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Pacific Northwest National Laboratory
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Potential Groundwater Recharge from the Infiltration of Surface Runoff in Cold and Dry Creeks, Phase 2

SR Waichler

December 2005

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Prepared for
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Richland, Washington 99352

Summary

Runoff (streamflow) from Cold and Dry Creeks was studied as part of a larger effort to evaluate natural recharge to the Hanford Site. Natural recharge to the Site can take the form of direct infiltration of precipitation, lateral inflow of groundwater, and infiltration of streamflow. This report is concerned with the streamflow pathway and considers both historical runoff events and probabilistic extreme events. The observed runoff events were used to fit models of runoff generation, hydrograph shape, and channel infiltration. The models were then used to estimate the magnitude and location of potential recharge from several design storm events based on previous studies of maximum precipitation probability.

The Cold and Dry Creek watersheds were divided into upper, middle, and lower basins, based on the U.S. Geological Survey stream gauge locations described by Dinicola (1997). The upper basins are the primary areas of runoff generation, while the middle and lower basins are areas of infiltration. Hourly weather data and 15-minute streamflow data from January 1995, a period of significant runoff, were used to evaluate the meteorological conditions of the relatively rare runoff generation and to fit and calibrate the models. Frozen ground and melting snow appeared to play important roles in the runoff generation. Hydrographs of Cold and Dry Creeks indicated rapid cresting of streamflows and subsequent rapid recession, with 8 distinct events in Cold Creek. For each runoff event, the duration, volume, and volume of the causative precipitation were tabulated. Curve numbers were computed using the Soil Conservation Service method. A linear relationship between precipitation duration and streamflow duration was also derived. The curve numbers and duration relationship were subsequently used to estimate runoff and hydrograph shape from the design storms of maximum precipitation. A first-order decay model was fit to the observed streamflows at the upper and lower Cold Creek gauges and used to estimate the spatial pattern of infiltration of streamflow (recharge) resulting from the design storms. The double-triangle hydrograph model was also fit to the data and used to complete the characterization of runoff from the design storms.

Four hypothetical rainfall events (design storms) were used to drive the runoff and infiltration models: 1) 4.6 inches over 6 hours, 2) 1.61 inches over 24 hours, 3) 2.16 inches over 3 days, and 4) 2.71 inches over 7 days. The first value is the "probable maximum precipitation" from Skaggs and Walters (1981), and the latter three values from Wigmosta and Guensch (2005) correspond to a return period of 100 years. For comparison, the largest rainfall event during January 1995 was 1.02 inches over approximately 3 days. Combined Cold and Dry Creek recharge volumes for the 100-year rainfall events were 7,700 ac-ft, 11,700 ac-ft, and 15,900 ac-ft, respectively. These recharge volumes are 7 to 14 times the average annual recharge rate for surface runoff estimated by Dinicola (1997), and fall between two estimates of direct recharge from infiltrating rainfall and snowmelt for the entire Hanford Site: 6,680 ac-ft/y (Fayer and Walters 1995) and 14,467 ac-ft/y (Jacobsen and Freshley 1990). In Cold Creek, simulated streamflow and recharge volumes were largest just above the lower gage. In Dry Creek, simulated runoff volumes were largest at the upper gage, and recharge volumes are greatest in the ponding area downstream from the lower gage.

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Acronyms

ALE	Arid Lands Ecology Reserve
D	duration
HMS	Hanford Meteorological Station
PMP	probable maximum precipitation
Qp	peak flow rate
SCS	Soil Conservation Service
USGS	U.S. Geological Survey

1.0 Introduction

The hydraulic gradient in the upper unconfined aquifer is a key factor in determining the fate and transport of subsurface contaminants at the Hanford Site. This gradient is influenced by the location and amount of recharge from the ground surface. Natural recharge to the aquifer results from direct infiltration of rainfall and snowmelt and from the infiltration of surface runoff, primarily in ephemeral streams (Dinicola 1997). Most of the groundwater recharge from streamflow is thought to occur in Cold and Dry Creeks, located in the western portion of the Hanford Site (Figure 1). Annual recharge from this source was estimated by Dinicola (1997) to be 1,175 ac-ft/y. This source of groundwater recharge is of particular interest because of its role in maintaining the west-east hydraulic gradient in the unconfined aquifer between runoff events and temporarily increasing the gradient immediately after such events.

