Ashley National Forest

Review of Vegetation Management and Water Yield With Local Application to the Ashley National Forest

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EXECUTIVE SUMMARY

Forest Service Policy Related to Water Yield

The current Forest Service Manual (FSM) states that timber harvest plans can be considered to increase water yields, but that such practices should only be implemented if "cost-effective, environmentally and scientifically feasible, and consistent with other resource uses and values." (U.S. Forest Service 2004 - FSM 2522.12). The Intermountain Region (Region 4) has further defined policy related to water yield management in a letter to all Forest Supervisors (U.S. Forest Service 2002), which is summarized in the following paragraph:

"The number one driver that affects water yield is precipitation. As human population continues to grow, particularly in the arid Intermountain Region, we expect to see increasing pressures placed on the demand for water. That demand will continue to come from both consumptive (irrigation, drinking water, etc) and non-consumptive (fishing, rafting, etc) sources. Our ability to appreciably change the amount and timing of water is limited by many constraints, and the practical physical reality is, we are not able to make significant changes on a large scale. Consequently, the most effective management of National Forest System Lands will emphasize "optimal" water yield rather than "maximum" water yield. Optimum water yield implies healthy vegetative and aquatic ecosystems, which supply clean water for all beneficial uses of that water, both consumptive and non-consumptive. In Forest Planning, designating certain geographical areas for production of water yield has proved ineffective in other Forest Service regions over the last couple decades, and there is no reason to believe a similar approach in the Intermountain Region would be fruitful."

Literature Review

Research in small experimental watersheds has clearly shown that forest management can increase annual water yields (Hibbert 1967, Bosch and Hewlett 1982, Stednick 1996). Increased water yields are caused by reduced evaporation and transpiration in the growing season and increased snow accumulation in the winter, leading to augmented spring snowmelt runoff (Troendle 1983). However, the opportunities to increase water yield over large areas by removing vegetation are quite limited – due to a number of complicating factors:

- Research studies on very small forested basins (most less than 1 mi^2) indicate measurable increases in water yield when more than 20% of the basin is harvested (Stednick 1996). This magnitude of disturbance in large watersheds is limited by physical, biological, ecological, legal, and practical constraints.
- Measuring water yield increases is difficult and often inconclusive (Troendle and Nankervis 2000). The yield increases, while likely there, are not within our ability to detect on basins of 10 mi^2 and larger (Schmidt and Wellman 1999). If treatments are maintained over time, long term projections of streamflow increase are in the range of 3-6% (Harr 1983, Troendle and Nankervis 2000), which is within the error of the very best stream gage data (+/- 5%).
- Increased water yields are temporary, depending on vegetation recovery rates. The greatest increases have been observed the first few years after treatment.
- Increased water yields from vegetation management are greatest in wet years and minimal or non-existent in dry years (Troendle 1983). In other words, droughts will remain droughts and wet periods (flooding) will be augmented. In most water short areas,

- Treatments focused on water yield often result in compromising other resource values, such as increased erosion and sedimentation in streams, aquatic habitat degradation, siltation of water conveyance and diversion structures, water quality impacts, increased landslide and debris flow activity, altered terrestrial wildlife habitats, and recreational or aesthetic values.
- Researchers have found that Colorado River water allocations were based on one of the wettest periods in the past 5 centuries, and that droughts more severe than any 20th to 21st century event are part of the western climatic regime (Woodhouse et al. 2006, Carson 2005, MacDonald and Tingstad 2007). If climate change brings more periods of drought, water yield treatments will be less effective, since no changes in flow have been observed in dry years. In addition, impacts to other ecosystem values could be intensified as forest and aquatic ecosystems adjust to changing climates.

Ashley National Forest Discussion

Local observations on the Ashley N.F. demonstrate that a long term program of managing for increased water yield is currently not feasible or compatible with desired conditions.

- Forest Plan Standards and Guidelines related to other resources and values preclude the level of harvest necessary to create measurable increases in water yield (20% of the forested area in a watershed at a given time).
- In addition to resource constraints, the combined fuels and timber vegetation treatments on the Ashley N.F. (~5,000 acres per year) are currently not of sufficient scale to create and maintain the disturbed area sufficient for measurable water yield increases in the major watersheds that drain to downstream communities.
- Vegetation management for a variety of purposes (fuels treatments, timber harvest, habitat improvement, aspen regeneration etc) could temporarily increase water yields on a small scale, but the changes would be difficult or impossible to detect at the watershed scale. The best opportunities to enhance water yield, if any exist, are in places where aspen or meadow communities have been replaced by conifer species.
- Local observations on the Ashley N.F., water yield research, and regional policy all demonstrate the numerous constraints and limitations of augmenting water yields. The Ashley N.F will continue to focus on healthy watersheds and optimal flow, instead of maximum flow. Optimal flow implies healthy vegetative and aquatic ecosystems, which supply clean water for all beneficial uses of that water, both consumptive and non-consumptive (U.S. Forest Service 2002).

FOREST SERVICE POLICY RELATED TO WATER YIELD

The current Forest Service Manual (FSM) states that vegetation management can be considered to increase water yields, but that such practices should only be implemented if "cost-effective, environmentally and scientifically feasible, and consistent with other resource uses and values." (U.S. Forest Service 2004 - FSM 2522.12)

The policy of the Intermountain Region regarding vegetation management, water yield and watershed health was defined in a letter to all Forest Supervisors, and provides an excellent overview of this issue (U.S. Forest Service 2002). A letter with similar direction was released in the Rocky Mountain Region of the Forest Service during the same time period (U.S. Forest Service 2002a). The following paragraphs are excerpts from the Intermountain Region letter:

