Prepared in cooperation with the U.S. Air Force

Precipitation-Runoff, Suspended-Sediment, and Flood-Frequency Characteristics for Urbanized Areas of Elmendorf Air Force Base, Alaska

Water-Resources Investigations Report 98-4265

U.S. Department of the Interior
U.S. Geological Survey

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By Timothy P. Brabets

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED UNITS

Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
inch per hour (in/hr)	25.4	millimeter per hour
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
pound, avoirdupois (lb)	0.4536	kilogram
pound per second (lb/s)	0.4536	kilogram per second
ton per day (ton/d)	0.9072	megagram per day
pound per acre per inch [(lb/acre)/in.]	44.13	kilogram per hectare per meter

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F-32)/1.8

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ABBREVIATED UNITS

mg/L, milligrams per liter

mm, millimeters

Precipitation-Runoff, Suspended-Sediment, and Flood-Frequency Characteristics for Urbanized Areas of Elmendorf Air Force Base, Alaska

By Timothy P. Brabets

ABSTRACT

The developed part of Elmendorf Air Force Base near Anchorage, Alaska, consists of two basins with drainage areas of 4.0 and 0.64 square miles, respectively. Runoff and suspended-sediment data were collected from August 1996 to March 1998 to gain a basic understanding of the surface-water hydrology of these areas and to estimate flood-frequency characteristics. Runoff from the larger basin averaged 6 percent of rainfall, whereas runoff from the smaller basin averaged 13 percent of rainfall. During rainfall periods, the suspended-sediment load transported from the larger watershed ranged from 179 to 21,000 pounds and that from the smaller watershed ranged from 23 to 18,200 pounds. On a yield basis, suspended sediment from the larger watershed was 78 pounds per inch of runoff and from the smaller basin was 100 pounds per inch of runoff. Suspended-sediment loads and yields were generally lower during snowmelt periods than during rainfall periods.

At each outfall of the two watersheds, water flows into steep, natural channels. Suspended-sediment loads measured approximately 1,000 feet downstream from the outfalls during rainfall periods ranged from 8,450 to 530,000 pounds. On a yield basis, suspended sediment averaged 705 pounds per inch of runoff, more than three times as much as the combined sediment yield from the two watersheds. The increase in suspended sediment is most likely due to natural erosion of the streambanks.

Streamflow data, collected in 1996 and 1997, were used to calibrate and verify a U.S. Geological Survey computer model—the Distributed Routing Rainfall Runoff Model-Version II (DR3M-II). The model was then used to simulate annual peak discharges and runoff volumes for 1981 to 1995 using historical rainfall records. Because the model indicated that surcharging (or ponding) would occur, no flood-frequency analysis was done for peak discharges. A flood-frequency analysis of flood volumes indicated that a 10-year flood would result in 0.39 inches of runoff (averaged over the entire drainage basin) from the larger watershed and 1.1 inches of runoff from the smaller watershed.

INTRODUCTION

Elmendorf Air Force Base is located in southcentral Alaska, adjacent to Anchorage, the State's largest city (fig. 1). The mission of the base is to provide air defense for the Alaska North America Defense (NORAD) region and to provide the deployment of personnel and equipment to world-wide locations. The base encompasses about 20 mi^2 and includes a major runway, operation facilities, and military housing.

Most of the roads, housing, and runway at Elmendorf are concentrated in an approximately 5-square-mile area. Runoff from this urbanized area enters a number of catch basins. These catch basins are connected by a network of stormwater pipes, which transport the flow westward, where it eventually is discharged at two outfall locations. The stormwater from these two outfalls flows into natural stream channels. Near the Port of Anchorage, the flow enters a culvert and discharges into Cook Inlet.

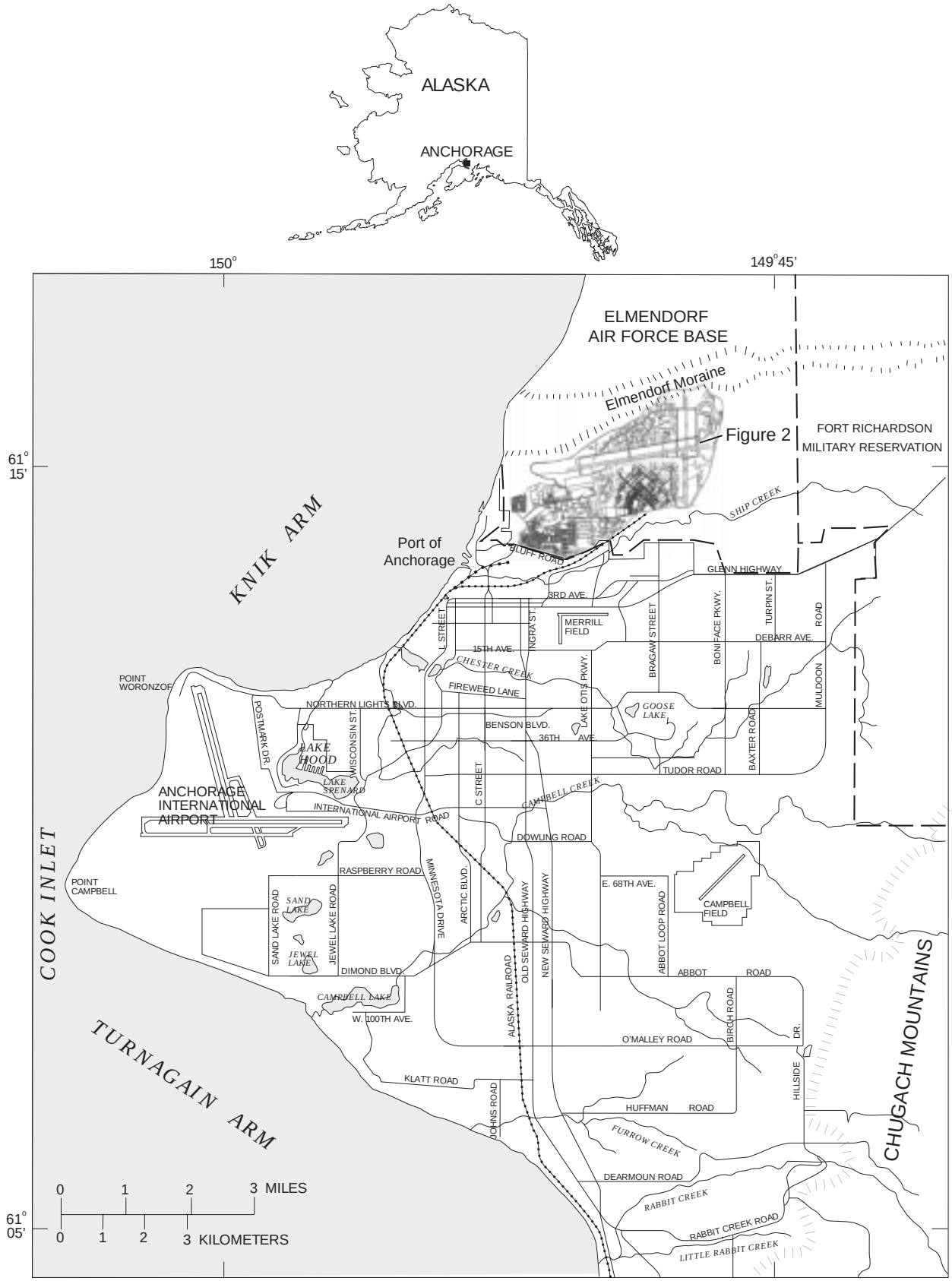

Figure 1. Location of Elmendorf Air Force Base near Anchorage, Alaska.

Under the requirements of the Federal Clean Water Act, the National Pollution Discharge Elimination System (NPDES) permitting program, and the State of Alaska Water Quality Regulation (18 AAC 70), stormwater runoff from the urbanized part of the base may require treatment using a sedimentation basin before it can be discharged into Cook Inlet.

Sedimentation basins are usually designed to detain a flood volume of a specific recurrence interval for a period sufficient to remove a given percent of a particular size sediment. Likewise, in a stormwater runoff system, the sizes of culverts or pipes are based on their ability to pass a flood of a particular recurrence interval. Thus, reliable and accurate precipitation-runoff, suspended-sediment, and flood-frequency characteristics are needed to ensure both a functional and cost-effective sedimentation basin or stormwater drainage system.

Purpose and Scope

This report summarizes the precipitation-runoff, suspended-sediment, and flood-frequency characteristics of the urbanized areas of Elmendorf Air Force Base. The objective of this study was to determine these characteristics so that Air Force personnel could determine if a sedimentation basin is required. If a sedimentation basin is required, the Air Force could use the results of this study to help design the structure. Data collected over a 2-year period were used to determine the precipitation-runoff and suspended-sediment characteristics. The flow and precipitation data were used to calibrate and verify a rainfall-runoff model. Once the rainfall-runoff model was verified, historical rainfall data were used to simulate storm volumes and peak discharges for a 15-year period. Flood-frequency techniques were then used with the simulated data to determine recurrence intervals for storm runoff volume.

Physical Setting

Elmendorf Air Force Base is located in the northern part of what is commonly referred to as the "Anchorage Bowl." This area is bounded on the north, west, and south by two estuaries—Knik and Turnagain Arms of Cook Inlet—and on the east by the Chugach Mountains (fig. 1). Most of the terrain is a gently sloping glacial outwash plain, with the exception of the Elmendorf moraine (fig. 1). Located on the northern part of the base, the Elmendorf moraine is a hummocky ridge of glacial deposits of mixed grain size.

Long-term average annual precipitation for the study area is about 15 in. at the Anchorage International Airport, of which about 8.5 in. consists of rainfall (National Climatic Data Center, 1998). Precipitation as rainfall occurs from about mid-April to about mid-October. The remaining 6.5 in. of water-equivalent precipitation is about 70 in. of snow that occurs during the winter months. Air temperatures in the Anchorage area range from an average monthly minimum during the coldest month, January, of 3.2 ˚F to an average monthly maximum during the warmest month, July, of 65.3 ˚F.

The urbanized area of Elmendorf Air Force Base is located near the southern boundary of the base. Runoff from this area is collected in a number of catch basins, which are connected by a network of stormwater pipes. There are two primary drainages (fig. 2). Watershed 1 drains an area of 4 mi^2. This watershed consists of the main runway, aircraft hangars, support facilities, and military housing. Sixty-seven percent of this watershed is composed of pervious area, 7 percent is **effective impervious area**[1], and 26 percent is **non-effective impervious area**. Watershed 2 drains an area of 0.64 mi^2. This watershed consists primarily of

[1]**Bold** words are defined in the "Glossary" at the end of the report.

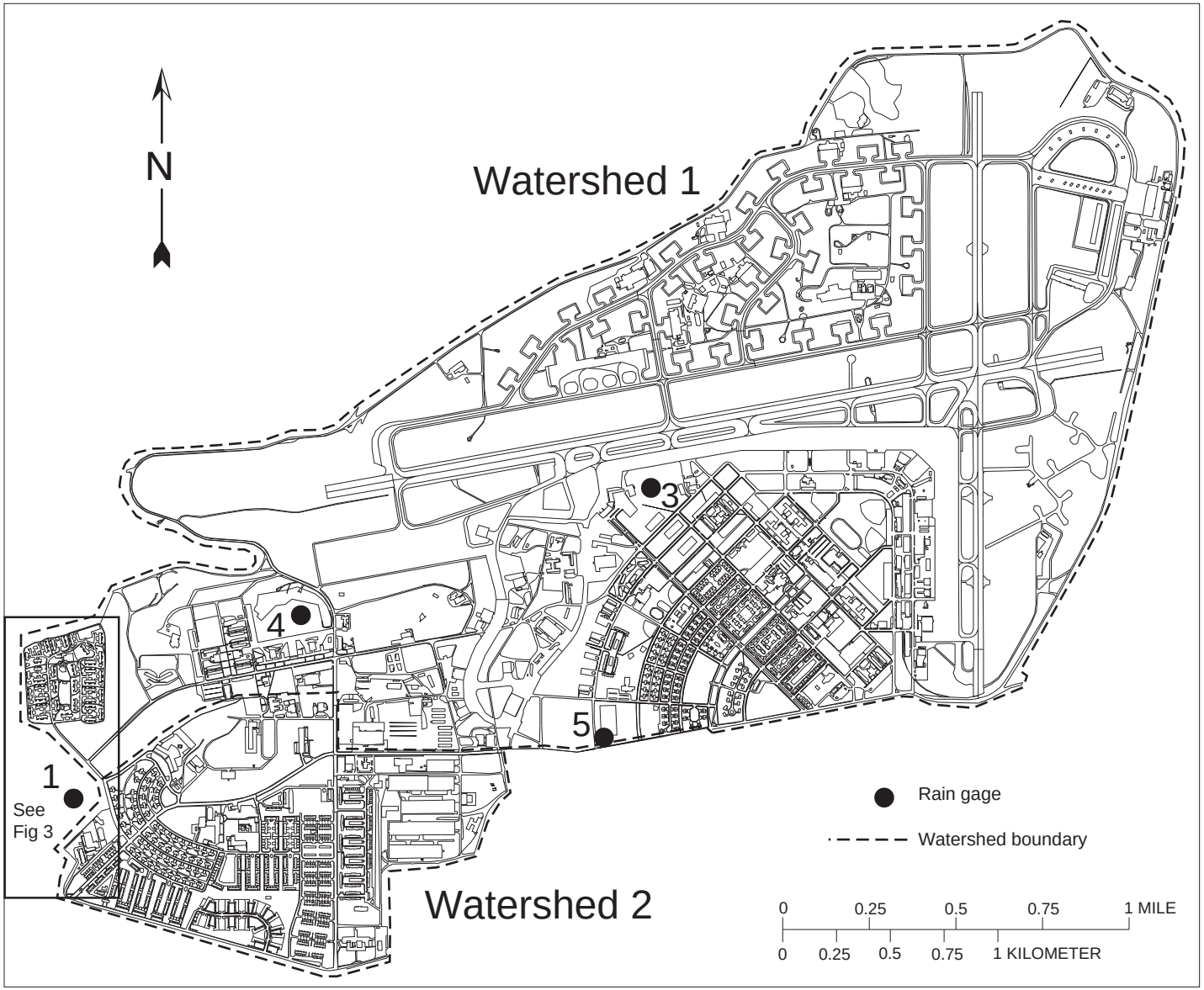

Figure 2. Developed area of Elmendorf Air Force Base, Alaska.

military housing and warehouses. Fifty-nine percent of this basin is composed of pervious area, 13 percent is effective impervious area, and 28 percent is non-effective impervious area.

The outfalls of watersheds 1 and 2 are 60-inch and 48-inch culverts, respectively, that discharge directly into steep-gradient natural channels, which then merge into a single channel (fig. 3). The streambed of the channels consist of boulders, cobbles, gravel, and fine sediments. The banks along the channels are composed of fine unconsolidated sediments and, when saturated, will slough into the channels. At the downstream end of the single channel, water re-enters a culvert and eventually discharges into Cook Inlet.