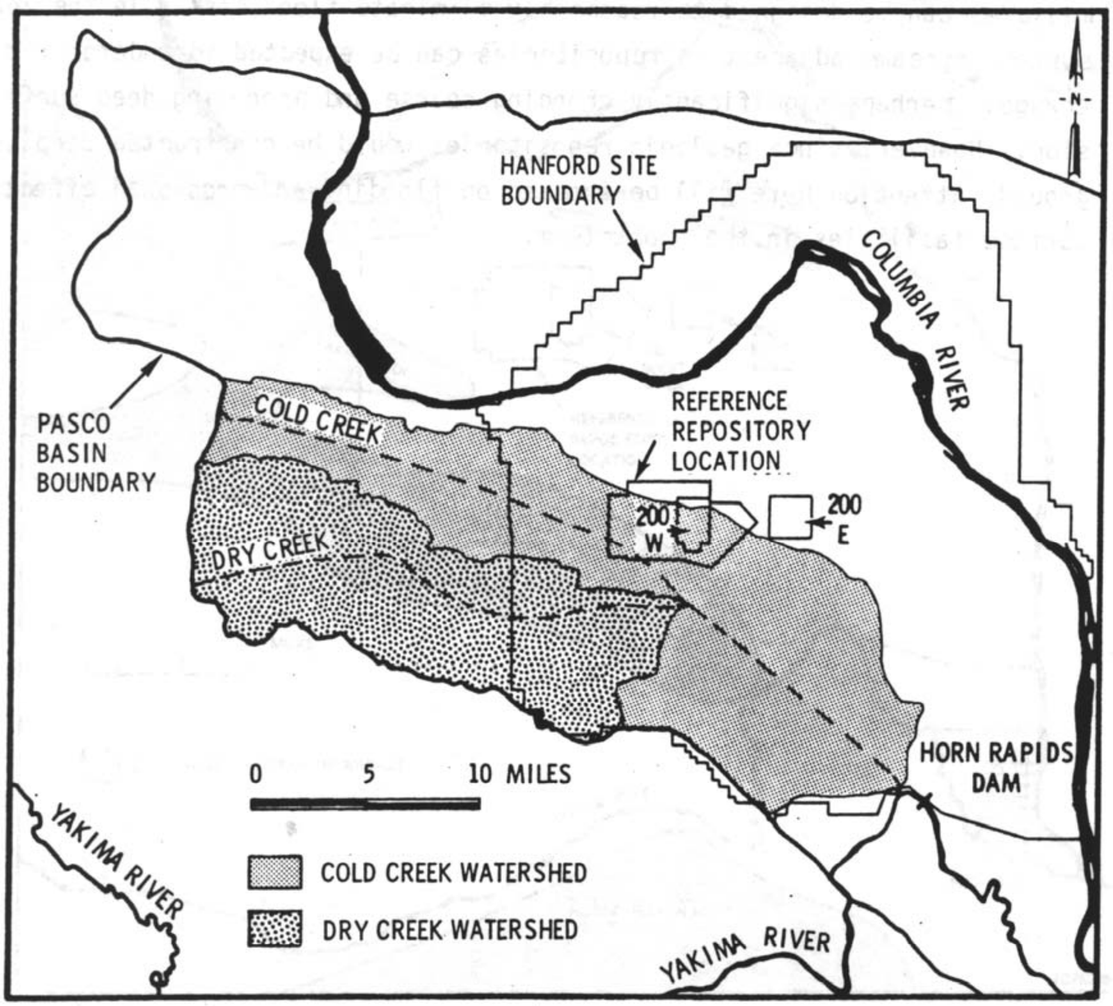


Figure 1. Location of Subwatersheds and Stream Gages in the Study Area

In Phase 1 of this study, Wigmosta and Guensch (2005) estimated potential runoff from the Cold and Dry Creek basins using two hypothetical precipitation events and the Soil Conservation Service (SCS) curve number approach (Soil Conservation Service 1972). For the probable maximum precipitation over 6 hours (4.6 inches, [Skaggs and Walters 1981]), they estimated a runoff volume of 7 to 11 times the annual recharge, depending on assumed curve number. A storm with a 100-year recurrence interval and 7-day duration had an estimated precipitation of 2.71 inches. and produced 3 to 5 times the annual recharge. The Phase 1 report concluded with a list of the key assumptions underlying the SCS curve number method and its application to Cold and Dry Creeks.

The purpose of this phase 2 study was to extend the work of Wigmosta and Guensch (2005). First, weather and high-resolution runoff data from storm events during January 1995 were analyzed in greater detail. Next, a simple runoff and recharge model was constructed from the SCS curve number and hydrograph methods and using an exponential-decay channel infiltration equation proposed by Lane et al. (1985). The model was then used to estimate the magnitude and location of potential recharge from several design storm events. A list of Phase 2 project files and directories are provided in the Appendix.

2.0 Description of Watersheds

The Cold and Dry Creek basins are defined by basalt ridges trending East-West, with the upper portions of the watersheds originating in the Yakima Firing Range and the lower portions lying in the Arid Lands Ecology Reserve (ALE). The upper elevations exceed 4000 ft, while the lower elevations near State Highway 240 are approximately 650 ft. This