Chapter 2
Effects of Timber Harvesting on Streamflow in the Alsea Watershed Study

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The Alsea Watershed Study was the nation's first long-term watershed study to simultaneously consider the effects of timber harvesting on water and water related resources (fish habitat and fish populations) (Brown 1972). The study began in 1957 as a cooperative effort between Oregon State University (then Oregon State College) and other federal and state agencies to address the effects of integrated land management on the stream environment (Harr and Krygier 1972; Moring 1975; Harris 1977). The Alsea River Basin, in the Oregon Coast Range, was selected because of the diversity of land ownership, active timber harvesting, and its close proximity to the university. The initial goal to assess these potential effects at the large watershed level proved to be too ambitious and was reduced to three small watersheds in the Alsea River Basin. The final selection of the watersheds reflected similar geographic location, exposure, elevation, and land ownership of the participants, namely the USDA Forest Service and Georgia Pacific Company (now Plum Creek Timber Company), a private timber company.

The temperate coniferous forest in the western United States typically consists of well-developed overstories and understories. The overstory plant community of the temperate coniferous forest is dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). The understory consists of vine maple (*Acer circinatum*), red alder (*Alnus rubra*), salmonberry (*Rubus spectabilis*), rhododendron (*Rhododendron macrophyllum*), and others (Meehan 1991). The temperate coniferous forest of the Pacific Northwest of the United States extends from central Alaska to central California, including the Coastal Range of Alaska, British Columbia, Washington, Oregon, and California (Chamberlin et al. 1991).

Rain is the dominant form of precipitation in the temperate coniferous forest of the Pacific Northwest of the United States and drives the hydrology of small forested streams (Chamberlin et al. 1991). The climate of the Alsea watersheds is a maritime climate with mild temperatures, winter precipitation, and

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J. D. Stednick (ed.), *Hydrological and Biological Responses to Forest Practices*.

a summer drought. Approximately 90% of the annual precipitation of 2500 mm occurs from October through April (Fig. 2.1). Precipitation events during the winter months generally occur as slow-moving, low-intensity frontal systems. These frontal storms usually occur frequently over the season, so precipitation volumes are up to an order of magnitude different between the wet and dry seasons. Convective storms are the primary cause of precipitation events during the summer and early fall. These storms are generally short in duration, but can often be of moderate to high intensity.

The largest precipitation events of the year occur in the winter on a soil mantle that is close to saturation, leaving most of the precipitated moisture available for runoff. This results in streamflow events that are 1000 to 5000 times larger than those observed in the summer for similar sized storms (Harr 1976) (Fig. 2.2). Increased streamflow resulting from the processes described previously causes the greatest contribution to annual water yield to occur during the wet winter months (Chamberlin et al. 1991).

Thick vegetation will also result in high rates of evapotranspiration during the growing season. These high rates of evapotranspiration contribute to the drying of the soil mantle, resulting in increased soil storage capacity during the summer months, which in turn contributes to the lack of streamflow response to summer precipitation events (Harr 1976; Hewlett and Helvey 1976).

Three watersheds were selected for the study: Flynn Creek, Deer Creek, and Needle Branch. Data on streamflow, sediment yield, temperature, and nutrients were collected during the study and compared to relations developed during the pretreatment period (1959–1966). The effects of treatment on the parameters of interest were evaluated in posttreatment (1967–1973) (Harr and Krygier 1972; Moring 1975; Harris 1977). Watershed elevations range from 135 to 490 m with mean slopes of 35 to 40%. Soils are derived from the Tyee sandstone formation: 80% of the soils are Bohannon and Slickrock series. Bohannon soils are stony,

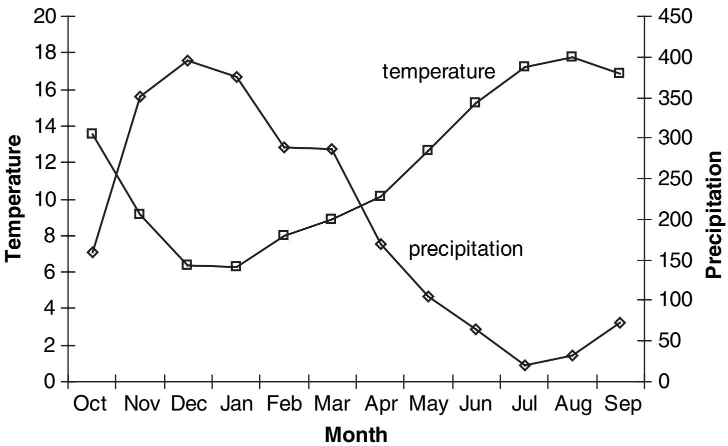

Fig. 2.1 Mean monthly temperature (°C) and precipitation (mm) as measured at Tidewater, OR

