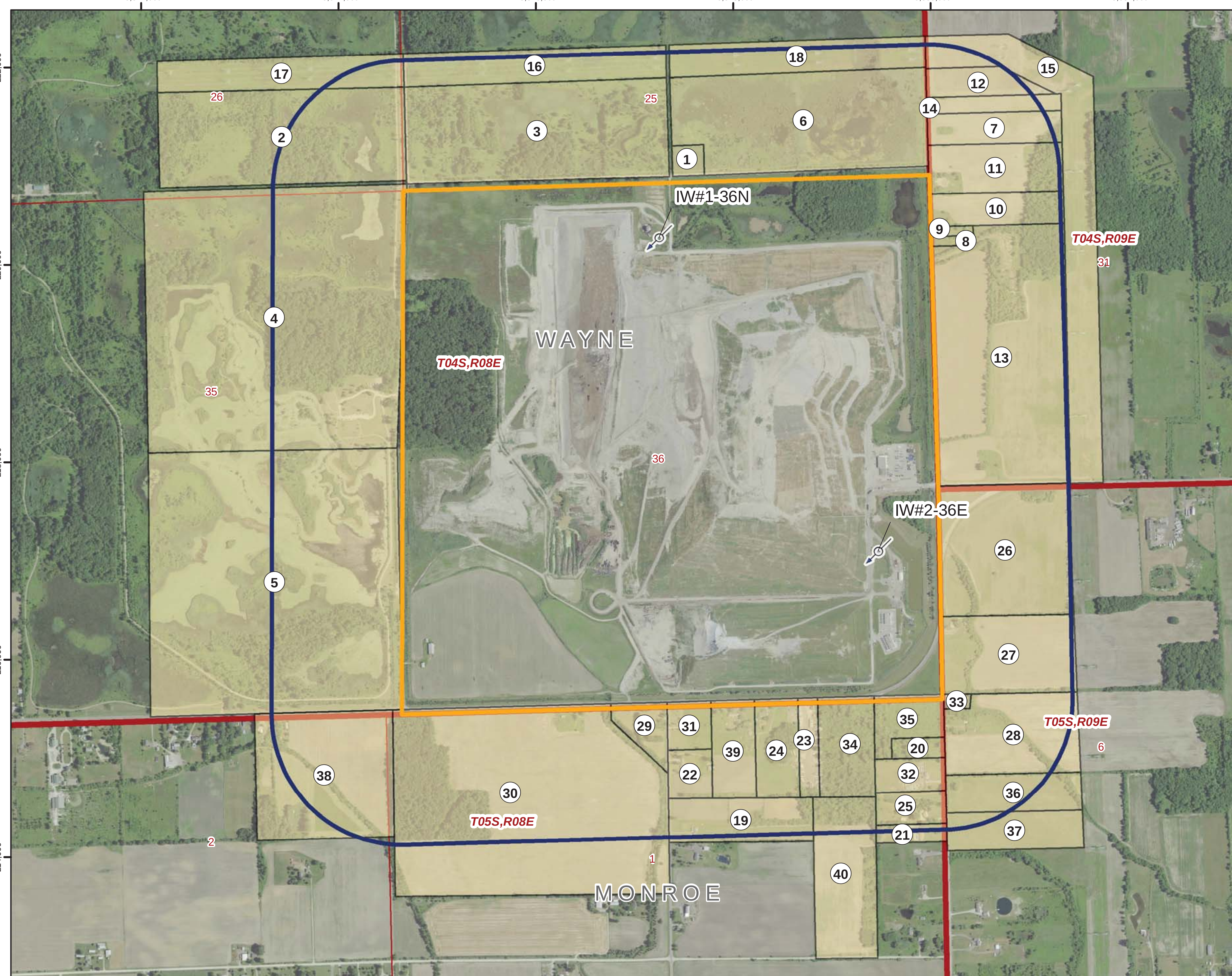


Coordinate System: NAD 1983 StatePlane Michigan South FIPS 2113 Feet

Service Layer Credits: NAIP - USDA Conus Prime

## Legend

- Proposed Well Location
- Adjacent Land Owners within 1/4-Mile
- Carleton Farms Landfill Property
- 1/4-Mile Radius from Property Boundary

Note:
Refer to Table B.6-1 for property parcel information associated with parcel labels in figure.

N

0 500 1,000 1,500 2,000 Feet

1 in = 1,000 feet

REPUBLIC SERVICES

Figure B.6-1
Property Parcels Adjacent to the Carleton Farms Landfill

2019 Permit Application

| | | |
|---|---|---|
| Scale: 1:12,000 | Date: May 2020 | |
| 2019_CFL_EGLE_Fig_B.6-01.mxd | By: WEK | Checked: CW |

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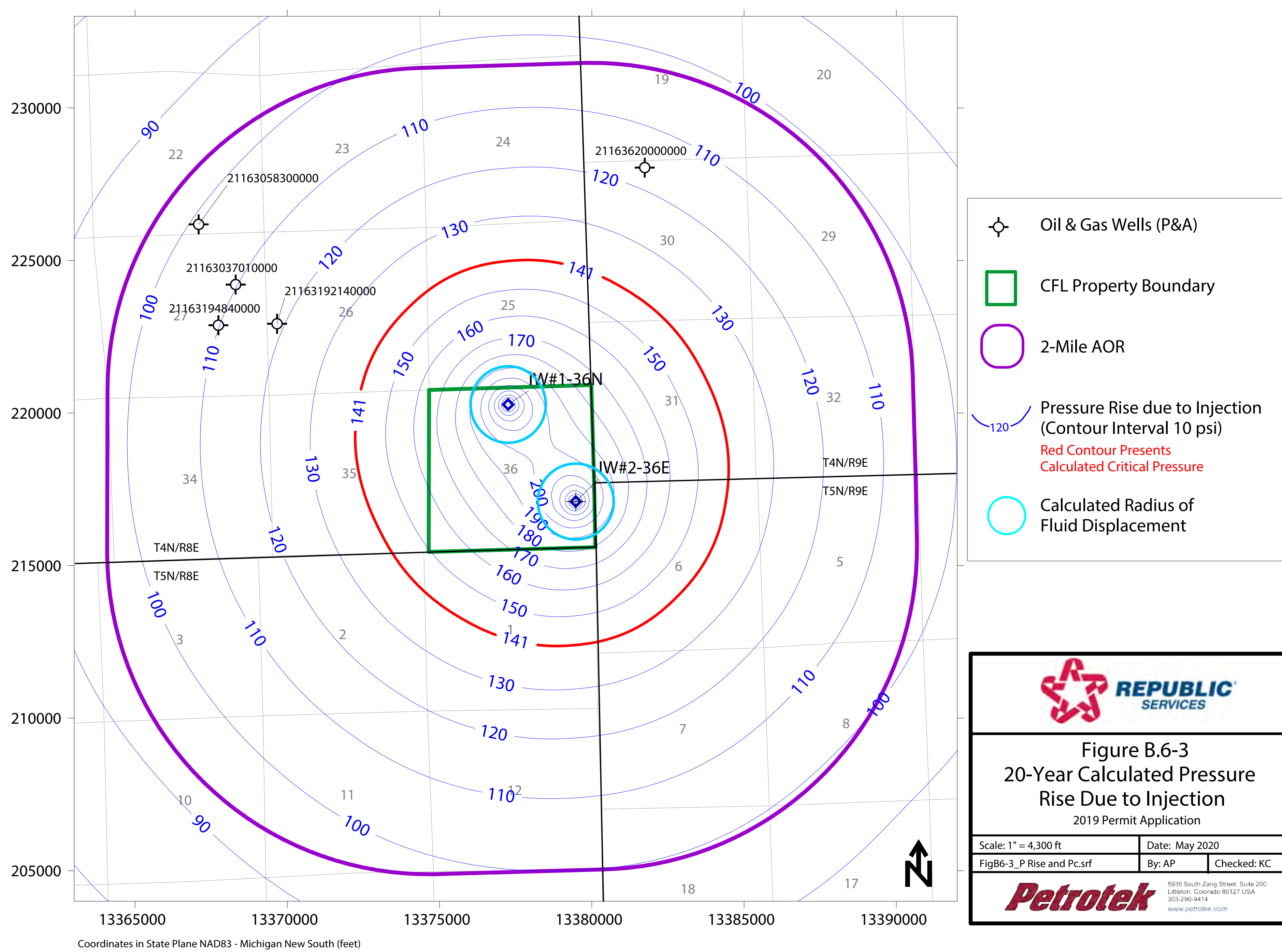


REPUBLIC SERVICES

**Figure B.6-3**
**20-Year Calculated Pressure Rise Due to Injection**
2019 Permit Application

| Scale: 1" = 4,300 ft | Date: May 2020 | |
| --- | --- | --- |
| FigB6-3_P Rise and Pc.srf | By: AP | Checked: KC |

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### B.7 A map showing the vertical and areal extent of surface waters and subsurface aquifers containing water with less than 10,000-ppm total dissolved solids. A summary of the present and potential future use of the waters must accompany the map.

