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SURFACE WATER FLOW AND INFILTRATION MODEL SUMMARY REPORT VOLUME 1 OF 2 NOVEMBER 1993 DRAFT FINAL

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Surface Water Flow and Infiltration Model Summary Report

Fernald Environmental Management Project

Fernald, Ohio

November 1993
Volume 1 of 2

U.S. Department of Energy
Fernald Field Office

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SURFACE WATER FLOW AND INFILTRATION MODEL SUMMARY REPORT

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

NOVEMBER 1993

VOLUME 1

U.S. DEPARTMENT OF ENERGY
FERNALD FIELD OFFICE

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LIST OF ACRONYMS

COE	U. S. Army Corps of Engineers
CPC	contaminant of potential concern
DOE	U.S. Department of Energy
EPA	U. S. Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation
GMA	Great Miami Aquifer
GMR	Great Miami River
REM	routine environmental monitoring
MUSLE	Modified Universal Soil Loss Equation
RI/FS	remedial investigation/feasibility study
SCS	Soil Conservation Service
SSOD	storm sewer outfall ditch
SWF&IM	Storm Water Flow and Infiltration Model
SWIFT	Sandia Waste Isolation Flow and Transport
SWRB	storm water retention basin
USDA	U.S. Department of Agriculture
USGS	U. S. Geological Survey
USLE	Universal Soil Loss Equation

1.0 INTRODUCTION

The Fernald Environmental Management Project (FEMP) is a former uranium processing facility owned by the U.S. Department of Energy (DOE). Today the facility is the focus of extensive environmental restoration activities and remedial investigations/feasibility studies (RIs/FSs) are being performed. In support of these activities, the surface water at the FEMP is being studied and modeled to estimate the possible migration of contaminants through this pathway.

1.1 GENERAL SURFACE HYDROLOGY CONDITIONS AT THE FEMP

The FEMP is located within the Great Miami River (GMR) drainage basin above the river's present day flood plain. The natural surface water drainage system is dominated by the GMR, located approximately 0.6 miles to the east and 1.5 miles to the south of the site (Figure 1-1). The river flows generally to the southwest and has a drainage area of approximately 3360 square miles at the Hamilton gauge, which is located about 10 miles upstream from the FEMP site. The GMR flows into the Ohio River about 24 miles downstream of the FEMP site. Only a small portion of surface water from the northeast corner of the FEMP eventually drains to the GMR; the rest eventually drains to Paddys Run, a small, intermittent stream which flows along the western edge of the FEMP site. Paddys Run originates north of the FEMP and discharges into the GMR approximately 1.5 miles south of the property. Several small drainage courses discharge to Paddys Run, the largest of which is the Storm Sewer Outfall Ditch (SSOD).

Currently, the storm water runoff from portions of the FEMP property is collected and pumped to the GMR. Storm water runoff from the former production area and the waste pit area is collected and discharged to the GMR by way of Manhole 175 and the main effluent line (Figure 1-1). The former production area, where uranium was processed, is located in the center of the FEMP property. The waste pit area, where wastes from the uranium processing were stored, is located between the former production area and Paddys Run. Surface water flow from the production area discharged to the SSOD until 1986 when the first storm water retention basin (SWRB) was put into operation. The SWRB allows for solids in the storm water to settle before discharging to Manhole 175. The storm water collection system around the waste pit area was installed under CERCLA Removal Action No. 2; before mid-1992 runoff from this area discharged into Paddys Run.

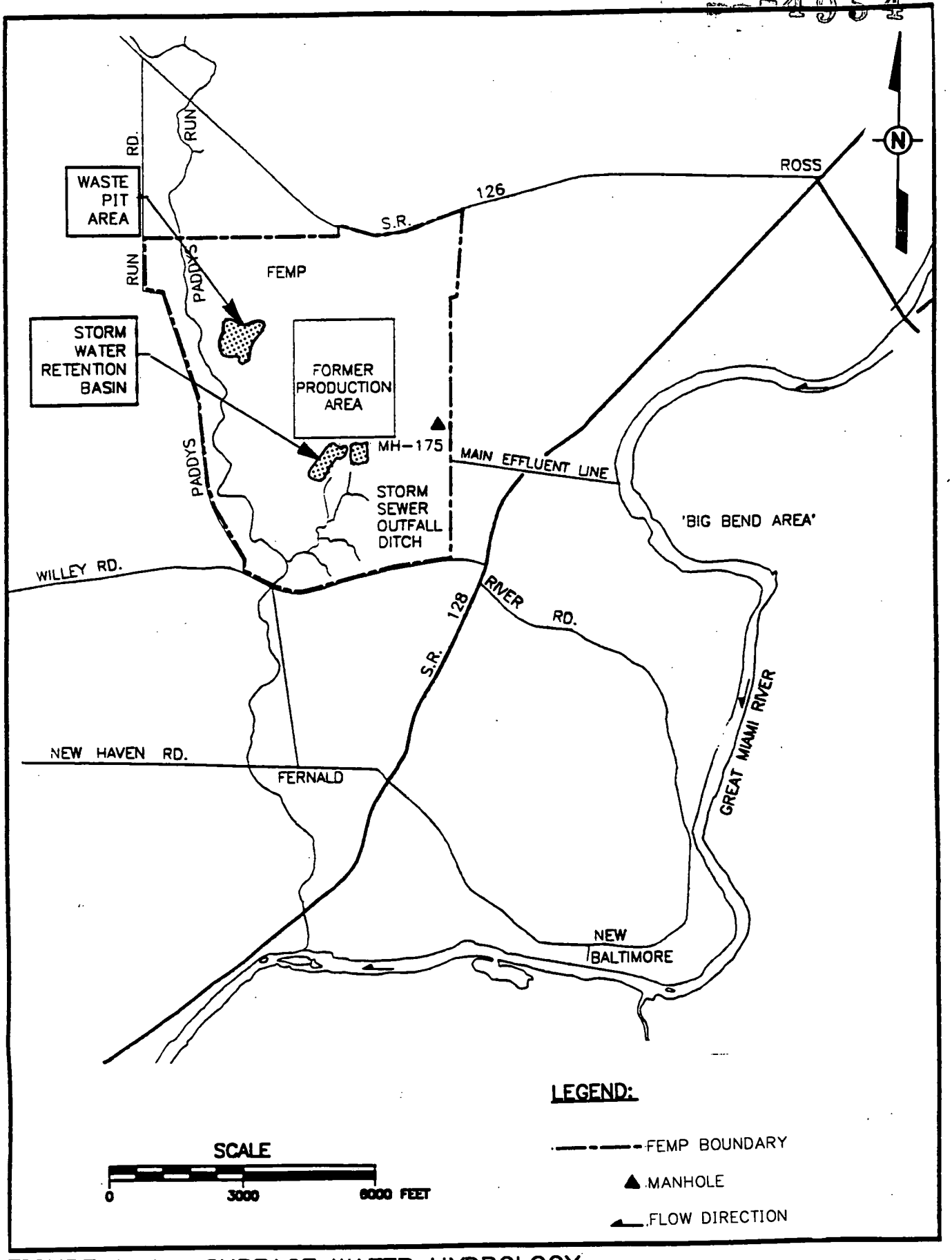

FIGURE 1-1. SURFACE WATER HYDROLOGY

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Portions of Paddys Run and the SSOD have cut into glacial outwash deposits which form the water bearing unit of the Great Miami Aquifer (GMA). The stream bed elevations of Paddys Run and the SSOD are generally above the groundwater elevation of the GMA in the vicinity of the FEMP site. This condition creates a situation in which some of the water flowing in the streams is lost into the surrounding ground (losing stream). During the ongoing studies being conducted at the FEMP, it was learned that Paddys Run and the SSOD are directly connected with the underlying GMA and that a potential pathway exists for contaminant transport into the aquifer through their streambeds.

1.2 OBJECTIVES

The following sections briefly describe the objectives of the different aspects of modeling the surface water at the FEMP site. These sections also discuss the purpose of this report with respect to the overall surface water modeling task.

1.2.1 Overall Objectives of Modeling the Surface Water Pathway

The purpose of surface water modeling at the FEMP is to quantify the effect of rainwater coming into contact with contaminated soil and the subsequent transport of the contaminants with the runoff. The main objectives of modeling the surface water pathway are to predict the future concentrations of contaminants in surface water and sediments and to estimate the amount of contaminants reaching the GMA from infiltration through the streambeds of Paddys Run and the SSOD. These estimates of contaminants reaching the GMA via surface water will then be used as contaminant loading rates in the groundwater solute transport model.

1.2.2 Objectives of the Surface Water Flow and Infiltration Model Report

The primary purpose of the Surface Water Flow and Infiltration Model (SWF&IM) Summary Report is to provide information concerning the hydrology and hydraulics of the Paddys Run drainage basin needed to conduct modeling of future contaminant transport in the surface water at the FEMP site. The technical approach to be used for the fate and transport modeling is also described in the SWF&IM Report.

The results of the SWF&IM Report will be used for each operable unit-specific RI/FS. The contaminant transport modeling within the surface water pathway will be completed as follows: (1) the general/regional hydrology and hydraulic calculations are performed once for the SWF&IM

Report; (2) each operable unit will use these results for each waste source area; (3) for each waste area, each contaminant of potential concern (CPC) will be screened to determine if the CPC needs to be modeled further in the surface water pathway; and (4) if the CPC is not screened out, its concentrations in the surface water and sediment and its loading to the GMA will be calculated following the approach described in this report. Figure 1-2 is a flow chart of this process for completing the modeling of the surface water pathway at the FEMP site.

1.3 TECHNICAL SPECIFICATIONS OF THE SURFACE WATER FLOW AND INFILTRATION MODEL REPORT

The SWF&IM Report provides the following information for the modeling of surface waters at the FEMP:

- Selection of a representative storm event used to estimate average dilution and infiltration factors in and through surface water bodies at the FEMP
- Definition of the extent of connection of the surface water bodies with the GMA
- Quantification of the amount of infiltration that occurs from the surface waters to the GMA during a representative storm event
- Determination of the hydraulics of flow in Paddys Run and the SSOD to produce a stage versus discharge relationship (rating curve) at several cross section locations along both Paddys Run and the SSOD
- Presentation of the overall modeling approach including a detailed discussion of the procedures which will use the results of this report in modeling the migration of contaminants in surface water at the FEMP
- Presentation of a summary of the data available for fate and transport model performance evaluation.

Each of these items are discussed in subsequent sections of this report.

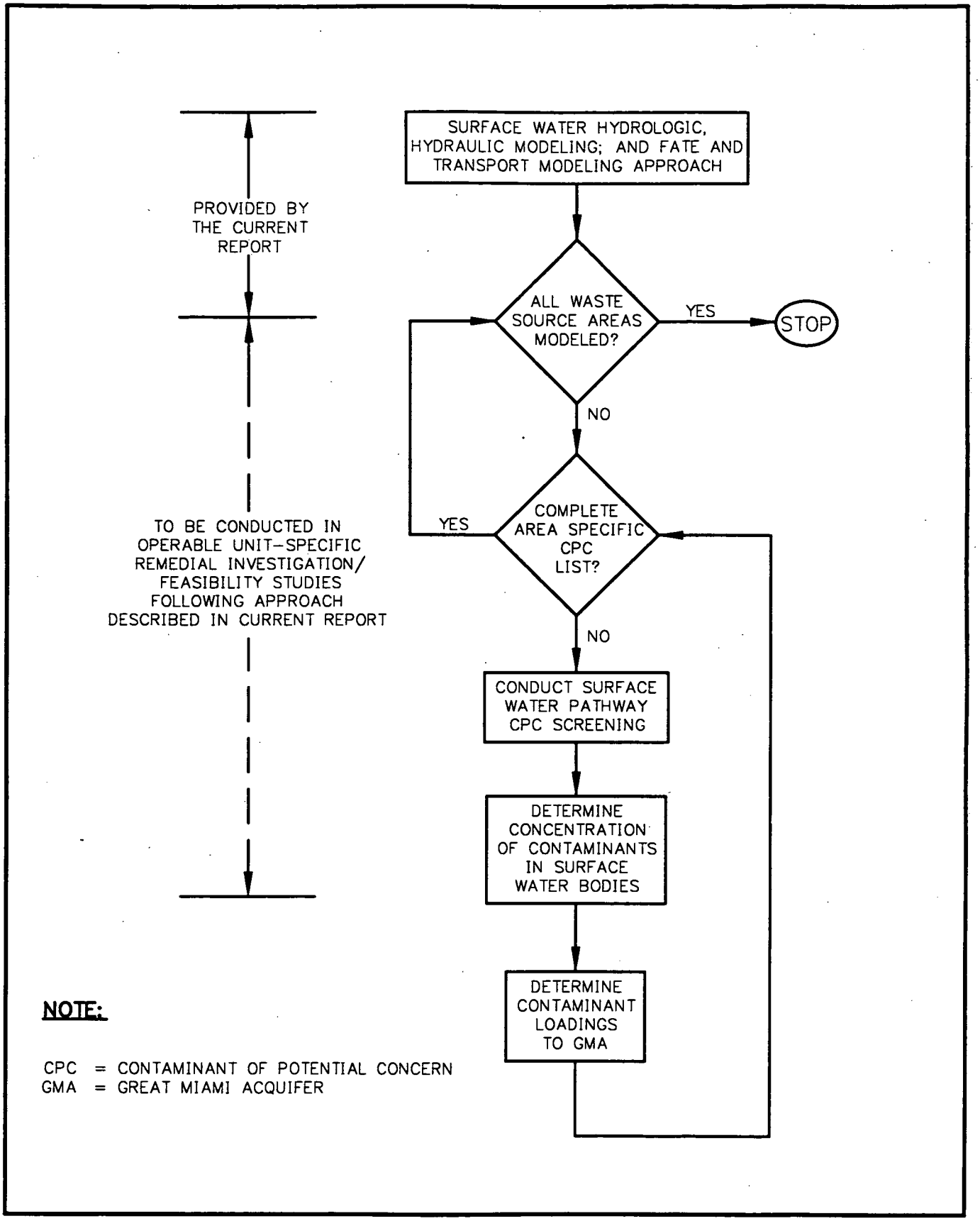

FIGURE 1-2. STAGES FOR COMPLETION OF MODELING THE SURFACE WATER PATHWAY

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2.0 OVERVIEW OF THE MODELING APPROACH

The following sections briefly describe the various models and their relationships to each other as they are used in simulating the surface water contaminant pathway at the FEMP site. A flow chart (Figure 2-1) shows the relationships of the models, which are indicated by double boxes. At the top of the flow chart are the inputs to the models. The storm event indicated is the rainfall event used to characterize the runoff and infiltration in the Paddys Run drainage basin. The source characteristics are the physical and chemical properties used to describe the contaminated source areas. Source depletion is the set of calculations used to account for the amount of contaminated soil lost per year and used to limit the amount of contaminated soil to the amount available. Besides the models and the inputs, Figure 2-1 shows the output that can be expected from each of the different steps in the model.

2.1 SURFACE WATER FLOW AND INFILTRATION MODEL

The SWF&IM is a subset of the larger overall approach to modeling the surface water pathway of contaminants and provides results to be used in later contaminant transport calculations. In general, the SWF&IM is only concerned with the movement of water and does not consider contaminant transport. Figure 2-1 shows the overall modeling approach and the SWF&IM's part in the approach.

The SWF&IM consists of the following components. The rainfall and runoff are simulated with the HEC-1 modeling code (U.S. Army Corps of Engineers, 1990). Rating curves for cross sections along Paddys Run and the SSOD are generated using Mannings equation (Henderson, 1966). Mannings equation is applied along Paddys Run and the SSOD to determine the elevation of water in the stream (stage) at each cross section location for a given flow rate (discharge). This relationship between stage and discharge at a cross section of a stream is called a rating curve.

To calculate infiltration from surface water to the GMA, the computer code VS2DT (Healy, 1990) is applied at each cross section. A time-varying depth of water is input into the VS2DT program for the infiltration calculations to simulate the fluctuation of flow depths in the streams during a storm event. The stream water depth is based on the runoff hydrographs from HEC-1 combined with the rating curves developed with Mannings equation. The output from the VS2DT provides the infiltration volumes to the GMA along the length of Paddys Run and the SSOD. The runoff hydrographs and

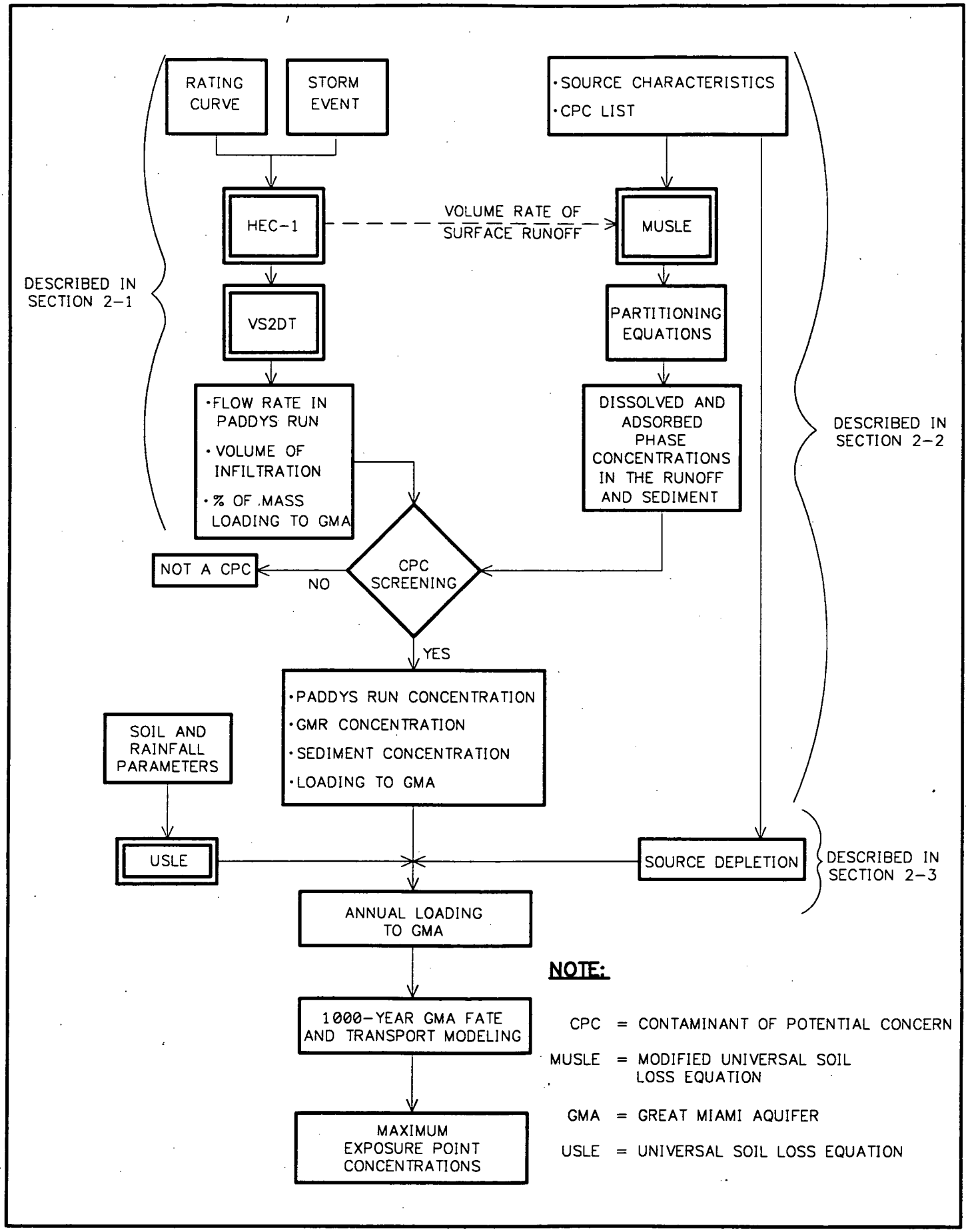

FIGURE 2-1. SURFACE WATER PATHWAY MODELING APPROACH

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infiltration information are then used in calculating contaminant concentrations and loadings. The models described in this section are shown in the upper left portion of Figure 2-1.

The SWF&IM Report presents the approach to be used in calculating the concentration of contaminants in FEMP surface water bodies and contaminant loadings to the GMA; the calculations will be performed and used in the individual operable unit RI/FS reports.

2.2 CONCENTRATION OF CONTAMINANTS IN SURFACE WATER BODIES

The concentration calculations require estimates of the surface water flow rates and volumes and estimates of the amount of contaminant being transported from the source soil with the runoff. The contaminant can move with the runoff in two phases; adsorbed to sediment eroded from the land surface or dissolved in the runoff itself. The amount of contaminant adsorbed to the sediment and the amount dissolved in the surface water runoff are estimated with partitioning equations presented in the Superfund Exposure Assessment Manual (EPA, 1988). The amount of sediment generated from a single storm event is estimated with the Modified Universal Soil Loss Equation (MUSLE), also presented in the Superfund Exposure Assessment Manual (EPA, 1988).

The contaminant transport in the GMA is simulated for 1000 years with the groundwater solute transport model for the RI/FS. This long duration could make the depletion of the source soil an important consideration in determining the contaminant loadings to the GMA and concentrations in the surface waters. The depletion of the source soil is calculated using the Universal Soil Loss Equation (USLE), also presented in the Superfund Exposure Assessment Manual (EPA, 1988). The USLE is used to calculate the annual amount of soil loss. Based on the annual loss, the number of years until all of the contaminated soil has eroded away (or become depleted) is calculated. Once the soil has been depleted the loadings to the surface water and the GMA will cease.

The concentration of contaminants in Paddys Run and the SSOD is calculated by combining runoff from subbasins with contaminated areas with runoff from uncontaminated subbasins. This mixing is based on dilution factors between the subbasin and the receiving stream (Paddys Run or the SSOD). These calculations are performed using the dilution factors and dissolved contaminant masses from the partitioning equations. The concentration in the GMR is calculated in a similar manner except that the flow in the GMR is not calculated using HEC-1, but is based on the average flow data for the

GMR presented in previous reports (Miami Conservancy District, 1992). A more detailed discussion of this procedure is presented in Section 4.1 of this report.

To be conservative, the procedure for estimating concentrations in the surface waters will assume that no mass of contaminant is lost to infiltration through the streambeds. This assumption would represent a worst case scenario for concentrations in the surface water. If a storm event occurred when the streambeds are saturated (i.e., immediately following a previous storm event or in the spring when storm events occur frequently), little or no dissolved contaminant would infiltrate through the streambeds. If the storm event occurred at any other time more contaminant would likely infiltrate, leaving less contaminant for the concentration in the surface waters. The models described in this section are shown in the right portion of Figure 2-1.

2.3 CONTAMINANT LOADINGS TO THE GREAT MIAMI AQUIFER

Two contaminant loading rates are calculated to simulate the loading to the GMA for the entire year: the loading due to a single representative storm event and an average loading to be applied over six months of the year. It is assumed that the aquifer is not loaded during the other six months of the year. The assumption to load the GMA for only six months is based on the concept that flow in Paddys Run, and hence the contaminant loading, does not occur continually throughout the year since Paddys Run and its tributaries are often dry for extended periods. The single representative storm event loading rate is used to simulate the relatively few large storm events per year that create substantial amounts of runoff. The average loading is used to represent the common storm events that occur during the year. A more detailed discussion of this procedure is presented in Section 4.3 of this report.

To be conservative, the procedure for estimating contaminant loadings in the groundwater due to infiltration through the streambeds of Paddys Run and the SSOD is based on infiltration calculations that assume the streambeds are initially unsaturated. This condition will create the upper bound of infiltration and also the upper bound of contaminants passing through the streambed. This would represent the worst case scenario for loadings to the GMA from surface waters infiltrating through the streambeds. The procedures described in this section are shown in the center of Figure 2-1.

2.4 MODELING APPROACH USED IN PREVIOUS RI REPORTS

Previous remedial investigations for Operable Units 1 (DOE, 1993a) and 4 (DOE, 1993b) performed surface water modeling to estimate the amount of contaminants transported with runoff. The final RI report for Operable Unit 4 was completed in November 1993 and the draft RI report for Operable Unit 1 was completed in October 1993. The surface water runoff from both Operable Units 1 and 4 flows directly to Paddys Run. Both of these reports used the following approaches for modeling the surface water.

- A 1-year, 24-hour storm event was used to estimate runoff and contaminant concentrations originating from source soil.
- MUSLE was used to estimate sediment generated by the 1-year, 24-hour storm event.
- Partitioning equations from the Superfund Exposure Assessment Manual (EPA, 1988) were used to calculate the amount of contaminant in runoff and adsorbed to sediments.
- Both reports calculated the concentration of contaminants in Paddys Run based on simple dilutions of dissolved contaminants in surface water runoff from the source. The flow rate in Paddys Run between January and May was estimated to be between 0.2 and 4.0 ft^3/s, (Dames and Moore, 1985); Operable Unit 4 used a flow rate of 0.2 ft^3/s based on the low range and Operable Unit 1 used the high range of 4.0 ft^3/s.
- Both reports calculated the concentrations of contaminants in the GMR by diluting Paddys Run flow with the average flow rate in the GMR.

Operable Unit 4 did not estimate contaminant loadings from Paddys Run to the GMA while Operable Unit 1 did, assuming that 30 percent of the contaminant mass in Paddys Run infiltrates during storm events.

3.0 SURFACE WATER FLOW AND INFILTRATION MODEL DEVELOPMENT AND SIMULATION

The SWF&IM consists of three main components: the simulation of runoff, the simulation of flow in the streams of the FEMP (i.e., Paddys Run and the SSOD), and the simulation of infiltration through the streambeds. The simulation of runoff is accomplished with the HEC-1 model using rainfall and land surface data as input. The output from the HEC-1 model is in the form of runoff hydrographs (discharge versus time relations) that are needed as input in simulating the depth of flow of water in Paddys Run and the SSOD. This depth of flow is then input into the VS2DT model as the source of infiltrating water. In addition to describing the characteristics of the Paddys Run drainage basin, the following sections discuss each of these three main components in greater detail.

3.1 DESCRIPTION OF PADDYS RUN DRAINAGE BASIN

Paddys Run is an intermittent stream which drains a 15 square mile catchment which includes most of the FEMP site. The drainage basin extends approximately 8 miles north of its confluence with the GMR and approaches 3 miles in width at its widest point. The Paddys Run drainage basin, with the exception of the FEMP, is primarily rural, characterized by farm fields and woods with occasional residential areas scattered throughout. The land surface in the vicinity of the FEMP is relatively flat. At the perimeter of the drainage basin, the land is characterized by steep slopes leading to the hilltop drainage divides.

Paddys Run flows only a portion of the year, typically during the late winter and spring months when storm events are common. During the summer and fall months, Paddys Run is generally dry.

As described in Section 1.1, the former production area is situated in the center of the FEMP property. Currently, the storm water runoff from this area of the FEMP is collected in a storm sewer system and discharged to the SWRB. The SWRB is divided into two chambers; the first was placed in operation in November 1986 and the second in December 1988. The SWRB discharges to Manhole 175 which discharges via an effluent line to the GMR (see Figure 1-1).