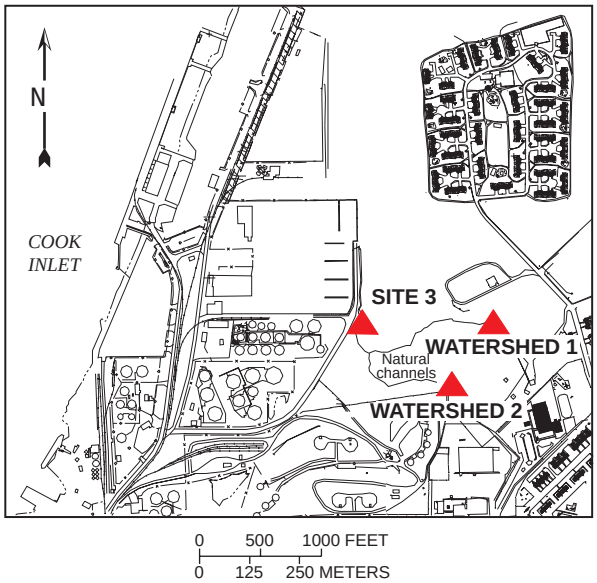

Figure 3. Location of outfalls and monitoring sites, Elmendorf Air Force Base, Alaska.

Approach

Monitoring stations (fig. 3) were established at the outfalls of watersheds 1 and 2. Water-level recorders and automatic water samplers were installed at these two sites, and a tipping-bucket rain gage was installed at the watershed 1 outfall. Three additional rain gages (fig. 2) were established to quantify the distribution of rainfall. Suspended-sediment samples were collected during **rainfall-runoff** and **snowmelt**-runoff periods, and analyzed for total concentration. About 40 percent of these samples also were analyzed for particle-size distribution. Concentrations of the suspended-sediment samples collected during individual storms were integrated over a discharge hydrograph to determine the suspended-sediment load per storm. Monitoring of runoff and suspended sediment at watersheds 1 and 2 during rainfall periods began in August 1996 and ended in September 1997. Runoff and suspended-sediment data were collected at these two sites during the snowmelt periods of March 1997 and March 1998.

In March 1997, a third suspended-sediment monitoring site (site 3, fig. 3) was established near the base of a bluff, about 1,000 ft downstream from the outfalls. The natural channels between the outfalls of watersheds 1 and 2 and site 3 drop about 100 ft in elevation. Site 3 was established to determine if suspended-sediment characteristics change as runoff travels downstream from the two outfalls to site 3. No major tributaries discharge into the channels between the two outfalls and site 3. Therefore, the discharge at site 3 was computed as sum of the discharge at the two outfalls. Suspended-sediment data were collected at site 3 during rainfall periods in 1997 and the snowmelt periods of March 1997 and March 1998.

Basin characteristics associated with urban runoff were determined for the two basins. Characteristics—such as drainage area and amount of pervious and impervious area—were obtained through the use of a 1996 Geographical Information Systems (GIS) coverage of the base. This coverage included cultural features such as streets, sidewalks, buildings, and open areas. Other characteristics—such as size of stormwater pipes and slopes of streets—were obtained from data provided by the Civil Engineering Department of Elmendorf Air Force Base.

Data collected during the rainfall-runoff periods in 1996 and 1997 were used to calibrate and verify the rainfall-runoff model, DR3M-II (Distributed Routing Rainfall-Runoff Model—Version II; Alley and Smith, 1982a). DR3M-II is primarily an urban runoff model for routing storm runoff through a system of pipes or natural channels using rainfall as the primary input.

Once DR3M-II was calibrated, a synthesis of past rainfall-runoff events for watersheds 1 and 2 was undertaken. This was accomplished by using rainfall data collected at the Anchorage International Airport from 1981 to 1995. Using this rainfall record as input to a calibrated model, historical peak discharges were estimated. These synthesized peak discharges were then used as input to the Water Resources Council's 17B flood-frequency program (Interagency Advisory Committee on Water Data, 1982) to determine the peak discharges and runoff volumes for different recurrence intervals.

Streamflow and rainfall data were collected at 5-minute intervals and are stored in electronic format in the USGS National Water Information System (NWIS). The suspended-sediment data also are stored in NWIS. The GIS coverage of the urbanized area of Elmendorf Air Force Base is archived in the Alaska District. All data are available upon request from the USGS office in Alaska shown on page II of this report.

PRECIPITATION-RUNOFF CHARACTERISTICS

In most investigations of urban water resources, streamflow is a key variable. For example, peak runoff rates are used to design storm drainage structures. Runoff data are used to compile loadings of water-quality constituents, such as suspended sediment and nutrients. The runoff from a catchment or basin is highly dependent on the precipitation that falls within its drainage area. Precipitation is also the primary temporal and spatial distribution input variable to the runoff model, DR3M-II, used in this study. Thus, accurate measurements of precipitation are also necessary.

Precipitation

During 1996, precipitation at the Anchorage International Airport totaled 14.32 in., of which 7.13 in. (water equivalent) was snow. Although the yearly total was close to the long-term mean, a comparison of individual monthly totals with long-term mean monthly totals indicated that the months of May, June, July, and September were significantly below the mean, whereas precipitation in August was near the mean. The precipitation amounts collected by the tipping-bucket rain gages on Elmendorf Air Force Base were quite similar to those at the airport and reflect the same trends (table 1).

In 1997, precipitation at the International Airport totaled 19.26 in., of which 5.04 in. (water equivalent) was snow. Comparisons of the monthly totals indicated that the months of June and July were below the mean, whereas the month of May was slightly above the mean. Precipitation for August and September was at least 2 in. above the mean. With the exception of August and September, the rain gages on Elmendorf reflected the same trends. Differences in trends are apparent in August and September, although some of the differences can be explained by the amount of precipitation reported for August 31 (0.17 in.) and September 1 (2.30 in.). For example, precipitation at the gage operated at the International Airport by the National Weather Service is reported at 12 noon daily; thus, the data reflect the rain that occurred from 12 noon on August 31 to 12 noon on September 1.

Storm precipitation totals at the two watersheds during the period August 1996 to September 1997 ranged from 0.05 to 2.69 in. (tables 2 and 3). Duration of these storms, which mainly consisted of light or steady rain,

Table 1. Precipitation measured at various locations during the study period

[All data in inches; --, gage not in operation; see figure 2 for location of watershed 1 rain gages]

Month	Watershed 1 rain gage				Anchorage International Airport[a]	
	1 (Outfall)	3	4	5	Rain gage	Long-term monthly mean[b]
1996						
May	0.31[c]	--	--	--	0.20	0.73
June	.37[c]	--	--	--	.40	1.04
July	1.55[c]	--	--	--	1.93	2.70
Aug.	2.10	1.75	--	--	2.53	2.44
Sept.	1.87	1.49	1.57	1.33	1.93	2.70
1997						
May	1.08	.99	.72	.90	1.07	.73
June	.81	.84	.76	.79	.66	1.04
July	1.68	1.62	1.54	1.46	1.35	2.70
Aug.	7.58	7.05	5.96	7.58	6.06	2.44
Sept.	1.46	1.37	1.08	1.29	4.83	2.70

[a]Data from National Weather Service
[b]From 1964 to the present
[c]Data from rain gage located at runway of Elmendorf Air Force Base, operated by the U.S. Air Force

ranged from 4 to 14 hours. Maximum precipitation intensity recorded during the study period was 0.96 in/hr on August 21, 1997.

Notable storms occurred on August 21 and August 31, 1997. Each of these storms lasted approximately 12 hours and their precipitation amounts (2.69 in. and 2.37 in., respectively) were significantly greater than those for any other storms that took place during the study. In the Anchorage area, the August 21 and August 31, 1997 storm totals have been exceeded only by a storm on August 26, 1989, in which more than 6 in. of rain fell in a 48-hour period (Larry Rundquist, National Weather Service, oral commun., 1998). Both August 1997 storms caused minor flooding in certain locations on the base.

Runoff

At the outfall of watershed 1, a **baseflow** component of approximately 1.5 ft^3/s was present throughout the study period. During rainfall periods, runoff from watershed 1 ranged from 1 to 14 percent of rainfall (table 2) and averaged 6 percent. This relatively low percentage of runoff is probably due to the large percentage of pervious and ineffective impervious area in the basin (93 percent) and the infiltration of rainfall. At the outfall of watershed 2, runoff occurred only during storms and periods of snowmelt. Runoff ranged from 2 percent to 33 percent of rainfall (table 3) and averaged 13 percent. The higher percentage of runoff in watershed 2 relative to watershed 1 is probably due to the larger percentage of effective impervious area (13 percent) in this basin.

Spring snowmelt periods occurred from about March 28 to April 13, 1997, and from March 16 to April 6, 1998. During these periods, distinct diurnal fluctuations in flow occurred (figs. 4 and 5). Runoff increased during the day when air temperatures rose above freezing and then decreased during the night as air temperatures fell below freezing. Comparison of runoff for the two snowmelt periods indicates that watershed 1 had more runoff during snowmelt than watershed 2. Although more snow fell in the winter of 1996-97 (7.13 in. of snow-water equivalent) than in the winter of 1997-98 (5.04 in of snow-water equivalent), the amount of runoff from each watershed during the 1997 and 1998 snowmelt periods was nearly equivalent. In addition to plowing sidewalks and streets, the Air Force picks up and hauls snow to snow dumps outside of the basins during winter. Thus, the amount of snowfall each winter may not be an accurate indicator of the runoff amount.

Table 2. Storm rainfall-runoff characteristics of watershed 1, August 1996 to September 1997, Elmendorf Air Force Base, Alaska

Date[a]	Storm rainfall (inches)	Storm runoff (inches)	Runoff as percent of rainfall	Date[a]	Storm rainfall (inches)	Storm runoff (inches)	Runoff as percent of rainfall
8-9-96	0.36	0.012	3	6-22-97	0.16	0.007	4
8-22-96	0.56	0.014	3	7-10-97	0.78	0.046	6
8-25-96	0.11	0.002	2	7-13-97	0.12	0.006	5
8-29-96	0.12	0.001	1	7-14-97	0.19	0.019	10
8-30-96	0.07	0.004	6	7-24-97	0.33	0.018	5
8-31-96	0.07	0.003	4	8-9-97	0.74	0.067	9
9-11-96	0.05	0.001	2	8-11-97	0.39	0.040	10
9-15-96	0.24	0.014	6	8-12-97	0.39	0.045	12
9-21-96	0.37	0.017	5	8-15-97	0.18	0.011	6
9-21-96	0.31	0.007	2	8-21-97	2.69	0.307	11
9-25-96	0.29	0.014	5	8-25-97	0.14	0.008	6
9-27-96	0.07	0.007	10	8-26-97	0.56	0.058	10
9-27-96	0.18	0.007	4	8-31-97	2.37	0.316	13
5-14-97	0.17	0.005	3	9-9-97	0.22	0.028	13
5-17-97	0.15	0.005	3	9-17-97	0.13	0.013	10
5-30-97	0.57	0.039	7	9-18-97	0.27	0.037	14
6-6-97	0.15	0.007	5	9-21-97	0.11	0.008	7
6-19-97	0.38	0.018	5	9-29-97	0.08	0.004	5
				Average			**6**

Table 3. Storm rainfall-runoff characteristics of watershed 2, August 1996 to August 1997, Elmendorf Air Force Base, Alaska

Date[a]	Storm rainfall (inches)	Storm runoff (inches)	Runoff as percent of rainfall	Date[a]	Storm rainfall (inches)	Storm runoff (inches)	Runoff as percent of rainfall
8-9-96	0.36	0.043	12	5-14-97	0.17	0.015	9
8-22-96	0.56	0.084	15	5-17-97	0.15	0.011	7
8-25-96	0.11	0.005	4	5-30-97	0.57	0.088	15
8-29-96	0.12	0.020	17	6-6-97	0.15	0.011	7
8-30-96	0.19	0.010	5	6-19-97	0.38	0.029	8
8-31-96	0.09	0.002	2	7-10-97	0.78	0.071	9
9-11-96	0.07	0.005	7	7-14-97	0.19	0.062	33
9-15-96	0.24	0.038	16	7-24-97	0.33	0.067	20
9-21-96	0.37	0.061	16	8-9-97	0.37	0.024	6
9-21-96	0.31	0.036	12	8-11-97	0.39	0.011	3
9-25-96	0.36	0.088	24	8-12-97	0.39	0.081	21
9-27-96	0.09	0.021	23	8-15-97	0.18	0.023	13
9-27-96	0.18	0.034	19	8-21-97	0.66[b]	0.096	14
				Average			**13**

[a]Date indicates start of storm. Some storms span more than one day. On some dates, more than one storm occurred; for example, one in the morning and one in the afternoon.
[b]Represents partial storm; gage was destroyed.

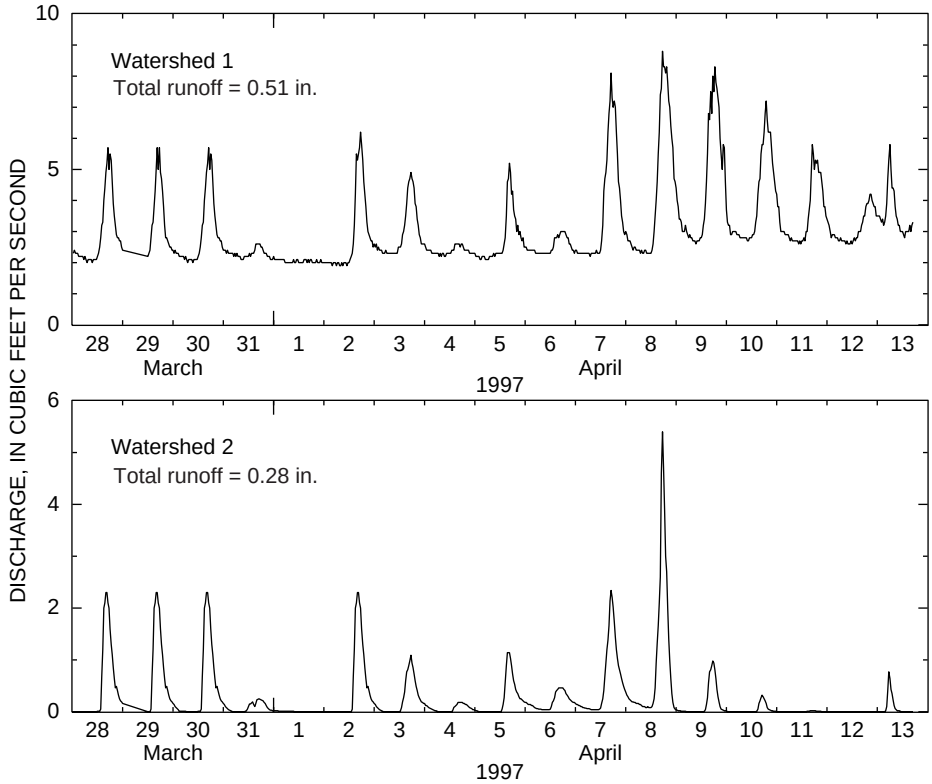

Figure 4. Runoff from watershed 1 and watershed 2, during snowmelt period of March 28 to April 13, 1997, Elmendorf Air Force Base, Alaska.

