediction of absolute water yield is less reliable. The uncertainties associated with the vegetation descriptions input to the model probably have a greater impact on the outcome than the model itself. The most reliable estimate of water yield is likely to be that for the year 1997, the reference year, because that is the year best represented by the available stand description data. Although we have equal confidence in the capability of the hydrologic model to simulate water yield for each of the 20-year time increments, those simulations used projected, or adjusted, stand characteristics. The reliability of the historical and future water yield simulations, relative to current conditions, are directly related to the reliability of the projection of forest stand conditions back or forward in time. Our approach to changing stand conditions over time

is simplistic. All hydrologic simulations used the average 30-year average monthly precipitation obtained from the Oregon State climate maps. Although this allows for comparing responses, particularly change in response under a constant climatic scenario, this approach did not address the dynamics in response (both total yield and change in yield) that would occur under the changing and dynamic climate regime from 1860 to 1997. For example, under a wetter than average regime, both total yield and the simulated changes would have been greater while under drier conditions the simulated flows and changes would have been less than those presented. As expected, the actual or measured streamflow would have strongly reflected the climatic variability and precipitation regime that occurred during the period and not the long term average scenario that we simulated. Reductions in water yield that may have resulted from vegetation change may or may not have been apparent in the measured flow because of the inherent variability in flow that may have occurred during the period. However, using a constant precipitation regime in the modeling effort does allow the effect of vegetation change to be identified more clearly.

Fewer risks are associated with the projection of future stand conditions than with projections into the past. Projecting current stand conditions into the future based on the age/basal area relationships simply allows younger stands to continue to mature while holding mature stands constant. As such, the projections of future stand conditions and water yield reflecting a no-disturbance scenario, with one exception, seems reasonable. The impact of the 2002 Hayman Fire is included in the simulations for 2020 to 2060 and is discussed separately. As was found for the North Platte River Basin (Troendle et al. 2003), water yield from the South Platte River Basin will continue to decline assuming the natural succession of the current forest vegetation is not interrupted (Table 3). As current stands continue to mature, water yield from NFS land can be expected to decline another 0.5 area inches, or an additional 72,000 acre-feet by the year 2060 (Table 3, Figure 8). In the North Platte study, projections indicated future water yields would decline an additional 0.32 area inches or 29,000 acre-feet from 1997 to 2017. Water yield from NFS land in the South Platte River Basin can be expected to decline an additional 0.2 area inches or 28,000 acre-feet during a similar timeframe (1997-2020).

As noted earlier, the stratification of all stands into one of three size classes for each period appears discontinuous (Table 2). In contrast, the basal area estimates for the stands that were aggregated into one of the three age classes were continuous, and that uniformity is expressed in the trend of simulated water yield from the South Platte River Basin for the 1860 to 2060 period (Figure 8). Water yield, and particularly the change in water yield, can be expected to be cyclical as the forest stands evolve and reset due to human or natural intervention. The impact of the resetting process is most dramatic at the level of the stand or hillslope and becomes more integrated and less obvious as the landscape scale. On average, the simulated water yield from NFS land in the South Platte River Basin appears to have been moderate during the mid- to late 1800s, then increased to a high during the early 1900s in response to declines in vegetation density. Water yield has since declined in relation to the increase in vegetation that has occurred since the early 1900s. Barring vegetation disturbance, this decline in water yield will continue at a more moderate rate into the near future (Figure 8). In the North Platte River Basin, stand characteristics were projected back to the year 1720 to show that the historical trends in water yield are cyclical. This projection was not done for the South Platte River Basin;

however, the same trend can be expected and is already partially reflected in the declining flows that were simulated to have occurred from 1920 to1860.

Of the six species occupying 95 percent of the area and contributing 95 percent of the total water yield from the forested portion of all NFS land in the South Platte River Basin, only three species (spruce-fir, lodgepole pine, and ponderosa pine) are dominant occupants and account for most simulated changes in water yield over time (Figure 9). Water yield from aspen, bristlecone pine, and Douglas fir follows the same trend over time, but both the total yield and the contribution to change in flow in the South Platte River Basin from these species is significantly smaller (Figure 9). Simulations indicate that although similar trends in water yield occurred for all six species, the combinations of stand characteristics driving the simulations differ among species (Figures 10-15). Douglas fir (Figure12), lodgepole pine (Figure13), and ponderosa pine (Figure 14), for example, were nearing complete hydrologic maturity (sawtimber) during the reference year 1997 and further declines in streamflow due to continued succession (barring intervention) are expected to be less than for the other three species. Based on current stand conditions, the natural progression of aspen (Figure 10), bristlecone pine (Figure 11), and spruce-fir (Figure 15) have a dominant impact on future declines in water yield.

Table 3. Simulated water yield from the NFS land in the South Platte River Basin from 1860 to 2060.

Year	Water yield[1] (area inches)	Water yield[2] (area inches)	Water yield[2] (acre-feet)
1860	4.3	3.8	546,726
1880	4.2	3.7	531,169
1900	5.1	4.6	658,680
1920	5.1	4.8	687,435
1940	4.5	4.2	610,367
1960	3.8	3.6	522,062
1980	3.3	3.1	453,486
2000	3.0	3.0	433,329
2020	2.8	2.8	411,309
2040	2.6	2.7	387,769
2060	2.4	2.5	367,062

[1]Estimate of water yield allowing spruce-fir to change with time
[2]Estimate of water yield holding spruce-fir constant for the entire period