3.2 RAINFALL AND RUNOFF SIMULATION

The objectives of the rainfall runoff simulation are to select a representative storm event and use it to simulate runoff in the Paddys Run drainage basin. The runoff is then used as input for the infiltration calculations for Paddys Run and the SSOD.

3.2.1 Meteorological Data and Selection of the Representative Storm Event

The amount of contaminant transport caused by surface water flow is dependent on the chemical characteristics of the contaminant, topography, and rainfall duration, intensity and volume. This study used a single storm event to approximate the yearly flow pattern and infiltration in Paddys Run and the SSOD. This single storm event was then used to characterize the large storm events that occur and to assist in determining the average yearly loadings to the GMA. Selection of a single representative storm is critical to secure reasonable results with this approach. A relatively small, common storm event may not produce erosion and sediment in appreciable quantities while a large, uncommon event may produce a substantial amount of erosion and sediment but not occur frequently enough to be significant.

3.2.1.1 1-Year, 24-Hour Storm Event Approach

A storm with a 1-year return period and a 24-hour duration was chosen as the representative storm, based on the recommendations in the Superfund Exposure Assessment Manual (EPA, 1988), to represent short-term releases of contaminants. The storm event simulated has a total precipitation depth of 2.5 inches, based on the Rainfall Frequency Atlas of the United States (Hershfield, 1961). (The volume of precipitation contained in a storm event is often reported in depth which can be converted to a volume by multiplying by the area that the precipitation has fallen on, usually assumed to be the entire drainage area for small to mid-size catchments.) The method used in HEC-1 to produce the storm hydrograph (the variation of rainfall intensity with time) requires the rainfall amounts (depth) for storms of various durations up to the length of the storm being modeled. The depth-duration data required by the HEC-1 model is listed in Table 3-1. Rainfall depths listed in Table 3-1 were obtained from the Rainfall Frequency Atlas of the United States (Hershfield, 1961), which provides contours of rainfall depth for the contiguous United States for various rainfall return periods and durations.

TABLE 3-1

DEPTH-DURATION DATA[a]
1-YEAR-RETURN INTERVAL STORM EVENT

Duration	Depth (in.)
5 minutes	0.33
15 minutes	0.625
60 minutes	1.1
2 hours	1.4
3 hours	1.48
6 hours	1.8
12 hours	2.1
24 hours	2.5

[a]Hershfield, D. M., 1961, Rainfall Frequency Atlas of the United States, Technical Paper No. 40, Department of Commerce, Washington, DC

The 1-year, 24-hour storm has a small enough return period that it occurs fairly frequently while at the same time it produces a significant amount of runoff from the subbasins. The storm runoff causes soil loss and contaminant transport through overland flow from the FEMP into Paddys Run. In addition, the 1-year, 24-hour storm has been used in other operable unit studies to define soil losses from individual waste units, allowing for consistency between this study and previous operable unit fate and transport studies (DOE, 1993a and 1993b).

3.2.1.2 Probability Weighting Method Approach

During the early stages of this study, attempts to select a representative storm were made using a probability weighting method to incorporate both large and small storm events. The weights were to be based on the return period of the particular storm event. The return period is the time that a storm of certain magnitude is likely to occur; i.e., a 1-year storm has a likelihood of occurring once a year. Generally, the longer the return period of the storm the larger the amount of rainfall. For each return period a set of storms with various durations exists, i.e., a 1-year, 12-hour storm event and a 1-year, 24-hour storm event are both possible. To define the representative storm, both the return period and duration need to be determined. A sensitivity analysis was performed to determine what storm duration would produce the greatest amount of contaminant in the runoff. That storm duration was then used for the representative storm since it is conservative. For a storm with the same return period, it was found that as the storm duration increased, the amount of contaminant in the runoff also increased. A 24-hour storm duration was chosen based on its widespread design use, the availability of rainfall data, and its acceptance by many regulatory agencies.

However, difficulties arose in weighting the different storm events which eventually led to the probability weighting method being abandoned. One of the problems was determining a threshold or lower bound below which the storm event would not produce a significant amount of contaminant in the runoff. Storms below this bound would not be included in the weighting. This threshold was determined by setting the allowable amount of contaminant in the runoff and back calculating the storm event using the MUSLE, from the Superfund Exposure Assessment Manual (EPA, 1988). Another problem was in determining what percentage of the yearly rainfall would fall below this threshold storm. Also, no method was available to accurately account for storm events between the standard storm events (e.g., runoff can be calculated and weighted for the standard 5-year and

10-year storms, but the 6.4-year storm event would be neglected). Therefore, the single storm event approach using a 1-year, 24-hour storm event was used for this study.

3.2.2 Conceptual Model

The Paddys Run drainage basin consists of land surfaces drained by streams and channels discharging to Paddys Run. As rain falls, a portion of it becomes runoff depending on land surface conditions. This runoff then collects and flows in the channels in the basin, moving from small channels to successively larger channels until reaching the basin outlet. The flow in the channels can come from the runoff or can enter the stream from groundwater. The flow that originates from the groundwater is base flow. Paddys Run in the vicinity of the FEMP is often dry and does not contain any base flow. The basin can be divided into subbasins so that the runoff from any particular area can be analyzed separately and then added together to yield the total hydrograph for the basin. These are the basic processes which were simulated with the rainfall and runoff calculations using HEC-1.

Storm water from the former production area of the FEMP and the waste pit area is currently collected and pumped to the GMR. Two scenarios for flow in Paddys Run drainage basin are calculated. One, Scenario 1, models the runoff hydrographs without flows from the former production area and waste pit area being included. This is the current flow condition at the FEMP site. The other, Scenario 2, considers that the storm water collection systems for the former production and waste pit areas fail and the storm water returns to its natural courses. The surface water flow from the former production area is assumed to follow the slight slope to the SSOD and the flow from the waste pit area is assumed to enter Paddys Run. This scenario is modeled because of the uncertainty of site conditions in the next 1000 years, the length of time that the loadings to the GMA will be calculated for in the remedial investigations.

For each of these two storm water management scenarios, two HEC-1 models are used, one for infiltration calculations and another for contaminant calculations, for a total of four. The subbasins used in the HEC-1 model for infiltration calculations are divided to allow a more detailed hydrologic analysis of the FEMP site in the contaminant calculations. This refinement made it possible to analyze peak flows and volumes from contaminant source areas. The HEC-1 model used for infiltration calculations and current conditions includes flow from the waste pit area because the subbasin containing this area was not divided in the infiltration calculations. Since this is a relatively

small area with a correspondingly small amount of runoff, it should not have a significant effect on the infiltration calculations.

Several assumptions are also made concerning the modeled characteristics of the Paddys Run drainage basin. It is assumed that the base flow in Paddys Run and the SSOD is negligible and that channel loss (i.e., infiltration through the streambed and evaporation) is negligible for runoff calculations. Negligible channel loss was an initial assumption which was later confirmed during the VS2DT sensitivity analysis (Section 5.1).

3.2.3 HEC-1 Simulation

The HEC-1 model used to simulate runoff into Paddys Run and its tributaries is needed for infiltration calculations (i.e., VS2DT) for this report and for input to the future contaminant calculations (i.e., MUSLE) to be done by each individual operable unit. The HEC-1 model was originally developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (COE) to assist in waterway design projects. As such, it is well documented and has been applied successfully to numerous regions across the United States. The program generates runoff hydrographs given either hypothetical or actual rainfall data. The program can calculate hydrographs from many different subbasins and then combine and route the hydrographs through the watershed. The HEC-1 program provides a wide variety of methods to generate and route hydrographs. The program considers only water transport and does not have the ability to simulate sediment generation, sediment transport, or contaminant transport.

The entire Paddys Run drainage basin is modeled by linking the various subbasins together within the HEC-1 model, which calculates a runoff hydrograph for each subbasin. The hydrographs are added together at locations called stations. The combined runoff hydrograph can then be routed through a channel reach by either of two methods: by using a separate routing step or by routing through a downstream subbasin in the same step that the downstream subbasin hydrograph is calculated. Both routing techniques are used in the HEC-1 simulations prepared for this report.

3.2.4 Input Data

The HEC-1 model requires input to represent the rainfall event and to describe the surface hydrological properties of the drainage area. The rainfall data used was described in Section 3.2.1.

Most of the parameters used to describe the drainage basin were taken from topographic maps of the watershed. Some information, such as Paddys Run cross section data used for channel routing was obtained from topographic maps developed from field surveys. Cross section plots are shown in Appendix A.

Not all of the precipitation falling on a drainage basin becomes runoff. Referred to as precipitation losses, the amounts are calculated by the U.S. Department of Agriculture's (USDA) Soil Conservation Service (SCS) curve number method. Infiltration, depression storage, and land surface interception account for precipitation losses. Interception and depression storage represent the surface storage of water by trees, grass or natural local depressions in the ground surface while infiltration accounts for the amount of rainfall which directly enters the ground surface. SCS curve numbers are estimated according to land use, vegetative cover, and soil type. The land use and vegetation are estimated from topographic maps and aerial photographs of the site. The soil types and their associated hydrologic parameters were taken from Soil Surveys of Hamilton (USDA, 1982) and Butler (USDA, 1980) Counties, Ohio. The soil survey mapping shows the entire county and the location of all the different soil types. In the curve number method each soil is classified as either A, B, C, or D based on its hydrologic characteristics. Only one or two curve numbers are input into HEC-1 for each subbasin. The curve number associated with each of the different soil types, land uses, and vegetation is then weighted and averaged to represent the whole subbasin for input into HEC-1. Table 3-2 provides the weighting procedure used to determine the SCS curve numbers for the subbasins. The final curve number(s) used for each subbasin is also presented in this table.

The basin and subbasin boundaries were derived using topographic maps created by the U.S. Geological Survey (USGS) and supplemented with topographic maps of the FEMP property. The USGS maps used have a scale of one inch equals 2000 feet and a contour interval of 10 feet. In the vicinity of the FEMP site more detailed maps exist and two were used in determining the input parameters for HEC-1. One map was developed for the 1992 Storm Water Permit Application and is based on 1985 aerial photographs. It uses a scale of three inches equals 1000 feet and a contour interval of one foot. The other topographic map, based on 1992 aerial photos, uses a scale of one inch equals 300 feet and a contour interval of one foot. The Paddys Run drainage basin was divided such that the physical characteristics are similar within each subbasin and the cross sections where hydrographs are desired are located at the outlet of each subbasin.

TABLE 3-2

SOIL CONSERVATION SERVICE (SCS) CURVE NUMBER WEIGHTING

Subbasin	Land Cover[a]	Hydraulic Condition	Hydrologic Soil Group[b]	Weighted SCS Number[c]	Average SCS Number
10	Woods 30%	Good	0.5C + 0.5B	0.5 x 71 + 0.5 x 55	
	Meadow 60%	Good	0.4C + 0.6B	0.4 x 71 + 0.6 x 58	65.4
	Hard surface 10%	--	0.5 C + 0.5B	0.5 x 84 + 0.5 x 90	
20	Woods 15%	Good	0.7C + 0.3B	0.7 x 70 + 0.3 x 55	
	Meadow 80%	Good	0.3C + 0.7B	0.3 x 71 + 0.7 x 58	63.7
	Hard surface 5%	--	0.5C + 0.5B	0.5 x 84 + 0.5 x 90	
30	Woods 10%	Fair	0.4C + 0.6B	0.4 x 73 + 0.6 x 60	
	Meadow 85%	Good	0.25C + 0.75B	0.25 x 71 + 0.75 x 58	63
	Hard surface 5%	--	0.5C + 0.5B	0.5 x 84 + 0.5 x 90	
50	Woods 20%	Fair	0.4C + 0.6B	0.4 x 73 + 0.6 x 60	
	Meadow 70%	Good	0.4C + 0.6B	0.4 x 71 + 0.6 x 58	66
	Hard Surface 10%	--	0.4C + 0.6B	0.4 x 84 + 0.6 x 90	
60	Woods 35%	Good	0.1C + 0.9B	0.1 x 70 + 0.9 x 55	
	Meadow 60%	Good	0.1C + 0.9B	0.1 x 71 + 0.9 x 58	59.8
	Hard surface 5%	--	0.1C + 0.9B	0.1 x 84 + 0.9 x 90	
70	Woods 10%	Fair	0.2C + 0.8B	0.2 x 73 + 0.8 x 60	61
	Meadow 65%	Good	0.2C + 0.8B	0.2 x 71 + 0.8 x 58	
	Hard surface 25%	--	0.2C + 0.8B	0.2 x 84 + 0.8 x 90	88.8
75	Woods 10%	Fair	0.2C + 0.8B	0.2 x 73 + 0.8 x 60	61
	Meadow 65%	Good	0.2C + 0.8B	0.2 x 71 + 0.8 x 58	
	Hard surface 25%	--	0.2C + 0.8B	0.2 x 84 + 0.8 x 90	88.8
80	Woods 10%	Fair	0.5C + 0.5B	0.5 x 73 + 0.5 x 60	65
	Meadow 65%	Good	0.5C + 0.5B	0.5 x 71 + 0.5 x 58	
	Hard surface 25%	--	0.5C + 0.5B	0.5 x 84 + 0.5 x 90	87
580	Woods 45%	Good	0.0B + 1.0C	0.0 x 55 + 1.0 x 71	
	Meadow 50%	Good	0.0B + 1.0C	0.0 x 58 + 1.0 x 71	71.95
	Hard Surface 5%	--	0.0B + 1.0C	0.0 x 84 + 1.0 x 90	

TABLE 3-2 (Continued)

Subbasin	Land Cover[a]	Hydraulic Condition	Hydrologic Soil Group[b]	Weighted SCS Number[c]	Average SCS Number
PDAR[d]	Woods 0%	Good	0.0B + 1.0C	0.0 x 55 + 1.0 x 71	
	Meadow 20%	Good	0.0B + 1.0C	0.0 x 58 + 1.0 x 71	86.20
	Hard Surface 80%	--	0.0B + 1.0C	0.0 x 84 + 1.0 x 90	
581	Woods 0%	Good	0.5B + 0.5C	0.5 x 55 + 0.5 x 71	
	Meadow 85%	Good	0.4B + 0.6C	0.4 x 58 + 0.6 x 71	69.43
	Hard Surface 15%	--	0.0B + 1.0C	0.0 x 84 + 1.0 x 90	
582	Woods 15%	Good	0.5B + 0.5C	0.5 x 55 + 0.5 x 71	
	Meadow 75%	Good	0.5B + 0.5C	0.5 x 58 + 0.5 x 71	66.53
	Hard Surface 10%	--	0.5B + 0.5C	0.5 x 84 + 0.5 x 90	
100	Woods 5%	Fair	0.2C + 0.8B	0.2 x 73 + 0.8 x 60	
	Meadow 90%	Good	0.2C + 0.8B	0.2 x 71 + 0.8 x 58	62.1
	Hard surface 5%	--	0.2C + 0.8B	0.2 x 84 + 0.8 x 90	
110	Woods 15%	Fair	0.1C + 0.9B	0.1 x 73 + 0.9 x 60	
	Meadow 75%	Good	0.1C + 0.9B	0.1 x 71 + 0.9 x 58	61.9
	Hard surface 10%	--	0.1C + 0.9B	0.1 x 84 + 0.9 x 90	
120	Woods 85%	Good	0.9C + 0.1B	0.9 x 70 + 0.1 x 55	
	Meadow 10%	Good	0.9C + 0.1B	0.9 x 71 + 0.1 x 58	69.4
	Hard surface 5%	--	0.9C + 0.1B	0.9 x 84 + 0.1 x 90	
130	Woods 10%	Fair	0.7C + 0.3B	0.7 x 73 + 0.3 x 60	
	Meadow 85%	Good	0.7C + 0.3B	0.7 x 71 + 0.3 x 58	68.2
	Hard surface 5%	--	0.7C + 0.3B	0.7 x 84 + 0.3 x 90	

TABLE 3-2 (Continued)

Subbasins Divided for Contaminant Calculations

Subbasin	Land Cover[a]	Hydraulic Condition	Hydrologic Soil Group[b]	Weighted SCS Number[c]	Average SCS Number
60	Woods 30%	Good	0.9B + 0.1C	0.9 x 55 + 0.1 x 71	
	Meadow 65%	Good	0.9B + 0.1C	0.9 x 58 + 0.1 x 71	59.88
	Hard surface 5%	--	0.5B + 0.5C	0.5 x 84 + 0.5 x 90	
560	Woods 25%	Good	0.7B + 0.3C	0.7 x 55 + 0.3 x 71	
	Meadow 70%	Good	0.7B + 0.3C	0.3 x 58 + 0.3 x 71	62.63
	Hard surface 5%	--	0.5B + 0.5C	0.5 x 84 + 0.5 x 90	
70	Woods 20%	Good	0.2B + 0.8C	0.2 x 55 + 0.8 x 71	
	Meadow 75%	Good	0.9B + 0.1C	0.9 x 58 + 0.1 x 71	62.39
	Hard surface 5%	--	0.5B + 0.5C	0.5 x 84 + 0.5 x 90	
WPA[e]	Woods 5%	Good	1.0B + 0.0C	1.0 x 55 + 0.0 x 71	
	Meadow 60%	Good	0.0B + 1.0C	0.0 x 58 + 1.0 x 71	76.85
	Hard Surface 35%	--	0.0B + 1.0C	0.0 x 84 + 1.0 x 90	
570	Woods 5%	Good	0.0B + 1.0C	0.0 x 55 + 1.0 x 71	
	Meadow 65%	Good	0.0B + 1.0C	0.0 x 58 + 1.0 x 71	76.70
	Hard surface 30%	--	0.0B + 1.0C	0.0 x 84 + 1.0 x 90	
75	Woods 25%	Good	0.4B + 0.6C	0.4 x 55 + 0.6 x 71	
	Meadow 65%	Good	0.4B + 0.6C	0.4 x 58 + 0.6 x 71	
	Hard surface 10%	--	0.5B + 0.5C	0.5 x 84 + 0.5 x 90	67.62
575	Woods 50%	Good	0.3B + 0.7C	0.3 x 55 + 0.7 x 71	
	Meadow 35%	Good	0.3B + 0.7C	0.3 x 58 + 0.7 x 71	
	Hard surface 15%	--	0.3B + 0.7C	0.3 x 84 + 0.7 x 90	69.82

[a]Estimated from USGS Topographic Map, Shandon, Ohio, N3915-W8437. 5/7.5, 1981, DMA 4062 I SW-Series V852.
[b]0.4C and 0.6B means 40% is hydrologic soil group C and 60% is hydrologic soil group B. Percentages of each group were determined from soil survey maps: Soil Survey of Butler Co., Ohio, USDA 1980; Soil Survey of Hamilton Co., Ohio, USDA, 1982.
[c]SCS curve number obtained from Schwab, G. O., et al., 1981, Soil and Water Conservation Engineering, John Wiley and Sons, Inc., New York, NY, pp. 74.
[d]Production area
[e]Waste pit area

The Paddys Run basin was divided into 15 subbasins for the HEC-1 model infiltration calculations. Figure 3-1 shows all the numbered drainage subbasins and Figure 3-2 focuses on the most pertinent. Figure 3-3 is a schematic of the HEC-1 model and shows the logical relation of the subbasins, channel routings, and stations in this simulation. The FEMP site is divided into seven subbasins for this simulation, of which 60, 70 and 75 directly drain to Paddys Run. These three subbasins were divided to coincide with cross section locations along Paddys Run and include flow from outside the FEMP boundaries. This level of subbasin detail was acceptable for infiltration calculations because they are based on the total flow in Paddys Run. The area drained by the SSOD is divided into four subbasins; PDAR, 580, 581, and 582. Subbasin PDAR contains the former production area (PDAR stands for production area). To model the scenario where flow from the former production area is collected and pumped outside the Paddys Run drainage basin (to the GMR), the PDAR subbasin is simply deleted from the HEC-1 model. The HEC-1 models with and without the PDAR subbasin are the two runoff models used for infiltration calculations.

For HEC-1 model contaminant calculations the subbasins described above were divided so as to allow a more detailed hydrologic analysis of the FEMP site, for a total of four models. This refinement allows for the determination of peak flows and volumes to be used in the MUSLE for operable unit-specific areas. Figures 3-4 and 3-5 show the new subbasin boundaries used for contaminant calculations and the schematic representation of the HEC-1 model, respectively. Subbasins 60, 70 and 75 are divided to separate the flow coming from the portion of the FEMP on the east side of Paddys Run from the flow coming from the west side, as follows:

- Subbasin 60 is divided into subbasins 60 on the west and 560 on the east.
- Subbasin 70 is divided into subbasins 70 on the west, 570 on the east, and WPA (WPA stands for waste pit area). The waste pit area, located between the former production area and Paddys Run, contains various liquid and solid wastes generated by plant operations. Storm water from here is currently collected and pumped to the GMR.
- Subbasin 75 is divided into subbasins 75 on the west and 575 on the east.

A total of 19 subbasins are used to model the Paddys Run drainage basin for contaminant calculations.

ACAD: C:\NG96\CRU5\PADD.DWG MB 10/19/93 PLOT

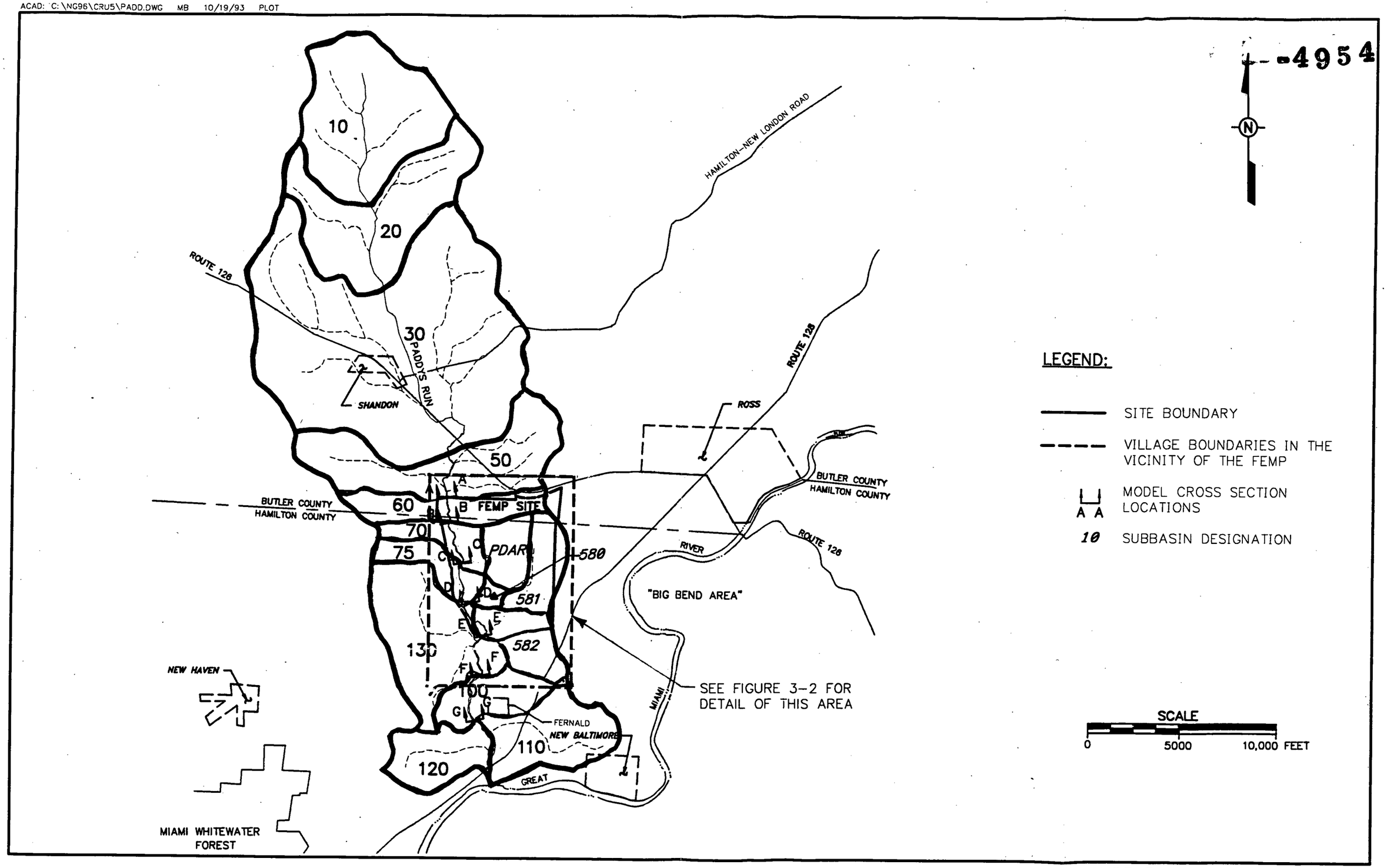

FIGURE 3-1.

