STATE OF MICHIGAN
DEPARTMENT OF ENVIRONMENTAL QUALITY
LANSING

RICK SNYDER
GOVERNOR

C. HEIDI GRETHER
DIRECTOR

August 29, 2018

The Michigan Department of Environmental Quality (MDEQ) strives to protect human health, safety and welfare, and the environment through a multitude of programs that encourage environmental stewardship and regulate the activities of businesses and residents alike to minimize adverse environmental impacts. The Remediation and Redevelopment Division is responsible for overseeing public and private efforts to clean up and manage risk at sites of environmental contamination.

The Wurtsmith Air Force Base (WAFB) was one of the first sites in Michigan where per- and polyflouralkyl substances (PFAS) contamination was found. The base existed as a small community with its own drinking water supply from 1942 to 1997. Like many other Air Force bases, WAFB used Aqueous Film Forming Foam (AFFF) since 1970 as standard practice to put out fires and for conducting fire training exercises. In 2010, the DEQ confirmed PFAS releases on the base had occurred. In 2009, the U.S. Environmental Protection Agency (USEPA) Office of Water developed Provisional Health Advisory values for perflourooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) of 200 and 400 parts per trillion (ppt), respectively, based on the evidence available at that time. However it was not until 2010 that environmental and health concerns related to PFAS became evident. The science has evolved since then, and in May 2016, the USEPA issued a lifetime drinking water Health Advisory for PFOA and PFOS of 70 ppt, singly or combined.

The MDEQ has been actively investigating PFAS contamination of groundwater at WAFB since 2010. To conduct a risk assessment of the hazards related to environmental contamination to humans requires knowledge of two components: (1) the toxicity of the chemicals, and (2) exposure to the chemicals. As more information on the toxicity of PFOA and PFOS became available after 2009, the concern for potential long-term health effects to the residents and workers at WAFB increased. The MDEQ budget approved by the state legislature (2016 Public Act 268) included boilerplate language instructing the department to "Conduct a study on the effects of long-term exposure to perfluorinated compounds." While the department does not have the authority or the expertise to conduct health studies, the department does collaborate with the Department of Health and Human Services, and the MDEQ has the ability to conduct investigations which can provide the exposure data required for a health study.

In 2015, the MDEQ requested the consultants on contract for the project to conduct a study of the capture zones of the water supply wells and pump and treat purge wells located at WAFB. The objective of the study was to determine if the drinking water supplied by the groundwater wells located on the base prior to 1997 (when the on-base water supply was connected to the Oscoda public water supply) was contaminated with PFAS. Potentially several thousand veterans and residents employed on the base during this time period consumed the water. Although this study was not intended to determine what concentrations of PFAS existed in the water supply, it was conducted to determine the potential for human exposure to contaminated drinking water.

The "*Capture Zone Delineation at Former Wurtsmith Air Force Base*" was prepared by DLZ Michigan, Inc., an environmental consulting firm providing technical support to the MDEQ at WAFB. The report was provided to the MDEQ in February 2018, and as part of the MDEQ's review of its finding, it was provided to Dr. David Hyndman, Hydrogeology Professor and Chair of the Department of Earth and Environmental Sciences, for peer review. Dr. Hyndman's comments, dated June 19, 2018, are enclosed. The peer review comments were provided to DLZ Michigan, Inc., who in turn responded (also attached) and revised the report (August 2018) as noted.

The MDEQ appreciates and respects the comments of Dr. Hyndman, as well as the response by DLZ Michigan, Inc. The MDEQ concedes that the model used in the study was chosen due to its simplicity and the ability to use existing data, as opposed to a more sophisticated model which would have required additional research to provide the variables needed to run the more sophisticated model. However, the direction to the consultant was limited to ascertain if the water supply system on the base was drawing PFAS-contaminated groundwater, and not to provide a comprehensive analysis of the volume or concentration of contamination in the aquifer or drinking water supplied by the wells.

The MDEQ believes the conclusion in the report that the "water supply wells at the WAFB were likely impacted by PFAS ... during the period of 1978 to 1997" is reasonable, and within the scope of the study. The conclusion provides a starting point for health professionals to begin an evaluation of potential health impacts to WAFB personnel and residents who lived and worked at the base during that time period. With sufficient funding and resources, additional models could be employed to provide a detailed assessment of the full nature and extent of PFAS impacts in the aquifer and the resulting water supply, as needed to build on and corroborate the conclusions of this study. The MDEQ supports the request by the veterans and WAFB personnel for a health study and is available to provide additional assistance as appropriate and as current resources permit, if requested by health professionals engaged in that endeavor.

Sincerely,

Susan Leeming, Director
Remediation and Redevelopment Division
517-284-5144

Enclosures

CAPTURE ZONE DELINEATION AT FORMER WURTSMITH AIR FORCE BASE (WAFB)

PREPARED FOR:

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
REMEDIATION AND REDEVELOPMENT DIVISION
CONSTITUTION HALL
525 WEST ALLEGAN STREET
LANSING, MICHIGAN 48933

PREPARED BY:

DLZ MICHIGAN, INC.
1425 KEYSTONE AVENUE
LANSING, MICHIGAN 48911

DLZ PROJECT NO.: 1341-6550-37

AUGUST 2018

DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

CAPTURE ZONE DELINEATION AT FORMER WURTSMITH AIR FORCE BASE (WAFB)

PREPARED FOR:

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
REMEDIATION AND REDEVELOPMENT DIVISION
CONSTITUTION HALL
525 WEST ALLEGAN STREET
LANSING, MICHIGAN 48933

PREPARED BY:

DLZ MICHIGAN, INC.
1425 KEYSTONE AVENUE
LANSING, MICHIGAN 48911

DLZ PROJECT NO.: 0941-6337-00

AUGUST 2018

TABLE OF CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

DLZ Michigan, Inc. (DLZ) was retained by the Michigan Department of Environmental Quality (MDEQ) to complete capture zone delineations for the former Wurtsmith Air Force Base (WAFB) water supply and pump and treat system wells. The purpose of the capture zone delineation was to determine whether drinking water supply wells may have been impacted by poly- and perfluorinated alkyl substances (PFAS) prior to 1997, when the water supply was switched to the Oscoda Municipal Water System. The base water supply was changed to the Huron Shores Regional Utility Authority (HSRUA) in the early 2000s.

1.1 Site History

The WAFB was used by the military as an air base from approximately 1924 to 1993. The base was expanded in 1958 to support the Air Force Strategic Air Command. The expansion included expanding the airfield, construction of maintenance hangars, a dormitory complex, family housing, a community center, exchange shops and a theatre. The WAFB had a drinking water supply system, consisting of several water supply wells, which operated from 1942 to 1997, when the water supply was switched to the Oscoda Municipal Water System. The water supply wells were screened within the shallow aquifer.

1.2 Site Description

The former WAFB is in Oscoda, Michigan (Figure 1). The site consists of 5,221 acres and is located less than one mile west of Lake Huron. The site is bounded by Van Etten Lake to the east and northeast, Van Etten Creek to the east, the Huron National Forest to the south, and the Alpena State Forest to the west.

1.3 Water Supply Wells and Pump and Treat Purge Wells

Ten drinking water supply wells formerly operated at the site (AF1, AF2, AF3, AF4, AF5, AF18, AF19, AF30, AF31, and AF32). A number of pump and treat purge wells were later installed to collect contaminated groundwater. Purge wells AF55, AF56, AF57, AF58, AF59, and AF60 were installed to collect water from a trichloroethylene (TCE) groundwater plume. Purge wells AF55 through AF60 were later replaced by purge wells AS-PW1, AS-PW-2, AS-PW3, AS-PW-4, and AS-PW-5 (the Arrow Street pump and treat system). Drinking water wells AF1, AF2, AF3, and AF18 were converted to pump and treat purge wells after contaminants were discovered in drinking water. The Mission Street Pump and Treat System, consisting of purge wells MS-PW-1`, MS-PW-2, MS-PW-3, and MS-PW-4, and the Benzene Plant pump and treat system, consisting of wells BZ-PW-1, BZ-PW-2, BZ-PW-3, and BZ-PW-4 were also installed to remediate groundwater contaminant plumes at the site. A Historical Water Supply Well and Purge Well Use Timeline is provided as Table 1. The Timeline summarizes the operating history of the water supply wells and the pump and treat purge wells.

1.4 PFAS Concentrations in Groundwater

PFAS were first detected in groundwater samples at the WAFB in 1998 and 1999 at fire training area FT-02 (Moody et al, 2000 and Moody et al 2003). The source of the PFAS is believed to be Aqueous Film Forming Foam (AFFF), which had been used to extinguish fires at United States Air Force Bases since the early 1970's. Monitoring performed by the MDEQ starting in 2010 indicated that PFAS were found in samples from every

monitoring well that was analyzed (MDEQ, 2017). PFAS concentrations in groundwater at the WAFB are shown in Figure 2.
Use of AFFF at the WAFB began in 1970 (AR 471539). The Final Preliminary Assessment Report (AR 471539) listed 20 areas where AFFF was "stored, handled, used, or released". These areas are depicted in Figure 3 and include:

- Aircraft crash sites: (KC-135 and A-6 crash sites) where AFFF was used to put out fires.
- Fire Training Area FT-02: where AFFF was used in fire training exercises.
- Areas where AFFF was stored: Building 5084 AFFF Pump Station, Building 5091 Fire Station, Building 5092 Vehicle Operations, Buildings 5600-5610 Defense Reutilization and Marketing Office.
- Areas where AFFF use or release was documented: Base Operations Area, Fire Station Buildings 16, 20, and 45, Building 5063 Maintenance Hangar and AFFF Retention Lagoon, Building 5306 Integrated Maintenance, Alert Aircraft Area, Wastewater Treatment Plant (WTP) Sludge Drying Beds, WTP Aeration Lagoons, WTP Seepage Lagoons, WTP Sludge Disposal Area, and Sanitary Sewer System

As of January 10, 2018, the MDEQ has established drinking water criteria for perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), which are each a constituent of PFAS family of compounds. The residential and nonresidential drinking water criteria for the combined concentrations of PFOA and PFOS are 0.070 ug/L (70 parts per trillion (ppt)). According to MDEQ (2017), remediation of PFAS is difficult and inefficient using conventional treatment technologies. Recent analysis of the Arrow Street, Benzene Plant, and Mission Drive pump and treat system's discharge to surface water has measured PFAS concentrations in the range of 10^3 ppt. The State of Michigan generic discharge limit to surface water is 12 ppt for PFOS and 12,000 ppt for PFOA.

2.0 OBJECTIVES AND SCOPE OF WORK

The objective of this study was to estimate the capture zones for the water supply wells and pump and treat purge wells located at the WAFB to determine if the capture zones likely extend into areas where PFAS have been detected. The scope of work consisted of the following tasks:

- Groundwater elevation data, collected in 1980, 1989, and 1995 and surface water elevations were used to determine the regional groundwater flow direction. A potentiometric surface for each of the years listed above was generated.

- Development of a two-dimensional, analytical groundwater flow model and a particle-tracking model to calculate the capture zones for the water supply wells and pump and treat purge wells at the WAFB.

3.0 LOCAL GEOLOGY AND HYDROGEOLOGY

The aquifer at the site is unconfined and consists of medium to coarse sands with some gravel. The sand and gravel layer extends to an average depth of 65 feet below ground surface (bgs). The sand and gravel aquifer is underlain by a clay layer which is relatively impermeable. The depth to groundwater ranges from approximately 10 to 25 feet bgs. Groundwater flows to the east towards Van Etten Lake and Van Etten Creek, and to the south towards the Au Sable River. A groundwater divide extends across the WAFB such that groundwater south of the divide flows south towards the Au Sable River and groundwater north of the divide flows east towards Van Etten Lake and Van Etten Creek (AR 15, AR 27, AR 77).

