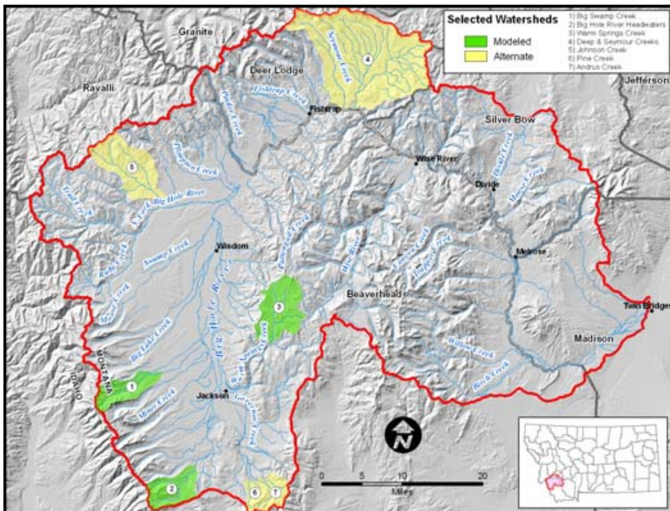
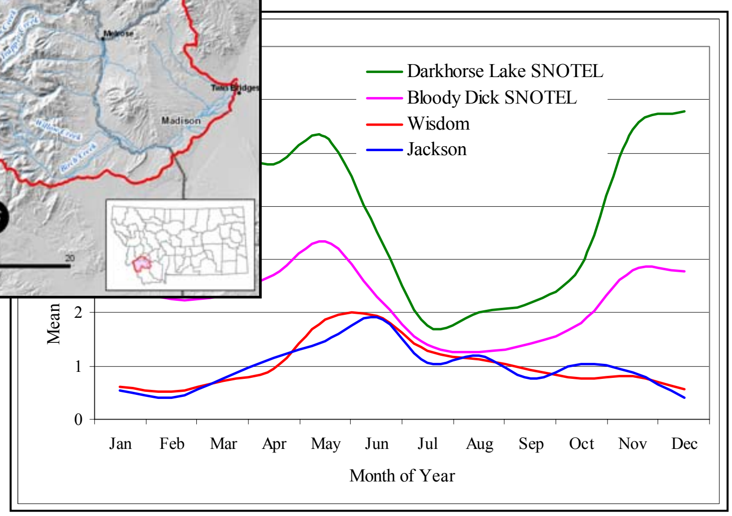
Vegetation Change

and

Impacts to the Annual Water Budget
Big Hole River, Montana





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1.0 INTRODUCTION

This report provides research and analysis on upland vegetation change over time in the upper Big Hole River watershed and the impact of this change on the availability of water for instream flow and irrigation. Also included are recommendations for forest management that could improve steam flows. Previous studies investigated reservoir storage alternatives (Portage, DTM, and Mainstream, 2005) and other water management alternatives (DTM, Mainstream, and Portage, 2005). Follow up efforts of these two studies are currently in progress.

1.1 EXECUTIVE SUMMARY

This study represents a look at vegetation changes and hydrologic impacts over a relatively short period, 50 years. Natural cycles in these environments generally occur over much longer, 300 to 500-year, intervals. The conclusions drawn from the vegetation change analysis and water budget modeling are still valid for understanding the processes and impacts from changes over longer cycles. The processes of vegetative succession, fire, insect infestation and disease in the Big Hole River watershed are consistent with processes occurring throughout the Northern Rocky Mountains. The modeling results and conclusions drawn from this study are well supported by the current body of scientific research.

Five primary tasks are addressed by this study and form the main sections of this report:

1) Map historic and current vegetation conditions for selected sub-watersheds in the upper Big Hole River watershed;
2) Assess the changes in vegetation between the historic and current periods;
3) Assess the impacts to the water budget resulting from the changes in vegetation;
4) Propose causes for the changes in both vegetation and water yield; and
5) Make management recommendations to mitigate any impacts.

Three sub-watersheds to the Upper Big Hole watershed were selected for further study: Warm Springs Creek, Big Hole Headwaters, and Big Swamp Creek. These basins provide significant flows to the mainstem of the Big Hole River and represent varied topography, land use, and geology.

Tasks 1 and 2 resulted in one current and two historic landcover data sets for each of the three sub-watersheds. These data represent a synthesis of black and white aerial photography and satellite imagery. Each data set is a 30-meter grid that assigns each grid cell to one of 15 landcover classes. The two historic data sets are the result of a conservative and a liberal approach to determining which grid cells changed classes between the current and historic times. The liberal approach shows more conifer encroachment between the historic and current periods. Comparing the historic and current data sets shows that conifer encroachment has occurred within the study area. Some of the encroachment has occurred at the forest fringe and infill of grasslands, while a larger percentage of change occurred due to densification of existing forested areas. The results were similar between the Warm Springs Creek and Big Hole Headwaters watersheds. The Big Swamp Creek watershed showed little change, due to timber harvest activities that balanced out conifer encroachment in other areas.

SWAT (Soil Water Assessment Tool) was selected to model the impacts to the water budget resulting from the changes in vegetation. SWAT is a daily time step model that creates simulated hydrographs from a set of input data such as vegetation, soils, and climate. For this study, the only parameter that was changed in the modeling was the vegetation data layer. This way we could assess the hydrologic response of each watershed resulting from the change in landcover. The results of the SWAT modeling were consistent with regional research and indicate that annual yields increase as conifer area decreases. Changes in yield were minimal when using the conservative historic vegetation cover, and only slightly better when using a vegetation data set that shows significant conifer encroachment.

There are many factors influencing the current water shortage in the Big Hole River. Conifer encroachment is a small part of that picture. Changes in climate, irrigation practices, land management, and human use all contribute to the reduced flows.

While this study and associated research indicate that yields can be increased through aggressive vegetation management, the timing of the additional yield does not help to maintain instream flows during the summer months. Reducing canopy cover reduces precipitation interception, especially during the winter. This allows snowpack to accumulate more efficiently. It also results in less shading leads to an early runoff with higher peaks. Summer flows are actually reduced. Viable management alternatives are limited to water storage and delivery issues.

Conifer encroachment is a natural process. It can be accelerated by changes in land use and management practices, but is mainly the result of long-term succession in the vegetation, climate, fire cycles, and chance events.

1.2 General Characteristics

The Big Hole River follows an arcing course approximately 160 miles from its headwaters on the Montana/Idaho border of southwest Montana to its mouth near Twin Bridges, Montana (Figure 1). The Big Hole River originates as a high-altitude mountain stream in the Beaverhead Mountains south of Jackson, flowing 10 miles north into the Upper Big Hole valley. From there, it flows north for 50 miles through a broad high elevation valley on the western margin of the Pioneer Mountains. Between Pintlar Creek and Fishtrap Creek, the river turns northeastward and enters a canyon that wraps around the northern portion of the Pioneer Range. Near Divide, the river turns southward and flows through a series of canyons and open valleys, past Melrose and Glen until it swings eastward to its ultimate confluence with the Beaverhead River, near Twin Bridges. Twin Bridges marks the confluence of the Big Hole, Beaverhead, and Ruby Rivers, which combine to form the Jefferson River.

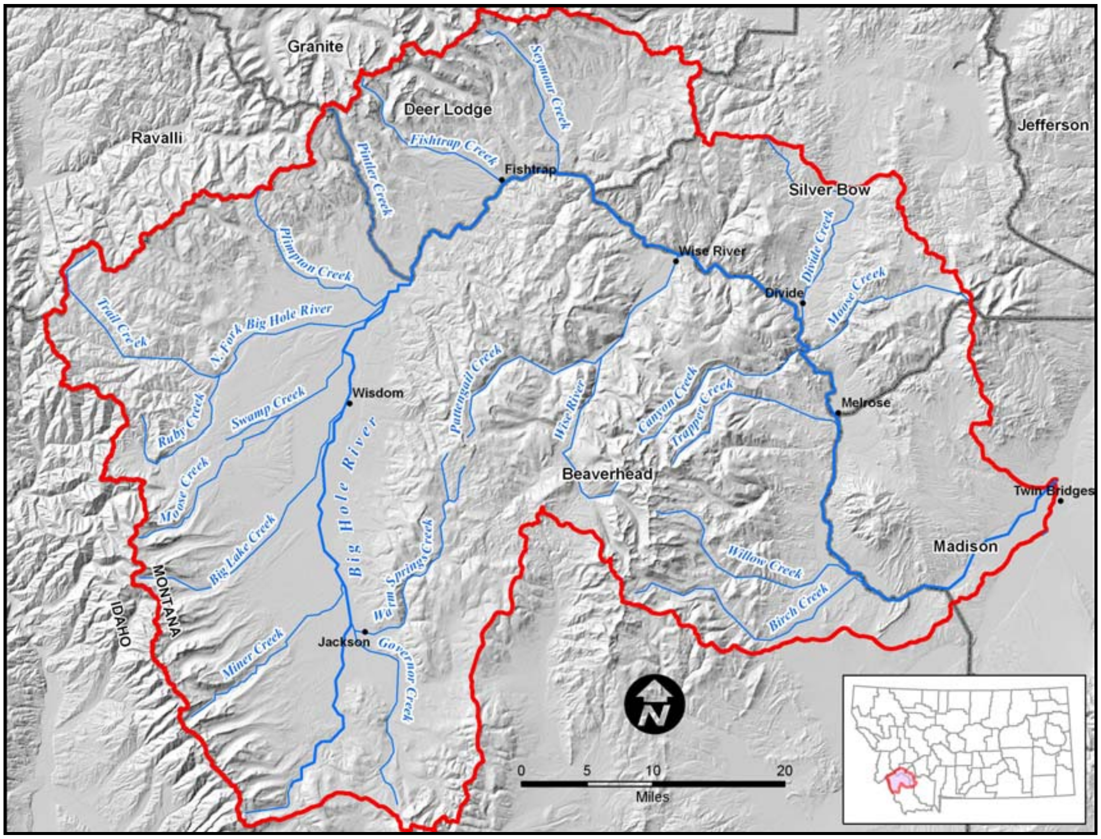

Figure 1. The Big Hole River watershed.

The upper Big Hole River valley is one of the widest and highest elevation valleys in southwest Montana. The valley is approximately 32 × 52 miles in dimension, and the valley floor elevation exceeds 6,000 feet throughout. Much of the valley bottom consists of Quaternary alluvial and glacial deposits often overlying Tertiary aged sedimentary rocks of the Bozeman Formation. The Beaverhead Mountains along the western edge of the watershed consist mostly of Proterozoic age quartzite, argillite, limestone, and shale. The Pioneer Mountains, which consist dominantly of Cretaceous granitic intrusive rocks, comprise the eastern boundary of the watershed. The northern boundary, defined by the Anaconda Range, consists mostly of Tertiary granitic intrusive rocks. Oil exploration drilling in the 1980s revealed thick accumulations of Tertiary sediments filling the upper Big Hole River valley. These basin fill deposits, which approach 14,000 feet in depth, are thicker than any other in the region (Alt and Hyndman 1986).

Long cold winters and short, moderately hot and dry summers characterize the climate of the upper Big Hole River watershed. Average monthly minimum temperatures and maximum temperatures range from 1.8 to 78.1 degrees F in January and July, respectively. The valley portions of the watershed are semiarid with average annual precipitation of 11.82 inches/year at Wisdom. Headwater portions of the watershed receive considerably more precipitation, reaching an average 53 inches/year in the headwaters of Berry Creek, located in the southwest portion of the watershed. The growing season is short, with about 88 frost-free days per year. Maximum daily temperatures are below freezing for an average of 75 days per year.

1.3 HYDROLOGY

The hydrology of the Big Hole River and its tributaries reflects significant alteration of natural flow conditions due to water use practices. Dewatering and its associated impacts to aquatic habitat play a large role in the current management efforts in the watershed. This report addresses one possible cause for reduced in stream flows, vegetation change. This section describes hydrologic conditions in the Big Hole River watershed, focusing on the upper Big Hole River watershed.

Publicly available stream gage data document the magnitude, timing and patterns of stream flow in the Big Hole River watershed (Table 1).

Site Number	***Station Name***	***Upper Basin?***	***Drainage Area(mi^2)***	***Begin Date***	***End Date***	***Period of Record (Years)***
6024470	Swamp Creek near Wisdom MT	Yes	66.1	3/28/1995	9/30/1996	1.5
6024510	West Fork Ruby Creek near Wisdom MT	Yes	13.4	4/1/1995	9/30/1996	1.5
6025270	Moose Cr above Maclean Cr nr Divide MT	No		10/1/1997	9/30/1999	2
6025250	Big Hole River at Maiden Rock nr Divide MT	No		10/1/1997	9/30/2002	5
6026400	Big Hole River near Twin Bridges MT	No	2762	7/25/1979	10/1/1981	2
6024580	Big Hole River near Wise River MT	No	1611	6/1/1979	10/2/1981	2
6026210	Big Hole River near Glen MT	No	2655	10/1/1997	Present	7
6025000	Big Hole River near Dewey MT	No	1990	9/1/1910	9/30/1913	3
6024540	Big Hole River below Mudd Cr nr Wisdom MT	No	1267	10/1/1997	Present	7
6023500	Big Hole River near Jackson MT	Yes	44	4/29/1948	10/31/1953	5.5
6024000	Miner Creek near Jackson MT	Yes	17.6	5/24/1948	10/31/1953	5.5
6025800	Willow Creek near Glen MT	No	35.6	8/1/1962	9/30/1999	37
6024450	Big Hole River below Big Lake Cr at Wisdom MT	Yes	575	5/1/1988	Present	16
6024500	Trail Creek near Wisdom MT	Yes	71.4	6/29/1948	7/20/1972	24
6025700	Willow Cr Diversions to Birch Cr nr Glen MT	No		4/21/1946	9/30/1966	20
6024590	Wise River near Wise River MT	No	214	9/28/1972	9/30/1985	13

Site Number	*Station Name*	*Upper Basin?*	*Drainage Area(mi^2)*	*Begin Date*	*End Date*	*Period of Record (Years)*
6026000	Birch Creek near Glen MT	No	36	5/1/1946	10/6/1976	30
6025500	Big Hole River near Melrose MT	No	2476	10/1/1923	Present	81

Table 1. Available USGS gaging stations and periods of record in the Big Hole River watershed.

It is important to note that the short, recent periods of record for gages in the upper basin reflect impacted hydrologic conditions. Therefore, it is not possible to use the gage data to quantify natural conditions, or to quantify long-term hydrologic trends. However, two historic stream gages, Big Hole River near Jackson (Van Houten Lake) and Miner Creek near Jackson recorded stream flow data from 1948 to 1953. These gages provide information on the hydrology of upland forested watersheds in the basin. The Big Hole River near Jackson gage is in one of the sub-basins chosen for vegetation change analysis in this study. Both gages show peak water yields occur between late May and mid-June. The graphs are roughly symmetric, with gradual rise and fall with peak runoff and recession. Peak flows were around 300-500 cfs for the Big Hole near Jackson gage and slightly less for the Miner Creek gage. Winter flows ranged between 5 and 20 cfs at both gages (Figure 2).

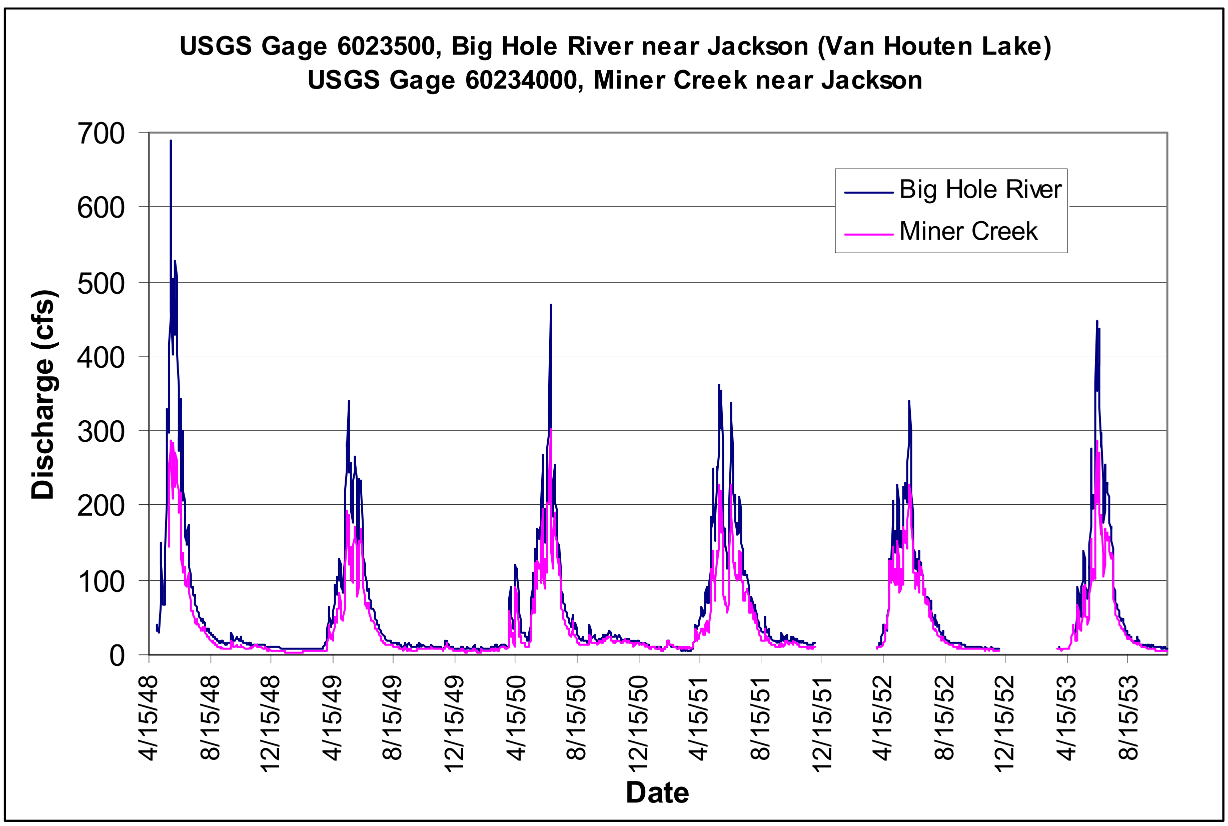

Figure 2. Daily discharge at two historic headwater stream gages in the upper Big Hole River watershed.

1.4 CAUSES OF WATER SHORTAGE IN THE BIG HOLE RIVER

Water in the upper Big Hole River is in short supply during the summer irrigation season, after peak runoff. Demands for water can exceed supply, resulting in very low flows (less than 20 cfs) at the stream gauging station at Wisdom (DTM, Mainstream, and Portage, 2005).