PADDYS RUN DRAINAGE SUBBASINS FOR HEC-1 MODEL INFILTRATION CALCULATIONS

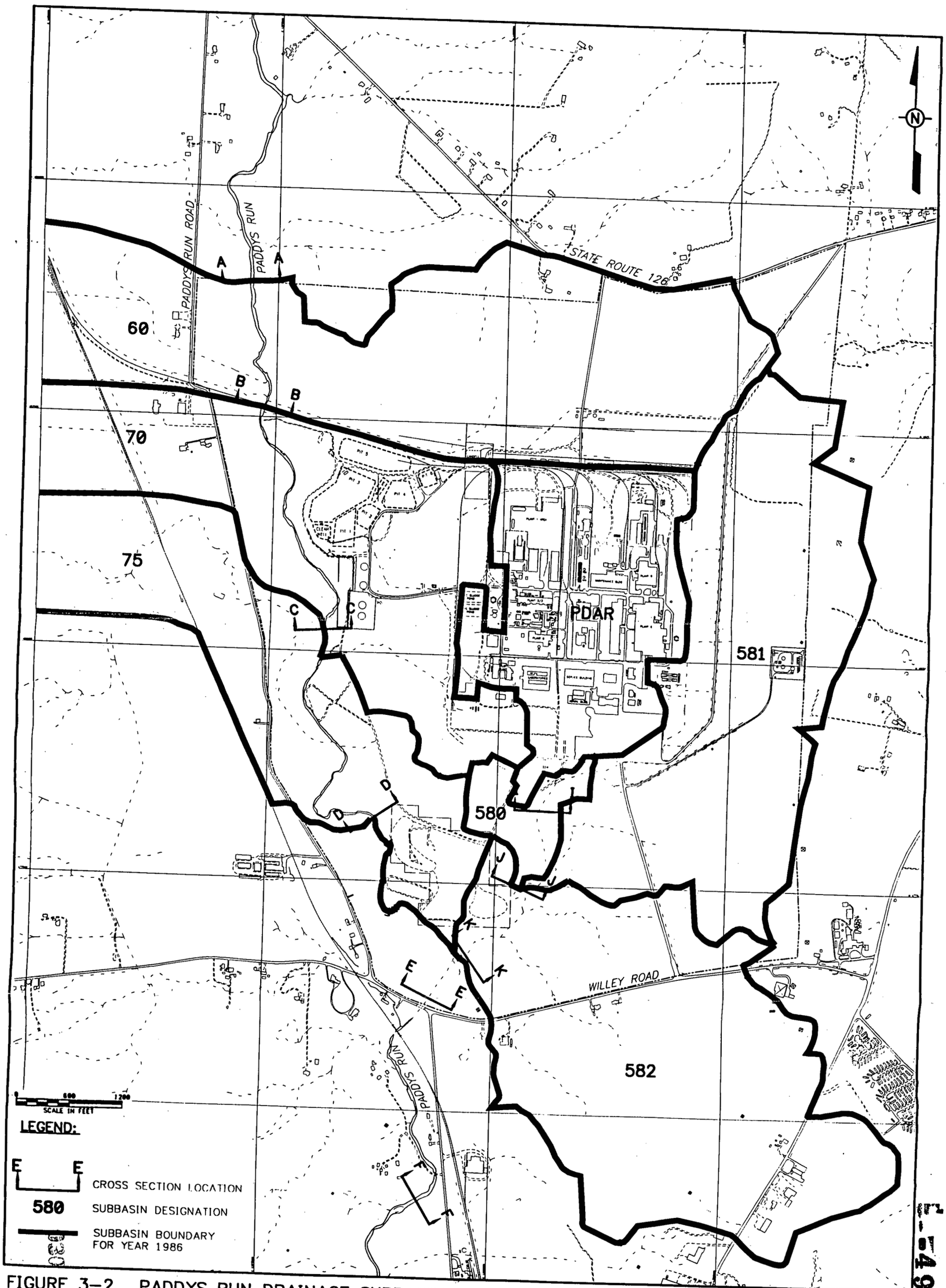

FIGURE 3-2. PADDYS RUN DRAINAGE SUBBASINS
FOR HEC-1 MODEL INFILTRATION CALCULATIONS

E-49954

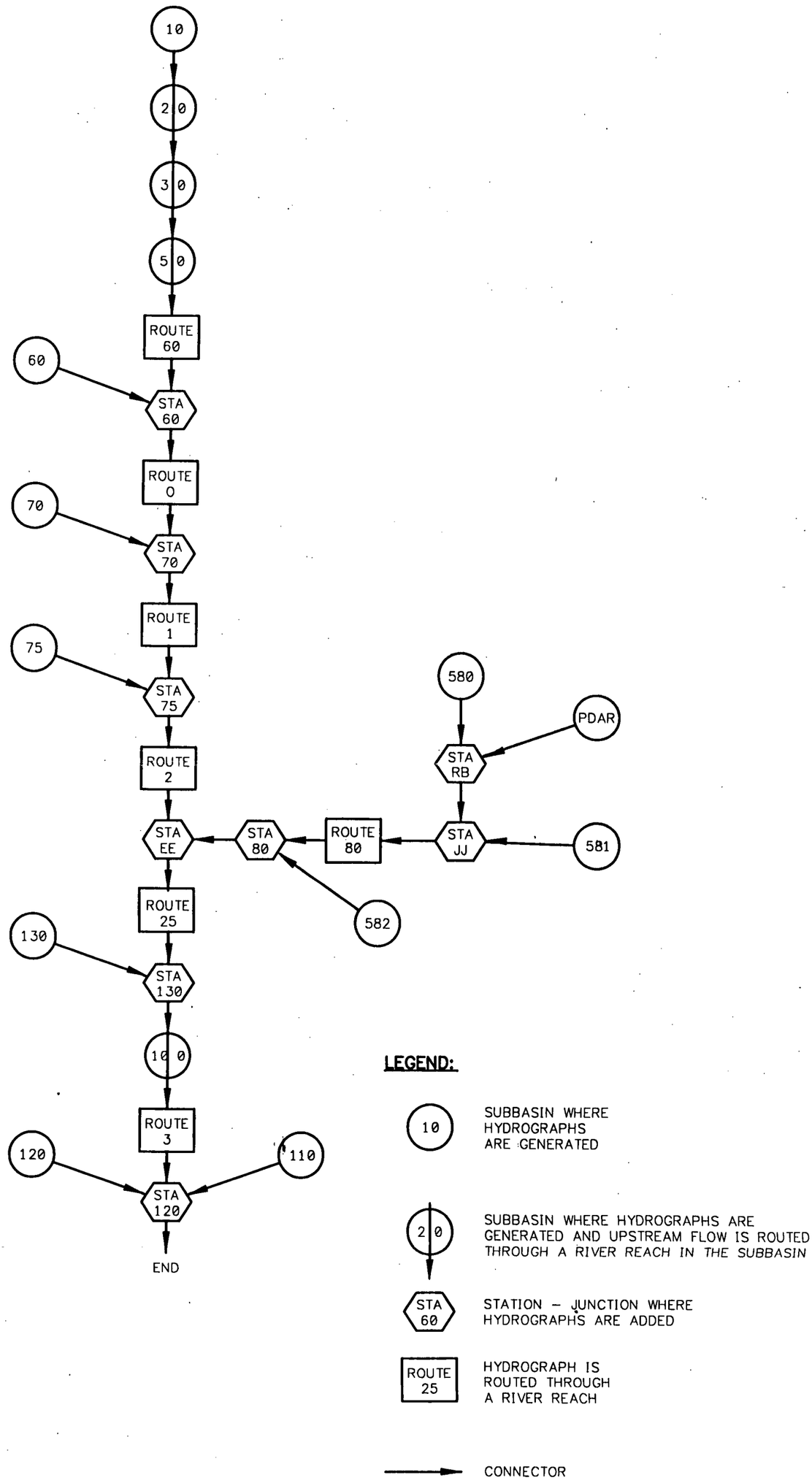

FIGURE 3-3. SCHEMATIC OF HEC-1 MODEL OF PADDYS RUN FOR INFILTRATION CALCULATIONS

P-4654

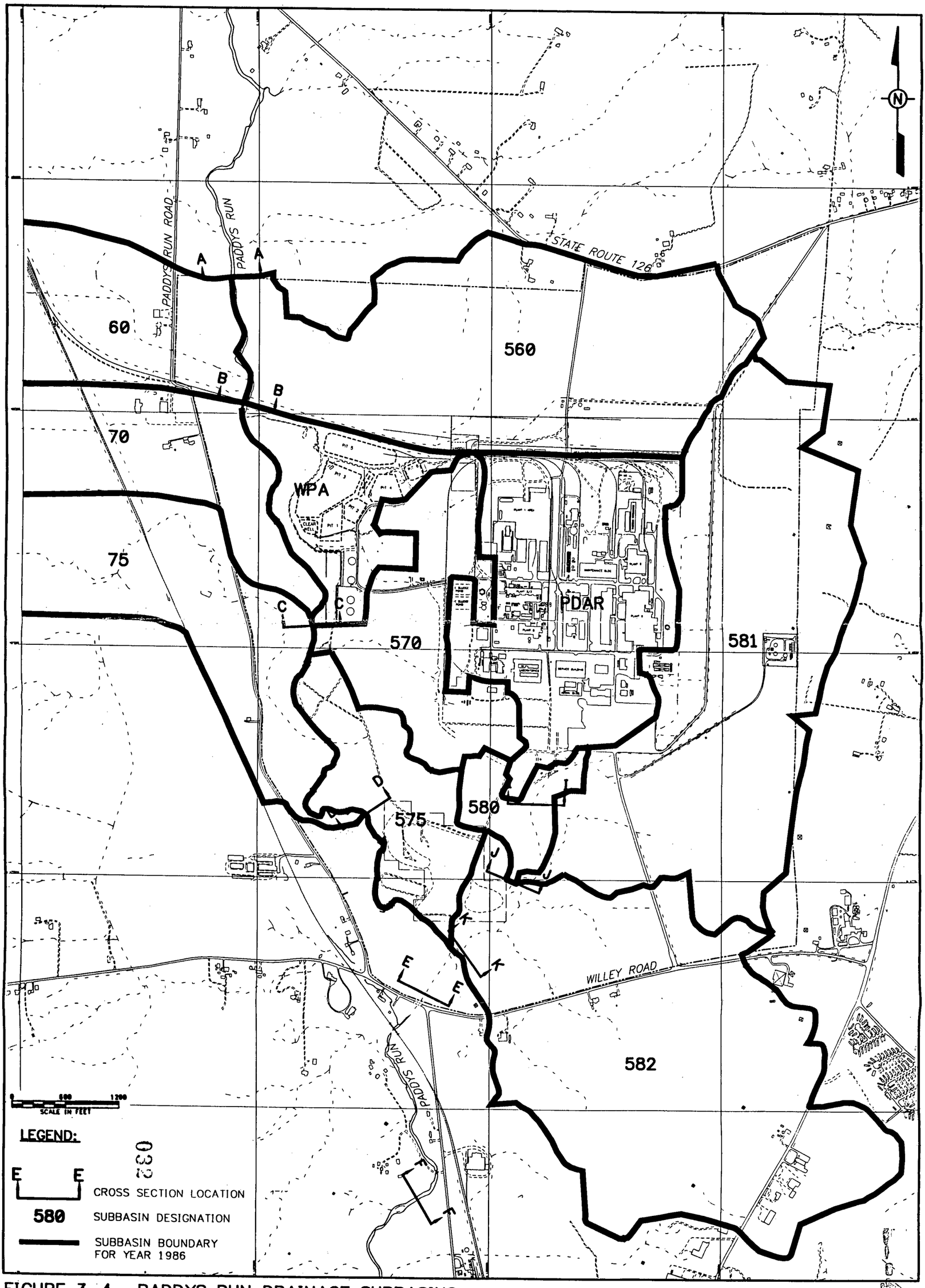

FIGURE 3-4. PADDYS RUN DRAINAGE SUBBASINS FOR HEC-1 MODEL CONTAMINATION CALCULATIONS

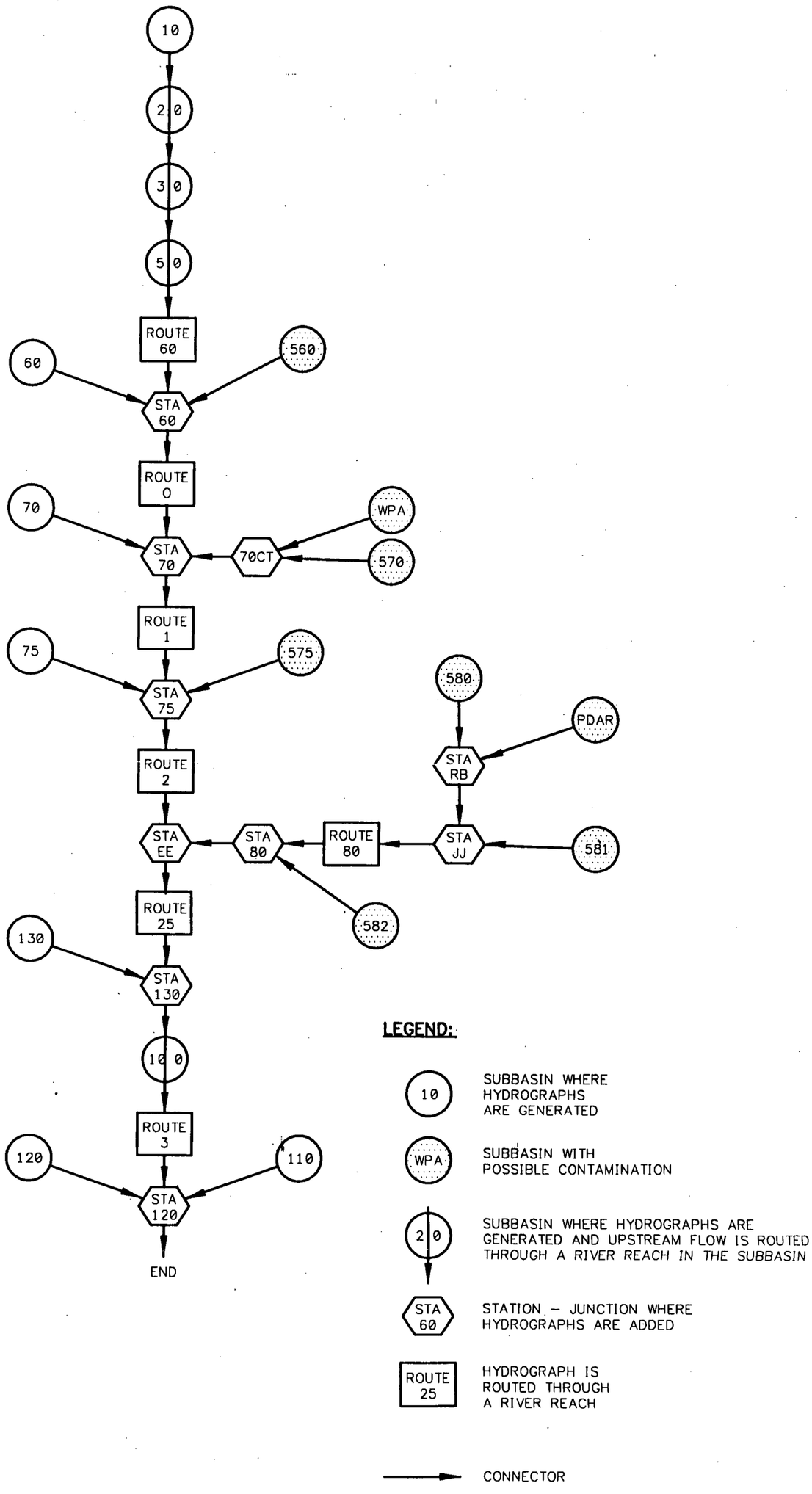

FIGURE 3-5. SCHEMATIC OF HEC-1 MODEL OF PADDYS RUN FOR CONTAMINANT CALCULATIONS

Table 3-3 provides a comparison of peak discharge, time of the peak discharge and the total flow volume at cross sections along Paddys Run for the HEC-1 models used for infiltration calculations and the ones used for contaminant calculations. The overall flow in Paddys Run did not change appreciably between the models.

Kinematic wave and Muskingum-Cunge methods (COE, 1990) are employed to calculate subbasin flow and channel routing in the HEC-1 simulation. In these approaches, the various physical processes of water movement over the basin surface (with associated infiltration), flow into stream channels, and flow through the channel network are modeled using equations of conservation of mass and energy. Parameters such as channel roughness, slope, catchment lengths and areas, and stream channel dimensions are required to define the processes. In the simulation, various features of irregular surface geometry of the subbasins were read from the topographic maps and were approximated by two types of basic elements; (1) an overland flow element and (2) a stream flow or channel flow element. Two separate overland flow elements can be used to describe the different overland flow conditions that exist within the subbasins. One element is often used for impervious areas and the other for pervious areas. If a subbasin is predominately one or the other, usually only one element is used. Up to three types of stream elements can be used including subcollector channels, collector channels, and a main channel. These three stream elements flow successively into one another starting with the subcollector channel. Depending on the subbasin characteristics not all three elements are required. Tables 3-4 and 3-5 list all data used to characterize overland flow and channel flow elements for each subbasin. The parameters used do not necessarily reflect any particular drainage component in the subbasin but are typical or average for the subbasin. The input files used for the HEC-1 simulation are presented in Appendix B.

3.2.5 Results

The output from the HEC-1 model includes runoff hydrographs, peak discharges, and the total volume of runoff from each subbasin and cross section location in the model. Plots of the runoff hydrographs at each cross section location are presented in Appendix C. Plots of hydrographs from both the infiltration and contaminant HEC-1 models are shown for comparison. A summary of the output for all four of the HEC-1 models is presented in Table 3-6 and Appendix B. The peak discharge in Paddys Run resulting from the 1-year, 24-hour storm event varies from cross section location to cross section location; however, the peak discharge is approximately 400 cfs. The flow

TABLE 3-3

COMPARISON OF HEC-1 MODELS USED FOR INFILTRATION AND CONTAMINANT CALCULATIONS

		Infiltration Model			Contaminant Model		
Cross Section Location	HEC-1 Model Station	Peak Flow (ft^3/s)	Time of Peak Flow (hr)	Total Discharge ($ft^3 \times 10^6$)	Peak Flow (ft^3/s)	Time of Peak Flow (hr)	Total Discharge ($ft^3 \times 10^6$)
C-C	STA 70	382	14.17	6.62	384	14.17	6.70
D-D	STA 75	394	14.33	7.07	385	14.33	7.07
E-E	STA E-E	421	14.50	8.64	417	14.50	8.63
F-F	STA 130	459	14.67	9.83	454	14.67	9.82
G-G	SUB 100	376	15.17	10.0	379	15.17	10.0
H-H	STA 120	403	15.33	11.1	406	15.33	11.1

TABLE 3-4

SUBBASIN CHARACTERISTICS FOR THE OVERLAND FLOW ELEMENT FOR THE HEC-1 MODEL SIMULATION

Infiltration Calculations - 15 Subbasins

Subbasin	Overland Flow Length[a] (ft)	Overland Flow Slope[a] (ft/ft)	Resistance Factor[b] n	% Subbasin Area[a]	Drain Area[a] (sq. mi.)	SCS Curve Number[c]
10	150	0.07	0.4	100	1.869	65.4
20	200	0.075	0.4	100	1.589	63.7
30	200	0.08	0.4	100	5.188	63
50	200	0.04	0.4	100	1.288	66
60	200	0.08	0.4	100	0.599	59.8
70	150	0.013	0.4	75	0.313	61
	200	0.013	0.15	25		88.8
75	150	0.013	0.4	75	0.408	61
	200	0.013	0.15	25		88
PDAR[d]	150	0.01	0.15	100	0.294	86.2
580	100	0.01	0.25	100	0.036	71.9
581	200	0.025	0.25	100	0.456	69.4
582	200	0.025	0.30	100	0.487	66.5
100	180	0.1	0.4	30	0.51	62.1
110	200	0.2	0.4	50	0.832	61.9
120	150	0.03	0.3	50		69
	100	0.28	0.4	100	0.561	69.4
130	200	0.033	0.4	100	1.385	68.2

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TABLE 3-4 (Continued)

Contaminant Calculations - 19 Subbasins

Subbasin	Overland Flow Length[a] (ft)	Overland Flow Slope[a] (ft/ft)	Resistance Factor[b] n	% Subbasin Area[a]	Drain Area[a] (sq. mile)	SCS Curve Number[c]
60	200	0.08	0.4	100	0.282	59.9
560	200	0.10	0.4	100	0.317 0.599	62.9
70	200	0.01	0.4	100	0.121	62.4
570	200	0.017	0.25	100	0.120	76.7
WPA[e]	200	0.024	0.15	100	0.072 0.313	76.8
75	150	0.15	0.40	100	0.288	67.6
575	200	0.013	0.15	25	0.120 0.408	69.8

[a]Estimated from USGS topographic map, Shandon, Ohio, N3915_W8437.5/7.5, 1981, DMA 4062 ISW-Series V852.
[b]Table 3.5, HEC-1 User's Manual.
[c]See Table 3-2 for SCS curve number calculation procedure.
[d]Production area
[e]Waste pit area

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TABLE 3-5

SUBBASIN CHARACTERISTICS FOR THE CHANNEL FLOW ELEMENT FOR THE HEC-1 MODEL SIMULATION
Infiltration Calculations

Element	Length[a] (ft)	Slope[a]	Manning[b] n	Area[a] (sq. mi.)	Shape	Width (ft)	Side Slope (ft/ft)	Route Upstream Flow
Subbasin 10								
Subcollector channel	500	0.07	0.045	0.06	Trapezoid	0	1	
Collector channel	3200	0.05	0.045	0.47	Trapezoid	0	1	
Main channel	5200	0.015	0.045		Trapezoid	0	1	No
Subbasin 20								
Collector channel	4500	0.065	0.045	0.132	Trapezoid		1	
Main channel	4800	0.015	0.045		Trapezoid	0	1	Yes
Subbasin 30								
Subcollector channel	3600	0.05	0.045	0.18	Trapezoid	0	1	
Collector channel	6000	0.007	0.045	1.297	Trapezoid	0	1	
Main channel	10800	0.003	0.045		Trapezoid	20	1	Yes
Subbasin 50								
Collector channel	5000	0.02	0.045	0.322	Trapezoid	0	1	
Main channel	2800	0.002	0.035		Irregular	--	1	Yes
Route 60								
Main channel	1600	0.004	0.035		Irregular		1	Yes
Subbasin 60								
Collector channel	4500	0.04	0.02	0.15	Trapezoid	5	1	
Main channel	1600	0.004	0.035		Irregular		1	No
Route 0								
Main channel	2986	0.004	0.025		Irregular			Yes

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TABLE 3-5 (Continued)

Element	Length[a] (ft)	Slope[a]	Manning[b] n	Area[a] (sq. mi.)	Shape	Width (ft)	Side Slope (ft/ft)	Route Upstream Flow
Subbasin 70								
Main channel	4000	0.013	0.045		Trapezoid	5	1	No
Route 1								
Main channel	3093	0.003	0.025		Irregular			Yes
Subbasins Divided for Contaminant Calculations								
Subbasin 75								
Main channel	4000	0.013	0.045		Trapezoid	5	1	No
Route 2								
Main channel	2773	0.002	0.025		Irregular			Yes
PDAR								
Main channel	2600	0.005	0.015	--	Circular	2	--	No
580								
Collector channel	500	0.100	0.04	0.020	Trapezoid	0	1	No
Main channel	600	0.010	0.035	--	Trapezoid	5	1	No
581								
Collector channel	1000	0.020	0.04	0.080	Trapezoid	0	1	No
Main channel	3300	0.012	0.030	--	Trapezoid	5	1	No
Route 80								
Main channel	1300	0.009	0.035	--	Irregular	--	--	Yes

TABLE 3-5 (Continued)

Subbasins Divided for Contaminant Calculations

Element	Length[a] (ft)	Slope[a]	Manning[b] n	Area[a] (sq. mi.)	Shape	Width (ft)	Side Slope (ft/ft)	Route Upstream Flow
582								
Collector channel	3600	0.022	0.045	0.033	Trapezoid	5	1	No
Main channel	3800	0.015	0.025	--	Trapezoid	26	2.27	No
Route 25								
Main channel	2613	0.002	0.025		Trapezoid	52.8	4.55	Yes
Subbasin 100								
Collector channel	4000	0.01	0.045	0.412	Trapezoid	5	1	
Main channel	2773	0.0003	0.025		Trapezoid	27.2	26.32	Yes
Route 3								
Main channel	3626	0.0025	0.025		Trapezoid	63.6	7.3	Yes
Subbasin 110								
Collector channel	500	0.04	0.045	0.21	Trapezoid	0	1	
Main channel	10,000	0.009	0.025		Trapezoid	20	3.33	No
Subbasin 120								
Collector channel	500	0.2	0.045	0.15	Trapezoid	0	1	
Main channel	8000	0.021	0.045		Trapezoid	20	3.33	No
Subbasin 130								
Collector channel	5000	0.016	0.045	0.588	Trapezoid	5	1	
Main channel	1800	0.02	0.025		Trapezoid	52.8	4.55	No

TABLE 3-5 (Continued)

Subbasins Divided for Contaminant Calculations

Element	Length[a] (ft)	Slope[a]	Manning[b] n	Area[a] (sq. mi.)	Shape	Width (ft)	Side Slope (ft/ft)	Route Upstream Flow
Subbasin 60								
Main channel	4500	0.04	0.03	--	Trapezoid	0	1	No
Subbasin 560								
Main channel	4800	0.01	0.04	--	Trapezoid	0	1	No
Subbasin 70								
Main channel	4600	0.013	0.045	--	Trapezoid	0	1	No
Subbasin 570								
Main channel	1800	0.017	0.030	--	Trapezoid	0	1	No
WPA								
Main channel	1800	0.024	0.030	--	Trapezoid	0	1	No
Subbasin 75								
Main channel	4000	0.013	0.045	--	Trapezoid	5	1	No
Subbasin 575								
Main channel	650	0.067	0.045	--	Trapezoid	5	1	No

[a]Estimated from USGS topographic map, Shandon, Ohio, N3915_W8437.5/7.5, 1981, DMA 4062 ISW-Series V852.
[b]Table 4.2, Henderson, F.M., 1966, Open Channel Flow, MacMillan Publishing Co., Inc.

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Table 3-6
SUMMARY OF HEC-1 MODEL RESULTS

Infiltration Calculations

	Scenario 1[b]		Scenario 2[c]	
Station[a]	Peak Flow (ft^3/s)	Time of Peak (hr)	Peak Flow (ft^3/s)	Time of Peak (hr)
SUB 10	119	13.00	119	13.00
SUB 20	183	13.17	183	13.17
SUB 30	340	13.67	340	13.67
SUB 50	377	13.83	377	13.83
ROUTE 60	368	14.00	368	14.00
SUB 60	11	13.83	11	13.83
STA 60	378	14.00	378	14.00
ROUTE 0	373	14.17	373	14.17
SUB 70	64	12.53	64	12.53
STA 70	382	14.17	382	14.17
ROUTE 1	382	14.33	382	14.33
SUB 75	83	12.33	83	12.33
STA 75	394	14.33	394	14.33
ROUTE 2	380	14.50	380	14.50
PDAR	180	12.17	—	—
SUB 580	6	12.50	6	12.50
SWRB	183	12.17	—	—
SUB 581	48	12.67	48	12.67
STA J-J	194	12.17	53	12.67
ROUTE 80	192	12.33	53	12.83
SUB 582	30	13.00	30	13.00
STA 80	196	12.33	78	12.83
STA E-E	421	14.50	407	14.50
ROUTE 25	421	14.67	407	14.67
SUB 130	102	13.00	102	13.00
STA 130	459	14.67	445	14.67
SUB 100	376	15.17	360	15.17
ROUTE 3	375	15.33	360	15.33
SUB 110	52	13.00	52	13.00
SUB 120	74	12.67	74	12.67
STA 120	403	15.33	387	15.33

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TABLE 3-6 (Continued)
Contaminant Calculations

Station[a]	Scenario 1[b] Peak Flow (ft^3/s)	Scenario 1[b] Time of Peak (hr)	Scenario 2[c] Peak Flow (ft^3/s)	Scenario 2[c] Time of Peak (hr)
SUB 10	119	13.00	119	13.00
SUB 20	183	13.17	183	13.17
SUB 30	340	13.67	340	13.67
SUB 50	377	13.83	377	13.83
ROUTE 60	368	14.00	368	14.00
SUB 60	5	13.50	5	13.50
SUB 560	12	13.17	12	13.17
STA 60	380	14.00	380	14.00
ROUTE 0	374	14.17	374	14.17
SUB 70	3	14.67	3	14.67
SUB 570	30	12.50	30	12.50
WPA	27	12.33	—	—
70 CT	53	12.33	—	—
STA 70	384	14.17	381	14.17
ROUTE 1	374	14.33	375	14.33
SUB 75	30	12.67	30	12.67
SUB 575	16	12.5	16	12.50
STA 75	385	14.33	385	14.33
ROUTE 2	376	14.50	372	14.50
PDAR	180	12.17	—	—
SUB 580	6	12.50	6	12.50
SWRB	183	12.17	—	—
SUB 581	48	12.67	48	12.67
STA J-J	194	12.17	53	12.67
ROUTE 80	192	12.33	53	12.83
SUB 582	30	13.00	30	13.00
STA 80	196	12.33	78	12.83
STA E-E	417	14.50	399	14.50
ROUTE 25	416	14.67	390	14.67
SUB 130	102	13.00	102	13.00
STA 130	454	14.67	—	—
SUB 100	379	15.17	360	15.17
ROUTE 3	379	15.33	359	15.33
SUB 110	52	13.00	52	13.00
SUB 120	74	12.67	74	12.67
STA 120	406	15.33	386	15.33

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[a]SUB - subbasin; STA - station; PDAR - production area; SWRB - storm water retention basin; WPA - waste pit area; 70 CT - [STA] 70-contaminant transport.