Figure A.4-4 (Section A.4) is a topographic map of CFL area, and shows there are mappable surface water features in the immediate vicinity of CFL, although survey has shown there are no such features within a 1,320 ft radius of the proposed well locations except for Mosquito Drain (see Attachment C, Environmental Assessment Report). See Section A.4 for additional discussion. Surface water is not a local drinking water source.

Figure B.7-1 (Section B.7) presents the Michigan Stratigraphic Column which shows both the name and age of rock units including those that may be subsurface aquifers. The Michigan Groundwater Atlas discusses aquifers present in Michigan (Olcott, 1992), and data from this source indicates that CFL is underlain by a surficial layer composed of glacial clay and intermittent sands, that is underlain by the regional Silurian-Devonian aquifer system.

Site specific data obtained during hydrogeologic studies supporting landfill permitting (City Management Corporation, 1991) identified shallow water-bearing intervals in the CFL area that are monitored as part of the landfill operating permit requirements. This study verified that glacial clay/sand occur above bedrock, and the Devonian Detroit River Group (i.e., Lucas Formation) is the bedrock unit that underlies the landfill area (Figure B.7-2). Bedrock is overlain by glacial clay, above which a discontinuous sand layer may be present. Thickness of surficial sand varies from 0-13 feet, and glacial clay varies from 80 feet thick near the northern boundary of Sumpter Township to less than 40 feet at the southern boundary; glacial sediments are approximately 53 feet thick at the IW#1-36N well location and 30 feet thick at the IW#2-36E well location. The 1991 hydrogeologic report also states that the primary groundwater aquifer occurs in the carbonate rock formation underlying glacial material, which is locally fractured and exhibits solution features at the bedrock surface. It is also noted that this report states that karst or zonation at the carbonate surface is expected to be minimal due to the “apparently uniform distribution of fractures in the upper portion of the rock formation”. Figure B.7-3 and B.7-4 present local cross sections that show overlying glacial material above bedrock at the CFL area.

Bedrock aquifers are typically confined in the region. Groundwater flow in the uppermost bedrock carbonate aquifer is from northwest to southeast in Sumpter County (City Management Corporation, 1991), as verified by local potentiometric surface maps (Figure B.7-5). According to the Hydrogeologic Report, groundwater wells in the region range in depth form 17 to over 100 feet, with an average dept of 47 feet, and are typically drilled to the uppermost bedrock surface. Figure A.4-6a presents the location of water wells around the CFL area. Data used to construct this map verifies that most water wells are completed within the upper bedrock surface, i.e., the Lucas Member of the Detroit River Group, which subcrops immediately below the surficial glacial material.

The specific geologic unit that subcrops below overlying glacial material varies within Wayne and Moore Counties due to erosion, and the USGS (Apple and Reeves, 2007) states that the Bass Islands and Salina Group, where present immediately below glacial material, are the lowermost units within the Silurian-Devonian aquifer system that may be a source of drinking water at the bedrock-glacial material interface. However, both of these units are far below ground level at CFL, and are not used as underground sources of drinking water due to depth, water quality, occurrence of water in shallower intervals, and availability of public water supplies. It should be noted that karst solution features may be present in shallow carbonate units, significantly increasing local porosity and permeability. Further, as indicated by Nicholas et al. (1994), average well depths for bedrock wells in Monroe County are typically less than 200 feet, and generally corresponds to the top of the bedrock unit that underlies alluvium or glacial deposits, meaning that drinking water wells are typically completed in whatever formation that subcrops in the area, which can vary due to bedrock dip.

**Groundwater Use and Water Quality**

As indicated above, use of groundwater as a drinking water source in the CFL area is minimal, due to the availability of water supply through the Detroit Water and Sewer Department, and because groundwater quality in bedrock aquifers is poor and generally considered non-potable due to high mineralization and high sulfur content. Water quality data obtained as part of the original landfill construction permit application indicated the following average ion concentration in groundwater obtained from the fractured upper surface of the Detroit River Group carbonate (Lucas Formation) below glacial clay:

- 213.1 ppm Ca
- 101 ppm Mg
- 89 ppm $HCO_3$
- 1215 ppm $SO_4$
- 99 ppm sodium
- 196 ppm chloride

The USGS Groundwater Atlas (Olcot, accessed 2019) states that the regional Silurian-Devonian groundwater aquifer system includes the Detroit River Group, Sylvania Sandstone, Bois Blanc-Bass Islands in Wayne and Monroe counties, with underlying units of the lower Silurian serving as confining units. The Groundwater Atlas also indicates that the water quality specific to the Silurian-Devonian aquifer system becomes quite saline in the general vicinity of CFL, indicating that while the unit may be water bearing, the water quality can vary significantly with depth exceeding 100,000 mg/L TDS just east of the facility. Figure B.7-6 presents a general water quality portrayal of the Silurian-Devonian aquifer system, which indicates that the water quality below the CFL within this system may exceed the 10,000 mg/L TDS, particularly with depth. The Groundwater Atlas states “Downdip, at, or near the contract of overlying rocks, dissolved-solids concentrations increase to 1,000 milligrams per liter….A short distance farther downdip, the water is a brine; dissolved solids concentrations in excess of 160,000 milligrams per liter have been reported in water from these rocks in the center of the Michigan Basin". As shown in the site-specific listing above, water quality within the uppermost bedrock aquifer immediately below glacial clay exhibits very high sulfate content as well as other dissolved solids, confirming regional assumptions.

Water quality calculations can be performed to assess the concentration of total dissolved solids, and to hence identify the base of the lowermost underground source of drinking water. These calculations were performed at the EDS #2-12 well (Subsurface, 2002), which is relatively close to the CFL; these calculations determined that the formation fluids below a depth of 387 feet RKB exhibited total dissolved solid concentrations in excess of 10,000 ppm. This depth corresponds to the base of the Sylvania Sandstone at the EDS #2-12 location, which occurs below a thick Detroit River Group at EDS #2-12. At CFL, the Detroit River Group (Lucas Formation) appears to be relatively thin, as the Sylvania Sandstone occurs at about 135 feet BGL in at least one location. Taking this into account and water quality calculations performed at the EDS wells, the base of the lowermost USDW is conservatively assigned to the unit below the Sylvania Sandstone, i.e., the Bois Blanc Formation, the base of which is estimated to be approximately 400 feet below ground level.

## REFERENCES

Apple, Beth A and Howard W. Reeves, 2007, Summary of Hydrogeologic Conditions by County for the State of Michigan, USGS Open File Report 2007-1236.

City Management Corporation, 1991, Carleton Farms Act 641 Construction Permit Application.

Olcott, P.G. Groundwater Atlas of the United States, Segment 9, Iowa, Michigan, Minnesota, Wisconsin. USGS Hydrologic Investigations Atlas, 730-J.

Subsurface, 2002, UIC Class I Petition Revision Following Construction of EDS #1-12 and #2-12, Environmental Disposal Systems, Inc., Romulus Michigan.

# STRATIGRAPHIC NOMENCLATURE FOR MICHIGAN


**Michigan Dept. of Environmental Quality**
**Geological Survey Division**
Harold Fitch, State Geologist
and
**Michigan Basin Geological Society**

Stratigraphic Nomenclature Project Committee:
Dr. Paul A. Catacosinos, Co-chairman
Mr. Mark S. Wollensak, Co-chairman

Principal Authors:
Dr. Paul A. Catacosinos
Dr. William B. Harrison III
Mr. Robert F. Reynolds
Dr. David B.Westjohn
Mr. Mark S. Wollensak


2000


**Acknowledgements**

This work is the product of the combined efforts of the geological communities of Michigan and the surrounding states and provinces. Below are given just a representative few of the contributors:

***Academia:*** Dr. Aureal T. Cross, Michigan State University; Dr. Robert H. Dott, Jr., University of Wisconsin; Mr. William D. Everham, Ph.D. Candidate, Michigan Technological University.