study was primarily concerned with four subwatersheds and corresponding U.S. Geological Survey (USGS) streamflow gages: 1) the area above Upper Cold Creek gage, 2) the area between Upper Cold and Lower Cold gages, 3) the area above Upper Dry Creek gage, and 4) the area between Upper Dry Creek and Lower Dry Creek gages (Figure 1, Table 1). For convenience, the areas above the upper gages are referred to as the upper basins, the areas between the gages are called the middle basins, and the areas downstream of the lower gages are called the lower basins. Stream reaches are similarly referred to as upper, middle, and lower.

Table 1. Subwatershed Evaluations and Areas in Upper Cold and Dry Creek Basins

Subwatershed	**Corresponding Gaging Station**	**Dinicola (1997) Subwatersheds**	**Min Elev**	**Mean Elev**	**Max Elev**	**Number GIS Gridcells**	**Area from GIS Coverage**	**Area from Dinicola (1997)**
			(ft)	**(ft)**	**(ft)**		**(mi^2)**	**(mi^2)**
Upper Cold	Upper Cold	COLD4 + COLD3	1428	2553	4108	71903	28.8	28.6
Middle Cold	Lower Cold	COLD2	942	1654	2838	29740	11.9	10.7
Lower Cold		COLD1						
Upper Dry	Upper Dry	DRY4	1109	2154	4203	156614	62.7	56.9
Middle Dry	Lower Dry	DRY3 + DRY2	663	1657	3648	166421	66.7	64.3
Lower Dry		DRY1						
Elevations determined from GIS digital elevation maps, grid resolution = 32.213 m.								

Downstream of the lower gages, no runoff generation from local uplands has been observed, but channel characteristics in these areas are of interest for infiltration of flows generated in the middle and upper basins. More information about the stream gaging stations can be found in Dinicola (1997). A field reconnaissance to all four subwatersheds and selected locations along the lower reaches was made on August 24, 2001 (with the exception of Upper Cold Creek, for which private land access was not available).

