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Camp and Clear Creeks, El Dorado County: Chronology and Hydrologic Effects of Land-Use Change

ABSTRACT

As part of the Sierra Nevada Ecosystem Project's Camp Creek/Clear Creek case study, modeling was done to assess the relative hydrologic effect of fifty years of land management in two basins. The Camp Creek Basin encompasses 8,425 ha (20,821 acres), ranges in elevation from 975 to 2,316 m (3,200 to 7,600 ft), and is managed by the Eldorado National Forest to provide timber and other products. The Clear Creek Basin encompasses 3,068 ha (7,580 acres), ranges in elevation from 512 to 1,250 m (1,680 to 4,100 ft), and has been extensively developed with low-density housing as well as ranching. The goal of this project was to quantify changes in runoff timing and volume stemming from changes in land management over time. Hydrologic effects were quantified for representative climatic conditions occurring in high-, medium-, and low-magnitude water years. Aerial photographs and a geographic information system (GIS) were used to quantify changes in cover density, impervious area, and other information for 1940, 1952, 1966, 1976, 1986, and 1991.

Disturbance in the Camp Creek Basin has been primarily associated with logging and roads. Between 1940 and 1991, April runoff increased by about 18% for the medium- and high-magnitude water years. For these years, and associated with decreasing forest cover and an increasing road network, annual snowmelt and subsurface flows increased over time, and annual ground water and evapotranspiration amounts decreased. For the medium-magnitude water year on Camp Creek, runoff shifted to earlier in the melt season, and summer base flows were smaller when compared with outflows predicted with the 1940 land-use condition.

Disturbance in the Clear Creek Basin has been primarily associated with residential development and roads. Because Clear Creek is lower in elevation and does not accumulate a seasonal snowpack, its runoff pattern does not have an April peak. High-flow months are between December and April, depending on storm occurrence. For the medium- and high-magnitude water years, predicted stream-flow increases in February, March, and April ranged from 1% to 4%. For the low-magnitude water year, the increase was between 14% and 18%. The change in total runoff was due to a large increase in the surface runoff contribution to total flow, and it is distinctly different from the Camp Creek response to land-use change. Evapotranspiration losses, ground water, and subsurface flows all declined during the analysis interval. Runoff responses to storms occurred faster in Clear Creek by the end of the analysis period, a result associated with changes in land condition.

Because the basins are at such different elevations, their hydrologic responses are different even under similar inputs. For these two basins, however, fifty years of changes in hill slope condition due to forest management and suburbanization appear to produce changes in runoff timing and volume and to change the relative contribution of flow components.

INTRODUCTION

The Sierra Nevada Ecosystem Project (SNEP) is an assessment of the entire Sierra Nevada ecoregion. Late successional for-

Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources, 1996.

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ests, watersheds, and significant natural areas are critical concerns, but the assessment also includes the social, economic, and ecological components of the entire set of Sierra Nevada ecosystems. In areas of the Sierra Nevada such as the 243,000 ha (600,000 acre) Cosumnes River Basin (figure 52.1), humans have been modifying the landscape for at least 150 years. Landscape disturbances include fire, logging, mining, water resource development, residential and road construction, and grazing. By the 1940s, road building and land clearing were common in the middle elevations of the Cosumnes, and logging was common in the upper elevations. In the 1960s, however, the pace of resource extraction accelerated, and demands for housing and water began to increase in the foothills below the lands that had become national forests. By the 1980s, many of the other river basins in the Sierra Nevada had been developed to supply hydropower, irrigation, or municipal water supplies. Retirement, recreation, and vacation communities in the Sierran foothills became widespread as Sacramento and other Central Valley towns grew. This growth has led to concerns about fragmentation of ecosystems and wildlife habitat, the role of wildland fire, and the effect of land disturbance on the hydrologic regime and the associated riparian ecosystems.

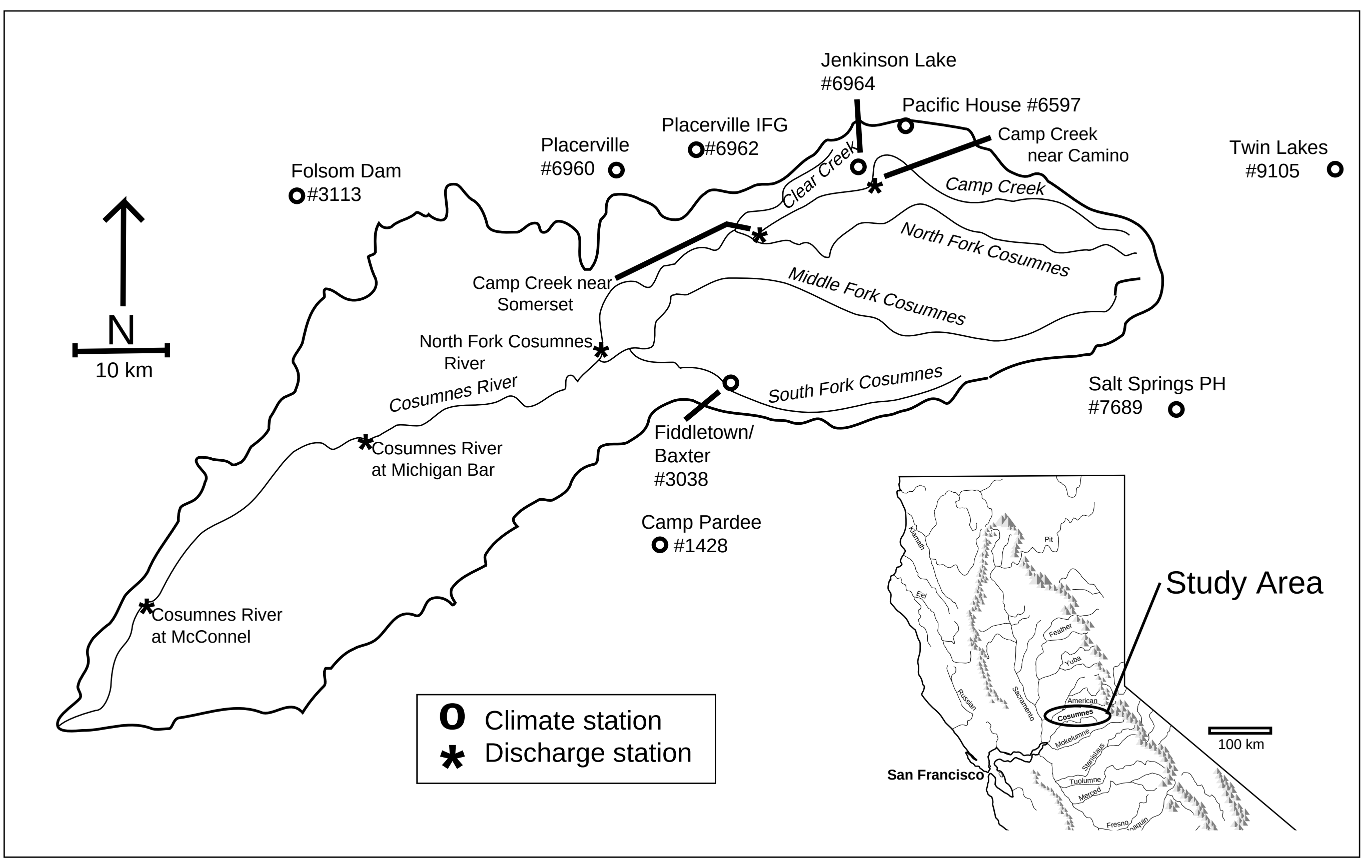
The Cosumnes River Basin was selected by the SNEP Science Team as a case study area because it is typical of many basins in terms of development. It is atypical in that there are no major dams on the system, although diversions are common and a municipal water supply dam disrupts natural flow in the Camp Creek and Sly Park Creek tributaries to the North Fork of the Cosumnes.

Suburbanization and forest management are two major uses of the Sierra Nevada and the Cosumnes basin. The SNEP team selected two small catchments within the Cosumnes for intensive analysis of the effects of these two uses. The two catchments have an extensive soils, fire, and road-network database and are in close proximity. Only Camp Creek has a stream gauge, but few small basins such as Clear Creek are gauged anywhere in the Sierra Nevada.

This project uses a process model to assess changes in runoff volume and timing between 1940 and 1991. Trends in vegetative cover, road extent, fire, and other factors were quantified at approximately ten-year intervals, and the changes were incorporated into the land-use condition portion of the hydrologic model. A thirty-three-year record of precipitation and runoff was ranked, and low-, medium-, and high-magnitude water years were selected to represent

FIGURE 52.1

Location of study area and climate and discharge stations in the Cosumnes River Basin, California.



drought, normal, and wet years. The hydrologic model was configured for each of the land-use conditions, and analysis was done for each of the three types of water years. The results were compared to assess the effects of changes in land use and water-year magnitude. A companion report to this one is an analysis of changes in sediment yields associated with the same set of land-use changes (McGurk et al. 1996).

STUDY SITE DESCRIPTION

The Camp Creek Basin ranges from 975 to 2,316 m (3,200 to 7,600 ft) in elevation and is managed by the Eldorado National Forest (ENF) to provide timber and other products (figures 52.2 and 52.3). Camp Creek is about 20 km (12.4 mi) east of Placerville, has a west-facing aspect, and is a tributary to the North Fork of the Cosumnes. A 8,246 ha (20,821 acre) portion of the Camp Creek Basin was selected by the SNEP Hydrology Team and is the contributing area upstream of a U.S. Geological Survey (USGS) gauging station (#113315, Camp Creek near Camino). Because the portion of the Camp Creek Basin between the #113315 and the #113330 stations (Camp Creek near Somerset) is not all within the ENF boundaries and has not been extensively logged or roaded because of the steepness of the canyon, it was excluded from the analysis.

The Clear Creek Basin is 3,068 ha (7,580 acres) in size, ranges from 512 to 1,250 m (1,680 to 4,100 ft), and has been extensively developed with low-density housing (figure 52.4). The Clear Creek Basin has a southwest aspect and is predominantly private land.

Both basins are composed primarily of loam soils (Cohasset, Josephine, Mariposa, and McCarthy series) (Mitchell and Silverman n.d.; Rogers 1974), but Clear Creek has some areas with clay soils. Camp Creek soil depths range from 66 to 178 cm (26 to 70 in) and average 88 cm (35 in). Clear Creek soils range from 45 to 131 cm (18 to 52 in) and average 103 cm (41 in). Clear Creek has grass- and shrublands along with forested areas, but Camp Creek is almost entirely forested with mixed conifers. Clear Creek slopes range from 9% to 41% and average 24%. Camp Creek slopes range from 15% to 43% and average 31%.

METHODS

Scale of Analysis

This study is local in scale and assesses the land-use and hydrologic changes in two small basins in the central Sierra Nevada. It is likely that the sequence of land-use developments and the forest management activities that have taken place in the Camp and Clear Creek Basins are typical of activities that have occurred across a much wider scale. Suburbanization and logging are common uses of much of the western slope of the Sierra Nevada, so impacts documented here should have wide application.

A fifty-year period between 1940 and 1991 was selected for analysis for several reasons. One factor was data availability; aerial photographs are uncommon prior to 1940, and stream discharge and climate station data are less common as well. Both basins were relatively undeveloped in 1940. Logging was certainly being practiced in the Camp Creek Basin by 1940, but records that would allow a detailed compilation of practices, locations, and yield are too sparse to allow analysis. Further, logging and development had not progressed to the levels that they did in the post–World War II era.

Land-Use History

Land-use information was acquired from a variety of public sources. The ENF's Supervisor's Office and the Placerville Ranger District provided most of the logging, grazing, and road information. Aerial photographs supplied information on the date of construction of roads. The construction dates of new residences were obtained from the El Dorado County Assessor's Office records and parcel maps.

A considerable amount of land-use information was acquired from the raster-based geographic information system (GIS) used by the ENF, the Distributed Wildland Resource Information System. DWRIS was used extensively during this project, both as a source of basic land-use information layers (roads, plantations that resulted from clear-cuts, soils, fire extent, slope) and to determine area and distance of land uses derived from the photographs. DWRIS coverage included the Clear Creek Basin because a number of sections west of the national forest boundary are public land.

Aerial photographs were acquired for the following dates: 1940, 1952, 1965/66 (hereafter referred to as 1966), 1976, 1986, and 1991. In addition, 1988 orthophotoquads (7.5-minute mosaics of aerial photographs, rectified to a uniform scale) were obtained. Mosaics were created out of photocopies of each of the six sets of aerial photographs, and the mosaics were analyzed successively by date for clear-cuts and roads.

The grouping of land-use changes into photo intervals is not a perfect process. We recognize that an activity such as logging could occur in 1953 and be assigned to the 1966 photo series, thereby ignoring twelve years of recovery. Because aerial photos are often the only source of information, it is rarely possible to assign a more accurate date to a disturbance. However, the primary disturbances in the early photo intervals are roads and structures, which do not "recover" in terms of their effects on runoff; roads and structures create impervious areas that are essentially permanent. The dates of the fires were known, and a thirty-year recovery was presumed.

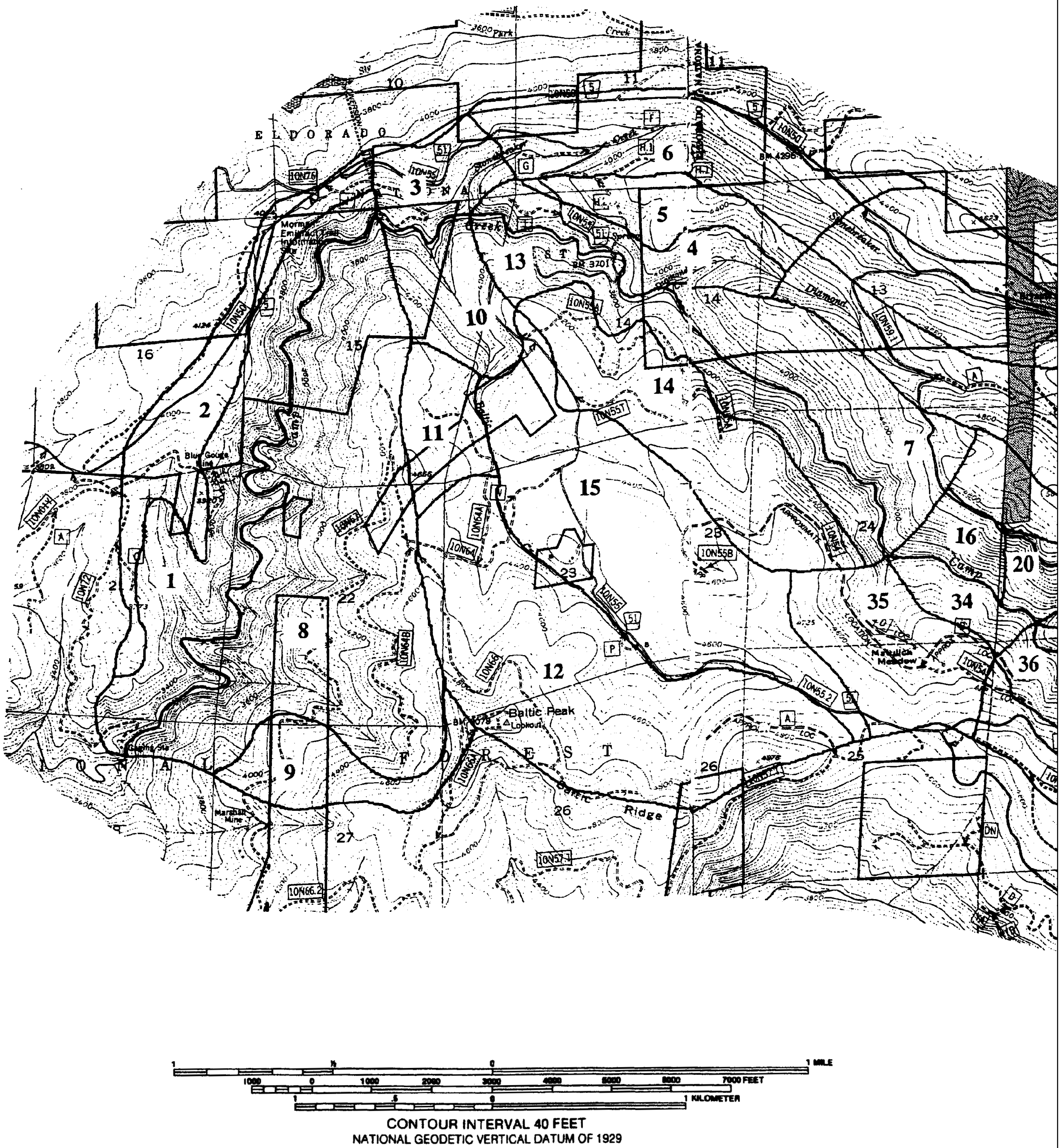


FIGURE 52.2

Map of lower Camp Creek, a tributary to the North Fork of the Cosumnes River, showing Hydrologic Response Units with labels, located in the Eldorado National Forest, California.


