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FY 1999 Progress Report On: Potential Groundwater Recharge From the Infiltration of Surface Runoff in Cold and Dry Creeks

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December 2005

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Abstract

The volume of water available for groundwater recharge through the infiltration of surface runoff in Cold and Dry Creeks was estimated for a 100-year storm and the Probable Maximum Precipitation (PMP) of Skaggs and Walters (1981). A 100-year, 7-day design storm was developed from 40 years of precipitation data measured at the Hanford Meteorological Station (HMS). Runoff measured in Upper Cold Creek was used with HMS precipitation data to calculate curve numbers for the Soil Conservation Service rainfall-runoff model. The estimated water available for recharge from surface runoff produced by the 100-year storm is 3-6 times the annual recharge rate from direct infiltration of precipitation over the Hanford Site. Potential recharge from the PMP is 7-11 times the annual volume of direct recharge.

Summary

The rate of groundwater movement in the uppermost unconfined aquifer beneath the Hanford Site to the Columbia River is dictated by an east to west head gradient in the aquifer. This gradient is in turn influenced by the amount and spatial distribution of recharge. The purpose of this study was to estimate the volume of water available for groundwater recharge from infiltration of surface runoff in Cold and Dry Creeks resulting from a 100-year, 7-day storm.

The approach used to estimate potential recharge was to construct numerical models to simulate rainfall-runoff and channel recharge processes and use these models with a 100-year design storm as input. Specific tasks addressed in FY1999 included: 1) constructing a digital elevation model of the study area, 2) gaining an understanding of runoff generation to guide development of the design storm and numerical models, 3) developing an appropriate design storm using 40 years of precipitation data from the Hanford Meteorological Station, and 4) constructing a numerical rainfall-runoff model of Cold and Dry Creeks.

The estimated water available for recharge from surface runoff produced by the 100-year storm is 3-6 times the annual recharge rate from direct infiltration of precipitation over the Hanford Site. Potential recharge from the PMP is 7-11 times the annual volume of direct recharge.

