Flood Insurance Study
Hydrologic Analysis

For

Chester Creek

Spokane County, Washington

Prepared for

FEMA Region X
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EXECUTIVE SUMMARY

A detailed hydrologic analysis of Chester Creek in Spokane County and the City of Spokane Valley, Washington was conducted. The objective of the analysis was to establish flood magnitude-frequency estimates for use in a Flood Insurance Restudy of the watercourse. The analysis was conducted using the Hydrological Simulation Program Fortran (HSPF; EPA, 1997).

The hydrology of Chester Creek was previously analyzed using HSPF by HYDMET (1997) for watershed planning purposes (CH2M Hill, 1997). The model developed for that analysis was refined for use in the current study. The refinements included incorporating more detailed channel survey information, updating the land use to reflect current conditions, including the effects of infiltration from the stream channel and six storage areas identified in the lower reaches of the basin, extending the simulation through year 2002 for a total simulation period of 54-years, and recalibrating the model to recorded stream flow and regional information from adjacent basins. Frequency analyses were performed using the 54 years of simulated stream flow information and are presented in this report for each subbasin.

An HSPF model of Chester Creek calibrated to historical anecdotal evidence was submitted as a draft report for review to Michael Baker Jr., Inc. in February 2004 (WEST, 2004). That review concluded that the infiltration rates used were consistent with optimal infiltration conditions but did not consider reduced infiltration resulting from frozen soil conditions or sealing of pond and ditch bottoms by fine sediment over time. Based on an analysis of regional gage data, Michael Baker Jr., Inc. recommended that the HSPF model be revised to reflect infiltration rates that are 33 percent of the “optimum” values previously considered (MBJr., 2004). This report summarizes the results of that recommendation.

The key findings of the hydrologic analysis include:

- Simulated and recorded discharges compare well with the limited data available for the Dishman-Mica Road gage location.

- The discharge along the mainstem of Chester Creek reaches a maximum in the central portion of the watershed at the outlet of Subbasin 9 near Thorpe Road. A 100-year return period flood discharge of 215 cfs was predicted at that location. Floods equal to or greater than a 10-year return period event overflow into the Painted Hills Golf Course across Thorpe Road. Floodwaters entering the golf course were determined to infiltrate and not return to Chester Creek. Downstream of Thorpe Road, the remaining flow in Chester Creek infiltrates into glacial outwash and the discharge decreases with distance downstream.

- Chester Creek enters a borrow pit (Storage Area 2) constructed in 1998 as part of road improvements to Dishman-Mica Road. Stream flow entering the borrow pit infiltrates and discharge to downstream reaches has not occurred since the borrow pit was constructed. Hydrologic simulations showed some discharge occurring from this storage area for all simulated flood events starting at the 2-year recurrence interval. During flood events water will overflow from the borrow pit and result in discharge to the downstream channel.

- The 100-year return period discharge rate at 24th Avenue (Cross Section K) downstream of the borrow pit was estimated at approximately 55 cfs with a discharge of 4 cfs at 2nd Avenue indicating only shallow sheet flow at the downstream extent of the study area.

- Uncertainty is associated with the developed hydrologic estimates due to the lack of long-term records of precipitation and flow measurements specific to the Chester Creek watershed. The HSPF results were calibrated to a limited record of stream flow data and regional basin data and downstream flooding conditions based on assumed soil infiltration rates. It should be recognized that the long-term infiltration characteristics of the soil can change due to sedimentation along the channel, vegetation, and land use changes.

- There are significant differences between the magnitude of hydrologic estimates defined by prior investigations and those developed by the current study. These differences have significant implications for water surface elevations and the extent of the floodplain. The major differences between the prior and current studies are related to assumptions regarding land use conditions and soil infiltration characteristics. It is evident that these assumptions have a significant effect on the resulting hydrologic estimates.

Recommendations of the study to address the potential uncertainty in the hydrologic estimates include the following:

- Watershed changes that would affect soil infiltration characteristics in the lower basin should be monitored. This should include monitoring of land use conditions and sedimentation conditions along channels and within the borrow pit.

- Additional precipitation and stream flow measurements should be collected that would allow improvement of model calibration and verification.

- Future reanalysis of the hydrologic estimates should be conducted if soil infiltration conditions in the basin change or if an improved record of basin specific precipitation and flow records is developed. Additionally, if land use conditions in the basin change significantly the hydrologic estimates should be updated.

- In recognition of the uncertainties involved with the hydrologic analysis of the basin, until a long term record of basin specific precipitation and stream flow data is developed, consideration should be given to defining hydrologic estimates based on future land use conditions that consider the influence of the recently constructed borrow pit. It is recognized that both existing and future land use condition floodplains could be delineated on FEMA FIRM maps. A future land use condition floodplain would be expected to define a conservatively larger estimate of the 100-year floodplain extent.

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1 INTRODUCTION

A detailed hydrologic analysis was conducted to characterize flood-frequency relations for Chester Creek near Spokane, Washington. A vicinity map of the study area is shown in Figure 1. The analysis was conducted to provide hydrologic data required for a Federal Emergency Management Agency (FEMA) Flood Insurance Restudy of Chester Creek.

The hydrologic estimates for Chester Creek used in the effective FEMA Flood Insurance Study (FEMA, 1992) were developed based on the TR-20 rainfall/runoff simulation program (SCS, 1965). It is recognized that several factors were not considered by that analysis. Those factors include the high infiltration capacity of soils in the lower reaches of the basin and the recent construction of a 'borrow pit' between Schaffer Road and 28th Avenue intended to retain and infiltrate floodwaters.

A second prior study of the hydrology of Chester Creek (HYDMET, 1997) was conducted as part of a watershed planning study (CH2M Hill, 1997). The HYDMET analysis was based on the Hydrological Simulation Program Fortran (HSPF; EPA, 1997) and was conducted to provide peak flow estimates for flood control planning and design purposes. The HYDMET study was also conducted prior to the construction of the borrow pit and considered future land use development conditions.

Initially, the objective of the current study was to incorporate the storage and infiltration characteristics of the borrow pit into the existing HYDMET HSPF model. However, examination of the model revealed additional model characteristics requiring improvement. As a result, the HYDMET HSPF model input was significantly refined. Changes to the HYDMET HSPF model included:

- Routing tables (FTABLES) were updated to reflect more detailed channel survey data and hydraulic routing information developed using the Corps of Engineers HEC-RAS model (USACE, 2003).

- Existing condition land use was updated to reflect current conditions.

- Existing land use was used to compute flood magnitude-frequency estimates rather than future build-out conditions used in the HYDMET study.

- Scaling factors used to transpose precipitation from Spokane Airport to the watershed for long-term simulations were revised to reflect more recent mean annual precipitation information for the watershed.

- Model parameters that define the amount of moisture loss and runoff to the stream channel (PERLNDs) were refined through calibration.

Climate data recorded since the HYDMET analysis was completed in January 1997 was added to the model database, extending the available simulation period from October 1948 through September 2002 (54 years).

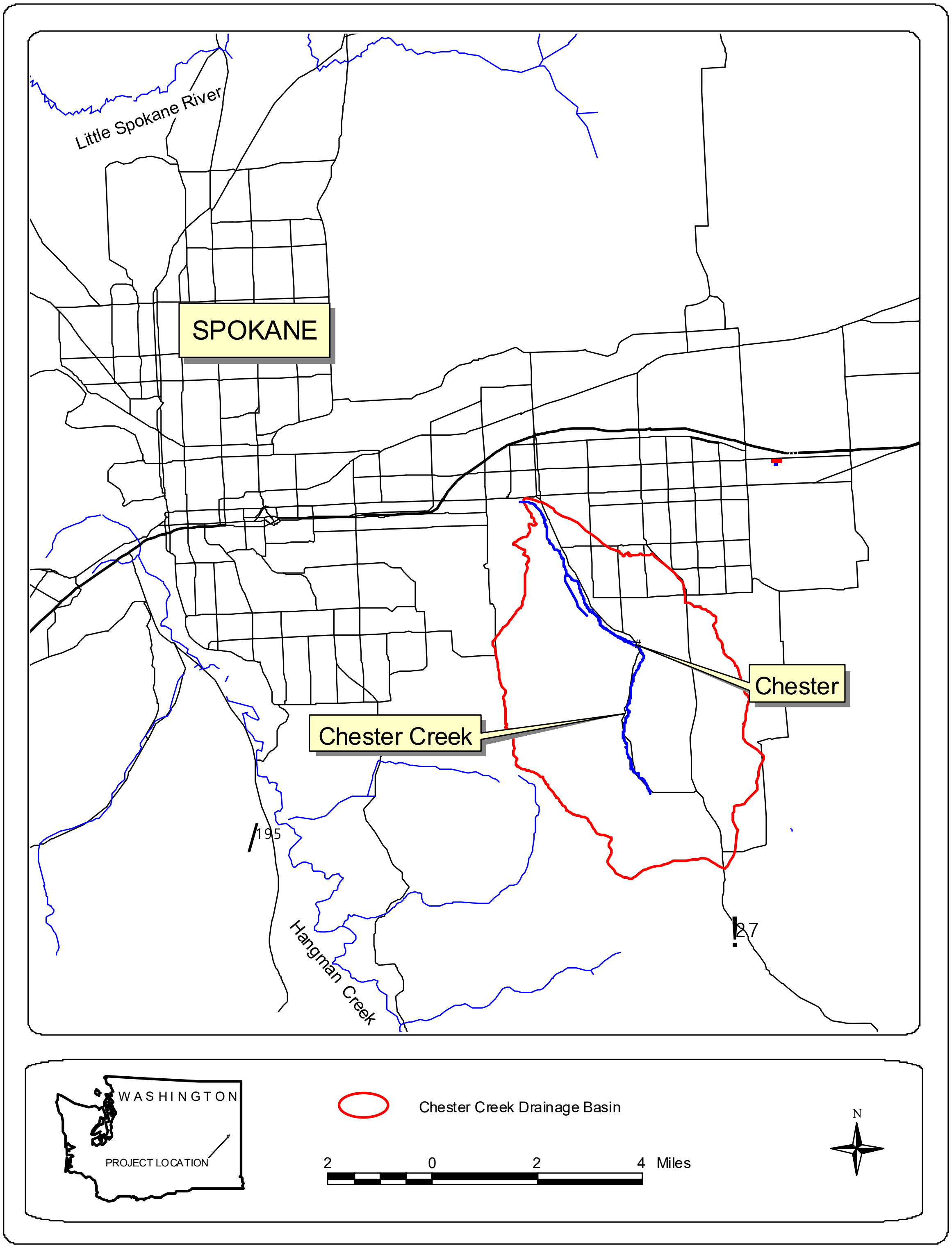


Figure 1: Vicinity map

1.1 *Watershed Characteristics*

The Chester Creek watershed is located in Spokane County and the recently incorporated City of Spokane Valley. A map of the watershed is shown in Figure 2. The Chester Creek channel flows from south to north. The watershed is approximately oval shaped with an east-west width of about 4 miles and north-south length of about 9 miles. The study area has a drainage area of 23.5 square miles at its downstream limit (2nd Avenue).