4.0 AQUIFER PROPERTIES AND MODEL ASSUMPTIONS

Aquifer properties used in groundwater modeling and capture zone delineations were based on the data gathered from the literature and from previous groundwater modeling studies. Aquifer properties and model assumptions are listed below (AR 15, AR 27, AR74, AR 77, AR 1401.1, Toltest 2004).

1. Thickness of upper sand and gravel layer: 65 feet (AR 15, AR 27, AR 77, AR 1401.1)

2. Depth to groundwater: ranges from 10 to 25 feet (AR 15, AR 27). Average depth to groundwater = (10 + 25)/2 = 17.5 feet

3. Aquifer saturated thickness (b): 65-17.5 = 47.5 feet.

4. Hydraulic conductivity (K): 120 ft/day (AR 27, AR 77).

5. Specific yield: 0.2 (AR 15, AR 1410.1)

6. Aquifer Transmissivity: K x b = 120 ft/day x 47.5 ft = 5,700 ft^2/day = 42,636 gal/day/ft

7. Water supply well and purge well horizontal coordinates: listed in Table 2.

8. Water supply well and purge well pumping rates: listed in Table 3 (AR 74, AR 77, AR 1410.1, Toltest 2004).

9. Duration of pumping at water supply and purge wells: 30 days (assumed pumping time to assure steady state conditions at wellfields.

5.0 GROUNDWATER MODELING

5.1 Modeling Approach

The modeling approach consisted of three stages:

- Initially potentiometric surface maps were generated using data from monitoring wells and surface water elevations. A potentiometric surface grid file was produced.
- A two-dimensional analytical groundwater model was used to calculate drawdowns in the water table under pumping conditions. The potentiometric surface grid files were superimposed on the drawdown grid files to estimate the stressed potentiometric surface.
- A particle tracking program was used to estimate the capture zones of the water supply and purge wells.

5.2 Groundwater Elevations and Potentiometric Surface Maps

Groundwater elevation and surface water elevation data for the years 1980, 1989, and 1995 were used to generate potentiometric surface maps. The years 1980, 1989, and 1995 were selected to define the potentiometric surface for the following reasons:

- These years had groundwater elevation measurements from a large number of wells.
- Groundwater elevation measurements from these years were available from wells with a wide distribution across the WAFB.
- These dates extend across the time when PFAS were in use at the WAFB and the water supply system was in use.

Groundwater elevation data files consisted of groundwater elevations and horizontal state plane coordinates (northings and eastings) at each monitoring well. The groundwater elevation data files also included surface water elevations and horizontal coordinates from Van Etten Lake, Lake Huron, and local ponds. DLZ used the computer program SURFER to produce gridded potentiometric surface maps for the years 1980, 1989, and 1995 by the kriging method. The potentiometric surface maps are provided as Figures 3, 4, and 5.

Monitoring wells in the general vicinity of the purge and water supply wells were not used for groundwater elevation data to define the regional potentiometric surface because they were within the cone of depression of the pumping wells. DLZ used the analytical model CAPZONE to estimate the 0.02 ft cone of depression contour line for the pumping wells and excluded all monitoring wells within the 0.02 ft cone of depression contour from the data base used to define the potentiometric surface. Thus, the potentiomentric surface maps (Figures 3, 4, and 5) do not show any effects of drawdown from the pumping wells.

5.3 Stressed Potentiometric Surface and Particle Tracking

A two-dimensional, analytical groundwater flow model and a particle-tracking model were used to calculate the capture zones for the water supply and purge wells at the WAFB. DLZ employed CAPZONE (Bair *et al.*, 1992) and GWPATH (Shafer, 1992) to calculate the capture zone of each well.

CAPZONE, developed by the Ohio State University Hydrogeology Program, is an analytical flow model for simulating groundwater flow to wells in an unconfined, semi-confined, or confined aquifer. GWPATH estimates horizontal or vertical fluid pathlines and travel times in fully saturated, complex groundwater flow domains. GWPATH also calculates and displays time-related capture zones of pumping wells on a stressed potentiometric surface.

CAPZONE computes drawdowns due to pumping at one or multiple locations, using either the Theis equation or the Hantush-Jacob equation. The Theis (unconfined aquifer) solution was used to compute drawdowns at the WAFB wellfields. This simulation of drawdowns was accomplished by initially assuming a zero hydraulic gradient across the site, then running the model with the wells pumping until steady state conditions were achieved. CAPZONE corrects drawdowns automatically for spatial changes in saturated thickness due to pumping from wells in unconfined aquifers.

The SURFER grid file, representing the regional potentiometric surface was superimposed on the CAPZONE drawdown file, to create a stressed potentiometric surface under pumping conditions. The modeling was performed for nine separate years, which were selected based on changes in pumping rates that could influence capture zone size. The simulated stressed potentiometric surfaces under pumping conditions are listed below:

- 1978 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1978 pumping rates, superimposed on 1980 SURFER potentiometric surface grid file.

- 1980 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1980 pumping rates, superimposed on 1980 SURFER potentiometric surface grid file.

- 1982 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1982 pumping rates, superimposed on 1980 SURFER potentiometric surface grid file.

- 1983 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1983 pumping rates, superimposed on 1980 SURFER potentiometric surface grid file.

- 1985 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1985 pumping rates, superimposed on 1989 SURFER potentiometric surface grid file.

- 1987 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1987 pumping rates, superimposed on 1989 SURFER potentiometric surface grid file.

- 1989 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1989 pumping rates, superimposed on 1989 SURFER potentiometric surface grid file.

- 1995 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1995 pumping rates, superimposed on 1995 SURFER potentiometric surface grid file.

- 1997 Pumping Potentiometric Surface - CAPZONE pumping well drawdown file using 1997 pumping rates, superimposed on 1995 SURFER potentiometric surface grid file.

The nine stressed, steady state potentiometric surfaces created by modeling the wells at the wellfields were used as input for GWPATH to conduct particle tracking. Using the "reverse tracking" option within GWPATH, the time of travel pathlines and capture zones for the WAFB supply and purge wells were calculated. DLZ assumed a travel time that would trace the particles back to the year 1968, just before the use of AFFF, which reportedly began in 1970 (AR 471539). Thus the 1978 particle tracking used a 10-year travel time, the 1980 particle tracking used a 12-year travel time, the 1982 particle tracking used a 14-year travel time, etc. Figures 6, 7, 8, 9, 10, 11, 12, 13, and 14 depict the capture zones of the water supply and purge well capture zones. Capture zones for the water supply wells can be distinguished from the pump and treat purge wells, as they are plotted in different colors. The capture zones are plotted on a base map which shows the current approximate extent of the PFAS groundwater plume. Thus, if a capture zone extends into an area in which groundwater is contaminated with PFAS, one may assume that the PFAS could have impacted the water supply, or purge well.

6.0 CONCLUSIONS

- The regional direction of groundwater flow in the area is to the east and south.

- Particle tracking results for each of the years modeled (1978, 1980, 1982, 1983, 1985, 1987, 1989, 1995, and 1997) indicate that capture zones for the water supply and purge wells extend across areas in which PFAS have been detected. These results from the capture zone analysis suggest that the drinking water supply wells at the WAFB were likely impacted by PFAS, and that WAFB personnel and residents may have been exposed to PFAS in drinking water during the period from 1978 to 1997.

- These results also suggest that the pump and treat systems at the WAFB collected PFAS impacted water. The residential and nonresidential drinking water criteria for the combined concentrations of PFOA and PFOS are 0.070 ug/L (70 ppt). According to MDEQ (2017), remediation of PFAS is difficult and inefficient using conventional treatment technologies. Recent analysis of the Arrow Street, Benzene Plant, and Mission Drive pump and treat system's discharge to surface water has measured PFAS concentrations in the range of 10^3 parts per trillion (ppt). The State of Michigan generic GSI criteria are 12 ppt for PFOS and 12,000 ppt for PFOA. Thus, it is likely that PFAS were present in the effluent from the pump and treat systems for some time. This water, treated for contaminants other than PFAS, at some point contained PFAS above the current GSI criterion for PFOS, which was discharged to surface water bodies. The discharge limits would be established by the Michigan Water Resources Division in a NPDES Permit or for the military and other federal agencies a Substantial Requirements Document (SRD).

- These conclusions do not contradict the findings of the MDEQ January 2017 Hydrant Report.

7.0 REFERENCES

Administrative Record (AR) 15, 1983. Ground-Water Contamination at Wurtsmith Air Force Base, Michigan; U.S. Geological Survey Water Resources Investigations Report 83-4002.

Administrative Record (AR) 27, 1986. Assessment of Ground-Water Contamination at Wurtsmith Air Force Base, Michigan 1982-1985; U.S. Geological Survey Water Resources Investigations Report 86-4188.

Administrative Record (AR) 74, 1990. Installation Restoration Program Phase II – Confirmation/Quantification Stage 2 Wurtsmith Air Force Base, Michigan: An Environmental Data-Base System Volume II.

Administrative Record (AR) 77, 1990. Installation Restoration Program Phase II – Confirmation/Quantification Stage 2 Wurtsmith Air Force Base, Michigan: Hydrogeology Near Wurtsmith Air Force Base, Michigan.

Administrative Record (AR) 1410.1, 2002. Final Consolidated Remedial Action Plan 0Installation Restoration Program Phase II – Confirmation/Quantification Stage 2 Wurtsmith Air Force Base, Michigan: Hydrogeology Near Wurtsmith Air Force Base, Michigan.

Administrative Record (AR) 471539, 2016. Final Perfluorinated Compounds Preliminary Assessment Former Wurtsmith Air Force Base, Michigan. AMEC Foster Wheeler.

Bair, Scott E., Springer, Abraham E., and Roadcap, George S., 1992. CAPZONE. International Ground Water Modeling Center, Colorado School of Mines, Golden, CO 80401.

Michigan Department of Environmental Quality, 2017. PFC Concentrations in Water Retained within Fire Hydrants at Former Wurtsmith Air Force Base (WAFB).

Moody, C.B., 2000. Occurrence and Distribution of Perfluorinated Surfactants in Groundwater Contaminated by Fire-Fighting Activity. Oregon State University Ph.D. Thesis.

Moody, C.A., Hebert, G.N., Strauss, S.H., and Field, J.A., 2003. Occurrence and persistence of perfluorooctanesulfonate and other perfluorinated surfactants in groundwater at a fire-training area at Wurtsmith Air Force Base, Michigan, USA. Journal of Environmental Monitoring 5: pp 341-345.

Shafer, John M., 1992. GWPATH 4.0 Ground-Water Pathline and Travel Time Analysis.

TolTest, 2004. Monthly Technical Status Report for December 01-31, 2003.