> The Forest Service has a long history of managing for "favorable conditions of flow." The enabling legislation that created the first National Forests, "The Organic Act," stated the purpose of the National Forests was to "provide for favorable conditions of flow and a continuous supply of timber." In the late 1800's extensive timber harvest lead to higher spring flooding, and was depriving ranchers and farmers of valuable late summer water for irrigation. People of the day were worried that continued over harvest of timber in the western mountains would ruin ranching and farming, as well as deplete timber supply. Thus, for over 100 years the Forest Service has recognized the link between healthy forest and healthy watersheds.
>
> Research has shown that it takes extensive vegetation manipulation to realize any increases in water yield, and that the predominant time of year in which water yield can be increased is during flood events (Schmidt and Wellman 1999). Consequently landslide activity can increase, erosion can increase, and stream channels can become destabilized. As the unstable stream channels erode, the water table drops, and riparian zones are lost. Healthy riparian zones act as nature's reservoirs, and meter out water yield for late season flows. It was precisely this type of stream damage that likely was occurring in the late 1800's, triggering the Organic Act and the formation of the National Forests.
>
> Current research treatments designed to generate water yield have been necessarily limited to a few very small basins (mostly less than one square mile) in elevations and aspects most conducive to water yield increases. Our ability to increase water yield on a larger watershed basis is limited by many constraints, including land ownership, vegetation type, fish and wildlife needs, legal water quality requirements, elevation and terrain. Larger watersheds have more constraints, both physical and legal, that limit our ability to fully apply a research prescription.
>
> The number one driver that affects water yield is precipitation. As human population continues to grow, particularly in the arid Intermountain Region, we expect to see increasing pressures placed on the demand for water. That demand will continue to come from both consumptive (irrigation, drinking water, etc) and non-consumptive (fishing, rafting, etc) sources. Our ability to appreciably change the amount and timing of water is limited by many constraints, and the practical physical reality is, we are not

able to make significant changes on a large scale. Consequently, the most effective management of National Forest System Lands will emphasize “optimal” water yield rather than “maximum” water yield. Optimum water yield implies healthy vegetative and aquatic ecosystems, which supply clean water for all beneficial uses of that water, both consumptive and non-consumptive. In Forest Planning, designating certain geographical areas for production of water yield has proved ineffective in other Forest Service regions over the last couple decades, and there is no reason to believe a similar approach in the Intermountain Region would be fruitful.

In the arid west the most effective and reliable ways to increase water availability is through conservation measures. Although outside the scope of direct Forest Service authority, we should encourage conservation to the extent practical through public information and education. For more information, an excellent source within Utah is a document titled “Utah’s Water Resources: Planning for the Future” and can be found at http://www.nr.utah.gov/wtrresc/waterplan/.

LITERATURE REVIEW

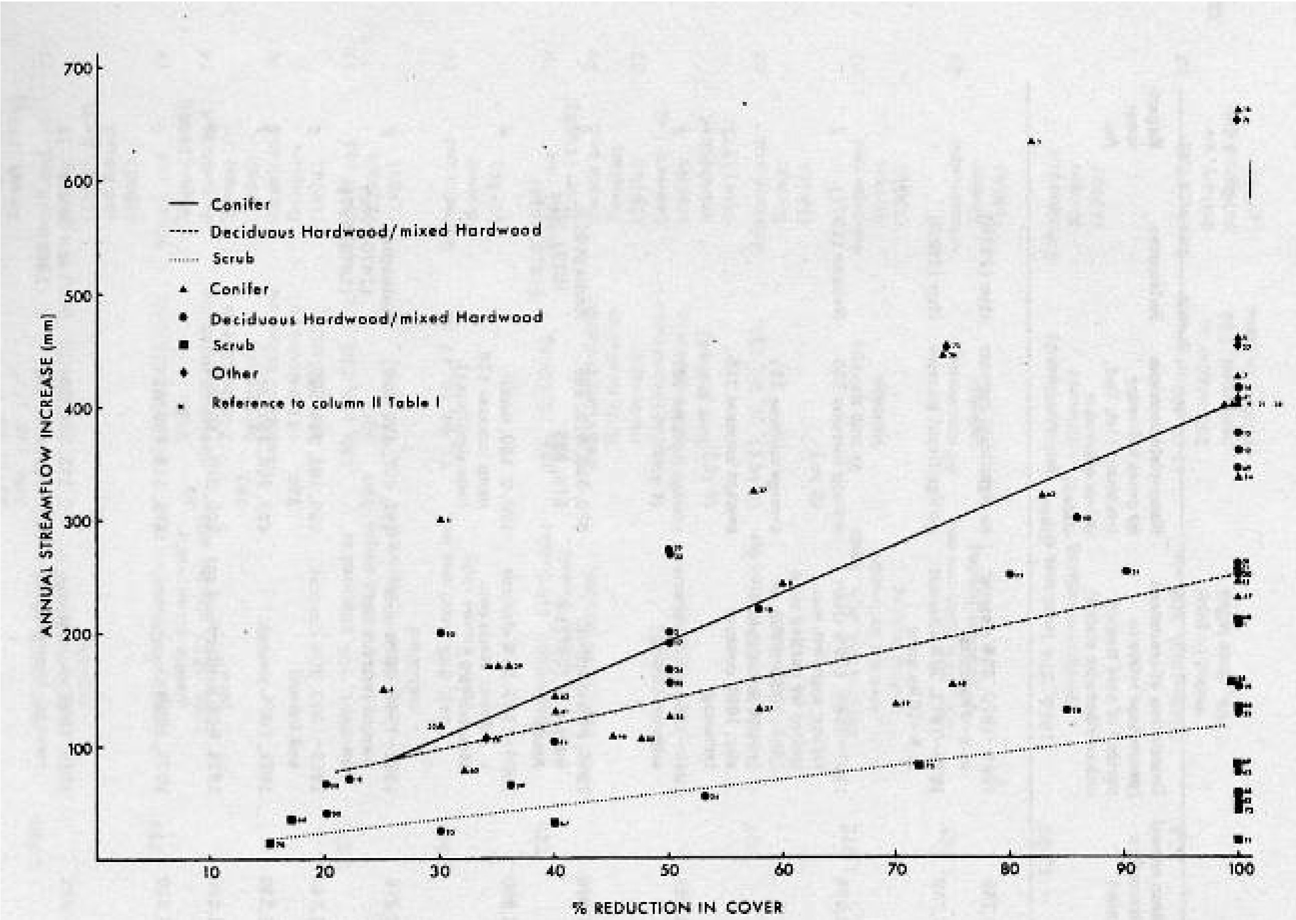
Summary of Water Yield Research

The influence of timber harvest on forest hydrology has long been a source of concern and debate. In 1909, the first paired catchment study in the United States began at Wagon Wheel Gap, Colorado. The objective of the study was to assess the effect of removing forest vegetation on annual water yield (Stednick 1996). At this time serious scientific thought was directed toward evaluating the effect of vegetation manipulation on sustained water yield for beneficial use (Ziemer and Lisle 1998). Since then, numerous studies have been done to evaluate the effect of timber harvest on annual water yield.