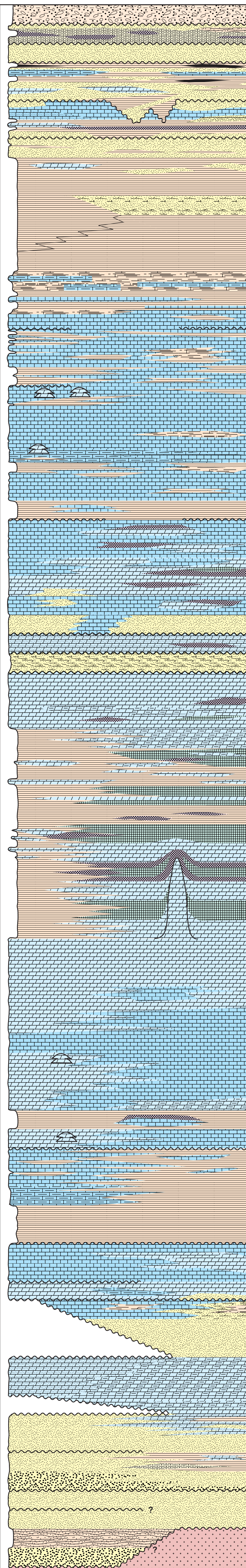
***Government:*** Dr. Terry R. Carter, Ontario Ministry of Natural Resources; Mr. John M. Esch, Michigan Department of Environmental Quality; Dr. Brian D. Keith, Indiana Geological Survey; Mr. Lawrence H Wickstrom, Ohio Geological Survey.

***Industry:*** Mr. Donald J. Bailey, Consultant; Mr. Jimmy R. Myles, Scot Energy; Mr. Dan E. Pfeiffer, Pfeiffer Exploration Services.

A complete listing of all contributors will be found in the Stratigraphic Lexicon for Michigan, of which this column is an integral part.


| GEOLOGIC TIME: ERA | PERIOD | EPOCH | NORTH AMERICAN STAGES | OUTCROP NOMENCLATURE: GROUP | FORMATION | MEMBER | SUBSURFACE NOMENCLATURE: FORMATION | GROUP |
|---|---|---|---|---|---|---|---|---|
| Cenozoic | Quaternary | Pleistocene | Wisconsinan | | Glacial Drift | | Glacial Drift | |
| Mesozoic | Jurassic | Middle | Oxfordian | | Ionia Fm | | Ionia Fm | |
| Paleozoic | Pennsylvanian | Late | Conemaugh | | Grand River Fm | | Grand River Fm | |
| | | Early | Pottsville | | Saginaw Fm | | Saginaw Fm | |
| | | | | | ?—?—? | | ?—?—? | |
| | | | | | Parma Ss | | Parma Ss | |
| | | | | | ?—?—? | | ?—?—? | |
| | Mississippian | Late | Meramecian | | Bayport Ls | | Bayport Ls | |
| | | | | | Michigan Fm | | Michigan Fm | |
| | | | Osagian | | Marshall Ss | | Marshall Ss | |
| | | Early | Kinderhookian | | Coldwater Sh | | Coldwater Sh | |
| | | | | | Sunbury Sh | | Sunbury Sh | |
| | Devonian | Late | | | Ellsworth Sh (western) / Berea Ss (eastern) | | Ellsworth Sh (western) / Berea Ss (eastern) | |
| | | | | | Bedford Sh (eastern) | | Bedford Sh (eastern) | |
| | | | Chautauquan | | Antrim Sh | Upper Mbr | Upper Mbr (Antrim Sh) | |
| | | | | | | Lachine Mbr | Lachine Mbr | |
| | | | | | | Paxton Mbr | Paxton Mbr | |
| | | | | | | Norwood Mbr | Norwood Mbr | |
| | | | Senecan | | Squaw Bay Ls | | Squaw Bay Ls | |
| | | Middle | Erian | Traverse Gr | Thunder Bay Ls | Partridge Point Mbr | Traverse Ls | Traverse Gr |
| | | | | | | Potter Farm Mbr | | |
| | | | | | | Norway Point Mbr | | |
| | | | | | Alpena Ls | Four Mile Dam Mbr | | |
| | | | | | | Newton Creek Mbr | | |
| | | | | | Long Lake Ls | Killians Mbr | | |
| | | | | | | Genshaw Mbr | | |
| | | | | | Ferron Point Fm | | | |
| | | | | | Rockport Quarry Ls | | | |
| | | | | | Bell Sh | | Bell Sh | |
| | | | | | Rogers City Ls | | Dundee Ls | |
| | | | | | Dundee Ls | | | |
| | | | Ulsterian | Detroit River Gr | Anderdon Ls | Mackinac Breccia | Lucas Fm | Detroit River Gr |
| | | | | | Lucas Fm | | | |
| | | | | | Amherstburg Fm | | Amherstburg Fm | |
| | | | | | Sylvania Ss | | Sylvania Ss | |
| | | | | | Bois Blanc Fm | | Bois Blanc Fm | |
| | | Early | | | Garden Island Fm | | Garden Island Fm | |
| | Silurian | Late | Cayugan | Bass Islands Gr | Rasin River Dol | | undifferentiated | Bass Islands Gr |
| | | | | | Put-in-Bay Dol | | | |
| | | | | | St. Ignace Dol | | | |
| | | | | Salina Gr | Pte. aux Chenes Fm | | Salina G Unit | Salina Gr |
| | | | | | | | Salina F Unit | |
| | | | | | | | Salina E Unit | |
| | | | | | | | Salina D Unit | |
| | | | | | | | Salina C Unit | |
| | | | | | | | Salina B Unit | |
| | | | | | | | Salina A-2 Carb | |
| | | | | | | | Salina A-2 Evap | |
| | | | | | | | Ruff Fm | |
| | | | | | | | Salina A-1 Evap | |
| | | | | | | | Cain Fm | |
| | | Middle | Niagaran | Engadine Gr | Bush Bay Fm | | Guelph Dol | Niagara Gr |
| | | | | | Rapson Creek Fm | | | |
| | | | | | Rockview Fm | | Lockport Dol | |
| | | | | Manistique Gr | Cordell Fm | | undifferentiated | Manistique Gr |
| | | | | | Schoolcraft Fm | | | |
| | | | | Burnt Bluff Gr | Hendricks Fm | Fiborn Ls Mbr | undifferentiated | Burnt Bluff Gr |
| | | | | | Byron Fm | | | |
| | | | | | Lime Island Fm | | | |
| | | Early | Alexandrian | Cataract Gr | Cabot Head Sh | | Cabot Head Sh | Cataract Gr |
| | | | | | Manitoulin Dol | | Manitoulin Dol | |
| | Ordovician | Late | Cincinnatian | Richmond Gr | Big Hill Fm | | Queenston Sh | Richmond Gr |
| | | | | | Stonington Fm | Ogontz Mbr | Utica Sh | |
| | | | | | | Bay de Noc Mbr | | |
| | | | | | Bill's Creek Sh | | | |
| | | Middle | Mohawkian | | Collingwood Sh | | Collingwood Sh | |
| | | | | | Trenton Fm | Groos Quarry Mbr | Trenton Fm | |
| | | | | | | Chandler Falls Mbr | | |
| | | | | | Black River Fm | | Black River Fm | |
| | | | | | | | Glenwood Fm | |
| | | | Chazyan | | <unconformity> | | St.Peter Ss | |
| | | | Whiterockian | | | | | |
| | | Early | Canadian | | Au Train Fm | | Foster Fm | Prairie du Chien Gr |
| | | | | | | | undifferentiated | |
| | Cambrian | Late | Trempealeaun | | <unconformity> | | Trempealeau Fm | |
| | | | Franconian | | Munising Fm | | Franconia Fm | Munising Gr |
| | | | Dresbachian | | | Miner's Castle Mbr | Galesville Ss | |
| | | | | | | Chapel Rock Mbr | Eau Claire Fm | |
| | | | | | | Basal Cgl | Mount Simon Ss | |
| Precambrian | Middle Proterozoic Eon | | | | Jacobsville Ss | | Pre-Mt. Simon Clastics | |
| | | | | Oronto Gr | Freda Ss | | | |
| | | | | | Nonesuch Sh | | Precambrian Crystalline Basement Complex | |
| | | | | | Copper Harbor Cgl | | | |
| | Archean to Middle Proterozoic Eons | | | Precambrian Crystalline Basement Complex | | | | |

