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HYDROGEOLOGY OF THE 200 AREAS LOW-LEVEL BURIAL GROUNDS--AN INTERIM REPORT

Volume 1: Text

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D. W. Wallace
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J. S. Wilbur

January 1989

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

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201-225	A10
226-250	A11
251-275	A12
276-300	A13

PREFACE

This report presents information derived from the installation of 35 ground-water monitoring wells around six low-level radioactive/hazardous waste burial grounds located in the 200 Areas of the Hanford Site in southeastern Washington State. This information was collected between May 20, 1987 and August 1, 1988.

The contents of this report have been divided into two volumes. This volume contains the main text. Volume 2 contains the appendixes, including data and supporting information that verify content and results found in the main text.

SUMMARY

This report documents information collected by the Pacific Northwest Laboratory at the request of Westinghouse Hanford Company. Presented in this report are the preliminary interpretations of the hydrogeologic environment of six low-level burial grounds, which comprise four waste management areas (WMAs) located in the 200 Areas of the Hanford Site. This information and its accompanying interpretations were derived from sampling and testing activities associated with the construction of 35 ground-water monitoring wells as well as a multitude of previously existing boreholes. The new monitoring wells were installed as part of a ground-water monitoring program initiated in 1986. This ground-water monitoring program is based on requirements for interim status facilities in compliance with the Resource Conservation and Recovery Act (1976). This work was initiated in response to Consent Agreement and Compliance Order DE 86-133 issued to the U.S. Department of Energy by the State of Washington.[a]

The 35 new monitoring wells were installed around these low-level burial grounds: 16 in the 200-East Area and 19 in the 200-West Area. Installation of these wells was initiated on May 20, 1987, and was completed on November 30, 1987, in compliance with the Consent Agreement and Compliance Order.

Geologic sampling, aquifer testing, and initial ground-water sampling were performed during the installation of these monitoring wells. Laboratory analyses of the sediment samples have been only partially completed, and routine ground-water sampling has not yet begun. Preliminary interpretations of the available information suggest the following:

1. Discontinuities exist in the lateral extent of the confining beds (lower Ringold clays beneath the 200-West Area and the uppermost basalt flow beneath the 200-East Area) that form the base of the uppermost aquifer in the vicinity of WMA-2 and WMA-3.

(a) Letter from Kathleen D. Mix, Assistant Attorney General, State of Washington, Olympia, Washington, to Robert Carosino, Attorney, U.S. Department of Energy, Richland, Washington, October 2, 1986.

2. A basalt high extends above the water table, diverting ground-water flow to the west from beneath WMA-2.

3. Ground-water flow directions are difficult to determine in the 200-East Area because of the small hydraulic gradient (0.1 ft/ 1,000 ft). However, preliminary interpretations suggest that the ground water flows westward, and that additional downgradient well(s) may be necessary along the western portion of WMA-2. Flow directions in the 200-West Area are northerly and indicate that perhaps only two of the monitoring wells installed at WMA-4 are located immediately downgradient from that WMA. Vertical hydraulic gradients beneath the 200-West Area are downward within the uppermost aquifer.

4. Results of aquifer testing at these wells demonstrated that hydraulic properties within both Hanford and Ringold Formation sediments are highly variable both laterally and vertically.

5. Results of initial sampling indicate that contaminants are present in the ground water beneath each of the WMAs. However, contamination likely originated from past operation of adjacent liquid disposal sites, not from these WMAs that received solid waste.

Physical and geochemical analyses of sediment samples, routine water-level measurements, and routine ground-water sampling and analysis will further refine the understanding of the hydrogeologic conditions beneath these WMAs, and will provide better indication of the adequacy of this monitoring system.

ACKNOWLEDGMENTS

The authors wish to acknowledge the numerous well site geologists who spent long hours in the field collecting and documenting borehole samples and well construction details. Golder Associates and EBASCO, Inc., provided supplementary well site geologist support during periods of high activity, and their help was greatly appreciated. ONWEGO Drilling Co., Inc., installed the monitoring wells in the 200-West Area, and Kaiser Engineers Hanford Company installed the wells in the 200-East Area. The authors also wish to acknowledge the former project managers, D. A. Myers and R. B. Kasper. Numerous other Pacific Northwest Laboratory and Westinghouse Hanford Company personnel contributed to the completion of this phase of the project.

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VOLUME 1 CONTENTS

PREFACE iii

SUMMARY v

ACKNOWLEDGMENTS vii

1.0 INTRODUCTION 1.1

2.0 DESCRIPTION OF THE LOW-LEVEL BURIAL GROUNDS 2.1

2.1 SITE LOCATION AND LAYOUT 2.1

2.2 FACILITY OPERATORS 2.4

2.3 DISPOSAL PRACTICES BEFORE 1987 . . . . . 2.4

2.4 CURRENT DISPOSAL PRACTICES 2.5

2.5 DESCRIPTION AND INVENTORIES OF THE WASTE MANAGEMENT AREAS 2.8

2.5.1 Waste Management Area 1 . . . . . 2.9

2.5.2 Waste Management Area 2 . . . . . 2.16

2.5.3 Waste Management Area 3 . . . . . 2.20

2.5.4 Waste Management Area 4 . . . . . 2.27

3.0 ENVIRONMENTAL SETTING 3.1

3.1 REGIONAL PHYSIOGRAPHY 3.1

3.2 CLIMATE AND METEOROLOGY 3.5

3.2.1 Wind 3.5

3.2.2 Temperature and Humidity 3.8

3.2.3 Precipitation 3.9

3.3 STRATIGRAPHY 3.9

3.3.1 Columbia River Basalt Group 3.9

3.3.2 Ellensburg Formation 3.11

3.3.3 Suprabasalt Sediments 3.11

3.4 TECTONIC FRAMEWORK 3.16

3.4.1 Structural Geology of the Region 3.16

3.5 SEISMICITY 3.21

3.6 REGIONAL HYDROLOGY 3.22

3.6.1 Surface Water 3.22

3.6.2 Ground Water 3.25

4.0 HYDROGEOLOGIC CHARACTERIZATION 4.1

4.1 INVESTIGATIVE APPROACH 4.1

4.2 AVAILABLE DATA BASE 4.2

4.2.1 Previous Studies 4.2

4.2.2 Data Bases 4.6

4.3 INVESTIGATIVE METHODS 4.7

4.3.1 Design and Installation of the Ground-Water Monitoring System 4.8

4.3.2 Geologic Sampling 4.12

4.3.3 Borehole Geophysical Logging 4.16

4.3.4 Well Development 4.17

4.3.5 Aquifer Testing 4.19

4.3.6 Surveying 4.22

4.3.7 Water-Level Measurements 4.22

4.3.8 Physical Testing of Borehole Samples 4.23

4.3.9 Mineralogy and Geochemical Testing of Borehole Samples 4.27

5.0 GEOLOGY OF THE WASTE MANAGEMENT AREAS 5.1

5.1 INTRODUCTION 5.1

5.2 GEOMORPHOLOGY 5.2

5.3 GEOLOGY OF WASTE MANAGEMENT AREAS 1 AND 2 . . . . . 5.7

5.3.1 Saddle Mountains Basalt 5.24

5.3.2 Ringold Formation 5.27

5.3.3 Hanford Formation 5.29

5.4 GEOLOGY OF WASTE MANAGEMENT AREAS 3 AND 4 . . . . . 5.38

5.4.1 Saddle Mountains Basalt 5.62

5.4.2 Ringold Formation 5.63

5.4.3 Plio-Pleistocene Unit 5.78

5.4.4 Early "Palouse" Soil 5.87

5.4.5 Hanford Formation 5.90

5.4.6 Recent Eolian Deposits 5.97

6.0 HYDROLOGY OF THE WASTE MANAGEMENT AREAS 6.1

6.1 RECHARGE 6.1

6.1.1 Natural Recharge 6.1

6.1.2 Artificial Recharge. 6.2

6.2 HYDROLOGY OF THE UNSATURATED ZONE 6.4

6.3 GROUND-WATER MOVEMENT IN THE UNCONFINED AQUIFER SYSTEM 6.5

6.3.1 Waste Management Areas 1 and 2 . . . . . 6.6

6.3.2 Waste Management Areas 3 and 4 . . . . . 6.16

7.0 GROUND-WATER QUALITY 7.1

7.1 WATER QUALITY IN THE UNCONFINED AQUIFER BENEATH WASTE MANAGEMENT AREAS 1 AND 2 . . . . . 7.1

7.1.1 Indications from Previous Studies 7.1

7.1.2 Predevelopment and Aquifer Test Sample Analyses 7.5

7.2 WATER QUALITY IN THE UNCONFINED AQUIFER BENEATH WASTE MANAGEMENT AREAS 3 AND 4 . . . . . 7.5

7.2.1 Indications from Previous Studies 7.6

7.2.2 Predevelopment and Aquifer Test Sample Analyses from the Top of the Unconfined Aquifer 7.6

7.2.3 Predevelopment and Aquifer Test Sample Analyses from the Bottom of the Unconfined Aquifer. 7.7

7.3 IMPACT OF WASTE MANAGEMENT AREAS ON THE GROUND-WATER QUALITY 7.7

8.0 PLANNED WORK 8.1

8.1 PHYSICAL TESTING OF BOREHOLE SAMPLES 8.1

8.2 MINERALOGICAL AND GEOCHEMICAL TESTING OF BOREHOLE SAMPLES 8.1

8.3 MODELING 8.1

8.4 WATER-QUALITY MONITORING 8.4

9.0 RECOMMENDATIONS 9.1

10.0 REFERENCES 10.1

Volume 2 contains:

APPENDIX A - DATA INVENTORY AND LITHOLOGIC LOG SUMMARIES FOR EXISTING BOREHOLES NEAR THE 200 AREAS LOW-LEVEL BURIAL GROUNDS A.1

APPENDIX B - WELL CONSTRUCTION SUMMARIES FOR 200-EAST AREA WELLS B.1

APPENDIX C - WELL CONSTRUCTION SUMMARIES FOR 200-WEST AREA WELLS C.1

APPENDIX D - ANALYTICAL RESULTS FOR THE PREDEVELOPMENT AND AQUIFER TESTS OF GROUND-WATER SAMPLES D.1

APPENDIX E - AQUIFER TESTING OF WELLS IN THE 200-EAST AREA E.1

APPENDIX F - AQUIFER TESTING OF WELLS IN THE 200-WEST AREA F.1

APPENDIX G - SURVEY REPORTS FOR GROUND-WATER MONITORING WELLS AROUND WASTE MANAGEMENT AREAS 1, 2, 3, AND 4. . . . . G.1

APPENDIX H - PROCEDURE, WATER-LEVEL DATA, AND HYDROGRAPHS H.1

APPENDIX I - FIELD MOISTURE CONTENT OF CORE-BARREL SAMPLES FROM WELLS IN THE 200-EAST AND 200-WEST AREAS I.1

APPENDIX J - PARTICLE-SIZE AND CALCIUM CARBONATE DATA FOR 200-EAST AREA WELLS J.1

APPENDIX K - PARTICLE-SIZE AND CALCIUM CARBONATE DATA FOR 200-WEST AREA WELLS K.1

APPENDIX L - BOREHOLE GEOPHYSICAL LOGGING PROCEDURES L.1

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FIGURES

1.1 Location of the 200 Areas of the Hanford Site 1.2

2.1 Location of Waste Management Areas 1 and 2 in the 200-East Area 2.2

2.2 Location of Waste Management Areas 3 and 4 in the 200-West Area 2.3

2.3 Typical Storage Module in the Low-Level Retrievable Storage Units 2.9

2.4 Aerial Photograph of the 200-East Area 2.11

2.5 Aerial Photograph of the 200-West Area 2.13

2.6 Layout of Burial Ground 218-E-10 . . . . . 2.15

2.7 Layout of Burial Ground 218-E-12B. 2.18

2.8 Layout of Burial Ground 218-W-3A 2.22

2.9 Layout of Burial Ground 218-W-3A-E 2.26

2.10 Layout of Burial Ground 218-W-5 . . . . . 2.28

2.11 Layout of Burial Ground 218-W-4C 2.29

3.1 Divisions of the Columbia Intermontane Province and Adjacent Provinces 3.2

3.2 Geomorphic Units Within the Central Highlands and Columbia Basin Subprovinces that Contain the Columbia River Basalt Group 3.3

3.3 Paleoflow Directions and Landforms Associated with Proglacial Cataclysmic Flooding in the Central Columbia Plateau 3.4

3.4 Late Quaternary Landforms Within and Adjacent to the Pasco Basin 3.6

3.5 Hanford Site Wind Roses, 1979 Through 1982 . . . . . 3.7

3.6 Stratigraphic Nomenclature of Units Penetrated Within the Pasco Basin 3.10

3.7 Distribution of Ringold Formation Section Types 3.13

3.8 Structural Subprovinces of the Columbia Plateau 3.17

3.9 Structural Elements of the Yakima Fold Belt Subprovince . . . 3.19

3.10 Tectonic Structures Adjacent to the 200 Areas, Top of Basalt Map 3.20

3.11 Location of Surface Water Features, Including Ponds, Ditches, and Principal Dams 3.23

3.12 Generalized East-West Cross Section Through the Hanford Site in the Vicinity of the 200 Areas Low-Level Burial Grounds 3.27

3.13 Water-Table Elevations for June 1987 . . . . . 3.28

4.1 Presumed Ground-Water Gradients and Flow Directions Used to Select Monitoring Well Locations 4.3

4.2 Schematic of Well Design Used Around the 200-West Area Low-Level Burial Grounds 4.13

4.3 Sediment Classification Scheme Used in the ROCSAN Program . . 4.24

5.1 Example of the Borehole Data Correlation Charts Used in This Study 5.3

5.2 Geomorphic Features Surrounding the 200 Areas 5.5

5.3 Topography of Waste Management Areas 1 and 2 . . . . . 5.8

5.4 Topography of Waste Management Areas 3 and 4 . . . . . 5.9

5.5 Generalized Stratigraphy for Waste Management Areas 1 and 2 . . . . . 5.12

5.6 Location of Monitoring Wells and Geologic Cross Sections Around Waste Management Areas 1 and 2 . . . . . 5.13

5.7 Geologic Cross Section A-A′, Waste Management Area 1 . . . . . 5.14

5.8 Geologic Cross Section B-B′, Waste Management Area 1 . . . . . 5.15

5.9 Geologic Cross Section C-C′, Waste Management Area 1 . . . . . 5.16

5.10 Geologic Cross Section D-D′, Waste Management Area 1 . . . . . 5.17

5.11 Geologic Cross Section E-E′, Waste Management Area 2 . . . . . 5.18

5.12 Geologic Cross Section F-F′, Waste Management Area 2 . . . . . 5.19

5.13 Geologic Cross Section G-G′, Waste Management Area 2 . . . . . 5.20

5.14 Geologic Cross Section H-H′, Waste Management Area 2 . . . . . 5.21

5.15 Isopach of the Post-Basalt Sediments Beneath Waste Management Areas 1 and 2 . . . . . 5.22

5.16 Fence Diagram of the Generalized Stratigraphy Beneath Waste Management Areas 1 and 2 . . . . . 5.23

5.17 Surface of the Elephant Mountain Member in the 200-East Area 5.26

5.18 Isopach of the Ringold Formation Beneath Waste Management Areas 1 and 2 . . . . . 5.30

5.19 Isopach of the Hanford Formation Middle Sand Unit Beneath Waste Management Area 1 . . . . . 5.33

5.20 Isopach of the Hanford Formation Upper Coarse-Grained Unit Beneath Waste Management Area 1 . . . . . 5.34

5.21 Isopach of the Hanford Formation Lower Coarse-Grained Unit Beneath Waste Management Area 1 . . . . . 5.35

5.22 Surface of the Hanford Formation Lower Coarse-Grained Unit Beneath Waste Management Area 1 . . . . . 5.36

5.23 Surface of the Hanford Formation Middle Sand Unit Beneath Waste Management Area 1 . . . . . 5.37

5.24 Location of Waste Management Areas 3 and 4 in the 200-West Area 5.39

5.25 Geologic Cross Section A-A′, Waste Management Area 3 . . . . . 5.41

5.26 Geologic Cross Section B-B′, Waste Management Area 3 . . . . . 5.43

5.27 Geologic Cross Section C-C′, Waste Management Area 3 . . . . . 5.45

5.28 Fence Diagram of the Stratigraphy Beneath Waste Management Area 3 . . . . . 5.47

5.29 Geologic Cross Section D-D′, Waste Management Area 4 . . . . . 5.49

5.30 Geologic Cross Section E-E′, Waste Management Area 4 . . . . . 5.51

5.31 Geologic Cross Section F-F′, Waste Management Area 4 . . . . . 5.53

5.32 Geologic Cross Section G-G′, Waste Management Area 4 . . . . . 5.55

5.33 Geologic Cross Section H-H', Waste Management Area 4 . . . . . 5.57

5.34 Fence Diagram of the Stratigraphy Beneath Waste Management Area 4. . . . . 5.59

5.35 Generalized Stratigraphy for Waste Management Areas 3 and 4. . . . . 5.62

5.36 Surface of the Top of Basalt Beneath the 200-West Area 5.64

5.37 Isopach of the Basal Ringold Unit Beneath the 200-West Area. 5.66

5.38 Isopach of the Basal Ringold Unit Beneath the 200-West Area. 5.67

5.39 Surface of the Top of the Basal Ringold Unit Beneath the 200-West Area. 5.68

5.40 Surface of the Top of the Basal Ringold Unit Beneath the 200-West Area 5.69

5.41 Isopach of the Lower Ringold Unit Beneath the 200-West Area. 5.71

5.42 Surface of the Top of the Lower Ringold Unit Beneath the 200-West Area 5.72

5.43 Isopach of the Lower/Upper Basal Ringold Units Beneath the 200-West Area 5.73

5.44 Isopach of the Middle Ringold Unit Beneath the 200-West Area. 5.76

5.45 Surface of the Top of the Middle Ringold Unit Beneath the 200-West Area 5.77

5.46 Isopach of the Upper Ringold Unit Beneath the 200-West Area. 5.80

5.47 Surface of the Top of the Upper Ringold Unit Beneath the 200-West Area 5.81

5.48 Examples of the Variation in Natural-Gamma Response and Calcium Carbonate Content for the Plio-Pleistocene and Adjacent Stratigraphic Units. 5.83

5.49 Isopach of the Plio-Pleistocene Unit Beneath the 200-West Area 5.85

5.50 Surface of the Top of the Plio-Pleistocene Unit Beneath the 200-West Area 5.86

5.51 Isopach of the Early "Palouse" Soil Beneath the 200-West Area 5.89

5.52 Surface of the Top of the Early "Palouse" Soil Beneath the 200-West Area 5.91

5.53 Isopach of the Total Hanford Formation Beneath the 200-West Area 5.92

5.54 Isopach of the Basal Slack-Water Sequence Beneath the 200-West Area 5.95

5.55 Isopach of the Coarse-Grained Sequence Beneath the 200-West Area 5.96

5.56 Surface of the Top of the Basal Slack-Water Sequence Beneath the 200-West Area 5.98

6.1 Plan View of the 200 Areas Showing Locations of Reprocessing Facilities and Major Receiving Ponds and Cribs 6.3

6.2 Saturated Thickness of the Unconfined Aquifer Beneath Waste Management Areas 1 and 2 . . . . . 6.9

6.3 Water-Table Surface Beneath Waste Management Areas 1 and 2, Measured on March 8, 1988 . . . . . 6.11

6.4 Water-Table Surface Beneath Waste Management Areas 1 and 2, Measured on June 29, 1988 . . . . . 6.12

6.5 Water-Table Elevations for the Hanford Site, Measured in June 1987 . . . . . 6.14

6.6 Water-Table Surface Beneath the 200 Areas, Measured in December 1987 . . . . . 6.15

6.7 Water-Table Surface Beneath Waste Management Areas 3 and 4, Measured on March 9, 1988 . . . . . 6.21

6.8 Water-Table Surface Beneath Waste Management Areas 3 and 4, Measured on June 30, 1988 . . . . . 6.22

6.9 Hydrograph of Well 299-W18-15 Near U Pond 6.24

6.10 Generalized Hydrogeologic Cross Section Beneath Waste Management Areas 3 and 4 . . . . . 6.26

7.1 Total Beta Plumes Within the 200 Areas for 1987 . . . . . 7.2

7.2 Tritium Plumes Within the 200 Areas for 1987 . . . . . 7.3

7.3 Nitrate Plumes Within the 200 Areas for 1987 . . . . . 7.4

TABLES

2.1 Owners and Operators of the 200 Areas Low-Level Burial Grounds 2.4

2.2 Solid Radioactive-Mixed Waste Received Between 1968 and December 31, 1987 . . . . . 2.6

2.3 Estimated Radiologic Inventory for Burial Ground 218-E-10 . . 2.17

2.4 Hazardous Constituents Disposed to Burial Ground 218-E-10 Between 1968 and December 31, 1987 . . . . . 2.17

2.5 Estimated Radiologic Inventory for Burial Ground 218-E-12B . . 2.20

2.6 Hazardous Constituents Disposed to Burial Ground 218-E-12B Between 1968 and December 31, 1987 . . . . . 2.21

2.7 Estimated Radiologic Inventory for Burial Grounds 218-W-3A, 218-W-3A-E, and 218-W-5 . . . . . 2.24

2.8 Hazardous Constituents Disposed to Burial Grounds 218-W-3A, 218-W-3A-E, and 218-W-5 Prior to December 31, 1987 . . . . . 2.25

2.9 Estimated Radiologic Inventory for Burial Ground 218-W-4C . . 2.30

2.10 Hazardous Constituents Disposed to Burial Ground 218-W-4C Prior to December 31, 1987 . . . . . 2.30

3.1 Estimates of Wind Extremes at the Hanford Site 3.8

4.1 Past Hydrogeologic Studies of the 200 Areas. 4.4

4.2 Well Construction Information for 200-East Area Wells 4.14

4.3 Well Construction Information for 200-West Area Wells 4.15

5.1 Characteristics Used to Distinguish Sedimentary Units 5.4

5.2 Stratigraphic Contacts in 200-East Area Wells 5.11

5.3 Results of X-Ray Fluorescence Analysis of Basalt Samples from Waste Management Areas 1 and 2 . . . . . 5.24

5.4 Examples of Grain-Size Distribution of Ringold Formation Sediments Beneath Waste Management Area 1 . . . . . 5.28

5.5 Examples of Particle-Size Distribution of Hanford Formation Sediments Beneath Waste Management Areas 1 and 2 . . 5.32

5.6 Stratigraphic Contacts in 200-West Area Wells 5.61

5.7 Results of X-Ray Fluorescence Analysis of Basalt Samples from the 200-West Area 5.63

5.8 Hydrometer and Permeameter Test Data on Three Lower Ringold Split-Spoon Samples 5.70

5.9 Examples of Particle-Size Distribution in the Middle Ringold Unit Beneath Waste Management Areas 3 and 4 . . . . . 5.75

5.10 Examples of Particle-Size Distribution and Calcium Carbonate Content of the Upper Ringold Unit Beneath Waste Management Areas 3 and 4 . . . . . 5.79

5.11 Examples of Particle-Size Distribution and Calcium Carbonate Content of the Plio-Pleistocene Unit Beneath Waste Management Areas 3 and 4 . . . . . 5.84

5.12 Examples of Particle-Size Distribution and Calcium Carbonate Content of the Early "Palouse" Soil Beneath Waste Management Areas 3 and 4 . . . . . 5.88

5.13 Examples of Particle-Size Distribution and Calcium Carbonate Content of Hanford Formation Sediments Beneath Waste Management Areas 3 and 4 . . . . . 5.93

6.1 Thicknesses and General Lithology of the Unsaturated Zone Beneath the Waste Management Areas 6.5

6.2 Summary of Aquifer Test Results for 200-East Area Wells . . . 6.8

6.3 Summary of Aquifer Test Results for 200-West Area Wells . . . 6.18

8.1 Laboratory Analyses of 200-East Area Borehole Samples 8.2

8.2 Laboratory Analyses of 200-West Area Borehole Samples 8.3

1.0 INTRODUCTION

This report presents the current understanding of the hydrogeology of six low-level burial grounds (LLBGs) located in the 200-East and 200-West Areas of the Hanford Site in southeastern Washington State (Figure 1.1). The information presented in this report was collected and interpreted by the Pacific Northwest Laboratory (PNL) at the request of Westinghouse Hanford Company (WHC). The majority of this information was derived from sampling and testing activities performed during the recent construction of 35 ground-water monitoring wells. These activities were conducted under a quality program based on applicable criteria of ANSI/ASME NQA-1 (1986) as reflected in PNL's quality assurance manual. The program implemented meets the intent of the U.S. Environmental Protection Agency (EPA; Stanley and Verner 1983).

A ground-water monitoring project for the 200 Areas LLBGs was initiated in 1986 in response to Consent Agreement and Compliance Order DE 86-133 issued to the U.S. Department of Energy (DOE) by the State of Washington.[a] The ground-water monitoring project is based on requirements for interim status facilities (these are defined as being authorized to continue interim operations while engaged in the process of obtaining final permits), as defined by the Resource Conservation and Recovery Act (RCRA; 1976) and as amended in 1984. These regulations are promulgated by the EPA in 40 CFR 265 Subpart F (EPA 1984), and by the State of Washington Department of Ecology (hereafter called Ecology) in Washington Administrative Code (WAC) 173-303-400 (Ecology 1986).

The ground-water monitoring project for the 200 Areas LLBGs is both a background monitoring project and an indicator evaluation (detection level) required to provide immediate detection of significant amounts of hazardous waste constituents that migrate from the waste management area (WMA) to the uppermost aquifer. The initial plan for this program was issued in February 1987 (PNL 1987). This plan grouped individual waste trenches and burial

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(a) Letter from Kathleen D. Mix, Assistant Attorney General, State of Washington, Olympia, Washington, to Robert Carosino, Attorney, U.S. Department of Energy, Richland, Washington, October 2, 1986.

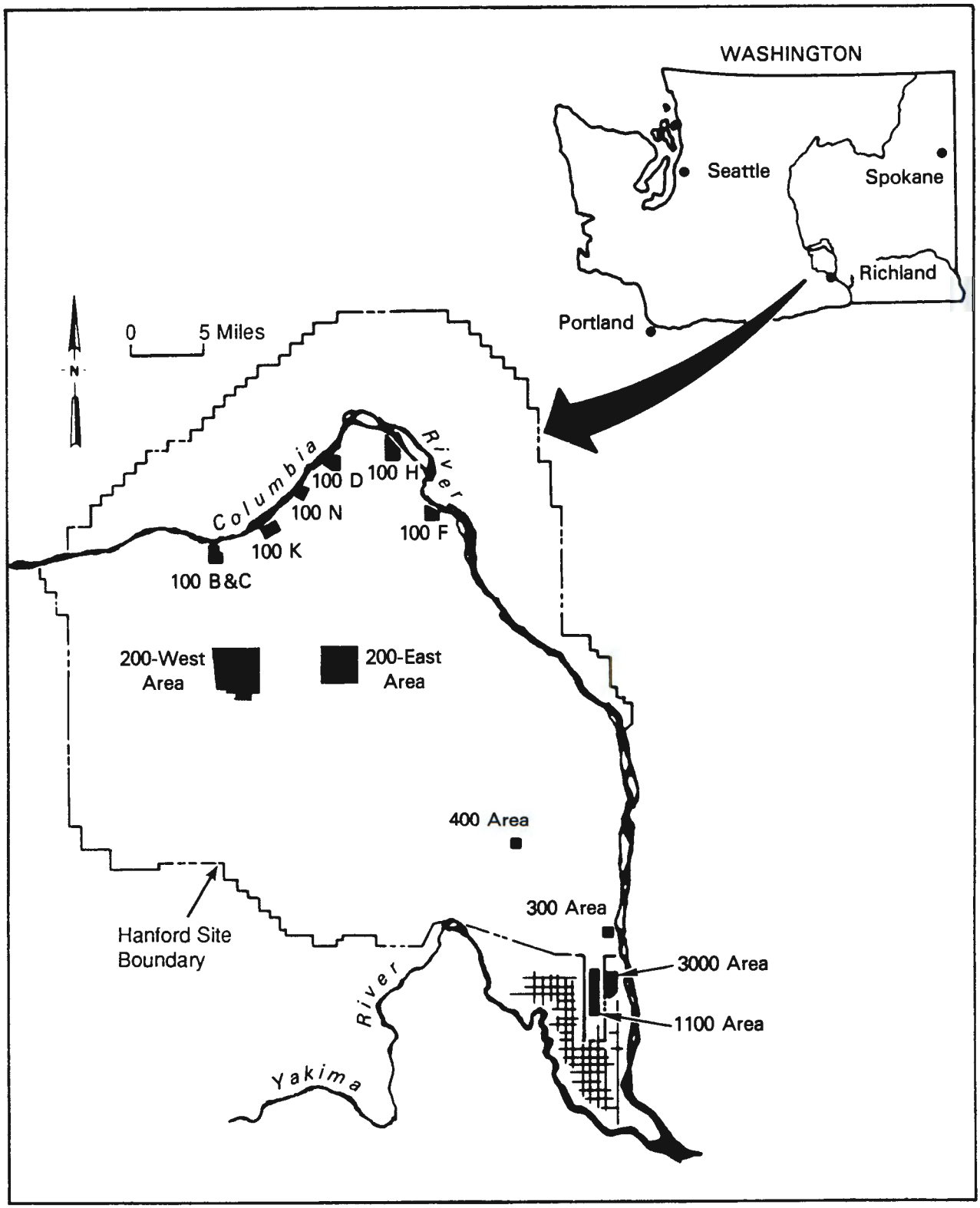

FIGURE 1.1. Location of the 200 Areas of the Hanford Site

grounds into four WMAs, with a separate ground-water monitoring system planned for each. Five specific objectives were identified in this plan:

1. Develop a more complete picture of the hydrogeology in the area of the burial grounds.
2. Determine the vertical distribution of hydraulic potential in the aquifer in the vicinity of the burial grounds.
3. Determine the range and distribution of hydraulic conductivity values for the glaciofluvial sediments and Ringold Formation.
4. Determine storativity and effective porosity of the Hanford and Ringold Formations.
5. Determine, based on site-specific sampling and analyses, the physical and geochemical parameters controlling contaminant movement, and whether contaminants (by species or group) have entered the ground-water system from the LLBGs.

Installation of ground-water monitoring wells was a necessary element for achieving these objectives. Thirty-five wells were planned for these burial grounds: 16 in the 200-East Area and 19 in the 200-West Area. These wells were planned to provide hydrogeologic characterization data, as well as long-term ground-water monitoring capabilities. Installation of these wells began on May 20, 1987, and was completed on November 30, 1987.

Geologic sampling, aquifer testing, and predevelopment ground-water sampling were performed during the installation of the monitoring wells. The initial evaluation of these data in addition to preexisting data is the focus of this report. Collection and evaluation of additional data from these new wells are ongoing, and the conclusions, recommendations, and plans that can be made at this time are based on the available data. The purposes of this report are to provide input for development of a Revised Ground-Water Monitoring Plan, which will assess the adequacy of the hydrogeologic characterization and the newly installed ground-water monitoring system, and to identify additional activities, if any, required to achieve full compliance with these regulations.

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2.0 DESCRIPTION OF THE LOW-LEVEL BURIAL GROUNDS

This section describes the location and physical layout of the 200 Areas LLBGs, the facility operators, the general disposal practices, and the operational history of burial grounds within each WMA. The purpose of this section is to provide the reader with a basic understanding of the disposal facilities and the waste constituents of interest. It is not intended to provide complete details of the current waste disposal practices or investigations, and is based only on information available through August 1, 1988.

2.1 SITE LOCATION AND LAYOUT

The LLBGs are located in two controlled areas on the Hanford Site, the 200-East Area and the 200-West Area. These two areas (also referred to as the Separations Areas) contain the nuclear fuels reprocessing and plutonium separations facilities, as well as the majority of radioactive waste storage and disposal facilities on the Hanford Site. More than 45 years of operations in these areas have resulted in the storage, disposal, and accidental release of radioactive and/or hazardous wastes. Solid wastes generated by the operating facilities have routinely been disposed in designated shallow-land burial trenches or stored in retrievable storage units (RSU). These burial trenches and/or RSUs have been constructed in groups referred to as LLBGs. Only the following burial grounds are of interest to this investigation: 218-E-10, 218-E-12B, 218-W-3A, 218-W-3A-E, 218-W-4C, and 218-W-5. Other burial grounds or other portions of these burial grounds may be incorporated into this ground-water monitoring project in the near future, and will be incorporated into the Revised Ground-Water Monitoring Plan.

For ease of monitoring, the LLBGs are grouped into four WMAs. One of these WMAs encompasses portions of three burial grounds, while the other WMAs cover portions of only one burial ground each. Figures 2.1 and 2.2 illustrate the locations of the burial grounds and their relationship to the WMAs. The submarine compartment disposal portion of burial ground 218-E-12B was not included in WMA-2. The unused portions of the burial grounds, designated for future expansion, are also not included in these WMAs.

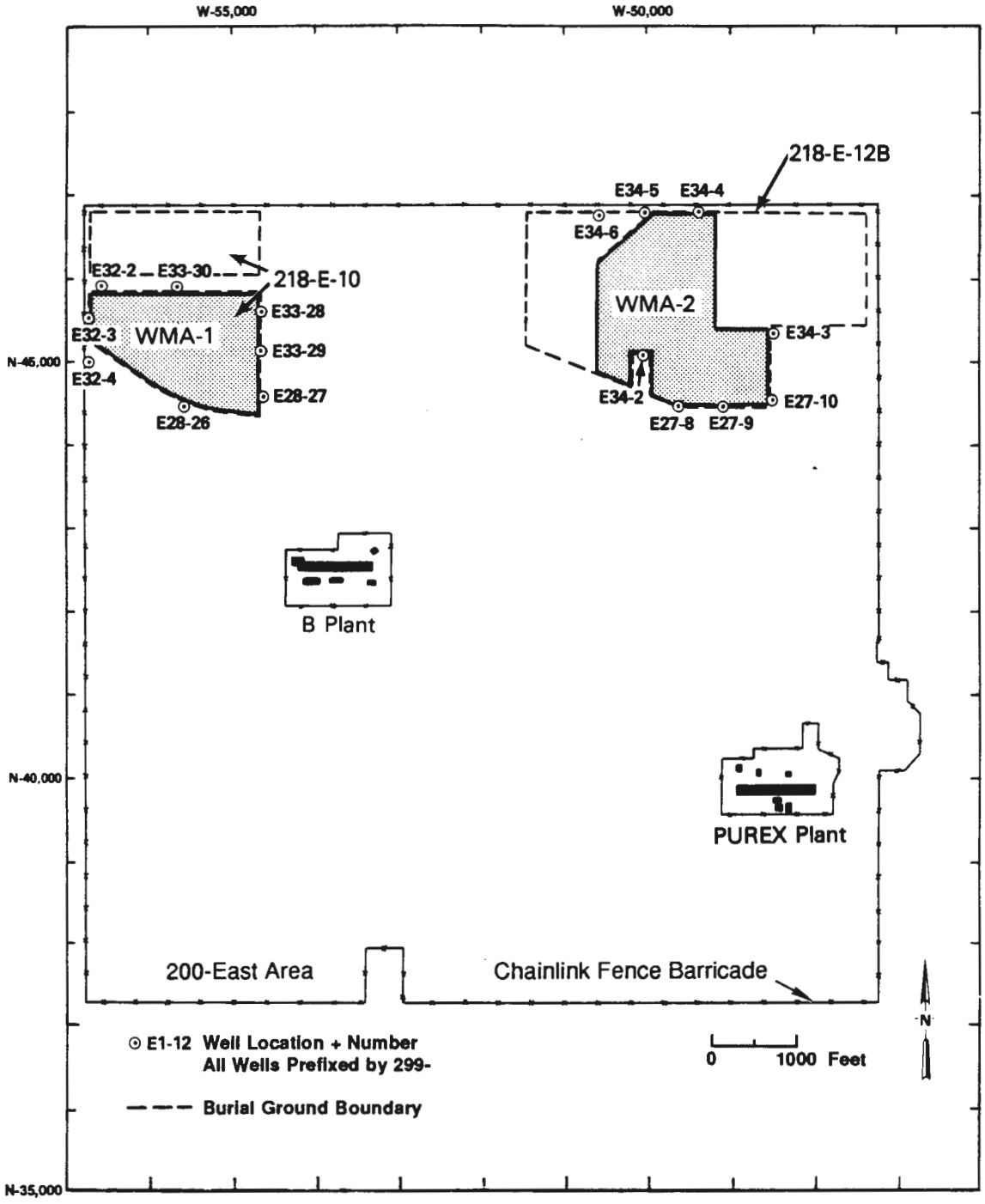

FIGURE 2.1. Location of Waste Management Areas 1 and 2 in the 200-East Area

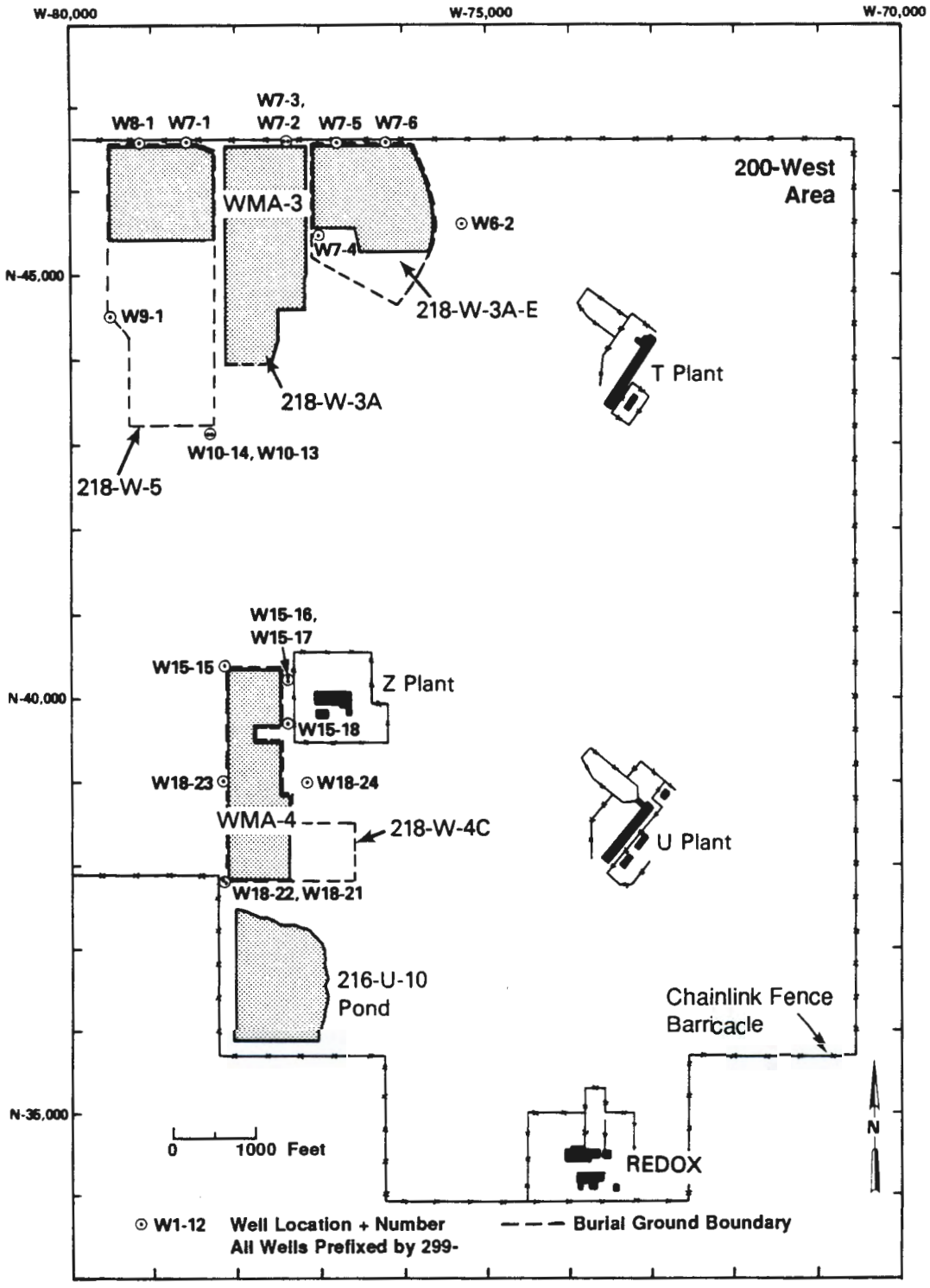

FIGURE 2.2. Location of Waste Management Areas 3 and 4 in the 200-West Area

2.2 FACILITY OPERATORS

The 200 Areas LLBGs have been operated by several companies under contract to DOE or its predecessors. The owners, operating contractors, and their respective periods of operation are listed in Table 2.1.

2.3 DISPOSAL PRACTICES BEFORE 1987

Solid low-level radioactive, transuranic (TRU), and radioactive-mixed wastes have been stored or disposed of in shallow unlined trenches since 1944. Low-level radioactive waste is defined as radioactive material not classified as high-level waste, spent nuclear fuel, or by-product material. Transuranic waste is defined as radioactive waste that is contaminated with alpha-emitting transuranium nuclides with half-lives greater than 20 years and concentrations greater than 100 nCi/g (DOE 1987, p. 8.19).

TABLE 2.1. Owners and Operators of the 200 Areas Low-Level Burial Grounds (from Wilson 1987)

Owners	Operators
December 1942	December 21, 1942
Manhattan Engineer District of the U.S. Army Corps of Engineers	E. I. du Pont de Nemours and Company
	September 1, 1946
January 1947	
	General Electric Company
U.S. Atomic Energy Commission	January 1, 1966
	Isochem
	September 1, 1967
1974	
U.S. Energy Research and Development Administration	Atlantic Richfield Hanford Company
1977	July 1, 1977
U.S. Department of Energy	Rockwell Hanford Operations
	June 29, 1987
	Westinghouse Hanford Company

Radioactive-mixed waste is waste that contains both radioactive and hazardous materials. Between 1944 and 1970, all solid waste (bulk quantities of trash, soiled clothing, failed equipment, and laboratory and process waste) was routinely placed in designated shallow-land burial trenches and covered with soil (DOE 1987). These wastes were packaged in cardboard boxes, wooden boxes, steel drums, concrete burial vaults, or other containers. Initially, no attempt was made to segregate these wastes as to type or level of radioactivity. Before 1968, essentially all solid wastes disposed in the 200 Areas LLBGs were generated during operation of the 200 Areas facilities or from offsite government facilities. After 1968, wastes from 100 Area operations were also designated for burial in the 200 Areas LLBGs. Since May 1970, solid waste classed as TRU waste has been segregated from the other solid wastes and placed in 20-year RSUs (DOE 1987, p. 3.8). Solid wastes from the 300 Area operations have been buried in the 200 Areas LLBGs since 1972. Small volumes of solid waste generated by offsite government operations have also been buried there (ERDA 1975, p. II.1-48). Some of the hazardous constituents received in solid radioactive waste in the past are listed in Table 2.2.

2.4 CURRENT DISPOSAL PRACTICES

Solid low-level radioactive and radioactive-mixed wastes reading greater than 200 mR/h at contact are disposed in unlined burial trenches in the 200 Areas LLBGs. Transuranic wastes and some radioactive-mixed wastes are stored in RSUs in the 200 Areas LLBGs, but are designated for removal and storage in an approved aboveground radioactive-mixed waste storage facility. Some of these wastes are designated as Dangerous Waste and Extremely Hazardous Waste under Ecology regulations (Ecology 1986).

Only those hazardous materials that exist as co-contaminants with the radioactive contaminants are disposed at Hanford. Nonradioactive hazardous materials (with the exception of lead for shielding) are not allowed to be mixed with the radioactive waste for storage or disposal.

Only radioactive solid waste is accepted for storage/disposal in the burial grounds facilities. However, small quantities of radioactive waste containing free liquid organic chemicals are occasionally accepted for storage in the RSUs. Before storage or disposal, the wastes are treated and/or

TABLE 2.2. Solid Radioactive-Mixed Waste Received Between 1968 and December 31, 1987

Acetonitrile
Acid
Aliquat 336
Aluminum nitrate
Amalgamated mercury
Anase
Antifreeze
Asbestos
Barium
Batteries
Beryllium
Beryllium zinc
Beryllium zirconium
Butyl acetate
Cadmium
Carbon tetrachloride
Carcinogens
Caustic
Charcoal
Chromium
Copper
Copper sulfate
Corrosive
Cortisporin
Creosote
Cyclohexane
Cyclohexanone
DDCP
Dibutyl phosphate
Dioxane
Ethanol
Ethanolamine
Ethylene glycol
Freon 12
Freon II
Glycerine
Hexane
Hexanol
Isopropanol
Isopropyl alcohol
Kerosene
Lead
Lead brick
Lead cadmium
Lead shielding
Lead pies
Lithium fluoride
Mercury
Methanol
Napthlamine tritium
Napthyalene
Nitrate
Nitric acid
Normal paraffin hydro
Oil
Organic
Polychlorinated biphenyls
Polychlorinated biphenyl, oil
Paint thinner
Perchloroethylene
Phosphoric acid
Polyurethane
Potassium chloride
Potassium nitrate
Psuedocumene
Silver
Silver nitrate
Slaked lime
Sodium
Sodium chloride
Sodium diuranate
Sodium fluoride
Sodium hydroxide
Sodium nitrate
Solvents
Sulfuric acid
Tar
Toluene
Tributyl phosphate
Trichlorethane
Triclorethylene
Trioctyl phosphine 0
Tetrahydrofuran
Uranium hexafluoride
Vinyl chloride
Xylene
Xylene/psuedocumene
Xylene/toluene
Zirconium

packaged in selected systems specifically engineered to isolate the wastes. Low-level scintillation liquids generated at Hanford or other DOE facilities consist primarily of xylene, toluene, or a mixture of the two chemicals. The scintillation liquid is used as a carrier fluid for liquid scintillation counting, primarily to measure tritium and carbon-14 concentrations. These liquid wastes are sealed in small (20-mL) glass vials. As many as 2,000 of these vials are then overpacked into a 55-gal galvanized or aluminized steel drum. Other low-level liquid wastes, consisting primarily of solvents and reagents used in research and development projects, are sealed in small (up to 15-gal) metal or plastic containers that are overpacked in 55-gal galvanized steel drums. The drummed wastes are then transported to the storage facilities. All containers in storage are designed to meet 40 CFR 264.175 (EPA 1981), 40 CFR 270.15 (EPA 1983), and WAC 173-303-630 (Ecology 1986).

Radioactive wastes that are reactive, pyrophoric, incompatible with other waste in the same containers, or explosive are not accepted for disposal or storage until they are converted to "safe" forms. Radioactive wastes that are corrosive are also not accepted unless internal container protection has been provided.

Various waste types are segregated into separate trenches or facilities within the burial grounds. Each shipment of waste received at the 200 Areas LLBGs must be accompanied by accurate and complete solid waste burial records and uniform hazardous waste manifests. The waste generator is required to complete these forms and identify and quantify all hazardous constituents present. The waste generator also enters the burial compliance check sheet approval number on these forms.

Operations personnel perform radiological surveys and visual inspection of waste packages, and review the accompanying documentation on receipt of waste. If the waste and accompanying documentation are determined to be acceptable, the waste is stored or disposed according to Hanford radioactive solid waste packaging, storage, and disposal requirements.

Two types of disposal trenches are used in the burial grounds: "V" trenches and wide-bottom trenches. "V" trenches are normally dug 16 ft deep and 0 to 16 ft wide at the bottom. Trench slopes range from 1:1 to 1:1.5. Waste placed into these trenches is backfilled with a minimum of 8 ft of soil as needed. Wide-bottom or industrial trenches may be as deep as 50 ft

and from 16 to more than 100 ft wide at the bottom. Trench slopes are usually 1:1.5 to avoid sloughing. If vehicular activity is required in the trench, the bottom of the trench is covered with several layers of crushed gravel. This layer also provides a base for stacking waste. All waste is either boxed, drummed, or self-contained (i.e., equipment). A wide-bottom trench is backfilled when equipment is available, usually when less than 100 linear ft of stacked waste are in the trench.

The RSUs consist of trenches or asphalt pads. Fire-retardant plywood is placed on the bottom of the trenches when asphalt is not present. Plywood is also placed between and on top of layers of waste placed both on the asphalt pads and in the trenches. All TRU waste and low-flashpoint liquid organic waste is then covered with a layer of heavy plastic and at least 4 ft of soil. Figure 2.3 shows a typical storage module in a low-level RSU.

Approximately 740,000 ft^3 of radioactive solid waste per year are stored or disposed in the 200 Areas LLBGs. Approximately 20,000 ft^3 of this waste are classed as TRU waste, and have been placed in RSUs and other storage facilities. Solid waste, designated as mixed waste (radioactive and hazardous) and disposed or stored at the Hanford Site, is currently estimated to be approximately 14,000 to 35,000 ft^3/yr (DOE 1987).

2.5 DESCRIPTION AND INVENTORIES OF THE WASTE MANAGEMENT AREAS

This section describes the operational use and approximate inventories of each of the WMAs and their associated burial grounds. Descriptions of the burial grounds are taken from Maxfield (1979), DOE (1986a), Waste Information Data System (WIDS), and Solid Waste Information Management Systems (SWIMS), both managed by WHC. The quality of these data varies with the standard practices in place at the time the data were collected. The accuracy and completeness of early data are highly questionable, while later data are much better. Figures 2.4 and 2.5 are aerial photographs of the 200-East and 200-West Areas, respectively, showing the location of each WMA.

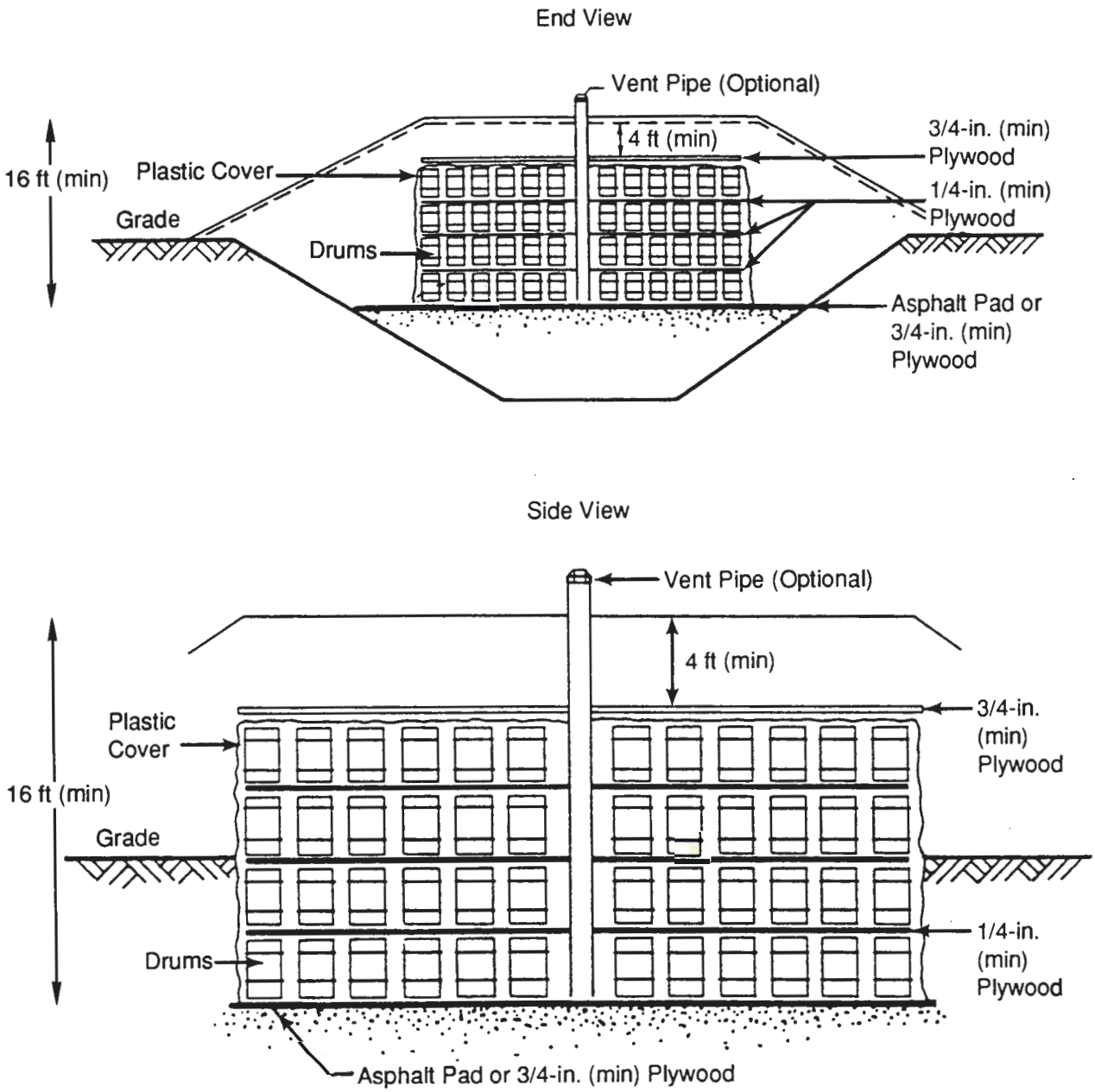

FIGURE 2.3. Typical Storage Module in the Low-Level Retrievable Storage Units

2.5.1 Waste Management Area 1

Waste Management Area 1 (WMA-1) covers all the 218-E-10 burial ground (see Figure 2.1). This burial ground covers an estimated 2.4 x 10^6 ft^2 and consists of 18 trenches running north-south and 1 trench running east-west (Figure 2.6). Trench 1 is 24 ft deep with bottom dimensions of 15 by

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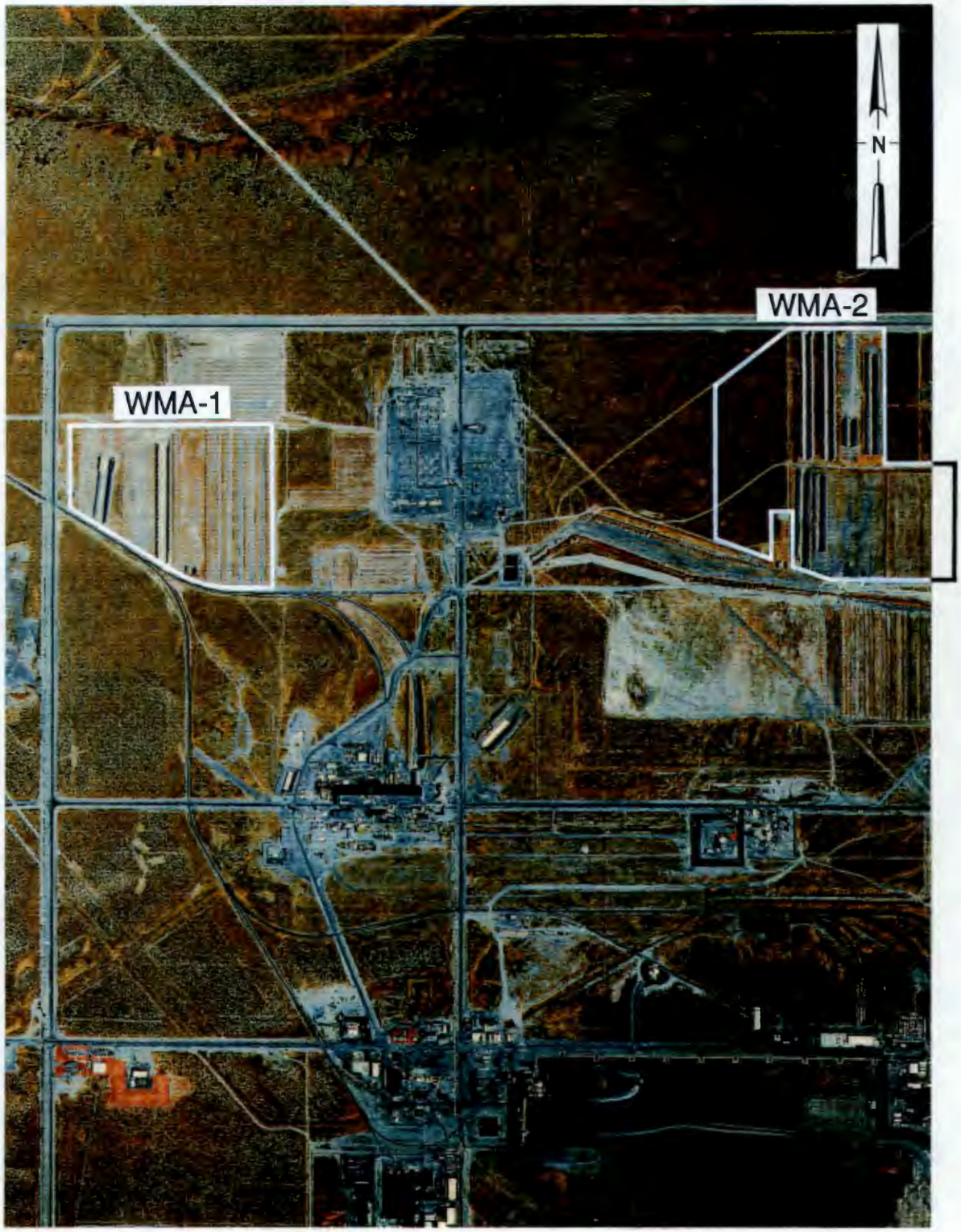

FIGURE 2.4. Aerial Photograph of the 200-East Area

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FIGURE 2.4. Aerial Photograph of the 200-West Area

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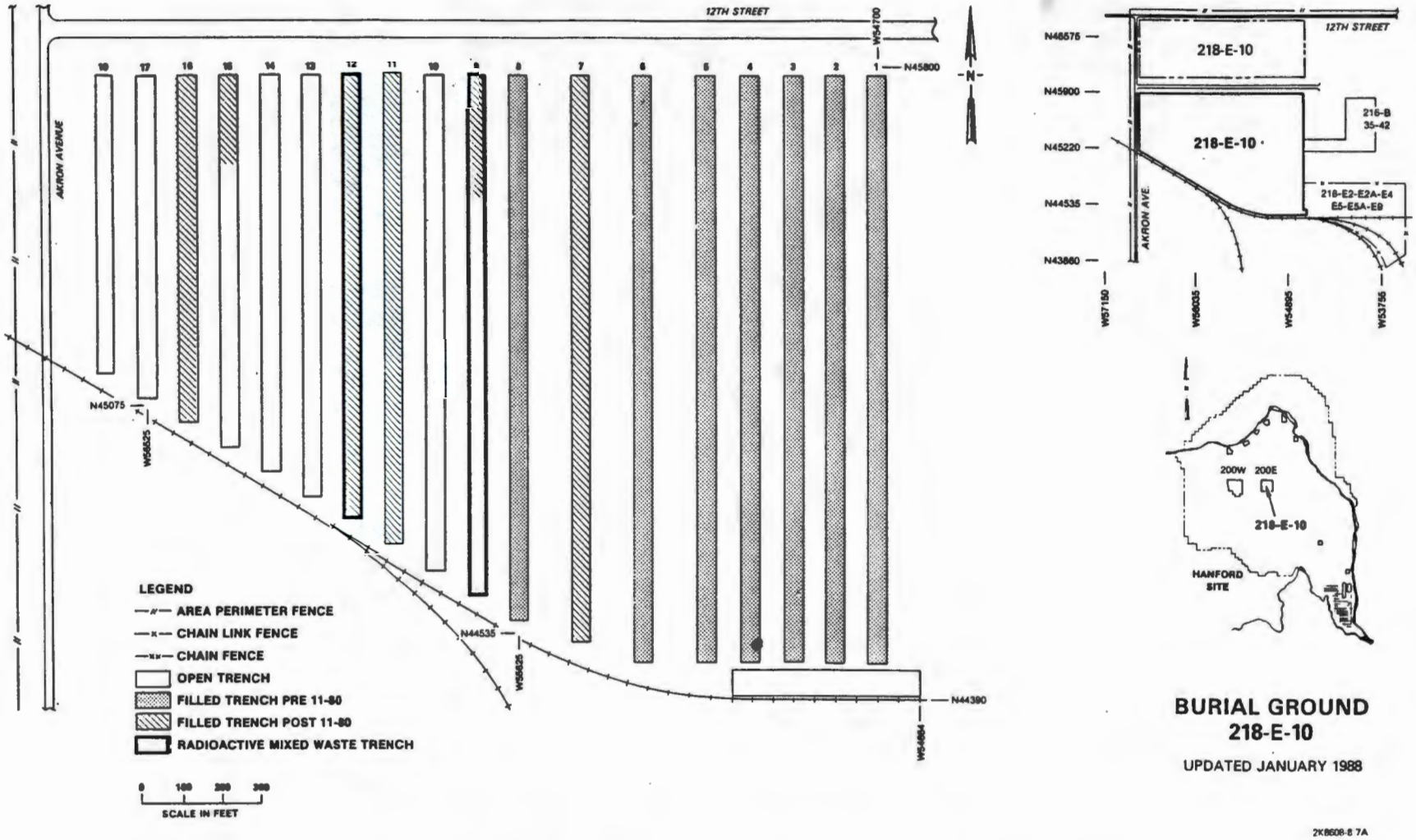


FIGURE 2.6. Layout of Burial Ground 218-E-10

1,300 ft. Trenches 2 through 18 are 15 ft deep, 16 ft wide, and vary in length from 805 to 1,145 ft. The east-west trench has bottom dimensions of 100 ft long by 15 ft wide. Details of the burial ground can be found in engineering drawing H-2-92004 (sheets 1 and 2) and H-2-99274 (sheets 2, 3, 4, and 5).[a]

Disposal operations began at this site in 1960 and continue to the present. Waste disposed of at this site has been received from the Plutonium-Uranium Extraction (PUREX) Plant, B Plant, and N Reactor, and consists primarily of "drag-off" wastes, failed equipment, and mixed industrial wastes (Maxfield 1979). The one trench oriented east-west contains 69 concrete hot cell cover blocks and 4 centrifuge blocks. The tops of the bails of these blocks are reportedly only 18 in. below grade. The approximate total waste volume for this WMA was 25,000 yd^3 as of January 1988, with an estimated total radiologic inventory of more than 2,000,000 Ci (decayed through September 30, 1987). A summary of the radiologic inventory is presented in Table 2.3. The hazardous constituents disposed to the burial ground between 1968 and December 31, 1987 [taken from the (SWIMS) data base] are presented in Table 2.4.

2.5.2 Waste Management Area 2

Waste Management Area 2 (WMA-2) covers the central portion of burial ground 218-E-12B (see Figure 2.1). The eastern portion of this burial ground is used for burial of radioactive submarine components. At the time of the compliance plan (PNL 1987), these submarine components, classed as by-product waste, were regulated under a separate Part A permit; therefore, this area was not included in WMA-2. The western portion of 218-E-12B, which was designated for future expansion, also was not included in WMA-2 because it is not yet in use.

The 218-E-12B burial ground began receiving waste in 1967 and is still listed as an active site. This burial ground covers approximately 8.6 x 10^6 ft^2 and contains 94 trenches that run north and south (Figure 2.7); 61 trenches are 1,212 ft long, 31 are 960 ft long, and the remaining trenches

---

(a) Engineering drawings on file with Westinghouse Hanford Company, Richland, Washington.

TABLE 2.3. Estimated Radiologic Inventory for Burial Ground 218-E-10. Taken from the WIDS[a] Data Base

Radionuclide	Activity, Ci[b]
^{14}C	83
^{54}Mn	8
^{60}Co	3,700
^{90}Sr	950,000
^{103}Ru	7
^{137}Cs	1,100,000
^{152}Eu, ^{154}Eu, ^{155}Eu	650
Total uranium	1
Total plutonium	560

(a) Waste Information Data System.
(b) Decayed through September 30, 1987.

TABLE 2.4. Hazardous Constituents Disposed to Burial Ground 218-E-10 Between 1968 and December 31, 1987. Taken from the SWIMS[a] data base.

Lead
Asbestos

(a) Solid Waste Information Management System.

vary in length from 307 to 1,901 ft. The trenches are generally 16 ft deep, with bottom widths from 0 to 10 ft. Some portions of the burial ground have been covered with an additional 2 ft of soil over the initial backfill and revegetated with shallow-rooted plants. Details of the burial ground can be found in engineering drawings H-2-33276 (sheets 1, 2, and 3) and H-2-99274 (sheets 6, 7, 8, 9, 10, and 11).

Waste disposed at this burial ground has been listed as miscellaneous dry waste (Maxfield 1979). Transuranic waste is present in parts of trenches 17 and 27. The volume of waste disposed in the 218-E-12B burial ground is estimated at 48,000 yd^3, with a total radiologic inventory of over 160,000 Ci (decayed through September 30, 1987). A summary of the radiologic

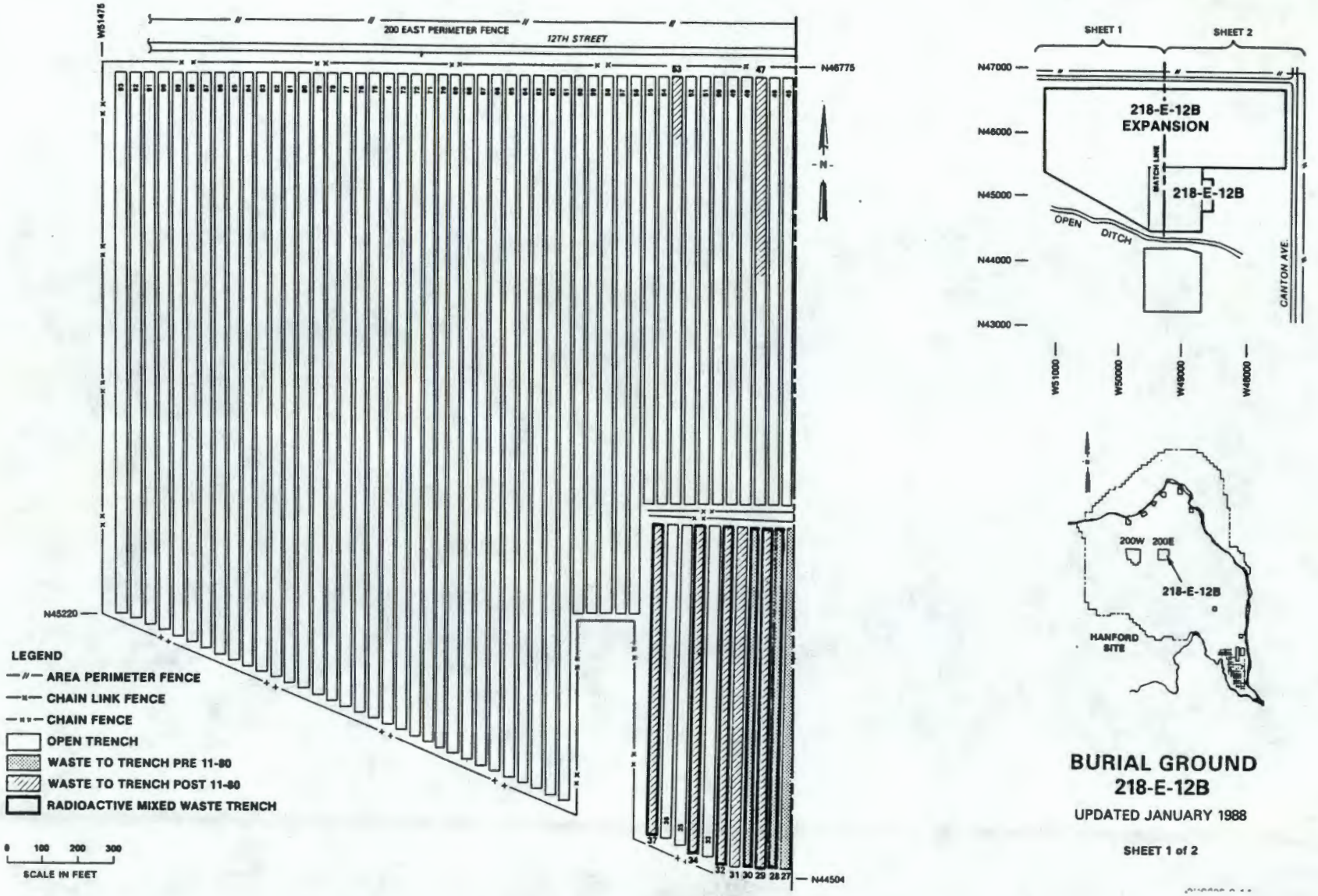


FIGURE 2.7. Layout of Burial Ground 218-E-12B

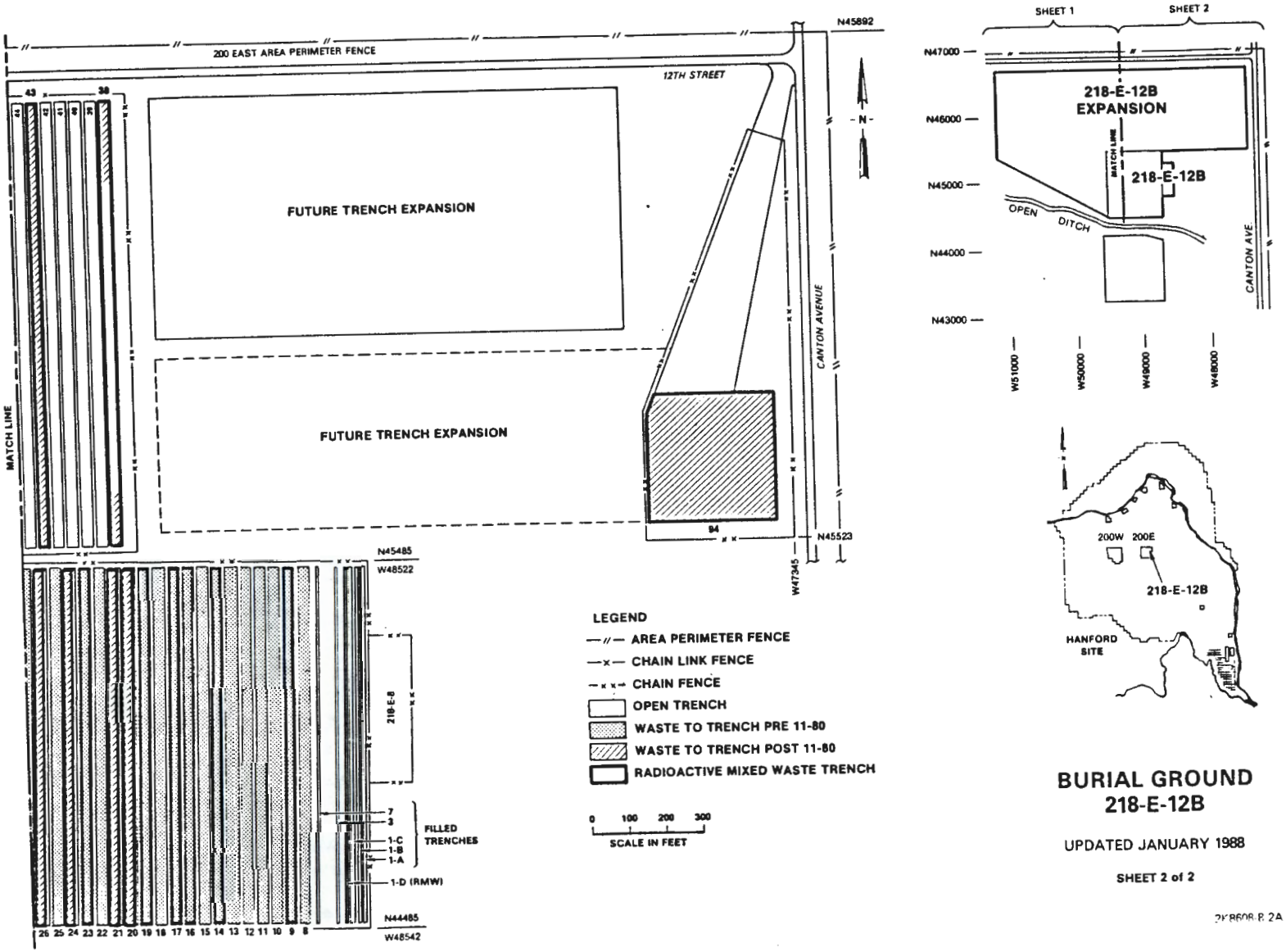


FIGURE 2.7. (contd)

inventory is presented in Table 2.5. A list of the hazardous constituents disposed between 1968 and December 31, 1987 is presented in Table 2.6.

2.5.3 Waste Management Area 3

Waste Management Area 3 (WMA-3) covers all of burial ground 218-W-3A and portions of 218-W-3A-E and 218-W-5 (see Figure 2.2). Those portions of 218-W-3A-E and 218-W-5 not included in WMA-3 are designated for future expansion and, currently, are not in use.

Burial ground 218-W-3A began receiving waste in 1970. This burial ground covers an area of 2.2×10^6 ft^2 and consists of 61 dry and industrial waste trenches (Figure 2.8), which are from 403 to 930 ft long. Details of the burial ground can be found in engineering drawings H-2-34880 (sheets 1 and 2) and H-2-99275 (sheet 3). Wastes disposed to this burial ground include: TRU and non-TRU wastes; waste from Three Mile Island cleanup; irradiated fuel elements from General Electric, Vallecitos, California; large concrete burial boxes of radioactive soil from a salt waste spill; and industrial waste.

TABLE 2.5. Estimated Radiologic Inventory for Burial Ground 218-E-12B. Taken from the WIDS[a] data base.

Radionuclide	Activity, Ci[b]
^{14}C	3
^{54}Mn	400
^{59}Fe	5
^{58}Co	20
^{60}Co	63,000
^{63}Ni	37,000
^{90}Sr	28,000
^{137}Cs	28,000
Total plutonium	170

(a) Waste Information Data System.
(b) Decayed through September 30, 1987.

TABLE 2.6. Hazardous Constituents Disposed to Burial Ground 218-E-12B Between 1968 and December 31, 1987. Taken from the SWIMS[a] data base.

