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DRAFT

Review of Vegetation Management and Water Yield

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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).

Overview

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.

- Streamflow response to a change in forest cover is strongly related to climate, species composition, and the percentage change in vegetation density (Troendle *et al.* 2010), as well as slope, aspect, geology, and soil depth.

- Increased water yields are temporary, depending on vegetation recovery rates. The greatest increases have been observed in the first years after treatment. (Troendle and King 1985 and Rosa 1961).

- 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 the interior mountain west streamflow increases occur primarily during the spring and early summer months, with no detectible increases in streamflow in the late summer and fall (Troendle *et al.* 2010 and Hubbart et al. 2007), when irrigation water is most in demand.

- 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). Even 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%).

- Treatments focused on water yield may 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.

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 mountain west, 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.

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.

The Fool Creek study represents the longest and most comprehensive study in the Rocky Mountain region, and the process-based understanding that has been developed at Fool Creek applies widely throughout the snowmelt dominated mountain west (Troendle and King 1895). The Fool Creek watershed annual water yields were calibrated against flows in East St. Louis Creek for a period of 15yr. In 1954 through 1956), 40 percent of the Fool Creek watershed was clearcut in alternating cut and leave strips. The mean annual hydrographs for the 15-year calibration period and the first 15 years after harvest clearly shows that, on average, forest harvest increased both annual and peak flows (fig. 4) (Troendle and King 1895).

Figure 4.The average hydrograph from the Fool Creek Watershed for the 15-year period both before and after treatment.

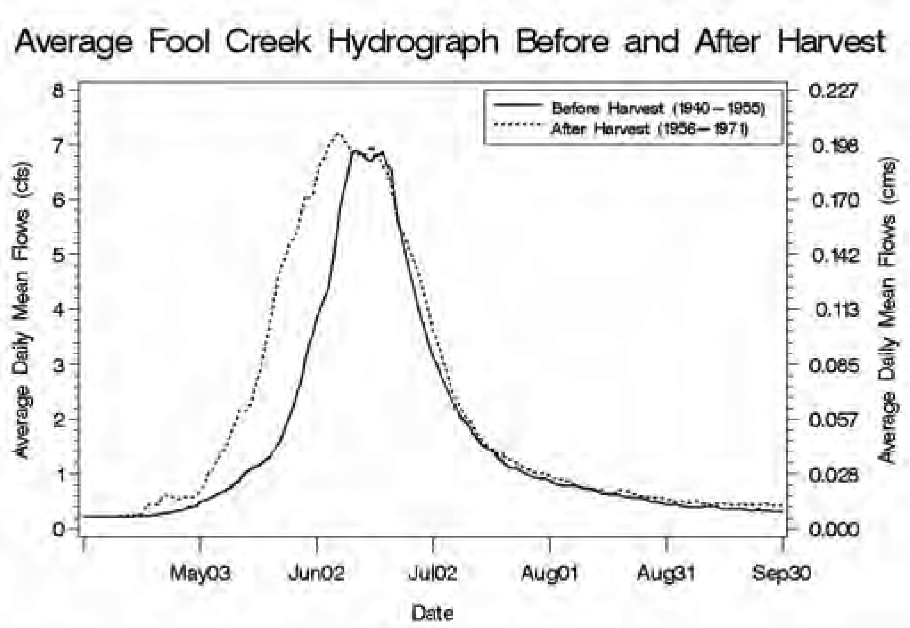
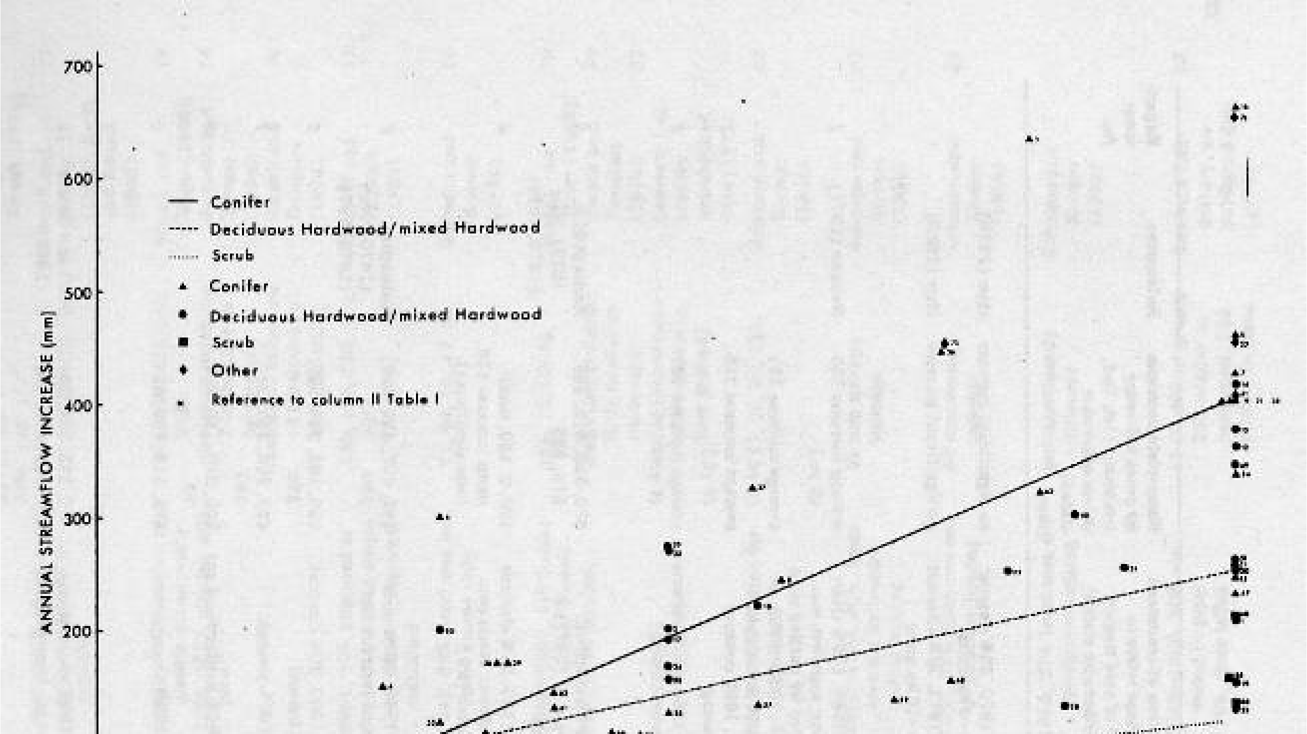