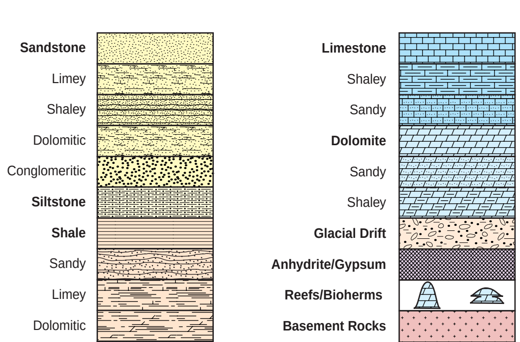
DOMINANT LITHOLOGY



## RELATED TERM CORRELATION

| STRATIGRAPHIC POSITION | RELATED TERMS |
|---|---|
| Ionia Fm | Jurassic Red Beds |
| Michigan Fm | Clare Dolomite, Brown Lime, Stray Dolomite, Stray Sandstone, Stray-Stray Sandstone, Stray-Stray-Stray Sandstone, Triple Gyp |
| Coldwater Sh | Coldwater Red Rock, Speckled Dolomite, Wier Sand |
| Antrim Sh | Charlton Black Shale Member, Elltrim, Chester Black Shale Member, Upper Black Shale, Light Antrim, Lower Black, Lower Antrim Middle Antrim, Middle Gray Antrim, Dark Antrim, Middle Gray Shale, Unit 1A, Unit 1B, Unit 1C, Crappo Creek Grey Shale Member |
| Dundee Ls | Reed City Member/Dolomite/Anhydrite |
| Lucas Fm | Freer Sandstone, Horner Member, Iutzi Member, Massive Salt/Anhydrite, Sour Zone, Big Anhydrite, Richfield Zone/Member/Sandstone, Big Salt |
| Amherstburg Fm | Filer Sandstone, Meldrum Member, Black Lime |
| St. Ignace Dolomite | Salina H Unit |
| Salina B Unit | Big Salt, B Salt |
| Ruff Formation | Salina A-1 Carbonate, Rabbit Ears Anhydrite, |
| Cain Fm | Salina A-0 Carbonate |
| Guelph Dolomite | Brown Niagara, Niagaran Reef, Pinnacle Reef, Engadine Dolomite |
| Lockport Dolomite | Gray Niagara, White Niagara |
| Burnt Bluff Gr | Clinton Formation |
| Trenton Fm | Cap Dolomite |
| Black River Fm | Van Wert Zone, Sneaky Peak, Black River Shale |
| Glenwood Fm | Goodwell Unit, Zone of Unconformity |
| St. Peter Sandstone | Bruggers Sandstone, Jordan Sandstone, Knox Sandstone, Massive Sand |
| Prairie du Chien Gr | Foster Formation, New Richmond Sandstone, Lower Knox Carbonate, St. Lawrence Formation, T-PDC, Oneota Dolomite, Brazos Shale |
| Trempealeau Fm | Lodi Formation |
| Galesville Ss | Dresbach Sandstone |
| Pre-Mt. Simon Clastics | Precambrian "Red Beds" |

## LEGEND




REPUBLIC SERVICES

Figure B.7-1
Michigan Stratigraphic Column

2019 Permit Application

| Scale: NTS | Date: September 2019 | |
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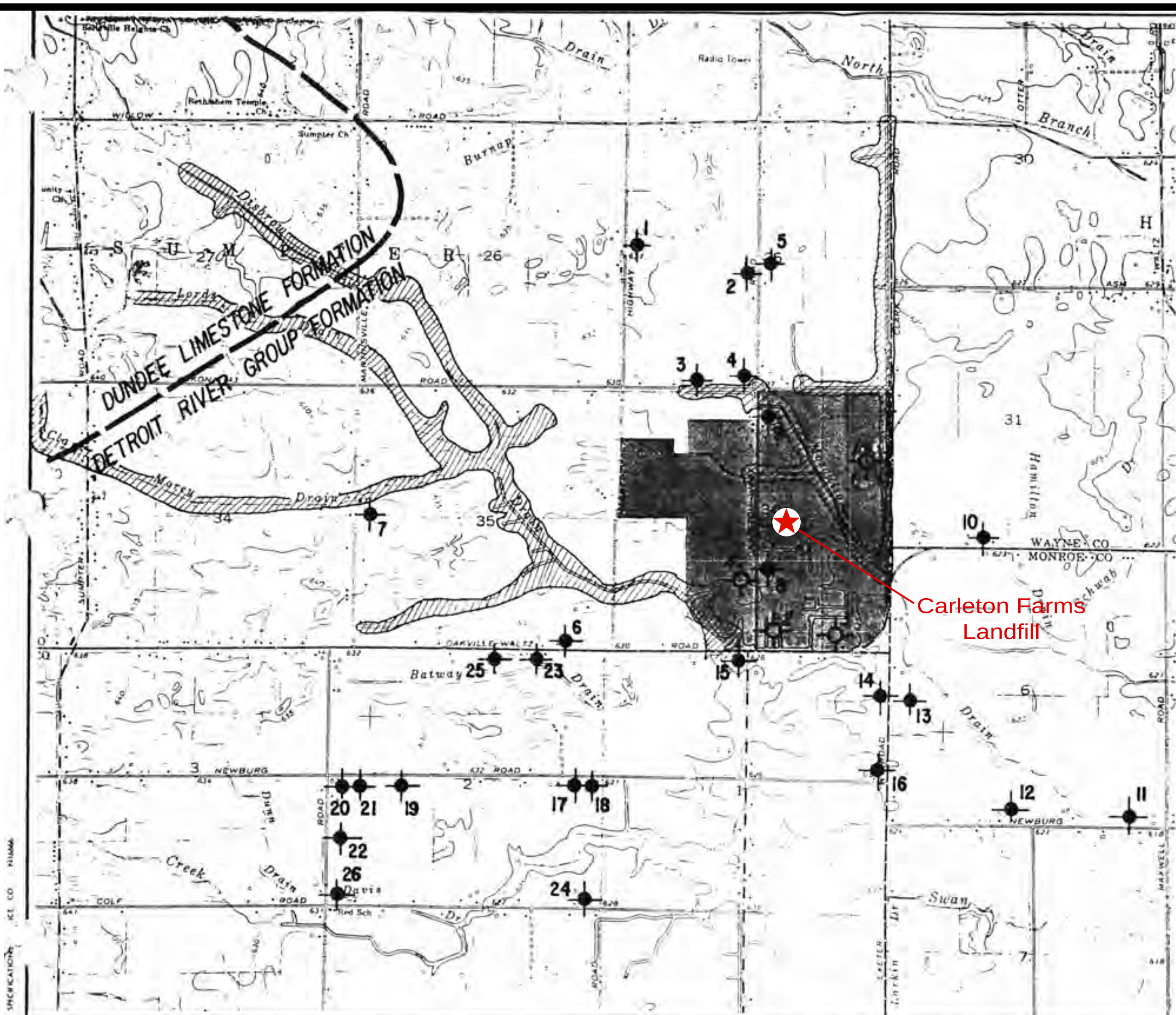


NORTH

SCALE FEET

0 1000 2000 4000

# LEGEND

PROPOSED ENVIRONMENTAL MANAGEMENT SYSTEMS LANDFILL SITE ( Property under control as of December 20, 1988 )

Approximate Location of WATER WELL of Record

SUBCROP CONTACT ( Between the Dundee Limestone Formation and the Detroit River Group Formation )

Approximate Location of 100-YEAR FLOOD PLAIN BOUNDARY as determined by the Federal Emergency Management Agency ( FEMA ).

Approximate location of WATER WELL Observed by Neyer, Tiseo & Hindo, Ltd. ( record not available )

# NOTES

- The position of the contact between the Dundee Limestone and the Detroit River Dolomite Formations was determined from available test boring information and geologic data provided in : Report on Investigation 3 - Geology for Land and Groundwater Development in Wayne County, Michigan, By A. J. Mozola, Published in 1969 by the MDNR; Groundwater Quality in Southeast Michigan - Considerations for Area Wide Water Quality Planning, By Robert F. Gorman, Published in 1978 By the Southeast Michigan Council of Governments.
- 100-Year Flood Plain Boundaries were interpreted from Flood Insurance Rate Maps ( FIRM ) Prepared by the Federal Emergency Management Agency, ( FEMA ) for Sumpter Township, Michigan. Boundaries shown are approximate.
- This map was taken from the USGS 7.5 Minute Carleton, Michigan Quadrangle.