Batteries
Copper
Creosote
Freon 12
Lead
Lead shielding
Mercury
Oil
Polyurethane
Sulfuric acid
Tar

(a) Solid Waste Information Management System.

The total volume of waste is estimated at 110,000 yd^3. The total radiologic inventory (decayed through September 30, 1987) is estimated at over 730,000 Ci. A summary of the radiologic inventory for the 218-W-3A burial ground is provided in Table 2.7. A list of the hazardous constituents disposed prior to December 31, 1987 is provided in Table 2.8.

Burial ground 218-W-3A-E was placed in operation in 1981. This burial ground covers an area of approximately 2.7×10^6 ft^2 and consists of 31 trenches, with lengths of approximately 1,075 to 1,246 ft, bottom widths of 18 to 48 ft, and depths of 16 to 20 ft (Figure 2.9). A minimum of 8 ft of backfill is placed over the waste. Details of the burial ground can be found in engineering drawings H-2-75351 (sheets 1 and 2) and H-2-99275 (sheets 3, 4, and 8). The waste disposed in this burial ground is described as miscellaneous waste (rags, paper, rubber gloves, disposable supplies, broken tools, etc.) and industrial waste (failed equipment, tanks, pumps, ovens, agitators, heaters, hoods, jumpers, vehicles, and accessories). An estimated 12,000 yd^3 of waste had been disposed as of January 27, 1988. The estimated total radiologic inventory for this burial ground is greater than

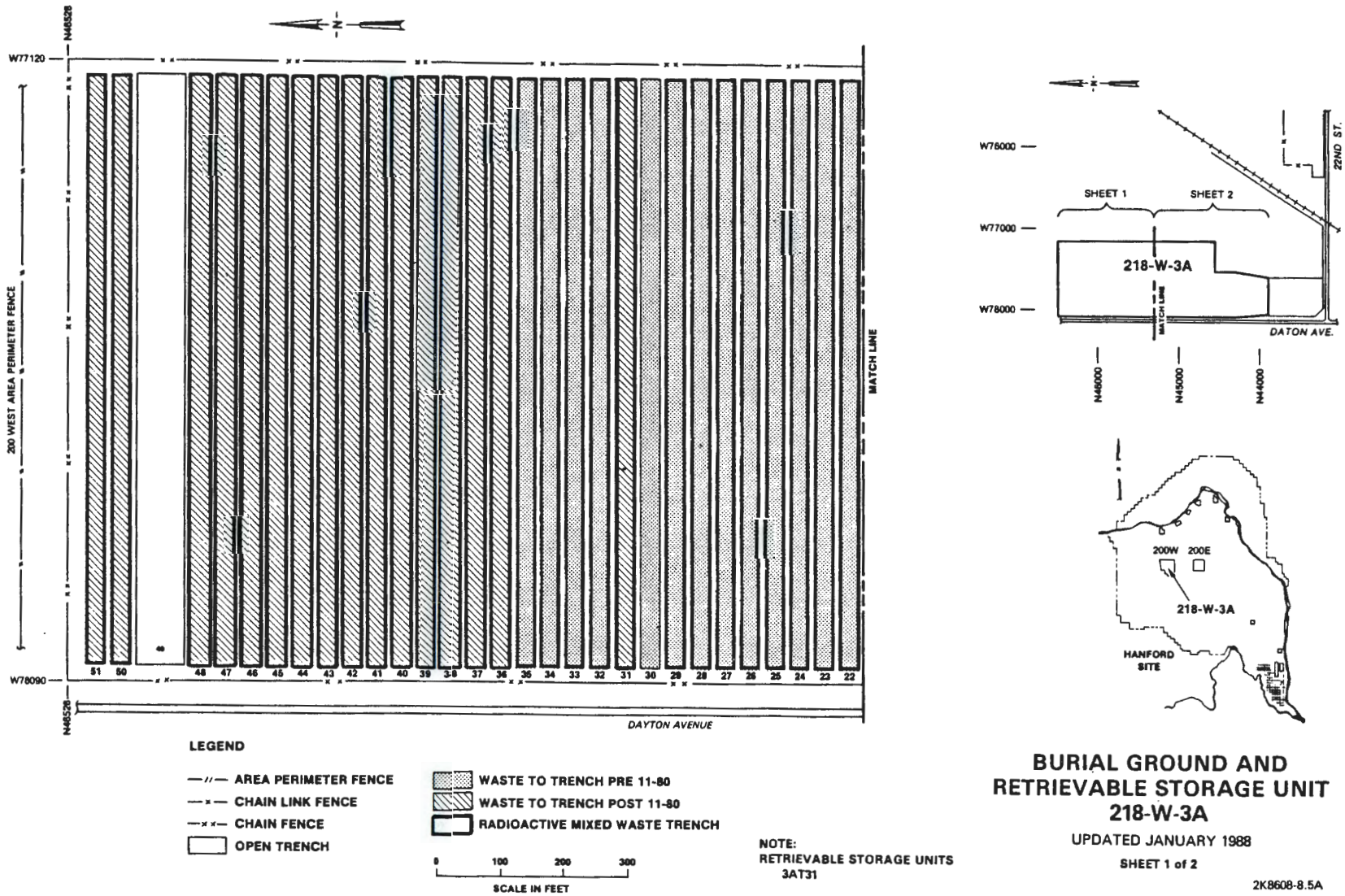
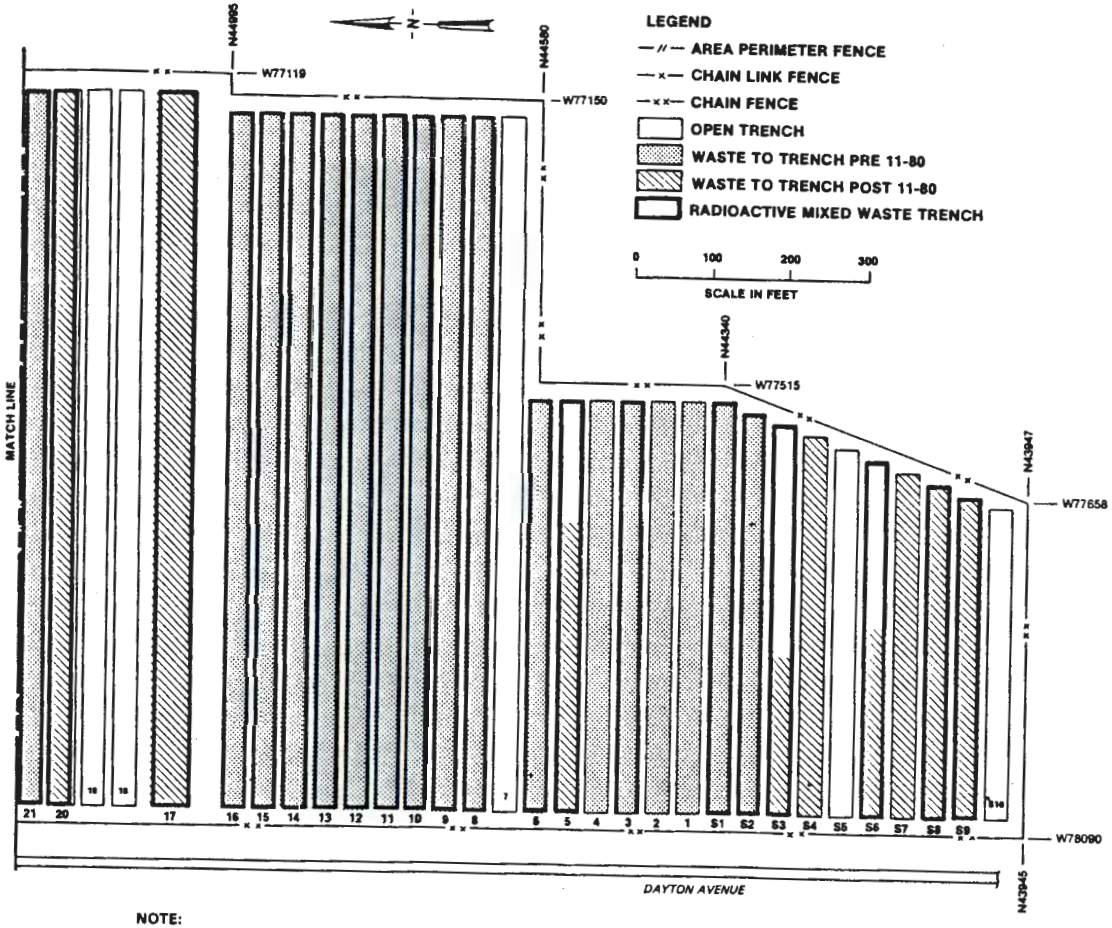
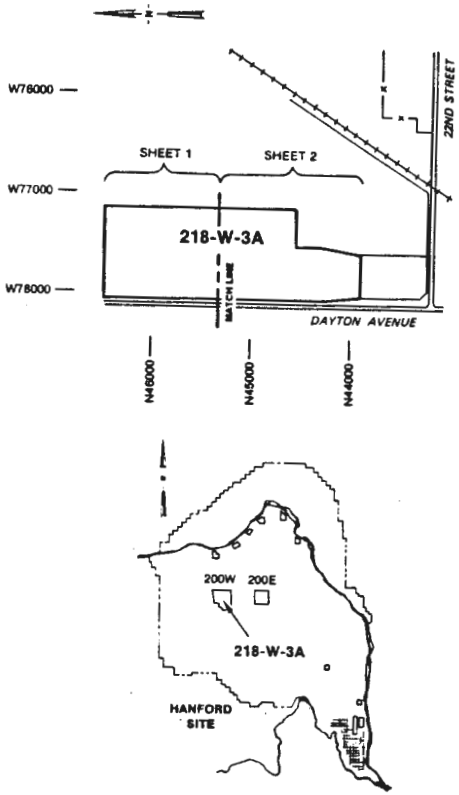


FIGURE 2.8. Layout of Burial Ground 218-W-3A



NOTE:
STORAGE RETRIEVABLE UNITS
3AT5
3ATS3
3ATS6



BURIAL GROUND AND RETRIEVABLE STORAGE UNIT 218-W-3A

UPDATED JANUARY 1988

SHEET 2 of 2

2K860R-R 4A

FIGURE 2.8. (contd)

TABLE 2.7. Estimated Radiologic Inventory for Burial Grounds 218-W-3A, 218-W-3A-E, and 218-W-5. Taken from the WIDS[a] data base.

Radionuclide	Activity, Ci[b]
Burial Ground 218-W-3A	
^{3}H	180,000
^{14}C	4,300
^{22}Na	1
^{54}Mn	15
^{60}Co	61,000
^{85}Kr	1,700
^{90}Sr	150,000
^{106}Ru	23
^{125}Sb	170
^{134}Cs	1,800
^{137}Cs	310,000
^{147}Pm	1,200
^{152}Eu, ^{154}Eu, ^{155}Eu	22,000
^{241}Am	71
Total uranium	88
Total plutonium	3,300

Radionuclide	Activity, Ci[b]
Burial Ground 218-W-3A-E	
^{3}H	23,000
^{14}C	10
^{54}Mn	13
^{60}Co	5,700
^{85}Kr	12
^{90}Sr	15,700
^{106}Ru	1
^{137}Cs	17,000
^{152}Eu, ^{154}Eu, ^{155}Eu	120
Total uranium	22
Total plutonium	1

Radionuclide	Activity, Ci[b]
Burial Ground 218-W-5	
^{3}H	910
^{14}C	6
^{54}Mn	7
^{59}Fe	1
^{58}Co	210
^{60}Co	2,300
^{90}Sr	40
^{106}Ru	1
^{137}Cs	73
^{152}Eu, ^{154}Eu, ^{155}Eu	91
^{241}Am	3
Total uranium	4
Total plutonium	1

(a) Waste Information Data System.
(b) Decayed through September 30, 1987.

TABLE 2.8. Hazardous Constituents Disposed to Burial Grounds 218-W-3A, 218-W-3A-E, and 218-W-5 Prior to December 31, 1987. Taken from the SWIMS[a] data base.

Burial Ground 218-W-3A

Acetonitrile
Aliquat 336
Amalgamated mercury
Anase
Asbestos
Barium
Batteries
Beryllium
Beryllium zinc
Butyl acetate
Cadmium
Carbon tetrachloride
Carcinogens
Caustic
Charcoal
Chromium
Copper
Cortisporin
Cyclohexane
Cylcohexanone
DDCP
Dibutyl phosphate
Dioxane
Ethanol
Ethanolamine
Ethylene glycol
Freon II
Glycerine
Hexane
Hexanol
Isopropanol
Isopropyl alcohol
Kerosene
Lead
Lead brick
Lead cadmium
Lead shielding
Lithium fluoride
Mercury
Methanol
Napthlamine tritium
Napthyalene
Nitric acid
Normal paraffin hydro
Oil
Organic
Phosphoric acid
Polyurethane
Psuedocumene
Silver
Silver nitrate
Slaked lime
Sodium
Sodium hydroxide
Solvents
Tar
Toluene
Tributyl phosphate
Triclorethylene
Trioctyl phosphine O
Tetrahydrofuran
Uranium hexafluoride
Xylene
Xylene/psuedocumene
Xylene/toluene
Zirconium

Burial Ground 218-W-3A-E

Aluminum nitrate
Asbestos
Beryllium
Beryllium zirconium
Carcinogens
Charcoal
Chromium
Copper
Freon II
Lead
Lead brick
Lead pies
Lead shielding
Mercury
Nitrate
Oil
Polychlorinated biphenyls, oil
Perchloroethylene
Potassium chloride
Potassium nitrate
Silver
Sodium chloride
Sodium fluoride
Sodium hydroxide
Sodium nitrate
Sulfuric acid
Tar
Trichlorethene
Zirconium

Burial Ground 218-W-5

Charcoal
Lead
Lead brick
Lead shielding
Oil
Slaked lime

(a) Solid Waste Information Management System.

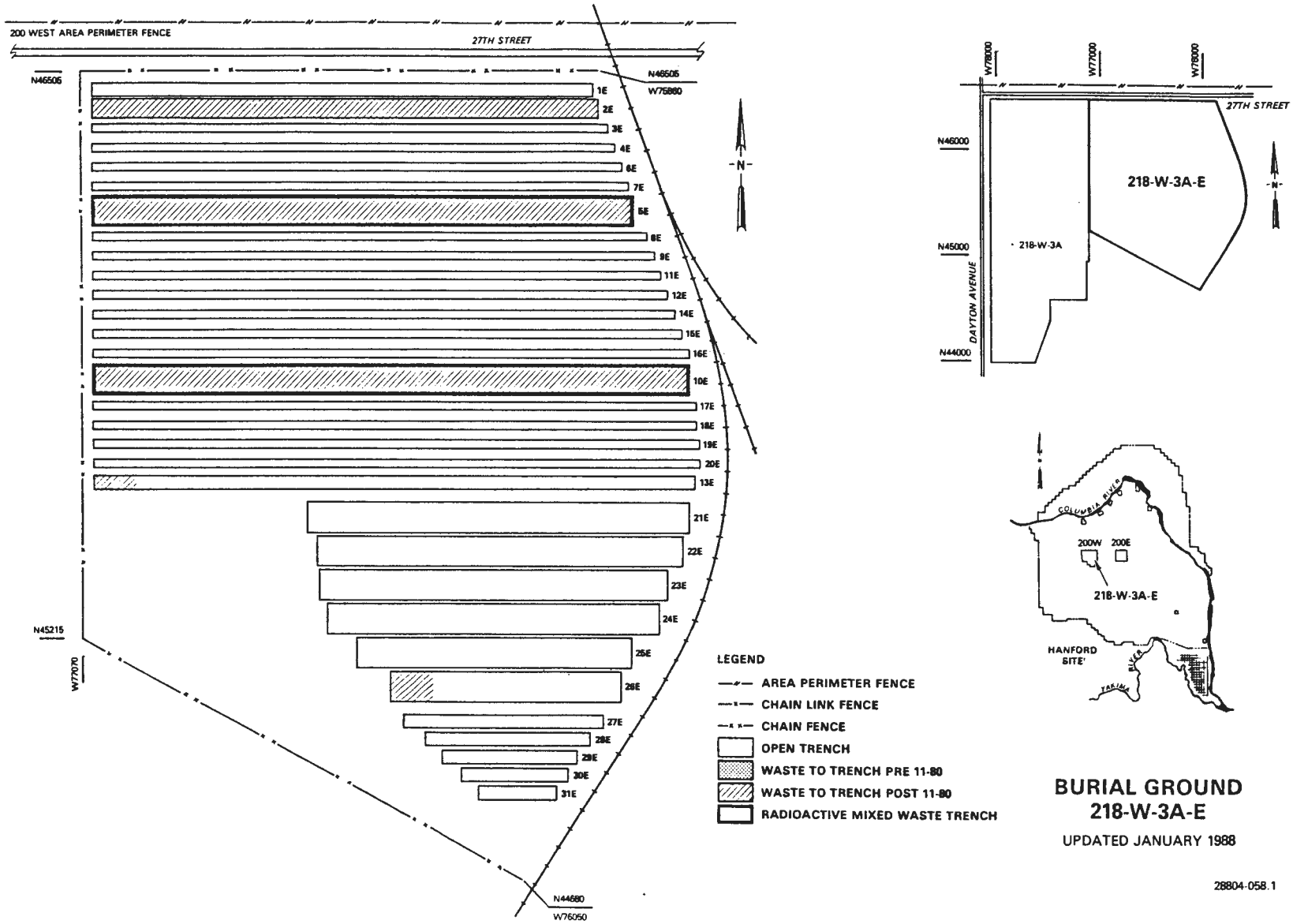


FIGURE 2.9. Layout of Burial Ground 218-W-3A-E

61,000 Ci. A summary of the radiologic inventory for burial ground 218-W-3A-E was provided in Table 2.7. The list of hazardous constituents disposed prior to December 31, 1987 was presented in Table 2.8.

Burial ground 218-W-5 began receiving waste in 1986, and covers an area of 3.7×10^6 ft^2 (Figure 2.10). The portion included in WMA-3 consists of 22 waste trenches. These trenches are 15 to 40 ft wide, 530 to 1,160 ft long, and 17 to 20 ft deep. Details of this burial ground can be found in engineering drawings H-2-94677 (sheets 1 and 2) and H-2-99275 (sheets 2, 3, 6, and 7). The total radiologic inventory for this burial ground is estimated at over 3,600 Ci. A summary of this radionuclide inventory was also provided in Table 2.7. The list of hazardous constituents disposed prior to December 31, 1987 was also provided in Table 2.8.

2.5.4 Waste Management Area 4

Waste Management Area 4 (WMA-4) covers the 218-W-4C burial ground, except for an eastern extension that is designated for future expansion and is not in use (see Figure 2.2). The 218-W-4C burial ground began receiving waste in 1978 and is still active. This burial ground covers approximately 2.2×10^6 ft^2. The portion included in WMA-4 contains 59 trenches running east-west (Figure 2.11). Some of these trenches are designated as retrievable storage. These trenches range from 299 to 719 ft long. Details of the burial ground can be found in engineering drawings H-2-37437 (sheets 1, 2, and 3) and H-2-99275 (sheets 9 and 10).

The Navy Reactor Core Trench (north end) contains a number of submarine reactor core barrels. Trench 1 contains drums with plutonium-contaminated soil from the 216-Z-9 Crib and noncombustible TRU waste (from WIDS). Trench 4 contains drums of assorted combustible TRU waste and one module of noncombustible TRU waste. The remaining trenches contain segregated TRU wastes. As of January 27, 1988, 16,000 yd^3 of waste have been placed in this burial ground, with an estimated total radiologic inventory of 640,000 Ci (from WIDS). Table 2.9 summarizes the estimated radionuclide inventory for this burial ground. A list of the hazardous constituents disposed prior to December 31, 1987 is presented in Table 2.10.

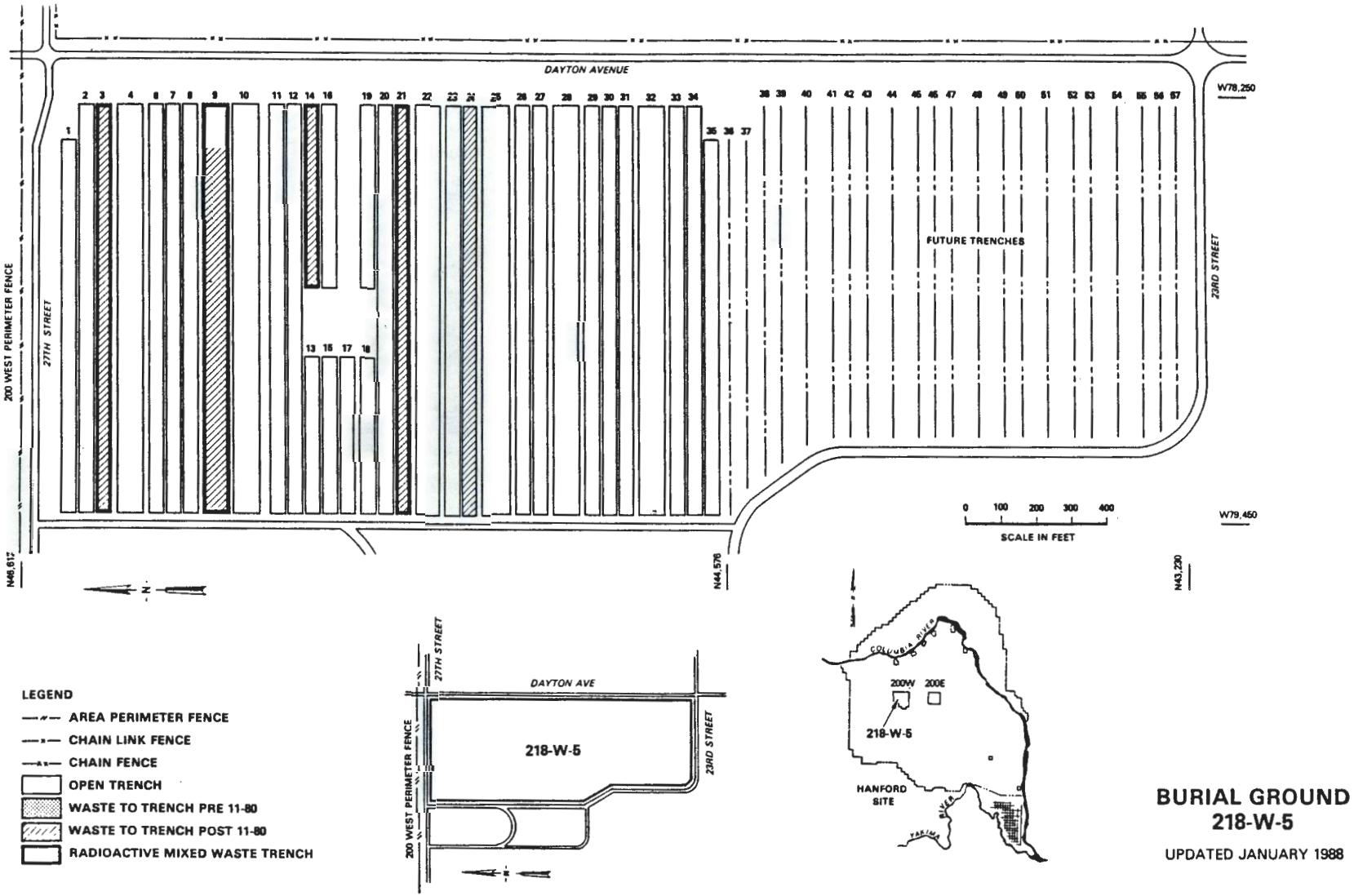
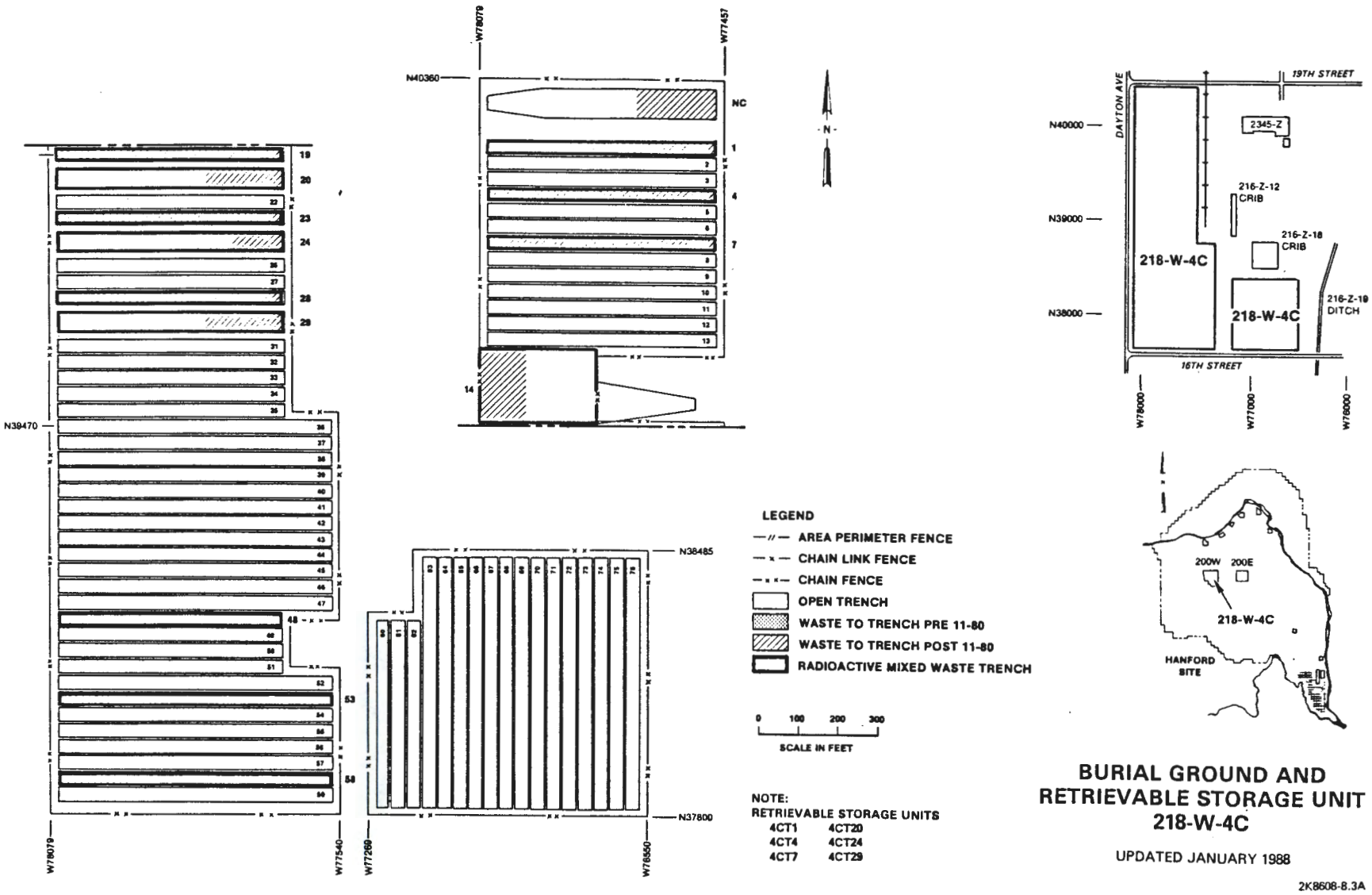


FIGURE 2.10. Layout of Burial Ground 218-W-5



BURIAL GROUND AND RETRIEVABLE STORAGE UNIT 218-W-4C

UPDATED JANUARY 1988

2K8608-8.3A

FIGURE 2.11. Layout of Burial Ground 218-W-4C

TABLE 2.9. Estimated Radiologic Inventory for Burial Ground 218-W-4C. Taken from WIDS[a] data base.

Radionuclide	Activity, Ci [b]
^{3}H	30
^{14}C	1
^{54}Mn	430
^{59}Fe	91
^{58}Co	310
^{60}Co	320,000
^{63}Ni	8,800
^{90}Sr	130,000
^{106}Ru	8
^{137}Cs	140,000
^{152}Eu, ^{154}Eu, ^{155}Eu	18
^{241}Am	490
Total uranium	7
Total plutonium	39,000

(a) Waste Information Data System.
(b) Decayed through September 30, 1987.

TABLE 2.10. Hazardous Constituents Disposed to Burial Ground 218-W-4C Prior to December 31, 1987. Taken from the SWIMS[a] data base.

Acid	Organic
Antifreeze	Paint thinner
Beryllium	Slaked lime
Chromium	Sodium
Copper	Sodium diuranate
Copper sulfate	Sodium fluoride
Corrosives	Sodium hydroxide
Lead	Sodium nitrate
Lead brick	Solvents
Lead shielding	Tar
Mercury	Uranium hexafluoride
Nitric acid	Vinyl chloride
Oil	Zirconium

(a) Solid Waste Information Management System.

3.0 ENVIRONMENTAL SETTING

The 200 Areas LLBGs are located in the central portion of DOE's Hanford Site in south-central Washington. This section describes the regional environmental setting of the Hanford Site, including its physiography, climate, geology (stratigraphy, tectonic framework, seismicity), and hydrology.

3.1 REGIONAL PHYSIOGRAPHY

The Hanford Site lies within the Central Plains and Yakima Folds physiographic regions within the Columbia Basin subprovince of the Columbia Intermontane Province (Figures 3.1 and 3.2). The dominant geologic characteristics of the Columbia Intermontane Province have resulted from flood basalt volcanism and regional deformation. The Columbia Plateau is the portion of the Columbia Intermontane Province that is covered by the Columbia River Basalt Group (Thornbury 1965).

The physiography of the Hanford Site is dominated by the low-relief plains of the Central Plains region and a few basaltic ridges of the Yakima Folds region (Gable Mountain-Umtanum Ridge, Yakima Ridge, and Rattlesnake Hills), which rise above these plains in the western portion of the Hanford Site.

The surface topography of the Hanford Site has been modified by two principal geomorphic processes: 1) Pleistocene cataclysmic flooding, and 2) Holocene eolian activity. Cataclysmic flood deposits formed when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington forming the channeled scabland. The last major flood occurred approximately 13,000 years ago, during the late Pleistocene. Landforms in the Pasco Basin, left behind as a result of late Pleistocene flooding, are shown in Figure 3.3. Among these are anastomosing flood channels, giant current ripples, bergmounds (Fecht and Tallman 1978), and giant flood bars. One of these flood bars forms a prominent terrace, referred to as Cold Creek bar (Bretz et al. 1956). The 200 Areas of the Hanford Site are located along this bar.

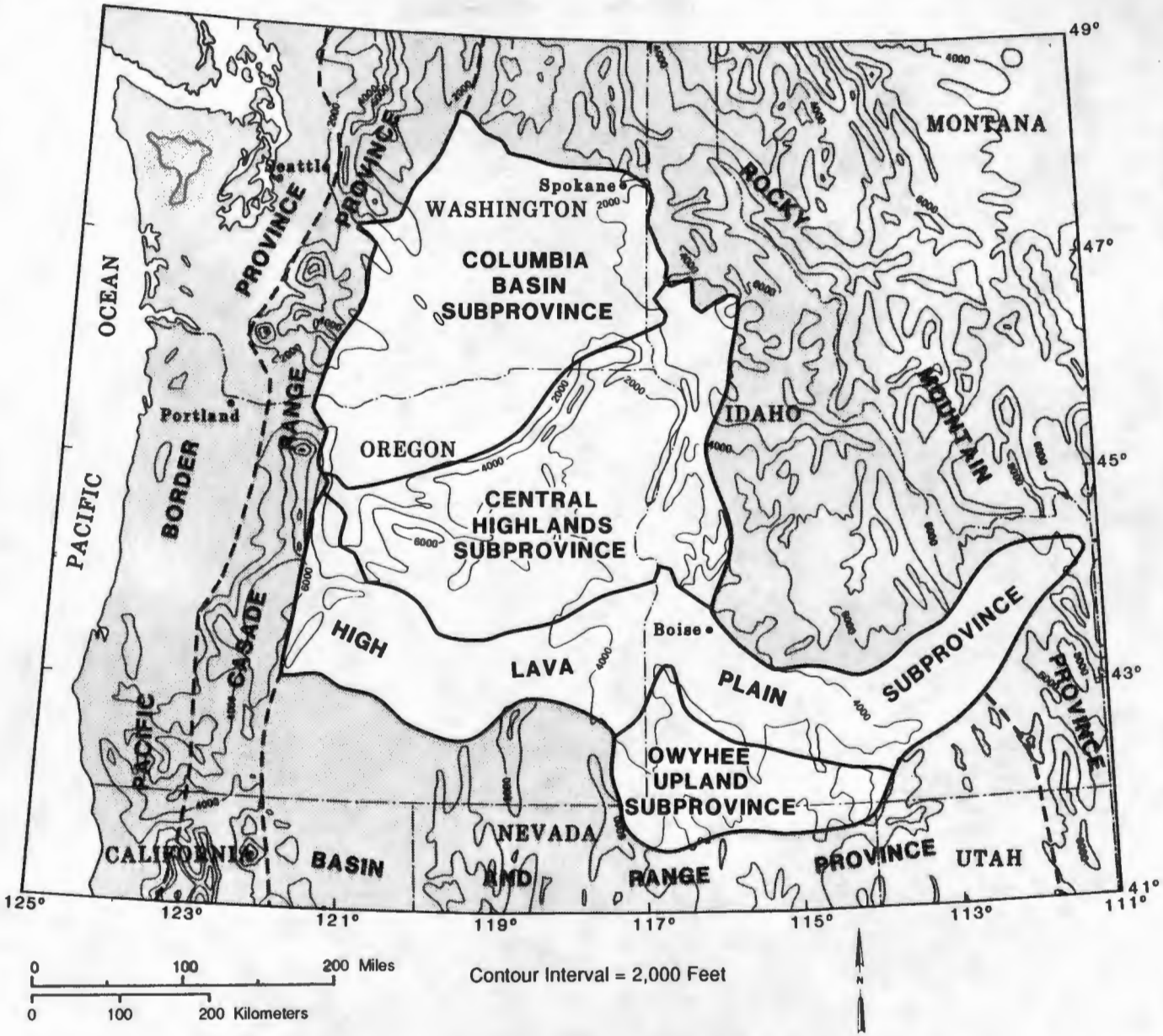


FIGURE 3.1. Divisions of the Columbia Intermontane Province and Adjacent Provinces (after Freeman et al. 1945, p. 56; Thornbury 1965, p. 445)

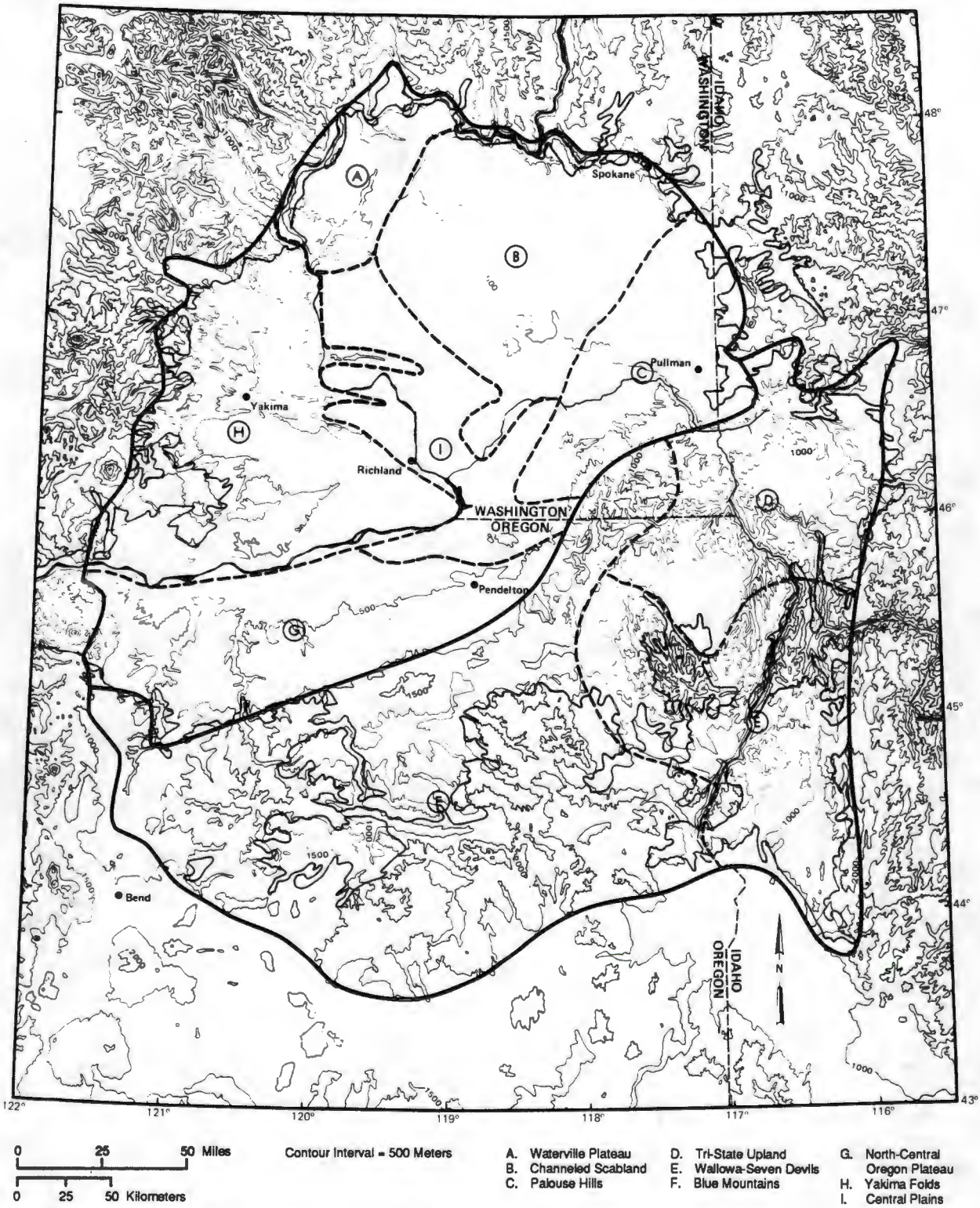


FIGURE 3.2. Geomorphic Units Within the Central Highlands and Columbia Basin Subprovinces that Contain the Columbia River Basalt Group (after Thornbury 1965)

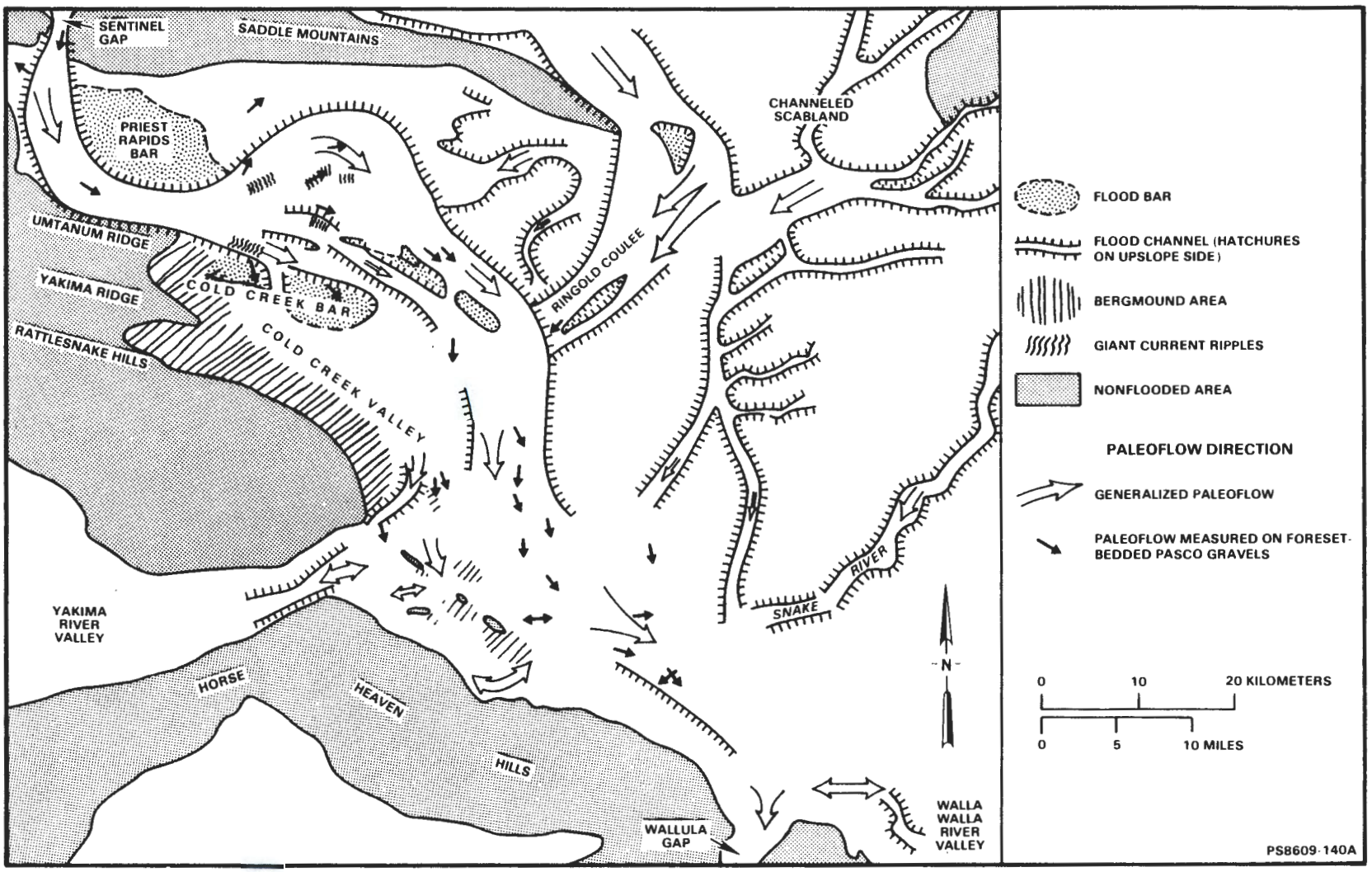


FIGURE 3.3. Paleoflow Directions and Landforms Associated with Proglacial Cataclysmic Flooding in the Central Columbia Plateau (from DOE 1988)

Since the end of the Pleistocene, winds have locally reworked the flood sediments, depositing mostly dune sand in the Central Plains and loess (wind-blown silt) around the margins of the Pasco Basin. Much of the dune sand has been stabilized by anchoring vegetation. However, stabilized dunes are easily reactivated in areas where vegetation is disturbed by fire or man. The distribution of stabilized versus active sand dunes is shown in Figure 3.4.

At least two other geomorphic processes are active within the Pasco Basin: landsliding and alluviation. Landslides have occurred along the north limbs of some Yakima Folds and along steep river embankments such as the White Bluffs (see Figure 3.4). Alluviation is restricted to the flanks of the Yakima Folds (i.e., alluvial fans) and immediately adjacent to the major stream channels (Columbia River, Yakima River) in the form of alluvial plains (see Figure 3.4). Neither landsliding nor alluviation are active processes within or near the 200 Areas.

3.2 CLIMATE AND METEOROLOGY

The Cascade Range greatly influences the climate of the Hanford Site by causing a rain shadow effect and by serving as a source of cold air drainage, which has a considerable effect on the wind regime of the Hanford Site.

Climatological data have been collected at the Hanford Meteorological Station (HMS), located between the 200 Areas, since 1945 (Cushing 1988). Temperature and precipitation data are also available from nearby locations for the period 1912 through 1943. A summary of these data through 1980 has been published by Stone et al. (1983). Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200 Areas plateau.

3.2.1 Wind

Prevailing wind directions on the 200 Areas plateau are from the northwest in all months of the year (Figure 3.5). Secondary maxima occur for southwesterly winds.

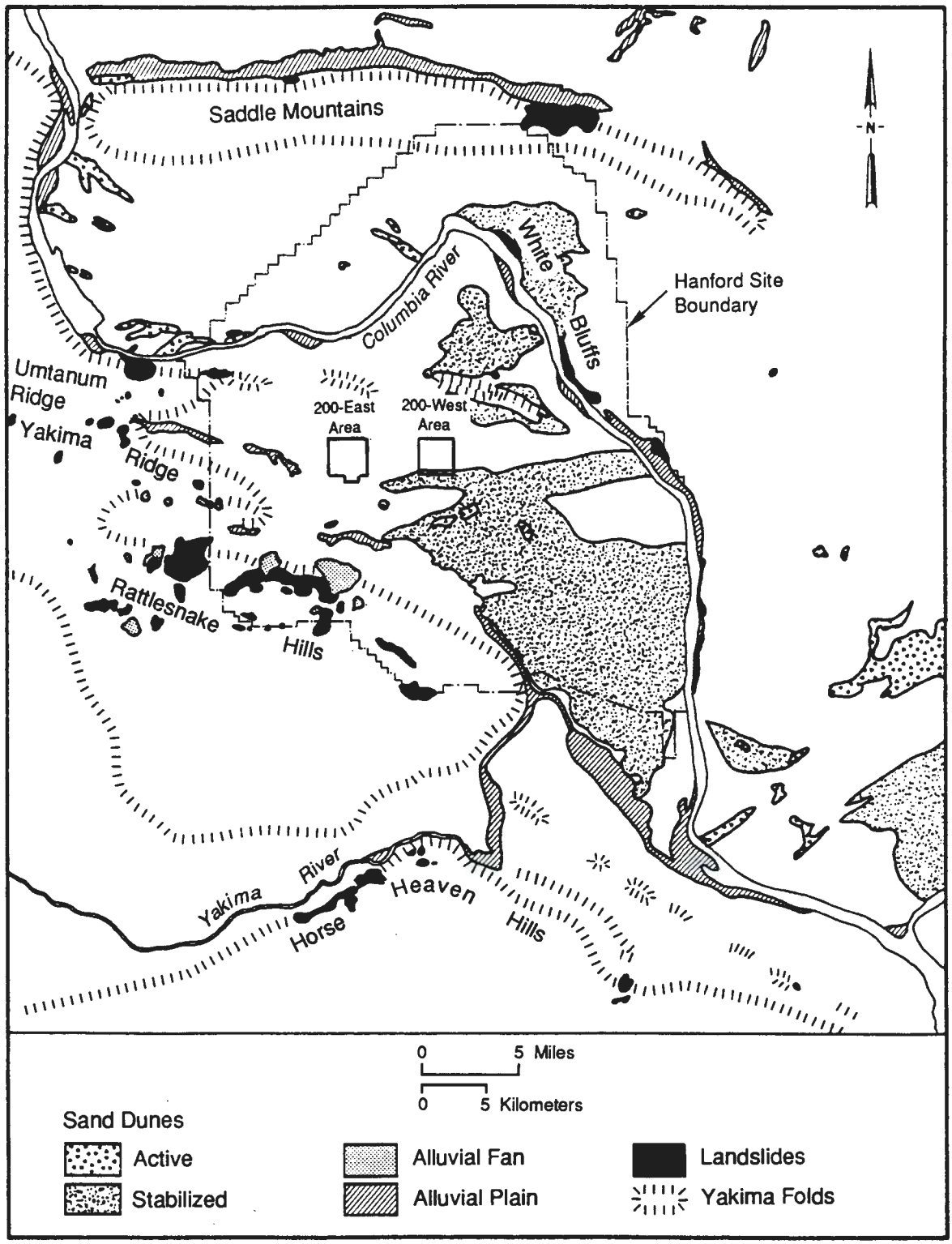


FIGURE 3.4. Late Quaternary Landforms Within and Adjacent to the Pasco Basin (modified from Myers/Price et al. 1979)

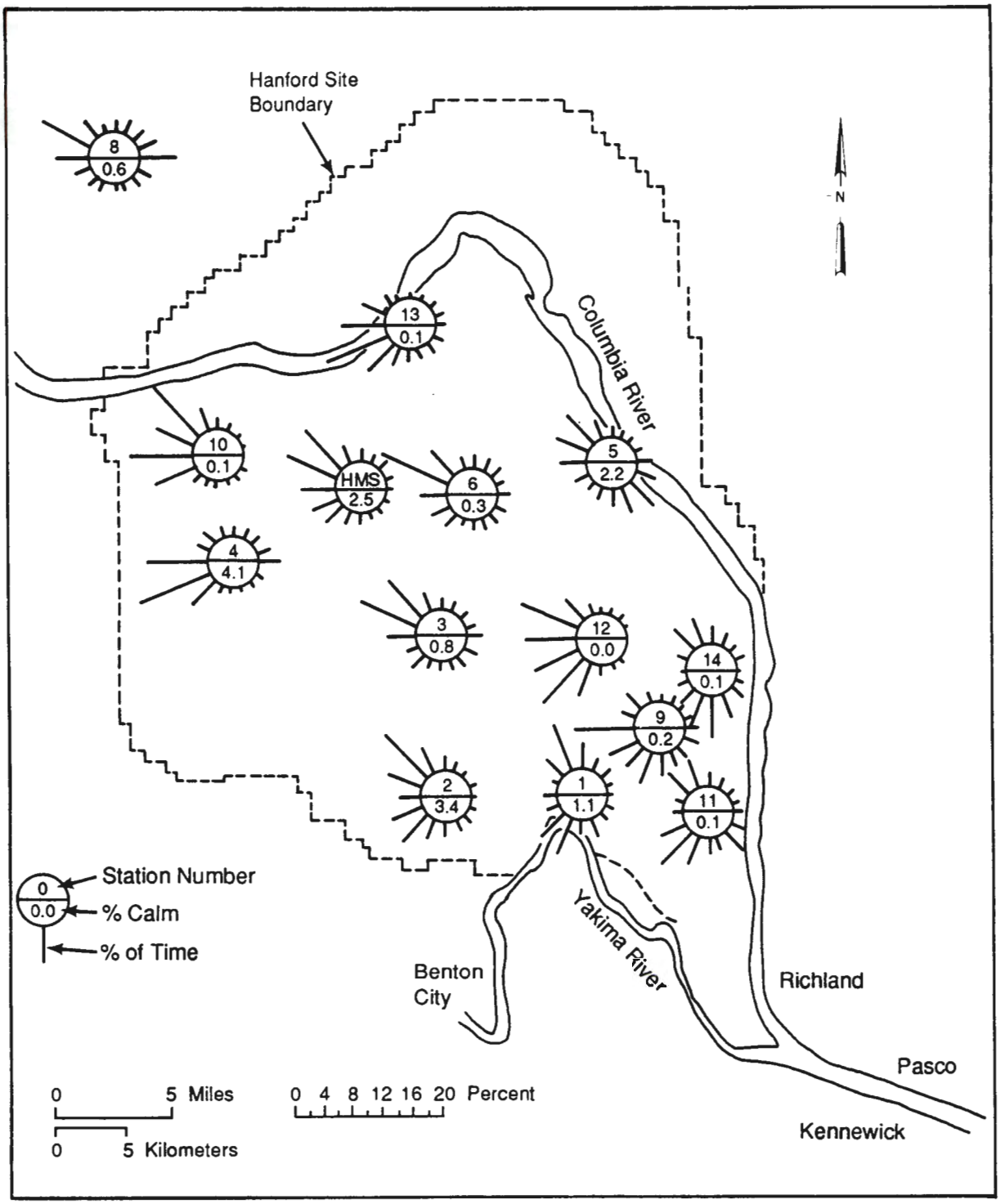


FIGURE 3.5. Hanford Site Wind Roses, 1979 Through 1982 (Stone et al. 1983). Stations 6 and HMS are most representative of conditions in the 200 Areas.

Monthly average wind speeds are lowest during the winter months, averaging 6 to 7 mph, and highest during the summer, averaging 9 to 10 mph. Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 31 mph. Estimates of wind extremes are presented in Table 3.1

Tornados are infrequent and generally small in the northwestern portion of the United States. Grazulis (as cited in DOE 1987) lists no violent tornados for the region surrounding Hanford. The HMS climatological summary (Stone et al. 1983) and the National Severe Storms Forecast Center data base list 22 separate tornado occurrences within 100 mi of the Hanford Site from 1916 through August 1982. Two additional tornados have been reported since August 1982.

3.2.2 Temperature and Humidity

Ranges of daily temperatures vary from normal maxima of 35.6°F in early January to 95°F in late July. The record maximum temperature is 114.8°F, and the record minimum temperature is -27°F.

The annual average relative humidity at the HMS is 54%. It is highest during the winter months, averaging approximately 75%, and lowest during the summer, averaging approximately 35%.

TABLE 3.1. Estimates of Wind Extremes at the Hanford Site (from Stone et al. 1983)

Return Period, yr	Peak Gusts, mph: 50 ft Aboveground	Peak Gusts, mph: 200 ft Aboveground
2	60	68
10	71	80
100	85	94
1,000	99	109

3.2.3 Precipitation

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 6.3 in. Most of the precipitation occurs during the winter, with nearly half of the annual amount occurring in the months of November through February. Days with greater than 0.5 in. precipitation occur less than 1% of the year. Rainfall intensities of 0.5 in/h persisting for 1 h are expected once every 10 years. Rainfall intensities of 1 in/h for 1 h are expected only once every 500 years. Winter monthly average snowfall ranges from 0.3 in. in March to 5.3 in. in January. The record snowfall of 24.4 in. occurred in February 1916. Snowfall accounts for approximately 38% of all precipitation during the months of December through February.

3.3 STRATIGRAPHY

Geologic materials underlying the Hanford Site consist of numerous formally and informally recognized stratigraphic units (Figure 3.6). These units are discussed in three groups: 1) the Columbia River Basalt Group, 2) the Ellensburg Formation, and 2) the suprabasalt sediments.

3.3.1 Columbia River Basalt Group

The Columbia River Basalt Group (see Figure 3.6) comprises an assemblage of tholeiitic, continental flood basalts of Miocene age. These flows cover an area of more than 63,000 mi^2 in Washington, Oregon, and Idaho and have an estimated volume of approximately 170,600 km^3 (Tolan et al. 1987). Isotopic age determinations suggest flows of the Columbia River Basalt Group were erupted during a period from approximately 17 to 6 million years before present (mybp), with more than 98% by volume being erupted in a 2.5 million-year period (17 to 14.5 mybp) (Long and Duncan 1982; McKee et al. 1977).

Columbia River basalt flows were erupted from north-northwest-trending fissures or linear vent systems in north-central and northeastern Oregon, eastern Washington, and western Idaho (Swanson et al. 1975; Waters 1961). The Columbia River Basalt Group is formally divided into five formations, from oldest to youngest: Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Of these, only the

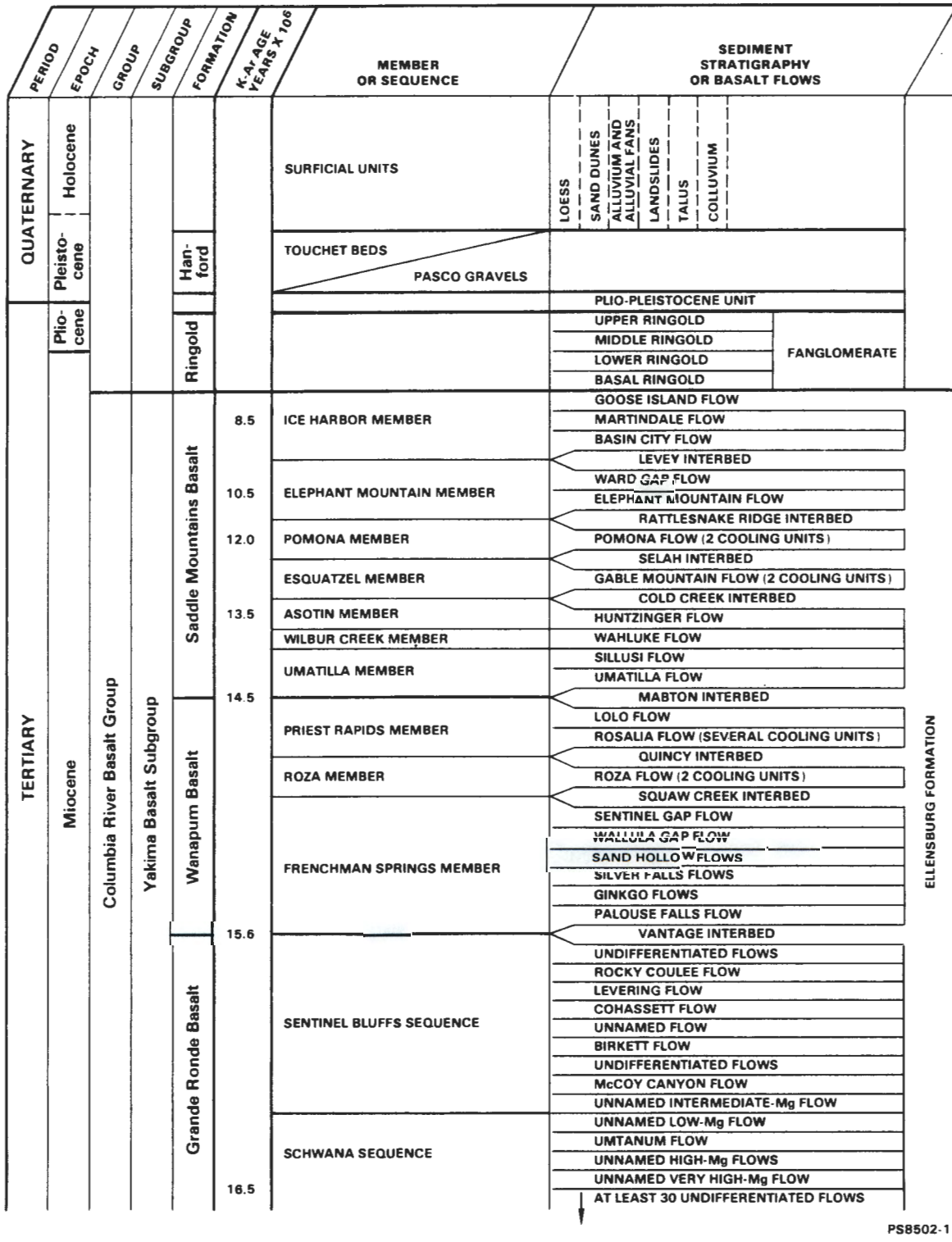


FIGURE 3.6. Stratigraphic Nomenclature of Units Penetrated Within the Pasco Basin

Grande Ronde, Wanapum, and Saddle Mountains Basalts are present in the Pasco Basin (see Figure 3.6). The Saddle Mountains Basalt forms the uppermost basalt unit in the Pasco Basin, except along some of the bounding ridges where Wanapum and Grande Ronde Basalts are exposed.

3.3.2 Ellensburg Formation

The Ellensburg Formation (see Figure 3.6) includes epiclastic and volcaniclastic sedimentary rocks that are interbedded with the Columbia River Basalt Group in the central and western parts of the Columbia Plateau (Schmincke 1964; Swanson et al. 1979a). The age of the Ellensburg Formation is principally Miocene, although locally it may be equivalent to early Pliocene. The thickest accumulations of the Ellensburg Formation lie along the western margin of the Columbia Plateau, where Cascade Range volcanic and volcaniclastic materials interfinger with the Columbia River Basalt Group. Within the Pasco Basin, deposits of the Ellensburg Formation are primarily restricted to the Wanapum and Saddle Mountains Basalts. The lateral extent and thickness of interbedded sediments generally increase upward in the section (Reidel and Fecht 1981). Two major facies, volcaniclastic and fluvial, are present either as distinct or mixed deposits.

3.3.3 Suprabasalt Sediments

The suprabasalt sediments within and adjacent to the Hanford Site (see Figure 3.6) were derived from a variety of sedimentary environments, although the fluvial-lacustrine Ringold Formation and glaciofluvial Hanford formation dominate the preserved stratigraphic record (Bjornstad 1984, 1985; Brown 1959; Routson and Fecht 1979; Tallman et al. 1981). The following discussion on the suprabasalt sediments is divided into three sections: 1) late Neogene deposits, 2) Plio-Pleistocene hiatus, and 3) Quaternary deposits.

Late Neogene Deposits

Late Neogene (i.e., late Miocene to Pliocene) deposits, younger than the Columbia River Basalt Group, are represented by the Ringold Formation within the Pasco and Quincy Basins of the central Columbia Plateau (Grolier and Bingham 1978; Gustafson 1973; Newcomb et al. 1972; Rigby and Othberg 1979). The fluvial-lacustrine Ringold Formation was deposited in generally

east-west-trending valleys by the ancestral Columbia River and its tributaries in response to development of the Yakima Folds. While exposures of the Ringold Formation are limited to the White Bluffs within the central Pasco Basin and to Smyrna and Taunton benches within the Othello Basin, extensive data on the Ringold Formation are available from boreholes in these basins.

The Ringold Formation is classified into three facies associations [referred to as stratigraphic section types (Figure 3.7)] that represent variations in the paleogeography during Ringold time. Section Type I, comprised of gravel and associated sand and silt, represents a migrating channel deposit of the major, throughgoing, ancestral Columbia and (or) Snake River systems confined to the central portion of the Pasco Basin. Section Type II is comprised mostly of overbank sand, silt, and clay deposited along the margins of the basin, beyond the influence of the main channel. Section Type III, a fanglomerate, occurs locally around the extreme margins of the basin, and is comprised of mostly angular basaltic debris derived from side-stream alluvium shed off bedrock ridges.

Two approaches have been used to subdivide Section Type I Ringold Formation deposits in the central Pasco Basin: one is based on lithofacies and the other on upward-fining cycles. Newcomb (1958) divided the Ringold Formation into three lithofacies: a coarse-grained middle unit bounded above and below by fine-grained units. Tallman et al. (1979) describe a fourth lithofacies unit, the coarse-grained basal Ringold unit, which underlies the fine-grained lower Ringold unit in the west-central Pasco Basin. The basal Ringold unit is further subdivided into a coarse- and fine-grained subunit within the central Cold Creek syncline (Bjornstad 1984). A second approach is that used by Puget Sound Power and Light Company (PSPL 1982) south and east of Gable Mountain, where they divided the subsurface Ringold Formation into four fluvial cycles (Units I through IV).

Plio-Pleistocene Hiatus

The late Pliocene to early Pleistocene is generally characterized as a period of regional incision on the Columbia Plateau. Within the Pasco Basin, this is reflected by the abrupt termination and eroded nature of the top of

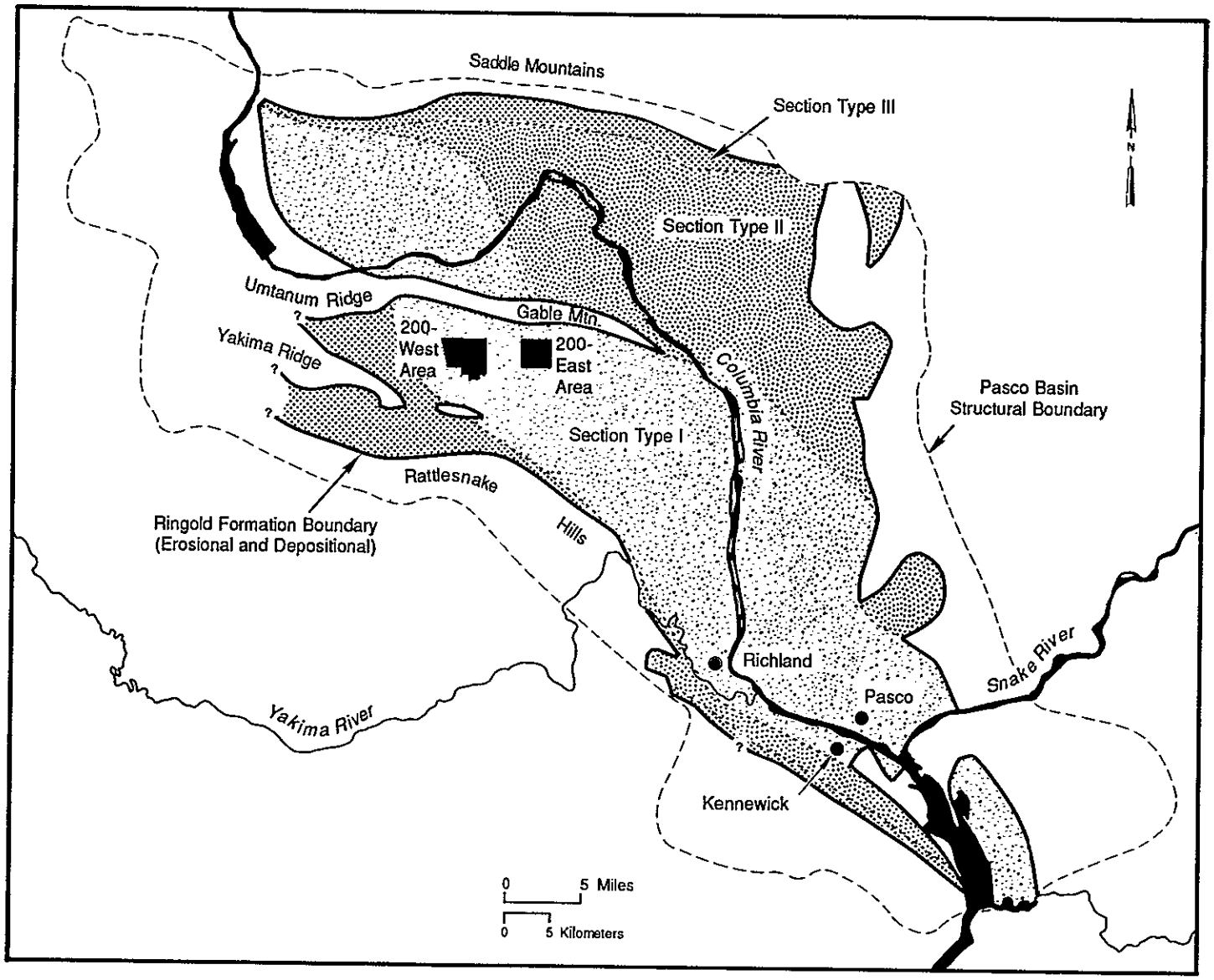


FIGURE 3.7. Distribution of Ringold Formation Section Types

the Ringold Formation (Bjornstad 1985; Brown 1960a; Newcomb et al. 1972). Following incision, a well-developed soil formed atop the eroded surface.

The exact timing and duration of incision are unknown; however, it probably occurred during the interval from 2 to 1 mybp. Incision is bracketed between 0.9 mybp and equal to, or greater than, 3.4 mybp, the respective ages of the basalt from Haystack Butte (Bela 1982) and the youngest age reported from the Ringold Formation. Haystack Butte lava lies near river level within the Columbia River Gorge, approximately 90 mi southwest of the Pasco Basin, indicating that incision (as much as 492 ft in the Pasco Basin) had ceased by 900,000 years ago.

Quaternary Deposits

Aggradation of sediments resumed during the Quaternary following the period of late Pliocene to early Pleistocene incision. Quaternary deposits are associated with a variety of depositional processes, including those associated with volcanism, glaciation, lakes, rivers, wind, and mass wasting. In the central Columbia Plateau, the Quaternary record is dominated by proglacial cataclysmic flood deposits with lesser amounts of fluvial and eolian deposits, which lie below, between, and above flood deposits (Bjornstad et al. 1987). Nonflooded areas on the Columbia Plateau are often mantled by alluvium, colluvium, or loess (wind-blown silt).

Cataclysmic Flood Deposits. Proglacial flood deposits blanket low-lying areas over most of the central Columbia Plateau. Most cataclysmic flood deposits that are preserved are late Pleistocene; the last major flood sequence is dated at approximately 13,000 years ago by the presence of Mount St. Helens Set "S" tephra (Mullineaux et al. 1978) with these sediments. The largest and most frequent floods came from glacial Lake Missoula in northwestern Montana; however, smaller floods may have escaped downvalley from glacial Lakes Clark and Columbia along the northern margin of the Columbia Plateau (Waitt 1980). Another source of Pleistocene flood waters came down the Snake River from glacial Lake Bonneville (Malde 1968). Lake Bonneville flood deposits have not been positively identified within the Pasco Basin. This may be because of erosion and (or) burial by younger flood

deposits from Lake Missoula. The last Lake Bonneville flood occurred approximately 14,000 to 15,000 years ago (Scott et al. 1982).

Two types of flood deposits are normally observed: a coarse-grained main-channel facies and a finer grained, slack-water facies. Within the Pasco Basin these are referred to as the Pasco Gravels and Touchet Beds, members of the Hanford formation (Myers/Price et al. 1979).

Deciphering the history of cataclysmic flooding in the Pasco Basin is complicated not only by floods from multiple sources, but also because paths of Lake Missoula flood waters migrated and changed course with the advance and retreat of the Cordilleran ice sheet (Baker and Bunker 1985). Cataclysmic floods inundated the central Columbia Plateau several times during the Pleistocene. At least three major flooding episodes (early, middle, and late Pleistocene) are recognized in the Pasco Basin, although many more minor flood events probably occurred during each of these major episodes. The evidence for the different ages of flooding includes changes in magnetic polarity, truncated clastic dikes, and soil development atop flood sequences.

Clastic dikes are commonly associated with, but not restricted to, cataclysmic flood deposits on the Columbia Plateau. While there is general agreement that clastic dikes formed during cataclysmic flooding, a primary mechanism to satisfactorily explain the formation of all dikes has not been identified (WPPSS 1981). Among the more probable explanations are fracturing initiated by hydrostatic loading and hydraulic injection associated with receding flood waters. Seismicity may also have a role in their formation, although there is no evidence available to establish a connection.

Other Quaternary Deposits. Alluvium is present, not only as a surficial deposit along major river and stream courses (see Figure 3.4), but also in the subsurface, where it is found underlying and interbedded with proglacial flood deposits. Two types of alluvium are recognized in the Pasco Basin: quartzitic mainstream and basalt-rich sidestream alluvium. Colluvium (talus and slopewash) is a common Holocene deposit in moderate- to high-relief areas, and, like dune sand, which is found locally in the arid central plateau, is not commonly preserved in the stratigraphic record.

Varying thicknesses of loess or sand mantle much of the Columbia Plateau. Active and stabilized sand dunes are widespread over the Pasco Basin (see Figure 3.4).

Landslide deposits in the Pasco Basin are of variable age and genesis. Most are associated with north limbs of Yakima Folds or are found along steep river embankments, such as the White Bluffs (see Figure 3.4).

3.4 TECTONIC FRAMEWORK

The Columbia Plateau is a part of the North American continental plate and lies east of the Cascade Range. The plateau is bounded on the north by the Okanogan Highlands, on the east by the Northern Rocky Mountains and Idaho Batholith, and on the south by the High Lava Plains and Snake River Plain.

3.4.1 Structural Geology of the Region

The Columbia Plateau can be divided into three informal structural subprovinces: Palouse, Blue Mountains, and Yakima Fold Belt (Figure 3.8). These structural subprovinces are delineated on the basis of their structural fabric, unlike the physiographic provinces that are defined on the basis of landforms. The Hanford Site is located near the junction of the Yakima Fold Belt and the Palouse Subprovinces.

Blue Mountains Subprovince

The Blue Mountains Subprovince is a structurally diverse region dominated by the complexly faulted Blue Mountains anticlinorium in its northern portion and a series of structural basins in its central and southern portions. The structural basins are generally of two types: 1) fault-bounded basins (e.g., the LaGrande, Baker, and Unity Basins) and 2) fold-bounded basins (e.g., the John Day Basin). In the northern and central portions of the Blue Mountains proper, two important fault systems have been recognized: the Hite Fault System and the LaGrande Fault System.

Palouse Subprovince

The Palouse Subprovince is primarily a regional paleoslope that dips gently toward the central Columbia Plateau and exhibits only relatively mild structural deformation. The Palouse Slope is underlain by a wedge of

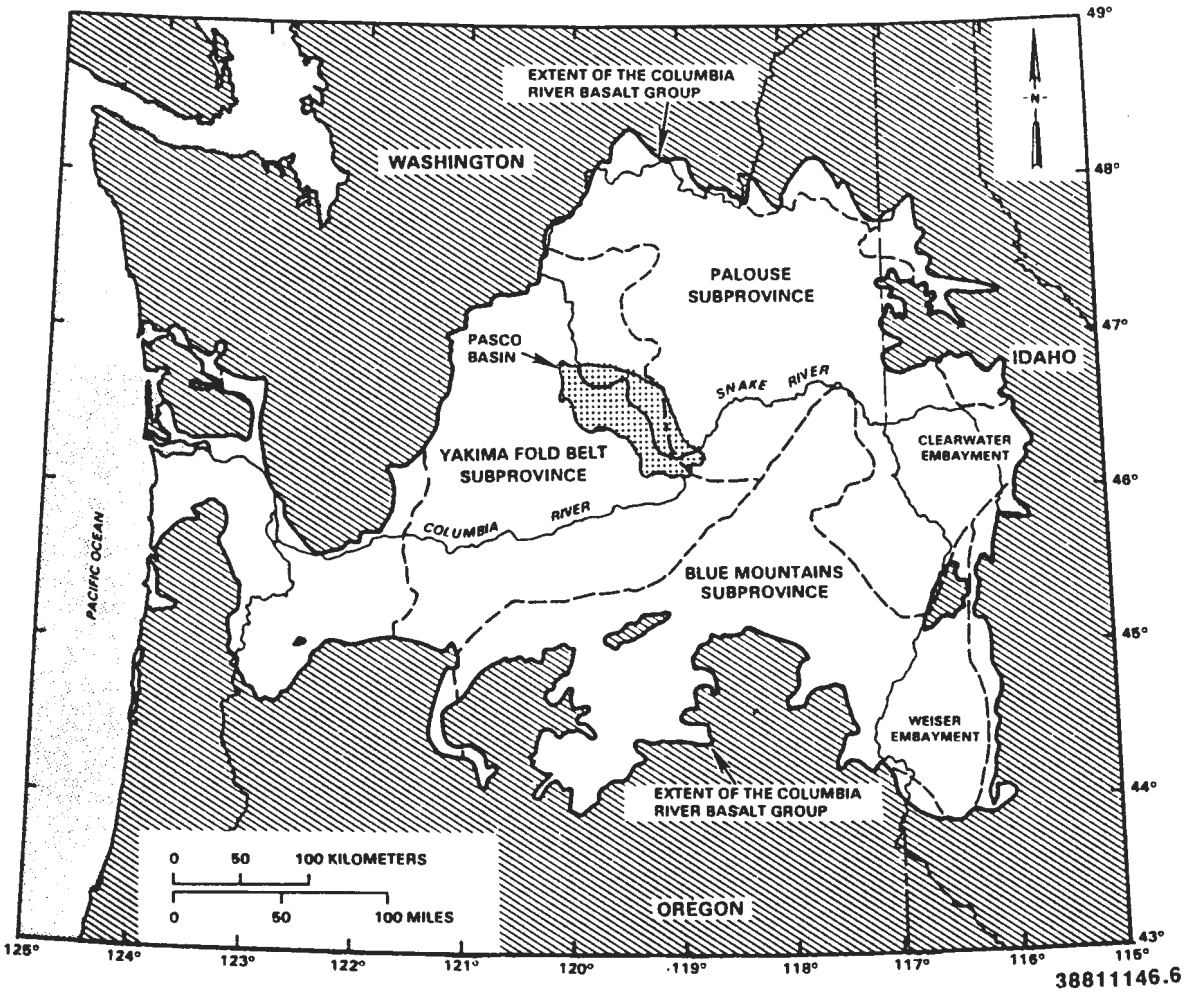


FIGURE 3.8. Structural Subprovinces of the Columbia Plateau

Columbia River basalt that thins gradually toward the east and north and laps onto the adjacent highlands.