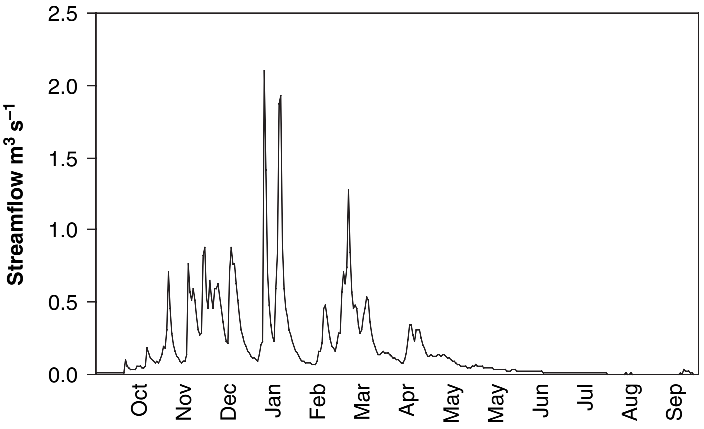

Fig. 2.2 Daily streamflow ($m^3\ s^{-1}$) for Flynn Creek Water Year 1972

Fig. 2.3 Harvest unit in Deer Creek shortly after logging

generally less than 60 cm deep, and derived from sandstone residuum. Slickrock soils are derived from sandstone colluvium and range in depth to 140 cm. Rates of infiltration and percolation are high, and overland flow on undisturbed forest soil has never been observed.

Table 2.1 Summary of treatments and areas for each watershed

	Needle Branch	Flynn Creek	Deer Creek
Total area, ha	71	202	303
Area in roads 1965, ha[1]	3.6	0	11
Percent in roads[1]	5	0	4
Logged area 1966, ha	58	0	77
Percent logged	82[2]	0	25
Burned area 1966, ha	58	0	23
Percent burned	82	0	8

[1] Includes landings, road cutbanks and fill slopes, and tractor skid trails.
[2] In 1956, 13 ha in the headwaters of Needle Branch were logged.

Fig. 2.4 Needle Branch harvest unit with no streamside buffer left

Before treatment, vegetation consisted of various amounts of red alder and 120-year old Douglas-fir. Pure stands of Douglas-fir covered about 76% of Needle Branch and 17% of Deer Creek. Alder covered 30% of Flynn Creek. The remainder supported mixed stands of Douglas-fir and red alder (Harr and Krygier 1972).

Flynn Creek (202 ha) served as the control watershed, Deer Creek (303 ha) was harvested in three small patchcuts, with uncut forest left along the stream channels of 15 to 30 m wide (Brown 1972) (Fig. 2.3). The total area harvested in Deer Creek was 77 ha or 25% of the watershed area (Table 2.1). Needle Branch (71ha) was nearly completely clearcut with no streamside vegetation left (Fig. 2.4). Approximately 18% of upper Needle Branch watershed was harvested in 1956 (see Fig. 1.1).

Logging roads were constructed into Deer Creek and Needle Branch between March and August 1965 and were mostly located on ridgelines.

Roads were separated from logging for only one season. Logging began in March 1966 and was completed by November 1966. Most logging was done by high-lead yarding, but tractor skidding was done on the lower part of Needle Branch. As typical for the period, logging slash was burned after logging. The slash on Needle Branch was dry and resulted in a very hot fire in October 1966. Due to a depressed log market, logs were temporarily stored in Deer Creek landings and logging was not completed until summer 1969. One unit was burned in May 1967, one in 1968, and the lower unit in August 1969, but the vegetation regeneration resulted in cool fires.

Methods

Hydrometeorologic data were collected on all three systems for 15 years beginning in water year 1959 (October 1958). Data were collected for 7 years before logging (1959–1965 water years), 1 year during logging (1966), and 7 years posttreatment (1967–1973).

Measurements of precipitation, streamflow, sediment transport, and water temperature near the mouths of the watersheds before, during, and after logging provided the data needed to evaluate the potential effects of logging on streamflow. Streamflow data, sediment concentrations, and water temperature data collected by the U.S. Geological Survey (USGS) at the gauging stations are published in their basic data reports. Precipitation data were collected in forest openings near the mouths of the watershed by Oregon State University personnel. The original data were collected in English units, and converted to metric for this volume.