[b]Scenario without the retention basin

[c]Scenario with the retention basin.

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coming from the FEMP property (i.e., subbasins 70, 75, and the SSOD) forms an early peak in the overall runoff hydrograph. This is caused by the difference in the time the flow from the FEMP property enters Paddys Run and when the upstream flow reaches the FEMP site. The flow from the subbasins coming from the FEMP directly enters Paddys Run while the upstream flow is delayed by the amount of time it takes the upstream flow to reach the site.

3.3 SIMULATION OF STAGE IN PADDYS RUN AND THE SSOD

The stage in Paddys Run and the SSOD is simulated to produce information for use in the infiltration calculations. In order to accomplish this, rating curves (discharge versus depth) are developed at several cross section locations. The HEC-1 model provided hydrographs in terms of discharge rate versus time at each cross section location. The rating curves for each cross section are combined with the runoff hydrographs to produce a stage versus time relationship for each cross section during the simulated storm event. This information is then used for the infiltration simulation.

Eight cross sections in Paddys Run are used in the calculations. The cross sections are located approximately 2000 feet apart and cover Paddys Run from the GMR to the northern FEMP boundary. The cross sections along Paddys Run are based on topographic maps developed from survey data and are identified as A-A through H-H (Figures 3-1 and 3-2).

Three cross sections are used in the SSOD and are spaced approximately 1200 feet apart. The SSOD cross sections are based on the 1992 topographic mapping developed from aerial photography of the FEMP site and are identified as I-I through K-K. The cross sections determined from the topographic mapping differ somewhat from two surveyed water sample location elevations in the SSOD. Because survey information is generally considered more accurate than aerial topography, it was decided that the elevations of the three cross sections in the SSOD would be based on the surveyed water sample location elevations. The SSOD stream bed elevations are based on a linear interpolation between the surface water sample locations. The cross sections are used to determine stream depth versus cross sectional area relationships for points along Paddys Run and the SSOD. Four of the cross sections along Paddys Run and all the SSOD cross sections are used in the infiltration calculations.

Rating curves (depth-discharge relationships) are developed for each of the cross sections. These depth-discharge relationships are calculated with Mannings equation (Henderson, 1966), an empirical

equation widely used to calculate either water depth or discharge in a channel, depending on what information is given. Mannings equation assumes that the flow is steady (not changing with time) and uniform (flow properties not changing with distance along the stream). The use of Mannings equation is a justifiable simplification to the probable actual flow conditions because the sensitivity analysis (discussed in Section 5.1) shows that the infiltration calculations are fairly insensitive to the discharge rate in the surface water bodies and it is assumed they are also insensitive to the depth of flow. The Mannings roughness coefficient and slope for each cross section used in a rating curve calculation are listed in Table 3-3 (the same cross sections were used in the HEC-1 analysis for routing flow). Appendix A shows the geometries of cross sections A-A through K-K. The resulting rating curves are presented in Appendix D.

3.4 INFILTRATION SIMULATION

3.4.1 Conceptual Model

The top layer of soil in the vicinity of the FEMP property consists of relatively impermeable glacial overburden deposits. Underlying this layer are permeable glacial outwash deposits that form the water bearing unit of the GMA. Water readily infiltrates into the unsaturated outwash deposits due to its porous nature. The stream channels of Paddys Run and the SSOD have cut through the glacial overburden into the outwash deposits (Figure 3-6). The water table elevation in the GMA in and around the FEMP property is generally lower than the streambed elevation which forms an unsaturated (vadose) zone between the water table and the stream bed. Significant amounts of water can infiltrate from the stream to the unsaturated glacial outwash deposits and then enter the GMA. This migration is the basis for modeling the surface water as a possible pathway of contamination to the groundwater.

The infiltration model simulates flow from the stream channels into the unsaturated and saturated zones of the glacial outwash deposits. For the reaches of Paddys Run and the SSOD which flow on top of the glacial overburden, infiltration is negligible due to the low streambed permeability. Therefore, within these reaches infiltration rates are not calculated. When Paddys Run cuts deep enough into the glacial outwash deposits so that the streambed elevation matches the water table elevation, infiltration again becomes negligible because the water elevations are in equilibrium. Infiltration was calculated from the location where the streams cut into the glacial outwash deposits to the location where streambed elevation matches the water table elevation.

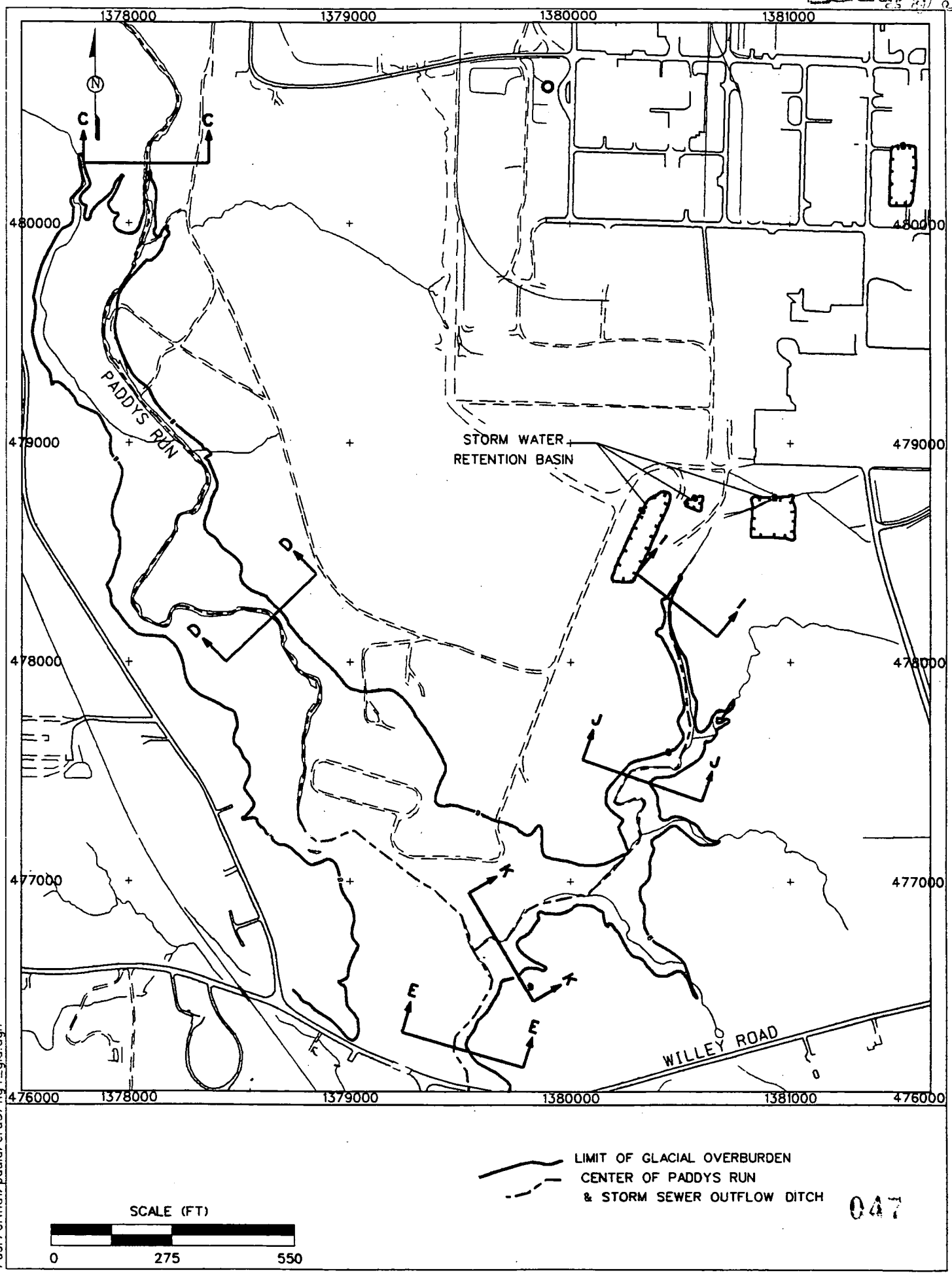

FIGURE 3-6. LIMIT OF GLACIAL OVERBURDEN

Paddys Run's streambed is glacial overburden at cross sections A-A and B-B and glacial outwash at cross sections C-C through H-H. Cross section C-C is very close to the limit of the glacial overburden in Paddys Run, so the infiltration calculations are begun there. Figure 3-6 shows the limit of the glacial overburden and the cross sections used in this study. All of the cross sections in the SSOD are in the glacial outwash deposits. Cross section I-I is very close to the limit of glacial overburden in the SSOD so infiltration calculations are begun there. The water table and stream bed elevations intersect near cross section F-F, where infiltration again becomes negligible; therefore, the infiltration calculations are stopped and infiltration is assumed to be zero.

The simulations assume there is no baseflow in Paddys Run above cross section F-F. This means that Paddys Run and the SSOD have no flow at the beginning of the storm event. It was also assumed that the glacial outwash deposits are unsaturated down to the groundwater table before the storm event. The effect of water infiltrating through the streambeds was assumed to not significantly effect the runoff hydrographs so that the heads input into VS2DT based on the runoff hydrographs are not adjusted for the amount of water in the streams lost to infiltration.

3.4.2 Infiltration Model (VS2DT)

VS2DT is a USGS numerical model which simulates water movement through variably saturated porous media. Simulated regions can be one-dimensional columns, two-dimensional vertical cross sections, or axially symmetric, three-dimensional cylinders. Infiltration through the channel of Paddys Run was calculated using VS2DT which was able to take into account the wetting front as it advanced through the vadose zone to the water table once flow in Paddys Run and the SSOD began. Following this, the model simulates the lateral migration of water away from the stream as a mound forms in the aquifer underneath Paddys Run and the SSOD.

At each of the six cross sections where infiltration calculations are performed (in both Paddys Run and the SSOD), a two-dimensional finite-difference grid was designed to simulate water movement through the cross section under the stream channels. Only one-half of the cross section was simulated due to the symmetry of the region. The vertical dimension was set from the groundwater table to the streambed. The grid spacing varies in both the horizontal and vertical directions with the finest grid spacing occurring under the stream channel where the infiltration begins. Figure 3-7 shows the model

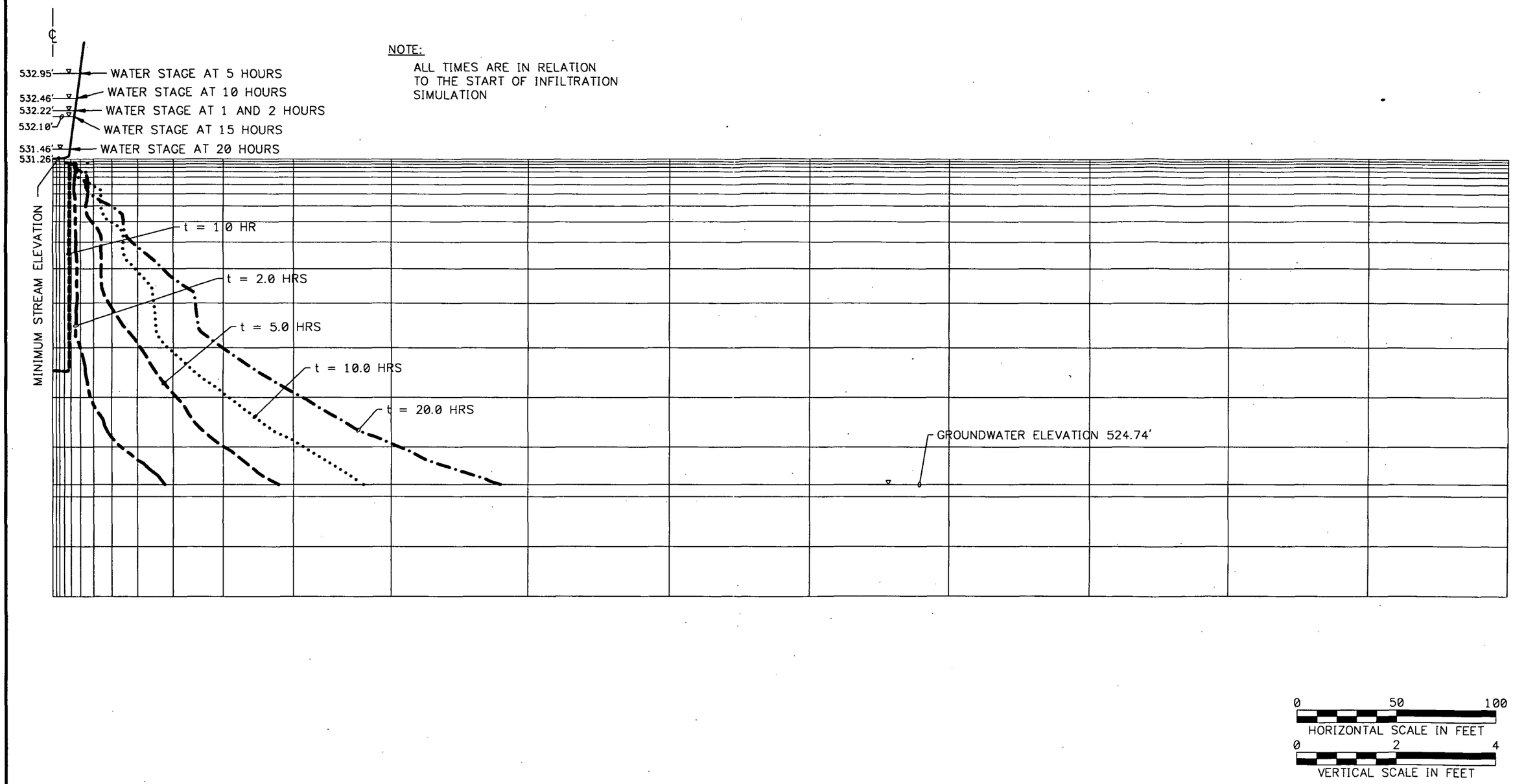

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FIGURE 3-7.
VS2DT MODEL GRID AND MOUND OF SATURATION UNDER PADDYS RUN AT CROSS SECTION D-D

grid used for cross section D-D and the mound of saturation formed under the stream during the 1-year, 24-hour storm event.

The horizontal dimension of the infiltration model grid was extended far enough so that no infiltrating water reaches the model boundary at any time during the simulation. The bottom boundary of the model was set by the initial groundwater table elevation.

The top boundary of the model grid contains several constant head cells which are used to simulate the depth of flow in the stream cross section. The width of the constant head cells are defined to match the stream width. Paddys Run stream width was based on the distance from edge of water to edge of water in the topography developed from survey data. The stream width in the SSOD was based on engineering judgment relating the size of the SSOD to Paddys Run. The stream widths used in the model are shown in Table 3-7.

The streams are simulated in the model using a constant head boundary at the streambed with a head value equal to the water head (depth) in the stream at a given time. Since stream head varies during the storm, the simulation is divided into discrete time periods so that the head can be varied between periods. In each period, the stream head is averaged and used as input for the constant head cells. In Paddys Run the infiltration calculations are divided into two-hour increments. In the SSOD the runoff hydrographs are shorter in duration and change more rapidly with time. The two-hour time increments are too large to accurately match the changing head in the SSOD so one-hour periods are used for the first several time periods at the beginning of the storm event when the head is changing rapidly.

The duration that the infiltration simulations are performed is based on the period when the depth of flow in the cross section was greater than 0.1 foot, when most of the flow has been discharged. When modeling the current conditions (flow from the production area is diverted), very little runoff reaches cross section I-I at the head of the SSOD; the depth of flow is less that 0.1 foot for all but a one-hour period. So the duration of the infiltration simulations at this cross section is based on the period when 98 percent of the flow has been discharged. The duration of the infiltration simulations in the SSOD ranges from 13 to 15 hours; those in Paddys Run range from 18 to 20 hours. A sample VS2DT input file is presented in Appendix E.

TABLE 3-7

INPUT PARAMETERS FOR VS2DT

Cross Section	Distance From Upstream Cross Section (ft)	Groundwater Elevation[a] (ft)	Stream Bed Elevation[b] (ft)	Half Width of Stream Bed (ft)[b]	Vertical Saturated Conductivity[c] (ft/day)	Horizontal Saturated Conductivity[c] (ft/day)	Simulation Time (hr)	Porosity[c] (vol/vol)	Residual Moisture[d] (vol/vol)
C-C		525.83	539.9	12	45	450	18	0.39	0.069
D-D	3093	524.74	531.26	9	45	450	20	0.39	0.069
E-E	2773	523.35	525	13	45	450	20	0.39	0.069
F-F	2613	520.74	520						
I-I		523.00	549.60	5	45	450	14	0.39	0.069
J-J	1100	523.43	539.45	5	45	450	15	0.39	0.069
K-K	1300	523.96	527.40	5	45	450	15	0.39	0.069

[a]DOE, December, 1990 "Groundwater Report," FMPC, Fernald Ohio, Vol. 12 of 13, Appendix K, Figure K-28.
[b]See Appendix B.
[c]IT, 1993, "Groundwater Modeling Report, Summary of Model Development," Final, prepared for the U.S. Dept. of Energy, FEMP, Cincinnati, OH.
[d]Lappala, E.G., et al., 1993, "Documentation of Computer Program VS2D to Solve the Equations of Fluid Flow in Variably Saturated Porous Media," in: Water Resources Investigations Report, 83-4099, U.S. Geological Survey, Denver, CO.

Linear interpolation is used to calculate total infiltration in the reaches between seven cross sections in Paddys Run and the SSOD, where the infiltration is simulated by VS2DT or assumed (i.e., cross section F-F).

3.4.3 Input Data

At each cross section the VS2DT model requires input concerning the thickness of unsaturated material to the groundwater table. This distance is taken as the difference between the minimum cross section elevation and the groundwater table. The minimum stream elevations are taken from the cross sections shown in Appendix A. The groundwater table elevations under each stream channel cross section are based on water level elevations measured in the 2000-series monitoring wells located near each cross section. The groundwater elevations are based on a sampling round in the 2000-series wells in April 1990. Since most storm events will occur during the wet season (usually the spring months of the year), it was felt that using the groundwater elevations from that portion of the year would yield more realistic results. The VS2DT model also requires head elevation data at the streambed for each of the cross section locations for use in the infiltration calculations. This information was provided from the HEC-1 runoff hydrographs and the cross section rating curves.

The hydraulic properties of the glacial outwash deposits are assumed to be similar to the values used for the GMA. The saturated vertical hydraulic conductivity is assumed to be 45 ft/day and the porosity is assumed to be 0.39 based on values used in previous reports (IT, 1993). Saturated-unsaturated hydraulic conductivity curves use the Van Genuchten equation (Healy, 1990) to simulate variably saturated aquifer conditions. Fitting parameters were chosen from representative soil types taken from the VS2DT manual. The soil type in the VS2DT manual which most closely matched the properties of the glacial outwash deposits was sand. The hydraulic conductivity and the porosity were used to compare the glacial outwash deposits' properties with the properties of soil in the VS2DT manual. Soil moisture contents are initialized by the program after fixing the aquifer's water table elevation and defining a minimum saturation level of 20 percent of full saturation. This allows the model to create an initial saturation gradient through the vadose zone.

3.4.4 Results

The VS2DT model reports information concerning infiltration through the streambeds of Paddys Run and the SSOD at every hour of the infiltration simulations. The pertinent output from VS2DT includes total flux (total infiltration through the stream channel) through the constant head boundaries and the percent saturation in each cell of the model grid. This output was then processed to arrive at the results needed for this study. The subsequent sections discuss the results and required processing.

3.4.4.1 Infiltration Rate

The VS2DT model simulates the wetting front of the infiltrating water as it travels through the unsaturated soil under the streambed. The wetting front eventually reaches the groundwater table and forms a mound of saturation under the stream. Figure 3-7 shows the location of the wetting front at several times during the infiltration simulation at cross section D-D.

Based on the total infiltration amount at each cross section at each hour, the hourly amount of infiltration in each stream reach is calculated and converted to a rate. The results of the VS2DT model (Table 3-8) show a variable infiltration rate depending on the depth to the water table below the channel. The channel reach between cross section C-C, approximately 14 feet above the water table, and cross section D-D, approximately 6.5 feet above the water table, experiences an infiltration rate ranging between 3 and 24 inches per hour (in./hr) through the streambed. The channel reach between cross section E-E, only 1.65 feet above the water table, and cross section F-F, approximately at the water table elevation, has an infiltration rate of 0.1 to 2.5 in./hr. These results show the effect of unsaturated zone thickness on the inflow of water to the aquifer. The channel reach between cross sections D-D and E-E is an intermediate step between channel reaches C-C to D-D and C-C to E-E and has a rate of 0.8 to 10 in./hr. Plots of the infiltration rate versus time for each channel reach are shown in Appendix F.

The infiltration rates generally begin high and decrease as the infiltrating water saturates the glacial outwash deposits between the streambed and the groundwater table and as the depth of flow in the stream channel cross section decreases. This same general trend is also observed in the infiltration results for the cross sections located in the SSOD. Cross sections I-I and K-K are 26.6 and 16 feet, respectively, above the groundwater table. In this channel reach the outwash deposits between the stream and the groundwater never become completely saturated. The infiltration rate is more

TABLE 3-8
SUMMARY OF VS2DT MODEL RESULTS

Stream Reach	Scenario 1[a] Maximum Infiltration Rate (in./hr)	Scenario 1[a] Minimum Infiltration Rate (in./hr)	Scenario 2[b] Maximum Infiltration Rate (in./hr)	Scenario 2[b] Minimum Infiltration Rate (in./hr)
CC-DD	23.8	2.7	23.8	2.7
DD-EE	11.1	0.8	11.1	0.8
EE-FF	2.5	0.1	2.3	0.1
II-JJ	29.3	3.2	14.2	0.3
JJ-KK	24.8	8.5	20.9	4.2

[a]Scenario without the retention basin.
[b]Scenario with the retention basin.

dependent on the flow in the stream than the groundwater elevation. The infiltration rates for channel reaches I-I to J-J and J-J to K-K are 3 to 29 and 8 to 24 in./hr, respectively, based on the simulation including flow from the former production area.

3.4.4.2 Total Infiltration Volume

The total infiltration volume in Paddys Run and the SSOD is calculated by first calculating the total infiltration volume in each channel reach in the infiltration simulation (i.e., between cross section C-C and D-D, between cross sections D-D and E-E, etc.). The total infiltration at the cross section locations on the ends of the channel reach are linearly interpolated and multiplied by the length of the channel reach to yield the total infiltration in the reach. The overall total infiltration is then the sum of the infiltration amounts in each of the channel reaches.

The total amount of infiltration in Paddys Run and the SSOD for the case which includes flows from the former production area is approximately 2.6 million cubic feet (ft^3). Approximately 8.6 million ft^3 of runoff is created in the Paddys Run drainage basin upstream of cross section F-F (the location where the infiltration calculations are stopped). This means that roughly 30 percent of the total runoff generated by a 1-year, 24-hour storm event infiltrates through the streambeds of Paddys Run and the SSOD. For the current site conditions where the production area does not contribute flow to the SSOD, approximately 2.3 million ft^3 (or roughly 29 percent) infiltrates from 7.9 million ft^3 of total runoff.

3.4.4.3 Contaminated Runoff Infiltration Volume

The general results of the overall amount of contaminated runoff which infiltrates Paddys Run and the SSOD are presented here. Section 4.3 presents the method for calculating the amount of infiltration and contaminant contributed by each subbasin into each reach in Paddys Run and the results. This information will be used in determining the loadings to the GMA for the groundwater solute transport model.

The total infiltration percentages are based on the individual infiltration percentages discussed in Section 4.3. For the scenario which includes flow from the former production area, approximately 39 percent of the contaminated flow coming from subbasins infiltrates. For the scenario in which the flow from the former production area is not included, approximately 37 percent of the contaminated

flow infiltrates. These percentages will be related to the percent of dissolved contaminant in the runoff which reaches the GMA by infiltrating through the streambeds of Paddys Run and the SSOD.

3.4.5 Verification

The Groundwater Modeling Report (IT, 1993) notes a high degree of correlation between the Paddys Run and aquifer hydrographs. The data used to make this correlation are based on continuous 60-minute readings using pressure transducers and a data logger measured in Monitoring Well 2014, located approximately 25 feet away from Paddys Run near cross section E-E. On April 14, 1989, a storm event caused a rapid rise in the Paddys Run stage elevation from 526.5 to 531.5 feet. Within two hours, the water level in Monitoring Well 2014 started to rise above its initial elevation of 523.2 feet. Within the following two-hour period, the water level rose to its maximum height of 524.2 feet.

It is not possible to directly compare the results of the infiltration model with the hydrograph data because the magnitude of the storm event and initial conditions were not the same as the 1-year, 24-hour storm used in the VS2DT modeling. However, the results from the infiltration model and the field data are compared on a qualitative basis. In the infiltration model (cross section E-E), the stream bed and groundwater elevations are set at 525 and 523.35 feet, respectively. The simulated storm event produces a rapid rise in the Paddys Run stage elevation from 525 to 527.6 feet. The water table elevation at the approximate location of Monitoring Well 2014 rises almost instantaneously and achieves its maximum elevation of 525 feet within one hour.

The difference in response between the infiltration model and the field data may be attributed partially to the difference in the initial water table elevation. In the case of the model, the distance between the stream bed and the initial water table was only 1.65 feet. The high initial water table results in less available pore space for infiltrating water, consequently producing a more rapid response in the water table. Although a direct comparison cannot be made, the response of the infiltration model was generally similar to the response observed in the field.

A mass balance between the amount of flow in the streams and the amount of infiltration is performed to ensure that more water did not infiltrate through the streambeds than was available. At each cross section and at each hour, the volume of flow in the streams and the volume of infiltration through the streambeds is calculated (see Appendix G for calculations). In some cases, at the tail of the runoff

hydrograph, when the flow of water becomes fairly small, the integration of VS2DT model results show more infiltration than what is available. When this happened the infiltration volumes are adjusted so that only up to 100 percent of the flow in the stream infiltrates.

In order to make an independent comparison of the volume of water which infiltrates into Paddys Run, a calculation is made of the volume of unsaturated voids available to be filled with water. This calculation checks the order of magnitude of VS2DT infiltration results. It assumes that water will only infiltrate to fill the unsaturated voids so that once the volume of voids under Paddys Run are filled, infiltration would stop. This simple calculation also assumes infiltrated water does not move horizontally to fill unsaturated areas which are not under the stream bed.