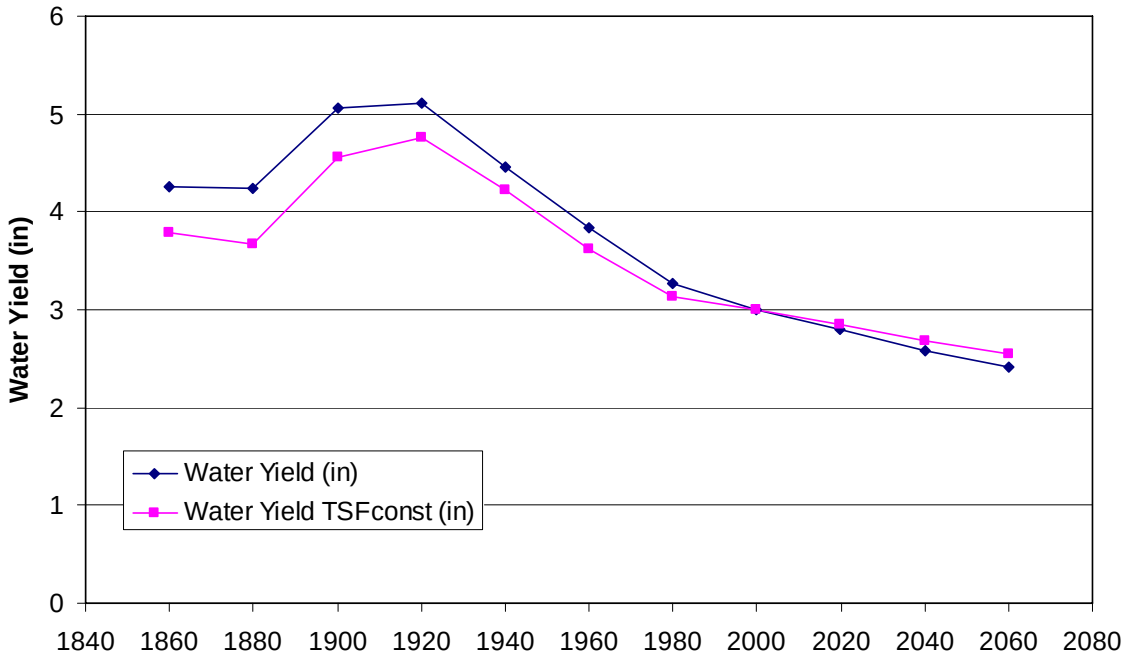

Figure 8. Historical water yield from the forested portion of all NFS land in the South Platte River Basin for two scenarios: 1) holding the spruce-fir component constant over time and 2) allowing spruce-fir to change with time in the same manner the other specie densities are adjusted.

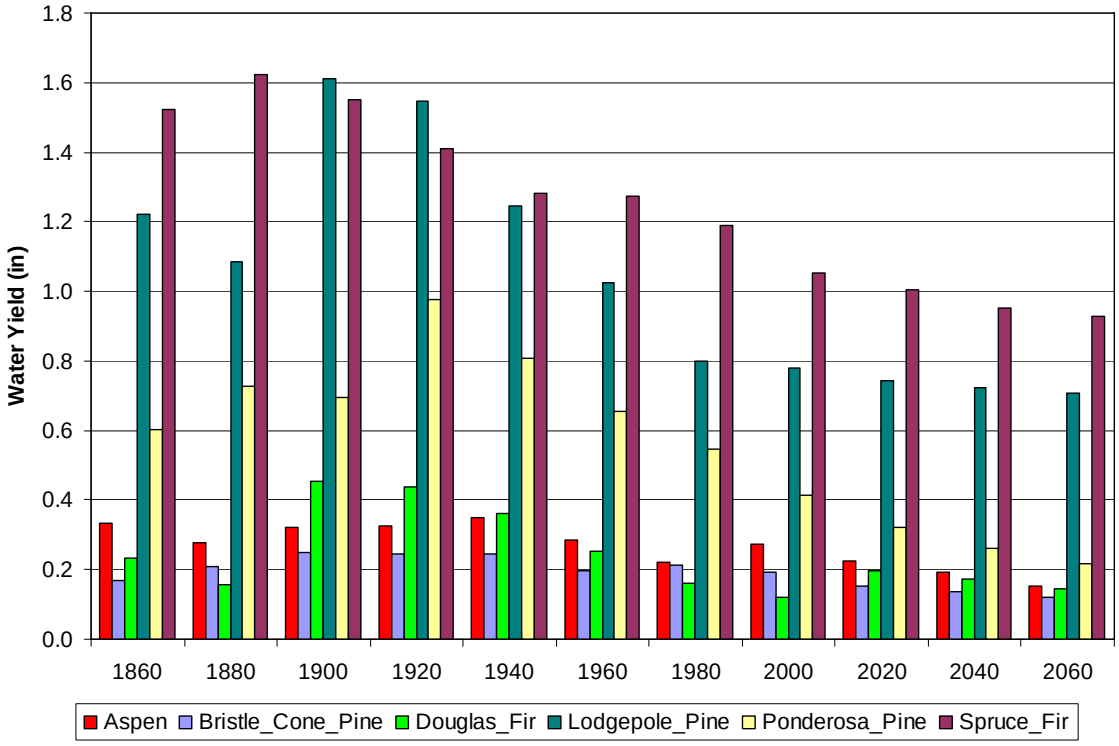

Figure 9. The contribution to total water yield made by the six species account for 95 percent of the total water yield from the forested portion of all NFS land in the South Platte River Basin. Spruce-fir, lodgepole pine, and ponderosa pine dominate the total production and account for most of the changes in water yield over time. In this presentation, spruce-fir is allowed to change with time; otherwise it would remain constant at a level equivalent to the 2000 level from 1860 to 2000 and then decline as indicated from 2000 (1997) to 2060.