Precipitation

Weighing-type rain gauges (Belfort®) located near the gauging stations were serviced weekly. Precipitation data were reduced to daily values and compiled. Precipitation data allowed comparison between watersheds and comparison to the long-term record at Tidewater, Oregon. Double-mass analysis of cumulative precipitation suggested no change in areal distribution of precipitation after logging, thus streamflow changes are the result of logging and not precipitation differences (Harris 1977). Precipitation data were published through February 1968 (Harris 1977). In the process of compiling the AWS historical records, the remaining precipitation data (through September 1973) were located at Oregon State University and reduced (Table 2.2). The precipitation data records were marked "corrected" until February 1968. No documentation of this "correction" was located. Precipitation data records from February 1968 to the end of the study were not "corrected". The original reporting of the precipitation data (Harris 1977) suggested that the wettest and driest years

Table 2.2 Annual precipitation (mm) for Tidewater, OR and the three study watersheds for all years

Water year	Tidewater	Flynn Creek	Needle Branch	Deer Creek
1959	2599	2634	2940	2769
1960	2074	2090	2332	2244
1961	2560	2689	2790	2827
1962	2149	2176	2300	2248
1963	2224	2123	2223	2236
1964	2333	2422	2454	2525
1965	2309	2390	2344	2495
1966	2263	2249	2127	2347
1967	2396	2249	2127	2347
1968[1]	2383	2996	2990	2964
1969	2577	2262	2350	2260
1970	2301	2401	2551	2702
1971	2834	3317	3637	3429
1972	2901	3042	2952	2780
1973[2]	1808	1139	1077	1128

[1] Data from Harris 1977 through February 1968; unpublished data were compiled for the remaining years
[2] Data from January to September 1973

were 1972 and 1973, respectively, based upon precipitation data from Tidewater. The additional Alsea precipitation data indicated that the wettest year was 1971. Because the data were collected at the low point of the basin, they probably do not represent average precipitation over the basin. The frontal storm systems that generate most of precipitation would have orographic effects (i.e., increased precipitation with increased elevation) (Harris 1977).

Streamflow

The USGS built stream gauging stations at each watershed outlet in 1958. Broadcrested compound V-notch concrete weirs were built on Deer Creek and Flynn Creek (Fig. 2.5). Because of the smaller watershed area and stream channel size, Needle Branch had a smaller compound V-notch crest with vertical concrete walls. Each concrete weir had concrete cutoff walls built into the stream bank to prevent water short-circuiting of the control structure. The weirs are connected to the stilling well with two inlet pipes, one each for low flow and high flow conditions. The gauging house on the stilling well had a Leopold-Stevens® A-35 recorder that recorded stage at a 1:0.1 scale. Streamflow measurements were made by the USGS and the stage-discharge relation frequently updated. Discharge measurements for high and medium flows were typically done with Price® or pygmy current meters, while low flows were

Fig. 2.5 Broad crested compound V-notch weir on Deer Creek

measured volumetrically (Harris 1977). Discharge records were considered to be good to excellent for all three stations.

Stream gauges were operated daily by Oregon State Game Commission personnel, with funding from Oregon State University, and serviced at intervals by the USGS (Moring 1975). Streamflows were converted from gauge heights to streamflow by hand and are part on the USGS streamflow records. During 1963–1965, six additional streamflow gauges were established in Deer Creek by the Oregon State University, School of Forestry, to monitor streamflow upstream at two locations on Deer Creek proper and on four tributaries (two with timber harvesting) (Table 2.3). Only some of these streamflow records were located, and are currently stored at the Oregon State University Forest Research Laboratory. This later study assessed the effects of logging and logging with roads on peak flows (Harr et al. 1975).

Table 2.3 Watershed characteristics for Deer Creek subbasins (adapted from Hall and Krygier 1967; Harr et al. 1975)

	I	II	III	IV	V	VI
Watershed area (ha)	3.4	56	40	16	12	231
Area logged (%)	0	30	65	90	0	25
Area in roads (%)*	0	3	12	0	5	5

* Includes landings, road cutbanks and fill slopes, and tractor skid trails (Harr et al., 1975).

Streamflows typically are low during the early fall months. As winter precipitation increases, the soil mantle becomes wet and responds to individual winter precipitation events. Most precipitation events occur as rain, and snowfalls on the Oregon Coast are relatively rare, short-lived, and add little water to the annual budget. The dry mantle storms are easily separated from the wet mantle storms. As winter storms decrease, the soil mantle drains and streamflow decreases to low flow conditions. There were no records of zero streamflow during the Alsea Watershed Study period.

Results

The principal method used to assess the effects of logging on water resources was to develop pretreatment relations between the treatment watersheds (Needle Branch and Deer Creek) and the control watershed (Flynn Creek). Regression equations were developed to estimate values of dependent variables (treatment watersheds) from values on the independent variable (Flynn Creek) (Table 2.4). Prediction limits at the 95% confidence interval were used to assess treatment departures (Harris 1977).

Selected streamflow characteristics were used to assess the effects of logging on the stream regimen. Annual runoff was used as the total amount of water leaving the watershed. Peak flows and three-day high flows represented the instantaneous peak flows and three-day high flow volumes. Low flows were daily flows in August and September (Harris 1977). Results presented in this chapter follow the format and methods of the earlier work (notably Harris 1977).

Annual Runoff

Generally, annual water yield increases following timber harvest, due to decreased evapotranspiration and interception on the harvested site, coupled with any physical disturbances caused by timber harvesting. This increase is

Table 2.4 Prediction equations derived from pretreatment streamflows (after Harris 1977).