The approximate lower 1/5 of the watershed is much flatter and urbanized compared to the upper portion of the watershed. The lower portions of the watershed are underlain by deep glacial outwash deposits of high infiltration capacity. Valley bottom soils have been characterized as variable, ranging from silts to sands and gravels (CH2M Hill, 1997). The upper basin is much steeper and relatively undeveloped. The hillslopes in the upper basin are primarily conifer forest while valley bottoms are typically pasture. The upper watershed is underlain by bedrock and the soils are described as shallow and fine textured. The watershed varies in elevation from 1,984 ft at 2nd Avenue to a high point of approximately 3,680 ft along the western watershed boundary.

The Chester Creek channel is distinct only in the upper reaches of the basin. Between Thorpe Road and Schafer Road, the channel transitions from a well-defined channel to a broad wetland. Downstream of the borrow pit, located between Schaffer Road and 28th Street, no defined channel is evident. The borrow pit was developed as part of improvements to Dishman-Mica Road in 1998 and is intended to act as a storm water retention and infiltration facility. The outflow from culverts beneath Schaffer Road flows directly into the downstream borrow pit. Prior to construction of the borrow pit, the flow path in that location transitioned from wetland to pasture. It is apparent from the existing channel conditions and historic observations that the lower Chester Creek channel is significantly influenced by the high infiltration capacity of the glacial outwash soils in that area.

1.2 *Climate*

In general, the Spokane area has a mild, arid climate during the summer months and a cold, coastal type in the winter. Most of the air masses that reach the Spokane area are brought in by the prevailing westerly and southwesterly circulations. Frequently, much of the moisture in the storms that move eastward and southeastward from the Gulf of Alaska and the eastern Pacific Ocean is precipitated as the storms are lifted across the Coast and Cascade Ranges. The mean annual precipitation over the Chester Creek watershed is approximately 20 inches (Oregon Climate Service, 1997).

As air masses move up the east slope of the Columbia Basin, cooling and condensation frequently occurs that is necessary for formation of clouds and precipitation. Infrequently, the Spokane area comes under the influence of dry continental air masses from the north or east, resulting is high temperatures and very low humidity in the summer and sub-zero temperatures in the winter. In the winter, southward movements of severely cold arctic air masses generally occur on the east side of the Continental Divide and do not affect Spokane.

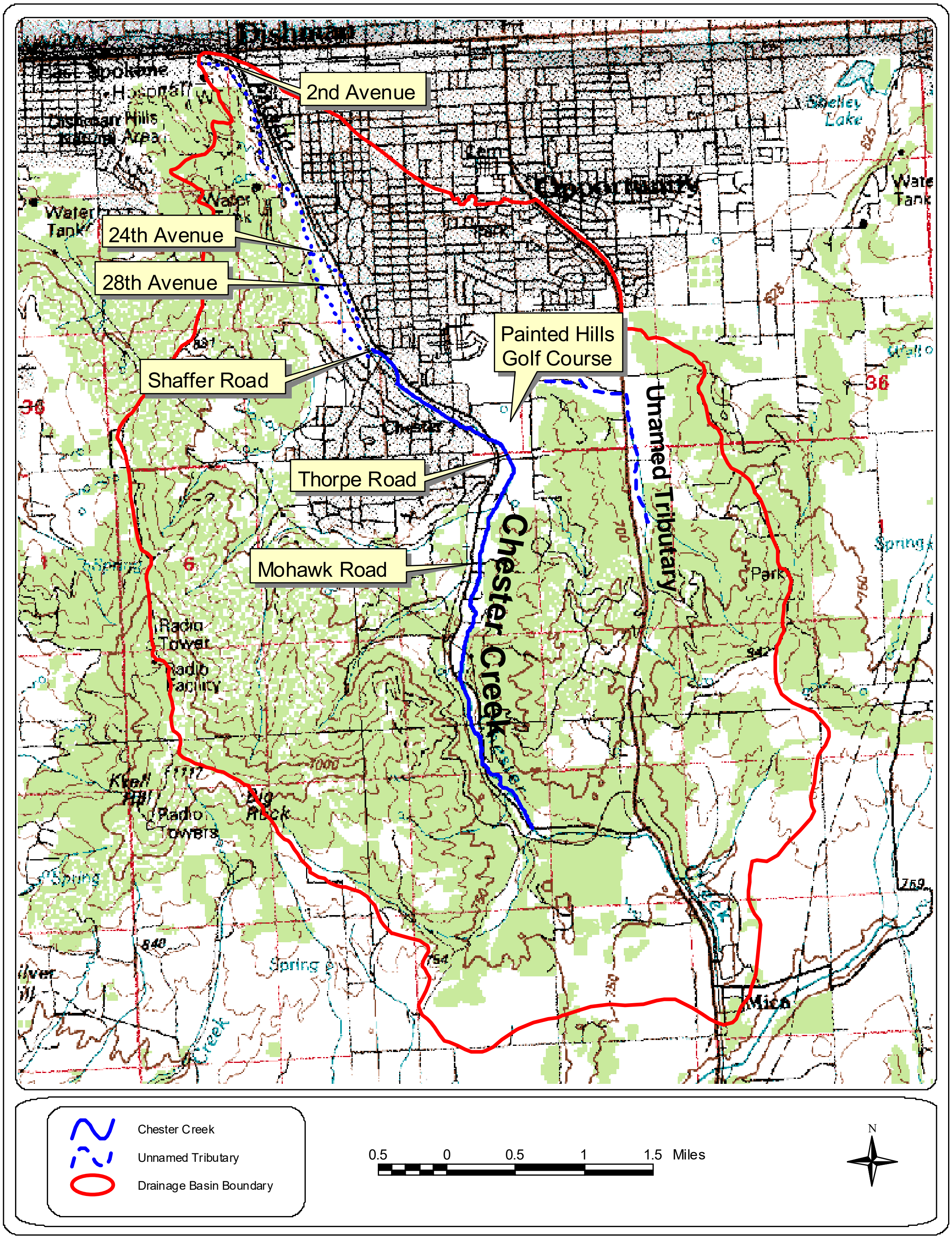


Figure 2: Watershed map

Approximately 70 percent of the total annual precipitation in the Spokane area falls between September and April and about half of that falls as snow. Winter weather includes many cloudy or foggy days and below freezing temperatures with occasional snowfall of several inches in depth. Sub-zero temperatures and large snowfalls are infrequent. Based on the 1951-1980 period, the average first occurrence of 32 degrees Fahrenheit in the fall is October 6 and the average last occurrence in the spring is May 4. The growing season usually extends over nearly six months from mid-April to mid-October. Irrigation is required for all crops except dry-land type grains.

1.3 *Principal Flood Problems*

The available climatological records and historic information indicate that Chester Creek may experience major flood events due to combinations of winter rainfall and snowmelt. In general, winter rainfall combined with snowmelt has been observed to cause flooding in the lower portion of the watershed during the winter and early spring months. However, flooding due to intense localized short-duration summer thunderstorms may also be expected.

Specific information on historic floods in the Chester Creek basin is limited. A few anecdotal descriptions and limited photographs of historic floods are available. Historically, floods are reported (CH2M Hill, 1997) to have spread out over the floodplain in the lower basin, forming lakes “for a few days.” Frozen ground conditions can affect runoff and infiltration characteristics in the basin; however, it has also been suggested that the combined probability of occurrence for a deep snow pack that would contribute to substantial snowmelt, significant rainfall, and frozen ground conditions may be significantly less that 1 percent.

Severe property damage from erosion and flooding along Chester Creek is reported to occur as result of major runoff events (CH2M Hill, 1997). The Painted Hills Golf Course and nearby residential areas have been noted to occasionally flood. Road closures due to flooding have also been noted to occur almost every winter at Thorpe Road. Floodwaters have also been observed to cross Bowdish Road during some runoff events. According to long-time residents (CH2M Hill, 1997), portions of the Chester Creek channel have been dredged periodically to address the flood problems. Fine sediments from the steep upper watershed deposit in the flatter channel and wetland areas of the lower watershed. The location of flooding has been observed to be worse upstream at Thorpe Road before dredging and downstream at Shaffer Road after dredging.

Several floods have been observed along Chester Creek in recent years. In early 1996, a minor flood event occurred that produced flows at Schafer Road and was observed to completely infiltrate before reaching 28th Avenue. In January 1997, a flood event estimated to be nearly a 100-year return period event occurred that inundated Thorpe Road for several weeks but did not extend downstream of 24th Avenue.

Community and agency concerns about the extent of flooding and uncertainties regarding existing floodplain mapping resulted in the development of a watershed plan for Chester Creek. The goal of that plan was to identify management recommendations for issues of drainage and flooding, water quality, and riparian habitat. Because of that watershed planning effort, projects to construct various improvements along Chester Creek between Thorpe Road and Schaffer Road have been implemented by Spokane County. In 1998, a project to install new culverts and extensive dredging of the channel between Thorpe Road and Schaffer Road was implemented. Additionally, as part of a Spokane County improvement project for Dishman-Mica Road, a large volume borrow pit was constructed to act as a retention and infiltration facility for the floodwaters of Chester Creek.

Gage Records

No long-term flow gage records exist for Chester Creek. Data for regional gages in the vicinity of Chester Creek were collected and gages noted to have low unit per runoff area were identified and are discussed later in this report..

Limited gage measurements of the flow along Chester Creek were made as part of a previous hydrology investigation (HYDMET, 1997). The gage data were collected at a location near the Dishman-Mica Road crossing of Chester Creek from December 1994 through March 1995 and November 1995 through February 1996. No significant flood events occurred during the period of record.

2 HSPF MODEL DEVLOPMENT

An HSPF model (EPA, 1997) of the study area was developed to define required flood frequency data for Chester Creek [See Appendix A for electronic data files for HSPF model]. The HSPF model was selected for several reasons: 1) It had been previously applied to the basin and existing input data was available (HYDMET, 1997), and 2) The HSPF model provides continuous simulation of hydrologic processes required to investigate the influence of watershed soil infiltration capacity, rainfall, and snowmelt. Detailed review of the existing model defined needs for various improvements. In the following sections, the methods and data used to develop the model for the current study are described.

2.1 *Subbasin Definitions*

HSPF is a conceptual, continuous, hydrologic model where surface, shallow subsurface (interflow), and groundwater flows can be simulated, lagged, and combined as discharge into a stream network. In application, the watershed to be modeled is divided into a number of subbasins that are connected by channel reaches. Subbasin delineations are based on topography, hydrologic characteristics, the channel network, and locations where computed stream flows are desired. For the purposes of the hydrologic analysis, the Chester Creek watershed was partitioned as shown in Figure 3.