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Acronyms

CN   curve number

GIS   Geographic Information System

HMS   Hanford Meteorological Station

PMP   Probable Maximum Precipitation

PNNL   Pacific Northwest National Laboratory

SCS   Soil Conservation Service

1.0   Introduction

The rate of groundwater movement in the uppermost unconfined aquifer beneath the Hanford Site to the Columbia River is dictated by an east to west head gradient in the aquifer. This gradient is in turn influenced by the amount and spatial distribution of recharge. Natural recharge to the aquifer results from two sources: 1) direct infiltration and percolation of rainfall and snowmelt, and 2) infiltration and percolation of surface runoff. Recharge from the first source has been estimated at 5,425 ac-ft/y by Bauer and Vaccaro (1990), 6,677 ac-ft/y by Fayer and Walters (1995), and 14,467 ac-ft/y by Jacobson and Freshley (1990). Recharge from the second source is thought to result primarily from infiltration and percolation of storm runoff generated in the Cold and Dry Creek basins located along the western portion of the Hanford Site (Figure 1). This source of recharge has been estimated at 450 ac-ft/y by Newcomb et al. (1972) and 1,175 ac-ft/y by Dinicola (1997). Recharge from Cold and Dry Creeks may be of particular importance because it occurs to the west and helps maintain the west-east head gradient in the aquifer.
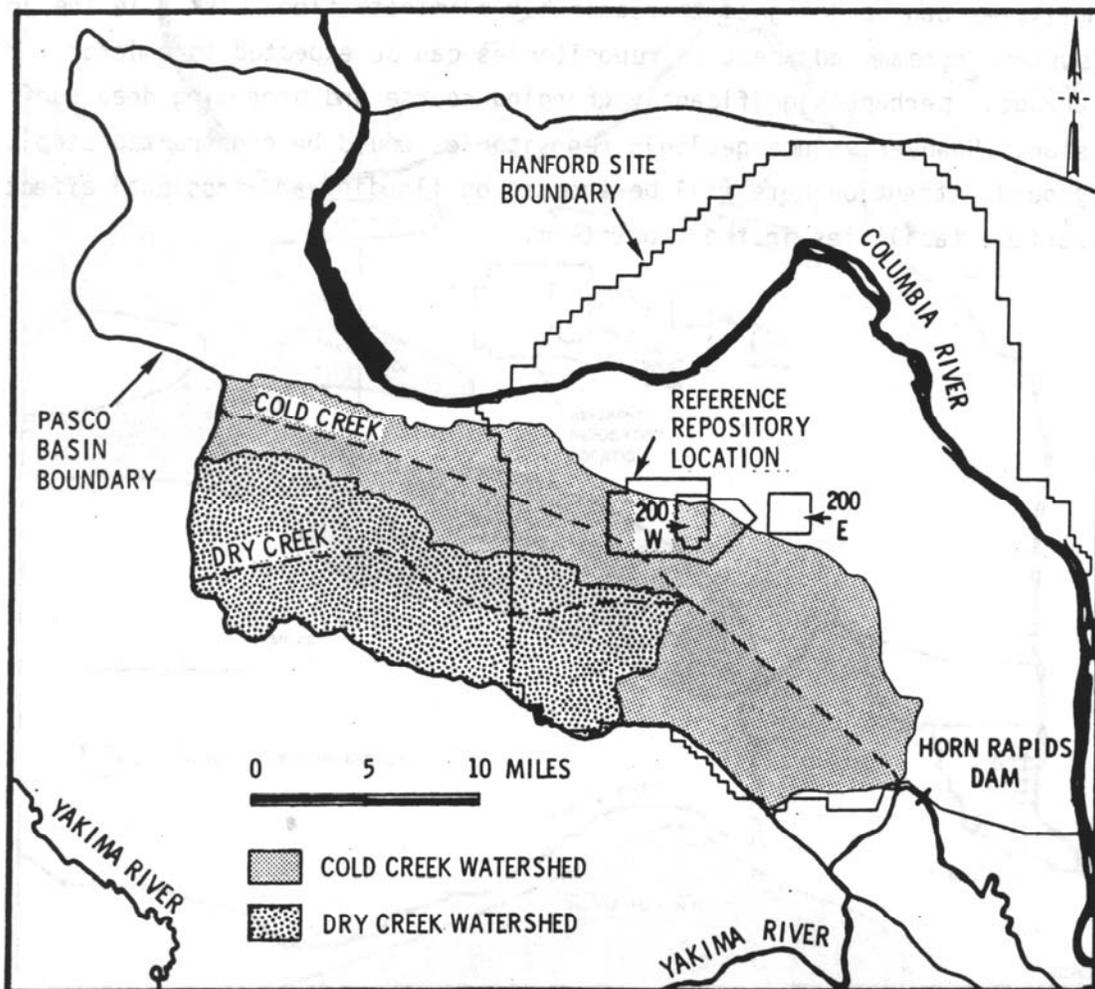

Figure 1.   Cold and Dry Creek Watersheds (from Skaggs and Walters 1981)

The purpose of this study was to estimate the volume of water available for groundwater recharge from infiltration of surface runoff in Cold and Dry Creeks resulting from a 100-year storm. The approach used to estimate potential recharge was to construct numerical models to simulate rainfall-runoff and channel recharge processes and use these models with a 100-year design storm as input. Specific tasks completed in FY1999 included: 1) constructing a digital elevation model of the study area (Section 2), 2) gaining an understanding of runoff generation to guide development of the design storm and numerical models (Section 3), 3) developing an appropriate design storm using Hanford Meteorological Station (HMS) meteorological data (Section 4), and 4) constructing a numerical rainfall-runoff model of Cold and Dry Creeks (Section 5).

