ASPEN AND SHRUBBY CINQUEFOIL RESPONSE TO STREAMFLOW AUGMENTATION, AND THEIR GROUNDWATER RELATIONSHIPS

T.H. McCoy
R.J. Henszey
T.A. Wesche
Q.D. Skinner

1994
WWRC-94-18

Technical Report

Submitted to

The Department of the Interior
U.S. Geological Survey
and
Wyoming Water Resources Center
University of Wyoming
Laramie, Wyoming

Submitted by

Thomas H. McCoy
Robert J. Henszey
Thomas A. Wesche
and
Quentin D. Skinner
Department of Range Management
and
Wyoming Water Resources Center
University of Wyoming
Laramie, Wyoming

July, 1994

ABSTRACT

A previously ephemeral stream in southeastern Wyoming has been used since 1985 to convey a portion of the City of Cheyenne's water supply. This study was initiated to evaluate the response of aspen (*Populus tremuloides* Michx.) density, and shrubby cinquefoil (*Pentaphyloides floribunda* Pursh.) density and canopy cover to streamflow augmentation and altered groundwater levels. Depth-to-groundwater suitability relationships were investigated for both species.

Aspen density declined significantly as a result of streamflow augmentation on sites that became saturated or inundated for several consecutive growing seasons. Shrubby cinquefoil density also decreased significantly where the soil was saturated or inundated for several consecutive growing seasons. Conversely, shrubby cinquefoil canopy cover increased on one site as a result of flow augmentation.

Both aspen and shrubby cinquefoil showed a wide range of tolerance for groundwater levels, but neither showed a distinct relationship to depth to groundwater. Other environmental factors may play a significant role in determining the distribution of these species.

ACKNOWLEDGEMENTS

The authors wish to thank Craig Hines, Travis Bray, Donald Wiley, Andrew Wiley, Lanny Goyn, and Christopher Goertler for their invaluable assistance in the field.

Funding for this report was provided by the Department of the Interior, U.S. Geological Survey and the Wyoming Water Resources Center. Cooperation from the U.S. Forest Service, Medicine Bow National Forest was appreciated.

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INTRODUCTION

The Clean Water Act, National Environmental Policy Act, and other legislation have increased interest relating to the importance of wetlands and riparian areas in our landscape. The resulting need for detailed information pertaining to specific plant-water relationships in wetlands and riparian areas is well documented (Kusler and Kentula 1990, Mitsch and Gossenlink 1986).

Little research has been done to quantify surface and ground water relationships of riparian plant species. Recently, Peacock (1992) and Henszey (1993) investigated these requirements for several riparian plant species in the subalpine and montane zones of southeastern Wyoming. My research is a continuation of those studies and includes aspen (*Populus tremuloides* Michx.) and shrubby cinquefoil (*Pentaphyloides floribunda* Pursh.).

Aspen is an important species economically, aesthetically, and ecologically (DeByle and Winokur 1985). Aspen has relatively high water requirements though it is not necessarily considered a phreatophyte or riparian obligate. In the Great Lake states, well drained surface soils in the upper 0.60 to 0.90 m are beneficial to aspen, and the presence of a permanent or intermittent water table enhances aspen growth (DeByle and Winokur 1985). In Wisconsin, Wilde and Zicker (1948) report that for aspen growing on coarse soils underlain by an impervious substrata, maximum growth occurs with the water table at -0.84 m and decreases sharply when the water table is above -0.46 m or below -1.52 m. Aspen is classified by Walters et al. (1980) as tolerant to flooding. Tolerant is defined as trees that can withstand flooding for most of one growing season with limited root development during that period. Because most soils in the West are well drained, growth problems associated with too much water have not been extensively studied (DeByle and Winokur 1985).

Though of negligible economic value, shrubby cinquefoil is an overstory dominant in several subirrigated plant associations and provides excellent erosion protection (Hansen et al. 1988). The ecology of shrubby cinquefoil has been seldom studied. Habitat factors mentioned throughout the limited literature are that shrubby cinquefoil is shade intolerant, requires sites with high levels of soil moisture where subirrigation is common, and frequently inhabits transitional zones between wetlands and uplands (Elkington and Woodell 1963, Hansen et al. 1988, Scotter 1975). Flooding or elevated water tables are a common occurrence on many shrubby cinquefoil sites. Water tables may persist in the rooting zone throughout the growing season on wetter sites, but may be as deep as 1 m below the soil surface during the growing season on drier sites (Hansen et al. 1988). Little, however, is known regarding the specific plant-groundwater relationship of shrubby cinquefoil.

Habitat suitability indices (HSI), or habitat suitability criteria, are commonly used in fisheries and wildlife habitat management to help evaluate or predict the consequences of land use practices

(Bovee 1986). HSI's relate a dynamic environmental factor to a biological response variable, creating a quantitative measure of the range of environmental suitability for a specific species and life stage. Many environmental variables can be related to plant response. Ecologists have long utilized gradient analysis but often with qualitative variables (e.g. wet to dry) (Ricklefs 1990, Whittaker 1973). Recently, quantitative suitability curves were developed for specific plant species in southeastern Wyoming based upon their relationship to groundwater by Peacock (1992) on the Snowy Range Observatory (SRO) and Henszey (1993) on the Pole Mountain Research Watershed.

Included within the Pole Mountain Research Watershed, the South Fork of Middle Crow Creek (SFMCC) was historically an ephemeral water course. This channel was converted to a perennial stream by flow augmentation to mitigate wetland and riparian area loss from the City of Cheyenne's Stage II water development project (U.S.D.A. Forest Service 1980). This action provided a unique research opportunity to investigate the physical and biological response of several riparian plant species to elevated water levels caused by flow augmentation. As a result, this research was developed to address the following objectives:

1. Quantify the response of aspen and shrubby cinquefoil stands on the SFMCC to streamflow augmentation.

2. Develop depth-to-groundwater suitability relationships for aspen and shrubby cinquefoil on the SFMCC and adjacent non-augmented watersheds.

The null hypothesis was:

> H_o: Streamflow augmentation, and the resulting changes in surface and groundwater levels, had no effect on aspen (density) or shrubby cinquefoil (density and canopy cover) on the SFMCC.

Because inferential statistics were not used to evaluate depth-to-groundwater suitability relationships for aspen and shrubby cinquefoil the following theoretical hypothesis was tested:

> H: There is no relationship between depth-to-groundwater and aspen (density) or shrubby cinquefoil (density and canopy cover) on the SFMCC and adjacent non-augmented watersheds.

METHODS

STUDY AREA.

The South Fork of Middle Crow Creek (SFMCC) is contained within the Wyoming Water Resources Center's Pole Mountain Research Watershed, located 32 km east of the City of Laramie, Wyoming, in the Medicine Bow National Forest (Figure 1). Originating at 2,507 m above mean sea level, the SFMCC flows easterly for approximately 16.1 km from its headwaters to its confluence with the Middle Fork of Crow Creek. The study area encompasses 8.3 km^2 starting near the Vedauwoo Campground. The upper 40% of the study area is characterized by a narrow, steeper gradient (3.2-4.6%), geologically confined valley dominated by shallow soils and aspen communities. The lower 60% of the study area has a lower gradient (0.8-1.4%) with wider valleys and deeper alluvial soils. Sedge (*Carex* spp.), tufted hairgrass (*Deschampsia cespitosa* (L.) Beauv.), and willow (*Salix* spp.) communities dominate the lower portion of the SFMCC within the study area, with aspen and shrubby cinquefoil also being common along the meadow edges. The study area also includes four adjacent, non-augmented watersheds which were used to compare with conditions on the SFMCC. Six exclosures were constructed in 1984 along the SFMCC to protect the developing riparian area from livestock grazing (Figure 1).

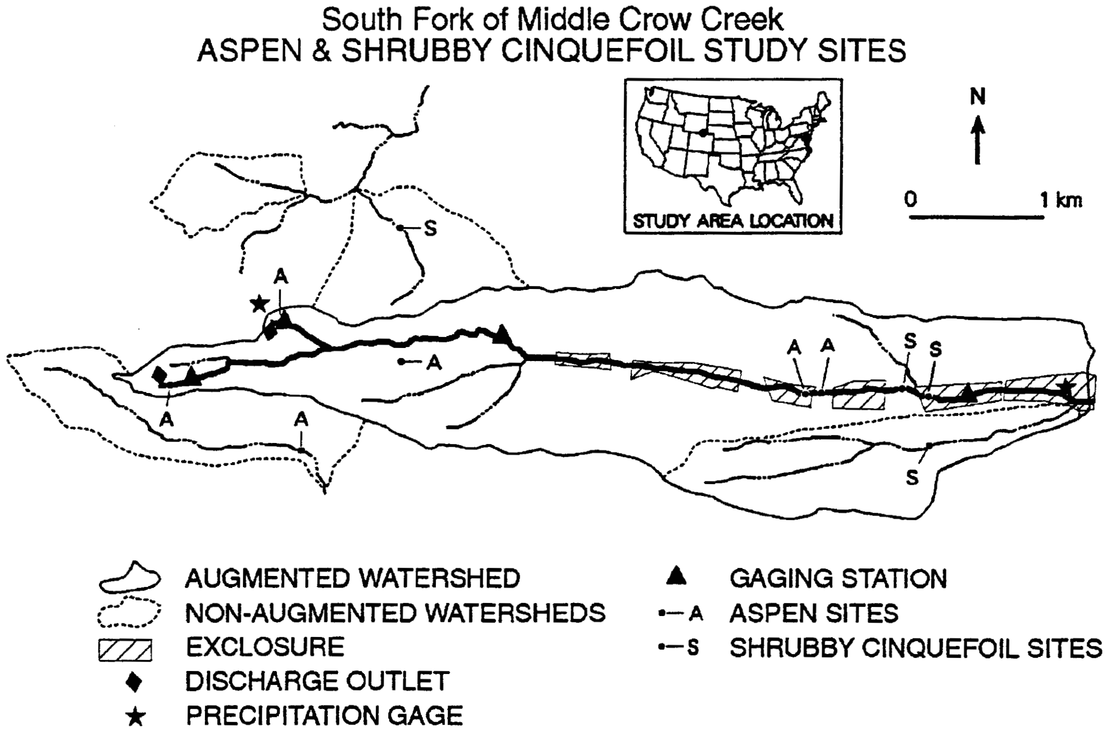


Figure 1. Map of the Pole Mountain Research Watershed, Wyoming, showing the SFMCC and non-augmented comparison watersheds, vegetation study sites, sampling instrumentation, livestock exclosures, and discharge outlets.

The SFMCC was originally an ephemeral stream that flowed primarily in response to snow melt in the spring and intense summer thunder storms. Before flow augmentation about 1% of the upper reach and 23% of the lower meadow reach had formed a distinct channel (Henszey 1993). Streamflow augmentation resulting from the implementation of the Stage II Project began in August 1985. A combined total of approximately 56 Ls^{-1} have been continuously released from two discharge outlets, one on the SFMCC and the other on a tributary near the upper end of the watershed (Figure 1). Flow from the outlets is continuous except for 1 month during peak runoff in the late spring or when maintenance activities require the outlets to be closed.

The additional water from flow augmentation spreads across the lower gradient unchannelized sites, flooding the valley bottom with approximately 5-10 cm of water traveling as sheet flow down the valley. Subsequent channel development has caused the water table to seek a new equilibrium that has not yet been clearly defined. Approximately 50% of the channel appears to still be developing (Henszey 1993).

SAMPLING PROCEDURES.

Suitable sites were not available for all levels of grazing (i.e., inside or outside of grazing exclosures) so stratification of stand types by grazing intensity was not attempted. While this may have induced some bias in the sampling, it was considered negligible because the grazing is managed under a deferred rotation system (U.S.D.A. Forest Service 1991a, 1991b) that minimized impacts.

Surfacewater Hydrology. The SFMCC study area lies within a 38 to 48 cm precipitation zone and is dominated by late spring and summer rain events (U.S.D.A. Soil Conservation Service 1982). Precipitation has been continuously monitored at the upper and lower ends of the study area since 1985 by two alter-shield equipped Belfort weighing-bucket precipitation gages (Figure 1). Annual precipitation has ranged from 39 to 52 cm for the water years (October to September) 1986 to 1993. Streamflow has also been continuously measured throughout the study by four Parshall flumes equipped with Stevens Type-F stage recorders (Figure 1). Two additional stagerecorder equipped Parshall flumes were installed below the study area to evaluate water conveyance efficiency through the system.