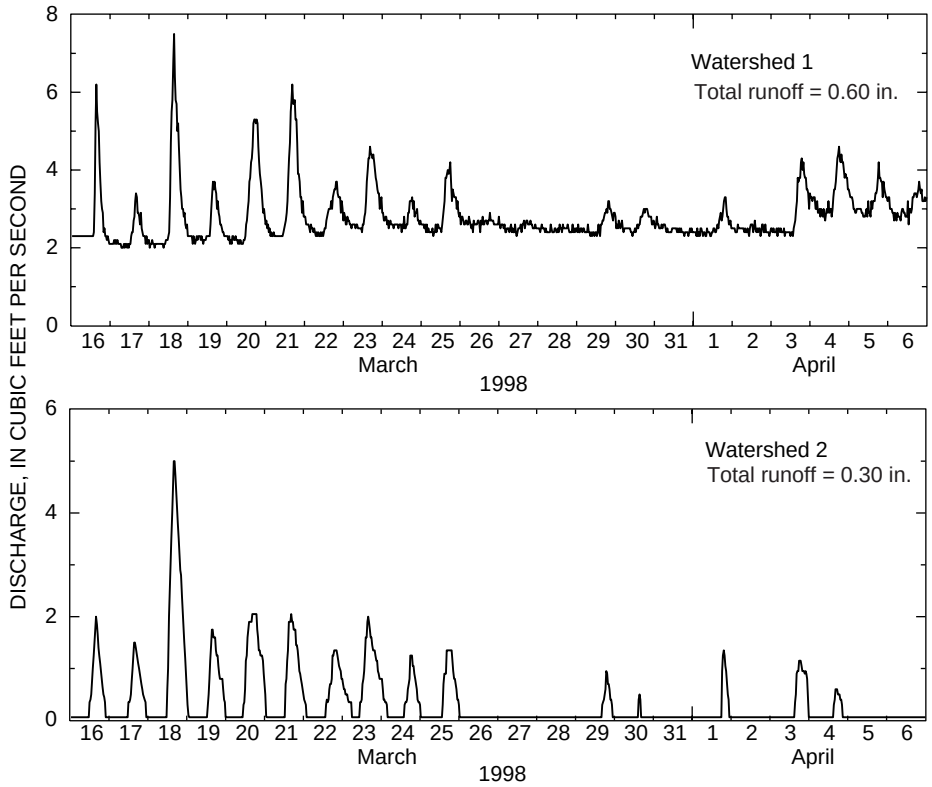

Figure 5. Runoff from watershed 1 and watershed 2, during snowmelt period of March 16 to April 6, 1998, Elmendorf Air Force Base, Alaska.

Peak Flows

A comparison of the peak discharges for the two watersheds (table 4) for rainfall periods indicated that peak discharges at watershed 1 were higher than peak discharges at watershed 2 except for three storms. During each of these three storms, a higher rainfall intensity took place at the beginning of the storm. The higher rainfall intensity combined with the amount of impervious area of watershed 2 resulted in higher peak discharges compared with lower intensity rainfall. As an index for comparison between the two watersheds, the peak discharges were converted to unit discharges. This comparison shows that in most cases, the unit discharges for watershed 2 are higher than the discharges for watershed 1 (table 4).

Comparing the peak discharges that occurred during the snowmelt periods (figures 4 and 5) with the peak discharges that occurred during rainfall periods (table 4) indicates that the peak discharges from snowmelt were lower than the highest peak discharges from rainfall periods. During the 1997 and 1998 snowmelt periods, the peak discharges were 8.8 and 7.5 ft^3/s, respectively, for watershed 1, and the peak discharges were 5.4 and 5.0 ft^3/s, respectively, for watershed 2. During the 1996 and 1997 rainfall periods, the peak discharges were 30 and 60 ft^3/s, respectively, for watershed 1, and the peak discharges were 20.9 and 28 ft^3/s, respectively, for watershed 2. From the two years of data collection it appears that the annual (or highest) peak discharge occurred as a result of rainfall instead of snowmelt.

Differences in both magnitude and timing of flow are apparent from the discharge hydrographs for watersheds 1 and 2 (fig. 6). Sharp peaks (i.e. rapid rise and fall of the hydrograph trace) reflect runoff from impervious surfaces in the drainage basins, as well as the effects other factors such as basin shape, size, and distribution of precipitation. The hydrographs for September 25, 1996 and July 24-25, 1997 (high intensity precipitation periods) show a rapid

Table 4. Peak discharges from rainfall periods for watersheds 1 and 2, August 1996 to September 1997, Elmendorf Air Force Base, Alaska

[ft^3/s, cubic foot per second; $(ft^3/s)/mi^2$, cubic foot per second per square mile;--, no data]

Date	Watershed 1		Watershed 2	
	Peak discharge (ft^3/s)	Unit discharge [$(ft^3/s)/mi^2$]	Peak discharge (ft^3/s)	Unit discharge [$(ft^3/s)/mi^2$]
8-10-96	6.8	1.7	3.7	5.8
8-22-96	14.2	3.6	20.9	32.6
8-25-96	4.9	1.2	0.73	1.1
8-29-96	5.3	1.3	8.2	12.8
8-30-96	8.5	2.1	2.1	3.3
8-31-96	7.8	2.0	0.25	.39
9-11-96	4.0	1.0	2.4	3.8
9-15-96	15.1	3.8	7.0	10.9
9-21-96	18.1	4.5	9.2	14.4
9-21-96	10.3	2.6	9.0	14.1
9-25-96	30	7.5	18.5	28.9
9-27-96	11.4	2.8	5.0	7.8
9-27-96	7.7	1.9	4.4	6.9
5-14-97	5.0	1.2	2.2	3.4
5-17-97	5.1	1.3	2.3	3.6
5-30-97	27.7	6.9	14.4	22.5
6-6-97	6.7	1.7	2.6	4.1
6-19-97	9.0	2.2	3.0	4.7
6-22-97	15.8	4.0	--	--
7-10-97	20.4	5.1	6.9	10.8
7-13-97	4.7	1.2	--	--
7-14-97	23.9	6.0	20	31.2
7-24-97	26.7	6.7	28	43.8
8-9-97	31.2	7.8	6.6	10.3
8-11-97	24.4	6.1	2.4	3.8
8-12-97	30.9	7.7	7.5	11.7
8-15-97	7.6	1.9	2.5	3.9
8-21-97	60	15	23	35.9
8-25-97	10.7	2.7	--	--
8-26-97	33.1	8.3	--	--
8-31-97	49.1	12.3	--	--
9-9-97	8.8	2.2	--	--
9-17-97	14	3.5	--	--
9-18-97	28.8	7.2	--	--
9-21-97	8.0	2.0	--	--
9-29-97	4.7	1.2	--	--

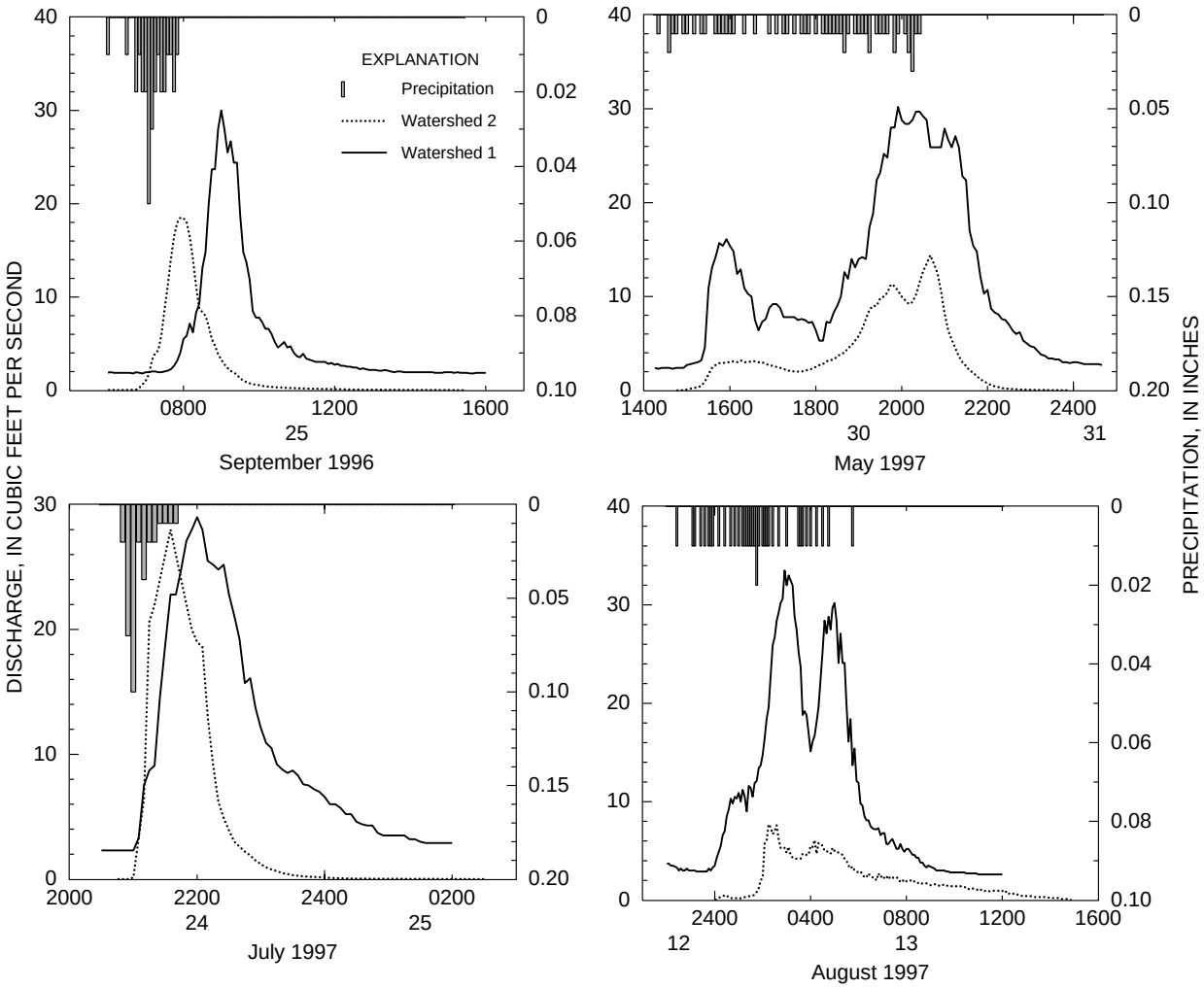

Figure 6. Comparison of discharges of watershed 1 and watershed 2, for various rainfall periods, Elmendorf Air Force Base, Alaska.

rise to the peak for both watersheds (fig. 6). In these types of storms, the peak discharge for watershed 1 was higher than the peak discharge for watershed 2, but the peak discharge for watershed 2 occurred before the peak discharge for watershed 1. For storms of lower intensity and longer duration—such as the May 30, 1997 and August 12-13, 1997 storms—the peak discharge took longer to occur. In these types of storms, the duration of the peak discharges for both watersheds is nearly equivalent. Watershed 2 did not have as rapid a rise to the peak discharge as watershed 1, but rather had a prolonged period of runoff.

SUSPENDED-SEDIMENT CHARACTERISTICS

In Alaska, no formal water-quality criteria are in place for suspended sediment in relation to either human health or aquatic life. However, sediment is a stormwater contaminant that not only poses an aesthetic concern, but can exert harmful physical effects by covering fish spawning sites or altering habitat of benthic organisms (U.S. Environmental Protection Agency, 1977). Suspended sediment in urban runoff also is likely to have other contaminants adsorbed onto it (U.S. Environmental Protection Agency, 1977).

Suspended-Sediment Concentrations

At the watershed 1 outfall, 198 samples were collected during rainfall periods and analyzed for suspended-sediment concentration. Concentrations of these samples ranged from 7 to 1,672 mg/L, with a median value of 73 mg/L. Fifty-seven samples also were analyzed for sand/fine particle-size distribution. The analyses indicated that in 44 of these samples, 70 percent or more of their sediment was finer than 0.062 mm. This factor indicates it is likely that most of the suspended sediment transported at the outfall of watershed 1 consists of silt and clay particles.

At watershed 1, a total of 29 samples were collected and analyzed for suspended sediment during the two snowmelt periods of 1997 and 1998. Concentrations of these samples ranged from 2 to 1,293 mg/L with a median value of 36 mg/L. Seventeen of the samples also were analyzed for sand/fine particle-size distribution. In each of these samples, 83 percent or more of the sediment was finer than 0.062 mm, indicating that most of the suspended sediment is composed of silt and clay particles. On the basis of this limited number of samples and comparison of the boxplots (fig. 7A) for rainfall and snowmelt periods, it appears that the range in suspended-sediment concentrations during snowmelt periods is slightly larger than that during rainfall periods.

At the watershed 2 outfall, 108 samples were collected for analysis of suspended sediment during rainfall periods in 1996 and 1997. Concentrations of these samples ranged from 3 to 2,783 mg/L with a median value of 115 mg/L. Fifty-five of the samples also were analyzed for sand/fine particle-size distribution. The analyses indicated that in 54 of the samples, 70 percent or more of their sediment was finer than 0.062 mm. Thus, similar to watershed 1, it is likely that most of the suspended sediment transported past this site consists of silt- and clay-sized particles.

At watershed 2, a total of 25 samples were collected and analyzed for suspended sediment during the snowmelt periods of March 1997 and 1998. Concentrations of these samples ranged from 16 to 996 mg/L with a median value of 82 mg/L. Thirteen of the samples were also analyzed for sand/fine particle-size distribution and all 13 analyses indicated that 96 percent or more of the suspended sediment was finer than 0.062 mm, indicating silt- and clay-sized particles. On the basis of this limited number of samples and comparison of the boxplots for rainfall and snowmelt (fig. 7B), it appears that the ranges in suspended-sediment concentrations for watershed 2 during snowmelt are smaller than ranges in concentrations for rainfall periods.

At site 3, suspended-sediment samples for rainfall periods were collected only during 1997. For the 96 samples collected, concentrations of suspended sediment ranged from 11 to 8,394 mg/L with a median value of 999 mg/L. Twenty of the samples also were analyzed for sand/fine particle-size distribution and all analyses indicated that 92 percent or more of the suspended sediment was finer than 0.062 mm, indicating clay- and silt-sized particles.

At site 3, suspended-sediment samples for snowmelt periods were collected in 1997 and 1998. A total of 31 samples were collected and concentrations ranged from 50 to 4,213 mg/L with a median concentration of 576 mg/L. Of the 17 samples analyzed for sand/fine particle-size distribution, all analyses indicated that 93 percent or more of each sample was composed of silt- and clay-sized material. On the basis of the limited data collected at this site, comparison of the boxplots of suspended-sediment concentrations for rainfall and snowmelt (fig. 7C) indicates a slightly larger range in concentrations for rainfall periods.