Several areas of flood storage that can affect the hydrology and floodplain of Chester Creek are located within the basin. The flood storage areas include facilities specifically designed for this purpose, a golf course, and areas where the drainage is controlled by major road embankments, railroad embankments and/or culverts. The major flow paths and flood storage areas identified in the basin are shown in Figure 3.

Storage Area 1 is the Painted Hills Golf Course. It is located near the midpoint of the study area. Available historic photographs dated 1949 and 1950 and anecdotal reports indicate the golf course to be a site of frequent flood storage. Flow escapes the Chester Creek channel approximately 3,000 ft upstream of the golf course due to limited channel capacity, and follows the right overbank until it crosses Thorpe Road and enters the golf course. The flow entering the golf course does not rejoin the main channel due to the topography of the area and a small levee system along the right bank of the main channel. As the golf course has no outlet, the flow is stored until it infiltrates.

Storage Area 2 is the borrow pit that was constructed in 1998 between Schaffer Road and 28th Avenue as part of improvements to the Dishman-Mica Road. The borrow pit was constructed to retain and infiltrate floodwaters from Chester Creek that pass downstream of Schaffer Road. Since the borrow pit was constructed, no overflows from the borrow pit have been observed.

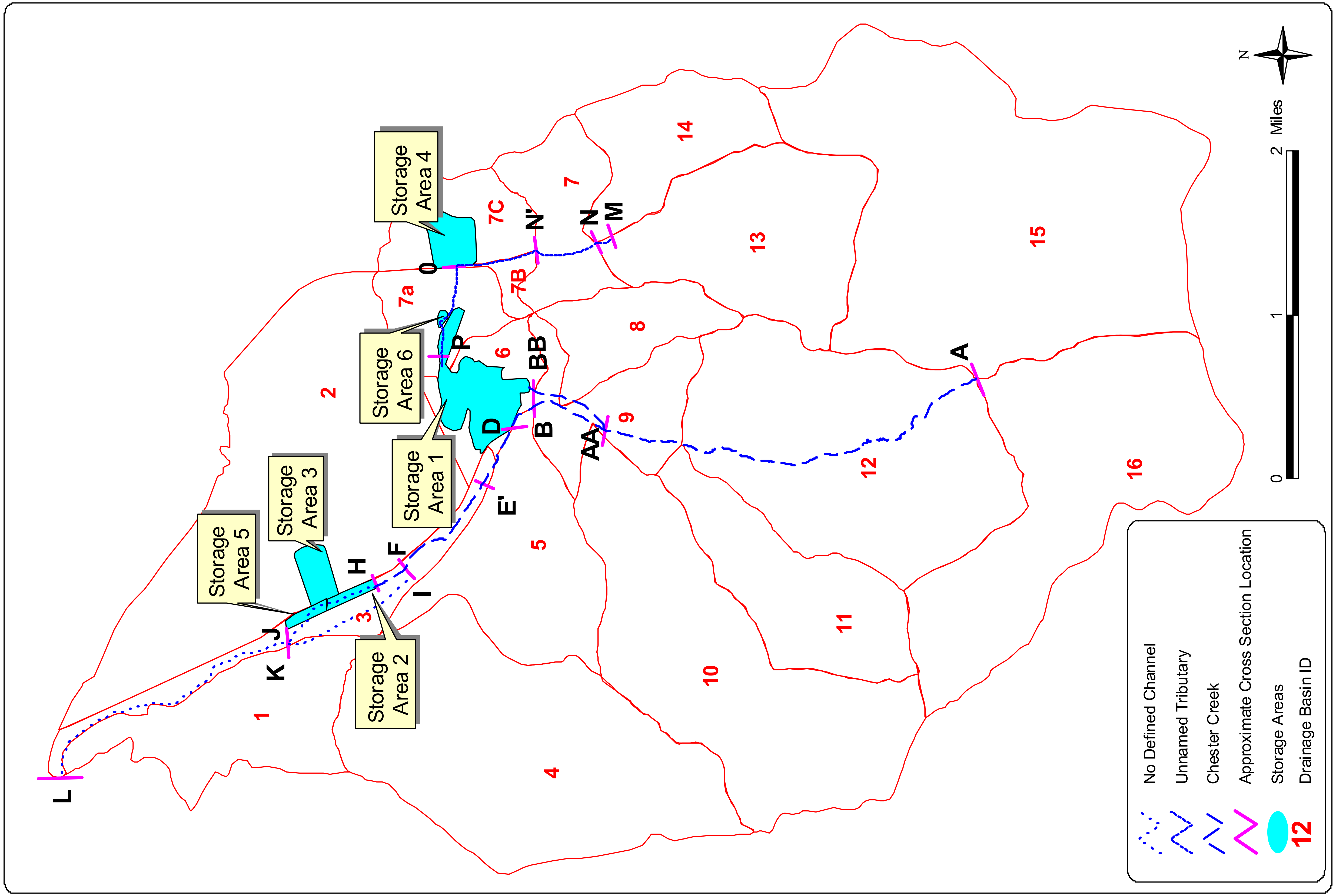


Figure 3: Major flow paths and storage areas

Storage Area 3 is located in the Kokomo residential area, just downstream of the borrow pit and to the east of Dishman-Mica Road. Dishman-Mica road was recently raised to help mitigate potential flooding of the Kokomo area (Spokane County, 1997). As part of this construction, an 18” culvert was installed to allow the roadside ditch on the east side of Dishman-Mica road to drain to the borrow pit (Chad Coles, County Roads Division, personal communication, November 19, 2003). When the water surface elevation in the borrow pit exceeds elevation 1999.0, ft the culvert would allow flow, estimated to be a maximum of approximately 5 cfs for the 100-year recurrence interval flood event, under Dishman-Mica Road and into the Kokomo residential area where it would pond and infiltrate.

Storage Area 4 is located in the right overbank area to the east of State Highway 27 along an unnamed tributary to Chester Creek. Water escapes the main channel of this tributary due to limited channel. Flow in the right overbank is expected to pond in the Storage Area 4 until it infiltrates.

Storage Area 5 is located just to the west of Dishman Mica Rd. and just north of 28th Avenue, immediately downstream of Storage Area 2. This storage area is bounded by 24th Ave to the south, the railroad track embankment to the west, and Dishman Mica Road to the east. Water can pond in this area during larger flood events due to the limited capacity of a culvert through the railroad embankment, the only downstream outlet.

Storage Area 6 is a large gravel pit which serves as the terminus of the unnamed tributary on Chester Creek.

2.2 *Geology*

The geology of the watershed was defined based on 1:100,000 scale mapping created by the Washington State Department of Natural Resources (DNR, 2001). For hydrologic modeling purposes, each geologic association was assigned to one of two categories; bedrock or glacial outwash as shown in Table 1 and Figure 4.

Table 1: Surficial geologic associations and relationship to HSPF geology categories

Geologic Association	Geologic Code	HSPF Category
Continental sedimentary deposits or rocks	Mc(l)	Bedrock
Heterogeneous metamorphic rocks	pChm(p)	Bedrock
Alluvium	Qa	Outwash
Outburst flood deposits, gravel, late Wisconsin	Qfg	Outwash
Loess	Ql	Bedrock
Alaskite-aplite-pegmatite	TKiaa	Bedrock

Subbasin 2, which is the most densely developed area of the watershed, is underlain by highly infiltrative glacial flood deposits. Stormwater infiltration systems (drywells) infiltrate runoff in this area and this subbasin does not contribute to floods in Chester Creek. The topography in this area is flat and during large floods that exceed the drywell capacity, water would be stored at the inlet of the dry well and would eventually infiltrate as the flood subsided. Furthermore, there are no apparent surface connections that would allow for water ponded at the dry well inlets to flow into Chester Creek.

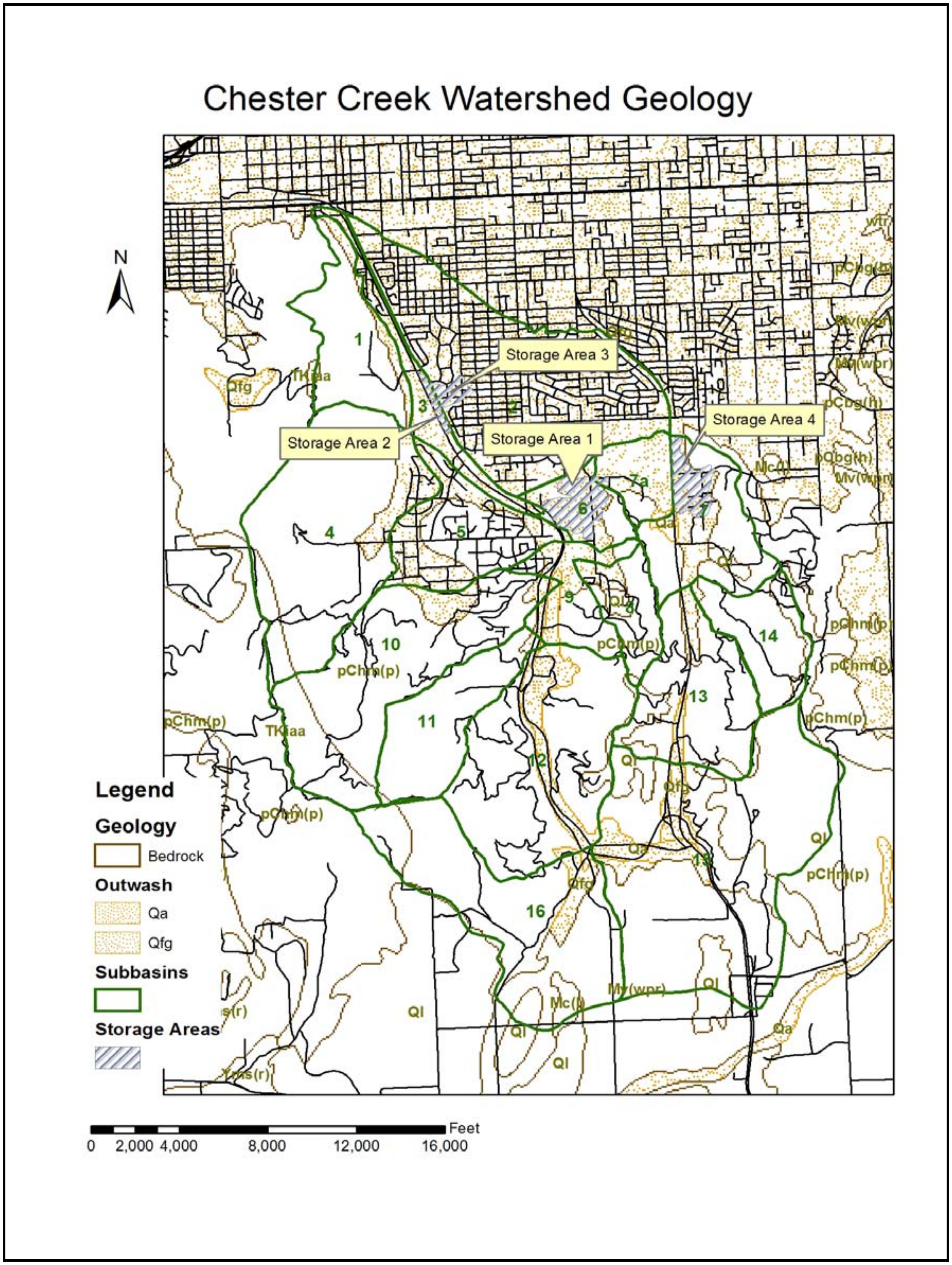


Figure 4: Chester Creek watershed geology

In general, the upper reaches of the watershed are underlain by bedrock. The majority of infiltrated moisture in these areas moves laterally along the bedrock surface, reaching the stream as interflow. The rate of interflow is proportional to the slope of the bedrock and is much slower than the rate of surface overland flow.