2.0   Digital Elevation Model

A digital elevation model containing the study area (Figure 2) was constructed to provide geo-referenced terrain information for further analysis and possible linkage with the Hanford Site groundwater model. The model was constructed at a resolution of 200-m from U.S. Geological Survey digital elevation data using the Geographic Information System (GIS) Arc/Info. The channel network was delineated along with major subbasins (Figure 2) using Arc/Info Hydrologic Analysis tools.
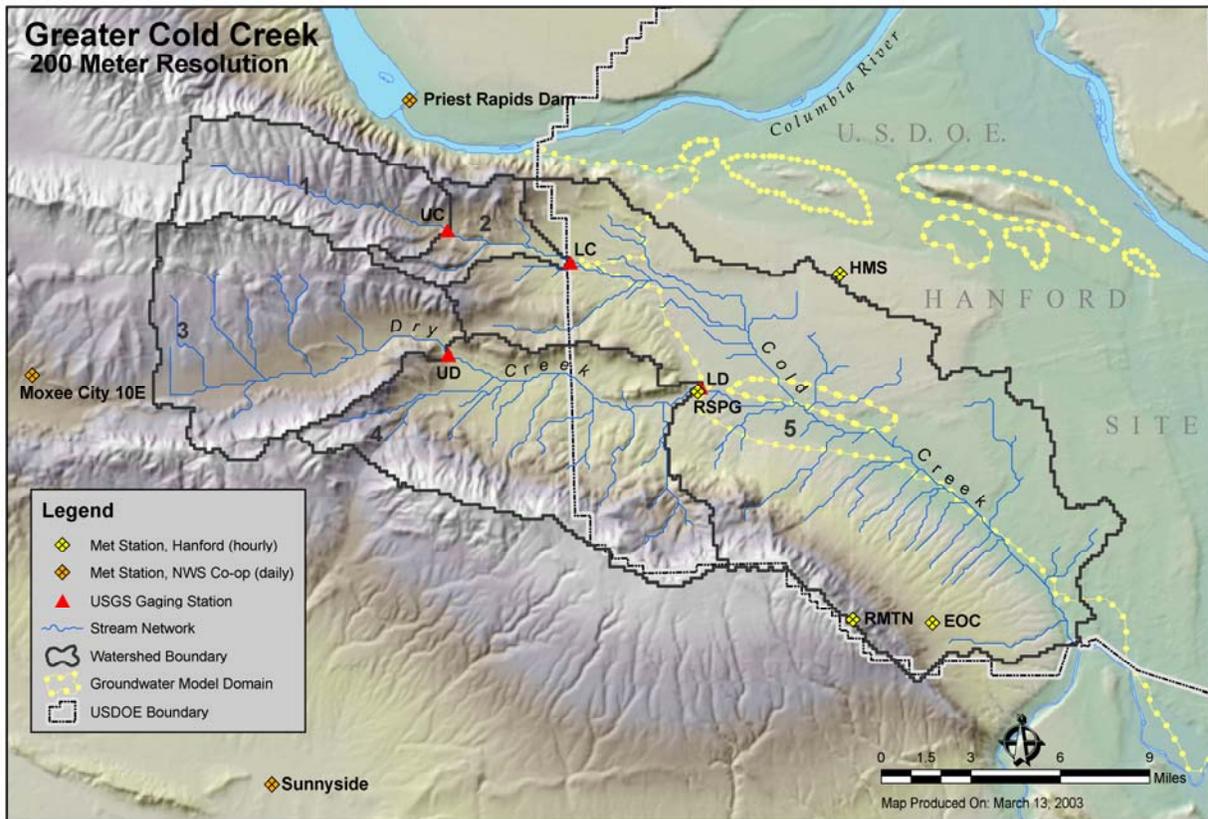

Figure 2.   200-Meter Digital Elevation Model of the Study Area Showing Major Subbasins, Meteorological Stations, and Streamflow Measurement Stations in the Cold and Dry Creek Watersheds

3.0   Runoff Production in Cold and Dry Creeks

The Cold and Dry Creek basins cover 363 square miles within and to the west of the Hanford Site (Figure 1). The entire area is underlain by basalt that is exposed at or near the surface on ridges in the western portions of the Cold Creek basin. The basalt is covered by a deep layer of loess and/or alluvial sediments in the Dry Creek valley and in the lowland plain of the Hanford Site. The upper Cold Creek basin contains steep side slopes with thin soils draining to a narrow valley with minimal alluvial fill. As a result, almost all surface runoff is conveyed downstream with little channel infiltration. The Upper Dry Creek basin is composed of wide, steep slopes that drain to gentle slopes with deep soils. Runoff can infiltrate channel bottoms in both tributaries and the mainstream. The lower sections of Cold and Dry Creeks contain steep slopes with shallow soils that drain to more gentle slopes with deeper soils. Both lower Cold and Dry Creek contain valleys with extensive alluvial deposits.