Yakima Fold Belt Subprovince

The principal characteristics of the Yakima Fold Belt Subprovince are a series of segmented, narrow, asymmetric anticlines that have wavelengths between 3 and 19 mi and amplitudes commonly less than 0.6 mi. These anticlinal ridges are separated by broad synclines or basins that, in many cases, contain thick accumulations of Neogene- to Quaternary-age sediments.

Thrust or high-angle reverse faults, with fault planes that strike parallel to subparallel to the axial trends, are principally found along the

limbs of the anticlines (Bentley et al. 1980; Hagood 1985; Reidel 1984; Swanson et al. 1979b, 1981). The amount of vertical stratigraphic offset associated with these faults varies but commonly exceeds hundreds of feet.

The deformation of the Yakima Folds occurred under north-south compression, and was probably contemporaneous with the eruption of the basalt flows (Reidel 1984). The fold belt was growing during the eruption of the Columbia River Basalt Group and continued to grow through the Pliocene, into the Pleistocene, and perhaps to the present.

Cold Creek Syncline

The Cold Creek syncline (Figures 3.9 and 3.10) lies between the Umtanum Ridge-Gable Mountain uplift and the Yakima Ridge uplift, and is the principal structural unit that contains the 200 Areas. The Cold Creek syncline is an asymmetric and relatively flat-bottomed structure, whose amplitude is higher and wavelength is shorter west of the Hanford Site.

The Yakima Barricade geophysical anomaly (see Figure 3.10) occurs on the west side of the Cold Creek syncline and coincides with a west-to-east change in hydraulic gradient. The data suggest that this feature is either a steeply dipping fold or a high-angle fault that formed during the late Miocene to early Pliocene; movement ended by late Pliocene.

Umtanum Ridge-Gable Mountain Structural Trend

The Umtanum Ridge-Gable Mountain structural trend is a segmented anticlinal ridge, extending for a length of 85 mi in an east-west direction and passes north of the 200 Areas (see Figure 3.10). This structure consists of five segments. From the west, Umtanum Ridge plunges eastward and joins the Gable Mountain-Gable Butte segment just east of the western boundary of the Hanford Site. The easternmost segment, the Southeast anticline, trends southeast off the eastern boundary of the Gable Mountain-Gable Butte segment.

Umtanum Ridge is an asymmetrical, north-vergent to locally overturned anticline with a major thrust to high-angle reverse fault on the north side (Goff 1981; PSPL 1982) that dies out eastward toward Gable Mountain. Gable Mountain and Gable Butte are two topographically isolated, anticlinal ridges

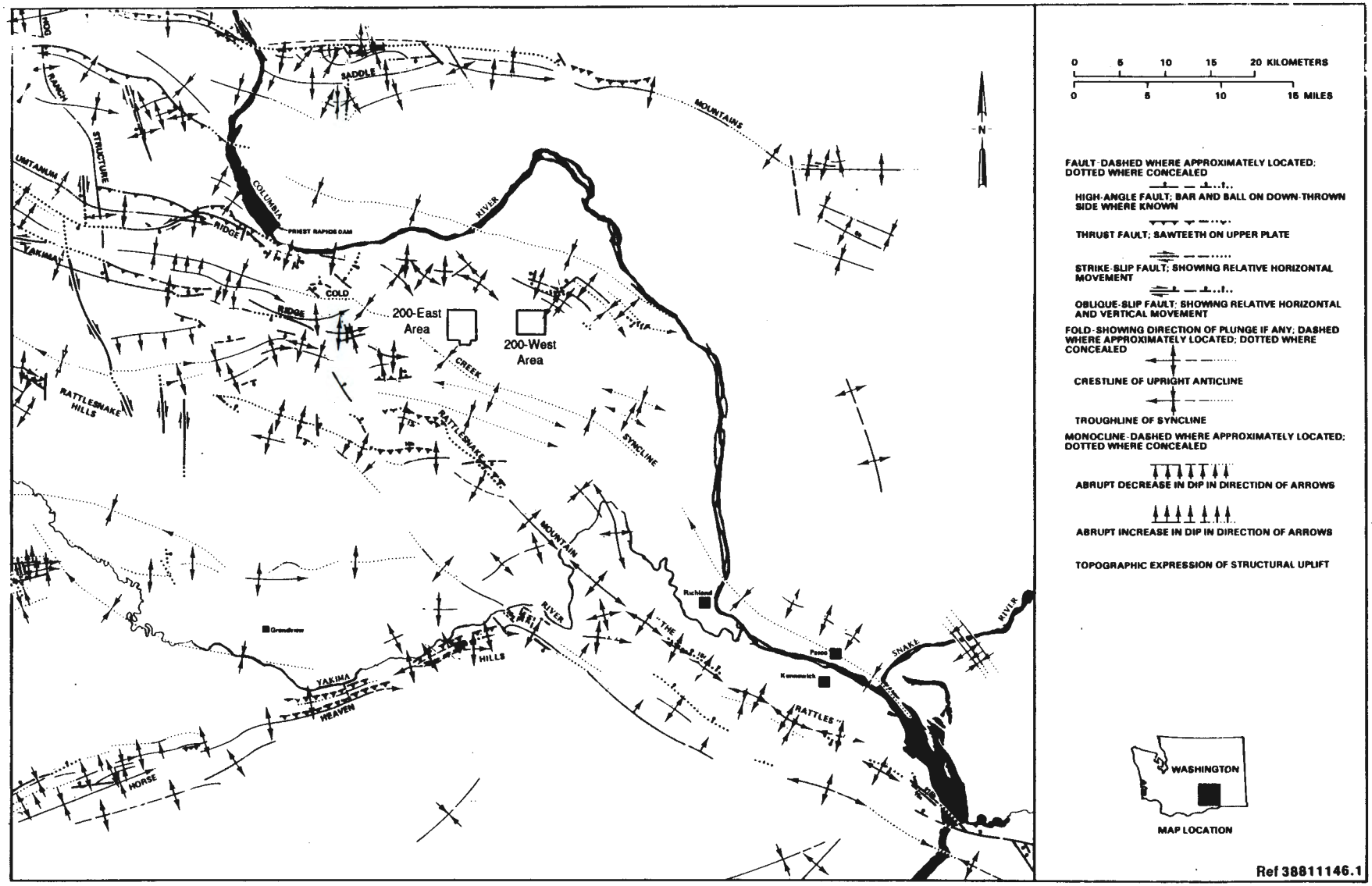


FIGURE 3.9. Structural Elements of the Yakima Fold Belt Subprovince

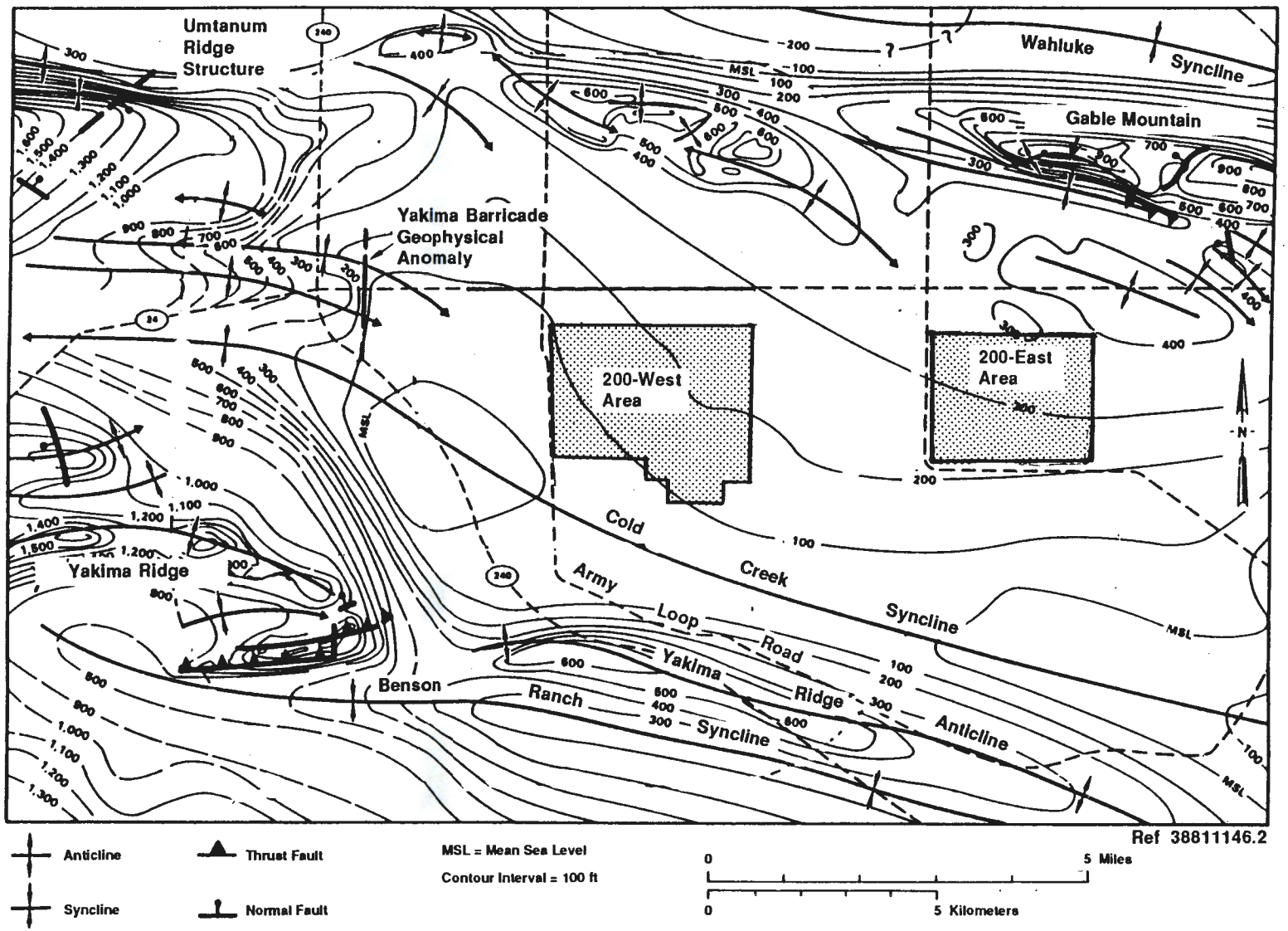


FIGURE 3.10. Tectonic Structures Adjacent to the 200 Areas, Top of Basalt Map

that are comprised of a series of northwest-trending, doubly plunging, en echelon anticlines, synclines, and associated faults. Capable faulting has been identified on Gable Mountain (NRC 1982; PSPL 1982).

Yakima Ridge

The Yakima Ridge uplift extends from west of Yakima, Washington, to the center of the Pasco Basin, where it forms the southern boundary of the Cold Creek syncline (see Figures 3.9 and 3.10). The easternmost surface expression of the Yakima Ridge uplift is represented by an anticline that plunges eastward into the Pasco Basin (Myers/Price et al. 1979, Plate III). The eastern extension of Yakima Ridge is mostly buried beneath a cover of suprabasalt sediments. The structural style of the buried eastward extension is assumed to be similar to the exposed parts.

3.5. SEISMICITY

The Pasco Basin is located in an area of relatively low seismicity with respect to the surrounding area in the central Columbia Plateau. Earthquake records for the Pacific Northwest extend back to approximately 1850; however, these early records are very qualitative. Earthquakes occurring before 1969 were documented from reports of tremors that were felt (Coffman and von Hake 1982; Fifer 1966; NRC 1982; Rasmussen 1967; WCC 1980, 1982; WPPSS 1981). Earthquakes since 1969 have been instrumentally recorded. The following summarizes the detailed evaluations of these instrumental recordings presented by DOE (1988).

Earthquake activity beneath the Hanford Site is confined to the crust, and is characterized primarily by shallow swarms of microearthquakes that occur predominantly in the basalts. Focal mechanisms for basalt and subbasalt events indicate north-south compression and reverse faulting along nearly east-west planes.

Two areas of shallow swarm activity, the Coyote Rapids and Cold Creek swarm areas, are located within 6.2 mi of the 200 Areas. A total of 91 events occurred in the Coyote Rapids swarm area from 1969 to 1986, the bulk of which appear to congregate into two 3- to 6-mi, roughly east-west lineations at either end of the west leg of the Columbia River horn. The

depth distribution of events in this area appears to be bimodal, with a sharp falloff from the surface and a broad maximum between 2.5 to 4.3 mi deep. Approximately 70% of the events were located in the upper 2.5 mi, and 98% (all but two events) in the upper 5 mi, although all may be at depths shallower than 5 mi.

Most of the Coyote Rapids events (76, or approximately 85%) have magnitudes (coda-length) of 1.5 or less. The two largest events in this area occurred during swarms on October 25, 1971 (3.8 coda-length magnitude), and on October 20, 1983 (3.4 coda-length magnitude).

A second area, referred to as the Cold Creek swarm area, is located 3 to 5 mi south of the 200-West Area. A total of 15 events occurred in this area in 1979 and 1981, all less than 3 mi deep. The largest event had a 2.4 coda-length magnitude.

3.6 REGIONAL HYDROLOGY

The Pasco Basin contains a number of natural and manmade surface-water bodies, a major unconfined aquifer, and numerous confined aquifers.

3.6.1 Surface Water

The Hanford Site occupies approximately one-third of the land area within the Pasco Basin. Primary surface-water features associated with the Hanford Site are the Columbia and Yakima rivers and their major tributaries, the Snake and Walla Walla rivers. With the exception of the Columbia River, there are no perennial streams within the Hanford Site. West Lake, approximately 10 acres in size and less than 3 ft deep, is the only natural lake within the Hanford Site (DOE 1988). Several surface ponds and ditches are present, and are generally associated with nuclear fuel reprocessing and waste disposal activities (Figure 3.11). A network of dams and multipurpose water resource projects is located along the course of the Columbia River (see Figure 3.11).

The Columbia River is considered to be free flowing along approximately two-thirds of the Hanford Site. This area of the river, referred to as the Hanford reach, extends from Priest Rapids Dam to the headwaters of Lake

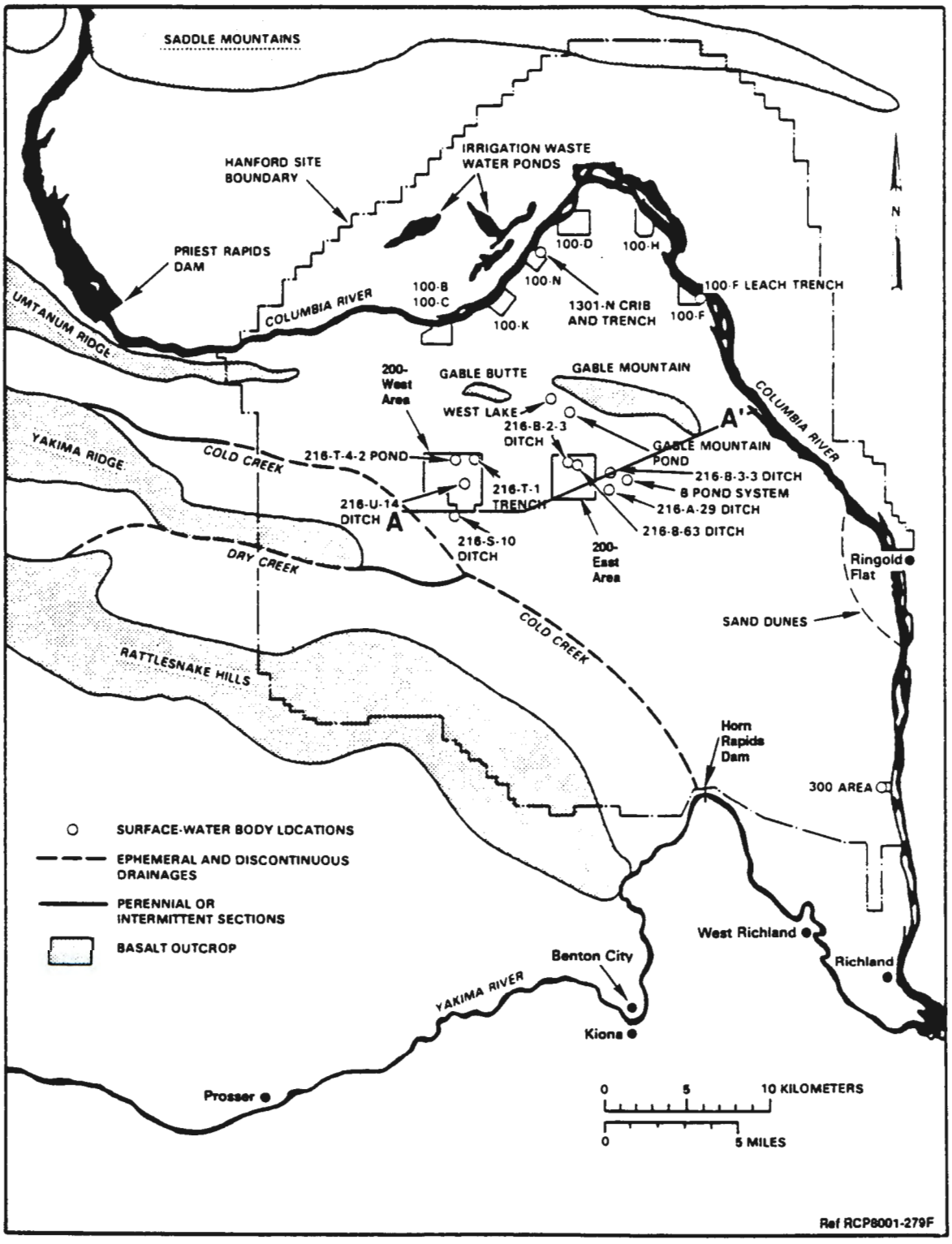


FIGURE 3.11. Location of Surface Water Features, Including Ponds, Ditches, and Principal Dams

Wallula (the reservoir behind McNary Dam). The flow has been inventoried and described in detail by the U.S. Army Corps of Engineers (DOE 1986b). Flow along this reach is controlled by Priest Rapids Dam. Several drains and intakes are also present along this reach, including irrigation outfalls from the Columbia Basin Irrigation Project and Hanford Site intakes for onsite water use.

Total estimated precipitation over the Pasco Basin is approximately 3×10^{10} ft^3 annually, averaging less than 6.2 in/yr. Mean annual runoff from the basin is estimated to be less than 1.0×10^8 ft^3/yr, or approximately 3% of the total precipitation. The remaining precipitation is assumed to be lost through evapotranspiration, with a small component (perhaps less than 1%) recharging the ground-water system (DOE 1988).

Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system. Both streams drain areas along the western part of the Hanford Site, and cross the southwestern part of the site toward the Yakima River. Surface flow, which may occur during spring runoff or after heavier than normal precipitation, infiltrates and disappears into the surface sediments. Rattlesnake Springs, located on the western part of the site, forms a small surface stream that flows for approximately 1.8 mi before disappearing into the ground. Approximately one-third of the Hanford Site is drained by the Yakima River system.

The Yakima River, bordering the southern portion of the Hanford Site, has a low annual flow compared to the Columbia River. For a period of 57 years of record, the average annual flow of the Yakima River is approximately 3.7×10^3 ft^3/s, with monthly maximum and minimum flows of 1.7×10^4 and 1.6×10^2 ft^3/s, respectively. Recorded flow rates of the Columbia River have ranged from 1.6 to 6.4×10^5 ft^3/s, during the runoff in spring and early summer, to 3.5×10^4 to 1.6×10^5 ft^3/s, during the low-flow period of late summer and winter (Jamison 1982). The average annual Columbia River flow in the Hanford reach, based on 65 years of record, is approximately 1.2×10^5 ft^3/s (DOE 1987). Normal river elevations within the site range from 394 ft above mean sea level, where the river enters the site near Vernita, to 341 ft, where it leaves the site near the 300 Area.

Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several upstream dams. While no 100-yr flood-plain maps have been made for the Hanford reach of the Columbia River, the 200 Areas are far above the flood level of an even larger flood, a hypothetical 50% breach of Grand Coulee Dam (DOE 1987).

Routine water-quality monitoring of the Columbia River is conducted by DOE for both radiological and nonradiological parameters. Reports on the monitoring have been published annually by PNL since 1973 (e.g., Jaquish and Mitchell 1988). Ecology has issued a Class A (excellent) quality designation for Columbia River water along the reach from Grand Coulee Dam, through the Pasco Basin, to McNary Dam. This designation requires that all industrial uses of this water be compatible with other uses, including drinking, wildlife habitat, and recreation. In general, the Columbia River water can be characterized by a very low-suspended load, a low nutrient content, and an absence of microbial contaminants (DOE 1988).

3.6.2 Ground Water

Ground water occurs both within an unconfined aquifer system, consisting of fluvial and lacustrine sediments, and within a system of deeper confined to semiconfined aquifers in the basalt flow tops, flow bottoms, and sedimentary interbeds (DOE 1988). These deeper aquifers are intercalated with aquitards, consisting of basalt flow interiors. Vertical flow and leakage across the aquitards are inferred from water-level or potentiometric surface data, but the flow and leakage are not quantified and direct measurements are not available (DOE 1988). The multiaquifer system within the Pasco Basin has been conceptualized as consisting of four primary geohydrologic units: 1) suprabasalt Hanford and Ringold Formation sediments, 2) Saddle Mountains Basalt, 3) Wanapum Basalt, and 4) Grande Ronde Basalt.

Unconfined Aquifer System

The unconfined aquifer is the uppermost regionally extensive aquifer beneath the Hanford Site and lies at depths ranging from less than 1 ft, near West Lake and the Columbia and Yakima rivers, to more than 350 ft, near the center of the site. Ground water within the unconfined aquifer system is

contained within the glaciofluvial sands and gravels of the Hanford formation and the fluvial-lacustrine sediments of the Ringold Formation. The position of the water table beneath the western portion of the Hanford Site is generally within the middle Ringold unit. In the northern and eastern portions of the site, the water table is generally within the Hanford formation. Hydraulic conductivities for the Hanford formation (2,000 to 10,000 ft/d) are much greater than those of the middle unit of the Ringold Formation (610 to 3,050 ft/d) (Law et al. 1987). The main body of this aquifer occurs within the middle unit of the Ringold Formation.

The base of the unconfined aquifer system is conceptualized as the basalt surface. On a local scale, the silts and clays of the lower/fine-grained basal units of the Ringold Formation separate unconfined ground water from semiconfined ground water present in the coarse facies of the basal Ringold unit. Thickness of the unconfined aquifer system is on the order of 500 ft west of the 200-West Area. Laterally, the unconfined aquifer system is bounded by anticlinal basalt ridges, which extend above the water table. A generalized east-west geologic cross section, showing the position of the water table and major stratigraphic units beneath the Hanford Site, is presented in Figure 3.12. The location of this cross section is shown in Figure 3.11.

Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia rivers. The movement of precipitation through the unsaturated (vadose) zone has been studied on the Hanford Site to define the movement of water in the vadose zone. Gee (1987) reviewed all available information and concluded that recharge rates at the Hanford Site are widely variable, ranging from less than 0.04 to 4 in/yr, depending on soil texture and amount of vegetation present.

Artificial recharge occurs from the disposal of large volumes of waste water on the Hanford Site (principally in the 200 Areas) and from large irrigation projects surrounding the Hanford Site. Artificial recharge from

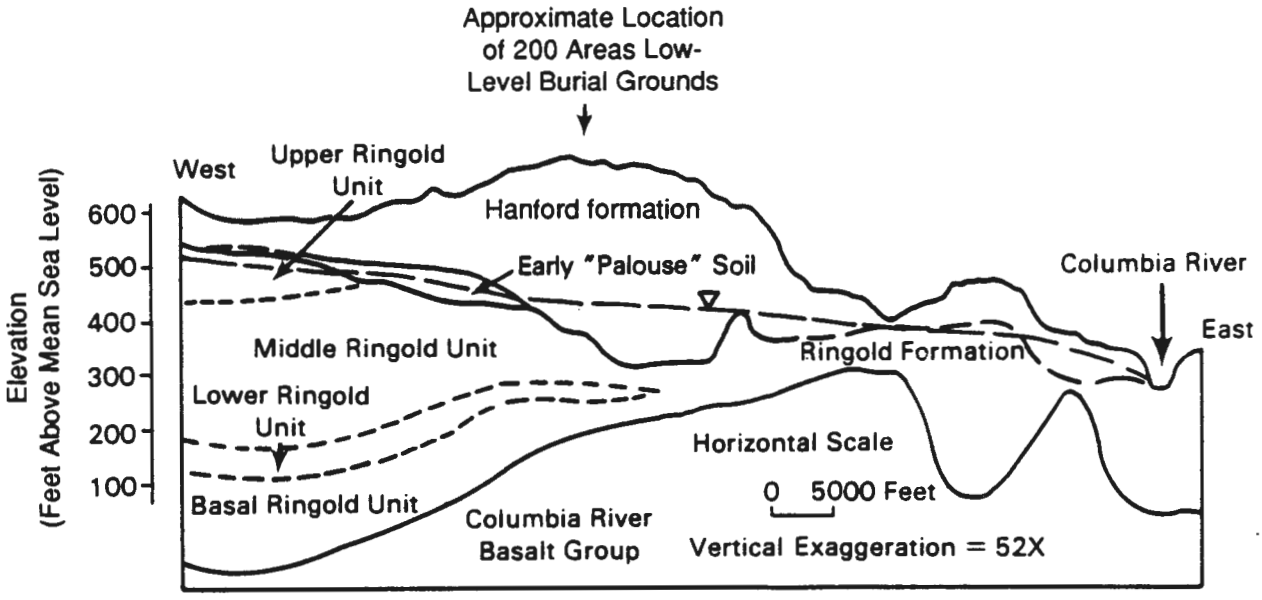


FIGURE 3.12. Generalized East-West Cross Section Through the Hanford Site in the Vicinity of the 200 Areas Low-Level Burial Grounds

the 200 Areas waste-water disposal facilities is estimated to be approximately 10 times the natural recharge on the Hanford Site (Graham et al. 1981).

From the recharge areas to the west, the ground water flows downgradient to the discharge areas, primarily along the Columbia River. This general west-to-east flow pattern is interrupted locally by the ground-water mounds in the 200 Areas. From the 200 Areas, there is also a component of ground-water flow to the north, between Gable Mountain and Gable Butte. Figure 3.13 illustrates the water-table conditions beneath the Hanford Site.

Water levels in the unconfined aquifer have risen because of artificial recharge mechanisms. Waste-water ponds on the Hanford Site have artificially recharged the unconfined aquifer below the 200-East and 200-West Areas. The increase in water-table elevations was most rapid from 1950 to 1960 (Zimmerman et al. 1986). Between 1970 and 1980, the aquifer apparently had nearly reached equilibrium between its ability to transmit water and the recharge, as evidenced by only small increases in water-table elevations

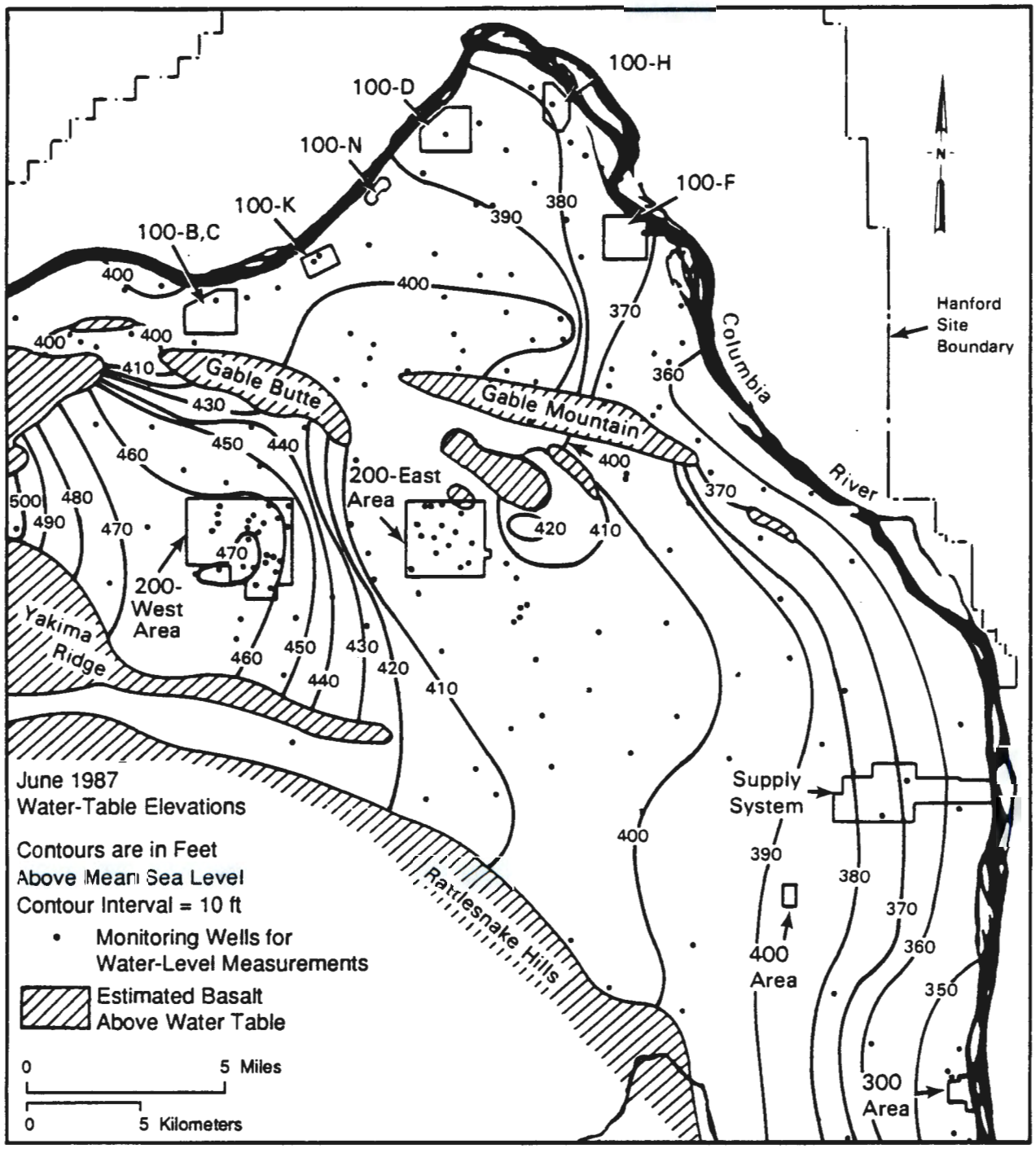


FIGURE 3.13. Water-Table Elevations for June 1987 (Schatz et al. 1987)

(Zimmerman et al. 1986). Waste-water discharges from the 200-West Area were significantly reduced in 1984 (DOE 1988), and the water levels there are now slowly declining.

Waste waters discharged on the Hanford Site have reached the unconfined aquifer. The primary constituents that have reached the aquifer are tritium, iodine-129, ruthenium-106, technetium-99, uranium, nitrate, and chromium (DOE 1987). Other constituents that have reached the ground water in isolated instances include strontium-90, cesium-137, minor amounts of longer lived radionuclides, carbon tetrachloride, cyanide, and trichloroethylene (DOE 1987). The ground water is routinely and extensively monitored to trace the movement of contaminants and to determine any impact from the site to the public (Graham et al. 1981). Ground-water monitoring reports are produced annually (e.g., Jaquish and Mitchell 1988; Serkowski et al. 1988).

Confined Aquifer System

Confined aquifers are present in the sedimentary interbeds and/or interflow zones that occur between dense basalt flows of the Saddle Mountains Basalt, Wanapum Basalt, and Grande Ronde Basalt. The main water-bearing portions of the interflow zones are networks of interconnecting vesicles and fractures of the flow tops and flow bottoms.

Local recharge to the shallow basalts is believed to result from infiltration of precipitation and runoff along the margins of the Pasco Basin. Regional recharge of the deep basalts is thought to result from interbasin ground-water movement originating northeast and northwest of the Pasco Basin in areas where the Wanapum and Grande Ronde Basalts crop out extensively (DOE 1986b). Ground-water discharge from the shallow basalt is probably to the overlying unconfined aquifer and the Columbia River. The discharge area(s) for the deep ground waters has not been determined, but flow is believed to be generally southeastward, with discharge speculated to be south of the Hanford Site (DOE 1986b).

Erosional "windows" through the dense basalt flow interiors provide the potential for direct interconnections between the unconfined and uppermost confined aquifers. Graham et al. (1984) and Strait and Moore (1982) and indicated that some contamination was present in the uppermost confined

aquifer (Rattlesnake Ridge) south and east of Gable Mountain Pond. Graham et al. (1984) evaluated the hydrologic relationships between the Rattlesnake Ridge aquifer and the unconfined aquifer in this area and delineated a potential area of intercommunication beneath the northeastern portion of the 200-East Area.

4.0 HYDROGEOLOGIC CHARACTERIZATION

The ground-water monitoring plan for the 200 Areas LLBGs (PNL 1987) identified five specific objectives. All or portions of these required the collection of site-specific hydrogeologic data. These objectives are paraphrased below:

- Develop a more complete understanding of hydrogeology.
- Determine the vertical distribution of hydraulic potential in the aquifer.
- Determine the range and distribution of hydraulic conductivity values for the Hanford and Ringold Formation sediments.
- Determine the storativity and effective porosity of the Hanford and Ringold Formation sediments.
- Determine the physical and geochemical parameters controlling contaminant movement, and determine whether contaminants from the LLBGs have entered the ground-water system.

This section discusses the investigative approach, available data base, and investigative methods used to achieve these objectives.

4.1 INVESTIGATIVE APPROACH

A phased approach was adopted to install ground-water monitoring wells and to collect hydrogeologic data around the four LLBG WMAs. This approach called for installation of a separate ground-water monitoring system around each WMA. The boreholes for these systems would be dual-purpose, providing site-specific data on the hydrogeology of each WMA and long-term ground-water monitoring. Thirty-five dual-purpose (monitoring/characterization) wells were installed around the four WMAs. Additional monitoring wells will be installed, if necessary, based on analyses from the initial monitoring well systems.

The locations of the 35 wells [as outlined in the ground-water monitoring plan (PNL 1986, 1987)] were chosen to comply with the minimum requirements for ground-water monitoring systems [40 CFR 265 (EPA 1984) and

WAC 173-303 (Ecology 1986)]. Each system was designed to include a minimum of two upgradient wells that would provide background water-quality data and allow statistical validation of the data. At least three wells were located downgradient of each WMA. The systems planned for the 200-West Area also included upgradient and downgradient deep wells (completed at the bottom of the aquifer), each paired with a shallow well (completed in the top of the aquifer). These deep wells were selected to provide data on the distribution and continuity of major hydrogeologic units to the base of the unconfined aquifer system.

The locations of the 200-West Area wells were chosen to assess and accommodate the changing ground-water flow regime. Ground-water levels have been declining in this area since deactivation of the 216-U-10 Pond (U Pond) in 1984. As the ground-water mound beneath U Pond continues to decline, the radial flow away from this mound will shift slowly back to a predominantly eastward flow, which may cause some downgradient wells to become upgradient wells. A similar situation could also result in the 200-East Area when the 216-B-3 Pond (B Pond) is deactivated. Declining water levels in both the 200-West and 200-East Areas may also cause some wells to become dry. Figure 4.1 illustrates presumed ground-water gradients and flow directions when well locations were selected (PNL 1987).

4.2 AVAILABLE DATA BASE

Numerous regional geologic and hydrologic studies are available for the Columbia Plateau, Pasco Basin, and Hanford Site. These studies were previously discussed in Section 3.0. The focus of Section 4.2 is to describe those published studies and the available data bases that pertain to the hydrogeologic environment of the 200 Areas.

4.2.1 Previous Studies

Numerous hydrogeologic, geochemical, unsaturated zone, and ground-water hydrology studies of the 200 Areas have been performed over the last 40 years. These studies have been grouped into similar topical areas and are listed in Table 4.1. The ground-water monitoring plan (PNL 1987) was developed using a hydrogeologic conceptual model consistent with the geology

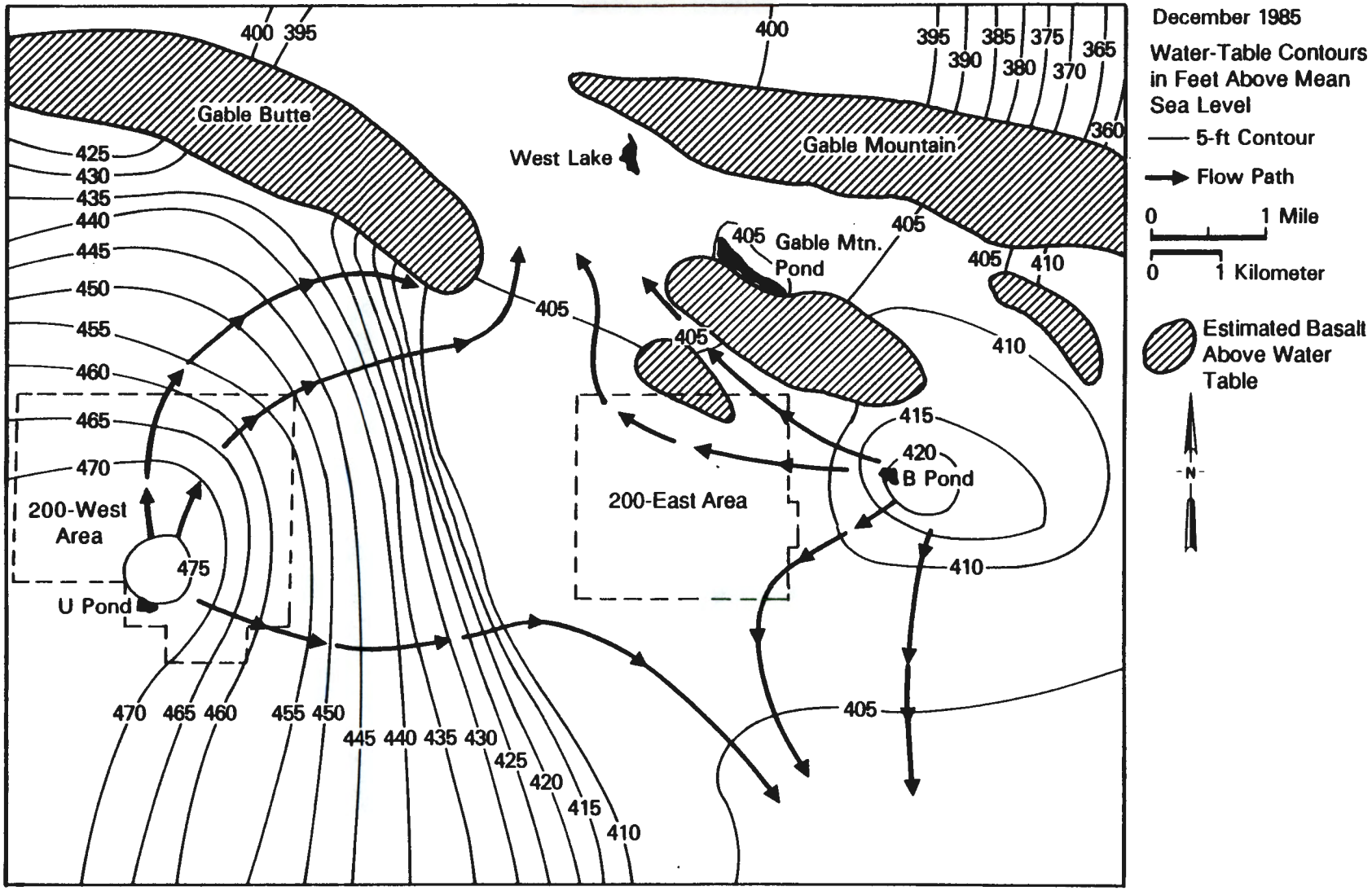


FIGURE 4.1. Presumed Ground-Water Gradients and Flow Directions Used to Select Monitoring Well Locations (PNL 1987)

TABLE 4.1. Past Hydrogeologic Studies of the 200 Areas[a]

Author	Year Published
Separations Areas Hydrogeology	
Brown and Ruppert	1948, 1950
Parker and Piper	1949
Newcomb et al.	1972
McHenry	1957
Brown and Brown	1958
Brown	1959, 1960a
Brown and Haney	1965
LaSala and Doty	1975
Fenix and Scisson	1976
Brown and Isaacson	1977
Webster	1977
Routson and Fecht	1979
Tallman et al.	1979
Myers and Price	1981
Bjornstad	1984, 1985
DOE	1988
Waste Site-Specific Geology	
Brown	1960b, 1963
Price and Fecht	1976a through 1976 m
Last and Marratt	1978a, 1978b
Fecht et al.	1979a, 1979b
Van Luik et al.	1980
Swanson et al.	1988
Separations Areas Ground-Water Hydrology	
Honstead et al.	1955
McConiga	1955
Bierschenk	1957a through 1957c
Bierschenk and McConiga	1957
Bierschenk	1959a, 1959b
Raymond and McGhan	1960
Brown and Haney	1964
Kipp and Mudd	1973, 1974
Deju	1974
Deju and Summers	1975
Ledgerwood and Deju	1975
Gephart et al.	1976
Eddy et al.	1978
Graham et al.	1981

TABLE 4.1. (contd)

Author	Year Published
Separations Areas (contd)	
Hall	1981
Strait and Moore	1982
Graham et al.	1984
Zimmerman et al.	1986
Jensen	1987
Unsaturated Zone Moisture Movement	
Brownell et al.	1971
Hsieh et al.	1973a, 1973b
Enfield et al.	1973
Isaacson et al	1974
Brownell et al.	1975
Last et al.	1976
Jones	1978
Gee and Heller	1985
Gee	1987
Geochemistry of Separations Areas Soils	
McHenry and Honstead	1957
Benson	1960
Brown	1970
Routson	1974
Routson et al.	1978, 1980, 1981
Delegard and Barney	1983
Delegard and Gallagher	1983
Waste Site-Specific Contaminant Distribution	
ARHCO Staff	1973
Ames	1974
Price and Ames	1975
Price et al.	1979
Routson et al.	1979
Smith	1980
Kasper	1982
Van Luik and Smith	1982
Last	1980, 1983
Marratt et al.	1985

(a) For complete references, see Section 10.0.

described in Tallman et al. (1979) and the aquifer characteristics described by Graham et al. (1981, 1984). Other references used most frequently during this study included the following: Bjornstad (1984, 1985), DOE (1988), Fenix and Scisson (1976), Gee (1987), Routson et al. (1981), and Webster (1977).

4.2.2 Data Bases

Over 1,400 wells have been drilled in and immediately surrounding the Separations Areas. Completion information for wells throughout the Hanford Site has been documented by McGhan et al. (1985). Borehole logs (driller's and/or geologist's) of these wells are compiled into three replicate hard copy files (one maintained by PNL's Geosciences Department and two maintained by Westinghouse Hanford Company's Environmental Engineering Group and Environmental Field Services Group). Fecht and Lillie (1982) summarized the borehole logs from the 600 Area (surrounding the Separations Areas). In addition, numerous borehole logs have been summarized and entered into the computerized Hanford Ground-Water Data Base (HGWDB). Borehole samples have routinely been recovered from each borehole at 5-ft increments since before 1960 (Brown 1960c). These samples are archived in the Hanford Geotechnical Sample Library maintained by Boeing Computer Services Richland (BCRS). Additon (1977) produced a catalog of these samples. Thousands of the samples have been tested for their particle-size distribution and calcium carbonate content. Raw data from these analyses have been entered into the computerized ROCSAN Data Base System maintained by BCSR. ROCSAN software calculates weight percentages of the measured size classes and classifies the sediment into one of 19 sediment classes. Fecht and Price (1977a through 1977l) and Fecht et al. (1978a, 1978b) have documented these data from boreholes near high-level waste tanks and liquid-waste disposal cribs, respectively.

Geophysical logs have been run on a large percentage of the boreholes on the Hanford Site. These logs are compiled into hard-copy files maintained by PNL's Geosciences Department (Blair et al. 1981) and/or are available from published reports (e.g., Jackson et al. 1976; Summers et al. 1975). Water-level data and ground-water chemistry data from wells throughout the Hanford Site have been entered into the computerized HGWDB. Water-level data have

also been documented in previous reports and in semiannual water-table maps (e.g., Schatz and Ammerman 1988). Ground-water chemistry data have been published in annual environmental reports (e.g., Jaquish and Mitchell 1988; Serkowski et al. 1988).

The extremely large number of boreholes in the 200 Areas, the large amount of data available for each borehole, and the variability in data quality preclude incorporation of all hydrogeologic information into the characterization efforts. To limit the amount of data to be incorporated, only those wells that were within 1,000 ft of the WMAs and that extend into the unconfined aquifer were examined. A selected number of these wells, which had granulometric analyses, geochemical analyses, and/or geophysical log data associated with them, were directly included in our characterization efforts. The data inventories and lithologic logs for these wells are summarized in Appendix A. A few additional wells were used to map the surfaces of selected geologic units (Section 5.0).

4.3 INVESTIGATIVE METHODS

Hydrogeologic characterization data were collected in the field during installation of each monitoring well. Samples of the borehole cuttings were collected and described, and water levels were measured. Geophysical logs were run after each borehole reached its total depth. Predevelopment ground-water samples were collected to determine if well development/aquifer testing waters could be disposed of to the ground surface or if they needed to be contained. If it was possible, the well was developed and hydrologically tested. The final construction and development of each well were then monitored. On completion of the drilling effort, each new well was surveyed to obtain its location coordinates and the elevation of the top of its casing and well pad.

Hydrogeologic data were also generated in the laboratory. Each borehole sample was analyzed for its particle-size distribution; samples from the 200-West Area were also analyzed for calcium carbonate content. These data were used to aid correlation of the hydrogeologic materials between boreholes.

Hydrologic properties of unsaturated zone materials were determined by laboratory analyses of selected borehole samples for field moisture content, saturated hydraulic conductivity (in progress), and water retention (drying characteristic curve; in progress). Saturation (wetting characteristic curve) analyses were originally planned, however, current PNL unsaturated flow models do not use these data. Thus, analyses were postponed indefinitely. Only drive-barrel samples were selected for these analyses based on preliminary cross-borehole correlations. Laboratory tests of hydrologic properties from the saturated zone were limited to vertical hydraulic conductivity tests of split-barrel samples from a clayey confining bed beneath the 200-West Area.

Geochemical tests were conducted on selected samples from both the unsaturated and saturated zones. These tests consisted of petrographic and mineralogic examinations [in progress at Washington State University (WSU)], x-ray diffraction analyses (in progress at WSU and PNL), x-ray fluorescence (XRF) analyses (in progress at WSU and PNL), total and inorganic carbon analyses (in progress at PNL), and cation exchange capacity determinations [in progress at Oregon State University (OSU)]. In addition, a few chemical and/or radiologic analyses were conducted on selected samples exhibiting higher moisture content and/or suspected of containing some contamination.

4.3.1 Design and Installation of the Ground-Water Monitoring System

The ground-water monitoring system was designed to meet the requirements of 40 CFR 265 Subpart F (EPA 1984). The rationale used to design this system, as well as the methods used for its installation, are discussed below.

Monitoring System Design

The functional design criteria and requirements for the ground-water monitoring systems were defined by WHC. These requirements were established to meet the applicable criteria identified in 40 CFR 265 Subpart F (EPA 1984) and WAC 173-303 (Ecology 1986), as defined below:

The ground-water monitoring system must be capable of yielding ground-water samples for analysis and must consist of:

1. Monitoring wells installed hydraulically upgradient from the limit of the WMA. Their number, location, and depths must be sufficient to yield ground-water samples that are: a) representative of background ground-water quality in the uppermost aquifer near the facility and b) not affected by the facility.

2. Monitoring wells installed hydraulically downgradient at the limit of the WMA. Their number, location, and depth must ensure that they immediately detect any statistically significant amounts of hazardous waste or hazardous waste constituents that migrate from the WMA to the uppermost aquifer.

3. All monitoring wells must be cased in a manner that maintains the integrity of the monitoring well borehole. This casing must be screened and packed with gravel or sand, where necessary, to enable sample collection at depths where appropriate aquifer flow zones exist. The annular space above the sampling depth must be sealed with suitable material to prevent contamination of samples and the ground water.

Additionally, it was required that the location and construction details for these initial-phase monitoring wells should support a plausible final compliance monitoring system, and that the design life of the wells should include the active life of the burial grounds plus the 30-year postclosure period.

The reasoning behind the location of the individual wells was presented earlier in the discussion of our investigative approach, and was documented in the detection-level ground-water monitoring plan (PNL 1987).

Kasper and Myers (1987) performed an engineering study to provide a technical and cost basis for selection of the monitoring well design and construction methods and materials. This study concluded that the preferred final casing and screen material was type 304 stainless steel. The chemical stability and structural strength of this material were deemed adequate to

provide service for the 50-plus-year design life. The preferred casing and screen size was 4-in. inside diameter (ID). The preferred well construction method was to use cable-tool drilling equipment to drill an oversized borehole temporarily supported by at least 8-in.-ID casing. The actual monitoring well would then be constructed inside the borehole. The annular space would be sealed using RCRA-acceptable (EPA 1986b) well seal material as the temporary casing was removed.

Construction specifications were developed, based on the above requirements, preferred design, and construction methods and materials. These specifications are documented in the ground-water monitoring plan (PNL 1987).

Monitoring Well Installation

Sixteen single wells were installed around the 200-East Area WMAs. Twelve of the boreholes for these wells were drilled to the top of basalt, which occurs at a relatively shallow depth in that area. The remaining four boreholes were drilled a maximum of 20 to 30 ft into the unconfined aquifer. The wells were completed with 20 ft of stainless steel screen extending 14 to 17 ft into the unconfined aquifer, except near the basalt high, where a maximum of 8 ft of aquifer was encountered.

In the 200-West Area, 15 shallow (top-of-aquifer) wells and 4 deep (bottom-of-aquifer) wells were installed. Only one deep borehole was drilled to the top of basalt. Three other deep boreholes were drilled to the top of the fine-grained lower/basal unit of the Ringold Formation. Each of these four deep wells was completed in the bottom 10 to 30 ft of the unconfined aquifer. The 15 shallow wells were completed in the top 17 to 27 ft of the aquifer. The large screen intervals were selected to allow for declining water levels. The 30-ft screens were placed nearest U Pond, where the largest water-level declines are expected.

Boreholes were drilled with cable-tool drill rigs using drive-barrel (when available and drilling conditions permitted) or hard-tool methods. When using the drive-barrel method, a drive barrel (a short length of heavy-walled pipe) is driven into the sediments and withdrawn, and the sediment is removed from the drive barrel. This drilling method yields samples of geologic materials that are representative of the actual moisture content and

geologic materials that are representative of the actual moisture content and grain-size distribution. However, this method is difficult to use when gravels are very large or when sediments are saturated. Hard-tool drilling consists of driving a solid metal bit into the sediments, breaking them up, and mixing them with added water to form a slurry, which is then bailed out of the borehole. The bailed slurry provides the samples for geologic characterization.

Boreholes were drilled to depth using successively smaller sizes of temporary carbon-steel casing to support the walls of the borehole. The casings were telescoped one inside the other, so that each size of casing was in contact with only approximately 100 ft of sediments. This facilitated extraction of the temporary casing, once the final stainless steel casing was in place. The beginning casing was generally 16 or 20 in. in diameter. The wells were drilled to their final depth with 8-in.-I.D. casing. A straightness test was then performed by running a 6-in.-diameter 20-ft length of casing down the borehole. No measurement was made of the well's deviation from vertical. If it passed smoothly, the well was deemed acceptable. A 10-ft-long, 8-in.-telescoping (7-7/8-in.-outside diameter) stainless steel screen was then installed, and the 8-in. casing pulled back approximately 9 ft to expose the screen for use in aquifer testing.

After the aquifer test, silica sand was used to backfill the hole to the desired depth at which the 4-in. stainless steel screen and casing would be set. Once the stainless steel permanent casing and screen were set in the hole, silica sand was used to fill the annulus between the 8-in. and 4-in. casing to 5 ft above the top of the stainless steel screen. The temporary casing was extracted as the sand pack and bentonite seals were installed. Five feet of bentonite pellets were then placed on top of the sand pack. In some of the first wells to be completed, Volclay[a] grout was the annular sealant from the top of the pellets to the surface. It was later determined that either dry bentonite granules or bentonite slurry would provide a better and less expensive seal in the vadose zone than would the Volclay grout. Consequently, bentonite granules were used in the vadose zone in the 200-East

(a) Volclay is a product of American Colloid Company, Skokie, Illinois.

Area, and bentonite slurry was used in the 200-West Area, depending on the individual drilling contractor's preference.

The upper 3 to 5 ft of annulus were sealed with concrete. A 4- by 4-ft concrete pad was placed around the well, and a brass marker was placed in the pad. Each brass marker was embossed with the well number. Protective guard posts were installed around each well. Figure 4.2 shows the schematic design for both the shallow and deep wells drilled within the 200-West Area. An identical design was used for 200-East Area wells, except that some wells were completed at the top of basalt instead of the lower Ringold.

The well construction was documented on: 1) geologist's Drill Logs, 2) As-Built Diagrams, 3) Well Completion Report/Title III Inspection Lists, 4) Inspection Plans, and 5) geophysical logs. These were previously documented by PNL (1988a). The Well Completion Report/Title III Inspection Lists, As-Built Diagrams, and borehole data correlation charts for each well are presented in Appendixes B and C. Summaries of the pertinent well information are presented in Tables 4.2 and 4.3 for the 200-East and 200-West Areas LLBGs, respectively.

4.3.2 Geologic Sampling

Two 1-pint sediment samples were collected every 5 ft and/or at changes in lithology. Where possible, the sampled materials were recovered from the borehole using a drive barrel. A third sample was collected for moisture content analysis from each sampled interval above the water table that was retrieved by a drive barrel. Where hard-tool drilling was necessary, the sampled materials were recovered with a bailer. Each sample was described by the well site geologist and recorded on the Drill Logs. These descriptions included a textural name, estimated particle-size distribution, sorting, gross mineralogy, clast roundness, color, reaction to hydrochloric acid, consolidation, changes from previous sample, and any unusual findings. The collection and documentation of these samples were performed in accordance with the procedures given in Last and Liikala (1987). A summary of the geologic materials penetrated by each borehole is recorded on the As-Built Diagrams and borehole data correlation charts presented in Appendixes B and C.

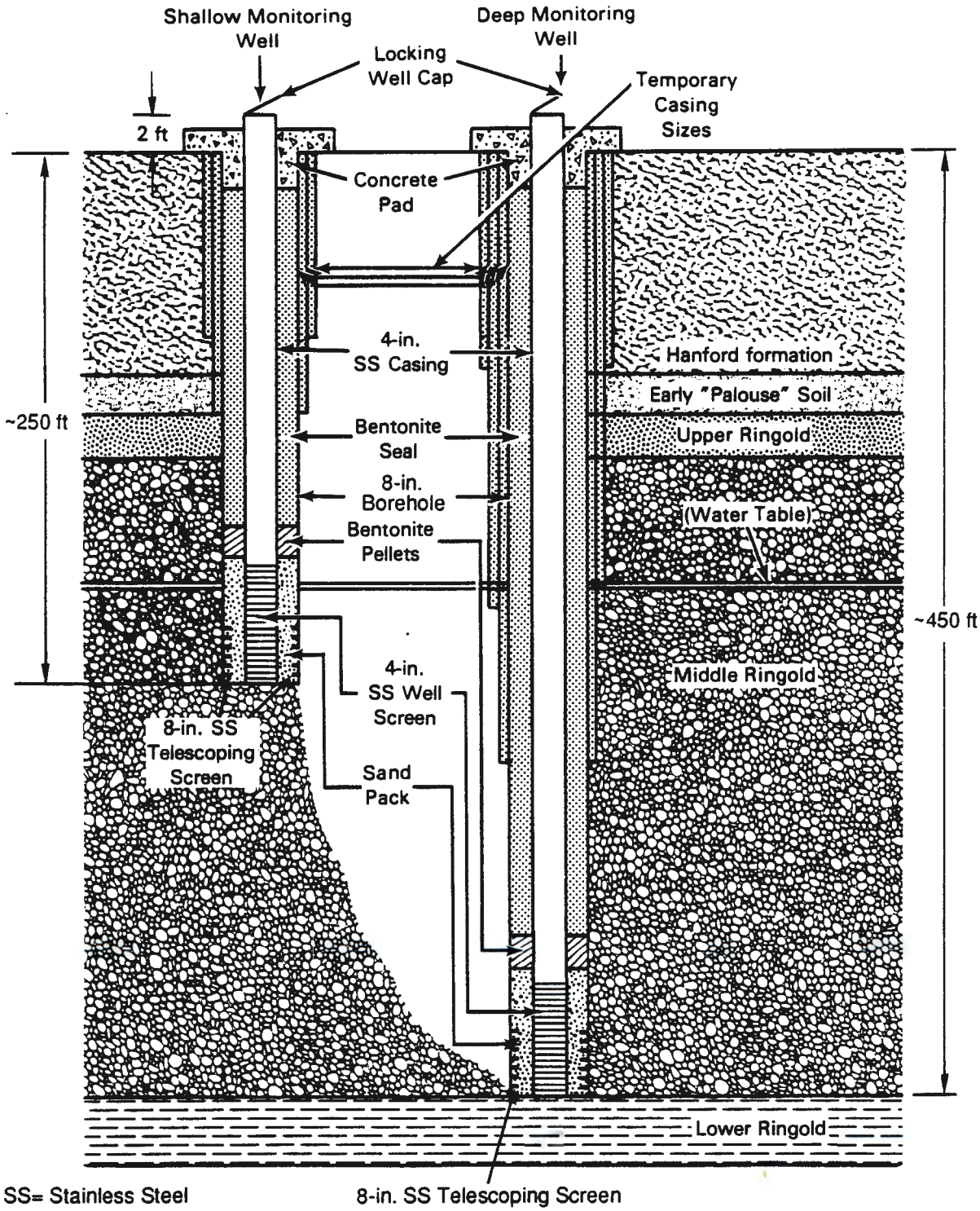


FIGURE 4.2. Schematic of Well Design Used Around the 200-West Area Low-Level Burial Grounds

TABLE 4.2. Well Construction Information for 200-East Area Wells[a]

Well Number (data base number)	Coordinates	Casing Elevation, ft/MSL	Drill Depth, ft	Depth to Water, ft[b]	Depth to Bottom, ft	Screen Interval, ft	Hydrogeologic Unit	Date Completed
299-E27-8 (2599)	N 44496 W 49642	637.83	257	232.76	246	226 to 246	Hanford	9-30-87
299-E27-9 (2700)	N 44484 W 49122	629.21	245	223.98	239	219 to 239	Hanford	8-21-87
299-E27-10 (2701)	N 44520 W 48522	624.47	240	218.84	233	213 to 233	Hanford	8-19-87
299-E28-26 (2706)	N 44446 W 55606	687.26	328.5	282.39	299	279 to 299	Hanford/ Ringold	11-6-87
299-E28-27 (2707)	N 44595 W 54670	680.37	301.5	275.6	290	270 to 290	Hanford	9-30-87
299-E32-2 (2711)	N 45904 W 56565	670.06	289	265.46	278	258 to 278	Hanford	9-30-87
299-E32-3 (2712)	N 45631 W 56721	676.51	304	271.84	286	266 to 286	Hanford/ Ringold	9-30-87
299-E32-4 (2713)	N 44985 W 56713	685.88	311	281.31	298	278 to 298	Hanford/ Ringold	9-30-87
299-E33-28 (2708)	N 45596 W 54668	664.23	278	259.34	276	256 to 276	Hanford	11-6-87
299-E33-29 (2709)	N 45124 W 54665	673.77	290	268.99	283	263 to 283	Hanford	9-30-87
299-E33-30 (2710)	N 45903 W 55660	663.7	280	258.89	275	255 to 275	Hanford	9-30-87
299-E34-2 (2598)	N 45076 W 50048	630.8	241.5	223.50	240	220 to 240	Hanford	9-30-87
299-E34-3 (2702)	N 45337 W 48488	611.52	214	205.80	213	193 to 213	Hanford	8-19-87
299-E34-4 (2703)	N 46791 W 49419	587.56	177	Dry	177	157 to 177	Hanford	8-19-87
299-E34-5 (2704)	N 46791 W 50014	590.79	192	184.66	191	171 to 191	Hanford	8-15-87
299-E34-6 (2705)	N 46784 W 50609	597.83	195	192.8	195	175 to 195	Hanford	8-19-87

(a) Purge volume was 40 gal for each well.
(b) Depth to water measured from top of casing; all other measurements are from ground surface.
MSL = Mean sea level.

TABLE 4.3. Well Construction Information for 200-West Area Wells[a]

Well Number (data base number)	Coordinates	Casing Elevation, ft/MSL	Drill Depth, ft	Depth to Water, ft[b]	Depth to Bottom, ft	Screen Interval, ft	Hydrogeologic Unit	Date Completed
299-W6-2 (2692)	N 45571 W 75302	692.45	248.0	230.47	245	225 to 245	Middle Ringold	11-13-87
299-W7-1 (2686)	N 46551 W 78601	690.71	245.0	228.61	244	224 to 244	Middle Ringold	7-30-87
299-W7-2 (2687)	N 46519 W 77385	675.59	236.0	214.48	222	202 to 222	Middle Ringold	9-30-87
299-W7-3 (2688)	N 46520 W 77420	676.14	475.0	216.28	470	449 to 470	Middle/basal Ringold	11-23-87
299-W7-4 (2689)	N 45435 W 77040	671.69	235.0	208.35	233	203 to 233	Middle Ringold	11-19-87
299-W7-5 (2690)	N 46509 W 76816	673.03[c]	229.0	210.51	228	208 to 228	Middle Ringold	11-19-87
299-W7-6 (2691)	N 46509 W 76219	678.64	243.0	218.03	229	209 to 229	Middle Ringold	11-2-87
299-W8-1 (2676)	N 46551 W 79200	701.33	270.5	238.82	256	236 to 256	Middle Ringold	7-23-87
299-W9-1 (2685)	N 44508 W 79507	737.73	295.0	272.09	286	266 to 286	Middle Ringold	10-22-87
299-W10-13 (2683)	N 43137 W 78297	699.04	250.0	232.11	247	227 to 247	Middle Ringold	9-25-87
299-W10-14 (2684)	N 43143 W 78330	699.43	462.0	232.90	447	427 to 447	Middle Ringold	11-18-87
299-W15-15 (2680)	N 40330 W 78103	697.96	255.0	228.32	253	223 to 253	Middle Ringold	9-2-87
299-W15-16 (2681)	N 40269 W 77387	684.89	243.5	214.51	238	208 to 238	Middle Ringold	9-2-87
299-W15-17 (2682)	N 40221 W 77387	684.64	450.0	214.71	432	422 to 432	Middle Ringold	10-28-87
299-W15-18 (2677)	N 39705 W 77383	685.71	242.5	214.81	238	208 to 238	Middle Ringold	8-4-87
299-W18-21 (2678)	N 37794 W 78080	668.62	227.0	198.54	226	196 to 226	Middle Ringold	7-29-87
299-W18-22 (2679)	N 37831 W 78109	668.49	445.0	199.17	447	416 to 447	Middle Ringold	9-25-87
229-W18-23 (2675)	N 38987 W 78120	696.81	255.0	226.74	251	221 to 251	Middle Ringold	7-1-87
299-W18-24 (2674)	N 38998 W 77180	684.35	240.0	213.14	235	205 to 235	Middle Ringold	8-11-87

(a) Diameter of all wells is 4 in.
(b) Depth to water measured from top of casing; all other measurements are from ground surface.
(c) 1.89 ft of casing were added between January 7 and January 14, 1988. Well has not been resurveyed.
MSL = Mean sea level.

Additional samples were taken where contamination was suspected or where samples were desired for special analyses. When basalt was encountered, hand-selected chips were sampled from the borehole cuttings for chemical identification of the basalt flow. Split-barrel samples of the lower/basal Ringold silt and clay were taken for permeameter testing.

4.3.3 Borehole Geophysical Logging

Each borehole was geophysically logged to assist identification and cross-borehole correlation of hydrogeologic units, and to provide a subjective basis for interpolating between geologic sample intervals within a single borehole. These logs are not intended to provide quantitative data on the physical nature (bulk density, porosity, etc.) of the geologic formations.

Each borehole was geophysically logged when it reached its maximum depth and before well completion. Three different geophysical tools were used consecutively to log the borehole: natural gamma (gross gamma ray), porosity (neutron-epithermal-neutron), and density (gamma-gamma). The operating procedures used to perform this logging are presented in Appendix L. At the time of the logging, the boreholes were cased with between three and five different sized carbon steel casings, one telescoped inside the other. In general, a 16-in. starter casing was used for the top 20 to 60 ft of the borehole. The casing sizes were then reduced to 12, 10, and finally 8 in. at approximately 100-ft intervals. Thus, the geophysical logs (particularly the porosity and density logs) from all but the lower (~100-ft) portion of each borehole are not considered to reflect (entirely) the formation responses and may be of little or no value. Also, note that the water table is generally encountered in the lower 20 to 30 ft of the boreholes; this also influences the geophysical log responses. For the sake of completeness, all logs have been included in the borehole data correlation charts in Appendixes B and C.

The geophysical logging equipment used in this study was routinely calibrated to ensure proper working of the equipment; however, the equipment was not calibrated to provide quantitative data on the physical properties of the geologic materials under the conditions described above (i.e., multiple and

large-diameter casings). It is uncertain as to where even subjective information can be obtained from the porosity and density logs. However, the natural-gamma logs in combination with textural and geochemical data are useful for identifying certain stratigraphic units, particularly fine-grained beds (Section 5.4.3).

4.3.4 Well Development

Well development was conducted in three stages: predevelopment, where ground-water samples were collected; initial development, which included aquifer testing; and final well development. The following sections discuss the methodologies used in each stage of the well development.

Predevelopment Sampling

Initial ground-water samples were collected from each borehole before initial development, aquifer testing, and final well completion. The purpose of these samplings was to determine if the ground-water chemistry were acceptable for surface discharge of borehole development and aquifer testing waters. These data are not intended for use in examining possible ground-water contamination from the burial grounds; ground-water samples to be collected as part of normal ground-water monitoring activities will address this issue. The predevelopment samples were taken after the borehole had reached its total drilled depth and the aquifer testing screen (8-in. telescoping) had been set. These samples were generally collected using a Teflon[a] bailer and analyzed by the United States Testing Company, Inc., Richland, Washington, for volatile organic chemicals, gross alpha and beta radiation, gamma radiation, tritium, total strontium, plutonium, and, occasionally, uranium. In addition, samples from the 200-East Area were analyzed for cyanides and semivolatile organics (acid base neutral by gas chromatograph mass spectrometry). Three wells in the 200-West Area and one in the 200-East Area were analyzed for the complete suite of constituents described in Appendix VIII of 40 CFR 261 (EPA 1986a) and listed in WAC 173-303-9905 (Ecology 1986). Borehole waters were deemed acceptable for

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(a) Teflon is a registered trademark of E. I. du Pont de Nemours and Company, Wilmington, Delaware.

surface discharge only if these rapid analyses indicated that contaminant levels were below 10% of the designated WAC 173-303 (Ecology 1986) hazardous waste guidelines or 1/25 of the Derived Concentration Guides (DCG) for radionuclides. Only one well (299-E28-26) exceeded these limits; the uranium level was greater than 1/25 of the DCG, and thus this well was not aquifer tested or developed using a pump. The results of these initial ground-water samples are presented in Appendix D.

Initial Borehole Development

Each borehole (constructed of 8-in. carbon steel casing and 10-ft-long, 8-in. telescoping stainless steel screen) was initially developed by bailing until it was cleared of sediment, as determined by the well site geologist (usually about 1 h). A submersible pump was then installed in each borehole, except 299-E28-26, 299-E34-4, 299-E34-6, 299-W7-5, 299-W9-1, and 299-W15-18, which were developed by other means. These pumps were used to develop the boreholes while providing information on the optimum pumping rate to aid design of the aquifer tests. This development pumping was generally conducted for 1 to 4 h at variable pumping rates of between 3 and nearly 200 gpm. The specifics of each initial development are documented on the Drill Logs (PNL 1988a), the aquifer test data sheets (Appendixes E and F), and the summary in PNL (1988b).

Final Well Development

Following aquifer testing and installation of the permanent well screen and sand pack, each well was developed by bailing until the water was free of sand and other fine-grained material, as determined by the well site geologist. This development usually lasted for a period of approximately 1 h. Each borehole was then visually inspected using a downhole video camera. Based on these inspections, several wells were bailed a second time and a few were bailed a third time. Each well was later developed using a submersible pump until the water was sand free (<8 mg/L) and turbid free (<5 nephelometric turbidity units), as measured in the field. (This development is still in progress.)

4.3.5 Aquifer Testing

Aquifer tests were performed on all wells, except well 299-E28-26 that had high uranium concentrations, well 299-E34-4 that encountered basalt above the water table and is dry, and well 299-E34-6 that encountered only approximately 2 ft of water above the basalt. The tests at the remaining wells were all constant discharge tests, except at well 299-W9-1 that yielded very little water and, thus, was tested by slug injection/withdrawal methods.

The constant discharge tests were designed to stress the aquifer as much as possible by pumping at a maximum constant rate. The tested wells were drilled to depth (at least 10 ft below the water table) and cased with temporary, 8-in.-diameter carbon steel casing and screened with a 10-ft section of 8-in.-telescoping stainless steel screen. The lower 8 to 9 ft of screen were exposed by back-pulling the temporary casing. Wells were generally pumped using a 20-hp submersible pump at a constant rate for up to 8 h. Discharge was measured using in-line flow meters. Totalizers on large-diameter flow meters read to the nearest 100 gal, while the small flow meter used in some 200-West Area tests read to the nearest 1 gal. A measured 5-gal bucket and/or 55-gal drum was used to check the performance of the in-line flow meters. Discharge was stabilized at a constant rate with variations of no more than ±10%.

Water pumped out of the well was disposed at least 1,000 ft away from the well and any waste sites. Water-level responses were measured during both the drawdown period and during the recovery period (after pumping had been terminated). These measurements were made using an electric water-level indicator (E-tape) and/or a pressure transducer. The E-tape measurements may be no more accurate than 0.5 ft relative to the top of the well casing, but are accurate to within at least 0.1 ft between successive measurements. The E-tape was placed in a stilling well wherever possible. Pressure transducers, like the E-tapes, were used only for relative measurements. These transducers were capable of measuring pressure ranges of 0 to 5, 0 to 10, and 0 to 15 psi.

Steel tapes were used to obtain accurate measurements at the beginning and end of each test. Observation wells were used during 10 of the constant discharge tests. Two tests were conducted at each of the four paired wells in the 200-West Area; two tests (one in 200-West and one in 200-East) were near existing monitoring wells.

A slug injection/withdrawal test was performed on well 299-W9-1 because the aquifer yield of the tested interval was too low to conduct a constant discharge test. This well was completed with the 4-in. stainless steel casing and screen, and was developed only by bailing before performing the test. The slug consisted of a 10-ft, 2.375-in.-diameter pipe filled with sand and sealed at both ends. This pipe displaced 0.31 ft^3 of water. The slug was lowered instantly into the aquifer until completely submerged. After the water level reached equilibrium, the slug was rapidly removed from the aquifer. Aquifer response was measured using a 0- to 10-psi pressure transducer and verified using an E-tape. Both the injection and withdrawal tests were monitored for 180 min.

The following methods were used to analyze the drawdown and recovery data obtained from the constant discharge and recovery tests:

- Theis method (Theis 1935)
- Cooper-Jacob straight-line method (Cooper and Jacob 1946; Lohman 1972).

The underlying assumptions in using these methods included the following:

- The aquifer was of infinite areal extent.
- The aquifer was homogeneous, isotropic, and of uniform thickness within the radius of influence of the pump test.
- The pumped well penetrated, and received water from, the full thickness of the aquifer by horizontal flow.
- The well was pumped at a constant discharge rate.
- The static level of the piezometric surface was horizontal within the radius of influence of the well.

- The well diameter was infinitesimal (storage in the well is neglected).
- The water removed from storage is discharged instantaneously with decline of head.

Although some of these assumptions were obviously violated (e.g., full penetration, homogeneity), the results obtained using these techniques do provide a comparison of the hydraulic properties between the Hanford and Ringold Formations, the primary hydrogeologic units tested.

Data corrections for borehole storage were applied to some analyses. Casing storage effects were analyzed using the equation by Hargis (1979):

$$t_c = 360{,}000 \times r_c^2/T$$

where t_c = time of pumping after which casing storage effects dissipate, min

r_c = radius of the well casing over the interval of drawdown, ft

T = transmissivity of the aquifer, ft^2/d.