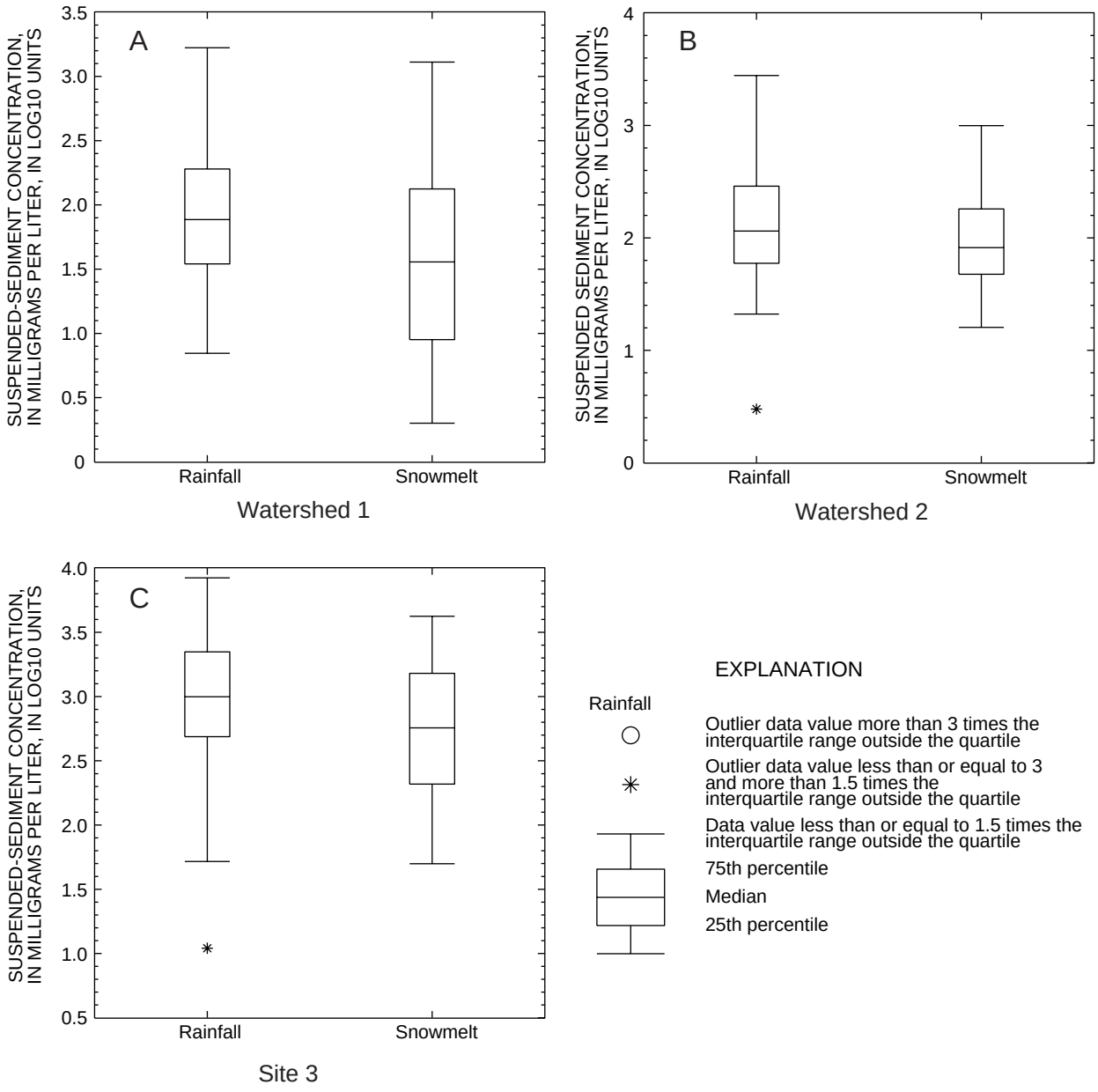

Figure 7. Boxplots of suspended-sediment concentrations for rainfall and snowmelt periods for watershed 1, watershed 2, and site 3, Elmendorf Air Force Base, Alaska.

Comparing the median values of suspended-sediment concentrations for both rainfall and snowmelt periods clearly indicates the differences in concentrations between the two outfall sites and site 3. No major tributaries discharge into the reach of channel between the two outfalls and site 3. Therefore, the increased suspended-sediment concentrations at site 3 are likely the result of natural erosive effects of the water as it flows down the steep gradient of the bluff.

Relation Between Suspended-Sediment Concentration and Discharge

During rainfall-runoff periods, sediment is washed from the urbanized areas of Elmendorf Air Force Base. During these rainfall periods, suspended-sediment concentrations at the outfalls of watersheds 1 and 2 followed one of two patterns: (1) concentrations followed fluctuations in water discharge throughout the storm (fig. 8A) or (2) concentrations were high-

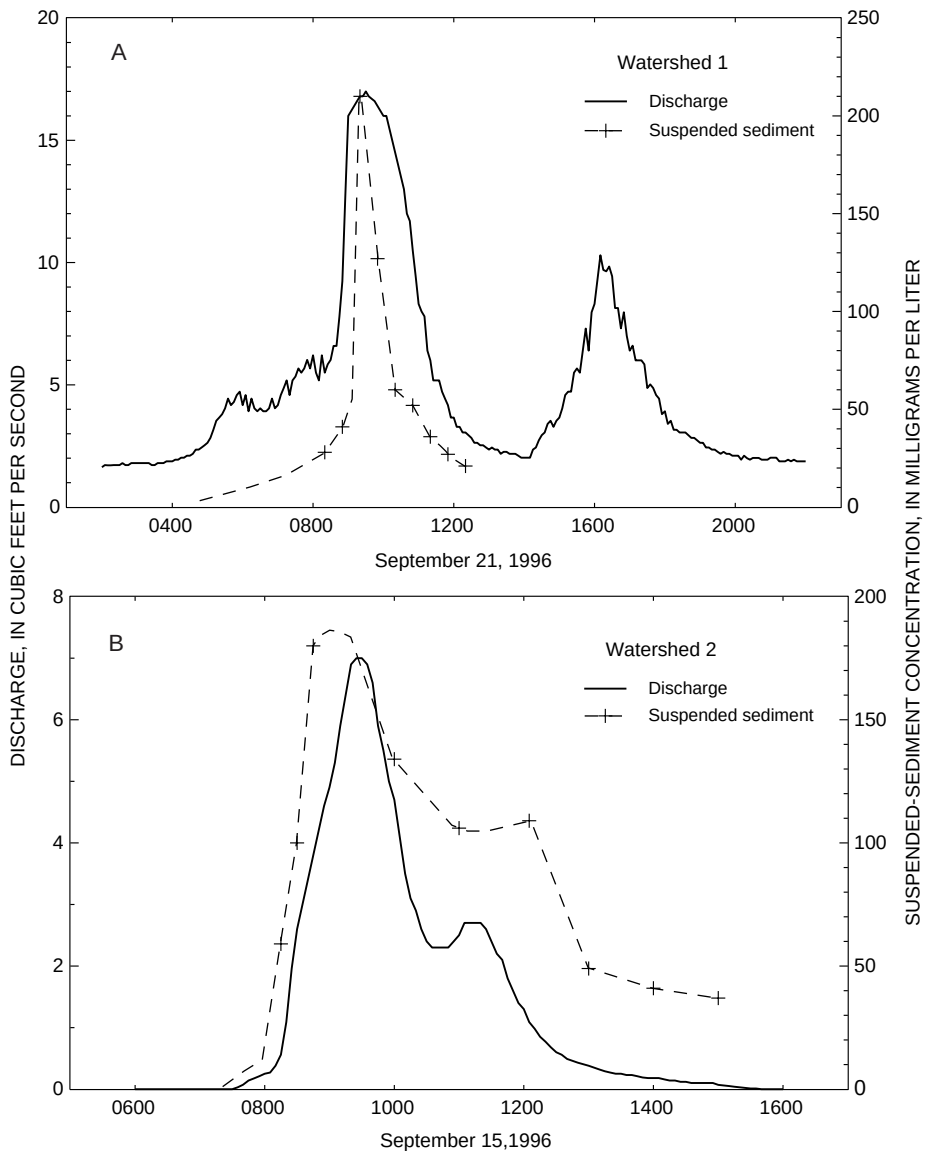

Figure 8. Discharge and suspended-sediment concentration during selected rainfall periods, September 1996, for watershed 1 and watershed 2, Elmendorf Air Force Base, Alaska.

est during the initial part of the storm—peaking prior to the time of the peak water discharge—and then decreased less rapidly than discharge (fig. 8B). In comparing the suspended-sediment concentrations with their concurrent discharges (fig. 9), for each watershed, there is a range of suspended-sediment concentrations for a given discharge. The range in concentrations depends on a number of factors. One factor may be whether the sample was collected during the rising or falling stage of the storm, although this is not apparent for this study. Other factors may be the time of year, the antecedent conditions, or the source of runoff within the watershed.

During snowmelt periods, the sediment that has accumulated on roads and other impervious areas during the winter is washed off. The highest sediment concentrations for the two snowmelt periods occurred at the highest discharges at the beginning of the snowmelt period. However, as the material is removed from the surfaces, for an equivalent discharge that occurred later in the snowmelt period, the corresponding sediment concentration was usually lower. Thus a wide variation in concentration for a given discharge was evident at the three sites (fig. 10). No trend was apparent at watershed 2, but because it is difficult to measure flow below 1 ft^3/s during snowmelt at this site, the discharge values may have considerable errors.

Suspended-Sediment Loads

Sediment-transport curves were developed for watersheds 1, 2, and site 3 to determine the relation between instantaneous discharge and suspended-sediment load. Separate transport curves were developed for rainfall periods (fig. 11) and snowmelt periods (fig. 12). The following relations were obtained by ordinary least squares regression of the logarithms of discharge and suspended-sediment load:

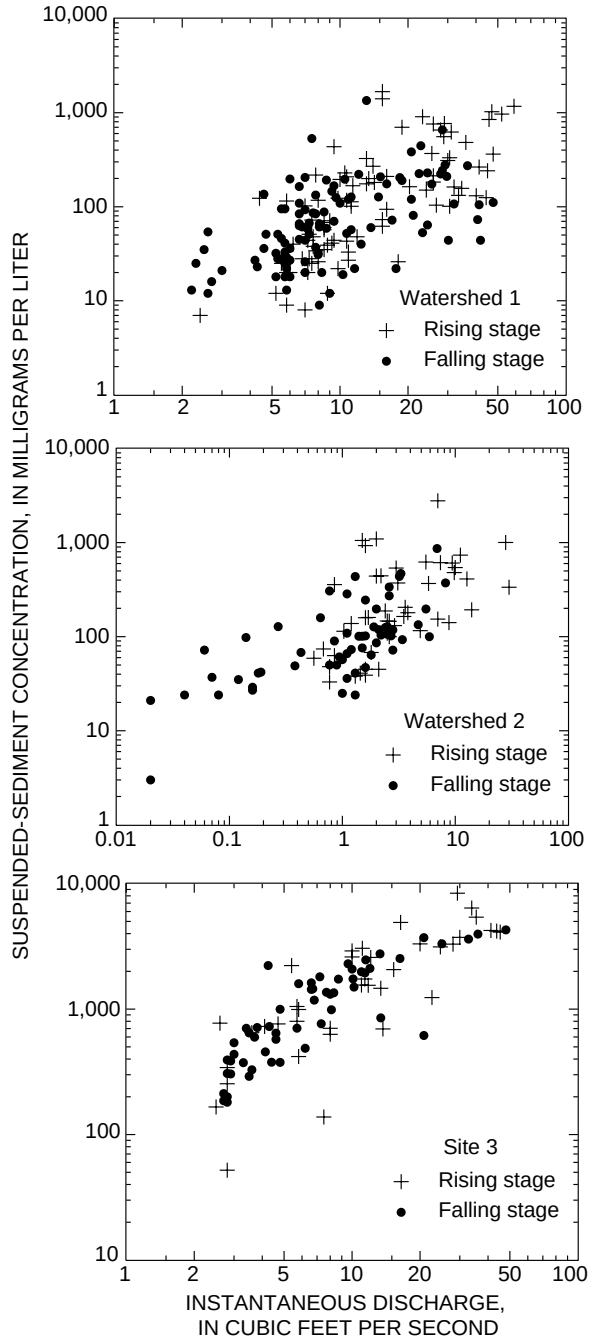

Figure 9. Instantaneous discharge and suspended-sediment concentration during rainfall periods for watershed 1, watershed 2, and site 3, Elmendorf Air Force Base, Alaska.

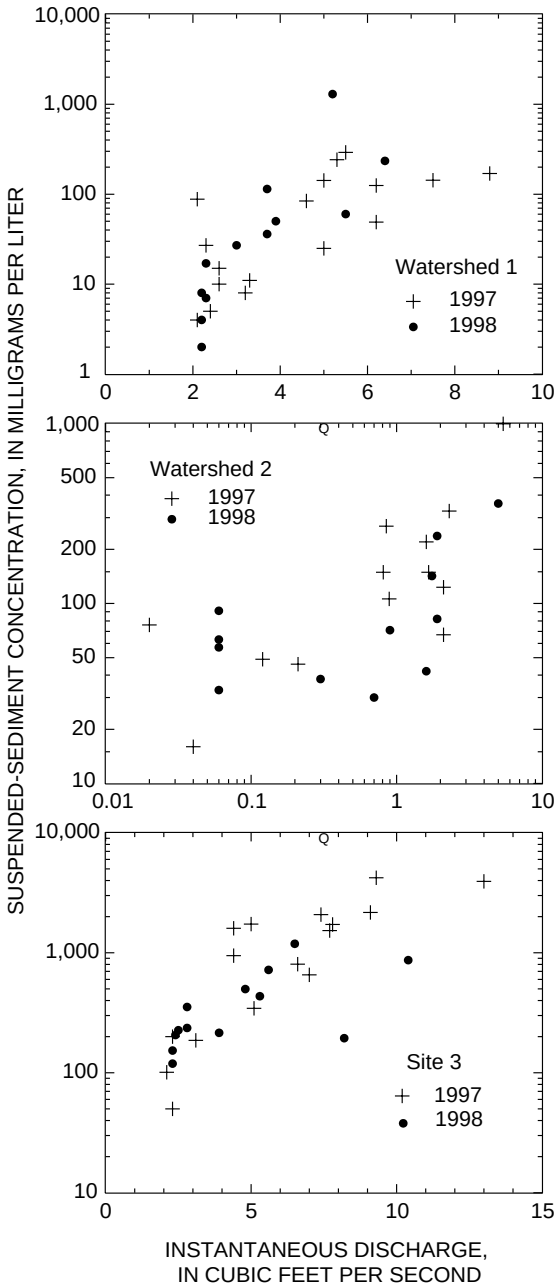

Figure 10. Instantaneous discharge and suspended-sediment concentration during snowmelt periods for watershed 1, watershed 2, and site 3, Elmendorf Air Force Base, Alaska.