The total volume of unsaturated voids under the streambed is calculated by taking the streambed elevation and subtracting the elevation of the groundwater table to arrive at the thickness of unsaturated material along the stream. These thicknesses are then multiplied by the length of the stream and an average width of the stream. The streambed elevation information was taken from the 1992 topographic maps of the FEMP site. Because these elevations produce an undulating surface, these elevations are averaged to form a smooth surface for the streambed volume calculations (see Figure 1 in Appendix H). The groundwater elevations are based on water surface elevations in the 2000-series wells along Paddys Run. Groundwater elevation data from 1988 to 1993 are averaged and used to calculate the volume. Only well data with 20 or more data points are used in the average. The stream width used was based on the average width (edge of water to edge of water as shown on the topographic maps.

The average groundwater elevations used for the volume calculation are roughly 3 feet lower than the elevations used in the VS2DT infiltration calculations. The independent calculation yielded a total volume of 2.02 million ft^3. When this is adjusted by the porosity of the GMA (0.39 - Table 3-7), the volume of available voids is 0.78 million ft^3.

The VS2DT model allows for lateral flow of water so that the width of saturation under Paddys Run is wider than the width of the stream, forming a mound of saturation beneath the streambed. At the end of the simulation, the width of the groundwater mound was approximately 100 to 400 feet (see Figure 2 in Appendix H). The groundwater mound becomes very thin at its outer edges and does not

contain a large percentage of the volume. Approximately 2 million ft^3 of infiltration was calculated with the VS2DT model in Paddys Run only. The saturated mound would account for the difference between the VS2DT model results and the independent volume calculation. While the results of the volume calculation are different for the two methods, they are within an order of magnitude and indicate that the results from the VS2DT method are reasonable.

4.0 DEVELOPMENT OF CONTAMINANT LOADING TERMS

This section describes the models and assumptions proposed to estimate the concentration of contaminants in surface water runoff and sediment in the upcoming RI/FS studies. The following discussion provides the approach only; the actual calculations are conducted by each operable unit-specific RI/FS, as shown in Figure 1-2. How to estimate the year-long loadings to the GMA from contaminated surface water infiltrating through the beds of Paddys Run and the SSOD is also discussed. The year-long loadings employ two different rates (Figure 4-1); one describes the loading produced from the representative 1-year, 24-hour storm event while the other, related to yearly sediment generation, represents the rest of the storm events which occur during the year. This second loading rate is applied at a constant rate over six months of the year. The other six months have a loading rate of zero which represents the times of the year when Paddys Run is dry and cannot provide a pathway for contaminants to the GMA.

4.1 SURFACE RUNOFF AND SEDIMENT CONCENTRATIONS

In order to calculate the amount of contaminants in surface runoff and sediment generated from a single storm event, the procedures in the Superfund Exposure Assessment Manual (EPA, 1988) are used. As the contaminant moves in Paddys Run and is mixed with uncontaminated flow the concentrations are calculated based on a mass balance approach.

4.1.1 Sediment Generation

The MUSLE is used to calculate the amount of sediment generated from each subbasin containing contaminated areas. The MUSLE equation takes the following form:

$$Y(S)_e = a\,(V_r q_p)^{0.56}\,K\,LS\,C\,P \qquad (4\text{-}1)$$

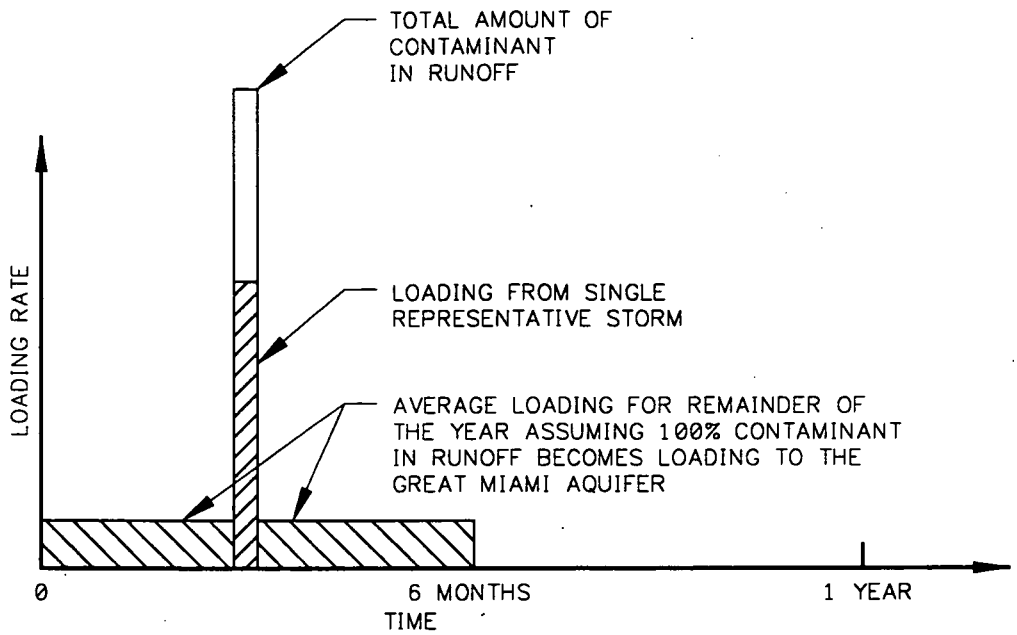

FIGURE 4-1. SIMULATED LOADING RATE PATTERN TO THE GREAT MIAMI AQUIFER

Where

Y(S)e	=	sediment yield (mass per event)
a	=	conversion constant
V_r	=	volume of runoff (volume, from HEC-1 output)
q_p	=	peak flow rate (volume / time, from HEC-1 output)
K	=	soil erodibility factor (mass/area/unit erosion potential from County Soil Survey)
LS	=	slope length factor (dimensionless, from Superfund Exposure Assessment Manual)
C	=	cover factor (dimensionless, from Superfund Exposure Assessment Manual)
P	=	erosion control practice factor (dimensionless, from Superfund Exposure Assessment Manual)

The volume of runoff and the peak flow rate can be calculated based on equations presented in the Superfund Exposure Assessment Manual; however, since this information is available from the HEC-1 output presented in this report, the HEC-1 results will be used. The HEC-1 analysis is more detailed than the equations in the Manual and should yield more consistent results since the same HEC-1 output was used in other parts of this overall analysis (i.e., infiltration calculations). The output from MUSLE will be the total amount of sediment produced (in mass) from each subbasin.

4.1.2 Partitioning Equations

Calculations to determine the amount of contaminant in the runoff and in sediment for each subbasin need to be performed for each CPC. These calculations would likely be done in a spreadsheet format. The following equations calculate the amount of adsorbed and dissolved contaminants available in the top 0.4 inch of soil (EPA, 1988).

$$S_s = (1/(1+\theta_c/(K_d\beta)))\ C_i\ A_c\ \beta \qquad (4\text{-}2)$$

$$D_s = (1/(1+(K_d\beta/\theta_c))\ C_i\ A_c\ \beta \qquad (4\text{-}3)$$

where

S_s = adsorbed substance quantity (mass)

D_s = dissolved substance quantity (mass)

θ_c = available water capacity (dimensionless)

K_d = sorption partition coefficient (volume/mass)

β = soil bulk density (mass/volume)

C_i = total substance contamination (mass/area-in.)

A_c = contaminated area (area-in.)

The amount (mass) of contaminant and concentrations are given by the following equations:

$$PX_i = (Y(S)_e / aA\,\beta)(S_{s1} + S_{s2} + S_{s3}) \quad (4\text{-}4)$$

$$PQ_i = (Q_r / R_t)(D_{s1} + D_{s2} + D_{s3}) \quad (4\text{-}5)$$

$$C_e = PQ_i / V_r \quad (4\text{-}6)$$

$$C_s = PX_i / Y(S)_e \quad (4\text{-}7)$$

where

PX_i = adsorbed substance loss per event (mass)

PQ_i = dissolved substance loss per event (mass)

C_e = concentration of contaminant in runoff per subbasin (mass/volume)

C_s = concentration of contaminant in sediment per subbasin (mass/mass)

$Y(S)_e$ = sediment yield (mass, from MUSLE)

Q_r = total storm runoff (depth, from HEC-1 output)

R_t = total storm rainfall (depth, from HEC-1 input)

V_r = storm runoff volume (volume, HEC-1 output)

A = total subbasin area (area-in.)

S_{s1} = adsorbed substance quantity for contaminated area one in the subbasin (mass)

D_{s1} = dissolved substance quantity for contaminated area one in the subbasin(mass)

a = conversion constant

The procedures in the Superfund Exposure Assessment Manual only deal with an area that is uniformly and completely contaminated. At the FEMP only certain areas within each subbasin are

actually contaminated. The equations presented here have been modified slightly so that the concentrations calculated for each subbasin take into account the uncontaminated portions of the subbasin as well. The above equations have two parameters: 'A' is the entire subbasin while 'A_c' is only the area that is contaminated. The Superfund Exposure Assessment Manual only has a parameter for the contaminated area. The first terms in the equations to calculate the PX_i and PQ_i (the mass of contaminant released in the adsorbed and dissolved phases respectively) are just ratios of subbasin parameters not specifically associated with the contamination. Using the overall subbasin parameters and not ones specific to the contaminated areas does not change the results of the mass of contaminant released since the underlying assumption in these equations is that the parameters within a subbasin are homogeneous. The mass of contaminant released (PQ_i and PX_i) is the same but the concentration is based on the total amount of sediment and runoff produced in the subbasin, not just the amounts produced from the contaminated areas.

The result from this step in the overall procedure is the contaminant concentration in the runoff and sediment from each subbasin. The sediment concentrations are complete at this point; the runoff concentration calculations are continued to account for the mixing of contaminated runoff with runoff from uncontaminated subbasins outside of the FEMP property. These calculations are described in the next section.

4.1.3 Estimation of Concentrations in Runoff in Paddys Run, SSOD, and the GMR

The concentrations in Paddys Run, the SSOD, and the GMR are calculated based on the 1-year, 24-hour storm event. The concentration in Paddys Run or the SSOD caused by a single contaminated subbasin are required for evaluation of each individual operable unit in the ongoing RI/FS at the FEMP site. The concentrations in Paddys Run and the SSOD resulting from the contaminated flow from an individual contaminated area are calculated with dilution factors. These dilution factors will relate the concentration in the runoff coming from the contaminated subbasin with the resulting concentration in the receiving stream (either Paddys Run or the SSOD). The dilution factor for each individual contaminated subbasin is discussed in Section 4.1.3.1.

To be conservative, the procedure for estimating concentrations in the surface waters assumes that no mass of contaminant is lost to infiltration through the streambeds. This assumption represents a worst-case scenario for concentrations in the surface water. If a storm event occurs when the

streambeds are saturated, little or no dissolved contaminant would infiltrate through the streambeds. If the storm event occurred at any other time more contaminant would likely infiltrate, leaving less contaminant for the concentration in the surface waters.

The combined effect of multiple contaminated subbasins entering Paddys Run and the SSOD also needs to be evaluated. Where several contaminated subbasins enter Paddys Run at the same point, the average concentration of the contaminated subbasins is calculated based on a flow-volume weighting of the concentration from each subbasin. The average concentration is then used to calculate the resulting concentration in Paddys Run.

The total concentration in Paddys Run is calculated at cross sections C-C, D-D and E-E, as shown in Figure 3-4. These locations include contamination entering Paddys Run at that point and contamination, if any, which entered Paddys Run upstream of that point.

The concentration in the GMR resulting from contaminated flow from Paddys Run is calculated based on the average flow rate in the GMR. Each of the above-mentioned calculations are discussed below.

4.1.3.1. Dilution Factors for Individual Contaminated Subbasins

To estimate the contaminant concentrations in Paddys Run and the SSOD, dilution factors are calculated for each contaminated subbasin. The dilution factors are applied to the runoff contaminant concentrations (i.e., C_e as described in Section 4.1.2) from each contaminated subbasin. These dilution factors are based on the flows in the receiving stream (Paddys Run or the SSOD) when the peak flow from the contaminated subbasins enters the receiving stream.

The flow from the contaminated subbasins is assumed to be uniformly contaminated with a constant concentration over the duration of the flow. The rates at which contaminants reach the receiving stream are greatest when the flow from the contaminated subbasin is the greatest, at the time of the peak discharge from the subbasin. Generally the maximum concentration in the receiving stream occurs when the most contaminant enters the stream. To be conservative, this maximum concentration is reported as the concentration in the receiving stream. The ratio of the peak flow in the contaminated subbasin to the flow in the receiving stream at the time of the peak discharge of the contaminated subbasins is used as the dilution factor. Figure 4-2 graphically shows the relationship

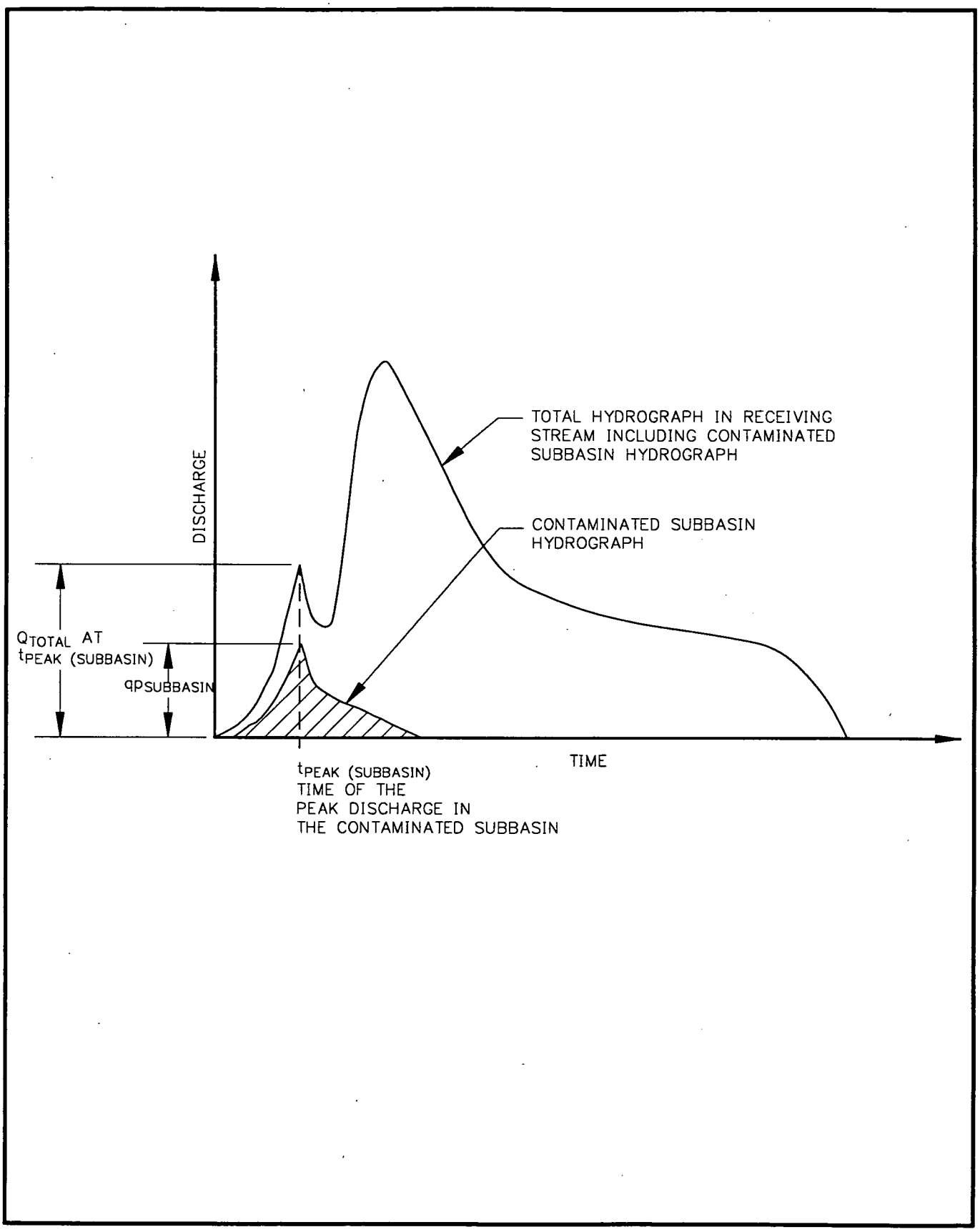

FIGURE 4-2. RUNOFF HYDROGRAPH RELATIONSHIP USED TO CALCULATE DILUTION FACTORS

between the contaminated subbasin hydrograph, the total hydrograph in the receiving stream, and the discharges at the time of the maximum flow from the contaminated subbasin.

As an example, the following equations are used to calculate the dilution factors for the WPA subbasin (waste pit area) of the HEC-1 model used for contaminant calculations. The total hydrograph (including subbasin WPA) in the receiving stream is STA 70 in the HEC-1 model (Figure 3-5). The dilution factors for the other contaminated subbasins are calculated in a similar manner. All of the dilution factors are presented in Table 4-1.

$$DF_{(WPA)} = qp_{(WPA)} / Q_{STA70(WPA)} \quad (4\text{-}8)$$

Where

$DF_{(WPA)}$ = dilution factor for subbasin WPA (dimensionless)

$qp_{(WPA)}$ = peak flow from subbasin WPA (volume/time)

$Q_{STA70(WPA)}$ = flow rate in the STA 70 hydrograph at the same time as the peak flow in subbasin WPA (volume/time)

The concentration in Paddys Run due to subbasin WPA can then be calculated with the following equation:

$$C_{Paddy(WPA)} = C_{e(WPA)} (DF_{(WPA)}) \quad (4\text{-}9)$$

Where

$C_{Paddy(WPA)}$ = concentration in Paddys Run due to subbasin WPA (mass/volume)

$C_{e(WPA)}$ = concentration of contaminant in the runoff from subbasin WPA (mass/volume); calculation of this value is described in Section 4.1.2.

4.1.3.2 Weighted Contaminant Concentrations for Multiple Subbasins Entering Paddys Run

The contaminated flow entering Paddys Run at cross section location C-C is due to the flow from subbasins WPA and 570 (Figure 3-5). The contaminated flow entering Paddys Run at cross section location E-E is due to the four contaminated subbasins (PDAR, 580, 581, 582) that drain to the SSOD. The HEC-1 model combined the runoff hydrographs of the contaminated subbasins flowing to

TABLE 4-1

DILUTION FACTOR

Subbasin[a]	Runoff Depth (in.)	Area (mi^2)	Runoff Volume (ft^3)	Peak Discharge	Total Hydrograph	Flow when Contributing Subbasin Peaks	Dilution Factor
Scenario 1 - Without Retention Basin							
SUB 560	0.23	0.32	1.70×10^5	12.0	STA 60	60.0	0.200
WPA	0.73	0.07	1.20×10^5	27.0	STA 70	53.0	0.509
SUB 570	0.73	0.12	1.99×10^5	30.0	STA 70	48.0	0.625
SUB 575	0.45	0.12	1.23×10^5	16.0	STA 75	76.0	0.211
SUB 580	0.52	0.04	4.34×10^4	6.0	STA J-J	137.0	0.044
PDAR	1.26	0.24	7.06×10^5	180.0	STA J-J	194.0	0.928
SUB 581	0.43	0.46	4.49×10^5	48.0	STA J-J	115.0	0.417
SUB 582	0.34	0.49	3.68×10^5	30.0	STA 80	101.0	0.297
STA 80			1.57×10^6	196.0	STA E-E	199.0	0.985
STA 70 CT			3.19×10^5	53.0	STA 70	53.0	1.000
Scenario 2 - With Retention Basin							
SUB 560	0.23	0.32	1.70×10^5	12.0	STA 60	60.0	0.200
SUB 570	0.73	0.12	2.04×10^5	30.0	STA 70	31.0	0.968
SUB 575	0.45	0.12	1.25×10^5	16.0	STA 75	61.0	0.262
SUB 580	0.52	0.04	4.83×10^4	6.0	STA J-J	47.0	0.128
SUB 581	0.43	0.46	4.60×10^5	48.0	STA J-J	53.0	0.906
SUB 582	0.34	0.49	3.87×10^5	30.0	STA 80	69.0	0.435
STA 80			8.95×10^5	78.0	STA E-E	134.0	0.582

[a]WPA - waste pit area; PDAR - production area; STA - station; STA 70 CT - Station 70-contaminant transport

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cross section locations C-C and E-E at stations 70 CT and STA 80, respectively. The combined hydrographs at those two stations are used to simulate the incoming contaminated flow to Paddys Run.

The concentration in the combined hydrographs at stations 70 CT and STA 80 is based on the average concentration from the contributing contaminated subbasins. The average concentration is based on a volume weighting of the concentrations in the runoff from each of the contaminated subbasins.

The average concentration of the flow from subbasins 570 and WPA entering Paddys Run at cross section location C-C is given by the following equation:

$$C_{570\text{-}WPA} = (C_{e(WPA)} V_{WPA} + C_{e(570)} V_{570}) / (V_{WPA} + V_{570}) \qquad (4\text{-}10)$$

Where

$C_{570\text{-}WPA}$	=	volume weighted average concentration entering Paddys Run at cross section C-C due to subbasins 570 and WPA (mass/volume)
$C_{e(WPA)}$	=	concentration in the runoff from subbasin WPA (mass/volume)
V_{WPA}	=	total volume of runoff from subbasin WPA (volume)
$C_{e(570)}$	=	concentration in the runoff from subbasin 570 (mass/volume)
V_{570}	=	total volume of runoff from subbasin 570 (volume)

The above equation can also be used to model the current conditions at the FEMP in which the flow from the waste pit area is collected and pumped to the GMR. To model that scenario, the terms pertaining to the waste pit area would simply be deleted from the above equation.

The average concentration in the SSOD is given by the following equation (for the case which includes flow from the former production area [PDAR]):

$$C_{SSOD1(TOTAL)} = (C_{SSOD(580)} V_{580} + C_{SSOD(PDAR)} V_{PDAR} + C_{SSOD(581)} V_{581} + C_{SSOD(582)} V_{582}) / V_{SSOD} \qquad (4\text{-}11)$$

and

$$V_{SSOD} = V_{580} + V_{PDAR} + V_{581} + V_{582} \quad (4\text{-}12)$$

Where

$C_{SSOD1(TOTAL)}$ = volume weighted average concentration in the SSOD for the case which includes flow from the former production area (mass/volume)

$C_{SSOD(580)}$ = concentration in the SSOD due to subbasin 580 (mass/volume)

V_{580} = total volume of runoff from subbasin 580 (volume)

$C_{SSOD(PDAR)}$ = concentration in the SSOD due to subbasin PDAR (mass/volume)

V_{PDAR} = total volume of runoff from subbasin PDAR (volume)

$C_{SSOD(581)}$ = concentration in the SSOD due to subbasin 581 (mass/volume)

V_{581} = total volume of runoff from subbasin 581 (volume)

$C_{SSOD(582)}$ = concentration in the SSOD due to subbasin 582 (mass/volume)

V_{582} = total volume of runoff from subbasin 582 (volume)

V_{SSOD} = total volume of flow in the SSOD (volume)

To calculate the contaminant concentrations for current conditions (i.e., with the SWRB in place and diverting flow from subbasin PDAR to the GMR), the following equation is used to calculate the average concentration in the SSOD:

$$C_{SSOD2(TOTAL)} = (C_{SSOD(580)} V_{580} + C_{SSOD(581)} V_{581} + C_{SSOD(582)} V_{582}) / V_{SSOD} \quad (4\text{-}13)$$

and

$$V_{SSOD} = V_{580} + V_{581} + V_{582} \quad (4\text{-}14)$$

Where

$C_{SSOD2(TOTAL)}$ = volume weighted average concentration in the SSOD for the case which does not include flow from the former production area (mass/volume)

All of the total subbasin flow volumes are presented in Table 4-1.

4.1.3.3 Maximum Concentrations in Paddys Run

The maximum concentration of contaminants in Paddys Run at cross section locations C-C, D-D and E-E is based on the peak flow, the incoming concentration, and the concentration from upstream sources. Calculating the concentration at the time of the peak discharge is similar to the approach used for calculating the dilution factors for each individual contaminated subbasin. This yields the maximum concentrations in Paddys Run.

The maximum concentration in Paddys Run due to contaminated subbasins WPA and 570 at cross section location C-C is given by the following equation:

$$C_{Paddy(CC)} = (C_{Paddys(560)}\ Q_{ROUTE0(70CT)} + C_{(570\text{-}WPA)}\ (qp_{70CT}))\ /\ (Q_{STA70(70ct)}) \qquad (4\text{-}15)$$

Where

$C_{Paddy(CC)}$	=	maximum concentration in Paddys Run at cross section location C-C
qp_{70CT}	=	peak discharge from the combination of subbasins 570 and WPA hydrographs (Station 70CT) (volume / time)
$Q_{STA70(70CT)}$	=	discharge in the total hydrograph in Paddys Run at the same time as the peak discharge qp_{70CT} (volume / time)
$Q_{ROUTE0(70CT)}$	=	discharge in the upstream hydrograph in Paddys Run at the same time as the peak discharge qp_{70CT} (volume / time)
$C_{Paddys(560)}$	=	concentration in Paddys Run due to subbasin 560

The concentration in Paddys Run at cross section location D-D is due to the contamination already in Paddys Run from cross section location C-C and the inflow from subbasin 575. The maximum concentration in Paddys Run at cross section location D-D is given by the following equation.

$$C_{Paddy(DD)} = (C_{Paddys(CC)}\ Q_{ROUTE1(575)} + C_{575}\ (qp_{575}))\ /\ (Q_{STA75(575)}) \qquad (4\text{-}16)$$

Where

$C_{Paddy(DD)}$ = maximum concentration in Paddys Run at cross section location D-D (mass/volume)

$Q_{STA70(575)}$ = discharge in the upstream hydrograph in Paddys Run at the same time as the peak discharge qp_{575} (volume / time)

C_{575} = concentration in the runoff from subbasin 575 (mass/volume)

qp_{575} = peak discharge from the subbasin 575 hydrographs (volume / time)

$Q_{ROUTE1(575)}$ = discharge in the total hydrograph in Paddys Run at the same time as the peak discharge qp_{575} (volume / time)

The concentration in Paddys Run at cross section location E-E is due to the contamination already in Paddys Run from cross section location D-D and the inflow from the SSOD. The maximum concentration in Paddys Run at cross section location E-E is given by the following equation.

$$C_{Paddy(EE)} = (C_{Paddys(DD)}\ Q_{ROUTE\ 2(SSOD1)} + C_{SSOD1(TOTAL)}\ (qp_{STA80})) / (Q_{STAEE(SSOD1)}) \qquad (4\text{-}17)$$

Where

$C_{Paddy(EE)}$ = maximum concentration in Paddys Run at cross section location E-E (mass/volume)

$Q_{ROUTE\ 2(SSOD1)}$ = discharge in the upstream hydrograph in Paddys Run at the same time as the peak discharge qp_{STA80} (volume / time)

$C_{SSOD1(TOTAL)}$ = concentration in the runoff from the SSOD (mass/volume)

qp_{STA80} = peak discharge from the total SSOD hydrograph (volume / time)

$Q_{STAEE(SSOD1)}$ = discharge in the total hydrograph in Paddys Run at the same time as the peak discharge qp_{STA80} (volume / time)

The maximum concentration at cross section E-E is calculated both with and without the former production area contributing flow to Paddys Run. The above equations are written including flow from the former production area. The equations can be used without the flow from the former production area if the SSOD1 subscripts are changed to SSOD2. The maximum concentration in Paddys Run is the maximum of $C_{Paddy(CC)}$, $C_{Paddy(DD)}$, and $C_{Paddy(EE)}$.