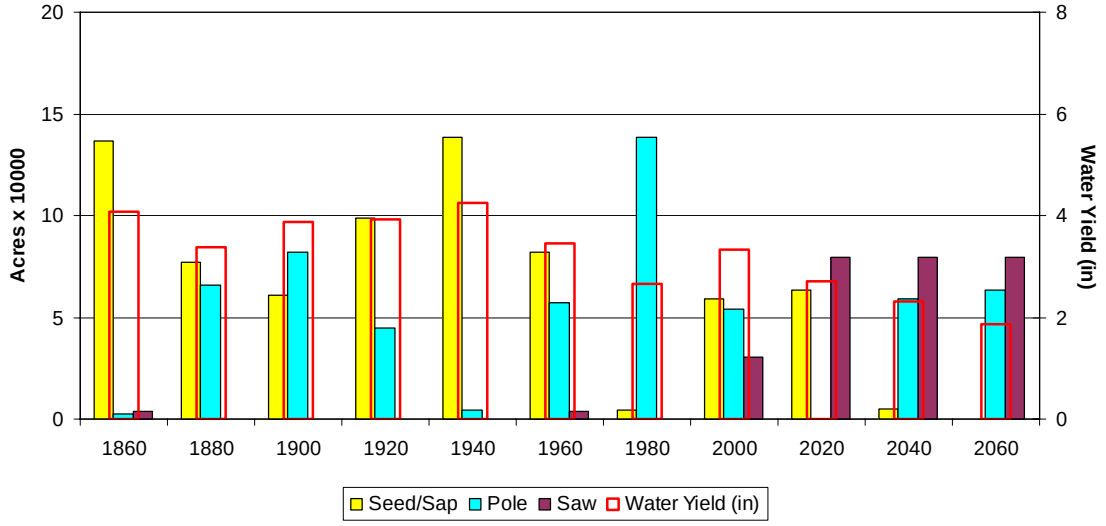

Figure 10. Age class distributions and resultant water yield for aspen from 1860 to 2060. Future streamflow declines (2020-2060) will occur as current stands continue to evolve into the sawtimber class.

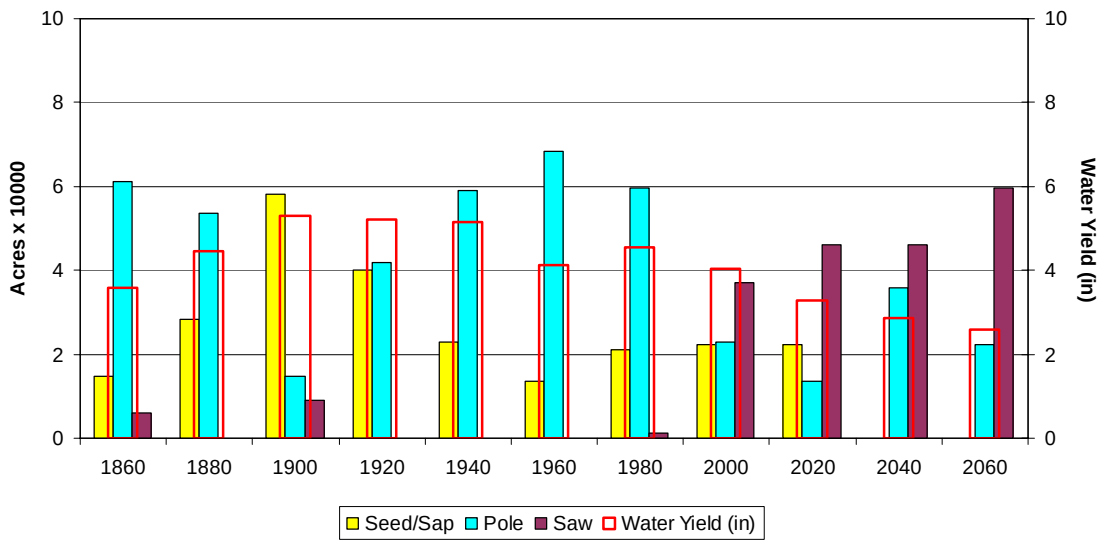

Figure 11. Age class distributions and resultant water yield for bristlecone pine from 1860 to 2060. Future streamflow declines (2020-2060) will occur as current stands continue to evolve into the sawtimber class

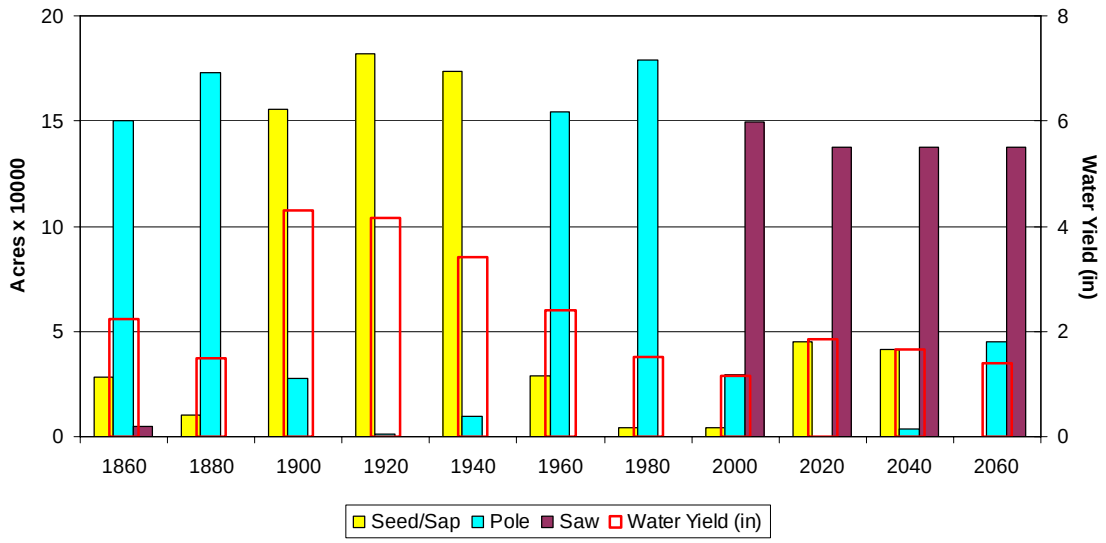

Figure 12. Age class distributions and resultant water yield for Douglas fir from 1860 to 2060. Future streamflow declines (2020-2060) will be minimal as current stands have already evolved into the sawtimber class.