Figure 4. above illustrates that while water yield increases, the increase is almost entirely confined to the spring and summer runoff with nearly no change to the base flow period when addition irrigation water is needed. Many studies have shown that the increased runoff shown in figure 4 is typical of the effect of forest disturbance in the mountain west (Bates and Henry 1928; Swanson and Hillman 1977; Swanson and others 1986; Troendle and Bevenger 1996; Troendle and King 1987; Troendle and Reuss 1997; Hubbart et al. 2007).

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 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 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.* 2010).

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

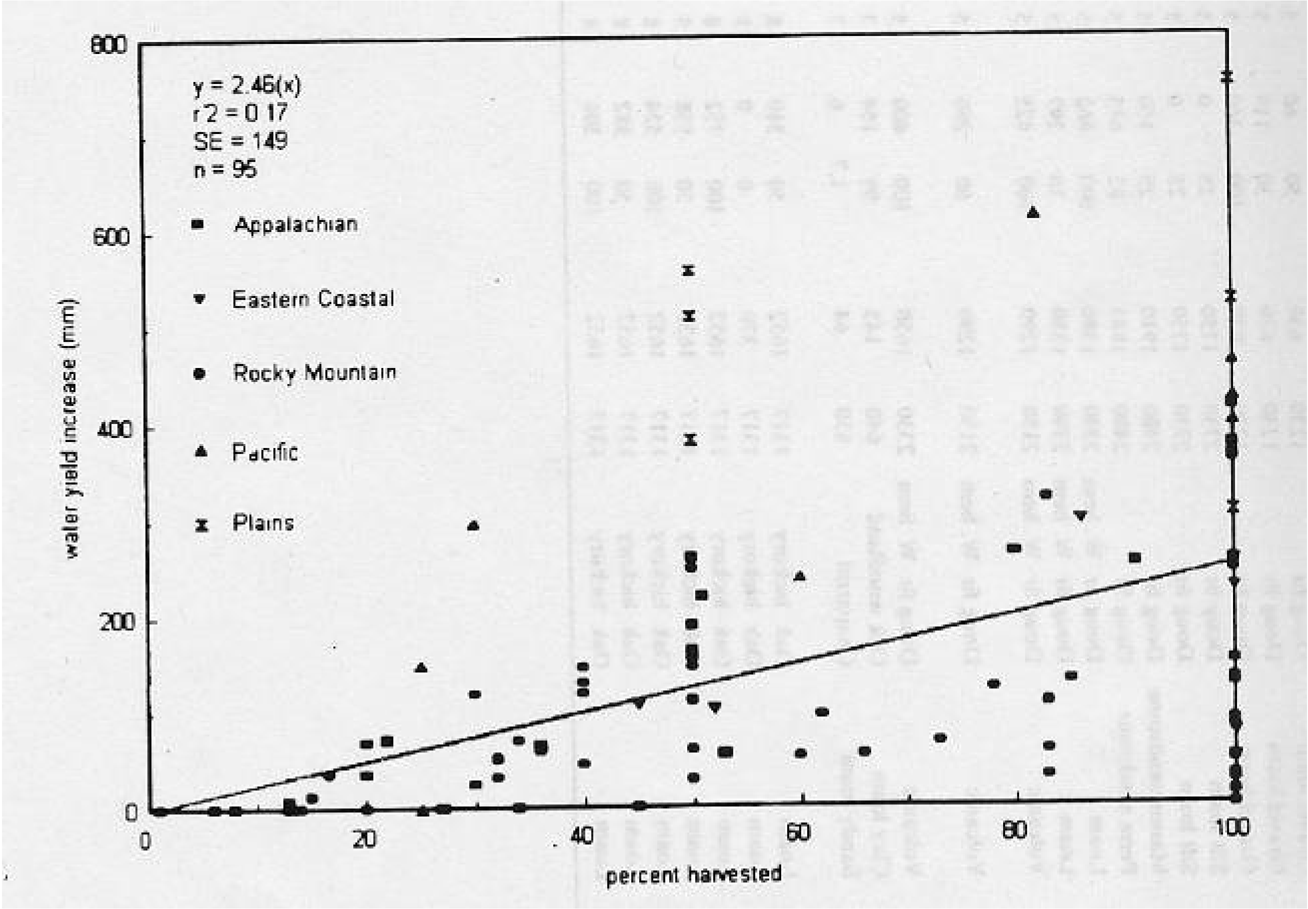


Table 1. Regression model statistics for annual water yield increase versus percent harvest area for all studies and by hydrologic region (Stednick 1996).