One of the first major reviews of the water yield literature included 39 catchment studies throughout the world (Hibbert 1967). This review made the following generalizations: (1) reduction of forest cover increases water yield, (2) establishment of forest cover on sparsely vegetated land decreases water yield, and (3) response to treatment is highly variable and for the most part, unpredictable (Hibbert 1967).

A subsequent review of the literature added 55 catchment experiments for a total of 94 (Bosch and Hewlett 1982). The results of this review are displayed in Figure 1, which displays the maximum water yield (annual streamflow) increase during the first 5 years after reduction in forest cover. Although statistical inference is low with such a wide degree of scatter in the data, the authors did make some general conclusions. They suggested that these trendlines are useful for practical planning purposes such as estimating "the direction and approximate magnitude of past and future changes in streamflow as a function of forestry operations" (Bosch and Hewlett 1982).

Figure 1. Water yield increases from 94 catchment studies following changes in vegetation cover (Bosch and Hewlett 1982).



The 1982 review by Bosch and Hewlett supported the first two conclusions of Hibbert's 1967 review that, (1) reduction of forest cover increases water yield and (2) establishment of forest cover decreases water yield. It is interesting to note however, that Bosch and Hewlett were "less inclined" to support the Hibbert's third conclusion that water-yield response to afforestation and deforestation is unpredictable. Bosh and Hewlett concluded that coniferous forest, deciduous hardwood and shrub/grass cover have (in that order) a decreasing influence on the water yield of the parent watershed, which seems more predictable that Hibbert (1967) suggested. Bosch and Hewlett also reported increases in water yield diminish in proportion to the rate of vegetation recovery.

The 1982 review also analyzed some of the errors associated with catchment experiments. Surface water divides and subsurface water divides do not always match. Consequently, water yield changes per unit area can be seriously distorted (especially in small watersheds). In larger watersheds it becomes increasingly difficult to control treatments, estimate precipitation and to measure streamflow accurately (Bosh and Hewlett 1982).

Stednick (1996) compiled and reviewed 95 paired catchment studies in the United States which reported the effects of timber harvest on annual water yields. Only paired catchment studies were used because other approaches, such as time-trend analysis in a single catchment, have no climatic control to separate vegetation cover effects from climatic effects. In addition, by using the paired catchment approach, the annual water yield change resulting from timber harvest is independent of the variation in rainfall from year to year (Stednick 1996).

The 1996 review also reported the maximum water yield increase recorded in the 5 years after treatment or harvest. In most cases, the maximum increase in water yield occurred the year following treatment. Results were variable, ranging from 0 to 615 mm increase in annual water yield. Figure 2 and Table 1 summarize the results of Stednick's review.

Figure 2. Annual water yield increase (mm) in paired catchment studies (Stednick 1996).

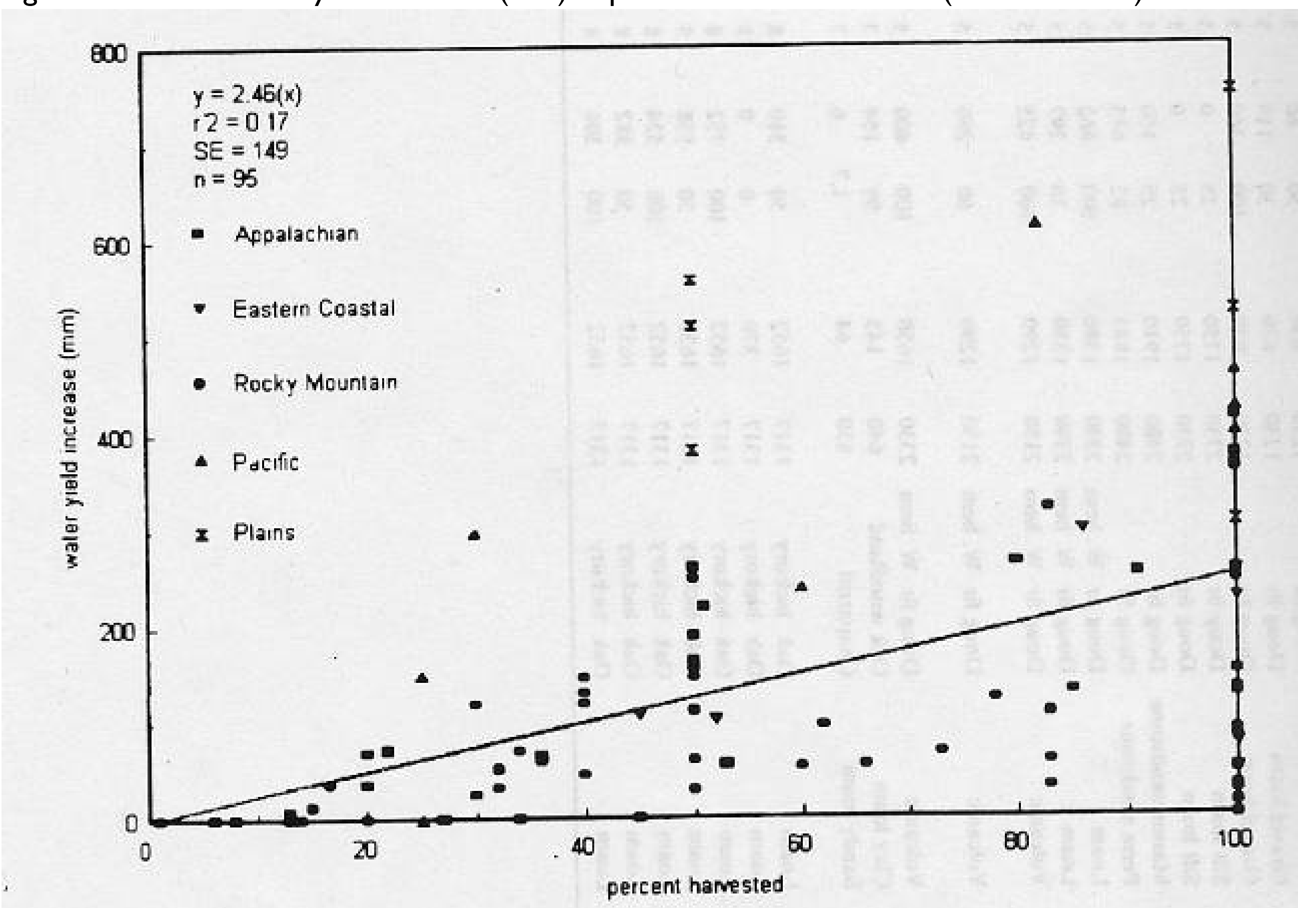


Figure 2 shows the wide degree of variability in the data, but also illustrates the general relationship between percent harvested and annual water yield increase. The percent catchment area harvested was assumed to be directly proportional to basal area, thus a 25% basal area removal equated to harvesting 25% of the catchment area. These results coincide with the findings of Bosch and Hewlett (1982).