The lower reaches of the watershed are underlain by deep, highly infiltrative, glacial outwash deposits. Soils formed in areas with glacial flood burst (outwash) deposits consist of sand and gravels that have high infiltration rates. The majority of rainfall in these areas infiltrates and percolates to the groundwater table. The elevation of the regional groundwater table is well below the Chester Creek streambed, and flow is lost from the creek in the lower reaches underlain by the outwash deposits.

The permeability of soils formed over glacial flood deposits range from 2.5 to greater than 10 inches per hour, according to the Soil Conservation Service (SCS, 1968). Two infiltrometer tests performed in the vicinity of the borrow pit in the lower reaches of the watershed (Subbasin 3, Storage Area 2) revealed surface infiltration rates of 7.1 and 12.1 inches per hour (Spokane County, 1996). At depths of 8 feet and 18 feet, infiltration rates of 660 and 280 inches per hour were noted. Thirteen test pits were excavated as part of the development of the Chester Creek watershed plan (CH2M Hill 1997) near Thorpe Road and Schafer Road. In general, soils range from silty sand near the surface to coarse sand at depth. As part of the Chester Creek watershed planning study, a maximum infiltration rate of 8 inches per hour was assumed to estimate the size of possible infiltration facilities (CH2M Hill, 1997).

The rate of stream flow loss along the lower reaches is likely variable, depending on the amount of fine-grained material, eroded from the upper reaches of the watershed, which has been deposited over the glacial outwash deposits. Given the uncertainty in establishing the actual loss rate for the lower reaches, a range of infiltration rates were simulated with the hydrologic model to identify the sensitivity of the final flood discharge results on the assumed infiltration rate. Additionally, photographs of water levels in the borrow pit taken at the time of floods in February 1999 and April 2000 were used during the calibration to estimate an appropriate channel loss rate.

2.3 *Land Cover*

Existing land use was used for all simulations. Land use was derived by an analysis of aerial photographs and Geographical Information System (GIS) coverage of the watershed. Three land cover classes were considered in analyzing the watershed hydrology; forest, grass, and impervious. The percentage of each cover allocated to the mapped land uses are shown in Table 2 according to relationships developed by Sutherland (1995).

Table 2: Land use and percentage of HSPF cover categories

Land Use	HSPF Land Cover Classes		
	Impervious (Effective Impervious)	Grass (Developed Pervious)	Forest (Undeveloped Pervious)
Undeveloped	0%	0%	100%
Rural	4%	0%	96%
Med Density	10%	90%	0%
Suburban	23%	77%	0%

2.4 *HSPF PERLND Areas*

The area within each subbasin was classified into areas of common land cover and geologic/soil type called PERLNDS (short for pervious land segments). The total surface area belonging to each PERLND type was computed using land use, geology, and topography overlaid in a GIS. The HSPF model computes the hydrologic response of each PERLND within a subbasin on a per-unit-area basis and proportions the amount of surface runoff, interflow and groundwater entering the stream from each subbasin consistent with the computed PERLND area totals. The land use used in the analysis is summarized in Table 3.

Table 3: Summary of Chester Creek existing land use.

	Subbasin Land Use (acres)					
Subbasin	Impervious	Urban Outwash	Undeveloped Outwash	Urban Bedrock	Undeveloped Bedrock	Subbasin Total Area
C1	0.0	0.0	89.3	0.0	487.0	576.3
C2*	418.3	1392.4	0.0	0.0	0.0	1810.6
C3	29.8	266.9	0.0	0.9	0.0	297.6
C4	0.0	0.0	185.1	0.0	1367.4	1552.5
C5	63.9	296.3	0.0	279.0	0.0	639.3
C6	10.5	0.0	195.3	0.0	57.2	263.0
C7	25.9	0.0	218.0	0.0	403.9	647.8
C7A	10.2	0.0	205.0	0.0	39.2	254.4
C8	0.0	0.0	50.2	0.0	246.8	297.0
C9	0.0	0.0	158.9	0.0	197.3	356.1
C10	0.0	0.0	111.8	0.0	1279.2	1391.0
C11	0.0	0.0	15.5	0.0	588.9	604.3
C12	0.0	0.0	220.6	0.0	1223.2	1443.8
C13	0.0	0.0	86.1	0.0	724.1	810.2
C14	0.0	0.0	6.3	0.0	430.7	437.0
C15	0.0	0.0	248.1	0.0	2068.8	2317.0
C16	0.0	0.0	92.2	0.0	1272.9	1365.2

* Runoff from Subbasin C2 Infiltrates and does not Contribute to Flow in Chester Creek

2.5 *Stream Definition/ Channel Routing*

Runoff computed by the HSPF model is routed through the stream network using a kinematic wave hydrologic routing algorithm. The principal input for this routine is a stage-storage-discharge rating table, called an FTABLE, which was developed for each subbasin. FTABLES were developed for the mainstem and lower east branch using hydraulic information from a HEC-RAS model (USACE, 2003) of the Chester Creek channel and floodplain. FTABLES for reaches outside of the HEC-RAS study area were computed using open channel hydraulic calculations (Chow, 1959) with a single representative cross section for each subbasin.

2.6 *Climate Time Series Input*

Snow accumulation and melt was included in the hydrologic computations performed by the HSPF model. HSPF uses an energy budget snow simulation algorithm that requires a number of time series data in addition to precipitation and evaporation. These additional time series included: temperature, solar radiation, wind, and dew point. The simulation period was based on hourly data for the Spokane Airport weather station (Station 45-7938), which spanned October 1948 through September 2002. Several of the required time series data were not available or were incomplete over this period. Estimation equations/algorithms were used to fill in the missing portions of the time series, as described in the following sections.

2.6.1 Precipitation

Hourly precipitation is available for the Spokane Airport Station from October 1948 through September 2002. The Spokane Airport record was transposed to the watershed according to the ratio of the mean annual precipitation for the watershed and gage locations. The watershed mean annual precipitation was determined to be 20 inches based on mapping developed by Oregon Climate Service (1997) using GIS techniques. The mean annual precipitation at the Spokane Airport was computed from the record to be 16 inches, which resulted in a precipitation scaling factor of 1.25.

2.6.2 Temperature

Hourly temperature data was derived from daily maximum and minimum temperature data from the Spokane Airport. A disaggregation routine was used to distribute the daily maximum and minimum temperatures to hourly values. This routine assumed that the minimum occurs at 6 AM and the maximum occurs at 4 PM for each day.

2.6.3 Solar Radiation

Daily solar radiation was estimated using an approach by Hamon et al. (1954), which required inputs of daily cloud cover and watershed latitude. Daily cloud cover was available from the Spokane Airport gage from 1965 through 1995. Mean monthly cloud cover for rainy versus rain free days was computed using this information, which was subsequently used to estimate cloud cover for missing periods.

2.6.4 Evaporation

Daily potential evapotranspiration was estimated for the simulation period using the Jensen-Haise (ASCE, no date) approach, which uses inputs of daily average air temperature and solar radiation. Daily pan evaporation data were available for the Spokane Airport Station from 1966 through 1996. The estimated values compared favorably with the available pan evaporation data collected at the Spokane Airport. The pan evaporation data was scaled by 0.72 to convert from pan evaporation to potential evapotranspiration for the comparisons.

2.6.5 Dew Point Temperature

Daily dew point temperatures were available from the Spokane Airport from 1984 through 2002. Prior to 1984, daily minimum temperature was used to estimate the dew point temperature.

2.6.6 Wind Speed

Daily wind speeds were available from the Spokane Airport from 1984 through 2002. Prior to 1984, mean monthly wind speeds were used.

3 HSPF MODEL CALIBRATION

Calibration of the HSPF model was performed to ensure that the hydrologic processes simulated by the model were representative of the conditions in the Chester Creek watershed. Hourly climatic data were used as input to the model and the model parameters adjusted until simulated and recorded flow rates matched as closely as possible.

There is no long-term climate or snowpack data available for the Chester Creek watershed. Therefore, climate and snow depth data from the Spokane Airport were used to calibrate the model. Discharge measurements were available for Chester Creek near the Dishman-Mica Road Crossing for the periods December 1994 through March 1995 and November 1995 through February 1996. These measurements were collected as part of the HYDMET (1997) analysis.

The calibration was accomplished in a two-step process. First, the parameters controlling snow accumulation and melt were calibrated to observed snow depth data collected at the Spokane Airport for water years 1948 through 2002. Second, the parameters controlling runoff were calibrated to the Chester Creek stream flow record.

3.1 *Snow Accumulation and Melt*

Figure 5 shows a comparison between simulated and recorded snow depths for two high snow depth years (1949, 1950) and one low snow depth year (1951). Similar results were obtained for the entire period simulated, however this period is shown for brevity. A close match between simulated and recorded snow depth is indicated by the figure, indicating that the timing and amount of moisture input to the soil from snowmelt matches what actually occurs at the Spokane Airport.

