EVALUATION OF GROUND-WATER FLOW BY PARTICLE TRACKING, WRIGHT-PATTERSON AIR FORCE BASE, OHIO

by William L. Cunningham, Rodney A. Sheets, and Charles W. Schalk

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CONVERSION FACTORS

Multiply	By	To obtain
	Distance	
mile (mi)	1.609	kilometer
	Flow	
gallons per minute (gal/min)	3.785	liters per minute
million gallons per day (Mgal/d)	0.04381	cubic meters per second

Evaluation of Ground-Water Flow by Particle Tracking, Wright-Patterson Air Force Base, Ohio

By William L. Cunningham, Rodney A. Sheets, *and* Charles W. Schalk

Abstract

The U.S. Geological Survey (USGS) and Wright-Patterson Air Force Base (WPAFB) began a Basewide Monitoring Program (BMP) in 1992. The purpose of the BMP was to establish a long-term ground-water and surface-water sampling network in order to (1) characterize current ground-water and surface-water quality; (2) describe water-quality changes as water enters, flows across, and exits Base boundaries; (3) conduct statistical analyses of water quality; and (4) estimate the effect of WPAFB on regional water quality.

As part of the BMP, the USGS conducted ground-water particle-tracking analyses based on a ground-water-flow model produced during a previous USGS study. This report briefly describes the previous USGS study, the inherent assumptions of particle-tracking analyses, and information on the regional ground-water-flow field as inferred from particle pathlines. Pathlines for particles placed at the Base boundary and particles placed within the identified Installation Restoration Program sites are described.

INTRODUCTION

Wright-Patterson Air Force Base (WPAFB or "the Base") is in parts of Greene, Clark, and Montgomery Counties near the city of Dayton in southwestern Ohio (fig. 1). The Base overlies highly permeable glacial-drift deposits of the Mad River buried-valley aquifer. Near the Base, the aquifer is used as a source of drinking water for the nearby cities of Dayton and Fairborn, as well as for WPAFB.

Landfilling and other forms of waste disposal associated with aviation and research activities have been practiced in the WPAFB area since the 1920's. Studies began in the 1980's to identify and control environmental contamination on and off the Base (Weston, Incorporated, 1983, 1985, 1989; Dames and Moore, 1986a, 1986b; IT Corporation, 1990). The USGS reported the results of using a numerical model to simulate ground-water flow in the region; the model was based on results of hydrogeologic and geochemical investigations (Dumouchelle and others, 1993). As a result of these studies, 65 potential waste-disposal sites—termed Installation Restoration Program (IRP) Sites—have been identified and grouped into 12 Operable Units (OU's).

In 1992, the USGS entered into an agreement with WPAFB for a Basewide Monitoring Program (BMP). The purpose of the BMP was to establish a long-term Basewide ground-water and surface-water sampling network in order to (1) characterize current ground-water and surface-water quality; (2) describe water-quality changes as water enters, flows across, and exits Base boundaries; (3) analyze water quality statistically; and (4) estimate the effect of WPAFB on regional water quality. As part of the BMP, the USGS analyzed ground-water pathlines by means of the previously developed ground-water-flow model.

The purpose of this report is to provide particle-pathline information to illustrate directions of ground-water flow across the Base with respect to OU's and IRP sites. These results may be used by WPAFB in planning for (1) future base-wide monitoring studies, (2) a ground-water OU, (3) future remediation schemes, and (4) ongoing OU studies. This report