Groundwater Hydrology. A total of 72 shallow groundwater observation well transects were established in the study area. Transect locations were based upon channel gradient, vegetation type, type of channel control (geologic, beaver dam, or vegetative), and presence of livestock grazing exclosures. Each transect typically consisted of four wells cased in perforated 5 cm diameter PVC pipe spaced across a transect perpendicular to the channel. Wells were typically installed to depths from 1 to 4 m below the surface depending on site characteristics. Groundwater well transects were used to measure depth to groundwater across the site (Henszey 1993). Groundwater stage was typically measured once a month, but was often measured more frequently during the growing season. Groundwater monitoring from October to April was reduced to a small number of representative well transects for the winter season. In March 1993, Stevens Type F stage recorders were installed on nine wells to continuously monitor groundwater stage in or near each sampling site.

Plant Response to Streamflow Augmentation.

Vegetation sampling sites were coded numerically, beginning with sampling sites in the upper potion of the study area and continuing to the bottom (Table 1). Letters were then assigned as follows. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type. For aspen, N = narrow valley bottom and

Table 1. Location, treatment, and relationship to exclosures of aspen and shrubby cinquefoil sampling sites on the Pole Mountain Research Watershed. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type. For aspen, N = narrow valley bottom and W = wide valley bottom, while F = flat valley bottom and S = sloping valley bottom for shrubby cinquefoil.

Aspen Sampling Sites				
Cross section	Site	Valley Type	Treatment	Exclosure
138	Site 1AN	Narrow	Augmented	No
A176	Site 2AN	Narrow	Augmented	No
B100	Site 3NN	Narrow	Non-Augmented	No
17406	Site 4AW	Wide	Augmented	Yes
17803	Site 5AW	Wide	Augmented	No
K400	Site 6NW	Wide	Non-Augmented	No

Shrubby Cinquefoil Sampling Sites.				
Cross section	Site	Valley Type	Treatment	Exclosure
20024	Site 1AF	Flat	Augmented	No
D200	Site 2NF	Flat	Non-Augmented	No
20792	Site 3AS	Sloping	Augmented	Yes
C100	Site 4NS	Sloping	Non-Augmented	No

W = wide valley bottom, while F = flat valley bottom and S = sloping valley bottom for shrubby cinquefoil.

Aspen Density. Four aspen study sites, each associated with an existing well transect, were established along the SFMCC in 1985 (Figure 1). Two sites were located in the upper narrow valley bottom portion of the study area and two in the lower wide valley bottom portion (Table 1). One of the two wide bottom sites is in a livestock exclosure. In 1986 two non-augmented aspen sites were established on drainages adjacent to the SFMCC (Table 1). These two locations were selected to represent similar sites on the SFMCC. Neither non-augmented site was in an exclosure.

The aspen sampling layout consisted of four, 2 m wide belt transects established parallel to the well transect (Figure 2), each spaced at 2 m intervals beginning at the well transect. Two belts were located on the upstream side of the well transect, and two belts on the downstream side. The belts extended slightly beyond the edge of the aspen stand. Each belt was then subdivided into three blocks. The flooded block was the flooded valley bottom on flow augmented sites and the ephemeral channel on non-augmented sites. Upslope, on either side of the flooded block, the transition block extended up to the edge of the aspen stand. The upland blocks extended slightly beyond the aspen stand on each side to measure any expansion of the aspen stand.

Aspen sampling was conducted in the fall or winter of 1985, 1986, 1987, and 1993 by recording mature live aspen density for each belt, by block. For this study, all aspen taller than 1.4 m (breast height) were considered mature. The winter of 1985-86 was considered to be the pretreatment sample because streamflow augmentation began in August of 1985 at the end of the aspen growing season. Therefore, flow augmentation had little effect on the aspen stands until the following growing season.

Shrubby Cinquefoil Density. Two shrubby cinquefoil study sites were established on well transects during the fall of 1985 on the lower portion of the SFMCC (Figure 1, Table 1). One site was located inside

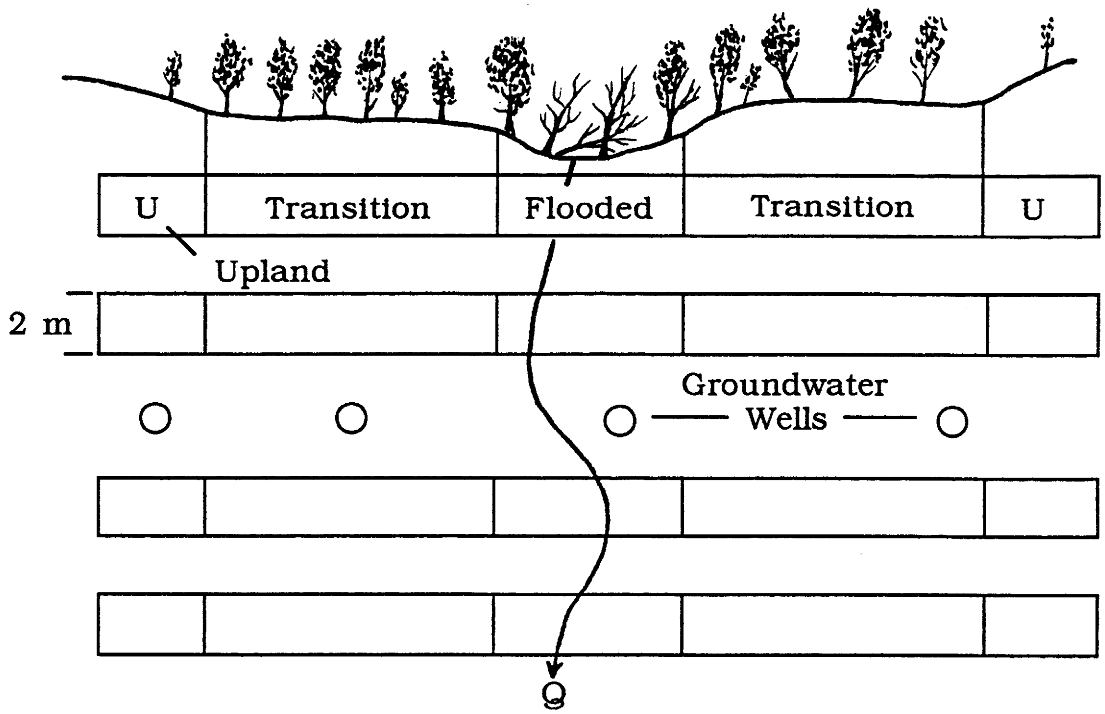


Figure 2. Sampling layout used for aspen density measurement.

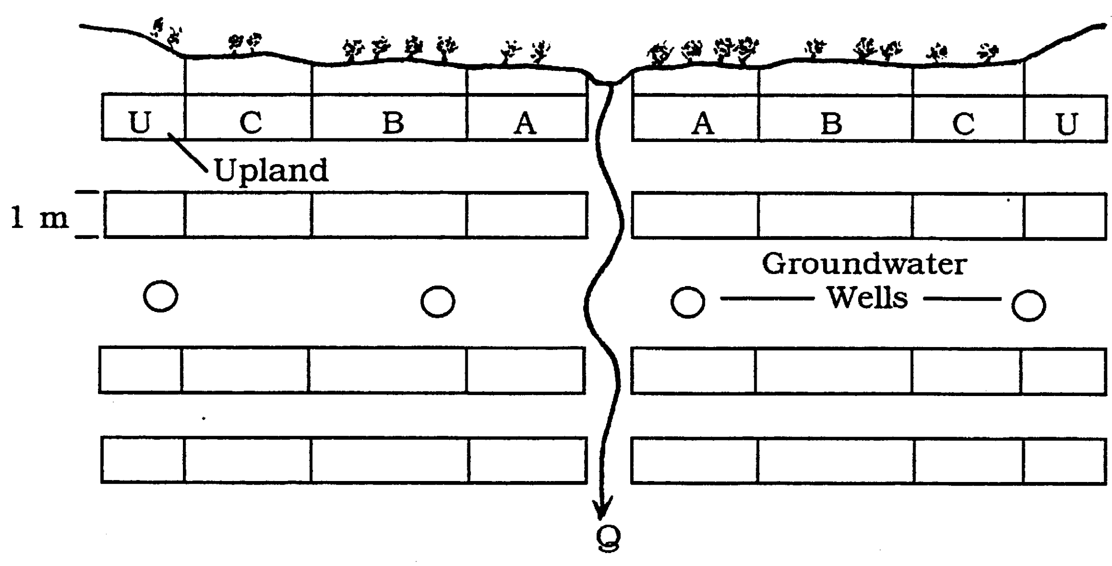


Figure 3. Sampling layout used for shrubby cinquefoil density measurement, and the base design used for shrubby cinquefoil percent canopy cover measurement.

a grazing exclosure on a reach characterized by gently sloping valley walls. The second study site was in a flat, relatively wide valley bottom outside of a grazing exclosure. In the summer of 1986 two additional non-augmented shrubby cinquefoil sites were established along well transects on adjacent ephemeral drainages (Figure 1). These locations were selected because of similarity to the SFMCC sites.

Initial efforts to sample shrubby cinquefoil (1985 and 1986) used a method similar to that used for sampling aspen (Figure 3). Four, 1 m wide belt transects were established parallel to a well transect; two belts on the upstream side of the well transect and two on the downstream side. The inner belts were spaced 2 m from the well transect with the outer belts 3 m beyond the inner belts. On sites with gently sloping valley bottoms, the belts were subdivided into four blocks (A, B, C, Upland, with A being nearest the channel), based upon distance from the channel. Belts on the flat bottomed site were divided into blocks (low and high density, valley edge, and upland) based upon an estimate of a distinct change in shrubby cinquefoil density. The sloping bottomed flow augmented site and the flat bottomed non-augmented site also had a flooded block along the channel between the A blocks. Sampling consisted of going through each belt, by block, and determining mature shrub density. Mature plants were identified by numerous stems and/or stem diameter greater than 6.5 mm. Because the stem diameter criterion for shrubby cinquefoil classification was changed after the first sampling season (1985) analysis was performed on the second season's data (1986). Data from all years are reported.

Shrubby Cinquefoil Canopy Cover. Because it was difficult to determine individual plants within "clumps" of shrubby cinquefoil, a new sampling technique was superimposed over the existing belts for the 1987, 1988, and 1993 sampling seasons. Randomly located point intercept lines were placed perpendicular to the original belts, with each line extending to the outer edge of the outermost belts (Figure 3). The lines were grouped such that each block contained four point intercept lines. The same line locations were used for all sampling seasons. A sampling pin was lowered along the line at 10 cm increments with the first hits on live or dead shrubby cinquefoil canopies recorded.

Sampling was conducted between July and early September to assure that the shrubs were exhibiting their full annual growth, but had not yet gone dormant. Both sampling techniques described above were used for the 1993 sampling season.

ANALYSIS

Surface and Groundwater Hydrology.

A box-and-whisker plot (SAS Institute Inc. 1990) of mean daily streamflow discharge summarized by month for the study period was generated for the middle flume (Figure 1) within the study area (Appendix Figure 14). Box-and-whisker plots representing all point-in-time sampled depth-to-groundwater measurements were used to describe the groundwater hydrograph for each stand type. Point-in-time observations were summarized by month, except for May to June which was divided into bi-weekly periods. Each box represents the 25th to 75th percentile of the observations connected by a line through the median. Whiskers (the lines on either side of the box) bound the 10th to 90th percentile of the observations. This representation portrays variation of groundwater levels within and between months.

Development of depth-to-groundwater duration curves required several steps. First, continuous daily mean depth-to-groundwater levels were estimated from point-in-time measurements. For flow augmented sites, regression analysis (Proc REG, SAS 1985b) was used to transform point-in-time sampled groundwater data into estimated continuous data based on nearby continuously monitored groundwater or streamflow levels. On non-augmented sites and where a good correlation could not be achieved through regression analysis for flow augmented sites ($p > 0.10$), point-in-time groundwater measurements were expanded into continuous data by Proc EXPAND (SAS 1988). The daily means were then converted to cumulative frequency distributions with Proc FREQ (SAS 1985a). Depth-to-groundwater duration curves were created from the cumulative frequency distributions by plotting depth on the Y-axis against percent time (duration) on the X-axis. A given point on the curve shows the percent of time that the groundwater was at or above a specified level.

Plant Response to Streamflow Augmentation.

A graphical presentation was used to analyze data and demonstrate the response of both aspen and shrubby cinquefoil to streamflow augmentation and altered groundwater levels. This entailed graphing the measured response variables (aspen density, and shrubby cinquefoil density and percent canopy cover) through the study period. Further analysis used paired t-tests for response values between first and last years for each sampling method to detect if a significant difference ($p \leq 0.05$) occurred. Individual block types on each site ($n = 4$ on flooded blocks, $n = 8$ on all other blocks) were considered an experimental unit.

Depth-to-Groundwater Suitability Relationships.