Casing storage effects were also analyzed using the equation by Schafer (1978):

$$t_c = 0.6(d_c^2 - d_p^2) \ / \ (Q/s)$$

where t_c = time when casing storage effect becomes negligible, min

d_c = inside diameter of well casing, in.

d_p = outside diameter of pump column pipe, in.

Q/s = specific capacity of the well, gpm/ft of drawdown at time, t_c.

Data from the slug test performed in well 299-W9-1 were analyzed by the following methods:

- Bouwer and Rice method (Bouwer and Rice 1976).
- Hvorslev method (Hvorslev 1951).

The Hvorslev method was analyzed using a microcomputer program by Thompson (1987), which included an expansion to evaluate a variety of well configurations (after Cedergren 1977).

The underlying assumption in using these time-lag permeability tests is that the permeability of the materials is low.

The aquifer test design, raw data, analysis method, and analytical results are presented in Appendix E for the 200-East Area wells and in Appendix F for the 200-West Area wells. Aquifer test results are summarized in Section 6.0.

Water-quality samples were collected periodically throughout 25 of the development and/or constant discharge tests to determine the effects of pumping on the water quality. These samples were analyzed for the same constituents as were the predevelopment samples. Results of these analyses are presented in Appendix D, along with the predevelopment analyses.

4.3.6 Surveying

Each well was surveyed by Kaiser Engineers Hanford following the completion of all wells. The center of the well casing was surveyed for its horizontal position relative to the Hanford Plant Coordinate System. The accuracy of these measurements is estimated to be ±0.5 ft. The top north edge of the casing and the top of the brass survey marker in the well pad were surveyed for their vertical elevation relative to either the 200-East or 200-West datum. The accuracy of these measurements is estimated to be ±0.02 ft in the 200-East Area and ±0.04 ft in the 200-West Area. An "X" was stamped at the survey location on top of the casing. The survey data reports are provided in Appendix G.

4.3.7 Water-Level Measurements

Water-level measurements have been collected from each well at least once a month since the beginning of December 1987. These measurements have been made in duplicate using a steel tape, according to PNL procedure. This procedure was modified such that measurements must be taken until two agree to within ±0.02 ft. Each of the steel tapes is calibrated against a

standardized steel tape to ±0.10 ft. These data are presented in Appendix H, along with a copy of the procedure and hydrographs.

4.3.8 Physical Testing of Borehole Samples

Borehole samples were analyzed for their physical and hydrologic characteristics in PNL's soil laboratory. Samples were analyzed for field moisture content, particle-size distribution, calcium carbonate content, hydraulic conductivity (in progress), and water retention (drying characteristic curve in progress). Three split-barrel samples from a clayey horizon beneath the 200-West Area were analyzed for vertical hydraulic conductivity.

Water Content (Field Moisture)

Samples collected for moisture analyses were placed in airtight containers, sealed with tape, and enclosed in plastic bags to prevent moisture loss. At the end of each day, the samples were placed in a refrigerator, where they remained until the next working day when the analysis was run. After the plastic bag was removed, the entire sample was weighed, oven dried at 105°C for 24 h, and reweighed in accordance with American Society for Testing and Materials procedure D 2216 (ASTM 1986). These data are presented in Appendix I.

Particle-Size Analysis

Particle-size analysis was done using both sieving and sedimentation procedures. Sieve analysis was done on one of the two pint jar samples from all core-barrel and hard-tool sample intervals. Sieve sizes consisted of those with 2.00-, 1.00-, 0.50-, 0.25-, 0.125-, and 0.063-mm sieve openings. The weight of material retained on each sieve was then determined. Instead of splitting each sample down to 150 g, the entire sample from the pint jar was used for sieving.

The raw data were then entered into the ROCSAN data base system, and the ROCSAN program was run. This calculated the total weight percent and particle-size distribution of the sample, and classified the sample according to one of the 19 sediment classes described in Figure 4.3. The ROSCAN output is presented in Appendixes J and K.

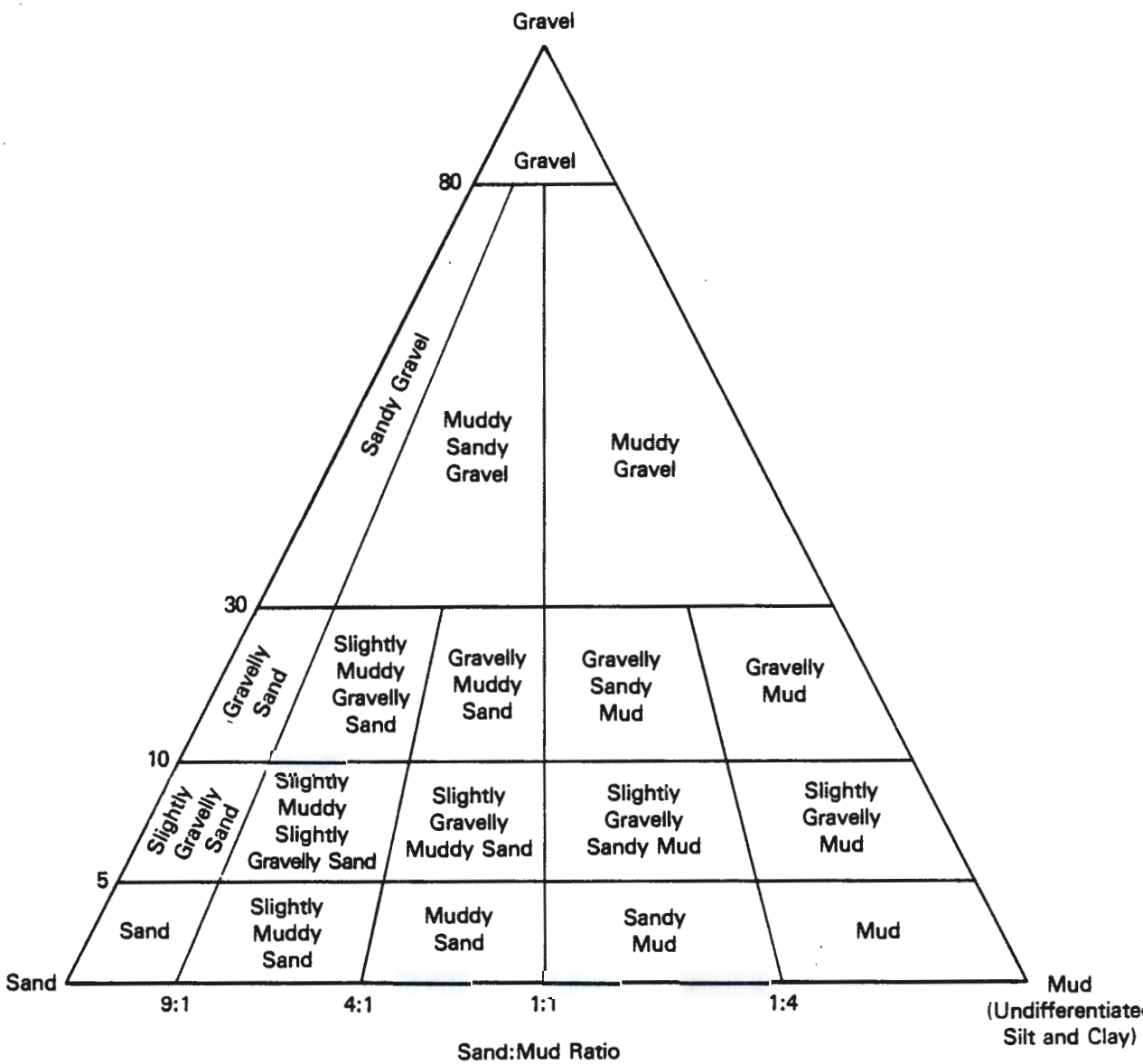

FIGURE 4.3. Sediment Classification Scheme Used in the ROCSAN Program (after Folk 1974)

Three split-barrel samples from the clayey horizon beneath the 200-West Area were analyzed for a complete particle-size range using the hydrometer method described by Gee and Bauder (1986). This procedure was slightly modified by dispersing the samples with an ultrasonic homogenizer instead of the standard mechanical mixer. The data are presented in Section 5.0.

Calcium Carbonate Analysis

Calcium carbonate analysis was determined for each of the 200-West Area samples analyzed for particle-size distribution. The calcium carbonate content was determined using a volumetric calcimeter method described by Allison and Moodie (1965). These data, based on $\%CaCO_3$, were also entered into the ROCSAN data base and are included in the ROCSAN output in Appendix K.

Hydraulic Conductivity of Core-Barrel Samples

Hydraulic conductivity measurements were made on 15 selected core-barrel samples from the unsaturated zone. These measurements were made using the constant-head method described by Klute and Dirksen (1986). During this procedure, the loose sediment was packed into a cell 5.36 cm in diameter by 3 cm high, until a bulk density of 1.6 g/cm^3 was reached. One sample (from the 65-ft level of well 299-W7-2), however, would not pack greater than 1.4 g/cm^3. The ends of the cell were closed with lids having an inflow valve at one end and an outflow valve at the opposite end. The inflow valve was then connected to the constant head device, and the outflow valve was connected to a collection vessel. Starting with a saturated sample, an initial time was recorded and the water allowed to flow through the sample for a predetermined amount of time. The amount of water discharged from the sample was then recorded, and the hydraulic conductivity calculated. (These data were not available at the time of this report.)

Hydraulic Conductivity of the Split-Barrel Samples

Three split-barrel samples were analyzed for their vertical hydraulic conductivity using the falling-head method also described by Klute and Dirksen (1986). In this procedure, a 10-cm-long section was cut out from the end of each 4-in.-diameter split-barrel core, while still wrapped in the sample liner. The sides of the core were then sealed to the liner, which was used as the containing cell. End caps, one with an inflow valve and one with an outflow valve, were placed on opposite ends of the cell. The inflow valve was then connected to a standpipe of known cross-sectional area and height. The samples were saturated before testing by slowly wetting them from the bottom. A solution of 0.01-M calcium chloride was used to ensure no interaction with the clay. Because the flow rates were extremely low, this

saturation process took several months. At the start of the test, an initial measurement was made of the hydraulic head in the standpipe. The dilute calcium chloride solution was then allowed to flow from the standpipe through the sample for a given length of time. The ending head level in the standpipe was then recorded. Test runs were repeated five times and the values averaged to calculate the hydraulic conductivity. These values are presented in Section 5.0.

Water Retention

Water-retention characteristics were measured on the selected core-barrel samples used in the hydraulic conductivity analyses. Measurements were made at 5-, 10-, 15-, 20-, 30-, 40-, 50-, and 75-cm head pressures using hanging water columns. Pressure Plate Extractors[a] were used for 510-, 1020-, and 3060-cm head pressures.

The hanging water column analyses were performed using the saturated core-barrel samples used in the hydraulic conductivity analyses. These samples were transferred to the porous plates in the Buchner funnels while they were still in their containing rings. The hanging water column is made by creating a continuous column of water from the bottom of the porous plate through a cork in the neck of the funnel and into a narrow tube long enough to allow measurement of the desired pressure heads. The pressure head is measured from the center of the soil cell, which is in continuous contact with the column of water to the open end of the tubing (i.e., the open water surface). After equilibrium is reached at each head level, the soil cell is weighed, and the weight is recorded. After the final head value equilibrium has been achieved, the sample is oven dried, and the water content at each level is calculated.

For the Pressure Plate Extractor analyses, samples were packed into containing rings on a porous plate and allowed to stand for 24 h. Equilibrium water contents were obtained by pressure draining the samples in the extractor at the desired test level. At the end of each pressure run, the

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(a) Pressure Plate Extractors are a product of Soilmoisture Equipment Corp., Santa Barbara, California.

sample was weighed and oven dried to determine the moisture content at that pressure (Klute 1986). (Results of these analyses were not available at the time of this report.)

4.3.9 Mineralogy and Geochemical Testing of Borehole Samples

Selected borehole samples were tested by WSU, PNL, and OSU for various mineralogical and geochemical parameters. These tests included petrography and mineralogy (in progress at WSU), x-ray diffraction analyses (in progress at WSU and PNL), XRF analysis (in progress at WSU and PNL), cation exchange capacity (in progress at OSU), and total and inorganic carbon analysis (in progress at PNL).

Petrography and Mineralogy (WSU)

Loose grain-mounted thin sections were made from 54 selected borehole samples. Six duplicate thin sections were also made. These thin sections were stained for determination of both plagioclase and potassium feldspars. Point counting of all minerals present was then performed on each of these thin sections at 300 counts of framework grains per slide. (Results were not available at the time of this report.)

X-Ray Diffraction Analyses (WSU)

Grain sizes were segregated by sieving portions of the same 54 samples analyzed above. Randomly oriented, sand-sized samples and basally oriented clay samples were then pretreated and prepared. These samples were run on the x-ray diffraction unit and the mineralogies quantitatively determined from the diffraction patterns. (Results were not available at the time of this report.)

X-Ray Diffraction Analyses (PNL)

Aliquots of 10 borehole samples were separated into sand-, silt-, and clay-size fractions. The sand- and silt-size fractions were ground, and randomly oriented samples were prepared for analysis. Basally oriented samples were prepared from the clay-size fractions. These samples were run on an x-ray diffractometer, and minerals were quantitatively determined from the diffraction patterns. (Results were not available at the time of this report.)

X-Ray Fluorescence Analyses (WSU)

Aliquots of the 54 selected borehole samples were sieved to segregate the grain sizes. Selected grain sizes were then crushed and pretreated. These prepared samples were then run on the XRF unit, and both the normalized and unnormalized major and trace element weight percentages were determined. (Results were not available at the time of this report.)

X-Ray Fluorescence Analyses (PNL)

The XRF analyses of 40 borehole samples were carried out by procedures and quality control for energy dispersive XRF spectrometry using the backscatter fundamental approach with a Kevex 0810 system. (Results were not available at the time of this report.)

Cation Exchange Capacity (OSU)

Aliquots of 40 borehole samples were sieved to recover the less than 2-mm-size fraction. This fraction was then analyzed for cation exchange capacity by ammonium acetate (pH = 7) extraction. (Results were not available at the time of this report.)

Total and Inorganic Carbon Analyses (PNL)

Aliquots of 40 borehole samples were analyzed for total carbon and inorganic carbon. Total carbon was determined by a dry-combustion coulometric technique, as described by Huffman (1977). Inorganic carbon was determined by the same coulometric technique, except that the samples were digested in 3 N HCl at 80°C for 10 min rather than combusted. Both total and inorganic carbon procedures were calibrated with reagent-grade calcium carbonate. (Results were not available at the time of this report.)

5.0 GEOLOGY OF THE WASTE MANAGEMENT AREAS

This section provides interpretations of the geology beneath each of the WMAs in the 200-East and 200-West Areas. These interpretations are based primarily on the field descriptions and laboratory analyses of borehole cuttings from 35 monitoring wells recently installed around the four WMAs. In addition, data from existing boreholes were used, including six core holes to the top of basalt. Information from published reports also aided these interpretations.

5.1 INTRODUCTION

Samples of the geologic materials encountered by each new borehole were collected at 5-ft-depth intervals and at obvious lithologic changes. These sediment samples were obtained via one of two cable-tool drilling methods: 1) drive barrel or 2) hard tool. The drive-barrel method produces representative samples, which, when analyzed for grain size, reflect an accurate measurement of the true grain-size distribution. The hard-tool method, which uses a heavy metal bit to break up the gravels and adds water to form a mud slurry, produces a disturbed sample. These hard-tool samples can produce granulometric results that are skewed more toward the finer grained fractions than what might have resulted from an undisturbed sample. With either method, however, the variation caused by the drilling and sampling methods is expected to be less than the natural variation in the sediments (Brown 1960c).

Twenty-three well site geologists were involved with the sample collection and description efforts. These geologists followed the standard procedures and guidance documented by Last and Liikala (1987) for collecting and describing the borehole samples. These sample descriptions systematically included a cursory textural classification (after Folk 1974) and estimates of particle-size distribution, sorting, gross mineralogy, roundness, color, reaction to hydrochloric acid, and relative consolidation. In addition, each sampled interval was analyzed in the laboratory for its particle-size distribution, and samples from the 200-West Area were also analyzed for calcium carbonate content.

The field descriptions and laboratory results for the new monitoring wells were entered into a computerized data base. Each data category for a given borehole was then sorted by sample depth and graphically displayed at a preselected scale. All graphs for a given well were plotted side by side on a data correlation chart (Figure 5.1). The data used in these plots include 1) quantitative granulometric, moisture content, and calcium carbonate data; 2) borehole geophysical logs; and 3) qualitative estimates of basalt content, color, hydrochloric acid reaction, and drilling rate. These data, plotted together at the same scale, provide the basis to identify stratigraphic and lithologic units. The stratigraphic units were identified from the borehole data correlation charts based on the characteristics given in Table 5.1, as originally presented in DOE (1988). Lithologic units were identified within the boundaries of stratigraphic units where large and distinct changes were observed in the correlation charts between successive depths and these changes could be traced between a number of boreholes. Large changes unique to a single borehole were interpreted as a discontinuous lens. Minor changes in individual well samples are interpreted to reflect the natural variations and, to a lesser degree, some sampling variation within a given lithologic unit.

The following discussions describe the geomorphology of the WMAs, followed by the geology of WMA-1 and WMA-2 in the 200-East Area and the geology of WMA-3 and WMA-4 in the 200-West Area.

5.2 GEOMORPHOLOGY

The surface topography of the 200 Areas is the result of two geomorphic processes: 1) Pleistocene cataclysmic flooding and 2) Holocene eolian activity. Cataclysmic flooding, which ended approximately 13,000 years ago (Mullineaux et al. 1978), created Cold Creek bar (Bretz et al. 1956), a prominent flood feature within the Pasco Basin (see Figures 3.4 and 5.2). The last flood(s) covered the 200 Areas with a blanket of coarse-grained deposits, which become finer grained to the south. The northern boundary of the flood bar is defined by an erosional channel running east-southeast before turning south near B Pond. This erosional channel formed during

Well 299-W10-14

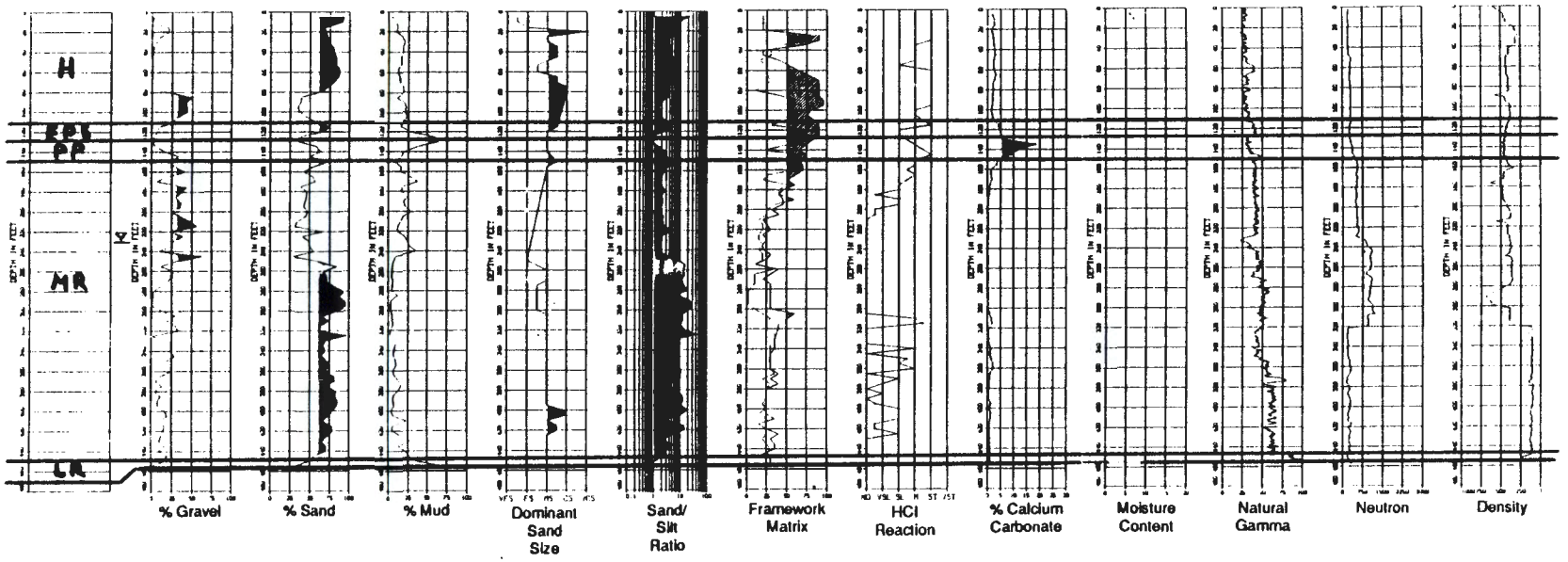

FIGURE 5.1. Example of the Borehole Data Correlation Charts Used in This Study

TABLE 5.1. Characteristics Used to Distinguish Sedimentary Units (modified from DOE 1988)

Formation	Hanford formation		Plio-Pleistocene unit		Ringold Formation				
Unit	Pasco Gravels	Touchet Beds	Fanglomerate Facies	Calcrete Facies	Upper	Middle	Lower	Basal	
Subunit								Fine grained	Coarse grained
Thickness, ft	300	210	10	85	0 to 108	180 to 328	0 to 56	0 to 66	20 to 151
Texture	Sandy gravel to gravelly sand	Sand to mud	Muddy sandy gravel	Mud to sand	Sand to mud; occasional gravel	Sandy gravel	Mud	Mud to sand	Gravelly sand to sandy gravel
Sedimentary Structure									
Primary	Large-scale foreset bedding	Graded bedding; planar to ripple lamination	Crude sub-horizontal bedding	Not present	Planar-tabular cross bedding; ripple lamination	Crude sub-horizontal bedding	Moderately to well laminated	Ripple lamination	Planar lamination; crude sub-horizontal bedding
Secondary	Occasional caliche	Load structures; clastic dikes; occasional caliche	Intercalated caliche layers	Pedogenic platy to massive calcrete; bioturbation	Load structures	Not present	Not present	Pedogenic blocky illuviation; caliche stringers and nodules; bioturbation	Not present
Roundness of gravel (mode/range)	Subrounded/ angular to well rounded	Not applicable	Subangular/ angular to subangular	Not applicable	Well rounded/ subrounded to well rounded	Well rounded/ subrounded to well rounded	Not applicable	Not applicable	Well rounded/ subrounded to well rounded
Sorting	Poor	Poor to moderate	Poor	Poor	Moderate to well	Moderate to well	Well	Poor to well	Moderate to well
Natural-gamma activity	Low	Moderate to high	Low	Moderate to high	Moderate to high	Low	High to very high	Low to high	Low to moderate
Basalt content									
Framework (%)	50 to 90	Not applicable	90 to 100	Not applicable	20 to 40	20 to 40	Not applicable	Not applicable	10 to 50
Matrix (%)	10 to 30	10 to 30	75 to 100	0 to 10	5 to 20	5 to 20	Not present	0 to 75	5 to 20
$CaCO_3$ (relative abundance/ occurrence)	Moderate/ rinds on gravel; reworked caliche clasts	Moderate/fine grained and disseminated	Low-high/ intercalated pedogenic layers	High/advanced pedogensis; massive to platy	Low/ occasional coatings or cement	Low/ occasional coatings or cement	Not present	Low to high/ caliche stringers and nodules	Low/ occasional coatings or cement
Environment of deposition	Glaciofluvial (high energy)	Glaciofluvial (low energy)	Fluvial/ colluvial (side-stream facies)	Subaerial	Fluvial (low energy)	Fluvial (high energy)	Lacustrine and (or) fluvial (low energy)	Fluvial (low energy to subaerial)	Fluvial (high energy)

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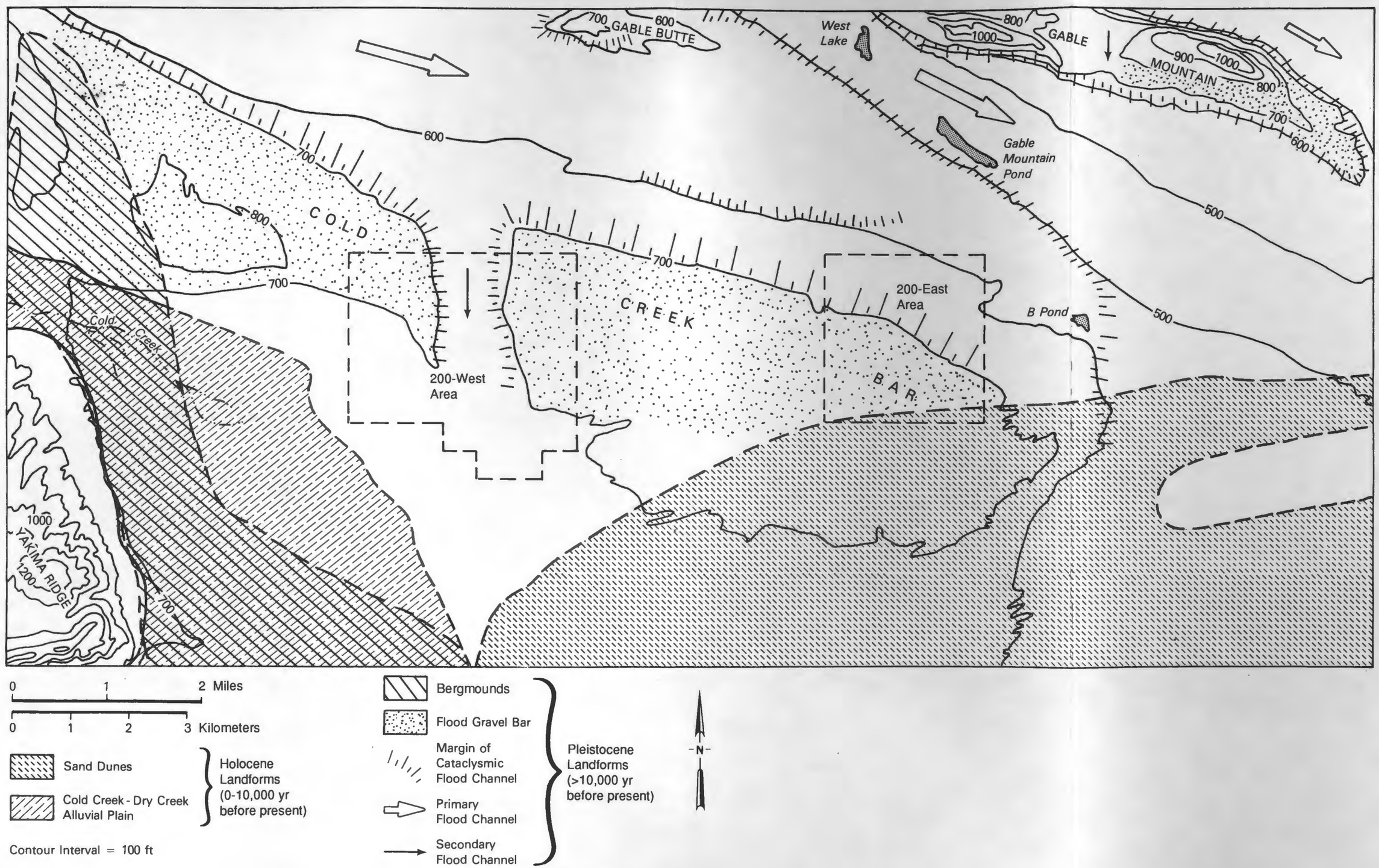

FIGURE 5.2. Geomorphic Features Surrounding the 200 Areas

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waning stages of flooding as flood waters drained from the basin (Bjornstad et al. 1987). The northern half of the 200-East Area lies within this flood channel (see Figure 5.2). A secondary flood channel running southward off the main channel bisects the 200-West Area. This secondary channel allowed flood waters above the 680-ft elevation to drain into Cold Creek valley.

Since the end of the Pleistocene, winds have locally reworked the surface of the glaciofluvial sediments, depositing a thin veneer of eolian sand in places. Holocene sand dunes are present along the southern boundary of the 200-East Area (see Figure 5.2). Holocene alluvium, associated with the Cold Creek-Dry Creek alluvial plain, was deposited less than 1 mile southwest of the 200-West Area (see Figure 5.2).

The terrain surrounding WMA-1 and WMA-2 dips to the north-northeast, with an average slope of approximately 22 ft/1,000 ft (less than 2 degrees). The ground surface elevation ranges from approximately 685 ft in the southwestern corner of WMA-1 to approximately 580 ft in the northeastern corner of WMA-2 (Figure 5.3). In the 200-West Area, the surface within WMA-3 dips to the east toward the axis of the small secondary flood channel discussed above. In WMA-4, the surface dips to the south. The maximum amount of relief between WMA-3 and WMA-4 is approximately 100 ft. Elevations range from a high of approximately 760 ft to the northwest in WMA-3 to approximately 660 ft along the southern margin of WMA-4 (Figure 5.4).

Construction and operation of the burial grounds resulted in dramatic reworking of the surficial materials and modifications to the local topography.

5.3 GEOLOGY OF WASTE MANAGEMENT AREAS 1 AND 2

The stratigraphy beneath WMA-1 and WMA-2 has been interpreted primarily from field and laboratory analyses of cable-tool borehole samples collected during the installation of 16 ground-water monitoring wells and 10 previously existing boreholes located within approximately 1,000 ft of WMA-1 and WMA-2. Data generated in the field during installation of the new wells included: 1) geologist's Drill Logs, 2) As-Built Diagrams, 3) Well Completion

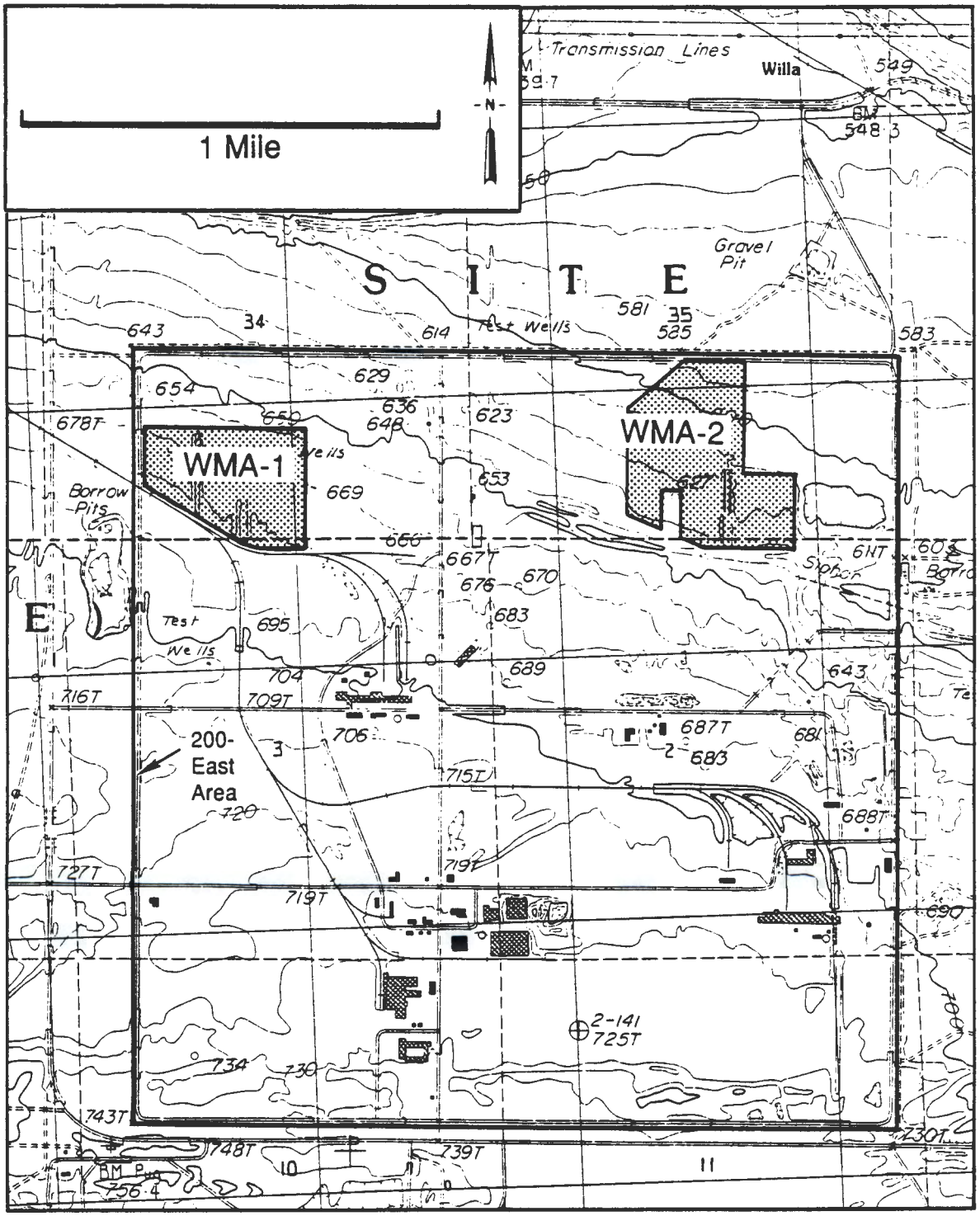


FIGURE 5.3. Topography of Waste Management Areas 1 and 2 (contour interval = 10 ft)

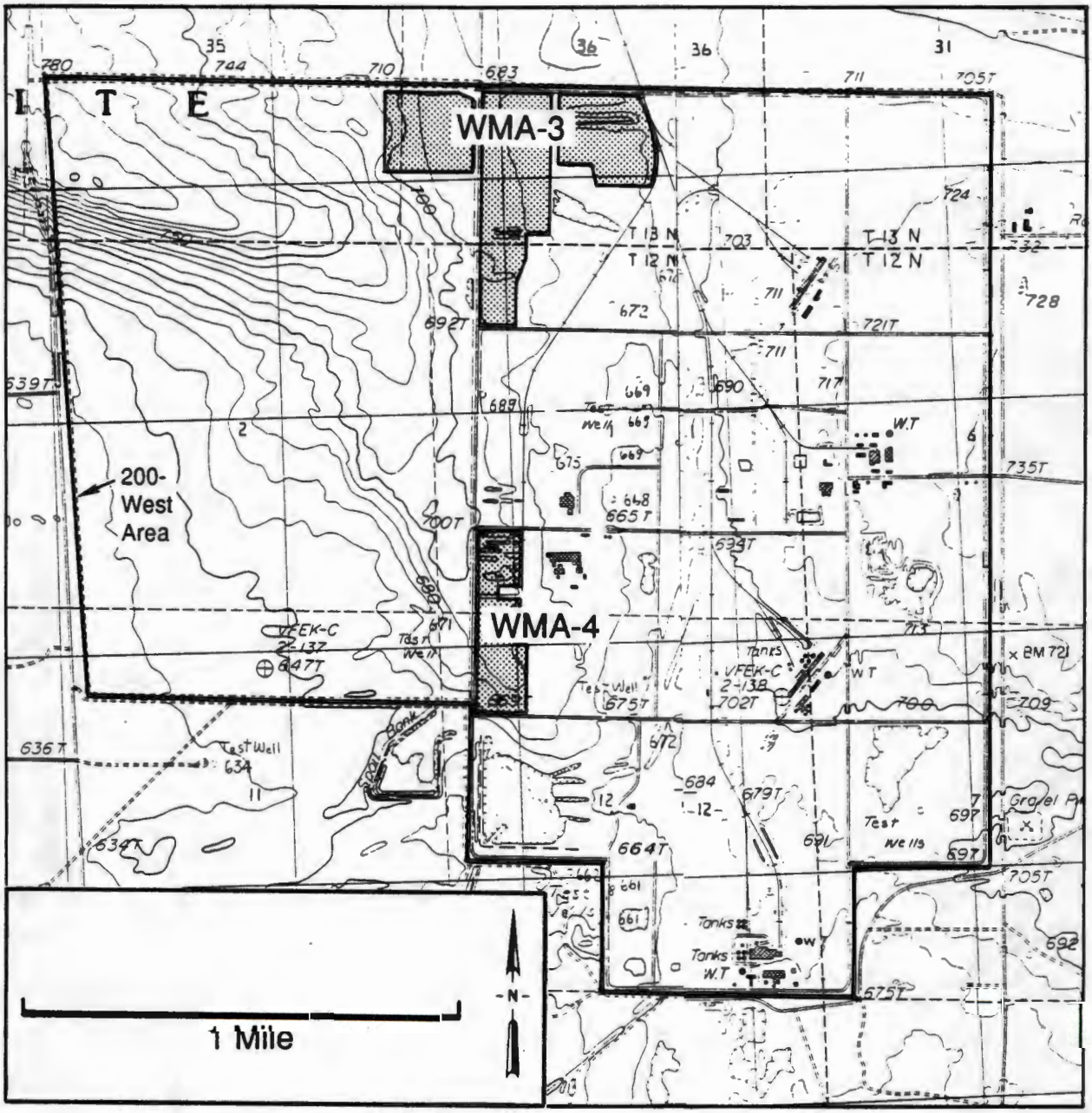


FIGURE 5.4. Topography of Waste Management Areas 3 and 4 (contour interval = 10 ft)

Report/Title III Inspection Lists, 4) Inspection Plans, and 5) geophysical logs. The geologist's Drill Logs and Inspection Plans from these wells have previously been documented by PNL (1988a) and are not included in this report. The As-Built Diagrams and Well Completion Report/Title III Inspection Lists are included in Appendix B. Borehole samples collected during the drilling effort were analyzed in the laboratory for their moisture content (where appropriate) and particle-size distribution. These data are presented in Appendixes I and J, respectively. Borehole data from the geologist's Drill Logs, geophysical logging, and laboratory analyses were composited on borehole data correlation charts. Identification of stratigraphic and lithologic units (Table 5.2) for the newly installed wells was derived from these borehole data correlation charts. These charts are included in Appendix B.

For the 10 previously existing wells listed in Table 5.2, stratigraphic contacts were picked based on the combination of two or more of the following: 1) granulometric data, 2) calcium carbonate content, 3) natural-gamma response, and 4) driller's Drill Logs. An inventory of the data used and lithologic log summaries for the previously existing wells are presented in Appendix A. In general, data from these previously existing wells are not as complete or as reliable as data from the new wells.

The depth and elevation of each stratigraphic contact and the corresponding thickness of each stratigraphic unit encountered by each borehole were listed in Table 5.2. Figure 5.5 illustrates generalized stratigraphic/lithologic sections beneath WMA-1 and WMA-2.

Four geologic cross sections were constructed around each of these WMAs. The locations of these cross sections, along with locations of all boreholes used in this study, are shown in Figure 5.6. Figures 5.7 through 5.10 illustrate the geologic cross sections beneath WMA-1, and Figures 5.11 through 5.14 illustrate the cross sections beneath WMA-2. The lateral extent of the stratigraphic and facies contacts illustrated on these cross sections are all questionable and are based on preliminary interpretations. These may change as a result of additional drilling and/or analysis.

TABLE 5.2. Stratigraphic Contacts in 200-East Area Wells

Borehole	Surface Elevation, ft above MSL	Depths, ft					Elevations, ft above MSL				Thicknesses, ft			
		Water Table	Top of Sand	Top of Basal Coarse Unit	Top of Ringold	Top of Basalt	Top of Sand	Top of Basal Coarse Unit	Top of Ringold	Top of Basalt	Upper Coarse Unit	Sand Unit	Basal Coarse Unit	Ringold Fm
WMA-2														
*299-E26-1	617	216	UD	UD	NP	225	UD	UD	NP	392	UD	UD	UD	NP
299-E27-8	638	233	UD	UD	NP	257	UD	UD	NP	381	UD	UD	UD	NP
299-E27-9	629	224	UD	UD	NP	245	UD	UD	NP	384	UD	UD	UD	NP
299-E27-10	624	219	UD	UD	NP	240	UD	UD	NP	384	UD	UD	UD	NP
299-E34-2	631	224	UD	UD	NP	241	UD	UD	NP	390	UD	UD	UD	NP
299-E34-3	612	206	UD	UD	NP	213	UD	UD	NP	399	UD	UD	UD	NP
299-E34-4	588	Dry	UD	UD	NP	>177	UD	UD	NP	<411	UD	UD	UD	NP
299-E34-5	591	185	UD	UD	NP	189	UD	UD	NP	402	UD	UD	UD	NP
299-E34-6	598	193	UD	UD	NP	194	UD	UD	NP	404	UD	UD	UD	NP
*699-47-50	584	?	UD	UD	NP	215	UD	UD	NP	369	UD	UD	UD	NP
*699-47-51	583	Dry	UD	UD	NP	159	UD	UD	NP	424	UD	UD	UD	NP
WMA-1														
*299-E28-9	701	296	80	190	?	>350	621	511	?	<351	80	110	>162	?
*299-E28-20	690	285	35	165	?	?	655	525	?	?	35	130	?	?
299-E28-26	687	282	77	172	310	326	610	515	377	361	77	95	154	16
299-E28-27	680	276	110	185	NP	>302	570	495	NP	<378	110	75	>117	NP
*299-E32-1	656	255	55	195	NP	272	601	461	NP	384	55	140	77	NP
299-E32-2	670	265	42	184	NP	287	628	486	NP	383	42	142	103	NP
299-E32-3	677	272	64	195	299	>304	613	482	378	<373	64	131	>109	>5
299-E32-4	686	281	72	180	297	>311	614	506	389	<375	72	108	>131	>14
*299-E33-5	629	222	50	155	NP	236	579	474	NP	393	50	105	81	NP
*299-E33-8	648	246	60	210	NP	257	588	438	NP	391	60	150	47	NP
*299-E33-21	663	262	46	215	NP	279	617	448	NP	384	46	169	64	NP
*299-E33-26	633	229	55	135	NP	239	578	498	NP	394	55	80	104	NP
299-E33-28	664	259	22	155	NP	>278	642	509	NP	<386	22	133	>123	NP
299-E33-29	674	269	60	215	NP	290	614	459	NP	384	60	155	75	NP
299-E33-30	664	259	75	205	NP	279	589	459	NP	385	75	130	74	NP

MSL = Mean sea level.
NP = Not present.
UD = Units undifferentiated.
* = Previously existing wells.

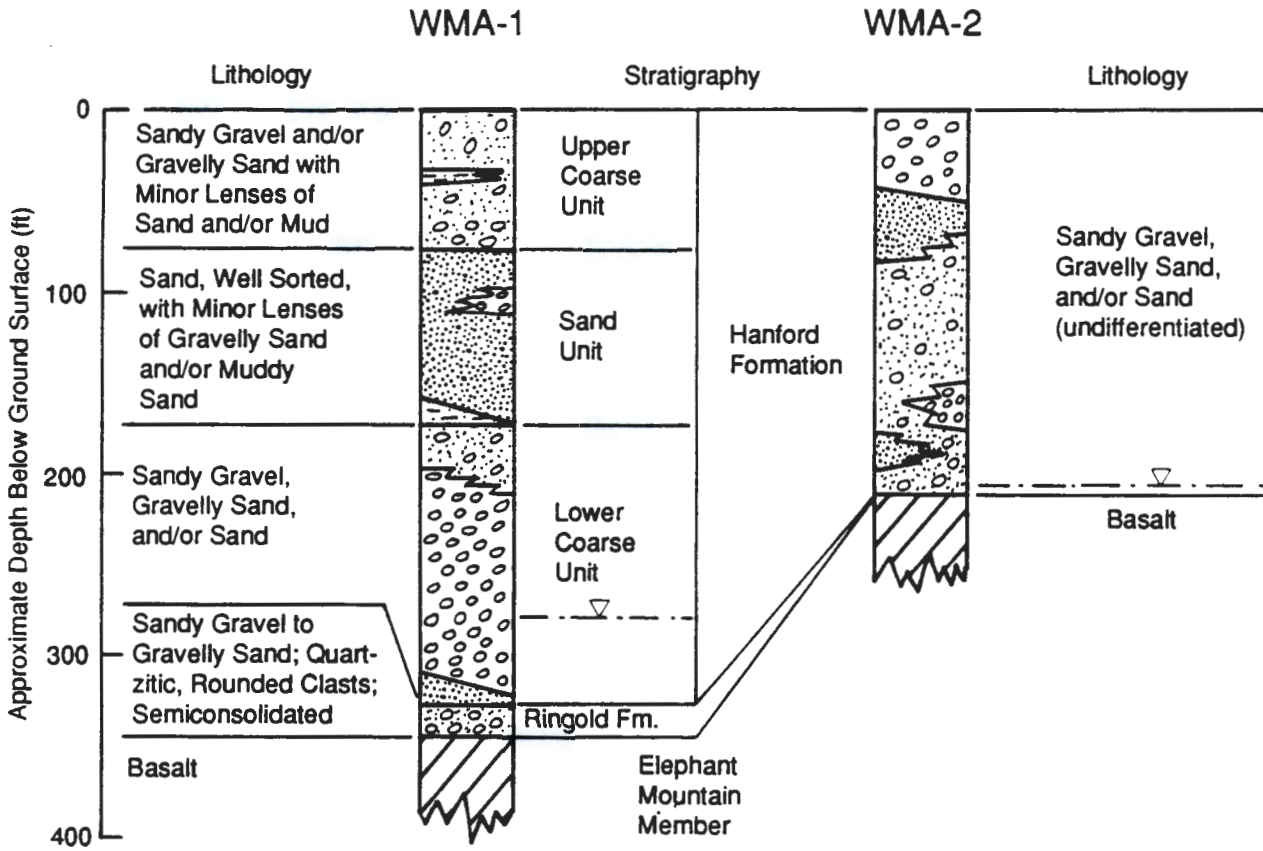


FIGURE 5.5. Generalized Stratigraphy for Waste Management Areas 1 and 2

Three geologic formations are present beneath the 200-East Area (see Figure 5.5): 1) the late-Miocene Saddle Mountains Basalt (Elephant Mountain Member), 2) the Miocene/Pliocene Ringold Formation, and 3) the Pleistocene Hanford formation (informal name). Other units, such as the early "Palouse" soil and the Plio-Pleistocene unit, present in the 200-West Area, have not been identified in the 200-East Area. These units may have been present in the 200-East Area at one time, but have subsequently been eroded via down-cutting by the Columbia River and/or Pleistocene cataclysmic flooding. The combined thickness of the post-basalt sediments is shown in Figure 5.15. Figure 5.16 illustrates the three-dimensional relationships between the formations present in the northern part of the 200-East Area.

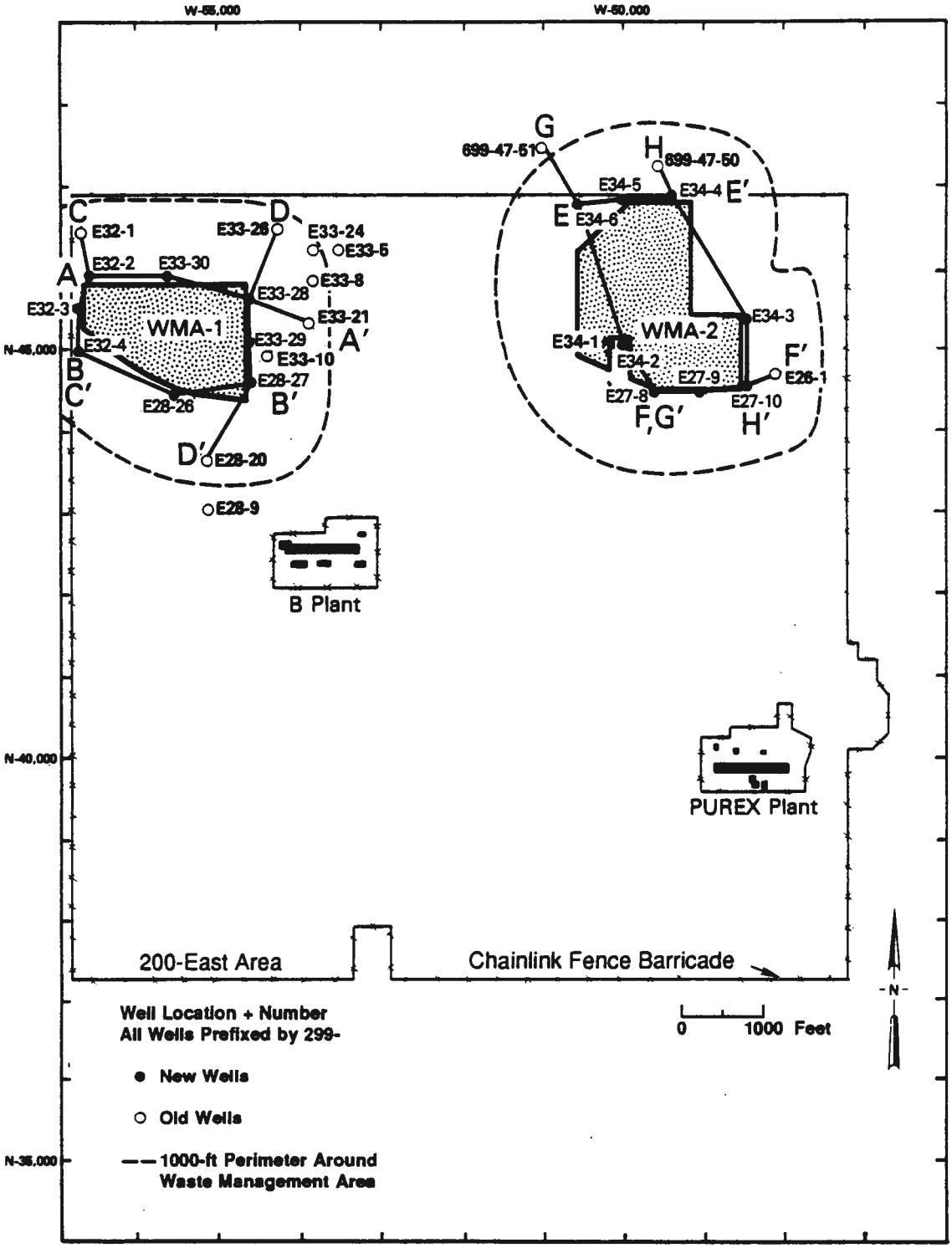
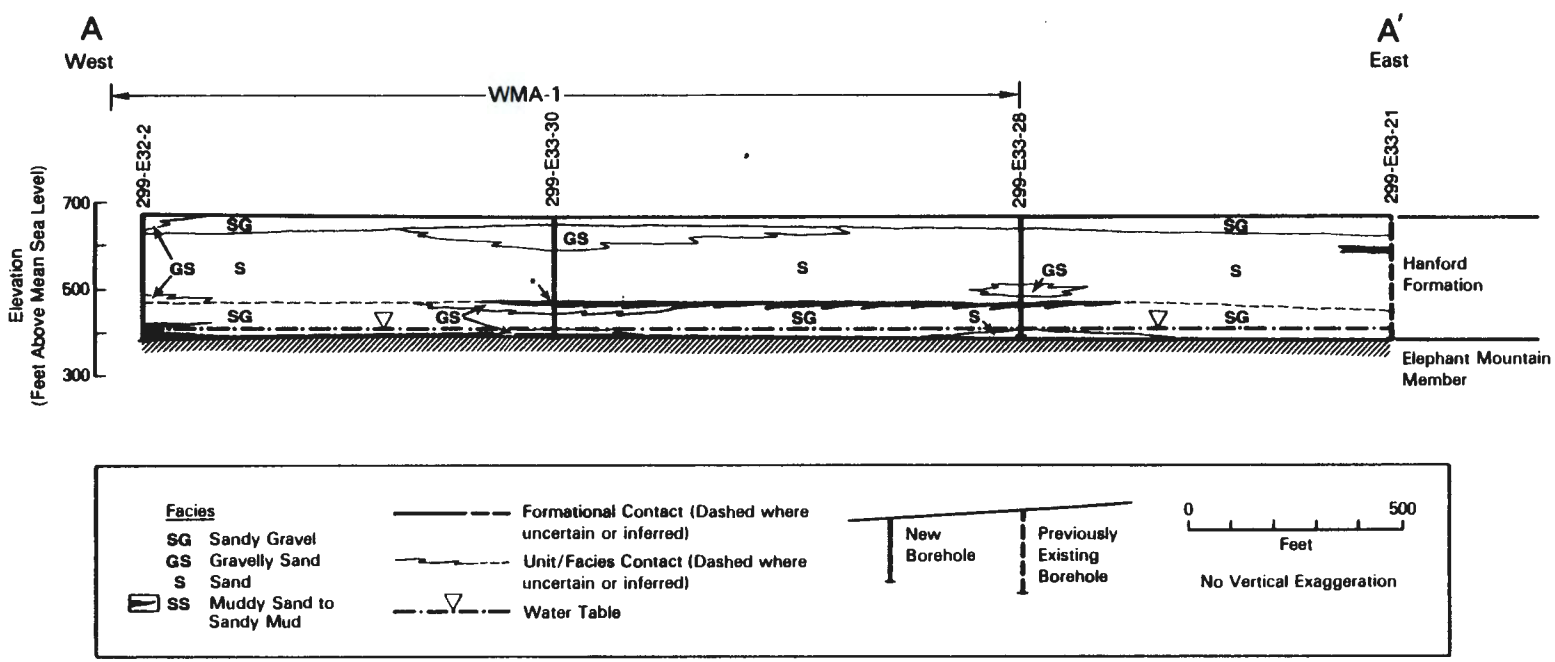


FIGURE 5.6. Location of Monitoring Wells and Geologic Cross Sections Around Waste Management Areas 1 and 2



*Hydrometer Analysis
2% Sand
82% Silt
16% Clay

FIGURE 5.7. Geologic Cross Section A-A', Waste Management Area 1

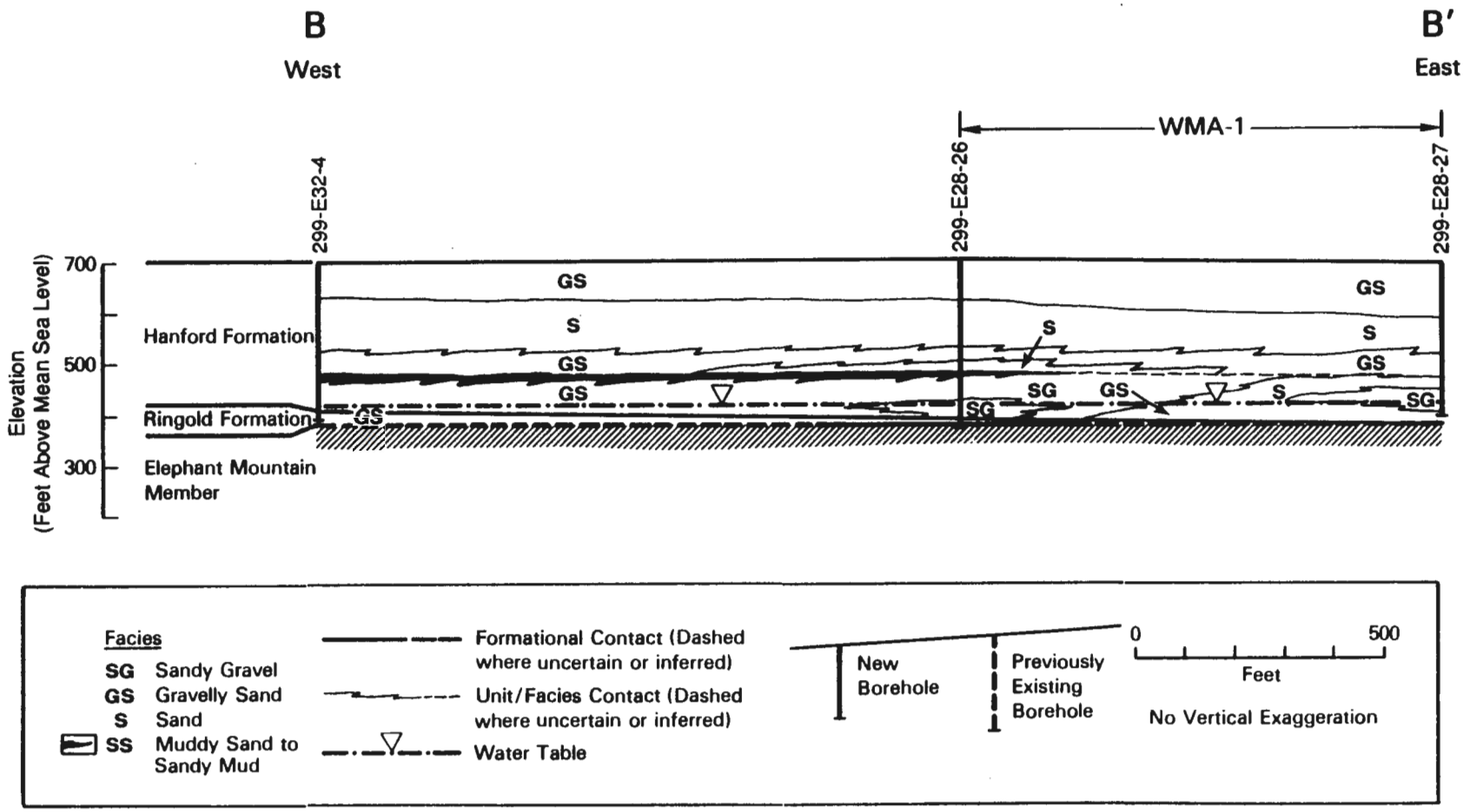


FIGURE 5.8. Geologic Cross Section B-B′, Waste Management Area 1

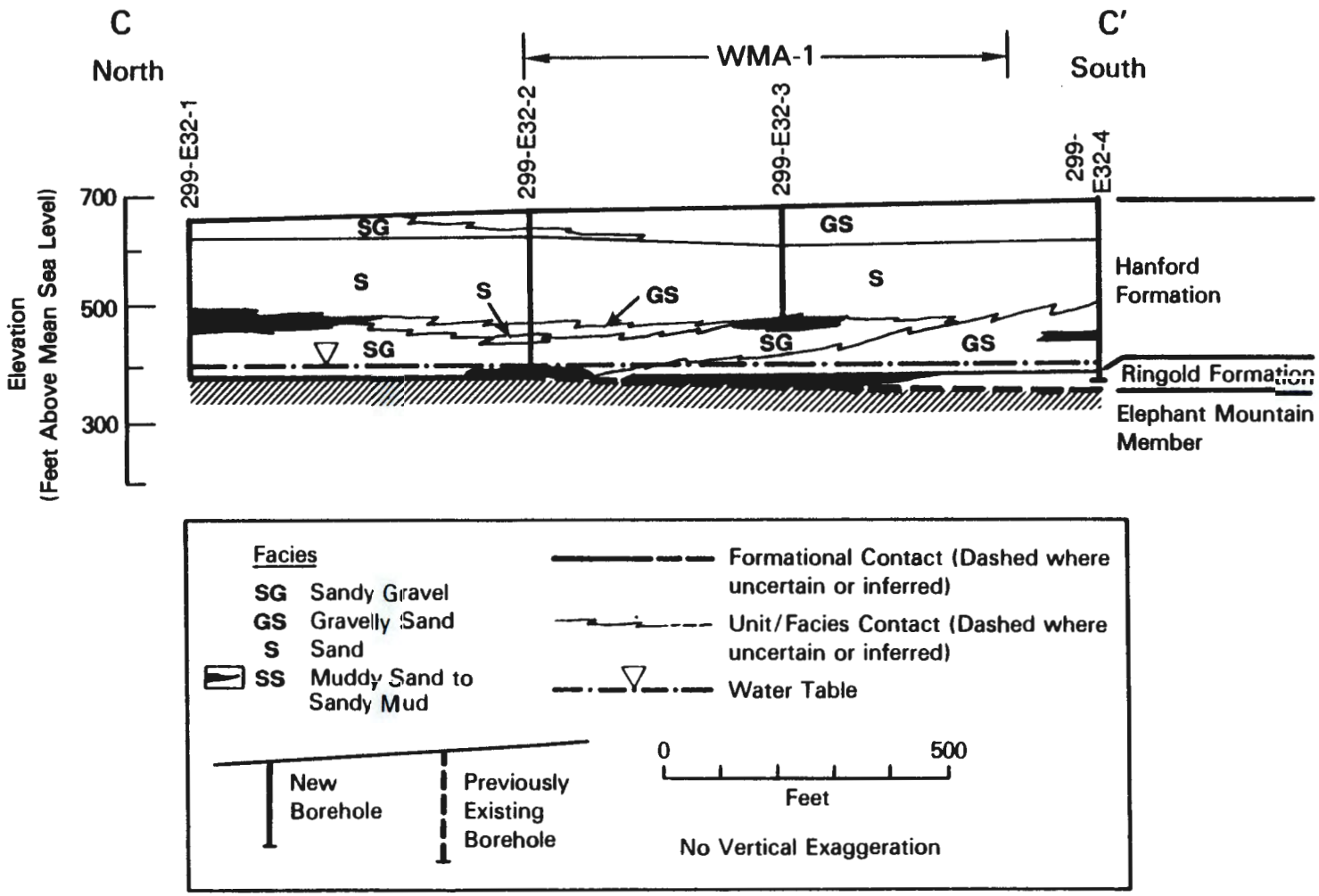


FIGURE 5.9. Geologic Cross Section C-C′, Waste Management Area 1

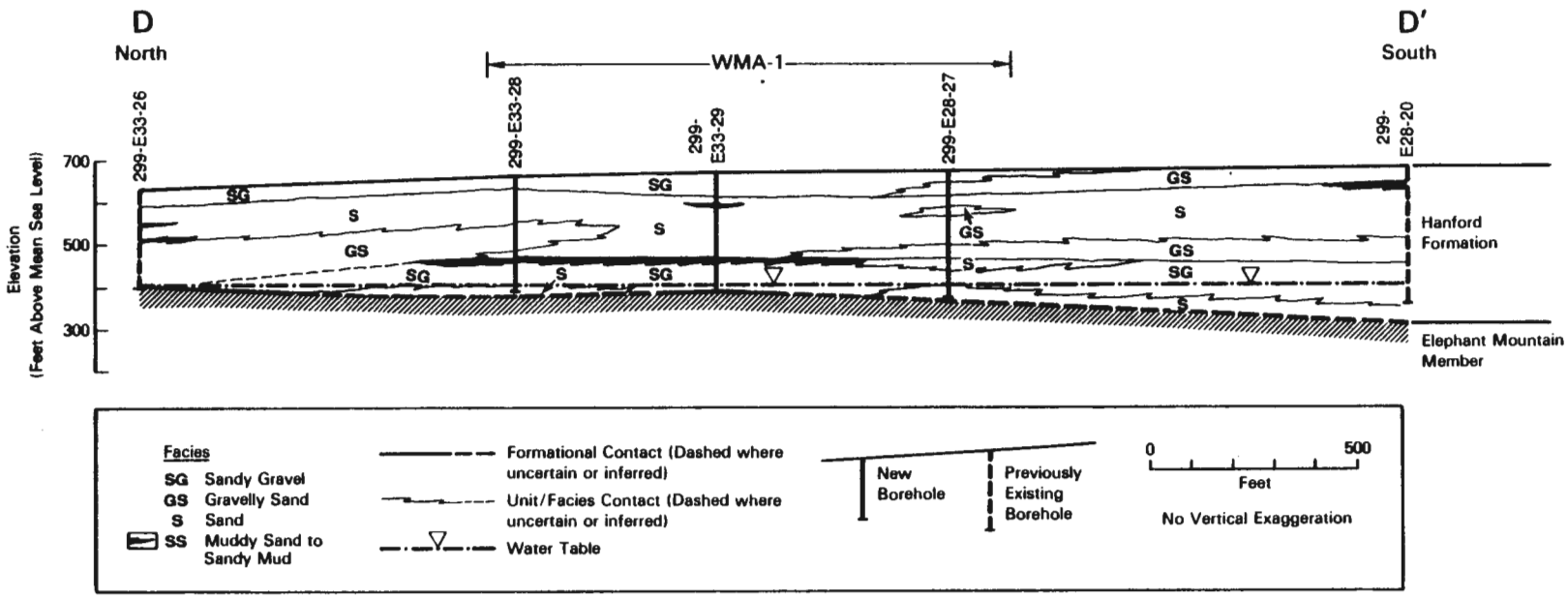


FIGURE 5.10. Geologic Cross Section D-D', Waste Management Area 1

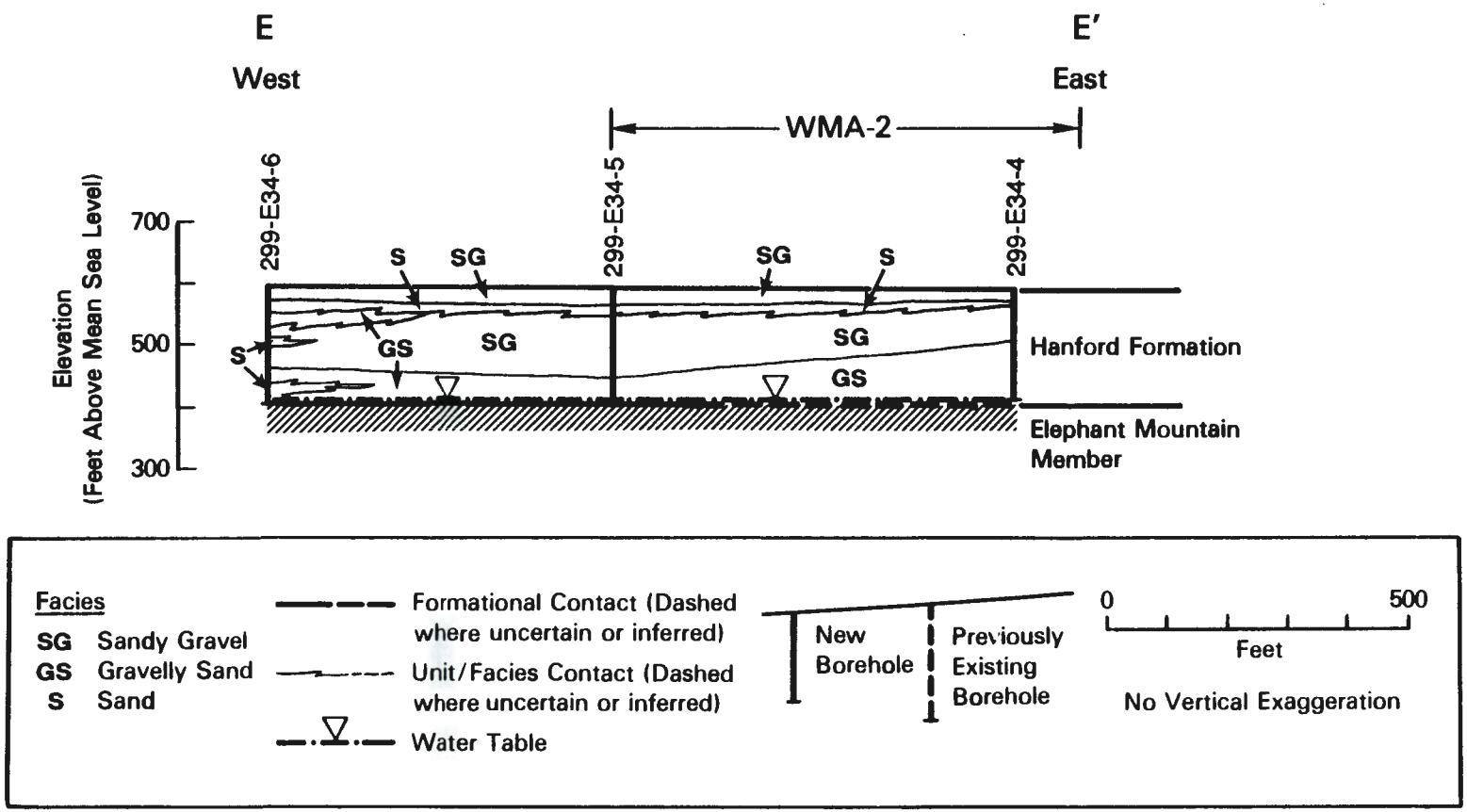


FIGURE 5.11. Geologic Cross Section E-E', Waste Management Area 2

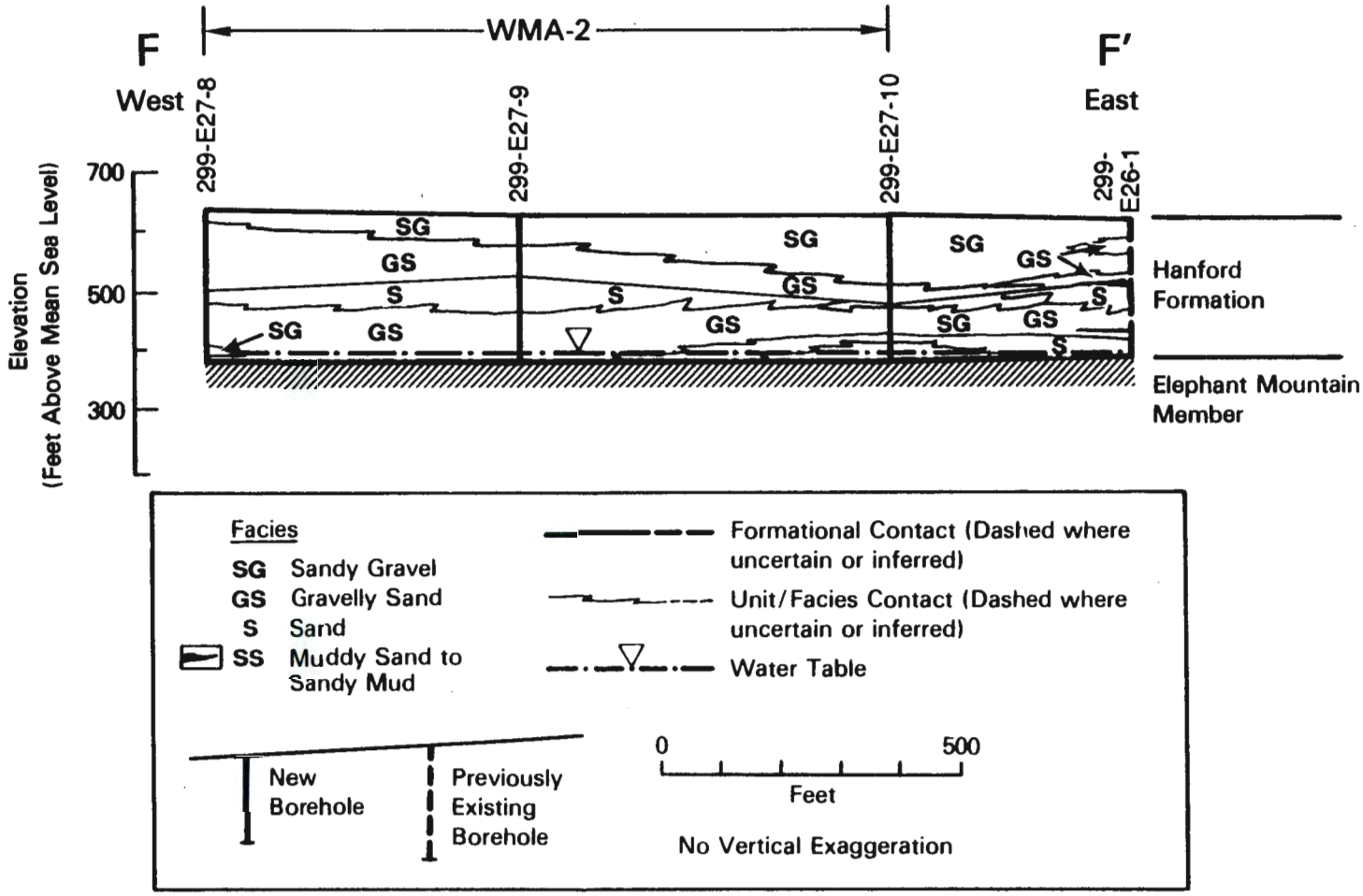


FIGURE 5.12. Geologic Cross Section F-F', Waste Management Area 2

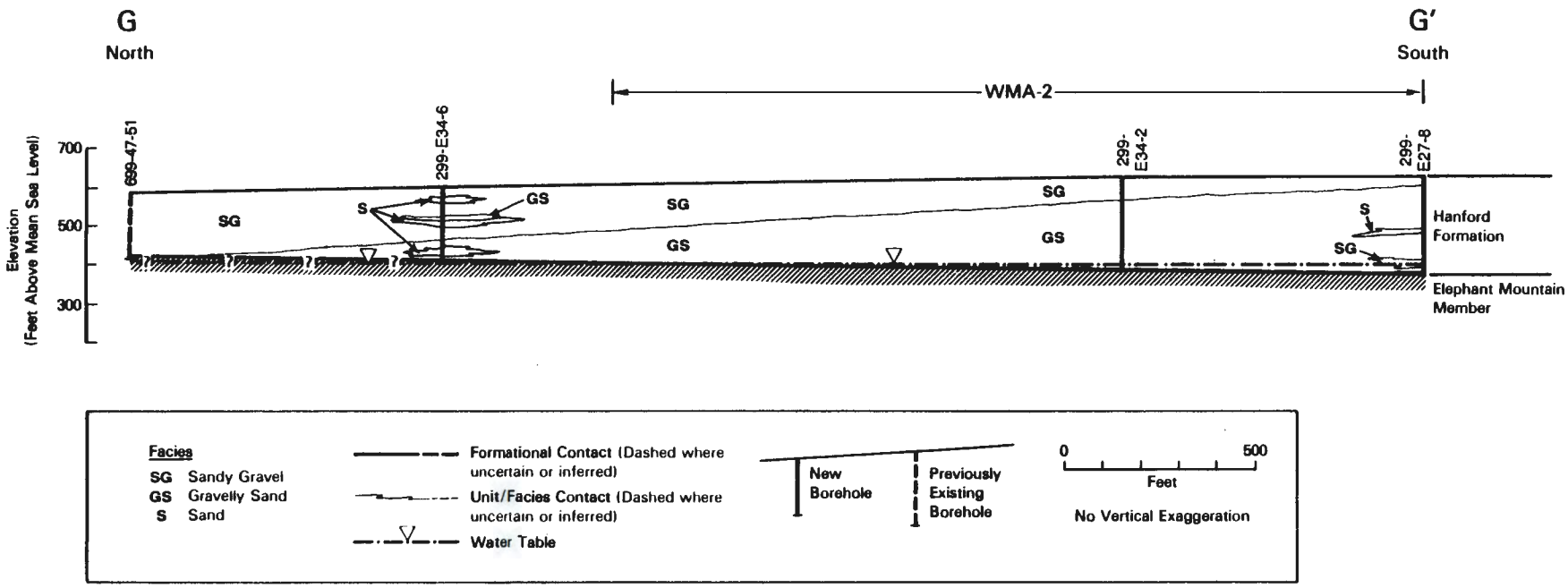


FIGURE 5.13. Geologic Cross Section G-G', Waste Management Area 2

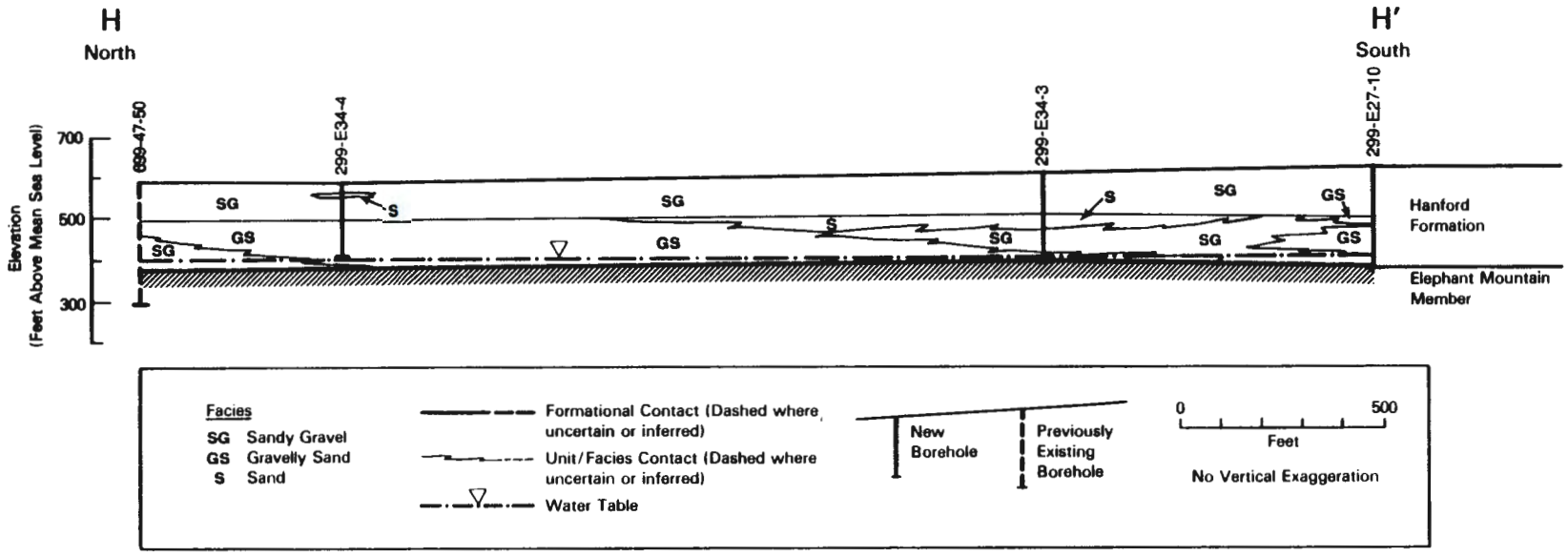


FIGURE 5.14. Geologic Cross Section H-H', Waste Management Area 2

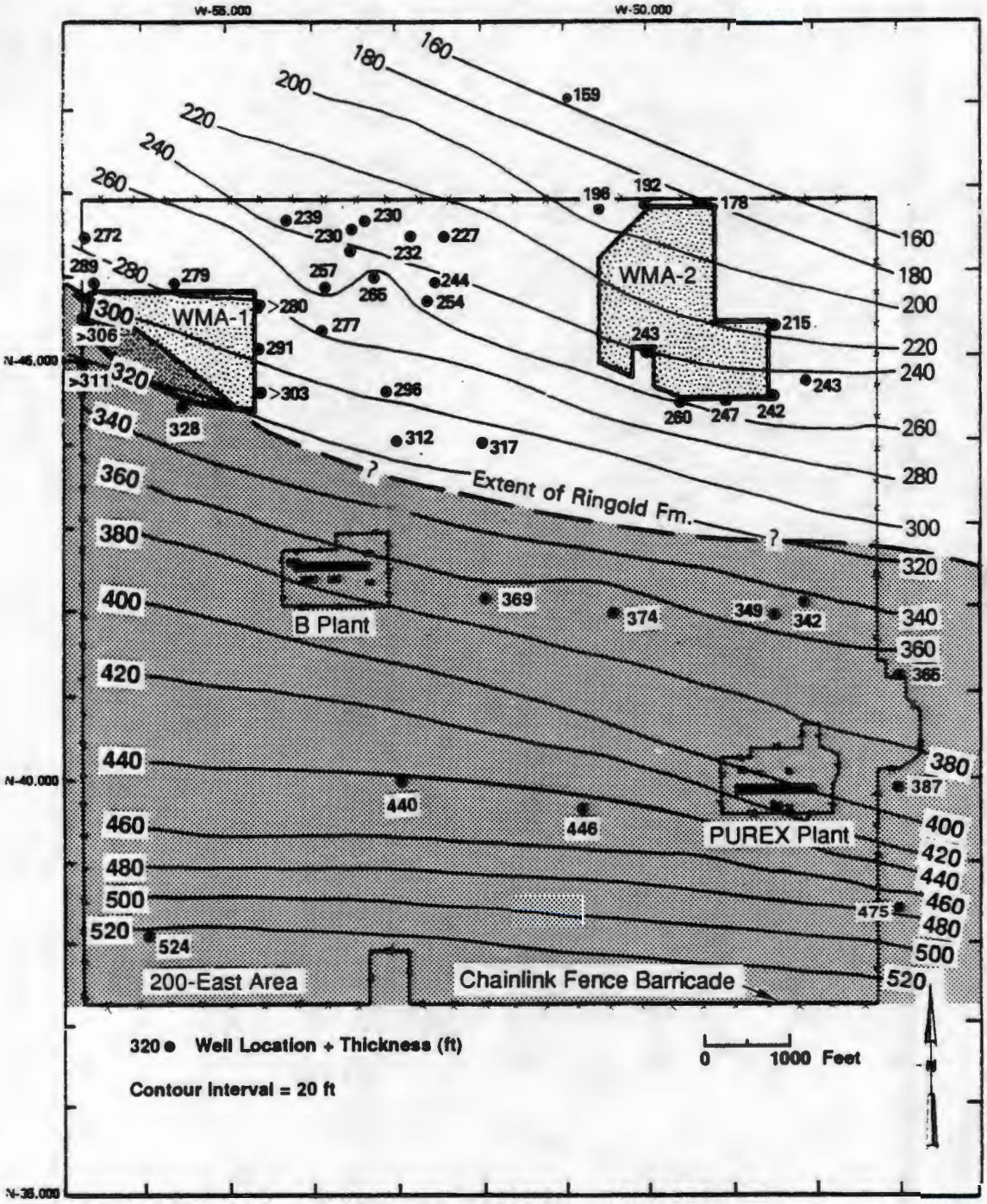


FIGURE 5.15. Isopach of the Post-Basalt Sediments Beneath Waste Management Areas 1 and 2