Table 1. Regression model statistics for annual water yield increase versus percent harvest area for all studies and by hydrologic region (Stednick 1996).

Hydrological region	Number	*n*	Slope	r^2	SE	*p* value	Threshold for response
All studies	–	95	2.46	0.17	149	0.0001	20
New England/Lake states	1	3	–	–	–	–	–
Appalachian Mountains and Highlands	2	29	2.78	0.65	75	0.0001	20
Eastern Coastal Plain and Piedmont	3	7	1.84	0.02	97	0.0051	45
Rocky Mountain Inland Intermountain	4	35	0.94	0.01	66	0.0001	15
Pacific Coast	5	12	4.40	0.65	118	0.0001	25
Continental/Maritime	6	0	–	–	–	–	–
Central Sierra Province	7	2	–	–	–	–	–
Central Plains	8	7	6.15	0.31	197	0.0009	50

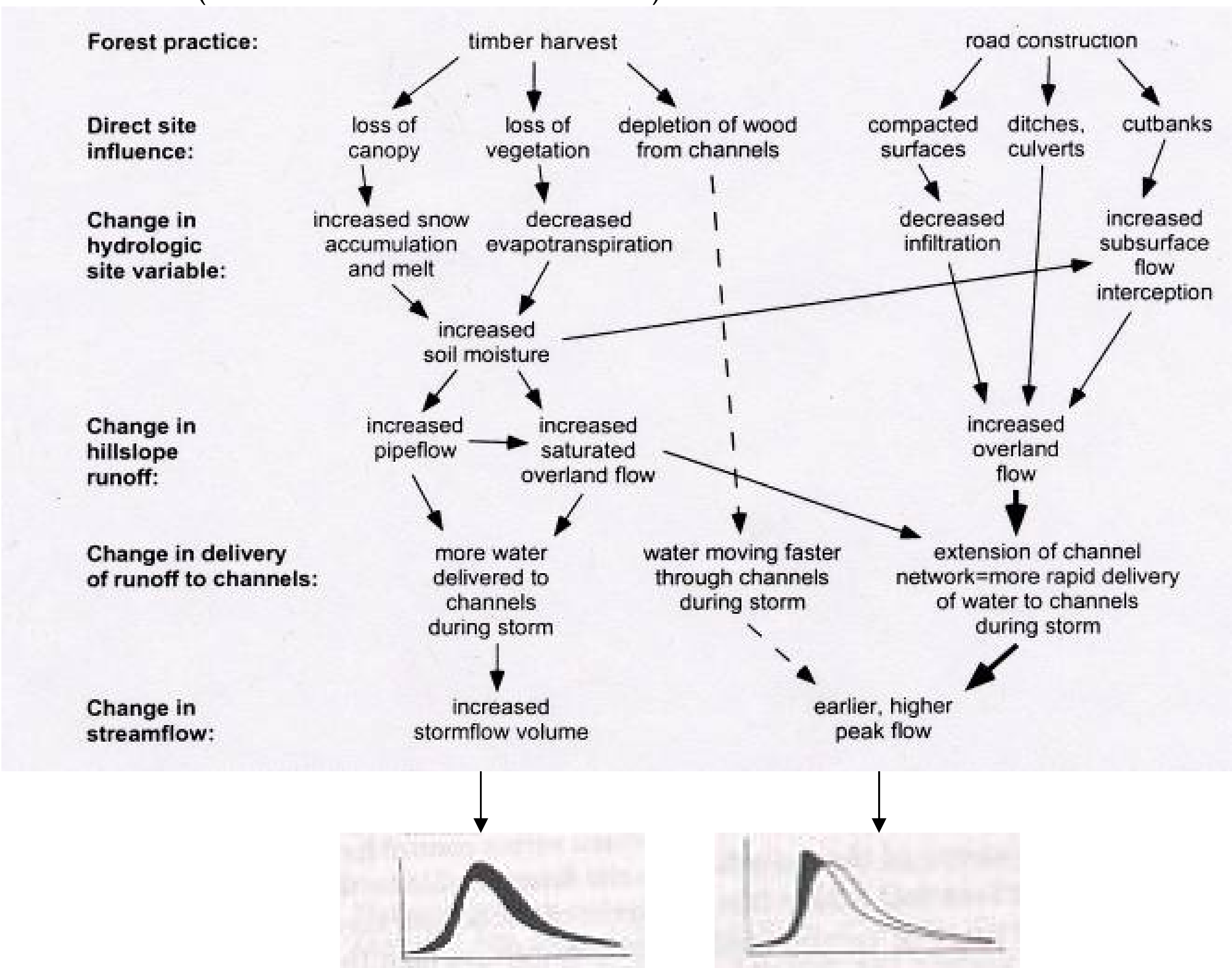
The threshold of response is harvest area required for measureable increase in annual water yield.

Table 1 suggests that approximately 20% of the catchment must be harvested for a measurable increase in water yield (average value from all studies), and has been cited as a general threshold for response in other summaries on the water yield issue (Schmidt and Wellman 1999, Troendle *et al.* 2006). The threshold of harvested area ranged from 15% in the Rocky Mountain area to 50% in the Central Plains. It should be noted that reductions in forest cover below the 20% threshold could produce increases in streamflow that are too small or gradual to detect (Bosch and Hewlett 1982, Stednick 1996, MacDonald and Stednick 2003, Troendle *et al.* 2006).