Site	Prediction Equation	r^2 value
	Annual runoff (mm)	
Needle Branch	= (0.91) (Flynn) + 91.7	$r^2 = 0.80$
Deer Creek	= (1.03) (Flynn) – 124.9	$r^2 = 0.97$
	Peak flow ($m^3\ s^{-1}\ km^{-2}$)	
Needle Branch	= (0.93) (Flynn) +0.227	$r^2 = 0.90$
Deer Creek	= (0.92) (Flynn) +0.100	$r^2 = 0.99$
	Low flow ($m^3\ s^{-1}$)	
Needle Branch	= (0.245) (Flynn) – 0.585	$r^2 = 0.77$
Deer Creek	= (1.91) (Flynn) + 0.460	$r^2 = 0.88$

generally observed immediately following timber harvest, and decreases as vegetation recovers (Harr 1976; Hewlett and Helvey 1976; Chamberlin et al. 1991; Stednick 1996). The soil mantle is closer to saturation during the summer with no vegetation to transpire moisture from the soil. This leads to higher runoff during the beginning of the wet season because there is less soil moisture deficit to make up in the soil. As vegetation recovers following timber harvest, more soil moisture is transpired during the summer months. This leads to an increasingly dry soil mantle for the fall storms, which in turn leads to lower levels of runoff following precipitation events. This period of lower runoff continues until the soil moisture deficit has been satisfied. Ultimately the recovery of the soil moisture deficit in the summer leads to decreasing annual water yield, and a return to preharvest conditions. An analysis of annual water yield studies from paired watershed studies suggests that at least 20% of the watershed needs to be harvested to be detected using streamflow monitoring methods and a key factor governing changes in annual water yield is the proximity of harvest to streamflow source areas (Stednick 1996).

The mean annual runoff was approximately 1920 mm per year for all three watersheds (Harris 1977). Flynn Creek annual runoff ranged from 1195 to 2785 mm. After logging on Needle Branch, the mean runoff of 2353 mm was 483 mm or 26% greater than the predicted runoff (Harris 1977) (Fig. 2.6). Annual water yield increases were 20% to 31% greater than predicted in the posttreatment period. Water yield increases tended to increase with increased annual precipitation. Annual water yields were variable over time and did not suggest a return to pretreatment water yield levels.

On Deer Creek, the actual mean runoff of 1952 mm after logging was 64 mm or 3% greater than the predicted runoff of 1888 mm (Harris 1977) (Table 2.5)

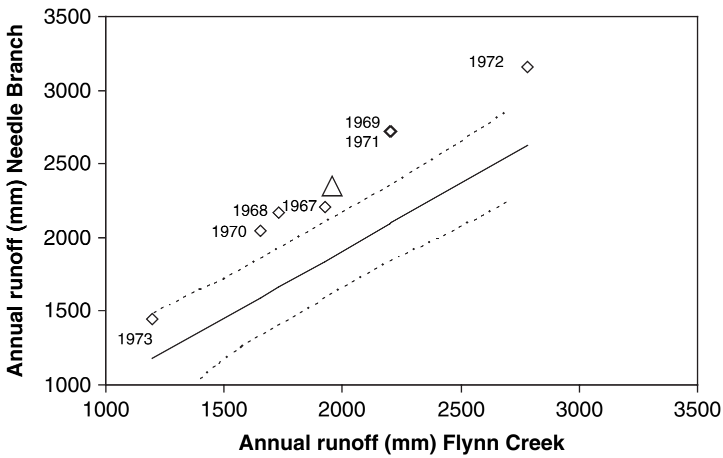

Fig. 2.6 Annual water yield regression between Flynn Creek and Needle Branch, and observed annual water yields after harvesting for the seven posttreatment years

Table 2.5 Annual runoff (mm) for all watersheds for all years

Water year	Flynn Creek	Needle Branch	Deer Creek
1959	1996	2135	1997
1960	1833	1767	1722
1961	2370	2173	2277
1962	1688	1565	1632
1963	1757	1596	1643
1964	1961	1912	1902
1965	2212	2052	2171
Prelogging mean	1973	1886	1907
1966 (logging)	1721	1734	1710
1967	1924	2209	1849
1968	1727	2173	1764
1969	2202	2716	2106
1970	1650	2045	1706
1971	2208	2717	2300
1972	2784	3162	2694
1973	1195	1446	1244
Post-logging mean	1956	2353	1952

and was not significantly different (Fig. 2.7). A covariance analysis using precipitation data at Tidewater and annual runoff for Needle Branch indicated that there was a significant difference in prelogging and post-logging runoff; the relations between hydrologic characteristics of watersheds before and after logging are significantly different; and the slope of the regression lines before and after logging are parallel. For Deer Creek, the analysis showed no