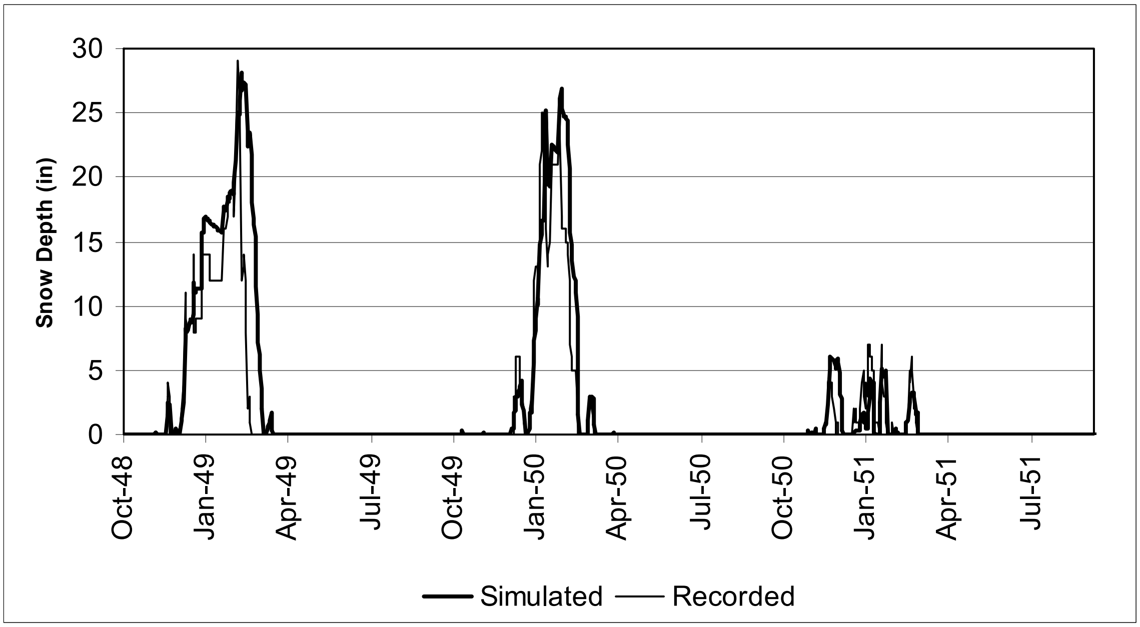


Figure 5: Comparison of simulated and recorded snow depth, Spokane Airport

3.2 *Stream Flow Calibration*

Stream flow data collected as part of the Chester Creek watershed planning effort (CH2M Hill 1997) for the winter months of 1995 and 1996 was used to calibrate the soil (PERLND) parameters of the model. The stream gage was located near the Dishman-Mica Road crossing and received runoff from approximately 12 square miles. The majority of the watershed upstream of the gage is composed of relatively shallow soils over rock with storm water runoff dominated by shallow subsurface flow. Downstream of the gage, the watershed is composed almost entirely of glacial flood deposits. These consist of sand and gravel that have a high infiltration rate. In this area, all stream flow in Chester Creek infiltrates and is lost to the outwash deposit even for moderate-to-large floods.

As part of the HYDMET HSPF analysis, precipitation was measured in the Chester Creek watershed at two locations concurrent with stream flow gage measurements for the 1995-1996 period. The local precipitation data used for calibration in that study was not available for use in the current study. Alternatively, data from the Spokane Airport was translated to the watershed for both calibration and long-term simulations.

Close agreement between simulated and recorded stream flow was achieved (Figure 6). This indicates that the model is adequately simulating the runoff processes in the Chester Creek watershed. As with any hydrologic model, there is uncertainty with regard to the ability of the model to accurately predict stream flow. The uncertainties in the model calibration are discussed later in this report.

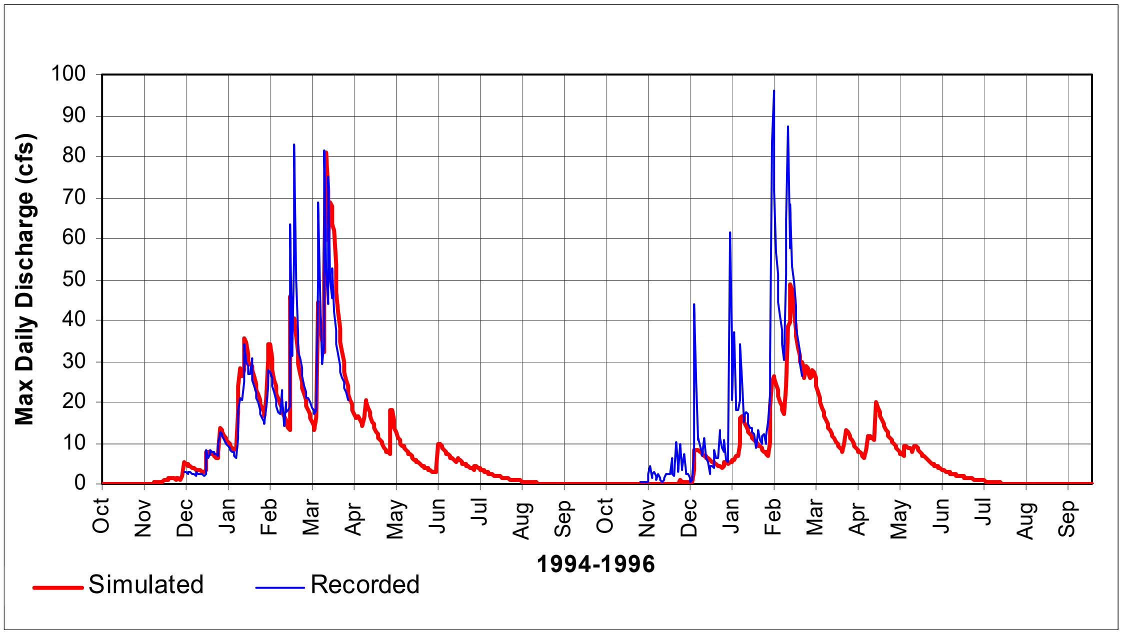


Figure 6: HSPF model calibration, Chester Creek at Dishman-Mica Road simulated and recorded maximum daily discharge (WY 1994-1996)

The final HSPF parameter set is listed in Table 4. The Lower Zone Storage Nominal (LZSN) parameter was significantly lower as compared to the values in the HYDMET model, which ranged from 8 inches to 15 inches. The LZSN parameter defines the soil moisture storage and is depleted only by evapotranspiration.

Table 4: Calibrated HSPF parameter set for pervious areas

Pervious Land Type	FOREST	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
Bedrock Undeveloped	0.800	5.50	0.20	400	0.10	0.50	0.975
Bedrock Developed	0.100	5.50	0.10	400	0.10	0.50	0.975
Outwash Undeveloped	0.800	5.50	2.00	400	0.05	0.50	0.975
Outwash Developed	0.100	5.50	0.80	400	0.05	0.50	0.975

Pervious Land Type	PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
Bedrock Undeveloped	0.0	0.0	2.0	2.0	0.0	0.0	0.0
Bedrock Developed	0.0	0.0	2.0	2.0	0.0	0.0	0.0
Outwash Undeveloped	0.0	0.0	2.0	2.0	0.0	0.0	0.0
Outwash Developed	0.0	0.0	2.0	2.0	0.0	0.0	0.0

Pervious Land Type	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
Bedrock Undeveloped	0.20	0.20	0.35	6.0	0.60	0.60
Bedrock Developed	0.10	0.10	0.05	6.0	0.60	0.20
Outwash Undeveloped	0.20	0.20	0.35	0.0	0.60	0.60
Outwash Developed	0.10	0.10	0.05	0.0	0.60	0.20

3.3 *Calibration of Stream Flow Loss in Lower Reaches*

3.3.1 Calibration to Anecdotal Evidence

The lower reaches of the watershed are underlain by glacial flood deposits that are composed of highly infiltrative sand and gravel. In these areas, all stream flow in Chester Creek infiltrates and is lost to the outwash deposit. In 1998, material was excavated in the Chester Creek floodplain for use in a road improvement project for Dishman-Mica Road forming a borrow pit that now captures Chester Creek (noted as Storage Area 2, on Figure 3). Stream flow entering the borrow pit is retained and infiltrated. No discharge from the borrow pit to downstream reaches has occurred since its construction in 1998.

In December of 1996, a rain on snow event resulted in a large flood. The HSPF simulations indicated that this was the largest flood out of the 54-year simulation period. It was reported that all runoff from this flood infiltrated through the stream channel bottom before reaching 28th Street (HYDMET, 1997)

Stream flow data for the lower reaches of the watershed are not available for model calibration; however, photographs of the borrow pit during floods in January 1999 and April 2000 were available [See Appendix A for historic photographs]. The water surface elevation in the borrow pit was estimated to be about the same during each flood, with an elevation of approximately 1992 feet. The HSPF model simulations were performed using a range of stream channel and borrow pit infiltration rates to determine an infiltration rate that best matched the observed elevation in the photographs.

Soil infiltration rates were assumed to range between 0.2 and 9.0 inches per hour. The assumed infiltration rates were chosen to be consistent with published values (SCS, 1968), field measurements (Spokane County, 1996), field observations of channel characteristics (WEST, 2003), calibration to observed water levels within the borrow pit, and other anecdotal evidence of historic conditions of flooding (CH2M Hill, 1997). It was recognized from field observation and historic channel improvements that fine-grained sediments eroded from the upper watershed are deposited along the channel in the lower basin. It is also recognized that a sediment settling pond was constructed upstream of Thorpe Road and the channel from Thorpe Road to the borrow pit was dredged as part of recent channel improvements (CH2M Hill, 1997).

The infiltration rate in the borrow pit was assumed to be 9.0 inches per hour. This value is within the range of field measured infiltration values (CH2M Hill, 1997). In general, an infiltration rate of 4 inches per hour was assumed for the channel between Thorp Road and the borrow pit. However, it was observed during field reconnaissance and channel survey activities that the channel encompasses wetland areas between Bowdish Road and the borrow pit. Therefore, a stream channel infiltration rate of 0.2 inches per hour was assumed for the portion of the channel between the thalweg and a stage of two feet in that area. For wetted portions of the channel above a depth of two feet, and infiltration rate of 4 inches per hour was retained. These assumed values resulted in the closest match to the water surface elevations observed in photographs of the borrow pit during recent flood events (Figure 7).

Downstream of the borrow pit, no defined channel for Chester Creek exists. The flow spreads across relatively flat fields and pastures. The reaches downstream of the borrow pit (Reaches I-J and K-L) were assigned infiltration rates of 6.0 inches per hour. The assumed higher infiltration rate in these reaches are consistent with a reduced supply of fine sediments from the upper watershed and HSPF results that agree with the anecdotal record of historic flood conditions.