Linear interpolation between adjacent wells was used to determine depth-to-groundwater duration values at the center of each vegetation sampling block. The slope of the nearest block containing a well was used to determine depth-to-groundwater values for blocks lying beyond the outermost wells. Three duration values (D_{10} = 10%, D_{50} = 50%, D_{90} = 90%), representing the percent of time that the groundwater was at or above a specified level, were selected to portray the "typical" groundwater regime (shallowest D_{10}, median D_{50}, deepest D_{90}) at each sampling site. Depth-to-groundwater duration values were determined from depth-to-groundwater duration curves from each well. The duration values were then plotted against normalized measures of plant response (density for aspen, and density and canopy cover for shrubby cinquefoil) to create depth-to-groundwater suitability relationships. The response variables were normalized by dividing each year's score by the first year's score (e.g. $Density_{1985}/Density_{1985}$ ... $Density_{1993}/Density_{1985}$) to create a consistent scale between sites.

RESULTS

Groundwater Hydrology.

Non-augmented aspen sites exhibited a much greater range and consistently deeper groundwater levels than flow augmented sites (Figure 4). Monthly median groundwater levels for the flow augmented aspen sites ranged from a low of -0.43 m in July, before fall recharge, to a high of -0.10 m in April during spring runoff. Median groundwater levels on non-augmented aspen sites varied from a low of -2.35 m in January to a high of -0.51 m in early June following peak snow melt.

Monthly median groundwater levels for non-augmented shrubby cinquefoil sites showed a greater range than flow augmented sites, but the peak levels were similar (Figure 5). Flow augmented shrubby cinquefoil sites exhibited their lowest median groundwater levels, -0.80 m, in January and peaked in May at -0.30 m. The peak groundwater level for non-augmented shrubby cinquefoil sites was -0.24 to -0.29 m from mid April to early June. Because of an insufficient number of observations, box-and-whiskers for the December through March period could not be developed. Median groundwater levels on sampling sites dropped to near base levels by the end of the June through September growing season.

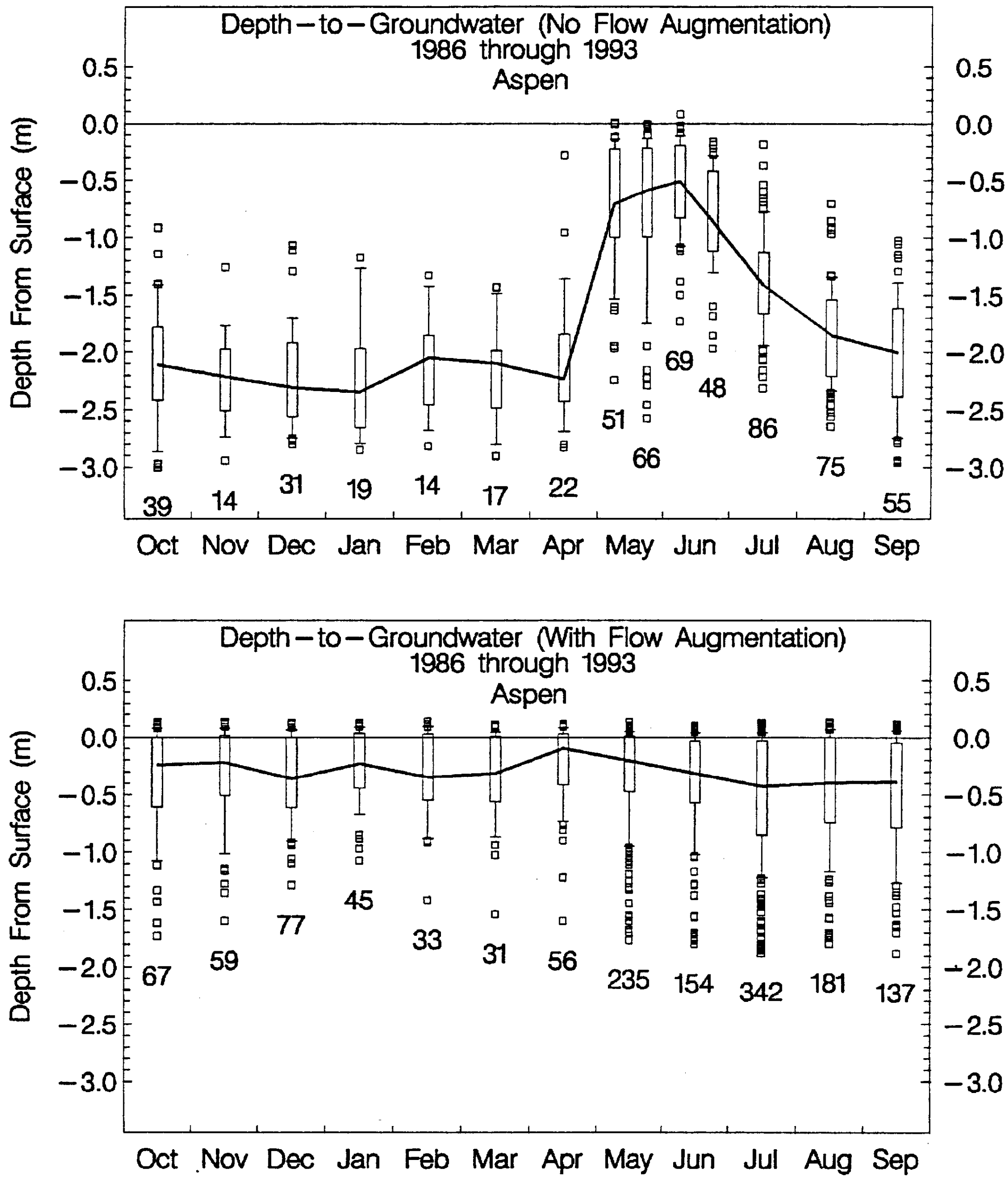
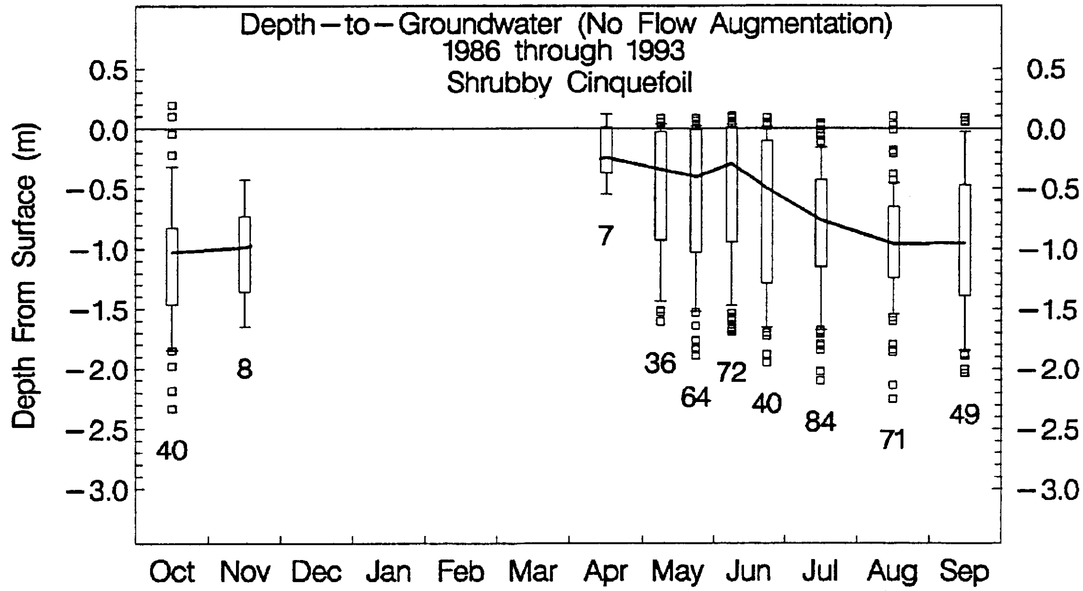


Figure 4. Groundwater hydrographs for all aspen sampling sites, flow augmented and non-augmented, showing the variation within each month (or half month). Boxes represent the 25th to 75th percentile and the whiskers the 10th to 90th percentile. Small boxes above and below the whiskers represent individual data points in the 0 through 9th and 91 to 100th percentile. The number of observations for each box is shown below the deepest observation.



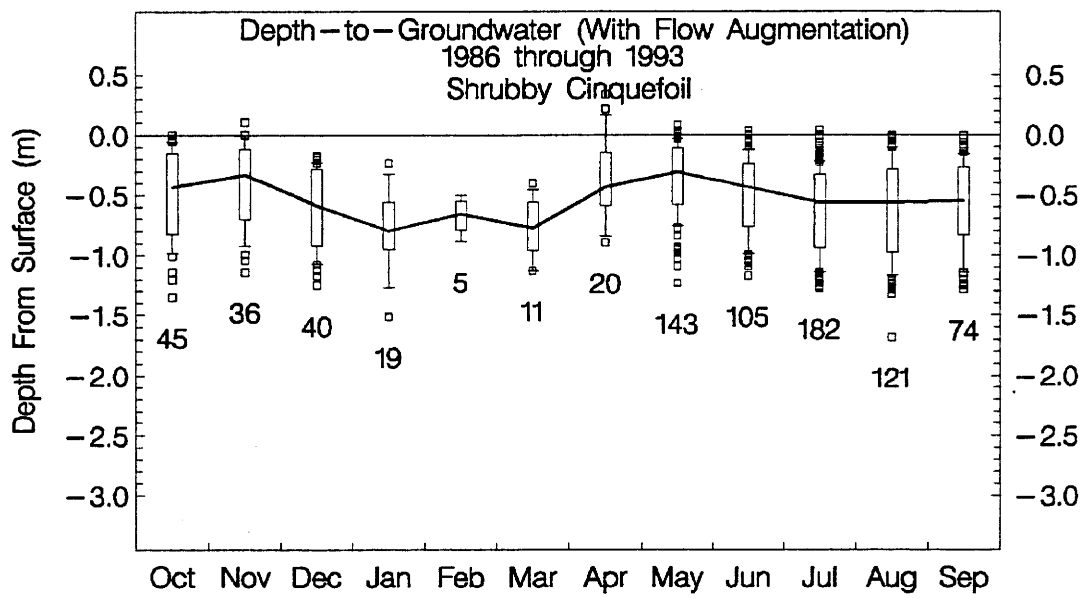


Figure 5. Groundwater hydrographs for all shrubby cinquefoil sampling sites, flow augmented and non-augmented, showing the variation within each month (or half month). Boxes represent the 25th to 75th percentile and the whiskers the 10th to 90th percentile. Small boxes above and below the whiskers represent individual data points in the 0 through 9th and 91 to 100th percentile. The number of observations for each period is shown below the deepest observation.

Depth-to-Groundwater Duration Curves.

Depth-to-groundwater duration curves for selected wells in each aspen block type (one each from narrow and wide bottom augmented sites and one from a non-augmented site) are presented in Figure 6. These curves indicate the percent of time that the groundwater was at or above a specific level for the growing season. Wells were selected based on the dataset quality and availability within block types.

Depth-to-groundwater duration values on the aspen sites showed two distinct patterns, one for flow augmented sites and one for non-augmented sites (Figure 6). These patterns suggest that the groundwater regimes were consistent between flow augmented sites and between non-augmented sites. Water levels on flow augmented sites were relatively constant through the growing season, reflecting the continuous flow augmentation. The non-augmented sites were more dynamic, showing a greater range and a steady decline that seldom stayed at one depth-duration for more than 2% of the time. The greatest range of observed water levels for selected wells in flow augmented aspen upland blocks during the growing season was -0.41 to -0.95 m, compared to -0.45 to -2.98 m for the non-augmented well (Figure 6). The greatest range for selected wells in flow augmented transition blocks was -0.17 m to -1.28 m, while the non-augmented well ranged from -0.29 to -2.39 m (Figure 6). Duration curves for wells in the flow augmented flooded blocks were similar. These wells varied from 0.06 to -0.60 m, and were at or above the surface 88% and 58% of the time (Figure 6). The non-augmented flooded block well ranged from a high of -0.08 m to a low of -1.96 m (Figure 6).