Historic climate records (1946 to present) indicate a gradual shift from wetter to drier winters and from colder to warmer spring temperatures. The average annual precipitation appears to be much the same as it was 50 years ago, while average annual temperatures have risen slightly. Both the lower winter snow pack and warmer spring temperatures reduce the amount of spring and summer runoff for both fisheries and agriculture. In addition, six consecutive drought years have compounded the long-term climate trends (DTM, Mainstream, and Portage, 2005).

Land use practices have also gradually changed in the upper Big Hole River watershed over the last 20-30 years. In some areas, a shift from hay production to irrigated pastures results in more water consumed in the late summer months, when hay was traditionally cut and irrigation ditches closed. In addition, the increased use of excavators and other mechanized equipment has allowed irrigators to gradually enlarge and expand irrigation systems. This also contributes to increased water consumption during the late summer months (Big Hole Water Management Alternatives, 2005). In addition, eradication of beaver in the late 1800s and early 1900s eliminated much of the natural storage capacity that likely existed in the watershed. While some beaver populations have returned to the main stem of the Big Hole, they have not reestablished in the tributaries. Both tributary streams and the mainstem Big Hole River would have had higher late season flows from the slow release of this natural storage.

The gradual changes in land use and irrigation practices, combined with gradual climate changes contribute toward a critical situation for instream flows in the upper Big Hole River watershed. In addition, several irrigation diversions convey water from the Big Hole River out of the watershed area above the Wisdom Bridge, exacerbating dewatering in this reach (DTM, Mainstream, and Portage, 2005).

1.5 ACKNOWLEDGEMENTS

This project was accomplished through a contract between the Big Hole Watershed Committee and DTM Consulting, Inc. Noorjahan Parwana, Executive Directory of the Big Hole Watershed Committee was instrumental in providing contract management and facilitating communication between the authors, the Technical Advisory Committee (TAC) and concerned parties within the watershed. Robert Ahl of the University of Montana was especially helpful in the modeling process and sharing the culmination of several years of research in water balance modeling in Rocky Mountain forests. The project team extends its gratitude to all involved parties that facilitated this effort.

2.0 HISTORIC AND CURRENT VEGETATION COMMUNITIES

The following sections discuss the available data sets and assess the identified changes in landcover.

2.1 DETAILED SUB-WATERSHEDS

For the vegetation assessment and subsequent hydrologic modeling to provide relevant, compelling, and useful information, sub-watersheds chosen for intensive analysis need to contain characteristics that are most representative of the Big Hole Watershed as a whole. Primarily, a watershed must be large enough to provide significant water volume contributions to the Big Hole River. Because the upper river represents the area of primary concern for water quantity, we limited the selection of watersheds to those upstream from Wisdom. Secondly, watersheds need to represent different management scenarios, including harvest, fire, and minimally managed natural areas. The selected watersheds cover a variety of management strategies with the exception of natural fire, which is generally lacking in the Big Hole watershed. According to Forest Service data, the largest natural fire to occur in the Big Hole basin (excluding the Mussigbrod fire) is approximately 80 acres. Finally, the highly variable geology present throughout the upper basin needed to be represented. To this end the selected watersheds cover the Proterozoic (Belt) meta-sedimentary rocks, covered by glacial till and outwash on the western boundary; the Cretaceous intrusive and Proterozoic (Belt) rocks, locally overlain by glacial till, of the Pioneers; and the Proterozoic (Belt) meta-sedimentary and Cretaceous intrusive rocks, overlain by Tertiary sedimentary deposits (Bozeman Formation) of the southern basin. Each of these geologic types leads to differing geographic setting, which in turn can lead to differences in hydrology.

With these criteria in mind, we selected the following watersheds (Table 2 and Figure 3):

- Big Swamp Creek – This watershed is one of the larger basins on the west side of the Big Hole valley. A significant portion of the watershed is at higher elevation, resulting in increased precipitation. As such, it is a critical source of water. Most other watersheds on the west side either flow into the North Fork of the Big Hole River, or are so narrow that they do not contribute significant water to the Big Hole River.
- Big Hole River Headwaters – This watershed is located in the southwest corner of the Big Hole valley. The geology is different from Big Swamp Creek to the north, resulting in a more bifurcated drainage pattern that is typical of the basins in this portion of the valley. Together these watersheds contribute a significant portion of the potential water to the valley. There is a historic gage on the Big Hole River just downstream from this drainage at the confluence with Pioneer Creek, although the period of record for this gage is only for 1948 - 1953. This gage is one of two sources of flow information from a headwaters basin.
- Upper Warm Springs Creek – The portion of Warm Springs Creek in the Pioneer Mountains upstream of Old Tim Creek is interesting for a couple of reasons. First, it has seen little to no management activity other than a few, small natural fires and some fire suppression. Therefore, it has numerous open parks that provided a good opportunity to

identify possible conifer encroachment. Secondly, the geology varies from the other selected watersheds by consisting primarily of granitic intrusive rock.

Attribute		***Watershed Summary Statistics***		
		Warm Springs	***Big Swamp Creek***	***Big Hole Headwaters***
Area	**Acres**	24512	10518	13643
	Hectares	9919.7	4256.5	5521.1
Elev (ft)	**Min**	7044	6778	7044
	Max	9403	10295	9780
	Avg	7805	8015	8041
	Std Dev	364	715	636

Table 2. Summary statistics for the Warm Springs, Big Swamp Creek, and Big Hole Headwaters sub-watersheds.

Alternate watersheds:

We assessed three other watersheds before selecting the primary basins. These watersheds were rejected for various reasons, but still may be interesting for further study.

- Andrus Creek & Pine Creek – These two drainages are adjacent to each other at the southern end of the valley. They represent lower elevation drainages and therefore lack the precipitation to contribute significantly to the water budget.
- Johnson Creek – This large watershed flows into the North Fork of the Big Hole River and therefore does not contribute flow to the critically dewatered stretch of the Big Hole. Most of its area burned in the Mussigbrod fire. Unfortunately, this watershed lacks complete historic photo coverage on the west end of the basin.
- Deep Creek/Seymour Creek – These watersheds lie at the north end of the Big Hole watershed and are interesting due to their large size and extensive harvested areas. They were not selected mainly due to the lack of historic photo coverage on the north end of the basins.

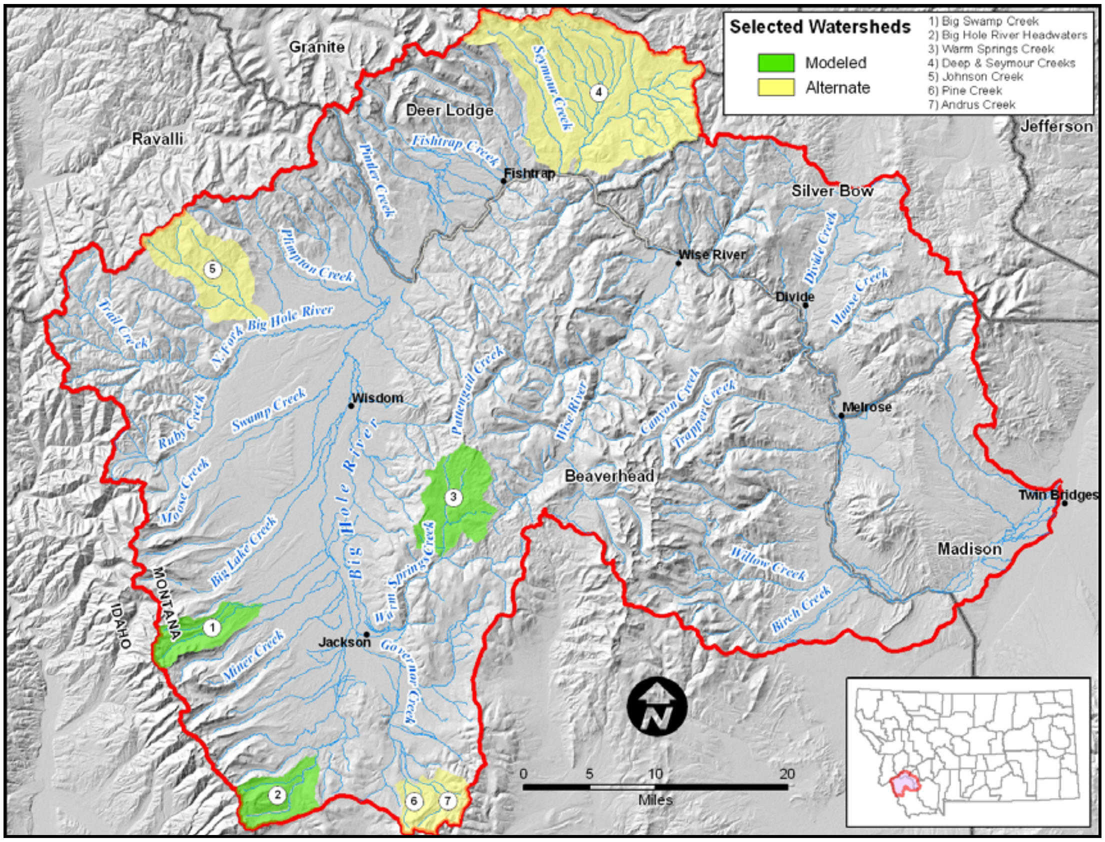

Figure 3. Selected watersheds.

2.2 AVAILABLE DATA

Three primary data sets were required for this project: vegetation, hydrologic, and climate. The available data and its limitations are discussed below.

2.2.1 Vegetation

The primary available vegetation data sets for the Big Hole watershed include Satellite Image Landcover Classification (SILC) coverages developed at the University of Montana, the Timber Stand Management Record Survey (TSMRS) from the Beaverhead-Deerlodge National Forest, and Montana GAP data from the University of Montana. Each data set has a specific purpose and a proper use. For this study, the SILC datasets provided the most comprehensive data both spatially and in terms of the attributes necessary to perform the required analysis.

SILC data was originally commissioned by the US Forest Service and produced by the Wildlife Spatial Analysis Laboratory at the University of Montana. SILC uses satellite imagery analysis techniques, stand-level inventory data, and field verification to identify land cover classes. For this project, 15 primary landcover classes were extracted from 1990s imagery according to research from the University of Montana (Ahl 2005). Class definitions are based largely on the hydrologic response and differences in these characteristics between landcover classes. The resulting landcover classes, associated vegetation, and hydrologic parameters critical to watershed scale hydrologic modeling are listed in Table 3.

Value	*Description*	*Code*	*Max HT (m)*	*Max LAI*	*Min LAI*	*Interception*
1	No Data	NNDD	0	0	0	0
2	Barren	BRRN	0	0	0	0
3	Water	WATR	0	0	0	0
4	Pasture	PSTR	0.5	1	0	0
5	Grassland	GLND	0.5	1.5	0	0.03
6	Shrubland	SLND	3.5	2	0	0.05
7	OpenForest	OPFR	10	2	1	0.15
8	Riparian Shrub	RIPS	3.5	2	0	0.1
9	Riparian Forest	RIPF	35	2	1	0.15
10	Quaking Aspen Forest	QAFR	15	2	1	0.15
11	Spruce-Fir Forest	SFFR	26	3	1.5	0.28
12	Lodgepole Pine Forest	LPFR	22	2.8	1.4	0.25
13	Douglas Fir Forest	DFFR	35	3.1	1.55	0.25
14	Ponderosa Pine Forest	PPFR	35	2.5	1.25	0.2
15	Transitional Forest	TRNS	10	2	1	0.1

Table 3. SILC landcover classes and associated hydrologic characteristics. Max HT = maximum vegetation height. LAI = Leaf Area Index. Interception = Annual Total Interception as proportion of total precipitation.

SILC landcover data sets are uniform grids of 30m by 30m cells, the resolution of the input satellite data. The area of any given incidence of landcover class is therefore at least 900 square meters. SILC classes are based on habitat type group, species, size class, and density attributes. However, SILC data sets have difficulty identifying size class and density, thus misclassifying a large proportion of the watershed as transitional forest. Much of this is attributable to the limited ability to identify differences in stand age at the resolution of the satellite imagery. Therefore, SILC landcover classes used in this analysis are attributed with information that pertains only to habitat type group and species.

TSMRS Dataset and limitations

The Forest Service developed the TSMRS to assist in managing timbered areas for harvest. It represents a significant mapping effort from aerial photography, followed by extensive field verification. This resulted in over 25,000 stand polygons for the areas within the Beaverhead National Forest area of the Big Hole watershed. Each polygon is attributed with information such as species, size, and crown closure. Since the development of the TSMRS, the underlying database is frequently updated with activities such as harvest, thinning, and burns. These activities, in addition to natural growth, are accounted for in the database.

TSMRS data are limited to areas within the National Forests. As such, using the TSMRS for modeling efforts that cross Forest boundaries is problematic. Additionally, the hydrologic model chosen for this study (SWAT) uses vegetation classes that are calibrated for the 15 SILC classes in Table 3.

SILC – TSMRS Composite Dataset

An effort was made to combine the best attribute information from both the TSMRS and SILC to create a composite dataset representing both datasets. Ultimately, this combined dataset was rejected for two reasons. First, incomplete coverage from the TSMRS resulted in a dataset that varied in attribute accuracy depending on whether an area was inside or outside the National Forest. Second, the resulting land cover classes have not been tested in the SWAT model and therefore the required modeling parameters are unknown.

2.2.2 Hydro Data

Hydrologic data is relatively limited in the Big Hole watershed. Available gaging station data is primarily focused on the main stem of the Big Hole River. Only one station is located on a modeled headwaters basin, Site Number 06023500 (Table 4). The other headwaters gage is located on Miner Creek. The Miner Creek basin was not selected because it is very narrow and does not contribute significant flows to the Big Hole River.

Site Number	*Site Name*	*Period of Record*	*Drainage Area (sq mi)*	*Months Recorded*
06023500	Big Hole River near Jackson	Apr 1948-Oct 1953	44	Jan-Dec
6024000	Miner Creek near Jackson	May 1948-Oct 1953	17.6	

Table 4. Available USGS streamflow gage stations and periods of record for headwaters drainages in the Big Hole River watershed.

While there is a concerted effort to improve this, the lack of historic flow information creates challenges in calibrating hydrologic modeling. These issues are discussed in detail later in this document.

2.2.3 Climate

Available climate data for the Big Hole Watershed is limited to four sites, two of which are located in the Big Hole valley at Wisdom and Jackson. In addition to the valley sites, two NRCS SNOTEL sites located in the Big Hole Headwaters sub-watershed provide climate data. To simulate the hydrology in the sub-watersheds, we used precipitation and temperature data measured at Jackson due to its close proximity to the sub-watersheds. Data obtained at the SNOTEL sites was used to help adjust the Jackson data for elevation and location differences. The Jackson weather station has been active since 1948 (Table 5), with some gaps in the data in the 1980s and late 1990s. The Bloody Dick SNOTEL site, located near the southern divide of the Big Hole watershed, has been active since 1979 and has recorded data continuously since that time. Located at 8700 ft (2652m), the Darkhorse Lake SNOTEL site has continuous precipitation and temperature data since 1980.

Station ID	***Station Name***	***Location***	***Period of Record***	***Elevation (m)***	***Mean Annual PPT (in)***
249067	Wisdom Weather Station	Wisdom, MT	Jun 1949 - Jul 2004	1847	11.83
244447	Jackson 1 SE Weather Station	Jackson, MT	Jul 1948 - Jul 2004	1975	12.4
436	Darkhorse Lake Snotel	Big Hole Headwaters sub-watershed	Oct 1980 - present	2652	48.9
355	Bloody Dick Snotel	Big Hole Headwaters sub-watershed	Oct 1979 - present	2301	26.93

Table 5. Available weather stations and periods of record in the Upper Big Hole River watershed.

Recorded annual precipitation since 1980 is highly variable and shows a pattern of oscillating periods of both above and below average precipitation. In the Big Hole valley, annual precipitation at Wisdom and Jackson from 1980 to 2002 ranged from 8 inches to almost 20 inches (Figure 4). Data gaps exist at Jackson for three to four months a year during 1980-1981 and 1985-1986. Based on comparison with data collected during this period at the other three weather sites, near average precipitation was assumed to occur during these years at Jackson,.

In the Big Hole Headwaters sub-watershed, annual precipitation ranged from around 20 inches to almost 66 inches (Figure 5). Temporal patterns of above average to below average annual precipitation paralleled the patterns found at Jackson and Wisdom in the Big Hole valley. The increased precipitation reflects these sites' high-elevation mountain locations. The 66.1 inches of annual precipitation at Darkhorse Lake in 1997 is the maximum recorded precipitation for all four weather sites.

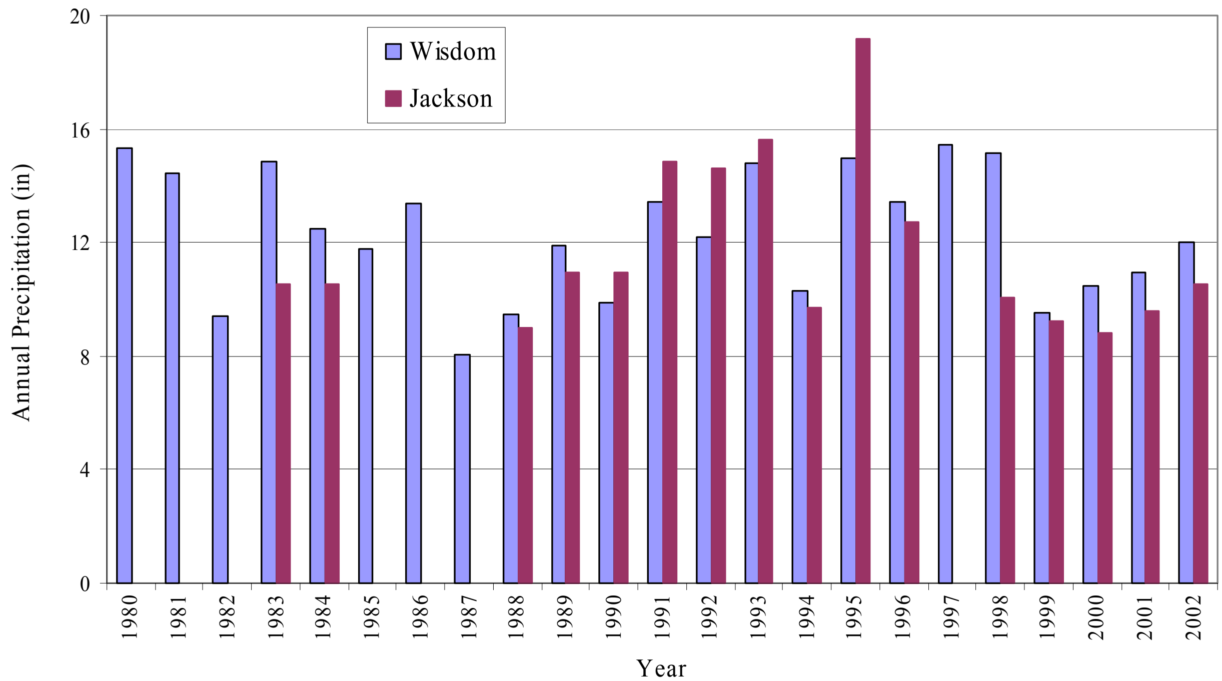

Figure 4. Annual precipitation for Wisdom, MT and Jackson, MT for the period 1980-2002.