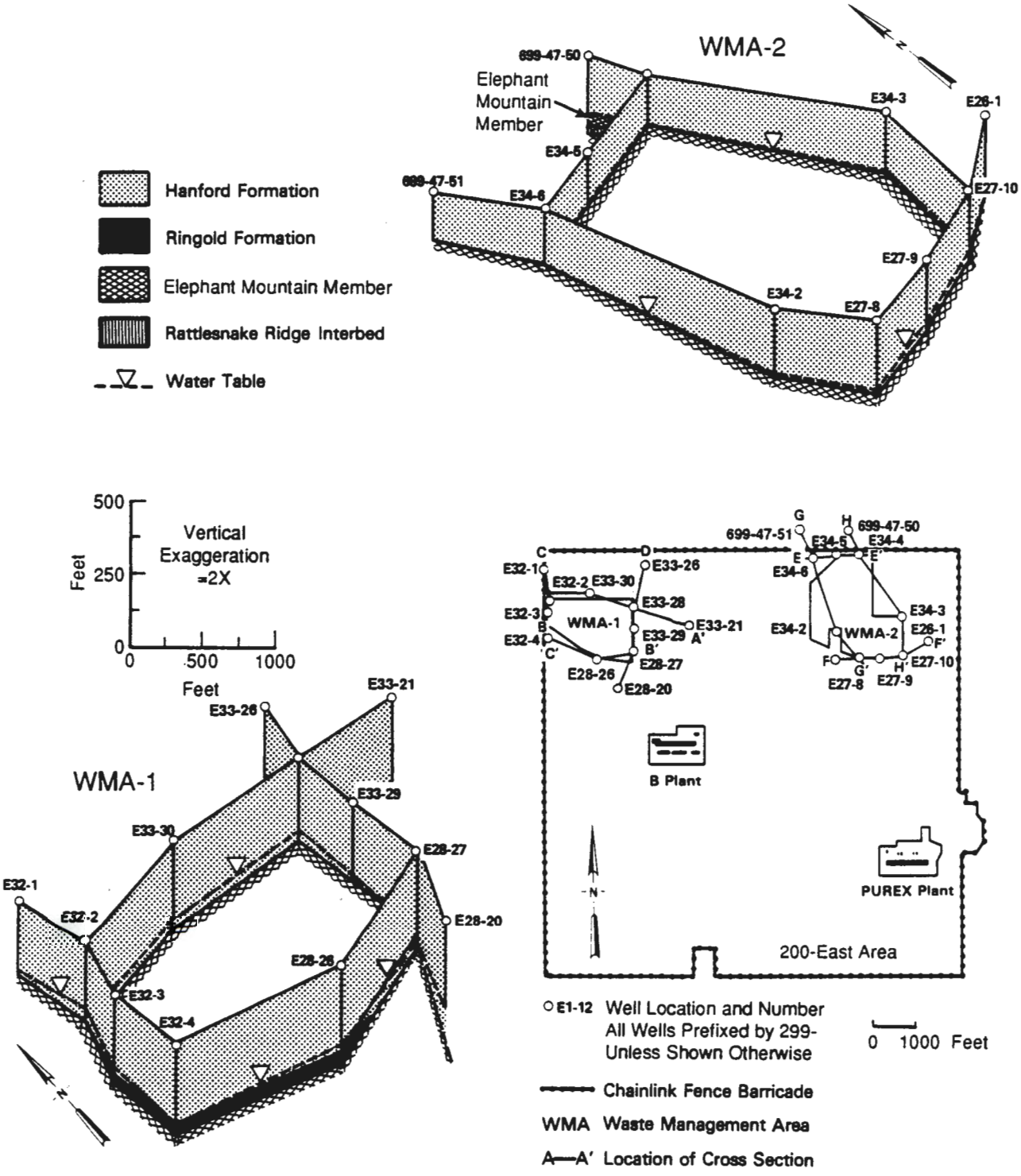


FIGURE 5.16. Fence Diagram of the Generalized Stratigraphy Beneath Waste Management Areas 1 and 2

5.3.1 Saddle Mountains Basalt

Basalt was encountered in 12 of the 16 boreholes drilled around WMA-1 and WMA-2. Samples of the basalt from wells 299-E34-2, 299-E34-4, and 299-E28-26 were sent to WSU for XRF analysis. The results of the XRF analysis (Table 5.3) indicate that all three basalt samples were of the Elephant Mountain Member chemical type (Wright et al. 1973). This tholeiitic basalt member has been dated at 10.5 mybp (McKee et al. 1977). This basalt member has been described (DOE 1988) as having medium- to fine-grained texture with abundant microphenocrysts of plagioclase and transitional to normal magnetic polarity. The Elephant Mountain Member is one of the youngest members of the Saddle Mountains Basalt and is the uppermost member expected to be found in this area (Graham et al. 1984; Tallman et al. 1979).

Generally, the top of a basalt flow is highly vesicular. However, only one of the three wells (299-E28-26) from which good basalt chips were retrieved contained even sparse vesicles, indicating its proximity to the flow top. Chips from the other two wells, 299-E34-2 and 299-E34-4, showed no evidence of vesicles. This suggests that erosion removed part or all of the

TABLE 5.3. Results of X-Ray Fluorescence Analysis[a] of Basalt Samples from Waste Management Areas 1 and 2 (by well number)

Constituent	299-E34-2 (241 ft)	299-E34-4 (177 ft)	299-E28-6 (326 ft)
SiO_2	51.33	51.99	51.72
Al_2O_3	12.93	13.24	13.09
TiO_2	3.601	3.417	3.564
FeO (and Fe_2O_3)	15.12	14.05	14.28
MnO	0.229	0.189	0.214
CaO	8.45	8.75	8.77
MgO	4.07	4.12	4.15
K_2O	1.34	1.20	1.12
Na_2O	2.36	2.52	2.52
P_2O_5	0.572	0.528	0.572

(a) Data are percentages of constituent present.

flow top from the Elephant Mountain Member in much of the studied area. This is consistent with data presented in Graham et al. (1984), who suggested the broad, gently dipping anticline just north of the 200-East Area was partially eroded by the Columbia River during Ringold time and/or by cataclysmic flooding during the Pleistocene.

Figure 5.17 is a map of the surface of the Elephant Mountain Member in the 200-East Area as modified from Tallman et al. (1979) and Graham et al. (1984). This map shows the Elephant Mountain Member dipping south-southwest toward the center of the Cold Creek syncline from a high just north of the 200-East Area. The dip on the surface of the Elephant Mountain Member ranges from approximately 10 ft/1,000 ft beneath WMA-2 to 20 ft/1,000 ft beneath WMA-1. Graham et al. (1984) characterized the Elephant Mountain Member in this area as consisting only of the oldest (Elephant Mountain I) of two Elephant Mountain basalt flows. They further stated that this flow is generally continuous throughout this area, with a thickness ranging from approximately 39 ft where partially eroded, to greater than 115 ft north of the 200-East Area near Gable Mountain. They characterized the Elephant Mountain Member hydrologically as an aquiclude, acting to confine the underlying Rattlesnake Ridge aquifer.

A depression delineated in the basalt surface (see Figure 5.17) just north of the 200-East Area is interpreted to be a pothole, typical of "channel scabland" features near Othello, Washington. Baker and Nummedal (1978) suggested that potholes resulted from progressive erosion as cataclysmic flood waters encountered well-developed columnar jointing of the basalt bedrock. Interpretation of this depression as an erosional feature is based on the absence of flow-top vesicles, abnormal thinness of the Elephant Mountain Member, and the erosional interpretation of Graham et al. (1984).

Graham et al. (1984) suggested that erosional "windows" through the Elephant Mountain Member could provide direct interconnection between the unconfined aquifer and the Rattlesnake Ridge aquifer. They postulated, based

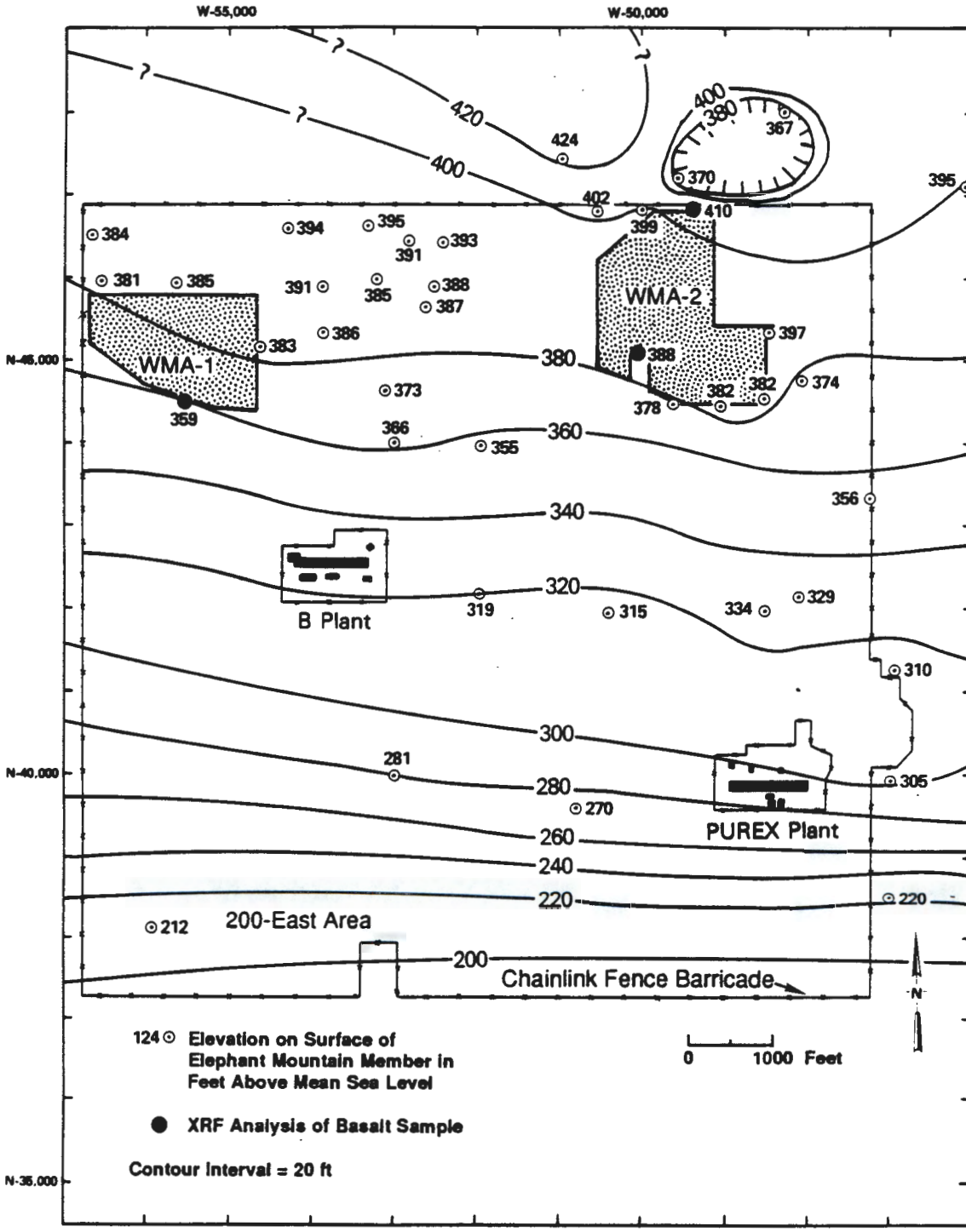


FIGURE 5.17. Surface of the Elephant Mountain Member in the 200-East Area (modified from Tallman et al. 1979 and Graham et al. 1984)

on low barometric efficiencies in the Rattlesnake Ridge aquifer, that one such "window" may exist in the same approximate area as the depression in the basalt surface.

5.3.2 Ringold Formation

Semiconsolidated sand and gravel directly overlying the Elephant Mountain Member were detected in three of the 16 newly drilled boreholes. These boreholes, 299-E28-26, 299-E32-3, and 299-E32-4, were all located in the west-central portion of the 200-East Area. These sediments are interpreted as belonging to the Ringold Formation, in part by their low percentage of basaltic clasts (refer to the characteristics listed in Table 5.1). This was particularly evident in 299-E28-26 and 299-E32-4, where the percentage of basaltic gravel decreases from an estimated 50% to 60% in the overlying Hanford formation sediments to an estimated 20% or less in the Ringold Formation.

The Ringold Formation in the 200-East Area displays the same characteristics as the coarse-grained basal and middle Ringold units described by Bjornstad (1984, 1985), DOE (1988), and Tallman et al. (1979). These Ringold Formation sediments are interpreted to be fairly uniform in texture, consisting primarily of moderate to poorly sorted gravelly sand to muddy sandy gravel. Laboratory analysis of the grain-size distributions indicates ranges of approximately 12% to 40% gravel, 50% to 70% sand, and 3% to 8% mud. One minor sand lens was encountered in well 299-E32-4. Table 5.4 lists examples of the grain-size distribution for these sediments. Hand-sample descriptions by the well site geologists indicate that the gravel clasts are composed primarily of 5% to 40% basalt, with quartzites, granite, metamorphics, and other lithologies making up the rest. Unbroken portions of the gravel clasts are described as sub- to well rounded. The sands are described as angular to subrounded, and consist predominantly of quartz, feldspar, mica, and litho-fragments (including 5% to 20% basalt). Color of the dry matrix ranged from light grey to olive grey. These sediments are described as unconsolidated to slightly consolidated, with observed hard-tool drilling rates of 1.5 to nearly 3.0 ft/h.

TABLE 5.4. Examples of Grain-Size Distribution (weight percent of total) of Ringold Formation Sediments Beneath Waste Management Area 1

Borehole /Depth	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	Class
299-E28-26 320 ft	31.1	11.7	26.8	17.4	6.9	2.7	3.4	Sandy gravel
299-E32-3 300 ft	11.8	10.9	17.0	33.6	15.4	5.6	5.7	Gravelly sand
299-E33-4 300 ft	35.0	12.4	12.5	11.8	12.2	7.8	8.4	Muddy sandy gravel

Classification of these Ringold Formation sediments with any one of the four Ringold units defined by Tallman et al. (1979) or Bjornstad (1985) is difficult. As indicated in Tallman et al. (1979) and corroborated by this study, the upper Ringold unit is completely missing beneath all of the 200-East Area and the lower, and perhaps the basal, Ringold units pinch out or are truncated in the northern portion of the 200-East Area. Because the lower Ringold unit (and fine-grained basal unit) is not present, the basal Ringold unit (coarse-grained facies) cannot be readily distinguished from the middle Ringold unit because the two units are texturally and mineralogically similar.

Figure 5.18 is an isopach map of the Ringold Formation beneath WMA-1 and WMA-2 as interpreted from the new wells, driller's logs of existing wells, and previously published interpretations (Graham et al. 1984; Tallman et al. 1979). Thickness of the Ringold Formation varies from zero beneath WMA-2 and the northeastern portion of WMA-1 to 16 ft in the southern portion of WMA-1 (see Figure 5.18). Evidently, most of the Ringold Formation was eroded from the northern part of the 200-East Area by the post-Ringold Columbia River and/or by cataclysmic floods. The extent of the Ringold Formation shown in Figure 5.18 roughly coincides with the northern edge of the Cold Creek bar (see Figure 5.2), suggesting cataclysmic flooding was responsible for the lack of Ringold deposits in this area.

5.3.3 Hanford Formation

Sediments of the glaciofluvial Hanford formation in the 200-East Area overlie the Ringold Formation and the Elephant Mountain Member where the Ringold is missing. Coarse-grained deposits (Pasco Gravels facies) predominate; however, there are significant amounts of fine-grained sediments as well, particularly in WMA-1. These consist mostly of well-sorted sand [plane-laminated sand facies of Bjornstad et al. (1987)] and occasional thin lenses of slack-water sand and silt, perhaps equivalent to the rhythmite facies. One such fine-grained sediment sample from borehole 299-E33-30 (203-ft level), analyzed for its particle-size distribution by the hydrometer method, contained 2% sand, 82% silt, and 16% clay (see Figure 5.7).

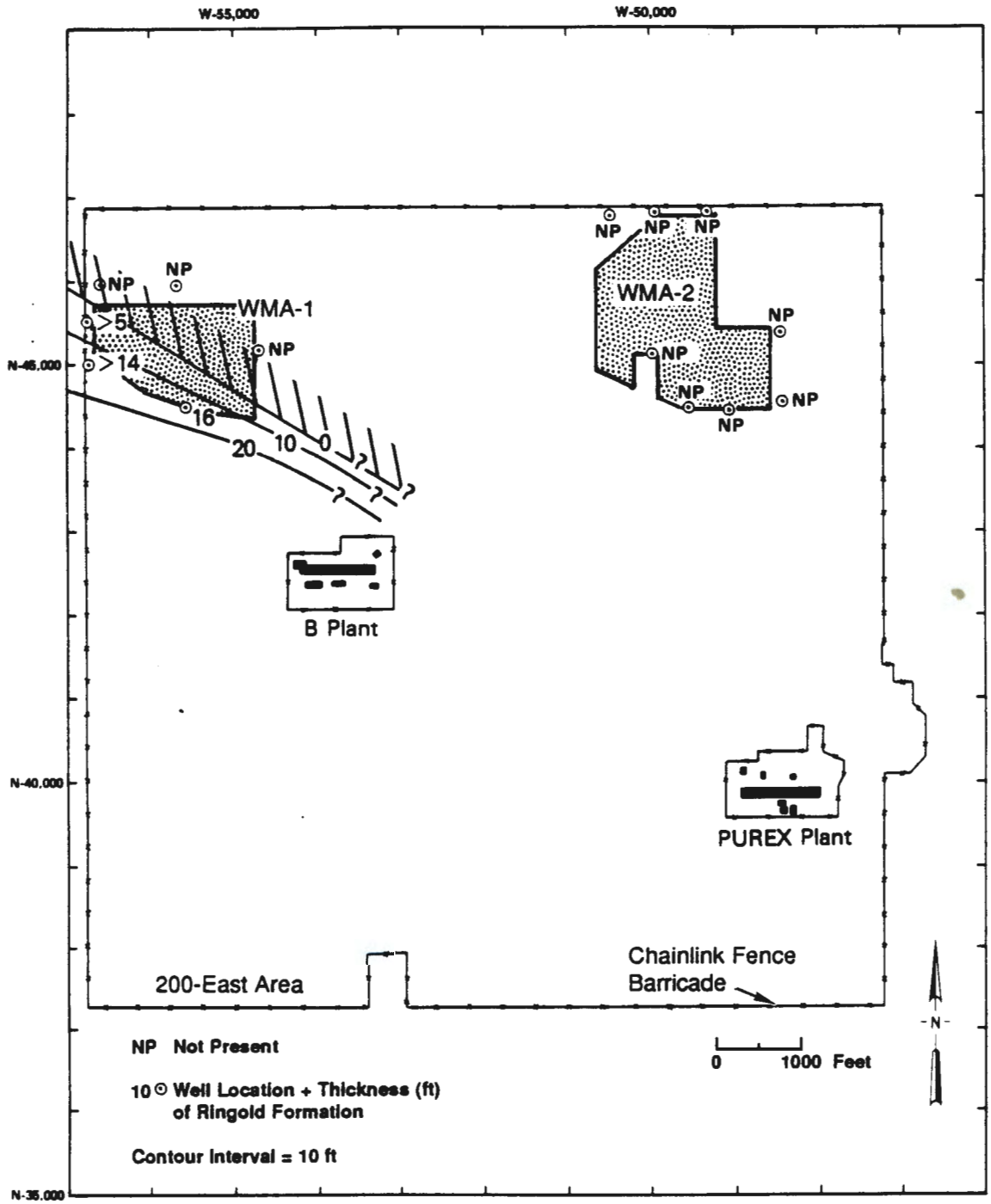


FIGURE 5.18. Isopach of the Ringold Formation Beneath Waste Management Areas 1 and 2

Within WMA-1, deposits of the Hanford formation can be divided into three informal units: 1) an upper coarse-grained unit, 2) a middle sand unit, and 3) a lower coarse-grained unit (see Figure 5.5). The names applied to these units represent only a gross generalization of their true nature, because any facies, ranging from sandy gravel to sandy mud, may be associated with these units. Examples of the grain-size distributions are presented in Table 5.5. The relatively thick (75- to 170-ft) middle sand unit is apparent only beneath WMA-1 (Figure 5.19); no attempt was made to correlate this unit eastward into WMA-2. As indicated in Figure 5.19, this unit is thickest in the east-central part of WMA-1 and thins dramatically to the north and south. In contrast, maximum thicknesses for the upper and lower coarse-grained units occur southeast and southwest of WMA-1, respectively (Figures 5.20 and 5.21).

Contours atop the lower coarse-grained and middle sand units are shown in Figures 5.22 and 5.23. While there is some suggestion for east-west-trending patterns in the isopach and structure-contour maps, perhaps reflecting paleoflood channels, these patterns are not consistent among the different units. Thus, changes in thickness and surface topography are probably a reflection of lateral facies changes within the Hanford formation, rather than paleo-geomorphic landforms.

Beneath WMA-2 the sediments of the Hanford formation consist of sequences of muddy sandy gravel, gravelly sand, and/or sand (see Figure 5.5). Examples of the grain-size distributions for these sediments were presented in Table 5.5. The basalt content of these sediments generally appears to decrease with depth. This may be the result of a greater degree of mixing of the flood deposits with basalt-poor Ringold Formation sediments at greater depths.

At the present time, it is not possible to perform any meaningful correlation of facies within the Hanford formation beneath WMA-2. Therefore, only a single isopach map of the Hanford formation sediments is applicable to WMA-2. Figure 5.15 shows that the Hanford formation ranges in thickness from approximately 180 ft in the northeastern portion to approximately 260 ft in the southwestern portion of WMA-2.

TABLE 5.5. Examples of Particle-Size Distribution (weight percent of total) of Hanford Formation Sediments Beneath Waste Management Areas 1 and 2

Unit	Borehole /Depth	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	Class
WMA-1									
Upper coarse grained	299-E28-27 55 ft	24.4	30.1	32.3	9.6	2.3	1.1	0.2	Gravelly sand
Middle sand	299-E32-03 120 ft	0.0	0.3	11.2	29.1	32.6	14.7	12.1	Slightly muddy sand
Lower coarse grained	299-E33-28 220 ft	63.6	11.3	12.4	5.3	3.0	1.8	2.6	Sandy gravel
WMA-2									
Undiffer-entiated	299-E27-08 60 ft	29.1	22.1	19.6	13.4	6.9	3.5	5.4	Gravelly sand
Undiffer-entiated	299-E27-10 180 ft	32.4	15.6	14.2	11.3	8.1	7.0	11.4	Muddy sandy gravel
Undiffer-entiated	299-E34-3 100 ft	4.6	27.3	39.2	12.4	7.8	3.6	5.1	Sand

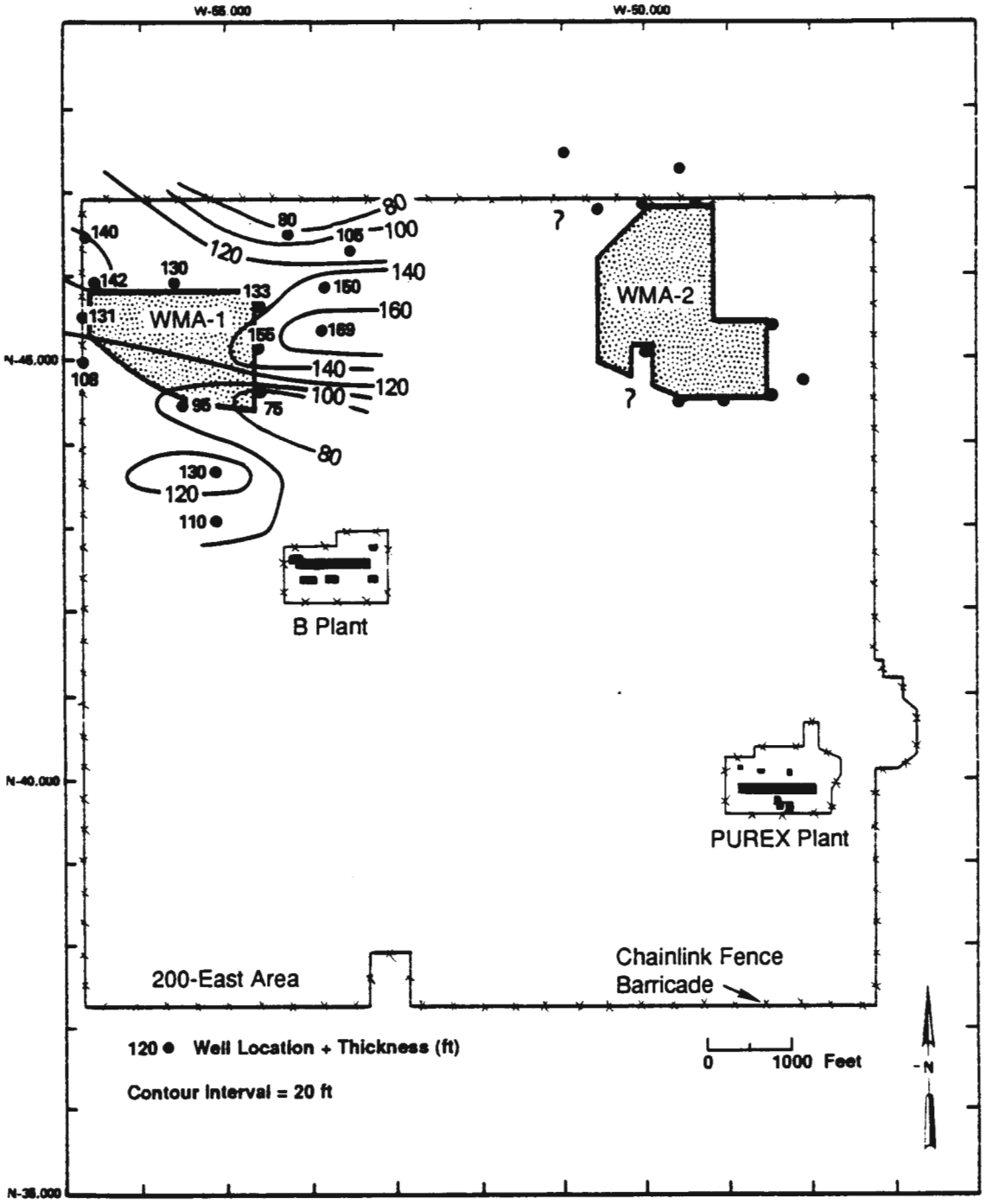


FIGURE 5.19. Isopach of the Hanford Formation Middle Sand Unit Beneath Waste Management Area 1

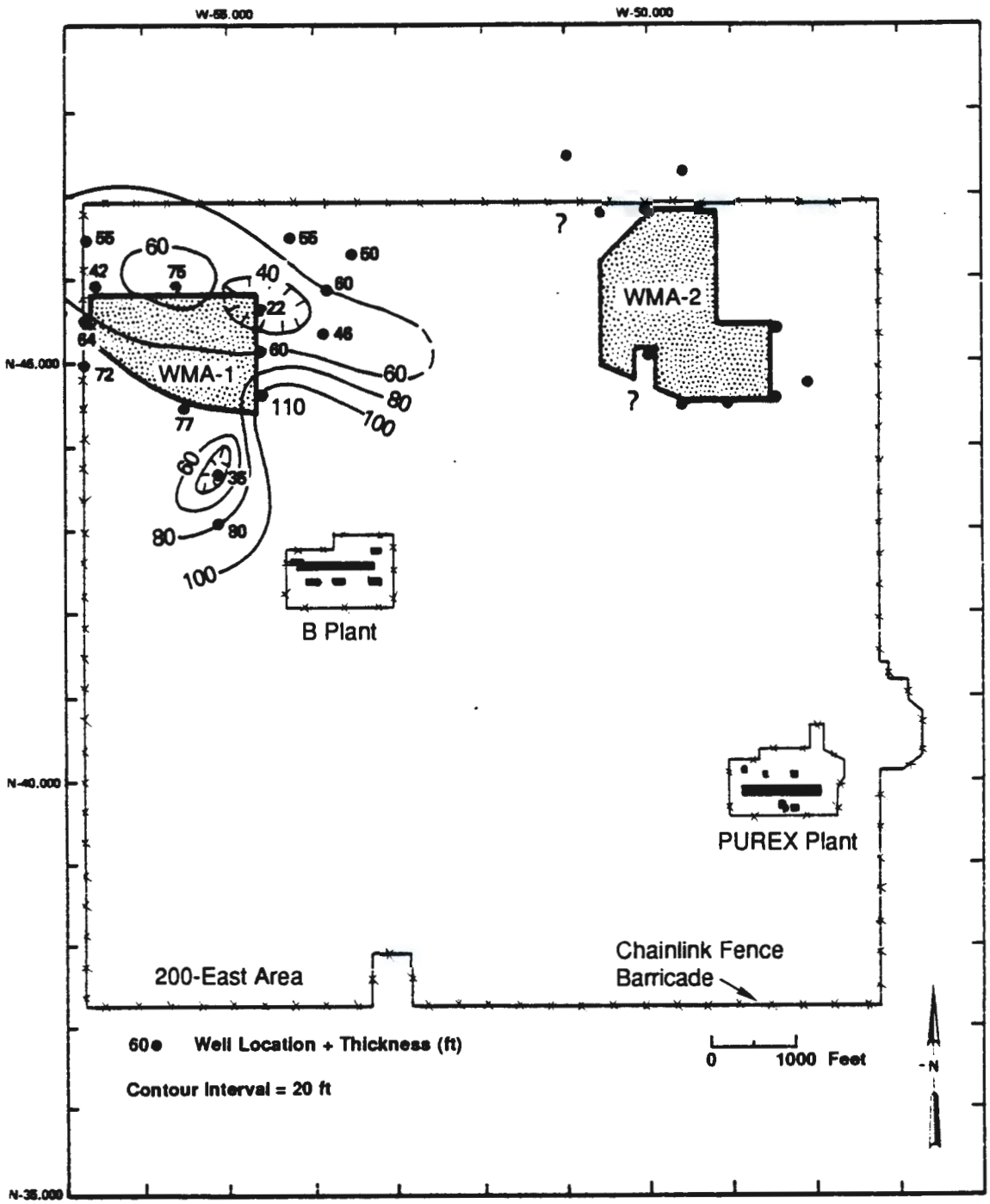


FIGURE 5.20. Isopach of the Hanford Formation Upper Coarse-Grained Unit Beneath Waste Management Area 1

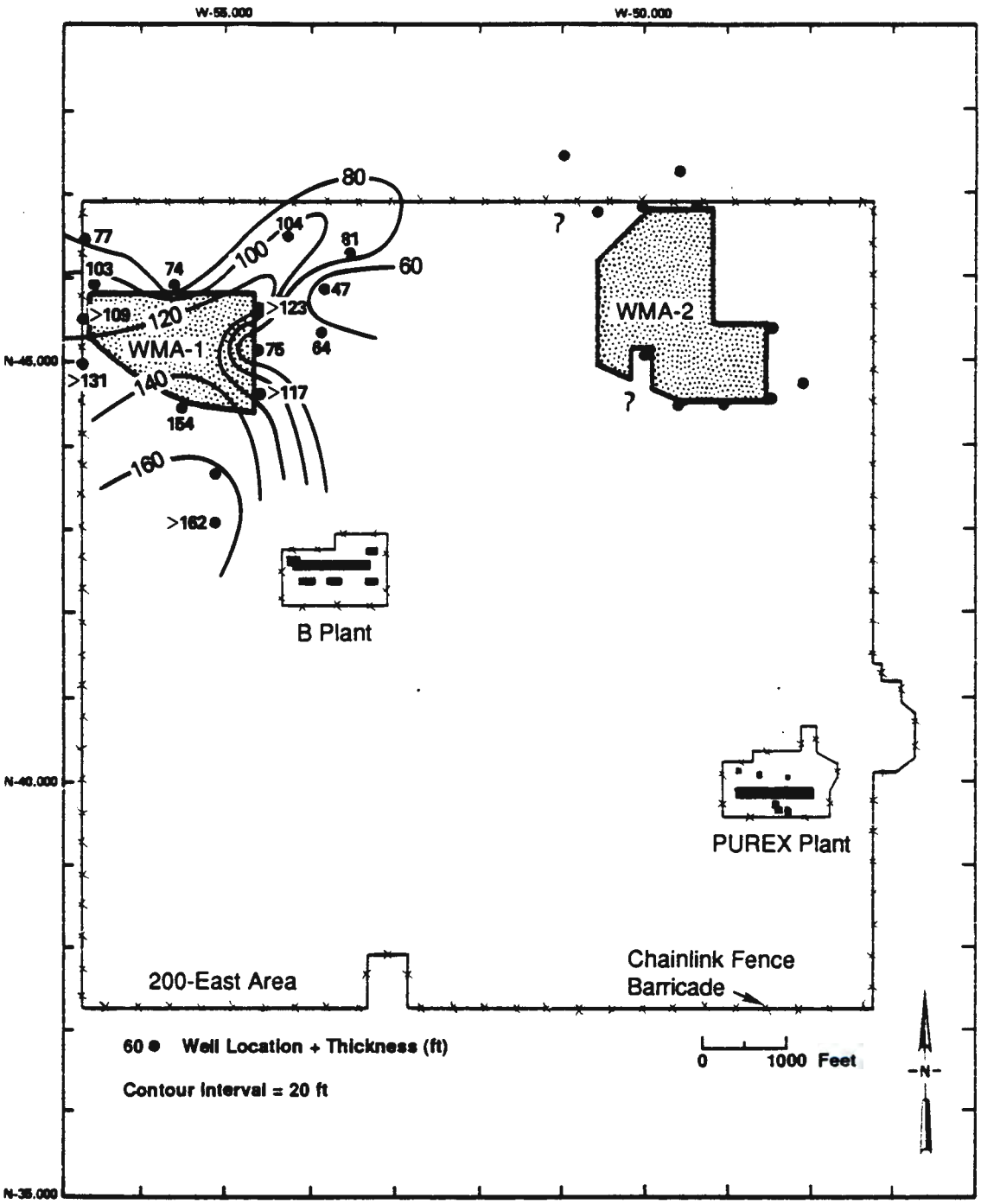


FIGURE 5.21. Isopach of the Hanford Formation Lower Coarse-Grained Unit Beneath Waste Management Area 1

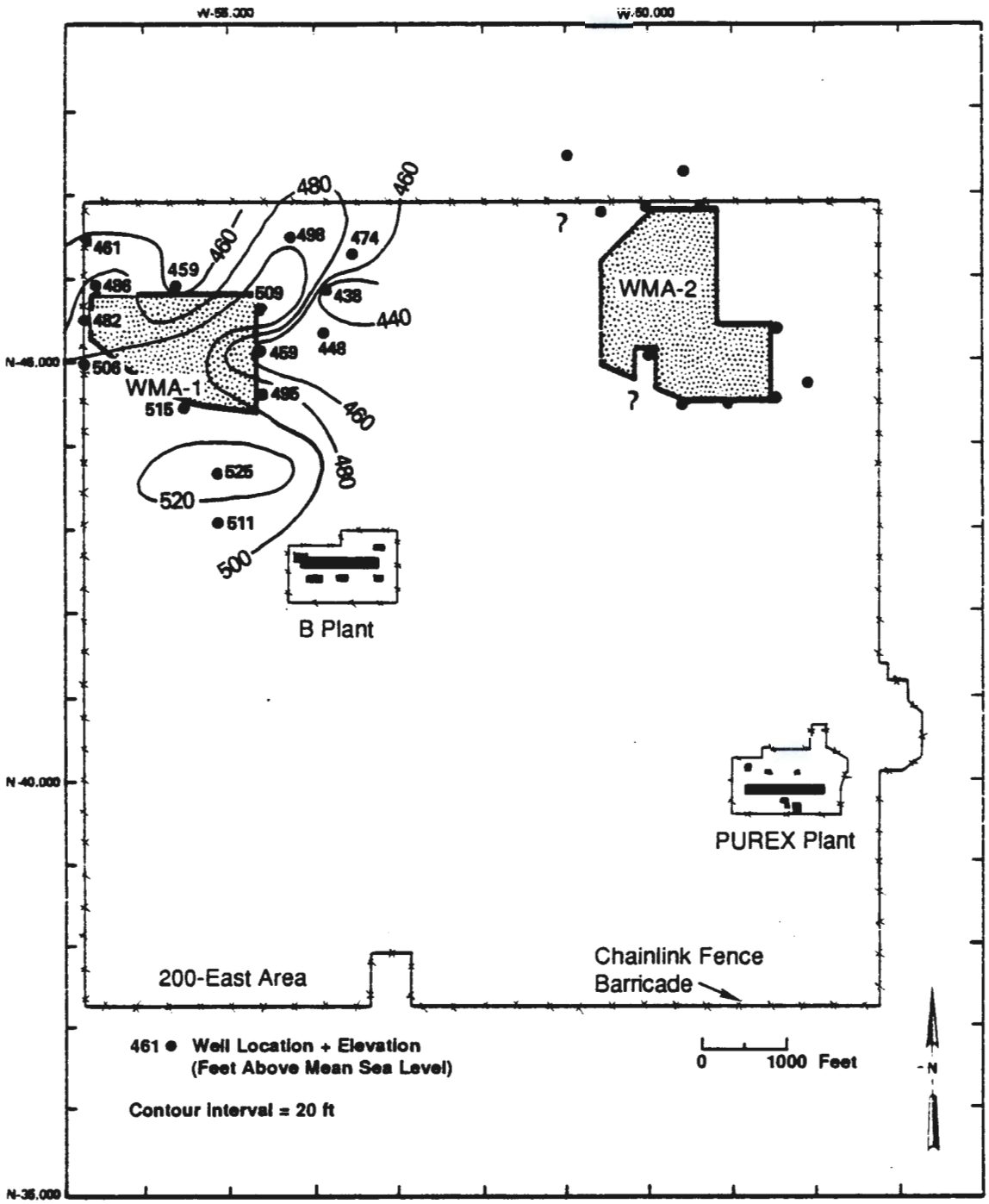


FIGURE 5.22. Surface of the Hanford Formation Lower Coarse-Grained Unit Beneath Waste Management Area 1

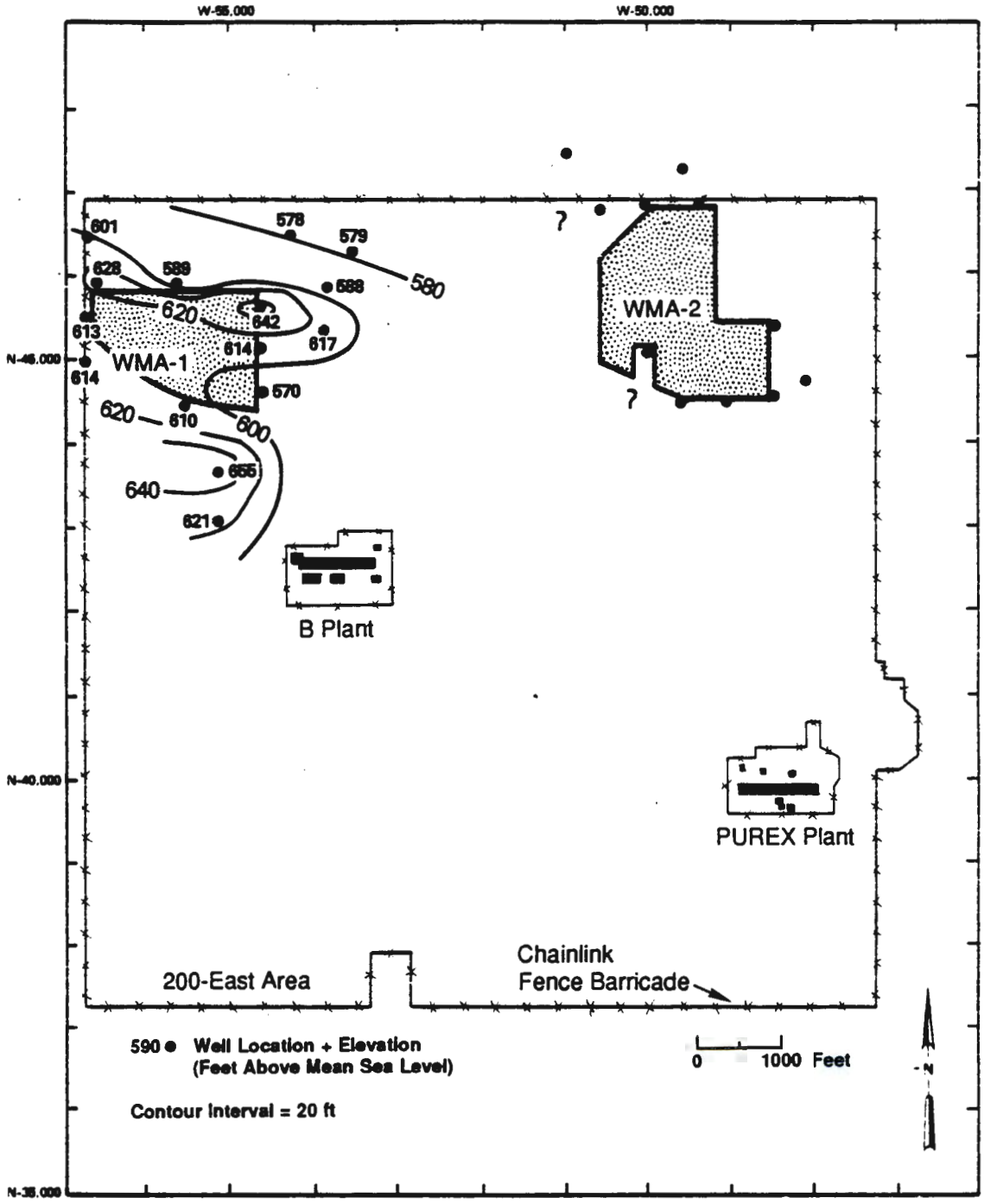


FIGURE 5.23. Surface of the Hanford Formation Middle Sand Unit Beneath Waste Management Area 1

Slightly higher moisture contents (11 to 16 wt% compared to the normal 2 to 4 wt%) were observed in some of the fine-grained lenses (see Appendix I). The possibility that these moist zones may have contained cyanide that migrated from nearby waste-water disposal trenches led to occasional field and laboratory analysis of these sediments for cyanide contamination. All analytical results for cyanide were negative or below detection limits. Few tests for calcium carbonate were performed because of the possibility of cyanide contamination and its reactivity in hydrochloric acid. Nevertheless, Fecht and Price (1977c, 1977d, 1977e) indicate that the calcium carbonate content of sediments in the north-central portion of the 200-East Area are low, ranging from approximately 1% to 3%. This is supported by hundreds of calcium carbonate analyses performed on borehole samples and recorded in the ROCSAN data base.

5.4 GEOLOGY OF WASTE MANAGEMENT AREAS 3 AND 4

The locations of WMA-3 and WMA-4 are in the north-central and south-central portions of the 200-West Area, respectively (Figure 5.24). The geologic characteristics beneath these areas have been interpreted from information collected from 40 boreholes, including 19 recently installed ground-water monitoring wells and 21 previously existing boreholes. Of the 40 boreholes included in this study, 24 represent shallow wells primarily drilled to intercept the water table (which lies between 180 and 240 ft below the surface), 3 terminate within the confining lower Ringold unit, and 13 intercept the uppermost basalt flow. Five of the 13 borings to the top of basalt are core holes, the same as those used in a stratigraphic study by Bjornstad (1984). The data from the 19 recently completed wells include: 1) detailed geologist's logs of cable-tool samples, 2) As-Built Diagrams, 3) Well Completion Report/ Title III Inspection Lists, 4) granulometric analyses, 5) calcium carbonate analyses, and 6) geophysical logs. Data from previously existing wells used for interpretation included two or more of the following: 1) driller's logs, 2) natural-gamma logs, 3) granulometric analyses, and/or 4) calcium carbonate analyses. The types of data available for each existing borehole are identified in Appendix A.

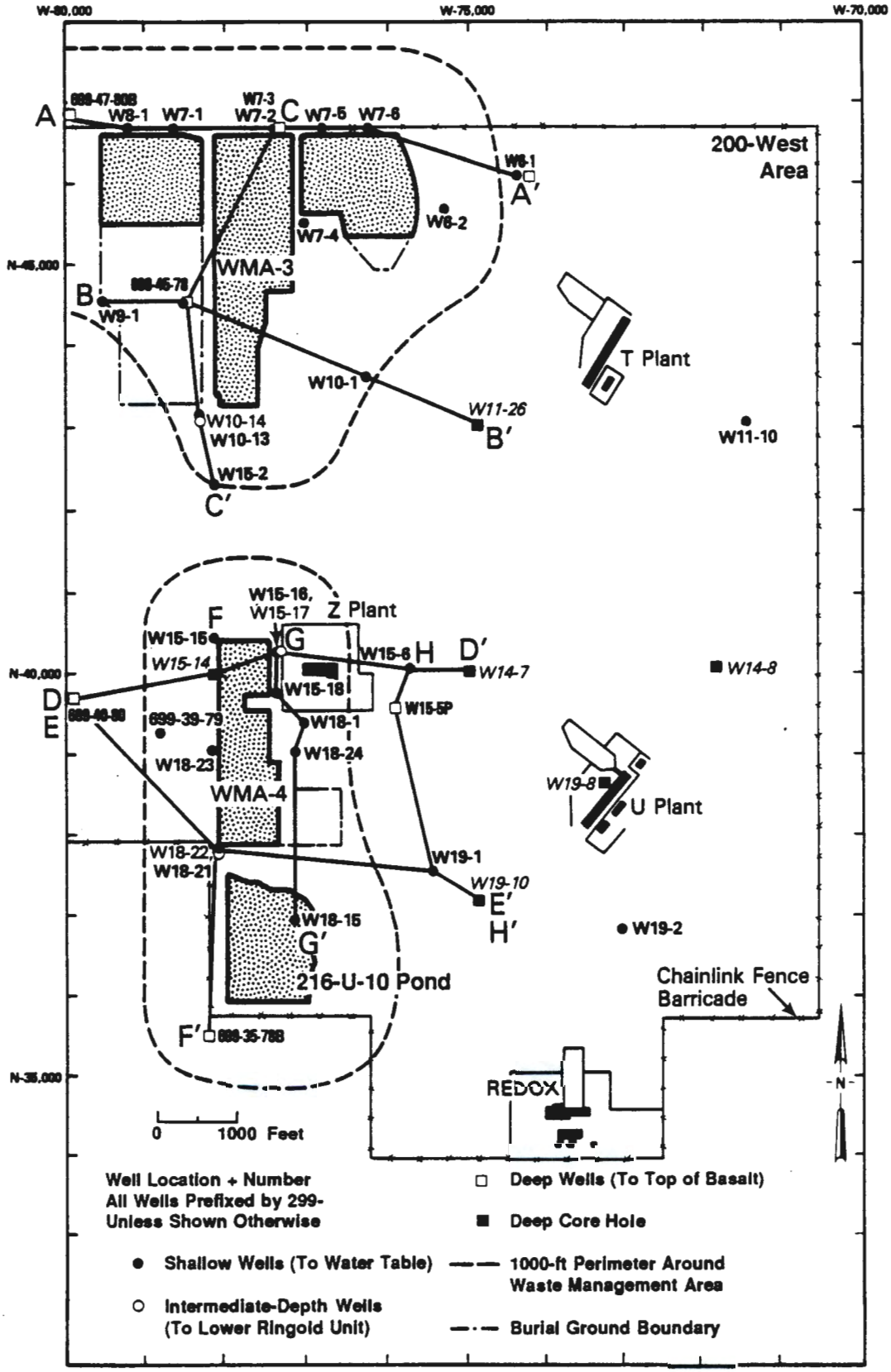


FIGURE 5.24. Location of Waste Management Areas 3 and 4 in the 200-West Area

The above data were evaluated in accordance with those characteristics used to distinguish between the various geologic units given in Bjornstad (1985) and DOE (1988). The five core holes provide the highest quality data, since geologic characteristics were preserved and could be observed through direct examination of the core. The newly installed wells are of the next best quality, followed by the previously existing wells, of which data are not as complete or collected in a consistent manner.

Depths to the various strata were plotted onto a total of eight geologic cross sections and two fence diagrams. These are represented in Figures 5.25 to 5.28 for WMA-3 and Figures 5.29 to 5.34 for WMA-4. The lateral extents of stratigraphic and facies contacts illustrated on these figures are all questionable and are based on preliminary interpretations. These interpretations may change as a result of additional drilling and/or analysis. Locations of these cross sections were shown in Figure 5.24. In addition, data on the thicknesses and surfaces of the stratigraphic units (presented in Table 5.6) have been plotted onto isopach and structure-contour maps. These are described and interpreted for each stratigraphic unit in subsequent sections. In general, isopach and structure-contour maps in the 200-West Area, presented in this report, reflect those presented in Landon and Bjornstad (1986) and Tallman et al. (1979).

While most of the same stratigraphic units are present beneath each of the WMAs in the 200-West Area, elevations and thicknesses vary considerably from one WMA to another. The general stratigraphic relationships between sediments in WMA-3 versus WMA-4 are shown in Figure 5.35. Unlike the 200-East Area, the suprabasalt sediments over most of the 200-West Area include a wide variety of stratigraphic and lithologic units, including four Ringold units (basal, lower, middle, and upper), the Plio-Pleistocene unit (Bjornstad 1984, 1985), the early "Palouse" soil (Tallman et al. 1979), and the glaciofluvial Hanford formation. These strata, in addition to the uppermost basalt unit, are discussed in the following sections. For additional information on the geology of the 200-West Area, refer to DOE (1988) and Tallman et al. (1979).