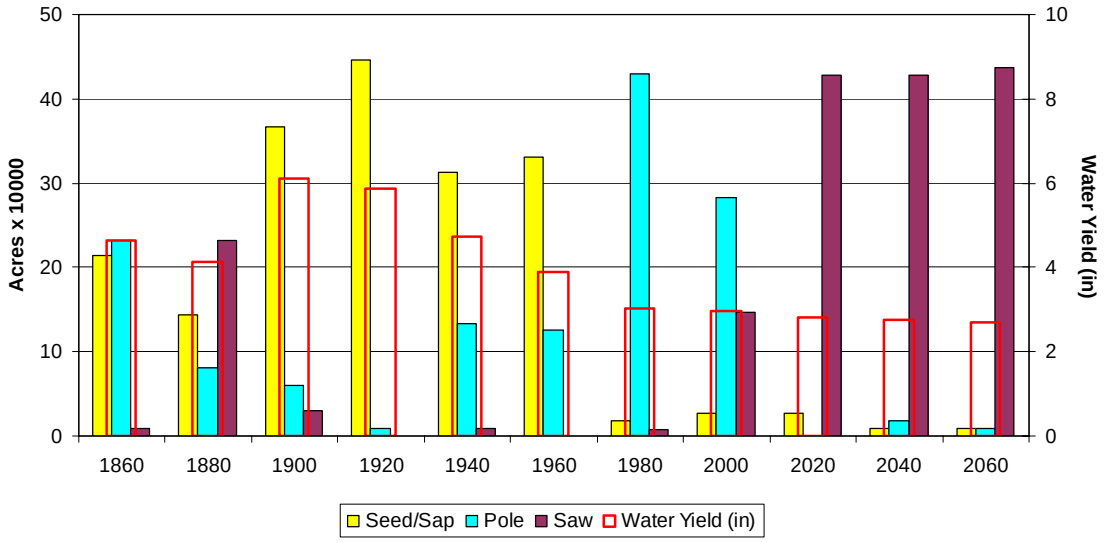

Figure 13. Age class distributions and resultant water yield for lodgepole pine from 1860 to 2060. Future streamflow declines (2020-2060) will be minimal as current stands have already evolved into the sawtimber class.

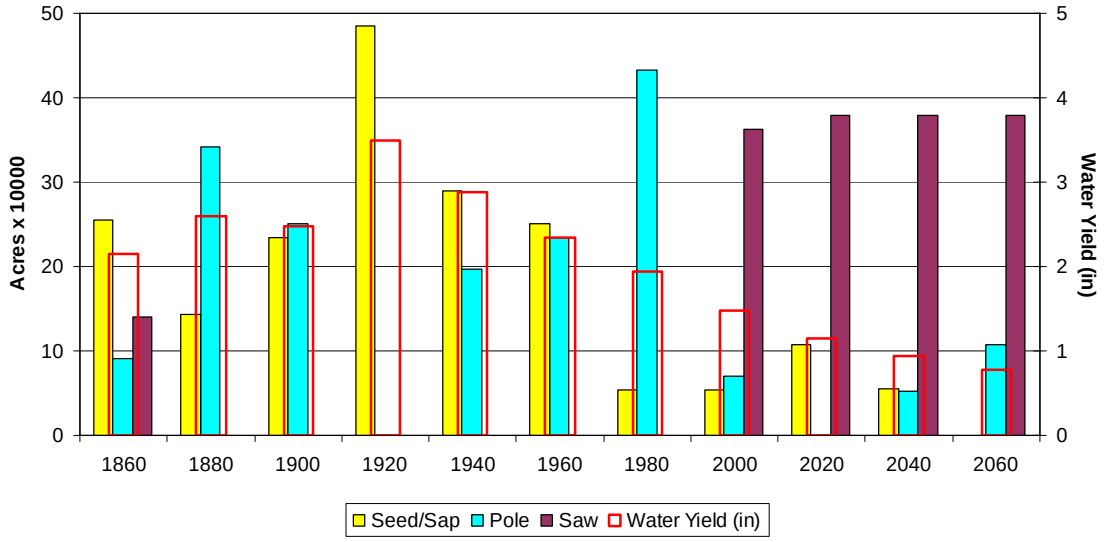

Figure 14. Age class distributions and resultant water yield for ponderosa pine from 1860 to 2060. Future streamflow declines (2020-2060) will occur as current seedling and sapling stands continue to evolve into the pole class.

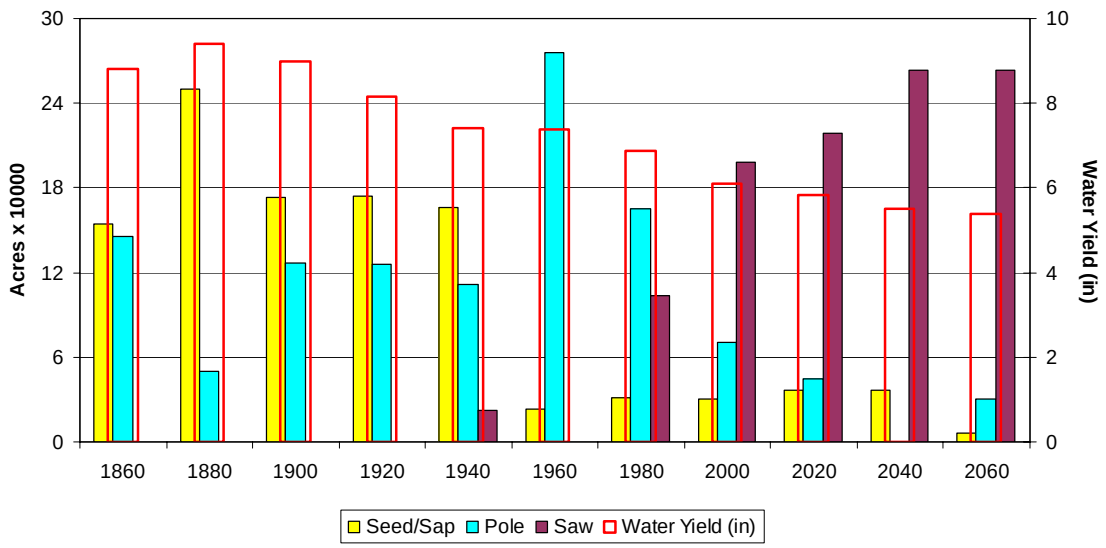

Figure 15. Age class distributions and resultant water yield for spruce-fir from 1860 to 2060. Future streamflow declines (2020-2060) will occur at a modest rate as current seedling and sapling stands continue to evolve into the pole class and poles into the sawtimber class.