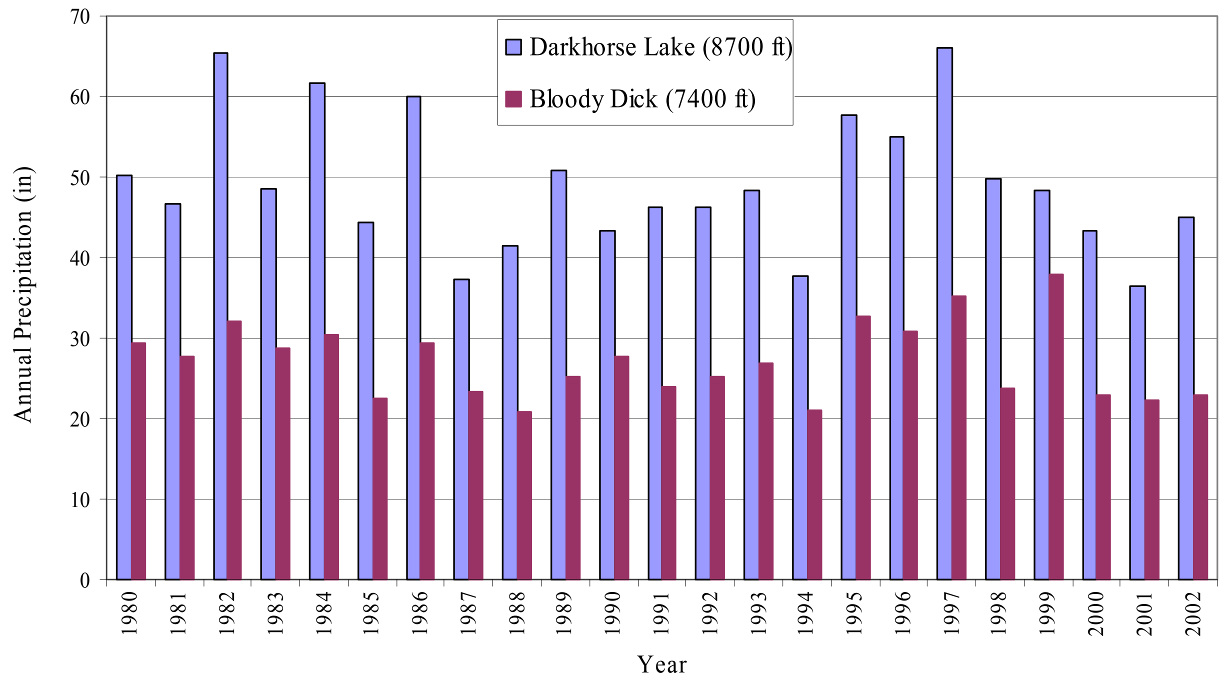

Figure 5. Annual precipitation for Darkhorse Lake and Bloody Dick SNOTEL sites for the period 1980-2002.

Mean monthly precipitation recorded at the four stations indicates that the highest amounts of precipitation occur in May and June for the valley sites of Wisdom and Jackson (Figure 6). The mountain SNOTEL sites also record elevated precipitation amounts in May, but also have elevated amounts during the winter months of November through January, and only slightly lesser amounts during the period February to April. Most of this precipitation occurs as snow and represents the primary source of flows to the Big Hole River. Precipitation declines sharply from May to July at the SNOTEL sites, and from June to July in the valley. This drop in precipitation correlates well with the considerable decline in the hydrograph for the USGS gaging stations located on the Big Hole River.

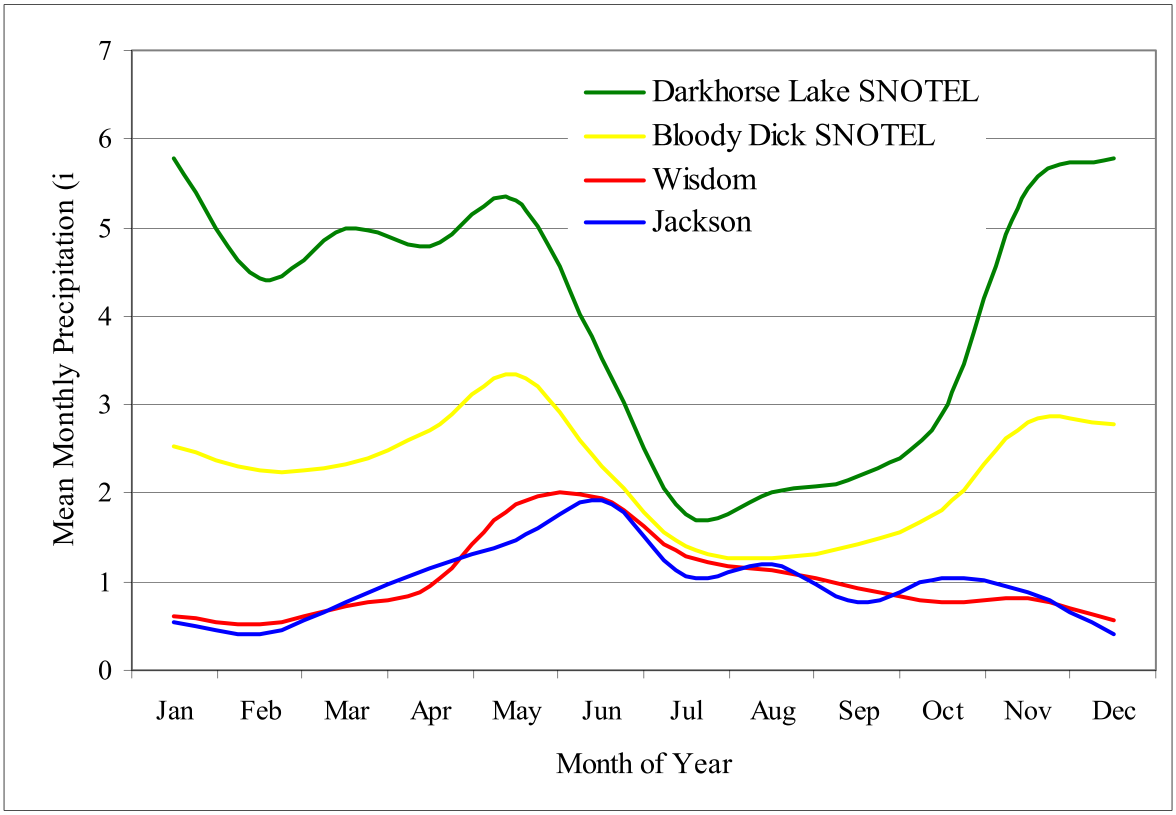

Figure 6. Mean monthly precipitation for the Wisdom and Jackson weather stations and the Darkhorse Lake and Bloody Dick SNOTEL sites.

2.3 Vegetation and Landcover Conditions

The process of creating consistent landcover data sets, analysis techniques, and the results of analysis are discussed in the following sections.

2.3.1 Methodology

Current and historic landcover conditions were assessed in order to determine changes occurring in the second half of the twentieth century. This required developing spatially consistent and comparable landcover data sets for each of the three sub-watersheds representing both the current and historic conditions. Developing these datasets required a combination of photo interpretation and image analysis techniques.

The 30-meter SILC datasets are the basis for creating landcover datasets representing current and historic conditions. The SILC classes were refined using high resolution aerial photography to better depict historical and current landcover conditions in the sub-watersheds. Photography from 1942 was used for the Big Swamp Creek and Big Hole Headwaters watersheds, while 1960s photographs were used for the Warm Springs watershed. These photographs were scanned, georeferenced, and mosaiced in the project GIS. Existing 1995 Digital Orthophoto Quadrangles (DOQ) produced by the USGS were used to assess current landcover for all watersheds. Thus, historical landcover conditions are the interpreted conditions on the ground in either 1942 or 1960, while current landcover conditions are those found on the ground in 1995.

Modification of the SILC data sets focused on identifying areas of the forest fringe that changed classes from 'grass' to 'transitional forest' or 'forest', or areas of 'transitional forest' that converted to 'forest'. Each case represents increased conifer coverage. The black and white aerial photos were first assessed for the presence or absence of forested areas. Specific forest species and types could not be determined, especially in the historic imagery, and are not critical to the SWAT hydrologic modeling process. Rather, areas of forested, partially forested, and non-forested areas in the aerial photos were determined by identifying image characteristics such as spectral brightness value (BV) ranges and thresholds for these areas.

Three primary refinements to the SILC data were performed for both the current and historic landcover data sets

1. Validation of SILC coniferous forest classes or reclassification of forest classes to transitional forest occurred depending on their spatial correlation to forested or partially forested areas, respectively, in the aerial photos. This reclassification captured disturbances such as insect or disease damage that resulted in reduction in canopy closure.
2. Reclassification of SILC coniferous forest classes to grassland occurred in those areas where aerial photos were completely non-forested.
3. Reclassification of SILC grassland classes to forest occurred through visual analysis due to the high variability of brightness values in non-forested areas in the aerial photo.

Examples of the resulting landcover datasets are shown only for the Big Hole Headwaters watershed. Similar patterns are seen in the other two watersheds.

2.3.2 Historical Vegetation Data Sets

Data layers representing historical conditions were created for each of the three sub-watersheds. These data layers are used for two purposes: (1) assessing the change in vegetation from the time of historic photography to present and (2) as input vegetation data layers for the SWAT modeling.

Historical data layers are modified according the analysis performed on the historic aerial photography described in the Methodology section above. The majority of the watershed areas show no changes in cover type from historic to current conditions. Most changes occur in the forest fringe and where forested areas become denser, thus highlighting areas of conifer encroachment.

In order to capture the possible range of historic vegetation conditions and the resultant change to the present conditions, two different historic reclassifications of the SILC data were generated. The first approach modified the original SILC data set based on a conservative, minimal reclassification of SILC forest classes. In this approach, SILC forest classes were reclassified only when the aerial photo characteristics definitively identified a misclassification of a SILC 'forest' value. In this case the associated SILC cell was reclassified as 'transitional forest' (Figure 7). The second, more liberal approach modified SILC more aggressively by reclassifying SILC forest classes at lower, but still reasonable, image value thresholds. Reclassification of SILC 'forest' classes to both 'transitional forest' and 'grassland' occurred in this scenario, creating a second historical vegetation SILC data set (Figure 8). We feel this classification adequately identified the maximum possible extent and area of grassland and transitional forest in the watersheds.

Using both historical data sets, a range in percent change in vegetation between historical and current conditions was established. This approach allows us to assess the sensitivity of the SWAT model to changes in vegetation cover, as well as simulating a range of possible management alternatives. Studying the differences in Figure 7 and Figure 8 shows subtle changes between the conservative and liberal reclassification approaches.

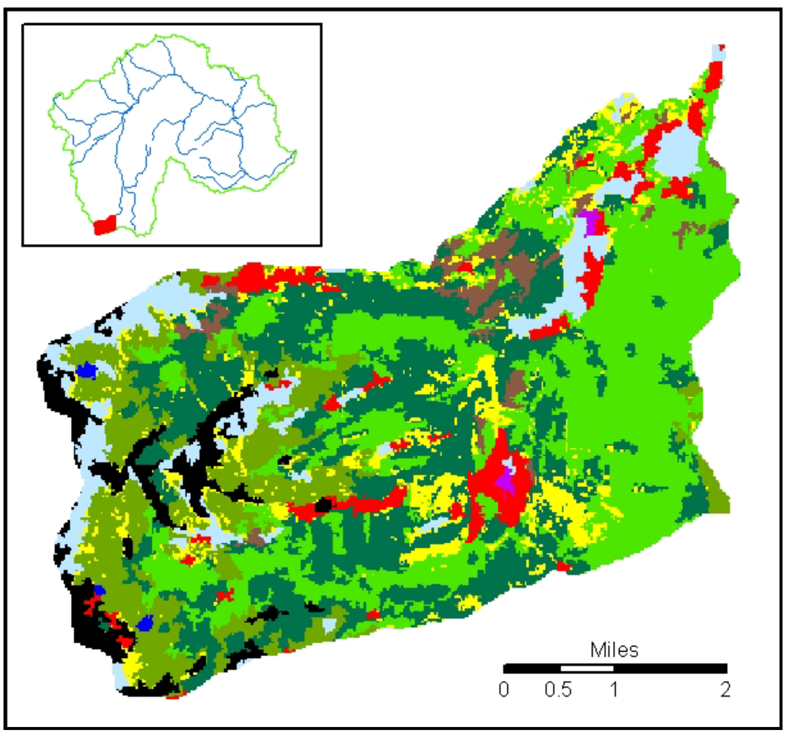

Figure 7. Historical vegetation cover derived using conservative classification method for the Big Hole Headwaters watershed. Transitional forests are shown in yellow, grassland is light blue, and conifer forests are shades of green.

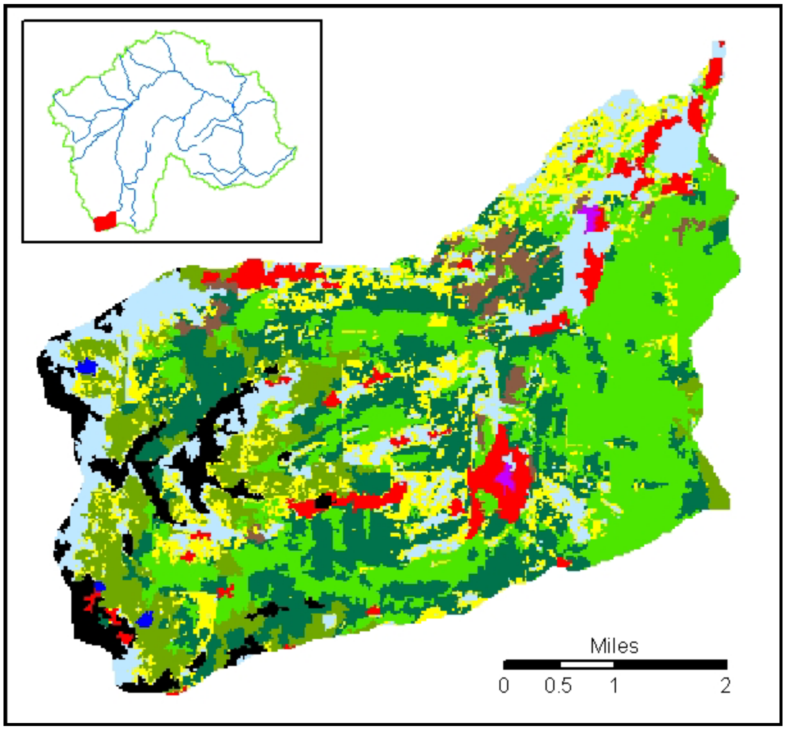

Figure 8. Historical vegetation cover derived using aggressive, liberal classification method for the Big Hole Headwaters watershed. Transitional forests are shown in yellow, grassland is light blue, and conifer forests are shades of green.

The historical vegetation data based on the conservative historic dataset show that between 66% and 79% of the landcover is coniferous forest in the three sub-watersheds (Table 6). Lodgepole pine composes the largest percentage of coniferous forest types in all three watersheds. Grasslands and less-forested areas characterize a low percentage of the landscape, 3.8% to 7.5%, indicating a general lack of open areas and higher mountain parks. Transitional forest and open forest areas range from about 6.5% to almost 11% of the watershed areas. Transitional forests are assumed to reflect areas where fire, insect kill, or disease has opened up the canopy.

The aggressive approach to obtaining a historical vegetation data set delineated grasslands and transitional forest areas over a much wider extent in the sub-watersheds than the conservative approach (Table 7). Between 6% and 14% of the landcover in the sub-watersheds are classified as grasslands. This represents a 3% to 6% change in the percent of total landcover when compared to grasslands in the conservative historical vegetation data set. The Big Hole Headwaters realized the largest difference in grasslands with a change from 7.6% to 14.0% representing an increase of 6.4% over the conservative approach. However, both Big Hole Headwaters and Warm Springs realized a similar absolute difference of around 900 acres of grassland.

Landcover	Warm Springs		Swamp Creek		Big Hole Headwaters	
	Acres	% of Total Area	Acres	% of Total Area	Acres	% of Total Area
Grassland	1612	6.6	402	3.8	1031	7.6
Open Forest	0	0.0	0	0.0	384	2.8
Transitional Forest	1819	7.4	676	6.4	1086	8.0
Spruce Fir	7577	30.9	1488	14.1	1781	13.1
Lodgepole	11727	47.8	4075	38.7	4232	31.0
Douglas Fir	3	0.0	1323	12.6	3656	26.8
Barren	396	1.6	2008	19.1	718	5.3
Shrubland	1377	5.6	399	3.8	692	5.1
Riparian	0	0.0	0	0.0	32	0.2
Quaking Aspen	0	0.0	58	0.6	0	0.0
Water	0	0.0	89	0.8	28	0.2
Total	24512	100	10518	100	13642	100

Table 6. Acres and percent of total watershed area for historical landcover classes using the conservative SILC modification approach.

Transitional forests accounted for between 10% and 14% of the landcover in the watersheds. This was an increase in the percent of total landcover of between 3% and 7% when compared to the conservative classification. Warm Springs realized the largest difference with 14.4%, representing a change of 6.9%. The increase in grasslands and transitional forests corresponded to a decrease in coniferous forests when compared to the conservative historical data set. Coniferous forests account for 60% to 68% of all landcover across the three sub-watersheds. These percentages are 6% to 11% lower than for coniferous forests in the conservative historical classification, reflecting the loss of coniferous forests to the grassland and transitional forest class delineations.

Aspen stands were likely more extensive than either of the historical data sets indicate. Aspen stands are difficult to delineate from the historic black and white photography without high-resolution scanning and detailed photo interpretation techniques.