Runoff in the study site is rare, generated primarily by winter precipitation and often augmented by snowmelt and possibly enhanced by frozen soils. Dinicola (1997) states: "*All runoff in the study area is ultimately lost to evaporation and infiltration. Cold and Dry Creek channels decrease in size downstream from the lower stream gauging stations until they eventually become indistinct in the terminal runout zones. Although there are no topographic barriers between the runout zones and the Yakima River, there is no geomorphic or botanical evidence to indicate that unchannelized flow from Cold or Dry Creek Basins proceeds downstream beyond these zones. Given that runoff is primarily generated during the winter months when evaporation rates are low, it is unlikely that much runoff is lost to evaporation.*"

4.0   Design Storm

Daily streamflow measurements for Upper Cold Creek (subbasin farthest to the northwest in Figure 2) are available from April 1, 1990 to March 14, 1995. Four runoff events occurred during this time period, one in March 1993 and three in January 1995. Each of these events was associated with two or more days of winter precipitation recorded at the HMS (Table 1 and Figures 3-4). Cold and Dry Creeks are at higher elevations than HMS so it is difficult to determine what fraction of the precipitation fell as snow or whether the ground was frozen.

Table 1.   HMS Rainfall and Runoff from Upper Cold Creek

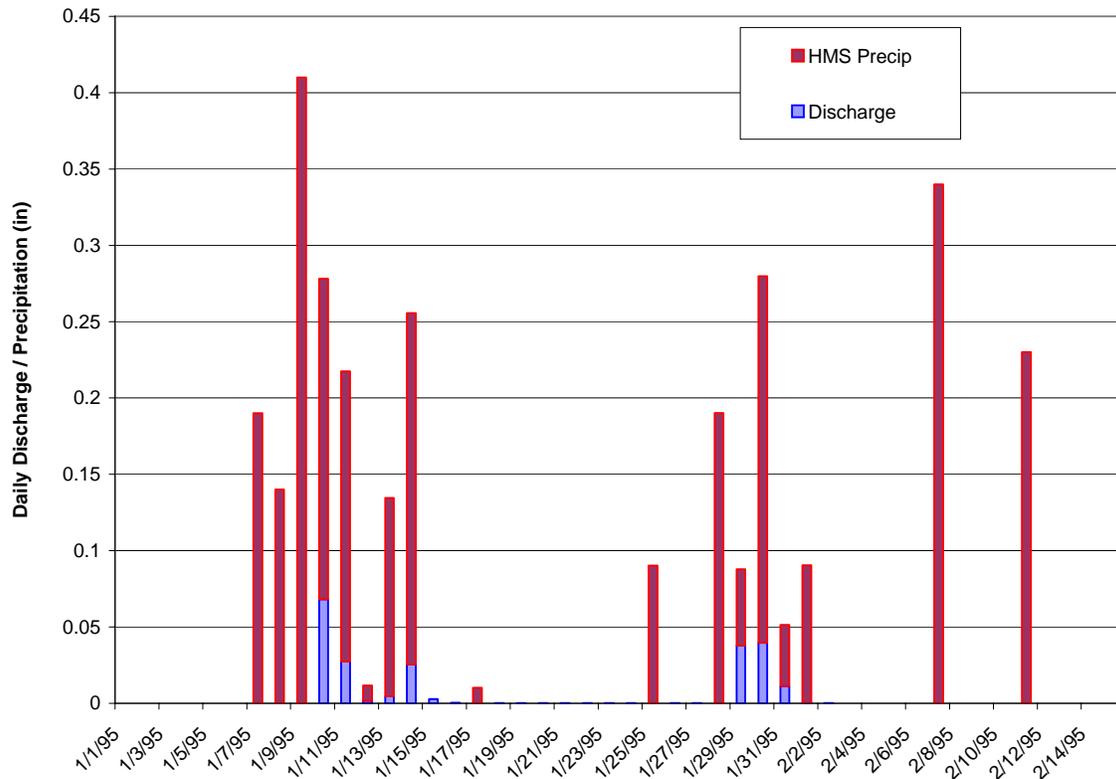| Storm	Duration (d)	Precipitation (in)	Runoff (in)	Potential Retention (in)	Curve Number	Antecedent Precipitation Index (in)
1/7-12/95	6	1.15	0.097	2.86	78	0.51
1/13-14/95	2	0.36	0.033	0.87	92	1.61
1/28-2/1/95	5	0.61	0.090	1.18	89	0.84
3/16-22/93	7	0.37	0.017	1.11	90	0.39