N
19
18
17
24
28
27
21
30
26
23
22
29
25
37
38
39
40
E L D O R A
N A T I O N A L
R E S T
R I D G E
10N50P
10N65A
10N22VA
10N68
10N60
10N65
10N59B
10N60A
10N58
10N58B
10N59.2
10N61
10N88
10N83.1
10N55.2
Little Pebble Canyon

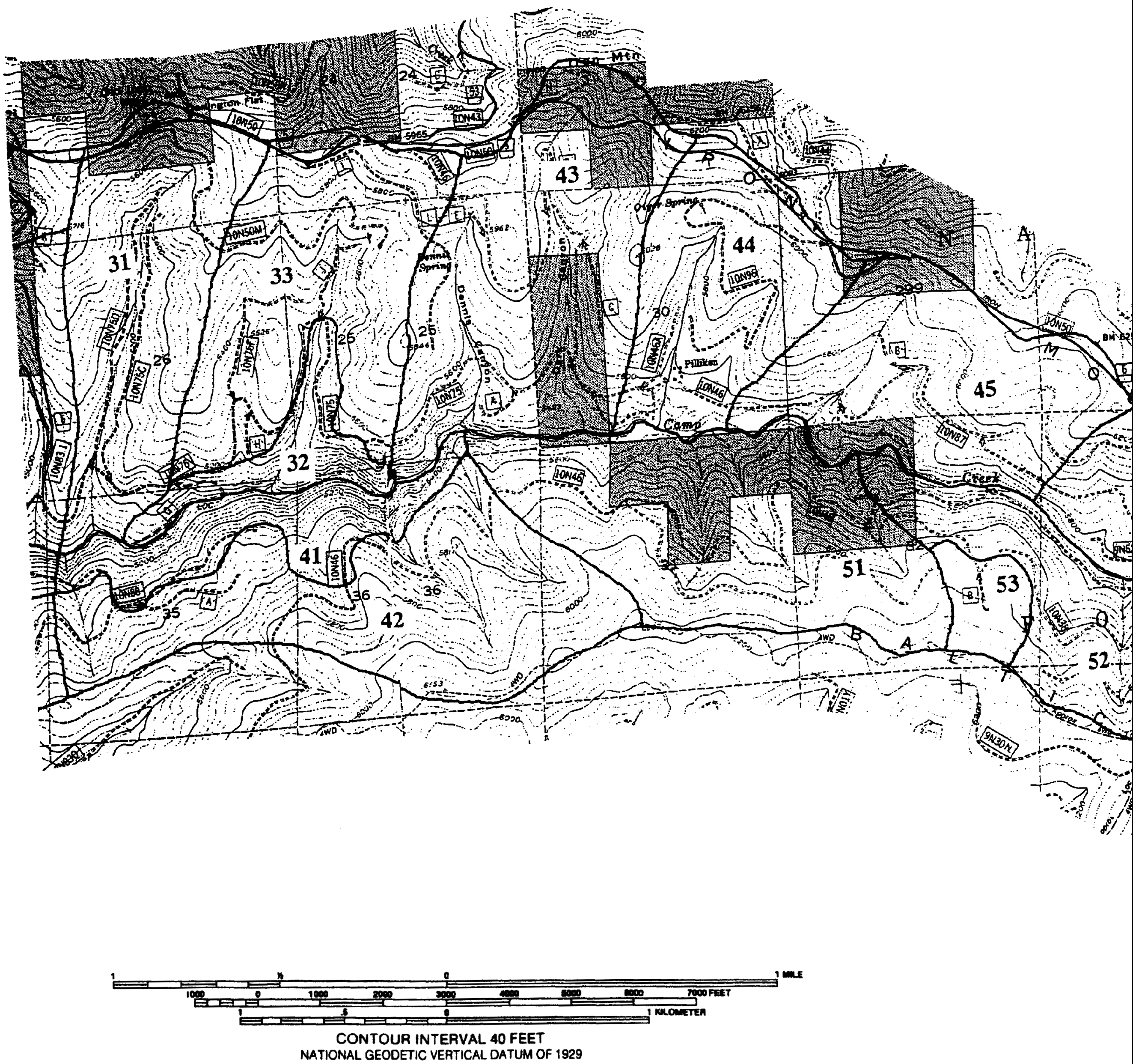
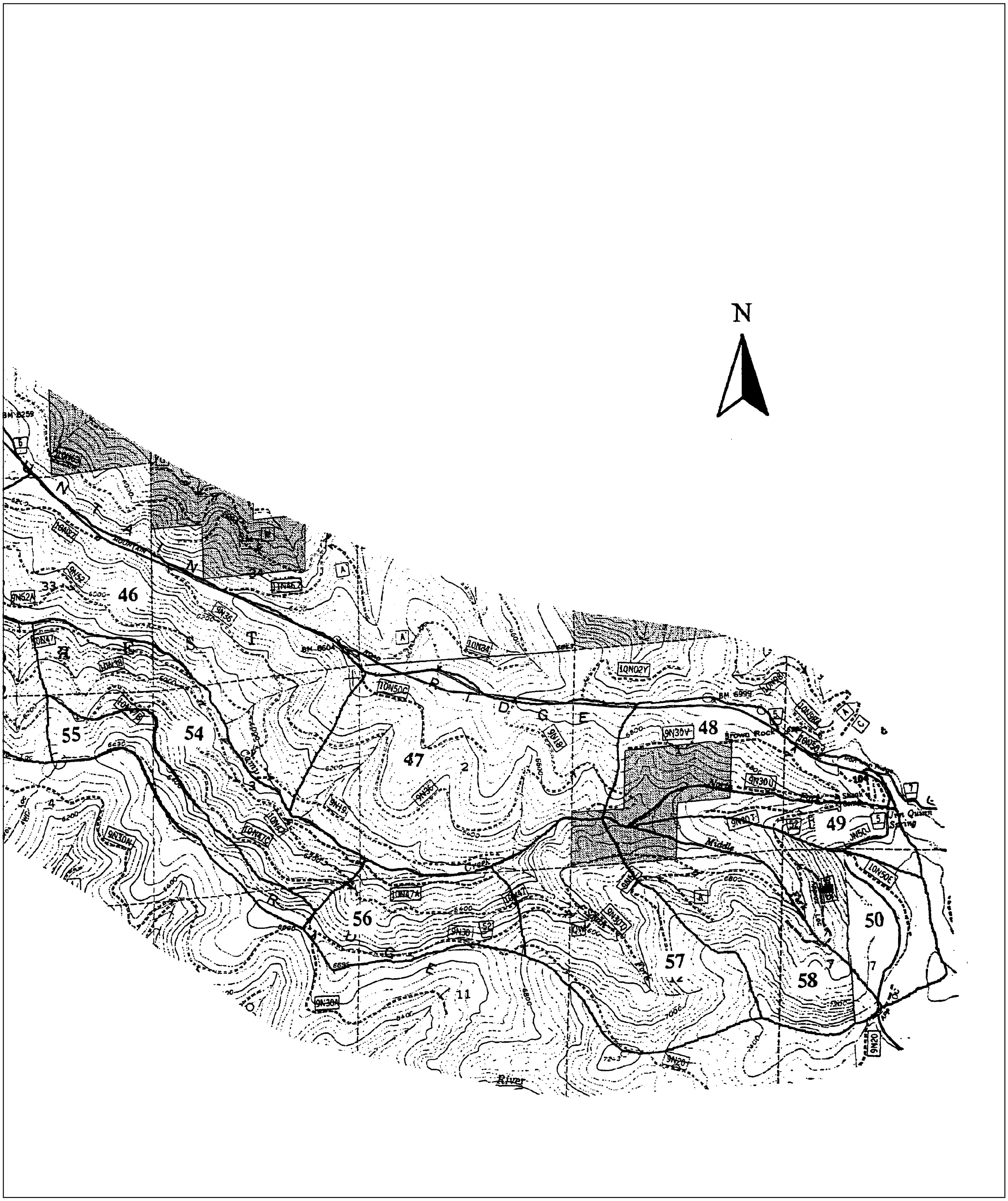


FIGURE 52.3

Map of upper Camp Creek, a tributary to the North Fork of the Cosumnes River, showing Hydrologic Response Units with labels, located in the Eldorado National Forest.


N
46
47
48
49
50
54
55
56
57
58
Middle
River

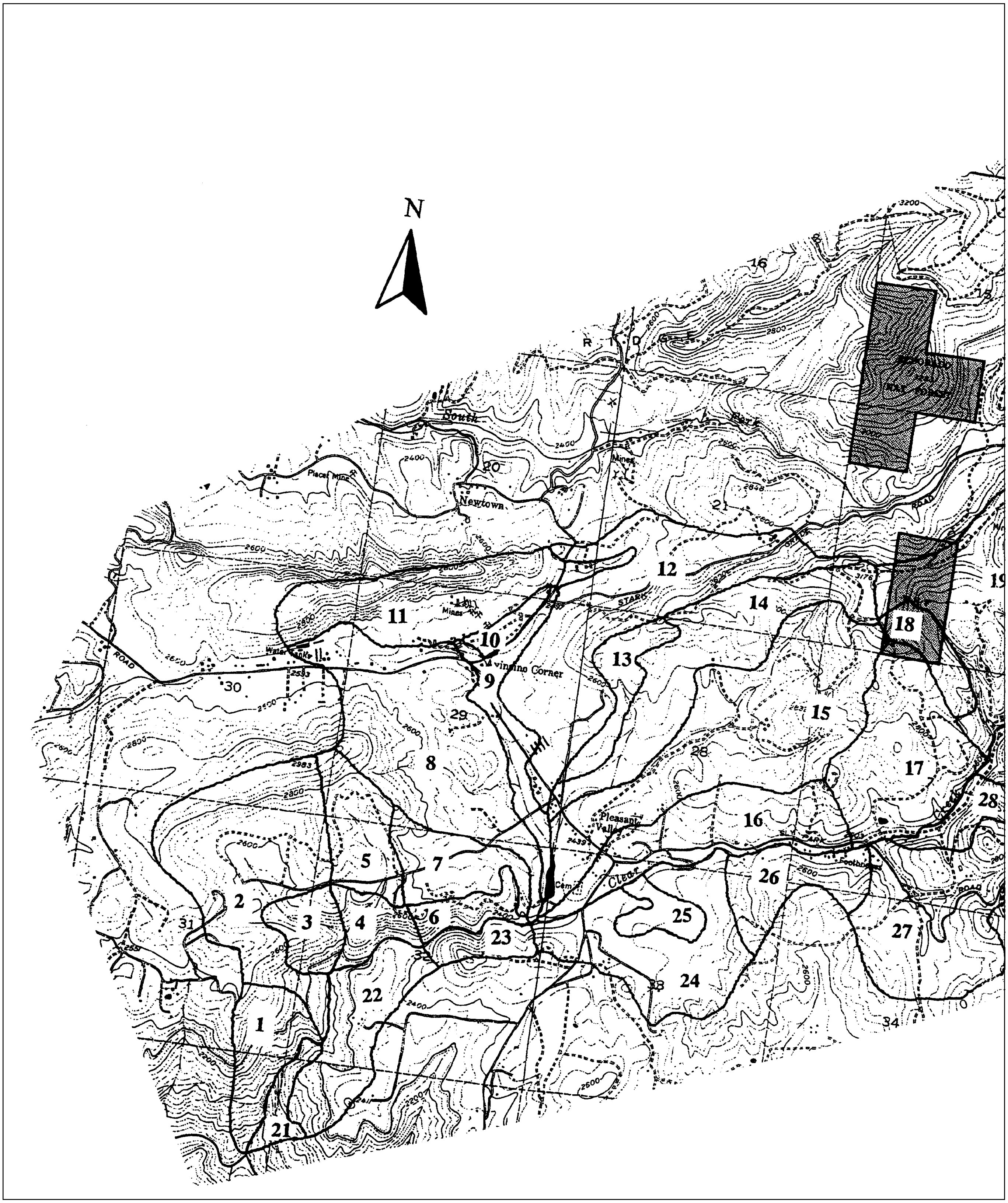


FIGURE 52.4

Map of Clear Creek, a tributary to the North Fork of the Cosumnes River, showing Hydrologic Response Units with labels, located in El Dorado County, California.


FOREST
E N F
11
12
49
52
53
56
Weber
Creek
South
Fork
45
48
51
50
40
47
14
20
38
39
37
44
46
42
18
43
41
35
36
Clear
Creek
55
54
SKY PARK
GUARD STATION
ELDORADO
NATIONAL FOREST
34
30
19
33
32
31
24
29
26
20
E L D O R A
CONTOUR INTERVAL 40 FEET
1 MILE
7000 FEET
1 KILOMETER

Disturbance Elements

Roads

Based on the ENF's definitions of road types and widths, five major classes of roads were mapped:

1. Dirt/four-wheel drive surface: 2.7 m (9 ft) wide
2. Improved dirt surface: 4.2 m (14 ft) wide
3. Improved gravel surface: 5.5 m (18 ft) wide
4. Improved paved surface: 6.7 m (22 ft) wide
5. Secondary highway surface: 7.3 m (24 ft) wide

In Clear Creek, there are 128.1 km (79.7 mi) of unpaved road, and 12.7 km (7.9 mi) of paved road. In Camp Creek, there are 232.5 km (144.5 mi) of unpaved road and 56.6 km (35.2 mi) of paved road. Iron Mountain Road, also known as the Mormon Emigrant Trail, runs along the northern boundary of Camp Creek and is the reason that this forested basin has such a large amount of paved road. Each road type is identified within DWRIS, and the appropriate width was attached to each segment to generate the total road area per hydrologic response unit (HRU). No extra width multiplier was used to account for cut-and-fill slopes along the roads because these slopes are seldom impervious.

Logging

Thirty-eight logging operations are documented in the Placerville Ranger District's files (table 52.1). These operations extend from 1953 to 1991. Prior to 1976, selective cutting was the dominant method of logging. Beginning in the mid 1980s, clear-cutting was used more extensively. Information about clear-cutting comes from the DWRIS plantation layer and from analysis of the 1986 and 1991 photos. An unusually large number of salvage sales were done between 1988 and 1991 due to drought-related insect outbreaks. About 80% of the Camp Creek Basin was included in salvage sales during this time, and many of the sales covered the same area in successive years.

Although logging was conducted in Camp Creek by public and private groups prior to 1953, the records are too poor to allow analysis. However, volumes of timber and areas cut can be estimated for the 1953 to 1991 period for the entire study area (figure 52.5). In order to produce figure 52.5, estimation of volume per acre for some sales was required to fill in missing entries in the Area Cut and Actual Volume columns in table 52.1. Clear-cutting volumes exceeded those from selective logging after 1977, even with the intensive salvage operations that were under way between 1988 and 1991.

Selective logging (e.g., group cutting, salvage) is a dispersed type of logging wherein individual trees or small groups of trees are cut from within a much larger sale area. The sales in table 52.1 illustrate the problem associated with attempting to map logging operations other than clear-cuts. The area cut is often a very small fraction of the sale area, and most of the ENF's sale records do not include maps identifying the specific areas. Some of the timber sale records do have "sale area" and "acres cut" entries, but most do not. In cases where location was provided, or volume was very large and could be assigned to one or more HRUs, percentage cover in the affected HRUs was reduced by 5%–10%. From a hydrologic standpoint, when selective cutting is done from existing roads and when canopy cover reductions are less than 5%, the effect on flow quantity and timing is probably negligible.

No information was found that documents the extent of logging in Clear Creek. The grasslands there now were typically present in the 1940 photos. In a few cases, enlargement of rangelands or minor harvesting was noted in the photos, but the extent was minimal.

Fire

Fire history (1911–91) for Camp and Clear Creeks is shown in table 52.2. Of the 608 ha (1,502 acres) affected by fire, 257 ha (636 acres) burned by 1920, prior to the period of this analysis. The 1915 and 1920 fires are shown in appendixes 52.1 and 52.2 under the 1940 time period. This inclusion is based on a common assumption that hydrologic recovery from fire or logging occurs in twenty-five to thirty-five years (Satterlund 1972).

Structures

The structures category encompasses the construction activities in Clear Creek. No structures were found in Camp Creek. Private residences are the dominant type of structure in Clear Creek, and most homes were built after the 1966 photo period. Structures create impervious areas that are presumed to be permanently "disturbed," analogous to roads. Impervious area per structure is estimated according to the following:

- Impervious roof area of house and garage is 232 m^2 (2,500 ft^2).
- Impervious area associated with driveway and walks is 232 m^2 (2,500 ft^2).

This assumption results in 464 m^2 (5,000 ft^2) of impervious area per structure unit. Although there may also be conversions from rangeland to pasture or lawn and some tree removal during subdivision and structure construction, these factors could not be detected from county records or aerial photos and are thought to be minor.

Grazing

Grazing appears to have a minor role in Camp Creek and has been relatively constant (about 150 animal unit months) since 1900, according to records kept by the ENF. No information was obtained for Clear Creek.

Model Selection

Two types of models are suitable for analyzing hydrologic change associated with land-use change: conceptual process models and distributed-parameter numerical models. Statistical models were not considered because of the need to document the contribution of hydrologic flow components to total runoff.

A range of conceptual models have been formulated and are typified by the Stanford Watershed Model (Crawford and Linsley 1966) and the Sacramento soil moisture accounting model (Peck 1976). Most conceptual models are nonlinear and time-invariant and have lumped parameters that are representative of gross watershed characteristics. These models are generally accepted as being reliable in forecasting important features of the hydrograph (e.g., timing, shape, and volume) (Sorooshian 1983).

Numerical models such as TOPMODEL (Moore et al. 1988) are spatially distributed, time-variant, and subdivide the basin into small cells using high-resolution, digital elevation data and detailed soil data. Numerical models provide detailed analysis of flow paths and runoff using kinematic routing and other complex mathematical techniques. Numerical models require comprehensive topographic and soil data and have typically been restricted to application to small basins.

The goal of this project was to discern the effects of long-term land-use changes on the hydrologic response of two medium-sized basins with rather coarse physiographic, cli-

TABLE 52.1

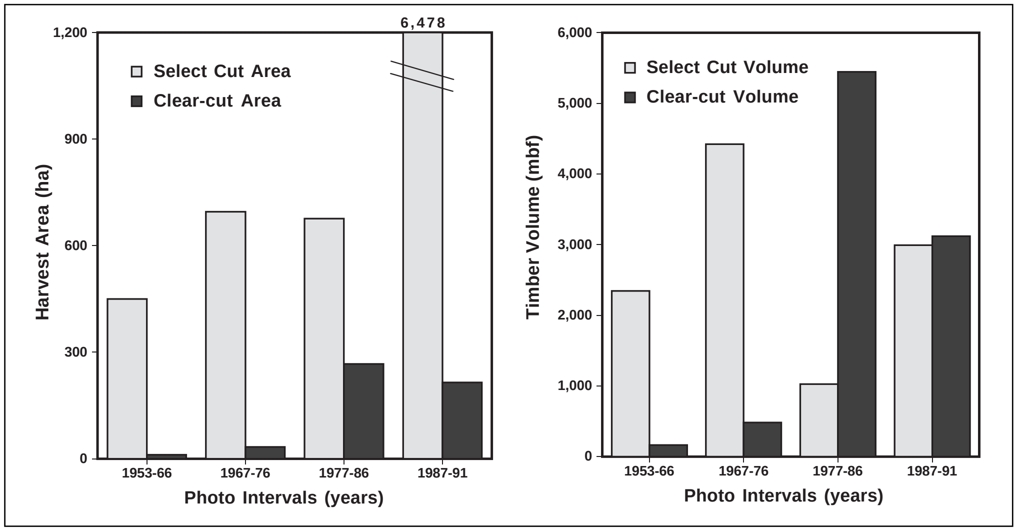
Logging history in the Camp Creek Basin, Eldorado National Forest.

					Volume	
Sale	**Date**	**Activity**	**Sale Area (ha)**	**Area Cut (ha)**	**Estimated (MBF)**	**Actual (MBF)**
1953–66 [a]						
Sly Park	5/64–11/64	Insect salvage	135	135	263	— [b]
Schenck	6/64–4/68	Group cut	1,004	630	46,400	47,983
1967–76						
Oiyer Spring	11/67–1/68	—	113	—	1,400	2,506
Pilliken	6/68–2/71	Group cut	402	171	13,600	—
Pebble Cyn	4/71–3/72	Fire salvage	56	56	1,470	—
Baltic Regen	4/71–11/71	Regen salvage	—	—	66	—
Lode	4/70–12/73	Group cut	53	30	2,400	—
Baltic	8/75–12/75	Salvage	35	35	296	—
Iron Park	5/75–3/76	Salvage	502	134	255	383
Brown Rock	7/76–8/76	Salvage	—	—	18	—
Matulich	7/76–3/77	Salvage	121	121	88	—
Brandon Cyn	8/76–2/77	Insect salvage	61	—	84	—
Dennis Cyn	9/76–8/78	Insect salvage	—	—	83	—
1977–86						
Corky	6/79–8/79	Insect salvage	24	4	141	—
Premat	6/80–12/81	Insect salvage	728	—	1,000	—
Iron Mtn.	7/81–11/82	Insect salvage	850	178	1,200	—
Diamond T	8/81–10/82	Insect salvage	111	24	249	465
Quinn	9/81–2/86	Various	1,803	601	25,000	—
Brandon	3/83–3/87	Clear-cut and other	411	80	5,720	—
Blue Gouge	5/79–10/84	—	13	13	643	—
Diamond	5/84–3/87	Clear-cut	389	63	5,270	5,252
Dennis	5/82–2/89	Clear-cut and regeneration	—	—	6,700	—
Pebble	11/85–5/89	Clear-cut and overstory removal	643	71	14,676	—
1987–91						
Diamond Jim	1988	Salvage	4,862	—	2,285	—
Bonetti	1989	Salvage	507	—	1,535	—
Iron	1989	Salvage	2,539	—	3,774	—
Morrison	1989	Salvage	23	—	45	—
Sleek	1989	Salvage	2,601	—	6,827	—
Jimbean	1990	Salvage	23	—	23	—
Quinn Addon	1990	Salvage	45	—	7,000	—
Rathole	1990	Salvage	814	—	3,641	—
Vancamp	1990	Salvage	1,630	—	2,358	—
Willow	1990	Salvage	27	—	51	—
Beetlebattle	1991	Salvage	20	—	12	—
Lost Larva	1991	Salvage	8	—	11	—
Peanut Bee	1991	Salvage	2,531	—	1,587	—
Pitchstream	1991	Salvage	1,649	—	759	—
Plum Dead	1991	Salvage	38	—	23	—

[a] No sale records for 1940–52.
[b] Dash indicates no data.