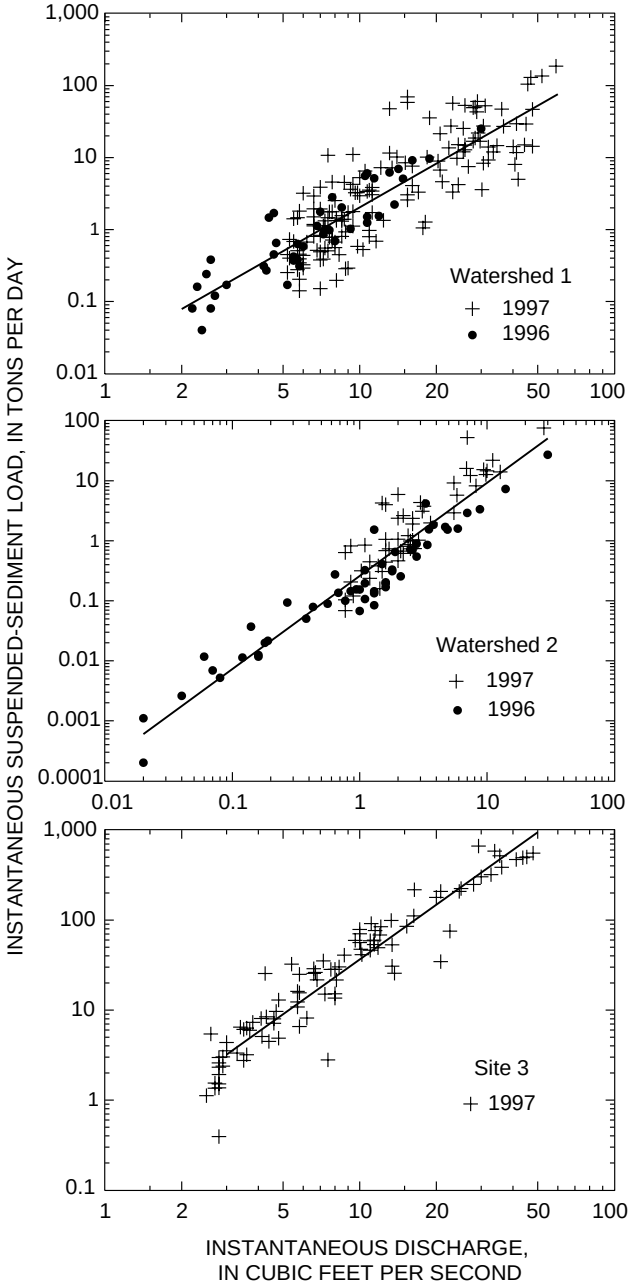

Figure 11. Instantaneous discharge and suspended-sediment load during rainfall periods for watershed 1, watershed 2, and site 3, Elmendorf Air Force Base, Alaska.

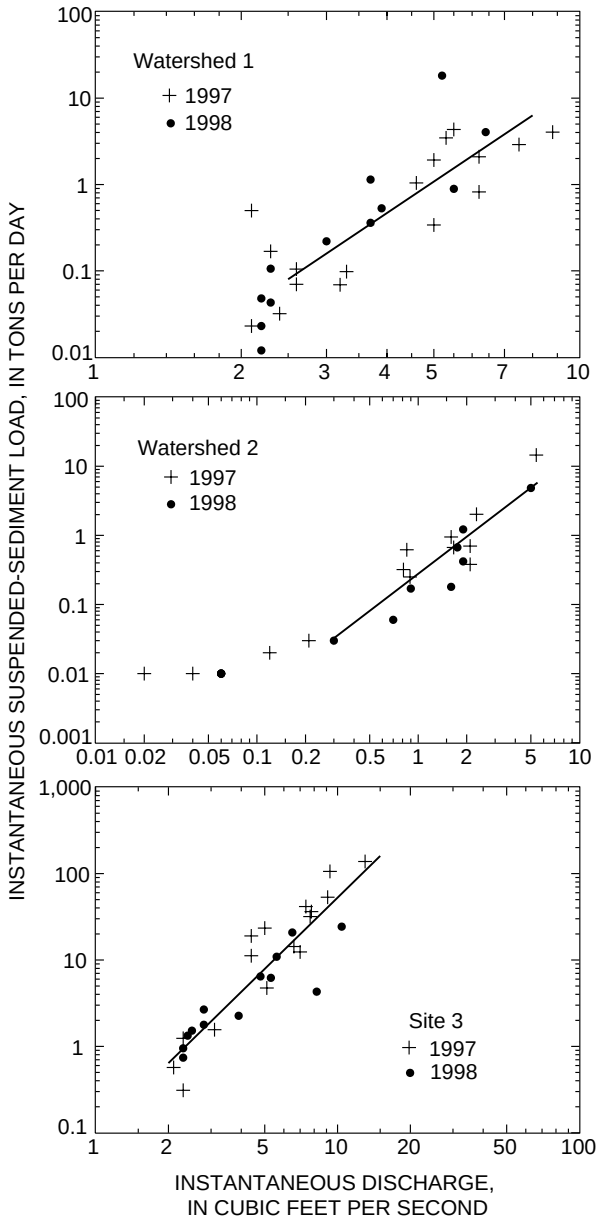

Figure 12. Instantaneous discharge and suspended-sediment load during snowmelt periods for watershed 1, watershed 2, and site 3, Elmendorf Air Force Base, Alaska.

Rainfall periods:

Watershed 1	Watershed 2	Site 3
$L = 0.019\ (Q)^{2.02}$	$L = 0.27\ (Q)^{1.54}$	$L = 0.35\ (Q)^{2.02}$
N = 198	N = 108	N = 96
R = 0.86	R = 0.94	R = 0.95
SE = 0.38	SE = 0.35	SE = 0.24

Snowmelt periods:

Watershed 1	Watershed 2	Site 3
$L = 0.003\ (Q)^{3.73}$	$L = 0.28\ (Q)^{1.78}$	$L = 0.10\ (Q)^{2.74}$
N = 29	N = 25	N = 29
R = 0.86	R = 0.88	R = 0.91
SE = 0.44	SE = 0.29	SE = 0.29

In all the equations,

L is instantaneous suspended load, in tons per day;

Q is instantaneous discharge, in cubic feet per second;

N is number of samples;

R is correlation coefficient; and

SE is standard error of estimate, in log units.

Although suspended-sediment loads will vary for a given discharge, some general observations can be made from the sediment-transport curves. On the basis of the equations, for most observed discharges, the highest suspended-sediment load will be transported past site 3 and lowest suspended-sediment load will be transported past the outfall at watershed 1 for both rainfall and snowmelt periods. For a particular discharge, less sediment will be transported during snowmelt periods than during rainfall periods. A number of factors can explain these characteristics. For example, part of the sediment load past site 3 is likely attributed to some erosion of the natural channel downstream from the outfalls of watersheds 1 and 2. Because sediment on impervious surfaces is more easily washed off than that from pervious surfaces and because watershed 2 has

more impervious area, more sediment is transported past the outfall of watershed 2 than past the outfall of watershed 1 for a given discharge. Finally, snowmelt periods are characterized by a gradual increase and decrease of flow over a number of days. Because of this runoff characteristic, less energy is available for transporting sediment for snowmelt periods than for rainfall periods when runoff occurs more rapidly.

During rainfall periods, storm loads of suspended sediment were determined for watersheds 1, 2, and site 3. The method of computation was to estimate a constituent concentration corresponding to each discharge (Alley and Smith, 1982b). This is done by linear interpolation between measured concentrations. The corresponding discharge is then multiplied by the constituent concentration and an appropriate conversion factor to compute instantaneous loads. The load curve is then integrated to determine the storm-runoff load (fig. 13).

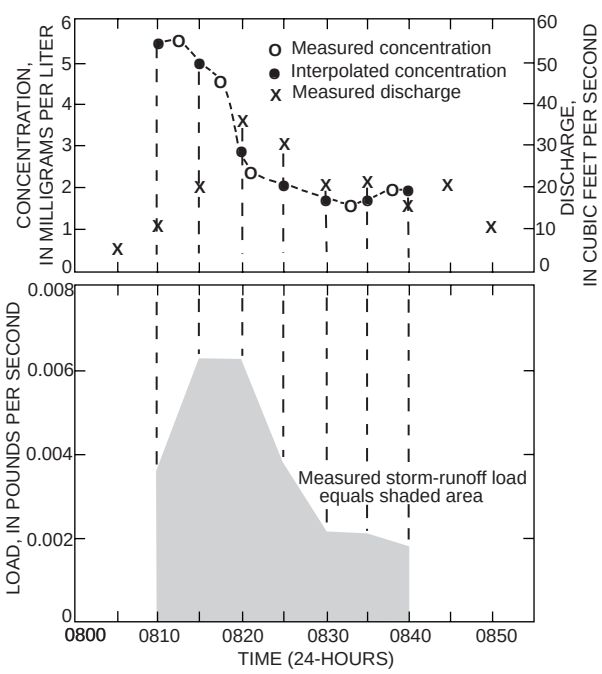

Figure 13. Computation of measured storm-runoff loads (hypothetical example). (From Brabets, 1987.)

Loads were computed only if a sufficient number of samples were collected throughout the storm.

The computed suspended-sediment loads from rainfall periods ranged from 179 to 21,000 lb at watershed 1 and from 23 to 18,200 lb at watershed 2 (table 5). However, at site 3, suspended-sediment loads ranged from 8,450 to 530,000 lb. Comparing storms for which load data were available for all three sites (table 5) indicates that the load of suspended sediment transported past site 3 ranges from 5 to 20 times higher than the combined total load from watersheds 1 and 2. This large increase in suspended-sediment load in a relatively short reach of channel (1,000 ft) with no incoming tributaries indicates that most of the sediment is probably due to channel erosion between watersheds 1 and 2 and site 3.

For comparative purposes, the suspended-sediment yields (load per area) for the three sites were computed. The suspended-sediment yields from rainfall periods ranged from 8.4 to 760 (lb/acre)/in. of runoff at watershed 1, from 9.1 to 462 (lb/acre)/in. of runoff at watershed 2, and from 134 to 2,520 (lb/acre)/in. of runoff at site 3 (table 5). Variations in yield can be attributed to a number of factors. These may include antecedent precipitation conditions, rainfall intensity, storm duration, or seasonal variation. The average sediment yield from watershed 2, [100 (lb/acre)/in.], is higher than that from watershed 1, [78.3 (lb/acre)/in.], but the average yield from site 3, [705 (lb/acre)/in.] is more than three times as much as the combined yield of watersheds 1 and 2.

An insufficient number of suspended-sediment samples were collected during the snowmelt periods to compute suspended-sediment loads using the method used for rainfall periods. For the snowmelt periods of 1997 and 1998, the sediment-transport equations that were developed for snowmelt periods were used to compute a daily sediment load for watersheds 1, 2, and site 3. Using the transport

Table 5. Suspended-sediment loads and yields from rainfall periods for watersheds 1, 2, and site 3, Elmendorf Air Force Base, Alaska

[DA, drainage area; in., inch; lb, pound; (lb/acre)/in., pound per acre per inch; -- no data]

Date	**Watershed 1** (DA: 2,560 acres)			**Watershed 2** (DA: 410 acres)			**Site 3** (DA: 2,970 acres)		
	Runoff (in.)	Suspended-sediment load (lb)	Suspended-sediment yield [(lb/acre)/in.] of runoff	Runoff (in.)	Suspended-sediment load (lb)	Suspended-sediment yield [(lb/acre)/in.] of runoff	Runoff (in.)	Suspended-sediment load (lb)	Suspended-sediment yield [(lb/acre)/in.] of runoff
8-22-96	0.014	1,300	35.6	--	--		--	--	--
8-25-96	.002	179	35.0	0.005	23	11.2	--	--	--
8-31-96	.003	277	36.1	--	--	--	--	--	--
9-11-96	--	--	--	.005	23	11.2	--	--	--
9-15-96	.014	958	26.7	.038	445	28.6	--	--	--
9-21-96	.017	922	21.2	.061	545	21.8	--	--	--
9-25-96	.014	1900	53.2	.088	2,250	62.4	--	--	--
9-27-96	.007	379	21.1	.034	390	28.0	--	--	--
5-17-97	--	--	--	.011	886	196	--	--	--
5-30-97	.039	16,700	167	.088	5,570	154	0.046	117,000	858
6-6-97	.007	854	47.6	.011	245	54.3	--	--	--
6-19-97	.018	910	19.7	.029	108	9.1	.019	20,000	345
6-22-97	.007	13,600	760	--	--	--	--	--	--
7-10-97	.046	1,200	10.0	--	--	--	--	--	--
7-12-97	--	--	--	--	--	--	.049	19,500	134
7-13-97	.006	250	16.3	--	--	--	.006	8,450	434
7-14-97	.019	421	8.6	.062	4,480	176	.025	86,200	1,160
7-24-97	.018	13,000	280	--	--	--	.025	185,400	2,520
8-9-97	.067	4,500	26.4	--	--	--	.061	75,900	418
8-11-97	.040	2,220	21.7	.011	734	163	.036	30,100	281
8-15-97	.011	1,250	44.5	.023	216	22.9	.013	26,300	700
8-21-97	.307	21,000	26.7	.096	18,200	462	.278	530,000	642
8-31-97	.316	8,750	10.8	--	--	--	--	--	--
9-9-97	.028	606	8.4	--	--	--	--	--	--
9-17-97	.013	2,000	60.1	--	--	--	.012	9,509	254
9-18-97	.037	5,960	62.9	--	--	--	--	--	--
Average			**78.3**			**100**			**705**

equations is not as accurate as the method used for the rainfall periods because the equations represent an average rather than a discrete sample at a particular time. However, the daily loads were computed to make some general comparisons with the loads computed from the rainfall periods.

During the 1997 and 1998 snowmelt periods, daily suspended-sediment loads ranged from 80 to 1,500 lb at watershed 1 and from 2 to 1,170 lb at watershed 2. At site 3, daily suspended-sediment loads ranged from 1,340 to 17,400 lb. On some days, the daily load of suspended sediment during the snowmelt period (table 6) was higher than the suspended-sediment load for a particular rainfall (table 5). Comparing the average load for the two snowmelt periods indicates that the load transported past site 3 is approximately 10 times higher than the combined load past watersheds 1 and

Table 6. Suspended-sediment loads and yields from snowmelt periods for watersheds 1, 2, and site 3, Elmendorf Air Force Base, Alaska

[DA, drainage area; in., inch; lb, pound; (lb/acre)/in., pound per acre per inch]

Date	**Watershed 1** (DA: 2,560 acres)			**Watershed 2** (DA: 410 acres)			**Site 3** (DA: 2,970 acres)		
	Runoff (in.)	Suspended-sediment load (lb)	Suspended-sediment yield [(lb/acre)/in.] of runoff	Runoff (in.)	Suspended-sediment load (lb)	Suspended-sediment yield [(lb/acre)/in.] of runoff	Runoff (in.)	Suspended-sediment load (lb)	Suspended-sediment yield [(lb/acre)/in.] of runoff
3-28-97	0.006	318	20.7	0.029	146	12.3	0.009	5,720	210
3-29-97	.011	361	12.8	.029	146	12.3	.013	5,720	143
3-30-97	.010	318	12.4	.030	152	12.4	.013	5,720	151
3-31-97	.005	134	10.5	.005	6	2.9	.005	2,200	148
4-1-97	.002	80	15.6	.000	0	0	.002	1,340	261
4-2-97	.010	318	12.4	.029	146	12.3	.013	5,720	152
4-3-97	.010	318	12.4	.015	47	7.6	.011	4,840	152
4-4-97	.006	157	10.2	.004	5	3.0	.006	2,200	129
4-5-97	.010	279	10.9	.015	47	7.6	.011	4,060	128
4-6-97	.007	183	10.2	.012	32	6.5	.008	3,040	133
4-7-97	.018	790	17.1	.035	206	14.4	.020	10,900	180
4-8-97	.021	1,160	21.5	.055	464	20.6	.026	17,400	228
4-9-97	.025	1,510	23.5	.010	24	5.8	.023	13,100	192
4-10-97	.021	1,060	19.6	.002	2	2.4	.018	8,930	164
4-11-97	.016	642	15.7	.000	0	0	.014	6,190	151
4-12-97	.012	408	13.3	.000	0	0	.010	4,440	144
4-13-97	.017	713	16.4	.006	9	3.6	.016	7,210	157
1997 average		**515**	**15.0**		**84.2**	**7.3**		**6,400**	**166**
3-16-98	.010	279	10.9	.028	140	12.2	.012	4,840	130
3-17-98	.005	134	10.5	.025	114	11.1	.008	3,040	132
3-18-98	.013	459	13.8	.093	1,170	30.6	.024	13,100	183
3-19-98	.007	183	10.2	.031	169	13.3	.010	4,060	132
3-20-98	.010	318	12.4	.052	419	19.6	.016	8,330	177
3-21-98	.014	515	14.4	.042	282	16.4	.018	8,930	168
3-22-98	.010	279	10.9	.028	135	11.7	.012	4,840	131
3-23-98	.012	408	13.3	.049	368	18.3	.017	8,330	164
3-24-98	.009	244	10.6	.023	100	10.6	.011	4,440	137
3-25-98	.010	318	12.4	.026	125	11.7	.012	5,270	145
3-26-98	.008	212	10.4	.000	0	0	.007	3,040	148
3-27-98	.007	183	10.2	.000	0	0	.006	2,740	153
3-28-98	.007	183	10.2	.000	0	0	.006	2,460	137
3-29-98	.008	212	10.4	.012	29	6.0	.008	3,360	132
3-30-98	.008	212	10.4	.000	0	0	.007	3,040	148
3-31-98	.007	183	10.2	.000	0	0	.006	2,460	137
4-1-98	.008	212	10.4	.014	38	6.6	.009	3,360	128
4-2-98	.007	183	10.2	.000	0	0	.006	2,460	137
4-3-98	.010	318	12.4	.022	86	9.5	.012	4,840	140
4-4-98	.015	576	15	.010	19	4.6	.014	6,690	157
4-5-98	.013	459	13.8	.000	0	0	.011	5,270	158
4-6-98	.012	408	13.3	.000	0	0	.010	4,440	144
1998 average		**294**	**11.6**		**14.5**	**8.0**		**4,970**	**146**

2. Similar to the rainfall periods, the higher sediment load at site 3 is probably due to the erosion of the channels downstream from the outfalls of watersheds 1 and 2. On a yield basis, the average suspended-sediment yield is higher during rainfall periods (table 5) than during snowmelt periods (table 6) for all three sites.