One data set characterizing current vegetation in the sub-watersheds was created for this project (Figure 9). The approach used to create the current vegetation data set was similar to the conservative, minimal approach used to create one of the historical landcover data sets. As in the conservative historical landcover data set, SILC forest classes were reclassified only to transitional forest in this classification.

Landcover	***Warm Springs***		***Swamp Creek***		***Big Hole Headwaters***	
	Acres	***% of Total Area***	***Acres***	***% of Total Area***	***Acres***	***% of Total Area***
Grassland	2509	10.2	646	6.1	1906	14.0
Open Forest	0	0.0	0	0.0	317	2.3
Transitional Forest	3517	14.3	1038	9.9	1714	12.6
Spruce Fir	6601	26.9	1280	12.2	1416	10.4
Lodgepole	10108	41.2	3706	35.2	3765	27.6
Douglas Fir	3	0.0	1294	12.3	3054	22.4
Barren	396	1.6	2008	19.1	718	5.3
Shrubland	1377	5.6	399	3.8	692	5.1
Riparian	0	0.0	0	0.0	32	0.2
Quaking Aspen	0	0.0	58	0.6	0	0.0
Water	0	0.0	89	0.8	28	0.2
Total	24512	100	10518	100	13642	100

Table 7. Acres and percent of total watershed area for historical landcover classes using the aggressive, liberal SILC modification approach.

2.3.3 Current Vegetation Data Set

The current vegetation data sets show that landcover in the three sub-watersheds is dominated by conifer forests with a range of 60% to over 80% (Table 8). Lodgepole pine composes the largest percentage of coniferous forest types in all three watersheds. Grasslands and less-forested areas characterize a much smaller proportion of the landcover in the sub-watersheds. Only 5% to 7.5% of the watersheds are grassland, and transitional forest and open forest areas comprise only 3.5% to about 8% of the total landcover in any one watershed. Conspicuously absent from the current vegetation data set are any large delineations of aspen stands. The Big Swamp Creek watershed is the only watershed with any aspen at all, and only 58 acres of the watershed, or 0.6% of the landcover in the watershed, are composed of aspen. This correlates inversely to the high density of conifer forests present in the watersheds and directly to the lack of disturbances that aspen favor.

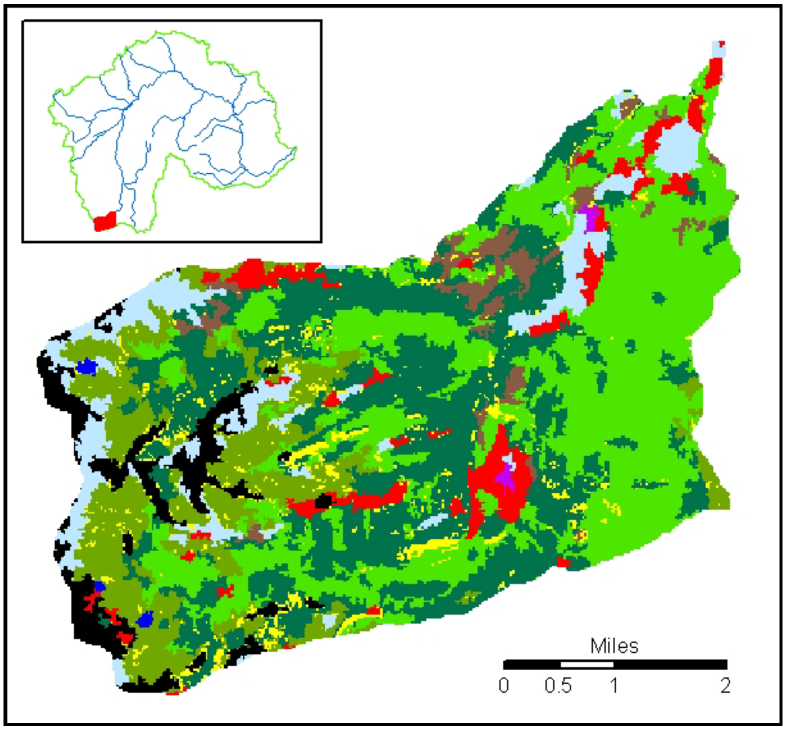

Figure 9. Current vegetation cover for the Big Hole Headwaters watershed. Transitional forests are shown in yellow, grassland is light blue, and conifer forests are shades of green.

Landcover	*Warm Springs*		*Swamp Creek*		*Big Hole Headwaters*	
	Acres	*% of Total Area*	*Acres*	*% of Total Area*	*Acres*	*% of Total Area*
Grassland	1697	6.9	535	5.1	1031	7.6
Open Forest	0	0.0	0	0.0	423	3.1
Transitional Forest	1391	5.7	880	8.4	483	3.5
Spruce Fir	7696	31.4	1677	15.9	1866	13.7
Lodgepole	11951	48.8	3568	33.9	4467	32.7
Douglas Fir	3	0.0	1305	12.4	3901	28.6
Barren	396	1.6	2008	19.1	718	5.3
Shrubland	1377	5.6	399	3.8	692	5.1
Riparian	0	0.0	0	0.0	32	0.2
Quaking Aspen	0	0.0	58	0.6	0	0.0
Water	0	0.0	89	0.8	28	0.2
Total	24512	100	10518	100	13642	100

Table 8. Current vegetation classes and component percentages for the Warm Springs, Big Swamp Creek, and Big Hole Headwaters sub-watersheds.

2.3.4 500 Year Simulated Vegetation Cover

In addition to the one current and two historical vegetation data sets, a fourth landcover data set predicting vegetation conditions after 500 years of natural process was created using the

SIMPPLLE model (Chew et al., 2002)(Figure 10). The data set is the result of succession and disturbance processes that occur upon an input landcover data set, in this case the base SILC landcover data. This process assumes that no management occurred and a natural fire regime was present without suppression. Because no human management of any kind takes place during the simulation, the 500-year data set represents what the natural landscape may look like.

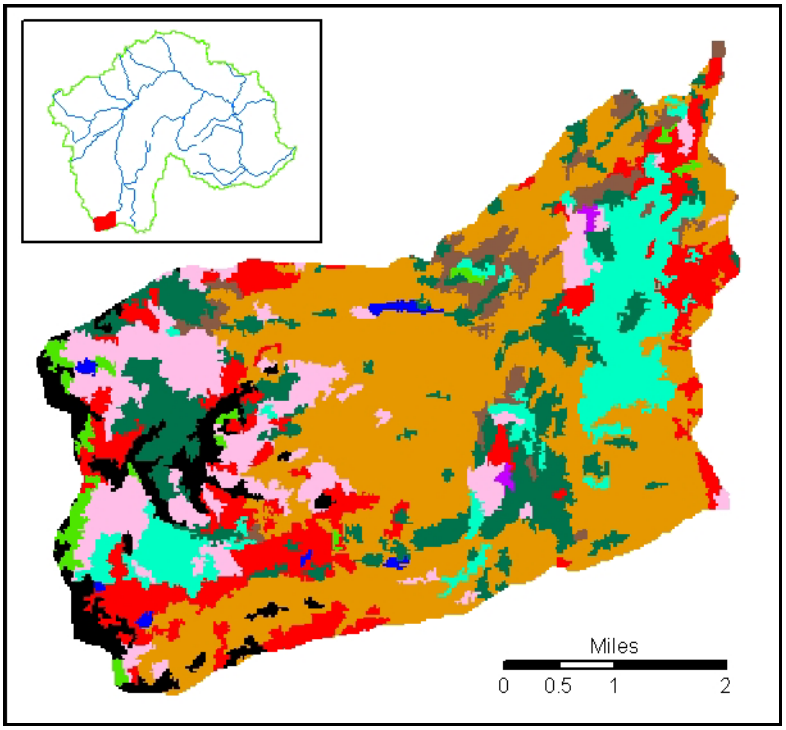

Figure 10. Simulated 500 year vegetation cover derived from SILC for the Big Hole Headwaters watershed. Aspen is shown in orange, grassland is light blue, and forests are shades of green.

Results of the 500-year simulation show that the landscape is dominated equally by quaking aspen and conifer forests (Table 9). Conifer forests comprise 34% to 42% of the total landcover in the sub-watersheds. 35% to 41% of the total landcover in the sub-watersheds is characterized by quaking aspen, while shrubland characterizes anywhere from 5% to 21% of the total landcover. Grasslands and disturbed forest areas characterize little area in any of the three sub-watersheds. Transitional forests are essentially non-existent while grasslands characterize only .2% to 5% of any given sub-watershed.

This simulation represents the culmination of a series of extreme events that occurred near the end of the 500-year model run. The large percentage of aspen is likely due to a large fire event that burned close to half of the watershed. While these events are possible, for example the Mussigbord fire in the Johnson Creek drainage, they happen infrequently. As such, we did not model the hydrology of the sub-watersheds using the simulated landcover.

Landcover	Warm Springs		Swamp Creek		Big Hole Headwaters	
	Acres	% of Total Area	Acres	% of Total Area	Acres	% of Total Area
Grassland	47	0.2	544	5.2	218	1.6
Open Forest	0	0.0	0	0.0	530	3.9
Transitional Forest	0	0.0	0	0.0	1	0.0
Spruce Fir	3487	14.3	1551	14.8	1525	11.2
Lodgepole	5520	22.6	1330	12.7	1375	10.1
Douglas Fir	1231	5.0	814	7.7	1749	12.8
Barren	396	1.6	1953	18.6	718	5.3
Shrubland	5180	21.2	511	4.9	1761	12.9
Riparian	0	0.0	0	0.0	32	0.2
Quaking Aspen	8574	35.1	3664	34.9	5660	41.5
Water	0	0.0	143	1.4	74	0.5
Total	24434	100	10510	100	13643	100

Table 9. 500 year simulated vegetation classes and component percentages for the Warm Springs, Big Swamp Creek, and Big Hole Headwaters sub-watersheds.

2.3.5 Limitations of data/analysis.

The use of aerial photography to refine and reclassify SILC data sets has limitations that can affect the accuracy of the reclassed data. These limitations include the spatial resolution of the data and the spatial coincidence between the aerial photos and SILC layers.

The spatial extents of the sub-watersheds were sufficiently large that it was necessary to perform analysis at the 30-meter spatial resolution of the SILC data set. Therefore, the 1-meter resolution aerial photos were generalized by resampling them to 30-meters. As a result, transition areas between different landcover types might be classified into any one of multiple landcover classes. This generalization reduces the accuracy of any given 30-meter cell and thus the spatial extent of any given landcover class may be reduced.

Spatial coincidence, the degree to which features from one image align with features from another, between the aerial photos and the SILC data sets also affects the accuracy of the reclassification. This was not a problem for the current landcover classification because the DOQ's were spatially referenced to a similar accuracy as the SILC data sets and therefore these data sets' spatial coincidence was high. The aerial photos used to assess historical landcover, however, were georeferenced in the GIS. The lack of ground control points and the highly variable topography in the sub-watersheds decreases the accuracy of the georeferncing process. This reduces the spatial coincidence between the historic aerial photography and the historical reclassification of the SILC data.

In critical areas, some scanned images were orthorectified in order to reduce the spatial errors in the referencing process. This was very time-consuming and only resulted in slightly better spatial fits.

3.0 CHANGES IN THE EXTENTS OF VEGETATION COMMUNITIES

Conifer encroachment into mountain grasslands is well documented in Montana and throughout the west (Arno and Gruell, 1986)(Keane et al., 2002). Douglas-fir, among other species, have expanded their local range into alpine grass parks and down valley sides. Areas that were previously maintained as grasslands by periodic fire are being invaded by conifer. This trend is visible throughout the Big Hole watershed.

It should be noted that the vegetation changes identified in this study are the result of process occurring over a relatively short period, 50 years. The natural processes controlling vegetation, climate, and the resulting hydrology happen over much longer, 300-500 year periods. Explanations for how the observed changes in this study fit in with the longer cycles are discussed in Section 5.

3.1 METHODOLOGY

Assessing changes in vegetation communities and the degree of conifer encroachment requires identifying what landcover types changed, how much change had occurred, and to what landcover type the original landcover changed to. To address the first two items, comparative statistics depicting the percent of total watershed area that each landcover type occupied, or relative abundance of each landcover type, in historical and current vegetation conditions were generated. A difference in the percent of total area for each landcover type between historical and current conditions was calculated to illustrate how much change occurred for each landcover type. To establish specifically what landcover type the historical landcover type changed to, a coincidence table is used to summarize the spatial correlation of landcover types between historical and current conditions.

3.2 RESULTS

The percent of total watershed area that each landcover type currently occupies is not significant ly different from historic conditions assessed using the conservative reclassification approach (Table 10). Grassland composition essentially saw little change across all three sub-watersheds. Transitional forests decreased in percent of total landcover by 1.8% in the Warm Springs sub-watershed and 4.4% in the Big Hole Headwaters sub-watershed from historical conditions. Transitional forest cover in the Big Swamp Creek increased by 1.9%. Conifer forests realized a slight increase in percent of total area of 1.4% and 4.1% for the Warm Springs and Big Hole Headwaters sub-watersheds, respectively. Alternatively, conifer forests occupy 3.2% less area in Big Swamp Creek than they did historically.

Changes in landcover were greater when comparing current conditions to historical conditions using the liberal reclassification approach in the Warm Springs and Big Hole Headwaters watersheds. Big Swamp Creek again realized minimal change in percent of total area for all landcover types (Table 10). Current grasslands and transitional forests encompass less area than historically, with grasslands occupying 1.1% to 6.4% less area, and transitional forests encompass 1.5% to 9.0% less area. Conifers encompass 2.6% to 14.7% greater area than historically. In the Big Swamp Creek watershed, the area of grasslands and transitional forests decreased least and the area of conifers increased least.

The changes in landcover from historical to current conditions in Big Swamp Creek are contrary to the theory of increasing conifer density due to encroachment upon grasslands and open park areas. However, moderate timber harvesting occurred within this watershed between the study periods. The loss of conifers due to harvesting activity appears to have balanced any conifer encroachment in Big Swamp Creek.

Although changes in the percent of total area for each landcover type vary moderately in some cases from historical landcover to current landcover conditions, the composition of vegetation communities in any watershed did not change significantly. Conifers dominate the landscape under all landcover conditions, historical and current, with the lowest value for percent of total landcover being near 60% (Big Swamp Creek liberal historical conditions).

Watershed	*Landcover*	*Current*	*Historic (Conservative)*		*Historic (Liberal)*	
		% of Total	*% of Total*	*Change in % of Total*	*% of Total*	*Change in % of Total*
Warm Springs	**Grassland**	6.9	6.6	-0.3	10.2	3.3
	Transitional Forest	5.7	7.4	1.7	14.3	8.7
	Conifer Forest	80.2	78.8	-1.4	68.2	-12.0
	Shrubland	5.6	5.6	0.0	5.6	0.0
	Other	1.6	1.6	0.0	1.6	0.0
	Total	100	100	0	100	0
Swamp Creek	**Grassland**	5.1	3.8	-1.3	6.1	1.1
	Transitional Forest	8.4	6.4	-1.9	9.9	1.5
	Conifer Forest	62.3	65.5	3.2	59.7	-2.6
	Shrubland	3.8	3.8	0.0	3.8	0.0
	Other	20.5	20.5	0.0	20.5	0.0
	Total	100	100	0	100	0
Big Hole Headwaters	**Grassland**	7.6	7.6	0.0	14.0	6.4
	Transitional Forest	3.5	8.0	4.4	12.6	9.0
	Conifer Forest	75.0	70.9	-4.1	60.4	-14.7
	Shrubland	5.1	5.1	0.0	5.1	0.0
	Other	8.8	8.5	-0.3	8.0	-0.8
	Total	100	100	0	100	0

Table 10. Percent of total area and change in percent of total area per landcover type between historical and current landcover conditions for Warm Springs, Big Swamp Creek, and Big Hole Headwaters sub-watersheds.

Assessment of the spatial correlation of landcover types between historical and current conditions identifies the specific changes in landcover types. Table 11 compares historical and current landcover types and how much, in percent, of each historical landcover type changed to a specific current landcover type.

A comparison of the current conditions with the conservative historical landcover conditions illustrates that all historical grasslands were unchanged, with 100% of those areas characterized currently as grasslands. The current area of grasslands in Warm Springs is an increase of 2.4%

from historical conditions because of the alteration of transitional forests, though this amounts to an absolute gain of only 43 acres. Alternately, only 15% to 25% of areas classified historically as transitional forests maintained that classification under current conditions. Most of the rest of these areas became more homogenous, higher density conifer forests. This accounts for most of the gain in conifer forests in the three sub-watersheds. However, while conifer forests realized little change, with 87% to 97% of those areas sustaining themselves from historical to current conditions, conifer forests that did change primarily became transitional forests. This may be attributable to events such as insect infestation, disease, or mild fire events and mutes the gain in conifer forests realized from the transition of historical transitional forests.

Grasslands changed more drastically from liberally classified historical landcover conditions. Current grasslands occupy 54% to 66% of the area that historically were grasslands in the sub-watersheds. Grasslands primarily became a forest type, as 22% to 33% of all historical grasslands became conifer forests, while 9% to 12% became transitional forests. Alternatively, patterns of change for transitional forests and conifer forests were similar to that for the change seen from the conservatively classified historical to current conditions. Transitional forests currently occupy only 5% to 12% of their historical area, while conifer forests occupy 86% to 98% of their historical area. As was the case with the historical conditions assessed using the conservative approach, most of the area that were historically transitional forests (87% to 90%) changed to conifer forests.

Historical Landcover	***Historic Landcover Classes***		***Current Landcover***			
			Grassland	***Forest***	***Aspen***	***Transitional Forest***
Conservative Classification	**Warm Springs**	**Grassland**	100.0	0.0	0.0	0.0
		Transitional Forest	2.4	72.8	0.0	24.8
		Forest	0.2	94.9	0.0	4.9
	Swamp Creek	**Grassland**	100.0	0.0	0.0	0.0
		Transitional Forest	0.0	84.4	0.0	15.6
		Forest	1.9	86.8	0.0	11.2
	Big Hole Headwaters	**Grassland**	100.0	0.0	0.0	0.0
		Transitional Forest	0.0	75.9	3.7	20.4
		Forest	0.0	97.3	0.0	2.7
Liberal Classification	**Warm Springs**	**Grassland**	65.7	22.8	0.0	11.5
		Transitional Forest	0.5	86.7	0.0	12.8
		Forest	0.2	95.9	0.0	3.9
	Swamp Creek	**Grassland**	59.1	31.6	0.0	9.3
		Transitional Forest	0.0	88.9	0.0	11.1
		Forest	2.4	86.3	0.0	11.2
	Big Hole Headwaters	**Grassland**	54.1	33.2	2.2	10.5
		Transitional Forest	0.0	90.3	3.8	5.9
		Forest	0.0	97.8	0.0	2.2

Table 11. Coincidence of historical landcover types to current landcover types in percent.