FIGURE 52.5

Logging extent by area and timber volume for Camp Creek, Eldorado National Forest, 1953–91 (select areas estimated).



mate, and soil information. The sizes of the basins, the lack of data, and the long analysis period mandated the use of a conceptual hydrologic model that included algorithms associated with changes in impervious area and vegetation type and density. The U.S. Geological Survey's Modular Modeling System (MMS) was selected because it is well documented, has seen extensive use, incorporates land-use change factors, and is in the public domain.

Modular Modeling System

The watershed model contained within the MMS is the USGS's Precipitation-Runoff Modeling System (PRMS) (Leavesley et al. 1983). PRMS is a conceptual process modeling system. To reproduce the physical reality of the hydrologic system as closely as possible, each component of the hydrologic cycle is mathematically expressed via known physical laws. Where physical laws or information are lacking, empirical relationships are used that have some physical interpretation and may be based on measurable watershed characteristics.

The MMS or PRMS has been used in a number of studies to investigate the effects of global climate change in California (Jeton and Smith 1993) and Colorado (Leavesley et al. 1992; Hay et al. 1993), to simulate runoff in small basins in Colorado (Norris 1986), to simulate dry-season runoff in Guam (Nakama 1994), to evaluate hydrologic response to surface coal mining (Stannard and Kuhn 1989), and to evaluate the effect of forest management on hydrology (Grant et al. 1990).

The watershed system embodied in PRMS is schematically depicted in figure 52.6. System inputs are precipitation, air temperature, and optional snow accumulation and solar radiation data. Precipitation is classified as rain or snow or mixed, based on temperature, and is delivered to the watershed surface. The energy inputs of temperature and solar radiation drive the processes of evaporation, transpiration, sublimation, and snowmelt. The watershed system is conceptualized as a series of four reservoirs whose outputs combine to produce the total system response.

Stream flow is the sum of the surface, subsurface, and base flow outputs. No channel routing is done when the model is run on a daily time step, as it was in this study.

Impervious Zone

One reservoir is the impervious-zone reservoir, which has no infiltration capacity and represents areas such as roads. This reservoir has a maximum retention storage capacity that must be filled before surface runoff will occur. Retention storage is depleted by evaporation when the area is snow free.

Soil Zone

The soil-zone reservoir represents that part of the soil mantle that can lose water through evaporation and transpiration. Average rooting depth of the predominant vegetation cover-

TABLE 52.2

Fire history for Clear Creek and Camp Creek Basins, El Dorado County, California, by photo interval and watershed.

Photo Interval	Total Area (ha)	Subarea (ha)	Year (ha)	Watershed
1911–39	257.46	256.10	1915	Camp Creek
		1.36	1920	Camp Creek
1940–52	0			
1953–66	0			
1967–76	336.46	97.50	1969	Camp Creek
		84.98	1972	Clear Creek
		153.98	1973	Camp Creek
1977–86	0			
1987–91	14.20		1988	Camp Creek

Total 1911–39 = 257.46
Total 1940–91 = 350.66

Total Clear Creek = 84.98
Total Camp Creek = 523.14

Grand total = 608.12

ing the soil surface defines the depth of this zone. Water storage in the soil zone is increased by infiltration of rainfall and snowmelt and depleted by evapotranspiration (ET). The depth and water-storage characteristics of the upper layer of this reservoir, termed the recharge zone, are user defined and based on vegetation type. Losses from the recharge zone are assumed to occur from evaporation and transpiration. Losses from the lower zone occur only through transpiration.

Infiltration into the soil zone depends on whether the input source is rain or snowmelt. All snowmelt is assumed to infiltrate until field capacity is reached. At field capacity, the soil zone is assumed to have a maximum daily snowmelt infiltration capacity. Snowmelt in excess of field capacity contributes to surface runoff. Infiltration in excess of field capacity is first used to satisfy recharge to the ground water reservoir, up to a maximum daily amount. Excess infiltration after recharge to the ground water reservoir becomes recharge to the subsurface reservoir.

For rainfall with no snow cover, the volume infiltrating the soil zone is computed as a function of soil characteristics, antecedent soil-moisture conditions, and storm size. For daily-flow computations, the volume of rain that becomes surface runoff is computed using a contributing-area concept. Daily infiltration is computed as net precipitation less surface runoff.

Subsurface Zone

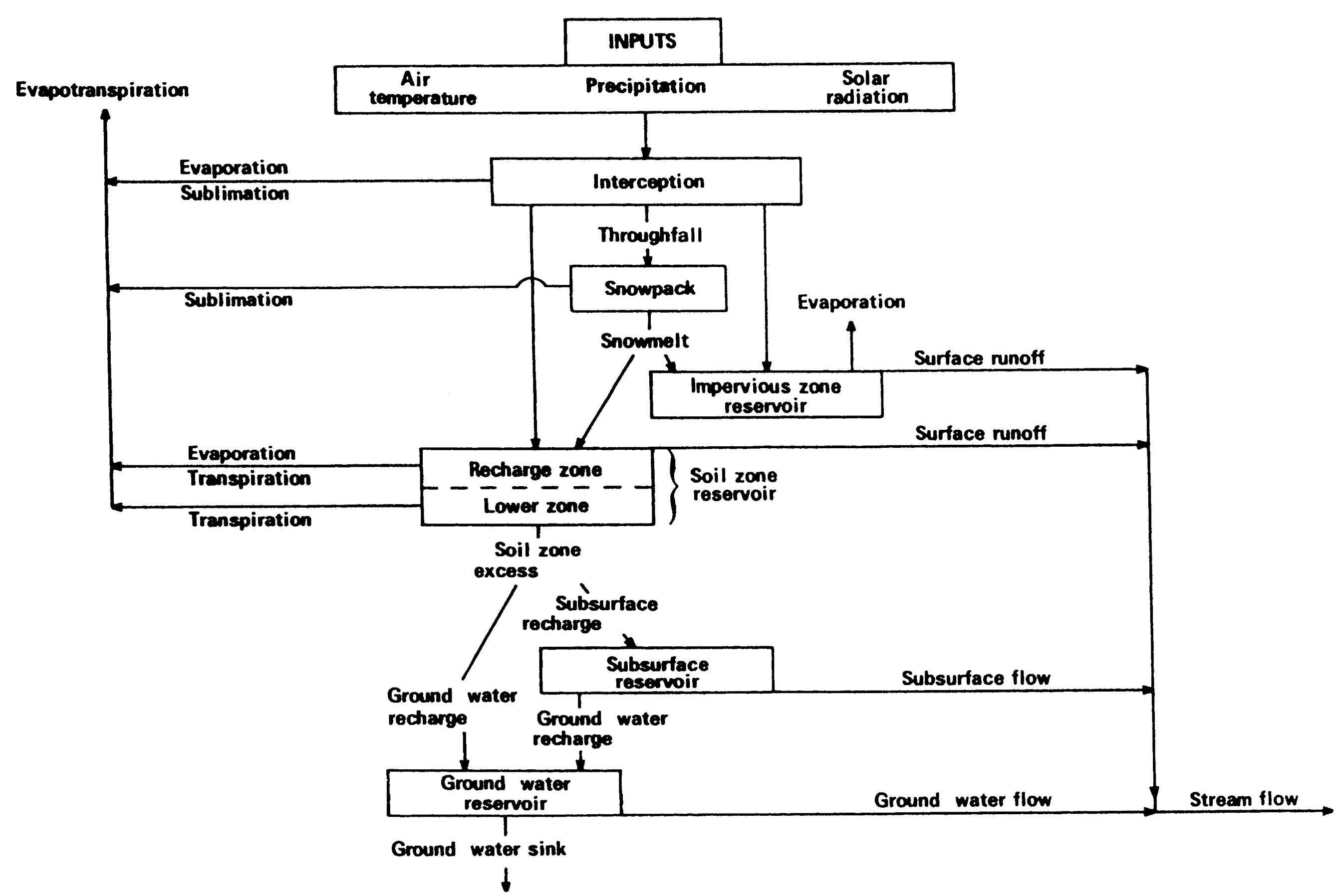
The subsurface reservoir routes the soil-water excess that percolates to shallow ground water zones near stream channels or that moves downslope from the point of infiltration to some point of discharge above the water table. Subsurface flow is considered to be water in the soil and ground water zones that is available for relatively rapid movement to a channel system.

Ground Water Zone

Recharge to the ground water reservoir can occur from the soil zone and the subsurface reservoir. Soil recharge has a daily upper limit and occurs only when the field capacity is exceeded in the soil zone. Subsurface recharge is computed daily

FIGURE 52.6

Schematic diagram of the mathematical watershed system and its inputs (after Leavesley et al. 1983).



as a function of a recharge rate coefficient and the volume of water stored in the subsurface reservoir. Release of ground water is controlled by a linear equation, and this release is the source of all stream base flow.

Hydrologic Response Units

Hydrologic models partition a basin into "homogeneous" grid cells or polygons, and PRMS is based on polygons called Hydrologic Response Units. HRUs are delineated based on physiographic properties that affect runoff generation: slope, aspect, elevation, vegetation type, soil type, and precipitation distribution. The goal of the polygon (HRU) delineation process is to subdivide the basin into units that respond similarly to rainfall-runoff processes and also to allow separation of historical land-use changes. Clear Creek was divided into smaller HRUs than Camp Creek because suburbanization occurs at a smaller spatial scale than forest management activities. Two sources of boundaries for Camp and Clear Creeks were obtained: the Calwater boundaries (Brandow 1994) were mapped at the 7.5-minute scale by the SNEP Geographic Information Center, and the GIS laboratory at the Supervisor's Office of the ENF supplied watershed boundary maps at the same scale. All boundaries were manually compared to the contour lines on the USGS quadrangle maps, and boundaries were changed where the Calwater or ENF boundaries were incorrect.

Once the major watersheds were defined, interior subwatershed boundaries were delineated based on topography. The subwatershed areas were then further partitioned based on slope and soil maps provided by the ENF. Soil types were grouped by water flow capability (Hydrologic Soil Groups B through D) and then overlaid with slope categories. The combination of the three flow classes and four slope categories yielded the final HRU boundaries. In the Camp Creek SNEP study area, fifty-eight HRUs were mapped, which ranged from 27.5 to 375 ha (68 to 926 acres) and averaged 145.3 ha (359 acres) (figures 52.2 and 52.3). Four additional HRUs were included downstream of the SNEP HRUs that comprised the contributing area between the two gauging stations (#113330 and #113315). In Clear Creek, fifty-six HRUs were mapped, which ranged from 8.5 to 184 ha (21 to 455 acres) and averaged 54.8 ha (135 acres) (figure 52.4). Aspect was manually derived from topographic maps, and vegetation type was derived from aerial photographs and compiled with area, elevation, slope, and soil depth (appendixes 52.3 and 52.4).

Historical Attributes by HRU

For each photo date, the land-use history was used to develop a set of attributes that incorporated the land-use changes prior to that photo date and characterized land condition for the basin for that interval. The attributes for each HRU included winter and summer percentage cover, impervious area, and a solar-canopy-penetration coefficient. The six sets of photo mosaics were overlaid by the HRU boundaries and percentage cover was subjectively determined. All photos were taken in the summer, and unless the vegetation cover type was conifer, percentage cover for winter was estimated based on the fraction of deciduous trees, shrubs, or grass. Impervious area was the percentage of the area of the HRU that was devoted to roads, residences and driveways, and portions of recently burned areas. The solar-canopy-penetration factor was estimated via a graphical procedure presented in the PRMS users manual (Leavesley et al. 1983).

Recovery from Disturbance

A complex recovery scheme was not incorporated in the analysis for several reasons. In most cases, the only source of information on activities was the aerial photos, so each road segment and logging activity could not be identified by exact date. Dates were known for fires, so a simple recovery scheme was implemented: 50% of the area of a fire in an HRU was set as impervious for the five years after a fire (Krammes and DeBano 1965; Dyrness 1976; Poff 1989), and thereafter the fire had no effect beyond a reduction in percentage cover that was estimated from the aerial photographs. A value of 50% was chosen to include compacted area created during fire suppression as well as to incorporate the effect of hydrophobic soils.

The width and surface type of county and ENF roads were identified in the land-use analysis. No recovery scheme was used with roads and structures; their areas are impervious and do not recover. To incorporate the effect of skid trails and compaction within the clear-cuts that began by 1976, the following scheme was implemented:

- 25% of the clear-cut area was assumed to be impervious in the interval in which the clear-cut first appeared
- 15% of the clear-cut area was assumed to be impervious in the next interval
- 5% of the clear-cut area was assumed to be impervious in the third interval
- None was assumed impervious thereafter

Climate and Runoff Data

Climate Stations

Climate and runoff data were obtained from several sources to develop a thirty-three-year record of daily temperature, precipitation, and stream discharge values used by PRMS (table 52.3; figure 52.1). Nine precipitation stations are in the master data set, and all but the Jenkinson Lake site are part of the climate network of the National Oceanic and Atmospheric Administration (NOAA). The Placerville station (#6960) and the Jenkinson Lake station (#6964) were used for the final modeling. The lake station is operated by the El Dorado Irrigation District (EID) and was given a NOAA-style site code of "#6964" for purposes of record keeping. Six temperature stations with maximum and minimum temperatures were used during varying steps in the modeling, but the Placerville station (#6960) was used in the final simulation runs.

Data quality at the NOAA climate stations is generally good, but all the temperature and precipitation stations had periods of varying lengths for which data were missing. Computer programs were written to identify the year, month, and duration of all missing data, and both manual and programmed patches were applied to the records. Nearby stations were used to allow interpolation of missing data for periods of 2–3 days. Month-long periods of missing data were filled by splicing records from neighboring stations after determining bias due to difference in elevation.

Discharge Stations

USGS discharge data for four stations were used during the analysis, but a modified Camp Creek gauge record was used in the final simulations. Water from Camp Creek is diverted to a municipal reservoir approximately 5 km (3 mi) upstream of the discontinued #113315 gauge. Jenkinson Lake (also known as Sly Park Reservoir) was built in 1955–56 in the Sly Park Creek Basin, just to the north of Camp Creek. Sly Park Creek flows into Camp Creek upstream of the #113330 Camp Creek gauge, so runoff from the Sly Park Basin is included with Camp Creek runoff in years with high runoff volumes. In normal or drought years, all the runoff from the Sly Park Basin above Jenkinson Lake and the diverted water from Camp Creek is exported via the Camino Conduit to the cities of Camino and Placerville by the EID. Except during exceptional winter storms or occasional spring runoff conditions, the only water flowing in Sly Park Creek is inflow from tributaries and hillslopes below the dam, and a release from the conduit or the dam of 0.057 cms (2 cfs) to satisfy water rights. The EID manages the reservoir and provided daily data for the Camp Creek diversion canal for the 1956–94 period. It also provided daily spill rates from the lake into Sly Park Creek. Spills are generally zero, but they can exceed 28 cms (1,000 cfs) during large storm events such as occurred in 1982 and 1983. Diversions from Camp Creek can exceed 25 cms (900 cfs), so the Camp Creek gauge record as measured by the USGS is not at all indicative of the natural flows.

To allow calibration of the hydrologic model, a more natural stream-flow record was required. To this end, daily diversion and reservoir spill flows were added or subtracted to the #113330 flow to create an "unimpaired" flow record, which was named #1133301 Camp Creek Unimpaired for record-keeping purposes. The flow correction algorithm is as follows:

1. Camp unimpaired equals observed Camp plus diversion
2. If Camp unimpaired is greater than spill, Camp unimpaired equals Camp unimpaired minus spill
3. If spill is greater than Camp unimpaired, Camp unimpaired equals zero

Diversions typically occurred in late winter and during spring runoff. Diversions are curtailed after June 1.

TABLE 52.3

Climate and stream discharge stations used in modeling Clear and Camp Creeks, El Dorado County, California.

Station	Index #	Basin	Elevation (m)	Data	Latitude	Longitude
Camp Pardee	1428	Mokelumne	201	P*,T,S	38°15'	120°51'
Fiddletown/Baxter	3038	Cosumnes	218	P,S	38°32'	120°42'
Folsom Dam	3113	American	107	P,T	38°42'	121°10'
Jenkinson Lake	6964	Cosumnes	1,058	P	38°43'	120°33'
Pacific House	6597	American	1,049	P,S	38°45'	120°30'
Placerville	6960	American	564	P,T,S	38°43'	120°49'
Placerville IFG	6962	American	840	P,T,S	38°44'	120°44'
Salt Springs PH	7689	Mokelumne	1,128	P*,T,S	38°30'	120°13'
Twin Lakes	9105	American	2,438	P,T	38°42'	120°02'

Station	Index #	Drainage Area (km^2)	Period of Record	Latitude	Longitude
Camp Creek near Camino	113315	83	1949–56	38°42'	120°32'
Camp Creek near Somerset	113330	163	1955–90	38°39'	120°40'
Camp Creek near Somerset, Unimpaired	1133301	163	1955–90	38°39'	120°40'
North Fork Cosumnes River near El Dorado	113335	531	1912–87	38°33'	120°50'
Cosumnes River at Michigan Bar	113350	1,388	1966–90	38°30'	121°03'
Cosumnes River at McConnel	113360	1,875	1941–82	38°22'	121°20'

P* indicates precipitation data, hourly recording summed to daily.
P indicates daily precipitation.
T indicates maximum and minimum temperature.
S indicates new snowfall or snow on ground.

Water-Year Ranking

Because watersheds respond differently to different water-year magnitudes, the thirty-three-year record was analyzed to identify high-, medium-, and low-magnitude water years. The relative magnitude of a water year can be judged by either the precipitation depth or the volume of the runoff. In this analysis, both the precipitation at the Placerville station and the unimpaired runoff at Camp Creek were used. Because the pattern of precipitation and runoff can vary greatly between two years that might have the same annual total, an additional ranking was done that included the mean ranks of monthly values between December and June. A table was prepared that assigned the smallest three years in the list to the low-magnitude year class, the middle three to the medium-magnitude class, and the top three to the high-magnitude class (table 52.4). The magnitude increases among the three in each class from top to bottom.

For the high-magnitude water year, 1983 was consistently the middle value in all four rankings. Water year 1983 was selected as the example of a high-magnitude precipitation and runoff year. Water year 1979 appears in three of the four rankings in the medium-magnitude category and was selected as representative of the medium-magnitude water year.

The 1977 water year appears as the driest year on record in three of the four rankings. The 1976 water year appears in two of the four classes and is the driest ranked by mean monthly precipitation. Because 1977 was the second year of a two-year drought, 1976 was selected as being more representative of drought years in general.

TABLE 52.4

Results of ranking water years from a 33-year record of Placerville Climate Station (#6960) and the Camp Creek Gauging Station (#1133301).