Natural Processes affecting Water Yield

Figure 3 displays a conceptual diagram of functional processes that alter the volume and magnitude of streamflow after timber harvest and the associated road construction. This diagram illustrates that in general, harvest activities and road building can combine to create increased flow volumes (water yield), and earlier, higher peak flows. The interaction of these processes can produce variable results, depending on site specific factors, but this figure illustrates the generally accepted hydrologic theory related to timber harvest and road building (Ziemer and Lisle 1998). The effect of management impacts on individual storm peak flows are greatest for low to moderate events, while extreme flow events are overwhelmed by precipitation input into the watershed (McCulloch and Robinson 1993).

Figure 3. Conceptual diagram of the functional processes related to timber harvest and road construction (modified from Ziemer and Lisle 1998).



It is beyond the scope of this paper to discuss all the interactions in this diagram, but the following key processes will be addressed: snow accumulation and melt, soil moisture and evapotranspiration, roads and drainage networks, and hydrologic recovery.

<u>Snow Accumulation and Melt</u>

The forest canopy intercepts snowfall, redistributes the snowpack, decreases wind velocities and shades the snowpack (Chamberlain *et al.* 1991). Timber harvest affects these processes in various ways, depending on the precipitation, temperature and wind patterns of the region. In the dry, cool winter climates of the interior west, intercepted snow may be blown easily from the trees. However, when wind speeds are low, snow may sublimate directly to the atmosphere and be lost from the snowpack (Chamberlain *et al.* 1991). Several studies have observed that clearing forest cover decreases interception and sublimation of snow, increasing total snow accumulation, which in turn, increases water yield during the spring snow melt season (Troendle 1983, Stednick and Troendle 2004).

The increased snow-water equivalent along with loss of shade and increased solar radiation can produce snow melt flows significantly higher and earlier than preharvest conditions (Chamberlain *et al.* 1991, Troendle 1983). The largest increases in water yield have been measured during wet years, with little or no change observed during dry years. During a dry year with less snowfall, the effect on snow accumulation processes is less pronounced (Troendle 1983, Stednick and Troendle 2004).

Soil moisture and Evapotranspiration

The effects of timber harvest (particularly clear-cutting) on soil moistures have been well documented. Various studies have observed higher soil moistures through the summer and into the fall after harvesting (Harr 1983, Troendle 1983, Stednick and Troendle 2004). Increased soil moisture or water content after logging is generally attributed to two factors: (1) timber harvest reduces a substantial area of leaves, branches and stems that would otherwise intercept precipitation and allow it to evaporate, and (2) tree roots are no longer able to extract water from the soil and transpire it into the atmosphere (Chamberlin *et al.* 1991). The combination of these two effects can significantly reduce rates of evapotranspiration, and therefore increase soil moisture and the amount of water available for streamflow and runoff.

In this condition, when the spring snow-melt or fall rains come, soils may quickly become saturated, making more excess water available for streamflow. Soil moistures can also help explain why little or no water yield increases are observed during dry years. During a very dry year, the residual and recovering vegetation uses the majority or all of the available water, which decreases soil moisture. Then during snowmelt and rain events, a substantial portion of water is required to recharge soil moisture and aquifers, making less water available for streamflow (Stednick and Troendle 2004).

Roads and Drainage Networks

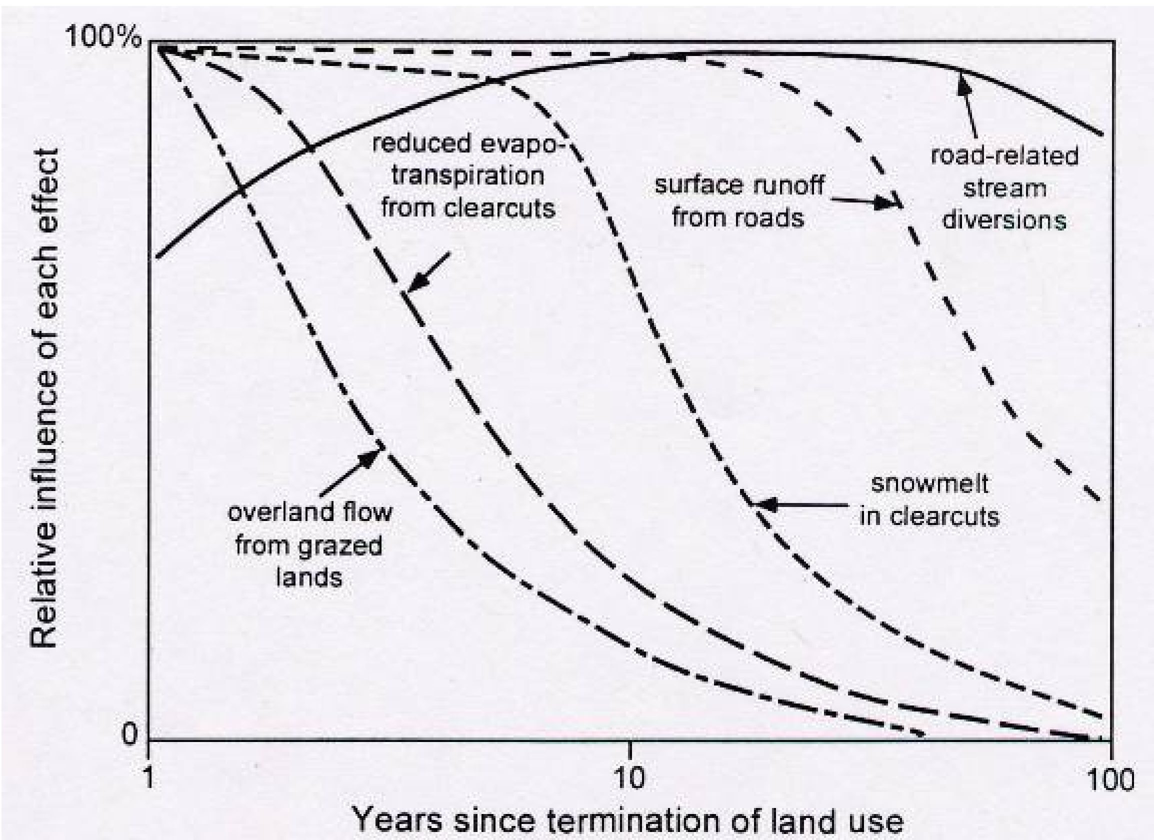
The roads associated with timber harvest have been identified as a major contributing factor to the timing and volume of peak streamflows, as well as increased erosion and sedimentation (Chamberlin *et al.* 1991, Gucinski *et al.* 2001). The influence logging roads have on peak flows depends on the arrangement of the road network in relation to the stream network (Jones *et al.* 1999,). In many cases roads function as an extension of the stream network, rapidly delivering large amounts of water to stream channels, producing earlier and larger peak flows (Jones *et al.* 1999). Not only do roads route surface water from hillsides directly to streams, they also can intercept subsurface flow and bring it to the surface (Chamberlin *et al.*1991).