REGIONAL HYDROLOGY & GEOLOGY

PROPOSED SANITARY LANDFILL
ENVIRONMENTAL MANAGEMENT SYSTEMS
SUMPTER TOWNSHIP, WAYNE COUNTY, MICHIGAN

NEYER, TISEO & HINDO, LTD.
CONSULTING ENGINEERS AND GEOLOGISTS
38955 HILLS TECH DRIVE • FARMINGTON HILLS, MI 48018

| | | |
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| PROJECT NO.: 88468 ow | DRAWN BY: Guy | DATE: 1 - 18 - 89 |
| SCALE: As Shown | CHECKED BY: RLB | SHEET 1 OF 1 |

REPUBLIC SERVICES

Figure B.7-2
Local Bedrock Subcrop Map,
Carleton Farms Landfill
2019 Permit Application

| | | |
|---|---|---|
| Scale: See Figure Scale | Date: September 2019 | |
| 2019_CFL_EGLE_Fig_B.7-02.pdf | By: WEK | Checked: CW |

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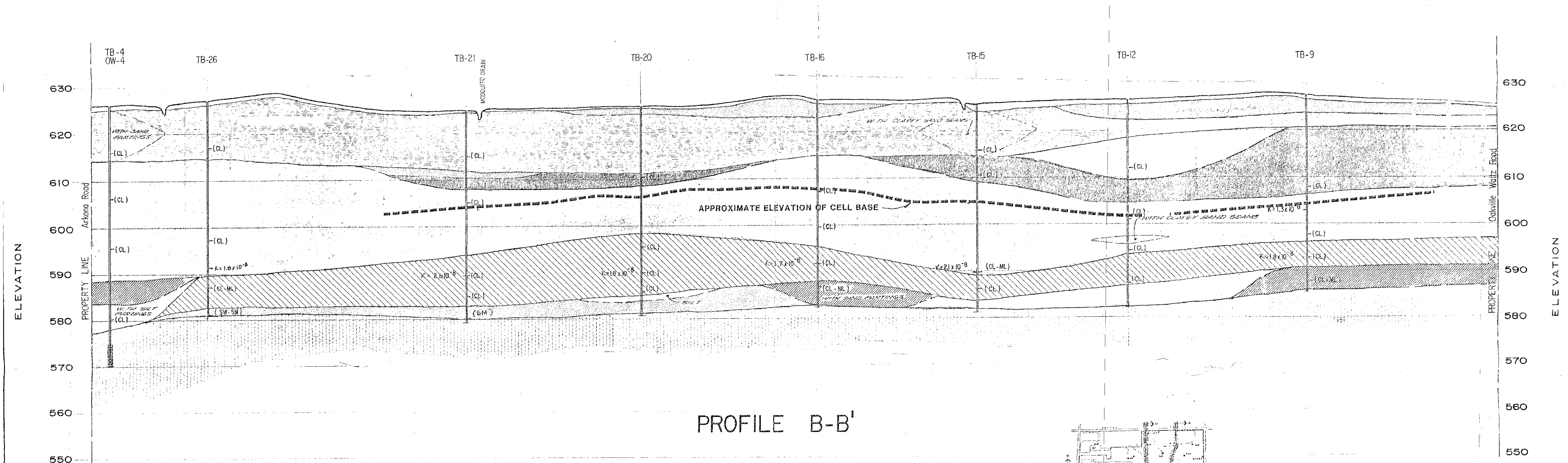



PROFILE B-B'

## LEGEND

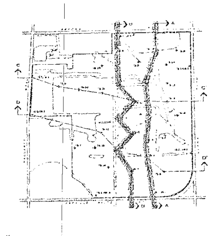
- TOPSOIL : Light Brown to Dark Brown SILTY SAND to SILTY CLAY
- Loose to Compact Brown to Gray SAND to SILTY SAND (with variations as shown on profile.)
- Stiff to Hard Mottled Brown and Gray SILTY CLAY with Little to Some Sand and Trace of Gravel (with variations as shown on profile)
- Hard Gray SILTY CLAY with Some Sand and Trace of Gravel
- Stiff to Very Stiff Gray SILTY CLAY with Little to Some Sand and Trace of Gravel (with variations as shown on profile)
- Stiff to Very Hard Gray SANDYCLAY with Some Silt and Trace of Gravel.
- Soft to Medium Gray SILTY CLAY with Trace to Some Sand and Trace of Gravel (with variations as shown on profile)
- Hard, Moderately to Closely Factured Tan to Gray Luminated to Massive LIMESTONE with Occasional Vugs
- $K = 2.0 \times 10^{-8}$ cm/sec COEFFICIENT OF VERTICAL PERMEABILITY
- (CL) UNIFIED SOIL CLASSIFICATION
- LOCATION OF OBSERVATION WELL SCREEN

## NOTES

- For the location of Geologic Profiles also see Plate 1 - Test Boring and Observation Well Location Plan.
- The information presented in the subsurface profile is generalized. Geologic contacts shown on this plate have been inferred from test boring data and may be different from that shown. For actual subsurface conditions at specific locations see the individual Logs of Test Boring.
- Reported permeabilities were determined by a Falling Head Test in a Consolidometer Cell. For additional information on soil properties, see the Tabulation of Laboratory Test data sheets in Appendix B.
- Unified [illegible] Classification designations were assigned according to ASTM Test Method [illegible]-85.

VERTICAL SCALE FEET
0 5 10 20

HORIZONTAL SCALE FEET
0 100 200 400



PROFILE LOCATION MAP
Not to Scale

NOTE
THIS PLATE SUPERCEDES ANY EARLIER VERSION CHANGES WILL BE LISTED IN THE REVISION BLOCK

GENERALIZED GEOLOGIC PROFILES A-A' & B-B'
PROPOSED SANITARY LANDFILL
ENVIRONMENTAL MANAGEMENT SYSTEMS
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| | | |
|---|---|---|
| PROJECT NO 88462 GW | DRAWN BY | DATE 12-9-88 |
| SCALE As Shown | CHECKED BY RLB | SHEET 1 OF 1 |

Plate 4

REPUBLIC SERVICES

Figure B.7-3
Local Surficial Cross Section B-B',
Carleton Farms Landfill
2019 Permit Application

| | | |
|---|---|---|
| Scale: See Figure Scale | Date: September 2019 | |
| 2019_CFL_EGLE_Fig_B.7-03.pdf | By: WEK | Checked: CW |

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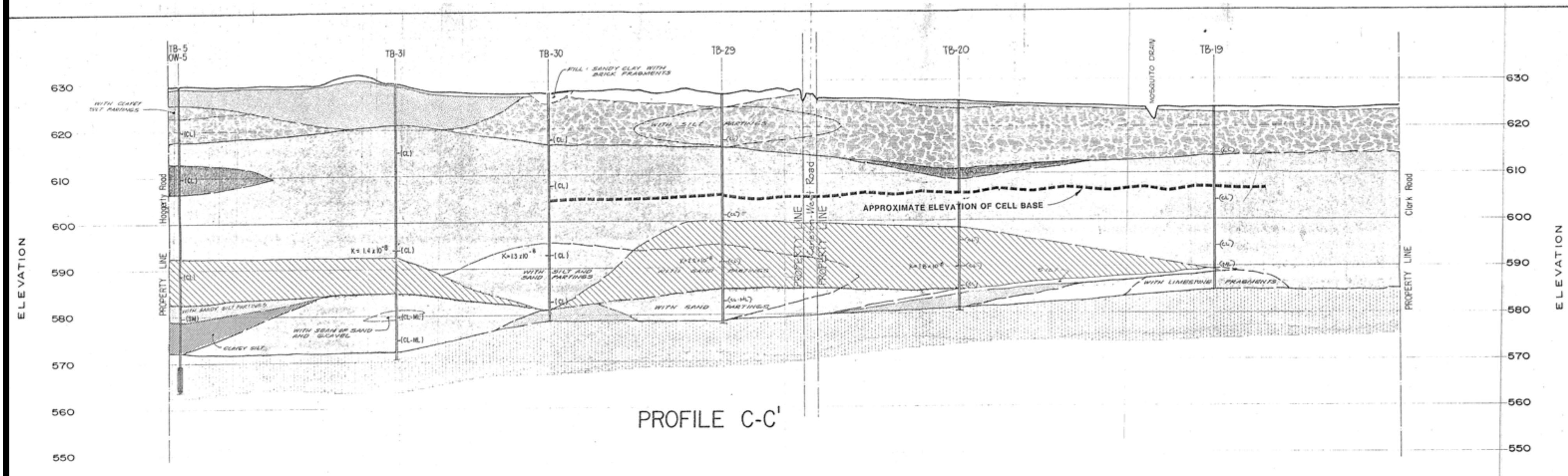


## LEGEND

- TOPSOIL: Light Brown to Dark Brown SILTY SAND to SILTY CLAY
- Loose to Compact Brown to Gray SAND to SILTY SAND (with variations as shown on profile)
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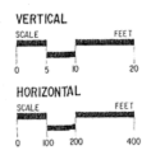
- Soft to Medium Gray SILTY CLAY with Trace to Some Sand and Trace of Gravel (with variations as shown on profile)
- Hard Moderately to Closely Factured Tan to Gray Laminated to Massive LIMESTONE with Occasional Vugs
- K=2.0 x 10^-8 cm/sec COEFFICIENT OF VERTICAL PERMEABILITY
- (CL) UNIFIED SOIL CLASSIFICATION
- LOCATION OF OBSERVATION WELL SCREEN

## NOTES

- For the location of Geologic Profiles also see Plate 1 - Test Boring and Observation Well Location Plan.
- The information presented in the subsurface profile is generalized. Geologic contacts shown on this plate have been inferred from test boring data and may be different from that shown. For actual subsurface conditions at specific locations see the individual logs of Test Boring.
- Reported permeabilities were determined by a Falling Head Test in a Consolidometer Cell. For additional information on soil properties, see the Tabulation of Laboratory Test data sheets in Appendix B.
- Unified Soil Classification designations were assigned according [illegible] ASTM Test Method D-2487-85.