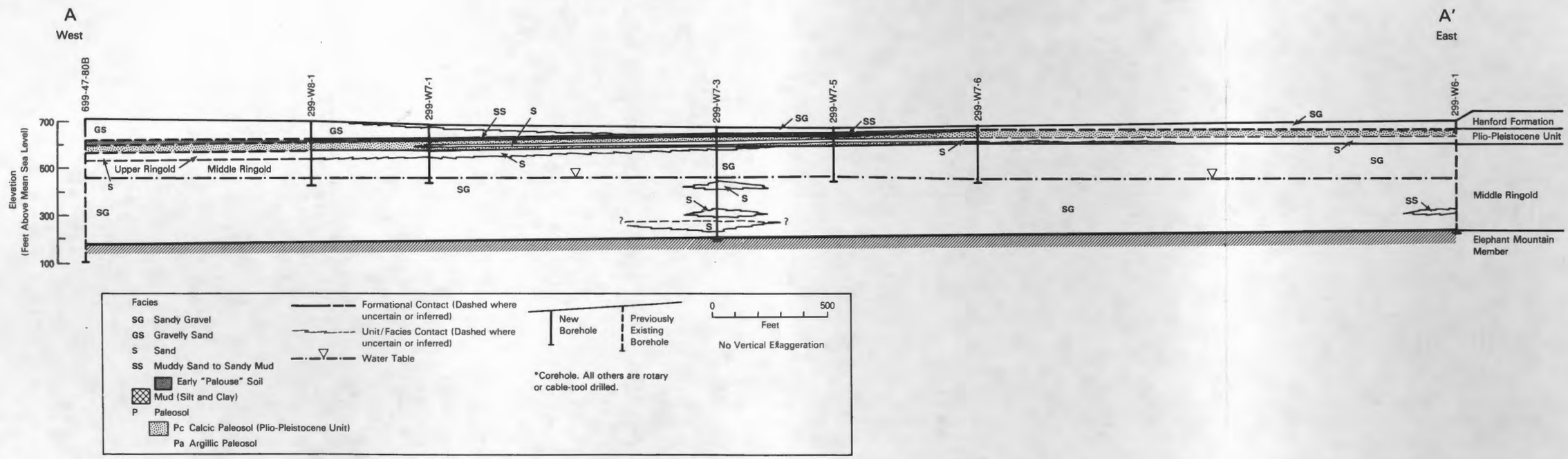


FIGURE 5.25. Geologic Cross Section A-A', Waste Management Area 3

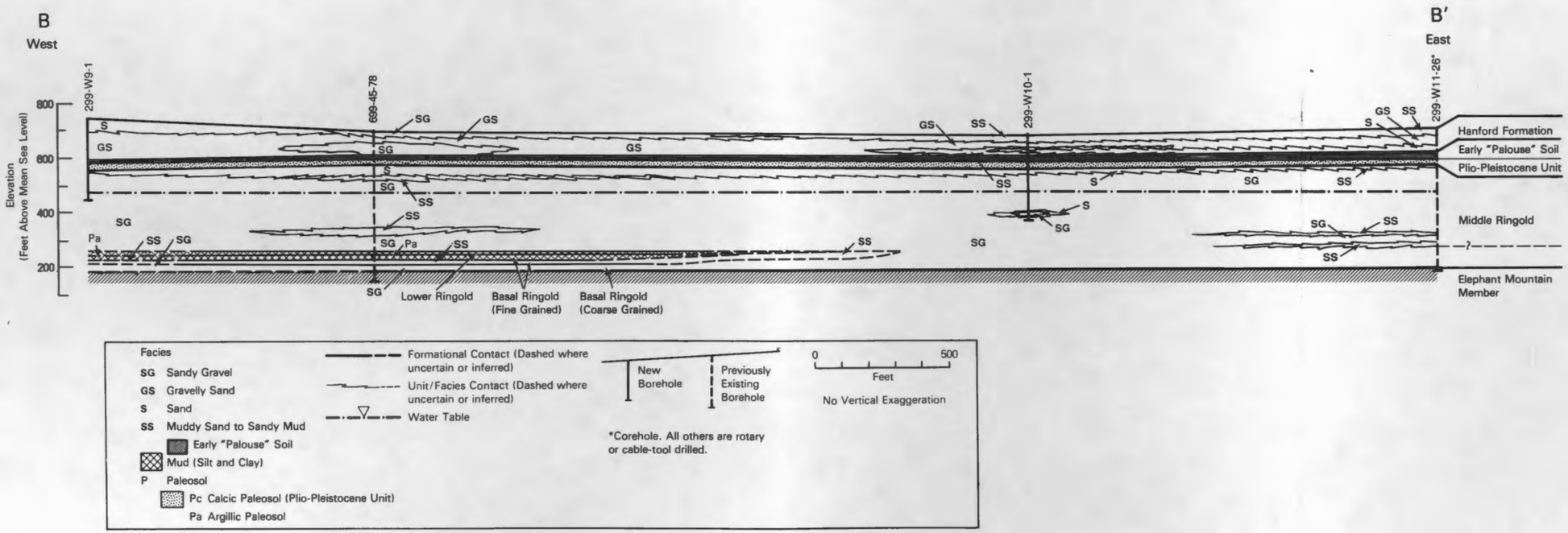


FIGURE 5.26. Geologic Cross Section B-B', Waste Management Area 3

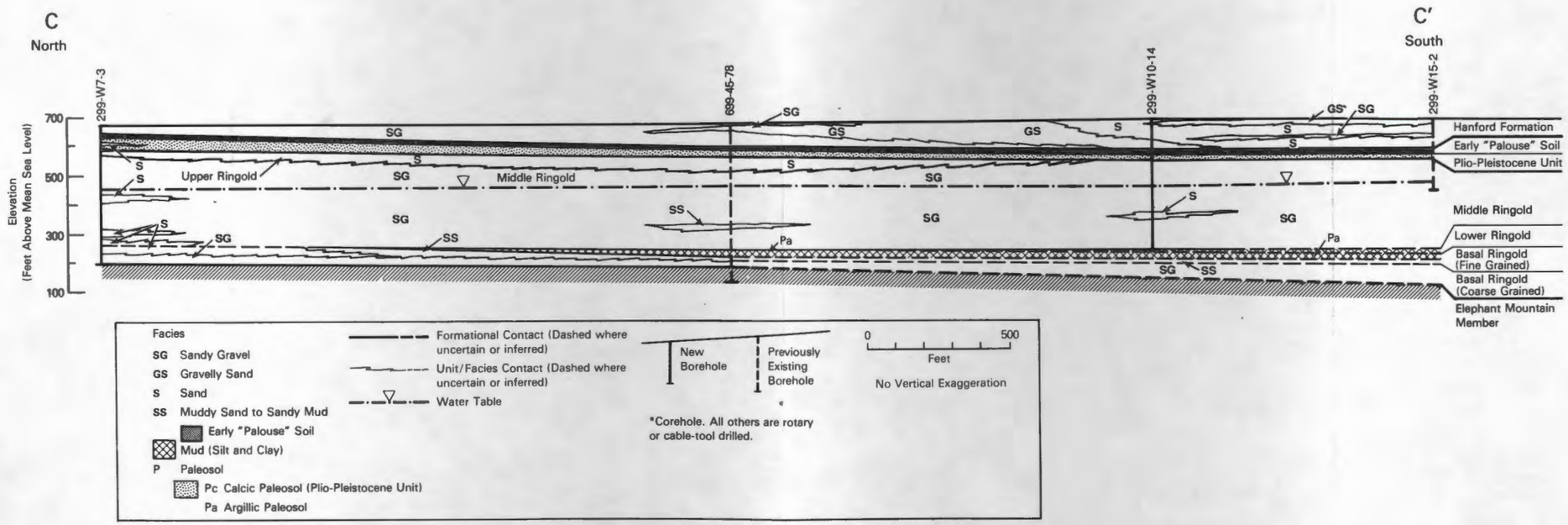


FIGURE 5.27. Geologic Cross Section C-C', Waste Management Area 3

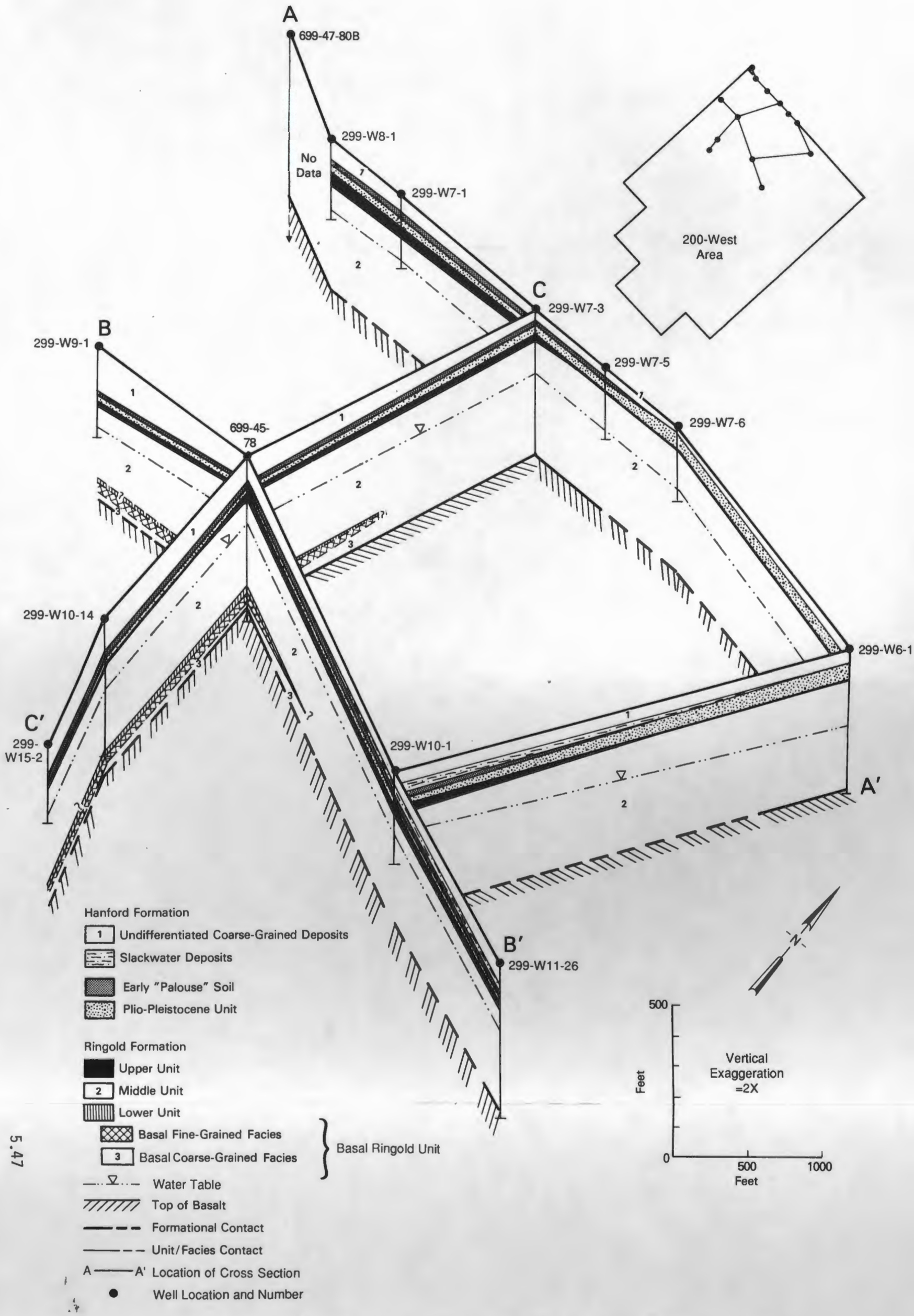


FIGURE 5.28. Fence Diagram of the Stratigraphy Beneath Waste Management Area 3

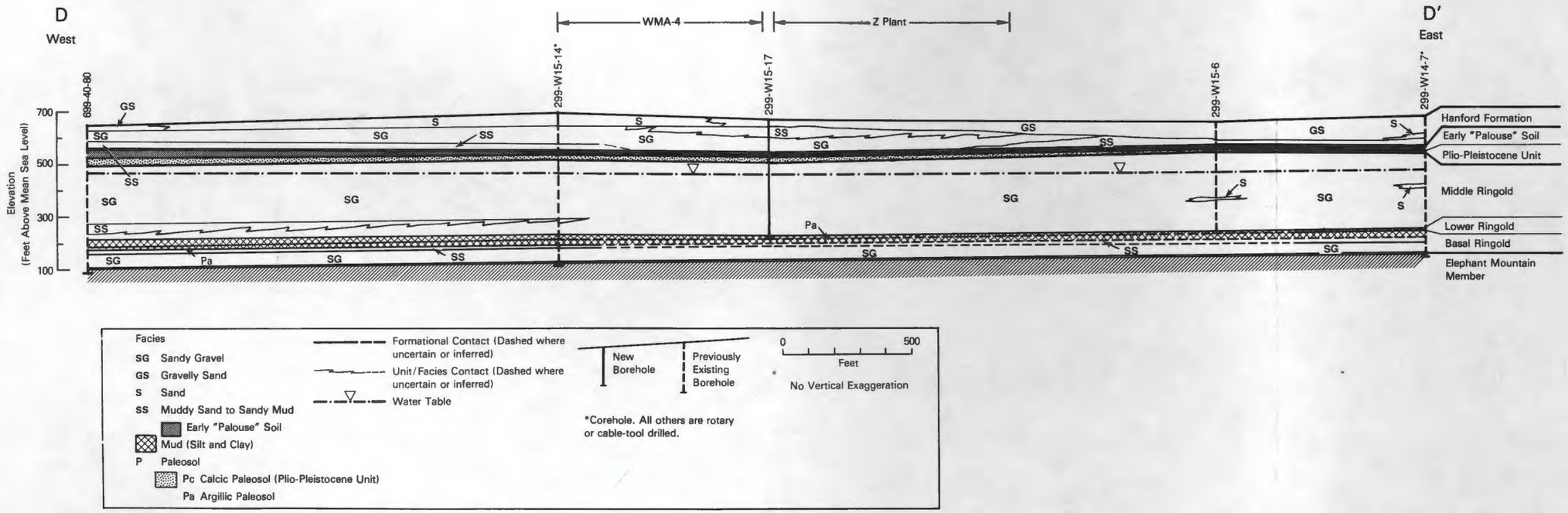


FIGURE 5.29. Geologic Cross Section D-D', Waste Management Area 4

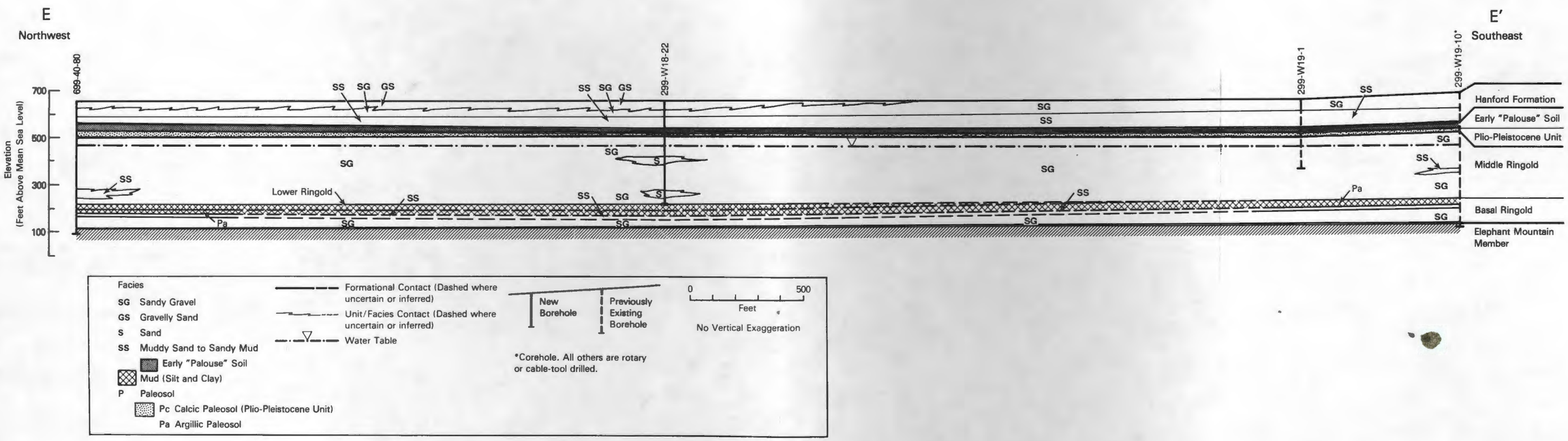


FIGURE 5.30. Geologic Cross Section E-E', Waste Management Area 4

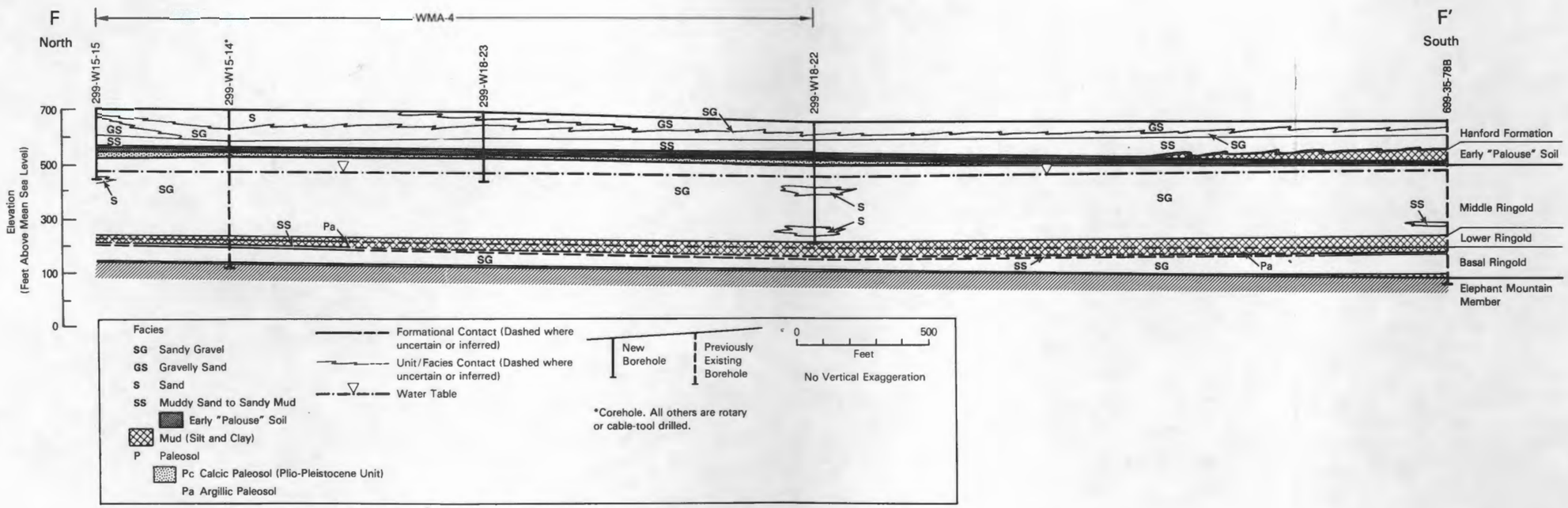


FIGURE 5.31. Geologic Cross Section F-F', Waste Management Area 4

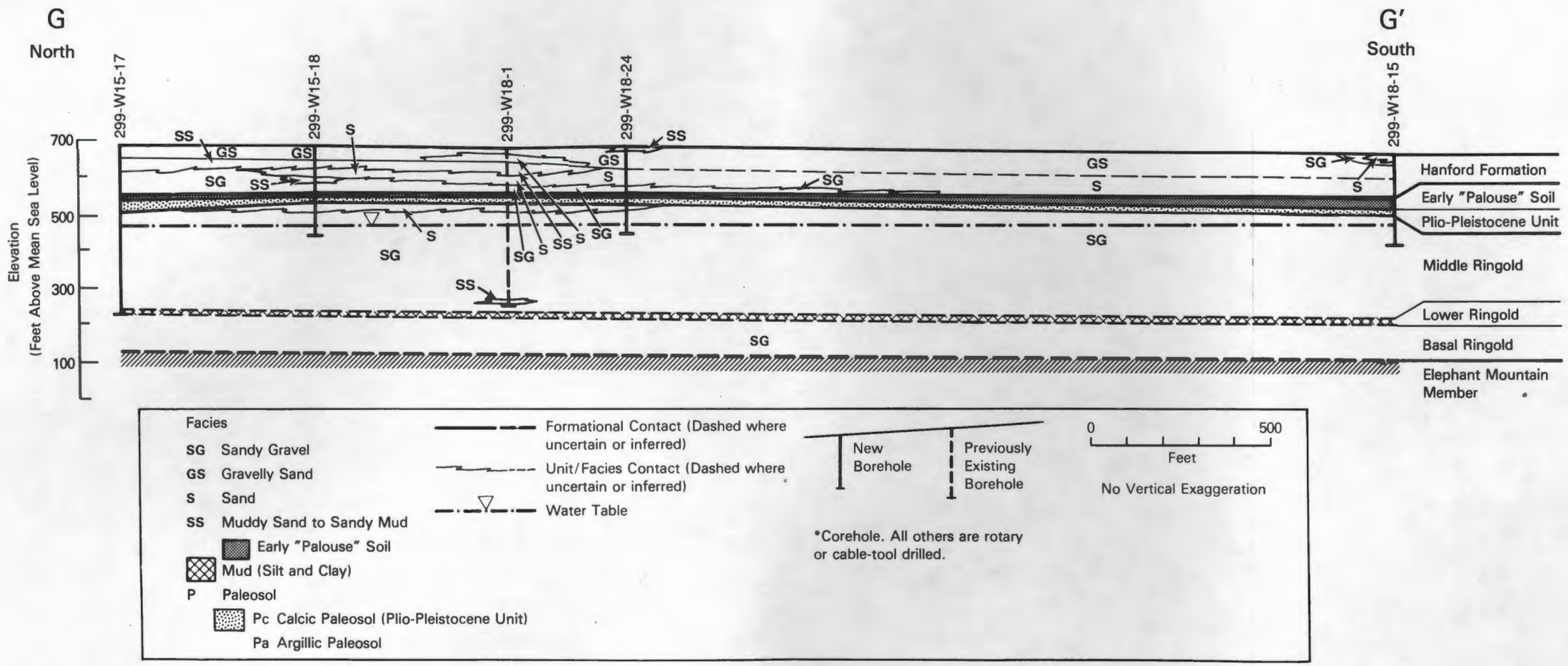


FIGURE 5.32. Geologic Cross Section G-G', Waste Management Area 4

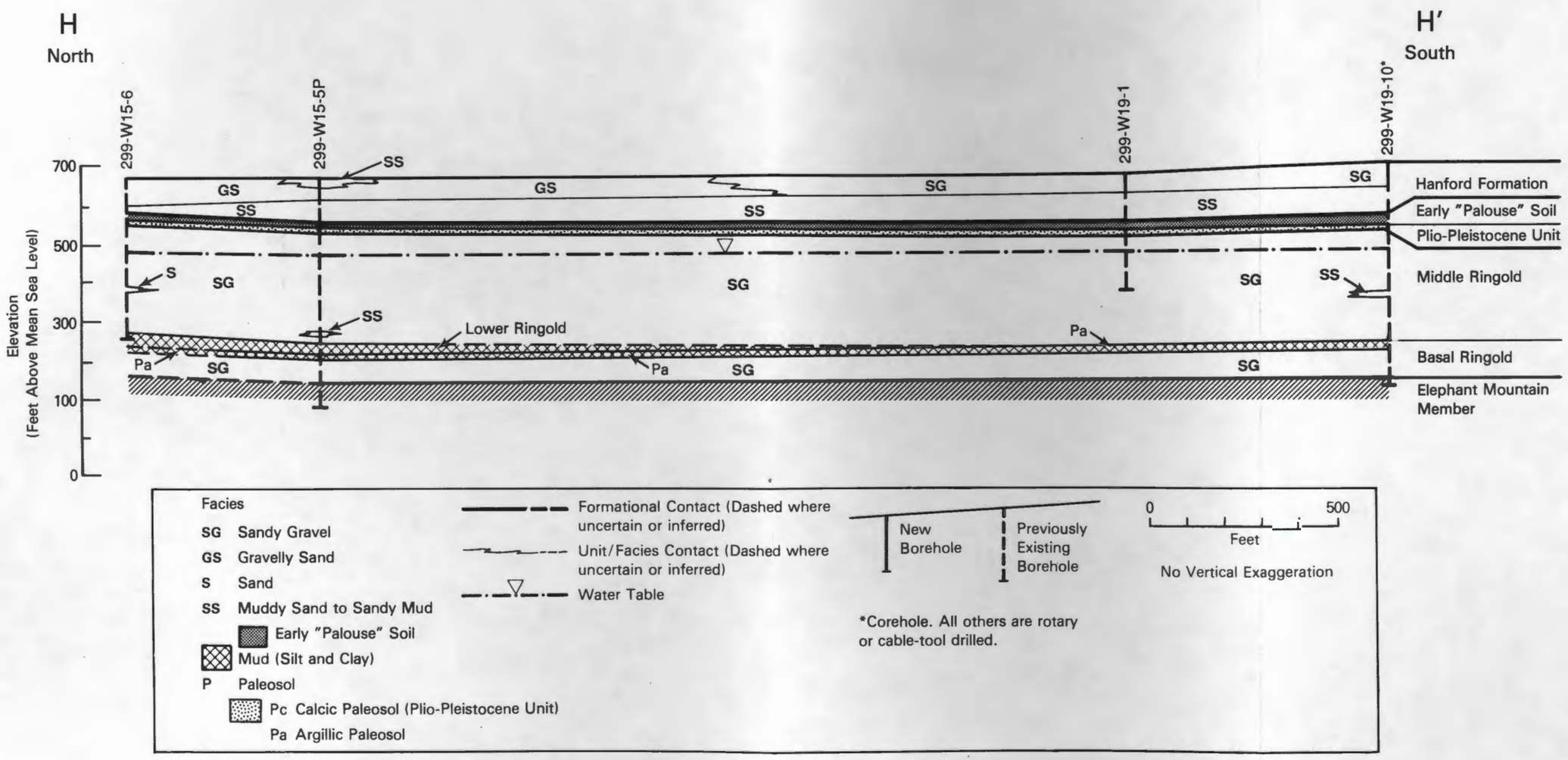


FIGURE 5.33. Geologic Cross Section H-H', Waste Management Area 4

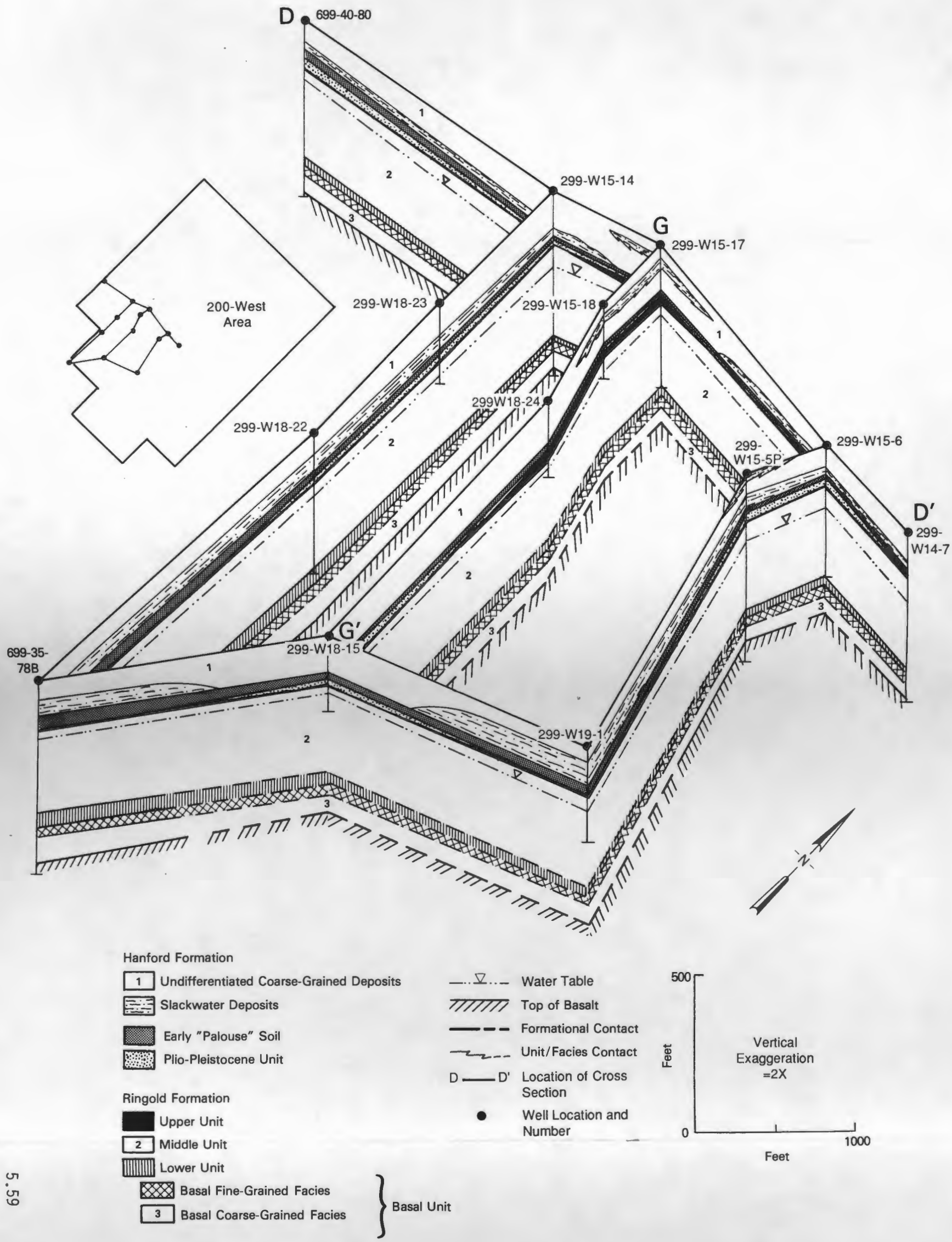


FIGURE 5.34. Fence Diagram of the Stratigraphy Beneath Waste Management Area 4

TABLE 5.6. Stratigraphic Contacts in 200-West Area Wells

Depth (feet below ground surface)

Borehole	Water Table	Top of Basal Slack-Water Sequence	Top of Early "Palouse" Soil	Top of Plio-Pleistocene Unit	Top of Upper Ringold	Top of Middle Ringold	Top of Lower Ringold	Top of Basal Ringold (fine)	Top of Basal Ringold (coarse)	Top of Basalt
299-W6-2	230	NP	59	68	NP	97	ND	ND	ND	ND
299-W7-1	228	NP	60	73	108	143	ND	ND	ND	ND
299-W7-2	214	NP	33	42	83	98	ND	ND	ND	ND
299-W7-3	216	NP	30	40	78	100	*	*	*	476
299-W7-4	208	NP	55	64	81	103	ND	ND	ND	ND
299-W7-5	210	NP	24	35	NP	76	ND	ND	ND	ND
299-W7-6	218	NP	NP	18	NP	76	ND	ND	ND	ND
299-W8-1	238	NP	72	87	119	152	ND	ND	ND	ND
299-W9-1	272	NP	149	159	184	193	ND	ND	ND	ND
299-W18-22	199	64	120	140	NP	153	445	ND	ND	ND
299-W10-13	232	NP	114	129	NP	144	ND	ND	ND	ND
299-W10-14	232	NP	112	127	NP	148	448	ND	ND	ND
299-W15-15	228	82	139	153	NP	174	ND	ND	ND	ND
299-W15-16	214	NP	132	140	159	177	ND	ND	ND	ND
299-W15-17	214	NP	137	144	160	176	442	ND	ND	ND
299-W15-18	214	NP	127	136	150	172	ND	ND	ND	ND
299-W18-21	198	61	119	139	NP	153	ND	ND	ND	ND
299-W18-23	226	98	144	159	NP	179	ND	ND	ND	ND
299-W18-24	213	NP	130	139	158	172	ND	ND	ND	ND
299-W15-14	224	115	141	156	170	175	459	474	507	564
299-W14-7	209	90	113	128	NP	135	425	432	475	519
299-W19-10	225	65	135	160	NP	170	NP	458	485	556
299-W11-26	226	70	90	110	130	141	*	*	*	505
RRL-3	220	NP	90	58	120	135	441	449	485	508
RRL-4	183	55	105	NP	NP	160	418	460	490	581
RRL-9	183	65	89	112	NP	150	438	460	490	547
299-W6-1	243	NP	NP	39	NP	98	*	*	*	462
DC-20B	ND	ND	ND	ND	ND	ND	ND	ND	ND	531
299-W10-1	207	43	76	94	115	142	ND	ND	ND	ND
299-W15-2	221	NP	109	121	NP	139	ND	ND	ND	ND
699-39-79	195	85	125	140	ND	ND	ND	ND	ND	ND
299-W18-1	200	NP	120	125	150	170	ND	ND	ND	ND
299-W15-6	190	66	90	98	NP	115	ND	ND	ND	ND
299-W15-5P	200	60	110	120	NP	145	430	455	480	525
299-W19-1	201	50	125	150	NP	160	ND	ND	ND	ND
299-W18-15	188	NP	120	140	NP	165	ND	ND	ND	ND
299-W14-8	232	108	164	178	NP	185	*	*	*	536
299-W19-2	232	88	158	185	203	240	ND	ND	ND	ND
299-W19-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	560
299-W11-10	273	NP	112	122	NP	130	ND	ND	ND	ND

Elevation (feet above mean sea level)

Borehole	Surface	Water Table	Top of Basal Slack-Water Sequence	Top of Early "Palouse" Soil	Top of Plio-Pleistocene Unit	Top of Upper Ringold	Top of Middle Ringold	Top of Lower Ringold	Top of Basal Ringold (fine)	Top of Basal Ringold (coarse)	Top of Basalt
299-W6-2	692	462	NP	633	624	NP	595	ND	ND	ND	ND
299-W7-1	690	462	NP	630	617	582	547	ND	ND	ND	ND
299-W7-2	675	461	NP	642	633	592	577	ND	ND	ND	ND
299-W7-3	676	460	NP	646	636	598	576	*	*	*	201
299-W7-4	671	463	NP	616	607	590	568	ND	ND	ND	ND
299-W7-5	673	463	NP	649	638	NP	597	ND	ND	ND	ND
299-W7-6	678	460	NP	NP	660	NP	602	ND	ND	ND	ND
299-W8-1	701	463	NP	629	614	582	549	ND	ND	ND	ND
299-W9-1	737	465	NP	588	578	553	544	ND	ND	ND	ND
299-W18-22	668	469	604	548	528	NP	515	223	ND	ND	ND
299-W10-13	699	467	NP	585	570	NP	555	ND	ND	ND	ND
299-W10-14	699	467	NP	587	572	NP	551	251	ND	ND	ND
299-W15-15	697	469	615	558	546	NP	523	ND	ND	ND	ND
299-W15-16	684	470	NP	552	544	525	507	ND	ND	ND	ND
299-W15-17	684	470	NP	547	540	524	508	242	ND	ND	ND
299-W15-18	685	471	NP	558	549	535	513	ND	ND	ND	ND
299-W18-21	668	470	607	549	529	NP	515	ND	ND	ND	ND
299-W18-23	696	470	598	552	537	NP	517	ND	ND	ND	ND
299-W18-24	684	471	NP	554	545	526	512	ND	ND	ND	ND
299-W15-14	699	475	584	558	543	529	524	240	225	192	136
299-W14-7	677	468	587	564	549	NP	542	252	245	202	159
299-W19-10	682	457	617	547	522	NP	512	NP	224	197	127
299-W11-26	694	468	624	604	584	564	553	*	*	*	190
RRL-3	689	469	NP	599	591	569	554	248	240	204	182
RRL-4	659	476	604	554	NP	NP	499	241	199	169	79
RRL-9	655	472	590	566	543	NP	505	217	195	165	108
299-W6-1	702	459	NP	NP	663	NP	604	*	*	*	238
DC-20B	712	ND	ND	ND	ND	ND	ND	ND	ND	ND	181
299-W10-1	674	467	631	598	580	559	532	ND	ND	ND	ND
299-W15-2	690	469	NP	581	569	NP	551	ND	ND	ND	ND
699-39-79	673	478	588	548	533	ND	ND	ND	ND	ND	ND
299-W18-1	680	480	NP	560	555	530	510	ND	ND	ND	ND
299-W15-6	661	471	595	571	563	NP	546	ND	ND	ND	ND
299-W15-5P	670	470	610	560	550	NP	525	240	215	185	145
299-W19-1	673	472	623	548	523	NP	513	ND	ND	ND	ND
299-W18-15	660	472	NP	540	520	NP	495	ND	ND	ND	ND
299-W14-8	695	463	587	531	517	NP	511	*	*	*	160
299-W19-2	694	ND	606	536	509	491	454	ND	ND	ND	ND
299-W19-8	705	ND	ND	ND	ND	ND	ND	ND	ND	ND	145
299-W11-10	728	455	NP	616	606	NP	598	ND	ND	ND	ND

Thickness, ft

Borehole	Hanford fm.					Ringold Fm.				
	Hanford formation Coarse-Grained Sequence	Hanford formation Basal Slack-water sequence	Hanford formation Total	Early "Palouse" Soil	Plio-Pleistocene Unit	Upper Ringold	Middle Ringold	Lower Ringold	Basal Ringold (fine)	Basal Ringold (coarse)
299-W6-2	59	NP	59	9	29	NP	ND	ND	ND	ND
299-W7-1	60	NP	60	13	35	35	ND	ND	ND	ND
299-W7-2	33	NP	33	9	41	15	ND	ND	ND	ND
299-W7-3	30	NP	30	10	38	22	*	*	*	*
299-W7-4	55	NP	55	9	17	22	ND	ND	ND	ND
299-W7-5	24	NP	24	11	41	NP	ND	ND	ND	ND
299-W7-6	18	NP	18	NP	58	NP	ND	ND	ND	ND
299-W8-1	72	NP	72	15	32	33	ND	ND	ND	ND
299-W9-1	149	NP	149	10	25	9	ND	ND	ND	ND
299-W18-22	64	56	120	20	13	NP	292	ND	ND	ND
299-W10-13	114	NP	114	15	15	NP	ND	ND	ND	ND
299-W10-14	112	NP	112	15	21	NP	300	ND	ND	ND
299-W15-15	82	57	139	14	21	NP	ND	ND	ND	ND
299-W15-16	132	NP	132	8	19	18	ND	ND	ND	ND
299-W15-17	137	NP	137	7	16	16	266	ND	ND	ND
299-W15-18	127	NP	127	9	14	22	ND	ND	ND	ND
299-W18-21	61	58	119	20	14	NP	ND	ND	ND	ND
299-W18-23	98	46	144	15	20	NP	ND	ND	ND	ND
299-W18-24	130	NP	130	9	19	14	ND	ND	ND	ND
299-W15-14	115	26	141	15	14	15	284	15	33	56
299-W14-7	90	23	113	15	7	NP	290	7	43	43
299-W19-10	65	70	135	25	10	NP	288	NP	27	70
299-W11-26	70	20	90	20	20	11	*	*	*	*
RRL-3	90	NP	90	8	22	15	306	8	36	22
RRL-4	55	50	105	55	NP	NP	258	42	30	90
RRL-9	65	24	89	23	38	NP	288	22	30	57
299-W6-1	39	NP	39	NP	59	NP	*	*	*	*
DC-20B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
299-W10-1	43	33	76	18	21	27	ND	ND	ND	ND
299-W15-2	109	NP	109	12	18	NP	ND	ND	ND	ND
699-39-79	85	40	125	15	ND	ND	ND	ND	ND	ND
299-W18-1	120	NP	120	5	25	20	ND	ND	ND	ND
299-W15-6	66	24	90	8	17	NP	ND	ND	ND	ND
299-W15-5P	60	50	110	10	25	NP	285	25	30	40
299-W19-1	50	75	125	25	10	NP	ND	ND	ND	ND
299-W18-15	120	NP	120	20	25	NP	ND	ND	ND	ND
299-W14-8	108	56	164	14	6	NP	*	*	*	*
299-W19-2	88	70	158	27	18	37	ND	ND	ND	ND
299-W19-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
299-W11-10	112	NP	112	10	8	NP	ND	ND	ND	ND

NP = Not present.
ND = No data.
* = Defining contact missing.

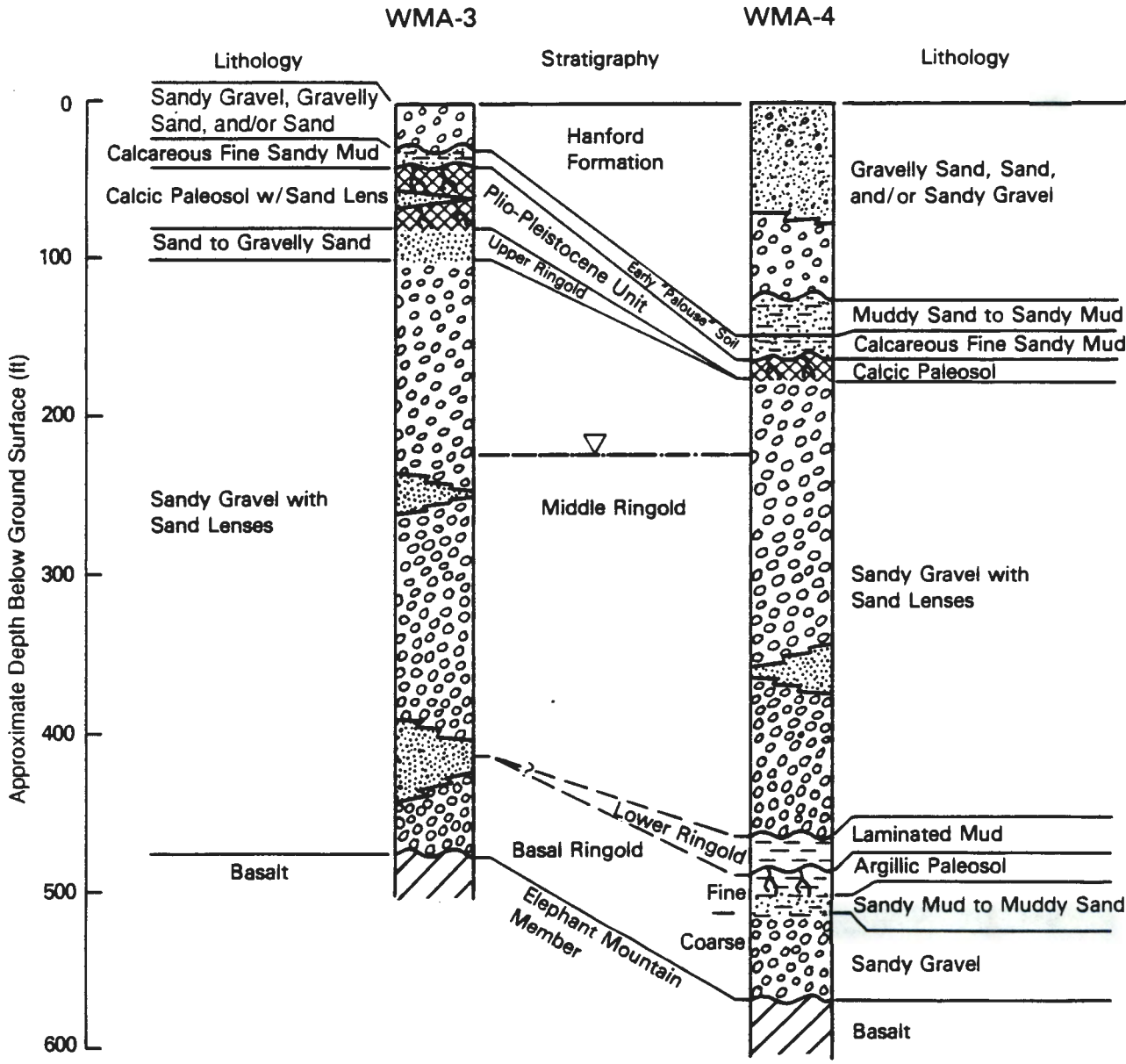


FIGURE 5.35. Generalized Stratigraphy for Waste Management Areas 3 and 4

5.4.1 Saddle Mountains Basalt

Sediments within the 200-West Area overlie the Elephant Mountain Member of the Saddle Mountains Basalt. Only one new well (299-W7-3) encountered the basalt. A sample of the basalt from this well was analyzed for major elements by the XRF method. The resulting data (Table 5.7) support the fact that the Elephant Mountain Member is the uppermost basalt unit. The surface

TABLE 5.7. Results of X-Ray Fluorescence Analysis[a] of Basalt Samples from the 200-West Area

Constituent	299-W7-3 (475 ft)
SiO_2	50.77
Al_2O_3	13.32
TiO_2	3.696
FeO (and Fe_2O_3)	15.73
MnO	0.197
CaO	8.52
MgO	3.83
K_2O	1.00
Na_2O	2.33
P_2O_5	0.613

(a) Data are percentages of constituent present.

of the top of basalt is represented in Figure 5.36. The configuration of the basalt surface is largely the result of downwarping of the basalt caused by north-south tectonic compression (DOE 1988). The 200-West Area lies on the northern flank of the resultant northwest-southeast-trending trough, referred to as the Cold Creek syncline. The axis of the Cold Creek syncline lies approximately one mile southwest of the 200-West Area (see Figure 3.10).

5.4.2 Ringold Formation

The fluvial-lacustrine Ringold Formation, which was deposited during late Miocene/Pliocene time, is subdivided into four units, principally on the basis of texture (DOE 1988). The combined thicknesses of the basal, lower, middle, and upper Ringold units range from approximately 350 to 420 ft in the 200-West Area. Based on the difference in relief between the top of the White Bluffs and the 200-West Area, 300 to 400 ft of Ringold Formation sediments may have been removed during a period of downcutting and erosion that followed Ringold Formation deposition (DOE 1988).

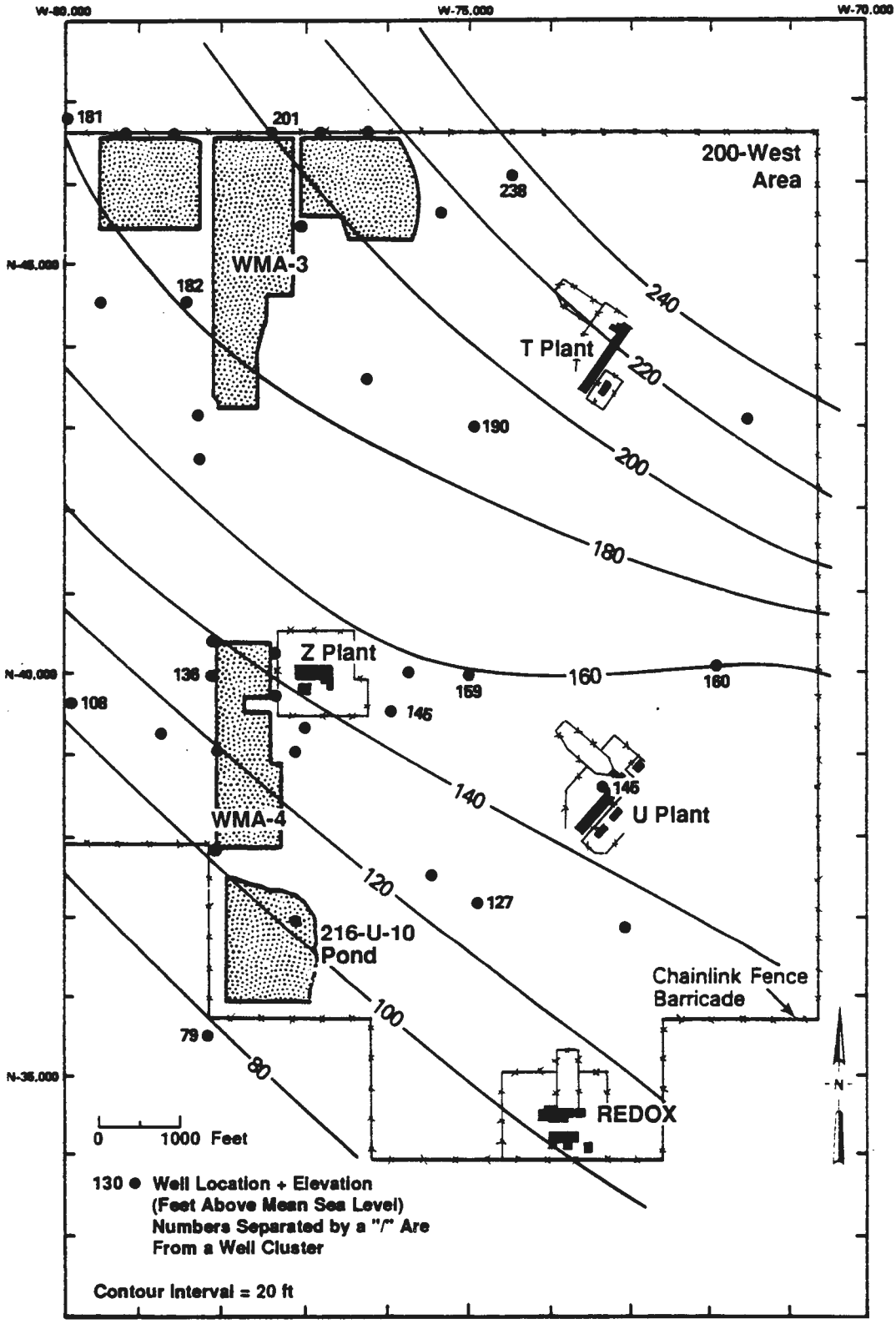


FIGURE 5.36. Surface of the Top of Basalt Beneath the 200-West Area (modified after Tallman et al. 1979)

Basal Ringold Unit

The basal Ringold unit, a fining upward fluvial cycle, has been detected in 7 out of 11 of the deeper wells examined in the 200-West Area. In general, the coarse-grained deposits of sandy gravel to gravelly sand at the base of the unit are included in the basal Ringold coarse-grained facies, while the overlying deposits of sand and mud are assigned to the fine-grained facies. The fine-grained facies is characterized by a fining upward sequence of micaceous sand and mud, and is capped by a well-developed argillic (mud-rich) paleosol (Bjornstad 1985). Characteristics of the basal coarse-grained facies include: 1) mostly rounded gravel clasts within a matrix of arkosic, well-sorted, medium to coarse sand; 2) a predominance of quartizitic, granitic, and/or volcanic porphyry lithologies; 3) low calcium carbonate content; and 4) low natural-gamma response (DOE 1988). The basal Ringold coarse-grained facies thickens from approximately 20 to 90 ft to the south-southwest toward the axis of the Cold Creek syncline (Figure 5.37). The fine-grained facies is thickest along a narrow band in the central 200-West Area (Figure 5.38). The surfaces atop the basal Ringold subunits (Figures 5.39 and 5.40) generally dip to the southwest, conformable with the top of basalt, evidently as a result of continued (post-Elephant Mountain Member) tectonic folding.

Lower Ringold Unit

The lower Ringold unit is another sequence of fine-grained sediments that overlies the fine-grained basal Ringold unit. Silt and clay of the lower Ringold unit are distinguished from the basal Ringold paleosol by: 1) the presence of well-developed laminae, 2) a distinct gray versus olive color, and 3) a significantly higher natural-gamma response in geophysical logs (DOE 1988). Only three of the newly installed wells encountered the lower Ringold unit. A split-spoon sample of this unit was collected at each of these three wells (299-W10-14, 299-W15-17, and 299-W18-22). Sedimentation tube (hydrometer) analyses of these samples revealed between 27% and 43% clay. Permeameter testing of undisturbed core sections revealed hydraulic conductivities on the order of 10^{-12} ft/d. Table 5.8 presents these data.

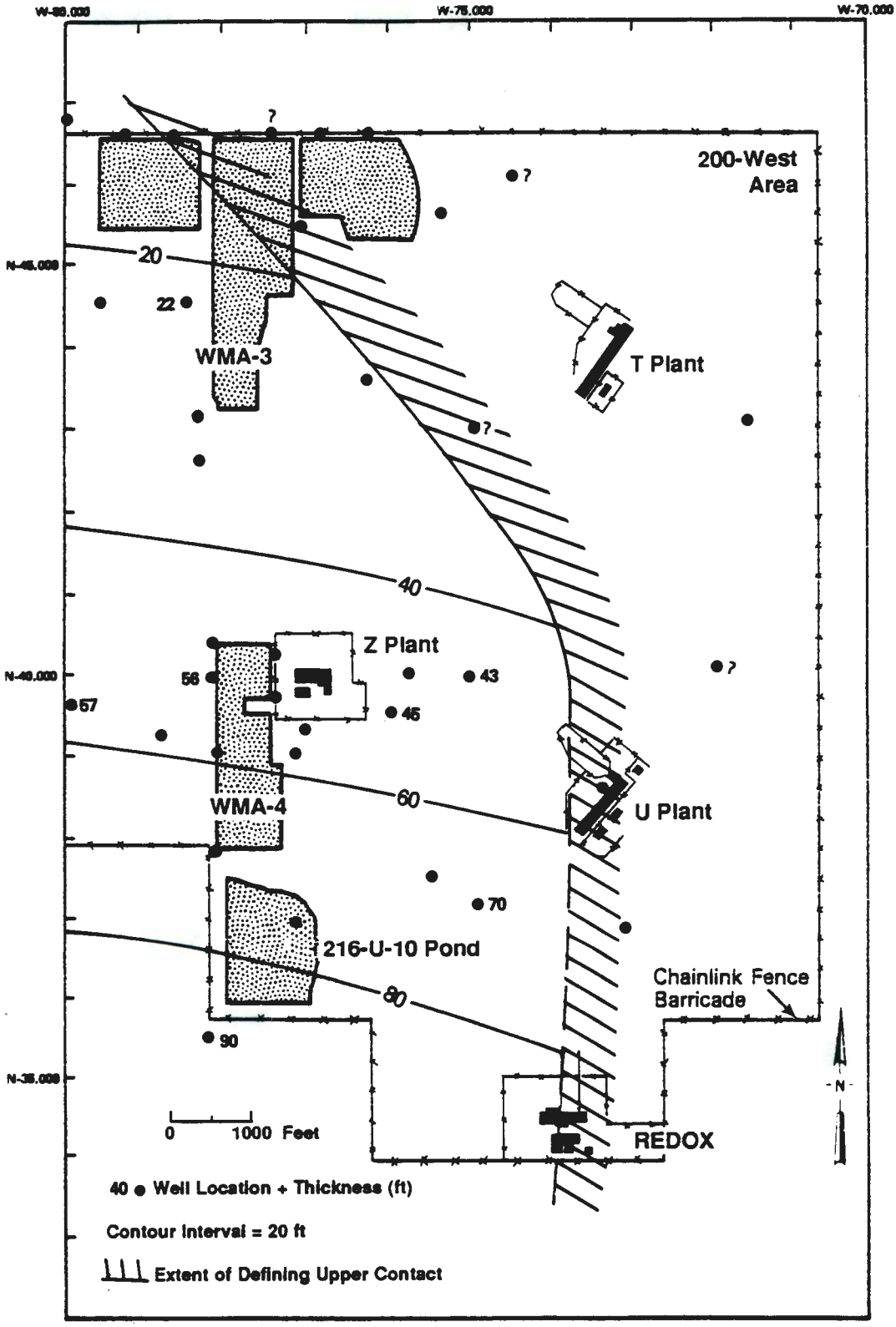


FIGURE 5.37. Isopach of the Basal Ringold Unit (coarse facies) Beneath the 200-West Area

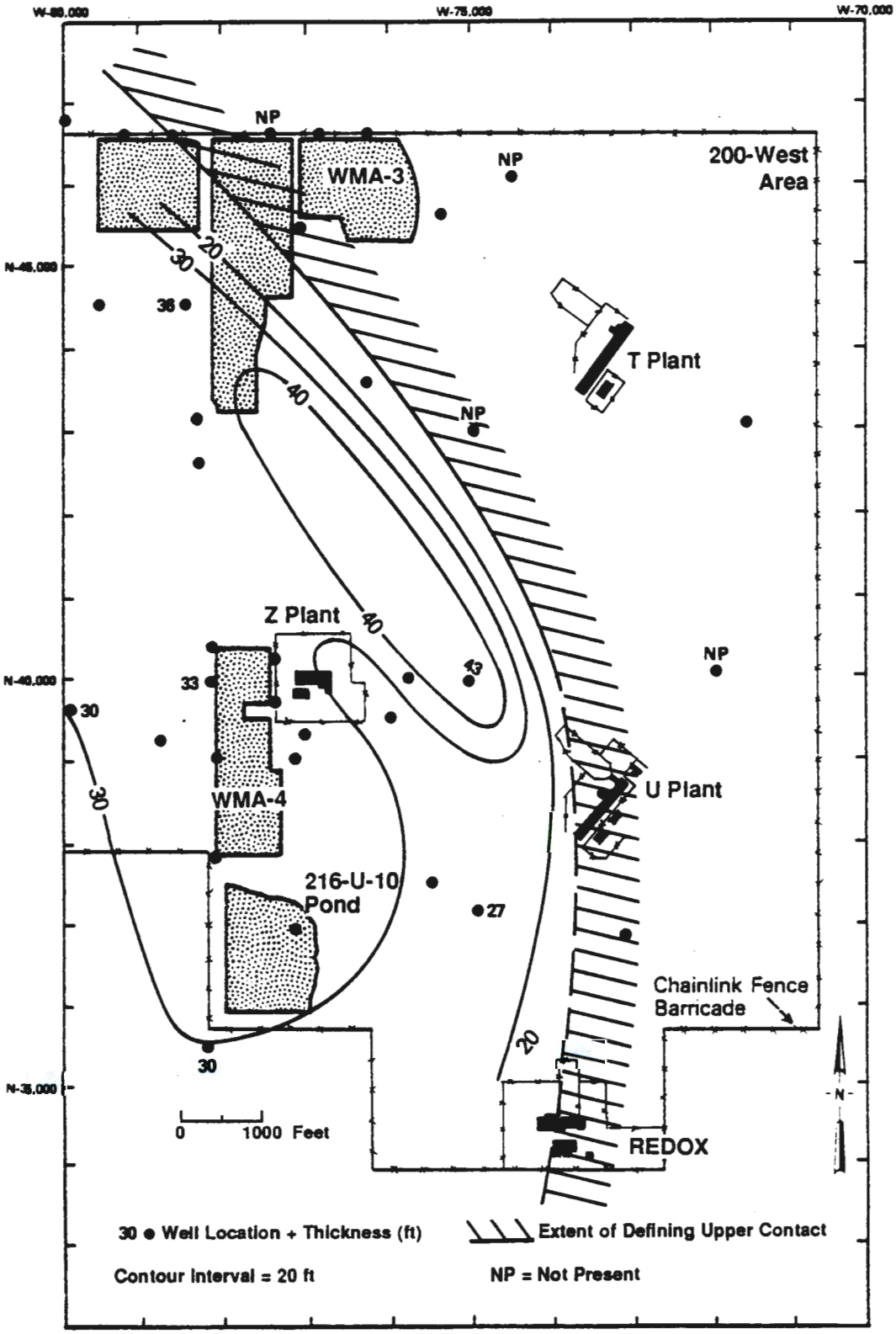


FIGURE 5.38. Isopach of the Basal Ringold Unit (fine facies) Beneath the 200-West Area

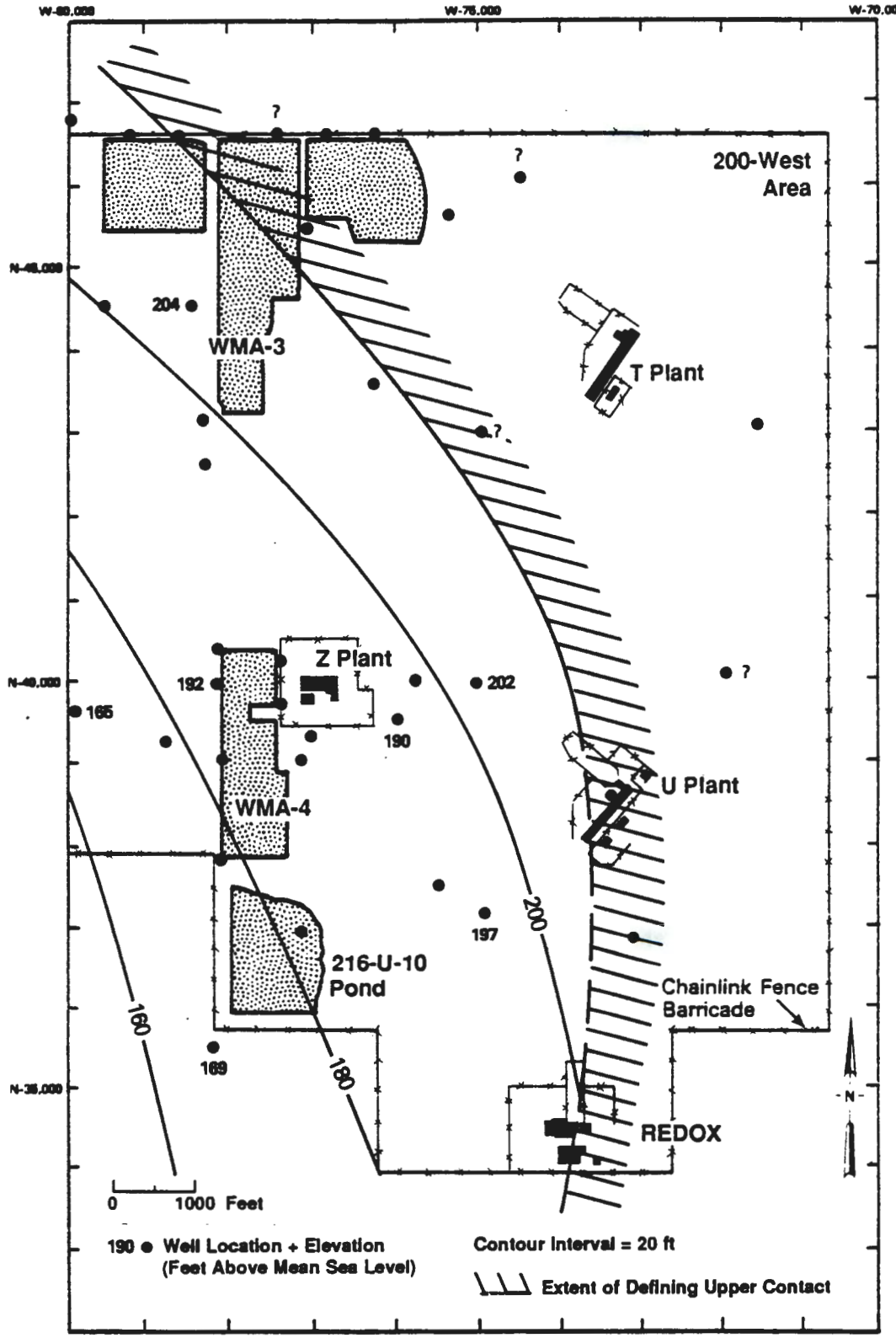


FIGURE 5.39. Surface of the Top of the Basal Ringold Unit (coarse facies) Beneath the 200-West Area

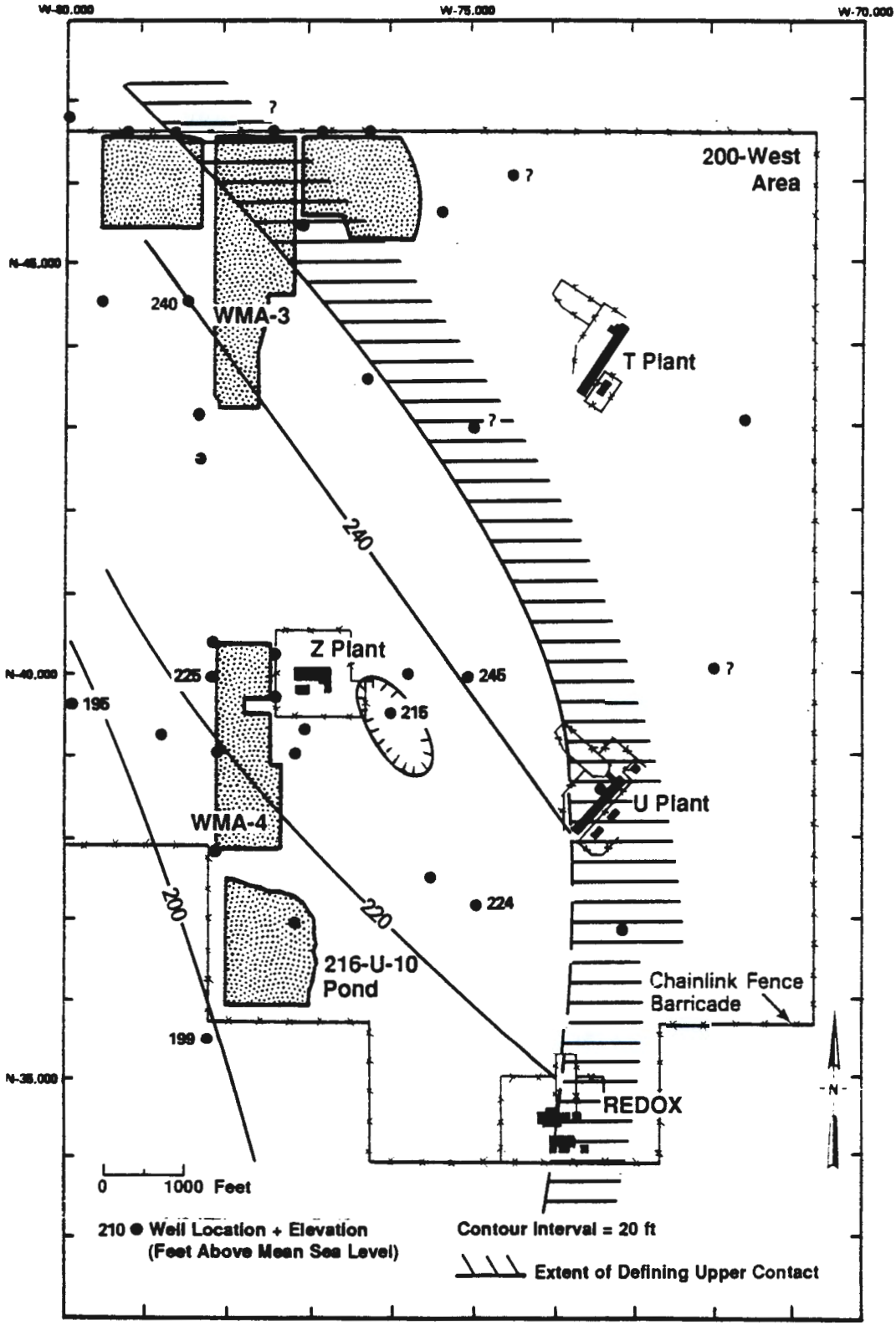


FIGURE 5.40. Surface of the Top of the Basal Ringold Unit (fine facies) Beneath the 200-West Area

TABLE 5.8. Hydrometer and Permeameter Test Data on Three Lower Ringold Split-Spoon Samples

Borehole/ Depth	% Sand	% Silt	% Clay	Class[a]	Vertical Hydraulic Conductivity
299-W10-14 460-462 ft	29	44	27	Clay loam	7.63×10^{-5} ft/d
299-W15-17 448-450 ft	25	32	43	Clay	1.82×10^{-5} ft/d
299-W18-22 455-456.7 ft	22	43	35	Clay loam	6.15×10^{-5} ft/d

(a) U.S. Department of Agriculture.

The lower Ringold unit, like the basal Ringold fine-grained subunit, pinches out in the eastern portion of the 200-West Area. The lower Ringold unit is thickest (approximately 40 ft) beneath WMA-4 and thins northward and pinches out beneath the northeastern portion of WMA-3 (Figure 5.41). Like the underlying units, the surface of the lower Ringold unit (Figure 5.42) generally dips to the southwest; however, there appears to be a secondary west-plunging trough atop the lower Ringold unit in the vicinity of WMA-4.

The thickness of the total confining fine-grained layer, which includes the basal Ringold fine-grained subunit in addition to the lower Ringold, reaches its maximum thickness (72 ft) southwest of WMA-4 (Figure 5.43). This confining bed separates the more-permeable middle and coarse-grained basal Ringold units. Where these fine-grained strata are missing, in the northern and eastern portions of WMA-3 for example (see Figures 5.37 through 5.42), it is not possible to differentiate between the middle Ringold and basal coarse-grained units, which share a common texture and mineralogy.

Middle Ringold Unit

The middle Ringold unit is composed of coarse-grained gravel and sand deposited in a high-energy fluvial environment. The sharp contact with the underlying lower Ringold unit is easily recognized by the sudden contrast in grain size. The middle Ringold unit is overlain by either the upper Ringold unit, the Plio-Pleistocene unit, the early "Palouse" soil, or the Hanford

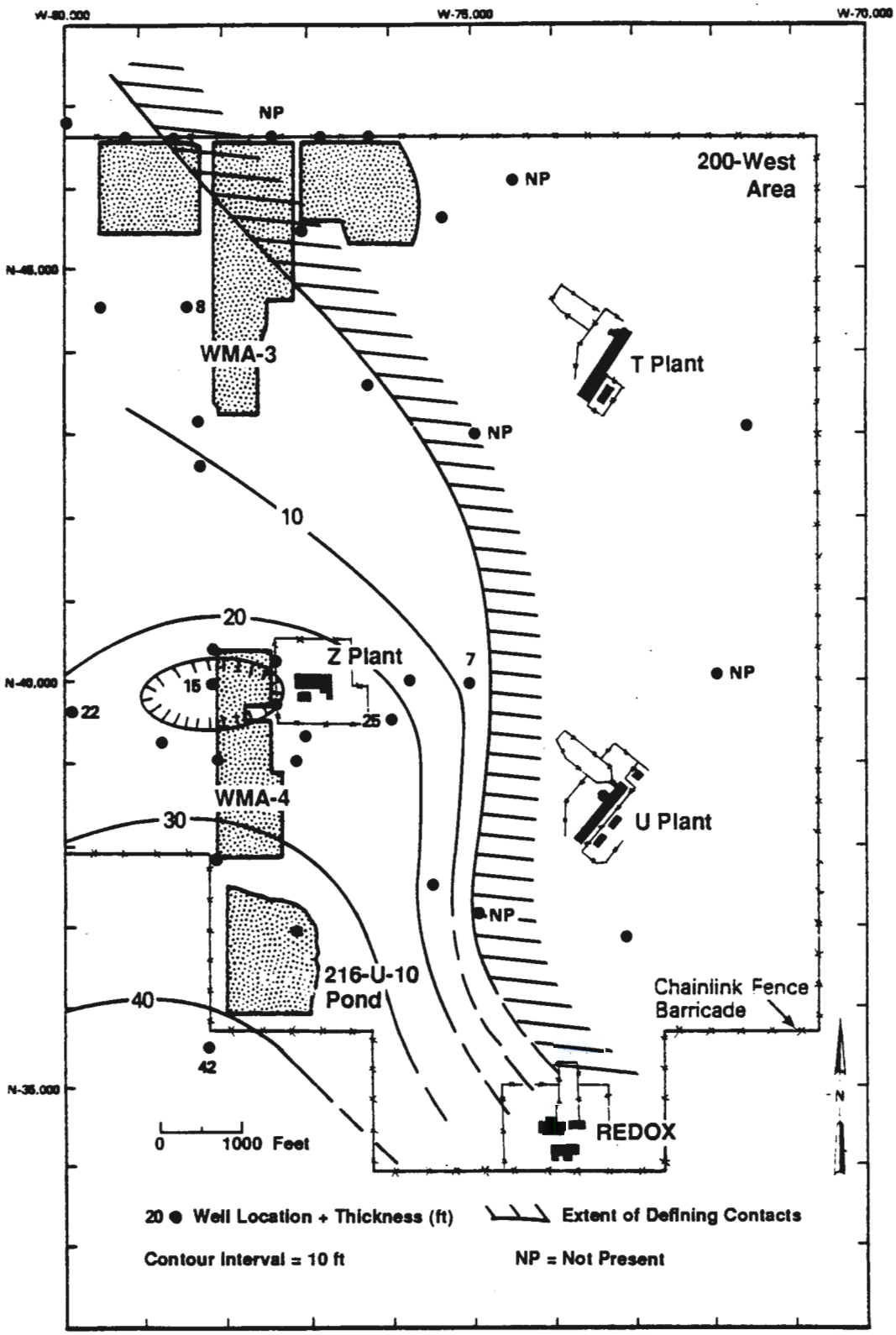


FIGURE 5.41. Isopach of the Lower Ringold Unit Beneath the 200-West Area

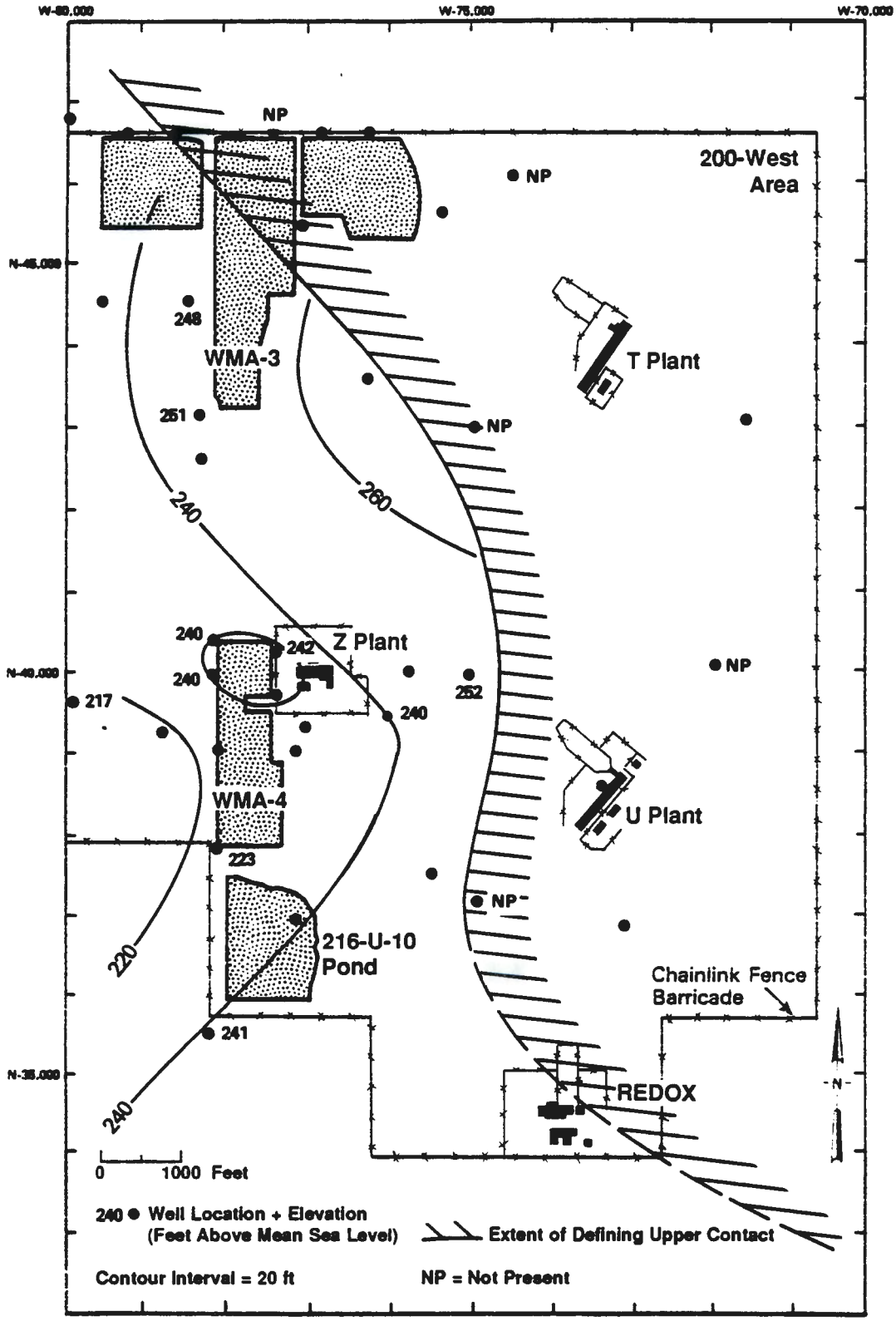


FIGURE 5.42. Surface of the Top of the Lower Ringold Unit Beneath the 200-West Area

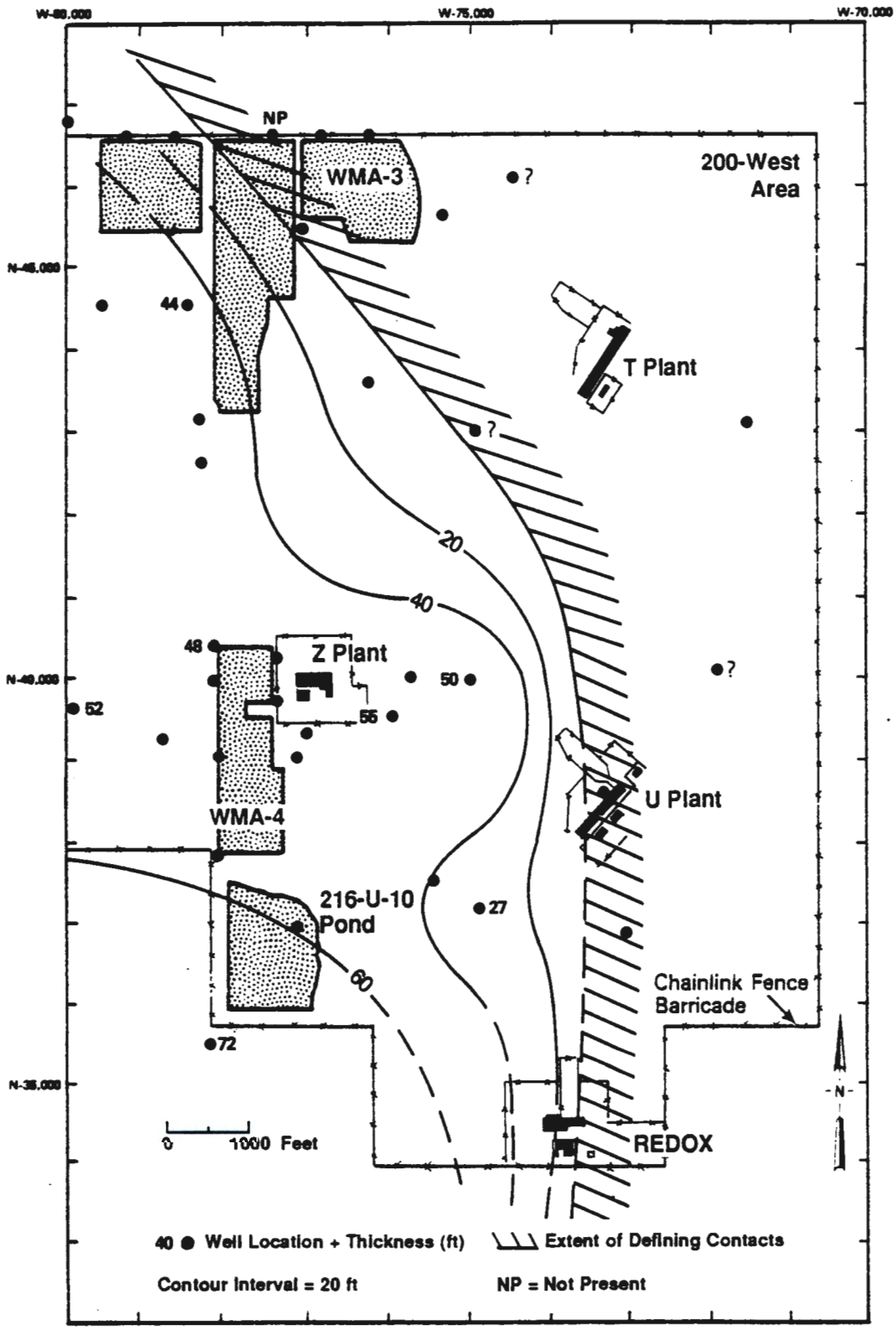


FIGURE 5.43. Isopach of the Lower/Upper Basal Ringold Units Beneath the 200-West Area

formation. Like the coarse-grained basal Ringold subunit, the characteristics used to define the middle Ringold are its: 1) coarse texture, 2) relatively high proportion of quartzite and granitic clasts, 3) relatively low calcium carbonate content, 4) partial consolidation, and 5) relatively low natural-gamma response. The uniform clast-supported texture of the middle Ringold unit is sometimes interrupted with thin zones of current-laminated sand.

All 19 of the new ground-water monitoring wells encountered the middle Ringold unit, but only 4 penetrated its entire thickness. The remaining 15 wells were terminated in the upper portion of the unit, where the water table lies. Borehole data from these new wells suggest that the unit consists mostly of a muddy sandy gravel, with a particle-size distribution of approximately 30% gravel, 60% sand, and 10% mud. Occasional sand stringers, consisting of approximately 90% sand, are also present. Examples of the particle-size distributions are presented in Table 5.9. The basalt content of the gravel clasts is generally estimated at less than 35% by volume. Calcium carbonate contents are generally less than 3% by weight, showing no reaction to moderate reaction to 10% hydrochloric acid.

The middle Ringold unit is generally 250 ft or more thick in the 200-West Area (Figure 5.44) and, thus, is the thickest suprabasalt unit in the area. The true thickness of the middle Ringold unit is uncertain in the northern and eastern portions of the 200-West Area where the bounding lower and fine-grained basal Ringold units are missing. Here, the texturally and mineralogically similar middle Ringold and coarse-grained basal Ringold facies lie in contact. Similar to underlying stratigraphic units, the upper surface of the middle Ringold generally dips to the southwest (Figure 5.45).

Upper Ringold Unit

The upper Ringold unit in the 200-West Area consists of finer textured deposits, which represent a transition to a lower energy fluvial environment, compared to the middle Ringold. The contact with the middle Ringold unit appears gradational, and is generally defined by the interval above the middle Ringold unit where the amount of light-colored arkosic sand exceeds the amount of gravel. Characteristics of the upper Ringold unit are its:

TABLE 5.9. Examples of Particle-Size Distribution (weight percent of total) in the Middle Ringold Unit Beneath Waste Management Areas 3 and 4

Borehole /Depth	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	Class
299-W7-4 110 ft	28.3	10.0	13.5	21.5	11.4	5.7	9.5	Slightly muddy gravelly sand
299-W15-17 345 ft	3.1	5.6	21.6	45.3	12.5	6.1	5.8	Sand
299-W18-21 155 ft	32.9	11.4	11.9	21.9	6.4	5.2	10.4	Muddy sandy gravel

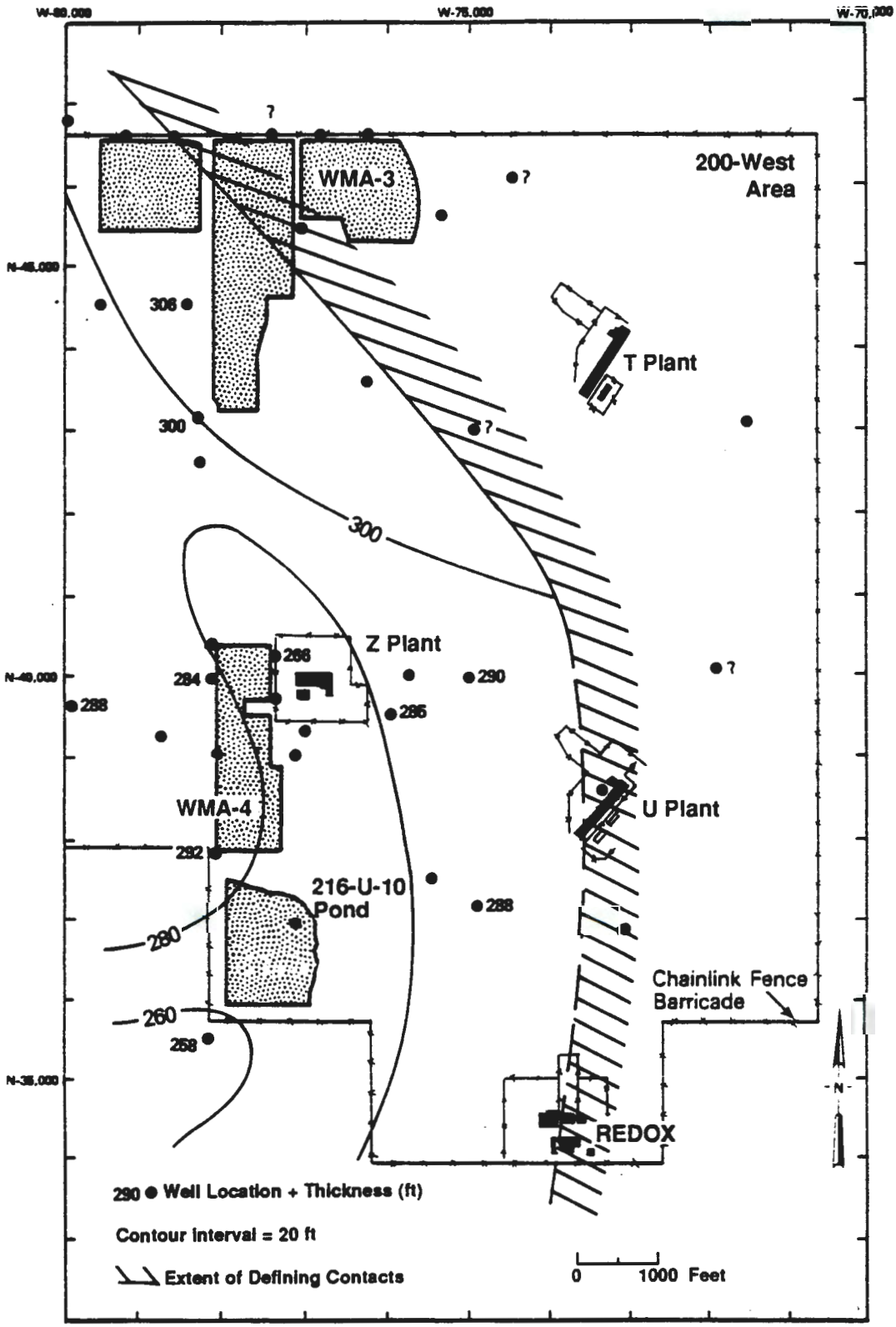


FIGURE 5.44. Isopach of the Middle Ringold Unit Beneath the 200-West Area

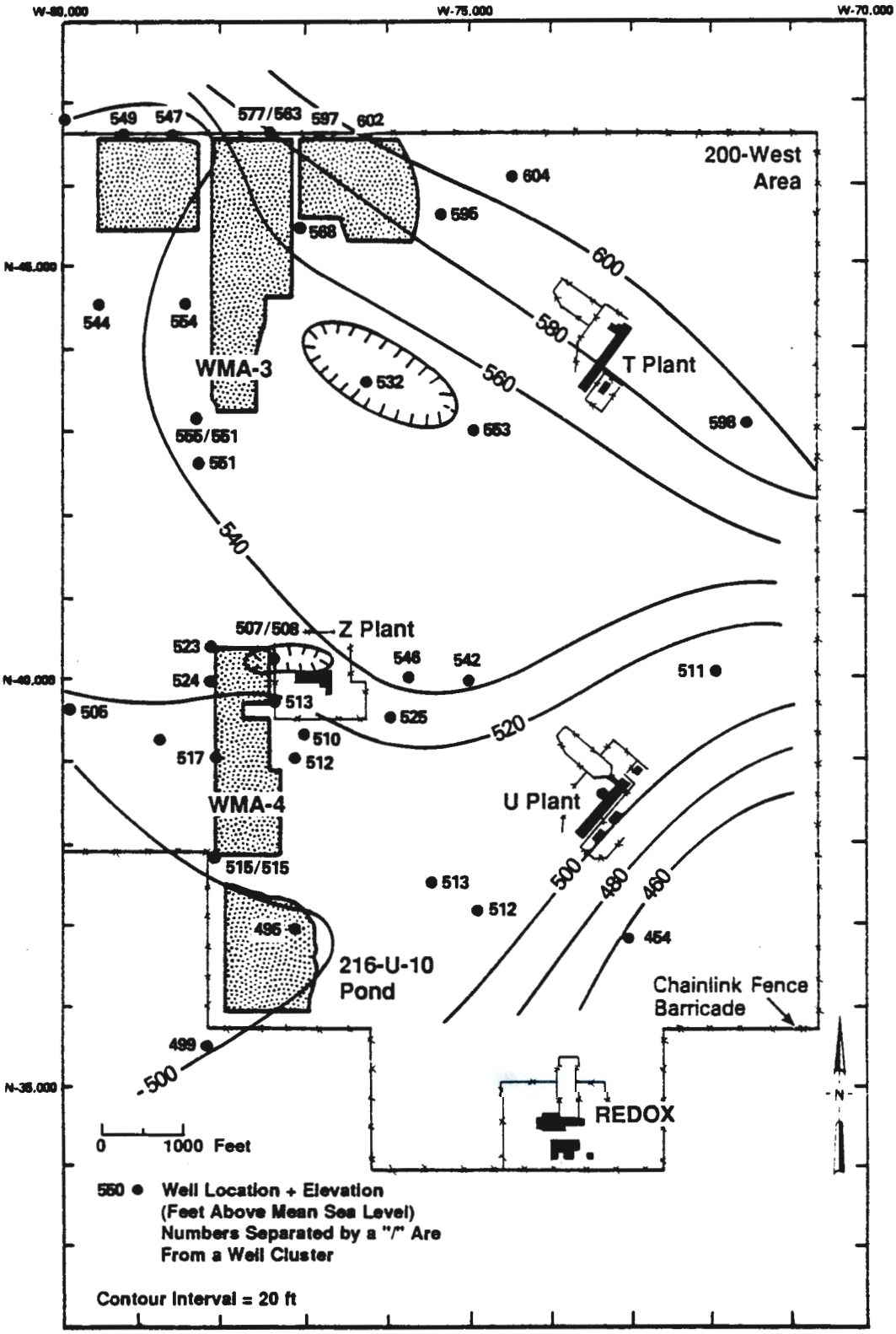


FIGURE 5.45. Surface of the Top of the Middle Ringold Unit Beneath the 200-West Area

1) abundance of well-sorted sand; 2) light color, caused primarily by the predominance of quartz and feldspar; and 3) variable natural-gamma response.

The upper Ringold unit was encountered in 10 of the 19 new wells. This unit is generally described as a slightly muddy sand to a gravelly sand, generally containing less than 12% gravel. Occasional gravel units are also present. Examples of the particle-size distribution of upper Ringold unit sediments is presented in Table 5.10. While the calcium carbonate content is usually low (<3 wt%), on occasion high-carbonate concentrations exist (e.g., >10 wt% in 299-W7-1), suggesting calcic soil development took place intermittently during upper Ringold time.