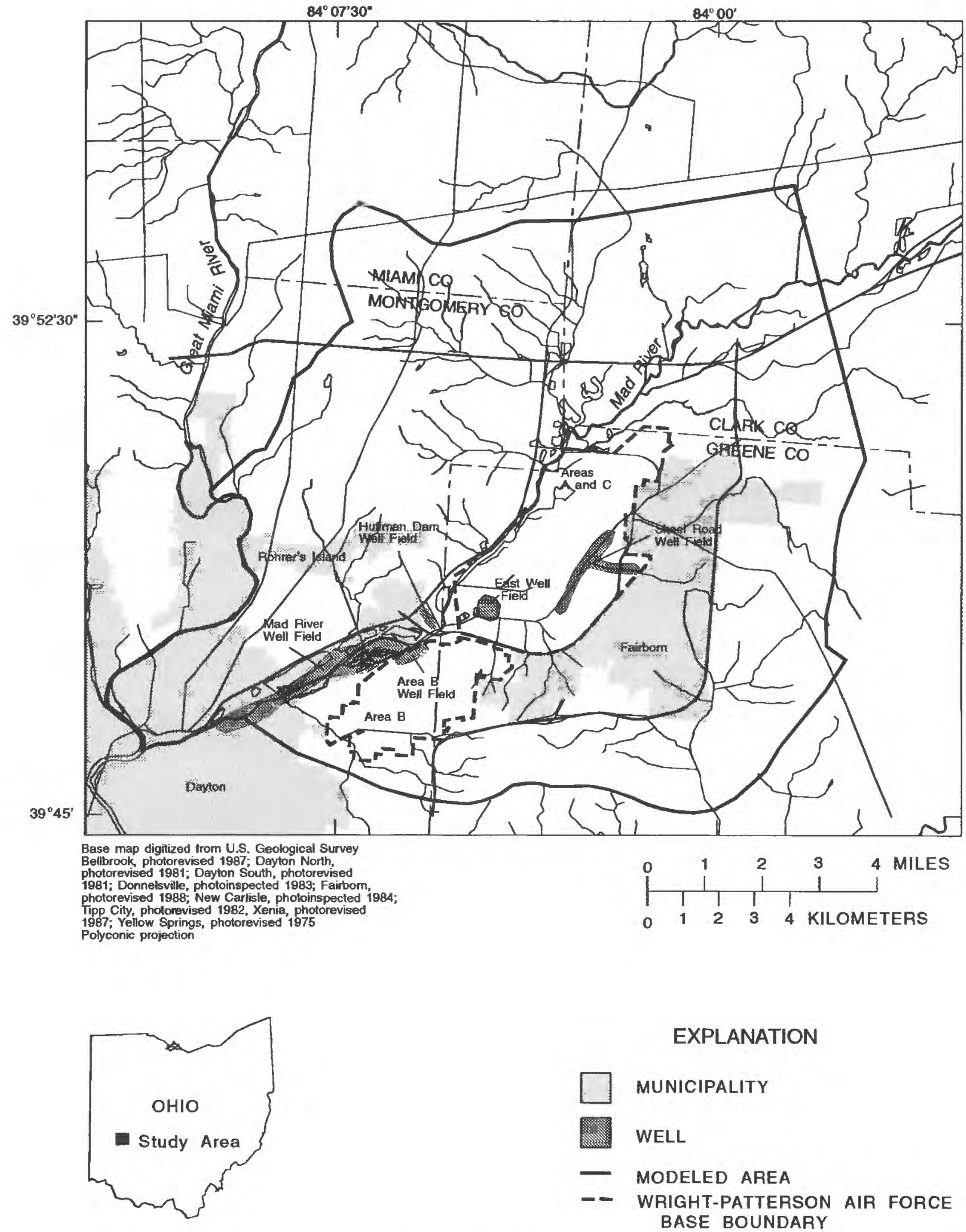

Figure 1. Location of Wright-Patterson Air Force Base and administrative areas. (Modified from Dumouchelle and others, 1993, fig. 1.)

briefly describes the previous USGS study, the assumptions inherent to this and to any particle-tracking analyses, and information on the regional ground-water-flow field as inferred from particle pathlines. Pathlines for particles placed at the Base boundary and particles placed within the identified IRP sites are described.

MODEL DESCRIPTION AND LIMITATIONS

Model Description

A three-dimensional ground-water-flow model calibrated to steady-state ground-water-flow conditions of October-December 1987 was developed by Dumouchelle and others (1993) for an area including the Base. The USGS computer code MODFLOW (McDonald and Harbaugh, 1988) was used for the simulation. The purpose of the model was, in part, to determine and evaluate sources and sinks of regional ground-water flow. These sources and sinks included the Mad River and its tributaries.

The Base overlies a productive buried-valley aquifer system that incises less permeable shales and shaley limestones. Upland areas adjoining the buried valleys are capped by limestone units that are used locally for ground-water supply. The model consists of three layers that simulate ground-water flow in the buried-valley aquifer as well as in the upland bedrock. Layer 1 simulates the unconfined nature of flow in the uppermost part of the buried-valley aquifer and the entire permeable thickness of the upland bedrock aquifer. Layer 2 of the model simulates the central part of the buried-valley aquifer, in which most of the water-supply wells are completed. Layer 3 of the model simulates the part of buried-valley aquifer that is bounded by the bottom of layer 2 and by the impermeable bedrock underlying the valley. Layers 2 and 3 were modeled as confined aquifers. The presence of discontinuous deposits of poorly permeable clays and silts defines the boundaries between layers 1 and 2 and between layers 2 and 3. Lateral boundaries to ground-water flow were based on the locations of ground-water divides and surface-water bodies, and on calculated flux through valley cross sections. The model was calibrated to water levels measured in 1987, results of a gain-loss study of the major rivers and tributaries, and vertical-gradient data collected at nested wells. A sensitivity analysis indicated that the simulated hydraulic heads and flows in the model were most sensitive to the hydraulic conductivity of the uppermost layer and to the riverbed hydraulic conductivity. Details of model parameters, construction, and calibration are described in the report by Dumouchelle and others (1993, p. 55-100).