FIGURES

Legend

- Former Wurtsmith AFB Installation Boundary
- Railroads
- Roads

Note:
1. Orthophoto from ESRI
2. Site Features from non DLZ sources, accuracy and methodology could not be verified

DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 1
Site Vicinity Map
Former Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,200 2,400 Feet
1 inch = 2,500 feet

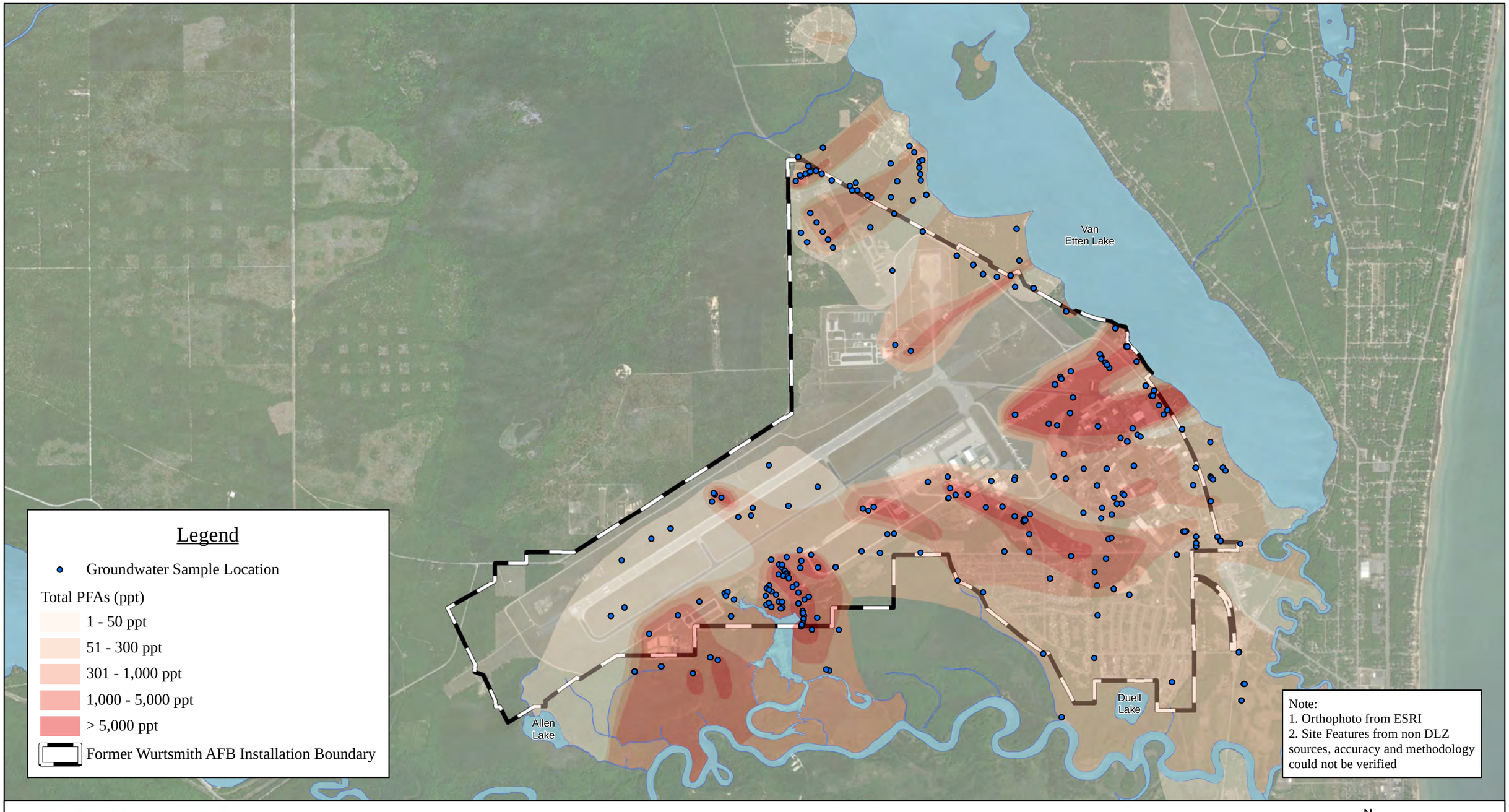
N W E S

Fig: 1

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Date: 2/5/2018

Document Path: M:\Proj\1341\6550 MDEQ EER Contract\37 Wurtsmith\GIS\MXDs\1-2018\Fig_1_site_vicinity.mxd



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 2
Estimated Extent of PFAs in Groundwater
Former Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

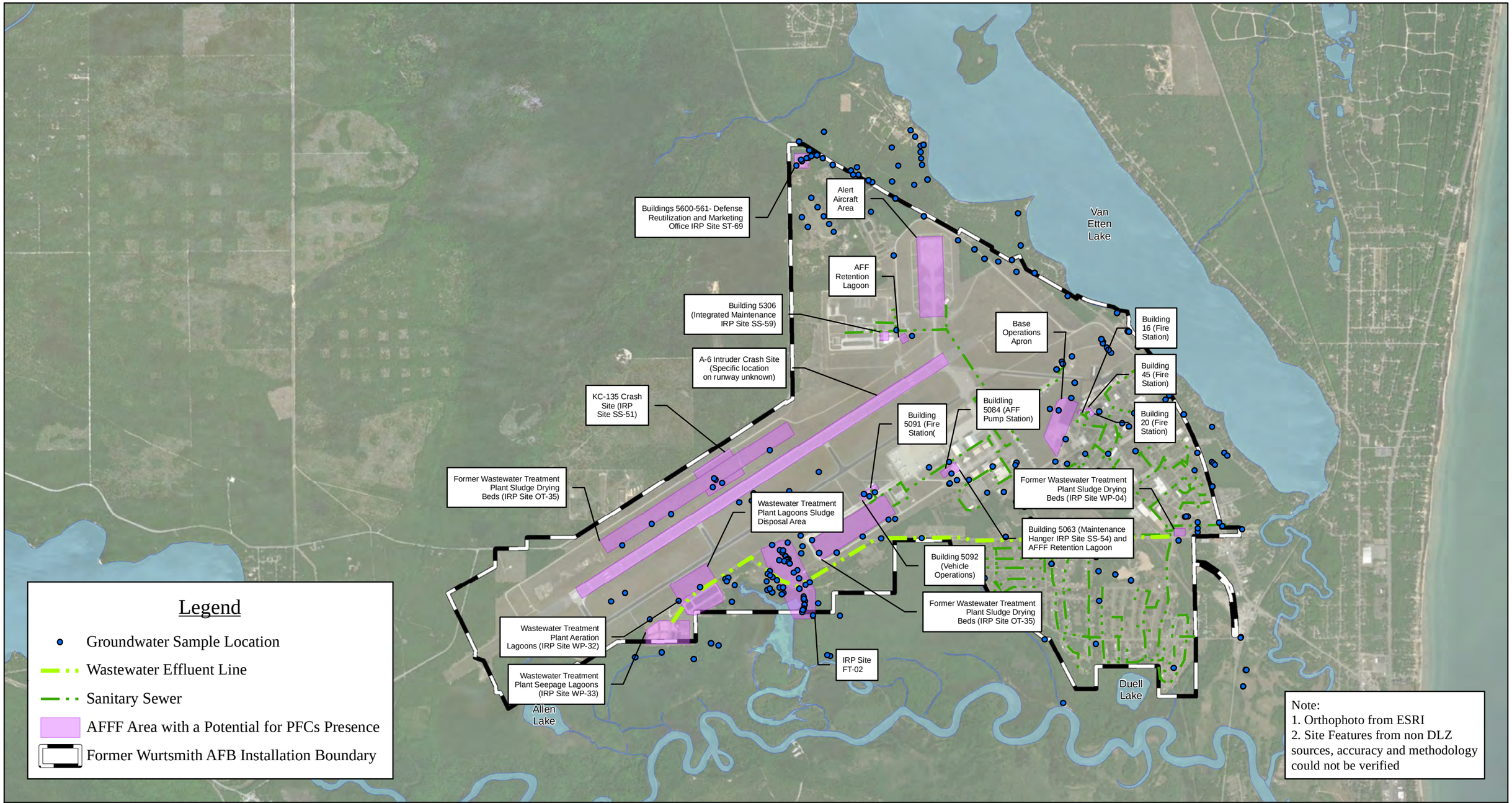
N
W E
S

Fig: 2

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\Proj\1341\6550 MDEQ EER Contract\37 Wurtsmith\GIS\MXDs\1-2018\Fig_2_PFA_Map.mxd

Date: 2/5/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 3
Potential AFFF Areas
Former Wurtsmith AFB

3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

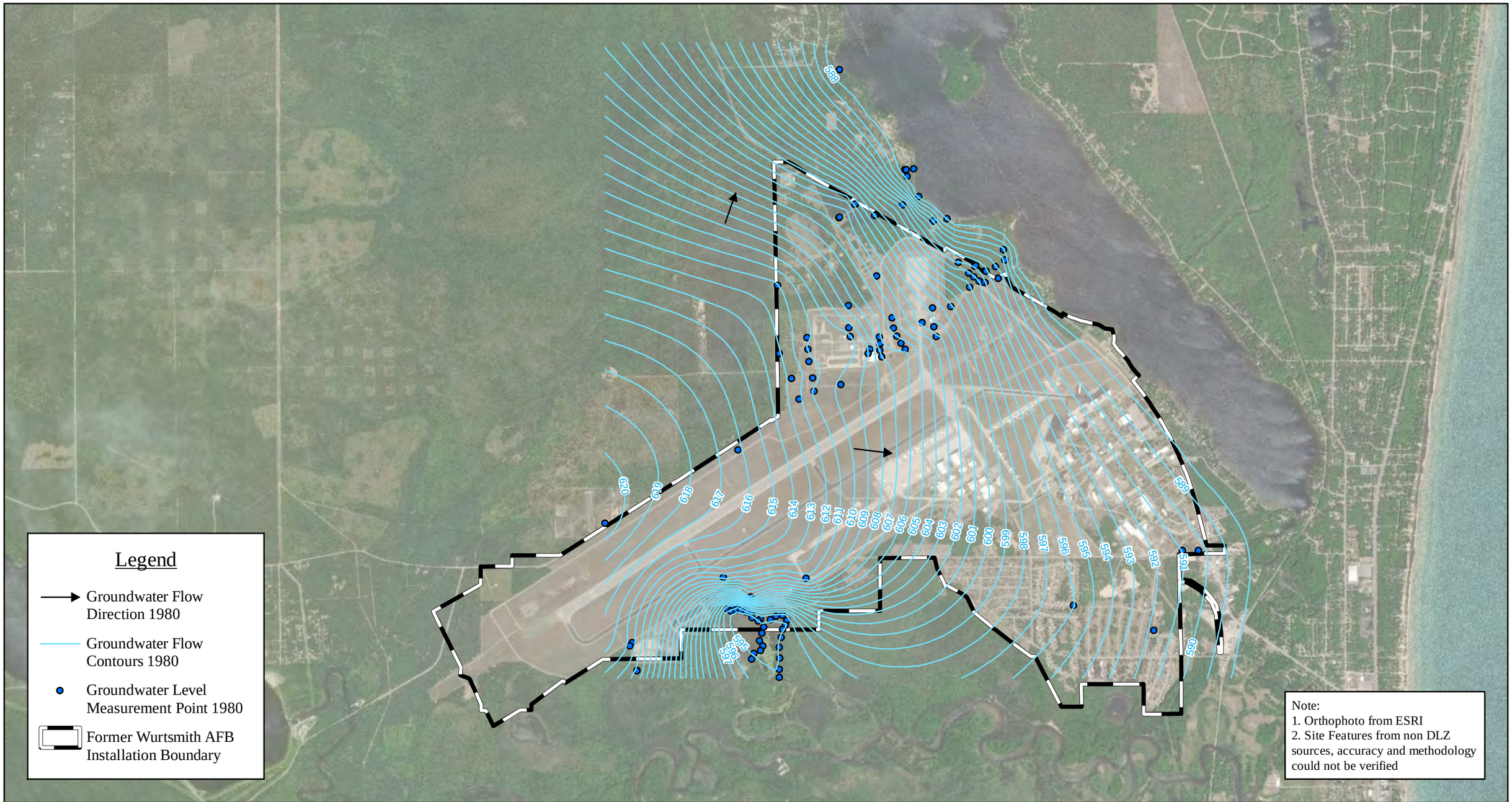
N
W E
S

Fig: 3

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Date: 2/6/2018

Document Path: M:\Proj\1341\6550 MDEQ EER Contract\37 Wurtsmith\GIS\MXDs\1-2018\Fig_3_Potential_AFFF Areas.mxd