The trends in water yield and in the change in water yield over time differ slightly among the three national forests (Figure 16). Both the MB and AR National Forests receive greater amounts of precipitation and yield more streamflow than the PSI National Forest. As noted earlier (Table1), the forested area on the AR National Forest is predominantly occupied by lodgepole pine with an important but lesser presence of ponderosa pine and spruce-fir. In contrast, the PSI National Forest is dominated by ponderosa pine with significant, but lesser, amounts of aspen, Douglas fir, and spruce-fir. Because inventory data for the PSI National Forest indicate that the average age of the sawtimber class for the four dominant species is much lower than for the same species on the other two Forests, there are differences in the temporal distribution of simulated water yield and water yield change. Streamflow from the PSI National Forest appears to have been the greatest during the early 1900s when the presence of ponderosa pine appears to have been minimal. In contrast, streamflow from the AR appears to have peaked during the late 1800s and, because the average age of sawtimber stands, particularly lodgepole pine, is greater on the AR than on the PSI, subsequent streamflow declines were more gradual. Simulated water yield from the portions of the AR and MBR National Forests within the South Platte River Basin are similar to the flows simulated for that portion of the same forests within in the North Platte River Basin. Simulations indicate that less water yield per unit area is generated from the PSI National Forest. However, there are more forested acres on NFS land in the South Platte River Basin (1.7 million acres) than in the North Platte River Basin (1.1 million acres) so that the reduction in total flow from forest land in the South Platte is actually greater than the simulated reduction in flow on the North Platte.

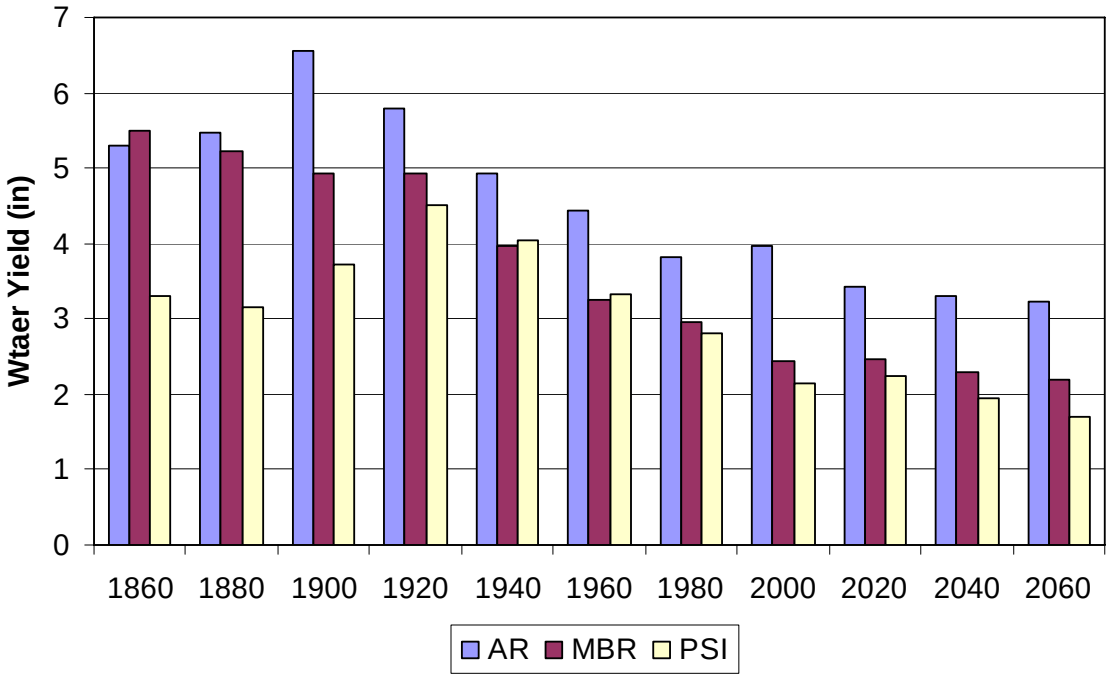

Figure 16. Unit area water yield, in area inches, from NFS lands in the South Platte River Basin. Precipitation and water yield are highest on the AR National Forest.

Disturbance Impacts on Water Yield

Impact of Fire on Water Yield

For the most part, the impacts of historic wildfires on NFS land in the South Platte River Basin are reflected in the characterization of the current forest conditions provided by the three Forests. In 2002, however, the largest wildfire in recorded Colorado history occurred in the South Platte River Basin. Known as the Hayman Fire, the boundary of the burned area encompassed about 140,000 acres. Stand data indicate that about 110,000 acres within that boundary were consumed by fire. The simulated water yield from the burned area for the year 2020 is about 4.5 area inches and represents a 3.4-area inch or 30,600-acre-foot increase over the reference water yield (Table 4). Simulations indicate that the water yield from the burned area will decline from 4.5 area inches in 2020 to 3.0 area inches in 2060, but still represent a 1.9-area inch (17,000 acre-foot) increase relative to the 1997 reference water yield. Contributions from the ponderosa pine and Douglas fir lands within the burn area represent more that 80 percent of the simulated water yield change.