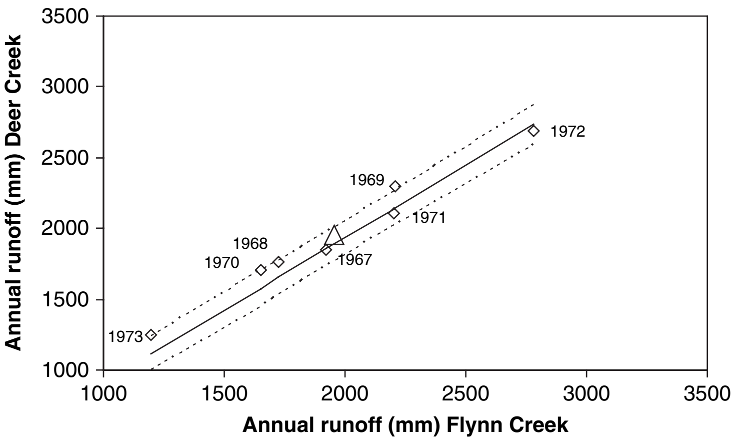

Fig. 2.7 Annual water yield regression between Flynn Creek and Deer Creek, with observed annual water yield after harvesting for the seven posttreatment years

significant difference between the prelogging and post-logging regression lines (Harris 1977).

Departures from the prediction equation (actual minus observed) were plotted over time. Needle Branch had significant and consistently positive increases in water yield after harvesting (Fig. 2.8). There was no discernible pattern in the increased annual water yields over time. The lowest increase was in the driest year (1973) and the highest increases in the wetter years. A similar plot for Deer Creek shows that water yield increases were not observed for every posttreatment year. Three of the seven posttreatment years had annual water yields less than predicted by Flynn Creek (Fig. 2.9).

Peak Flows

Peak flows result from the combination of incoming precipitation, interception, and the movement of water through the subsurface soil. The temperate coniferous forest environment generally exhibits seasonality in the runoff hydrograph, with peak flows occurring predominately in the wet winter season. Peak flows are important hydrologic characteristics because they are often responsible for moving large quantities of sediment in a river system, and are responsible for channel form. In the human environment, peak flows of various sizes are the driving design variables for culverts at road crossings, and in-stream structures.

The controlling hydrologic factor in temperate coniferous forest environments is rainfall, leading to large streamflows in the winter months when the

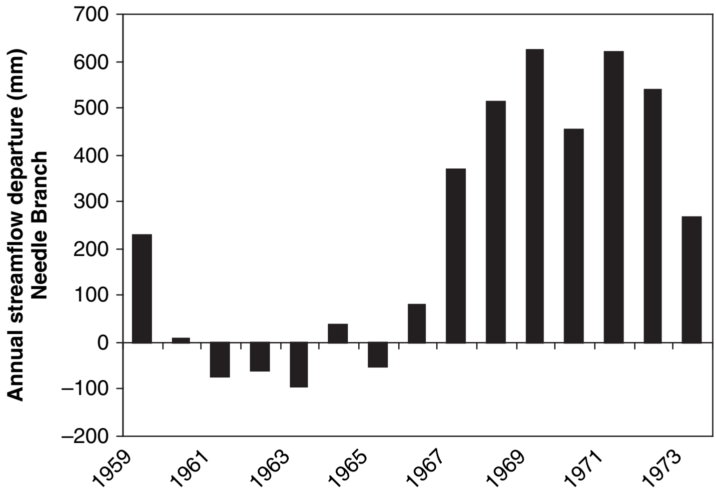

Fig. 2.8 Annual streamflow departure for Needle Branch from Flynn Creek prediction

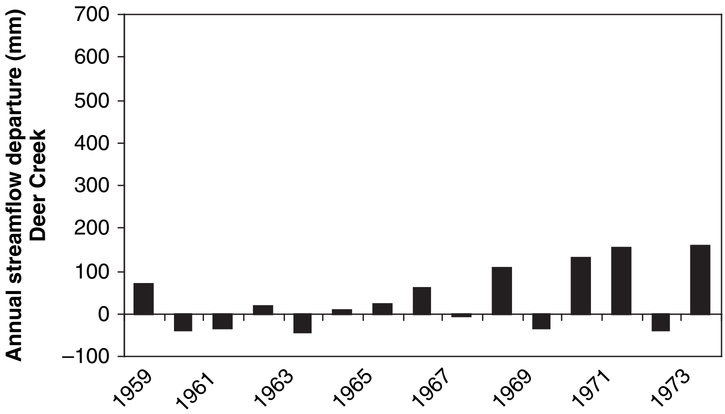

Fig. 2.9 Annual streamflow departure for Deer Creek from Flynn Creek prediction

majority of rainfall occurs, and low flows in the summer when little rain occurs. The highest annual peak flows generally occur during the winter months when precipitation is highest, the soil is generally near saturation, and the vegetation is not transpiring at peak levels (Harr 1976). Decreased evapotranspiration due to less vegetative cover causes the soil to be wetter than during pre-harvest conditions, resulting in earlier saturation of the soil mantle, and potentially higher peak flows (Harr 1976). This effect is not generally observed in the winter when the soil moisture is fully recharged in both harvested and unharvested watersheds. The timing of peak flows is dependent on the site-specific impacts of the particular timber harvest. The increase in fall soil moisture associated with decreased evapotranspiration has the greatest increase on peak flows with a one- to five-year recurrence interval (Harr 1976). Larger peak flows are not as susceptible to change by timber harvest, since the amount of precipitation during these storms will exceed increased soil moisture due to timber harvest (Harr 1976).