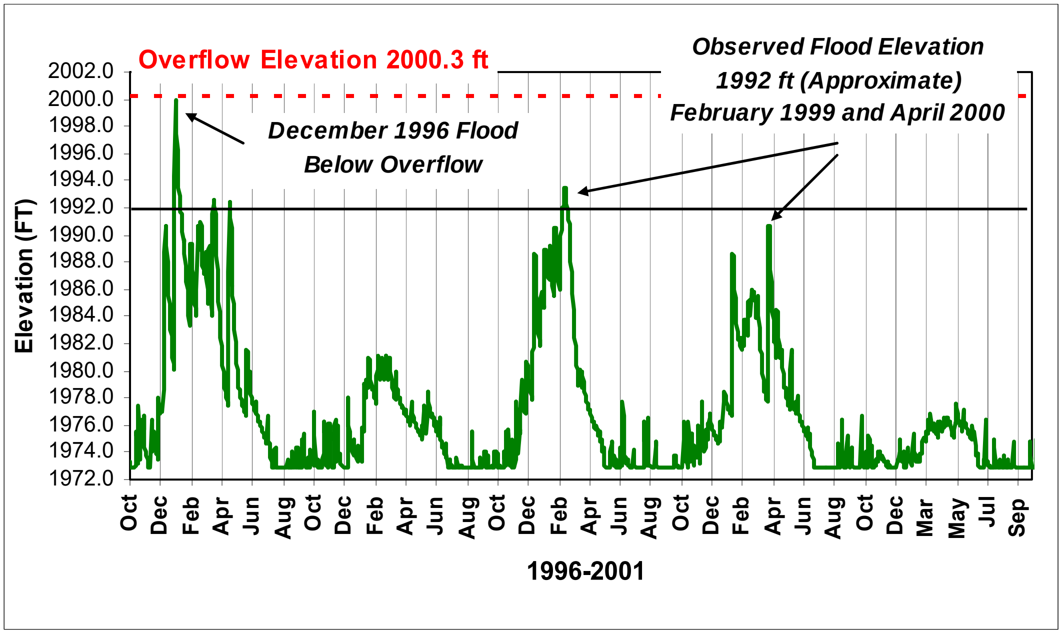


Figure 7: Simulated water surface elevation in the Dishman-Mica borrow pit (Storage Area 2)
Borrow Pit Infiltration Rate: 9.0 inches/hour
Stream Channel Infiltration Rate: 0.2-4.0 inches/hour

3.3.2 Calibration to Regional Data

An HSPF model of Chester Creek calibrated to historical anecdotal evidence as described in section 3.3.1 was submitted for review as a draft report to Michael Baker Jr. in February 2004. The conclusion of that review was that the infiltration rates used were, “consistent with infiltration facilities operating in perfect condition with summer time soil conditions” and that, “infiltration rates can be expected to fall considerably below the optimum values utilized… as the result of frozen soil conditions or the sealing of pond and ditch bottoms by fine sediment over time”. Michael Baker Jr., Inc. performed additional analysis based on regional data and sensitivity analysis to define infiltration rates to be utilized in the final model.

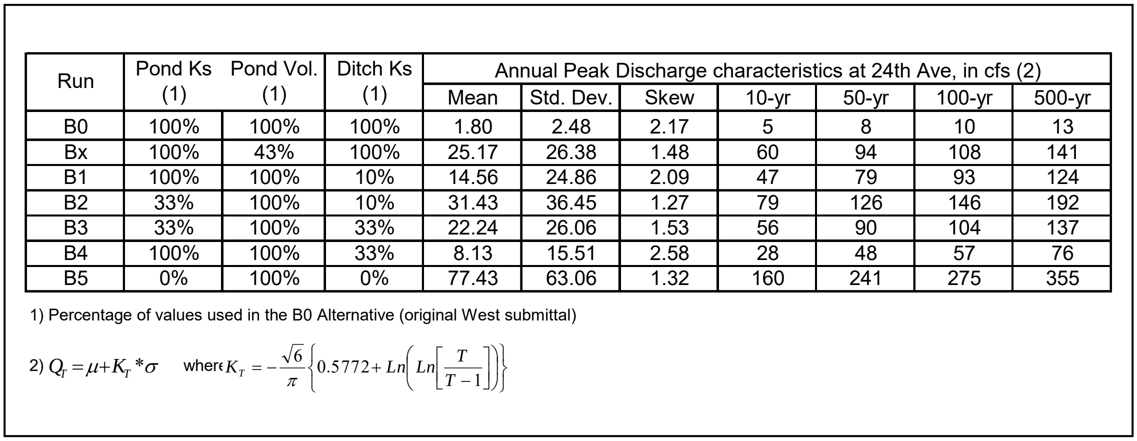
Several gages in the vicinity of Spokane County, WA were identified and five of the gages with the lowest discharge per unit drainage area were selected and assumed to be representative of gaged sites with high infiltration like Chester Creek (Table 5). The flood discharges for these basins were taken from the U.S. Geological Survey Water-Resources Investigations Report 97-4277 (USGS 1998).

Table 5: Gages located in Spokane County area with low discharge per unit drainage area.

Station name and number	Drainage area (mi^2)	Years of record	Q2 (cfs)	Q10 (cfs)	Q100 (cfs)
South Fork Rock Creek Trib near Fairfield, WA (12423700)	0.59	15	25	37	48
Little Spokane River at Elk, WA (12427000)	115	31	110	150	195
Bear Creek near Milan, WA (12429200)	10.5	13	50	82	120
Mud Creek near Deer Park, WA (12429800)	1.83	20	12	23	36
Blue Creek above Midnight Mine, WA (12433542)	6.0	12	5.6	24	71

A number of alternative infiltration scenarios with varying combinations of reduced ditch and pond infiltration rates were run to determine the impact of reduced infiltration on discharge at 24th Avenue. A summary of these runs including estimated peak 10-, 50-, 100-, and 500-year discharges for the 54-year simulation as calculated using Gumble frequency distribution determined from the mean and standard deviation of each simulated series is shown in Table 6.

Table 6: Alternative infiltration scenarios for the Chester Creek watershed model.



Run	Pond Ks (1)	Pond Vol. (1)	Ditch Ks (1)	Annual Peak Discharge characteristics at 24th Ave, in cfs (2)						
				Mean	Std. Dev.	Skew	10-yr	50-yr	100-yr	500-yr
B0	100%	100%	100%	1.80	2.48	2.17	5	8	10	13
Bx	100%	43%	100%	25.17	26.38	1.48	60	94	108	141
B1	100%	100%	10%	14.56	24.86	2.09	47	79	93	124
B2	33%	100%	10%	31.43	36.45	1.27	79	126	146	192
B3	33%	100%	33%	22.24	26.06	1.53	56	90	104	137
B4	100%	100%	33%	8.13	15.51	2.58	28	48	57	76
B5	0%	100%	0%	77.43	63.06	1.32	160	241	275	355

1) Percentage of values used in the B0 Alternative (original West submittal)

2) $Q_T = \mu + K_T * \sigma$ where $K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + Ln\left(Ln\left[\frac{T}{T-1}\right]\right)\right\}$

Alternative B0 represents the HSPF results determined from calibration of infiltration to anecdotal flood data. Alternatives B1-B4 are based on combinations of reduced infiltration rates (with respect to B0) and the resulting discharges at 24th Avenue. Alternative B5 represents the conservative case in which there is no infiltration. Reducing infiltration in ditch bottoms produces the largest impact on peak discharges. Reducing these values seems reasonable when winter conditions may produce frozen channel bottoms. Reduction in pond infiltration capacity also has a large impact on peak discharges; however, it is uncertain as to whether infiltration could be reduced to zero in ponds.

Alternatives BX, B0, B3 and B5 were plotted along with the "gaged low data" and the currently effective FIS discharges (Figure 8). From this comparison it was concluded that the discharge associated with scenario B3 with a 100 discharge of 104 cfs at 24th Avenue is reasonable. This peak discharge is seen to be similar to the discharges per unit drainage are indentified for the regional "gaged low data" gages (Figure 8).

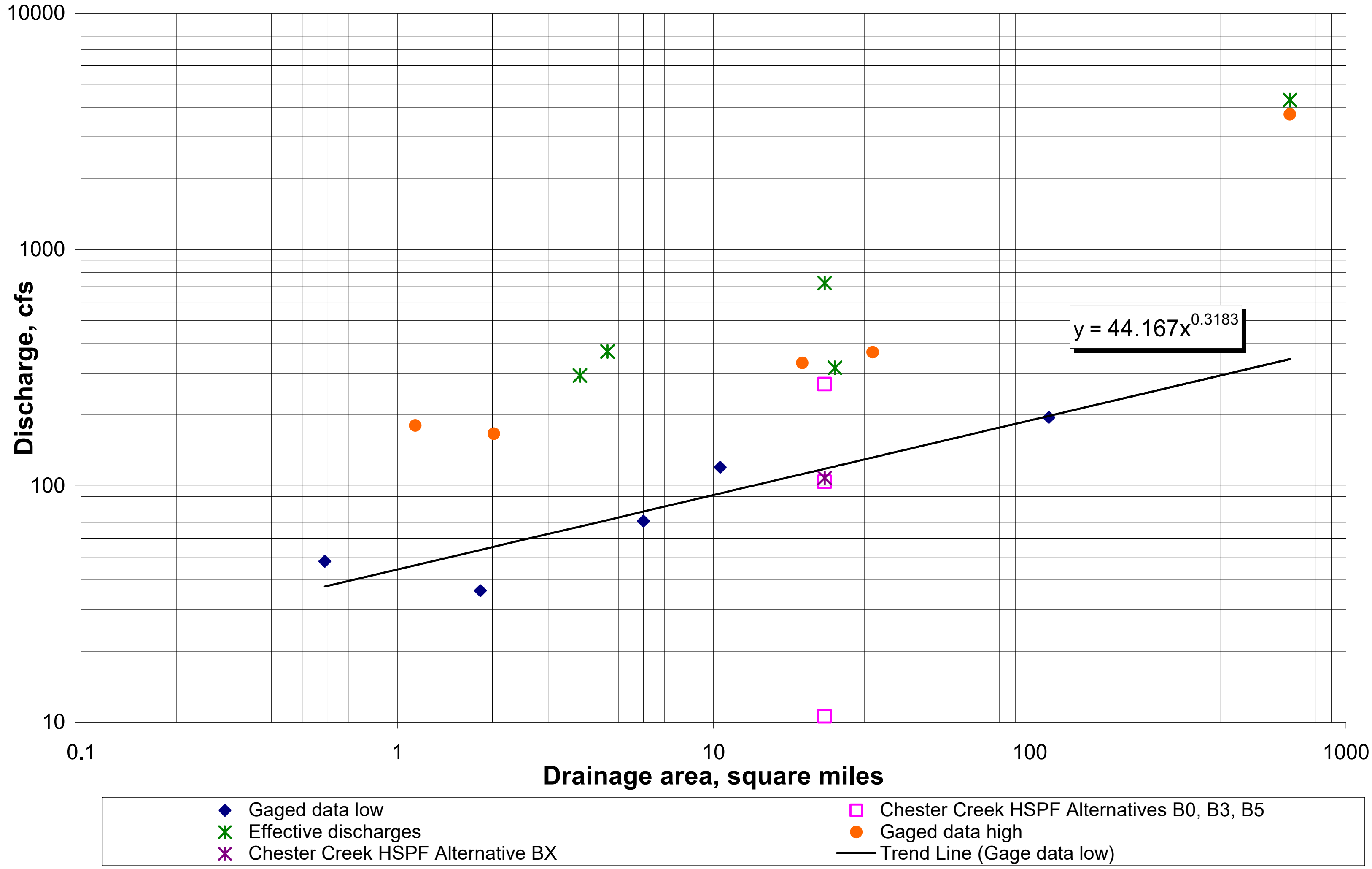
Since it is known that peak discharges in the Chester Creek basin are heavily impacted by the many storage areas found along the main channel, another alternative was run using the originally proposed infiltration rates but with storage capacity reduced by approximately 60%. The "man made" portions of the storage areas were identified and removed from the model in order to simulate only natural storage as might be found in the identified "gaged low data" basins. This scenario, identified as BX in Table 6 resulted in a peak discharge of 108 cfs at 24th Avenue which is again similar to the "gaged low data" and to scenario B3 (Figure 8). Based on this analysis it was concluded that the HSPF model be revised to reflect infiltration rates that are 33 percent of the infiltration rates originally identified over the previously submitted model (Alternative B3).