Pumping rates for the period of model calibration were obtained for all pumping centers producing more than approximately 10 gal/min. These centers are primarily in industrial areas, in municipalities, and on the Base. The city of Dayton's Mad River Well Field (fig. 2) was the largest pumping center included in the model; withdrawals were approximately 50 Mgal/d. For the steady-state calibration of the model, the Skeel Road and East Well Fields at WPAFB were pumped at 1.9 and 1.1 Mgal/d, respectively. Area B wells at WPAFB were not active for the time period used for the calibration.

Since model calibration (1988), wells designed to produce about 20 Mgal/d have been constructed on the downstream side of Huffman Dam, and a well producing approximately 0.9 Mgal/d has been completed about 1 mi northeast of Huffman Dam (fig. 1). Currently (1994), the Huffman Dam Well Field is pumping a combined total of approximately 2 Mgal/d. In a predictive simulation, these pumping centers and the current (1994) rates of pumping were added to the model that was produced by Dumouchelle and others (1993). Particle pathlines are based on this predictive simulation. Active centers of withdrawal for the model simulation on which the particle-tracking results are based are shown in figure 2. The pumping centers and rates for this predictive simulation (1994) are summarized in table 1. Area B wells were not active for the time period used for the calibration; the East Well Field has not been active since 1988, so was not simulated here.

Table 1. Rates of pumping near Wright-Patterson Air Force Base, 1987 and 1994 [Mgal/d, million gallons per day]

Well field	Pumping rate, 1987 (Mgal/d)	Pumping rate, 1994 (Mgal/d)
Mad River	50	50
Area B	0	1.7
East	1.1	0
Skeel Road	1.9	1.9
Huffman Dam	0	2
OU5 Extraction	0	.9

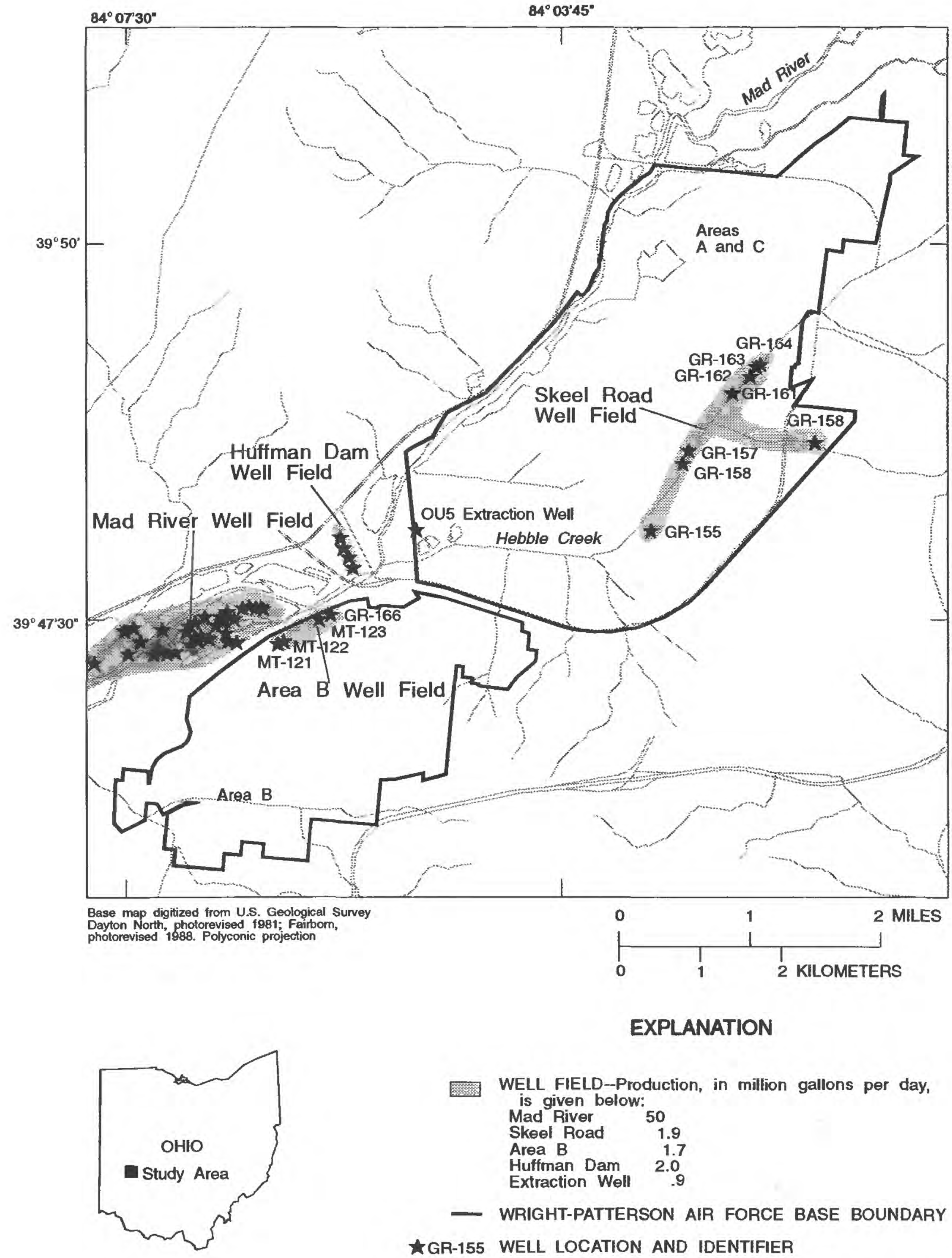

Figure 2. Locations of wells active in August 1994 and withdrawal rates at pumping centers.