The evaluation criterion for peak flows was selected as flows greater than 0.55 $m^3\ s^{-1}\ km^{-2}$ (or 50 $ft^3\ s^{-1}\ mi^{-2}$) (Harris 1977). In the prelogging period there were 15 peak flows on Flynn Creek above the threshold and 16 peak flows in the post-logging time period (Table 2.6). On Needle Branch, the mean peak flow increased to 1.19 $m^3\ s^{-1}\ km^{-2}$ or 20% greater than the predicted mean of 1.0 $m^3\ s^{-1}\ km^{-2}$ (Table 2.4).Three peak flow events in the post-logging period were outside (or greater than) the 95% confidence interval (Fig. 2.10). The mean of all posttreatment peak flows was within the regression confidence intervals.

After logging on Deer Creek, the actual mean of the peak flows increased 0.02 $m^3\ s^{-1}\ km^{-2}$ or 2% greater than the predicted mean of 0.86 $m^3\ s^{-1}\ km^{-2}$ (Table 2.5) (Harris 1977). Two peak flows were outside the 95% regression confidence intervals and the posttreatment mean was within the confidence intervals (Fig. 2.11). The mean of all posttreatment peak flows was within the

Table 2.6 Peak flows ($m^3\ s^{-1}\ km^{-2}$) on all three watersheds for the pre and posttreatment periods

Water year	Date	Flynn Creek	Needle Branch	Deer Creek
1959	Jan 9	0.74	0.89	0.77
1959	Jan 27	0.59	0.77	0.66
1960	Feb 9	0.60	0.81	0.63
1961	Nov 24	1.09	1.34	1.06
1961	Feb 10	0.90	1.13	0.99
1961	Feb 13	0.66	0.73	0.71
1962	Nov 22	0.64	1.17	0.76
1962	Dec 19	0.57	0.73	0.63
1962	Dec 20	0.60	0.69	0.61
1963	Nov 26	0.91	1.13	0.98
1964	Jan 19	0.88	1.13	0.90
1964	Jan 25	0.56	0.69	0.59
1965	Dec 1	0.60	0.69	0.65
1965	Dec 22	1.26	1.30	1.21
1965	Jan 28	1.92	2.02	1.88
Prelogging mean		0.84	1.02	0.87)
1967	Jan 27	0.98	1.34	0.98
1968	Feb 19	0.63	1.01	0.75
1969	Dec 4	0.63	0.97	0.65
1969	Dec 10	0.60	0.97	0.65
1969	Jan 7	0.57	0.81	0.67
1970	Jan 18	0.70	1.01	0.71
1970	Jan 23	0.60	0.89	0.73
1970	Jan 27	0.63	0.77	0.68
1971	Dec 30	0.81	1.25	1.06
1971	Jan 16	0.71	1.25	0.70
1971	Jan 25	0.57	0.89	0.69
1972	Jan 11	1.95	2.59	1.83
1972	Jan 20	1.67	1.93	1.61
1972	Mar 2	0.67	1.01	0.69
1973	Dec 21	0.78	1.46	1.07
1973	Dec 27	0.59	0.89	0.56
Post-logging mean		0.82	1.19	0.88

regression confidence interval, indicating no significant increase in peak flows after harvesting.

Many studies have shown that few changes in peak flows occur as a result of timber harvest, even clearcutting (Harris 1977; Harr 1980; Harr et al. 1982). This evidence suggests that changes in peak flows are not as important as were once thought, especially since the small to average peak flows, not the larger channel forming flows, are those most affected by timber harvest.