	Magnitude of Water Year		
Basis for Ranking	**Low**	**Medium**	**High**
Yearly Ranking			
By flow	1977	1957	1965
	1961	1972	1983
	1988	1979	1969
By precipitation	1977	1979	1958
	1987	1989	1983
	1976	1957	1982
Monthly Ranking			
By flow	1977	1957	1967
	1961	1979	1983
	1987	1972	1969
By precipitation	1976	1965	1982
	1977	1989	1983
	1985	1970	1958

Hydrologic Model Calibration

Physical process models such as MMS have numerous coefficients to allow adjustment of rates of energy or mass between reservoirs. They also have coefficients to allow extrapolation of the temperature and precipitation data from the climate station to the basin of interest. Calibration is the process of varying the coefficients to make the predicted daily hydrograph match the hydrograph for the unimpaired Camp Creek discharge station. In addition to matching the hydrographs, water input must match the sum of the outflows, must be physically reasonable, and must match hydrologic theory. Because MMS has a long history of use in many basins, each coefficient has a recommended range. In the calibration of the model to Camp Creek and Clear Creek, water balance was the first step. Correct identification of precipitation type was the second step. Adjustment between flow mechanisms to obtain matching peaks and recession curves was the third step.

Water Balance

The water balance in MMS can be examined at any time step, but monthly or yearly steps are the most effective. The MMS extracts sublimation of rain or snow from interception, so the residual, effective precipitation equals the sum of evapotranspiration (ET), surface runoff, subsurface runoff, ground water outflow, and changes in storage. The MMS estimates potential ET based on solar radiation (Jensen and Haise 1963), which is predicted by HRU from slope, aspect, and maximum and minimum temperatures (Leavesley et al. 1983). Actual ET is estimated based on soil water availability, vegetation type, and percentage cover. Monthly values and annual totals were referenced to data from an evaporation pan at Placerville (Farnsworth and Thompson 1982), and when the model's values ranged around those values for a number of years, the coefficients were judged to be correct. The sum of the annual ET and the runoff categories, plus any changes in storage, was less than 1.9% different than the total annual effective precipitation in all runs (table 52.5). Effective precipitation is the amount that is estimated to reach the soil surface, and it accounts for sublimation during interception.

Rain and Snow Discrimination

The MMS classifies precipitation as rain, snow, or a mixture of the two based on the maximum and minimum daily air temperatures for the HRU. Temperatures are predicted for each HRU from the temperature station based on the relative elevation of each and a specified lapse rate. Threshold temperature values are also declared above which all precipitation is rain and below which all precipitation is snowfall. A ten-year subset, water years 1973–83, was partitioned out of the thirty-three-year data set to speed the processing and simplify the calibration. Simulations of daily discharge were made for the ten-year period while adjusting temperature coefficients, lapse rate coefficients, and control values. Adjustments in model coefficients controlling discrimination between rain and snow were made so that the runoff following large storm events matched the observed runoff record.

Flow Component Adjustment

The MMS model sums surface runoff, subsurface outflow, and ground water outflow to create stream flow. In keeping with hydrologic theory, each reservoir releases water at a different rate and therefore stores precipitation for a different duration. Ground water storage is released the most slowly and comprises summer base flow, so adequate water must be moved into the ground water reservoir and released at a rate so that the post-snowmelt recession curve matches the observed recession curve. Surface runoff is thought to be rare in forest lands other than from near-channel saturated areas or from compacted surfaces (Dunne and Leopold 1978), but surface runoff occurs quickly and contributes to storm peaks. Subsurface runoff contributes to saturated areas and contributes water to the channel more slowly than surface runoff but faster than base flow. By adjusting the coefficients that control allocation of precipitation into these reservoirs and adjusting the coefficients that control release, the predicted hydrograph was matched to the observed hydrograph. This process was subjective, and several calibration strategies were tested. For Camp Creek, a runoff regime that allocated much of the precipitation into the subsurface reservoir appeared to best fit the observed hydrograph.

Clear Creek had no observed hydrograph with which to compare the predicted runoff, so the Camp Creek coefficients were initially applied except for the land-use parameters associated with land condition. Surface runoff was very large based on the Camp Creek coefficients, so the coefficients were adjusted to reduce the overwhelming surface flow component. In a basin with loam soils and reasonable amounts of vegetation, very large amounts of surface flow contradict hydrologic theory and experience (Dunne and Leopold 1978). Surface flow in Clear Creek remained, however, a larger component of total flow than in Camp Creek (table 52.5).

Other than mass balance, goodness-of-fit measures (e.g., root mean squared error) were not used during the calibration. The major reason was the poor quality of the observed discharge record. The large variability, especially during the recession phase of the annual hydrograph, produced spurious results when an attempt was made to optimize the model using root mean squared error as the objective function.

Interpretation of the results of a simulation model assumes that the important hydrologic processes and linkages are represented in the model. Because of the extensive development and wide use of MMS, we assume that the outputs are repeatable, conserve mass, and vary according to climate and basin inputs. Limitations include the inability to affix error bands to the predictions. We acknowledge that calibration is a subjective process, and different combinations of rate coefficients might appear as reasonable as the ones selected, yet weight the major processes differently.

Simulation Design

The precipitation record for the years 1983, 1979, and 1976 became the input data to the MMS in the evaluation of the effects on runoff generation of changes in land use over time. Soil-moisture accounting models such as MMS begin with a default set of values in the various reservoirs. For a representative simulation of any given year, the simulation should begin at least one year prior to the year of analysis so that the reservoir values are set properly. To set the reservoir value, two years of climate data were modeled prior to each of the three water years (1983, 1979, and 1976) that were analyzed. Each set of HRU attributes linked to the six photo dates was analyzed by the model with each of the three water years, so eighteen simulations were done for each of the two basins. Simulation output files included monthly and annual water balance results, plot files of predicted versus observed hydrographs, and plot files of the flow components.

TABLE 52.5

Annual water balance from simulation runs of the three water years with the 1976 land condition coefficients (cm).

Water-Year Magnitude	Ground Water Outflow	Subsurface Runoff	Surface Runoff	Evapo-transpiration	Sum of Fluxes	Effective Precipitation
Camp Creek						
Low	6.6	2.3	0.7	42.3	51.9	52.6
Medium	32.4	17.5	1.0	39.9	90.8	90.1
High	76.7	59.2	3.5	59.5	198.9	195.2
Clear Creek						
Low	4.9	2.1	2.0	34.1	43.1	44.3
Medium	18.2	16.1	3.8	40.4	78.5	77.1
High	49.0	63.3	13.3	54.4	180.0	177.1

RESULTS

Land Condition Changes

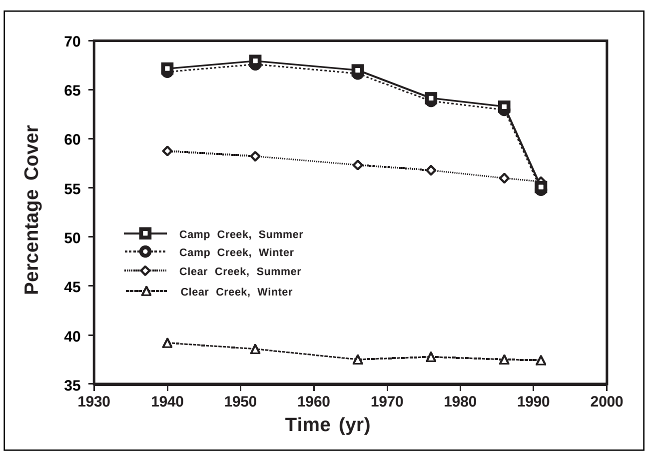
The partitioning of the basins into polygons allowed historical land-use change to be allocated by date to a particular HRU. Through acquired GIS layers and analysis of six series of aerial photographs, sets of land-use data were compiled for each of the following years: 1940, 1952, 1966, 1976, 1986, and 1991. Summaries of disturbance area were compiled for the Camp and Clear Creek Basins (appendicxes 52.1 and 52.2). These tables list the disturbances by category for each of the 118 HRUs. The disturbance is summed within each photo interval to allow comparison of the totals.

A decrease in percentage cover over time was observed in both basins (figure 52.7). Percentage cover was found to decrease in Clear Creek from 59% to 57% during the fifty-year study interval. Percentage cover in Camp Creek decreased from 68% to 55% between 1952 and 1991.

Impervious area associated with road building increased in both basins throughout the fifty-year period, but it slowed markedly in the last five-year interval (figure 52.8). Impervious area associated with residential development increased in Clear Creek from about 0.3% to 3.6% during the study interval. The increase was especially rapid between 1966 and 1986. Disturbed area in Camp Creek increased from near 0% to 7.4% during the study interval, and the large increases were associated with clear-cuts after 1976. The hectares of disturbed land in figure 52.8 are cumulative, and roads and houses are assumed to be impervious surfaces. Clear-cuts are termed disturbed areas and are treated differently from roads or houses, as described later.

FIGURE 52.7

Changes in mean percentage cover across all HRUs over time and for summer and winter in Clear and Camp Creek Basins, El Dorado County.



Clear Creek

The disturbance in the Clear Creek Basin is due entirely to roads, structures, and fire. Residential development in Clear Creek caused a 44 ha (109 acre) increase in road area and a 58 ha (143 acre) increase in area covered by structures and appurtenant impervious areas. Fire occurred in 1972 and affected 85 ha (210 acres) of Clear Creek. Road surface doubled between 1940 and 1952, and again between 1966 and 1976 (figure 52.8). The road network grew again between 1976 and 1986 but grew only a little between 1986 and 1991. This pattern of growth was associated with the platting of the subdivisions. Structures have had a more constant growth pattern as individual parcels within the subdivisions have been purchased and developed (figure 52.8). Structures have at least doubled in every photo interval except the most recent five-year interval. The slope of the housing curve is unchanged and very steep since 1976.

Camp Creek

The disturbance in the Camp Creek Basin is due to a combination of clear-cutting, roads, and fire. Forest management caused a decrease in percentage cover, an increase in road area from 11 to 107 ha (27 to 264 acres), and over 570 ha (1,412 acres) of clear-cuts. Fire occurred in 1969, 1973, and 1988 and affected 265 ha (655 acres) of Camp Creek. Roads show a steady increase in all intervals except 1991, supporting the supposition that the basin is fully roaded for logging activities (figure 52.8). Large increases in roads occurred in the intervals ending in 1976 and 1986. Clear-cuts were rare in the first three photo intervals but increased dramatically in the last three. The clear-cut area increased seven-fold in the 1976–86 interval and doubled during the 1986–91 interval. The 1991 clear-cutting occurred in addition to the salvage logging that covered 80% of the basin.

Although appendix 52.1 shows over 946 out of 8,426 ha (2,337 out of 20,821 acres) as disturbed by 1991, it is important to remember that this table does not recognize the recovery of forest vegetation. Although nearly 60% of the disturbance is due to clear-cutting, at least half that area was cut at least five years earlier. Nevertheless, it is evident that the rate of disturbance associated with forest management accelerated dramatically over the last three decades. The type of disturbance has changed, however, in that little new road construction appears to have been required during the most recent logging activities.

Hydrologic Simulation Results

Results from model simulations are grouped into monthly runoff trends over time and by water year, annual runoff trends over time and by water year, daily runoff values for the high- and medium-magnitude water years, annual flow component hydrographs for the medium-magnitude year, and

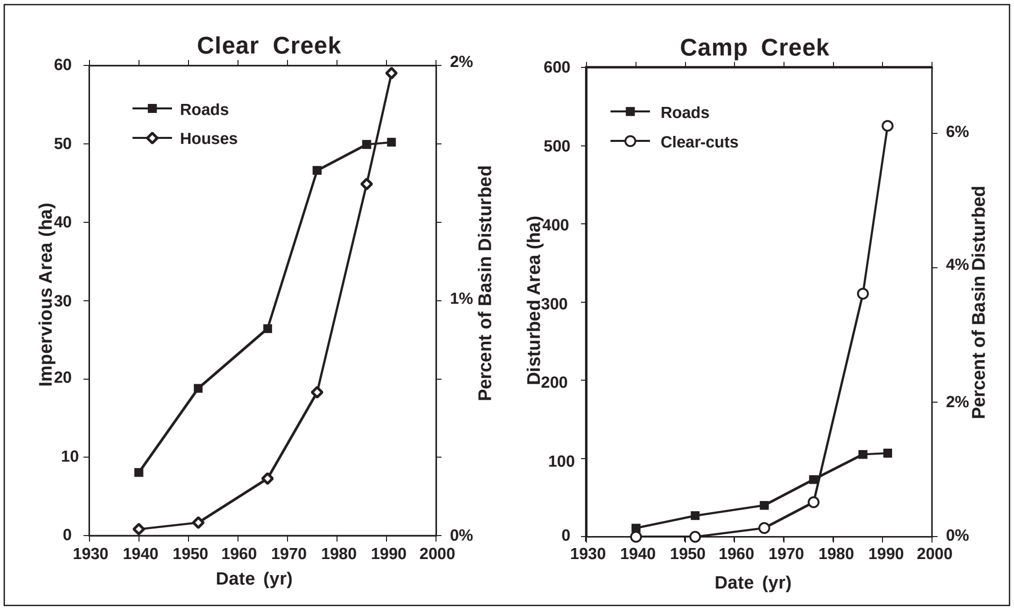


FIGURE 52.8

Trends in disturbed or impervious areas associated with roads, houses, and clear-cuts in Clear and Camp Creeks.

flow components over time and by water year. In subsequent sections, identification of trends is based on visual, not statistical, analysis of the plots. Statistical tests of the changes in predicted values over time are not possible, because no measures of variance can be calculated on each predicted value. In this report, runoff is discussed in terms of areal runoff depths rather than volume or flow rates. Runoff depths are analogous to precipitation depth across the basin and have the advantage of correcting runoff volume for size of the basin. This correction allows easy comparison between basins of different size.

Monthly Trends

Three water years (1983, high-; 1979, medium-; and 1976, low-magnitude) were analyzed to determine if hydrologic response changed based on water-year magnitude and over time because of land condition (figures 52.9 and 52.10). Monthly runoff depths for Clear Creek show minor increases after the 1966 photo period, concurrent with the increases in roads and in fire-affected area. The plot for the low-magnitude water year is not presented because the change in runoff depths over time is negligible. February, March, and April are the months with a slight change over time for the low-magnitude water year. For the medium-magnitude year, the increase over time is most notable in the major runoff months: January, February, and March (figure 52.10).

April and May runoff trends upward in the 1986 and 1991 years for both the high- and medium-magnitude water years in Camp Creek, associated with snowmelt (figures 52.8 and 52.9). For the low-magnitude water year in Camp Creek, the upward trend in runoff depth shifts to February and March, reflecting earlier melt of the snowpack. April runoff for the high- and medium-magnitude years shows the largest trend related to changes in land condition (figure 52.10). Although there is some variability, a predicted change in monthly runoff between 1940 and 1991 of over 2 cm (0.8 in) is notable.

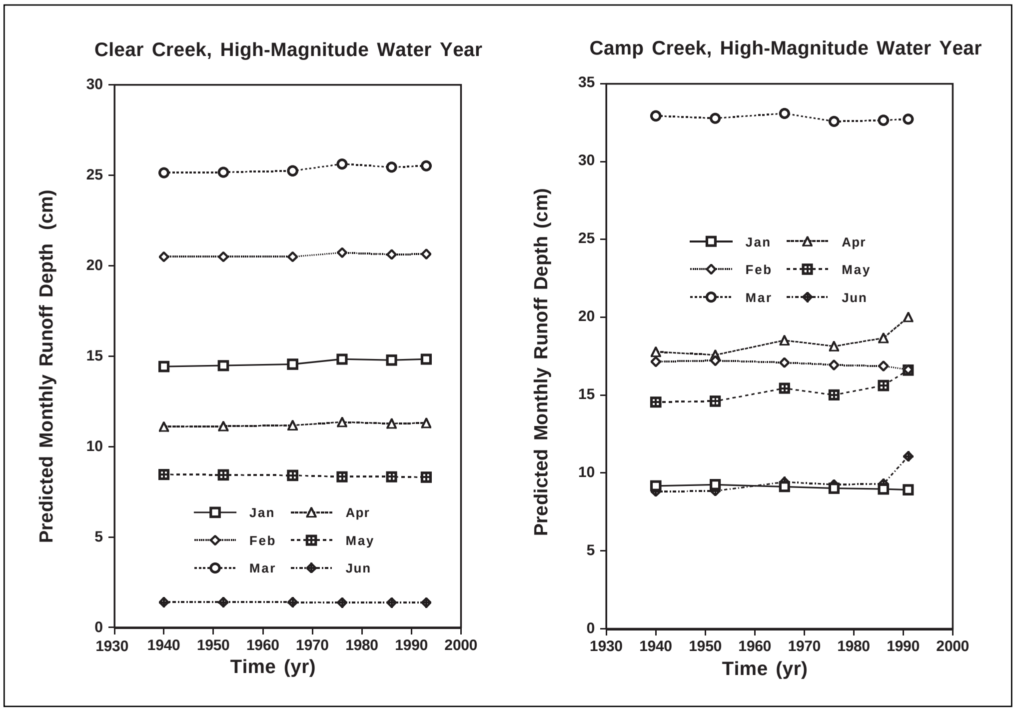
Annual Trends

Because daily values have wide variation and obscure trends, the annual hydrographs are plotted using mean monthly values rather than daily means (figures 52.11 and 52.12). The high-magnitude water year (October 1, 1982, through September 30, 1983) had in excess of 240 mm (9.5 in) of precipitation each month from November through March. March alone produced 380 mm (15.1 in) of precipitation, and the April precipitation was 180 mm (7.1 in). As a result, both Camp and Clear Creeks had large predicted monthly runoff depths of 32.9 cm (13.0 in) and 26.6 cm (10.5 in), respectively. Camp Creek has a larger monthly runoff depth because it is at a higher mean elevation than Clear Creek and therefore receives more precipitation. Camp Creek has a single runoff peak in March, while the largest of Clear Creek's two peaks was in December 1982. Because Camp Creek accumulates significant snow during cold storms, some storms may fail to produce runoff peaks. Clear Creek, however, only occasionally receives minor amounts of snow, and storm runoff is more immediate and larger in proportion to the basin size than Camp Creek's.

For the high-magnitude water year, no runoff change associated with land condition was found on Clear Creek (figure 52.11). The traces for the six photo intervals are almost identical. For Camp Creek, however, there is an apparent difference in the runoff regime during the last six months of the water year. The 1991 trace is elevated above the other years' traces in April, May, and June, coincides with the other traces in July, and then moves below the other traces in August and September. This pattern suggests that changes in land use extend the snowmelt runoff period and decrease late-summer base flow.

FIGURE 52.9

Predicted monthly runoff trends over time associated with changes in land condition for the high-magnitude water year in Clear and Camp Creek Basins.