PROFILE LOCATION MAP
Not to Scale

NOTE
THIS PLATE SUPERCEDES ANY EARLIER VERSION CHANGES WILL BE LISTED IN THE REVISION BLOCK

REVISED LOCATION OF CELL BASE AND TEST BORINGS 29, 20, 19 10-21-85.

**GENERALIZED GEOLOGIC PROFILES C-C' & D-D'**

PROPOSED SANITARY LANDFILL
ENVIRONMENTAL MANAGEMENT SYSTEMS
SUMPTER TOWNSHIP, WAYNE COUNTY, MICHIGAN

NEYER, TISEO & HINDO, LTD.
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| PROJECT NO. 88988 Gw | DRAWN BY: Guy | DATE: 12-19-88 |
| SCALE: As Shown | CHECKED BY: RLB | SHEET 1 OF 1 |

Plate 5

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Figure B.7-4
Local Surficial Cross Section C-C',
Carleton Farms Landfill
2019 Permit Application

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|---|---|---|
| Scale: See Figure Scale | Date: September 2019 | |
| 2019_CFL_EGLE_Fig_B.7-04.pdf | By: WEK | Checked: CW |


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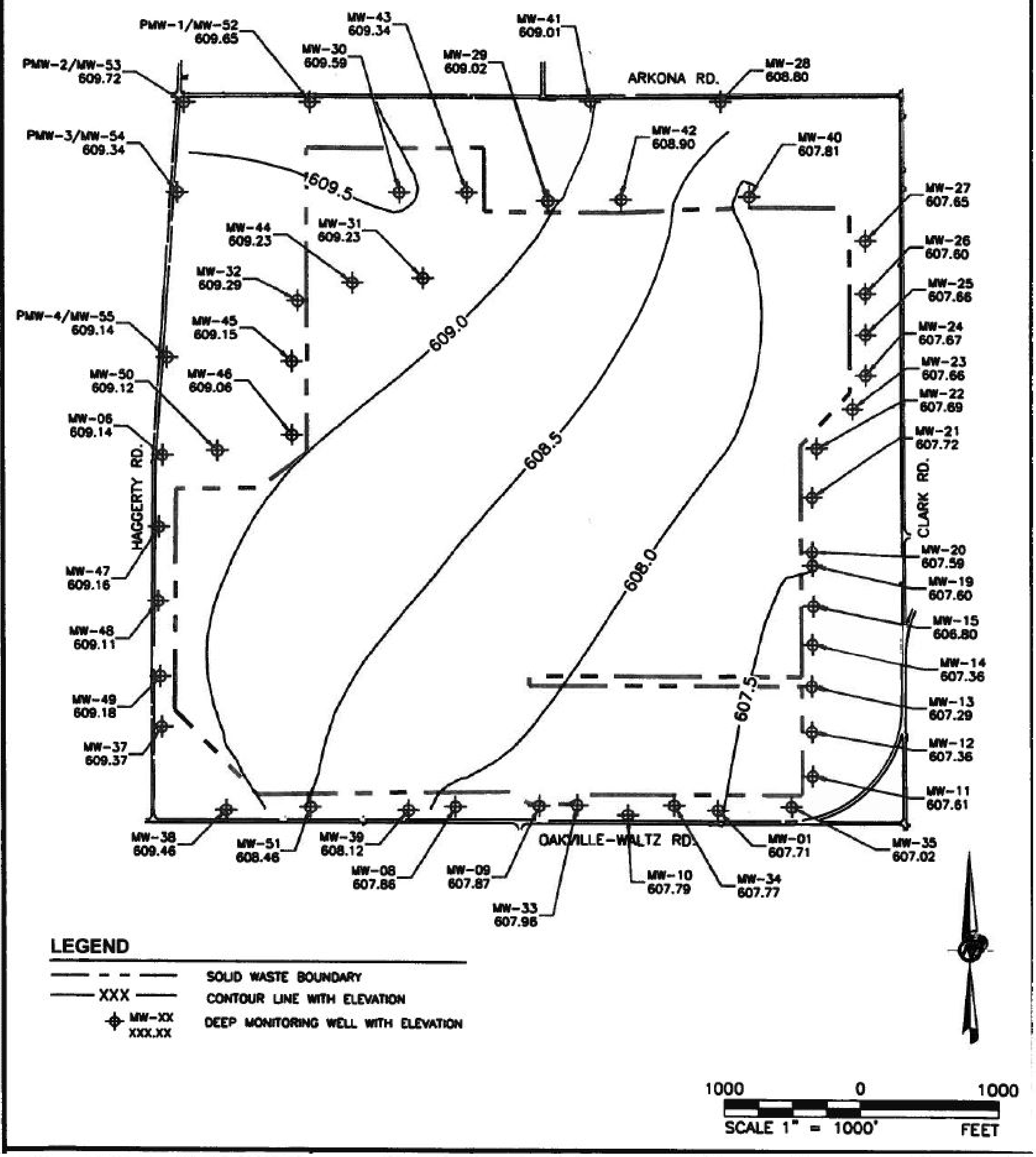


Golder Associates
Michigan

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**SECOND QUARTER 2011 MONITORING EVENT**
GROUNDWATER CONTOUR MAP
CARLETON FARMS LANDFILL
WAYNE COUNTY, MICHIGAN

REPUBLIC SERVICES, INC.

FIGURE 3

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Figure B.7-5
Potentiometric Surface Map,
Carleton Farms Landfill
2019 Permit Application

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| Scale: See Bar Scale | Date: September 2019 | |
| 2019_CFL_EGLE_Fig_B.7-05.pdf | By: WEK | Checked: CW |

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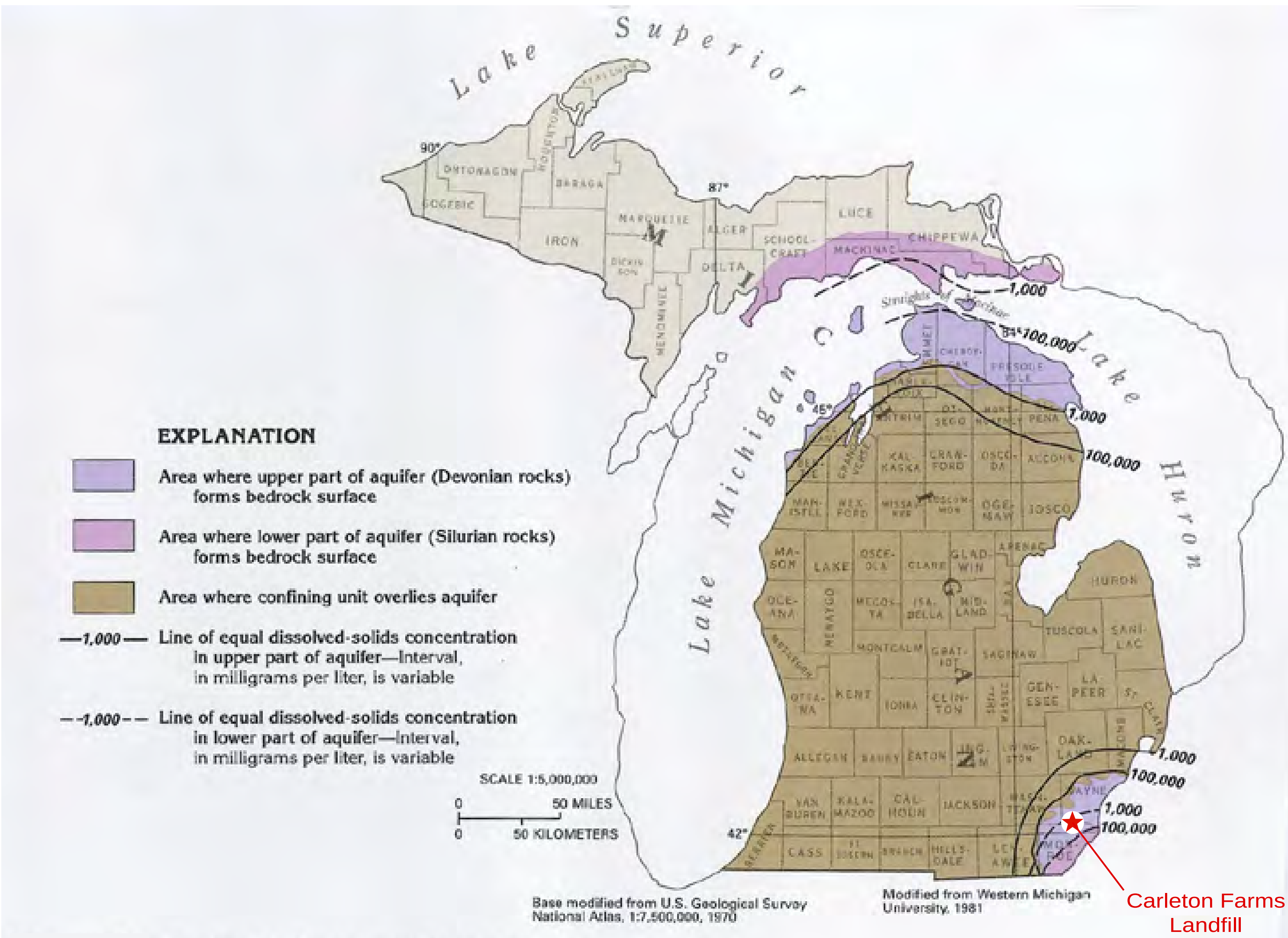