4.1.3.4 Maximum Concentration in the GMR

The maximum concentration in the GMR is calculated by taking the maximum concentration in Paddys Run multiplied by a dilution factor between Paddys Run and the GMR. This dilution factor is the peak flow rate in Paddys Run at the confluence of Paddys Run and the GMR from the HEC-1 model divided by the average flow rate in the GMR. This yields a conservative result because the concentration in Paddys Run is further diluted by incoming flow in the 1.5 miles of stream channel between the FEMP and the GMR. The concentration in the GMR is given by the following equation.

$$C_{GMR} = C_{Paddy(MAX)} (qp_{paddy}) / (qp_{paddy} + Q_{GMR(avg)}) \quad (4\text{-}18)$$

Where

C_{GMR}	=	concentration in the GMR (mass/volume)
qp_{paddy}	=	peak flow rate in Paddys Run at the confluence with the GMR (volume/time)
$Q_{GMR(avg)}$	=	average discharge in the GMR (from previous studies, 3,370 ft^3/s [DOE 1993a])
$C_{Paddy(MAX)}$	=	maximum of $C_{Paddy(CC)}$, $C_{Paddy(DD)}$, and $C_{Paddy(EE)}$

The dilution factor is calculated as 0.1217 when including flow from the former production area and 0.1157 when excluding the production area.

4.2 CPC SCREENING

The CPCs are screened mid-way through the modeling process to determine if the contaminant concentrations pose a significant risk that requires additional modeling in both the surface water and groundwater exposure routes. The dissolved contaminant concentrations in the surface water flow coming from each contaminated subbasin is screened to determine if concentrations in Paddys Run and the GMR need to be calculated. The dissolved contaminant concentrations in the GMA that originate from infiltration through Paddys Run and the SSOD are screened to determine if these contaminants need to be modeled in the groundwater solute transport model. The screening procedure for CPCs in surface water and in the groundwater is discussed below.

4.2.1 Surface Water CPC Screening

The approach used to calculate the contaminant concentration in the flow coming from each subbasin was discussed in Section 4.1.2. Those concentrations are compared to the 10^{-7} risk-based concentrations for carcinogens or 0.1 Hazard Quotient concentrations for noncarcinogens. These screening concentrations are derived by dividing the 10^{-6} risk-based concentrations or the Hazard Quotient of 1.0 by 10 (EPA, 1993). If the contaminant concentration in the flow from the subbasin is below the screening concentrations, then the contaminant is screened out and the concentrations in Paddys Run and the GMR are not calculated.

4.2.2 Groundwater CPC Screening

The concentration of CPCs that enter the GMA through the streambeds of Paddys Run and the SSOD due to a 1-year, 24-hour storm event are estimated for screening purposes with procedures presented in this section. The estimated concentration level is then compared to risk-based concentrations to determine if they pose a significant risk.

The estimated concentrations to the GMA will be compared to the 10^{-7} risk-based concentrations for carcinogens or the 0.1 Hazard Quotient concentrations for noncarcinogens. These screening concentrations are derived by dividing the 10^{-6} risk-based concentrations or the Hazard Quotient of 1.0 by 10 (EPA, 1993). If the contaminant concentration in the GMA is below the screening concentrations, then the contaminant is screened out and the contaminant's migration is not simulated in the groundwater solute transport model.

Determination of the concentration in the GMA due to contaminants infiltrating through the streambeds of Paddys Run and the SSOD is accomplished by mixing the estimated mass of contaminant which enters the GMA through the streambed with the volume of water in the GMA in one Sandia Waste Isolation Flow and Transport (SWIFT) cell plus the volume of infiltrated water. The concentration in the GMA is given by the following equation:

$$C_{GMA} = M_c / (V_{cell} + V_{Infil}) \qquad (4\text{-}19)$$

Where

C_{GMA}	=	estimated concentration in the GMA due to contaminated water infiltrating through the streambeds of Paddys Run or the SSOD
M_c	=	mass of contaminant entering the SWIFT cell
V_{cell}	=	volume of groundwater in layer 1 of the GMA in the average thickness cell block along Paddys Run or the SSOD
V_{Infil}	=	volume of water infiltrating into the SWIFT cell

The volume of water in the SWIFT cell is calculated from:

$$V_{cell} = (W_s)(L_{cell})(T)(\phi_{GMA}) \tag{4-20}$$

Where

W_s	=	average width of the streams used for modeling purposes (25 feet for Paddys Run and 10 feet for the SSOD)
L_{cell}	=	length of SWIFT cell (125 feet)
T	=	saturated thickness of layer 1 of the GMA in the SWIFT cell ($\cong$ 15 feet)
ϕ_{GMA}	=	total porosity of the GMA (0.39)

The percent of the contaminated subbasin runoff from the 1-year, 24-hour storm event which infiltrates into each stream reach along Paddys Run is presented in Section 4.3.1. These percentages are used to calculate the amount of water which infiltrates into each SWIFT cell and the contaminant mass that enters each SWIFT cell. For screening purposes, the reach length in which the highest percentage of contaminated runoff infiltrates is used. The volume of flow which infiltrates each cell is given by the following equation:

$$V_{Infil} = (I)\ V_{Subbasin}\ /\ N \tag{4-21}$$

Where

$V_{Subbasin}$ = total volume of flow from the contaminated subbasin (volume)

I = percent of the contaminated subbasin runoff which infiltrates through the streambed of Paddys Run or the SSOD; for the stream reach with the highest percentage of infiltration percent

N = number of SWIFT cells in the stream reach

The number of SWIFT cells in the stream reach is calculated by the following equation:

$$N = L_{reach} / L_{cell} \quad (4\text{-}22)$$

Where

L_{reach} = The length of the stream reach (length)

The mass infiltrating into each SWIFT cell is given by the following equation:

$$M_c = V_{Infil} \; C_{e(Subbasin)} \quad (4\text{-}23)$$

Where

$C_{e(Subbasin)}$ = concentration in the contaminated subbasin runoff (mass/volume)

4.3 CONTAMINANT LOADINGS TO THE GMA

The contaminant transport in the GMA is modeled to determine groundwater exposure point concentrations. The amount of contaminant infiltrating through the streambeds of Paddys Run and the SSOD is input as a loading term to the groundwater solute transport model. The loading is applied using two rates; one from the single representative storm event and another average rate to represent the storm events during the rest of the year. The procedures to determine these two loading rates are presented below.

4.3.1 Single Storm Event Loadings

The contaminant loadings to the GMA produced from the representative storm are calculated by determining the mass of dissolved contaminant that would enter each cell in the groundwater solute

transport model from infiltration through the beds of Paddys Run and the SSOD. The amount of mass that enters the GMA is based on the percent of a contaminated subbasin's total flow which infiltrates the stream beds. This percent is correlated to the percent of the total dissolved contaminant in the runoff which enters the GMA. This loading is similar to the procedure presented in Section 4.2.2, except the percent infiltration (I in the equation) will vary from stream reach to stream reach.

To be conservative, the procedure for estimating concentrations in the groundwater due to infiltration through the streambeds of Paddys Run and the SSOD is based on infiltration calculations that assume the streambeds are initially unsaturated. This condition creates the upper bound of infiltration and also the upper bound of the contaminant passing through the streambed. This represents the worst-case scenario for loadings to the GMA from surface waters infiltrating through the streambeds.

The infiltration rates through the streambeds of Paddys Run and the SSOD vary with both distance and time. The runoff flow rate, and hence the dissolved contaminant flow rate, from each different subbasin also varies with time. Because of the varying surface water flow and infiltration rates, an overall average of the amount of infiltration versus the overall total runoff might overestimate the amount of contamination infiltrating from one subbasin while underestimating the amount from another. While the overall average is calculated to characterize the general results, the percent of infiltration attributed to each subbasin in each channel reach in Paddys Run is calculated to describe the complex nature of the infiltration into the streambeds of Paddy Run and the SSOD.

4.3.1.1 Conceptual Model

The infiltration rates reported from the VS2DT model generally peak quickly and then decrease with time as the unsaturated zone beneath the streambeds becomes saturated. Because the overall infiltration rates are decreasing with time, the storm water runoff which reaches the streams first has a higher percentage of infiltration to flow. The HEC-1 results indicate that the majority of the contaminated runoff coming from the FEMP enters Paddys Run before the bulk of the uncontaminated flow from upstream subbasins reaches the sections of Paddys Run in the vicinity of the FEMP site. Because the contaminated runoff enters Paddys Run earlier than the upstream flow, the amount of contaminated runoff which infiltrates through the streambed can be disproportionate to the total amount of infiltration.

The majority of the storm water inflow to the SSOD comes from the FEMP property. Each of the four subbasins used in the HEC-1 model for the SSOD drainage basin enters the SSOD at essentially the same time. Because of this timing, it is possible to assume that the total amount of infiltration in the SSOD is proportionate to the amount of flow from the four subbasins. The flow from the SSOD is treated as a single inflow to Paddys Run with no distinctions made about subbasin source.

The VS2DT model reports infiltration rates that varied with position along Paddys Run. The highest infiltration rates in Paddys Run occur at cross section location C-C, located where Paddys Run cuts into the permeable glacial outwash deposits. As Paddys Run travels downstream, it cuts deeper into the outwash deposits and the thickness of the unsaturated zone beneath Paddys Run decreases. This decrease in unsaturated zone thickness causes the infiltration rates to decrease with distance along the stream channel from the highest rates at cross section C-C to the assumed infiltration rate of zero at cross section F-F (where the unsaturated zone thickness goes to zero). The subbasins which enter Paddys Run closer to cross section C-C have higher percentages of infiltration to flow because of the higher infiltration rates in this area of the stream.

The subbasin runoff which enters Paddys Run farther upstream also experiences a higher infiltration to flow percentage because the runoff travels over a longer length of streambed in which infiltration is possible. For instance, flow which enters Paddys Run near cross section location C-C travels over approximately 8500 feet of permeable streambed (distance from C-C to F-F) while flow entering Paddys Run at cross section location E-E only travels over approximately 2600 feet of permeable streambed (distance from E-E to F-F).

The HEC-1 model calculates the percent of infiltration to total flow from each subbasin (Figure 3-3). The infiltration percentages to total flow are calculated for subbasins 70, 75, and the flow from the SSOD. The total flow from the SSOD is taken as the flow at STA 80 in the HEC-1 model set up for infiltration calculations. The total SSOD drainage basin is referred to as subbasin 80 in the following discussion. The percentages of infiltration are calculated in the three stream reaches along Paddys Run where infiltration calculations were performed (reaches C-C to D-D, D-D to E-E and E-E to F-F).

The flow from subbasin 70 is assumed to enter Paddys Run at cross section C-C. The infiltration in the stream reach from C-C to D-D was attributed to subbasin 70 and the flow from upstream to uncontaminated subbasins. Similarly, the flow from subbasin 75 is assumed to enter Paddys Run at cross section location D-D. The infiltration in the stream reach from D-D to E-E is attributed to subbasins 75 and 70 and to upstream flow. Flow from the SSOD (subbasin 80) enters Paddys Run at cross section E-E. The infiltration in the final stream reach is attributed to subbasins 80, 75 and 70 and to upstream flow (Figure 4-3).

The total infiltration from subbasin 70 through the streambed of Paddys Run is the sum of the infiltrated volume attributed to subbasin 70 in each of the three stream reaches. The total infiltration for subbasin 75 is the sum of its infiltration contribution in the two downstream reaches of Paddys Run. The total infiltration from subbasin 80 consists of the infiltration attributed to it in the stream reach from section E-E to F-F plus the total amount of infiltration in the SSOD.

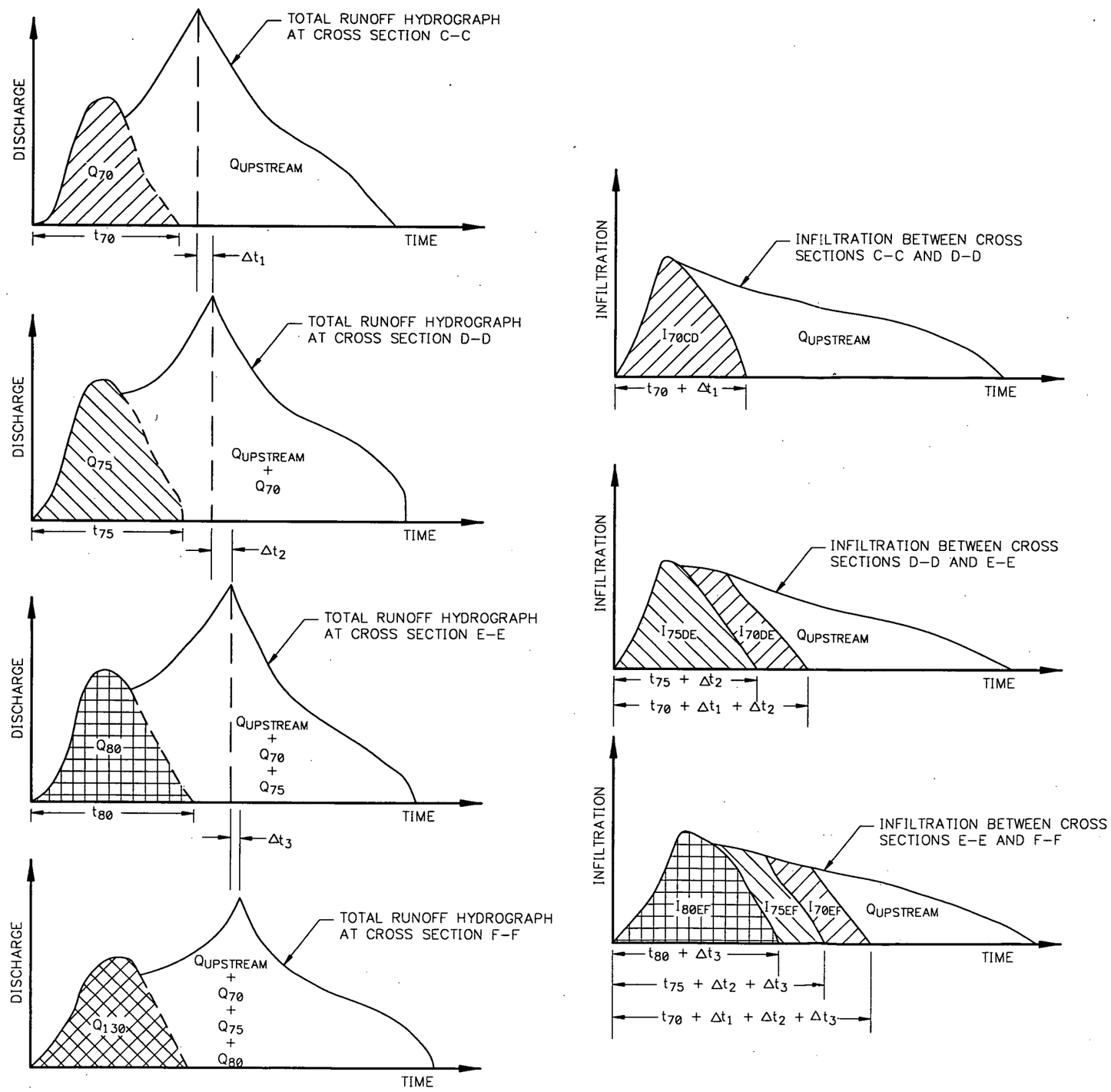
The flow in Paddys Run takes a certain amount of time to travel through each channel reach. For instance, flow which enters Paddys Run at cross section location C-C will not reach cross section D-D until some later time. This time is referred to as the reach travel time or lag time. The travel time for each reach in Paddys Run is assumed to be the difference between the arrival times of the peak flow from upstream subbasins at the beginning and at end of the channel reach. The travel times are used in determining of the subbasin-specific infiltration rates.

The proportion of infiltration attributable to each subbasin is assumed to be equal to the same proportion of runoff from each subbasin in the runoff total hydrograph of Paddys Run.

4.3.1.2 Calculation of Subbasin-Specific Infiltration Percentages

The following discussion of the procedure used to calculate the subbasin-specific infiltration percentages addresses each channel reach separately starting upstream with the reach between cross section locations C-C and D-D. Figure 4-3 shows an idealized representation of the various components of the subbasin-specific infiltration calculations.

At cross section location C-C the total runoff hydrograph is composed of contributions from subbasin 70 and upstream flow (STA 70 and ROUTE 0, Figure 3-3). At each time step of the runoff



LEGEND:

SAMPLE VARIABLE DEFINITIONS

t_{70} = DURATION OF SUBBASIN HYDROGRAPH

Δt_1 = HYDROGRAPH TRAVEL TIME BETWEEN SECTIONS

$t_{70} + \Delta t_1$ = TIME WHILE INFILTRATION FROM A SUBBASIN OCCURS BETWEEN SECTIONS

Q_{70} = DISCHARGE FROM SUBBASIN

I_{70CD} = PORTION OF TOTAL INFILTRATION BETWEEN SECTIONS ATTRIBUTABLE TO A SPECIFIC SUBBASIN DISCHARGE

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FIGURE 4-3.
SUBBASIN ORIGIN-SPECIFIC INFILTRATION RELATIONS

hydrograph, the ratio of the subbasin 70 flow to the total hydrograph flow at cross section location C-C is calculated. In Figure 4-3, the flow from subbasin 70 and upstream is identified as Q_{70} and $Q_{Upstream}$, respectively. The ratio is then multiplied by the infiltration rate, from VS2DT results, at each time point to determine the portion of infiltration which could be attributed to subbasin 70 at each time point. The numerical integration with time of the infiltration rates attributed to subbasin 70 produces the total infiltration from subbasin 70 (I_{70} in Figure 4-3) in that channel reach. Dividing the infiltration from subbasin 70 by the total runoff from subbasin 70 yields the percent of runoff which infiltrated in that channel reach.

The flow from subbasin 70 has the potential to infiltrate through the streambed in the reach from C-C to D-D while flow from subbasin 70 is in that reach. That time is taken as the duration of the subbasin 70 hydrograph (t_{70} in Figure 4-3) plus the travel time between sections C-C and D-D (Δt_1 in Figure 4-3). The ratio of subbasin 70 flow to the total flow at cross section C-C is lagged (shifted) by Δt_1 when it is multiplied by the infiltration rates for the stream reach between C-C and D-D. The lagging of the ratio is done to account for the travel time of the subbasin 70 hydrograph from C-C to D-D with respect to the infiltration simulation. For instance, if the peak discharge of subbasin 70 at cross section C-C occurred at time 12:00 and the peak discharge reached cross section location D-D at 12:10, Δt_1 would equal 10 minutes. The ratio of subbasin 70 flow to the total flow at the peak discharge of subbasin 70 is applied to the infiltration rate at time 12:10, when the peak reached the end of the channel reach.

The following equation is numerically integrated to calculate the infiltration through the streambed of Paddys Run between cross sections C-C and D-D due to subbasin 70:

$$I_{70CD} = \int_{0}^{t_{70}+\Delta t_1} I_{CC-DD}(t) \; \frac{Q_{70}(t - \Delta t_1)}{Q_{Upstream}(t - \Delta t_1) + Q_{70}(t - \Delta t_1)} \, dt \qquad (4\text{-}24)$$

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Where

I_{70CD}	=	infiltration in the channel reach from section C-C to D-D due to subbasin 70 (volume)
$I_{CC\text{-}DD}(t)$	=	total infiltration rate in the channel reach from cross section C-C to D-D, varying with time (volume/time)
$Q_{70}(t)$	=	discharge from subbasin 70 varying with time (volume/time)
$Q_{Upstream}(t)$	=	discharge from upstream varying with time (ROUTE 0 in the HEC-1 model) (volume/time)
Δt_1	=	travel time of the hydrographs from section C-C to D-D (time)
t_{70}	=	duration of subbasin 70 hydrograph

In the stream reach between cross sections D-D and E-E the infiltration is due to runoff coming from upstream, subbasins 70 and 75. The flow from subbasin 75 enters Paddys Run at cross section D-D. The flow already in Paddys Run coming from cross section C-C is a combination of upstream flow and flow from subbasin 70 routed through the channel reach from C-C to D-D. This combination is ROUTE 1 in the HEC-1 model. The equation used to calculate the contribution of subbasin 75 to the total infiltration in the channel reach between cross sections D-D and E-E is similar to the previous equation for subbasin 70.

$$I_{75DE} = \int_{0}^{t_{75}+\Delta t_2} I_{DD\text{-}EE}(t) \; \frac{Q_{75}(t - \Delta t_2)}{Q_{Route1}(t - \Delta t_2) + Q_{75}(t - \Delta t_2)} dt \qquad (4\text{-}25)$$

Where

I_{75DE}	=	infiltration in channel reach D-D to E-E attributed to subbasin 75
$I_{DD\text{-}EE}(t)$	=	total infiltration rate in the channel reach from cross section D-D to E-E, varying with time (volume/time)
$Q_{75}(t)$	=	discharge from subbasin 75 varying with time (volume/time)
$Q_{ROUTE\ 1}(t)$	=	hydrograph in Paddys Run at cross section D-D consisting of the addition of hydrographs from subbasin 70 and upstream flow routed through the channel reach from section C-C to D-D. (volume/time)
Δt_2	=	travel time of the hydrographs from section D-D to E-E (time)
t_{75}	=	duration of subbasin 75 hydrograph

In order to calculate subbasin 70's portion of infiltration in the channel reach from D-D to E-E, its contribution to the flow must be separated from ROUTE 1. The ratio of flow from subbasin 70 and upstream flow is assumed to remain the same in ROUTE 1. This assumption makes it possible to separate the flow in ROUTE 1 into components attributable to subbasin 70 and upstream flow. The ratio is lagged by Δt_1 to account for the travel time between cross section C-C and D-D. The following equation is used to separate the contribution of subbasin 70 from ROUTE 1.

$$Q_{70\,at\,DD}(t) = Q_{ROUTE1}(t)\,\frac{Q_{70}(t-\Delta t_1)}{Q_{70}(t-\Delta t_1)+Q_{Upstream}(t-\Delta t_1)} \qquad (4\text{-}26)$$

Where

$Q_{70\ at\ DD}(t)$	=	portion of ROUTE 1 attributed to subbasin 70 at cross section D-D (volume/time)

The contribution of subbasin 70 to the total infiltration in the channel reach from section D-D to E-E can now be calculated. The equation is similar to the one used to calculate subbasin 75's contribution to the channel reach from section D-D to E-E.

$$I_{70DE} = \int_{0}^{t_{70}+\Delta t_1+\Delta t_2} I_{DD-EE}(t) \frac{Q_{70atDD}(t-\Delta t_2)}{Q_{ROUTE1}(t-\Delta t_2)+Q_{75}(t-\Delta t_2)} dt \qquad (4\text{-}27)$$

Where

I_{70DE} = infiltration in the channel reach from section D-D to E-E due to subbasin 70 (volume)

The previous two equations can be combined to form the following equation which is used to calculate the contribution of subbasin 70 to the total infiltration in the channel reach from section D-D to E-E.

$$I_{70DE} = \int_{0}^{t_{70}+\Delta t_1+\Delta t_2} I_{DD-EE}(t) \left\{ \frac{Q_{ROUTE1}(t-\Delta t_2)}{Q_{ROUTE1}(t-\Delta t_2)+Q_{75}(t-\Delta t_2)} \right\} \left\{ \frac{Q_{70}(t-\Delta t_1-\Delta t_2)}{Q_{Upstream}(t-\Delta t_1-\Delta t_2)+Q_{70}(t-\Delta t_1-\Delta t_2)} \right\} dt \qquad (4\text{-}28)$$

The development of equations for infiltration amounts in the channel reach from section E-E to F-F is similar and will not be presented here. The flow in the reach from E-E to F-F consists of flow from ROUTE 2 and subbasin 80. To determine subbasin 75's contribution in this channel reach, the flow from ROUTE 1 and subbasin 75 are separated out of ROUTE 2. Subbasin 70 is then separated out of ROUTE 1. All of the infiltration amounts attributed to each subbasin in each channel reach are presented in Table 4-2.

Subbasin 70 contains Operable Units 1 and 4. The percentages presented in Table 4-2 for the amount of infiltration attributed to subbasin 70 can be applied to the contaminated runoff coming from those operable units. Similarly, the Southfield area of Operable Unit 2 is contained in subbasin 75 and the production area of Operable Unit 3 is contained in subbasin 80.

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TABLE 4-2

SUMMARY OF SUBBASIN AND REACH-SPECIFIC INFILTRATION RESULTS IN PADDYS RUN

Scenario 1
Without Retention Basin

Cross Section Location	Total Surface Water Volume (ft^3)	Total Infiltration Volume (ft^3)	Infiltration Volume from Sub 70 (ft^3)		Infiltration Volume from Sub 75 (ft^3)		Infiltration Volume from STA 80 (ft^3)		Infiltration from Upstream of Sub 70 (ft^3)	
C-C to D-D	$6.62 \times 10^{+6}$	$1.38 \times 10^{+6}$	$9.01 \times 10^{+4}$	25.2%					$1.29 \times 10^{+6}$	20.6%
D-D to E-E	$7.07 \times 10^{+6}$	$5.70 \times 10^{+5}$	$4.04 \times 10^{+4}$	11.3%	$6.21 \times 10^{+4}$	13.9%			$4.68 \times 10^{+5}$	7.5%
E-E to F-F	$8.64 \times 10^{+6}$	$6.69 \times 10^{+4}$	$4.96 \times 10^{+3}$	1.4%	$4.37 \times 10^{+3}$	1.0%	$1.72 \times 10^{+4}$	1.1%	$4.04 \times 10^{+4}$	0.6%
Total		$2.02 \times 10^{+6}$	$1.36 \times 10^{+5}$	37.9%	$6.65 \times 10^{+4}$	14.9%	$1.72 \times 10^{+4}$	1.1%	$1.80 \times 10^{+6}$	28.7%

Scenario 2
With Retention Basin

C-C to D-D	$6.62 \times 10^{+6}$	$1.38 \times 10^{+6}$	$9.01 \times 10^{+4}$	25.2%					$1.29 \times 10^{+6}$	20.6%
D-D to E-E	$7.07 \times 10^{+6}$	$5.69 \times 10^{+5}$	$3.98 \times 10^{+4}$	11.1%	$6.17 \times 10^{+4}$	13.8%			$4.68 \times 10^{+5}$	7.5%
E-E to F-F	$7.93 \times 10^{+6}$	$6.61 \times 10^{+4}$	$5.89 \times 10^{+3}$	1.6%	$5.03 \times 10^{+3}$	1.1%	$1.27 \times 10^{+4}$	1.5%	$4.25 \times 10^{+4}$	0.7%
Total		$2.02 \times 10^{+6}$	$1.36 \times 10^{+5}$	37.9%	$6.67 \times 10^{+4}$	14.9%	$1.27 \times 10^{+4}$	1.5%	$1.80 \times 10^{+6}$	28.8%

The SSOD has four subbasins draining to it: 580, 581, 582, and PDAR. Because all of the subbasins draining to the SSOD potentially contain contamination, the individual infiltration contribution of each subbasin to each channel reach is not calculated. The total infiltration in the SSOD is presented in Table 4-3. The percent of runoff which infiltrates the SSOD is calculated to be approximately 49 percent for Scenario 1 and 55 percent for Scenario 2 based on the flow from subbasins 580, 581, and PDAR. Subbasin 582 is excluded from the flow totals because it enters the SSOD near its confluence with Paddys Run and would contribute little to infiltration in the SSOD but would provide a large portion of the total flow coming from the SSOD. By not including subbasin 582, a more indicative percentage of infiltration in the SSOD is obtained.