Particle-Tracking Post Processor

Particle pathlines were computed on the basis of flow in each cell of the regional model by use of the USGS particle-tracking code MODPATH (Pollock, 1989). MODPATH is a three-dimensional post-processing program for particle tracking designed for use with output from simulations obtained with the computer code MODFLOW. MODPATH uses a semi-analytical particle-tracking scheme based on the assumption that the directional ground-water-velocity components within a model cell vary linearly. The velocity components are based on the intercell flow volumes computed by MODFLOW. The average linear velocity component across each face in a model cell is obtained by dividing the flow volume at a cell face by the cross-sectional area of the cell and the effective porosity of the material within the cell. Simple linear interpolation is used to compute the principal velocity components within a cell.

The particle-tracking scheme used by MODPATH is valid only for computing and interpolating advective velocities from intercellular flows such as those output by MODFLOW. Accordingly, the particle pathlines are based on advective particle movement and traveltimes—no diffusion, dispersion, or chemical or microbiological retardation is incorporated into the movement of particles that trace the particle pathlines. The analyses presented herein are based on a model of steady-state conditions. Changes in pumping or other stresses in the system over time will likely affect the particle pathlines and traveltimes.

Limitations

The most significant limiting factor in particle tracking is the numerical model on which the analyses are based. The numerical model from which the heads and flows are generated and used in particle tracking is a numerical representation of the physical flow system. Numerical approximations, convergence tolerances, and scale limitations all affect how well the model represents the physical flow system. Grid design, boundary conditions, and calibration data also can affect the accuracy of the model and, therefore, the particle-tracking analysis. Errors from numerical approximations are assumed to be minimized by trial-and-error adjustment during calibration (Dumouchelle and others, 1993, p. 78-86), but a discussion of the scale limitations is required here. The model developed previously was designed to investigate regional ground-water flow. Local flow, such as flow to small streams or flow adjacent to sources and sinks, may not be well represented by the model. However, the analyses presented by Sheets (1994) indicate that local flow, at the scale of particle pathlines, is well represented in the regional model. A complete discussion of the limitations of the ground-water-flow model is given in Dumouchelle and others (1993, p. 96-100).

EVALUATION OF GROUND-WATER FLOW BY PARTICLE TRACKING

Ground-Water-Flow Directions

Particle pathlines from the Base boundary to particle-discharge points are shown in figure 3. Particles were placed initially at the water table along the Base boundary. The following characteristics of the ground-water-flow field under the stated pumping conditions can be identified from the particle pathlines:

- Generally, ground water flows from the northeastern boundary of the Base to the Skeel Road Well Field.
- A ground-water-flow divide between discharge to the Mad River and flow beneath Huffman Dam exists near the middle of Area A and C, just south of well clusters USGS 4 and 33. Flow north of the divide is to the Mad River; flow south of the divide is to the downgradient ground-water-flow system.
- A topographic and bedrock upland feature near well cluster USGS 9 restricts regional ground-water flow in the area.
- In the southwestern part of Area B, a ground-water-flow divide exists between flow to the Mad River Well Field at Rohrer's Island and flow downgradient into other wells within the Mad River Well Field. The divide is near well cluster DG1.

Particle pathlines from the identified IRP hazardous-waste sites within OU's to particle discharge points are shown in figure 4. Particles were placed at the water table within the areas delineated as IRP sites. The following characteristics of the flow field can be identified from the particle pathlines:

- Ground water flows from OU2, at the northeastern boundary of the Base, through OU3 to the Mad River.