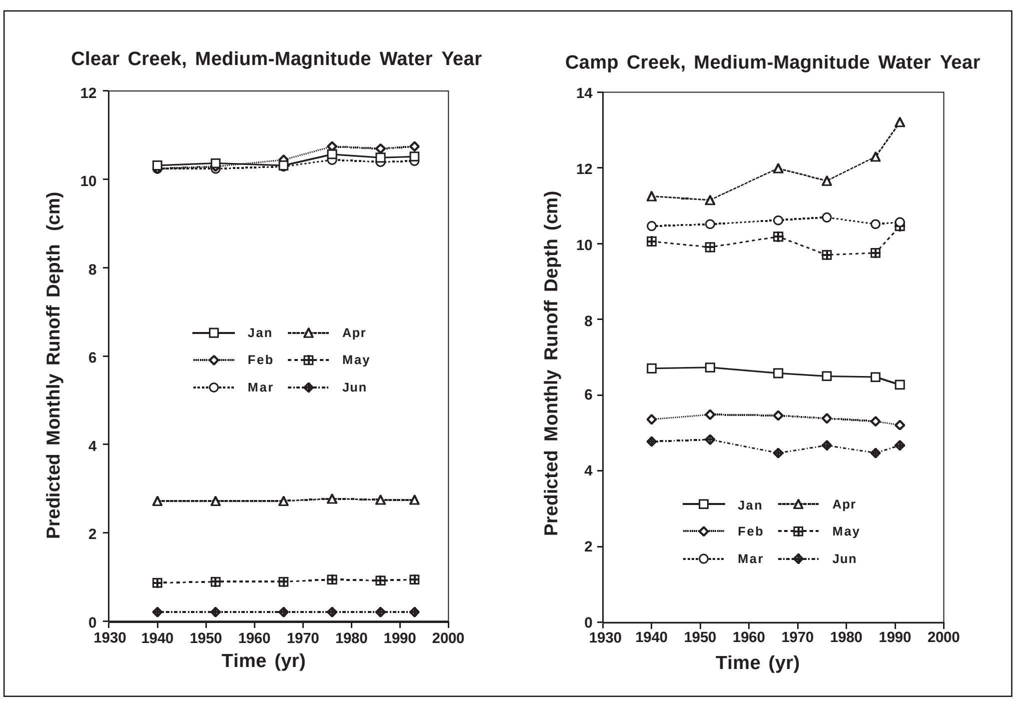
For the medium-magnitude water year on Clear Creek, an increase in February peak flows from 1940 to 1991 is visible, but the volume is minor (figure 52.12). The April peak on Camp Creek shows a larger increased runoff for 1966 and later years. There is also a slight decrease in summer base flow visible in July for the land condition associated with 1991. The difference in runoff timing between the low- and high-elevation basins is also apparent in figure 52.12. For the low-magnitude water year on Clear Creek, changes over time are negligible, so no figure is presented.

Daily Runoff

Predicted and observed daily discharges for Camp Creek for the high-magnitude water year illustrate the rapid increase

FIGURE 52.10

Predicted monthly runoff trends over time associated with changes in land condition for the medium-magnitude water year in Clear and Camp Creek Basins.



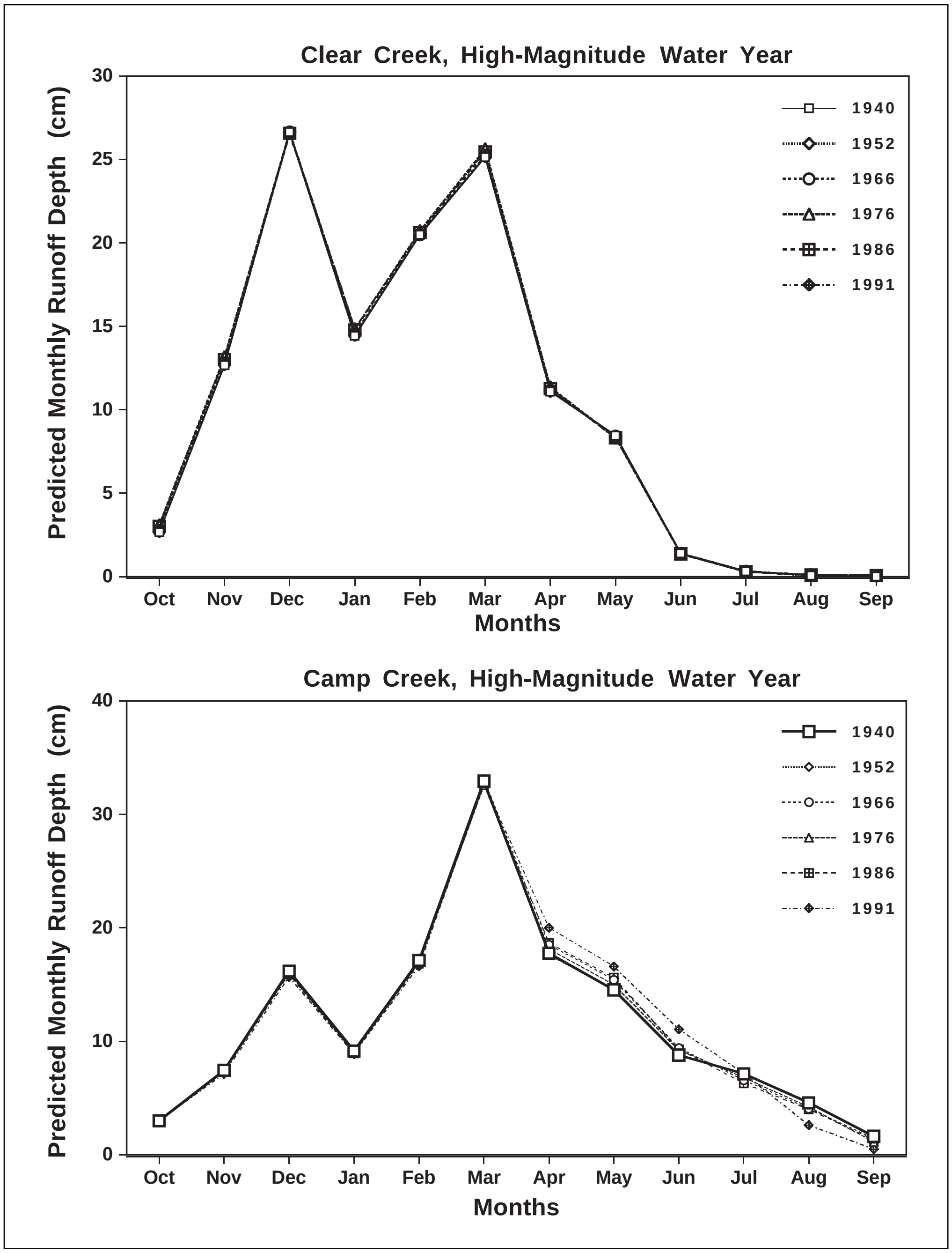


FIGURE 52.11

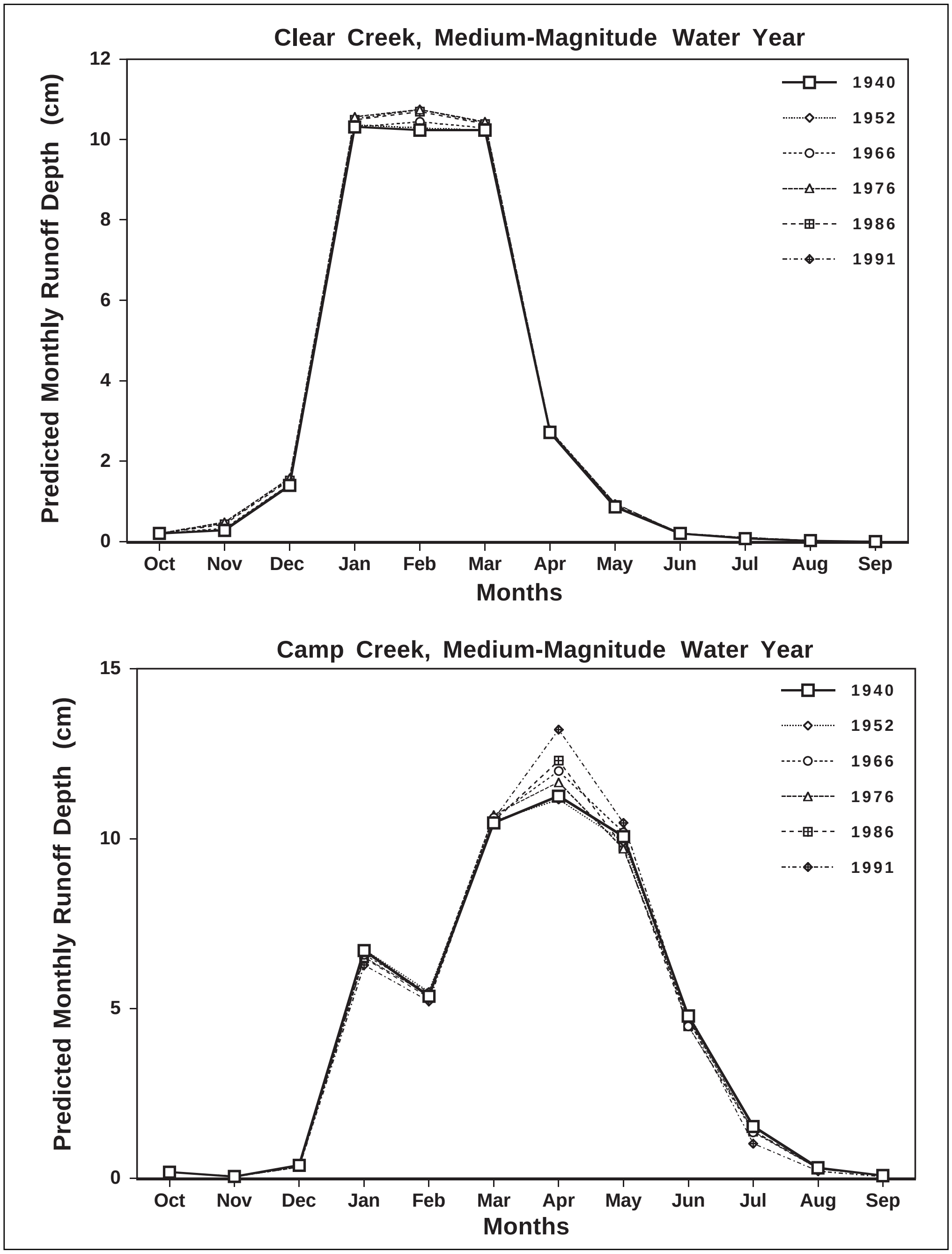
Predicted annual runoff patterns associated with six land condition descriptions between 1940 and 1991 for the high-magnitude water year in Clear and Camp Creek Basins.

in flow in the Camp Creek Basin and the moderate snowmelt runoff (figure 52.13). The Clear Creek hydrograph has a predicted trace and no observed trace because there is no stream gauge. Clear Creek simulations used only the Placerville precipitation station. The Camp Creek simulations used the Placerville precipitation station for the low-elevation HRUs and the Jenkinson Lake station for the high-elevation stations. Because of snow, the large peak flow near December 1 on the Clear Creek plot is much smaller on the Camp Creek plot.

The dashed line in the Camp Creek plot is the unimpaired outflow estimated from the USGS gauging station, Camp Creek near Somerset. In spite of efforts to compensate for the effects of the diversion from Camp Creek into Jenkinson Lake and the spill from the lake in times of high flow, the observed flow is not an accurate representation of flow from an unmodified basin. The EID record includes very large daily fluctuations in diversion flows, especially in April and May. There is no reason for EID to alternately open and close a very large discharge structure during a time when they are attempting to fill their reservoir, so the variations are believed to be er-

FIGURE 52.12

Predicted annual runoff patterns associated with six land condition descriptions between 1940 and 1991 for the medium-magnitude water year in Clear and Camp Creek Basins.



rors. These variations are reflected in the swings of the trace between near-zero flow and the estimated snowmelt discharge.

The predicted flow shown in figure 52.13 excludes flow generated from four HRUs between the discontinued upper Camp Creek gauge (#113315, drainage area of 83 km^2 [32 mi^2]) and the present Camp Creek gauge (#113330, drainage area of 163 km^2 [63 mi^2]). The drainage area shown for the present gauge includes the above-dam Sly Park Basin, an area that was not modeled in this analysis. In all but the most extreme years, water from that basin is trapped in Jenkinson Lake and exported to Placerville. The flow reconstruction technique that was used also excluded Sly Park Basin's runoff, in that spills were subtracted from the USGS record. The four excluded HRUs below Jenkinson Lake total 3,366 ha (8,316 acres), and the addition of their predicted contribution to runoff increased the predicted flows so that the observed and predicted flow peaks match better than shown in figure 52.13.

The medium-magnitude water year has predicted runoff peaks of between a quarter and a third of the high-magnitude water year (figure 52.14). The unimpaired runoff trace further illustrates the difficulty in reconstructing the Camp

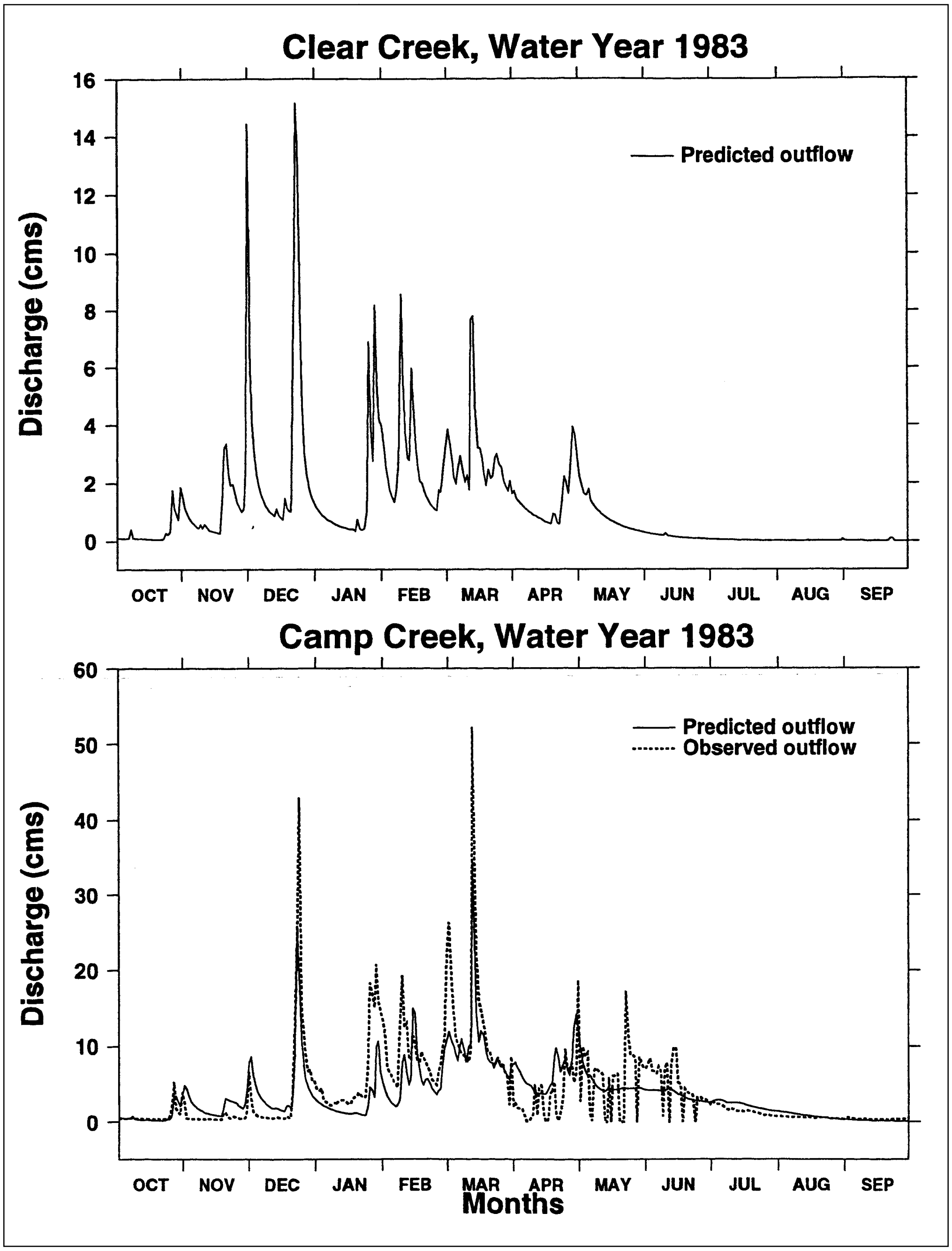


FIGURE 52.13

Predicted daily discharges for the high-magnitude water year for Clear and Camp Creek Basins, and observed discharges for Camp Creek Basin.

Creek record. The reconstruction of the record leads to slightly lower peaks in some years and higher average rates of flow in May and June. However, the unimpaired record is also quite variable in May and June because of large daily changes in the Camp Creek diversion rate and the slow decline in lake level when spill occurs. Current operating rules for Jenkinson Lake change on June 1, and the change from approximately 3.7 cms (130 cfs) to a near-zero flow is a product of the poor record from EID and the reconstruction algorithm, not natural processes. As with the high-magnitude water year, the peaks for both basins match in timing, and the results of snowpack accumulation and ablation (melting and evaporation) are evident in the Camp Creek plot.

Daily Flow Components

Total predicted runoff from the PRMS is composed of ground water outflow, subsurface outflow, and surface runoff, so the total flows for the medium-magnitude water year for Camp and Clear Creeks can be separated into their components (figure 52.15). The ground water outflow is proportional to the amount of water stored in the ground water reservoir, but the release rate is small compared to potential input. For the

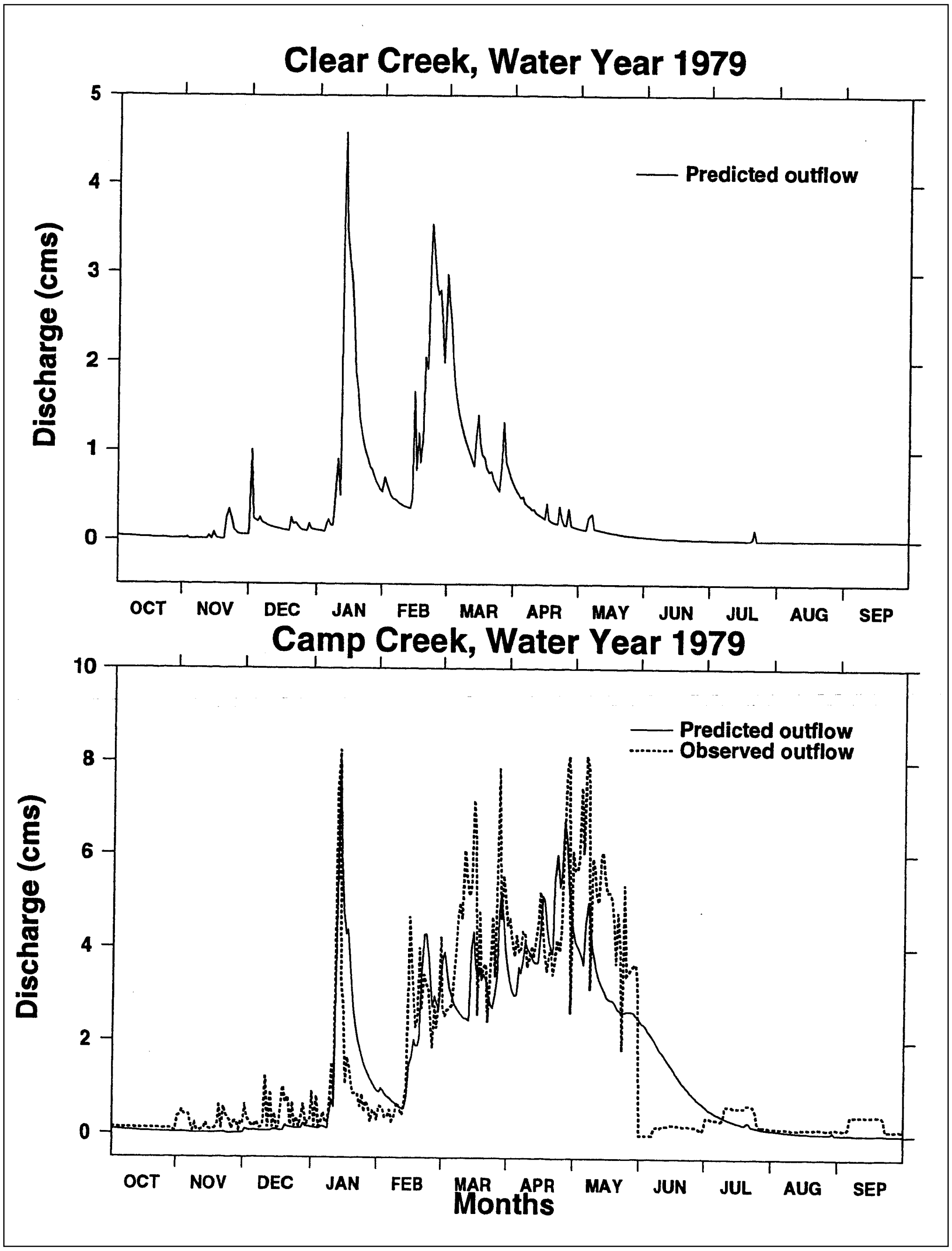


FIGURE 52.14

Predicted daily discharges for the medium-magnitude water year for Clear and Camp Creek Basins, and observed discharges for Camp Creek Basin.

medium-magnitude water year on Camp Creek, ground water accounts for 64% of the total outflow (excluding ET) (table 52.5). For the medium-magnitude water year on Clear Creek, ground water accounts for 48% of the total outflow. Subsurface runoff percentages are 34% and 42% for Camp and Clear Creeks, respectively. Surface flow percentages are 2% and 10% for Camp and Clear Creeks, respectively. This pattern is shown in figure 52.15, and the surface runoff component is especially noticeable for Clear Creek. The large ground water component for Camp Creek is created by melting snow and provides stream flow through the summer.