FLOOD-FREQUENCY CHARACTERISTICS

Long-term runoff records are not available for watersheds 1 and 2. To conduct a reliable flood-frequency analysis, flow records need to be extended in time to provide a larger data base. Several rainfall-runoff computer models have been developed that can synthesize peak flows and storm runoff volumes. For this study, the Distributed Routing Rainfall-Runoff Model—Version II (referred to as DR3M-II), developed by Alley and Smith (1982a) was utilized to synthesize the flow record for additional years at watersheds 1 and 2. No attempts were made to synthesize long-term runoff from snowmelt periods, primarily because most design criteria for sedimentation basins and culverts are based on runoff from rainfall.

Rainfall-Runoff Modeling

The DR3M-II is a deterministic model designed to simulate urban storm rainfall-runoff processes. The basic concept of DR3M-II is to divide a watershed into subbasins, called "overland flow segments," each with its own distinct physical characteristics. A channel network, which represents the drainage pattern of the watershed, is also developed. The overland flow segments and channel network are then combined to model the entire basin. In this study, watershed 1 was divided into 37 overland-flow segments and 27 channel segments (fig. 14, table 7) and watershed 2 was divided into 22 overland-flow segments and 24 channel segments (fig. 15, table 8).

Physical characteristics of the overland-flow segments and channel network such as slope, roughness, length, geometry, and effective impervious area serve as input to DR3M-II, along with unit rainfall, unit discharge, and daily rainfall. Soil moisture accounting, infiltration, and runoff parameters, which can be adjusted, also serve as input (table 9). Kinematic wave theory is used to route runoff across overland-flow segments and through the defined channel network to the outfall of the watershed. Three types of kinematic routing solutions are available (Alley and Smith 1982a): the method of characteristics, the implicit finite difference method, and the explicit finite difference method. For this study, the method of characteristics was chosen, because it was believed to be most applicable to watersheds 1 and 2, which are relatively small and have short routing lengths.

Calibration and Verification Procedures

The first step in the calibration and verification of DR3M-II was to assemble all the necessary rainfall and flow data for watersheds 1 and 2. Although somewhat arbitrary, it was decided to use only storms in which the rainfall totaled 0.10 in. or more because no significant amount of runoff occurred for storms less than 0.10 in. of rainfall. Using this criterion, 30 storms were chosen for watershed 1 and 22 storms were chosen for watershed 2. Approximately half the storms were used for calibration and the remaining half for verification. The selection of storms used for calibration and for verification was somewhat random, but efforts were made to ensure that the storms used in calibration had the same characteristics as those used in verification. For example, the two largest storms during the study period occurred on August 21 and August 31, 1997. Thus, one storm was used in the calibration process (August 31) and one storm in the verification process (August 21).

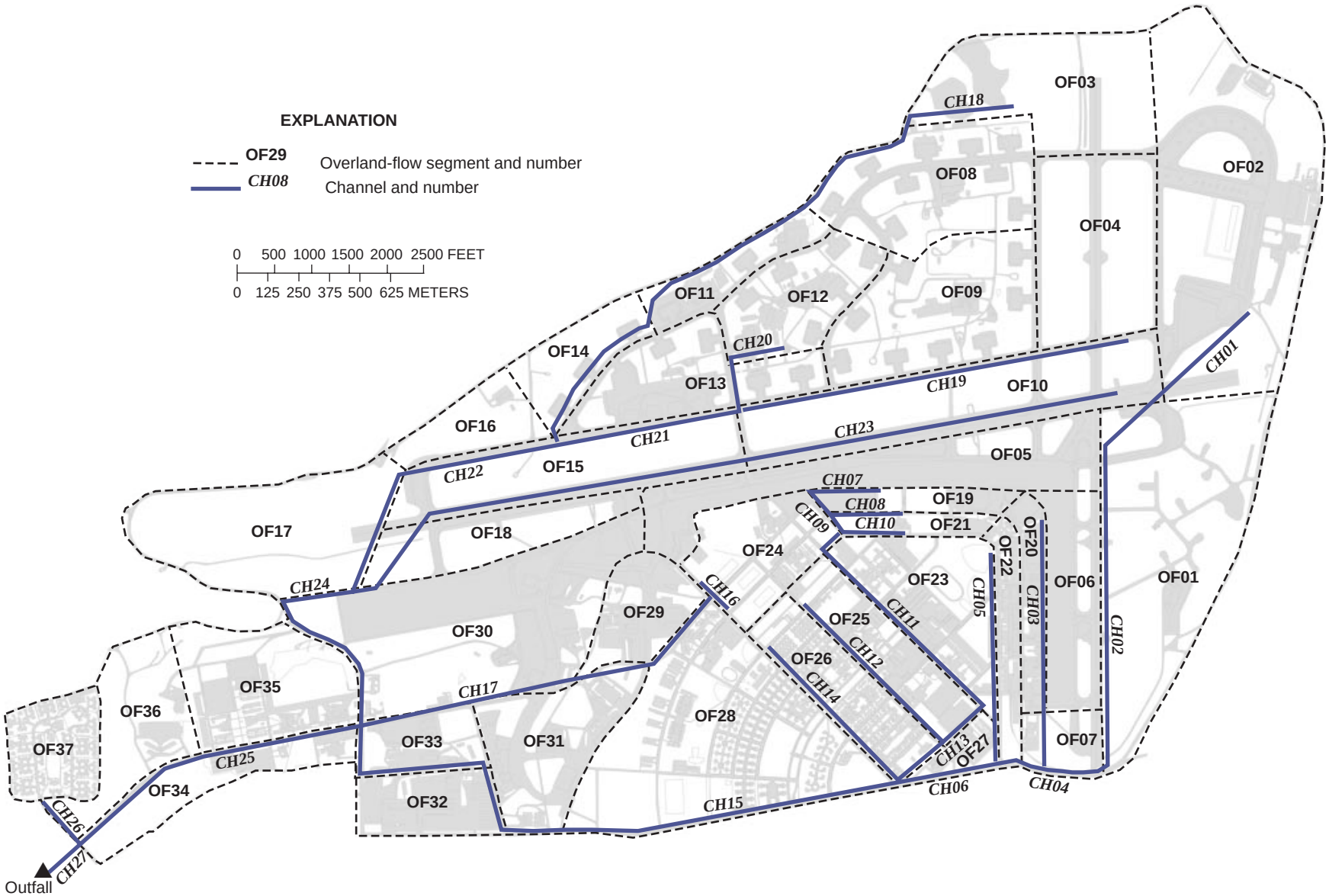

Figure 14. Overland-flow and channel segments of watershed 1, Elmendorf Air Force Base, Alaska, for DR3M - II.

Table 7. Overland-flow and channel segment characteristics of watershed 1 used for input of DR3M-II, Elmendorf Air Force Base, Alaska

Overland-flow segment					Channel segment			
Name (fig. 14)	Area (acres)	Impervious area (acres)	Length (feet)	Slope (foot/foot)	Name (fig. 14)	Length (feet)	Slope (foot/foot)	Roughness
OF01	158.7	22.6	1,871	0.008	CH01	2,640	0.008	0.024
OF02	200.8	80.5	3,314	.008	CH02	3,696	.004	.024
OF03	101.4	6.8	532	.036	CH03	1,109	.004	.011
OF04	92.6	20.3	722	.008	CH04	845	.004	.011
OF05	85.1	67.7	1,035	.008	CH05	2,851	.003	.011
OF06	50.4	40.5	1,983	.010	CH06	1,478	.003	.011
OF07	22.2	9.0	1,148	.010	CH07	3,590	.004	.011
OF08	97.8	36.7	513	.009	CH08	1,531	.004	.011
OF09	102.2	13.6	797	.008	CH09	422	.004	.011
OF10	116.0	47.8	455	.006	CH10	634	.003	.011
OF11	30.4	18.1	161	.006	CH11	4,277	.004	.011
OF12	56.4	20.7	1,792	.006	CH12	2,640	.006	.011
OF13	68.8	41.6	1,138	.004	CH13	845	.003	.011
OF14	37.7	8.9	199	.077	CH14	2,430	.004	.011
OF15	105.3	50.5	414	.006	CH15	8,500	.006	.011
OF16	30.3	2.8	331	.033	CH16	739	.006	.011
OF17	110.7	7.5	1,205	.022	CH17	6,600	.004	.011
OF18	39.4	6.3	156	.025	CH18	8,342	.006	.024
OF19	19.7	7.7	562	.004	CH19	5,597	.007	.024
OF20	8.6	6.8	340	.006	CH20	1,373	.006	.024
OF21	17.1	8.8	1,177	.004	CH21	2,640	.004	.024
OF22	29.0	21.1	444	.008	CH22	4,013	.004	.024
OF23	70.2	13.8	718	.014	CH23	11,141	.006	.024
OF24	53.8	13.5	3,170	.007	CH24	3,750	.004	.024
OF25	51.3	8.3	848	.010	CH25	4,224	.004	.011
OF26	56.1	28.7	1,008	.010	CH26	634	.004	.011
OF27	14.4	7.9	426	.007	CH27	400	.004	.024
OF28	170.1	17.6	873	.012				
OF29	38.1	18.5	253	.007				
OF30	161.5	70.6	1,068	.010				
OF31	73.4	33.1	378	.006				
OF32	37.4	16.2	194	.008				
OF33	30.0	5.9	200	.005				
OF34	43.1	12.5	447	.017				
OF35	67.6	11.6	699	.006				
OF36	65.8	8.7	680	.012				
OF37	31.4	10.3	2,162	.040				
Total[a]	**2,545**							

[a]Represents area computed by DR3M-II, within 1 percent of actual area

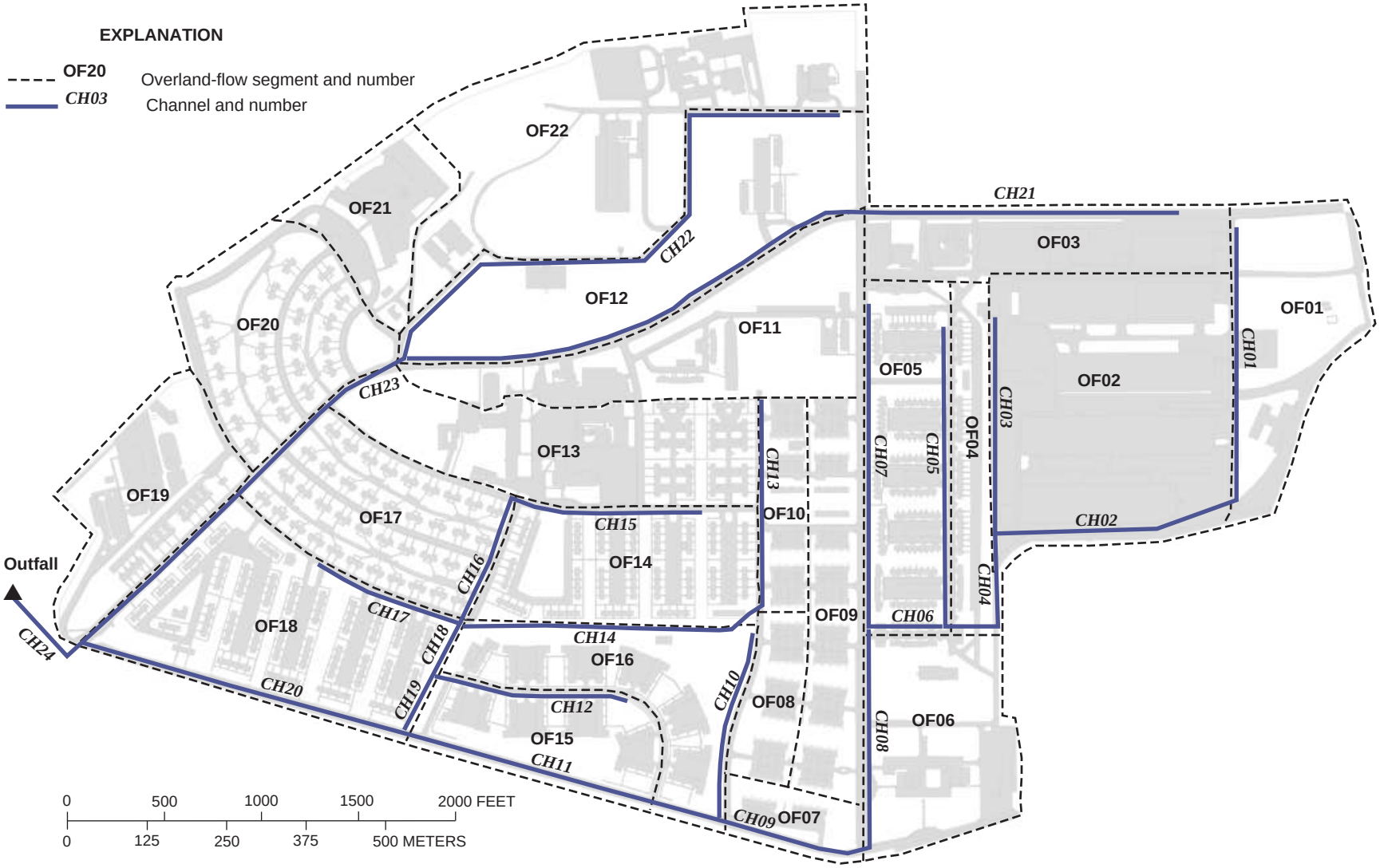

Figure 15. Overland-flow and channel segments of watershed 2, Elmendorf Air Force Base, Alaska, for DR3M - II.