Volumes have been written about the effects of road networks on stream systems. Additional impacts include water quality changes, accelerated erosion rates, mass wasting, surface erosion, failure of stream crossings, channel morphology alterations, and aquatic habitat degradation (Furniss *et al.* 1991, Gucinski *et al.* 2001).

Hydrologic Recovery

The recovery of hydrologic conditions after timber harvest depends on the rates of establishment and growth of vegetation (Ziemer and Lisle 1998). A conceptual diagram of hydrologic recovery after disturbance is illustrated in Figure 4. Of the processes that affect water yield, evapotranspiration in cleared areas recovers the quickest, as vegetation growth occurs. On the other hand, it can take several decades for the tree canopy to regain the size needed to restore natural rates of snow accumulation and melt. For these reasons, vegetation management in the sub-alpine zone of the Rocky Mountains has been an attractive management option for increasing water yields (Troendle 1983, Stednick and Troendle 2004). However, the concept of hydrologic recovery is a reminder that water yield treatments are temporary, and would need to be maintained over time – often at the cost of other resources and values (Schmidt and Wellman 1999).

Figure 4. Characteristic recovery times after various land uses (Ziemer and Lisle 1998).



Issues and Limitations of Large Scale Water Yield Increases

Research in small experimental watersheds has clearly shown that forest management can increase annual water yields (Hibbert 1967, Bosch and Hewlett 1982, Stednick 1996). However, by the mid 1980s it became apparent that opportunities to increase water yield over large areas by removing vegetation were quite limited – due to a number of complicating factors (Douglass 1983, Harr 1983, Harr 1987, Hibbert 1983, Kattleman *et al.* 1983, Krutilla *et al.* 1983, Ponce and Meiman 1983, Rector and MacDonald 1987, Troendle 1983, and Ziemer 1987). These limitations are still relevant today (Sedell *et al.* 2000, Troendle *et al.* 2006).

The Rocky Mountain Research station provided an excellent summary about the challenges of increasing water yields on a large scale (Schmidt and Wellman 1999), which is the key reference attached to the Intermountain Region water yield policy letter (US Forest Service 2002). These limitations and operational realities, along with other more recent observations are summarized below:

- Opportunities are limited by current legal constraints, land allocations, technological realities, societal values, and Forest Service mandates to manage for a wide range of uses (including ecological and biological sustainability).
- Research studies on very small basins (most less than 1 mi^2) indicate measurable increases in water yield when more than 20% of the vegetation cover is removed (Stednick, 1996). However, extrapolating these small watershed studies to larger basins is problematic for several reasons.
    - Monitoring and reporting the results of projected yield increases would be difficult to measure and most likely inconclusive (Troendle and Nankervis 2000, Troendle *et al.* 2007). The yield increases, while likely there, are not within our ability to detect on basins of 10 mi^2 and larger (Schmidt and Wellman 1999).
    - If treatments are maintained over time, long term projections of streamflow increase are in the range of 3-6% (Harr 1983, Troendle and Nankervis 2000), which is within the error of the very best stream gage data (+/- 5%).
    - Experimental treatment regimes, in order to assure measurable treatment effects, tend to be more extreme than conventional forest management practices.
    - Harvesting and then maintaining treatments in more than 20% of a large watershed is generally cost prohibitive, in addition to other legal, environmental and management constraints.
- Increased water yields from vegetation management are greatest in wet years and minimal or non-existent in dry years (Troendle 1983, Harr 1983, Stednick and Troendle 2004). In other words, droughts will remain droughts and wet periods (flooding) will be augmented.
    - In the Intermountain West, augmented water yields come from a combination of decreased evapotranspiration in the summer and increased snow accumulation through the winter, which creates increased spring snow melt (Troendle 1983).
    - In most water short areas, reservoirs are operated to maximize storage and are unable to capture and store significant yield increases associated with high spring runoff (flood) years.

- The scale of treatments necessary to increase water yield often result in compromising other resource values:
    - Increased stream channel erosion from augmented flows can alter channel morphology and aquatic habitats (Chamberlin *et al.* 1991, Burton 1997). Increased sedimentation can also affect water diversion and conveyance structures important to downstream communities.
    - Changes in water quality parameters including temperature, suspended sediment, dissolved oxygen, and nutrients (Chamberlin *et al.* 1991).
    - Activation of landslides (particularly Western Colorado, Utah, and Western Wyoming).
    - Altered terrestrial wildlife habitats.
    - Altered outdoor recreation settings and reduced scenic integrity
- Climate change could make water yield augmentation even more difficult and complicated in the future.
    - Researchers have found that Colorado River water allocations were based on one of the wettest periods in the past 5 centuries, and that droughts more severe than any 20th to 21st century event are part of the western climatic regime (Woodhouse *et al.* 2006, Carson 2005, MacDonald and Tingstad 2007). If climate change brings more periods of drought, water yield treatments will be less effective, as no significant changes in water yield have been observed in dry years.
    - As winter and spring temperatures have increased, the extent and depth of snowpacks have generally decreased in the Western United States (Mote *et al.* 2005). However, Julander (2002) has found no statistically significant trends in the Snotel sites of Utah, when accounting for vegetation and instrumentation changes. If snowpacks decrease over time, water yield treatments would also be less effective.
    - Impacts to other resource values could be intensified as forest and aquatic ecosystems adjust to changing climates. Ecosystems could become more vulnerable and sensitive to management related impacts.