The upper Ringold unit is discontinuous across the 200-West Area. The present distribution and large variations in thickness of the upper Ringold unit are most likely caused by erosion of the unit by post-Ringold fluvial processes. In the 200-West Area, upper Ringold sediments are thickest (up to 35 ft) along the northern border (Figure 5.46). More of the upper Ringold unit is preserved here because this area lies near the drainage divide separating Cold Creek valley from the Columbia River valley. Beneath WMA-3, the eroded surface of the upper Ringold unit dips southwest, but levels out to the south beneath WMA-4 (Figure 5.47).

5.4.3 Plio-Pleistocene Unit

The Plio-Pleistocene unit (Bjornstad 1984, 1985) in the 200-West Area represents a highly weathered paleosurface that developed atop the Ringold Formation (Brown 1959, 1960a). While some aggradation of new material may be associated with the Plio-Pleistocene unit, much of it represents in situ weathering of the uppermost Ringold Formation. Characteristics of the Plio-Pleistocene unit, which suggest it is a pedogenic calcrete, are its almost white color, high degree of cementation, and presence of animal burrow and root traces in core. The concentrations of secondary calcium carbonate cement, a weathering product, exceeds 30 wt% in some samples, and causes a vigorous reaction when tested with dilute hydrochloric acid. In places, this secondary cement may completely fill the interstices between sedimentary

TABLE 5.10. Examples of Particle-Size Distribution (weight percent of total) and Calcium Carbonate Content of the Upper Ringold Unit Beneath Waste Management Areas 3 and 4

Borehole /Depth	$CaCO_3$, %	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	Class
299-W7-2 95 ft	1.4	47.9	3.4	15.5	20.3	4.8	2.4	5.8	Muddy sandy gravel
299-W8-1 130 ft	4.6	0.9	2.2	18.3	43.5	13.3	5.6	16.2	Slight muddy sand
299-W18-24 171 ft	0.2	17.9	29.0	24.2	18.9	6.8	2.0	1.2	Gravelly sand

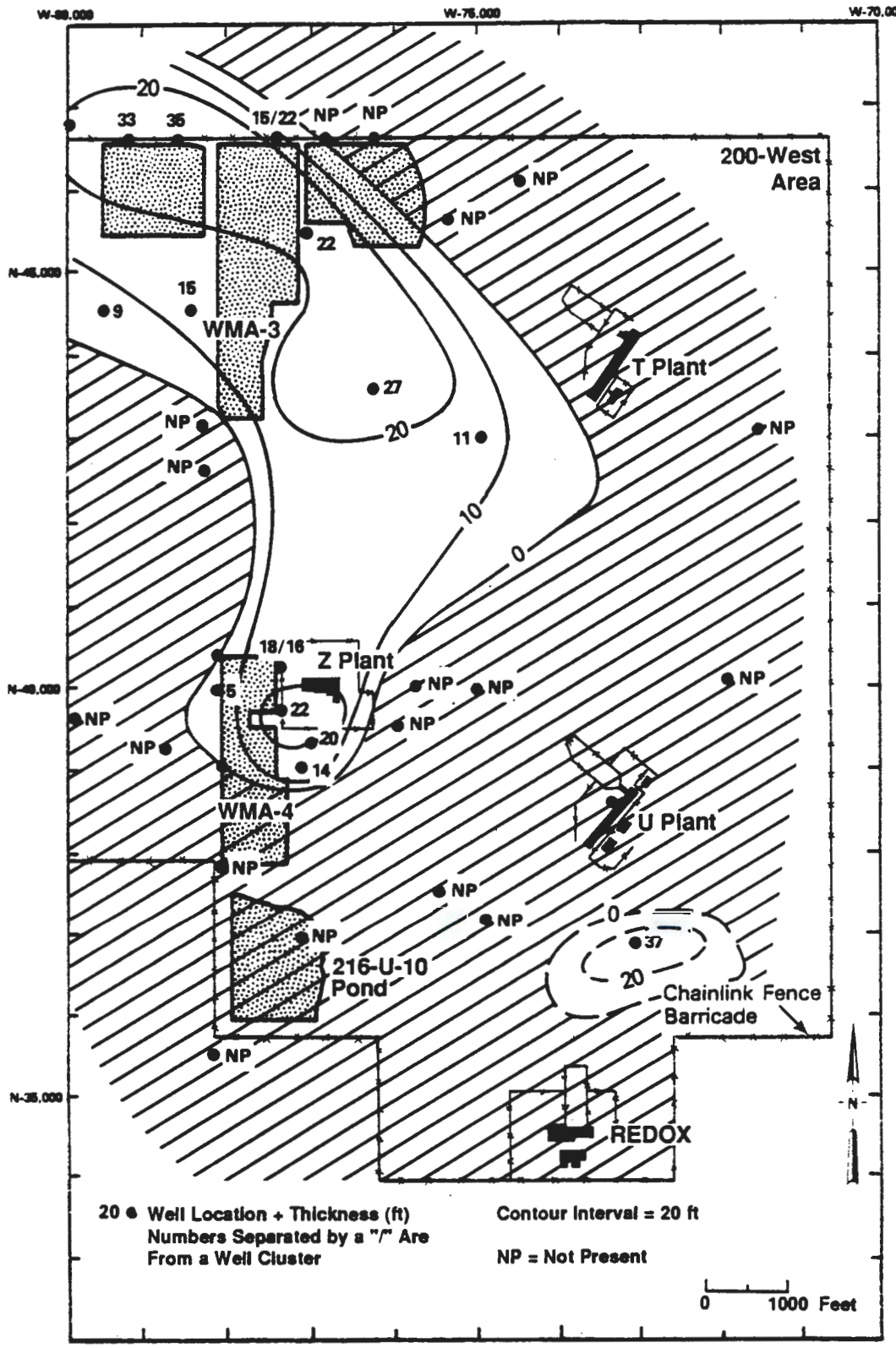


FIGURE 5.46. Isopach of the Upper Ringold Unit Beneath the 200-West Area

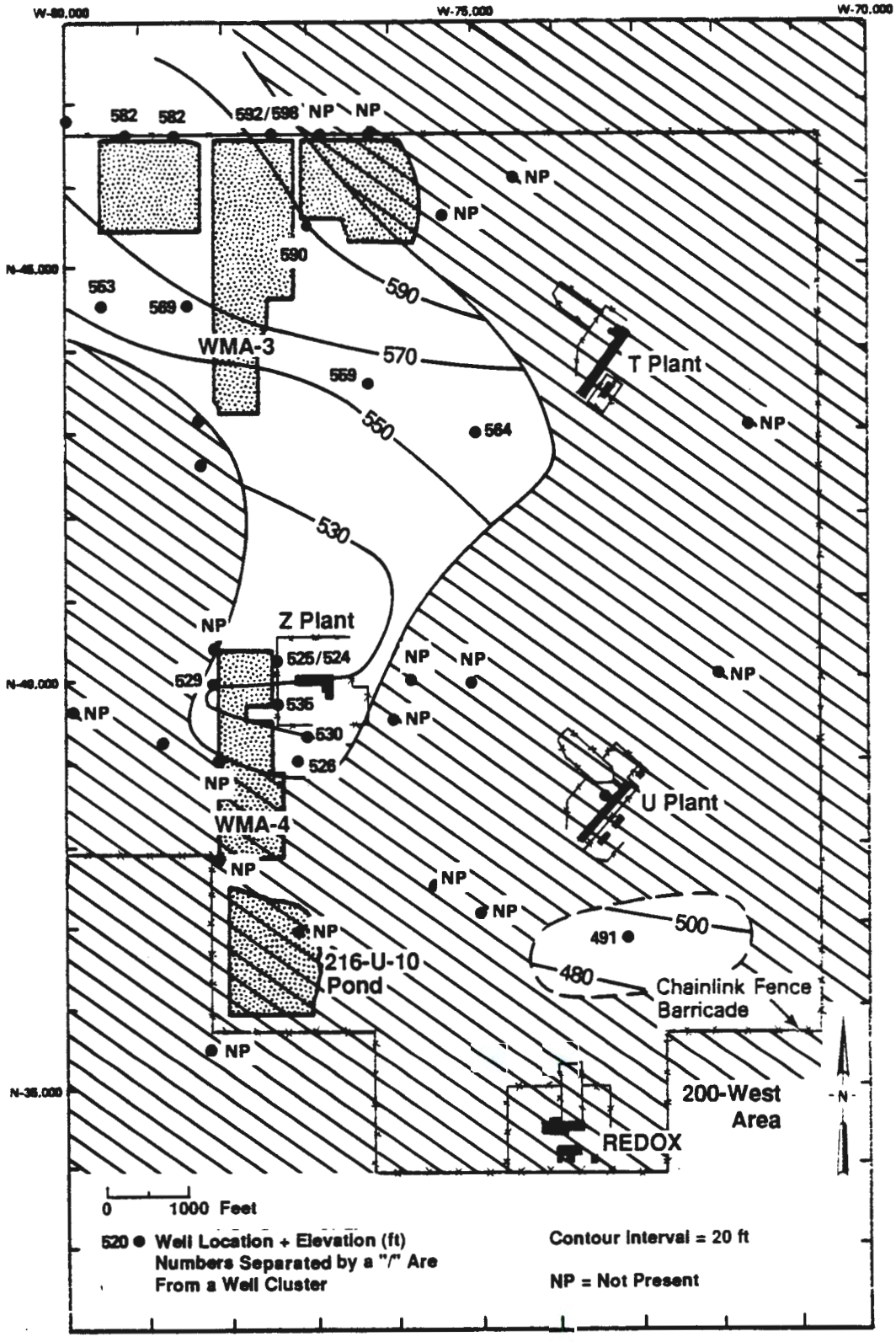


FIGURE 5.47. Surface of the Top of the Upper Ringold Unit Beneath the 200-West Area

particles. Similar residual deposits, caused by subaerial weathering in arid environments, are described in the geologic literature (Gile et al. 1966; Machette 1985).

Natural-gamma activity within the Plio-Pleistocene unit is erratic, being high in places and moderate to low elsewhere. Examples of the variation in natural-gamma response and calcium carbonate content for the Plio-Pleistocene and adjacent stratigraphic units are plotted in Figure 5.48.

The upper and lower contacts of the Plio-Pleistocene unit are chosen based on concentrations of calcium carbonate cement. The lower contact of the Plio-Pleistocene unit is gradational with the Ringold Formation and is somewhat controlled by the depth of weathering, which in turn may be a function of the texture of the primary material.

The Plio-Pleistocene unit is continuous across most of the 200-West Area and was encountered by all 19 new wells. The texture of this unit is generally described as gravelly sand to sandy mud. Examples of the particle-size distribution of these materials are presented in Table 5.11. Gravel clasts within this unit are generally greater than 50% basalt. Calcium carbonate contents are generally between 8 and 30 wt%.

The Plio-Pleistocene unit is thickest (approximately 60 ft) along the northern boundary (Figure 5.49). The thickness is greater to the north, in part, because of a relatively uncemented sand lens that divides two calcrete layers (e.g., see Figure 5.25); elsewhere, only a single massive calcrete layer is present. The sand lens represents either localized post-Ringold fluvial or eolian activity that did not take place in the southern portion of the 200-West Area.

The top of the Plio-Pleistocene unit, a paleotopographic surface, dips moderately (approximately 1.5 degrees) to the southwest in the northern portion of the 200-West Area, but flattens out and becomes somewhat undulatory to the south near WMA-4 (Figure 5.50). At one time, the Plio-Pleistocene surface may have been connected with fan and slopewash deposits that spread southward from Gable Mountain and eastward from Rattlesnake, Yakima, and Umtanum Ridges. This surface has since been removed north of the 200-West Area by erosion associated with a Pleistocene flood channel (see Figure 5.2).

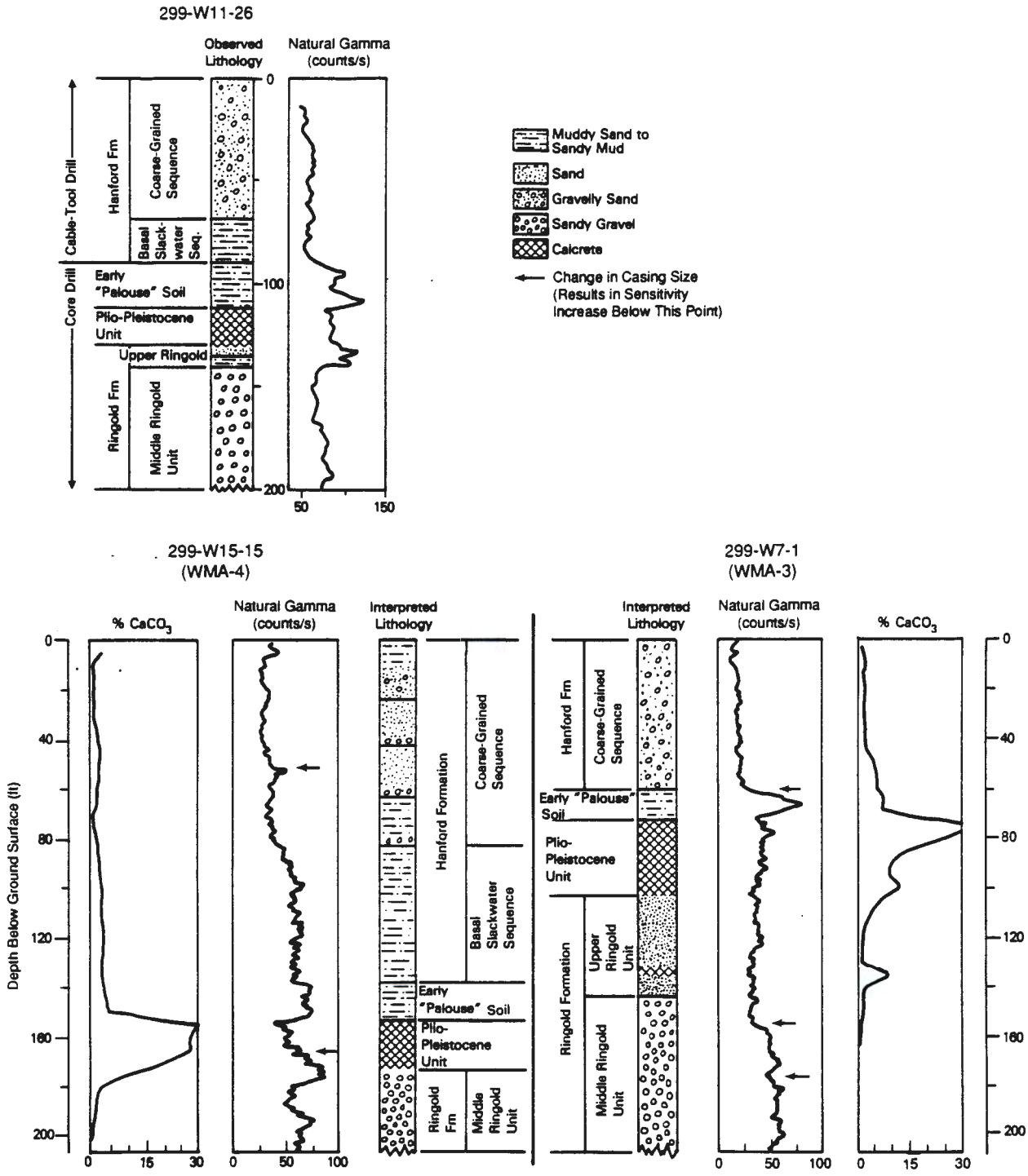


FIGURE 5.48. Examples of the Variation in Natural-Gamma Response and Calcium Carbonate Content for the Plio-Pleistocene and Adjacent Stratigraphic Units

TABLE 5.11. Examples of Particle-Size Distribution (weight percent of total) and Calcium Carbonate Content of the Plio-Pleistocene Unit Beneath Waste Management Areas 3 and 4

Borehole /Depth	$CaCO_3$, %	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	Class
299-W7-3 60 ft	8.0	27.5	13.9	13.1	10.2	6.4	7.4	21.5	Gravelly muddy sand
299-W9-1 175 ft	N/A	4.6	5.1	22.3	32.1	18.3	9.1	8.6	Sand
299-W15-16 140 ft	8.5	3.6	2.1	2.0	2.8	7.2	12.5	69.8	Sandy mud

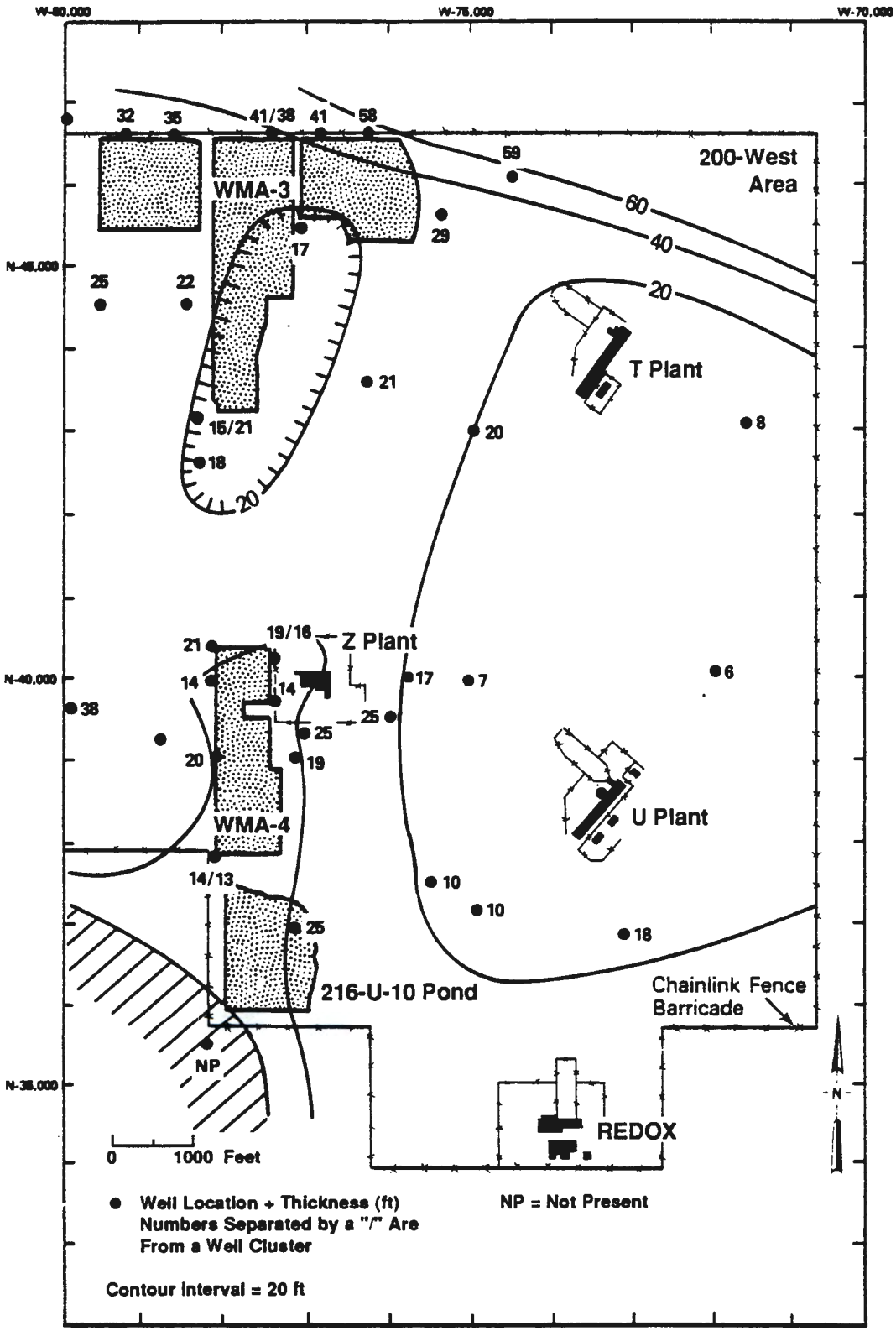


FIGURE 5.49. Isopach of the Plio-Pleistocene Unit Beneath the 200-West Area

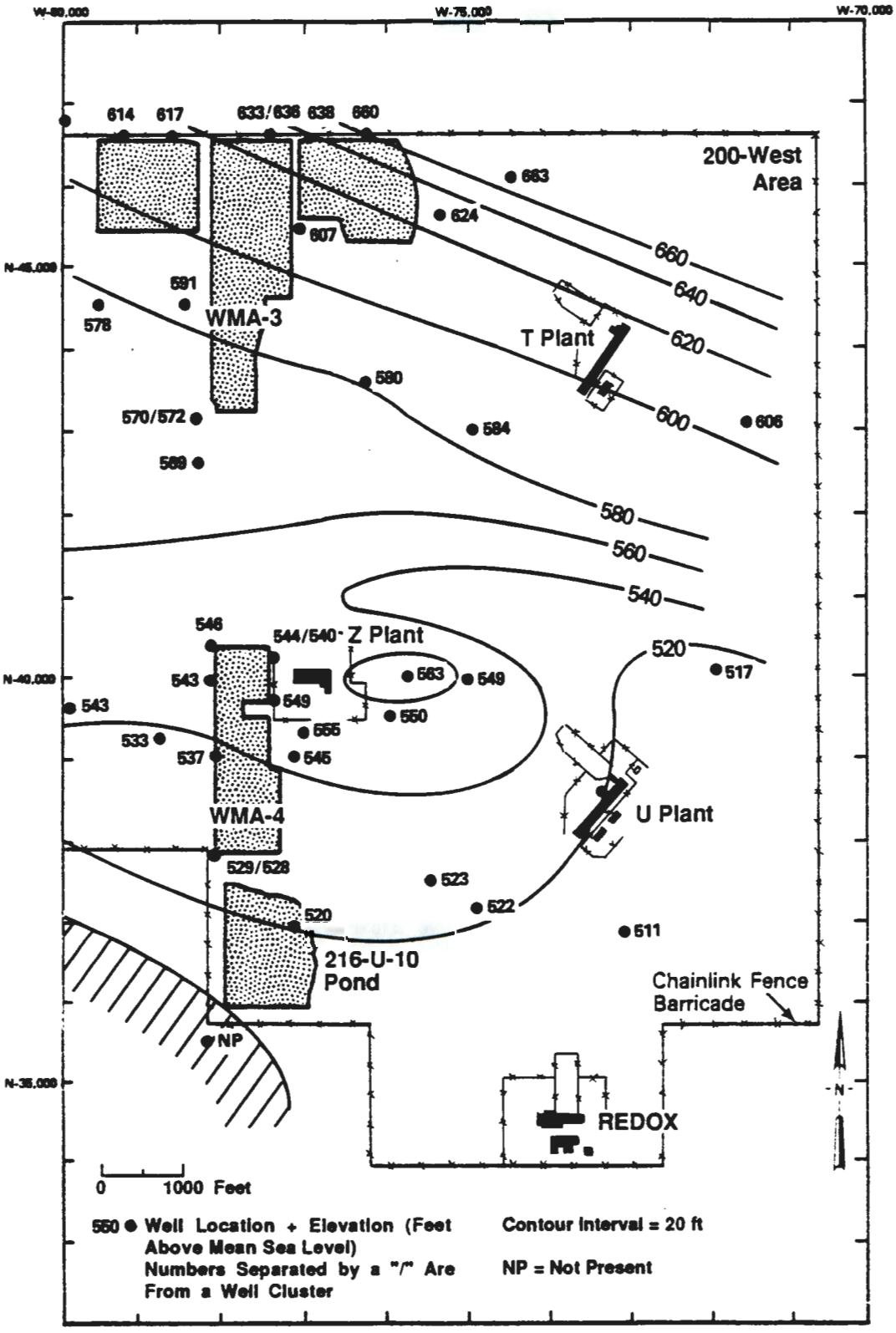


FIGURE 5.50. Surface of the Top of the Plio-Pleistocene Unit Beneath the 200-West Area

The Plio-Pleistocene unit is significant from a hydrologic perspective because it appears to represent a continuous low-permeability layer beneath WMA-3 and WMA-4. Therefore, the calcrete unit has the potential to laterally divert, toward the southwest, any natural or artificially recharged water that percolates through the vadose zone, especially in the vicinity of WMA-3.

5.4.4 Early "Palouse" Soil

Overlying the Plio-Pleistocene unit is an unconsolidated, muddy, fine sand to fine sandy mud believed to be loess (windblown silt and sand), derived from either the reworked Plio-Pleistocene unit or the upper Ringold material (Brown 1960a). Characteristics of the early "Palouse" soil (Tallman et al. 1979) include: 1) a uniform fine-grained texture, 2) unconsolidated nature, 3) high mica content, 4) moderate calcium carbonate content, and 5) high natural-gamma response. Compared to the Plio-Pleistocene unit, the early "Palouse" soil is relatively unconsolidated and less calcareous, and displays a consistently high natural-gamma response (see Figure 5.48).

This unit was identified from all but one of the new boreholes (299-W7-6) in the 200-West Area. These materials are described generally as muddy sand to sandy mud, consisting of approximately 50% sand and 50% mud. Examples of the particle-size distribution of these sediments are provided in Table 5.12. Calcium carbonate content of these materials is generally around 4% by weight (see Table 5.12).

The early "Palouse" soil is present in all but the northeastern corner of WMA-3 (Figure 5.51). Here, it apparently laps up onto and pinches out against the surface of the Plio-Pleistocene unit. Elsewhere, at borehole 699-35-78B, located in the southwestern corner of the 200-West Area, in place of the Plio-Pleistocene unit and the early "Palouse" soil lies a thick sequence (55 ft) of laminated mud. This mud apparently formed in a small localized lake, while surrounding areas underwent subaerial weathering, followed by aggradation of loess. Loess associated with the early "Palouse" soil is thickest (approximately 30 ft) in the southeastern portion of the

TABLE 5.12. Examples of Particle-Size Distribution (weight percent of total) and Calcium Carbonate Content of the Early "Palouse" Soil Beneath Waste Management Areas 3 and 4

Borehole /Depth	$CaCO_3$, %	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	Class
299-W7-5 30 ft	4.9	19.4	8.4	4.3	9.1	8.0	22.5	28.4	Gravelly muddy sand
299-W10-14 125 ft	5.2	2.9	1.9	4.5	10.5	9.0	11.9	59.5	Sandy mud
299-W18-21 130 ft	3.9	0.5	0.5	2.3	9.1	15.6	26.6	45.4	Muddy sand

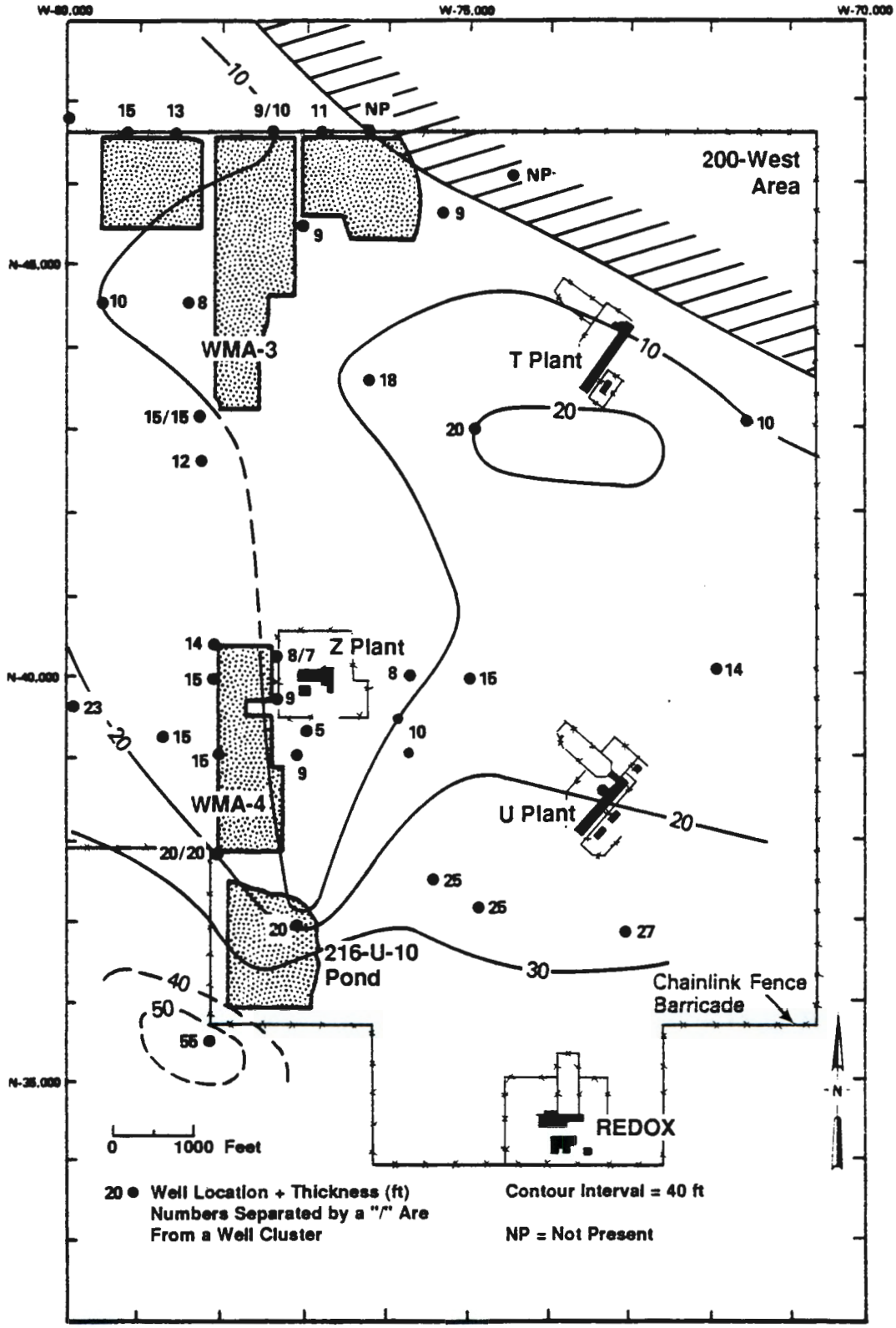


FIGURE 5.51. Isopach of the Early "Palouse" Soil Beneath the 200-West Area

200-West Area (see Figure 5.51). The surface of the early "Palouse" soil generally dips to the south, although the surface is somewhat irregular beneath WMA-4 (Figure 5.52).

5.4.5 Hanford Formation

Deposits of the glaciofluvial Hanford formation blanket the 200-West Area. The Hanford formation was deposited intermittently during the Pleistocene by proglacial floods. The location and relative distribution of various flood-geomorphic features, including giant current ripples, flood channels, gravel bars, and bergmounds, left behind as a result of the latest flood(s) were shown in Figure 5.2. The Hanford formation ranges in thickness (Figure 5.53) from approximately 150 ft along a narrow zone in the western portion of the 200-West Area to less than 20 ft along the extreme northern boundary where the resistant Plio-Pleistocene calcrete rises toward the surface (see Figure 5.27).

Two types of glaciofluvial flood deposits within the Hanford formation are recognized in the 200-West Area. One is a mostly fine-grained sequence of muddy sand to sandy mud present at the base of the Hanford formation. The other type consists of an overlying sequence of complexly interstratified deposits of coarse sand, gravelly sand, and/or sandy gravel. For the purposes of discussion in the 200-West Area, these two units will be referred to as the "basal slack-water sequence" and the "coarse-grained sequence" of the Hanford formation, respectively. Examples of the particle-size distribution and calcium carbonate content of these units are provided in Table 5.13.

The basal slack-water sequence is perhaps associated with an early or middle Pleistocene flood(s) (Bjornstad et al. 1987), suggesting earlier floods were less vigorous over the 200-West Area than those floods that occurred later in the Pleistocene. Characteristics of the basal slack-water sequence include a 1) fine-grained texture (sand and mud), 2) low calcium carbonate content (generally less than 3 wt%), and 3) moderate natural-gamma response. The early "Palouse" soil, which has a similar texture, is

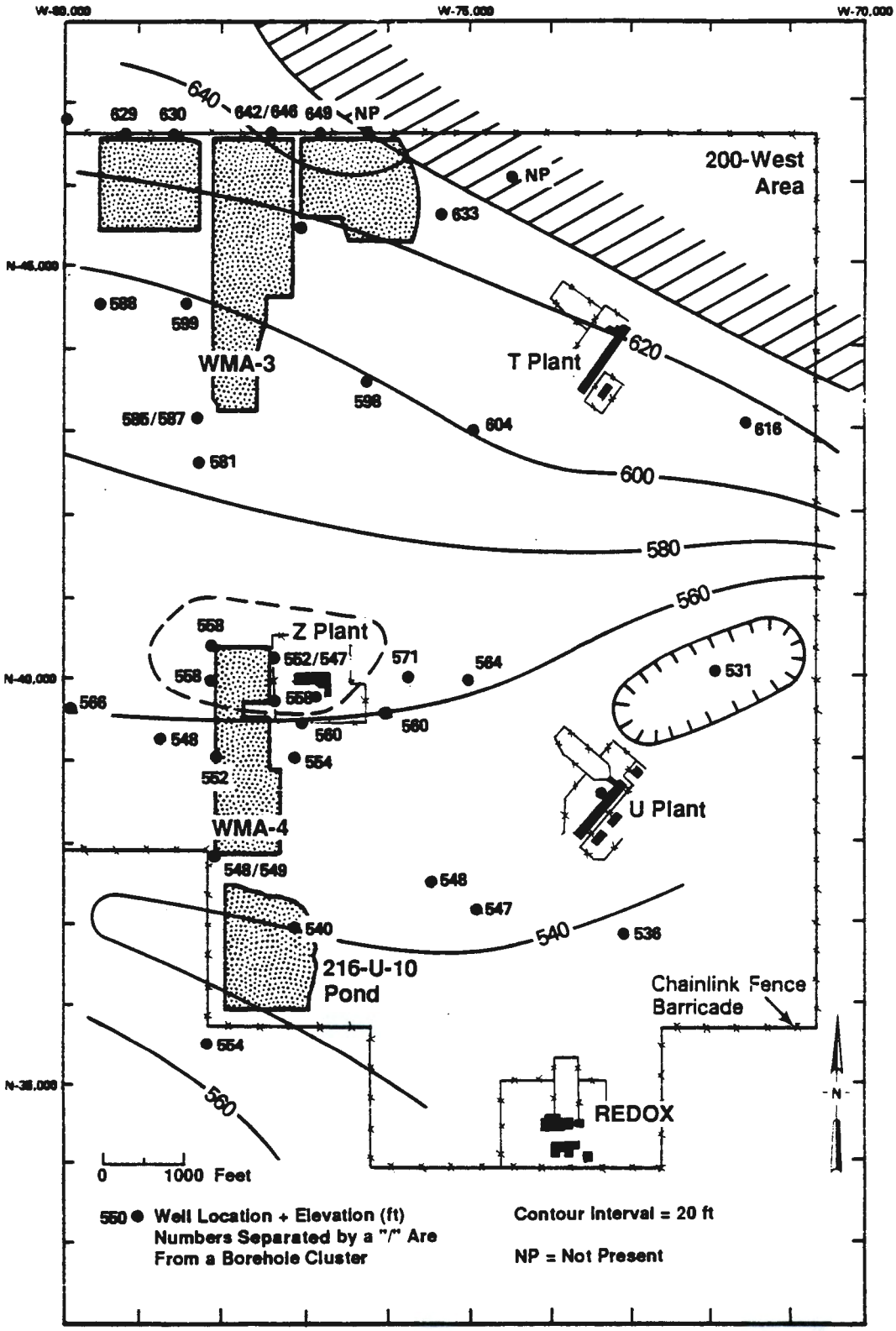


FIGURE 5.52. Surface of the Top of the Early "Palouse" Soil Beneath the 200-West Area

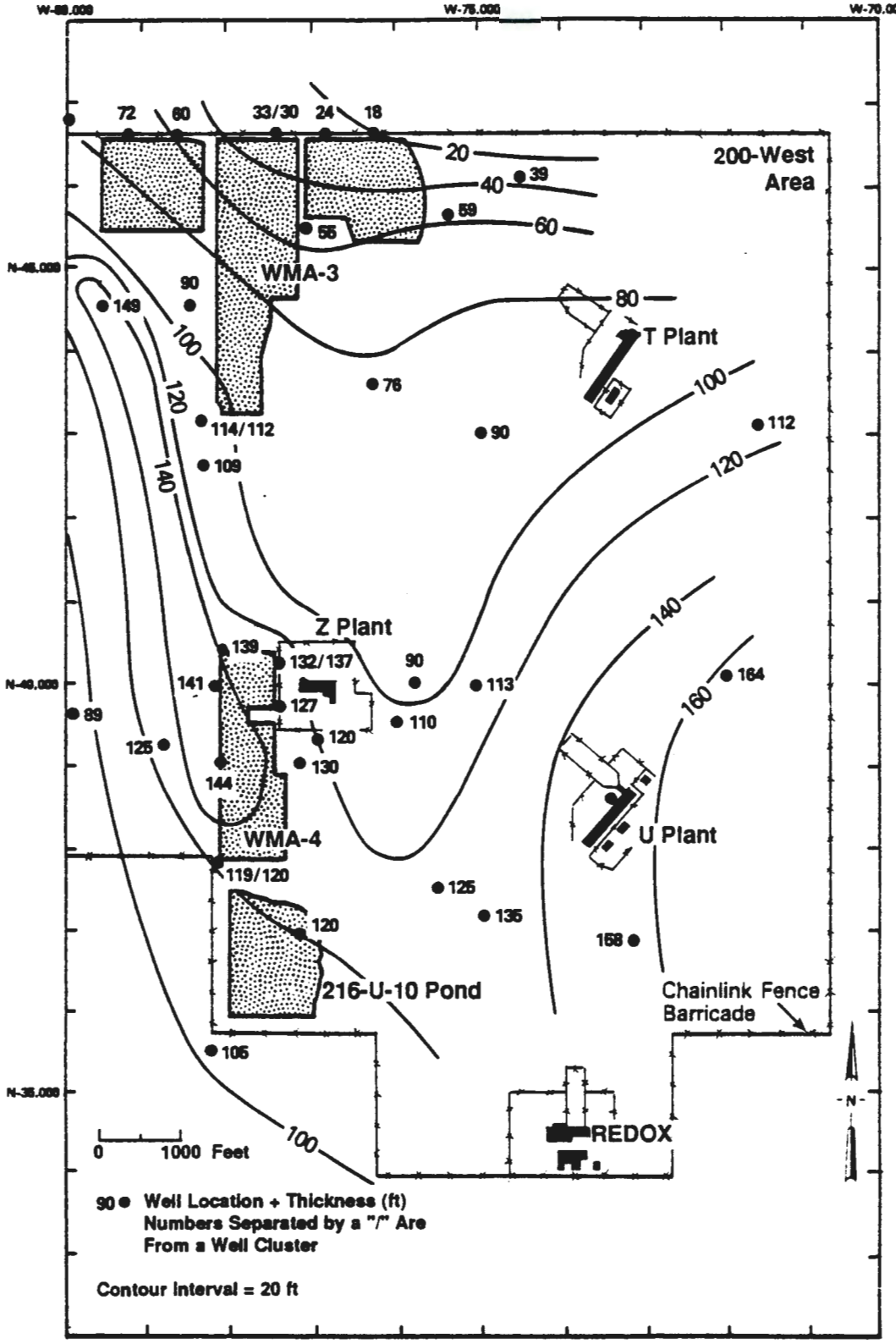


FIGURE 5.53. Isopach of the Total Hanford Formation Beneath the 200-West Area

TABLE 5.13. Examples of Particle-Size Distribution (weight percent of total) and Calcium Carbonate Content of Hanford Formation Sediments Beneath Waste Management Areas 3 and 4

Unit	Borehole /Depth	$CaCO_3$, %	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	Class
Coarse grained	299-W6-2 20 ft	1.9	40.6	12.2	9.1	12.4	8.8	5.8	10.8	Muddy sandy gravel
	299-W10-14 65 ft	3.2	0.8	1.8	23.5	34.8	15.4	9.8	13.9	Slightly muddy sand
Basal slack water	299-W15-15 85 ft	1.8	25.5	9.0	14.3	16.1	7.4	4.4	23.3	Gravelly muddy sand

differentiated from the basal slack-water sequence by a: 1) greater calcium carbonate content, 2) massive versus laminated structure in core samples, and 3) higher natural-gamma response.

The overlying coarse-grained sequence is probably associated with the latest flood episode(s), which formed the present network of flood channels just north of the 200-West Area (see Figure 5.2). The dynamic flow system during flooding and the resultant erosion and deposition make any attempts to correlate strata or determine the numbers of flood episodes preserved within the coarse-grained sequence difficult and tenuous. Characteristics of the coarse-grained sequence are a: 1) greater proportion of basalt clasts (generally estimated at greater than 60% by volume); 2) wide range in roundness of gravel clasts, ranging from angular to rounded; 3) generally poor sorting; 4) low calcium carbonate content (generally less than 3 wt%); and 5) low natural-gamma response.

The basal slack-water sequence is thickest (up to 75 ft) in the southeastern portion of the 200-West Area, as suggested in Figure 5.54. At least one (and perhaps two) buried paleo-flood channel is indicated on this figure. One is a buried, north-south-trending channel, indicated by tongue-shaped contours where the basal slack-water sequence was completely eroded away. This paleochannel, which lies beneath and just east of WMA-4, was cut and filled with the coarse-grained sequence deposits of the Hanford formation. At the same time, the maximum thickness of the coarse-grained sequence conforms to this paleochannel (Figure 5.55), suggesting the paleochannel was filled with coarse-grained flood deposits. The position of the buried paleochannel is coincident with a north-south-trending channel preserved at the surface (see Figure 5.2). The surficial channel transported flood waters above the 680-ft elevation into and down Cold Creek valley one or more times in the late Pleistocene. The coincident nature of older and more recent channels suggests that earlier floods may have followed the same course as the later floods. Thickness variations of the basal slack-water sequence suggest that a second possible paleochannel running southeast may split off the buried north-south-trending channel (see Figure 5.54).

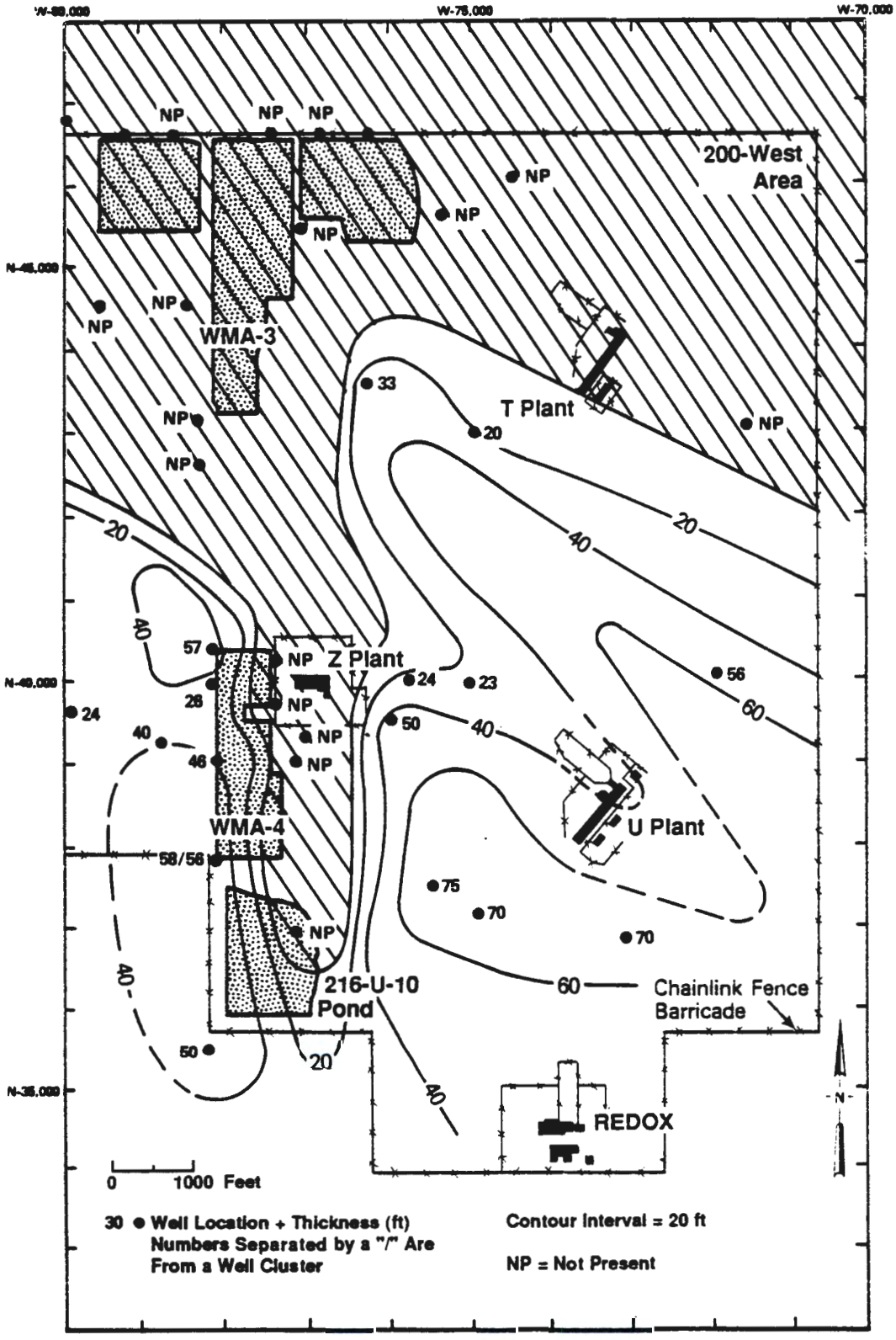


FIGURE 5.54. Isopach of the Basal Slack-Water Sequence (Hanford formation) Beneath the 200-West Area

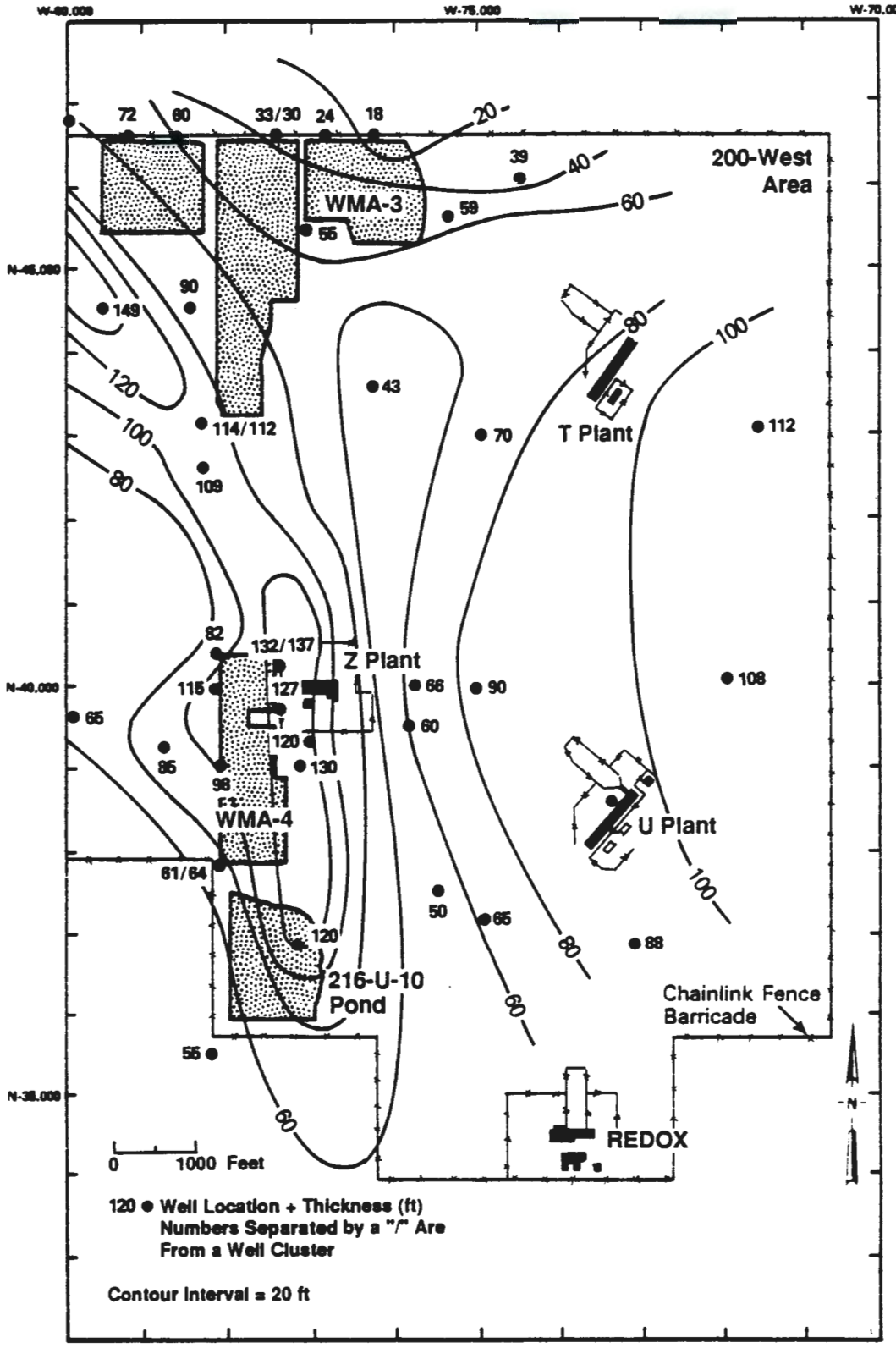


FIGURE 5.55. Isopach of the Coarse-Grained Sequence (Hanford formation) Beneath the 200-West Area

Where the basal slack-water sequence is preserved, its upper surface appears to be undulatory, with evidence for several low-relief, east-west-trending ridges (Figure 5.56). This probably represents an erosional surface left behind as a result of erosion and subsequent deposition of the coarse-grained sequence deposits.

5.4.6 Recent Eolian Deposits

Recent eolian sands at the surface locally blanket the glaciofluvial Hanford formation. These sands are thickest (up to 17 ft) in the northwestern portion of the 200-West Area. Because of scale and the limited distribution of the recent eolian sands, these sands are not included on geologic cross sections or fence diagrams.

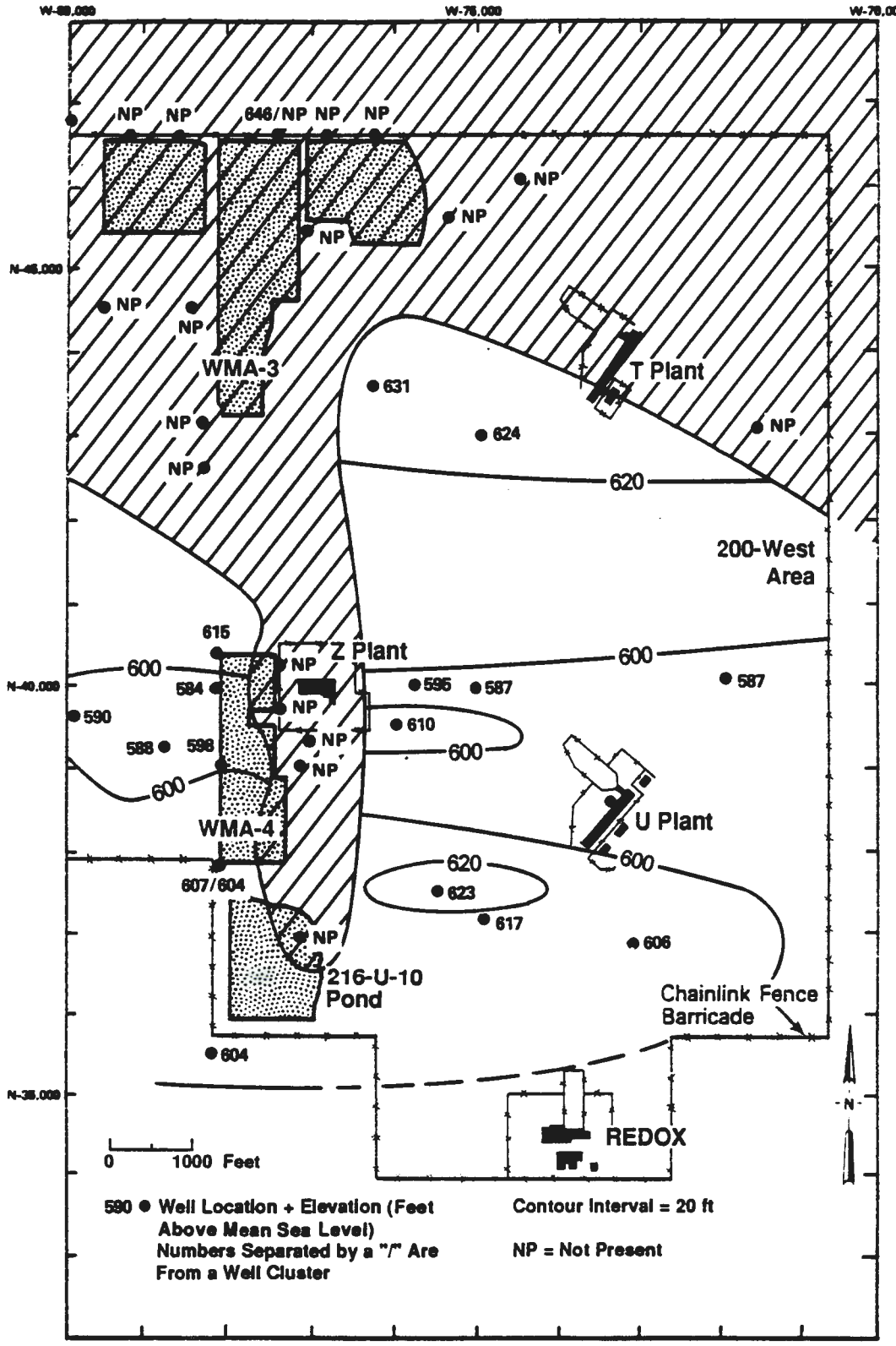


FIGURE 5.56. Surface of the Top of the Basal Slack-Water Sequence (Hanford formation) Beneath the 200-West Area

6.0 HYDROLOGY OF THE WASTE MANAGEMENT AREAS

The potential for movement of contaminants originating from wastes stored or disposed at WMAs is influenced by the nature of the geologic and hydrologic framework beneath the WMAs. An understanding of the hydrogeologic framework is crucial to evaluating the transport of these contaminants in the subsurface environment. On a local scale, specific to WMAs, this hydrogeologic framework can be broken down into the following three components: 1) recharge derived for both natural and artificial sources; 2) water movement in the unsaturated zone; and 3) ground-water movement in the underlying, unconfined aquifer system. The following sections present current knowledge of these aspects of the hydrogeologic framework as they relate to WMAs.

6.1 RECHARGE

Recharge to the WMAs and the ground-water system is derived from both natural and artificial (manmade) sources. Natural recharge originates from precipitation. If that precipitation is not removed from the surficial soils by evapotranspiration, it drains through the unsaturated zone and recharges the underlying aquifers. Artificial sources of recharge are derived from cooling-water discharges to ground from Hanford waste management operations.

6.1.1 Natural Recharge

The amount of natural recharge that infiltrates through the WMAs provides the principal mechanism for leaching and redistributing the contaminants disposed at these sites. Recharge from precipitation on the Hanford Site has been a central issue in waste management concerns. Gee (1987) reviewed all available information and concluded that recharge rates at the Hanford Site are widely variable; minimum recharge (<0.1 cm/yr) occurs where soils are fine textured and surfaces are vegetated with deep-rooted plants, and maximum recharge (10 cm/yr) occurs where coarse soils or gravel (void of vegetation) are present at the land surface. Gee (1987) also presented data suggesting that recharge rates at sites with coarse soils and shallow-rooted plants might be on the order of 6 cm/yr.

The surface cover over active portions of the burial grounds generally consists of coarse sandy gravel. Shallow-rooted plants (cheatgrass) slowly invade these disturbed areas, but tumbleweeds are selectively removed to prevent interaction with the wastes. In these areas, recharge rates are probably on the upper side of the range in recharge described by Gee (1987), perhaps on the order of 6 to 10 cm/yr. Inactive and stabilized portions of the burial grounds are generally covered with approximately 2 ft of clean, finer grained soil and revegetated with shallow-rooted plants. In these areas, recharge rates are probably lower, perhaps on the order of 6 cm/yr or less.

6.1.2 Artificial Recharge

Since 1944, the unconfined aquifer has received a relatively large volume of process cooling water that has been discharged to various ponds by waste management operations at Hanford (Zimmerman et al. 1986). In addition to these flows, smaller volumes of low- and intermediate-level radioactive liquid wastes have been or are being discharged to several subsurface disposal cribs or trenches. These major disposal ponds and subsurface disposal cribs are located in the vicinity of the 200 Areas (Figure 6.1). Some of these facilities, such as U Pond, no longer receive water and are now inactive.

Collectively, artificial recharge was estimated by Graham et al. (1981) to be approximately 10 times the natural inflow of ground water from areas upgradient to the 200 Areas. The total volume of water discharged from the facilities (see Figure 6.1) from 1943 to 1980 is estimated to be approximately 1.7×10^{11} gal (Zimmerman et al. 1986). This amount of recharge has impacted the unconfined aquifer system and has created large ground-water mounds near areas of large-volume discharges. These mounds are dominant features in the unconfined aquifer and are most pronounced beneath U Pond in the 200-West Area and B Pond near the 200-East Area.

The U Pond facility was decommissioned in 1984, so the ground-water mound beneath this facility is slowly declining; however, ground-water levels are still between 470 and 475 ft above mean sea level, which is approximately 60 ft above pre-Hanford conditions (ERDA 1975). Ground-water levels have

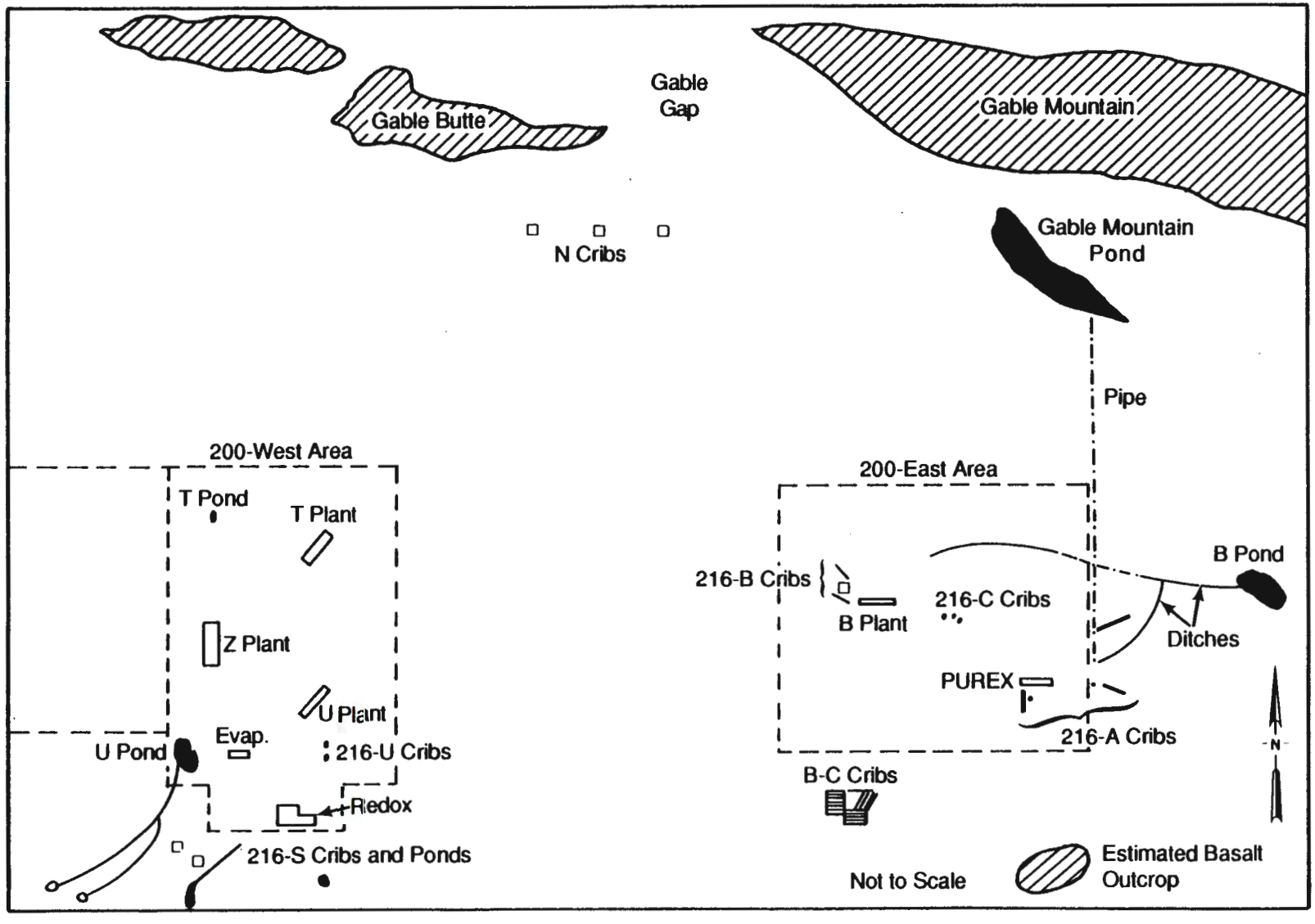


FIGURE 6.1. Plan View of the 200 Areas Showing Locations of Reprocessing Facilities and Major Receiving Ponds and Cribs (Zimmerman et al. 1986)

reached an elevation between 420 and 425 ft above mean sea level beneath B Pond, which is approximately 35 to 40 ft above pre-Hanford conditions. Besides the hydraulic and geochemical effects on the unconfined aquifer, these manmade discharges would not be expected to directly impact the WMAs described in this report.

6.2 HYDROLOGY OF THE UNSATURATED ZONE

The movement of water through the unsaturated zone to the underlying aquifer is controlled by many factors, which include the thickness of the unsaturated zone, the hydraulic properties of sediments in the unsaturated zone, and the moisture content of these sediments.

Generalized stratigraphic and lithologic columns representative of the major units identified in the unsaturated zone beneath each WMA were shown in Figures 5.5 and 5.35. The columns illustrated in Figure 5.5 indicate that the unsaturated zone in the 200-East Area is composed entirely of sediments belonging to the Hanford formation. In the 200-West Area, the unsaturated zone is composed of sediments belonging to, in ascending order, the middle and upper units of the Ringold Formation, the Plio-Pleistocene unit, the early "Palouse" soil, and the Hanford formation (see Figure 5.35).

The overall thickness of the unsaturated zone in the four areas varies from approximately 183 ft near WMA-2 to as much as 281 ft near WMA-1. The ranges of thickness of the unsaturated zone and the thicknesses of major lithologic units identified from available borehole data are given in Table 6.1. These data indicate that, in general, the Hanford formation is composed of sandy gravel, sand, and gravelly sand. The early "Palouse" soil identified near WMA-3 and WMA-4 is composed of a calcareous fine sandy mud. The Plio-Pleistocene unit also identified in WMA-3 and WMA-4 is a 15- to 35-ft-thick cemented calcic paleosol. The upper Ringold unit is sand to gravelly sand, and the middle unit is composed of mostly sandy gravel. The water table is currently positioned within the lower part of the Hanford formation beneath WMA-1 and WMA-2 and within the middle unit of the Ringold Formation beneath WMA-3 and WMA-4.

TABLE 6.1. Thicknesses and General Lithology of the Unsaturated Zone Beneath the Waste Management Areas

Waste Management Area	Thickness of Unsaturated Zone, range (mean), ft	General Lithologies in Ascending Order	Thickness, range (mean), ft
1	257-281 (268)	Sandy gravel	22-110 (60)
		Sand	75-155 (120)
		Sandy gravel	54-110 (100)
2	183-231 (223)	Sandy gravel to gravelly sand	183-231 (223)
3	207-272 (225)	Sandy gravel, gravelly sand, and/or sand	18-149 (70)
		Calcareous fine sandy mud	8-15 (10)
		Calcic paleosol with sand lens	15-58 (30)
		Sand to gravelly sand	15-35 (20)
		Sandy gravel	65-142 (100)
4	183-228 (207)	Gravelly sand, sand, and/or sandy gravel	61-137 (110)
		Muddy sand to sandy mud	0-58 (20)
		Calcareous fine sandy mud	5-20 (15)
		Calcic paleosol	13-25 (15)
		Sandy gravel	23-54 (40)

Laboratory analyses of the sediments of the unsaturated zone are still in progress; measurements of their physical and hydraulic properties are not yet available. Field moisture contents of the core-barrel samples, which are analyzed as percent by volume, indicate moisture contents that range from as little as 1% to 2% to as much as 18% water. Most measured water contents are commonly within a range of 2% to 6%. A summary of all measured values is presented in Appendix I.

6.3 GROUND-WATER MOVEMENT IN THE UNCONFINED AQUIFER SYSTEM

The uppermost aquifer beneath the WMAs in the 200 Areas is the unconfined aquifer system, which is located principally in the Hanford formation in the 200-East Area and in the middle unit of the Ringold Formation in the

200-West Area. Regional ground-water flow within this aquifer is generally from west to east. Locally, this movement is affected by ground-water mounds caused by artificial recharge from waste-water disposal. This mounding is more pronounced in the 200-West Area than in the 200-East Area, because the transmissivity of the sediments beneath the 200-West Area is much lower than that of the sediments found beneath the 200-East Area (Graham et al. 1981). Interpretation and correlation of the major hydrogeologic units within the unconfined aquifer are based on geologic sample descriptions, laboratory analyses of borehole samples, geophysical logs, and aquifer-testing results.

The following section presents descriptions of major hydrogeologic units, a summary of hydraulic properties of major units, and a discussion of the direction and rate of ground-water movement within the unconfined aquifer. Because of the local difference in hydrogeologic settings between the WMAs in the 200-East and 200-West Areas, the two areas are discussed separately.

6.3.1 Waste Management Areas 1 and 2

Major Hydrogeologic Units

The two hydrologically significant stratigraphic units found in boreholes in the 200-East Area wells are the Hanford and Ringold Formations. These units represent individual hydrogeologic units with unique hydrologic properties. Another significant unit encountered in the 200-East Area is the uppermost basalt unit, the Elephant Mountain Member that acts as a confining unit and forms the base of the unconfined aquifer system. This unit separates the unconfined aquifer system from the underlying Rattlesnake Ridge aquifer, the uppermost confined aquifer within the Columbia River basalts. The Elephant Mountain Member was encountered by 12 of the 16 wells drilled in the 200-East Area; the remaining 4 wells were completed above the basalt. The basalt is assumed to be laterally continuous in this area, except perhaps to the northeast of WMA-2, where a "pothole" in the surface of the Elephant Mountain Member is suspected. Graham et al. (1984) identified this area as a potential area of intercommunication between the unconfined aquifer and the Rattlesnake Ridge aquifer.

The unconfined aquifer was encountered in all the wells, except well 299-E34-4 where the Elephant Mountain Member was encountered above the water table. The water table in remaining wells is located in the Hanford formation. Thin (20 ft or less) sequences of Ringold gravels were identified just above basalt in only three wells (299-E28-26, 299-E32-3, and 299-E32-4). These wells are located beneath the southwestern portion of WMA-1. Only two of these wells (299-E32-3 and 299-E32-4) were pumped to determine aquifer characteristics; however, only data from well 299-E32-4 are valid. The minimum transmissivity in well 299-E32-4 was less than that encountered in most of the wells that were completed in only the Hanford formation. This reflects the distinction between the Hanford and Ringold Formations as separate hydrogeologic units.

Hydraulic Properties

Constant discharge aquifer tests were conducted in 13 of the 16 wells installed in the 200-East Area. Estimates of transmissivities determined from tests conducted in nine of the wells were considered to be representative of the Hanford formation. One test yielded a transmissivity representative of the Hanford/Ringold (gravels) Formation, and the remaining three did not yield sufficient data for analysis. A summary of the details and results from each test is presented in Appendix E and summarized in Table 6.2. A brief discussion of these properties by formation is presented below.

The Hanford formation is the uppermost hydrogeologic unit within the unconfined aquifer in the 200-East Area. This portion of the aquifer is generally highly transmissive. Results from aquifer testing performed during this study have shown that transmissivity values for the Hanford formation were variable. Transmissivities, a summary of which is shown in Table 6.2, ranged from 14,000 ft^2/d (well 299-E34-3) to 114,000 ft^2/d (well 299-E34-2). The resultant hydraulic conductivities, calculated from the saturated thickness map shown in Figure 6.2, ranged between 1,400 and 6,700 ft/d. In some of the tests, an upper limit of transmissivity and hydraulic conductivity could not be determined because the aquifer could not be stressed

TABLE 6.2. Summary of Aquifer Test Results for 200-East Area Wells

Well Number	Screened Interval Tested, ft	Formation	Aquifer Thickness, ft	Analysis Method	Type of Test	Transmissivity, ft^2/d	Hydraulic Conductivity, ft/d	Date Tested
299-E27-8	247-257	Hanford	28	Cooper-Jacob (1946)	Constant Discharge	>68,000	>2,400	8/19/87
299-E27-9	234-244	Hanford	23	Cooper-Jacob (1946)	Recovery	35,000	1,500	8/15/87
299-E27-10	230-240	Hanford	24	Cooper-Jacob (1946)	Recovery	35,000	1,500	8/11/87
299-E28-26	None	Hanford/ Ringold	46	Cooper-Jacob (1946)	None	--	--	None
299-E28-27	291-301	Hanford	37	Cooper-Jacob (1946)	Constant Discharge	>48,000	>1,300	9/29/87
299-E32-2	279-289	Hanford	25	Cooper-Jacob (1946)	--	Insufficient data	--	9/08/87
299-E32-3	291-301	Hanford/ Ringold	40	Cooper-Jacob (1946)	--	Insufficient data	--	9/02/87
299-E32-4	298-308	Hanford/ Ringold	40	Cooper-Jacob (1946)	Constant Discharge	>9,500	>240	9/21/87
299-E33-28	268-278	Hanford	21	Cooper-Jacob (1946)	Constant Discharge	>53,000	>2,500	10/21/87
299-E33-29	279.5-289.5	Hanford	24	Cooper-Jacob (1946)	Constant Discharge	>51,000	>2,100	9/17/87
299-E33-30	267-277	Hanford	22	Cooper-Jacob (1946)	Constant Discharge	>56,000	>2,500	9/24/87
299-E34-2	230-240	Hanford	17	Cooper-Jacob (1946)	Constant Discharge	85,000	5,000	8/07/87
299-E34-2	230-240	Hanford	17	Cooper-Jacob (1946)	Recovery	114,000	6,700	8/07/87
299-E34-3	203.5-213.5	Hanford	10	Cooper-Jacob (1946)	Constant Discharge	14,000	1,400	8/05/87
299-E34-3	203.5-213.5	Hanford	10	Cooper-Jacob (1946)	Recovery	14,000	1,400	8/05/87
299-E34-4	None	Hanford	None	Cooper-Jacob (1946)	--	--	--	None
299-E34-5	180.5-190.5	Hanford	4	Cooper-Jacob (1946)	--	Insufficient data	--	7/21/87
299-E34-6	None	Hanford	3	Cooper-Jacob (1946)	--	--	--	None

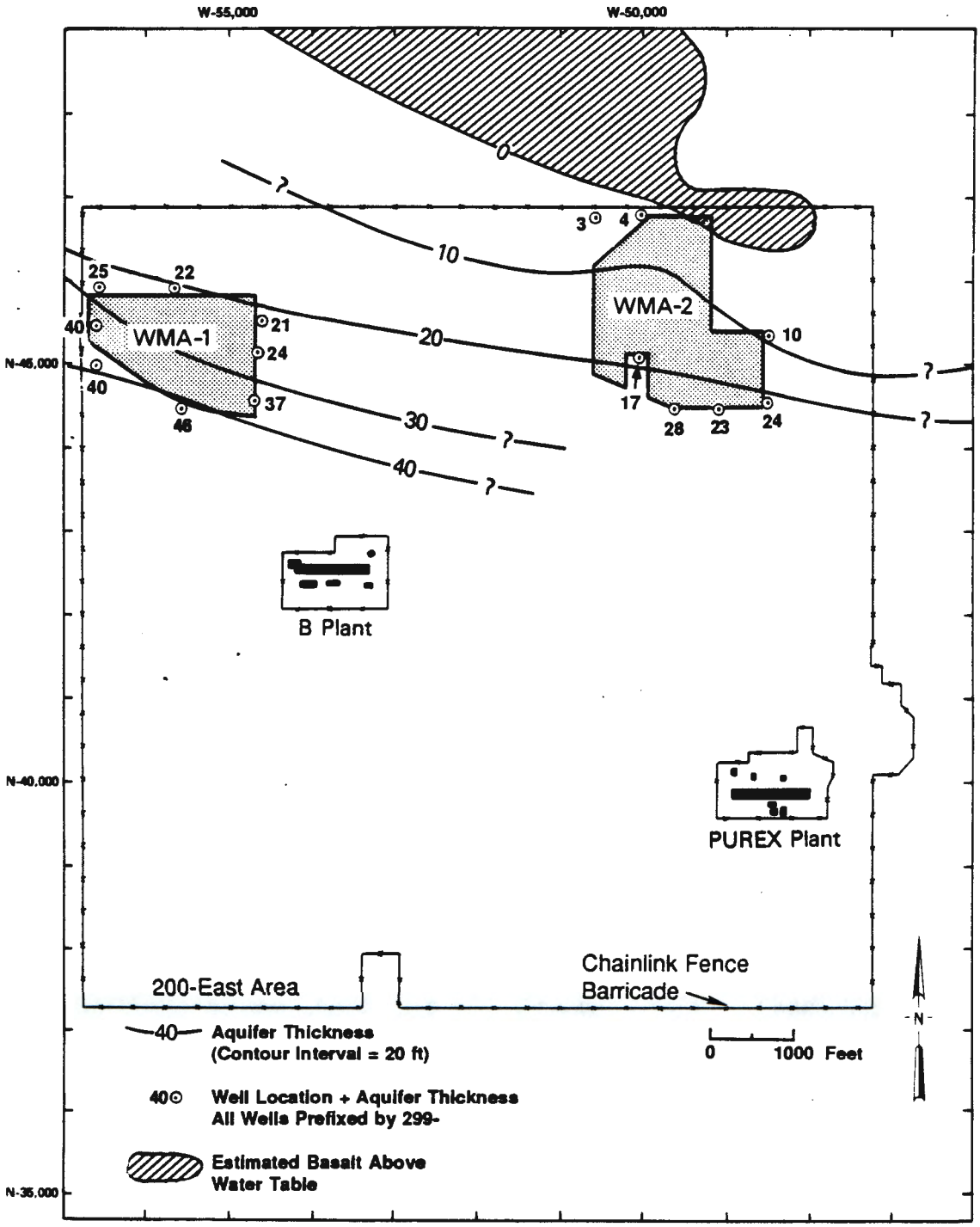


FIGURE 6.2. Saturated Thickness of the Unconfined Aquifer Beneath Waste Management Areas 1 and 2

sufficiently. The details of these tests and the types of methods used for test analyses are presented in Appendix E.