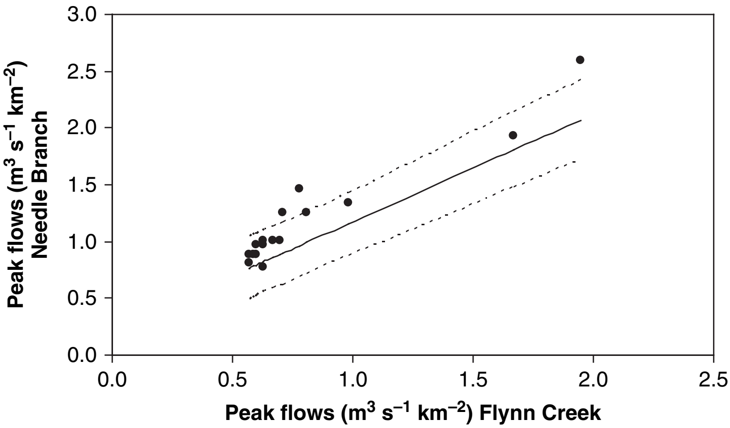

Fig. 2.10 Regression for peak flows between Flynn Creek and Needle Branch. Observed peak flows in posttreatment years are identified

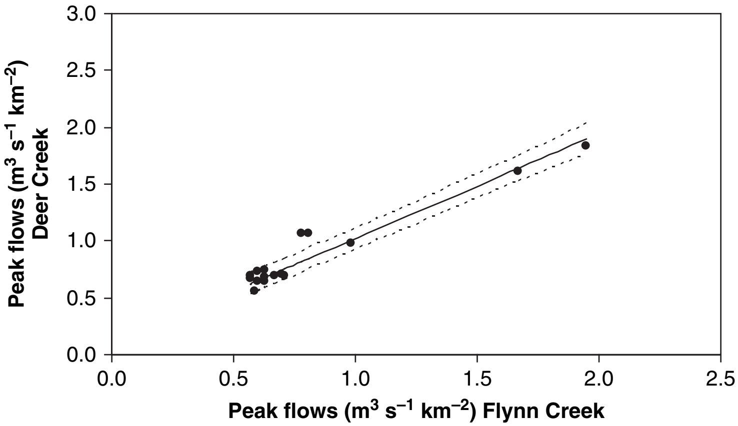

Fig. 2.11 Regression for peak flows between Flynn Creek and Deer Creek. Observed peak flows in posttreatment years are identified

Three-Day High Flow Runoff

The mean three-day high flow runoff for Flynn Creek in the pretreatment period was 114 mm compared to 116 mm, or 2 mm greater in the posttreatment period (Harris 1977). Deer Creek runoff in the post-logging period was 2.5 mm greater and Needle Branch was 31 mm greater. On Needle Branch, the predicted mean of the three-day high flow was significantly greater, 121 mm after logging compared to an actual mean of 150 mm. On Deer Creek, the predicted mean was 116 mm compared to the actual mean of 117 mm and not statistically different after harvesting.

Storm Hydrograph Changes

There has been continuing speculation about the influence of road building and clearcutting on the magnitude and frequency of peak flows (Harr et al. 1975). In the Western Cascade Mountains of Oregon, average peak flows in the fall from a 100% clearcut watershed increased 0.1 $m^3\ s^{-1}\ km^{-2}$, but winter peak flows were largely unchanged (Rothacher 1970). A similar pattern of smaller increases was noted when 25% of a watershed was harvested.

Deer Creek was divided into subwatersheds in an attempt to examine the effects of roading, clearcutting, and roading and clearcutting on streamflow (Harr et al. 1975). During the rainy season in western Oregon, storm runoff occurs under conditions of both recharging (fall season) and recharged (winter season) soil moisture conditions. Since the largest effects of road building and clearcutting on streamflow are expected to occur in the fall, data for this season were separated from the remainder of the rainy season. For Deer Creek, storm events were arbitrarily separated by date (September through November) and by antecedent moisture conditions as expressed as a baseflow of 0.038 $m^3\ s^{-1}\ km^{-2}$ (Harr et al. 1975).

There were few storm events suitable for the analysis of the effects of roads on peak flows because roads were separated from clearcutting for only one year. Study results were variable and a significant change in peak flow was only detected in Deer Creek subwatershed III, where roads occupied 12% of the total watershed area and 64% was logged (Harr et al. 1975). This became a management "rule-of-thumb" where no watershed should have more than 12% of its area in roads. This is a misrepresentation of the study results (Harr, personal communication 1996).

Needle Branch had 82% of the watershed harvested and 5% of the area was in roads. Roads had no detectable effect on storm hydrograph volume. Again, roads were only separated from logging by one year, and few storm events of sufficient magnitude were available for the analysis of the effects of roads on peak flows.

After logging, changes in total streamflow volume generally increased with increased watershed area harvested. Only Needle Branch had statistically significant increases in hydrograph volumes (Harr et al. 1975). Most increases were largest in the fall, when maximum differences in soil moisture content existed between cut and uncut watersheds. No consistent change in time to peak was noted among the watersheds (Harr et al. 1975).