Table 8. Overland-flow and channel segment characteristics of watershed 2 used for input of DR3M-II

Overland-flow segment					Channel segment			
Name (fig. 15)	Area (acres)	Impervious area (acres)	Length (feet)	Slope (foot/foot)	Name (fig. 15)	Length (feet)	Slope (foot/foot)	Roughness
OF01	18.6	0.0	509	0.004	CH01	1,550	0.004	0.024
OF02	36.9	29.0	1,037	.004	CH02	1,250	.004	.024
OF03	16.6	14.8	172	.004	CH03	1,200	.004	.025
OF04	8.1	3.6	295	.004	CH04	500	.004	.024
OF05	20.2	12.4	518	.012	CH05	1,700	.003	.011
OF06	17.5	4.3	1,525	.003	CH06	500	.003	.024
OF07	7.8	2.6	486	.004	CH07	1,750	.004	.011
OF08	15.1	8.4	750	.004	CH08	1,150	.004	.011
OF09	5.5	2.0	82	.004	CH09	700	.004	.011
OF10	5.0	1.7	168	.004	CH10	875	.003	.011
OF11	27.3	9.8	282	.006	CH11	1,650	.004	.011
OF12	30.2	5.1	312	.008	CH12	1,100	.006	.011
OF13	23.2	12.7	877	.012	CH13	1,300	.003	.011
OF14	23.4	7.8	887	.018	CH14	1,500	.004	.025
OF15	11.6	5.2	461	.012	CH15	1,150	.006	.011
OF16	12.6	3.0	500	.012	CH16	700	.006	.011
OF17	18.0	6.3	1,120	.006	CH17	1,250	.004	.011
OF18	29.2	13.1	1,018	.007	CH18	300	.004	.024
OF19	15.6	7.3	303	.006	CH19	300	.004	.011
OF20	19.7	7.3	381	.005	CH20	1,800	.002	.011
OF21	10.3	6.8	139	.005	CH21	4,225	.004	.011
OF22	36.6	5.9	495	.006	CH22	3,225	.004	.011
Total[a]	**409**				CH23	2,250	.004	.011
					CH24	400	.004	.024

[a]Represents area computed by DR3M-II, within 1 percent of actual area

Table 9. Definitions of parameters used in DR3M-II

[Modified from Alley and Smith, 1982a]

Parameter	Definition
	Soil moisture accounting
BMSN	Soil-moisture storage at field capacity, in inches.
EVC	A pan coefficient for converting measured pan evaporation to potential evaporation.
RR	The proportion of daily rainfall that infiltrates into the soil for the period of simulation, excluding days for which detailed rainfall-runoff simulations are performed.
	Infiltration
KSAT	The effective saturated value of hydraulic conductivity, in inches per hour.
PSP	Suction at wetting front for soil moisture at field capacity, in inches.
RGF	Ratio of suction at the wetting front for soil moisture at wilting point to that at field capacity.
	Runoff
ALPADJ	A calibration factor used to adjust the routing parameter α (alpha). The parameter α contains the effects of roughness, bed slope, and geometry
EAC	A multiplying factor to adjust the initial estimate of effective impervious area. Effective impervious areas are those impervious surfaces that are directly connected to the channel system.
IMP	The maximum depth of rainfall held in irregularities in impervious surfaces and unable to run off, in inches.

After the rainfall, flow, overland-flow segment, and channel segment data were compiled, the following procedures were used to calibrate DR3M-II for both watersheds.

(1) The parameters IMP and EAC (table 9) were optimized using only storms for which runoff is largely from the effective impervious area of the watershed. These types of storms had between 0.11 and 0.17 in. of rain and because runoff is assumed to be only from the effective impervious area, the soil moisture accounting and infiltration parameters are not adjusted. The general procedure for optimizing IMP and EAC is to determine the maximum depth of retention on impervious surfaces, IMP, for each watershed by use of the following equation:

$$IMP = (RF)(EIA) - (VOL)$$

where

RF is total rainfall, in inches;
EIA is effective impervious area, as a decimal fraction; and
VOL is volume of runoff, in inches.
Average *IMP* for each station equals

$$\frac{\Sigma IMP}{\text{Number of storms for the station}}$$

The average value of *IMP* was entered into the model and parameter EAC optimized. If the optimized value of EAC was greater than 1.00, the model is indicating that the amount of effective impervious area input to the model needs to be increased. If the optimized value of EAC was less than 1.00, the model is indicating that the amount of effective impervious area input to the model needs to be decreased. Thus, the goal of this procedure is to adjust the value of effective impervious area and IMP until the optimized value of EAC remains at 1.00.

(2) The model was calibrated for runoff volumes by optimizing the soil moisture accounting and soil infiltration parameters (table 9). In order to optimize these parameters correctly, only storms in which 0.50 in. or more of rainfall occurred were used, because it was believed that at least 0.50 in. of rain was needed for pervious runoff to occur. Alley and Smith (1982a) suggest ranges in values for these parameters, which were used in this study.

(3) After calibration of runoff volume was complete, the model was run to calibrate peak discharge and hydrograph timing. This was accomplished by adjusting the factor ALPADJ (table 9), which modifies the roughness and slope of channel and overland-flow segments. A value of ALPADJ greater than 1.0 effectively increases the slope and decreases the roughness, resulting in an increased peak flow and decreased time to the peak. Values of ALPADJ less than 1.0 produce the opposite results.

The simulation errors during the calibration process were summarized using the median absolute deviation (MAD), in percent:

$$\text{MAD} = 100 \text{ x } \{\text{median}|e_i|\}$$

where e_i is $\frac{(x_i - \hat{x}_i)}{x_i}$ and

x_i and $\hat{x}_i$ are the ith measured and simulated values, respectively.

The MAD statistic was used to summarize errors for two reasons: (1) the MAD statistic has the advantage of being insensitive to outliers (Alley, 1986), and (2) comparisons could be made with Alley's study (1986), which summarized MAD statistics for calibration and verification of DR3M at 37 catchments. If the MAD statistics were comparable to the results from Alley's study, it was believed that the model was sufficiently calibrated and verified. If the MAD statistics were not comparable to Alley's study, the calibration procedure was repeated.

Before the re-calibration procedure began, input data were rechecked and reasonable adjustments to parameters—such as the slope and roughness of the overland-flow and channel segments—were made.

Results

For both watersheds in the calibration of EAC, the model indicated that the amount of effective impervious area needed to be decreased. The fact that the amount of effective impervious area needed to be changed was not unexpected because any approach used to determine effective impervious area is subjective. For example, it is often difficult to determine which part of a house roof is effective impervious area, particularly for houses with a downspout close, but not connected, to a driveway. Streets without curbs and gutters also present a problem. From the original estimates of 1.0 mi^2 and 0.22 mi^2 of effective impervious area for watersheds 1 and 2, the final values used were 0.28 mi^2 and 0.08 mi^2, respectively. For watershed 1, most of the difference was due to changing the runway area from effective impervious area to non-effective impervious area. For watershed 2, the major difference was due to changing the housing areas (roofs, sidewalks) from effective impervious area to non-effective impervious area. The final values for IMP were 0.07 and 0.08 in. respectively, for watersheds 1 and 2 (table 10).

In calibrating the soil moisture accounting and infiltration parameters, EVC and RR did not have any effect on the model output and were left unchanged (table 10). The remaining parameters did affect the runoff volumes and the final values of these parameters were different from the initial estimates. Values for parameters BMSN, KSAT, PSP, and RGF were higher for watershed 1 than for watershed 2, most likely because watershed 1 has the larger amount of pervious area. All values for soil moisture accounting and infiltration were within the ranges recommended by Alley and Smith (1982a).

Table 10. Final values for selected parameters for DR3M-II
[See table 9 for definition of parameters]

Parameter	Watershed 1	Watershed 2
Soil moisture accounting		
BMSN	5.20	2.20
EVC	.75	.75
RR	.71	.71
Infiltration		
KSAT	.40	.18
PSP	1.10	.51
RGF	7.80	5.10
Runoff		
ALPADJ	1.00	1.30
EAC	1.00	1.00
IMP	.07	.08

The final model runs for the calibration and verification of runoff volumes for watersheds 1 and 2 were fairly consistent with Alley (1986) (tables 11-14). The MAD statistics were 22 and 23 percent respectively, for calibration and verification for watershed 1, and 20 and 18 percent, respectively, for calibration and verification for watershed 2. Alley's value of 19 percent for calibration is somewhat lower than the values determined for both watersheds, but the verification values for both watersheds are lower than Alley's value of 24 percent. Efforts were made to further lower the MAD statistics for runoff volume at both watersheds, but no realistic or acceptable adjustments to the parameters could be found. However, the final MAD statistics were believed to be acceptable and the model was considered to be calibrated and verified for runoff volume.

The final values for ALPADJ were 1.00 for watershed 1 and 1.30 for watershed 2 (table 10), within the limits recommended by Alley and Smith (1982a). Comparisons between observed and simulated discharges for water-

Table 11. Summary of DR3M-II calibration results for watershed 1, Elmendorf Air Force Base, Alaska

[in., inch; ft^3/s, cubic feet per second; MAD, median absolute deviation]

Storm date	Rainfall (in.)	Runoff volume			Peak flow		
		Observed (in.)	Simulated (in.)	$\left\lvert\frac{Obs-Sim}{Obs}\right\rvert$	Observed (ft^3/s)	Simulated (ft^3/s)	$\left\lvert\frac{Obs-Sim}{Obs}\right\rvert$
1996							
8-10	0.36	0.013	0.019	46	5.2	6.8	31
8-25	.12	.003	.005	66	3.3	3.2	3
9-21	.37	.017	.020	13	16.5	15.1	8
9-25	.29	.014	.017	21	28.2	25.6	8
9-27	.17	.007	.008	14	5.8	4.4	29
1997							
5-17	.15	.005	.007	40	5.1	5.7	12
5-30	.57	.037	.036	3	27.7	25.1	9
7-10	.96	.044	.063	31	20.4	23.7	16
7-14	.25	.018	.014	22	23.9	18.4	23
7-24	.33	.017	.023	35	26.7	35.2	32
8-11	.52	.038	.032	16	24.4	19.3	21
8-15	.18	.011	.008	27	7.6	5.0	34
8-25	.14	.008	.007	12	1.7	9.9	7
8-31	2.37	.303	.280	8	48.3	(a)	--
9-17	.18	.012	.009	25	14.0	6.6	53
MAD				22			21
Alley (1986)				19			20

[a]Simulated peak discharge not used because of surcharging

shed 1 (fig. 16) showed that peak discharges were similar; however, the timing of the peak discharges did not always coincide. For watershed 2, comparisons between observed and simulated discharges showed good agreement in the shape of the hydrographs (fig. 17). Simulated peak discharges were variable: some were higher and some were lower than the observed peaks. In general, the timing of the simulated peak discharges coincided with that of the observed peak discharges. The MAD statistics for calibration and verification for both watersheds for peak discharges were the same or below those of Alley's (tables 11-14), and thus the model was assumed to be fully calibrated and verified for peak discharge.

One notable output feature of DR3M-II was the indication of **surcharging** at watershed 1 channel segments 4 and 9 during the storms of August 21 and 31, 1997. DR3M-II will indicate surcharging when the capacity of circular-pipe segments is exceeded. DR3M-II does not account for pressurized flow in pipes and thus the actual discharge occurring in the pipe is probably higher than the discharge indicated by the model. When surcharging occurs, the model "stores" the water arriving at the upstream end of the segment in excess of the segment capacity. The volume stored increases without upper limit as the upstream inflow exceeds segment capacity. After the upstream inflow drops below segment capacity, the volume stored is

Table 12. Summary of DR3M-II verification results for watershed 1, Elmendorf Air Force Base, Alaska

[in., inch; ft^3/s, cubic feet per second; MAD, median absolute deviation]

Storm date	Rainfall (in.)	Runoff volume			Peak flow		
		Observed (in.)	Simulated (in.)	$\left\lvert\frac{\text{Obs-Sim}}{\text{Obs}}\right\rvert$	Observed (ft^3/s)	Simulated (ft^3/s)	$\left\lvert\frac{\text{Obs-Sim}}{\text{Obs}}\right\rvert$
1996							
8-22	0.33	0.015	0.018	20	12.6	14.8	17
8-31	.13	.003	.003	0	6.0	3.4	43
9-15	.27	.015	.013	13	13.3	12.0	10
9-21	.20	.007	.009	28	8.4	7.7	8
9-27	.11	.006	.005	17	9.5	5.2	45
1997							
5-14	.17	.005	.007	40	5.0	5.1	2
6-19	.38	.017	.021	23	9.0	9.3	3
7-14	.25	.018	.014	22	23.9	18.0	25
8-9	.77	.064	.047	26	31.2	23.1	26
8-12	.50	.043	.032	26	3.9	26.2	15
8-21	2.26	.294	.319	8	60	(a)	--
8-26	.56	.055	.043	22	33.1	33.1	0
9-9	.22	.026	.011	58	8.8	3.8	56
9-18	.27	.036	.021	42	28.8	29.1	1
9-21	.11	.008	.005	38	8.0	4.9	38
MAD				23			17
Alley (1986)				24			21

[a]Simulated peak discharge not used because of surcharging

released to the segment. The upstream inflow to the segment remains at the maximum capacity until the water stored at the upper end of that segment has been released. In summary, when surcharging occurs, the volume of runoff water is not lost by the model, but the simulated peak discharges may be in error because the model does not account for pressurized flow in pipes.

Flood-Frequency Analysis

A flood-frequency analysis defines the relation of flood magnitude to exceedence probability or to recurrence interval. A 50-year recurrence interval flood is a discharge that will be exceeded, on average, once every 50 years, or, in other words, it has a 0.02 probability of being exceeded in a given year. The occurrence of a 50-year flood in one year does not exclude the possibility that a flood of equal or greater magnitude will occur in the following year.

Method

After DR3M-II was calibrated and verified, it was used to generate annual peak flows and volumes for a long-term period. This was accomplished by obtaining long-term precipitation data from the site at the Anchorage International Airport. Data were used from this site because they were available in both an hourly format and a daily format. Long-term daily evaporation data from a site at Palmer, about 40 mi from Elmendorf Air Force Base, were available and also used.