Transmissivity values could not be determined from three of the tests because of invalid or insufficient data. The discharge rate was not constant during the initial part of the test in wells 299-E32-2 and 299-E32-3, which yielded invalid drawdown data. The drawdown data collected from well 299-E34-5 were insufficient for analysis. Refer to Appendix E for a summary of the aquifer tests. Well 299-E28-26 was not tested because it contained uranium concentrations greater than the discharge guidelines, as indicated in Section 4.3.4; i.e., 10% of the designated WAC 173-303 (Ecology 1986) hazardous waste guidelines or 1/25 of the DCGs for radionuclides.

Storativity could not be determined from the available aquifer test data for this study due to the lack of response in observation wells. A summary of values for the 200 Areas, reported by Graham et al. (1981), indicates that storativity ranges from 0.002 to 0.07, with the lower value being associated with the Ringold Formation and the higher value being associated with the Hanford formation. Specific yield values of 0.15 and 0.18 were also estimated at locations. Effective porosities have not been estimated as a part of this study near WMA-1 and WMA-2. Graham et al. (1981) reported values between 10% and 30%, with the lower values corresponding to the Ringold Formation and the higher values being associated with the Hanford formation.

Direction and Rate of Ground-Water Movement

Since December 1, 1987, ground-water elevations near the top of the unconfined aquifer have been measured routinely at one-week to one-month intervals at each new well and occasionally at selected existing wells. These elevations were calculated by subtracting the depth to water (measured by steel tape from the top of the casing) from the casing elevation. These elevations were used to develop water-table maps of the unconfined aquifer in the vicinity of the WMA-1 and WMA-2 (Figures 6.3 and 6.4), which were in turn used to delineate the direction of ground-water movement beneath these sites.

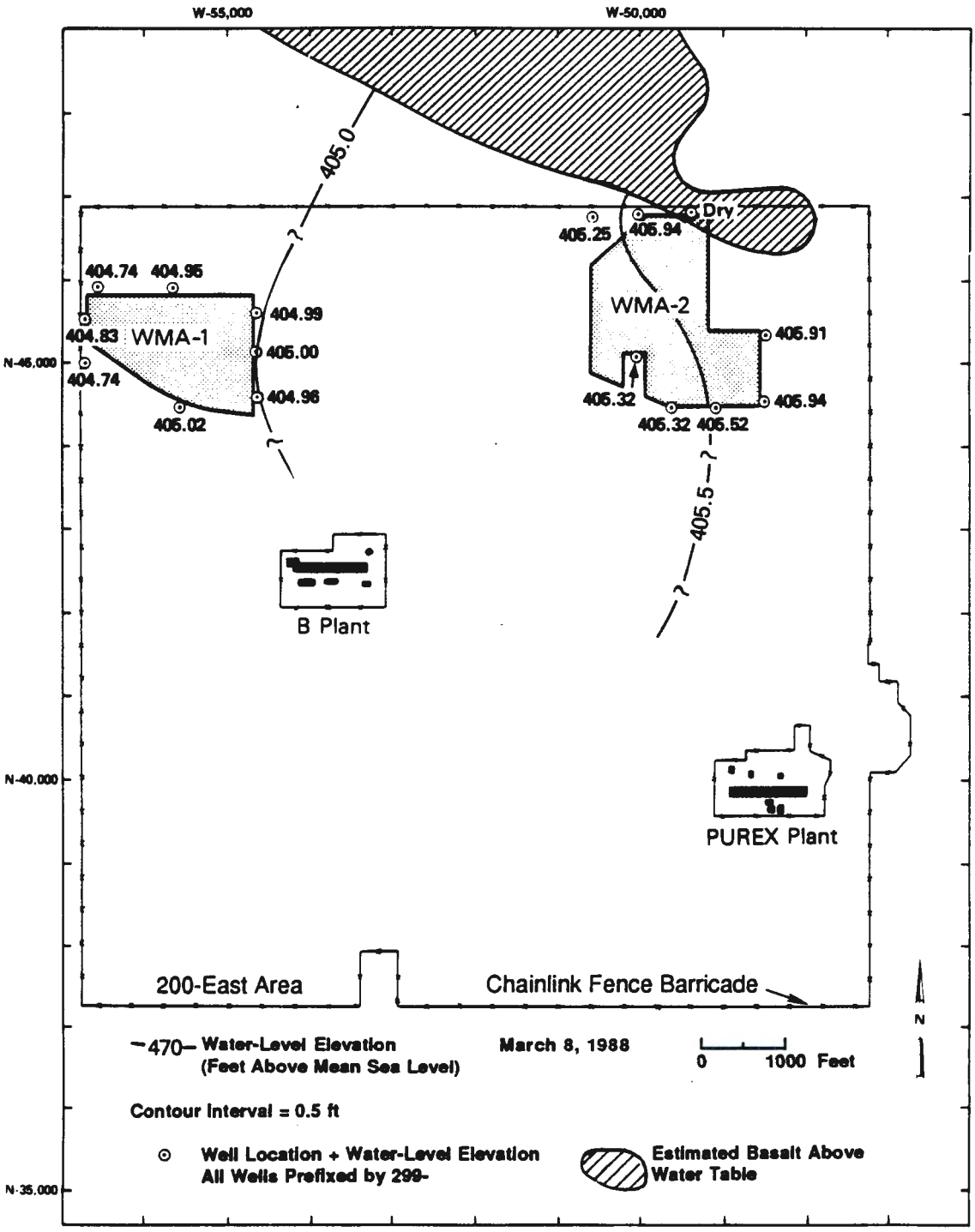


FIGURE 6.3. Water-Table Surface Beneath Waste Management Areas 1 and 2, Measured on March 8, 1988

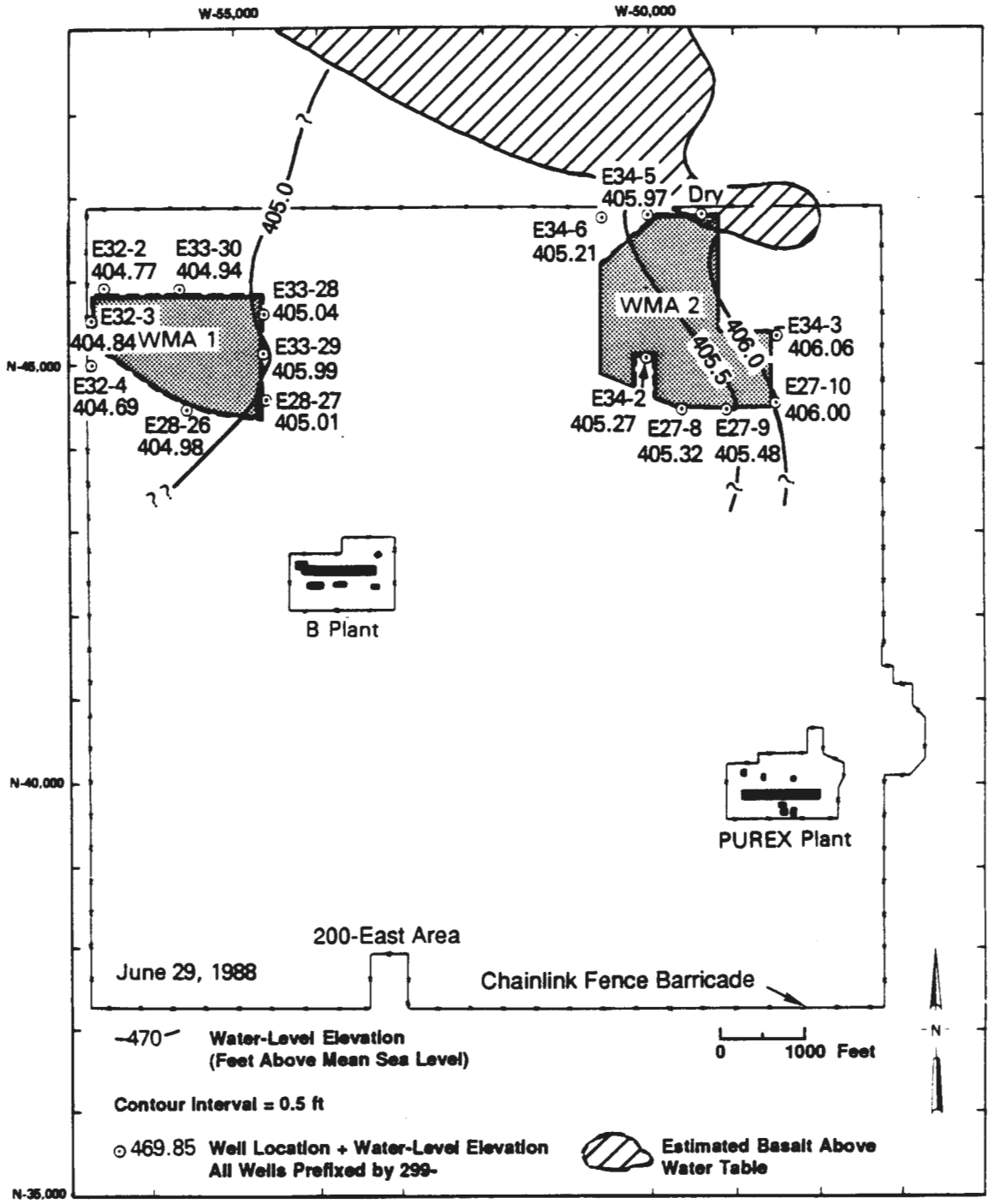


FIGURE 6.4. Water-Table Surface Beneath Waste Management Areas 1 and 2, Measured on June 29, 1988

Water-table maps in the 200-East Area beneath WMA-1 and WMA-2 have shown horizontal hydraulic gradients to be very small. Survey inconsistencies and inconsistent open intervals between old and new wells make correlation and interpretation of the ground-water levels extremely difficult. Therefore, only water-level data from the new wells (surveyed to a common reference benchmark) completed with similar open intervals at the top of the unconfined aquifer and measured on the same day were used to construct these water-table maps. Ground-water elevations measured in each new well are provided in Appendix H.

Interpretation of the water-table maps suggests that the general flow direction beneath WMA-1 and WMA-2 is toward the west. Regional water-level measurements (Figures 6.5 and 6.6) indicate that a local ground-water divide is present in the 200-East Area, where the regional eastward gradient meets the local westward gradient induced by the B Pond mound. Ground-water flow directions in the northern part of the 200-East Area reflect the influence of the nearby B Pond mound to the east and the basalt highs that form no-flow boundaries to the north. The location of the ground-water divide is not well established and appears to move as water levels fluctuate in response to changes in discharges to ground at facilities in the 200-East Area. The overall gradient measured on the local scale (as shown in Figures 6.3 and 6.4) is small; maximum differences in water levels are less than 1 ft across WMA-2 and less than 0.5 ft across WMA-1. As a result, the details of ground-water movement in the vicinity of the WMAs are difficult to discern. The measured gradient appears to be on the order of 0.1 ft/1,000 ft beneath WMA-1 and 0.4 ft/1,000 ft beneath WMA-2. Figure 6.6 shows that the overall head change between WMA-2 and the gap between Gable Mountain and Gable Butte appears to be on the order of approximately 0.1 to 0.2 ft/1,000 ft going from approximately 406 ft in the northeastern corner of the 200-East Area to approximately 403 to 404 ft in the gap.

Ground-water velocities beneath the WMAs were estimated using Darcy's law and some representative hydraulic conductivities, hydraulic gradients, and a conservative effective porosity of 0.1. For WMA-1, a local pore-water velocity based on hydraulic conductivities of 240 to 22,500 ft/d and a hydraulic gradient of 0.2 ft/1,000 ft resulted in a range of approximately

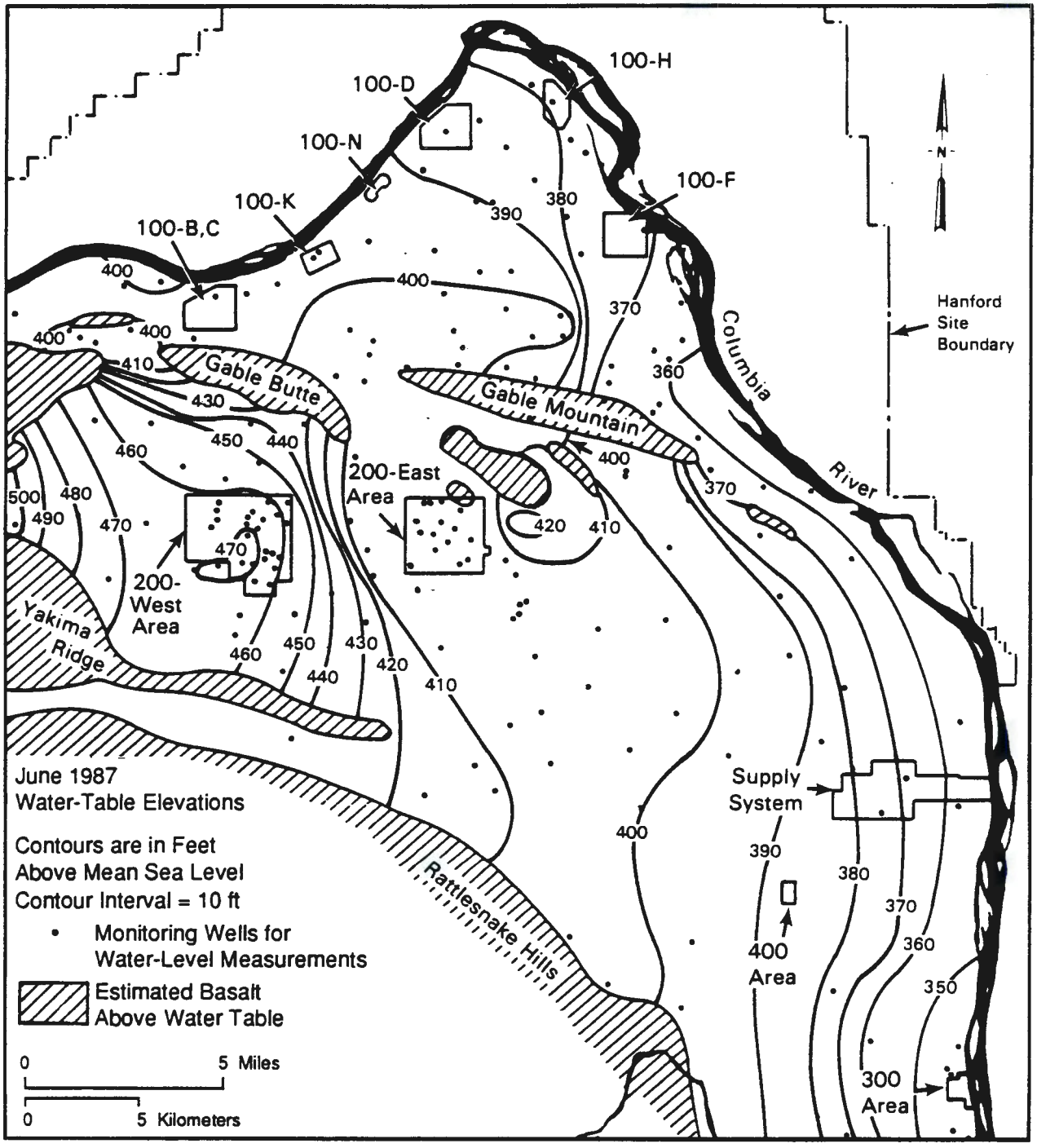


FIGURE 6.5. Water-Table Elevations for the Hanford Site, Measured in June 1987 (Schatz et al. 1987)

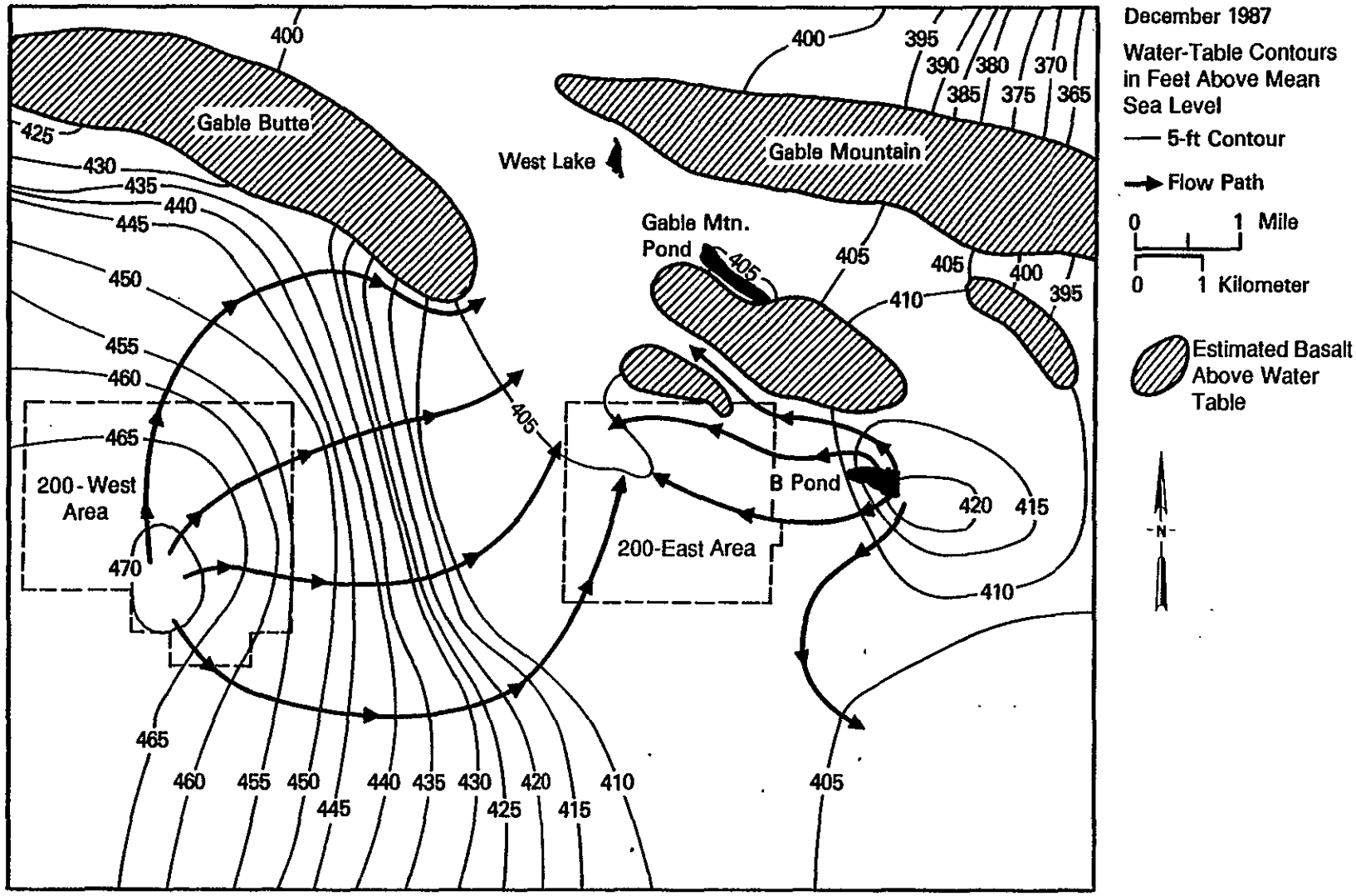


FIGURE 6.6. Water-Table Surface Beneath the 200 Areas, Measured in December 1987 (Schatz and Ammerman 1988)

<1 to 45 ft/d. For WMA-2, a local pore-water velocity based on hydraulic conductivities of 1,400 to 6,700 ft/d and a hydraulic gradient of 0.4 ft/1,000 ft resulted in values of 6 to 27 ft/d.

Small water-level fluctuations have been detected in new wells drilled near the WMAs between December 1987 and August 1988. Average water-level changes have been approximately 0.3 ft, with minimum and maximum changes being 0.2 ft (well 299-E33-28) and 0.5 ft (well 299-E27-10). These changes are minor adjustments to the water-table surface, primarily as a result of temporal changes in discharges at the nearby B Pond and other waste-water disposal facilities. Fluctuations resulting from seasonal changes in infiltration originating from precipitation are expected to be minimal.

6.3.2 Waste Management Areas 3 and 4

Major Hydrogeologic Units

Four hydrologically significant stratigraphic units were encountered in the saturated zone beneath the WMAs in the 200-West Area. These units include the middle Ringold unit, the lower Ringold unit, the coarse- and fine-grained facies of the basal Ringold unit, and the Elephant Mountain Member of the Columbia River Basalt Group. The units belonging to the Ringold Formation collectively compose the unconfined aquifer system in the vicinity of the WMAs, and each represents individual hydrogeologic units with unique hydrologic properties.

The middle Ringold unit comprises the uppermost part of the unconfined aquifer system beneath the 200-West Area. This unit was encountered by all 19 wells drilled in the 200-West Area, but was fully penetrated by only the 4 recently completed deep wells. No obvious confining units have been delineated within the middle Ringold unit; however, aquifer test data and slowly decreasing drill rates indicate that the middle Ringold unit becomes more indurated and less transmissive with depth. The lower Ringold unit and fine-grained facies of the basal Ringold unit combined consist of up to 70 ft of predominantly mud. These muds act as a single confining unit separating the middle unit of the Ringold Formation from the coarse-grained facies of the basal Ringold unit in WMA-4.

The coarse-grained facies of the basal Ringold unit acts as a confined aquifer where it is overlain by the lower and fine-grained basal Ringold units; however, the lower Ringold and fine-grained basal Ringold units are missing in the northern and eastern portions of WMA-3. This results in a single, undifferentiated, sandy gravel sequence belonging to the middle and basal Ringold units. Without the confining layers, it is not currently possible to hydraulically distinguish the middle Ringold unit from the coarse-grained basal Ringold unit in this area.

The Elephant Mountain Member acts as a confining unit that separates the unconfined aquifer system from lower confined aquifers found within the Columbia River basalts. Only 1 of the 19 wells (299-W7-3) recently installed in the 200-West Area was drilled deep enough to encounter this unit. Data from previous investigations (DOE 1988; Tallman et al. 1979) indicate that this unit is laterally continuous beneath the 200-West Area.

Hydraulic Properties

Aquifer hydraulic properties were determined by conducting constant discharge tests in 18 wells and a slug test in 1 well. Transmissivity values ranged from a low of 14 ft^2/d (well 299-W7-6) to a maximum of 51,000 ft^2/d (well 299-W18-21) in upper portions of the middle Ringold unit. Hydraulic conductivities, calculated by dividing the transmissivities by the saturated thicknesses given in Table 6.3, ranged from a low of 0.06 ft/d to as much as 200 ft/d. Transmissivities found in the more consolidated sediments at the base of the unconfined aquifer were lower, between 420 ft^2/d (well 299-W18-22) and 900 ft^2/d (well 299-W7-3), than in the upper part of the unconfined aquifer. Hydraulic conductivities, calculated by dividing the transmissivities by the saturated thicknesses given in Table 6.3, ranged from 1.7 to 4 ft/d. The shallow wells drilled along the northern boundary of the 200-West Area generally yielded lower transmissivities than those drilled closer to U Pond. The transmissivities ranged from 43 to 7,000 ft^2/d along the northern portion of the 200-West Area near WMA-3 and from 1,300 to 51,000 ft^2/d adjacent to U Pond and Z Plant.

Storativity values were determined from data collected from multiple aquifer tests using the Theis (1935) method. At one of the multiple well

TABLE 6.3. Summary of Aquifer Test Results for 200-West Area Wells

Well Number	Screened Interval Tested, ft	Stratigraphic Unit	Aquifer Thickness, ft	Analysis Method	Type of Test	Transmissivity, ft^2/d	Hydraulic Conductivity, ft/d	Date Tested
299-W6-2	238-248	Middle Ringold	245	Cooper-Jacob (1946)	Constant Discharge	350	1.5	11/05/87
299-W6-2	238-248	Middle Ringold	245	Cooper-Jacob (1946)	Recovery	500	2	11/03/87
299-W7-1	233-243	Middle Ringold	270	Cooper-Jacob (1946)	Constant Discharge	1,000	4	7/15/87
299-W7-1	233-243	Middle Ringold	270	Cooper-Jacob (1946)	Recovery	1,400	5	7/15/87
299-W7-2	212-222	Middle Ringold	260	Cooper-Jacob (1946)	Constant Discharge	430	2	9/16/87
299-W7-2	212-222	Middle Ringold	260	Cooper-Jacob (1946)	Recovery	740	3	9/16/87
299-W7-3	467-477	Middle/Basal Ringold	264	--	--	--	--	10/30/87 to 10/31/87
299-W7-4	223-233	Middle Ringold	265	Cooper-Jacob (1946)	Constant Discharge	3,300	12	11/12/87
299-W7-4	223-233	Middle Ringold	265	Cooper-Jacob (1946)	Recovery	2,800	11	11/12/87
299-W7-5	208-228	Middle Ringold	250	Cooper-Jacob (1946)	Constant Discharge	170	0.7	11/21/87
299-W7-6	231-241	Middle Ringold	245	Cooper-Jacob (1946)	Constant Discharge	14	0.06	10/14/87
299-W7-6	231-241	Middle Ringold	245	Cooper-Jacob (1946)	Recovery	40	0.16	10/14/87
299-W8-1	257-267	Middle Ringold	274	Cooper-Jacob (1946)	Recovery	80	0.3	7/11/87
299-W9-1	266-286	Middle Ringold	215	Bouwer-Rice (1976)	Slug With-drawal	43-65	0.2-0.3	10/23/87
299-W9-1	266-286	Middle Ringold	215	Hvorslev (1951)	Slug With-drawal	55	0.26	10/23/87
299-W10-13	227.5-237.5	Middle Ringold	221	Cooper-Jacob (1946)	Recovery	7,000	32	9/14/87
299-W10-14 (observa-tion well)	No screen (drilled to 240)	Middle Ringold	218	Cooper-Jacob (1946)	Recovery	3,500	16	9/14/87
299-W10-14	437-447	Middle Ringold (base)	218	Cooper-Jacob (1946)	Recovery	900	4	10/26/87

TABLE 6.3. (contd)

Well Number	Screened Interval Tested, ft	Stratigraphic Unit	Aquifer Thickness, ft	Analysis Method	Type of Test	Transmissivity, ft^2/d	Hydraulic Conductivity, ft/d	Date Tested
299-W15-15	245-255	Middle Ringold	230	Cooper-Jacob (1946)	Recovery	10,000	43	8/21/87
299-W15-16	227.5-237.5	Middle Ringold	230	Cooper-Jacob (1946)	Constant Discharge	5,000	22	8/20/87
299-W15-16	227.5-237.5	Middle Ringold	230	Cooper-Jacob (1946)	Recovery	12,000	52	8/20/87
299-W15-17 (observation well)	No screen (drilled to 220)	Middle Ringold	229	Theis (1935)	Constant Discharge	12,000	52	8/20/87
299-W15-17 (observation well)	No screen (drilled to 220)	Middle Ringold	229	Theis (1935)	Recovery	12,000	52	8/20/87
299-W15-17	422.5-432.5	Middle Ringold (base)	229	--	--	--	--	9/28/87
299-W15-18	232-242	Middle Ringold	243	Cooper-Jacob (1946)	Recovery	14,000	58	7/21/87
299-W18-21	215.5-225.5	Middle Ringold	250	Cooper-Jacob (1946)	Constant Discharge	1,300	5	7/14/87
299-W18-21	215.5-225.5	Middle Ringold	250	Cooper-Jacob (1946)	Recovery	51,000	200	7/14/87
299-W18-22	437.5-447.5	Middle Ringold (base)	248	Cooper-Jacob (1946)	Recovery	420	1.7	8/26/87
299-W18-23	241-251	Middle Ringold	246	Cooper-Jacob (1946)	Recovery	23,000	95	6/22/87
299-W18-23	241-251	Middle Ringold	246	Cooper-Jacob (1946)	Constant Discharge	27,000	110	6/22/87
299-W18-24	230-240	Middle Ringold	243	Cooper-Jacob (1946)	Recovery	44,000	180	7/17/87
299-W18-2 (observation well)	205-255	Middle Ringold	250	Theis (1935)	Recovery	17,000	70	7/17/87

sites, drilling at the deep well (299-W15-17) was temporarily halted at the same approximate depth as that of the shallow well (299-W15-16). The deep well (299-W15-17) was then bailed clean and used as an observation well while the shallow well (299-W15-16) was pumped. Storativity was determined from data collected from an existing well (299-W18-2) while pumping well 299-W18-24. Storativity values ranged from approximately 0.001 in well 299-W18-2 (while pumping well 299-W18-24) to 0.038 in well 299-W15-17 (while pumping well 299-W15-16).

Transmissivity could not be determined from the aquifer tests conducted in wells 299-W7-3 and 299-W15-17 because the data could not be analyzed due to excessive casing storage effects and lack of drawdown or recovery trends once casing storage effects dissipated.

Refer to Appendix F for a summary of the aquifer tests.

Direction and Rate of Ground-Water Movement

Since December 1, 1987, ground-water elevations near the top of the unconfined aquifer have been measured routinely at one-week to one-month intervals at each new well and at selected existing wells. These elevations were calculated by subtracting the depth to water (measured by steel tape from the top of the casing) from the casing elevation. These elevations were used to develop water-table maps of the unconfined aquifer in the vicinity of WMA-3 and WMA-4, which were in turn used to delineate the direction of ground-water movement beneath these sites. Figures 6.7 and 6.8 illustrate the water-table surface constructed from water levels measured on March 9, 1988, and June 30, 1988, respectively. Ground-water elevations measured in each new well are provided in Appendix H.

Interpretation of the water-table maps shown in Figures 6.7 and 6.8 suggests that the general ground-water flow directions are to the north-northeast beneath WMA-3 and to the northwest beneath WMA-4. These ground-water flow directions still reflect the influence of a ground-water mound created in the past by discharges at nearby U Pond. Even though U Pond has been decommissioned since 1984, the mound is expected to persist for a number of years as it dissipates to new lower equilibrium conditions (i.e., pre-discharge conditions). Ground-water levels beneath U Pond area are still

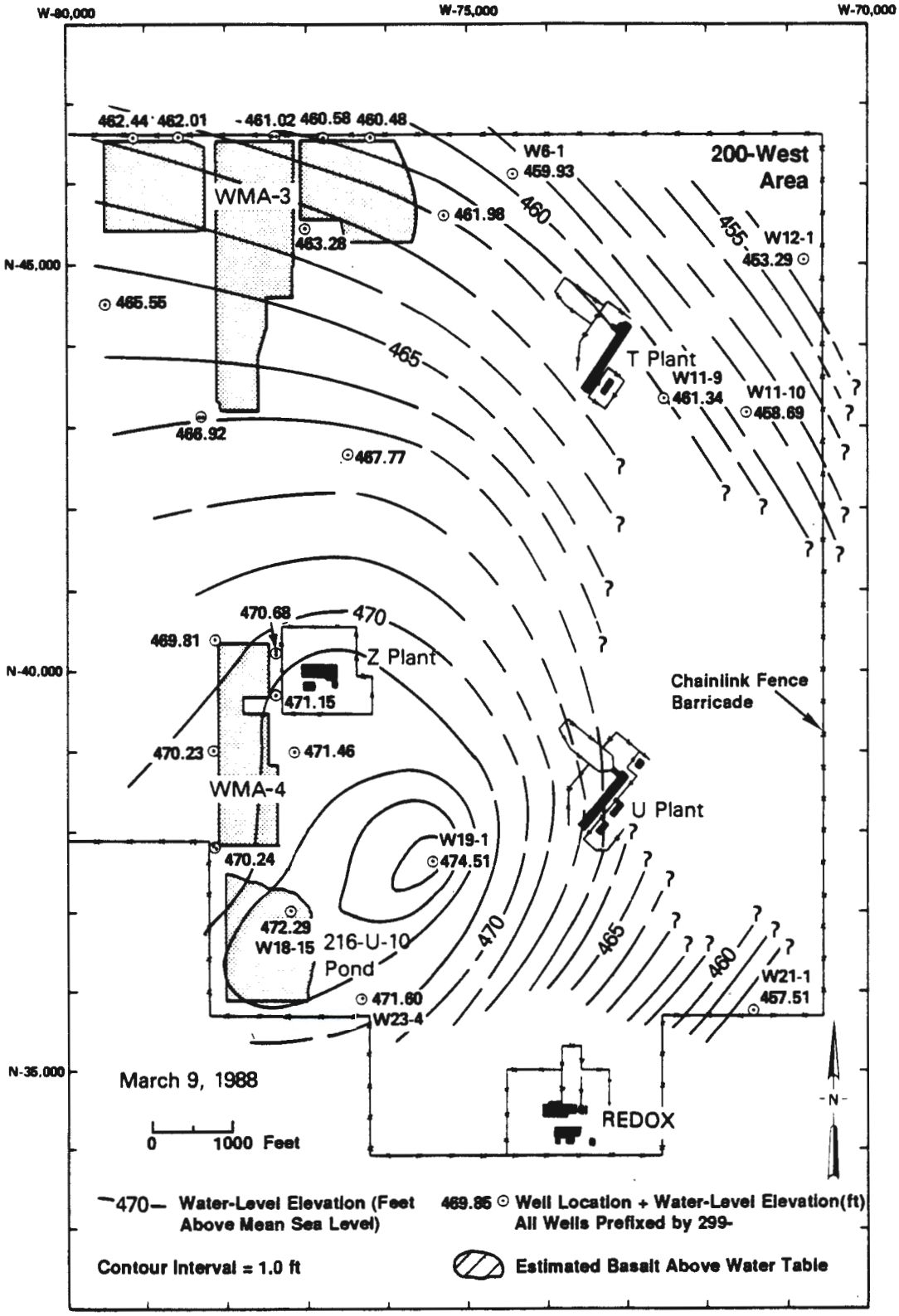


FIGURE 6.7. Water-Table Surface Beneath Waste Management Areas 3 and 4, Measured on March 9, 1988

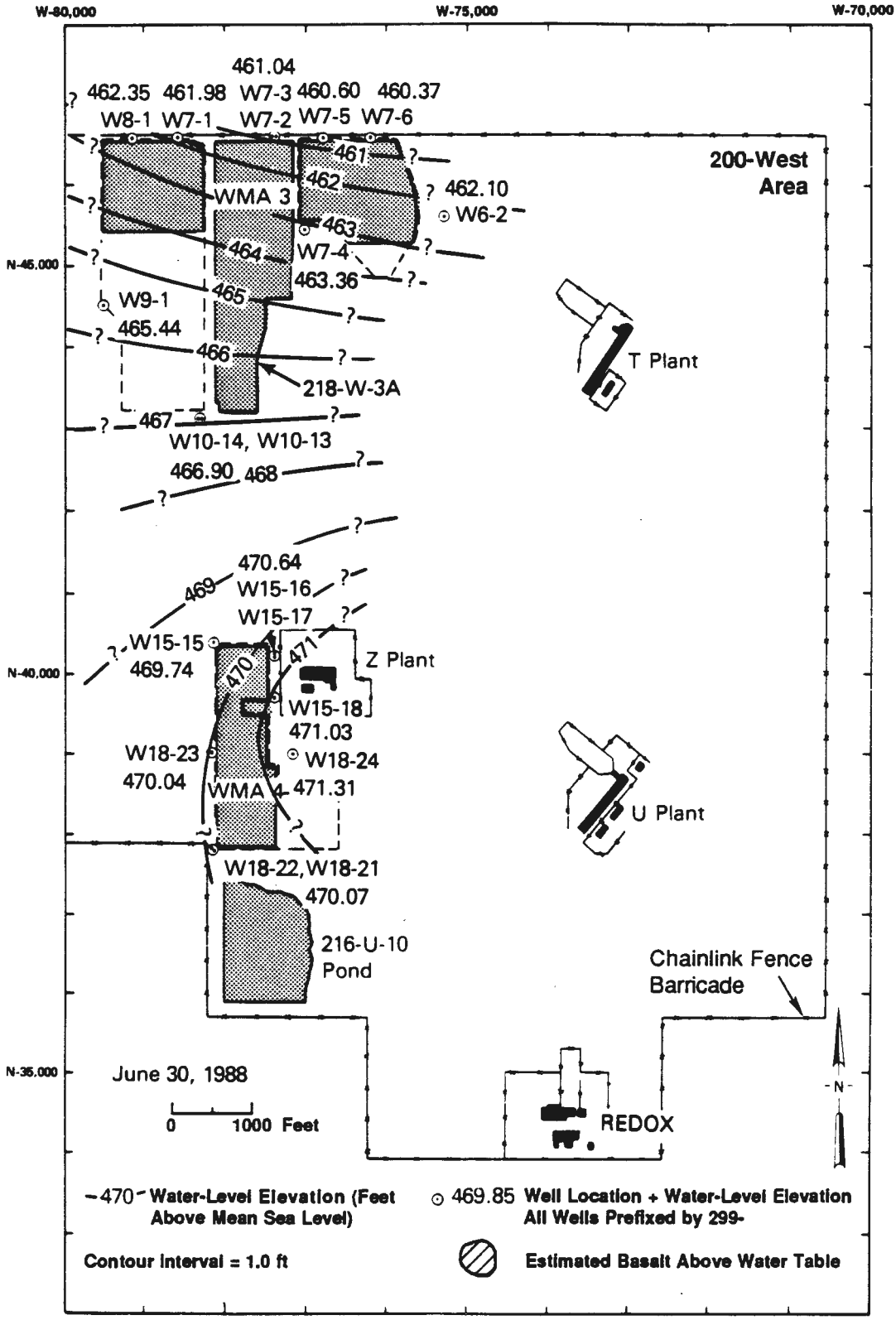


FIGURE 6.8. Water-Table Surface Beneath Waste Management Areas 3 and 4, Measured on June 30, 1988

between 470 and 475 ft above mean sea level, which is approximately 60 ft above pre-Hanford conditions (ERDA 1975). Shortly after U Pond was decommissioned in 1984, water levels in well 299-W18-15 (Figure 6.9), located close to the pond, had reached an elevation of approximately 486 ft above mean sea level. As Figure 6.7 indicates, this mound is now located northeast of U Pond, where waste-water disposal continues to the 216-U-14 ditch (near well 299-W19-1). Horizontal gradients interpreted from the water-table maps are on the order of 1.5 to 2 ft/1,000 ft beneath WMA-3 and 1 to 1.5 ft/1,000 ft beneath WMA-4.

Using Darcy's law and some representative hydraulic conductivities, hydraulic gradients, and an effective porosity of 0.1, ground-water velocities were calculated that might be considered representative of conditions beneath these facilities. For WMA-3, pore-water velocities based on hydraulic conductivities of 0.06 to 32 ft/d and a conservative hydraulic gradient of 2.0 ft/1,000 ft resulted in values of 0.001 to 0.6 ft/d. For WMA-4, pore-water velocities based on hydraulic conductivities of 1.7 to 200 ft/d and a conservative hydraulic gradient of 1.5 ft/1,000 ft resulted in values of approximately 0.03 to 3 ft/d. The magnitude of velocities in the 200-West Area was in general less than that calculated for the 200-East Area.

Small water-level fluctuations have been detected in new wells drilled near the WMAs between December 1, 1987, and August 1, 1988. Average water-level changes have been approximately 0.9 ft, with minimum and maximum changes being approximately 0.4 ft at well 299-W7-2 and 1.0 ft at well 299-W18-21. These changes are minor adjustments to the water-table surface and primarily are the result of changes in surface discharges at nearby U Pond and other waste-water disposal facilities in the 200-West Area. Fluctuations resulting from seasonal changes in infiltration originating from precipitation are expected to be minimal.

Because of the proximity of the WMAs to the U Pond ground-water mound, a decrease in head with depth is expected to be observed, which could create some downward vertical movement of ground water near the WMAs. The difference between the water-table elevation obtained from wells completed in the upper part of the unconfined aquifer and the potentiometric levels from

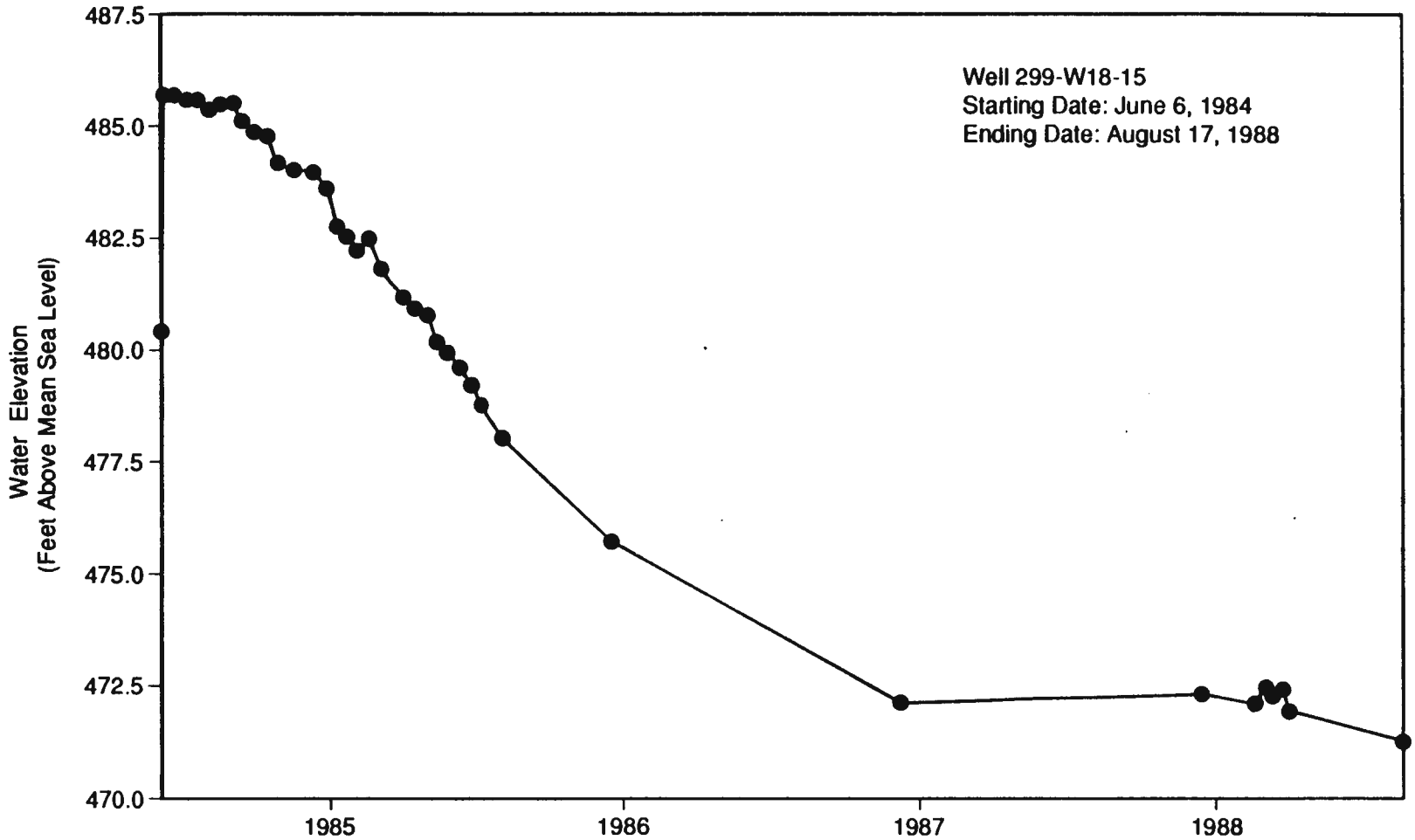


FIGURE 6.9. Hydrograph of Well 299-W18-15 Near U Pond

wells screened just above the confining unit (the lower/fine-grained basal units of the Ringold Formation) was measured at three locations near the WMAs. A generalized cross section through the WMAs showing the major hydrogeologic units and an interpretation of equipotential lines based on these measurements is depicted in Figure 6.10. Highest heads are shown in the vicinity of WMA-4, where the effects of the U Pond mound are most evident. Beneath WMA-4, the measured vertical head differences are approximately -0.9 to -1.0 ft (downward) at the southern end, decreasing to approximately -0.6 to -0.8 ft (downward) at the northern end. These vertical head differences continue to decrease to the north, away from the U Pond mound, reaching a low of approximately -0.4 ft (downward) beneath the southern portion of WMA-3. Another measurement of the vertical gradient was made beneath WMA-3 in an area where the confining bed associated with the lower fine-grained basal Ringold unit is nonexistent. Here, the middle Ringold unit merges with the coarse-grained basal Ringold unit. At this location, as shown in Figure 6.10, a head difference of approximately -1.3 ft was observed.

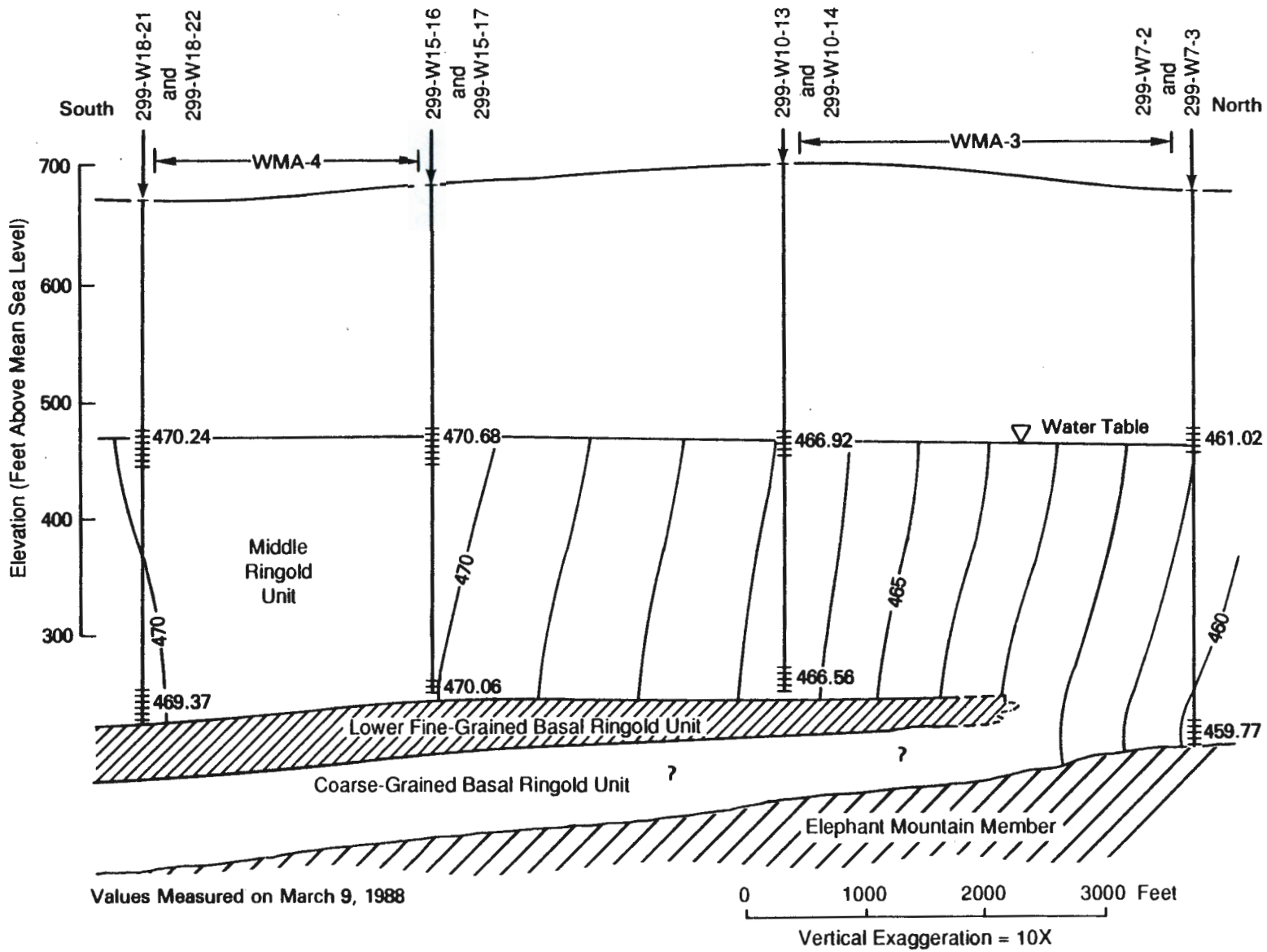


FIGURE 6.10. Generalized Hydrogeologic Cross Section Beneath Waste Management Areas 3 and 4. Lower and basal Ringold stratigraphy is approximated based on thickness data presented in Bjornstad (1984)

7.0 GROUND-WATER QUALITY

Information on ground-water quality is derived from three principal sources: 1) published reports, 2) chemical analyses of ground-water samples bailed from the borehole before development and aquifer testing of the 8-in.-telescoping screened interval, and 3) chemical analyses of ground-water samples collected from the discharge pipe during aquifer testing of the 8-in.-telescoping screened interval. Results from sample analyses were used to determine the method of disposal of the well water during development and aquifer testing activities. These ground-water samples were collected before construction and development of the final monitoring well, and thus are not to be considered representative of the ground-water quality. The analytical results (see Appendix D) from these samples are not of sufficient quality to be used except as possible indicators of the types of contaminants that should be included in the regular sampling and analysis plans.

The predevelopment and aquifer test samples were analyzed for volatile organic constituents, gross alpha and gross beta activities, gamma scan, tritium, total strontium, plutonium-239,240, plutonium-238, and occasionally uranium. In addition, samples from the 200-East Area were analyzed for cyanide and semivolatile organic constituents. Three wells in the 200-West Area and one in the 200-East Area were analyzed for the complete suite of constituents listed in Appendix VIII of 40 CFR 261 (EPA 1986a) and WAC 173-303-9905 (Ecology 1986).

7.1 WATER QUALITY IN THE UNCONFINED AQUIFER BENEATH WASTE MANAGEMENT AREAS 1 AND 2

The quality of the ground water found beneath WMA-1 and WMA-2 is discussed below.

7.1.1 Indications from Previous Studies

Serkowski et al. (1988) indicate that the unconfined aquifer beneath WMA-1 and WMA-2 is at least partially affected by total beta, tritium, and nitrate plumes located beneath the northern part of the 200-East Area. These plumes are illustrated in Figures 7.1, 7.2, and 7.3, respectively. Serkowski

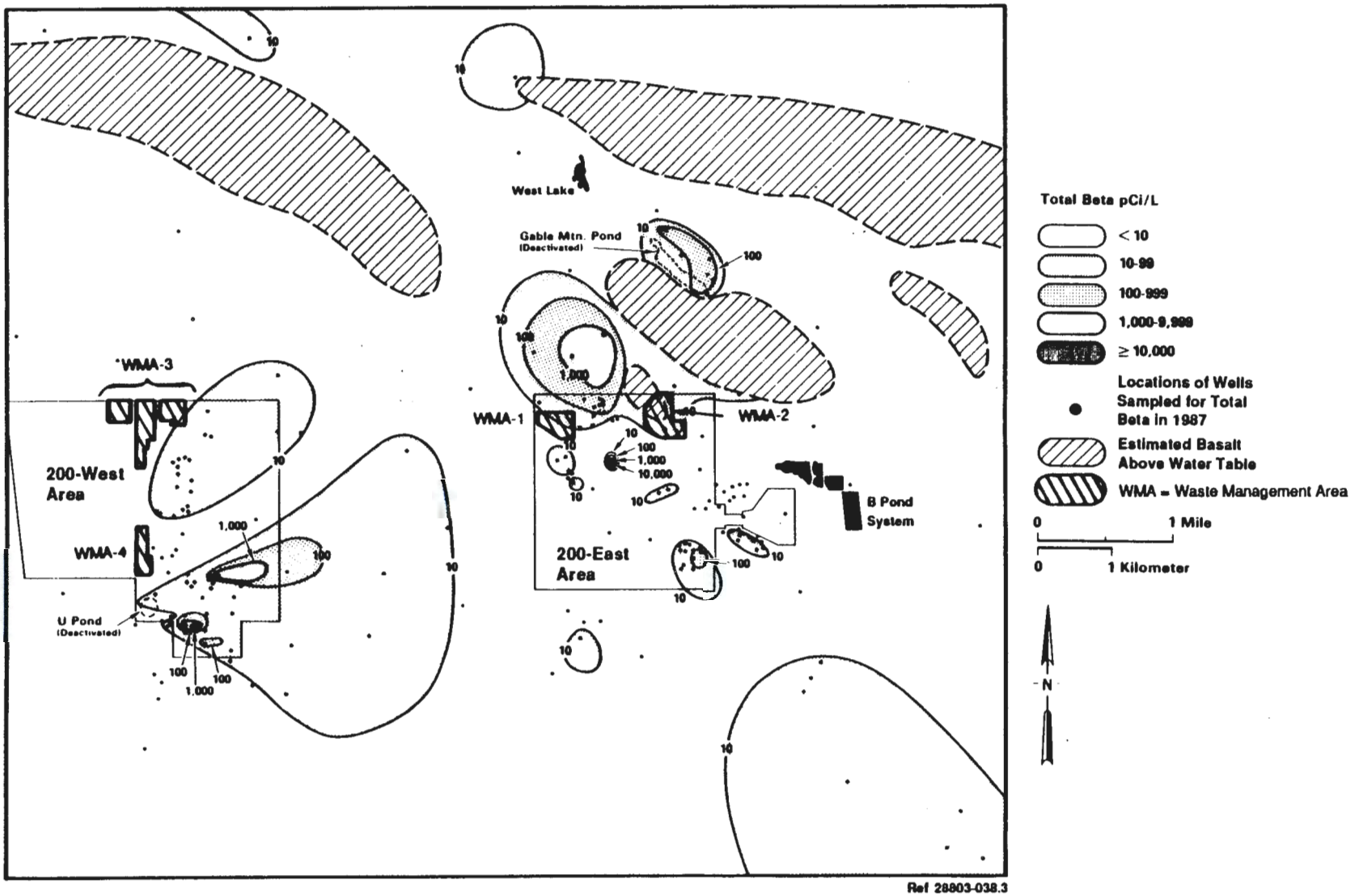


FIGURE 7.1. Total Beta Plumes Within the 200 Areas for 1987 (after Serkowski et al. 1988)

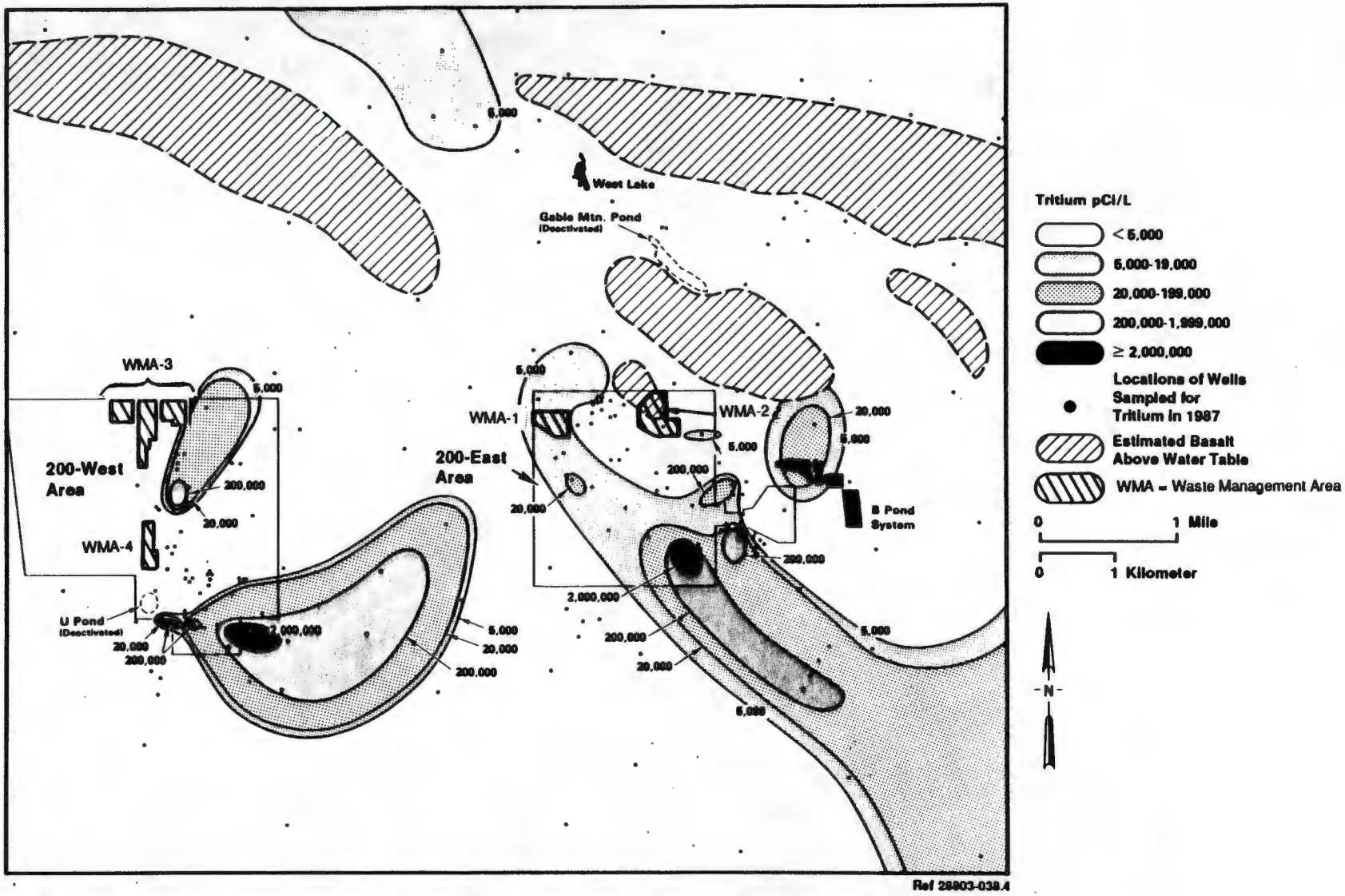


FIGURE 7.2. Tritium Plumes Within the 200 Areas for 1987 (after Serkowski et al. 1988)

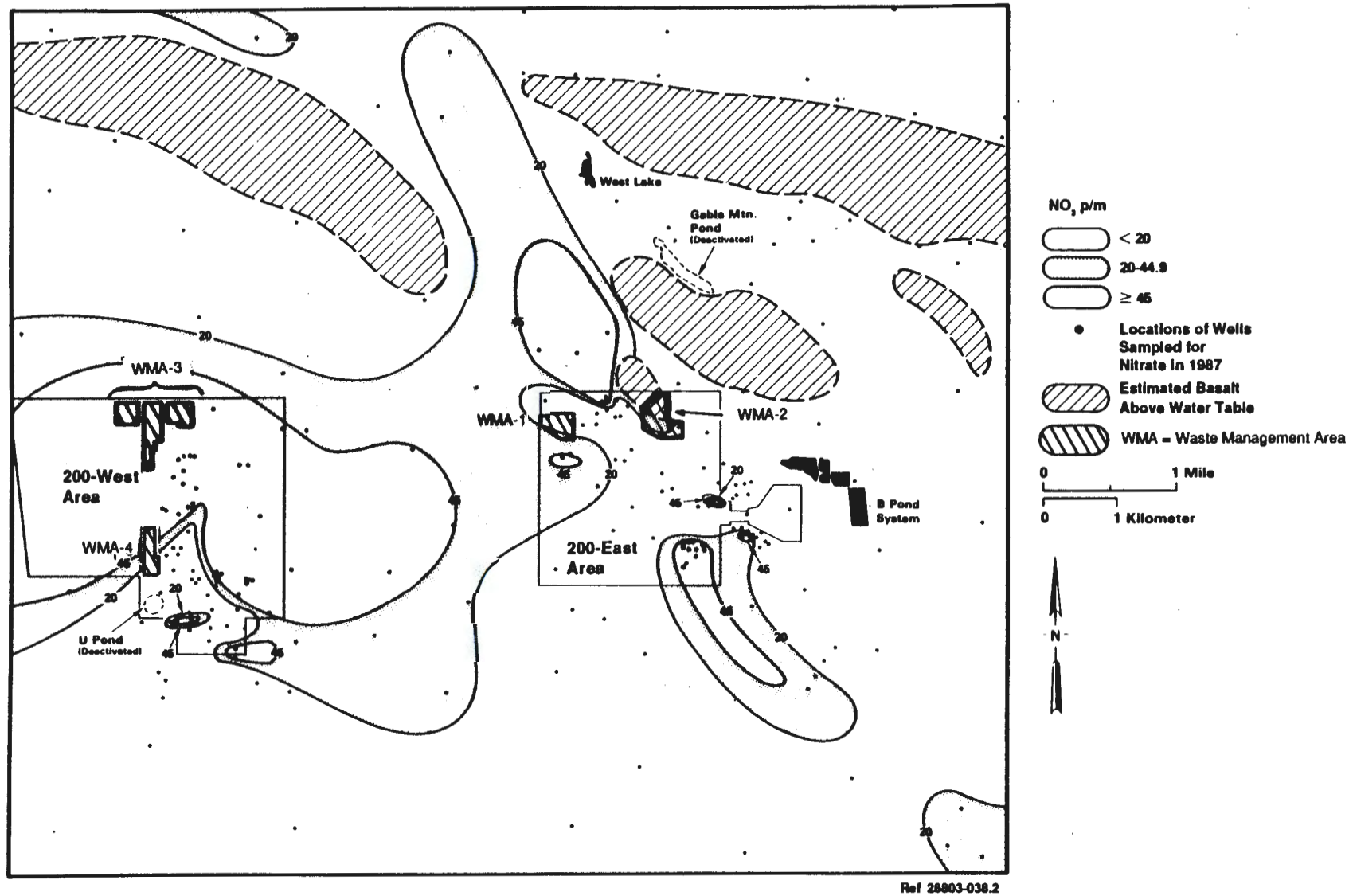


FIGURE 7.3. Nitrate Plumes Within the 200 Areas for 1987 (after Serkowski et al. 1988)

et al. (1988) also described the total beta plume as emanating from the inactive 216-BY Cribs and caused by technetium-99 contamination. They described a potential source of the tritium plume as being the active 216-B-55 Crib, and they implied that the 216-B-62 and 216-BY Cribs were possible sources of nitrate.

Evans et al. (1988) indicated the presence of cyanide in ground-water samples from a number of wells in and north of the 200-East Area. They indicated that this contamination was probably from the BY cribs. They also identified ammonia and elevated gross alpha activities in two wells near the 216-B-62 Crib, just south of WMA-1.

7.1.2 Predevelopment and Aquifer Test Sample Analyses

Bailed samples were collected from each well before development and initiation of aquifer testing, except well 299-E34-4, that was completed on a basalt high extending above the water table. Water samples were also collected during aquifer tests from seven wells: 299-E27-9, 299-E28-27, 299-E32-2, 299-E32-3, 299-E33-28, 299-E33-29, and 299-E33-30. Ground-water samples were analyzed for volatile organic constituents, gross alpha and gross beta activities, gamma scan, tritium, total strontium, strontium-90, plutonium-239,240, plutonium-238, cyanide, and occasionally uranium. Samples from well 299-E34-2 were analyzed for the complete suite of constituents listed in Appendix VIII of 40 CFR 261 (EPA 1986a) and WAC 173-303-9905 (Ecology 1986).

Analytical results for the predevelopment and aquifer test ground-water analyses are provided in Appendix D. These data suggest that the potential contaminants beneath WMA-1 and WMA-2 are total beta, tritium, and total alpha (probably uranium). Nitrate, iron, and manganese may also be present in notable quantities. Cyanide was not detected.

7.2 WATER QUALITY IN THE UNCONFINED AQUIFER BENEATH WASTE MANAGEMENT AREAS 3 AND 4

The quality of the ground water in the upper portion of the unconfined aquifer beneath WMA-3 and WMA-4 is discussed below.

7.2.1 Indications from Previous Studies

Serkowski et al. (1988) delineated total beta, tritium, and nitrate plumes beneath portions of the 200-West Area (see Figures 7.1, 7.2, and 7.3, respectively). Ground water beneath WMA-3 and WMA-4 may be affected by any one or all of these plumes. The total beta plume in the southern portion of the 200-West Area was described as being caused by technetium-99 and strontium-90 issuing from the 216-S Cribs, and beta-emitting uranium decay products from the plume originating from the 216-U-1/2 Cribs (Serkowski et al. 1988). The tritium plume sources in the 200-West Area are described as the inactive 216-S and 216-T Crib areas (Serkowski et al. 1988). The highest nitrate concentrations are described as resulting from disposal to the 216-T, 216-Z, 216-S-25, 216-U-1/2, and the 216-W-LWC Cribs.

Evans et al. (1988) identified detectable concentrations of tetrachloromethane [carbon tetrachloride (CCl_4)] beneath most of the 200-West Area. They reported a maximum concentration of 3,210 ppb in well 299-W15-11 (approximately 1,000 ft northwest of WMA-4). The maximum contaminant level for CCl_4 is 5 ppb. They also reported several elevated values of trichloroethylene (TCE) in the 200-West Area, which they described as associated with the CCl_4 plume. They suspected the source of the CCl_4 to be past discharges of degraded solvents from the Plutonium Finishing Plant to the cribs. They concluded there was no obvious immediate public health implications associated with the CCl_4 plume because the ground water in question is not a source of public drinking water. They also indicated that dispersion and dilution are likely to reduce the concentrations significantly by the time the plume reaches the Columbia River. The long-term public health issue was considered to be associated with eventual site abandonment, operational concerns, and regulatory considerations under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA 1980) or RCRA.

7.2.2 Predevelopment and Aquifer Test Sample Analyses from the Top of the Unconfined Aquifer

Ground-water samples were bailed from each well (except 299-W18-23) before development and two or three times during aquifer tests conducted at each shallow well. The ground-water samples were analyzed for volatile

organic constituents, gross alpha and gross beta activities, gamma scan, tritium, total strontium, strontium-90, plutonium-239,240, plutonium-238, and occasionally uranium. Results of the ground-water analyses are provided in Appendix D. These data suggest that the principal contaminants beneath WMA-3 and WMA-4 are tetrachloromethane (CCl_4) listed as tetrane, chloroform, and total alpha. Total beta, tritium, and methylene chloride may also be present in notable quantities; TCE was not detected.

7.2.3 Predevelopment and Aquifer Test Sample Analyses from the Bottom of the Unconfined Aquifer

Ground-water samples were bailed before development and collected two or three times during aquifer testing of each deep well. The ground-water samples were analyzed for volatile organic constituents, gross alpha and gross beta activities, gamma scan, tritium, total strontium, strontium-90, plutonium-239,240, plutonium-238, and occasionally uranium. In addition, each deep well (except 299-W10-14) was analyzed for the complete suite of constituents listed in Appendix VIII of 40 CFR 261 (EPA 1986a) and WAC 173-303-9905 (Ecology 1986). Results of the ground-water analyses are provided in Appendix D. These data suggest that the principal contaminants at the bottom of the unconfined aquifer beneath WMA-3 and WMA-4 might be chloroform, chromium, and lead. Total alpha, total beta, acetone, ammonium, arsenic, nitrate, toluene, xylene, and methylene chloride may also be present. Iron and manganese might also be found in notable quantities.

7.3 IMPACT OF WASTE MANAGEMENT AREAS ON THE GROUND-WATER QUALITY

Sufficient data are not yet available to assess the possible impacts of the WMAs on the unconfined aquifer. Representative ground-water samples from the new monitoring system have not yet been collected; thus, it is premature to speculate on any possible impacts.

8.0 PLANNED WORK

Characterization of the hydrogeologic system of the LLBGs is still in progress. This report has presented the information available as of August 1, 1988. At the time of this writing, several characterization activities were still in progress or were to be initiated in the upcoming months. A synopsis of these activities is discussed below.

8.1 PHYSICAL TESTING OF BOREHOLE SAMPLES

Selected borehole samples are being analyzed for their physical and hydrologic characteristics. The analyses still in progress as of August 1, 1988, include saturated hydraulic conductivity and water-retention characteristics. This work supports the first and third specific objectives of the hydrogeologic characterization effort: to develop a more complete picture of the hydrogeologic system, and to determine the range in hydraulic conductivities of the suprabasalt sediments.

The borehole samples for these analyses were selected based on preliminary hydrogeologic correlations. The samples and the analyses being performed are listed in Tables 8.1 and 8.2.

8.2 MINERALOGICAL AND GEOCHEMICAL TESTING OF BOREHOLE SAMPLES

Mineralogical, bulk soil chemistry, and cation exchange capacity analyses are being performed on a number of borehole samples. This work supports the fifth specific objective of the hydrogeologic characterization effort: to determine the geochemical parameters controlling contaminant movement.

The samples were selected based on preliminary hydrogeologic correlations. These samples and the types of analyses being performed are presented in Tables 8.1 and 8.2.

8.3 MODELING

Ground-water (both unsaturated and saturated) and geochemical modeling will support the first and fifth specific objectives of the hydrogeologic

TABLE 8.1. Laboratory Analyses of 200-East Area Borehole Samples

Borehole Depth, ft	Water Retention	Saturated Hydraulic Conductivity	Petrography	Geochemistry
299-E28-26				
40*			X	X
129-130	X	X	X	X
230	X	X	X	
295*			X	X
320*			X	X
299-E33-30				
40*			X	X
139-140	X	X	X	X
239-240	X	X	X	
260*			X	X
299-E34-2				
50*			X	X
150*			X	X
215*			X	
230*			X	X
299-E34-3				
50*			X	X
120*			X	X
165*			X	X
210*			X	X
Total	4	4	17	14

BOLD = Sample in saturated zone.
* = Hard tool sample.

characterization effort: to develop a more complete picture of the hydrogeologic system, and to determine whether or not contaminants have entered the ground-water system from the LLBGs.

Unsaturated zone water movement and transport calculations will be used to assess the impact of LLBGs on the unconfined aquifer. Geochemical modeling

TABLE 8.2. Laboratory Analyses of 200-West Area Borehole Samples

Borehole Depth, ft	Water Retention	Saturated Hydraulic Conductivity	Petrography	Geochemistry
299-W7-5				
10	X	X	X	X
299-W7-2				
40*			X	
65	X	X	X	X
94-95	X	X	X	X
154-155	X	X	X	X
219-220	X	X	X	X
299-W7-3				
320*			X	
450*			X	X
299-W10-13				
45	X	X	X	X
80	X	X	X	
115*			X	X
130*			X	
160*			X	X
200*			X	X
240*			X	X
299-W10-14				
340*			X	
440*			X	X
460*			X	
299-W15-16				
40	X	X	X	X
110	X	X	X	X
140*			X	
150*			X	X
190*			X	
225*			X	X
299-W15-17				
335*			X	
425*			X	X
450*			X	
299-W18-21				
25	X	X	X	
40	X	X	X	X
95			X	X
130*			X	
140*			X	X
170*			X	
210*			X	X
299-W18-22				
320*			X	
420*			X	X
447*			X	
Total	11	11	37	22

BOLD = Sample in saturated zone.
* = Hard tool sample.

will be used to assess the chemical alterations that might have taken place as the leachates migrate through the soil column to the ground water.

If any contaminants from the LLBGs have reached the unconfined aquifer, ground-water flow and contaminant transport modeling will be used to assess their impacts and their possible extent and rate of movement.

8.4 WATER-QUALITY MONITORING

Water-quality monitoring had not been initiated as of August 1, 1988. This activity was delayed primarily by: 1) the delays in receiving the sampling pumps and 2) the necessity to repeatedly develop the monitoring wells.

9.0 RECOMMENDATIONS

Preliminary interpretation of hydrogeologic systems beneath WMA-1, WMA-2, WMA-3, and WMA-4 has resulted in some unresolved questions and/or has raised new questions. These questions, and recommendations to resolve these questions, are provided here.

What are the actual ground-water flow directions beneath each of the WMAs? Are the monitoring wells located adequately to monitor the downgradient margins of the WMAs?

Expand the water-level measurement networks around each area. These networks would consist of existing wells, some of which would require modification to monitor a common hydrologic interval (i.e., top 15 ft of the aquifer). All the wells should then be resurveyed to a common reference benchmark.

Update and perform hydrologic modeling of the areas to aid interpretation of the ground-water flow directions, past, current, and future.

Depending on these evaluations, additional downgradient monitoring wells may be required along the western margin of WMA-2 and/or along the northern and western margins of WMA-4.

What are the physical relationships between the unconfined aquifer and the basal Ringold aquifer beneath the northern portion of WMA-3 where the lower Ringold/basal Ringold fine facies appears to be missing?

Renovate the existing well (699-45-78) and install a series of piezometers (if possible) to examine the physical integrity, through aquifer testing, of the fine-grained Ringold units and to determine the vertical hydraulic gradients between the basal Ringold and unconfined aquifers.

What is the physical relationship between the unconfined aquifer and the Rattlesnake Ridge aquifer near an area of potential aquifer intercommunication identified near the northern portion of WMA-2?

Examine the benefits of installing a series of piezometers in this area to examine the integrity of the basalt confining bed and to assess the vertical hydraulic gradients between the two aquifers.

To what degree does the cable-tool drill method tend to pulverize sediment samples, resulting in unrepresentative samples and estimates of hydrologic parameters?

Determine the true character of sediments in the 200-East Area by examining core from three boreholes in the 200-East Area and evaluate with respect to nearby cable-tool drilled wells.

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