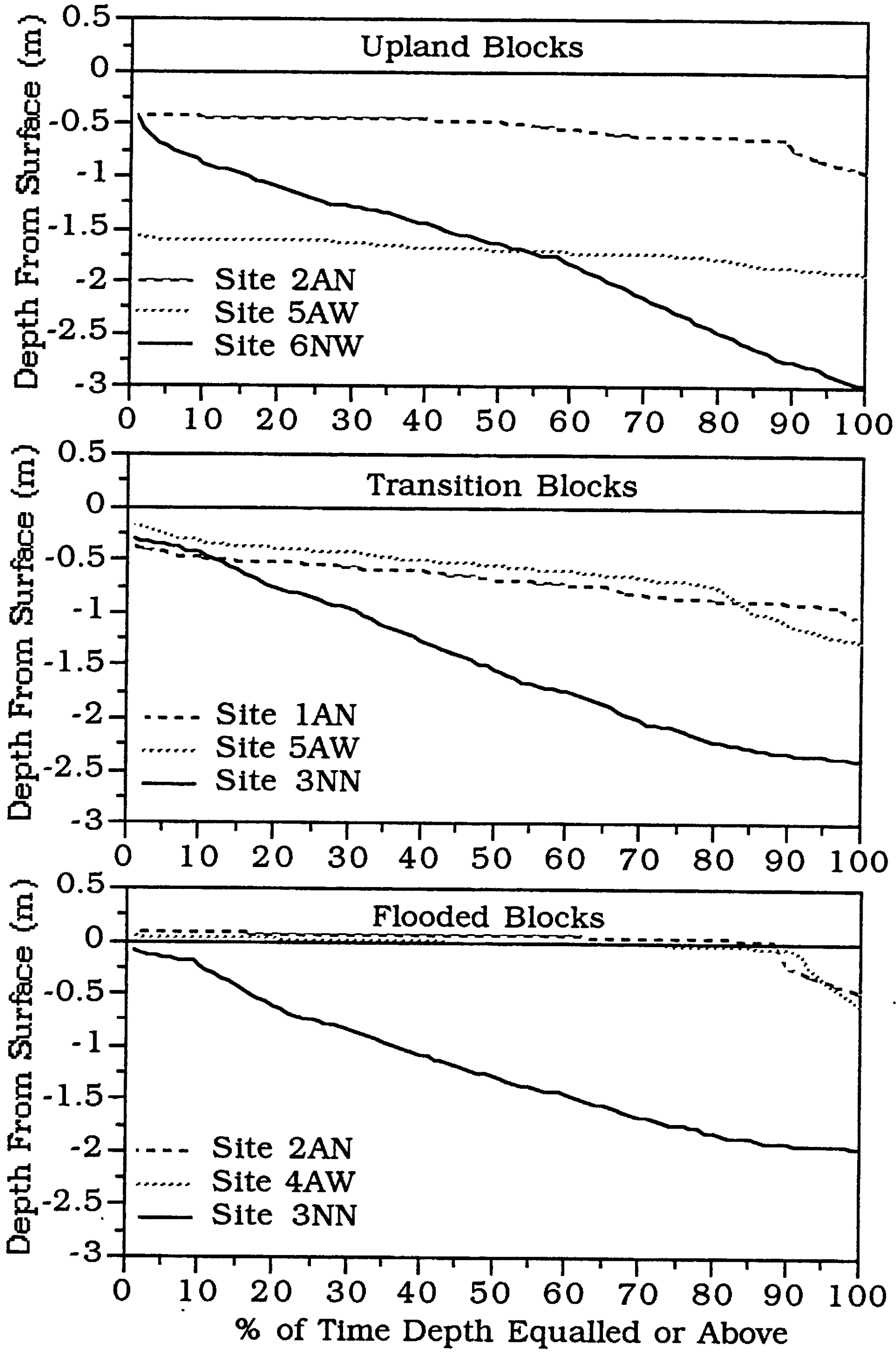


Figure 6. Depth-to-groundwater duration curves for selected wells in aspen sampling sites. Curves represent the growing season for the years 1987 to 1993. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type, (i.e. N = narrow valley bottom and W = wide valley bottom.

Because wells were not located within all individual block types all shrubby cinquefoil blocks were combined into two groups for depth-duration analysis, inner (A, B, and Flooded blocks) and outer (C and Upland blocks). The pattern of flow augmented shrubby cinquefoil wells (Figure 7) was similar to that of flow augmented aspen wells (Figure 6). However, the duration curves for non-augmented shrubby cinquefoil wells (Figure 7) showed more abrupt changes in slope and a smaller range than did the non-augmented aspen wells (Figure 6). For flow augmented wells in the outer shrubby cinquefoil blocks (Figure 7), the greatest range of groundwater levels was -0.76 to -1.68 m. Because of continuous flow augmentation, groundwater levels for these wells tended to stay at one general elevation for extended periods. The non-augmented well decreased gradually until approximately D_{14} to D_{16} when the water level dropped from -0.51 to -0.91 m and then continued a gradual decline to D_{100}. The non-augmented well also showed the greatest variation in groundwater levels for any shrubby cinquefoil site, -0.30 to -2.30 m (Figure 7).

Depth-to-groundwater duration curves for shrubby cinquefoil flow augmented and non-augmented wells were more similar to each other for wells in the inner block wells than the outer block (Figure 7). The greatest variation for flow augmented wells was 0.07 m to -1.05 m compared to 0.11 to -0.96 m for the non-augmented well. The non-augmented well remained relatively constant between, D_1 through D_{40}, then the water levels declined

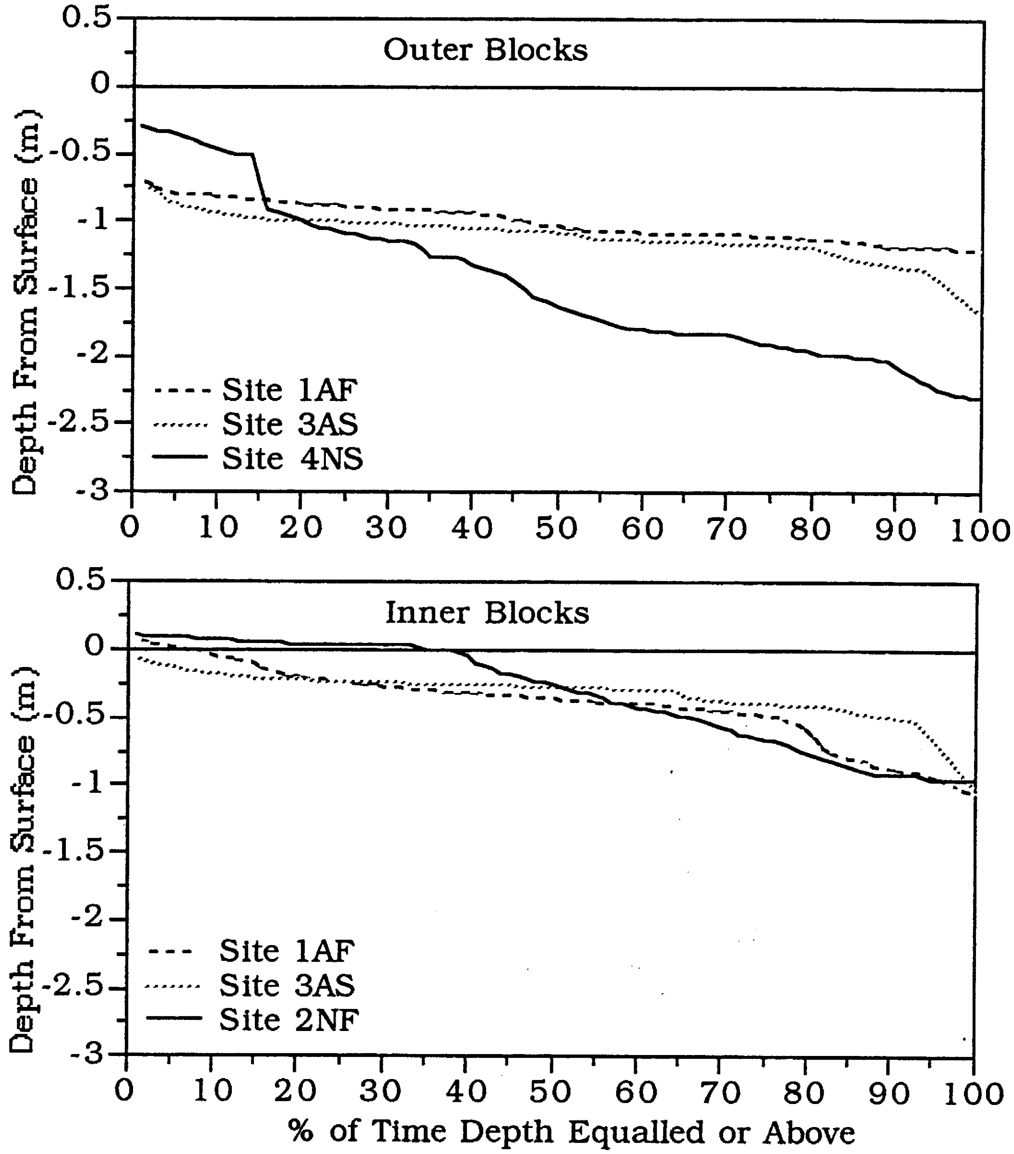


Figure 7. Depth-to-groundwater duration curves for selected wells in shrubby cinquefoil sampling sites. Curves represent the growing season for the years 1987 to 1993. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type (i.e. F = flat valley bottom and S = sloping valley bottom).

rapidly to D_{87} where it leveled out again. Water levels were at or above the soil surface 7% of the time for the flow augmented well and 37% of the time for the non-augmented well.

Plant Response to Streamflow Augmentation

Aspen. In general, aspen showed no response to streamflow augmentation unless soils were saturated or flooded for long durations (Figure 8). Aspen in all of the narrow bottom upland and transition blocks showed no significant change ($p \geq 0.1263$) as a result of streamflow augmentation (Figure 8). From 1985 to 1993 aspen density decreased at both of the wide bottom flow augmented transition blocks (Figure 8). Site 4AW declined ($p = 0.0142$) from 0.59 to 0.47 trees/m^2 and site 5AW decreased ($p = 0.0446$) from 0.35 to 0.29 trees/m^2. Density also decreased in all of the narrow bottom flooded blocks (Figure 8). Site 1AN decreased ($p = 0.0072$) from 0.41 to 0.18 trees/m^2, site 2AN decreased ($p = 0.0020$) from 0.81 to 0.23 trees/m^2, and site 3NN ($p = 0.0154$) from 0.71 to 0.61 trees/m^2. With the exception of the narrow bottom flooded block, non-augmented aspen sites remained unchanged ($p \geq 0.2658$) (Figure 8).

Shrubby cinquefoil. Flow augmentation had no significant effect ($p \geq 0.0569$) on shrubby cinquefoil density from 1986 to 1993 except in the A blocks near the channel (Figure 9). Density decreased ($p = 0.0032$) from 0.92 to 0.27 plants/m^2 on the A block of site 1AF, and from 2.08 to 2.03 plants/m^2 ($p = 0.0246$) on block A of site 3AS. With the exception of the C block on site 4NS, there was no change

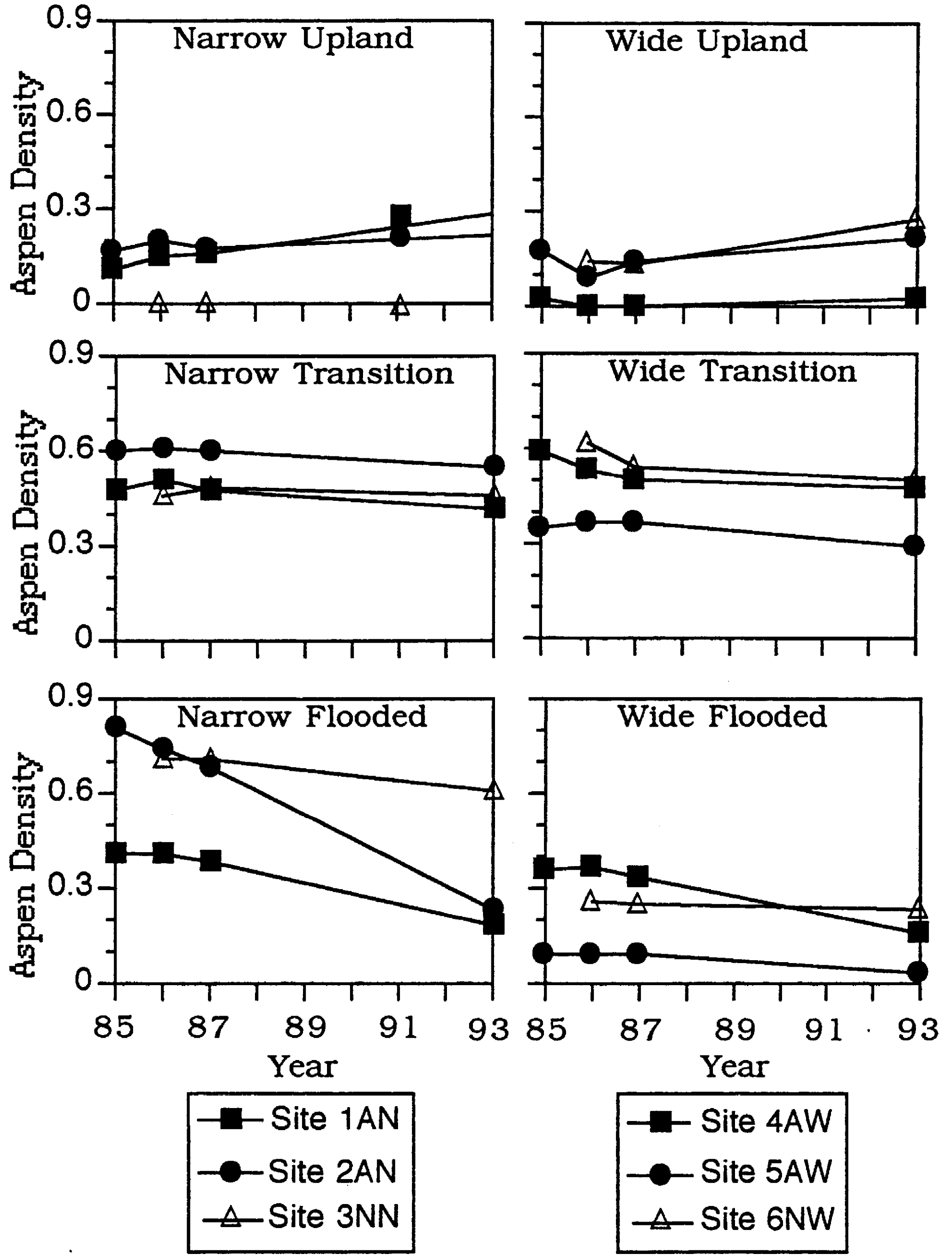


Figure 8. Mean aspen density (trees/m^2) response to streamflow augmentation. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type, (i.e. N = narrow valley bottom and W = wide valley bottom).