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

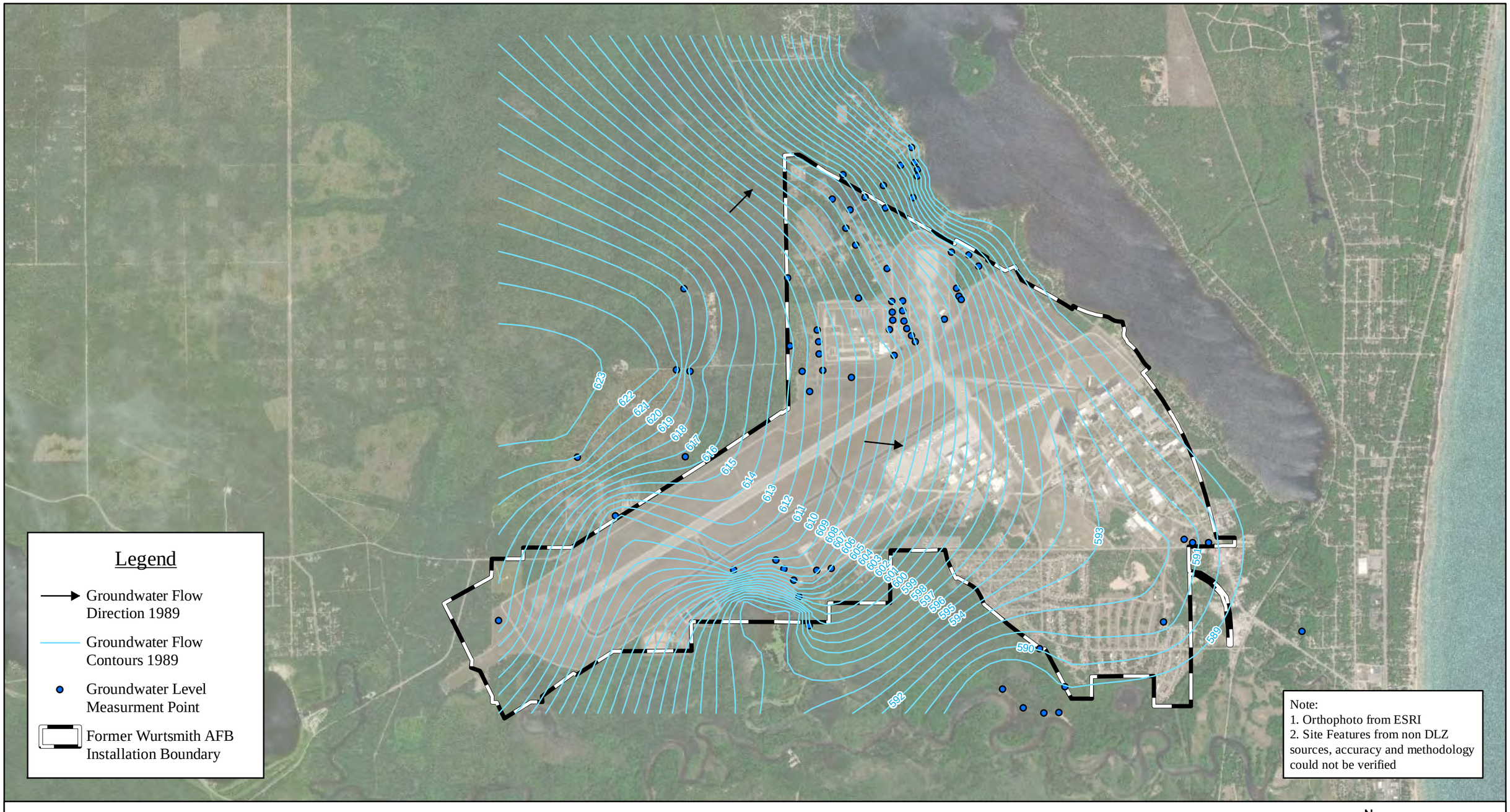
Figure: 4
Groundwater Potentiometric Surface Map 1980
Former Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

Fig: 4

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Date: 8/17/2018

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_4_Groundwater_flow_1980.mxd



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 5
Groundwater Potentiometric Surface Map 1989
Former Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

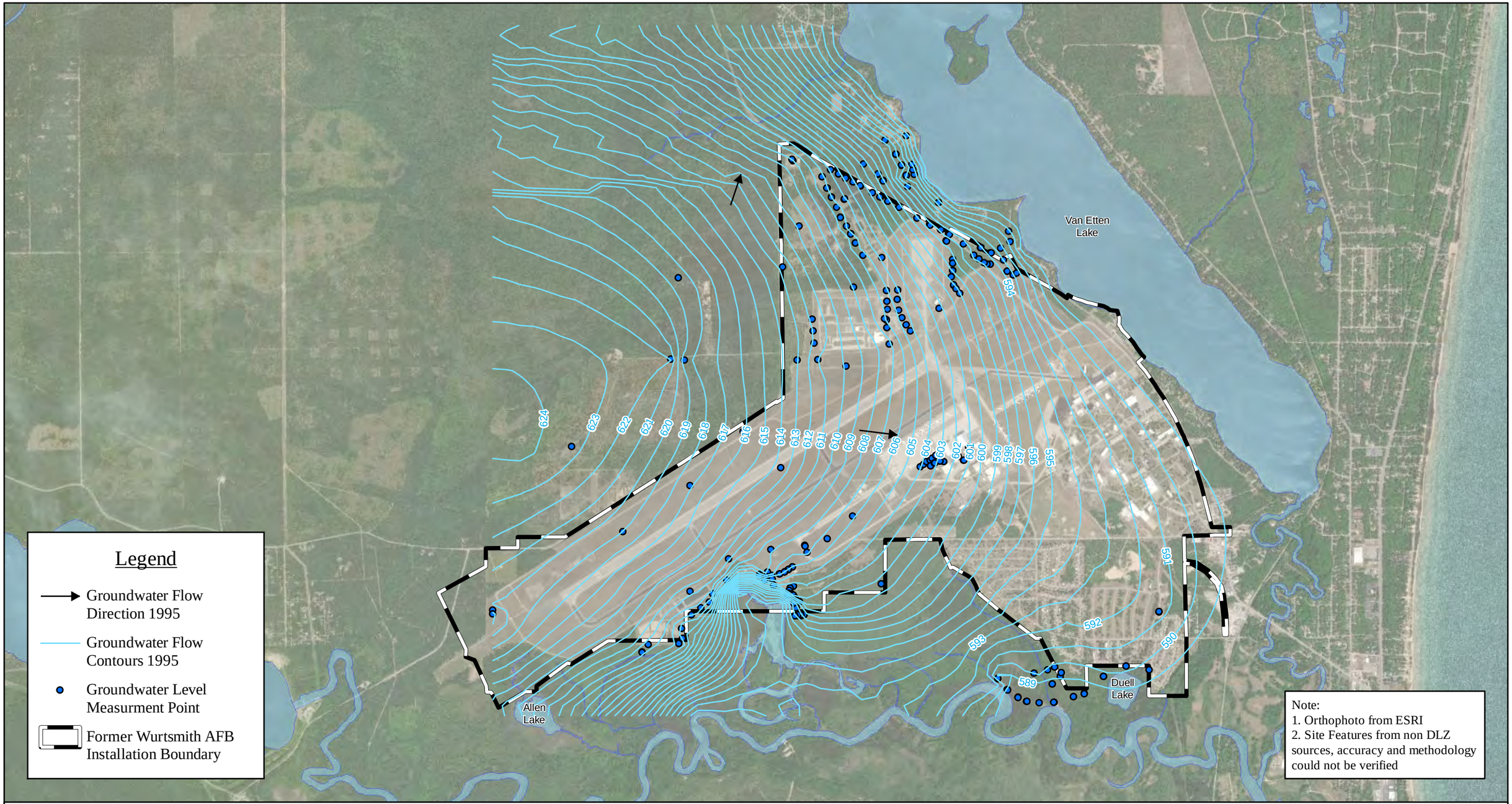
N W E S

Fig: 5

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_5_Groundwater_flow_1989.mxd

Date: 8/17/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 6
Groundwater Potentiometric Surface Map 1995
Former Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

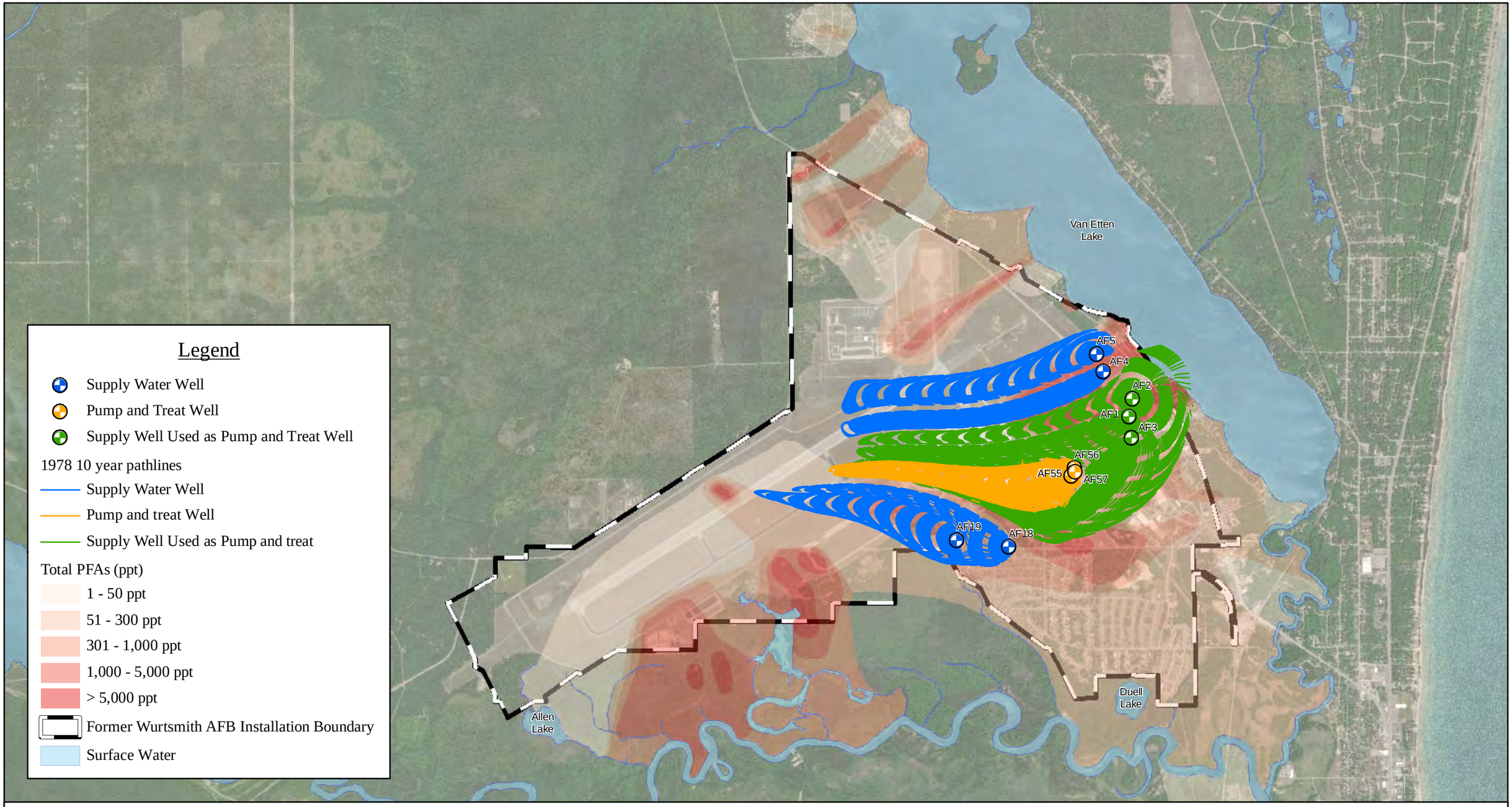
N
W E
S

Fig: 6

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Date: 8/17/2018

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_6_Groundwater_flow_1995.mxd