<u>North Platte River basin study, Colorado</u>

The difficulty in applying water yield augmentation on a large scale was illustrated in an important study that evaluated the potential to increase flows from three National Forests in the North Platte River basin of Colorado (Troendle and Nankervis 2000, Troendle *et al.* 2003). Modeling simulations indicated that water yield could be increased by 37,000 acre-feet per year by 2015, with a gradual increase, through the rotation, to a sustainable 50-55,000 acre-feet per year. This long term projection represents an increase of approximately 11% when averaged over the 502,000 acres suitable for timber harvest, or an increase of 4.6% when averaged over the entire land base in the study area.

The study identified several challenges with actually accomplishing these projected increases. In order to achieve the projected long term increase of 4.6%, the annual volume of timber needed from these three forests would exceed the annual volume of timber removed from all 11 National Forests in Colorado over the last 6 years (MacDonald and Stednick 2003). In addition, the detection of changes in water yield would be unlikely because of natural variability in streamflow and a lack of infrastructure needed to measure and document change (Troendle and Nankervis 2000, Troendle *et al.* 2007). It is unlikely that increases in streamflow could actually be detected as they exit National Forest System lands, assuming a stream gage was present to monitor them (Troendle and Nankervis 2000). This difficulty is exacerbated when considering that stream gages with an 'excellent' data rating have an error margin of +/- 5% (more than the projected increase).

The authors also noted that Forest Service mandates for multiple use and ecosystem sustainability effectively decrease the 'suitable and treatable' land base that could be dedicated to water yield augmentation. More broadly, they state that "extensive land areas suitable for water yield augmentation are not readily available on National Forest System (NFS) lands in the inland west" (Troendle and Nankervis, 2000, p.15).

North Fork Dry Fork and Brownie Creek paired watershed study, Uinta Mountains

An important local study about increased water yields and peak streamflow occurred in the Uinta Mountains (Burton 1997). While not designed to be an experiment, extensive timber harvest in Brownie Creek (25% of the basin) occurred in the 1960s, providing an excellent opportunity to evaluate the effects of timber harvest on a larger scale (~8 mi^2), compared to most experimental studies, which occurred in watersheds less than 1mi^2(Schmidt and Wellman 1999).

Evaluating a 20 year post-harvest streamflow record, Burton (1997) reported a 52 percent increase in water yield per year, and a 66 percent increase in peak flows. Interestingly, flood peaks occurred at about the same time or later in the runoff season as a result of timber harvest rather than 1 or 2 weeks earlier as reported in other studies in the Central Rocky Mountains (Troendle 1983, Troendle and Nankervis 2000). Although the timing of annual peak flow did not change, the observation that increased water yields came during the spring snowmelt season is consistent with other experimental studies (Harr 1983, Troendle 1983, Troendle and Nankervis 2000). In discussing the implications of this study, Burton (1997) noted that large scale alterations of forest cover, whether by timber harvest or other disturbance could lead to changes in channel morphology and aquatic habitats, causing serious, long-term disruption of aquatic ecosystem function and stability.

Troendle and Stednick (1999) questioned the magnitude of water yield and peak flow changes reported by Burton (1997), stating that these magnitudes were generally inconsistent with the larger body of experimental studies. They also stated that while timber harvest can certainly increase peak flows, this may or may not cause channel degradation. On average, peak flows are increased, but it is not necessarily the largest peaks that are increased (Troendle and Stednick 1999).

Burton (1999) responded to these concerns, defending the results of the study and offering some site specific explanations of why the magnitude of change could be different than those observed in smaller experimental watersheds. In addition, Burton (1999) also clarified that extensive channel instability and flood damage to local facilities in Brownie Creek occurred during wet years, and whether these negative impacts could be "solely attributed to timber harvest alterations of the flood regime is not known, but suspected" (Burton 1999).

In discussing these debates and results, Burton (2008 personal communication) reiterated that based on his field observations during the study, the documented increase in peak flow rates after harvest was the best explanation of stream channel degradation and flood damage in Brownie Creek. He also pointed out that any extensive harvest of large watersheds should take these concerns about altered flow regimes and stream ecosystems into account.

ASHLEY NATIONAL FOREST DISCUSSION

Forest Plan Standards and Guidelines

In the existing Ashley N.F. Land and Resource Management Plan, water yield is listed as a goal and objective (U.S. Forest Service 1986, pg IV-37). However, water yield improvement activities are only permitted if compatible with aquatic habitat objectives, stream channel stability ratings, Equivalent Clearcut Acre (ECA) standards, wildlife, recreation, visual quality objectives(VQO), erosion hazards, and landslide hazards (U.S. Forest Service 1986, pages IV 37-39). When considering all of these constraints listed in the forest plan, along with the other limitations identified in this report, a water yield augmentation program is unlikely on the Ashley N.F.

Leading up to the development of the existing forest plan in the mid 1980s, there were some interagency discussions about maximizing water yield in the upper Colorado River Basin states, with very keen interest from groups in Southern California (Tim Burton, personal communication). However, as summarized earlier, Burton's work suggests that maximizing water yields can come with various costs (increased flooding, infrastructure damages, stream destabilization, aquatic habitat degradation etc.)

Practical Considerations

Over the last 5-10 years, the timber program on the Ashley N.F. has treated approximately 2,000-2,500 acres per year (Jim MacRae, personal communication). The forest fuels program (including both prescribed fire and mechanical thinning) has treated an average of 3,000 acres per year (Chris Gambel, personal communication). Combining both the fuels and timber programs, the Ashley N.F. has been treating approximately 5,000-5,500 acres per year forest wide.

Putting the legal, social, and environmental constraints aside, the practical feasibility of a water yield augmentation program on Ashley N.F. can be evaluated by considering the amount of forest vegetation that would need to be removed to produce a measurable increase in flows. The major watersheds (HUC 5) that drain the suitable timber base on the Ashley N.F. include Sheep Creek, Carter Creek, Big Brush, Upper Ashley Creek, Dry Fork, and Whiterocks. They range in size from approximately 42,000 acres – 77,000 acres (NFS lands only). This HUC 5 scale would be useful because most of these watersheds have stream gages at or near the forest boundary that could be used to analyze flow data and water yield.