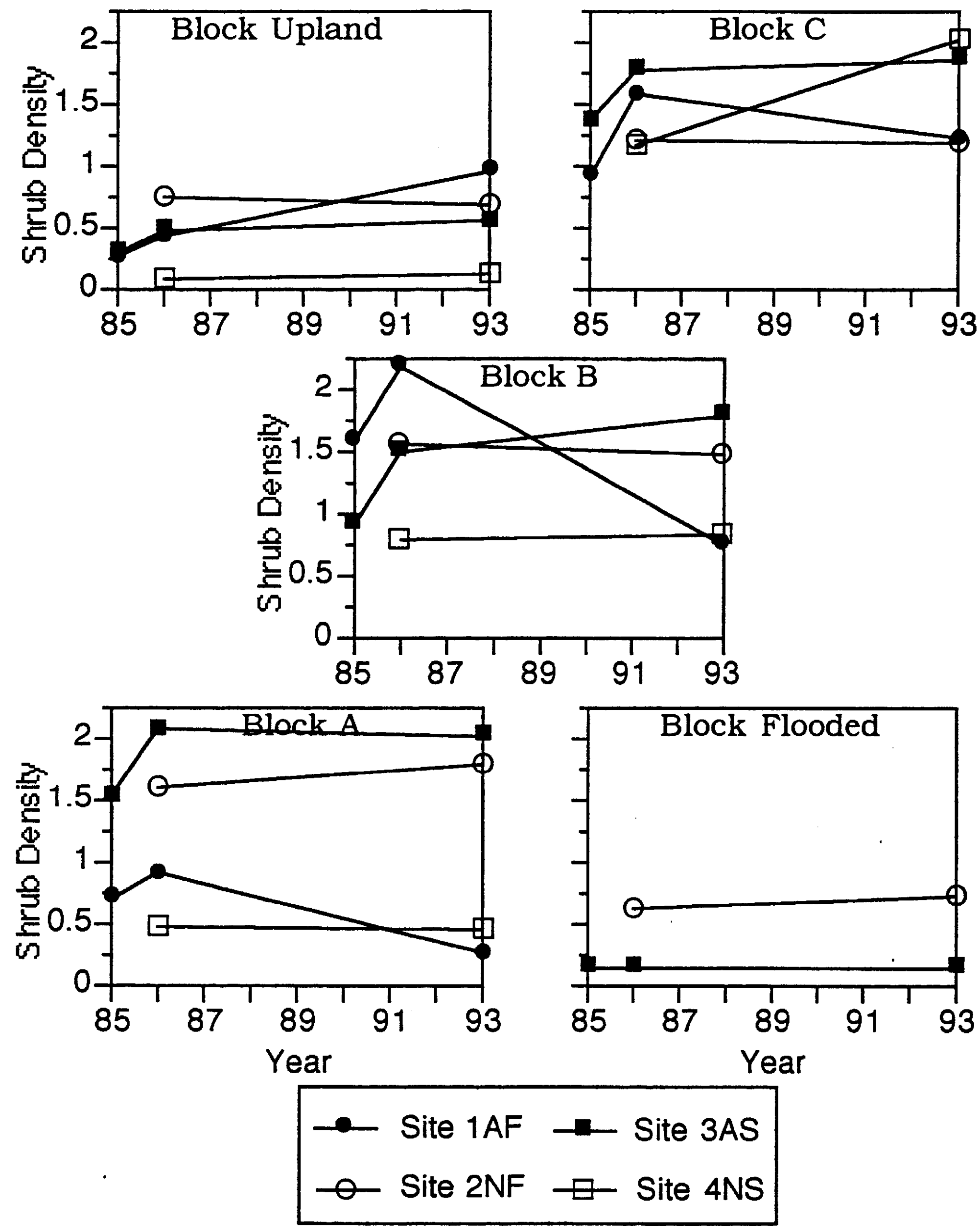


Figure 9. Mean shrubby cinquefoil density (plants/m^2) response to streamflow augmentation. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type (i.e. F = flat valley bottom and S = sloping valley bottom).

($p \geq 0.1675$) in shrubby cinquefoil density on any of the non-augmented sites. The C block on site 4NS showed a density increase ($p = 0.0252$) from 1.18 to 2.03 plants/m^2.

Percent shrubby cinquefoil canopy cover showed no significant change ($p \geq 0.1076$) between 1987 and 1993 on all flow augmented sites except the B and A blocks of site 3AS (Figure 10). Percent canopy cover increased ($p = 0.0321$) on the B block from 4.1 to 9.4%, and from 10.4 to 19.1% on the A block ($p = 0.0010$). Unlike the flow augmented sites, the only significant changes ($p < 0.05$) observed on non-augmented sites were in the Upland and C blocks. The percent canopy cover on the upland block of site 2NF decreased ($p = 0.0286$) from 3.8 to 1.8%, while the C block of site 4NS increased ($p = 0.0077$) from 4.6 to 7.0% (Figure 10). All other non-augmented blocks remained unchanged ($p \geq 0.1430$)

Depth-to-Groundwater Suitability Relationships.

Aspen. Aspen density showed no discernible relationship to groundwater at the depth-to-groundwater durations D_{10}, D_{50}, and D_{90}, therefore, no suitability curves were fitted (Figure 11). The observed range of depths to groundwater on aspen sampling sites were 0.07 to -2.61 m for D_{10}, -0.03 to -3.30 m for D_{50}, and -0.19 to -3.74 m for D_{90}.

Shrubby cinquefoil. Shrubby cinquefoil density and canopy cover also showed no relationship to the selected depth-to-groundwater durations (D_{10}, D_{50}, D_{90}) (Figure 12 and 13). The range of depths to groundwater observed for shrubby cinquefoil sampling sites were 0.06 to -1.13 m for D_{10}, -0.24 to -1.82 m for D_{50}, and -0.49 to -2.26 m for D_{90}.

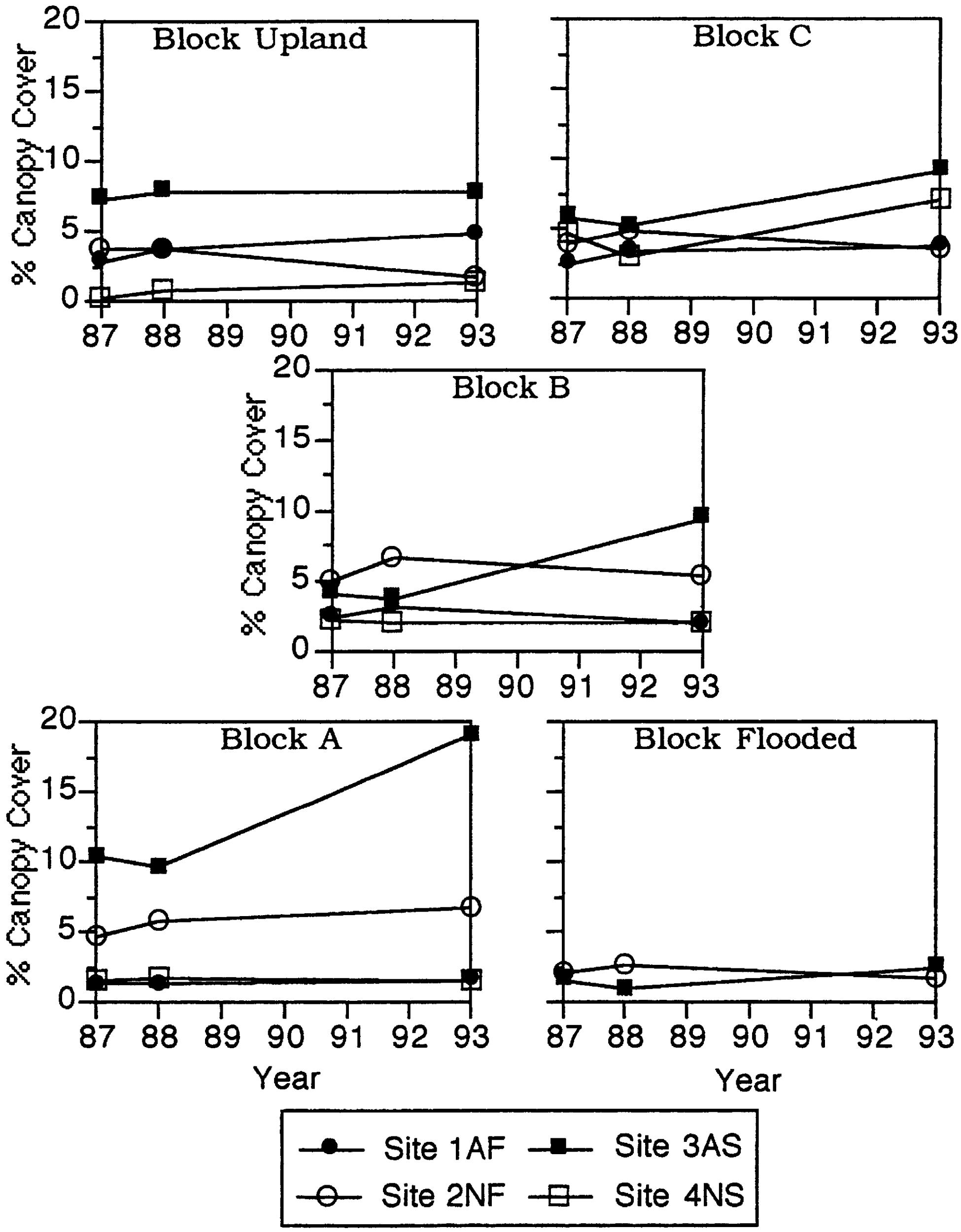


Figure 10. Mean shrubby cinquefoil % canopy cover response to streamflow augmentation for the years 1987-88,1993. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type (i.e. F = flat valley bottom and S = sloping valley bottom).