The Clear Creek ground water outflow reaches zero by early July for the medium-magnitude year, and this pattern matches observations of streams at this elevation. Clear Creek flow does not actually cease, as the model predicts, but only because the EID releases 0.06 cms (2 cfs) from the Camino Conduit during the summer months. The model predicts that Camp Creek would be dry at the gauge site by the end of August during low- and medium-magnitude water years, and USGS records support this prediction. Base flow upstream of the upper gauge (#113315) has been observed in August of several years, but flows are quite small.

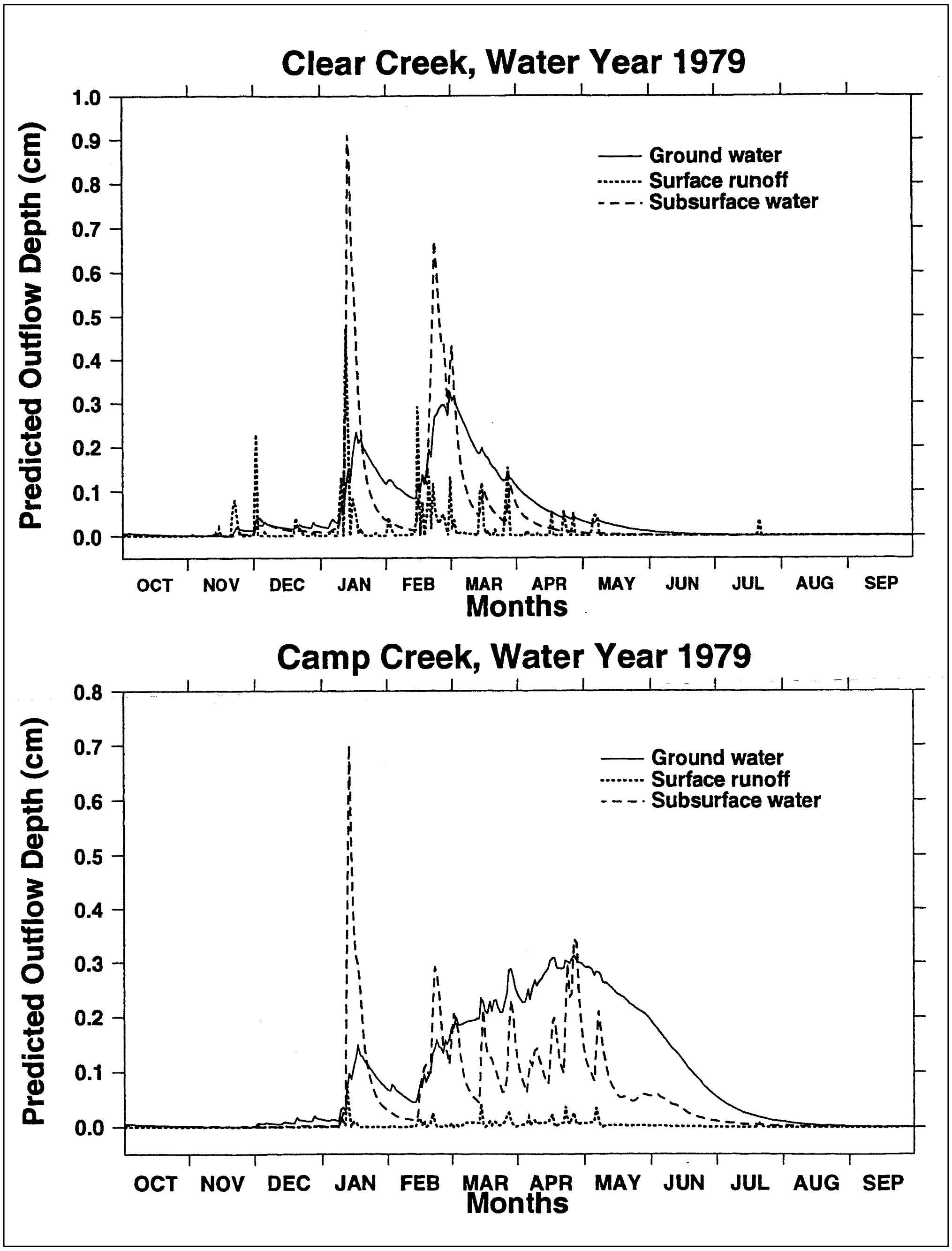


FIGURE 52.15

Predicted ground water, subsurface, and surface flows for the medium-magnitude water year for Clear and Camp Creek Basins.

Annual Flow Components

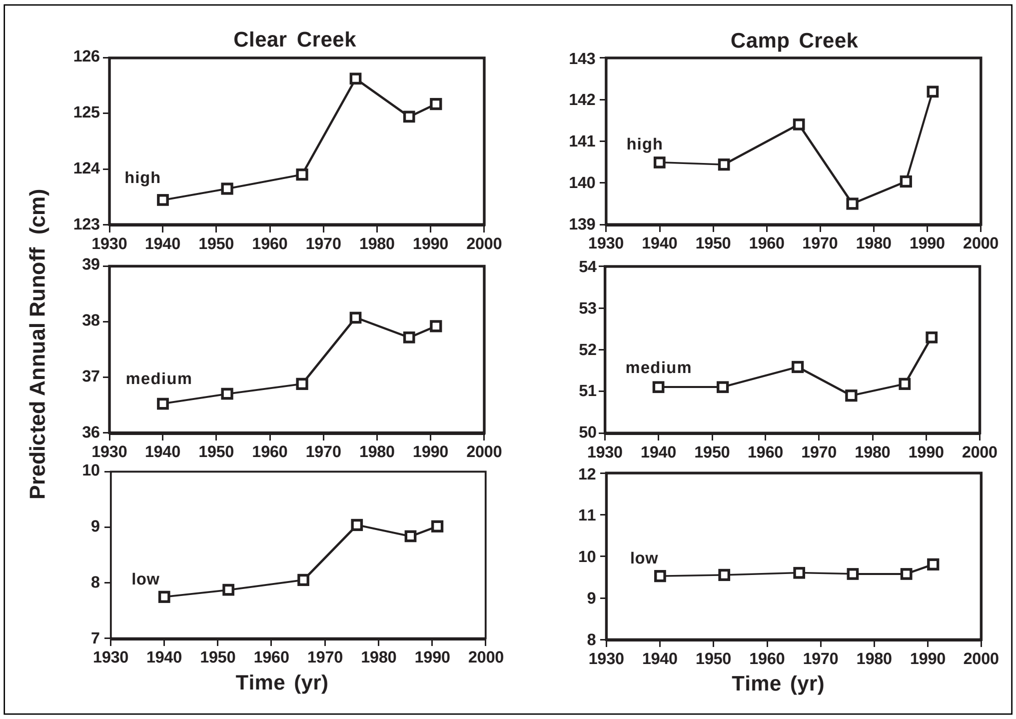
Trends in flow components can be analyzed over time to assess the effect of changes in land condition. Annual runoff depth for the three water years in both basins suggests the difference between them may be due to forest management and suburbanization (figure 52.16). Total flow increases consistently in Clear Creek over time, and the magnitude is greater with increasing precipitation magnitude. The large increase in 1976 may be attributed to a fire that burned 85 ha (210 acres) in 1972, a doubling of the road network, and a more than doubling of the area covered by structures.

The overall changes in Camp Creek are much less consistent. Runoff increases between 1976 and 1991 for the high- and medium-magnitude water years. In that total runoff is the sum of the other flow components, there may be compensatory changes in the components without overall changes.

Evapotranspiration. Except for the low-magnitude water year in Camp Creek, decreases in percentage cover caused decreases in ET over time (figure 52.17). The Clear Creek traces show a major effect of the 1972 fire mentioned above, but the overall trend of ET is down. Even when wetter years make

FIGURE 52.16

Predicted annual runoff for Clear and Camp Creek Basins, showing changes over time associated with changing land condition and water-year magnitude.

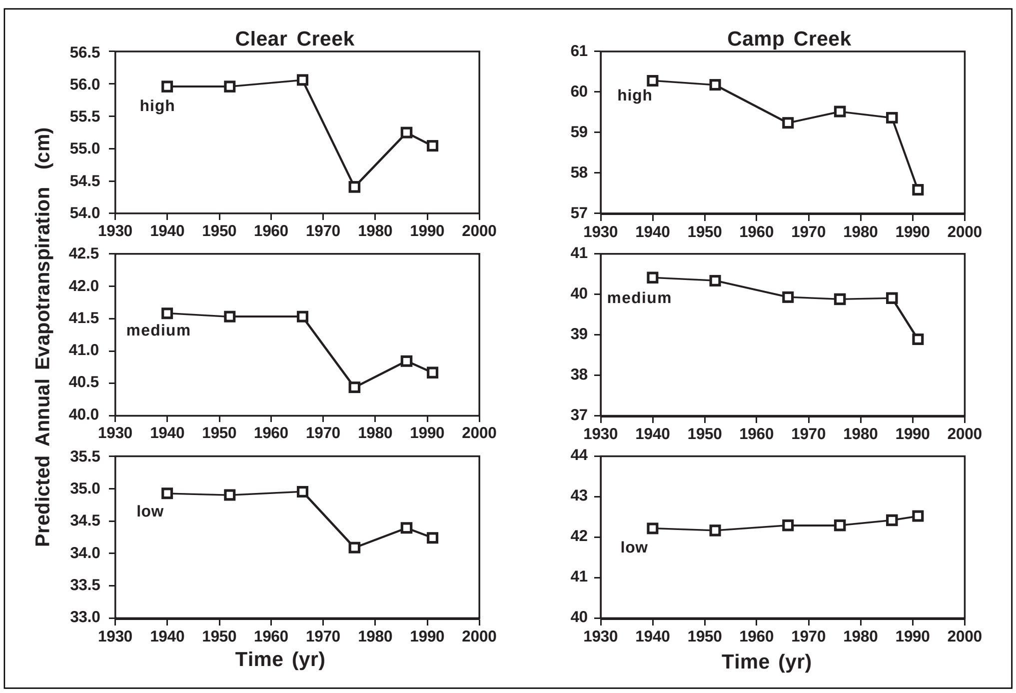


more moisture available, ET declines are larger. The decline over time in Camp Creek for the medium- and high-magnitude water years is consistently downward, and there is a large drop between 1986 and 1991. This change may be due to reductions in percentage cover associated with the aggressive insect salvage logging operations during that interval. During the low-magnitude water year, the vegetation in Camp Creek would be under moisture stress for much of the summer.

Annual Surface Runoff and Snowmelt. The surface runoff trend for Clear Creek is consistently upward for all three water years (figure 52.18). An especially large increase between 1966 and 1976 may be related to the large increase in the area ren-

FIGURE 52.17

Predicted annual evapotranspiration for Clear and Camp Creek Basins, showing changes over time associated with changing land condition and water-year magnitude.



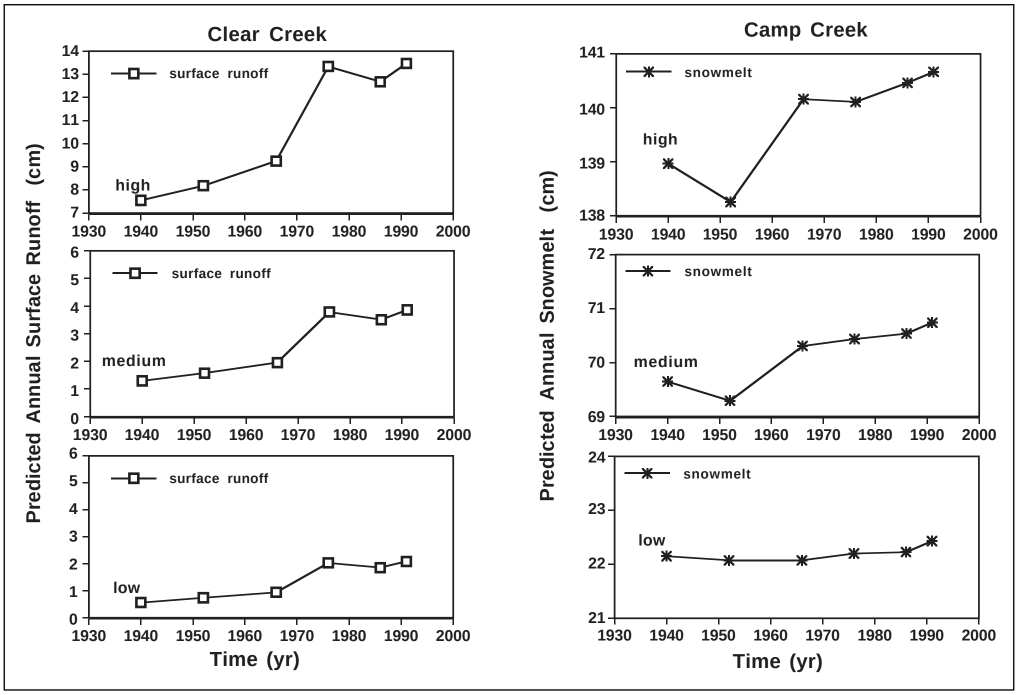


FIGURE 52.18

Predicted annual surface runoff for Clear Creek Basin and snowmelt for Camp Creek Basin, showing changes over time associated with changing land condition and water-year magnitude.

dered impervious by roads and structures. A slight decline occurs between 1976 and 1986 in spite of continued increases in the area covered by structures.

There was no change in surface runoff in Camp Creek between 1940 and 1991, but there was an interesting change in snowmelt depth (figure 52.18). After an initial decline between 1940 and 1952, snowmelt increased fairly consistently over time. Decreased percentage cover is generally thought to reduce interception losses and thereby increase the snowpack (McGurk and Berg 1987), and the PRMS annual interception estimates do decline slightly over time.

Annual Subsurface Outflow. Subsurface outflow decreases slightly over time for all water years for Clear Creek, but the

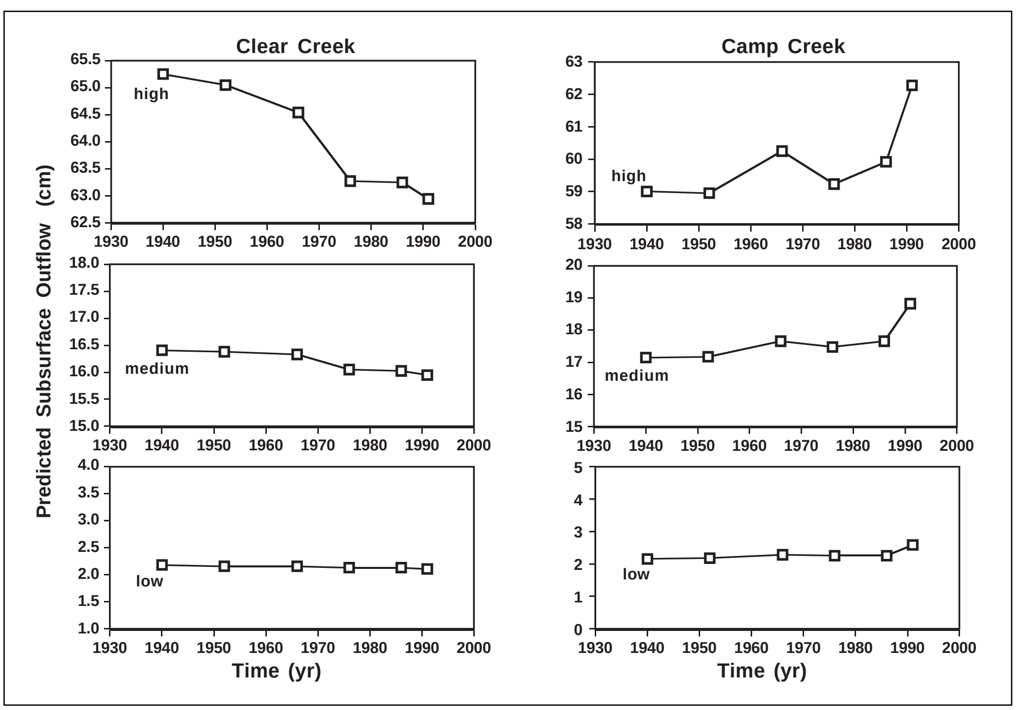


FIGURE 52.19

Predicted subsurface outflow for Clear and Camp Creek Basins, showing changes over time associated with changing land condition and water-year magnitude.

magnitude is largest for the high-magnitude water year (figure 52.19). This decline in subsurface flow is in opposition to the increase in surface runoff (figure 52.18), and in both cases the decreases are associated with the increase in impervious surface over time in the basin (figure 52.8). The increase in surface runoff, however, is about twice the decrease in subsurface flow for the high-magnitude water year.

The pattern of subsurface flows in Camp Creek (figure 52.19) closely resembles the annual runoff pattern for Camp Creek (figure 52.16). This is not surprising, in that the subsurface flow component makes up 34% of the annual total flow (table 52.5). Subsurface flow increases over time, and the magnitude is greater in wetter years. The change over time is negligible in the low-magnitude water year.

Ground Water Outflow. Both Camp and Clear Creeks have a consistent downward trend of ground water outflow over time as land condition changes (figure 52.20). This trend is certainly associated with the increase in impervious area (figure 52.8) and surface runoff (figure 52.18). The decreased ground water outflow has negative implications for summer base flow levels in the two basins. As stream flow decreases, aquatic fauna could be adversely affected by warmer water and lower concentrations of dissolved oxygen. To the extent that vegetation is using ground water, moisture stress might occur earlier in the year and become severe more often if ground water levels have declined and continued to do so. However, some experimental results outside the Sierra Nevada demonstrate an increase in base flow with decreased cover because of reduced ET and greater residual moisture storage (Kattelmann et al. 1983). Other authors have demonstrated decreased base flow with decreased cover (Harr 1980), so basin response is variable and depends on local characteristics.