Upper Cold Creek

Figure 3.   Daily HMS Precipitation and Runoff Measured from Upper Cold Creek for January 1 – February 16, 1995
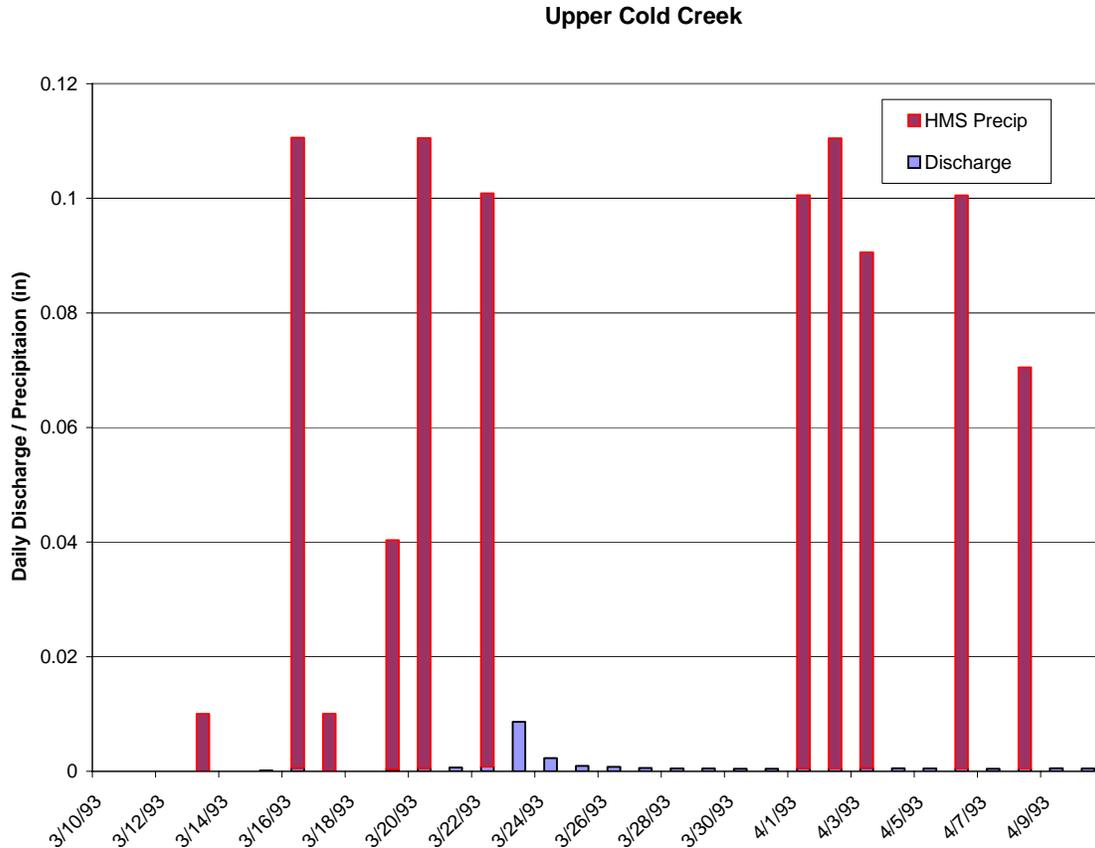
Upper Cold Creek

Figure 4.   Daily HMS Precipitation and Runoff Measured from Upper Cold Creek for
March 10 – April 11, 1993