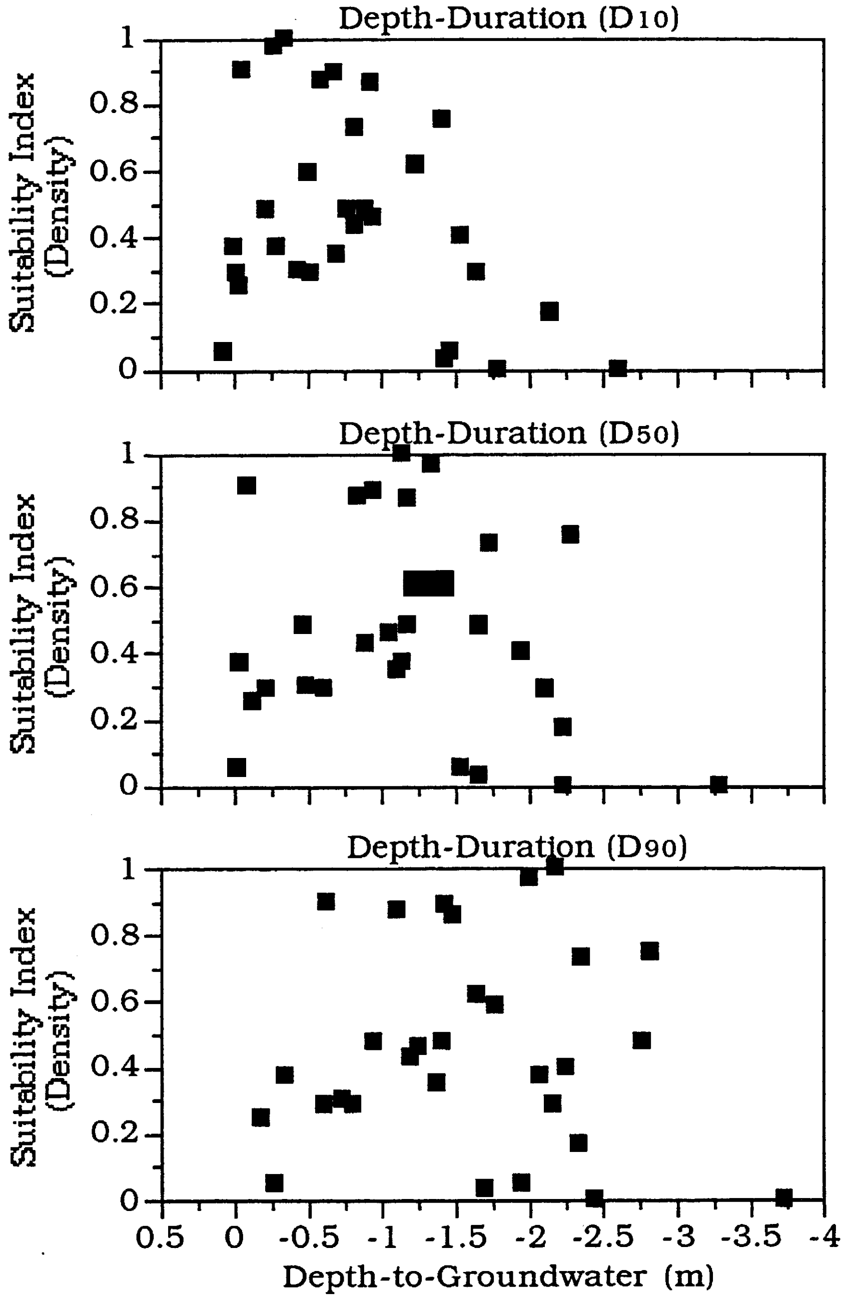


Figure 11. Aspen density depth-to-groundwater suitability relationships. Density response values were normalized by dividing each score by the single highest score. The duration series represent percent of time (D_{10} = 10%, D_{50} = 50%, D_{90} = 90%) for the growing season that the groundwater was at or above a given level.

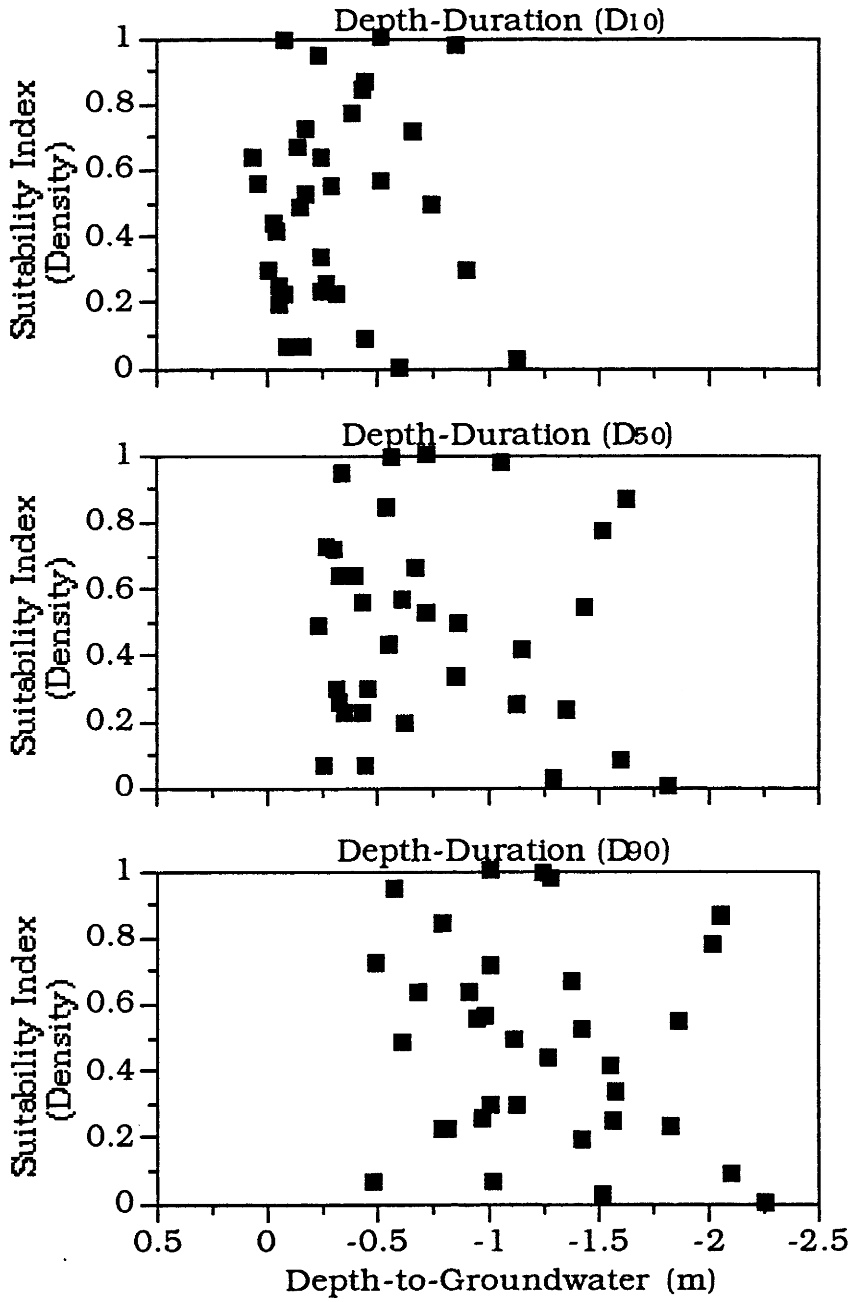


Figure 12. Shrubby cinquefoil density depth-to-groundwater suitability relationships. Density response values were normalized by dividing each score by the single highest score. The duration series represent percent of time (D_{10} = 10%, D_{50} = 50%, D_{90} = 90%) for the growing season that the groundwater was at or above a given level.

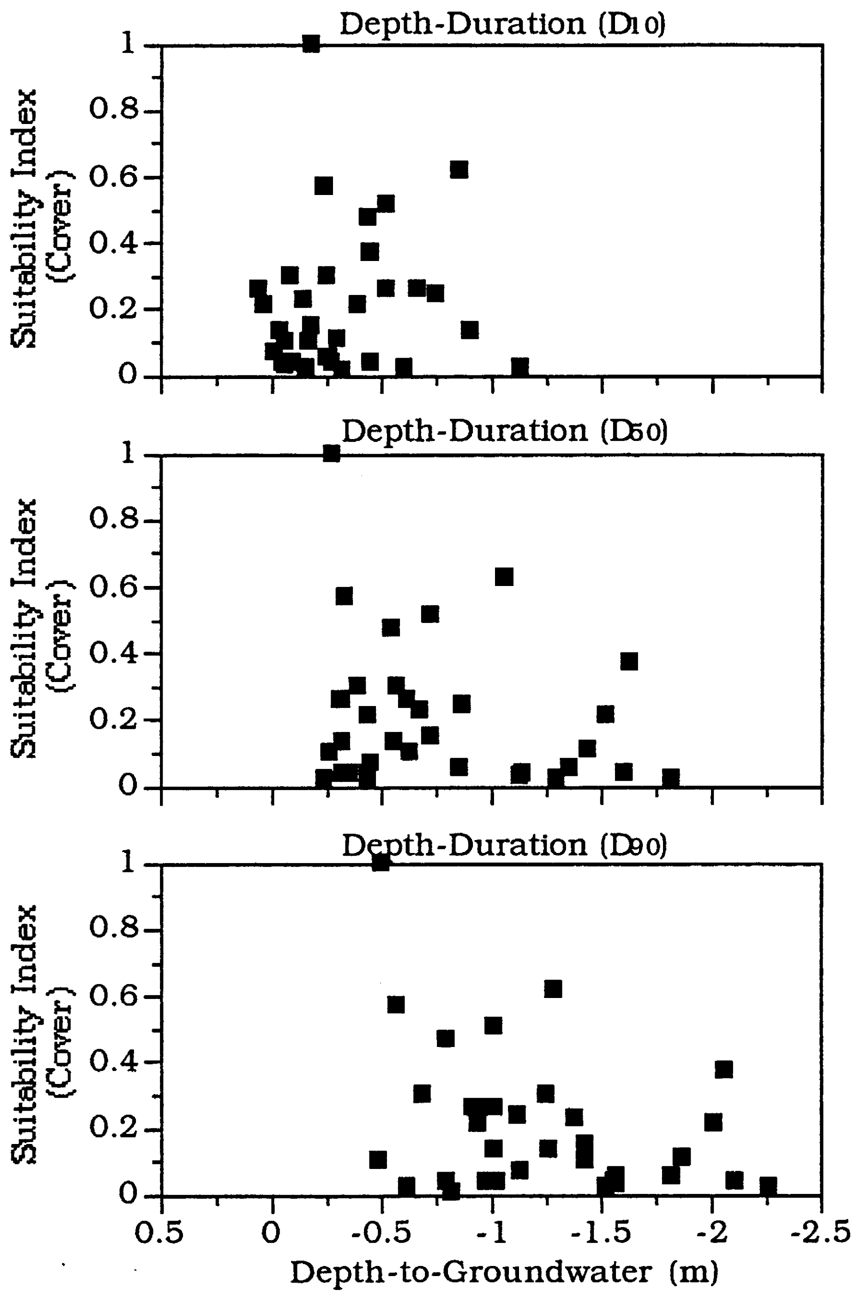


Figure 13. Shrubby cinquefoil percent canopy cover depth-to-groundwater suitability relationships. Density response values were normalized by dividing each score by the single highest score. The duration series represent percent of time (D_{10} = 10%, D_{50} = 50%, D_{90} = 90%) for the growing season that the groundwater was at or above a given level.

DISCUSSION

Groundwater Hydrology.

Box-and-whisker plots are an effective way to summarize both time sequence and variation in groundwater levels for several measuring periods. The shortcoming of box-and-whisker plots is that long term trends, such as lowered water levels resulting from drought, are hidden. In this case a traditional time line hydrograph would prove more appropriate (Henszey 1993). Periodic measurements were used in this study to develop box-and-whisker plots, but continuous measurements could also be used if available. Continuous recorders provide better groundwater information because they do not miss short term fluctuations due to events such as high intensity precipitation or snow melt events. If possible these short term events should be recorded because they may influence the associated riparian plant communities (Henszey 1993). Periodic measurements, however, can provide an accurate estimate of the groundwater regime if a sufficient number of measurements are made. When continuous recorders were installed in 1993, diurnal groundwater level fluctuations were observed. These fluctuations can possibly give an approximation of effective rooting depth and evapotranspiration if recorders are sensitive enough to detect these slight fluctuations (Henszey 1993, Henszey and Wesche 1993).

Nearly continuous streamflow augmentation has altered the groundwater regime for both aspen and shrubby cinquefoil sites on the SFMCC. Groundwater hydrographs for flow augmented aspen and shrubby cinquefoil sites were relatively similar, while non-augmented aspen sites exhibited a much greater range of groundwater levels than non-augmented shrubby cinquefoil sites. The groundwater hydrograph on both aspen and shrubby cinquefoil flow augmented sites was closer to the surface and more constant than non-augmented sites. The range between base groundwater levels and peak groundwater levels was greater on non-augmented sites than on the flow augmented sites, though peak groundwater levels on flow augmented and non-augmented sites were relatively similar (Figures 4 and 5).

Depth-to-Groundwater Duration Curves.

Depth-to-groundwater duration curves portray groundwater "availability and variability of sustained groundwater levels," but lack time sequence (Henszey 1993). They also readily show critical plant-related groundwater characteristics such as the percent of time that groundwater was at or above the soil surface or below the rooting zone (Henszey 1993). Both box-and-whisker plots and depth-to-groundwater duration information can be used to separate the groundwater regime associated with specific plant communities or species (Henszey 1993, Peacock 1992). This information in suitability format would be extremely valuable for wetland and riparian creation/restoration and management purposes (Kusler and Kentula 1990, Mitsch and Gossenlink 1986). For instance, management personnel could have at least a partial indication of potential vegetation on wetland or riparian restoration projects by comparing the anticipated groundwater regime to that observed in natural communities.