Several issues should be considered regarding the simulation of water yield after the Hayman Fire. First, the initial simulation of the change in water yield resulting from vegetation disturbance from the fire was for the year 2020 (18 years after the fire). The WRENSS Hydrologic Model simulates the annual water balance and annual water yield. Although the procedure can distribute the annual change in flow using a flow duration curve that includes peak flow, the procedure is not capable of simulating individual storm

responses. Potentially, the most significant hydrologic impact after fire is the increased storm response and elevated sediment production that can and did occur immediately after the fire. Hydrophobic soils that develop as a result of fire limit infiltration of rainfall, and sometimes snowmelt, into the soil causing a greater amount of surface or overland flow to occur. Surface flows carry more sediment and cause rapid responses in streamflow. The hydrophobic soil condition often dissipates within a few years after even the severest of fires and the capability of the soil to infiltrate precipitation quickly returns to pre-fire conditions. Vegetation gradually reoccupies the site, and the burned area begins hydrologic recovery. By 2020, 18 years after the burn, the area likely will be well vegetated with grasses, forbs, shrubs, and trees. The severity and extent of the Hayman Fire may retard reoccupation by woody vegetation, but woody vegetation will eventually reoccupy the site. The burned area will likely recover hydrologically in 80 or 90 years. Delays in seeding and regeneration could extend the recovery period while rapid re-growth could shorten the recovery period. The limited age/basal area data for the PSI National Forest and the species of interest suggest that on average it is a reasonable assumption that hydrologic recovery will occur in 80 or 90 years after the fire. Since the decline in water yield appears to occur most rapidly towards the end of the recovery period, the simulated increases in water yield in estimated to occur in 2060, 58 years after the fire, seem reasonable. In a study of the impacts of the 1988 Yellowstone fire on water yield, Troendle and Bevenger (1996) found that water yield on the burned watershed appeared to increase in proportion to the percentage of tree mortality and in similar proportion to that observed elsewhere after timber harvest or insect mortality. Peak flows after snowmelt did not appear to be increased; they may have decreased. The relative magnitude of the increases in water yield observed after the Yellowstone fire are similar, when adjusted for precipitation differences, to those simulated to occur after the Hayman Fire.

The 108,112 acres of forest vegetation consumed by the Hayman Fire represents about 6 percent of the 1,733,866 acres of NFS land in the South Platte River Basin. The increases in water yield that are simulated to occur on site (Table 4) represent increases in water yield of 0.21, 0.16, and 0.11 area inches from all NFS land in 2020, 2040, and 2060, respectively. These increases would not be detectable at any existing stream gauge in the basin, and the increases would not overshadow the 44,000 acre-foot decline (Table 3) in water yield that will occur as the burned area recovers and the balance of the vegetation on NFS land matures.

Table 4. The effect of the 2002 Hayman Fire on water yields from the burned area for the period 2020 - 2060. The year 1997 is the reference pre-fire year. Although included in the simulation total, bristlecone pine, cottonwood, limber pine, and lodgepole pine are not listed here as they contributed only about 1 percent to the total water yield from the burned area.

Specie	Area (acres)	Water yield (area inches)			
		1997	2020	2040	2060
Aspen	4,662	4.0	7.0	6.2	5.3
Douglas fir	41,499	1.0	4.5	3.7	2.6
Ponderosa pine	54,453	0.6	3.8	3.1	2.5
Spruce-fir	6,073	3.6	8.2	7.5	6.8
Total	**108,112**	**1.1**	**4.5**	**3.8**	**3.0**

Impact of Insects and Disease on Water Yield

Currently, a major infestation of insects, bark beetles and defoliators, is affecting forest stands throughout Colorado (Wulder et al. 2006), in nearby states, and in southwestern Canada. Although tree mortality resulting from bark beetle and defoliator attack are part of the ecosystem, the recent series of warm, dry years has caused the insect populations to explode. In addition, the dry years, warm temperatures, and greater plant density have caused greater stress to trees and trees are more susceptible to attack, particularly from the mountain pine bark beetle. Over time, tree mortality after large-scale infestations will affect watershed processes such as canopy interception, soil moisture storage, transpiration, and ground water recharge in a manner similar to timber harvest. Love (1955) reported on the impact of a beetle infestation in spruce stands on the White and Yampa Rivers in Colorado. About 80 percent of the trees over hundreds of square miles were killed. The forested area consisted primarily of Engelmann spruce and Subalpine fir. Water yield, measured at U.S. Geological Survey streamflow gauges, increased by as much as 22 percent (Love 1955) with one-half of the initial increase still detectable 25 years later (Bethlahmy 1974). In the past, spruce beetle outbreaks were known to occur at 117-year intervals in northwestern Colorado subalpine forests (Veblen et al. 1994).

Although a variety of tree species are affected by the mountain pine beetle (ponderosa pine, lodgepole pine, and limber pine) or by the spruce beetle (Engelmann spruce), the lodgepole pine type seems to be impacted the most severely and extensively during this current epidemic.

Of the 456,306 acres of lodgepole pine on NFS land in the South Platte River Basin (Table 1), almost 95 percent are classified as pole or sawtimber stands (Table 5) and are subject to mountain pine beetle attack. Stands classed as pole size have an average DBH between 4.9 and 9.0 inches, and the sawtimber size class represents stands with an average DBH greater than 9.0 inches. Historically, the mountain pine beetle has tended to attack the larger more decadent sawtimber trees. In the current outbreak, the warmer weather and drought conditions have allowed the insect population to thrive while trees

and other vegetation have become more stressed and more susceptible. The apparent result is that the infestation is widespread and severe, and increasingly smaller trees are aggressively attacked. As a result, trees in pole stands, as well as sawtimber stands, are being impacted. Although, current estimates of the severity and extent of the infestation are somewhat speculative, the consensus is that the epidemic is widespread and a significant percentage of smaller, pole size, trees will be killed along with the larger trees. Tree mortality, whether the result of fire, timber harvest, or insects and disease attack, changes the water balance on-site and can result in a change in water yield.

Table 5. Acreage of lodgepole pine stands on NFS land in the South Platte River Basin, by Forest and size class. Pole stands are those with an average DBH from 4.9 to 9.0 inches, and sawtimber stands are those with an average DBH greater than 9.0 inches. Pole and sawtimber stands represent nearly 95 percent of all lodgepole pine stands on the forests.