*The Silurian–Devonian aquifer in Michigan contains potable water in outcrop areas, but dissolved-solids concentrations rise to over 1,000 milligrams per liter near the periphery of the overlying confining unit and rapidly increase to brine concentrations downgradient.*

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Figure B.7-6
Water Quality Data,
Silurian-Devonian Aquifer
2019 Permit Application

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|---|---|---|
| Scale: See Figure Scale | Date: September 2019 | |
| 2019_CFL_EGLE_Fig_B.7-06.pdf | By: WEK | Checked: CW |

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# B.8 Geologic maps and stratigraphic cross sections of the local and regional geology.

## B.8.1 Regional Geology

### B.8.1.1 General History of the Michigan Basin

The Michigan Basin is an intracratonic basin that occupies an area of about 80,000 $mi^2$ (Catacosinos et al., 1991) (Figure B.8-1). The basin is nearly circular and was created by four different styles of subsidence: trough-shaped, regional tilting, narrow basin-centered and broad basin-centered (Howell and van der Pluijm, 1999). The basin is centered on Michigan's southern peninsula and is generally separated from other nearby basins by major arches. The basin is characterized structurally by several Paleozoic anticlines that trend northwest-southeast, which some authors (e.g., Wood and Harrison, 2002) present in association with basement faults or lineaments.

The Michigan Basin contains as much as 16,000 feet of sedimentary rock, covered by up to 1,200 feet of Pleistocene-age glacial drift (Catacosinos et al., 1991). Figure B.7-1 presents the stratigraphic column of Michigan, and Figure B.8-2 is a Geologic Map of Michigan, showing the subcrop configuration of strata in the Michigan Basin and the location of the Carleton Farms Landfill, referred to hereafter as CFL, or the Site. The Precambrian basement underlying the Michigan Basin is part of the Superior Province, and is approximately 1.2 to 1.5 billion years old. About 5,000 feet of thickened Precambrian-age sedimentary rock occurs above basement along a north-south trending linear trend associated with a gravity anomaly that has been interpreted by Catacosinos, et al. (1991) and others to be a portion of a buried ancient rift system. Adjacent to this trend, Cambrian rocks occur above the crystalline Precambrian basement, as is the case at CFL.

A gradual marine transgression occurred through the Late Cambrian. Late Cambrian deposits including the Mt. Simon Sandstone, Eau Claire Formation, Dresbach(Galesville) Sandstone, and Franconia Formation are probably marine in origin, with the source of sedimentary material originating from northeast. By the end of the Cambrian Period, most of the United States was under water. This circumstance continued through the Ordovician in the Michigan Basin area. Cambrian-Lower Ordovician units were deposited within a northerly transgressing epicontinental sea; the units are predominantly siliciclastic and can be over 4,500 feet thick in the center of the basin.

The Lower Ordovician Trempealeau Formation and Prairie du Chien Group were also generally deposited in a marine environment. A minor regression preceded the deposition of the onshore/nearshore St. Peter Sandstone. Deposition of the offshore marine shale and carbonates of the Trenton and Black River Formations was followed by another regression, with an accompanying unconformity. The late Ordovician Richmond Group, which includes the Utica Shale, is composed of shale deposited in a deep water environment.

During the Silurian, the Michigan Basin was an interior sea surrounded by low-lying land areas that partially isolated the sea from other bodies of water. In the absence of a significant nearby source of clastic material, the main deposits of the Silurian were evaporite and reef deposits. The Middle Silurian Niagara Formation was deposited throughout the lower peninsula of Michigan, and is composed of carbonate reef deposits. Progressive isolation of the Basin with respect to water influx is evidenced by deposition of the Salina Formation, which contains evaporates including anhydrite and halite that were deposited in the relatively restricted inland sea. During the Silurian, over 3,000 feet of sediment was deposited in the center of the Michigan Basin.

The base of the Devonian Period is represented by an unconformity as the seas regressed and land emerged, which was followed by transgression and subsequent deposition of carbonate-rich sequences through the early and middle Devonian. The Devonian-age Detroit River Group consists of carbonates and evaporites, with some shale. The Dundee Formation, which consists of carbonates, was deposited after the Detroit River Group. In the case of the CFL location, all sedimentary units above the Lucas Formation (Figure B.7-1) were removed by erosion and are not present at the site. The Lucas Formation is the bedrock formation that occurs at or near ground level in the CFL area, overlain by alluvium and glacial sediments.

### B.8.1.2 Regional Structural Geology

The CFL is located on the southeastern flank of the Michigan Basin as shown on Figures B.8-1 and B.8-2. The Michigan Basin resulted from epeirogenic down warping during the Paleozoic Era, and subsidence of the basin controlled the deposition of sedimentary units during the Paleozoic. Each Paleozoic unit dips toward the center of the basin, and generally thickens basin-ward. The basin extends into northwest Ohio and northeast Indiana and covers all of the Lower Peninsula of Michigan. The structural axis of the Findlay Arch is southeast of the Basin and the axis of the Kankakee Arch is to the southwest. Regional dip on the top of the Precambrian basement in the Carleton area is to the northwest at about 60 feet per mile.

Precambrian geomorphic features are present within Michigan, and provide insight as to the varying structural features evidence in the CFL area. As shown in Figure B.8-3a, the midcontinental rift extends in through the central portion of the Michigan Basin and underlies the current sedimentary column. To the east of this paleorift lies the Grenville Province (aka the Grenville Metamorphic Front/Province or Grenville Tectonic zone), which is the "continent-ward boundary of deformation of the fold-and-thrust belt from the Grenville orogeny, the sequence of orogenic events from ca. 1.3–0.98 Ga". (https://www.geosociety.org/gsatoday/science/G357A/article.htm#toclink2).

The sedimentary depositional centers of the Michigan Basin lie to the west of this feature. The CFL site occurs within the Grenville Zone or Province. As shown in Figure B.8-1, important structural features associated with this province are the Bowling

Green Fault Zone which lies over 10 miles southwest of the CFL, and the Howell fault, which occurs northwest of the area. Milstein (1989) also suggests that isopach variations in overlying Cambrian units reflect irregularities on the Precambrian surface: "prominent Precambrian features like the Washtenawa Anticlinorium in southeastern Michigan, and the Bowling Green Fault located along the Leawee and Monroe County boundary, are both reflected in the Cambrian sediments." The current northwest-southeast structural grain apparent in regional structural maps (e.g., Figure B.8-3) was imposed in late Mississippian to Pennsylvanian "possibly as the result of flexural foreland subsidence in response to the Alleghenian-Hercynian Orogeny…" (Catacosinos et al., 1991). These features extend to southeastern Michigan.

Wood and Harrison (2002) explored the occurrence and expression of faults within the Michigan Basin through mapping of post-Silurian sediments. They concluded that the "Michigan Basin is cut by numerous (12+) major faults lying below the glacial drift and below the topmost Jurassic sediments". The lineations generally trend northwest-southeast (Figure B.8-3b). These lineations are dominant features of the subsurface topography and are well documented, occurring as structural features expressed in units from at least the Late Devonian (Dundee time) to the Mississippian. Wood and Harrison (2002) state "These faults carve out [a] large depression in the Central Michigan Basin and appear to be responsible for shallow anticlines that hold or held a significant portion of the hydrocarbons in the Michigan Basin". The origin of these faults was attributed to deep-seated normal basement faults "rooted in the Precambrian rift sequence". Figure B.8-3b presents the location of these northwest-southeast trending features (Dundee Lineaments) presumably associated with basement faults.

### B.8.1.3 Regional Stratigraphy

Figure B.7-1 presents the stratigraphic column for Michigan. Figures B.8-4 and B.8-5 are regional cross sections available from the literature, and show regional stratigraphic correlations and geologic structure across the state into the southeastern portion of the Michigan Basin.