Runoff Timing

The timing and magnitude of predicted daily flow were analyzed by setting the runoff hydrograph in 1940 as the base year for each basin. The daily values for the hydrograph produced with the 1940 land conditions and the medium- and high-magnitude water years were subtracted from the daily hydrographs for the 1952, 1966, 1976, 1987, and 1991 land conditions. For Clear Creek, the subtraction yielded values that were generally positive and increased over time, confirming the above observation that runoff depths increased over time (figure 52.16). For Camp Creek, the subtraction also yielded values that were positive in 1966 and 1991, also confirming the results in figure 52.16.

For Clear Creek, the runoff peaks shifted forward in time as well as being larger in later years (figure 52.21). The spikes that trend positive and then negative indicate that early storm runoff for the 1976 land condition may be a day earlier as well as larger than the runoff predicted for the 1940 land condition. The shifts were evident for the 1976 and later storm responses for the high- and medium-magnitude years for Clear Creek. The pattern was more pronounced for the high-magnitude water year than for the medium-magnitude water year (figure 52.21) and was negligible in the low-magnitude year. In the results from Camp Creek, this characteristic sawtooth pattern was not observed. Camp Creek's snowmelt pattern was evident, however, and the analysis again demonstrated the increased snowmelt and decreased base flow illustrated in figure 52.11.

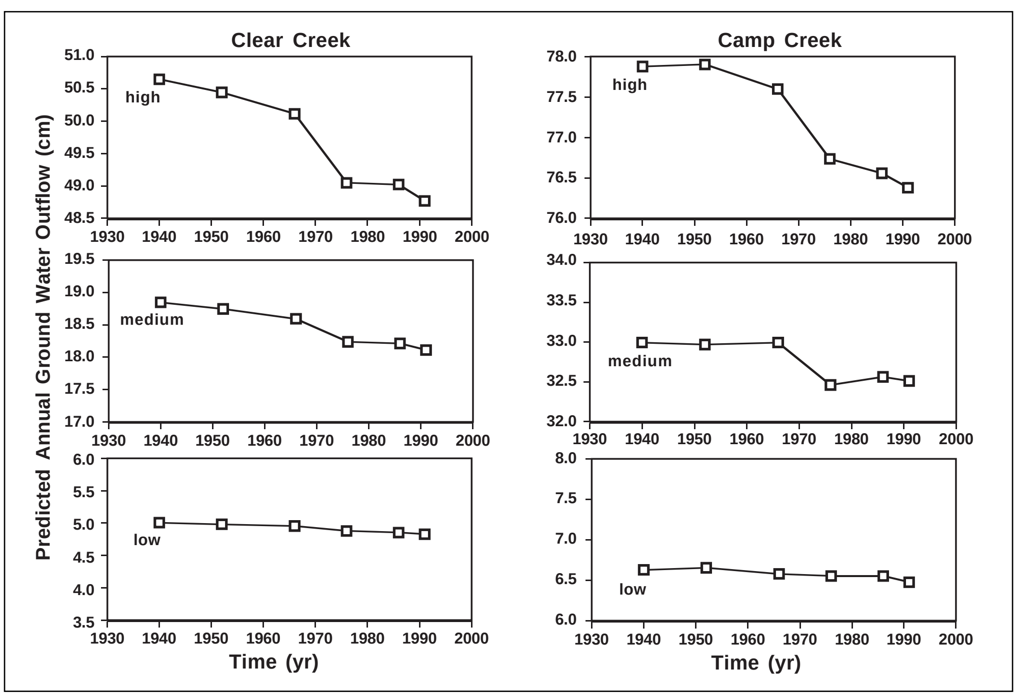


FIGURE 52.20

Predicted ground water outflow for Clear and Camp Creek Basins, showing changes over time associated with changing land condition and water-year magnitude.

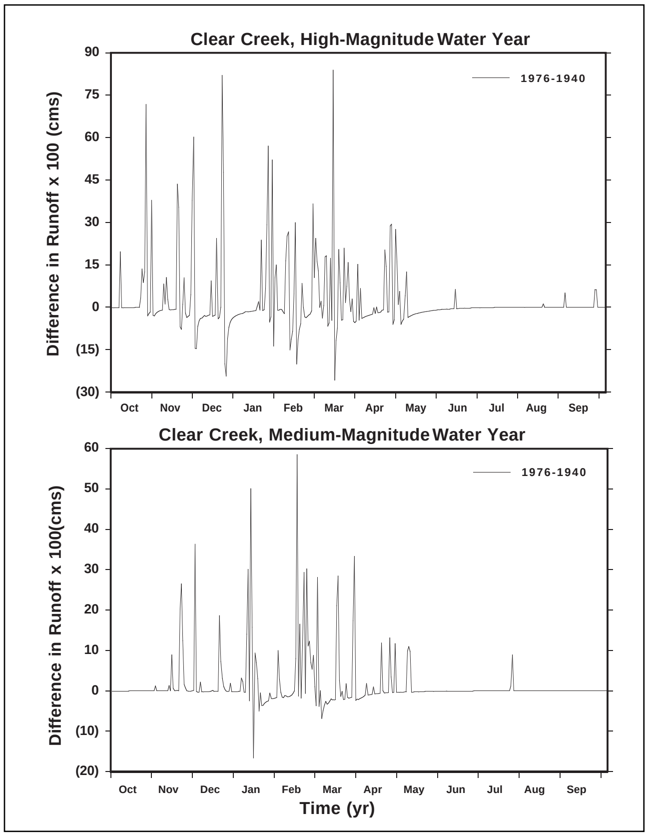


FIGURE 52.21

Sawtooth pattern indicating that changing land condition has caused earlier and greater runoff in 1976 than in 1940 for Clear Creek Basin.

DISCUSSION

Water-Year Trends

High-, medium-, and low-magnitude water years were included in this analysis so that the effect of the water year could be examined via modeling. In general, many changes were evident with the high- and medium-magnitude water years, and changes were negligible at the low-magnitude water year. Changes in monthly runoff trends (figures 52.9 and 52.10) were evident in both the medium- and high-magnitude water years, but the medium-magnitude curves revealed a major increase in April snowmelt runoff over time for Camp Creek. On Clear Creek, the medium-magnitude water year revealed runoff increases over time in January, February, and March (figure 52.10), illustrating the winter rainfall response of a low-elevation basin. For the annual runoff patterns (figures 52.11 and 52.12), the analysis of water years revealed the increased spring runoff and decreased summer base flow only in the high-magnitude water year for Camp Creek.

The analysis of flow components for the three water years also revealed trends linked to water-year magnitude. Clear Creek's increased flow over time was larger with larger-magnitude water years, but evident even in a drought year such as 1976 (figure 52.16). Camp Creek, however, shows virtually no change in runoff over time for the low-magnitude water year. Both basins showed declines in ET over time, except Camp Creek in the low-magnitude water year (figure 52.17). Clear Creek's surface runoff response to changing land condition was scaled to the magnitude of the water year (figure 52.18), but on Camp Creek surface runoff increased noticeably only for the high-magnitude water year (table 52.5). Camp Creek's snowmelt increased over time for the medium- and high-magnitude water years, but the increase was negligible in the low-magnitude water year (figure 52.18). Both basins showed larger changes in subsurface flow for the high-magnitude water year, but the change was slight for Clear Creek in the medium- and low-magnitude water years. Both basins showed similar trends in decreasing ground water outflow associated with changing land condition, and the trends are proportional to water-year magnitude (figure 52.20).

Land Condition Trends

Suburbanization and logging have been shown to cause changes in the hydrology of basins (Dunne and Leopold 1978). The changes are usually attributed to increases in impervious surface because of compaction and reduction in ET associated with removal of vegetation. By holding constant the PRMS coefficients other than percentage cover and impervious area and using the same three water years, this study isolated the effect of changes in percentage cover and impervious area associated with land-use change. The percentage cover declined over time for Clear Creek and declined after 1952 for Camp Creek (figure 52.7), and impervious or disturbed area increased over time (figure 52.8). For Camp Creek between 1940 and 1952, the increase in road area was small, no clear-cuts occurred, and percentage cover increased slightly. Because of this, there was generally little difference in the values of the flow components in figures 52.16–52.20 for the 1940 and 1952 photo periods. Road building, logging, and fire in Camp Creek caused increases in disturbed area and decreases in percentage cover after 1952, and there were concurrent changes in the predicted flow components. There is a large relative increase in runoff in 1991 (figure 52.16), concurrent with the largest decrease in percentage cover during the analysis period (figure 52.7).

Clear Creek's smooth decrease in percentage cover over time (figure 52.7) is paralleled by the steady increase in impervious area due to road building and home construction (figure 52.8). The trends in the plots of the flow components are similarly rather smooth except for the 1976 photo point (figures 52.16–52.20). As mentioned earlier, fire burned 85 ha (210 acres) in 1972, and this reduced percentage cover and increased impervious area for this photo interval alone. The fire caused exceptional increases in total flow and surface runoff and exceptional decreases in predicted ET, subsurface flow, and ground water flow.

Model Configuration and Application

A runoff model such as PRMS translates our conceptualization of the way hydrologic theory operates into a mathematical process model that predicts runoff from a basin. The model is based on the hydrologic processes that research has shown are important (Leavesley et al. 1983). Assumptions are incorporated in the application of the model, however. For example, because warm days occur during the winter in the Sierra Nevada, the model permits ET during winter. ET is estimated from temperature, and although ET rates are low in winter, conifers have been shown to transpire whenever air temperatures exceed 0°C (32°F) (Dunne and Leopold 1978).

Process models have shortcomings associated with the way they represent the basin. Overland flow from each HRU, for example, is summed with other outflows to become stream flow, regardless of the location of the HRU. It is possible that the overland flow in an HRU distant from a channel might be reabsorbed after flowing onto a neighboring HRU, but this form of model eliminates water fluxes in each HRU independently. The model does allow prediction of flow at any point along the “channel” because the contributing HRUs “upstream” can be grouped and fluxes reported for that group. This option was used to predict flow at the discontinued gauge site (#113315).

The inability to allocate disturbances to a particular location within an HRU is another shortcoming of process models. Roads or harvests that are near a channel are thought to be more likely to produce hydrologic effects than the same disturbance distant from a channel. This concern can be addressed to some degree by subdividing HRUs into smaller polygons with more homogeneous properties. If detailed physical and management data are not available, however, subdivision of the HRUs does not increase homogeneity, and modeling results do not improve. Subdivision of HRUs into smaller polygons also increases the computation time used to run the model. The PRMS can simulate a year of runoff for the Camp and Clear Creeks in less than a minute; the physical models that use small cells, short time steps, and mass flux and energy equations may take tens of hours on a similar computer to model a single year.

The results from the MMS type of process model are most useful when considered in a comparative manner, rather than as absolute measures of the effects of land-use change. The results from this analysis allow the comparison of two different land management strategies over a fifty-year period. Information on soils, vegetation, and other physiographic features is typically rather coarse in scale, whereas management activities are often fine-scale. Suburbanization occurs at an even finer scale than forest management. Depending on the goals of an analysis, the information available, and the area to be modeled, users can often apply process models to meet their needs and provide useful information.

CONCLUSIONS

As part of the SNEP Cosumnes River Basin case study, this study used a process hydrologic model to assess the relative effects on water flow, timing, and runoff generation processes from fifty years of suburban development and forest management in the Clear Creek and Camp Creek Basins, respectively. The land-use history documented an increase in roads, clear-cuts, structures, and burned areas over time. A land condition description was developed for each basin at six time periods, based on the availability of aerial photographs in 1940, 1952, 1966, 1976, 1986, and 1991. Information on land management was derived from aerial photos, unpublished data, and information from geographic information systems.

Based on analysis of the photographs, vegetation density in Clear Creek declined from 59% to 57% during the study interval and in Camp Creek declined from 68% to 55% after 1952. Impervious area associated with road building increased in both basins throughout the period but slowed markedly in the last five-year interval. In Clear Creek, impervious area associated with residential development increased from 0.3% to 3.6% throughout the study interval and increased dramatically after 1976. Disturbed area in Camp Creek associated with clear-cuts and roads increased from near 0% to 8.1%, and disturbance has increased dramatically since 1976, similar to the pattern in Clear Creek.

A thirty-three-year series of data from nine climate and four stream discharge stations was assembled and analyzed to identify high-, medium-, and low-magnitude water years, and three water years were selected to represent these classes. The hydrologic model was calibrated and percentage cover and impervious area information was incorporated so that six versions of the model existed for each basin, each representing the land conditions of a specific photo period. Simulations were done with each of the three water years, and the eighteen sets of output data were analyzed to determine the effect of water-year magnitude and land condition on the hydrology of the basins as predicted by the model.

The simulations showed that the changes in land condition were associated with changes in runoff depth in both the suburbanized and logged basins. The predicted mean monthly flow from Clear Creek increased over time, but the change was less evident for Camp Creek except in the high-magnitude water year. Surface runoff for both basins increased in the high-magnitude water year, but only in Clear Creek for the other years. Ground water flow and ET declined over time for both basins.

Changes in runoff timing and pattern were also found. Clear Creek's storm-based runoff was both larger and slightly earlier when the later years were compared to the 1940 year. Camp Creek's runoff, being at least partly based on snowmelt, showed an increased snowmelt flow during the runoff period and a decline in summer base flow for the high-magnitude water year. A predicted increase in the mean April flow was shown for Camp Creek for the 1986 and 1991 years.

The results obtained from this case study should have general application along the west slope of the Sierra Nevada. In many other basins, residential development is occurring at an elevation similar to Clear Creek's, and these basins would be likely to have a similar response to that demonstrated here. Forest management is similarly located both north and south of Camp Creek, so analogous results are to be expected. Because of these factors, this case study has wider application than to just these two basins.

Because the Clear and Camp Creek Basins are at different elevations and are of different size, direct comparisons of suburban development and forest management are somewhat difficult. Both basins showed definite changes in their hydrology over time, and those predicted changes are the result of changes in land condition, as simulated by the hydrologic model. Suburbanization in a rain-dominated basin appears to have the most distinct signature: increased runoff that is largely due to increases in surface runoff. The model predicts increases in snowmelt runoff when forest cover is reduced in a basin that receives a significant amount of snow.

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APPENDIX 52.1

Areas Occupied by Three Disturbance Types for Six Photo Intervals in Camp Creek Basin

		1940			1952			1966			1976			1986			1991		
HRU	Area (ha)	Road	Clear-cut	Fire	Road	Clear-cut	Fire	Road	Clear-cut	Fire	Road	Clear-cut	Fire	Road	Clear-cut	Fire	Road	Clear-cut	Fire
1	162.6	0	0	0	0	0	0	0.13	2.54	0	0.42	2.54	0	0.42	3.68	0	0.42	3.68	0
2	103.4	0.1	0	0	1.1	0	0	1.35	0	0	2.74	3.82	0	2.74	4.62	0	2.74	4.62	0
3	46.6	0.07	0	15.95	0.07	0	0	0.3	0	0	1.03	0	0	1.03	0	0	1.03	0	0
4	60	0	0	59.01	0.16	0	0	0.23	0	0	0.4	0	0	0.79	0	0	0.79	0	0
5	51.6	0	0	45.65	0	0	0	0	0	0	0.27	0	0	0.27	0	0	0.27	0	0
6	137.4	0.94	0	7.38	0.94	0	0	0.94	0.77	0	3.93	2.21	0	3.93	2.21	0	3.93	2.21	0
7	126.1	0	0	27.2	0.4	0	0	0.48	0	0	0.76	0	0	1.47	0	0	1.47	0	0
8	375	0	0	15.26	0.77	0	0	0.77	0	0	1.8	0	0	1.9	0	0	1.9	0	0
9	62.2	0	0	0	0.24	0	0	0.46	1.32	0	0.46	1.32	0	0.46	1.32	0	0.46	1.32	0
10	60.8	0	0	18.05	0	0	0	0	0	0	0	0	0	0.51	0	0	0.51	0	0
11	47.6	0	0	0	0	0	0	0	0	0	0	0	0	0.38	0	0	0.38	0	0
12	288.9	0	0	0	0	0	0	0.56	2.85	0	1.37	2.85	0	2.15	2.85	0	3.02	2.85	0
13	102.7	0	0	48.48	0	0	0	0	0	0	0	0	0	0.95	0	0	0.95	0	0
14	152.8	0	0	15.95	0	0	0	0	0	0	0	0	0	1.5	0	0	1.5	0	0
15	250.6	0	0	0	0	0	0	0.04	0	0	0.63	8.72	0	3.97	8.72	0	3.97	8.72	0
16	27.9	0	0	0	0	0	0	0	0	0	0	0	0	0.36	0	0	0.36	0	0
17	70	0	0	0	0	0	0	0	0	0	0	0	0	0.49	13.54	0	0.49	13.54	0
18	229.9	0	0	4.53	0.26	0	0	0.38	0	0	0.38	0	0	2.6	53.17	0	2.6	53.17	0
19	339.2	2.81	0	0	3.61	0	0	3.62	0	0	5.08	0	0	6.84	13.53	0	6.84	34.96	0
20	54.1	0	0	0	0	0	0	0	0	0	0	0	0	0.99	4.56	0	0.99	4.56	0
21	63.2	0	0	0	0.72	0	0	0.72	0	0	0.74	0	0	0.99	0	0	0.99	2.62	0
22	60.4	0	0	0	0.24	0	0	0.24	0	0	0.24	0	7.65	0.31	0	7.65	0.31	0	7.65
23	45	0	0	0	0.71	0	0	0.71	0	0	0.75	0	12.79	1.16	0	12.79	1.16	4.47	12.79
24	98.5	0	0	0	0.04	0	0	0.04	0	0	0.04	0	0	1.74	12.56	0	1.74	12.56	0
25	327.4	0	0	0	1.4	0	0	1.56	0	0	3.14	0	48.73	3.27	0	48.73	3.27	0	53.66
26	299.1	1	0	0	1.73	0	0	1.73	0	0	2	0	26.1	3.49	14.63	26.1	3.49	38.41	32.21
27	67.5	0.43	0	0	0.43	0	0	0.43	0	0	0.43	0	0	0.83	0	0	0.83	19.17	0
28	141.6	1.01	0	0	1.04	0	0	1.04	0	0	1.46	0	0	2.77	0	0	2.77	0	0
29	215.1	0	0	0	1.35	0	0	1.99	0	0	1.99	0	0	3.64	7.47	0	3.64	7.47	3.16
30	142.3	0.51	0	0	0.62	0	0	0.62	0	0	0.96	0	0	2.22	13.48	0	2.22	46.07	0
31	225.4	0.41	0	0	0.41	0	0	1.25	0	0	2.47	0	0	2.47	31.08	0	2.47	31.08	0
32	60.3	0	0	0	0	0	0	0.25	0	0	0.25	0	0	0.69	3.05	0	0.69	3.05	0
33	247.4	0.37	0	0	0.53	0	0	1.43	0	0	1.77	0	0	2.95	47.5	0	2.95	47.5	0
34	27.5	0	0	0	0	0	0	0	0	0	0	0	0	0.21	0	0	0.21	0	0
35	102.5	0	0	0	0.02	0	0	0.23	0	0	0.23	0	0	1.73	0	0	1.73	0	0
36	80.1	0	0	0	0	0	0	0.18	0	0	1.05	0	2.23	1.3	0	2.23	1.3	0	2.23
37	142.6	0	0	0	0.73	0	0	1.21	0	0	2.4	0	0	2.52	0	0	2.52	0	0
38	198.7	0	0	0	0.59	0	0	0.74	2.08	0	2.5	2.08	0	4.36	2.08	0	4.36	2.08	0
39	72.7	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0.95	0	0	0.99	0	0
40	78	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0	0	0.67	0	0
41	95.3	0.12	0	0	0.12	0	0	0.22	0	0	0.22	0	0	0.52	0	0	0.52	0	0
42	279.8	0.32	0	0	0.75	0	0	1.74	0	0	2.35	0	0	2.74	0	0	2.74	0	0
43	305.3	0.56	0	0	1.72	0	0	2.72	0	0	3.41	0	128	3.51	22.19	127.97	3.51	22.19	127.97
44	180.8	0.64	0	0	1.21	0	0	1.37	0	0	1.93	0	25.98	2.9	15.51	25.98	2.9	15.51	25.98
45	222	0.29	0	0	0.29	0	0	1.6	0	0	1.96	0	0	2.26	25.78	0	2.26	25.78	0
46	270.1	0.89	0	0	0.9	0	0	1.23	0	0	3.79	0	0	3.79	0	0	3.97	23.93	0
47	270.3	0.35	0	0	0.73	0	0	0.73	0	0	3.17	0	0	2.78	0	0	2.78	5.68	0
48	112.8	0.7	0	0	0.84	0	0	0.84	0	0	2.38	0	0	2.61	0	0	2.61	10.23	0
49	58.4	0	0	0	0.25	0	0	0.25	0	0	0.58	0	0	0.81	0	0	0.81	2.94	0
50	116.1	0	0	0	0.6	0	0	0.6	0	0	1.3	0	0	1.54	0	0	1.87	7.76	0
51	291.2	0	0	0	0.27	0	0	2.76	0	0	2.88	0	0	2.88	0	0	2.88	4.4	0
52	132.4	0	0	0	0.46	0	0	0.88	0	0	1.64	0	0	1.64	0	0	1.64	20.11	0
53	33.6	0	0	0	0.04	0	0	0.07	0	0	0.27	0	0	0.27	0	0	0.27	11.33	0