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 7
1978 10 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

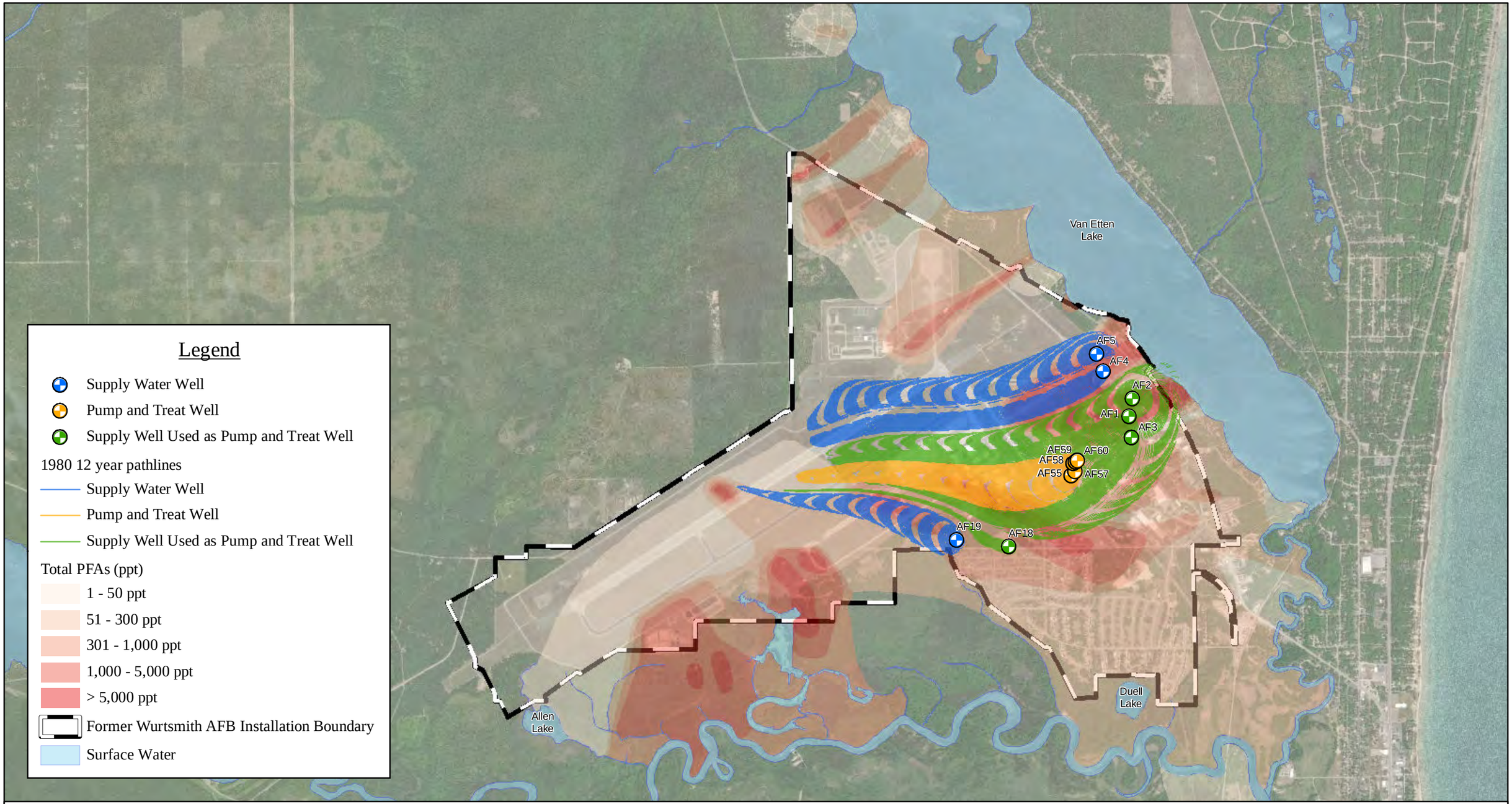
N W E S

Fig: 7

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_7_1978_10yr_Pathlines.mxd

Date: 8/16/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 8
1980 12 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

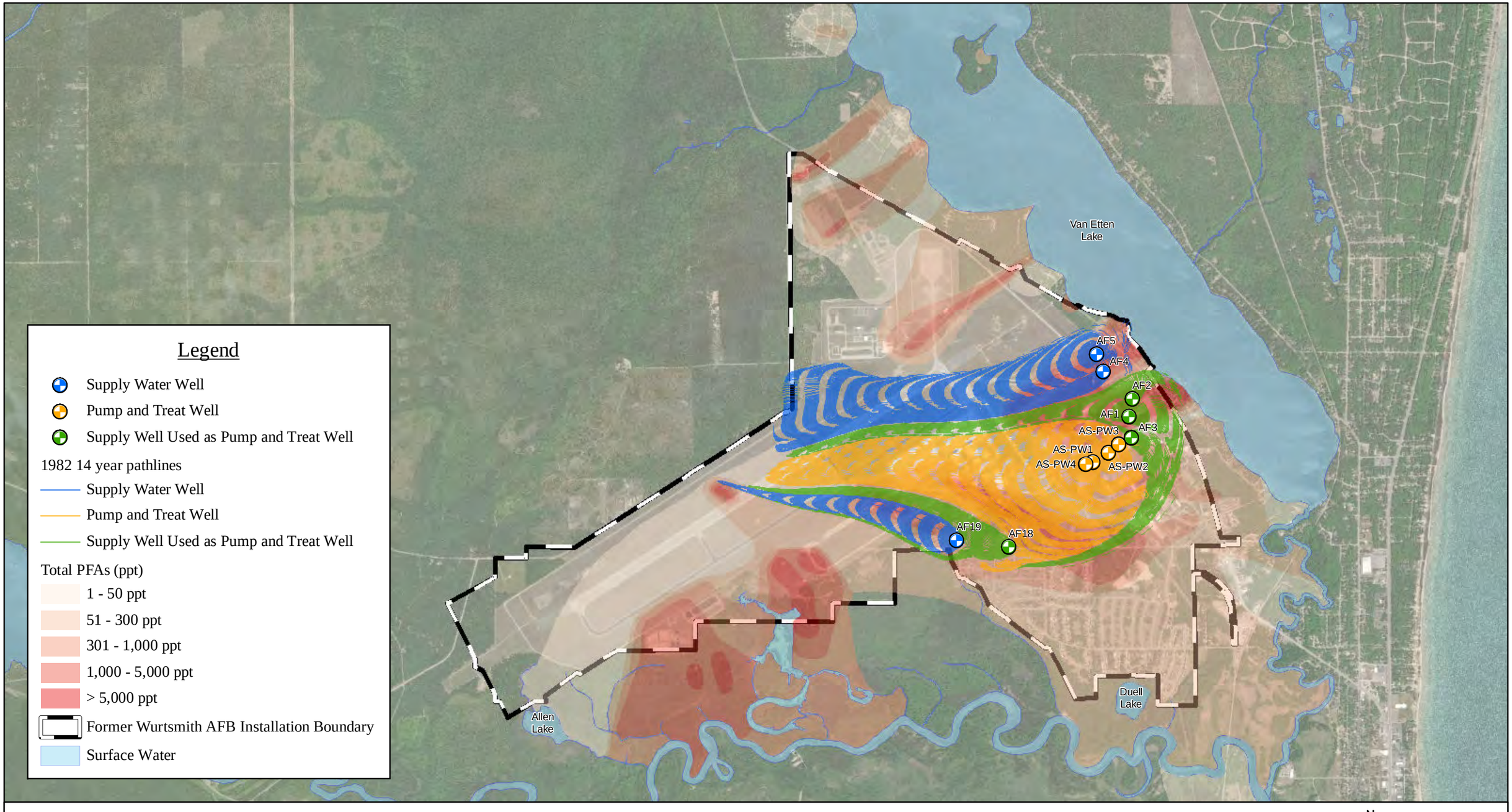
N
W E
S

Fig: 8

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_8_1980_10yr_Pathlines.mxd

Date: 8/16/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 9
1982 14 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

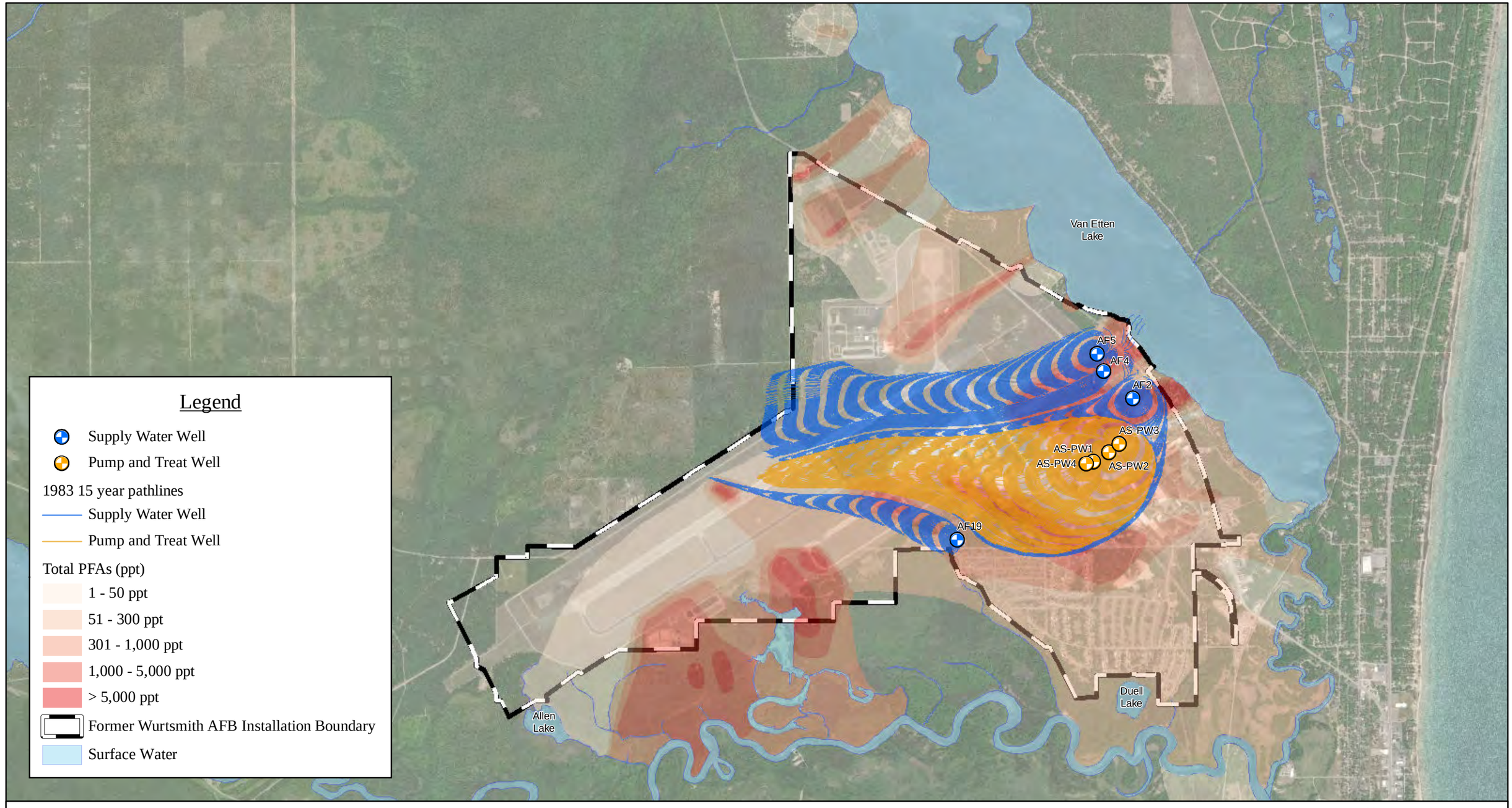
N
W E
S

Fig: 9

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_9_1982_14yr_Pathlines.mxd

Date: 8/16/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 10
1983 15 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