4.3.1.3 Total Infiltration Percentages

Total infiltration percentages are based on the individual infiltration percentages discussed in the previous section. For the scenario which includes flow from the former production area, approximately 30 percent of the total 8.6 million ft^3 of runoff infiltrates into the streambeds of Paddys Run and the SSOD. Approximately 39 percent of the of the flow coming from subbasins containing contamination (70, 75, 580, PDAR, and 581) infiltrates. Although a small portion of subbasins 582 and 60 possibly contain contamination, because the majority of the flow comes from uncontaminated areas, the runoff was not included when calculating the overall percent of contaminated flow which infiltrates.

For the scenario which excludes the flow from the former production area, approximately 29 percent of the total runoff of 7.9 million ft^3 of runoff infiltrates. Approximately 37 percent of the flow coming from subbasins containing contamination infiltrates. Table 4-4 summarizes the total infiltration percentages.

4.3.2 Yearly Loadings

The amount of dissolved contaminant produced from all storms during the year, excluding the representative storm event, is calculated by assuming the ratio of sediment produced and the amount of dissolved contaminant in the runoff is constant for all storm events. The single storm event calculations using MUSLE provides this ratio. The USLE is used to calculate the annual amount of sediment produced. If the ratio of dissolved contaminant to sediment remains the same throughout the

TABLE 4-3

SUMMARY OF INFILTRATION RESULTS IN THE STORM SEWER OUTFALL DITCH (SSOD)

	Scenario 1[a]	Scenario 2[b]
Total infiltration in the SSOD (ft^3)	$5.90 \times 10^{+5}$	$2.79 \times 10^{+5}$
Total flow in the SSOD (ft^3)	$1.198 \times 10^{+6}$ [c]	$4.921 \times 10^{+5}$ [d]
Percent of flow which infiltrates	49.2%	56.6%

[a]Scenario without the retention basin.
[b]Scenario with the retention basin.
[c]Based on flow from subbasins 580, PDAR, and 581. The flow from subbasin 582 enters the SSOD near its outfall and has little chance to infiltrate.
[d]Based on flow from subbasins 580 and 581.

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TABLE 4-4

OVERALL SUMMARY OF INFILTRATION RESULTS

	Scenario 1[a]	Scenario 2[b]
Total infiltration including Paddys Run and the SSOD (ft^3)	$2.61 \times 10^{+6}$	$2.29 \times 10^{+6}$
Total Runoff from Paddys Run and the SSOD to location F-F (ft^3)	$8.64 \times 10^{+6}$	$7.93 \times 10^{+6}$
Percentage of runoff which infiltrates	30.2%	28.9%
Total infiltration from contaminated subbasins (ft^3)	$8.09 \times 10^{+5}$	$4.94 \times 10^{+5}$
Total runoff from contaminated subbasins (ft^3)	$2.23 \times 10^{+8}$ [c]	$1.53 \times 10^{+8}$ [d]
Percentage of contaminated runoff which infiltrates	39.2%	36.7%

[a]Scenario without the retention basin.
[b]Scenario with the retention basin.
[c]Based on subbasins 70, 75, 581, 580, and PDAR from the HEC-1 Model used for infiltration calculations.
[d]Based on subbasins 70, 75, 581, and 580 from the HEC-1 Model used for infiltration calculations.

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year and the annual amount of sediment is known, then the annual amount of dissolved contaminant in the runoff can be calculated. The amount of dissolved contaminant produced from the single storm event is subtracted from the annual amount to arrive at the amount of dissolved contaminant from all other storm events of the year. The amount of dissolved contaminant from all storm events other than the representative storm is used for the average yearly loading rate.

The USLE equation can be modified to include a term called the sediment delivery ratio. The sediment delivery ratio represents the percentage of sediment which actually reaches the subbasin outlet to the total amount that is produced in the subbasin. To be conservative, the sediment delivery ratio is assumed to be 1 in calculating the yearly amount of dissolved contaminant. The calculated sediment delivery ratio is used in determining the yearly sediment yield from the subbasin to Paddys Run.

Because most storm events that occur during the year are likely to be smaller than the representative storm and produce less runoff and a greater percentage of infiltration, it is conservatively assumed that all the contaminant produced for the average yearly loading rate enters the GMA. This average yearly loading rate is applied at a constant rate over six months of the year and at zero over the other six months (Figure 4-1), thus excluding the times of the year when Paddys Run is dry and not providing a pathway for contaminants to the GMA. For modeling the long-term transport of contaminants in the groundwater, the total contaminant mass that infiltrates over the entire year is averaged and put into the groundwater solute transport model as a constant year-long loading rate.

4.4 SOURCE DEPLETION

The contaminant loading to the GMA will need to be simulated for as long as 1000 years for inclusion in the groundwater solute transport model. Because of this long time frame, the depletion of the source soil at the FEMP may become an important consideration. To account for this depletion, USLE will be used to estimate the yearly loss of soil due to erosion from each subbasin. This yearly loss will be converted to a depth of soil lost per year. The number of years until the contaminated soil is depleted would be calculated as the average depth of contamination in the surface soils divided by the depth of soil loss per year. After all the contaminated soil has eroded, the source will be considered depleted and loadings to the GMA by the surface water pathway stopped.

4.5 STORM WATER MANAGEMENT

As discussed previously, the surface water at the FEMP is modeled for two scenarios. One scenario is used for long-term modeling of contaminant fate and transport and the other for short-term modeling of contaminant fate and transport.

The first scenario considered that the storm water management controls at the FEMP (including the SWRB and the collection system around the waste pit area) have failed and the drainage patterns at the FEMP return to their natural patterns. The failure of the storm water management system is considered because of the uncertainty of maintenance of such a system hundreds of years into the future. The failure of the storm water management system will be assumed to occur after 70 years. This scenario will be used to model the long-term migration of contaminants, such as in the 1000-year-long groundwater solute transport simulation.

The second scenario considers the current conditions at the FEMP in which the flows from both the former production area and waste pit areas are pumped to the GMR. The second scenario would be used for the short-term modeling of contaminant fate and transport.

4.6 AVAILABLE DATA FOR MODEL PERFORMANCE EVALUATION

Most of the available sample data is not storm specific so it cannot be directly related to event-specific modeling results. The available sample data will be compared qualitatively to the modeled results. The sample data will be observed for general trends which the modeling will attempt to replicate.

4.6.1 Sediment Concentrations

Sediment data in Paddys Run and the SSOD was taken at 100-foot intervals for the Routine Environmental Monitoring (REM) program conducted at the FEMP site. Figures 4-4 through 4-8 show samples of this data for the years 1987 through 1991. The REM data is unvalidated but it is felt that it will be useful in identifying general trends at the FEMP site. Figure 4-9 shows the sediment data available from the ongoing RI/FS at the FEMP site. This data is validated.

4.6.2 Surface Water Concentrations

Samples of the available surface water data for the REM and RI/FS programs are shown in Figures 4-10 and 4-11, respectively. The figures only present data for the maximum uranium concentrations

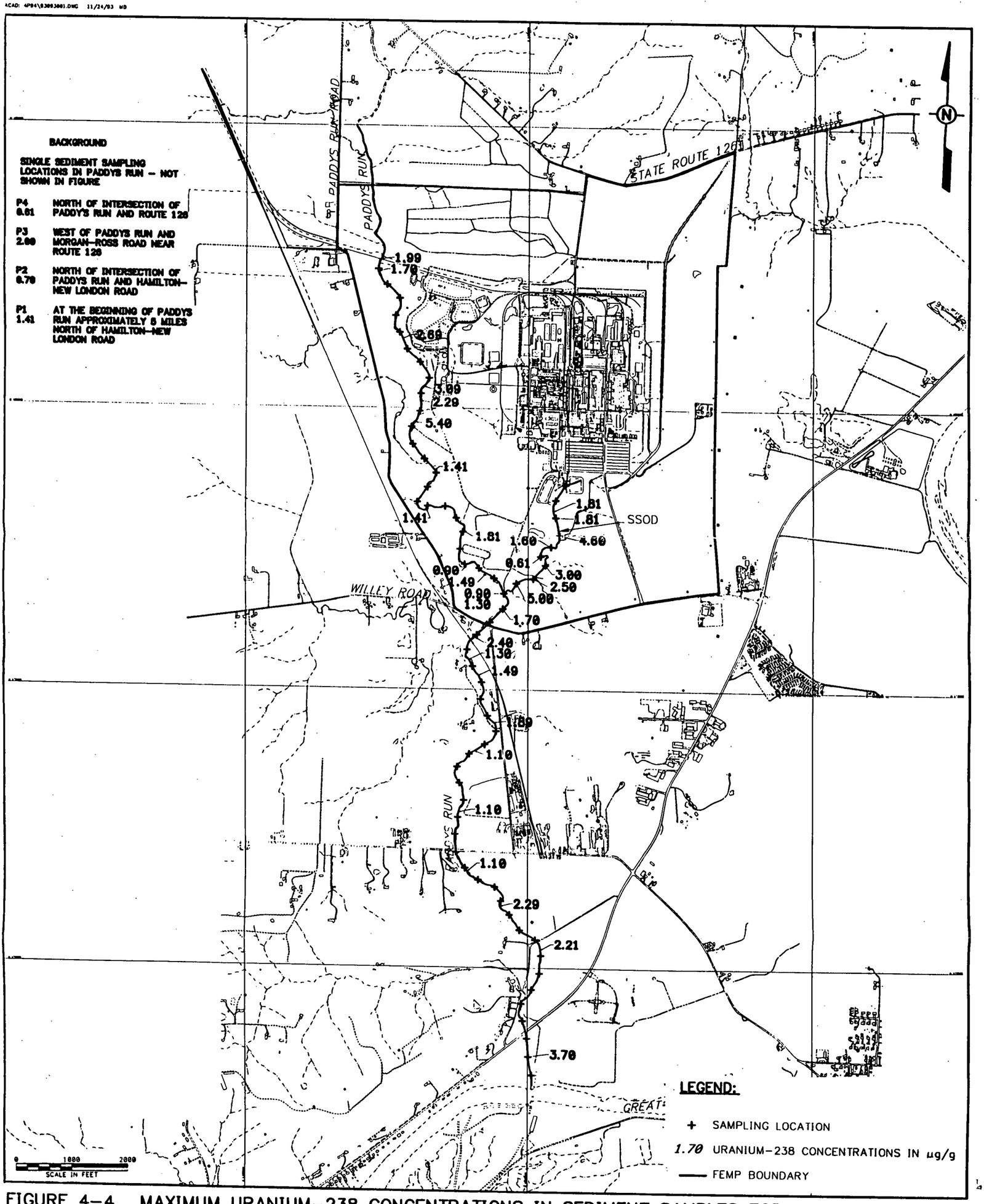

FIGURE 4-4. MAXIMUM URANIUM-238 CONCENTRATIONS IN SEDIMENT SAMPLES FOR 1991 FROM ROUTINE ENVIRONMENTAL MONITORING DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

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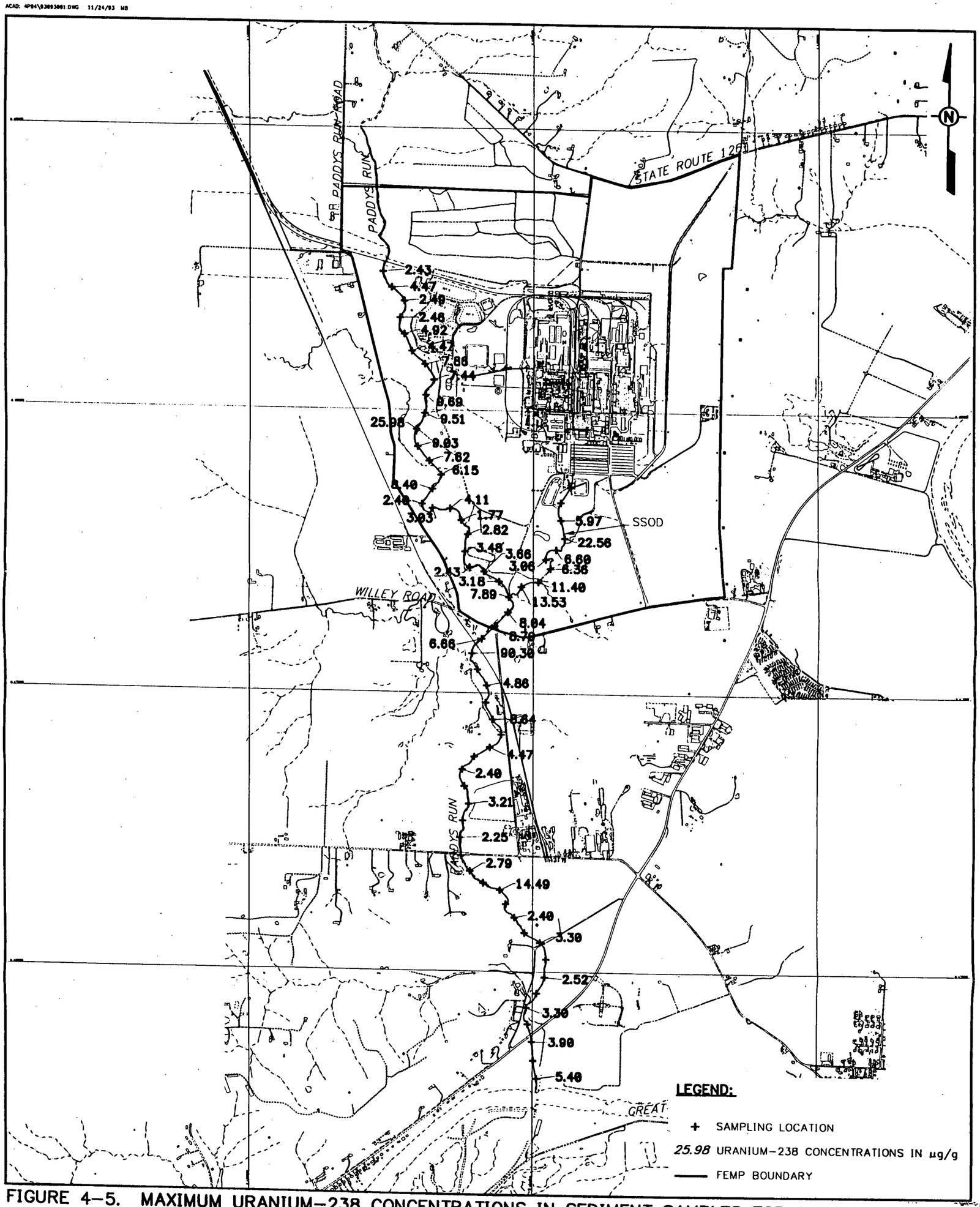

FIGURE 4-5. MAXIMUM URANIUM-238 CONCENTRATIONS IN SEDIMENT SAMPLES FOR 1990 FROM ROUTINE ENVIRONMENTAL MONITORING DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

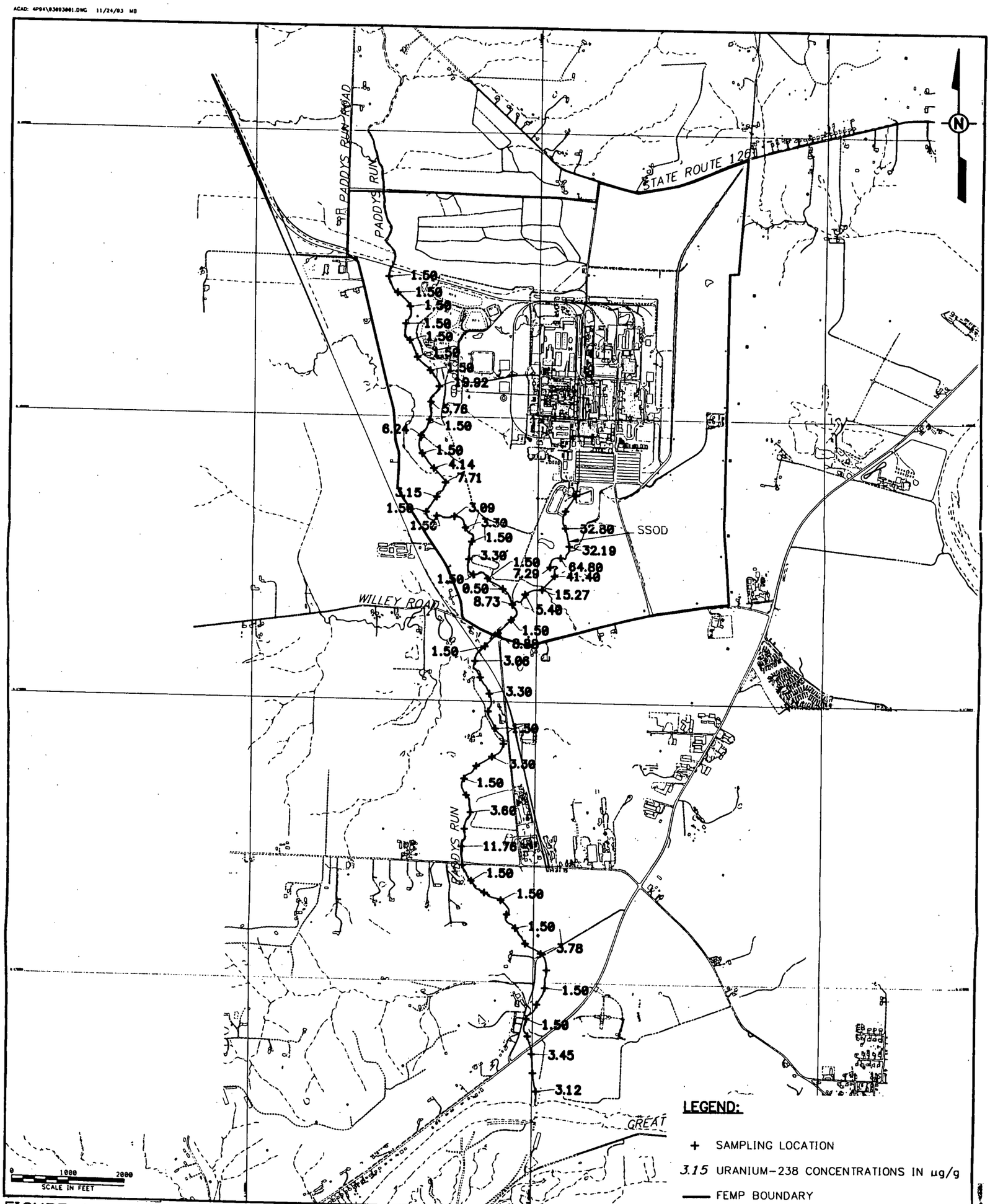

FIGURE 4-6. MAXIMUM URANIUM-238 CONCENTRATIONS IN SEDIMENT SAMPLES FOR 1989 FROM ROUTINE ENVIRONMENTAL MONITORING DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

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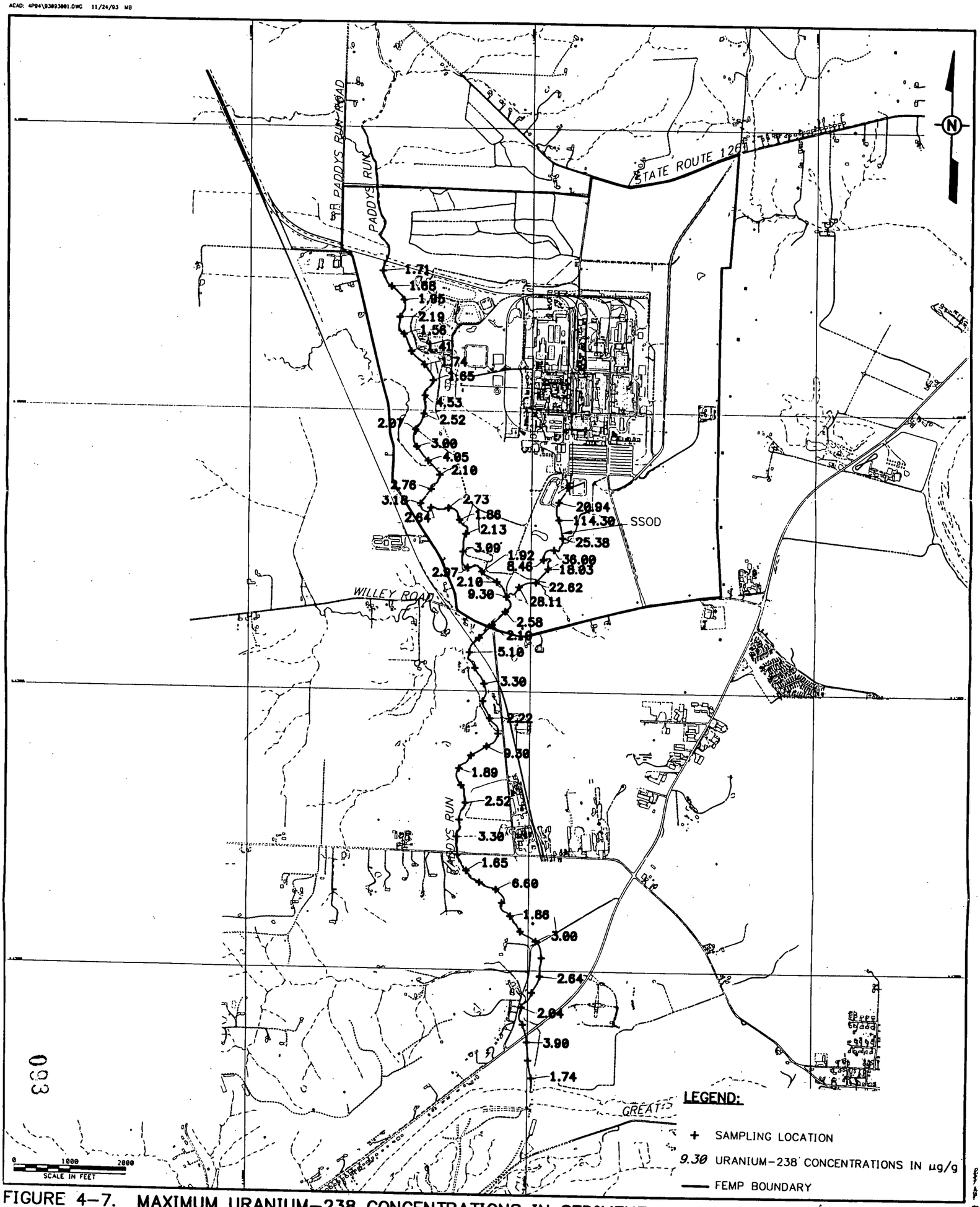

FIGURE 4-7. MAXIMUM URANIUM-238 CONCENTRATIONS IN SEDIMENT SAMPLES FOR 1988 FROM ROUTINE ENVIRONMENTAL MONITORING DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

093

ACAD: 4PG4\03003001.DWG 11/24/93 MB

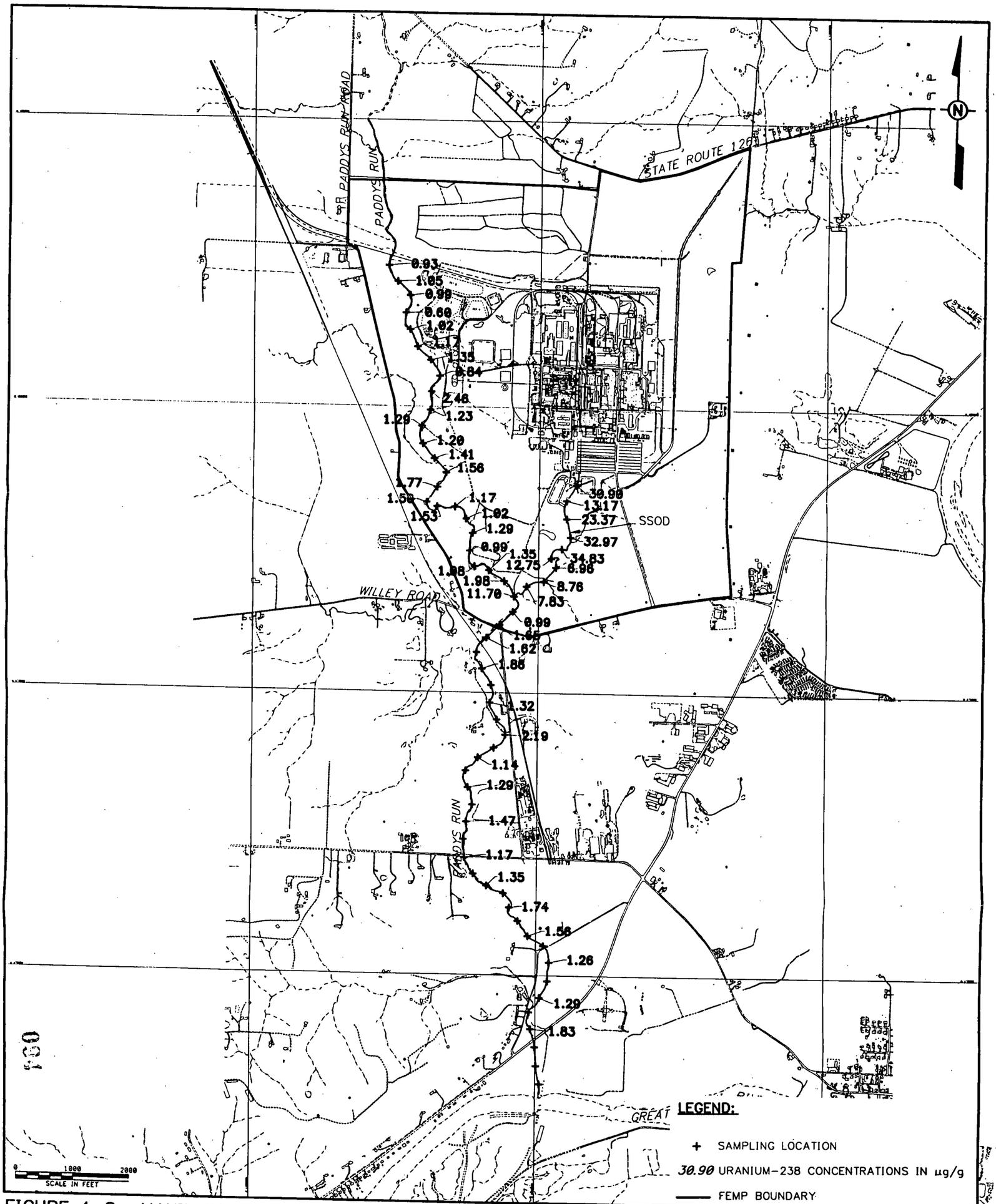

FIGURE 4-8. MAXIMUM URANIUM-238 CONCENTRATIONS IN SEDIMENT SAMPLES FOR 1987 FROM ROUTINE ENVIRONMENTAL MONITORING DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