HRU	Area (ha)	1940 Road	1940 Clear-cut	1940 Fire	1952 Road	1952 Clear-cut	1952 Fire	1966 Road	1966 Clear-cut	1966 Fire	1976 Road	1976 Clear-cut	1976 Fire	1986 Road	1986 Clear-cut	1986 Fire	1991 Road	1991 Clear-cut	1991 Fire
54	156.3	0	0	0	0.47	0	0	0.47	0	0	2.03	3.53	0	2.73	3.53	0	2.73	22.68	0
55	59.1	0	0	0	0	0	0	0	0	0	0.59	3.08	0	0.59	3.08	0	0.59	12.74	0
56	91.7	0	0	0	0	0	0	0	0	0	1	3.08	0	1.32	3.08	0	1.32	8.17	0
57	179.2	0	0	0	0	0	0	0	1.63	0	1.31	11.06	0	1.39	11.06	0	1.39	24.09	0
58	127	0	0	0	0.03	0	0	0.03	0	0	0.88	0	0	1.1	0	0	1.1	9.88	0
Totals	8426.3	11.3	0	257.4	26.8	0	0	39.6	11.2	0	73.9	44.29	251.4	107.3	324.3	251.4	108.8	571.5	265.6

APPENDIX 52.2

Areas Occupied by Three Disturbance Types for Six Photo Intervals in Clear Creek Basin

HRU	Area (ha)	1940			1952			1966			1976			1986			1991		
		Road	House	Fire	Road	House	Fire	Road	House	Fire	Road	House	Fire	Road	House	Fire	Road	House	Fire
1	36.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	117.2	0.45	0	0	1.17	0	0	1.17	0.09	0	1.19	0.19	0	1.19	0.84	0	1.19	0.98	0
3	21.8	0	0	0	0.15	0	0	0.15	0	0	0.15	0	0	0.15	0.04	0	0.15	0.09	0
4	18.6	0	0	0	0.04	0	0	0.04	0	0	0.04	0	0	0.04	0	0	0.04	0	0
5	38.3	0.23	0.04	0	0.66	0.04	0	0.66	0.04	0	0.67	0.19	0	0.67	0.51	0	0.67	0.74	0
6	16.8	0	0	0	0.28	0	0	0.33	0.04	0	0.33	0.04	0	0.33	0.19	0	0.33	0.19	0
7	36	0.28	0	0	0.59	0	0	0.59	0.04	0	0.59	0.09	0	0.59	0.42	0	0.59	0.61	0
8	133.4	0.62	0	0	0.97	0.09	0	1.13	0.19	0	1.78	0.32	0	1.78	0.74	0	1.78	1.17	0
9	31	0.51	0	0	0.57	0.04	0	0.57	0.04	0	0.93	0.04	0	0.93	0.04	0	0.93	0.09	0
10	8.5	0.28	0	0	0.55	0	0	0.55	0.09	0	0.76	0.09	0	0.76	0.14	0	0.76	0.19	0
11	81.7	0	0	0	0.21	0.09	0	0.21	0.09	0	0.27	0.14	0	0.27	0.23	0	0.27	0.51	0
12	137	0.97	0.04	0	1.93	0.09	0	2.11	0.23	0	2.88	0.42	0	2.88	1.44	0	2.88	1.81	0
13	24.2	0	0	0	0.03	0	0	0.07	0	0	0.07	0	0	0.07	0.04	0	0.07	0.04	0
14	90.3	0.11	0.08	0	0.18	0.09	0	0.45	0.14	0	0.84	0.19	0	0.84	0.19	0	0.84	0.19	0
15	156.6	0.56	0.23	0	0.83	0.28	0	1.43	0.7	0	2.01	0.93	0	2.21	1.72	0	2.21	2.05	0
16	73.4	1	0.09	0	1.29	0.14	0	1.79	0.56	0	2.58	1.11	0	2.58	2.83	0	2.58	3.12	0
17	84.9	0.04	0	0	0.2	0	0	0.86	0	0	1.16	0.56	0	1.7	0.98	0	1.7	1.21	0
18	19.9	0	0	0	0	0	0	0.07	0	0	0.2	0	0	0.35	0	0	0.35	0	0
19	121.6	0	0	0	0.79	0	0	0.88	0.09	0	1.32	0.09	3.04	1.32	0.23	3.04	1.32	0.6	3.04
20	117.2	0	0	0	0.01	0	0	0.18	0	0	2.55	0.28	64.91	2.59	1.11	64.91	2.59	1.53	64.91
21	12.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0	0	0.19	0
22	54.3	0	0	0	0.08	0	0	0.08	0	0	0.08	0	0	0.08	0	0	0.08	0	0
23	15.6	0	0	0	0	0	0	0.05	0	0	0.05	0	0	0.05	0.09	0	0.05	0.14	0
24	80.3	0.15	0	0	0.29	0	0	0.81	0.32	0	0.92	0.37	0	0.92	0.6	0	0.92	0.74	0
25	14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0	0	0.19	0
26	37.9	0	0	0	0	0.14	0	0.06	0.47	0	0.06	0.74	0	0.06	1.02	0	0.06	1.4	0
27	122.6	1.29	0.04	0	1.94	0.23	0	2.29	0.56	0	3.28	0.84	0	3.28	1.49	0	3.28	2.04	0
28	23.5	0	0	0	0.21	0.04	0	0.37	0.32	0	0.48	0.37	0	0.48	0.74	0	0.48	0.84	0
29	117.8	0.32	0.04	0	1.66	0.04	0	2.24	0.51	0	2.85	1.07	0	3	1.72	0	3	2.27	0
30	31.8	0	0	0	0.31	0	0	0.31	0	0	0.31	0	0	0.31	0	0	0.31	0	0
31	184.1	0.58	0	0	1.35	0	0	2.52	0.65	0	4.26	2.37	0	4.28	6.41	0	4.28	8.36	0
32	94.6	0	0	0	0.42	0	0	0.48	0	0	1.95	0.93	0	1.99	3.53	0	1.99	4.83	0
33	40.6	0	0	0	0.28	0	0	0.61	0	0	0.61	0.09	0	0.61	0.42	0	0.67	0.7	0
34	32.3	0	0	0	0	0	0	0	0	0	0	0	2.75	0	0	2.75	0.21	0	2.75
35	25.7	0	0	0	0	0	0	0.53	0.23	0	0.56	0.32	5.42	0.56	0.47	5.42	0.56	0.65	5.42
36	41.4	0	0	0	0	0	0	0.1	0	0	1.22	0.04	8.86	1.22	0.47	8.86	1.22	0.89	8.86
37	28	0	0	0	0	0	0	0.06	0	0	0.45	0	0	0.51	0	0	0.51	0	0
38	42.9	0	0	0	0	0	0	0.13	0	0	0.47	0.04	0	0.59	0.19	0	0.59	0.23	0
39	23.1	0	0	0	0	0	0	0.06	0	0	0.35	0	0	0.48	0	0	0.48	0	0
40	17.4	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0	0	0.14	0	0
41	20.2	0	0	0	0	0	0	0.11	0	0	0.78	0.09	0	0.78	0.37	0	0.78	0.65	0
42	20.2	0	0	0	0	0	0	0.06	0	0	0.17	0	0	0.17	0	0	0.17	0	0
43	11.5	0	0	0	0	0	0	0	0	0	0	0	0	0.48	0	0	0.48	0	0
44	24.5	0	0	0	0	0	0	0	0	0	0.01	0	0	0.2	0	0	0.2	0	0
45	39.6	0	0	0	0	0	0	0	0.04	0	0.51	0.09	0	0.69	0.28	0	0.69	0.42	0
46	38.1	0	0	0	0	0	0	0.4	0.23	0	0.91	1.72	0	0.93	2.93	0	0.93	3.85	0
47	20.9	0	0	0	0	0	0	0	0	0	0.25	0.42	0	0.25	1.11	0	0.25	1.53	0
48	16.1	0	0	0	0	0	0	0	0	0	0.12	0.19	0	0.14	0.37	0	0.14	0.42	0
49	112.5	0.51	0.04	0	0.66	0.14	0	0.66	0.19	0	1.7	0.19	0	1.7	0.32	0	1.7	0.42	0
50	10.4	0	0	0	0.01	0	0	0.09	0	0	0.69	0.19	0	0.69	0.84	0	0.69	1.02	0
51	14.5	0	0	0	0.06	0	0	0.06	0	0	0.06	0	0	0.06	0.09	0	0.06	0.09	0
52	66.5	0	0	0	0.24	0	0	0.24	0	0	0.44	0	0	0.44	0	0	0.5	0	0
53	52.3	0.03	0	0	0.16	0	0	0.16	0	0	0.17	0	0	0.35	0.19	0	0.35	0.42	0
54	39.2	0	0	0	0	0	0	0	0	0	1.72	0.65	0	1.72	4.32	0	1.72	5.35	0
55	94.5	0.1	0.23	0	0.1	0.23	0	1.25	0.74	0	2.08	1.76	0	2.19	3.39	0	2.19	4.46	0
56	80.8	0	0	0	0.48	0	0	0.68	0.65	0	1	1.11	0	1.03	1.53	0	1.03	1.81	0
Totals	3067.7	8.03	0.83	0	18.7	1.68	0	27.65	7.25	0	48.83	18.27	84.98	51.63	44.86	84.98	51.96	59.03	84.98

APPENDIX 52.3

Physical Attributes for the Hydrologic Response Units That Comprise Camp Creek Basin

HRU	Area (ha)	Soil Type	Slope (%)	Soil Depth (cm)	Aspect	Elevation (m)	Vegetation Type
1	162.7	Loam	43	72.9	SE	1112.5	Trees
2	103.4	Loam	23	92.2	SE	1188.7	Trees
3	46.6	Loam	38	109.7	S	1173.5	Trees
4	60	Loam	40	74.7	SW	1158.2	Trees
5	51.6	Loam	29	122.2	SW	1255.8	Trees
6	137.5	Loam	29	122.7	SW	1194.8	Trees
7	126.1	Loam	40	70.4	SW	1335	Trees
8	375	Loam	40	126.5	W	1219.2	Trees
9	62.2	Loam	33	118.1	NW	1341.1	Trees
10	60.8	Loam	43	69.6	NE	1204	Trees
11	47.6	Loam	26	69.6	NE	1341.1	Trees
12	288.9	Loam	25	124	NE	1432.6	Trees
13	102.7	Loam	43	105.9	NE	1188.7	Trees
14	152.8	Loam	27	114.6	NE	1341.1	Trees
15	250.6	Loam	15	97.8	W	1371.6	Trees
16	27.9	Loam	43	68.8	SW	1371.6	Trees
17	70	Loam	26	142.7	S	1493.5	Trees
18	229.8	Loam	20	119.6	W	1432.6	Trees
19	339.2	Loam	22	118.4	N	1432.6	Trees
20	54.2	Loam	43	177.8	SW	1371.6	Trees
21	63.2	Loam	34	126.5	N	1402.1	Trees
22	60.6	Loam	43	138.7	SW	1341.1	Trees
23	45	Loam	28	88.6	SW	1447.8	Trees
24	98.5	Loam	22	96.5	S	1487.4	Trees
25	327.4	Loam	28	77.7	S	1478.3	Trees
26	299.1	Loam	27	66	W	1554.5	Trees
27	67.5	Loam	33	66	NW	1511.8	Trees
28	141.6	Loam	25	66	S	1524	Trees
29	215.1	Loam	28	69.1	SE	1585	Trees
30	142.3	Loam	27	66	W	1630.7	Trees
31	225.4	Loam	30	68.1	S	1621.5	Trees
32	60.3	Loam	41	109.5	SW	1566.7	Trees
33	247.4	Loam	27	68.1	S	1694.7	Trees
34	27.5	Loam	44	127.3	N	1280.2	Trees
35	102.5	Loam	24	138.2	NE	1386.8	Trees
36	79.7	Loam	41	103.6	NE	1341.1	Trees
37	142.6	Loam	29	78.7	NE	1463	Trees
38	198.7	Loam	31	76.2	N	1499.6	Trees
39	72.7	Loam	39	80.8	N	1493.5	Trees
40	78	Loam	29	66	N	1597.2	Trees
41	95.3	Loam	43	109	NW	1603.2	Trees
42	279.8	Loam	27	67.6	NW	1691.6	Trees
43	305.3	Loam	26	75.4	S	1752.6	Trees
44	180.8	Loam	24	68.1	SW	1767.8	Trees
45	222	Loam	24	69.3	SW	1798.3	Trees
46	270.1	Loam	26	68.1	SW	1889.8	Trees
47	270.3	Loam	25	67.8	SW	1981.2	Trees
48	112.8	Loam	18	69.6	SW	2060.4	Trees
49	58.4	Loam	23	91.4	NW	2133.6	Trees
50	116.1	Loam	27	70.9	W	2164.1	Trees
51	291.2	Loam	28	72.9	N	1767.8	Trees
52	132.4	Loam	33	82.6	NE	1828.8	Trees
53	33.6	Loam	19	68.6	NE	1889.8	Trees
54	156.3	Loam	30	73.2	NE	1859.3	Trees

HRU	Area (ha)	Soil Type	Slope (%)	Soil Depth (cm)	Aspect	Elevation (m)	Vegetation Type
55	59.1	Loam	30	70.9	NE	1950.7	Trees
56	91.7	Loam	31	75.9	N	1950.7	Trees
57	179.3	Loam	30	78.7	NW	2072.6	Trees
58	127.0	Loam	33	91.9	N	2133.6	Trees
59	1226.6	Loam	19	102.6	S	1020.8	Trees
60	762.9	Loam	9	102.6	W	811.1	Trees
61	797.7	Loam	21	71.1	W	1077.5	Trees
62	578.3	Loam	15	66.0	SW	1058.9	Trees
SNEP Basin	8426.1						
Total	11791.6						

APPENDIX 52.4

Physical Attributes for the Hydrologic Response Units That Comprise Clear Creek Basin

HRU	Area (ha)	Soil Type	Slope (%)	Soil Depth (cm)	Aspect	Elevation (m)	Vegetation Type
1	36.5	Clay	35	124.2	SE	652.3	Shrubs
2	117.2	Loam	24	130.8	SE	816.9	Shrubs
3	21.8	Loam	33	77.2	SE	755.9	Trees
4	18.6	Loam	36	68.8	S	725.4	Trees
5	38.2	Loam	17	127.8	SE	841.2	Shrubs
6	16.7	Loam	27	74.2	SE	755.9	Shrubs
7	36	Loam	15	125.2	NE	737.6	Grass
8	133.4	Loam	16	121.9	NE	810.8	Grass
9	31	Loam	10	126.7	S	743.7	Grass
10	8.5	Loam	12	171.2	SE	755.9	Grass
11	81.7	Clay	29	120.1	SE	810.8	Shrubs
12	137	Loam	20	133.9	NW	819.9	Grass
13	24.2	Loam	17	127	S	792.5	Shrubs
14	90.3	Loam	18	75.2	S	853.4	Shrubs
15	156.6	Loam	17	126.7	SW	841.2	Trees
16	73.4	Loam	17	126.5	S	780.3	Grass
17	84.9	Loam	21	122.2	SE	853.4	Shrubs
18	19.9	Loam	29	110.5	E	883.9	Shrubs
19	121.6	Loam	30	70.6	SE	877.8	Shrubs
20	117.1	Loam	31	54.6	SE	893.1	Shrubs
21	12.6	Loam	41	137.2	W	609.6	Trees
22	54.3	Loam	23	149.9	W	682.8	Shrubs
23	15.6	Loam	30	76.2	N	762	Trees
24	80.3	Loam	14	128.8	NW	768.1	Grass
25	14.5	Loam	9	77.7	NW	755.9	Grass
26	37.9	Loam	24	122.4	N	804.7	Trees
27	122.6	Loam	22	124.2	W	841.2	Shrubs
28	23.5	Loam	40	100.6	W	826	Trees
29	117.8	Loam	26	93.7	N	841.2	Shrubs
30	31.8	Loam	40	71.6	W	865.6	Trees
31	184.1	Loam	21	120.9	W	969.3	Trees
32	94.6	Loam	21	106.9	W	944.9	Trees
33	40.6	Loam	33	130.3	NW	929.6	Trees
34	32.3	Loam	41	73.9	NW	914.4	Trees
35	25.7	Loam	40	66.8	S	914.4	Trees
36	41.4	Loam	25	90.7	NW	914.4	Shrubs
37	28	Loam	26	77.5	SE	975.4	Trees
38	42.9	Loam	25	103.1	W	960.1	Trees
39	23.2	Loam	23	49.5	SE	987.6	Shrubs
40	17.4	Loam	29	47.8	W	1036.3	Shrubs
41	20.2	Loam	24	82.6	SW	975.4	Trees
42	20.2	Loam	23	122.2	NW	999.7	Trees
43	11.5	Loam	16	42.7	S	1024.1	Grass
44	24.5	Loam	27	66.8	W	1018	Shrubs
45	39.6	Loam	23	45.5	SE	1036.3	Shrubs
46	38.1	Loam	19	116.8	S	1066.8	Trees
47	20.9	Loam	26	116.8	NW	1060.7	Trees
48	16.1	Loam	27	98.6	NW	1048.5	Trees
49	112.5	Loam	21	128.5	SE	1097.3	Trees
50	10.4	Loam	14	60.2	SW	1121.7	Shrubs
51	14.5	Loam	28	49.5	NW	1085.1	Trees
52	66.5	Loam	21	127.3	W	1121.7	Trees
53	52.3	Loam	21	119.6	W	1097.3	Trees
54	39.2	Loam	17	127	NW	1036.3	Trees
55	94.4	Loam	25	134.1	NW	1036.3	Trees
56	80.8	Loam	14	167.4	S	1170.4	Trees
Total	3067.6						

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