   A 7-day duration was selected for the design storm based on this limited data set. Annual maximum
seven-day precipitation totals for the HMS were tabulated for 1957-1997 (Figure 5). A log-Pearson
Type III distribution was fit to the annual maximums (Figure 6), and precipitation depths were calculated
for return periods of 2, 5, 10, 50, and 100 years (Table 2). This analysis yields a 100-year, 7-day
precipitation depth of 2.71 in. This value was nearly equaled during the last 7 days of 1996, when
precipitation totaled 2.68 in. (Figure 5). The 100-year, 7-day precipitation depth is well below estimated
Probable Maximum Precipitation (PMP) depths for summer thunderstorms made by Skaggs and Walters
(1981). They estimated 6-hour PMP depths of 7.3 and 4.6 in. for Upper Cold Creek and Lower Cold
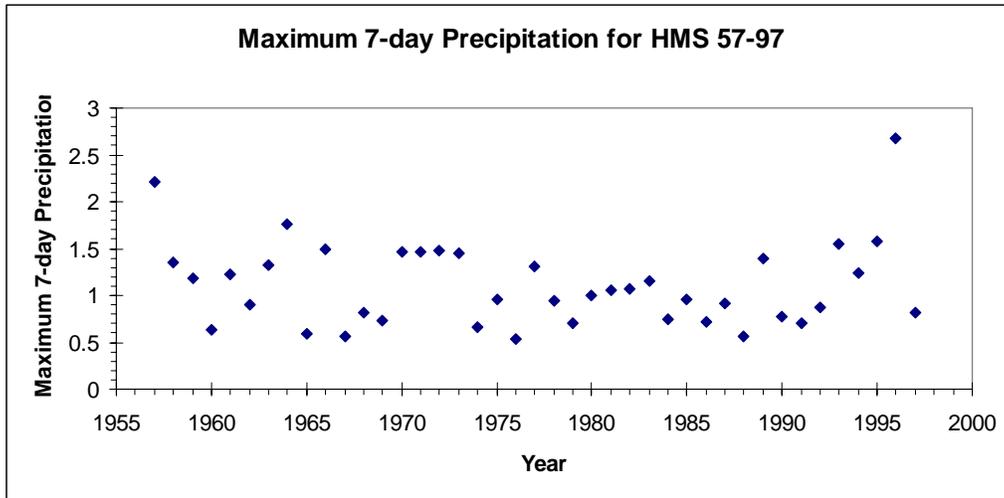Creek (at the Yakima River), respectively.

Figure 5.   Annual Maximum 7-Day Precipitation Totals at the HMS for 1957-1997
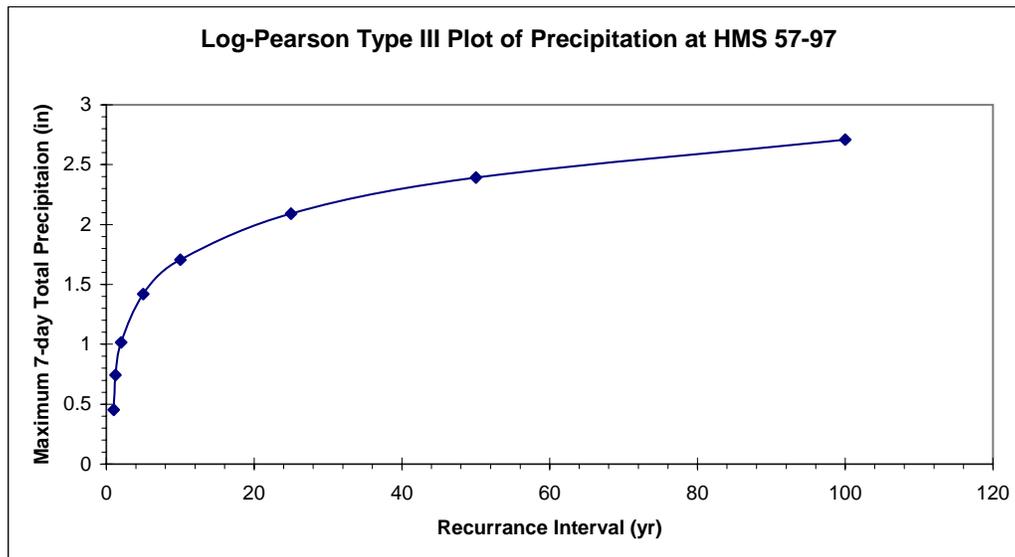
Figure 6.   Results of Log Pearson Type II fit to Annual Maximum 7-Day Precipitation Totals at the
HMS. The 100-year Recurrence Interval Corresponds to a Depth of 2.71 in.