In Upper Cold Creek, soils are thin and runoff generation is more frequent than in Upper Dry Creek, which has deeper soils and more opportunity for tributary flow to infiltrate before reaching the main channel (Dinicola 1997). Alluvium thickness and channel infiltration potential both increase in Upper Cold Creek from approximately 1 mile upstream of Lower Cold gage down to the broad, flat valley that parallels Highway 240. The Lower Cold gage is located 50 yards north of the Highway 24 crossing. In Dry Creek, alluvium and infiltration potential appear to greatly increase at the Upper Dry gage, where the channel enters a much wider valley. Upper Dry gage is located 50 yards east of the Highway 241 bridge. For about a mile above Lower Dry gage, the channel is deeply incised, with walls 10 yards high and a distance across of about 40 yards. Lower Dry gage is located immediately downstream of

Rattlesnake Spring, which produces perennial flow of about 0.5 cfs (Dinicola 1997). The perennial flow supports a vibrant riparian community that fills the channel. The perennial flow is completely infiltrated into the Dry Creek bed at a point about one-quarter mile upstream of the Benson ranch site.

3.0 January 1995 Storm and Runoff Events

Model design and calibration in this study were based on hourly weather data and 15-minute streamflow data from January 1995. Three periods of January 1995 experienced relatively large rainfall and runoff (Figures 2-4). Air temperatures were close to freezing during part of the month, and Dinicola noted that frozen ground and melting snow appeared to play a role in producing runoff during these events[1]. Individual storm events of corresponding precipitation and runoff were defined for modeling purposes (Table 2).

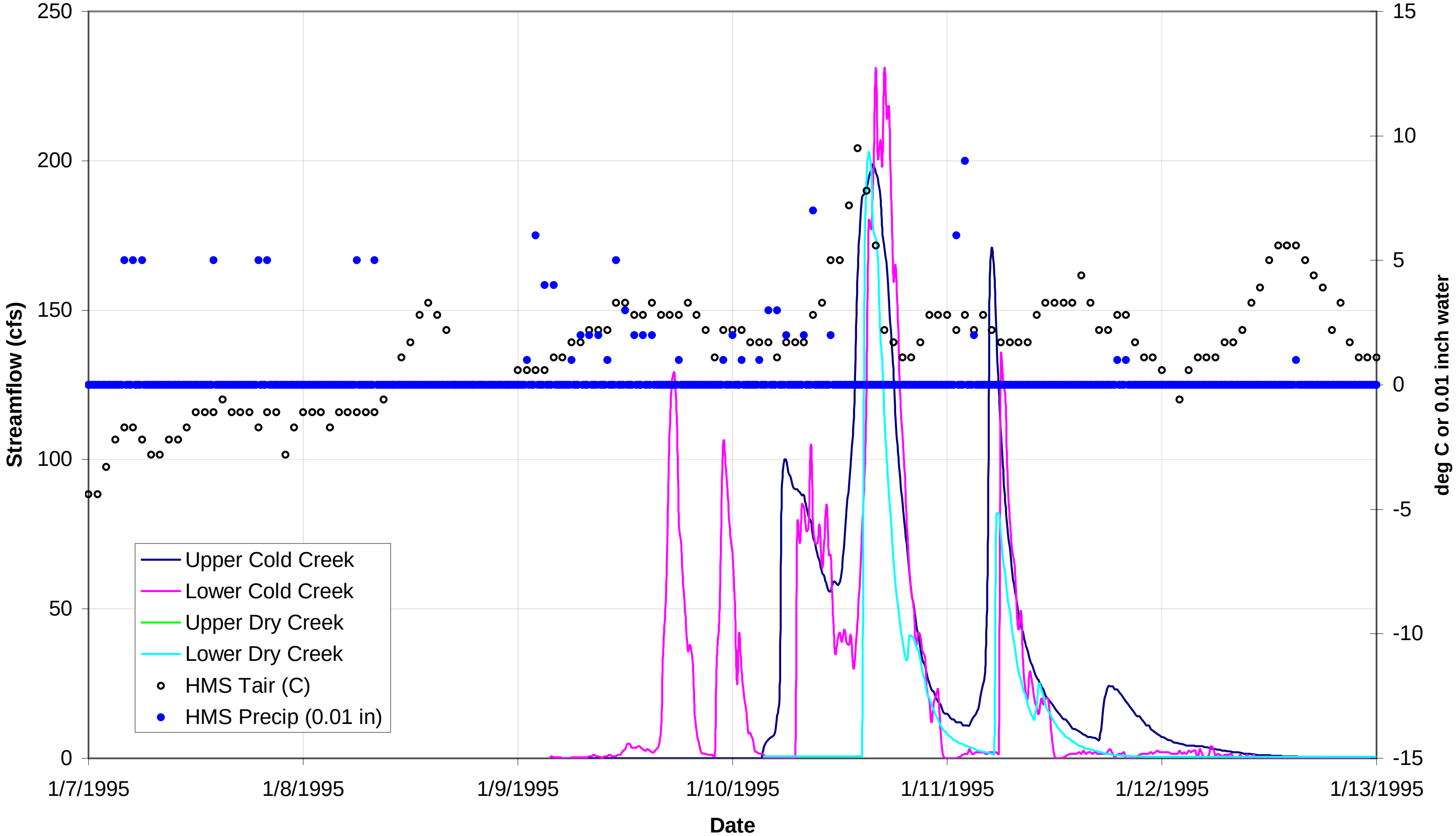
The hydrographs indicated very fast arrival and cresting of the streamflows suggesting powerful bores surging down channel. One flow at Lower Dry Creek shot up from its tiny perennial flow to 167 cfs in only 15 minutes, with the peak flow of 203 cfs occurring just one-half hour later (January 10, 1995, Figure 2). Recessions were rapid as well, with flows at Lower Cold Creek gage often decreasing to half the peak rate within a couple hours and to essentially zero within 6 hours.