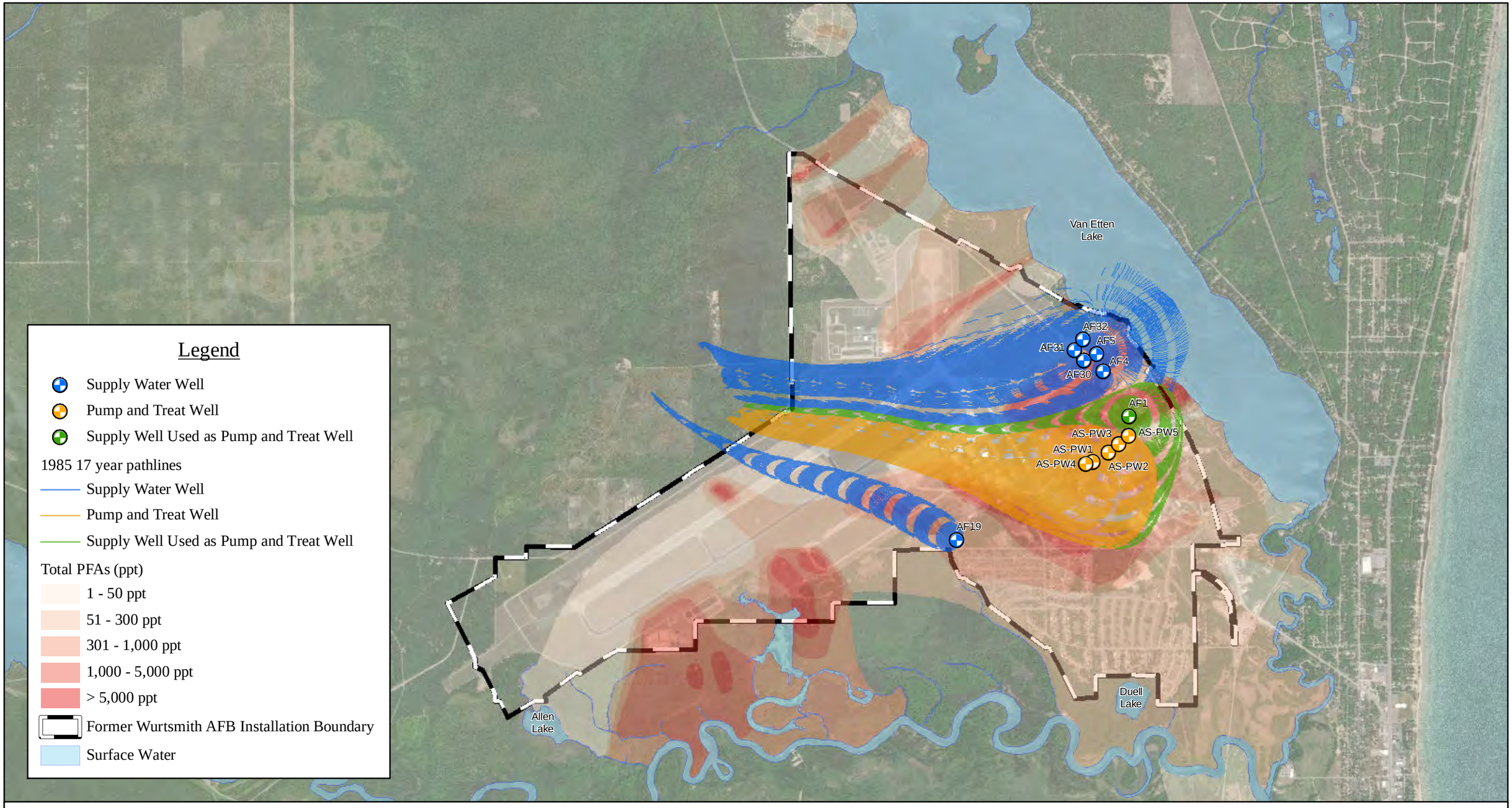
N W E S

Fig: 10

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Date: 8/16/2018

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_10_1983_15yr_Pathlines.mxd



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 11
1985 17 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

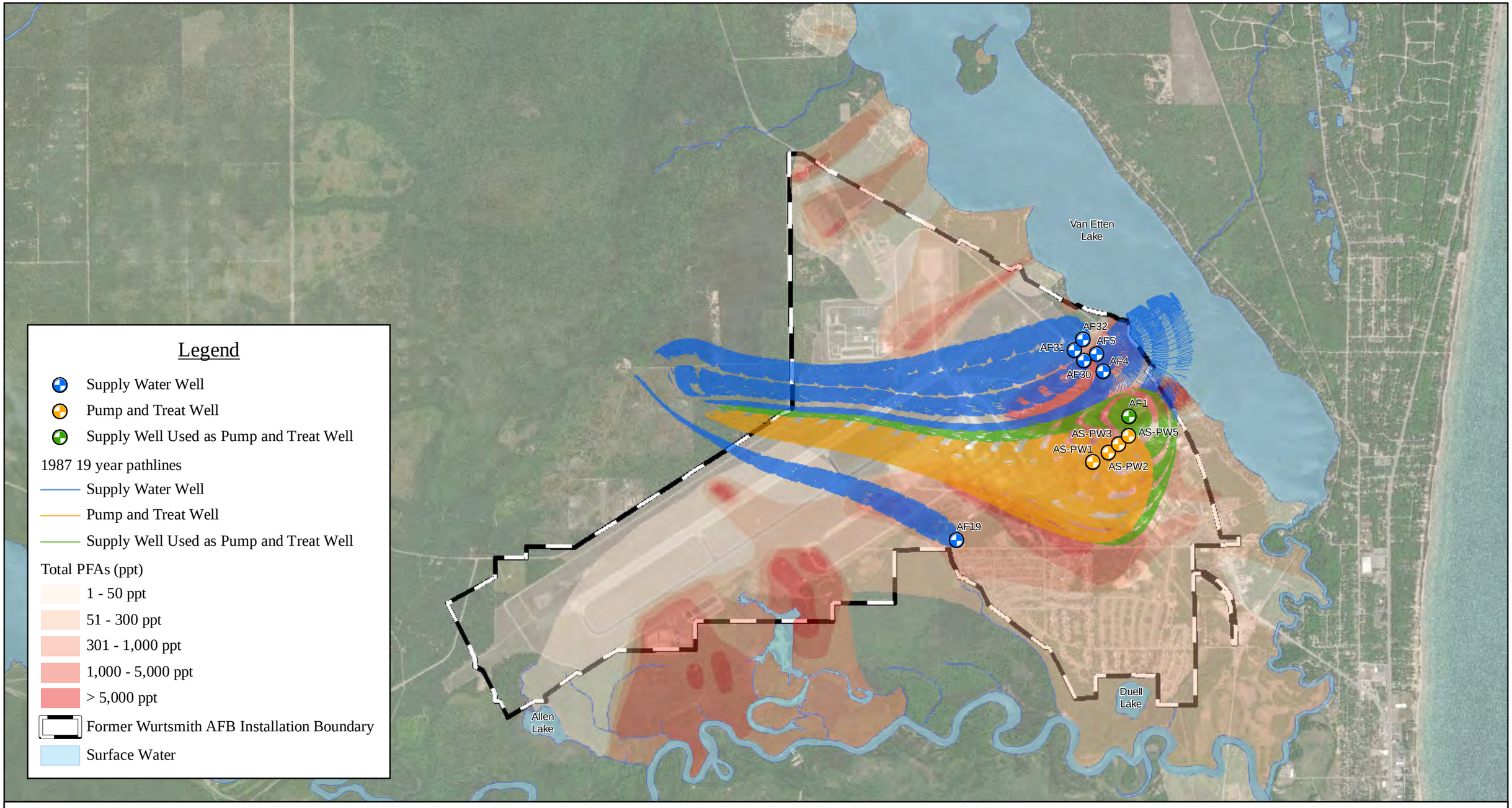
N W E S

Fig: 11

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_11_1985_17yr_Pathlines.mxd

Date: 8/16/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 12
1987 19 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

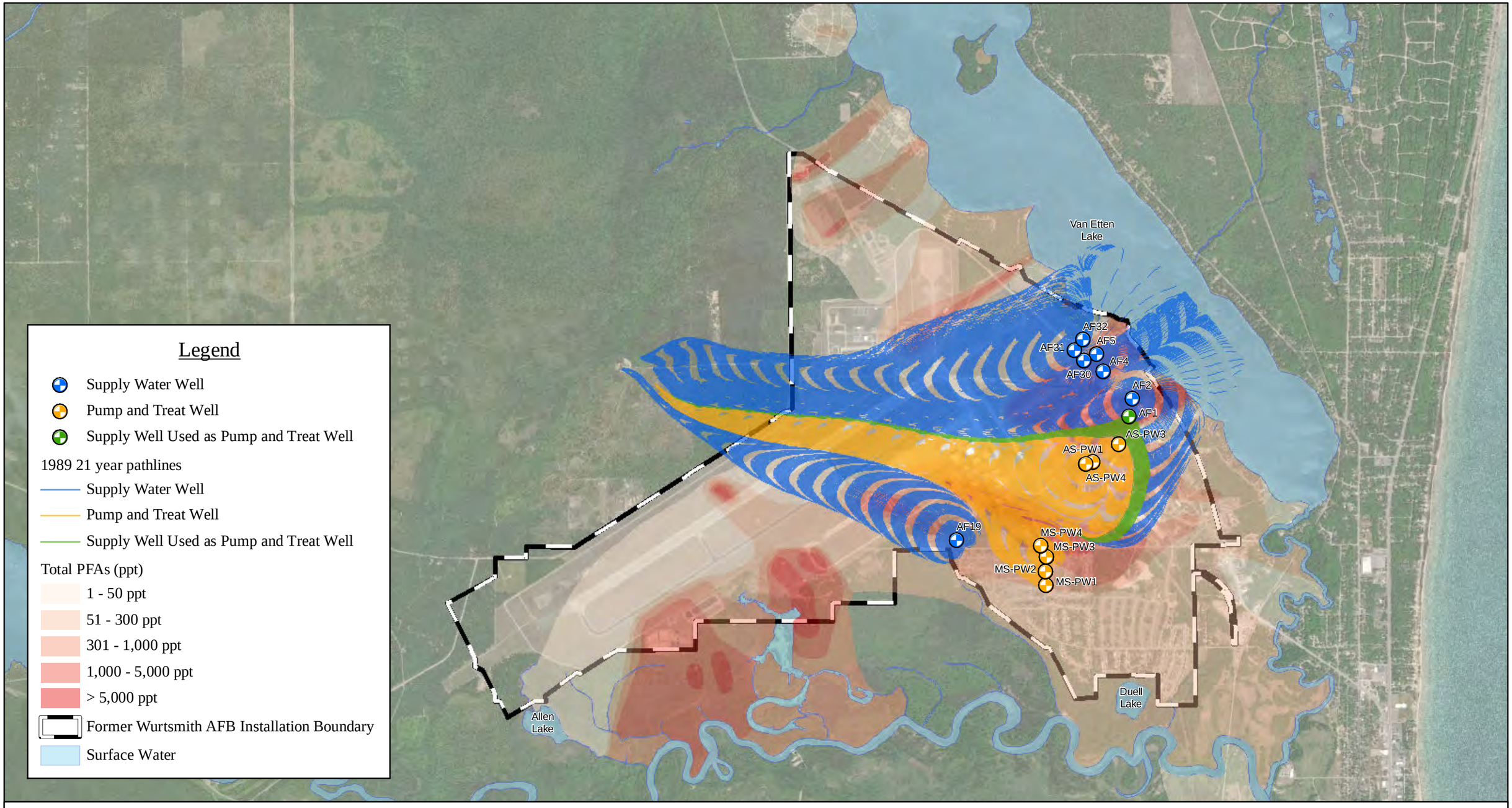
N W E S

Fig: 12

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_12_1987_19yr_Pathlines.mxd

Date: 8/16/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 13
1989 21 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,200 2,400 Feet
1 inch = 2,500 feet