Table 2.   Precipitation Amounts (in.) for 1 to 168 Hours (7-day) and Return Periods from
2 to 100 Years

Return	Duration (h)						
Period (y)	1	2	3	6	12	24	1682
2	0.22	0.31	0.36	0.48	0.61	0.70	1.02
5	0.31	0.42	0.47	0.64	0.81	.095	1.42
10	0.38	0.49	0.54	0.74	0.94	1.11	1.71
50	0.52	0.65	0.69	0.96	1.23	1.46	2.39
100	0.58	0.71	0.75	1.05	1.35	1.61	2.71

4.3

5.0   Rainfall-Runoff Model

Time constraints and data limitations dictated the use of a relatively simple rainfall-runoff model. Direct runoff for the 100-year design storm was estimated using the Soil Conservation Service Curve (SCS) number approach (Soil Conservation Service 1972). The method correlates rainfall and direct runoff as a function of soil type, vegetation cover, and hydrologic condition through the use of a curve number (CN):

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{1}$$

And

$$S = \frac{1000}{CN} - 10 \tag{2}$$

where Q is the direct runoff volume (in.), S is the potential retention (in.), and CN is the curve number. No runoff occurs until the cumulative rainfall exceeds an initial abstraction (0.2S) that accounts for the processes of interception, depression storage, and infiltration before direct runoff.

The precipitation and runoff data presented in Table 1 were used to calculate effective curve numbers through rearrangement of Equations 1 and 2:

$$CN = \frac{1000}{\dfrac{0.4P + 0.8Q - \sqrt{0.8PQ + 0.64Q^2}}{0.08} + 10} \tag{3}$$

where P and Q are given in columns three and four of Table 1. Curve numbers calculated from the four runoff events are between 78 and 92 (Table 1, column 6). These numbers are consistent with those of Skaggs and Walters (1981), who selected a curve number of 85 from the literature for a PMP in the Cold Creek region with sage or grass cover.

6.0   Preliminary Estimate of Water Available for Groundwater Recharge

Direct runoff estimated from Equation 1 for the PMP of Skaggs and Walters (1981) and the 100-year, 7-day design storm is presented in Table 3.

Table 3.   Estimated Runoff for the PMP and 100-Year, 7-Day Storm

	PMP			100-Year, 7-Day Storm		
	Precipitation	Runoff	Volume	Precipitation	Runoff	Volume
CN	(in)	(in)	(ac-ft)	(in)	(in)	(ac-ft)
78	4.6	2.38	45,990	2.71	0.93	17,950
85	4.6	3.00	58,084	2.71	1.35	26,094
92	4.6	3.70	71,614	2.71	1.89	36,560

Fayer and Walters (1995) estimated 6,677 ac-ft/y of groundwater recharge from direct infiltration and percolation of rainfall and snowmelt at the Hanford Site. Runoff volumes for the PMP are 6.9 to 10.7 times this annual rate, and 100-year, 7-day totals are 2.7 to 5.5 times the annual rate. The values in Table 3 provide a preliminary estimate of the volume of surface runoff available for groundwater recharge, subject to the following qualifications:

- The SCS model provides an adequate representation of the hydrologic response. The SCS rainfall-runoff relationship is a reasonable first approximation given the limited data available. Clearly, it is an oversimplification of the actual hydrologic processes occurring in the watershed, particularly the lack of snow, evapotranspiration, and frozen soils. However, water loss from evapotranspiration is minimal for a 6-hour summer thunderstorm or a 7-day winter storm. Furthermore, calculating CN from measured rainfall-runoff combines the effects of snowmelt and frozen soils into the curve number. The limited data set available for calibration is a concern. Use of a physically based model would overcome some of these concerns. Additional data collection and monitoring is recommended.

- A single curve number is appropriate for the entire Cold/Dry Creek watershed. Curve numbers were calculated from runoff measured in Upper Cold Creek, which contains thin soils that contribute runoff rapidly to the channel. Other portions of the watershed are likely to have lower rates of direct runoff (i.e., lower effective CN) because of deeper soils and greater water-holding capacity.

- All direct runoff is available for groundwater recharge. All evidence indicates that surface runoff from Cold and Dry Creeks infiltrates before reaching the Yakima River. The SCS method provides an estimate of storm runoff without baseflow. Therefore, the actual volume of water available for recharge may be greater, depending on the rate of near-surface evapotranspiration.

- The probability of the recharge event is equal to the probability of the precipitation event. Clearly, this is not the case as evidenced by the change in runoff with changing CN. The probability of a recharge event is a function of the probability of the precipitation event and the probability of the antecedent hydrologic conditions (soil temperature, soil moisture, etc.). Values associated with the higher curve numbers provide more conservative estimates.

7.0   References

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