Forest	Area (acres)		
	Sawtimber	Pole	Total
Arapaho-Roosevelt	113,486	231,745	345,231
Medicine Bow-Routt	3,045	885	3,930
Pike-San Isabel	29,900	50,570	80,471
Total	**146,431**	**283,201**	**429,632**

Although speculative, we simulated the potential hydrologic impact of several beetle kill scenarios in the lodgepole pine forest type on NFS land in the South Platte River Basin that are quite feasible given the severity of the epidemic. Troendle and Nankervis (2000) simulated the potential hydrologic impact of a beetle outbreak in spruce–fir stands in the North Platte River Basin and determined the impact on water yield could be significant. Based on input from R2 staff, we simulated three scenarios in lodgepole pine. First, we simulated the hydrologic impact of a 50-percent kill in all lodgepole pine sawtimber and pole size stands. Second, we simulated the impact of a 90-percent kill throughout both the sawtimber and the pole stands. Third, based on the consensus of the R2 staff that a 50-percent kill in the pole size stands (4.9 to 9.0 inch DBH) and a 90-percent kill in the sawtimber stands was the most likely expectation of what may actually occur during the next few years, we simulated that impact.

Given the significant percentage of the forest land occupied by the lodgepole pine type and the severity of expected mortality; the hydrologic impact of the beetle infestation is expected to be significant for any of the three scenarios (Table 6). If 90 percent of the trees in the sawtimber stands are killed along with 50 percent of the trees in the pole size stands; the increased annual water yield from the impacted area in the lodgepole pine type will average nearly 3.6 area inches or 129,000 acre-feet. The potential annual increase of 129,000 acre-feet of water resulting from the beetle kill in lodgepole pine represents one-half of the total declines in water yield in the South Platte River Basin that has been simulated to have occurred since 1920 because of increases in forest density.

Table 6. Simulated water yield from all pole and sawtimber stands in the lodgepole pine forest type on NFS land in the South Platte River Basin for resulting from differing intensities of beetle kill. Water yield is presented in area from the impacted area.

Forest	Water yield 1997 (area inches)	Water yield (area inches) after tree mortality (%) in all pole and sawtimber stands of lodgepole pine		
	Baseline	50% mortality	90% mortality	50% pole and 90% sawtimber mortality (acre-feet)*
AR	2.9	5.6	8.3	6.5 (103,600)*
MBR	2.8	5.7	8.6	8.0 (1,700)*
PSI	2.1	4.9	6.8	5.6 (23,500)*
Total	**2.7**	**5.5**	**8.1**	**6.3 (128,800)***

*Approximate increase in water yield, in acre-feet, relative to baseline (1997) water yield.

Obviously, the simulated impacts of the beetle infestation are speculative and based on an assumed degree of mortality. For example, if the estimated beetle kill were reduced to 50-percent mortality on the 146,431 acres of sawtimber stands alone (Table 5) and impacts in the pole size stands were excluded; the increase in annual water yield would still be about 35,000 acre-feet. Increasing the estimate of mortality to 90 percent in the sawtimber stands alone would result in a simulated increase in water yield in the South Platte River Basin of 65,000 acre-feet per year. Taking the simulation to extremes, 90-percent mortality in all the pole and sawtimber stands of lodgepole pine stands on NFS land in the South Platte River Basin would result in an increase in water yield of about 191,000 acre-feet per year.

The simulated changes in water yield after beetle mortality are probably reasonable for the chosen scenarios. Admittedly, the extent of mortality is speculative; however flights over the area and other visual observations indicate mortality will be widespread and significant. A conservative assumption that 50-percent mortality will occur in sawtimber stands alone results in a 35,000 acre-foot increase in water yield per year. On the other hand, the assumption that mortality will approach 90 percent in all pole and sawtimber stands is excessive. Alternatively, 90-percent mortality in sawtimber and 50-percent mortality in pole stands over the next few years, and the resultant 129,000 acre-foot increase in water yield, seems a reasonable estimate. As with the documented changes in the White River watershed (Love 1955), one can expect a gradual increase in water yield over the next 10 or 15 years that will persist for some time. Mortality on other government or privately owned land in the South Platte River Basin can be expected to follow a similar pattern. Estimates of the impact of the beetle infestation on water yield from the South Platte River Basin, which are based only on estimates for NFS land, are very conservative. Regarding lodgepole pine, the current beetle infestation will reset the system, hydrologically, and cause notable water yield changes. Because the majority of the lodgepole pine type in the South Platte River Basin occurs on the AR National Forest, the majority of the water yield increase will also occur from that forest.

For comparison, we did a similar analysis of the potential impacts of the beetle infestation on lodgepole pine in the North Platte River Basin where 530,000 acres of lodgepole pine are evenly split between the pole (258,000 acres) and sawtimber (272,000

acres) classes (Troendle and Nankervis 2000; Troendle et al. 2003). If mortality were to occur to 50 percent of the trees in the pole stands and 90 percent of the trees in the sawtimber stands on NFS land only, annual water yield in the North Platte River Basin could also increase by about 228,000 acre-feet. The beetle infestation in the lodgepole pine type will have a significant impact on water yield from the entire Platte River Basin

The simulated changes in water yield represent what is expected to occur a few years after mortality. When the trees die, the needles are retained for some time. During that time, the actual increases in water yield are somewhat less than simulated because the retained needles still intercept snow and allow interception losses to occur. Trees that are in the process of dying also transpire some water. After the trees are dead and the needles are shed, interception losses occur but are greatly diminished while transpiration losses are eliminated. Water yield increases are greatest after the needles and fine branches are shed, which could take 10 to 15 years. Hydrologic recovery, or return to pre-infestation hydrologic condition, probably occurs 50 to 80 years after regeneration is established. Because the stand resetting process should not cause soil disturbance, it can be assumed that infiltration of rainfall and snowmelt will not be impacted and overland flow is not an issue after mortality. Hydrologic response to summer rainfall events may increase slightly, locally because of wetter soils resulting from the reduced transpiration, but such increases in peak flows should not present a significant threat. Snowmelt peaks may or may not increase, depending on the proximity of the impacted lodgepole pine stands with other unaffected forest types and the elevation gradient that exists for the lodgepole pine type within the drainage of concern. One can expect earlier and more rapid melt to occur in the impacted areas that, when combined with more snow and wetter soils can result in greater and perhaps advanced contribution to peak flows. The actual impact on peak flows, however, depends on how these site-specific contributions synchronize or desynchronize streamflow when combined with the contributions from the balance of the drainage, or landscape. More than likely, peak flows from the landscape will not increase measurably and may even decrease.