Cold Creek followed a regular pattern of larger flows at the upper gage and lower flows at the lower gage. Lower Cold flows commence sharply a short time after the rise at Upper Cold Creek gage, suggesting that most if not all flow recorded at Lower Cold Creek gage originated as upper basin rather than middle basin runoff. This led to an assumption of no lateral inflow for the purposes of calibrating the channel infiltration model described in the next section.

In contrast, Dry Creek flows were minimal at the Upper Dry Creek gage but substantial at the Lower Dry gage. No flows were recorded at Upper Dry Creek in the digital dataset supplied by the USGS for January 1995. However, Dinicola witnessed flows up to 3 cfs at Upper Dry Creek gage, so data recording may have been inadequate. Also, the channel bed at Upper Dry Creek gage is relatively wide and free of vegetation, suggesting that significant flows do occur there. Five events were defined at Lower Dry Creek, and all were smaller than corresponding flows at Lower Cold Creek gage, even though the total area in Dry Creek is 68 percent larger than Cold Creek.

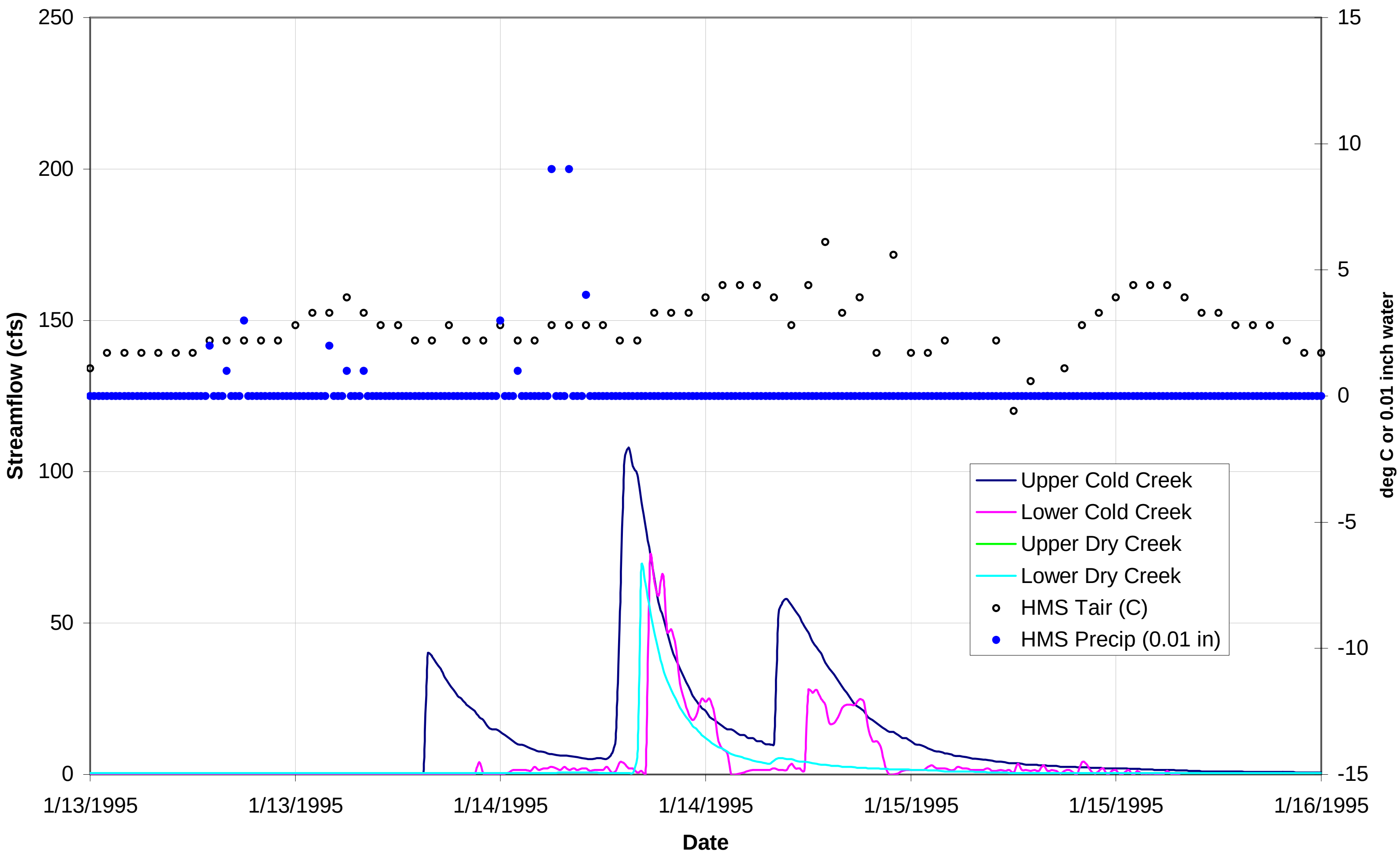
For each runoff event, start and end times, duration, and volume in basin area-inches were tabulated (Table 2). Corresponding times and depths for the presumed causative precipitation were also noted. Hourly precipitation measurements at several meteorological stations, corresponding lapse rates, and mean basin elevations were used to estimate basin average precipitation for each event. Basin average precipitation estimates using the various lapse rates are variable, and a decision was made to use the Hanford Meteorological Station (HMS) point measurements for the rest of the analysis.

[1] Email communication of field notes, 2001.



Runoff events: UC1, LC1, LD1 UC2, LC2, LD1

Figure 2. Precipitation, Air Temperature, and Streamflow January 7-12, 1995



Runoff events: UC3, LC6 UC4, LC3, LD3 UC8, LC7

Figure 3. Precipitation, Air Temperature, and Streamflow, January 13-15, 1995