Table 13. Summary of DR3M-II calibration results for watershed 2, Elmendorf Air Force Base, Alaska

[in., inch; ft^3/s, cubic feet per second; MAD, median absolute deviation]

Storm date	Rainfall (in.)	Runoff volume			Peak flow		
		Observed (in.)	Simulated (in.)	$\left\lvert\frac{Obs-Sim}{Obs}\right\rvert$	Observed (ft^3/s)	Simulated (ft^3/s)	$\left\lvert\frac{Obs-Sim}{Obs}\right\rvert$
1996							
8-10	0.37	0.043	0.037	14	3.7	1.9	49
8-25	.12	.005	.009	80	.7	1.8	71
8-30	.19	.010	.017	70	2.1	2.2	5
9-21	.37	.057	.043	30	9.2	5.6	38
9-25	.29	.053	.058	9	18.5	2.2	9
1997							
5-14	.17	.015	.015	0	2.2	2.0	9
5-30	.53	.088	.091	3	14.4	13.0	17
7-10	.78	.071	.099	39	6.9	5.0	28
7-14	.25	.062	.050	20	2.0	21.6	8
8-9	.37	.024	.042	75	6.6	7.1	8
8-15	.18	.023	.019	17	2.5	1.7	32
MAD				20			17
Alley (1986)				19			20

Table 14. Summary of DR3M-II verification results for watershed 2, Elmendorf Air Force Base, Alaska

[in., inch; ft^3/s, cubic feet per second; MAD, median absolute deviation]

Storm date	Rainfall (in.)	Runoff volume			Peak flow		
		Observed (in.)	Simulated (in.)	$\left\lvert\frac{Obs-Sim}{Obs}\right\rvert$	Observed (ft^3/s)	Simulated (ft^3/s)	$\left\lvert\frac{Obs-Sim}{Obs}\right\rvert$
1996							
8-22	0.56	0.084	0.100	16	20.9	16.0	23
8-29	.12	.020	.013	35	8.2	3.5	57
9-15	.27	.038	.027	29	7.0	5.6	20
9-21	.31	.036	.040	11	9.0	9.0	0
9-27	.17	.034	.016	53	4.4	1.6	63
1997							
5-17	.15	.011	.013	18	2.3	2.1	9
6-6	.15	.011	.013	18	2.6	2.4	9
6-19	.38	.029	.038	31	3.0	2.8	7
7-24	.33	.067	.068	1	28.0	33.9	21
8-12	.39	.081	.045	44	7.5	5.0	33
8-21	.63	.096	.109	13	23.0	23.7	3
MAD				18			20
Alley (1986)				24			21

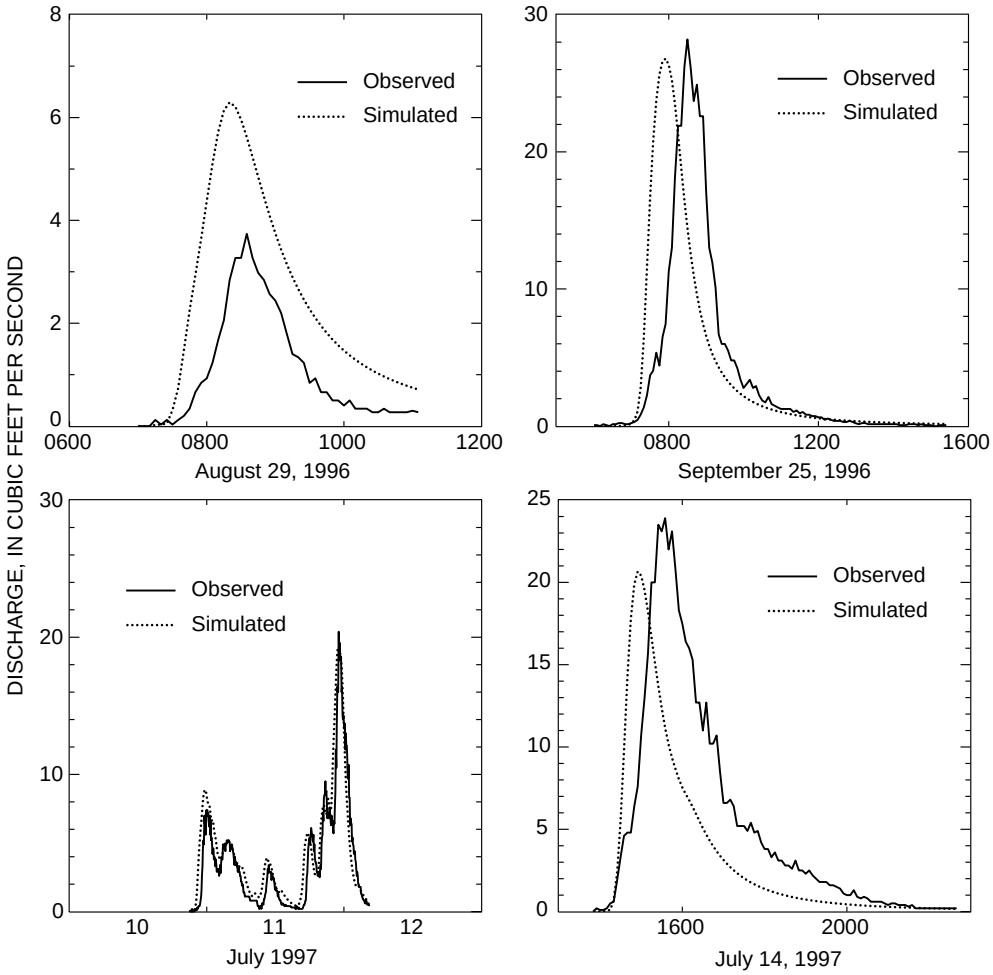

Figure 16. Observed and simulated discharges for various storms at watershed 1, Elmendorf Air Force Base, Alaska.

Peak discharges and storm runoff volumes were generated for the period 1981-95. For the simulation period, 10 to 22 rainfall periods were used as input to the DR3M-II. A rainfall period was chosen as input to the DR3M-II if more than 0.30 in. of rain fell. The model determined the peak discharge and runoff volume for each rainfall period, and the highest discharge and volume simulated by the model each water year was considered as the annual peak flow and peak volume of runoff. The peak discharges and runoff volumes for the 1981-95 period as well as the 1996-97 values were then analyzed according to the guidelines published in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) to determine flood-frequency statistics for the two watersheds.

Results

For both watersheds, many of the simulated storms indicated that surcharging took place during the particular storm (tables 15-16). The storms during which no surcharging took place had peak discharges and runoff volumes similar to those that were recorded during the study period. It is uncertain whether or not surcharging indicated by the model at a particular channel segment actually occurred or if pressurized flow occurred instead. If pressurized flow did occur in the pipe segments, the actual

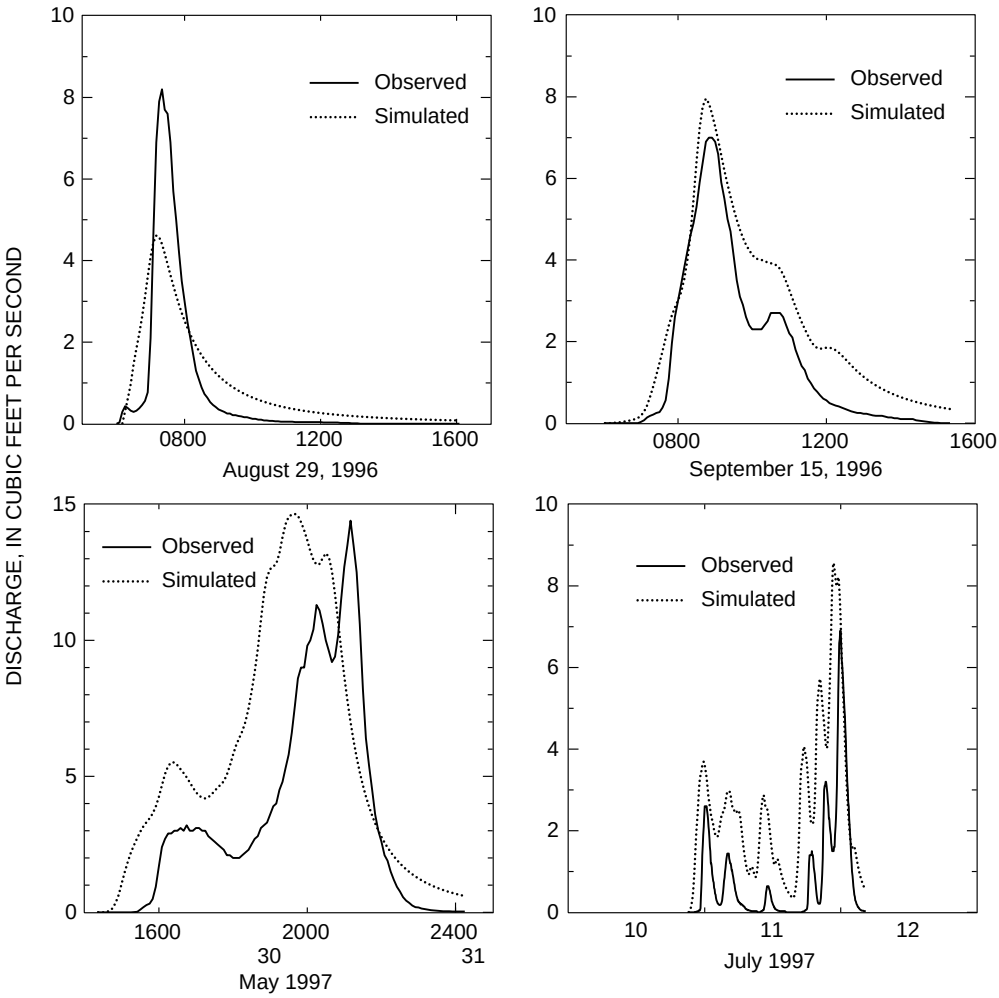

Figure 17. Observed and simulated discharges for various storms at watershed 2, Elmendorf Air Force Base, Alaska.

Figure 17. Observed and simulated discharges for various storms at watershed 2, Elmendorf Air Force Base, Alaska.

discharge would be higher than the predicted discharge. Because of this uncertainty, a flood-frequency analysis was not done for the peak discharges. However, since DR3M-II adequately accounts for the volume of runoff even if surcharging occurs, the flood volumes were analyzed using flood-frequency techniques.

The simulated runoffs were analyzed using techniques described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). On the basis of this analysis, storm runoffs and their associated recurrence intervals were determined (table 17).

The values produced by the flood-frequency analysis are reasonable. A higher percentage of runoff occurred during the study period at watershed 2 than at watershed 1 (table 17). The analysis also indicated that the runoff from the storm of 1989 was approximately a 100-year flood, which agrees with the observations made at several USGS gaging stations in the Anchorage area (U.S. Geological Survey, 1990). Thus, these values could be used as a guide in properly designing a sedimentation basin to accommodate a flood of a particular recurrence interval.

Table 15. Simulated runoff volumes and peak discharges, 1981-95, watershed 1, Elmendorf Air Force Base, Alaska

[in., inch; ft^3/s, cubic feet per second; --, peak discharge not listed because of surcharging]

Year	Storm rainfall (in.)	Runoff volume (in.)	Peak discharge (ft^3/s)	Remarks
1981	0.80	0.114	--	Surcharging at channel segments 4, 6
1982	1.28	.133	--	Surcharging at channel segments 4, 6
1983	.46	.037	35	No surcharging
1984	1.64	.158	--	Surcharging at channel segments 4, 6, 9
1985	.66	.088	--	Surcharging at channel segments 4, 6, 9
1986	.96	.083	--	Surcharging at channel segments 4, 6, 9
1987	.36	.068	40	No surcharging
1988	.79	.057	--	Surcharging at channel segments 4, 6
1989	6.05	2.17	--	Surcharging at many channel segments
1990	1.12	.162	--	Surcharging at channel segments 4, 6, 9
1991	1.41	.157	--	Surcharging at channel segments 4, 6, 9
1992	1.16	.111	--	Surcharging at channel segments 4, 6
1993	.57	.098	--	Surcharging at channel segments 4, 6, 9
1994	.87	.076	--	Surcharging at channel segments 4, 6
1995	.97	.071	30	No surcharging
1996	.29	.014	28	Recorded at gage
1997	2.69	.294	60	Recorded at gage

Table 16. Simulated runoff volumes and peak discharges, 1981-95, watershed 2, Elmendorf Air Force Base, Alaska

[in., inch; ft^3/s, cubic feet per second; --, peak discharge not listed because of surcharging]

Year	Storm rainfall (in.)	Runoff volume (in.)	Peak discharge (ft^3/s)	Remarks
1981	0.80	0.306	--	Surcharging at channel segments 4, 6, 8, 9, 11
1982	1.28	.533	--	Surcharging at channel segments 8, 9, 11, 19
1983	.46	.093	24	No surcharging
1984	1.64	.665	--	Surcharging at many channel segments
1985	.66	.304	--	Surcharging at many channel segments
1986	.96	.281	--	Surcharging at many channel segments
1987	.36	.140	28	No surcharging
1988	.79	.143	--	Surcharging at channel segments 8, 9, 11, 19
1989	6.05	3.99	--	Surcharging at many channel segments
1990	1.12	.562	--	Surcharging at many channel segments
1991	1.41	.652	--	Surcharging at many channel segments
1992	1.16	.524	--	Surcharging at many channel segments
1993	.57	.289	--	Surcharging at many channel segments
1994	.87	.220	41	No surcharging
1995	.97	.219	30	No surcharging
1996	.29	.119	21	Recorded at gage
1997	2.69		(a)	

[a]No peak discharge determined for 1997 because of the destruction of the gage during the August 21 storm

Table 17. Storm runoffs and recurrence intervals, watersheds 1 and 2, Elmendorf Air Force Base, Alaska

Recurrence interval	Runoff (inches)	
	Watershed 1	Watershed 2
2-year	0.08	0.29
5-year	.20	.67
10-year	.39	1.10
25-year	.78	2.00

SUMMARY AND CONCLUSIONS

Runoff and suspended-sediment characteristics from the urbanized areas of Elmendorf Air Force Base indicate the following:

- Two watersheds compose most of the developed area of Elmendorf Air Force Base. Runoff from one basin, which is 4.0 mi^2 in area, averages about 6 percent of rainfall. Runoff from the second basin, which is about 0.64 mi^2 in area, averages about 13 percent of rainfall.
- The 2-year combined average of suspended-sediment yield for the two watersheds is about 180 (lb/acre)/in. of runoff during rainfall periods. The 2-year combined average of suspended-sediment yield for the two watersheds is about 21 (lb/acre)/in. of runoff during snowmelt periods.
- At the outfalls of the two basins, flow enters natural channels that have steep gradients. Suspended-sediment yields increase along this channel to more than three times as much as the sediment yields derived from the two urbanized basins. On a load basis, suspended-sediment transport ranges from 5 to 20 times the combined load from the two watersheds during rainfall periods and about 10 times the combined load during snowmelt periods.
- A rainfall-runoff model was calibrated and verified for the two developed watersheds. Using a 15-year period of rainfall, annual peak discharges and flood volumes for the two sites were determined from 1981 to 1995. Flood-frequency techniques were then used to determine flood volumes for various recurrence intervals. For a 10-year flood, 0.39 in. of runoff (averaged over the entire drainage basin) would occur from the large watershed and 1.10 in. of runoff would occur from the small watershed.

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GLOSSARY

Baseflow. Sustained or fair-weather runoff. In most streams, baseflow is composed primarily of groundwater flow.

Impervious area, effective. Impervious areas that are directly connected to the channel drainage system, and do not drain to pervious areas. Streets with curbs and gutters, roofs that drain onto driveways, and paved parking lots are examples of effective impervious areas.

Impervious areas, noneffective. Impervious areas that drain to pervious areas, such as roofs that drain onto lawns.

Rainfall runoff. That part of the water from a rainstorm that appears at the outlet of a drainage basin.

Snowmelt. Water from melting snow that appears at the outlet of a drainage basin.

Surcharging. A term used by the DR3M-II to indicate ponding or backwater. Surcharging occurs when the model routes flow though a pipe and the capacity of the pipe is exceeded