4.0 IMPACTS TO THE WATER BUDGET

Estimating the impacts to the water budget resulting from changes in vegetation is best accomplished using a hydrologic simulation model. This section investigates the relationship between landcover and water yield in the upper Big Hole River watershed.

4.1 METHODOLOGY

Hydrologic output was simulated for each landcover scenario (current, conservative historical, and liberal historical) using the Soil Water and Assessment Tool (SWAT). SWAT, a basin-scale water modeling tool, was originally "developed to assist water resource managers in assessing the impact of management on water supplies and nonpoint source pollution in watersheds and large river basins" (Arnold et al., 1998). The suitability of SWAT for addressing the key issues in this study is based in the facts that SWAT: (1) is computationally efficient; (2) allows good spatial resolution; (3) utilizes readily available data layers as input; (4) allows modeling continuously through time using a daily time step; (5) can be used to simulate land management scenarios; and (6) produces reasonable results (Arnold et al. 1998).

Hydrologic simulations predict water yield for each sub-watershed based on the various landcover scenarios. To obtain a range in water yield per landcover scenario and differences in water yield between landcover scenarios, we simulated hydrology during three different years representing above average, below average, and average precipitation for the 30-year period from 1970 to 2000. This resulted in 9 hydrologic simulations for each sub-watershed. Precipitation data from the Jackson weather station was used as input into SWAT. 1995 was chosen to represent the above average year, with an annual total of 19.15 inches of precipitation. 2000 represented the below average year with 8.79 inches of precipitation, while 1984 was used for hydrologic simulations representing average precipitation years with 10.95 inches of annual precipitation.

Jackson is located in the upper Big Hole River valley at an elevation of 6479 feet, while the three studied sub-watersheds range in elevation from 6778 feet to over 10295 feet. The difference in elevation and related orographic effects generates significantly more precipitation in the sub-watersheds than in valley areas. As such, two methods were used to adjust the precipitation data for elevation. One method utilizes the snowfall-snowmelt routine integrated into SWAT and relies on "elevation bands to distribute temperature and precipitation with elevation" (Fontaine et al., 2002, p.209). The second method, used concurrently with SWAT's use of elevation bands, uses precipitation data from the Bloody Dick SNOTEL site located in the Big Hole Headwaters sub-watershed to define a precipitation lapse rate between the Jackson and Bloody Dick weather sites.

4.2 FINDINGS

The preliminary model runs were used to determine the validity of the hydrologic simulations and assess how accurately SWAT predicted hydrologic yield for the sub-watersheds. The best method for this is to compare the simulated hydrograph to real world data from the same basin. Unfortunately, existing hydrologic data is lacking in the Big Hole. The US Geological Survey did operate a stream flow gaging station near the mouth of the Big Hole Headwaters watershed from1948 to 1953. This allowed us to compare hydrologic output from the simulations conducted in the Big Hole Headwaters with stream flow recorded during one or more of these years. Hydrographs were compared between years that were most similar in climatic conditions.

Modeled water yield for all simulations consistently falls 30% to 40% below the historical water yield from the gaging station. However, the overall pattern of timing and relative volume of yield throughout the year was consistent between the simulated yield and actual yield recorded at the USGS gage for all comparisons. Figure 11 illustrates both the difference in overall yield and the similarity in patterns of yield between a current landcover hydrologic simulation conducted in the Big Hole Headwaters and actual flow recorded in 1950.

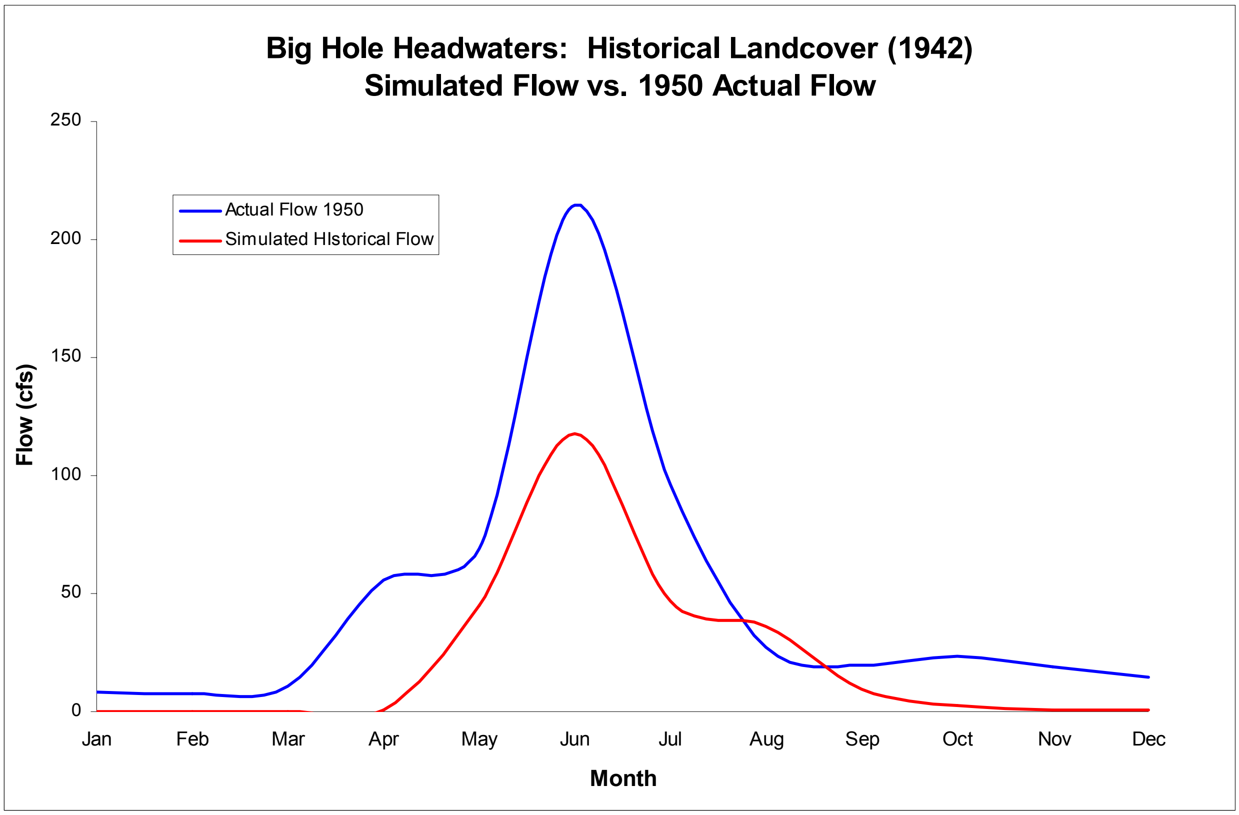

Figure 11. Comparison of actual flow recorded at USGS stream flow gage station in 1950 with simulated flow conducted in the Big Hole Headwaters under historic landcover and average precipitation conditions.

It should be noted that the hydrologic simulations in this study are not fully calibrated. As a result, the output can not be used to confidently predict the absolute differences in yield resulting from changes in vegetation. This is due to uncertainty related to both the climatic and environmental data used in the model. The consistently low simulated water yields are mostly the result of the limited weather data available throughout the Big Hole that results in modeled precipitation rates that are lower than actual conditions. This is seen in the model output as a lack of water availability throughout the year and lower than actual yields.

While the modeling is not calibrated to actual flow data for each of the sub-watersheds, some calibration is inherent in the SWAT model parameters. The modeling parameters for the 15 vegetation classes derived from SILC for the Northern Rocky Mountains have been calibrated to controlled test basins at the Tenderfoot Experimental Forest, MT (Ahl 2005). This allows the modeling to be performed confidently. The results from the historic landcover in the Big Hole Headwaters watershed were compared to the available historic flow data for that basin. The resulting hydrographs, while showing a difference in absolute yield, show excellent similarities in the timing of the rising and falling limbs of the hydrographs (Figure 11). The timing and shapes of the hydrographs are the most important factors in assessing a model. The yield is merely a result of the amount of precipitation in the watershed.

The results for each of the three sub-watersheds were very similar. Therefore, only graphs are presented for the Big Hole Headwaters watershed. Complete modeling results can be found in Appendix I.

A comparison between hydrographs for the water yields predicted under different landcover scenarios in the Big Hole Headwaters in 1984 illustrates similarity in the overall pattern of the hydrographs (Figure 12). This similarity is seen between the hydrographs for all the different landcover scenarios across the 3 sub-watersheds, regardless of the year in which the simulations took place.

The simulation incorporating liberal historical landcover conditions shows slightly higher yields in April and May and lower yield in June than the simulations for the current and conservative historical landcover scenarios.

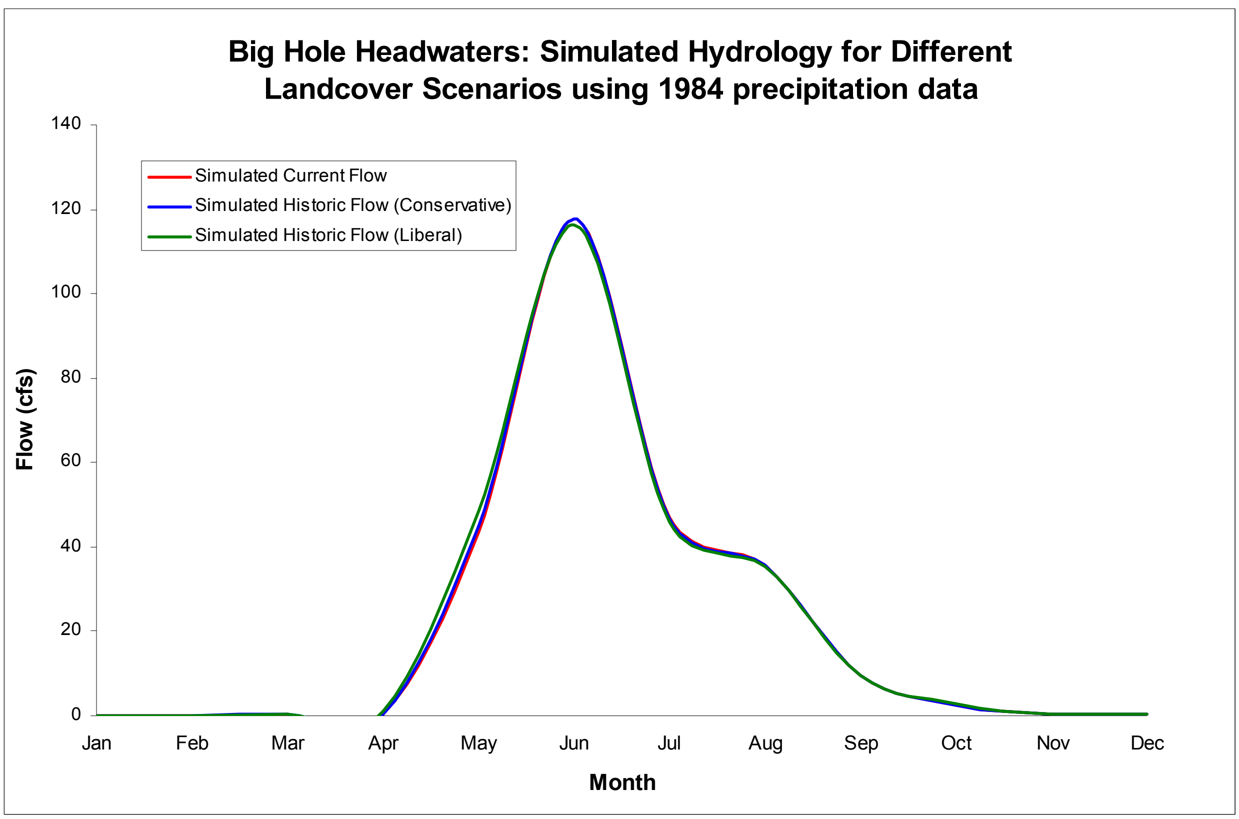

Figure 12. Simulated hydrographs for current landcover, conservative historical landcover, and liberal historical landcover scenarios in the Big Hole Headwaters using 1984 precipitation data.

Predicted annual water yield varied most between current and historical landcover conditions in the Warm Springs and Big Hole Headwaters sub-watersheds when historical water yield was simulated using the liberal historical landcover conditions (Table 12). The largest departure from current landcover hydrologic output consistently occurred during years when precipitation was below average, for both historical landcover scenarios, in these sub-watersheds. The smallest differences between current and historical landcover hydrologic output were seen in the year with above average precipitation. The Big Swamp Creek sub-watershed realized the largest difference in water yield between current and historical landcover conditions when historical yield was simulated with conservative historical landcover. Here, historical simulated water yield was less than water yield under current landcover conditions by .23% to .75%. The largest departure in any of the sub-watersheds occurred in the Big Hole Headwaters, under the liberal historical landcover scenario, with 2.22% more water yield occurring than under current landcover conditions.

Results of hydrologic output across the three sub-watersheds are indicative of differences between current and historical landcover conditions within these watersheds. Where the largest differences in landcover and were seen, in Warm Springs and Big Hole Headwaters, water yield varied the most between current and historical landcover scenarios. Much of these differences correlate to the reduction of grasslands and transitional forests over the study period. Conversely, the minimal difference in water yield was seen in Big Swamp Creek. This correlates with the general lack of overall landcover change in this sub-watershed.

Watershed	*Year*	*Historical (Conservative) Departure from Current (%)*	*Historical (Liberal) Departure from Current (%)*
Warm Springs	Dry (2000)	0.17	0.86
	Avg (1984)	0.11	0.16
	Wet (1995)	0.04	0.14
Big Swamp Creek	Dry (2000)	-0.75	-0.04
	Avg (1984)	-0.23	0.03
	Wet (1995)	-0.32	-0.06
Big Hole Headwaters	Dry (2000)	0.93	2.22
	Avg (1984)	0.57	1.00
	Wet (1995)	0.46	0.76

Table 12. Percent departure of hydrologic output from the current landcover scenario for the conservative and liberal historical landcover scenarios in below average, average, and above average precipitation years. Positive numbers indicate increased water yield.

Analysis of monthly water yields indicate that the largest water yield differences for all simulation years occurred during the snow runoff period, generally from April through June. The differences in water yield between hydrologic simulations for the Big Hole Headwaters using 2000 precipitation data indicate that much of the gain in water yield occurs during April and May (Table 13). Water yield simulated with liberal historical landcover shows an 18.16% and 6.08% increase in April and May, respectively, when compared to water yield simulated with current landcover. However, some of these gains are attenuated with lower water yield during the critical summer months of June through August. Here the liberal historical landcover water yields are about 1.5% to 4% lower when compared to current landcover simulations. These results are similar to those found for all watersheds and are further illustrated in the Big Hole Headwaters with simulations run during an average precipitation year (Figure 13).

Table 12 and Figure 13 also demonstrate that as conifer cover increases when moving from the historic liberal, to historic conservative, to current conditions runoff starts later with lower peak yields. Also late season flows are actually increased slightly. The reasons for this are discussed in Sections 5 and 6.

Month	***Historical (Consevative)***		***Historical (Liberal)***	
	Difference (acre feet)	***Departure from Current (%)***	***Difference (acre feet)***	***Departure from Current (%)***
Jan	-0.04	-3.51	-0.14	-14.93
Feb	0.33	55.33*	0.87	76.70*
Mar	0.00	6.36*	0.00	14.16*
Apr	31.66	6.37	102.25	18.02
May	47.07	1.68	177.99	6.08
Jun	-18.56	-0.49	-152.07	-4.16
Jul	-1.19	-0.17	-10.86	-1.57
Aug	-0.95	-0.31	-4.33	-1.41
Sep	2.26	0.17	0.99	0.07
Oct	32.30	4.03	106.83	12.18
Nov	2.79	1.96	7.62	5.18
Dec	0.48	0.87	0.58	1.06

***N**ot actual reflection on water yield difference due to negligible simulated water yield during winter months of January through March.

Table 13. Percent departure of hydrologic output from the current landcover scenario for the conservative and liberal historical landcover scenarios by month in the Big Hole Headwaters, 2000.

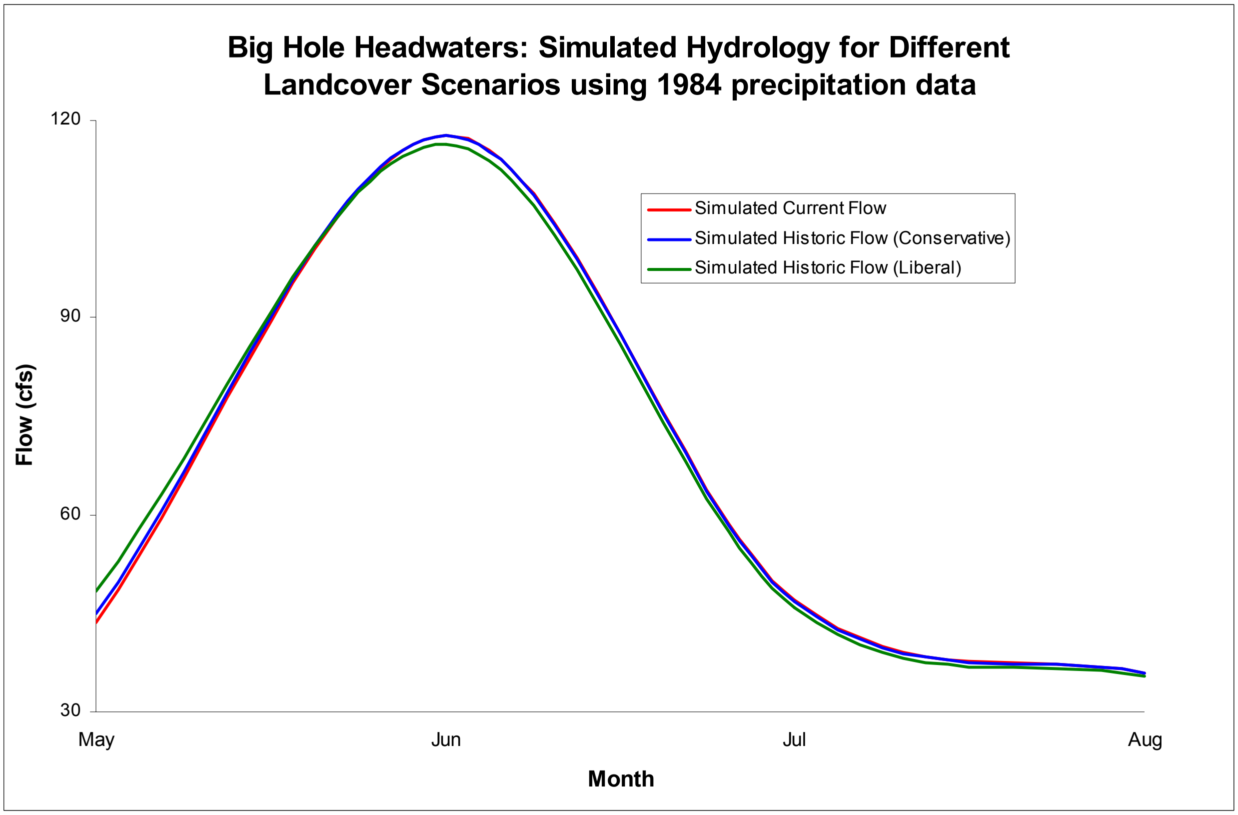

Figure 13. Simulated hydrographs for current landcover, conservative historical landcover, and liberal historical landcover scenarios in the Big Hole Headwaters, May through August using 1984 precipitation data.