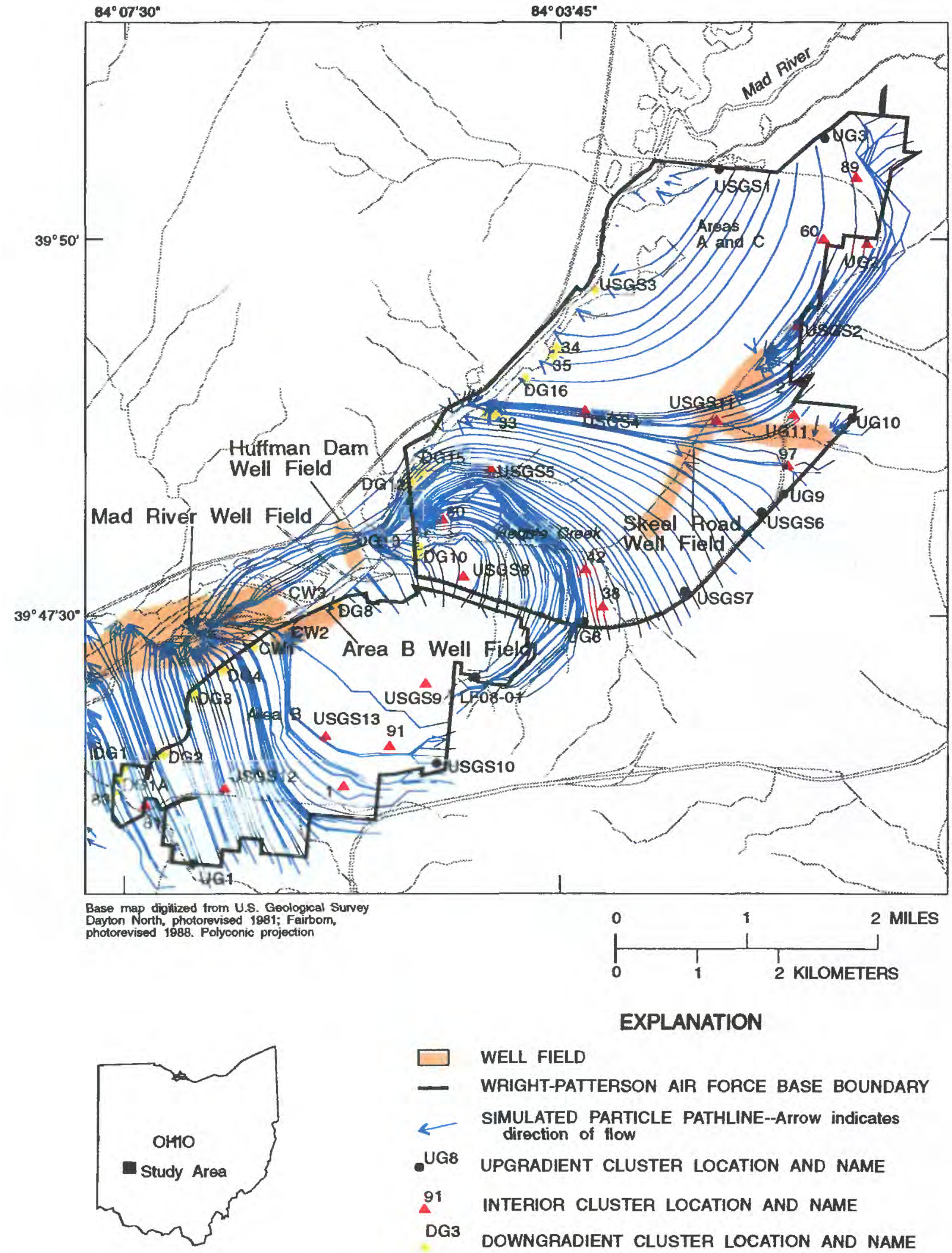

Figure 3. Particle pathlines from Base boundary to discharge points.