The beetle kill simulations were made assuming the mortality was evenly distributed across the polygon or area. This may or may not be the case because the mortality could be uniformly distributed, or patchy in nature. Because mortality is considered a partial impact, the water yield simulation is similar for either scenario.

Impact of Forest Management Activities on Water Yield

In contrast to the area affected by fire and insect mortality, forest management activities on the three Forests appear to have been relatively minor since 1997. The activities implemented consist mostly of partial stand removal practices primarily intended to reduce fuels, foster tree release, or to improve stand condition. About 38,000 acres of the 1.7 millions acres of NFS land has been treated in recent years. Of that, almost 24,000 acres were treated using a natural fuels broadcast or understory burn with the objective of impacting 20 to 40 percent of the residual basal area of the stand. The available data on disturbance activities are not polygon or year specific so site-specific simulations of hydrologic response are not possible. Data indicate that 78 percent of the activity occurred on the PSI National Forest with the balance occurring on the AR National Forest. In general, the management activities were not stand replacing. Only 2,600 of the 38,000 acres treated resulted in 50 to 100 percent of the basal area removed. The balance of the acreage treated received a less invasive partial removal, often understory, where less than 40 percent of the basal area was removed. About 80 percent of the activity (30,000 acres) on both forests occurred in ponderosa pine sawtimber stands and consisted of salvage cuts, understory burns, and thinning operations where 20 to 40 percent of the basal area was removed. Such treatments would be marginal in producing a measurable increase in water yield (Bosch and Hewlett 1982; Stednick 1996).

Because the activity data cannot be related to specific polygons, it is not possible to characterize the initial stand conditions or the basal area reduction that actually occurred in the impacted stand. Therefore, we cannot simulate and can only speculate on the impacts of forest management activities on water yield. Given that most of the activity occurred on the PSI National Forest and in the ponderosa pine type, the potential increase in water yield that might result from forest management is minimal relative to the simulated fire and insect impacts. The potential increase in water yield resulting from the net effect of recent and current management activities is about 5,000 acre-feet per year. If the current level of activity is projected into the future, the net increase would average 10,000 to 20,000 acre-feet per year over time.

Summary

Two significant conclusions were drawn from the assessment of the historical trends in water yield from NFS land in the South Platte River Basin. First, as was the case in the North Platte study, simulations suggest that a significant decline in water yield occurred from NFS land as a result of increases in forest density. However, apparent differences in specie composition and age distributions between the North and South Platte River Basins indicate that the cycle from high to low water yield is shorter in the South Platte River Basin. In both basins, however, the data indicate that the process is cyclical. As stands mature naturally, water yield declines; as stand regenerate, water yield increases. Without human intervention, this natural process is largely propagated by fire and insects. The second conclusion is that although water yield is expected to increase after catastrophic fires, such as the Hayman Fire, the potential effect of the current insect infestation, particularly in the lodgepole pine type, is a far more extensive and may be a more significant factor in effecting water yield. Mortality from the current mountain pine

beetle infestation may recapture much of the decline in water yield caused by growth or re-growth of forest stands over the past 80 or 90 years. Hydrologic impacts that may result from insect infestations are also occurring to some extent in other forest types and on other land not considered in this study so the impact of the infestations on water yield from the entire basin might be quite significant.

As part of the hydrologic evaluation of the North Platte River Basin a number of U. S. Geological Survey stream gauges were identified that were suitable for use in documenting future changes in streamflow (Troendle et al. 2003). A double-mass analysis procedure was used that relied on comparing the stability of response at one gauging site with response at other control sites. Some of the potential control sites identified were other stream gauges while some were long-term rain gauge or snow course monitoring sites. Monitoring sites in both the North Platte and South Platte River Basins were identified as stable and useable. Because of the widespread invasion of the mountain pine beetle, stream flow is likely to be impacted to some degree at all the streamflow monitoring sites in both the North and South Platte River Basins. However, this may not be the case for the rain gauge and snow course sites that were, or others that could be identified as useable. These sites can continue to be used as reference sites to document flow changes over time. Site visits to the precipitation sites would be mandatory to document that site (vegetation) changes were not occurring as a result of the infestation and that the measurement is still valid. In addition, one would want to verify that measurement at a particular precipitation site is not being impacted by other off-site activities such as cloud seeding. It should also be noted that if cloud seeding were occurring on watersheds of interest, the effect of that practice on streamflow, if any, would need to be partitioned as well and that could de done by careful selection of reference gauges. Given that precipitation monitoring sites (rainfall and snow pack) can be validated to be stable, and they have been shown to compare well with streamflow even when far removed from the stream gauging site, it would be possible to identify an existing monitoring network capable of documenting future changes in water yield. Given the potential magnitude of the current beetle infestation, identifying such a monitoring network would be appropriate at this time. Detection of change would be cumulative in nature and require several years of monitoring before departure could be validated (Troendle et al. 2003) but appropriate and useable monitoring sites should be identified as quickly as possible so that their integrity and availability can be insured into the future.

The recent occurrence of a catastrophic fire and the potential impacts of the current insect infestations, both hydrological and ecological, attest to the natural dynamics of streamflow generation from forested land.

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