5.0 CAUSES FOR VEGETATION CHANGES

The SWAT modeling for this project, as well as supporting literature, indicates that some annual water yield is lost due to the conversion of grass and shrub lands to conifer. Fire is largely believed to be the dominant influence on the noted vegetation changes in the Big Hole River watershed and throughout the west[1]. One must keep in mind, though, that there are many complex interacting processes affecting the water balance in the Big Hole River watershed. While this project focuses on the role of vegetation and the impacts of conifer encroachement on the water budget as a whole, it is impossible to do this without addressing the associated areas of study. The roles of vegetation, vegetation change, climate, insects, wildlife, and land management form a set of complex relationships that result in the current conditions we see in the Big Hole River watershed today. These relationships are not unique to the Big Hole.

5.1 CHRONOLOGY OF EVENTS

The vegetation conditions in the Big Hole watershed and throughout the Northern Rockies can be seen as the culmination of processes and events that started centuries ago. The following Chronology of Events lists many of the important periods and single events, and summarizes some of the landscape processes and characteristics. These topics are covered in greater detail in the following sections.

- **Pre-1492 – Pre-European Settlement**
  Represents the time before European settlement in the new world. Native cultures were well-established in the North America (population approximately 3.8 million) and the Rocky Mountain West. Native cultures used burning for a variety of purposes. The vegetation was adapted to short return intervals for low-intensity fires and 300 to 400-year return intervals for large landscape altering fires. Insect kills follow natural cycles.
- **1942 to early 1800s – Early European Settlement**
  Coastal areas, as well as areas east of the Mississippi are heavily impacted by European settlement. Forests are cleared for crops. Native populations drop to approximately 1 million in North America due to disease in settled areas. Rocky Mountain landscapes remain relatively intact and still show great influence of natural and native burn cycles. Insect kills continue to follow natural cycles
- **1860 – European Settlement Starts**
  Around 1860 European settlement begins in the Northern Rocky Mountains and Montana.
- **1861 – 1910 – Settlement Period**
  During this period, native populations were further reduced due to disease and conflict with the new settlers. Native use of the landscape begins to change drastically as they are displaced from their traditional grounds. Fire is still frequent in heavily used areas, but

[1] For a comprehensive discussion of the effects of fire exclusion in the Rocky Mountains, we recommend the following USDA publication: Cascading Effects of Fire Exclusion in the Rocky Mountain Ecosystems: A Literature Review (Keane et al. 2002).

the frequency of fire in other areas declines. The forests remain in natural and human caused fires cycles with large fires resetting extensive areas every 300-400 years and insects occasionally creating large kill areas.

- **Late 1800s to Present – Modifications for Agriculture**
  Extensive diversions and ditches have altered the natural water flows in the upper Big Hole River valley. Extensive beaver eradication likely removes natural water storage.
- **Early 1910 to 1930 –**
  Fires from native sources are essentially removed from the environment. Fires starts are mainly from natural sources. Large-scale fires and insect infestations maintain natural cycles as fuel loads, climate, and ignition sources permit. Lack of low-intensity fires allows some buildup of fuels.
- **1925 to 1935 -**
  Mountain Pine Beetle infestation is wide-spread in the Big Hole watershed.
- **1930 to Present – Fire Suppression**
  Aggressive fire suppression efforts are put into place. Most small fires extinguish naturally after burning from a few acres to several hectares. Fuel loading is somewhat increased due to the lack of moderate sized burns. Larger areas of the forest transition into older stages of succession. Fuel loading is increasing from the earlier beetle kill. Large-scale fires and insect infestations maintain natural cycles as fuel loads, climate, and ignition sources permit.
- **1941 to 1945 – Start of Conifer Invasion**
  Conifer invasion is first noted. This represents a time where seed crops coincided with very favorable moisture conditions (Arno and Gruel, 1986). Forests in the Big Hole show relatively open canopies in many areas resulting from the earlier insect infestation. Lack of small fires in the forest and the grasslands allows some conifer encroachment into upland savannahs and down the valley sides.
- **1950 -**
  Starting around the 1950s, better records were kept for climate, stream flow, and snowpack throughout the West. This coincides with a wetter climate. As such, deviations from these early records to current day show a steady decline of available water and a warmer, drier climate in general.
- **1950 – 1980 -**
  Conifer cover continues to increase as sapling trees grow and existing mature trees develop more closed canopies. Lack of periodic fire is likely accelerating fuel loading in the forest. Large-scale fires and insect infestations maintain natural cycles as fuel loads, climate, and ignition sources permit.
- **1980 to Present –**
  More large fires are seen and the total acres burned annually increases. This can be seen as part of a natural cycle that may be somewhat accelerated by fire suppression activities. Insect infestations maintain natural cycles as fuel loads, climate, and ignition sources permit.
- **2000 – Mussigbrod Fire**
  The Mussigbrod fire represents the only large scale, stand replacing fire documented in the Big Hole watershed. While this is the largest fire on record and comes after a long period of fire suppression, it is a typical fire for the region. The burn area is responding

with the early stages of revegetation. This is the only portion of the watershed with large areas of aspen, an early succession species that responds well to disturbance.

- **Present –**
  Much of the Big Hole watershed and the surrounding region have a large percentage of their area represented by mature forest conditions, elevated fuel loads, and relatively dense canopies. This is typical of forests in the Northern Rocky Mountains that tend to have large, stand replacing fires every 300 to 400 years. Most of the forest has not encountered high intensity fire for at least 100 years and is likely due for major fire activity if conditions permit. There is a current infestation of Douglas fir beetle in the lower elevation forests. If this outbreak has similar impacts to the infestations seen in from 1925 to 1935, it may result in approximately 40% reduction in Douglas fir biomass.

5.2 THE ROLE OF FIRE

Changes in forest composition are well documented throughout the west (Keane et al. 2002; Arno and Gruel 1986; Debyle and Winokur 1985; and others). The exclusion of fire from the natural environment through an aggressive policy of suppression starting in the 1930s is often cited as the primary, though not the only, catalyst for this change in forest structure and composition.

Most Rocky Mountain ecosystems evolved with fire (Arno 1980; Pyne 1982; Quigley and Arbelbide 1997)(from Keane et al 2002). Fire acts to control fuels build up, maintains open grassland savannahs, retards encroachment of tree species along the forest edges. Frequent, low-intensity ground fires help to control growth of understory, shade-tolerant species, thus maintaining a single layer canopy structure. The resulting lack of ladder fuels helps limit catastrophic, stand-replacing crown fires in all but the most intense fire regimes.

This critical role of fire was recognized even as fire suppression policies were implemented. As early as 1899, Gifford Pinchot recognized the importance of fire in maintaining North American Forests. Suppression was nonetheless adopted as the "more desirable management policy" (Keane et al. 2002; Mutch 1995).

Through the exclusion of fire, "forest composition has gone from early seral, shade-intolerant tree species to late seral, shade-tolerant species, while stand structure has gone from single-layer canopies to multiple-layer canopies" (Keane et al. 2002, p.3). While this vegetation transition is a natural process, it is largely hypothesized that the conversion from early to late seral stage forests has been accelerated.

Fire has long been an important controlling factor of vegetation and is largely agreed to be the dominant control of conifer encroachment. Historically, periodic fires from natural and human sources were effective in maintaining open grasslands communities throughout the Northern Rockies. While many cite the aggressive fire suppression policies following the extensive wildfire activity seen in 1910 (Keane et al., 2002) as the triggering event for creating conditions favorable for conifer encroachment, studies indicate the problem started well before then. Arno and Gruell (1986) reconstructed fire histories based on tree fire scarring in the Galena Study area outside Boulder, Montana. Results from this study "indicate that prior to 1890, fires occurring every few decades favored grasslands and confined tree growth to rocky or topographically moist sites. Since 1890 fires have been rare as a result of livestock grazing (which removes fine fuels), fire suppression, and cessation of ignitions by Native Americans." (Arno and Gruell, 1986, p.272). Similar findings by Barrett and Arno (1982), Denevan (1992) and Keane et al. (2002), among others, support this view.

5.2.1 Fire Size and Timing

Fire regimes in the Northern Rocky Mountains are diverse and vary depending on species, elevation and climatic setting. As such, impacts to the fire regimes due to fire control are often difficult to separate from those resulting from other natural processes (Romme, 1982). The Beaverhead-Deerlodge National Forest Draft Forest Plan acknowledges "fire is a natural process that we are attempting to restore across the landscape" (2005, p.37). Two somewhat competing theories are in effect today. First is that the systematic exclusion of fire throughout forest lands in the west has contributed significantly to converting land cover types, stand age and structure, and fire types. The other is that the increase in fire activity and intensity is part of a natural cycle that just happens to coincide with the modern policy of fire suppression.

The theory that fire suppression is the primary factor in creating the current forest conditions points to two primary controlling factors: (1) the end of native burning practices and (2) the policy of fire suppression. When combined, these two events have greatly reduced the annual acres burned and the average size of individual fires. Many people note the infrequency of small, low-intensity fires contributes to the recent occurrences of large, extremely intensive, stand replacing fires in recent decades. This trend is seen when you sum the total acres burned due to wildfire in 11 western states from 1916 through 2000 (Figure 14)(Keane et al., 2002, p.12). This shows that "the amount of area burned in the Western United States has actually increased even though we are currently using better fire suppression technology and are spending more money to fight fires" (Keane et al, 2002, p.12). The logical conclusion is that while fire suppression practices were initially successful, the result of suppression is in fires of increased intensity and spatial coverage.

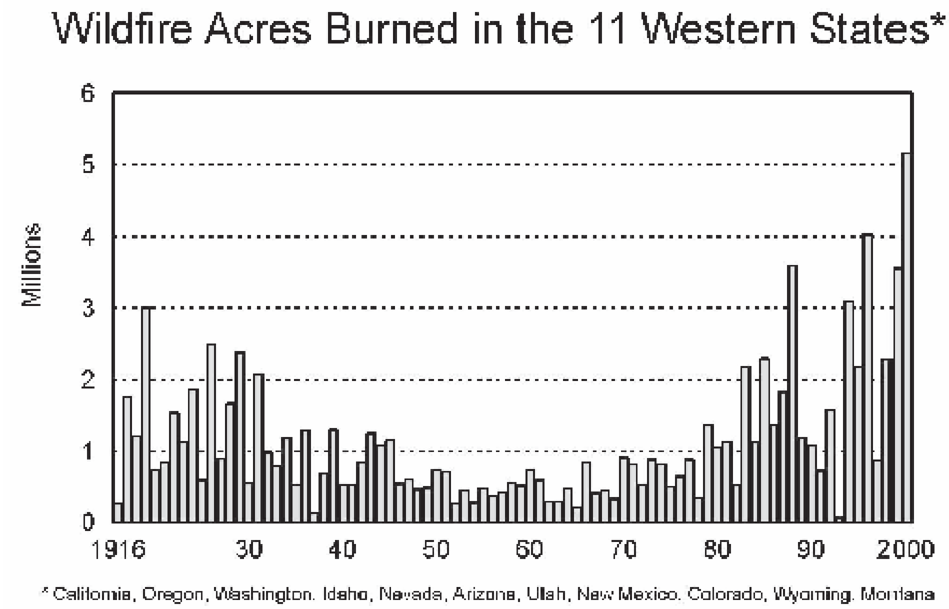

Figure 14. Annual area burned is increasing despite recent advances and increases in fire suppression technology and resources (Keane et al., 2002, p.12).

In contrast to this theory, many studies point out that large stand-replacing fires are a natural process in Northern Rocky Mountain ecosystems. The large Yellowstone National Park fires of 1988 are often attributed in part to a policy of suppression of all fires in the Park. Even before these fires, studies show that large fires in subalpine watersheds are the product of successional changes in the fuels complex that occur over 300 to 400 year intervals (Romme, 1982)(Romme and Despain, 1989). The fuels necessary to support these large burns develop over long periods. Ignitions occurring in other than optimal fuel and climatic conditions tend to "extinguish naturally before covering more than a few hectares" (Romme, 1982, p.199)(Romme and Despain, 1989) . These environments are characterized by large natural fire cycles every few centuries followed by a long period of low fire activity. Keane points out that this natural fuels cycle, rather than human fire suppression, is responsible for the low number and small size of fires leading up to the more recent large fires. One plausible explanation for the low level of fire activity in the last 250 years is that the mosaic of forest structures was "composed largely of early to middle successional stages, so it had relatively low flammability." (Romme and Despain, 1989, p.697).

5.2.2 Fire Suppression

Fire suppression started in earnest in the 1930s with the stationing of CCC crews throughout the west. These crews were very efficient in suppressing human and natural fire starts. Hot shot and smoke jumper crews further increased the efficiency of suppressing fires. Additionally, grazing and irrigation in the valley bottoms have eliminated valley grass fires except as limited, controlled field burning. As a result, the historic small and moderate-sized fires have generally not occurred over the past 70 years.

Romme and Despain (1989) put the Yellowstone fires of 1988 into historical perspective. Their research suggests that a major fire event was inevitable and that fire suppression merely resulted in delaying the onset. The fuels complex was building since the last extensive large-scale fire events on the Yellowstone Plateau in the 1700s. "…the fires of the late twentieth century were comparable, in total area burned, to the fires of the late seventeenth and early eighteenth centuries." (Romme and Despain, 1989, p.698). In their study area, approximately 34% of the area experienced stand-replacing events from 1690 to 1739. The same area has experienced stand-replacement across approximately 26% of the area from 1940-1988. "All evidence indicates that normal landscape dynamics in the Little Firehole River [Yellowstone National Park] watershed have not been significantly interrupted by human activities." Romme, 1982, p. 218). When put into historic perspective, the 1988 fires should not be considered abnormal events.

The Big Hole River upland areas are similar in composition to the Yellowstone Plateau and share similar fire histories. While fire suppression has likely reduced the number of small to moderate sized fires in the watershed, the 300 to 400 cycle of fuel build up followed by a large burn should be viewed as part of the natural process. These fires disturb large areas of the forest and resets them to the start of the vegetation succession process.

5.2.3 Native American Use of Fire

In the past several decades, our understanding and acceptance of the Native American's role in fire starts and vegetation is growing. The body of research addressing this topic is expanding and there is substantial evidence that native cultures throughout North America aggressively used fire to modify and maintain vegetation (Keane et al., 2002). The notion that the landscape was pristine prior to European influences and that native cultures lived without unduly impacting their surroundings is more attributed to a romanticized view of native cultures than to fact.

Fire was used by Native cultures for various purposes (Barrett and Arno, 1982):

- Maintenance of open stands to facilitate travel, and clearing travel routes through dense timber;
- Improvement of hunting by stimulating growth of desirable grasses and shrubs, to facilitate stalking, and to drive or surround game;
- Enhancement of production of certain foods and medicinal plants;
- Improvement of horse grazing;
- Clearing of campsite areas-reduced fire hazard and camouflage for enemies, and cleaning up refuse;
- Communication, by setting large fires; and
- Accidental burns from cook and campfires.

Denevan (1992) presents a strong argument that the environment was less impacted by human activity in 1750 than it was in 1492. Prior to European settlement, native populations in North America were on the order of 3.8 million. This dropped to approximately 1 million by 1800 due to the introduction of disease that the native populations had no resistance. In Montana this population reduction is seen in studies of fire return intervals west of the Continental Divide. This study showed that prior to European settlement (1860s), the mean return interval was significantly less than during the post-settlement period (1911-1980)(Barrett and Arno, 1982). There is also a documented difference in return intervals between heavily used and remote stands where areas used extensively by Native Americans show significantly shorter fire return intervals. During the fire suppression period (1930s to present), mean return intervals between fires increases dramatically and differences between heavy-use and remote stands are not significant.

These studies point towards forest environments that were significantly altered by the native cultures. Fire starts were more frequent, were effective at controlling fuel loads, and helped to create a mosaic of forest structure.

5.3 OTHER CRITICAL FACTORS

While fire is the dominant controlling factor for vegetation in the Northern Rockies, wildlife, insects, and climate can also have large impacts.

5.3.1 Wildlife/Insect

According to the Beaverhead National Forest Personnel (Beaverhead-National Forest, 2004), the numbers of ungulate game species currently greatly exceed the historic numbers of the same species. Census numbers of species tend to vary depending on a variety of environmental factors. The increase of ungulates in the Big Hole watershed may be contributing to a reduced number of Aspen due to grazing. Wildlife, though, should not have an impact on the numbers of conifer.

Insect infestation is well documented in the Big Hole. From approximately 1925-1935, a mountain pine beetle infestation caused a loss of approximately 13% of large trees. This amounted to close to a 40% loss in biomass. The deadfall from this infestation can still be seen in the understory of the many current stands. This is generally seen as a natural process and contributes to stand replacement. In areas where fire is not actively suppressed, the deadfall would likely be cleared out through local burn events. Currently, the 70-year-old deadfall from this infestation is contributing to the increased fuel loads in these stands.

The imagery used for the historic vegetation cover is from the late 1942 and 1960. As such, much of the open canopy and sparse forest density that is evident is the result of insect kill. The 50+ years between the historic data set and the current data set shows the response from this event and perhaps a return to more ‘natural’ conditions.

There is a current outbreak of Douglas fir beetle at lower elevations in the Big Hole and adjacent watersheds indicating that the forest conditions are likely primed for such an infestation. If one views insect kills as part of the natural process, the current infestation may effectively return large sections of the forest to conditions similar to those in the 1950s.

5.3.2 Climate

The magnitude and impacts of local, regional and global climate change are widely debated. Long-term weather data is very limited in the mountain west. Snowpack information for the upland areas of the Big Hole valley only goes back to the late 1970s to early 1980s. Weather data for the valley is slightly better with some records going back to the early 1950s. As such, we must look at regional trends for the northern Rocky Mountains and the Pacific Northwest in order to assess any climatic changes.