The pattern of depth-to-groundwater duration curves was similar between both aspen and shrubby cinquefoil flow augmented sites. Groundwater levels tended to stay at one general level for extended periods, reflecting continuous flow augmentation. However, like the groundwater hydrographs (Figure 4 and 5), the non-augmented aspen sites showed a much greater and more dynamic range of groundwater levels than non-augmented shrubby cinquefoil sites (Figure 4 and 5).

Plant Response to Streamflow Augmentation

Aspen. Aspen showed a varied response to 8 years of flow augmentation. Aspen in all upland blocks showed no change in density as a result of flow augmentation. This finding is consistent with Lynch (1955) who observed that aspen encroachment in adjacent uplands is limited by too little soil moisture. In Wisconsin, Wilde and Zicker (1948) noted that a permanent water table between -0.46 m and -1.52 m was beneficial to aspen growth, but growth declined sharply when the water table was above or below those levels. Only three of the aspen upland blocks on the SFMCC had groundwater levels within -0.46 to -1.52 m 90% of the time. Hence, the data suggests that other factors such as soil moisture are still limiting aspen expansion into the adjacent uplands, even with elevated groundwater levels resulting from flow augmentation.

Aspen density on the transition blocks of both wide valley bottom sites (4AW and 5AW) decreased as a result of flow augmentation. While depth-to-groundwater duration data indicate that the groundwater on the wide bottom transition blocks ranged between -0.62 and -1.26 m 90% of the time, the majority of the aspen mortality on the transition blocks took place near the border of the flooded block where the soil was saturated or inundated nearly continuously as a result of flow augmentation. Aspen density also decreased in all narrow valley bottom flooded blocks as a result of streamflow augmentation. The flow augmented flooded blocks were partially or completely inundated continuously with shallow standing water through the duration of the study except when flow augmentation was suspended. The few aspen that did survive in the flow augmented flooded blocks were almost invariably on small islands or pedestals where at least a portion of their roots were elevated above the continuous standing water. The flooded blocks of sites 4AW and 5AW were primarily dominated by sedge/willow communities before flow augmentation and the few aspen in these blocks were present on elevated areas which were relatively protected from augmented streamflow. Aspen density also decreased from natural causes on the flooded block of site 3NN which confounds the interpretation of the decrease on the flow augmented sites. Yet the mortality on site 3NN was much less than the flow augmented sites (1AN and 2AN), and from an ecological perspective appears insignificant.

Shrubby Cinquefoil. Shrubby cinquefoil showed a mixed response to streamflow augmentation. Density remained unchanged between 1986 and 1993 in all blocks on the flow augmented sites except the A blocks next to the channel. Like the narrow bottom flooded aspen blocks, most of the A block on shrubby cinquefoil site 1AF was saturated or inundated with shallow standing water through the first few growing seasons, presumably causing the density to decrease from 0.92 to 0.27 plants/m^2. While not statistically significant ($p = 0.0569$), the decline in shrubby cinquefoil density, 2.19 to 0.75 plants/m^2, on the B block of site 1AF appears significant in a biological sense. On the A block of site 3AS, density decreased following streamflow augmentation, but from an ecological perspective this change, 2.08 to 2.03 plants/m^2, appears insignificant.

Unfortunately, no baseline data exists for shrubby cinquefoil canopy cover, since this method was employed starting in 1987. As with density, shrubby cinquefoil canopy cover did not increase significantly on any of the flow augmented Upland or C blocks. However, the B and A blocks near the channel on site 3AS did increase providing evidence that streamflow augmentation and the resulting elevated groundwater levels benefited the mature shrubby cinquefoil plants on this site. A well defined channel existed on this cross section before streamflow augmentation suggesting that the elevated groundwater levels, which did not flood or saturate the soil surface, created favorable conditions for shrubby cinquefoil canopy cover. Changes also occurred on the Upland block of site 2NF and the C block of site 4NS indicating that the non-augmented shrubby cinquefoil stands on the study area were not entirely static during the study period. Like shrubby cinquefoil density, the small sample size

($n = 4$ for Flooded blocks, and $n = 8$ for A, B, C, and Upland blocks) may also be partially responsible for apparently large changes (e.g. density on the B block of site 1AF) showing no significant change ($p > 0.05$).

The results for both aspen (density) and shrubby cinquefoil (density and canopy cover) are consistent with the scientific literature. It appears that aspen and shrubby cinquefoil are intolerant of continuous flooding for extended durations. An elevated water table or subirrigation is noted as beneficial to both species, but neither occurs on poorly drained sites where the water table is at or above the soil surface for extended periods of time (Wilde and Zicker 1948, Peek 1963, DeByle and Winokur 1985, Hansen et al. 1988). Both species are common in the transition zone of the SFMCC between the wet valley bottom and the adjacent uplands which suggests that high soil moisture and/or a persistent water table are beneficial for growth, yet long duration saturated or flooded conditions inhibit both species. This observation is consistent with Henszey (1993) who observed a shift toward more water tolerant herbaceous species as a result of elevated surface and groundwater levels on the SFMCC. Flooding typically causes anaerobic conditions in soils (Kozlowski 1984). Without specific adaptations for dealing with anoxic conditions (e.g. aerenchyma), the plants may have been either killed outright by the toxicity or stressed to the point that they were opened to secondary infections causing mortality. Field observations suggest that aspen in the flow augmented upper flooded blocks did not show significant mortality until 1991, while aspen flooded in nearby beaver ponds on the SFMCC usually died within a year. Well oxygenated water spilling over rock riprap at the discharge outlets may have allowed limited gaseous exchange that in turn retarded mortality for approximately 6 years (Kozlowski 1984). Further investigation would be required to substantiate this assumption.

Mortality from wind throw was also observed on the upper flooded aspen blocks presumably the result of flowing water loosening and/or washing away rooting substrate. This observation is consistent with Kozlowski (1984).

Depth-to-Groundwater Suitability Relationships.

While used extensively by fisheries biologists for managing fisheries, suitability curves have seldom been applied quantitatively to plant species (Peacock 1992, Henszey 1993). Depth-to-groundwater suitability curves can be a useful tool for understanding groundwater relationships for many, though not all, wetland and riparian plant species and descriptive population parameters (e.g., density, biomass, frequency). For example, Peacock (1992) found relationships between frequency and depth to groundwater for water sedge (*Carex aquatilis* Wahl.), tufted hairgrass, and planeleaf willow (*Salix planifolia* Pursh.) on the Snowy Range Observatory. Similarly, Henszey (1993) observed a depth-to-groundwater relationship for sedges and tufted hairgrass biomass and density, and slimstem reedgrass (*Calamagrostis neglecta* (Ehrh.) Gaertn.) density, but not biomass on the Pole Mountain Research Watershed.

Like depth-to-groundwater duration curves, depth-to-groundwater suitability curves have management potential in terms of predicting the consequences of land uses. For example, as in this case, predicting plant response to streamflow augmentation, or conversely, predicting plant response to dewatering. While groundwater is a major factor in determining plant response and community composition in wetland and riparian areas, other environmental factors may also be important. For instance, soil texture, moisture, and chemistry may also play critical roles in determining plant response and community composition. Separate suitability curves can be constructed for each variable or incorporated on the same curve as suggested by Bovee (1986) and Whittaker (1973). To adequately describe the relationship of a species to a given environmental variable(s), suitability curves may have to be developed for different life-cycle stages and regional variation (Bovee 1986, Henszey 1993).

Aspen. Aspen showed a poor relationship to depth to groundwater (Figure 11). At none of the selected depth-to-groundwater durations were there clearly defined patterns of suitability. The optimum responses for aspen density were at -0.35 m (D_{10}), -1.14 m (D_{50}), and -2.19 m (D_{90}). However, very similar depth-to-groundwater levels also produced suitability values that ranged from near 1 to less than 0.1. Depths to groundwater deeper than -2.0 m (D_{10}), -2.5 m (D_{50}), and -3.0 m (D_{90}) appear to be less favorable to aspen growth on the SFMCC. In Wisconsin, Wilde and Zicker (1948) described similar findings with aspen growth decreasing sharply when the water table was above -0.46 m or below -1.52 m, with the optimum being -0.84 m. However, no duration information was provided. The deepest depth-to-groundwater values are from upland blocks where aspen may not have been able to make contact with any permanent water table or large enough quantities of soil moisture to expand into the uplands. This observation is consistent with Lynch (1955) who stated that aspen encroachment into adjacent uplands is limited by lack of soil moisture. Micro-topographical variations reduced the accuracy of groundwater measurements on the flooded blocks of the upper flow augmented aspen sites. Individual trees, or groups of trees, were slightly elevated above the water's surface where the surrounding soil surface was totally inundated. This caused the range of depth-to-groundwater values for suitability relationships for those blocks to be unrealistically elevated.

The data suggest that water levels at or very near the surface for 10 and 50% of the time, and shallower than -0.25 m for 90% of the time, are the upper limits for aspen suitability. Wells in aspen stands with water levels higher than this before flow augmentation were not available in this study. This may in part be explained by the fact that aspen on the SFMCC were not present on sites where water levels near the surface existed prior to flow augmentation, or came to exist following flow augmentation.

Shrubby Cinquefoil. Both shrubby cinquefoil density and canopy cover showed no discernible relationship to depth to groundwater at each of the selected duration's, D_{10}, D_{50}, D_{90} (Figure 12 and 13). This lack of trend suggests that other environmental factors, such as soil texture and competition, may also influence shrubby cinquefoil density and canopy cover. These results are consistent with Hansen et al. (1988), Peek (1963), and Elkington and Woodell (1963). They observed shrubby cinquefoil growing on a variety of moist to wet sites where flooding is common and the soil surface is well drained but not continuously saturated or flooded. Shrubby cinquefoil plants in the flooded and A block of the flat bottom non-augmented cross section occurred almost exclusively on small hummocks which, like aspen, unrealistically elevated the depth-to-groundwater values.

The linear interpolation method used to determine depth to groundwater at the center of sampling blocks assumes a linear depth-to-groundwater relationship between wells, and from outer wells into the uplands. The resulting potential lack of accuracy may have introduced unknown bias into interpolated depth-to-groundwater values which obscured significant depth-to-groundwater relationships for aspen and/or shrubby cinquefoil. Field experience though, suggests that the values used in this study are reasonably accurate. A more accurate method of relating a response to a specific depth to groundwater might reveal a more significant groundwater relationship for both species

The lack of apparent suitability relationships for both aspen and shrubby cinquefoil suggests that, except for long duration flooded conditions, both aspen and shrubby cinquefoil have a broad ecological tolerance for groundwater levels. Also, one or several other factors (e.g., light competition and soil texture) may play a dominant role in the distribution of aspen and shrubby cinquefoil in the Pole Mountain area. The presence of extensive aspen stands on adjacent uplands also indicates that a water table is not necessary for aspen growth. Conversely, shrubby cinquefoil stands in the study area invariably occur on sub-irrigated sites suggesting that a water table plays a significant role in the distribution of shrubby cinquefoil in the Pole Mountain area.

CONCLUSIONS

The long term affect of streamflow augmentation on the aspen and shrubby cinquefoil communities along the SFMCC remains to be seen. Channel incision and the resulting drop in groundwater levels may reverse initial changes caused by streamflow augmentation. Yet, from the results described previously, the following conclusions can be drawn to address the objectives and hypotheses presented in the Introduction.

1. Streamflow augmentation altered the groundwater regime on the SFMCC. Flow augmented groundwater levels are more constant with higher base levels. Peak groundwater levels appear to be similar to non-flow augmented sites.

2. Aspen appear to be relatively unaffected by streamflow augmentation unless subjected to saturated or inundated conditions for extended durations.

3. Shrubby cinquefoil appears to be sensitive to elevated groundwater levels resulting from streamflow augmentation. Saturated or inundated conditions for consecutive growing seasons adversely affect both shrubby cinquefoil density and

canopy cover. However, elevated groundwater levels may enhance shrubby cinquefoil canopy cover under certain conditions.

4. Except for long term saturated or inundated conditions, there appears to be no clearly defined depth-to-groundwater suitability relationship for aspen (density) or shrubby cinquefoil (density and canopy cover) on the Pole Mountain Research Watershed at the depth-durations tested, D_{10}, D_{50}, D_{90}.

LITERATURE CITED

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U.S. Fish Wildl. Serv. Biol. Rep. 86(7). 235 pp.

DeByle, N.V. and Winokur, R.P. 1985. Aspen: ecology and management in the western United States. U.S.D.A. Forest Service General Technical Report RM-119.