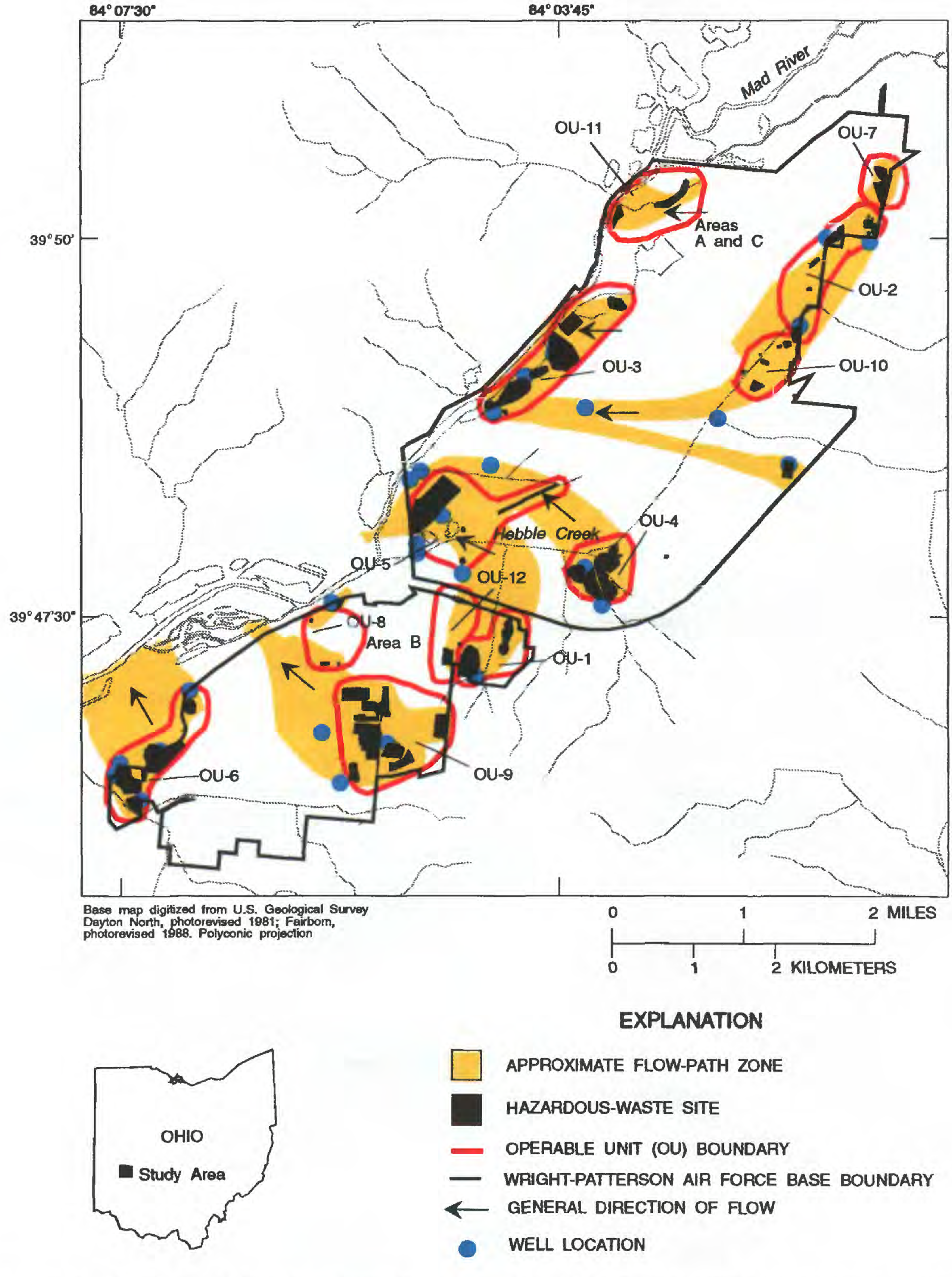

Figure 4. Directions of flow from hazardous-waste sites within Operable Units to discharge points.

- Ground water flows from OU1 through Areas A and C and then through OU5.
- Ground-water flows from OU9 to the Mad River Well Field.
- Ground water flow from OU6 is divided: some ground water discharges to the Mad River Well Field at Rohrer's Island and downgradient to other Mad River wells.
- Many BMP wells are completed within ground-water-flow paths from OU's.

Areas Contributing Recharge

Figure 5 illustrates areas within the model that contribute recharge to wells and streams. Particles were placed at the water table throughout the Base. Particles are color-coded according to their point of discharge. As figure 5 indicates, most of Areas A and C contribute recharge to the Mad River, a gaining stream in this reach along the buried valley. Areas that contribute recharge to the Skeel Road Well Field, the OU5 extraction well, and interceptor wells near Huffman Dam are also within Areas A and C. Most of Area B contributes recharge to the Mad River Well Field at Rohrer's Island. Area B also contributes recharge to the Area B Well Field and the interceptor wells near Huffman Dam.

Traveltime-related areas contributing recharge to the Mad River, Skeel Road, Area B, and Huffman Dam Well Fields, the OU5 Extraction Well, and the Mad River are shown in figure 6. Particles were placed at the water table and tracked to their discharge points. Traveltime-related areas were determined by assigning an effective porosity to each cell in the flow model. The effective porosity used for the particle-tracking simulation was 0.20, 0.25, and 0.15 for model layers 1, 2, and 3, respectively. The effective porosity within a model cell has a linear effect on the traveltime of a particle but has no effect on the particle pathlines. For example, an increase in the effective porosity would decrease the area associated with each traveltime listed in figure 6.

SUMMARY

As part of the BMP, the USGS analyzed ground-water pathlines by means of a ground-water-flow model produced during a previous USGS study. Results of this pathline analysis are summarized below.

- The most significant limiting factor in particle tracking is the numerical model on which the analyses are based; accordingly, all results described herein are limited by the assumptions of the numerical ground-water-flow model employed.
- At the northeastern boundary of the Base, ground water flows from OU2 through OU3 to the Mad River. Some ground-water flow is captured by the Skeel Road Well Field. A ground-water-flow divide between discharge to the Mad River and flow beneath Huffman Dam exists near the middle of Area A and C just south of well clusters USGS 4 and 33. Flow north of the divide is to the Mad River; flow south of the divide is to the downgradient ground-water-flow system.
- Ground water flows from OU1 through Areas A and C and then through OU5.
- Ground-water flow from OU6 is divided; some ground water discharges to the Mad River Well Field at Rohrer's Island, and the rest flows downgradient to other Mad River wells.
- Ground water flows from OU9 to the Mad River Well Field. A topographic and bedrock upland feature near well cluster USGS 9 restricts regional flow in the area.
- Many BMP wells are completed within ground-water-flow paths from the OU's.