After subtracting out the non-forested parts of these watersheds, a range of approximately 8,000-14,000 acres would need to be harvested at one time to achieve the 20% treatment threshold. This level of treatment focused in one watershed would be greater than the total acres treated across the entire forest each year (5,000-5,500 acres), and would equate to treating approximately 30-50% of the suitable timber base in these watersheds at one time. This information illustrates that an extensive water yield augmentation program is currently not feasible on the Ashley N.F. This is consistent with recent research observations that "most fuels and timber prescriptions are not likely to exceed the 20-percent basal area removal threshold necessary to result in a detectable change in flow" (Troendle *et al.* 2006).

Vegetation Composition and Historical Range of Variability

Vegetation modeling efforts have shown that vegetative communities on the Ashley N.F. are much closer to historical range of variability than many other forests in the Intermountain Region (Sherel Goodrich, personal communication). The vegetation types that could primarily influence water yield are those in the snow accumulation zone, such as mixed conifer, spruce, fir, lodgepole pine, and aspen. In many cases, the composition of these vegetation types is within expected ranges, and where departure occurs, it has generally been rated as Low or Moderate, with two exceptions rated as High: mixed conifer in the Round Park Landtype Association (LTA), and seral aspen in the North Flank LTA (U.S. Forest Service 2008).

A key vegetation conversion to mention, in terms of water yield, is the expansion of coniferous forests into aspen stands and meadow areas. The decline of aspen communities across the west has been well documented, and is largely attributed to the disruption of natural disturbance regimes, primarily fire suppression (Bartos 2001). This decline has many ecological implications, particularly when considering that aspen communities are second only to riparian areas in species diversity and abundance (Bartos and Campbell 1998). In addition to these ecological concerns, the decline of aspen has been suggested to have a significant affect on water yields (Bartos and Campbell 1998). In areas where coniferous forests have replaced aspen or meadow communities, water yields could potentially be reduced because of decreased snow accumulation in the winter and increased evapotranspiration in the summer.

The best opportunity to realize changes in water yield on the Ashley N.F, if any exist, are in aspen and conifer communities with the highest departure from expected conditions. However, these areas generally make up a small percentage of the broader watershed, and treatment areas comprise yet an even smaller percentage. Vegetation management for a variety of purposes (fuels treatments, timber harvest, habitat improvement, aspen regeneration etc) in these areas could temporarily increase water yields, but the changes would be difficult or impossible to measure at the watershed scale. For these reasons, along with others outlined in this report, water yield is not the primary goal of vegetation treatments, but could potentially be an undetectable, yet real side effect.

Undeveloped and Unroaded Areas

Specific to the Ashley NF, there is very limited, if any, potential to manipulate vegetative conditions on a large scale in order to increase water yield from undeveloped and unroaded areas (Sherel Goodrich, personal communication). This is primarily due to the limited extent of areas where vegetation manipulation is feasible. The majority of the undeveloped areas on the Ashley NF have not been managed in the past for a variety of reasons, such as difficult access, steep slopes, soil erosion and productivity, riparian values, wildlife values, or concerns for overall watershed health. In addition to these physical and ecological constraints, the management direction and regulatory processes related to vegetation management in these areas is unlikely to change in the near future.

Mean Annual Streamflow in the Uinta Mountains

As discussed previously, water yield increases in large drainage basins are very hard to detect (Troendle and Nankervis 2000). However, in order to investigate the assumption that lack of timber management could have decreased water yields over time, I investigated mean annual flow data, an indicator of annual water yield, for three unmanaged basins in the Uinta Mountains. Regression analyses of the Lake Fork (1964-2007), Yellowstone (1945-2007), and Uinta Rivers (1926-1983) showed no statistical trends in mean annual flow over the respective periods of record. From these data, we can not conclude that a lack of management has decreased annual water yields over time. Reservoirs constructed in the headwaters of these drainages are expected to alter the seasonal timing of flows (storage in spring, release in the summer/fall), but not the mean annual flow averaged over the entire year.

Mean annual flow data were also analyzed for two basins where active timber management has occurred. The Whiterocks drainage (1930-2007) showed no statistical trend. Interestingly, Ashley Creek, which has had extensive harvest in the upper watershed, showed a significant ($p=0.03$) decrease over the period of record (1915-2007). The Ashley Creek data is likely complicated by flow diversions and flow augmentation from Oaks Park reservoir. In addition, climatic variables and trends, natural variability, and measurement error could all be factors. This discussion helps illustrate the difficulty in detecting streamflow changes in large watersheds.

Summary

Local observations on the Ashley N.F. demonstrate that a long term program of managing for increased water yield is currently not feasible or compatible with desired conditions.

- Forest Plan Standards and Guidelines related to other resources and values preclude the level of harvest necessary to create measurable increases in water yield (20% of the forested area in a watershed at a given time).
- In addition to resource constraints, the combined fuels and timber vegetation treatments on the Ashley N.F. (~5,000 acres per year) are currently not of sufficient scale to create and maintain the disturbed area sufficient for measurable water yield increases in the major watersheds that drain to downstream communities.
- Vegetation management for a variety of purposes (fuels treatments, timber harvest, habitat improvement, aspen regeneration etc) could temporarily increase water yields on a small scale, but the changes would be difficult or impossible to detect at the watershed scale. The best opportunities to enhance water yield, if any exist, are in places where aspen or meadow communities have been replaced by conifer species.
- Local observations on the Ashley N.F., water yield research, and regional policy all demonstrate the numerous constraints and limitations of augmenting water yields. The Ashley N.F will continue to focus on healthy watersheds and optimal flow, instead of maximum flow. Optimal flow implies healthy vegetative and aquatic ecosystems, which supply clean water for all beneficial uses of that water, both consumptive and non-consumptive (U.S. Forest Service 2002).

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Process Notes – Water Yield Summary Paper

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In writing this summary paper, I requested help and review from our Regional Hydrologist Rick Hopson, who forwarded a message to all the watershed program managers in the region. Charlie Condrat (Wasatch Cache N.F), Barbara Drake (Humbolt-Toiyabe N.F.), and Katherine Foster (Manti LaSal N.F.) all responded with helpful ideas, examples, and references. I discussed National policy direction with Sherry Hazelhurst in the Washington Office, who offered some recent references to include and reiterated that Forest Service policy is well represented in the Region 4 water yield letter (U.S. Forest Service 2002). I also consulted with specialists from other agencies, including Randy Julander with the National Resources Conservation Service (NRCS) and Brian McInerny with the National Weather Service (NWS).