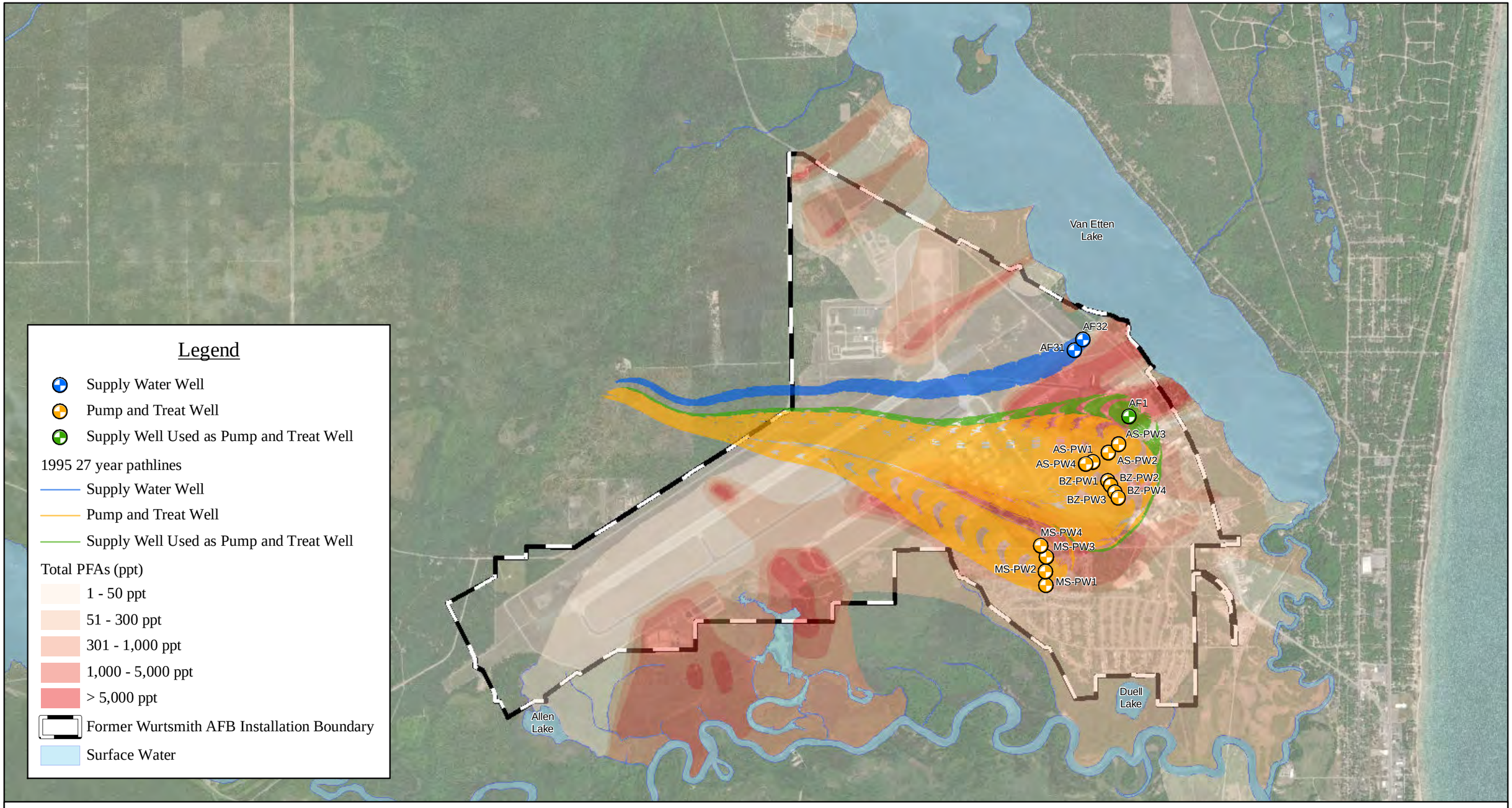
N W E S

Fig: 13

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_13_1989_21yr_Pathlines.mxd

Date: 8/16/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 14
1995 27 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

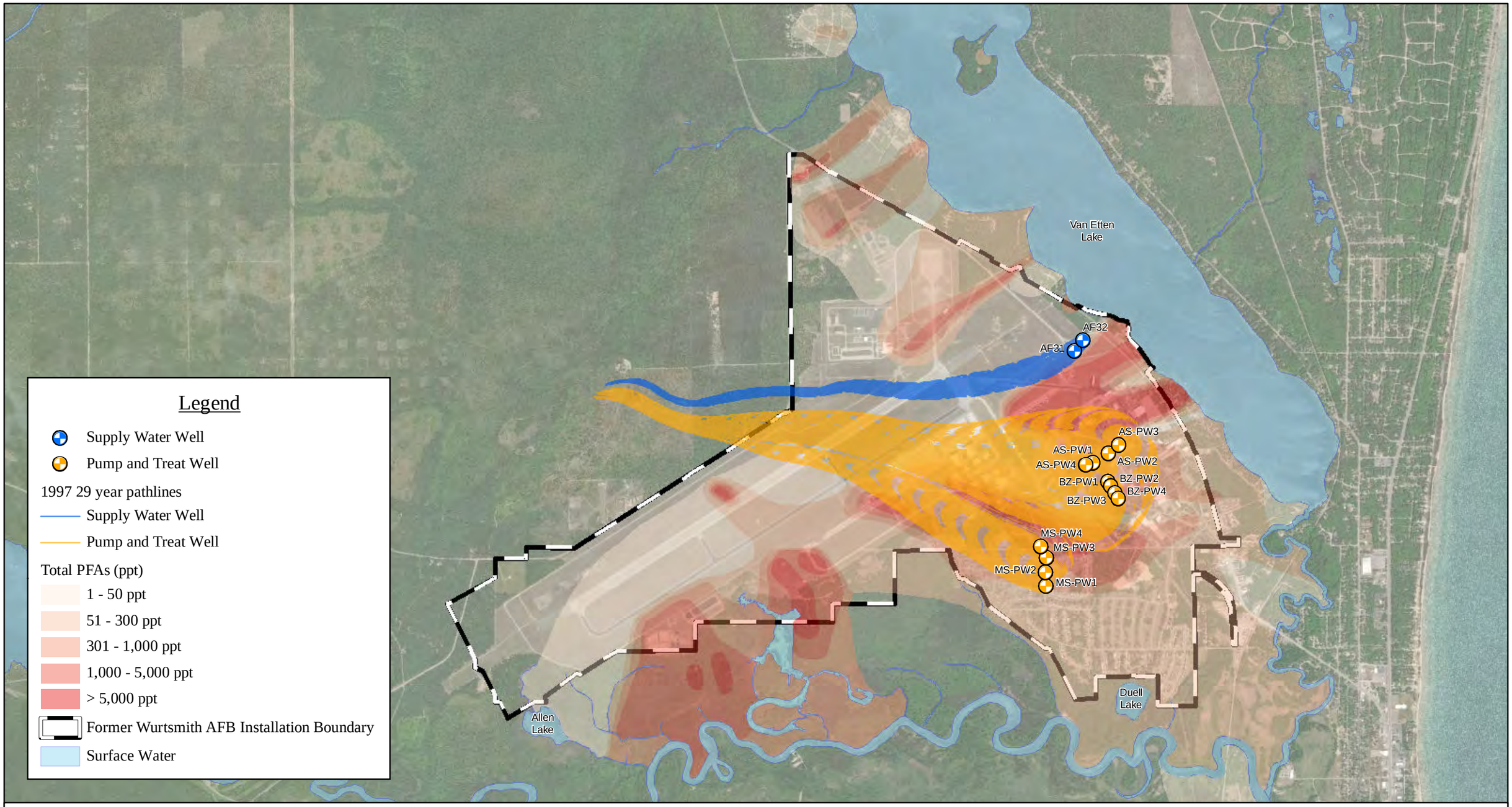
N W E S

Fig: 14

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_14_1995_27yr_Pathlines.mxd

Date: 8/16/2018



DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

Figure: 15
1997 29 Year Pathlines
Wurtsmith AFB
3961 E Airport Drive
Oscoda Twp, MI 48750
Michigan Department of Environmental Quality

0 1,250 2,500 Feet
1 inch = 2,500 feet

N
W E
S

Fig: 15

Drawn: GH Checked: Approved: DLZ Project No. 1341-6550-37

Date: 8/16/2018

Document Path: M:\proj\1341\6550 MDEQ EER Contract\37 WAFB State Funded Work\GIS\Fig_15_1997_29yr_Pathlines.mxd

TABLES

Table 1
Historical Water Supply Well and Purge Well Use Timeline

Well	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
AF1																												
AF2																												
AF3																												
AF4																												
AF5																												
AF18																												
AF19																												
AF30																												
AF31																												
AF32																												
AF55																												
AF56																												
AF57																												
AF58																												
AF59																												
AF60																												
AS-PW1																												
AS-PW2																												
AS-PW3																												
AS-PW4																												
AS-PW5																												
MS-PW1																												
MS-PW2																												
MS-PW3																												
MS-PW4																												
BZ-PW1																												
BZ-PW2																												
BZ-PW3																												
BZ-PW4																												

Capture Modeling Performed
Supply Water Well
Supply Well Used as Pump and Treat Well
Pump and Treat Well
Well Non-operational

AF = Air Force Water Supply or Purge Well
AS = Arrow Street Pump and Treat
BZ = Benzene Plant Pump and Treat
MS = Mission Street Pump and Treat

Table 2
Supply Well and Purge Well Coordinates

Well	Easting	Northing	Latitude	Longitude
AF1	19948847.51	417161.11	44.4564167	-83.3561337
AF2	19948938.76	417642.39	44.4577335	-83.3557612
AF3	19948917.98	416603.53	44.4548848	-83.3558904
AF4	19948157.44	418357.33	44.4597212	-83.3587194
AF5	19947981.94	418826.45	44.4610139	-83.3593692
AF18	19945652.35	413695.55	44.4470195	-83.3685331
AF19	19944257.99	413872.25	44.4475511	-83.3738638
AF30	19947650.13	418653.33	44.4605504	-83.3606482
AF31	19947402.51	418922.77	44.4612979	-83.3615838
AF32	19947627.72	419206.82	44.4620693	-83.3607078
AF55	19947317.57	415589.70	44.4521661	-83.3622246
AF56	19947397.30	415795.21	44.4527271	-83.3619095
AF57	19947406.78	415702.62	44.4524728	-83.3618776
AF58	19947363.90	415915.86	44.4530515	-83.3618743
AF59	19947423.89	415945.88	44.4531319	-83.3616432
AF60	19947473.88	415985.90	44.4532399	-83.3614499
AS-PW1	19947886.41	415944.40	44.4531197	-83.3600295
AS-PW2	19948300.27	416198.48	44.4538025	-83.3584326
AS-PW3	19948573.09	416420.43	44.4544019	-83.3573772
AS-PW4	19947693.62	415900.67	44.4530063	-83.3607698
AS-PW5	19948837.72	416650.38	44.4550236	-83.3563529
MS-PW1	19946639.57	412672.48	44.4441799	-83.3648015
MS-PW2	19946630.31	413035.91	44.4451771	-83.3648197
MS-PW3	19946652.30	413422.48	44.4462366	-83.3647173
MS-PW4	19946493.81	413721.50	44.4470622	-83.36531
BZ-PW1	19948288.47	415454.52	44.4517623	-83.3585132
BZ-PW2	19948361.36	415337.57	44.4514390	-83.3582396
BZ-PW3	19948480.28	415152.21	44.4509265	-83.3577931
BZ-PW4	19948563.26	414998.71	44.4505027	-83.3574826