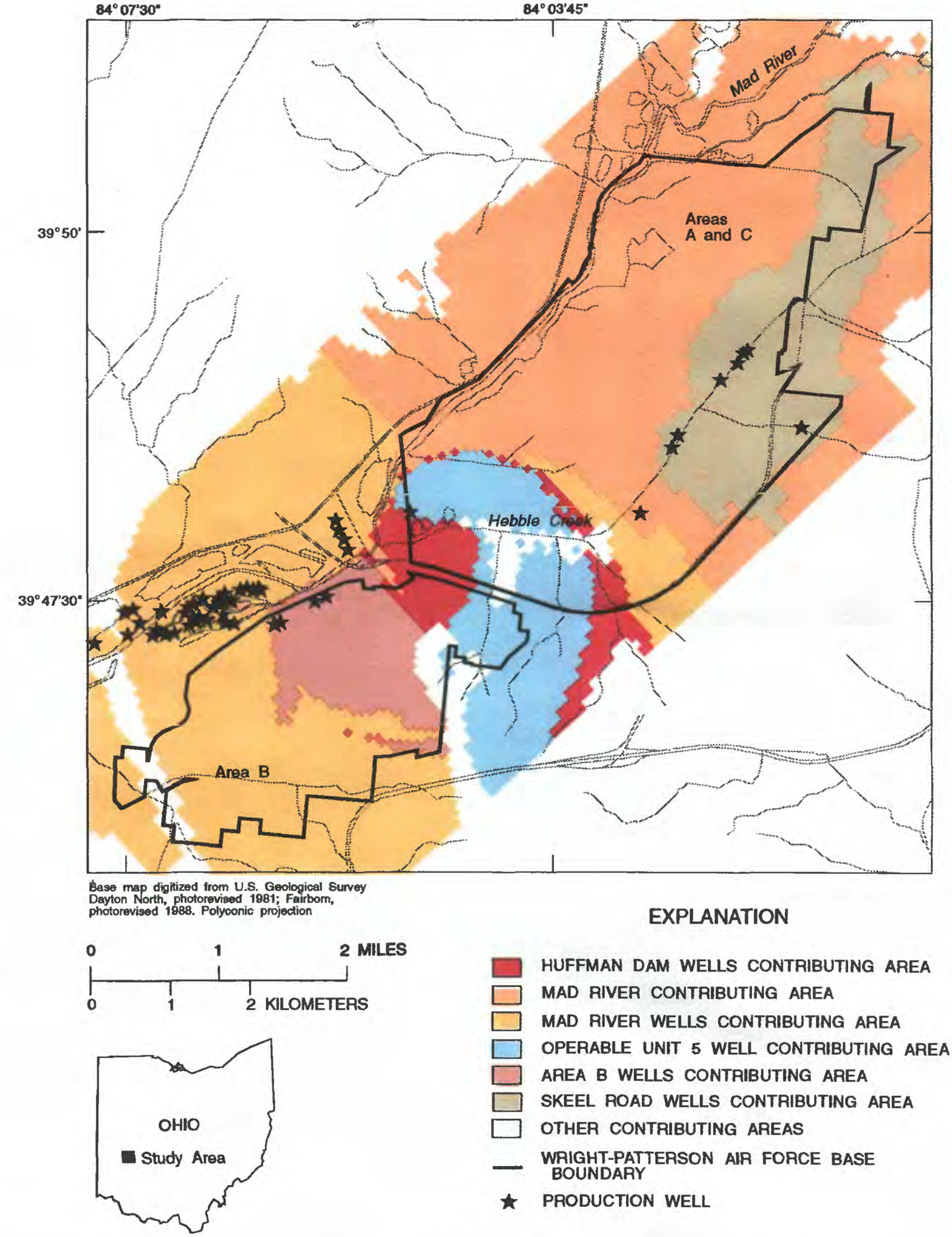

Figure 5. Areas contibuting recharge to selected wells and Mad River, Wright-Patterson Air Force Base.