Elkington, T.T. and Woodell, S.R.J. 1963. Potentilla fruticosa L. J. Ecology 51:769-781.

Hansen, P.L., Chadde, S.W. and Pfister, R.D. 1988. Riparian dominance types of Montana. Montana Forest and Conservation Experiment. Station. Miscellaneous Publication No. 49. Missoula, MT. 411 pp.

Henszey, R.J. 1993. Riparian zone changes caused by streamflow augmentation. Ph.D. dissertation, University of Wyoming. Laramie, WY.

Henszey, R.J. and T.A. Wesche. 1993. Hydrologic components influencing the condition of wet meadows along the central Platte River, Nebraska. Prepared for the Nebraska Game and Parks Commission, Lincoln. Prepared by HabiTech, Inc., Laramie, WY. 84 pp.

Lynch, D. 1955. Ecology of the aspen groveland in Glacier County, Montana. Ecol. Monog. 25:321-344.

Kozlowski, T.T. 1984. Flooding and plant growth. Academic Press, Inc., Orlando, Fl. 356 pp.

Kusler, J.A. and Kentula M.E. 1990. Executive Summary. In: Wetland Creation and Restoration - The State of the Science. Island Press, Washington, D.C.

Mitsch, W.J. and J.G. Gossenlink. 1986. Wetlands. Van Nostrand Reinhold Company, New York, NY. 539 pp.

Peacock, K. 1992. Surface and groundwater dynamics critical to the maintenance of subalpine riparian wetlands. M.S. Thesis, University of Wyoming. Laramie, WY.

Peek, J.M. 1963. Appraisal of moose range in southwestern Montana. J. Range Manage. 16(5):227-231.

Ricklefs, R.E. 1990. Ecology. W.H. Freeman and Company, New York, NY. 896 pp.

SAS Institute Inc. 1985a. SAS® Users Guide: Basics, Version 5 Edition. Cary, NC. 956 pp.

SAS Institute Inc. 1985b. SAS® Users Guide: Statistics, Version 5 Edition. Cary, NC. 1290 pp.

SAS Institute Inc. 1988. SAS/ETS® Users Guide, Version 6, First Edition. Cary, NC. 560 pp.

SAS Institute Inc. 1990. SAS/GRAPH® Software: Reference, Version 6, First Edition, Volume 1. Cary, NC. 664 pp.

Scotter, G.W. 1975. Effect of Picloram on cinquefoil and forage production at the Ya-Ha-Tinda Ranch, Alberta. J. Range. Manage. 28(2):132-138.

U.S.D.A. Forest Service. 1980. Environmental Impact Statement: Cheyenne Stage II Water Diversion Proposal. U.S.D.A. Forest Service, Medicine Bow National Forest, Laramie, WY.

U.S.D.A. Forest Service. 1991a. Allotment management plan: Green Mountain cattle allotment #507. Prepared by C.M. McClung, Laramie Ranger District, Medicine Bow National Forest, Laramie, WY. 8 pp. + appendices.

U.S.D.A. Forest Service. 1991b. Allotment management plan: Lodgepole cattle allotment #510. Prepared by C.M. McClung, Laramie Ranger District, Medicine Bow National Forest, Laramie, WY. 7 pp. + appendices.

U.S.D.A. Soil Conservation Service. 1982. 15-19" Foothills and mountains southeast. In: Technical guide section II E, major land resources area 48, revised April 1982. U.S.D.A. Soil Conservation Service, Casper, WY.

Walters, M.A., Teskey, R.O., and Hinckley, T.M. 1980. Impact of water level changes on woody riparian wetland communities. Volume VIII: Pacific Northwest and Rocky Mountain Regions. U.S.D.I. Fish and Wildlife Service. FWS/OBS-78/94 47 p.

Whittaker, R.H. 1973. Ordination and classification of communities. Dr. W. Junk b.v. 737 pp.

Wilde, S.A. and Zicker, E.L. 1948. Influence of the ground water table upon the distribution and growth of aspen and jack pine in central Wisconsin. Techn. Notes No. 30. Wis. State Cons. Dept., in coop. with Soils Dept., U.W., Madison, Wis.

APPENDIX

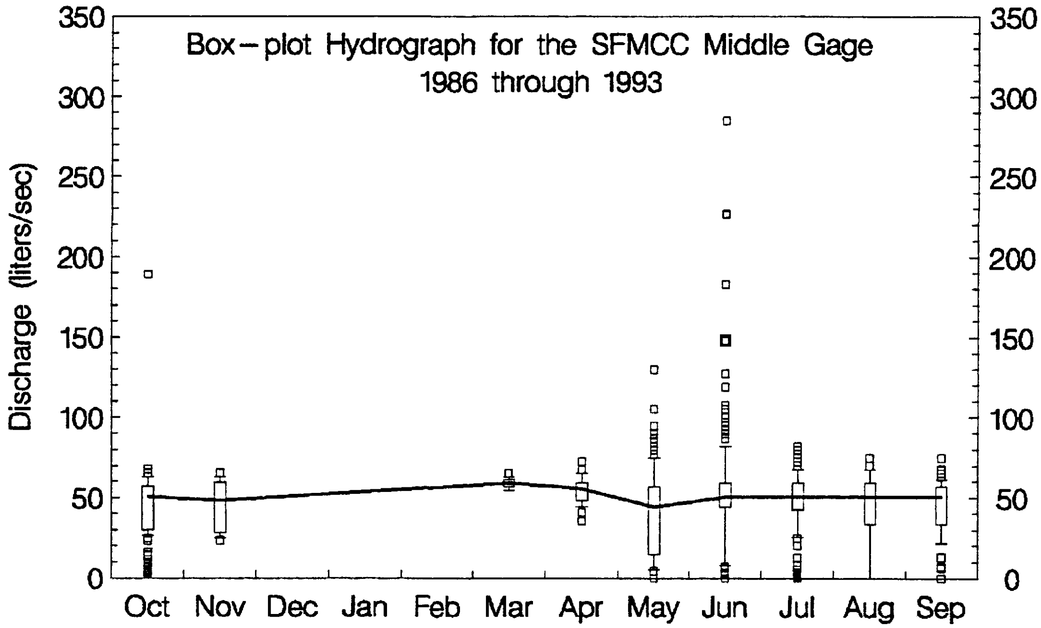


Figure 14. Streamflow hydrograph for the middle flume on the SFMCC. The line represents median monthly discharge for the growing seasons, June through September, from 1986 to 1993.

Table 2. Depth-to-groundwater duration values in 10% increments for selected wells on the Pole Mountain Research Watershed. Duration values derived for the growing seasons of 1987 to 1993. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type. For aspen, N = narrow valley bottom and W = wide valley bottom, while F = flat valley bottom and S = sloping valley bottom for shrubby cinquefoil.

Block Type/Site	Well	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Aspen											
Transition Block											
Site 2AN	A176/15	-0.43	-0.44	-0.45	-0.45	-0.47	-0.53	-0.60	-0.62	-0.74	-0.95
Site 5AW	17803/222	-1.61	-1.61	-1.63	-1.68	-1.70	-1.72	-1.74	-1.78	-1.86	-1.92
Site 6NW	K400/303	-0.89	-1.12	-1.28	-1.44	-1.64	-1.80	-2.16	-2.49	-2.76	-2.98
Side Slope Block											
Site 1AN	138/72	-0.49	-0.52	-0.56	-0.59	-0.69	-0.72	-0.82	-0.89	-0.89	-1.05
Site 5AW	17803/56	-0.33	-0.39	-0.43	-0.49	-0.56	-0.59	-0.66	-0.75	-1.08	-1.28
Site 3NN	B100/99	-0.43	-0.75	-0.95	-1.25	-1.54	-1.74	-2.00	-2.20	-2.33	-2.39
Flooded Block											
Site 2AN	A176/93	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.03	-0.23	-0.49
Site 4AW	17406/204	0.03	0.03	0.03	0.00	0.00	0.00	-0.03	-0.03	-0.07	-0.59
Site 3NN	B100/70	-0.23	-0.62	-0.85	-1.08	-1.28	-1.44	-1.67	-1.80	-1.90	-1.97
Shrubby Cinquefoil											
Outer Blocks											
Site 1AF	20024/380	-0.82	-0.89	-0.92	-0.92	-1.05	-1.08	-1.12	-1.12	-1.18	-1.21
Site 3AS	20792/78	-0.95	-0.98	-1.02	-1.05	-1.08	-1.15	-1.15	-1.18	-1.34	-1.67
Site 4NS	C100/294	-0.46	-0.98	-1.15	-1.31	-1.64	-1.80	-1.84	-1.97	-2.07	-2.30
Inner Blocks											
Site 1AF	20024/136	-0.03	-0.20	-0.26	-0.33	-0.36	-0.39	-0.46	-0.59	-0.89	-1.05
Site 3AS	20792/256	-0.16	-0.23	-0.23	-0.26	-0.26	-0.30	-0.36	-0.39	-0.49	-1.02
Site 2NF	D200/199	0.07	0.03	0.03	-0.03	-0.26	-0.43	-0.56	-0.75	-0.92	-0.95

Table 3. Aspen density values (trees/m^2) for the years 1985-87, 93. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type, (i.e. N = narrow valley bottom and W = wide valley bottom).

Block Type	Site	1985	1986	1987	1993
Upland Block					
	Site 1AN	0.11	0.15	0.16	0.29
	Site 2AN	0.17	0.20	0.18	0.22
	Site 3NN	-	0.00	0.00	0.00
	Site 4AW	0.02	0.00	0.00	0.02
	Site 5AW	0.17	0.09	0.14	0.21
	Site 6NW	-	0.14	0.13	0.27
Transition Block					
	Site 1AN	0.48	0.51	0.48	0.42
	Site 2AN	0.60	0.61	0.60	0.55
	Site 3NN	-	0.46	0.49	0.46
	Site 4AW	0.59	0.53	0.50	0.47
	Site 5AW	0.35	0.36	0.36	0.29
	Site 6NW	-	0.61	0.54	0.50
Flooded Block					
	Site 1AN	0.41	0.41	0.38	0.18
	Site 2AN	0.81	0.74	0.68	0.23
	Site 3NN	-	0.71	0.71	0.61
	Site 4AW	0.36	0.37	0.33	0.16
	Site 5AW	0.09	0.09	0.09	0.03
	Site 6NW	-	0.26	0.25	0.23

Table 4. Shrubby cinquefoil density (shrubs/m^2) for the years 1985-86, 93. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type (i.e. F = flat valley bottom and S = sloping valley bottom).

Block Type	Site	1985	1986	1993
Block Upland				
	Site 1AF	0.27	0.44	0.97
	Site 2NF	-	0.76	0.69
	Site 3AS	0.30	0.49	0.56
	Site 4NS	-	0.08	0.13
Block C				
	Site 1AF	0.93	1.58	1.23
	Site 2NF	-	1.22	1.20
	Site 3AS	1.38	1.78	1.86
	Site 4NS	-	1.18	2.03
Block B				
	Site 1AF	1.58	2.19	0.75
	Site 2NF	-	1.55	1.47
	Site 3AS	0.92	1.50	1.79
	Site 4NS	-	0.79	0.82
Block A				
	Site 1AF	0.72	0.92	0.27
	Site 2NF	-	1.61	1.80
	Site 3AS	1.54	2.08	2.03
	Site 4NS	-	0.49	0.47
Block Flooded				
	Site 3AS	0.16	0.16	0.16
	Site 2NF	-	0.64	0.73

Table 5. Shrubby cinquefoil % canopy cover for the years 1987-88, 93. The first letter in the site suffix represents treatment (i.e. A = flow augmentation and N = non-augmented) and the second letter represents valley type (i.e. F = flat valley bottom and S = sloping valley bottom).

Block Type	Site	1987	1988	1993
Block Upland				
	Site 1AF	2.9	3.7	4.8
	Site 2NF	3.8	3.8	1.8
	Site 3AS	7.3	7.9	7.8
	Site 4NS	0.3	0.7	1.3
Block C				
	Site 1AF	2.5	3.4	3.8
	Site 2NF	3.9	4.8	3.5
	Site 3AS	5.8	5.2	9.2
	Site 4NS	4.6	3.1	7.0
Block B				
	Site 1AF	2.4	3.1	1.9
	Site 2NF	5.0	6.6	5.4
	Site 3AS	4.1	3.7	9.4
	Site 4NS	2.2	2.0	2.0
Block A				
	Site 1AF	1.3	1.3	1.6
	Site 2NF	4.6	5.8	6.8
	Site 3AS	10.4	9.6	19.1
	Site 4NS	1.6	1.8	1.6
Block Flooded				
	Site 3AS	1.6	0.9	2.5
	Site 2NF	2.0	2.7	1.8