Regional analysis of snowpack measurements throughout the west indicate that snowpack levels have dropped significantly due to a 0.8 degree warming since the 1950s (Service 2004). Using modest projections of continued warming over the next 50 years, this same study points to a projected 60% reduction of snowpack levels in areas of the northwest. This in turn equates to a predicted 20% to 50% reduction in stream flows.

Whether these trends are part of a longer-term cycle or represent human induced impacts on the global climate are certainly open for debate. Complicating this climate picture is the fact that our earliest detailed snowpack information comes from a wet period in the longer-term climatic record. As such, the documented reductions in snowpack may simply be a return to more average conditions. Regardless of how this data is placed in the larger climatic picture, the reduced snowpack and warmer temperatures equate to earlier runoff and reduced summer stream flows.

Arno and Gruell point out, "Widespread invasion of sapling size trees occurred between 1941 and 1955 [in southwestern Montana], when seed crops apparently coincided with unusually favorable moisture conditions" (1986, p 272). This coincidence also helps explain the extensive conifer encroachment in the second half of the 20th century.

5.4 LAND USE ISSUES

Many other factors can influence landcover. While these may have local impacts to vegetation and water, on a watershed scale, they do not equal the impacts associated with fire. Several of these land use issues are discussed below.

5.4.1 Grazing

Some studies indicate that grazing was effective at maintaining grasslands and limiting conifer encroachment. The Upper Big Hole was heavily grazed starting in the late 1800s. This likely reduced grasses and thus the fuel loads for range fires.

5.4.2 Irrigation

Approximately 90,000 acres of the upper Big Hole River valley above Wisdom is managed for agriculture using flood irrigation (Roberts, 2004). For much of the spring and summer, soils are saturated and grasses no longer dry out. This creates unfavorable burning conditions across a large part of the valley. Fire suppression is actively used to protect crops and infrastructure. This virtually eliminates range fires that would typically occur in the valley and contribute to limiting conifer encroachment around the forest fringe.

5.4.3 Logging / Timber management and harvest

Timber harvest can play and important role in mimicking some fire processes. For example, in the Big Swamp Creek drainage, cover gained due to conifer encroachment was equal to loss due to harvest. Also, the Deep Creek watershed at the northern end of the Big Hole watershed has seen extensive clear cutting that has opened up the canopy and created disturbances.

5.5 CURRENT SITUATION IN THE BIG HOLE WATERSHED

Current thought in the Big Hole watershed acknowledges that many factors control the current vegetation/fuel conditions and fire regimes in the watershed. Several types of fires likely characterized the watershed up to the 20th century (Beaverhead-National Forest, 2004).

- valley grass fires that started either naturally or by Native Americans. These would typically run across the valley, up the side slopes and into the forest fringe. They were likely effective in periodically killing new conifer growth along the forest fringe and kept conifers from encroaching into the valley bottoms. They were effective at keeping low elevation parks open and provided a disturbance regime for reestablishment of aspen. Additionally, they provided fire starts for timber fires in the forest mid- and high-elevation areas.
- Less frequent moderate-sized fires of one to three thousand acres in size and of mixed intensity would provide smaller stand replacement events. Again, these provided the disturbance regime favored for the reestablishment of Aspen. Created a mosaic of stands with mixed age classes. Acted as natural barriers for fires to run into and prevented some fires from stepping up into large landscape level, stand replacement fires. These are usually naturally caused and extinguished naturally.

- Landscape scale fires would typically occur when all of the necessary factors were in place, including high temperatures, well-developed ladder fuels, dry fuels, and wind. These are infrequent (200 – 400 yrs) and result in large stand replacement events over a large landscape. These fires are extremely difficult to control if the conditions are correct. Some smaller fires may result in these types of events if the conditions are correct. Fire suppression may have delayed the occurrence of some of these large fires. Fire suppression has likely led to a more homogeneous landscape with more continuous fuel loads. This potentially results in landscape scale fires that are larger than they would have been historically. There is not the mosaic of different age stands and recent burns that would have slowed down these types of burns in the past.

With the exception of the 2000 Mussigbrod fire which burned approximately 72,000 acres, only a very small portion of the Big Hole Watershed has been affected by fire in the past 60 years. The Beaverhead National Forest shows that 876 recorded fires occurred between 1940 and 2001 (Figure 15). Though not all of these fires record total acres burned, the fires with information on the number of acres burned range from 0.1 to 86 acres in size and in any given year, the total number of acres burned was generally under 200 acres (Figure 16). 1981 differed from this trend when approximately 1,000 acres were burned, though this in no way represented an extreme fire year.

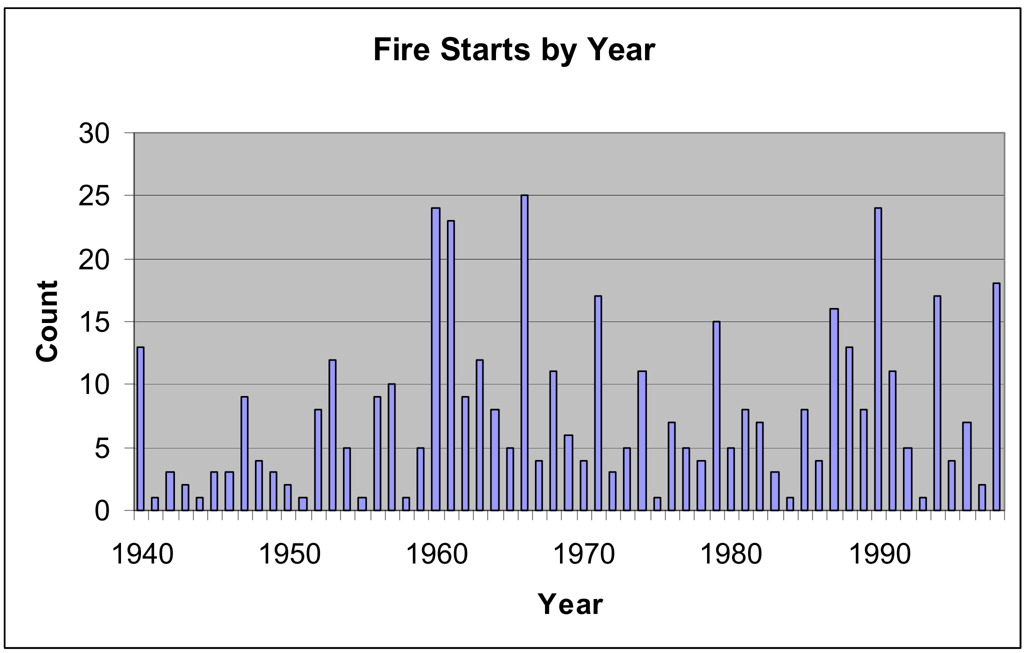

Figure 15. Fire starts by year in the Beaverhead-Deerlodge National Forest in the Big Hole River watershed from 1940 through 1998. (Source Beaverhead-Deerlodge National Forest GIS, 2004)

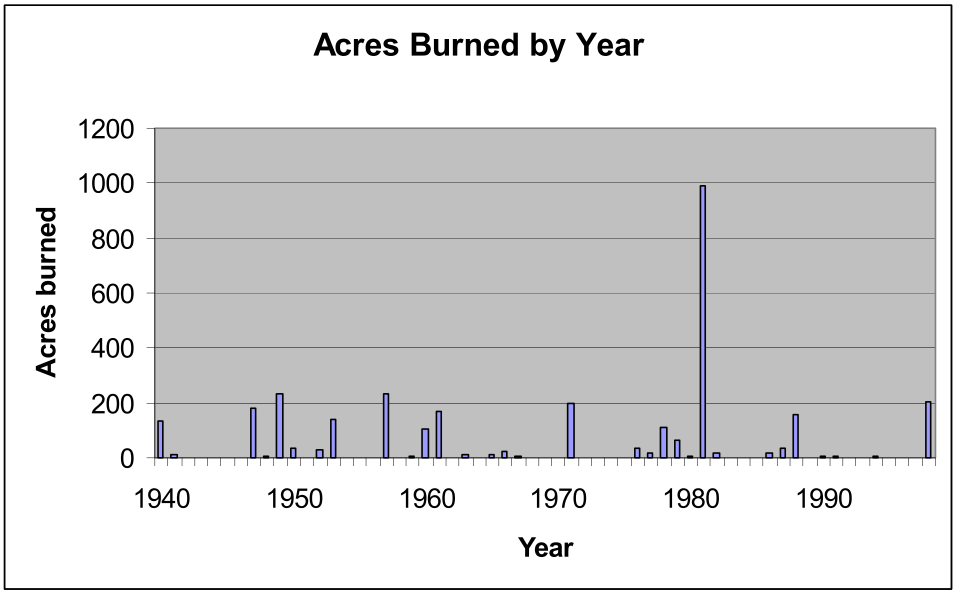

Figure 16. Total acres burned by year in the Beaverhead-Deerlodge National Forest in the Big Hole River watershed from 1940 through 1998. (Source Beaverhead-Deerlodge National Forest GIS, 2004)

Fire suppression has effectively limited the forest mosaic of trees of varying ages. Beaverhead National Forest personnel estimate that approximately 20% of the forest should generally be in sapling and pole timber at any given time (personal communication, Beaverhead-Deerlodge National Forest, 2004).

The exceptions to this are the Mussigbrod fire region and the Mount Hagan/Deep Creek sub-watershed. The Mussigbrod area is being naturally reseeded shows a strong return of aspen in the disturbed area. It is expected that these new Aspen groves will transition to conifers over the next 25-50 years. Approximately 20,000 acres of the Mount Hagan area was clearcut in the 1970s and early 1980s. Most of the cut areas were reseeded and currently stands in the 20-30' range. Some stands have since been thinned or had other prescriptive treatments.

6.0 MANAGEMENT RECOMMENDATIONS

Managing watersheds for water yield is a complicated topic and must take into account all aspects of the water balance. One must address both the water quantity and the timing of the water flow though the watershed. Research shows that water quantity is primarily dependent on climatic conditions, but is also influenced by the vegetation conditions in the watershed. The availability of that water for streamflow is dependent on the timing of the runoff and the natural/manmade storage available in the watershed.

Since the first paired watershed study in the United States began in 1909 at Wagon Wheel Gap, Colorado (Bosch and Hewlett, 1981), over 200 studies have been documented in literature (Stednick, 1996)(Bosch and Hewlett, 1981). A review of 94 of these studies by showed that no watershed has shown a decrease in annual yield from the basin after a reduction in cover through harvest, fire, or other event. This is the primary thinking behind the hypothesized link between conifer encroachment and reduced in stream flows seen in the Big Hole watershed and throughout the Rocky Mountain region. This loss of annual yield is attributed to both increased interception of precipitation by the denser canopy cover year round, reduced snowpack development over the winter, and increased root uptake by the older and denser conifer cover during the growing season. All but one highly refuted study (Burton, 1997; Troendle and Stednick, 1999) show that annual yields can be increased through canopy removal.

While increased annual yields may be desirable for maintaining in stream flows, opening the canopy also changes the timing of the runoff. Reduced canopy cover increases overall yield from basins, but that increased yield comes mainly as increased spring runoff and does not translate into increased mid to late season flows. Open areas lack the protective shading of winter snowpack and result in an earlier runoff of increased magnitude. This early runoff tends to offset and potentially negatively impact any gains in yield by reducing the amount of stored water available for mid to late season runoff. For example, Skidmore et al. (1994) reports an increased ablation rate of up to 57% for burned areas vs. mature forest stands. In fact, many studies, including the SWAT modeling performed for this study, show that the critical mid to late season flows required for irrigation and wildlife habitat in the Big Hole River watershed are actually reduced by decreasing the amount of canopy cover (Skidmore et al., 1994)(Skidmore, 2005). So while it is possible to increase basin water yields through vegetation change, water storage and delivery are actually the more important factors in enhancing flows during the summer.

Additionally, any efforts to manipulate water yield through vegetation management will probably only be valuable if they are done in conjunction with other management efforts within the basin.

With this in mind, the following management recommendations are divided into two groups: (1) Vegetation Management and (2) Storage and Delivery. The Vegetation Management section provides a Proposed Action, followed by a Discussion of the issues related to implementing that strategy. Information from the Beaverhead-Deerlodge National Forest's Revised Management Plan is included where appropriate.

6.1 Vegetation Management

Finding the balance between the positive effects of increased yield through reducing the total basal area and corresponding canopy closure of forested areas with the negative effects from wind scour, ablation, and early runoff is difficult. Studies in the Rocky Mountains show that a minimum of 15% of the total basal area of a drainage area must be removed (through patch cutting or thinning) in order for a measurable impact to be seen in water yield. Above a 30% removal of total basal area results in highly variable changes in yield. For example, compete harvesting (100% removal) resulted in total annual yield increases ranging from zero to over 350mm (Stednick 1996). This demonstrates the difficulty in setting target harvest rates for maximizing water yield.

6.1.1 Fire

Proposed Action:

Reestablish the natural fire processes. Wildland fire use for resource benefit has been used extensively to control fuel loads in forests and for mimicking natural burn events.

Discussion:

While historic fires in the valley areas were important in maintaining open grasslands and retarding the encroachment of conifers down the valley walls, it is generally not a strong management option. Native burning of grasslands and forest areas is well-documented throughout the Northern Rockies (Barrett and Arno, 1982)(Denevan, 1992)(Williams, 2001). Current development of infrastructure in the forest fringe and valley areas makes this option difficult to implement unless the practice enhances existing agricultural practices without threatening infrastructure.

Burning can be effective in reducing canopy cover. This in turn results in increased snowpack, decreased interception of precipitation, and can result in annual increases in water yield. One recent study (Skidmore et al, 1994) of a burned lodgepole pine forest in southwestern Montana indicated a 9% increase in snow water equivalence accumulation. Clearcut areas in the same study showed similar increases in snow water equivalence.

Beaverhead-Deerlodge National Forest set Fire Management Objectives in their Revised Management Plan. These include:

- Reducing the effects of unplanned and unwanted wildfire forestwide by reducing acres of fuels in condition class 2 and 3 for all fire regimes by approximately 70,000 to 105,000 acres across the forest.
- Complete wildland fire use plans within 3 years (which are part of the forestwide fire management plan) to allow wildland fire use for resource benefits. (Beaverhead-Deerlodge National Forest, 2005).

The Revised Management Plan calls for many of the management areas to include the use of wildland fire use or management ignited burns to achieve desired vegetation conditions. In discussing the fire management plan for Yellowstone National Park, Romme (1992, p.219) states, "The current fire management plan probably will be effective in maintaining the natural landscape patterns in the subalpine zone if most lightning-caused fires are allowed to burn naturally, including the very large fires…. Such large fires should not be viewed as unusual events occurring because of abnormally high fuel levels." A similar strategy would be appropriate for the Big Hole watershed.

6.1.2 Harvest

Proposed Action:

Utilize an aggressive harvest program to simulate fire effects on the landscape.

Discussion:

As was demonstrated earlier, harvest can be effective in increasing annual water yields from a watershed. Current harvesting practices may not create the types of forest textures necessary for effective increases in water yield (Beaverhead-Deerlodge National Forest, 2005). Research shows that the critical element in increasing water yield from a region is snowpack. Forested areas can be managed to enhance annual water equivalence in the snowpack. Numerous paired watershed experiments in snow-controlled hydrologic systems such as the Big Hole watershed demonstrate that various thinning and patch cutting applications can effectively increase snowpack values. The increases are largely attributed to snow that was previously intercepted by the canopy and vaporized back to the atmosphere. These studies indicate that patch cuts on the order of 5 times the tree height in diameter are most effective in increasing local snowpack values. The 5-tree-height is widely accepted as the best accumulator of snowpack (Figure 17)(Troendle and Meiman, 1984). Larger patch cuts can be also be effective, but can also have a negative impact if they get larger than 12 or 13 tree heights in diameter. This is largely due to an increased wind scour and sublimation losses. Smaller cuts loose their effectiveness due to shallow roots from the perimeter trees encroaching into the opening that capture the available water as root uptake (Ahl 2005).

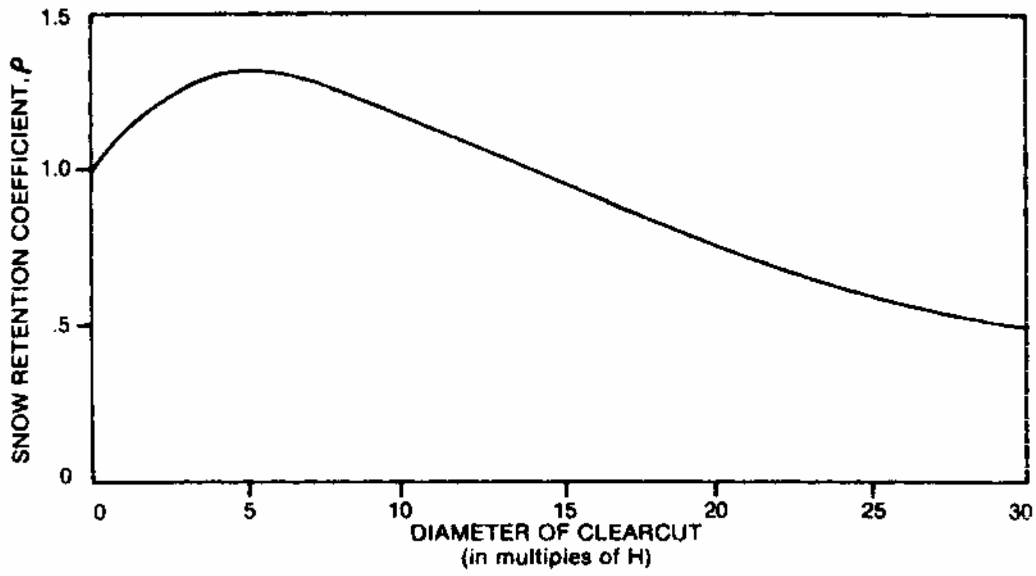

Figure 17. Snow retention as a function of clearcut size. H is height of surrounding trees. (Troendle and Leaf, 1980, p.88).

The operational and environmental costs of maintaining an aggressive harvest program make implementing this strategy on a large-scale difficult. Research shows that between 15% and 50% of the basal area of the forest must be cut to effectively increase yields. That means removal of up to every other tree across the forest. While this may be possible locally through thinning operations, to implement this on a forest-wide scale would be prohibitive.