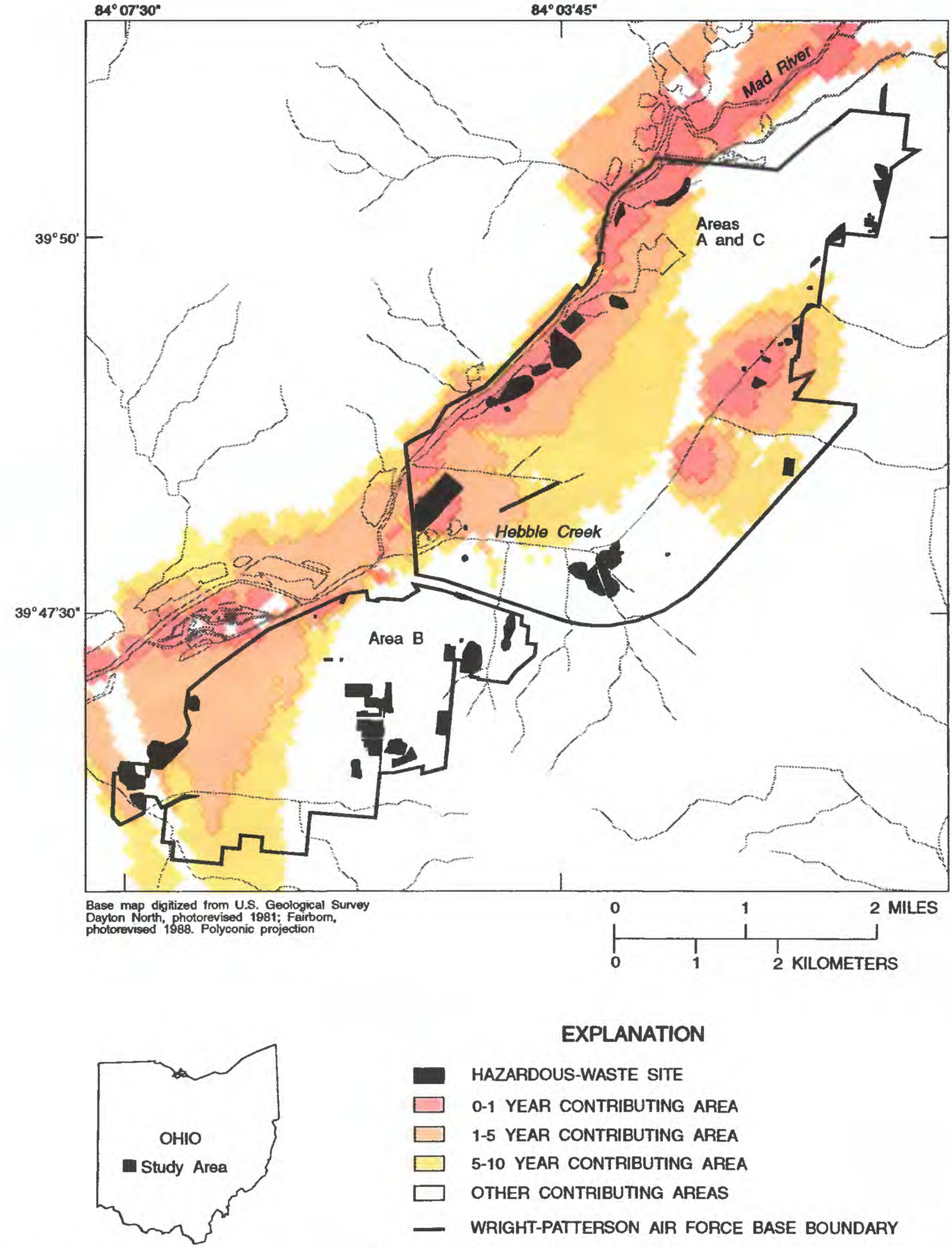

Figure 6. Traveltime-related areas contributing recharge to discharge points in and around Wright-Patterson Air Force Base.

REFERENCES CITED

Dames & Moore, Incorporated, 1986a, Installation Restoration Program report, site investigation report—landfills 8 and 10: Prepared for Wright-Patterson Air Force Base [variously paginated].

———1986b, Installation Restoration Program report, site investigation report—landfill 12: Prepared for Wright-Patterson Air Force Base [variously paginated].

Dumouchelle, D.H., Schalk, C.W., Rowe, G.L., and de Roche, J.T., 1993, Hydrogeology, simulated ground-water flow, and ground-water quality, Wright-Patterson Air Force Base, Ohio: U.S. Geological Survey Water Resources Investigation Report 93-4047, 152 p.

IT Corporation, 1990, Installation Restoration Program report, environmental investigation of ground-water contamination at Wright-Patterson Air Force Base, Ohio: Dayton, Ohio, Battelle Environmental Management Operations, prepared for Wright-Patterson Air Force Base [variously paginated].

McDonald, M.G. and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1 [variously paginated].

Pollock, D.W., 1989, Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open File Report 89-38, 188 p.

Sheets, R.A., 1994, Contributing recharge areas of water-supply-wells at Wright-Patterson Air Force Base, Ohio: U.S. Geological Survey Water Resources Investigations Report 94-4231, 35 p.

Weston, Roy F., Incorporated, 1983, Installation Restoration Program report, Phase II—problem confirmation and quantification study: Prepared for Wright-Patterson Air Force Base [variously paginated].

———1985, Installation Restoration Program report, Phase II—Stage 1 study: Prepared for Wright-Patterson Air Force Base [variously paginated].

———1989, Installation Restoration Program report, Phase II—Stage 2 report: Prepared for Wright-Patterson Air Force Base [variously paginated].