The recommended alternative has a significantly larger discharge downstream of Storage Area 2 (SA2) than previously identified. Due to the absence of a significant channel to contain Chester Creek downstream of SA2, flow is limited to local drainage ditches beside Dishman Mica Road, ditches along the railroad embankment and overland flow across fields and developed areas. Due to the limited conveyance, flow can overtop Dishman Mica Road and flow into the Kokomo residential area (SA3) adding to the water entering SA3 from the culvert under Dishman Mica road which connects to SA2.

Downstream of Storage Area 2 and adjacent to SA3 a single 3 foot culvert through the Union Pacific Railroad embankment limits potential discharge downstream of the culvert. For larger flood events it was noted that the newly recommended discharges cause water to fill SA3 causing it to overtop back over Dishman Mica Road in the downstream direction and head towards the culvert through the railroad embankment. For larger events the discharge exceeds the capacity of the culvert and forms a new storage area (Storage Area 5(SA5)) bounded by the railroad grade to the west and 24th Avenue to the south. Once SA5 and fills to the level of Dishman Mica Road (the boundary between SA3 and SA5) the storage areas combine and are assumed to have the same water surface elevation. As SA5/SA3 fill, the water surface elevation in the storage area can exceed the elevation of 28th Avenue (the boundary between SA2 and SA5) and backwater into SA2 before water will overtop the downstream boundaries of SA5/SA3. This occurs during the 100-year and 500-year flood events and the water surface elevation is assumed to be the same for SA2, SA3, and SA5 in this case.

The revised 100-year discharge at 24th Avenue is approximately ½ of the discharge identified under alternative B3. This is due to the additional inclusion of the culvert through the railroad embankment and of SA5. However, this is still consistent with alternative BX in which “man made” storage is removed, as SA5 would have been removed for that scenario.

Figure 8: Comparison of 100-year discharges in the vicinity of Spokane County, WA



3.4 *Calibration Uncertainty*

As with any hydrologic model, factors that contribute to model uncertainty include; among others, precipitation input, errors in stream flow observations, and the mathematical representation of the physical system by the model. In the case of the Chester Creek watershed model, the limited data available for calibration is likely the largest source of uncertainty, particularly in establishing the stream channel infiltration rate for the lower reaches of the watershed. As noted earlier, measured infiltration rates in the lower portion of the basin defined a wide range of values. Though the model was calibrated using all available information, it is recognized that significant variation in the assumed infiltration rates could have a significant impact on the resultant discharge rates.

Continuous stream flow records were available at the Dishman-Mica Road crossing for the winter months of water years 1995 and 1996. The stream flow recorder measured stream stage, which was subsequently converted to flow rate using a rating curve. It is noted that the rating curve was developed based on only four discharge measurements developed from a velocity current meter (HYDMET, 1997). The maximum measured discharge on the rating curve was 20 cfs. Consequently, all discharge values higher than 20 cfs are extrapolated. Thus, larger discharge estimation error would be expected the higher the recorded stream flow measurements were above 20 cfs.

Another source of calibration error was due to the lack of available precipitation data in the watershed. Continuous precipitation was recorded at two locations in the watershed as part of the HYDMET study; however, these data were not available for the current analysis. Precipitation recorded at the Spokane Airport (Station 45-7938) was transposed to the watershed for calibration. Differences in precipitation at the Spokane Airport relative to Chester Creek introduced another source of calibration error.

4 FLOOD FREQUENCY ESTIMATES

The calibrated HSPF model was used to compute flood discharge magnitude-frequency estimates, which will be subsequently used as input to a HEC-RAS hydraulic model for floodplain mapping purposes. In addition, water surface elevation magnitude-frequency estimates were computed for the flood storage areas in the watershed. Stream flow in the Chester Creek watershed was simulated using the HSPF model from October 1948 through September 2002, a period of 54 years. Annual maximum discharge and water surface elevation data were saved for each of the years simulated and magnitude-frequency estimates were computed using the methods described in the following section.

4.1 *Statistical Methods*

Because of the high infiltration rates of the stream channel, many of the simulated annual maximum values were zero or very near zero. This resulted in highly non-linear flood frequency relationships that were difficult to fit with conventional probability distributions, such as the Log-Pearson Type III (USGS, 1982). For this reason, a probability-plot regression approach (Stedinger et al., 1992) was used instead in all reaches of the basin.

The probability-plot regression approach uses a probability-related variable as the explanatory variable in a regression relationship with either peak discharge or maximum water surface elevation (Stedinger et al., 1992). The probability-plot approach is summarized below.

1. The annual maxima flood discharge or elevation values were ranked from highest to lowest and assigned a recurrence interval according to the Gringorten Plotting Position (Equation 1).

$$Tr = \frac{N + 0.12}{i - 0.44} \tag{1}$$

   Where: *Tr* is the recurrence interval of the peak (years),
   i is the rank of the annual maxima peak ordered from highest to lowest,
   N is the total number of years simulated (54 in this case).

2. A standardized variate (x) from the Extreme Value Type I distribution (Stedinger et al., 1992) was used as the explanatory variable (Equation 2), and was computed for each non-zero annual maximum. While variates from the Extreme Value Type I distribution were used for this analysis, other transforms, such as a simple logarithmic transform of the recurrence interval, can also be used as the explanatory variable in the regression approach.

$$x = -0.7797 * \left\{ 0.5772 + LN\left(LN\left[\frac{Tr}{Tr - 1} \right] \right) \right\} \tag{2}$$

3. The annual maximum flood discharge values were then regressed upon the variates computed in Step 2 using either a linear function or second order polynomial. The resulting regression equation was then used to compute flood discharge values corresponding to the desired recurrence intervals (annual exceedence probabilities).

An example of the approach is shown in Figure 9. Recurrence intervals, rather than standardized variates, have been shown on the Extreme value Type I plotting-paper for the convenience of the reader. A magnitude-frequency curve was computed using the Log-Pearson III distribution and is shown in Figure 9 for comparison. Note that the results using the Probability Plot Regression Approach better matched the simulated annual maxima data than the Log-Pearson III distribution, especially for rare floods. The poor fit of the Log-Pearson distribution is the result of several near zero values that distort the statistics and result in a large negative skew. The negative skew causes the curve to flatten at the upper end and produced a poor fit to the larger floods in the data set.

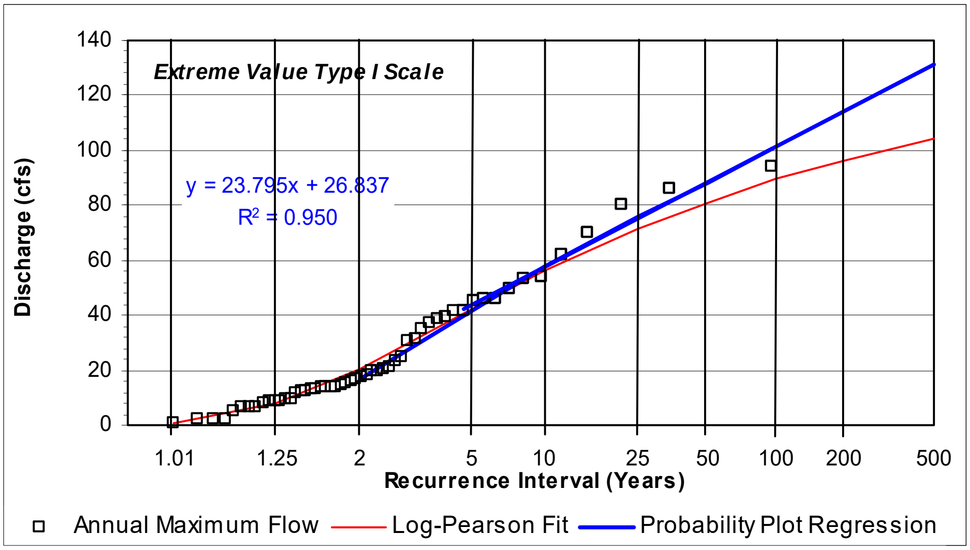


Figure 9: Magnitude frequency results, cross section A (Upper Subbasin 12) Probability Plot Regression and Log-Pearson III

4.2 *Magnitude-Frequency Results*

Final flood magnitude-frequency results computed using the 54 years of simulated stream flow and the revised regional calibration are presented in Table 7 and Table 8. The locations of the cross-sections defined in Table are shown in Figure 3. Values at the 10- 50-, 100- and 500-year recurrence interval are to be used as input to the HEC-RAS hydraulic model for floodplain mapping purposes.

It should be noted that uncertainty in the flood-frequency estimates increases for recurrence intervals greater than the number of years used to compute the statistics (54-years in this case). Thus, the extrapolation of simulated flows to the 100-year and 500-year recurrence intervals adds additional uncertainty to the estimates beyond those discussed in the calibration section of this report.