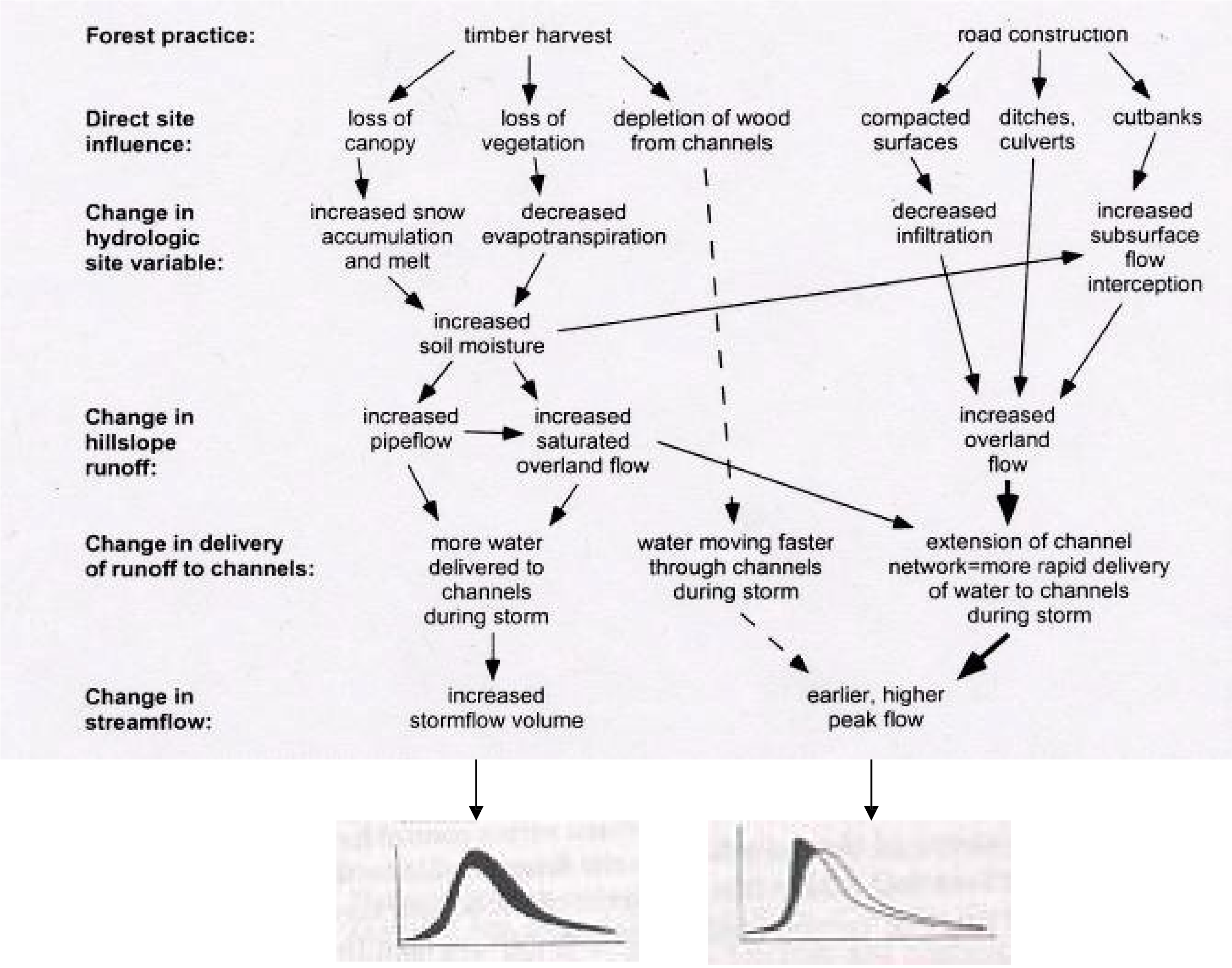
Hydrological region	Number	n	Slope	r^2	SE	p value	Threshold for response
All studies	–	95	2.46	0.17	149	0.0001	20
New England/Lake states	1	3	–	–	–	–	–
Appalachian Mountains and Highlands	2	29	2.78	0.65	75	0.0001	20
Eastern Coastal Plain and Piedmont	3	7	1.84	0.02	97	0.0051	45
Rocky Mountain Inland Intermountain	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.

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.