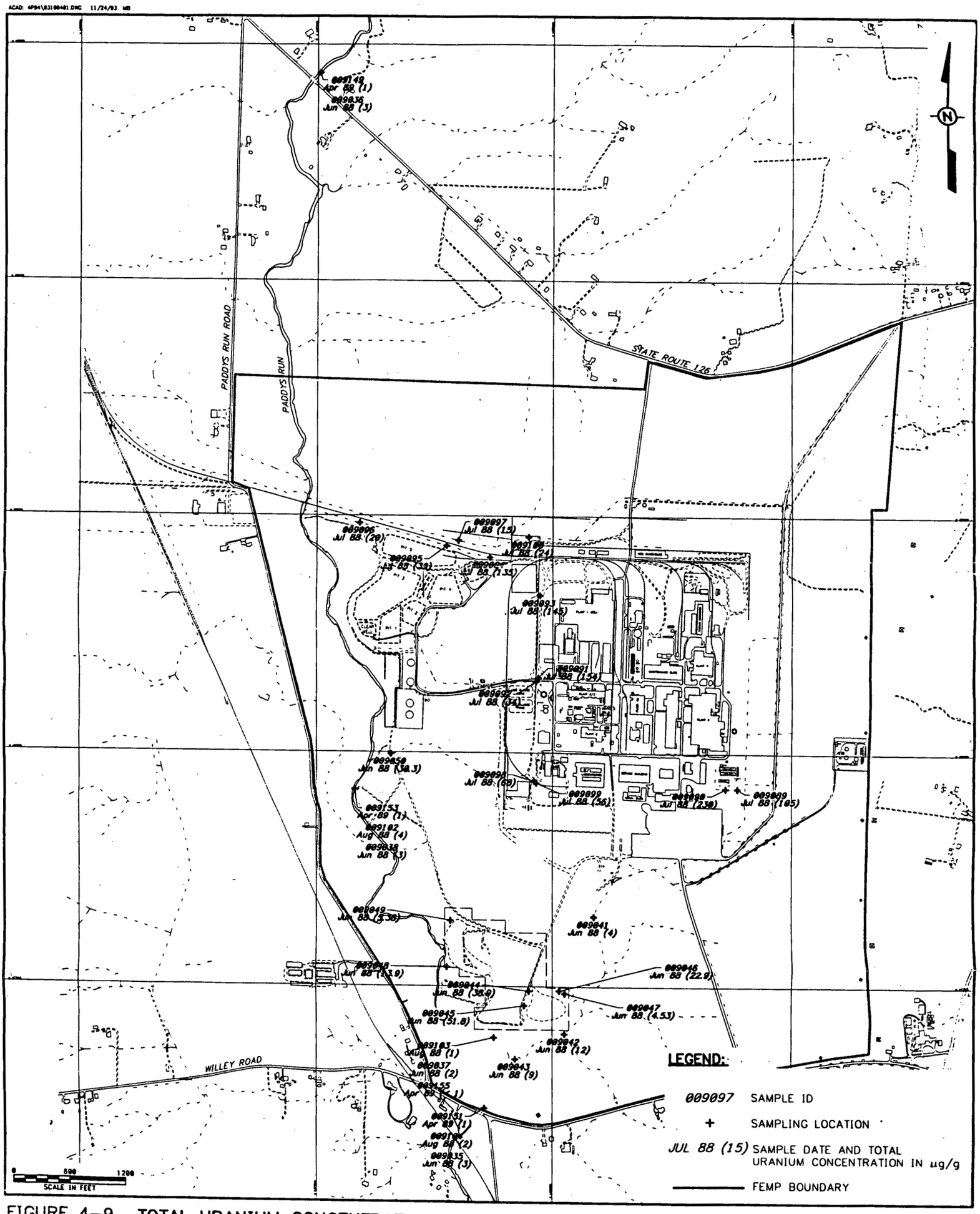

FIGURE 4-9. TOTAL URANIUM CONCENTRATIONS IN SEDIMENT SAMPLES FROM REMEDIAL INVESTIGATION /FEASIBILITY STUDY DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

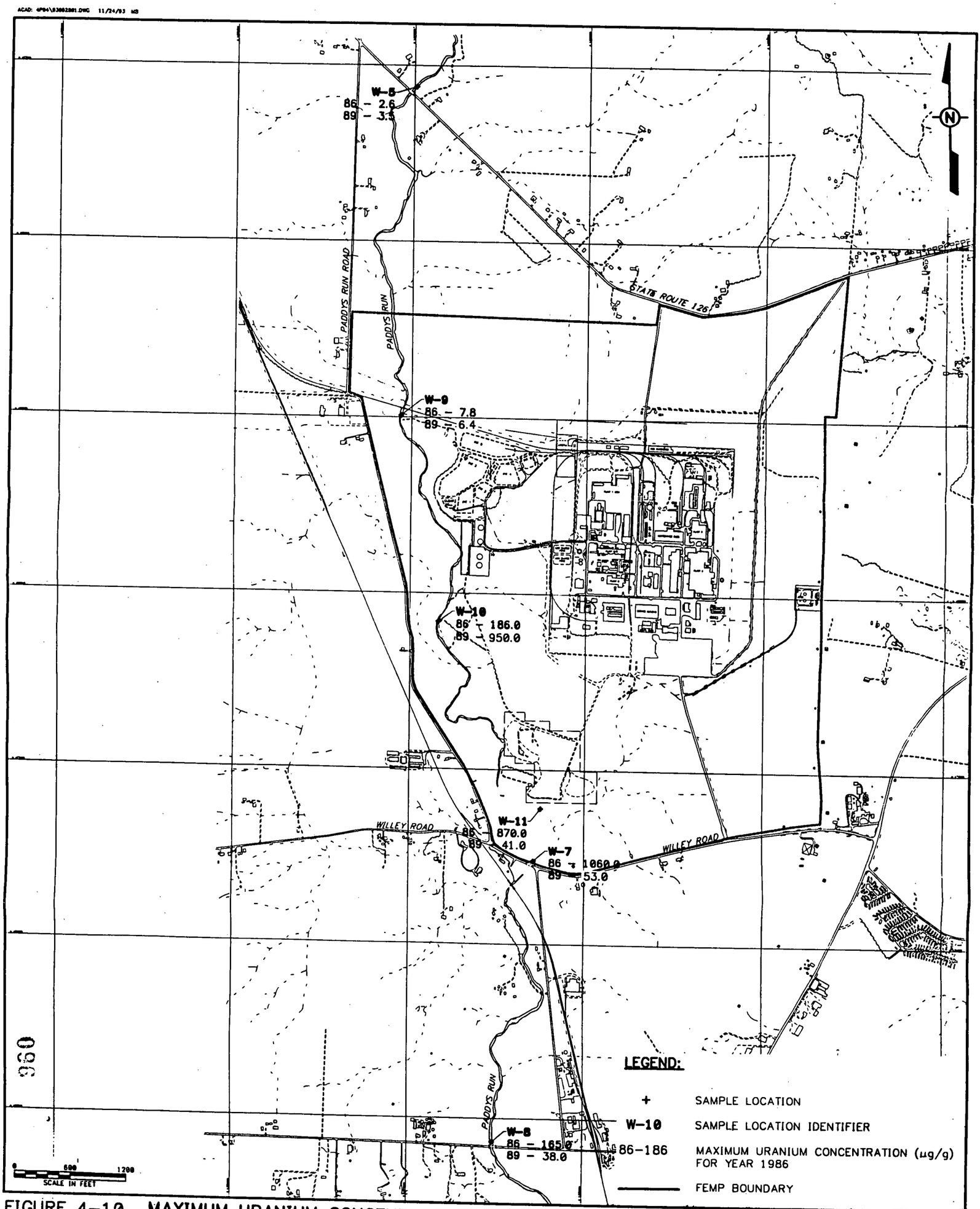

FIGURE 4-10. MAXIMUM URANIUM CONCENTRATIONS IN SURFACE WATER SAMPLES FROM ROUTINE ENVIRONMENTAL MONITORING DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

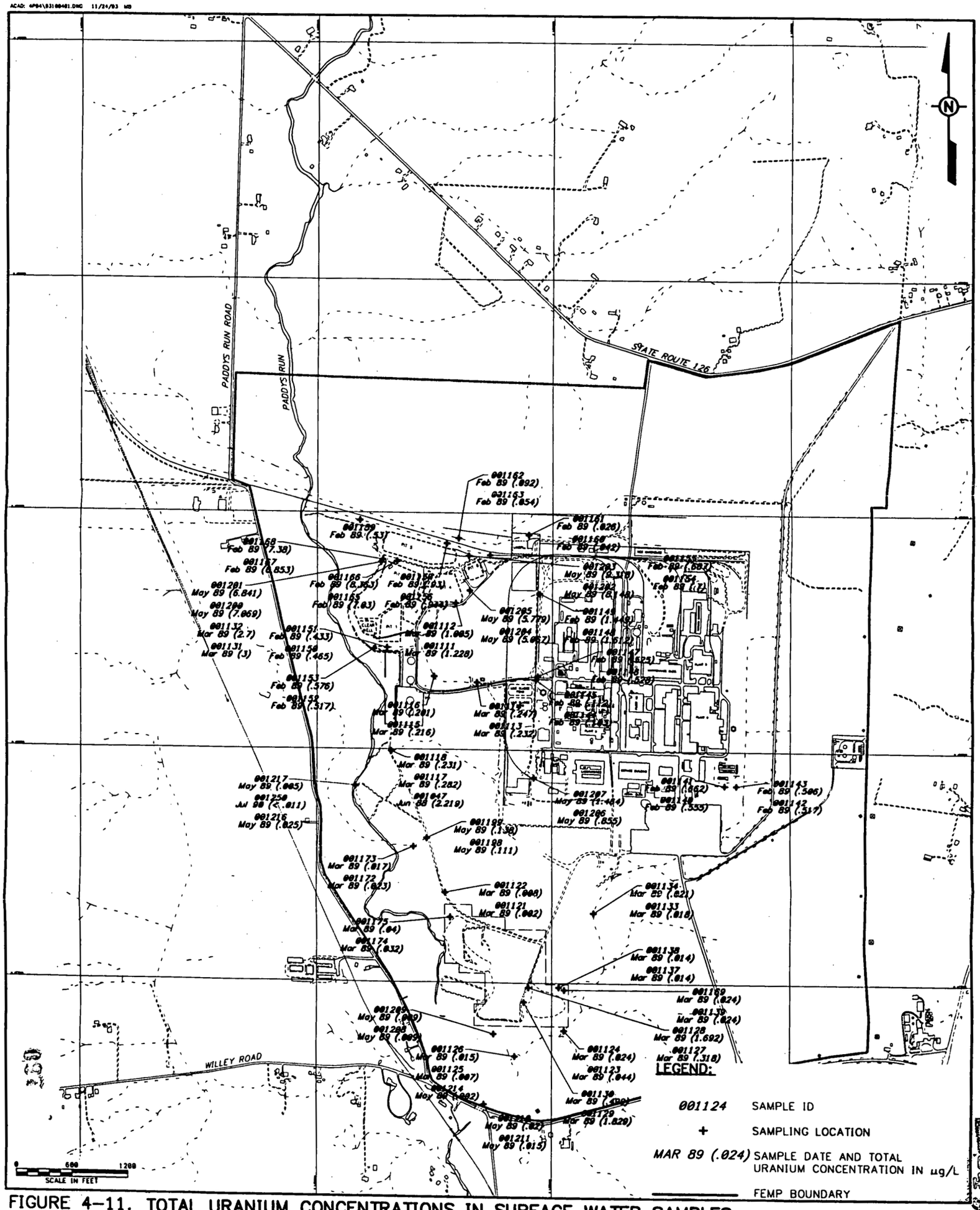

FIGURE 4-11. TOTAL URANIUM CONCENTRATIONS IN SURFACE WATER SAMPLES FROM REMEDIAL INVESTIGATION /FEASIBILITY STUDY DATA FOR THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

for the REM data and for the total uranium for the RI/FS data. Concentrations for other constituents are available but were not presented for the sake of brevity.

4.6.3 GMA 2000-Series Well Concentrations

The estimated concentration of contaminants reaching the GMA as described in Section 4.2.2 will be related to the concentrations found in 18 of the 2000-series wells which are located in close proximity to Paddys Run and the SSOD. The 2000-series monitoring wells are located in the upper GMA and are shown in Figure 4-12. The average and maximum concentrations of total uranium for the years 1990 through 1992 for RI/FS and non-RI/FS data is shown in Table 4-5. RI/FS data for total uranium concentrations in these wells is shown in Table 4-6 for the same years.

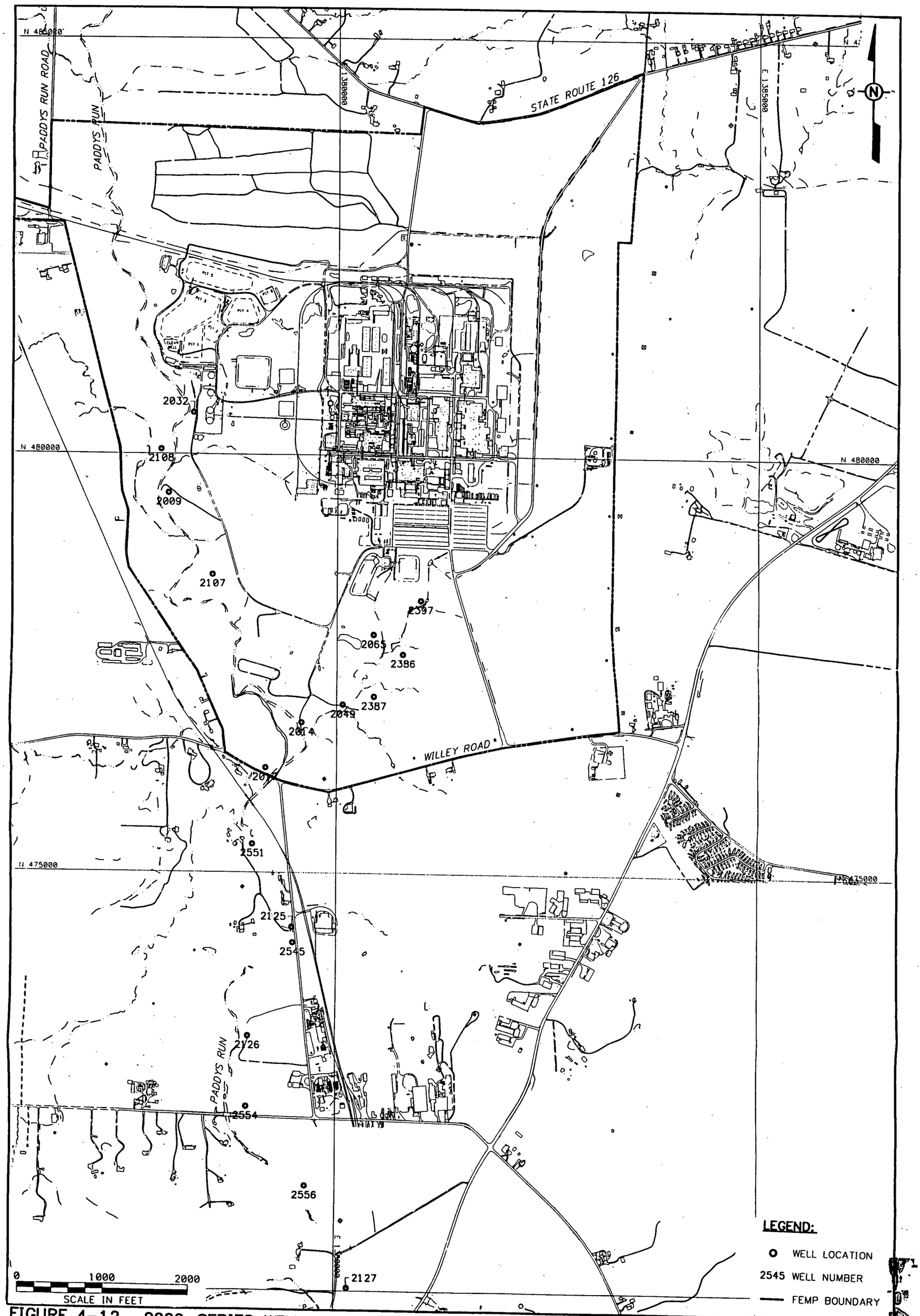

FIGURE 4-12. 2000-SERIES WELL LOCATIONS ALONG PADDYS RUN AND THE SSOD

TABLE 4-5

TOTAL URANIUM CONCENTRATIONS (ug/L) FROM THE 2000-SERIES MONITORING WELLS ALONG PADDYS RUN AND THE SSOD RI/FS AND NON-RI/FS DATA FROM 1990-1992

Well No.	1990 Max.	1990 Avg.	1991 Max.	1991 Avg.	1992 Max.	1992 Avg.
2009	13.60	13.60			19.70	18.67
2014	36.00	22.73			14.80	12.90
2017	5.35	4.29	5.94	4.41	7.50	6.45
2032	39.90	39.90				
2049	43.30	32.70				
2065	14.50	12.03	9.10	9.10	9.30	9.15
2107	5.25	4.29	12.00	12.00	12.00	11.15
2108	30.90	26.17				
2125	59.90	36.84	52.70	39.33	50.00	31.70
2126	1.08	0.80	0.64	0.45	<1.0	0.50
2127	19.20	8.82	6.16	4.09		
2386	6.67	6.66	13.00	13.00	9.70	9.50
2387	492.00	392.50				
2397	212.00	212.00	258.00	257.00		
2545	106.00	106.00	43.00	43.00		
2551	90.00	90.00	108.00	72.14		
2554	<1.0	0.50	<1.0	0.50		
2556	4.34	4.34	2.52	1.13	<1.0	0.50

TABLE 4-6

TOTAL URANIUM CONCENTRATIONS (ug/L) FROM THE 2000-SERIES MONITORING WELLS ALONG PADDYS RUN AND THE SSOD RI/FS DATA FOR 1990-1992

Well No.	1990 Max.	1990 Avg.	1991 Max.	1991 Avg.	1992 Max.	1992 Avg.
2009						
2014	36.00	36.00				
2017	3.59	3.59	5.94	4.23		
2032	39.90	39.90				
2049	43.30	43.30				
2065	11.40	11.40				
2107	3.44	3.44				
2108						
2125	27.40	27.40	51.50	43.93		
2126	<1.0	0.50	<1.0	0.45	<1.0	0.50
2127	8.39	8.39	6.16	4.09		
2386	6.67	6.66				
2387	492.00	392.50				
2397	212.00	212.00	258.00	257.00		
2545	106.00	106.00				
2551	90.00	90.00	108.00	72.14		
2554	<1.0	0.50	<1.0	0.50		
2556	4.34	4.34	2.52	1.13	<1.0	0.50

5.0 SENSITIVITY ANALYSIS

Sensitivity analyses of certain parameters used in the SWF&IM were performed to determine the model's uncertainty. Four sets of simulations were performed to examine the sensitivity of these parameters on the amount of infiltration from Paddys Run and the SSOD. The four simulations varied the SCS curve number, saturated hydraulic conductivity, groundwater table elevation, and fitting parameters in the Van Genuchten relative hydraulic conductivity equation. All of the sensitivity analyses were performed for the scenario that includes flow from the former production area.

5.1 SCS CURVE NUMBER SENSITIVITY ANALYSIS

The computed total runoff for Paddys Run is very sensitive to the SCS curve number. In the analysis, the SCS curve number in each subbasin was increased by five and ten percent, respectively. Total calculated runoff volume at cross section D-D in the period while flow is coming from the site increased from 5 million to 8 million ft^3 for the five percent case and to 10 million ft^3 for the 10 percent case. However, though variation of computed infiltration rate at cross section D-D in the first 4-hour period was apparent, it was negligible afterwards (Appendix I). The total infiltrated volume per foot of channel at cross section D-D was increased from 353 to 357 ft^3 for the five percent case and from 353 to 362 ft^3 for the 10 percent case.

This result shows why the assumptions of negligible channel loss used in the HEC-1 Model is valid; large changes in channel flow have a relatively minor effect on infiltration rate and volume.

5.2 SATURATED HYDRAULIC CONDUCTIVITY SENSITIVITY ANALYSIS

Saturated hydraulic conductivity (k) was increased from 450 ft/d to 600 ft/d and decreased to 300 ft/d in the sensitivity analysis. Infiltration rates in channel reaches C-C to D-D, D-D to E-E, and E-E to F-F are shown graphically in Appendix I. Infiltration rate was more sensitive to saturated hydraulic conductivity in channel reach C-C to D-D than in channel reaches D-D to E-E and E-E to F-F, because more unsaturated pore volume is available between C-C and D-D. The total infiltration through Paddys Run streambed in the storm event increased from 2.02 million to 2.39 million ft^3 for $k = 600$ ft/d and decreased to 1.53 million ft^3 for $k = 300$ ft/d.

5.3 RELATIVE HYDRAULIC CONDUCTIVITY EQUATION PARAMETERS SENSITIVITY ANALYSIS

Relative hydraulic conductivity was calculated using Van Genuchten's equation (Healy, 1990) in the infiltration model. Porosity of the GMA was considered to be well defined from previous regional groundwater flow models. Other fitting parameters (residual moisture content, scaling length, and pore-size distribution parameter) for sand presented in the VS2DT manual were chosen to vary in the infiltration calculation. In the sensitivity calculations (Appendix I), relative hydraulic conductivities computed using sand fitting parameters were compared with fitting parameters for Fresno medium sand and fine sand. A small variation of relative hydraulic conductivity computed using three sets of fitting parameters was presented when moisture content was above 0.15. In the sensitivity analysis, the fitting parameters for fine sand was input to the VS2DT model. Cross section C-C experienced a decrease in infiltration from 642 to 516 ft^3 per foot of channel.

5.4 GROUNDWATER ELEVATION SENSITIVITY ANALYSIS

The infiltration calculations in Paddys Run and the SSOD were rerun with the groundwater table lowered to the average groundwater elevation calculated for the independent volume of infiltration calculation discussed in Section 3.4.5. The total amount of infiltration in the SSOD and Paddys Run was calculated to be approximately 3.3 million ft^3 of infiltration. This is a 27 percent increase in infiltration from using a spring time groundwater elevation.

5.5 SUMMARY OF SENSITIVITY ANALYSES

The sensitivity analyses for the SCS curve number, the saturated hydraulic conductivity, and the relative hydraulic conductivity all produce a change in the total infiltration of 30 percent or less. Under the possible range of values, 30 percent uncertainty is acceptable for the intended use of the model results.

6.0 SUMMARY

In support of RI/FS activities at the FEMP the surface water is being studied and modeled to estimate the possible migration of contaminants through this pathway. The primary purpose of the SWF&IM Summary Report is to provide information concerning the hydrology and hydraulics of the Paddys Run drainage basin needed to conduct future modeling of contaminant transport in the surface waters. The approach to be used for the future fate and transport modeling is also described in the Report. The results of the SWF&IM Report will be used by each operable unit-specific RI/FS to complete the surface water contaminant transport calculations.

The two main water courses at the FEMP site are Paddys Run and the SSOD. Portions of Paddys Run and the SSOD have cut into glacial outwash deposits which form the water-bearing unit of the underlying GMA. The stream bed elevations of Paddys Run and the SSOD are generally above the groundwater table elevation in the GMA in the vicinity of the FEMP site, creating a situation in which some of the water flowing in the streams is lost into the surrounding ground. During the remedial investigation it was discovered that Paddys Run and the SSOD are directly connected with the underlying GMA and that a potential pathway exists for contaminant transport into the aquifer through their streambeds.

The purpose of surface water modeling at the FEMP is to quantify the effect of rainwater coming into contact with contaminated soils and the subsequent transport of the contaminants with the runoff. The main objectives of modeling the surface water pathway are to predict the concentration of contaminants in surface water and sediments, and to estimate the amount of contaminant reaching the GMA from infiltration through the streambeds of Paddys Run and the SSOD. These estimates of contaminants reaching the GMA via surface water will then be used as input into the groundwater solute transport model as mass loading rates.

The SWF&IM does not consider contaminant transport but is only concerned with the movement of the water. Rainfall and runoff is simulated with the HEC-1 modeling code. To calculate infiltration from surface water to the GMA, the computer code VS2DT is applied at cross sections along Paddys Run and the SSOD. A time-varying depth of water is input into the VS2DT program for the infiltration calculations to simulate the fluctuation of flow depths in the streams during a storm event.

The output from VS2DT provides the infiltration volumes to the GMA along the length of Paddys Run and the SSOD. The runoff hydrographs and infiltration information can then be used in calculating contaminant concentrations and loadings.

The VS2DT model predicts that approximately 30 percent of the total runoff in Paddys Run and the SSOD from a single representative storm event (a 1-year, 24-hour storm) infiltrates into the GMA. Based on VS2DT model results, it is estimated that 39 percent of the contaminant dissolved in the runoff from the same storm event infiltrates into the GMA through the streambeds of Paddys Run and the SSOD for the case including flow from the former production area. For the case in which the flow from the former production area is not included, approximately 37 percent of the dissolved contaminant in the runoff infiltrates.

The SWF&IM Report only presents the approach to be used in calculating the concentration of contaminants in the surface water bodies at the FEMP site. Given the amount of contaminant in the surface soil, future concentration calculations will require estimates of the surface water flow rates and volume and estimates of the amount of contaminant being transported from the source soil with the runoff. The amount of contaminant adsorbed to the sediment and the amount dissolved in the surface water runoff will be estimated with partitioning equations presented in the Superfund Exposure Assessment Manual (EPA, 1988). The amount of sediment generated from a single storm event will be estimated with the MUSLE, also presented in the Superfund Exposure Assessment Manual.

Two contaminant loading rates are calculated to simulate the loading pattern to the GMA for the entire year; the loading due to a single representative storm event and an average loading to be applied over six months of the year. It is assumed that the aquifer is not loaded during the other six months of the year.

The SWF&IM Report presents the information regarding hydrology and hydraulics of the Paddys Run drainage basin needed for the future contaminant calculations. This report also presents the overall modeling approach needed to complete the modeling of the surface water pathway of contaminant transport at the FEMP site.

7.0 REFERENCES

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