Table 7: Flood magnitude frequency estimates
Chester Creek Watershed existing land use

4.2.1.1.1 Location	2-yr	10-yr	25-yr	50-yr	100-yr	500-yr
Cross Section A	17	58	75	89	101	131
Subbasin 11+12	25	87	114	135	155	201
Cross Section AA, Upstream of Diversion	45	105	136	158	180	232
Cross Section B	40	118	130	139	147	167
Cross Section BB, Overflow to Golf Course	0	30	44	54	64	88
Cross Section D	40	115	128	138	148	170
Cross Section E'	40	113	127	137	147	169
Cross Section F	40	90	112	129	146	184
Cross Section H	35	83	106	122	139	178
Storage Area 2 Outlet	10	60	83	100	117	155
Subbasin 4 (Section I)	3	14	21	26	32	44
Cross Section J	0	1	2	3	4	5
Cross Section K	15	36	44	49	55	68
Cross Section L	1	2	3	3	4	5
Cross Section M	2	7	11	14	18	28
Cross Section N	3	11	17	22	28	45
Cross Section N’	5	12	18	24	30	46
Cross Section O	5	10	12	14	16	20
Storage Area 6 Outflow	0	0	0	2	4	7
Storage Area 1 Outflow	0	0	0	0	0	0

Table 8: Water surface elevation magnitude frequency estimates (ft)

Location	2-yr	10-yr	25-yr	50-yr	100-yr	500-yr	Overflow Elevation (ft)
Storage Area 1	2004.50	2007.19	2007.54	2007.80	2008.05	2008.64	2009.0
Storage Area 2	2000.50	2000.82	2000.96	2001.18	2001.48	2001.90	2000.3
Storage Area 3	1999.70	2000.45	2000.87	2001.18	2001.48	2001.90	1999.8
Storage Area 4	2016.90	2018.30	2018.99	2019.23	2019.47	2020.03	2025.0
Storage Area 5	1998.50	2000.45	2000.87	2001.18	2001.48	2001.90	2001.9
Storage Area 6	1996.10	2005.00	2008.50	2009.60	2009.70	2010.00	2009.5

4.3 *Verification*

A variety of anecdotal information and historic observations support the results of this analysis for existing watershed conditions. Field observations indicate that a defined channel for Chester Creek becomes progressively less discernible downstream of Schaffer Road. It is apparent that the frequently occurring flows necessary to form a channel are severely reduced or absent due to the high infiltration rate of the soils in the lower portion of the Chester Creek basin.

Long-term residents of the area familiar with the stream have observed “the entire stream eventually infiltrates in to the ground, even during major floods” (CH2M Hill, 1997). It was also observed that the flood in early 1996 “produced minor flows at Schafer Road and entirely infiltrated before reaching 28th Street”. A significantly larger flood event in January 1997, was observed to “extend to 24th Avenue prior to infiltration” (CH2M-Hill, 1997). It is further recognized that both these events occurred prior to the construction of the borrow pit floodwater retention and infiltration facility between Schafer Road and 28th Street.

The January 1997 flood event was identified by the current analysis to be the largest flood for the 54-year period of simulation. It was estimated to be an approximate 100-year return period flood event. The January 1997 occurred due do warm rain and rapid melting of the snow pack. From 30 December to January 2, about 1.03” of rain reduced Spokane’s snow pack depth from 20” to 7” (NWS, 1997).

A sensitivity analysis of the discharge per unit drainage area was conducted at gaging stations in the region. The discharge per unit area for Alternative B3 compares well to other regional gages with low runoff characteristics. Accordingly, the infiltration rates calibrated based on anecdotal evidence were reduced by 66% percent to be consistent with regional data.

A comparison of the estimated peak flow frequency estimates resulting from the current analysis, prior studies, and USGS regional regression methods is shown in Table 9. The comparison is made to illustrate the differences between the estimates. In general, the differences can be explained by the methods used to develop the estimates. The HYDMET HSPF (HYDMET, 1997) results are understood to represent the ultimate future development conditions within the Chester Creek watershed. Because of that assumption, it would be expected that the HYDMET peak flow estimates would be larger than estimates for existing (less developed) conditions. It is believed that the FEMA (1992) estimates were developed assuming frozen ground conditions. Since frozen ground would prevent soil infiltration, the FEMA estimates would be expected to be considerably larger than all other estimates.

The estimates derived from two sets of USGS regional regression equations are also noted in Table 9. Those estimates reflect the data upon which the regressions are based. The 1997 USGS regression equations for the study area were based on the basin characteristic of drainage area for 23 gage locations. The 1997 regressions also do not differentiate between the causes of floods (i.e., rainfall, snowmelt, or rain on snow). It is further noted that the 1997 regressions for the study area (Region 8) have a high standard error of prediction (119 percent for an exceedence probability of 0.01), which indicates a high level uncertainty about the estimates provided by the derived regressions. The 1974 USGS regression equations were defined from two groupings, one based on all data from eastern Washington and the other based on all data from western Washington. The equations were further refined into 12 regions using differences in surficial soils porosity. The regression equations for the study area are based on the characteristics of basin size, mean annual rainfall, and percentage of forest cover. The 1974 regressions similarly do not differentiate between the causes of floods (i.e., rainfall, snowmelt, or rain on snow). It is noted that large standard errors of prediction are associated with arid areas, such as the study area, and accordingly the 1974 regressions for the study area (Region 10) have a high standard error of prediction (129 percent for an exceedence probability of 0.01), which indicates a high level uncertainty about the estimates provided by the derived regressions.

Table 9: Comparison of 100-year return period flood frequency estimates

Estimate Source		Location			
		Mohawk Road	Thorpe Road	Schafer Road	24th Avenue
WEST HSPF with revised infiltration	100-year Discharge Estimate (cfs)	155	215**	146*	55*
	cfs/mi2	17	17	9	3
WEST HSPF with optimal infiltration	100-year Discharge Estimate (cfs)	155	215**	92*	1*
	cfs/mi2	17	17	5	<1
FEMA TR-20 (1992)	100-year Discharge Estimate (cfs)	405	405	644	722
	cfs/mi2	45	33	38	37
HYDMET Study HSPF (1997)	100-year Discharge Estimate (cfs)	278	403	478	N/A
	cfs/mi2	31	33	28	N/A
USGS Regression Equations (1997)	100-year Discharge Estimate (cfs)	299	366	457	506
	cfs/mi2	33	31	27	26
USGS Regression Equations (1974)	100-year Discharge Estimate (cfs)	190	228	322	364
	cfs/mi2	21	19	19	18

* These discharge values reflect the influence of infiltration.

** This value includes flow continuing downstream from Thorpe Road and flow diverted to the golf course.

5 CONCLUSIONS AND RECOMMENDATIONS

A detailed hydrologic analysis of Chester Creek in Spokane County and the City of Spokane Valley, Washington was conducted. The analysis established flood magnitude-frequency estimates for Chester Creek that are to be used in a Flood Insurance Restudy of the watercourse. The analysis was conducted using HSPF. Frequency analyses were performed using 54 years of simulated stream flow information.

The key findings of the hydrologic analysis include:

- Simulated and recorded discharges compare well with the limited data available for the Dishman-Mica Road gage location. The model also adequately replicated water surface elevations in the borrow pit (Storage Area 2) observed during flood events which occurred in February 1999 and April 2000.

- The discharge along the mainstem of Chester Creek reaches a maximum in the central portion of the watershed at the outlet of Subbasin 9 at Thorpe Road. A 100-year return period flood discharge of 215 cfs was predicted at that location. Floods equal to or greater than a 10-year return period event overflow into the Painted Hills Golf Course across Thorpe Road. Floodwaters entering the golf course were determined to infiltrate and not return to Chester Creek. Downstream of Thorpe Road, the remaining flow in Chester Creek infiltrates into glacial outwash and the discharge decreases progressively downstream.

- Chester Creek flows into a borrow pit (Storage Area 2) that was constructed as part of improvements to Dishman-Mica Road (Spokane County, 1998). The stream flow entering the borrow pit infiltrates and discharge to downstream reaches has not occurred since the borrow pit was constructed in 1998. Hydrologic simulations showed some discharge occurring from this storage area for all simulated flood events starting at the 2-year recurrence interval. During these events, water will overflow from the borrow pit and result in discharge to the downstream channel.

- The 100-year return period discharge rate at 24th Avenue (Cross Section K) downstream of the borrow pit was estimated at approximately 55 cfs with a discharge of 4 cfs at 2nd Avenue indicating only shallow sheet flow at the downstream extent of the study area.

A variety of anecdotal information and historic observations were identified to verify the results of the hydrologic analysis for existing watershed conditions. These include:

- A defined channel for Chester Creek becomes progressively less discernible downstream of Schaffer Road, indicating that frequently occurring flows necessary to form a channel are severely reduced or absent due to the high infiltration rate of the soils in the lower portion of the Chester Creek basin.

- Long-term residents of the area familiar with the stream have observed “the entire stream eventually infiltrates in to the ground, even during major floods” (CH2M Hill, 1997).

- A flood event in January 1997, estimated by the current HSPF analysis to be approximately a 100-year exceedence probability event, was observed to "extend to 24th Avenue prior to infiltration" (CH2M-Hill, 1997).

- In 1998, a borrow pit was constructed along Chester Creek between Schafer Road and 28th Avenue to retain and infiltrate floodwaters.

Despite the noted verification of study results, uncertainty associated with the developed hydrologic estimates includes the following important factors:

- No long-term records of precipitation or flow measurements specific to the Chester Creek watershed exist.

- Continuous stream flow records used for calibration were only available at the Dishman-Mica Road crossing for the winter months of water years 1995 and 1996. The stream flow record was based on a rating curve developed from flow measurements up to 20 cfs; therefore, larger errors would be expected for stream flow records above 20 cfs

- Soil tests in the watershed indicate highly variable soil infiltration characteristics. The soil infiltration rates used in the HSPF analysis are average assumed values, justified by calibration to a limited record of runoff conditions in the borrow pit downstream of Schafer Road.

- A variety of factors can affect the long-term infiltration characteristics of the soil. These factors include sedimentation along the channel, vegetation, and land use changes. Future soil infiltration characteristics may be significantly different from historic conditions.

- There are significant differences between the magnitude of hydrologic estimates defined by prior investigations and those developed by the current study. These differences have significant implications for water surface elevations and the extent of the floodplain. The major differences between the prior and current studies are related to assumptions regarding land use conditions and soil infiltration characteristics. It is evident that these assumptions have a significant effect on the resulting hydrologic estimates.

The following recommendations should be considered to address the potential uncertainty in the hydrologic estimates:

- Watershed changes that would affect soil infiltration characteristics in the lower basin should be monitored. This should include monitoring of sedimentation conditions along channels and within the borrow pit.

- Additional precipitation and stream gaging measurements should be collected that would allow improvement of model calibration and verification.

- Future reanalysis of the hydrologic estimates should be conducted if soil infiltration conditions in the basin change or if an improved record of basin specific precipitation and flow records is developed. Additionally, if land use conditions in the basin change significantly the hydrologic estimates should be updated.

- In recognition of the uncertainties involved with the hydrologic analysis of the basin, until a long term record of basin specific precipitation and stream flow data is developed, consideration should be given to defining hydrologic estimates based on future land use conditions that consider the influence of the recently constructed borrow pit. It is recognized that both existing and future land use condition floodplains could be delineated on FEMA FIRM maps. A future land use condition floodplain would be expected to define a conservatively larger estimate of the 100-year floodplain extent.

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7 APPENDIX A – Compact Disk “Chester Creek Hydrologic Analysis”

Electronic HSPF model files
Photo Log