Low Flows

Daily mean low flows measured in August and September in Needle Branch immediately after logging were higher than expected from the prelogging

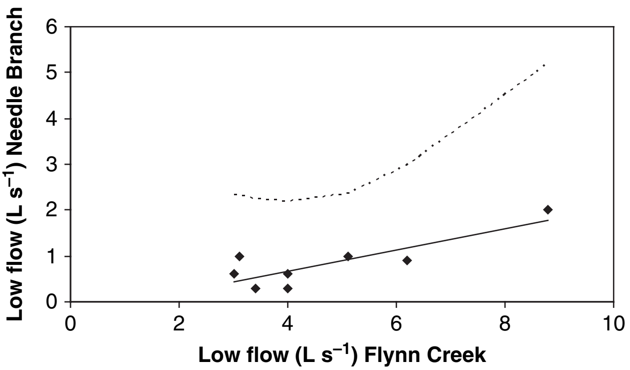

Fig. 2.12 Regression between low flows on Flynn Creek and Needle Branch and posttrreatment low flow observations.

relation (Fig. 2.12), but generally decreased each subsequent year toward the prelogging relation (Table 2.7) (Harris 1977). Recalculation of the low flow regression between Flynn Creek and Deer Creek showed a different regression (Fig. 2.13) than presented earlier (Harris 1977). The mean low flows measured on Deer Creek were significantly lower than predicted.

Table 2.7 Minimum daily flow (L s^{-1}) for all three watersheds for the period of record

Water year	Flynn Creek	Needle Branch	Deer Creek
Prelogging period			
1959	7.08	1.42	14.16
1960	3.96	0.57	8.78
1961	5.10	0.57	9.63
1962	5.66	0.57	9.91
1963	5.95	0.85	13.31
1964	6.23	0.85	12.18
1965	3.40	0.28	6.80
Mean	5.38	0.85	10.76
Logging period			
1966	3.12	1.13	6.51
Post-logging period			
1967	2.55	0.57	5.10
1968	8.78	1.98	13.59
1969	5.10	1.13	9.06
1970	3.96	0.57	7.36
1971	6.23	0.85	11.33
1972	3.40	0.28	5.10
1973	3.96	0.28	5.38
Mean	4.81	0.85	8.21

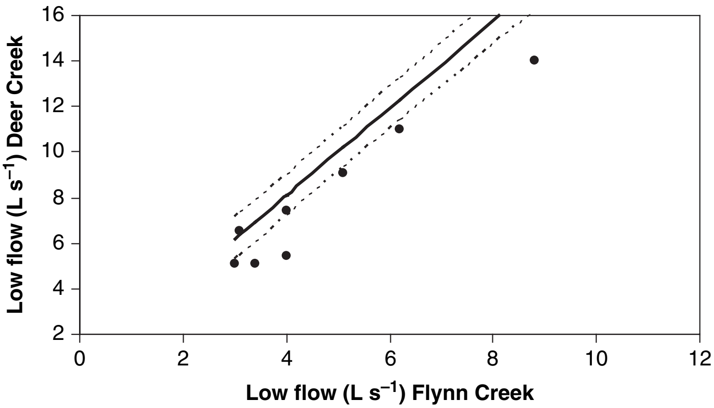

Fig. 2.13 Regression between low flows on Flynn Creek and Deer Creek and posttreatment low flow observations

Given the importance of low flows particularly as related to fish habitat and connectivity of pools, a subsequent analysis of low flows used the number of low flow days. The number of daily low flows less than 0.01 $m^3\ s^{-1}\ km^{-2}$ decreased for Needle Branch after logging when compared to Flynn Creek (Harr and Krygier 1972). The number of low flow days in Deer Creek decreased in two of the five posttreatment years (Harr and Krygier 1972).

Summary

Timber harvesting on Needle Branch increased annual water yield up to 31% over pretreatment conditions. The increases in annual water yields were greater in the wet years, and the posttreatment period of record did not suggest a hydrologic recovery or return to pretreatment water yields. Patch cutting with streamside vegetation in Deer Creek increased water yield by 3%. Timber harvesting did not increase mean peak flows on either treated watershed when compared to Flynn Creek. On Deer Creek, two of 16 peak flows were outside the confidence interval, and on Needle Branch three of 16 peak flows were outside the confidence interval. Daily low flows were increased on Needle Branch, and suggested a return to pretreatment conditions over time. The low flow response on Deer Creek showed streamflows lower than the pretreatment period. In general, additional research could be done on the effects of timber harvesting on streamflow responses.

This study was instrumental in illuminating the physical processes governing the hydrology of the temperate coniferous forest of the Pacific Northwest, and the changes in hydrologic process following timber harvest. The Alsea Watershed Study results, especially the effect of timber harvesting on water resources in Needle Branch is often cited as typical of forest management practices. It must be remembered that it was part of a study designed to have measurable responses. The understanding of hydrological processes as affected by timber harvesting with this study better afforded the development of best management practices (BMPs) designed to prevent or minimize adverse water resource damage.

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http://www.springer.com/978-0-387-94385-5

Hydrological and Biological Responses to Forest Practices
The Alsea Watershed Study
Stednick, J.D. (Ed.)
2008, XIV, 322 p. 85 illus., Hardcover
ISBN: 978-0-387-94385-5