Snow Accumulation and Melt

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

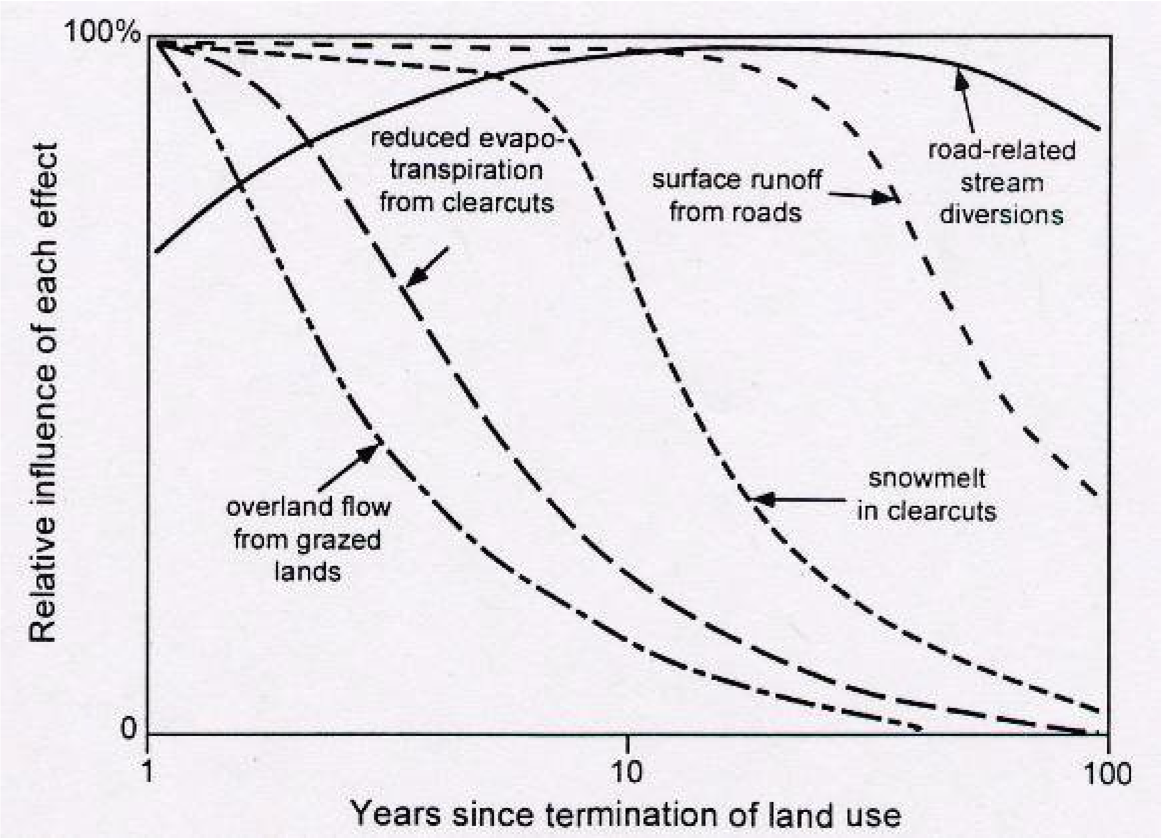
The roads associated with timber harvest have been identified as a major contributing factor to the timing and volume of peak streamflows, as well as increased erosion and sedimentation (Chamberlin *et al.* 1991, Gucinski *et al.* 2001). The influence logging roads have on peak flows depends on the arrangement 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). 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 Mountain 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, if they are present, 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
    - 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.
    - 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). 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.

North Platte River basin study, Colorado

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).

Mica Creek Experimental Watershed case study

Water yield investigations in the Mica Creek Experimental Watershed (MCEW) serves as an excellent example of what we should expect in the hydroclimatic regime of Western Montana. The Mica Creek Experimental Watershed (MCEW) is an example of a paired research watershed located in northern Idaho at approximately at 47.17°N latitude and 116.25°W longitude. The climatic regime consists of both continental and maritime weather systems that are common across much of Western Montana. With warm and dry summers, and cold and wet winters with occasional rain-on-snow events resulting from warmer Pacific air (Hubbart et al. 2007). The elevation Mica Creek Experimental watershed ranges from 3280 to 5250 ft above sea level, with an average annual temperature of 4.5°C and annual precipitation is approximately 1,450 mm, the majority of which falling in November through May, with over 70% falling as snow (Hubbart et al. 2007).

Streamflow flow was measured starting in 1991 at the Mica Creek Experimental Watershed (MCEW). The effects of road construction and two different harvest practices (50% clearcut, 50% partial cut) on water yield were examined. These treatments resulted in water yield increases in excess of 270 mm/yr (P _ 0.01) after clearcut harvesting, and by more than 140 mm/yr (P _ 0.01) after partial cut harvesting. Analyses of the monthly and seasonal distribution of flow revealed that the largest impacts on water yield from harvest practices occurred during the snow deposition and melt season from November through June. During the dry season (July through October) water yield increases after treatments where negligible (Hubbart et al. 2007).

These results are very similar to the results many other paired watershed studies conducted in the Western Rocky Mountains (Bosch and Hewlett 1982), that demonstrate that these areas with snow dominated precipitation regimes do not tend to see substantial late season (July-October) benefit from potential water yield increases.

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