AF = Air Force Water Supply or Purge Well

AS = Arrow Street Pump and Treat

BZ = Benzene Plant Pump and Treat

MS = Mission Street Pump and Treat

Table 3
Average Pumping Rates (GPM)

	Well	1978	1980	1982	1983	1985	1987	1989	1995	1997
Former Supply Wells	AF1	230.8	172.1	178.5		244.8	195.4	150.0	104.1	
	AF2	188.4	162.7	79.3	150.1			340.0		
	AF3	195.1	128.3	125.5						
	AF4	143.9	131.6	102.0	114.1	101.8	94.7	50.0		
	AF5	136.9	126.8	174.7	184.8	171.0	145.2	150.0		
	AF18	150.3	3.0	109.4						
	AF19	151.3	132.0	132.7	123.9	159.4	121.4	315.0		
	AF30					76.4	128.5	150.0		
	AF31					79.2	115.1	200.0	24.0	24.0
	AF32					64.6	124.3	200.0	21.0	21.0
Purge Wells	AF55	46.3	41.5							
	AF56	47.4								
	AF57	57.5	56.1							
	AF58		4.5							
	AF59		19.9							
	AF60		9.3							
Arrow Street PTS	AS-PW1			200.4	159.5	110.0	131.2	150.0	109.1	93.2
	AS-PW2			235.6	196.0	171.8	141.9		212.5	168.5
	AS-PW3			210.3	228.3	157.7	147.3	150.0	116.5	186.3
	AS-PW4			179.9	148.3	114.5		150.0	128.8	138.5
	AS-PW5					28.0	28.0			
Mission Street PTS	MS-PW1							14.0	36.8	29.6
	MS-PW2							18.0	83.3	30.7
	MS-PW3							80.0	36.1	50.3
	MS-PW4							45.0	41.7	32.0
Benzene Plant PTS	BZ-PW1								27.8	40.1
	BZ-PW2								35.4	83.0
	BZ-PW3								45.1	29.0
	BZ-PW4								31.3	30.1
Groundwater Elevation Data		1980	1980	1980	1980	1989	1989	1989	1995	1995

AF = Air Force Water Supply or Purge Well
AS = Arrow Street Pump and Treat
BZ = Benzene Plant Pump and Treat
MS = Mission Street Pump and Treat
PTS = Pump and Treat System

Supply Wells
Purge Wells

Pumping data in average gallons per minute (GPM) per operational day

To: Sue Leeming, Remediation and Redevelopment Division Director

From: Dr. David Hyndman, Hydrogeology Professor and Chair

Date: June 19, 2018

Subject: Review of Feb 2018 DLZ report: "*Capture Zone Delineation at Former Wurtsmith Air Force Base (WAFB)*"

I was asked to assess the scientific validity of the DLZ capture zone report, which attempted to delineate capture zones for historical wells at the former Wurtsmith Air Force Base and determine if water supply wells were affected by PFAS. The main approach used by DLZ was a simple linear superposition model to examine potential capture zones of different pumping wells through time.

It is unclear why this simple approach was used given several groundwater models have been developed for the site, which could more accurately characterize the dynamic nature of the capture zones for wells that were used for water supplies. The community standard code for groundwater models is MODFLOW, and a MODFLOW model for the WAFB region could have been used for this analysis. A capture zone analysis is a very simple step to develop with a MODFLOW groundwater model.

There are several major problems with the approach that DLZ used and the analysis presented in their report. This memo focuses the subset of issues associated with the capture zone analysis.

1. The capture zone analysis assumes the subsurface hydraulic conductivity and saturated thickness are homogeneous, which is not the case here or in other natural environments where heterogeneities are ubiquitous.
2. DLZ assumes superposition of the drawdown from the extraction wells (assumed steady state) on top of interpolated water level contours, which already have significant uncertainty and do not preserve mass balance in a system.
3. The water level data were already collected during the pumping period and thus these measurements already have cones of depression due to pumping. As a result, the superposition likely effectively doubles the effect of the drawdown.
4. Superposition is not linear in hydraulic head in an unconfined aquifer, rather it can be approximated as a linear function of head squared. However, this does not appear to have been considered in the DLZ analysis.

In my professional opinion, the approaches taken for this analysis and the associated results are not scientifically valid.

DLZ
ARCHITECTURE • ENGINEERING • PLANNING
SURVEYING • CONSTRUCTION SERVICES

INNOVATIVE IDEAS
EXCEPTIONAL DESIGN
UNMATCHED CLIENT SERVICE

OFFICE MEMORANDUM

DATE: August 22, 2018

TO: Robert Delaney, MDEQ

FROM: Michael Tuckey, DLZ

SUBJECT: Response to David Hyndman's review of the February 2018 report entitled "Capture Zone Delineation at Former Wurtsmith Air Force Base (WAFB)"

Initially the reviewer asks why the groundwater model MODFLOW was not used for the capture zone delineation. The Michigan Department of Environmental Quality (MDEQ) directed DLZ to prepare a screening level groundwater model to determine if capture zones for the water supply and purge wells at the WAFB extend into areas where perfluorinated alkyl substances (PFAS) have been detected. The modeling approach used by DLZ was previously recommended by the MDEQ as a method to delineate capture zones for well head protection areas. The modeling approach involved calculating drawdowns from the water supply and purge wells using an analytical model (CAPZONE). The regional groundwater elevations were estimated by contouring groundwater elevation data using the software program SURFER. The CAPZONE drawdown file was superimposed on the SURFER grid file to calculate the pumping potentiometric surface. The pumping potentiometric surface file was input into a particle tracking program (GWPATH) to calculate capture zones. This approach avoids the subjectivity involved in setting boundary conditions to estimate the potentiometric surface and the time consuming (i.e. expensive) process of model calibration that would be necessary using a finite difference model, such as MODFLOW. MDEQ was seeking to estimate capture zones for illustrative purposes and was not attempting to quantify PFAS concentrations in groundwater or drinking water over time.

Individual review comments from Dr. Hyndman are listed below in italic, followed by the DLZ response.

1. *The capture zone analysis assumes the subsurface hydraulic conductivity and saturated thickness are homogeneous, which is not the case here or in other natural environments where heterogeneities are ubiquitous.*

DLZ response: DLZ agrees that all aquifers are heterogeneous. The MDEQ directed DLZ to perform groundwater modeling for the WAFB using existing data. The scope of work did not include performing aquifer tests to delineate spatial variations in hydraulic conductivity. DLZ derived the estimates for hydraulic conductivity and aquifer thickness from previous groundwater modeling reports written by the United States Geological Survey (USGS, AR27 and AR77). The USGS used a single value for hydraulic conductivity (120 ft/day) in their groundwater model. DLZ also calculated the average aquifer saturated thickness (47.5 ft) from data provided in the USGS reports.

DLZ also reviewed additional modeling groundwater reports for the WAFB:

- URS (July 2003) used a single value for hydraulic conductivity (150 ft/day) for the sand aquifer. Floodplain deposits and clay deposits near the Au Sable River, near the south boundary of the model grid, were assigned hydraulic conductivities of 20 ft/day and 1.5 ft/day, respectively.

- MWH (2003) used two values for hydraulic conductivity for the sand aquifer. The main portion of the aquifer was assigned a hydraulic conductivity of 140 ft/day, and the downgradient portion of the aquifer near Van Etten Lake was assigned a hydraulic conductivity of 90 ft/day). Floodplain deposits and clay deposits near the Au Sable River, near the south boundary of the model grid, were assigned hydraulic conductivities of 20 ft/day and 1.5 ft/day, respectively.

DLZ's estimate of 120 ft/day for the aquifer is consistent with previous groundwater modeling efforts.

2. *DLZ assumes superposition of drawdown from extraction wells (assumed steady state) on top of interpolated water level contours which already have significant uncertainty and do not preserve mass balance in a system.*

DLZ response: DLZ disagrees with this statement. The water level contours are based on measurements of water levels obtained in the field as well as surface water elevations. The large number of available water elevation data points provide minimal uncertainly for the water level contours. DLZ believes the water level contours calculated by SURFER from field data are more accurate than water level contours calculated in a finite difference model, such as MODFLOW, which are interpolated from boundary conditions assumed by the modeler.

3. *The water level data were already collected during the pumping period and thus these measurements already have cones of depression due to pumping. As a result, the superposition likely effectively doubles the effect of the drawdown.*

DLZ response: DLZ agrees with the statement that the drawdown may have been overestimated. DLZ revised the model to eliminate overestimates of the drawdown. The following steps were performed:

- DLZ ran the CAPZONE model using pumping rates for each year to calculate the cone of depression for the pumping wells. The cone of depression 0.02 ft contour line was plotted, along with the monitoring well locations. All monitoring wells located within the 0.02 ft cone of depression contour were eliminated from the 1980, 1989, and 1995 groundwater elevation data bases. The regional water table elevations for 1980, 1989, and 1995 were contoured using the SURFER program and the revised groundwater elevation data bases. The revised potentiometric surface maps (Figures 4, 5, and 6) of

the revised report, display regional groundwater elevation contours unaffected by pumping from the purge and water supply wells. Drawdowns calculated by CAPZONE were then superimposed on the revised SURFER grid files to calculate the potentiometric surface under pumping conditions.

4. *Superposition is not linear in hydraulic head in an unconfined aquifer, rather it can be approximated as a linear function of head squared. However, this does not appear to have been considered in the DLZ analysis.*

DLZ response: superposition was used in the modeling in the CAPZONE program, as drawdowns from multiple pumping wells were added together to create a composite cone of depression, and the composite cone of depression data file was added to the regional groundwater elevation data file to create a potentiometric surface under pumping conditions. In theory, superposition is only valid for isotropic, homogeneous, confined aquifers because transmissivity does not change spatially or temporally. In unconfined aquifers transmissivity changes spatially, because drawdown near the pumping wells changes the aquifer thickness. CAPZONE corrects drawdowns for spatial changes in transmissivity using the Jacob equation. The CAPZONE user's manual provides the following statement; "If computed drawdowns are greater than 25% of the initial saturated thickness, use of this correction may not be valid in the immediate region around the pumping well because of large vertical flow components". DLZ calculated the average aquifer saturated thickness as 47.5 feet. Drawdowns exceeding 25% of the saturated thickness (11.9 ft) would be considered invalid. DLZ plotted drawdowns from the pumping wells calculated by CAPZONE for each year of the modeling simulations and no drawdowns exceeded 11.9 ft. The maximum drawdown calculated by the model was 9.0 feet. Therefore, DLZ assumes that the drawdown correction performed by CAPZONE for the unconfined aquifer is valid and that the superposition performed in the modeling is also valid.

REFERENCES

Administrative Record (AR) 27, 1986. Assessment of Ground-Water Contamination at Wurtsmith Air Force Base, Michigan 1982-1985; U.S. Geological Survey Water Resource Investigation Report 86-4188.

Administrative Record (AR) 77, 1990. Installation Restoration Program Phase II- Confirmation/Quantification Stage 2, Wurtsmith Air Force Base, Michigan: Hydrogeology near Wurtsmith Air Force Base, Michigan; U.S. Geological Survey Water Resources Division Lansing, Michigan.

URS, July 2001. Basewide Groundwater Flow Model and Capture Zone Analysis, June 2001.

MWH, July 2003. Groundwater Flow Model.

DLZ Michigan

Michael Tuckey, Ph.D., CPG.
Senior Geologist

Dale J. Corsi, PE.
Project Manager

M:\proj\1341\6550\37 WAFB state funded work\modeling report\ response to hyndman office memorandum