Other limiting factors for this strategy include elevation and climatic conditions. In order to be most effective, harvest operations would have to occur at the highest elevations. The lower elevation forests do not develop significant snowpacks that could contribute to water yields. Also, these snowpacks tend to melt very early in the spring and would therefore not help in providing late season flows. Finally, studies indicate that increased snowpack in dry years does not help maintain in stream flows. In drought years, any increased precipitation generally is either transpired by vegetation, or added to soils to increase soil moisture. As such, you are likely to only see the benefits of the increased snowpack in wet years when it is not necessarily needed (Ahl, 2005).

6.1.3 Beaverhead-Deerlodge National Forest Revised Management Plan

In late 2005 the Beaverhead-Deerlodge National Forest released the draft version of their Revised Land Resource Management Plan. This document describes the various management objectives and goals for the entire Forest, as well as for individual management areas. Table 14 below describes the overall goals for the Beaverhead-Deerlodge National Forest.

Vegetation Class	***Objectives and Standards***
All Vegetation	Restore or retain a mosaic of species and age classes of native trees, shrubs, grasses, and forbs that provide cover and forage for animals and perpetuate the diversity of plants and the microbial and insect communities upon which they are

	dependent.
Forested Vegetation	Maintain a mosaic of stand structures by species.
Douglas-fir	Increase the number of acres in the 0 to 5 inch DBH class by approximately 20,000 acres well distributed across the Forest. The increase would largely come from reducing the greater than 9 inch DBH class.
Lodgepole Pine	Reduce the number of acres in the 5 to 9 inch DBH class and greater than 9 inch DBH class by approximately 74,000 acres well distributed across the forest.
Aspen	Restore 13,000 to 66,000 acres of aspen, increasing the number of acres in the 0 to 5 inch DBH class well distributed across the forest. This would largely come from reducing the 5 to 9 inch DBH class in lodgepole pine.
Whitebark Pine/Sub-Alpine fir	Increase the number of acres in the 0 to 5 inch DBH class with the emphasis on Whitebark pine by approximately 45,000 acres, largely through the use of fire.
Grassland/Shrubland Restoration	Reduce 30,000 to 74,000 acres of Douglas-fir or other conifer encroachment on shrublands or grasslands.

Table 14. Summary of pertinent forestwide objectives and standards for the Beaverhead National Forest Draft Forest Plan (Beaverhead-Deerlodge, 2005, pp.7-8).

The Forested Vegetation Objectives are not broken down by management area. To put the management objectives for the conifer classes into perspective, the Beaverhead-Deerlodge National Forest is approximately 3.32 million acres. The forested area above Wisdom is approximately 235,000 acres, or around 7% of the National Forest area. If 7% of the proposed 20,000 acres of Douglas fir thinning were applied in the upper Big Hole forested zone, this would amount to 1,400 acres, or 0.6% of the forested zone. Similarly, if 7% of the proposed Lodgepole pine thinning were applied in the same area, this would equal approximately 5,180 acres, or 2.2% of the forested zone. These percentages are similar in scale to the changes in conifer coverage seen using our conservative approach. In general, studies show that you need to remove a minimum of 15% of the total basal area of conifers in order to see a consistent response in water yield. The resulting 3% total area of conifer thinning does not represent a 3% reduction in basal area. As such, the actual reduction basal area is somewhat less and a predictable hydrologic response would be difficult to rely on.

6.2 Storage and Delivery

The results of the SWAT modeling and regional research indicate that annual yields can increase through very aggressive vegetation management. Conifer encroachment is a natural process that can accelerate from changes in land use and management practices. While this study does indicate an increase in conifer cover and in-turn results in decreased annual water yields, the timing of the water delivery is the most important issue. Even if the upland forest areas were managed to enhance water supply, that additional water occurs during the runoff period and results in slightly diminished water flows in the summer months. These facts point toward the need for enhanced storage and delivery options in order to augment stream flows.

Two previous studies examined water management options that involve increasing either natural or man-made storage to augment late season flows. Two reports discuss these recommendations in detail. Please refer to these studies for their recommendations.

- Big Hole Water Storage Scoping Project and Water Management Review – Final Report – Water Management Alternatives (DTM, Mainstream, and Portage, 2005) This document discusses eleven recommended water management options to increase late season stream flows in the Upper Big Hole River watershed.
- Big Hole Water Storage Scoping Project and Water Management Review – Final Report – Reservoir Storage Alternatives (Portage, DTM, Mainstream, and, 2005). This document examines four potential sites for reservoir storage to augment late season stream flows in the upper Big Hole River watershed.

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Appendix I - Modeling Results

Warm Springs Annual Hydrologic Yield - 1984			
Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	13802	38	70
Historical (Conservative)	13817	38	70
Departure from Current (%)	0.11		
Historical (Liberal)	13824	38	68
Departure from Current (%)	0.16		
500 Year	13573	37	70
Departure from Current (%)	-1.69		

Warm Springs Annual Hydrologic Yield - 1995			
3Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	25860	71	111
Historical (Conservative)	25871	71	111
Departure from Current (%)	0.04		
Historical (Liberal)	25895	71	111
Departure from Current (%)	0.14		
500 Year	25513	70	111
Departure from Current (%)	-1.36		

Warm Springs Annual Hydrologic Yield - 2000			
Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	6862	19	39
Historical (Conservative)	6874	19	39
Departure from Current (%)	0.17		
Historical (Liberal)	6921	19	38
Departure from Current (%)	0.86		
500 Year	6774	19	32
Departure from Current (%)	-1.31		

Tables A1 – A3. Warm Springs hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 1984, 1995, and 2000.

Month	Warm Springs Monthly Hydrologic Yield (acre feet) - 1984						
	Current	Historic (Conservative)	Difference	Historic (Liberal)	Difference	500 Year	Difference
January	27.2	27.2	0.0	26.5	-0.7	25.1	-2.1
February	9.4	9.4	0.0	9.2	-0.2	8.7	-0.7
March	3.2	3.2	0.0	3.1	-0.1	2.9	-0.3
April	23.5	24.5	1.0	34.5	11.1	34.6	11.2
May	1361.6	1388.1	26.6	1576.1	214.6	1735.8	374.3
June	5406.4	5414.8	8.4	5455.9	49.6	5488.6	82.2
July	3112.4	3099.5	-12.8	2980.5	-131.9	2853.6	-258.7
August	2403.1	2396.5	-6.6	2320.8	-82.3	2152.2	-250.9
September	1042.0	1038.5	-3.4	1003.5	-38.4	910.4	-131.6
October	318.1	319.8	1.7	319.7	1.6	277.4	-40.7
November	67.2	67.0	-0.1	65.0	-2.2	58.4	-8.8
December	27.7	28.2	0.5	28.9	1.3	24.9	-2.8

Month	Warm Springs Monthly Hydrologic Yield (acre feet) - 1995						
	Current	Historic (Conservative)	Difference	Historic (Liberal)	Difference	500 Year	Difference
January	2.3	2.3	0.0	2.2	-0.1	2.1	-0.2
February	0.5	0.5	0.0	0.5	0.0	0.5	-0.1
March	1.4	1.6	0.2	2.6	1.2	1.2	-0.2
April	20.5	21.5	1.0	30.8	10.3	27.0	6.5
May	1962.8	1995.4	32.6	2251.6	288.8	2373.9	411.1
June	10699.8	10720.1	20.3	10871.8	171.9	11196.7	496.8
July	5731.2	5706.4	-24.8	5503.9	-227.3	5181.5	-549.7
August	3533.1	3518.7	-14.5	3395.1	-138.1	3161.5	-371.6
September	2375.8	2372.1	-3.7	2319.6	-56.2	2163.6	-212.2
October	1026.8	1027.2	0.3	1008.9	-17.9	931.0	-95.8
November	384.0	383.0	-1.0	383.7	-0.2	353.6	-30.3
December	121.4	122.4	0.9	124.7	3.3	120.4	-1.0

Table A4 – A5. Warm Springs monthly hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 1984 and 1995.

Month	*Big Hole Headwaters Monthly Hydrologic Yield (acre feet) - 2000*						
	Current	*Historic (Conservative)*	*Difference*	*Historic (Liberal)*	*Difference*	*500 Year*	*Difference*
January	1.1	1.0	0.0	0.9	-0.1	0.8	-0.2
February	0.3	0.6	0.3	1.1	0.9	0.1	-0.2
March	0.0	0.0	0.0	0.0	0.0	0.0	0.0
April	465.2	496.8	31.7	567.4	102.3	551.5	86.3
May	2749.7	2796.8	47.1	2927.7	178.0	3273.0	523.2
June	3806.1	3787.5	-18.6	3654.0	-152.1	3264.3	-541.8
July	703.1	701.9	-1.2	692.3	-10.9	663.6	-39.5
August	310.9	310.0	-0.9	306.6	-4.3	294.3	-16.7
September	1351.3	1353.6	2.3	1352.3	1.0	1342.6	-8.8
October	770.0	802.3	32.3	876.8	106.8	988.0	218.0
November	139.6	142.4	2.8	147.2	7.6	147.7	8.1
December	54.2	54.7	0.5	54.8	0.6	53.0	-1.2

Table A6. Warm Springs monthly hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 2000.

Big Swamp Creek Annual Hydrologic Yield - 1984			
Landcover	*Total Yield (acre feet)*	*Mean Daily*	*Std Dev*
Current	16120	44	93
Historical (Conservative)	16084	44	93
Departure from Current (%)	-0.23		
Historical (Liberal)	16126	44	93
Departure from Current (%)	0.03		
500 Year	15863	43	91
Departure from Current (%)	-1.62		

Table A7. Big Swamp Creek hydrologic yield for the current, conservative historical, liberal historical and 500 year landcover scenarios for 1984.

Big Swamp Creek Annual Hydrologic Yield - 1995			
Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	30930	85	148
Historical (Conservative)	30831	84	149
Departure from Current (%)	-0.32		
Historical (Liberal)	30912	84	149
Departure from Current (%)	-0.06		
500 Year	30387	83	144
Departure from Current (%)	-1.76		

Big Swamp Creek Annual Hydrologic Yield - 2000			
Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	10797	30	61
Historical (Conservative)	10716	29	62
Departure from Current (%)	-0.75		
Historical (Liberal)	10793	29	62
Departure from Current (%)	-0.04		
500 Year	10705	29	60
Departure from Current (%)	-0.86		

Tables A8 – A9. Big Swamp Creek hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 1995 and 2000.

Month	***Big Swamp Creek Monthly Hydrologic Yield (acre feet) - 1984***						
	Current	***Historic (Conservative)***	***Difference***	***Historic (Liberal)***	***Difference***	***500 Year***	***Difference***
January	26.0	25.9	-0.1	25.9	-0.1	24.4	-1.6
February	6.4	6.3	0.0	6.4	0.0	5.9	-0.5
March	0.5	0.5	0.0	0.5	0.0	0.4	-0.1
April	29.9	19.6	-10.3	25.7	-4.2	39.1	9.2
May	2556.8	2428.3	-128.5	2539.5	-17.3	2723.9	167.1
June	6977.6	7002.9	25.3	6979.4	1.8	6900.9	-76.7
July	3068.4	3110.6	42.2	3082.8	14.4	2881.3	-187.1
August	2294.1	2323.7	29.6	2303.9	9.7	2172.8	-121.4
September	812.5	829.2	16.6	818.3	5.8	755.2	-57.3
October	261.0	250.3	-10.7	256.4	-4.6	276.0	15.0
November	28.7	29.5	0.8	29.4	0.7	27.1	-1.6
December	58.1	56.6	-1.5	57.4	-0.7	56.1	-2.1

Table A10. Big Swamp Creek monthly hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 1984.

Month	Big Swamp Creek Monthly Hydrologic Yield (acre feet) - 1995						
	Current	Historic (Conservative)	Difference	Historic (Liberal)	Difference	500 Year	Difference
January	1.4	1.2	-0.1	1.3	0.0	1.4	0.0
February	0.1	0.0	0.0	0.1	0.0	0.1	0.0
March	2.3	1.9	-0.3	2.1	-0.2	1.9	-0.4
April	60.3	50.3	-10.0	57.0	-3.3	68.0	7.7
May	3985.8	3745.2	-240.6	3924.6	-61.2	4263.3	277.5
June	12610.0	12577.7	-32.3	12588.2	-21.8	12546.3	-63.7
July	8218.0	8392.0	174.0	8295.4	77.4	7671.3	-546.7
August	2552.3	2596.3	43.9	2561.4	9.1	2399.3	-153.0
September	2538.8	2553.4	14.6	2541.4	2.6	2450.1	-88.6
October	596.6	584.2	-12.4	592.3	-4.4	573.0	-23.6
November	234.2	208.0	-26.3	223.2	-11.0	259.2	25.0
December	128.9	119.5	-9.4	123.9	-5.0	151.6	22.7

Month	Big Swamp Creek Monthly Hydrologic Yield (acre feet) - 2000						
	Current	Historic (Conservative)	Difference	Historic (Liberal)	Difference	500 Year	Difference
January	1.5	1.6	0.1	1.5	0.0	1.2	-0.3
February	0.2	0.2	0.0	0.1	0.0	0.2	0.0
March	0.0	0.0	0.0	0.0	0.0	0.0	0.0
April	572.2	512.2	-60.0	557.1	-15.1	629.4	57.2
May	3426.2	3403.9	-22.3	3444.9	18.6	3511.2	85.0
June	3146.7	3191.9	45.1	3149.7	2.9	2919.8	-227.0
July	777.0	780.9	3.9	775.1	-2.0	720.2	-56.9
August	319.8	318.8	-1.0	317.7	-2.1	303.6	-16.2
September	1301.1	1301.4	0.4	1299.5	-1.5	1276.2	-24.8
October	991.3	948.0	-43.4	988.7	-2.6	1076.4	85.0
November	201.6	199.0	-2.5	200.3	-1.3	208.4	6.8
December	58.7	57.3	-1.4	57.8	-0.9	57.6	-1.1

Tables A11 – A12. Big Swamp Creek monthly hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 1995 and 2000.

Big Hole Headwaters Annual Hydrologic Yield - 1984			
Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	15584	43	101
Historical (Conservative)	15672	43	101
Departure from Current (%)	0.57		
Historical (Liberal)	15739	43	101
Departure from Current (%)	1.00		
500 Year	15650	43	97
Departure from Current (%)	0.42		

Big Hole Headwaters Annual Hydrologic Yield - 1995			
Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	30752	84	162
Historical (Conservative)	30893	84	162
Departure from Current (%)	0.46		
Historical (Liberal)	30984	85	161
Departure from Current (%)	0.76		
500 Year	30683	84	159
Departure from Current (%)	-0.22		

Big Hole Headwaters Annual Hydrologic Yield - 2000			
Landcover	***Total Yield (acre feet)***	***Mean Daily***	***Std Dev***
Current	10352	28	74
Historical (Conservative)	10449	29	74
Departure from Current (%)	2.22		
Historical (Liberal)	10582	29	71
Departure from Current (%)	2.22		
500 Year	10580	29	70
Departure from Current (%)	2.15		

Tables A13 – A15. Big Hole Headwaters hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 1984, 1995, and 2000.

Month	Big Hole Headwaters Monthly Hydrologic Yield (acre feet) - 1984						
	Current	Historic (Conservative)	Difference	Historic (Liberal)	Difference	500 Year	Difference
January	19.7	20.4	0.7	20.4	0.7	19.4	-0.3
February	4.6	4.9	0.3	4.9	0.3	4.5	-0.1
March	0.1	0.1	0.0	0.1	0.0	0.1	0.0
April	14.9	20.4	5.5	29.2	14.3	20.7	5.8
May	2299.1	2381.4	82.2	2569.7	270.6	2616.3	317.2
June	7168.7	7176.4	7.7	7138.6	-30.1	7307.4	138.7
July	3074.0	3059.0	-15.1	2985.1	-89.0	2749.5	-324.5
August	2063.8	2060.5	-3.3	2036.0	-27.8	1982.3	-81.5
September	731.8	732.7	0.9	724.2	-7.6	702.4	-29.5
October	159.7	167.5	7.8	179.4	19.6	199.0	39.2
November	24.5	24.6	0.1	24.5	-0.1	23.3	-1.2
December	22.6	24.1	1.5	27.0	4.4	25.2	2.6

Month	Big Hole Headwaters Monthly Hydrologic Yield (acre feet) - 1995						
	Current	Historic (Conservative)	Difference	Historic (Liberal)	Difference	500 Year	Difference
January	2.6	2.9	0.3	2.9	0.3	2.7	0.1
February	0.1	0.1	0.0	0.1	0.0	0.1	0.0
March	1.2	1.5	0.3	2.0	0.8	1.0	-0.2
April	31.2	37.6	6.4	48.1	16.9	36.4	5.2
May	3479.5	3605.3	125.8	3881.1	401.6	3878.2	398.8
June	13735.3	13747.9	12.6	13663.1	-72.1	13527.2	-208.0
July	8257.9	8222.8	-35.1	8130.0	-127.9	8093.2	-164.7
August	2144.9	2131.4	-13.5	2094.9	-50.0	2038.4	-106.5
September	2416.1	2425.8	9.7	2406.9	-9.2	2366.1	-49.9
October	402.3	416.1	13.9	429.9	27.6	416.6	14.3
November	182.8	195.7	13.0	209.9	27.1	204.6	21.8
December	97.3	105.3	8.0	114.7	17.4	117.4	20.2

Tables A16 – A17. Big Hole Headwaters monthly hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 1984 and 1995.

Month	***Big Hole Headwaters Monthly Hydrologic Yield (acre feet) - 2000***						
	Current	***Historic (Conservative)***	***Difference***	***Historic (Liberal)***	***Difference***	***500 Year***	***Difference***
January	1.1	1.0	0.0	0.9	-0.1	0.8	-0.2
February	0.3	0.6	0.3	1.1	0.9	0.1	-0.2
March	0.0	0.0	0.0	0.0	0.0	0.0	0.0
April	465.2	496.8	31.7	567.4	102.3	551.5	86.3
May	2749.7	2796.8	47.1	2927.7	178.0	3273.0	523.2
June	3806.1	3787.5	-18.6	3654.0	-152.1	3264.3	-541.8
July	703.1	701.9	-1.2	692.3	-10.9	663.6	-39.5
August	310.9	310.0	-0.9	306.6	-4.3	294.3	-16.7
September	1351.3	1353.6	2.3	1352.3	1.0	1342.6	-8.8
October	770.0	802.3	32.3	876.8	106.8	988.0	218.0
November	139.6	142.4	2.8	147.2	7.6	147.7	8.1
December	54.2	54.7	0.5	54.8	0.6	53.0	-1.2

Table A18. Big Hole Headwaters monthly hydrologic yield for the current, conservative historical, liberal historical and 500-year landcover scenarios for 2000.