#### B.8.1.3.1 Precambrian (Lower Confining Zone)

The Precambrian crystalline basement is described as primarily metasedimentary gneiss (mafic and felsic) formed by the metamorphism of igneous rock as well as shales, sandstones, carbonate and iron formations. Igneous intrusions may also occur within these units. The Precambrian basement is estimated to occur at approximately 3,827 feet below ground level (ft BGL) at the IW#1-36N location, or approximately 3,200 feet below mean sea level (ft BMSL) at the Site (Figure B.8-6), and serves as the lower Confining Zone. In southeast Michigan near the Site, the Precambrian dips at approximately 60 feet per mile to the northeast, toward the center of the Michigan Basin and may occur at least 14,000 feet or more below ground level near the basin center.

### B.8.1.3.2 Cambrian and Lower Ordovician Systems (Injection Interval and Injection Zone)

The Cambrian is composed of the Mt. Simon Sandstone and the Munising Group that includes the Eau Claire Formation, Dresbach (Galesville) Sandstone, and the Franconia Formation. The Trempealeau Formation and Prairie du Chien Group are Lower Ordovician in age, and the St. Peter and Glenwood Formations are Middle Ordovician in age, where present. All units from the Glenwood through Mt. Simon Formation are included in the injection zone; the injection interval includes units the Franconia/Dresbach, Eau Claire, and the Mt. Simon Formation.

Units from the Franconia to the top of the Mt. Simon comprise the Munising Group, although various authors have also included the Mt. Simon in the Munising Group. For the purposes of this report, the Munising Group is assumed to consist of the Mt. Simon, Eau Claire, and Franconia/Dresbach Formations.

***Mt. Simon Sandstone (Injection Interval)***

The Mount Simon Sandstone (Mt. Simon) is a massive sandstone that is present in the subsurface throughout much of Ohio, Indiana, Illinois, and the lower peninsula of Michigan. Figure B.8-7 is an isopach of the Mt. Simon in the Michigan Basin, and Figure B.8-8 is a structure contour map constructed at the top of the Mt. Simon. The Mt. Simon is thickest within the central portions of the Basin, and reaches a thickness of approximately 1,240 feet in the Gratiot County region. The Mt. Simon thins dramatically to the east side of the state where it is approximately 200-250 feet thick in areas of Wayne and Monroe county, and absent in Oakland county. At a close Mt. Simon data control point (i.e., the Romulus/EGT wells), the Mt. Simon is approximately 300 feet thick and occurs at approximately 4,240 feet BGL, noting that the depth to the top of the Mt. Simon is expected to be shallower at the CFL area due to changes in regional dip (i.e., approximately 3,500 feet BGL).

In the southern peninsula of Michigan, the Mt. Simon typically lies unconformably above the Precambrian Crystalline Basement Complex and is projected to occur at approximately 3,800-3,900 feet BGL at the Site. The Mt. Simon is described as a subrounded to rounded quartzitic sandstone that is generally fine to coarse grained and well sorted. It is pink to red, with a greater abundance of feldspar at the base of the unit. WMU (1981) states that “glauconite, anhydrite, and green shale are present in minor amounts with local dolomite cement”. Barnes et al. (2009) indicate that the Mt. Simon is composed of three basic units: a basal arkosic unit, a middle quartz arenite-glauconite unit, and an upper shale-rich unit that grades conformably into the Eau Claire Formation. Some authors and wellsite geologists may have attributed basal pre-Mt. Simon sediments (granite wash) to be part of the basal arkosic Mt. Simon unit.

Regional porosity development is generally related to the burial depth, with better porosity developed in areas with less overburden (Barnes et al. 2009). State-wide, literature has generally indicated that Mt. Simon porosity typically ranges from 4-20% and may also vary laterally where sandstones grade into more shale or carbonate-rich facies.

The Mt. Simon is a common target for fluid injection, and is under scrutiny as a potential target for $CO_2$ sequestration. WMU (1981) states that with respect to the Mt. Simon as a whole, regionally the "the permeable Cambrian quartz sandstone, siltstone, and arenaceous dolomite suitable for fluid injection comprise about 27% of the stratigraphic column". Barnes et al. (2009) conclude that "The Mount Simon Sandstone in Michigan is an important saline reservoir target for geological sequestration of $CO_2$ in Michigan". Various authors have concluded that the Mt. Simon has both the capacity to accept injectate and has "cap rocks" suitable to arrest vertical fluid migration.

### *Eau Claire Formation (Injection Interval)*

The Eau Claire Formation (Eau Claire) occurs conformably above the Mt. Simon in the southern peninsula of Michigan, and consists of interbedded sandstones, siltstones, and shales may also include thinly bedded dolomites (Milstein, 1989). It is described as appearing similar to the Mt. Simon, particularly in lower portions where the two units are conformable and the contact is therefore somewhat gradational. In the center of the Michigan Basin, the Eau Claire is composed of up to 100% shale and dense siltstone, with the proportion of shale in the formation decreasing toward the basin margins.

The thickness of the Eau Claire varies considerably within the Michigan Basin. WMU (1981), states that the Eau Claire ranges from 0-1,500 feet thick in the Michigan Basin, with the thickest deposits occurring in the central portion of the Basin. Milstein (1989) believes there to be about 800 feet of Eau Claire in the central portion of the basin. Milstein (1989) mapped the Eau Claire showing a maximum thickness of over 800 feet near the central basin and thinning to less than 100 feet along the eastern margin of the state (Figure B.8-9). The Eau Claire is mapped by Milstein (1989, Figure B.8-9) as being approximately 250-275 feet thick at the Site, although this thickness likely incorporateds portions of the Mt. Simon Formation and is actually thinner than mapped by Milstein.

The top of the Eau Claire occurs at about 3,000 feet BMSL (3,600 feet BGL) (Figure B.8-10) in southern Wayne and Monroe Counties, according to regional map data, local estimates are provided in Section B.8.2.2. The Eau Claire is included in the Injection Interval, and includes interbedded carbonates, shale, and other siliciclastic intervals.

### *Dresbach (Galesville) Sandstone and Franconia Formation (Injection Interval)*

The Dresbach (Galesville) Sandstone is also thickest in the central portion of the Michigan Basin, reaching its greatest thickness of over 600 feet in Gladwin County (Figure B.8-11a). Regional data show the Dresbach to be approximately 50-150 feet thick in southern Wayne and northern Monroe counties. Site specific estimates are presented in Section B.8.2.2. The Dresbach is described as medium grained silica-cemented sandstone that may have glauconite and dolomite, with some siltstone and shaley units present locally.

The Franconia Formation includes “a wide array of glauconitic dolomitic sandstone, shale, and sandy dolomite” that is sometimes indistinguishable from the underlying Dresbach Sandstone. At the CFL, these units are difficult to distinguish and thus referred to as the Franconia/Dresbach unit throughout this permit application. Milstein (1989) states that the Franconia is composed of a light pink to gray quartz sandstone that contains pyrite and abundant glauconite, but can be readily identified by gamma ray log. The Franconia has a maximum thickness of about 800 feet, and is estimated to be approximately 100-120 feet thick in the Site (Figure B.8-11b); local estimates are consistent with this regional data and are presented in Section B.8.2.2.

***Trempealeau Formation (Injection Zone)***

The Trempealeau Formation is Lower Ordovician in age and is a buff to light brown dolomite that can be sandy, shaly, and cherty, with some glauconite. Literature suggests that the formation is likely composed (from the top down) of the St. Lawrence, Lodi, and Jordan members (WMU, 1981). The St. Lawrence member is a sandy dolomite with dolomitic shales. The Lodi is a sandy dolomite with interbedded stringers of shale and sandstone, while the Jordan sandstone is fine grained quartz sandstone to sandy dolomite. This formation represents a transition between underlying sand-rich units and overlying carbonate rich intervals. Figure B.8-12 presents a regional isopach map of the Trempealeau Formation, and Figure B.8-13 presents a regional structural contour map. The Trempealeau Formation is approximately 100 feet thick below the Site area, and is more than 900 feet thick in the center of the Michigan Basin.

***Prairie du Chien Group (Injection Zone)***

The Prairie du Chien Group is Lower Ordovician in age, and consists of various layers primarily comprised of gray, sandy dolomite and dolomitic sandstone and includes the Shakopee [Foster] Formation as well as other major units identified by WMU (1981) as the Oneota Dolomite, New Richmond Sandstone, and Shakopee Dolomite. WMU (1981) states that in the subsurface “the entire Prairie du Chien Group has characteristics similar to dolomite”, and indicates that in some areas (near subcrop) the Prairie du Chien is porous. Smith, et al. (1993) described the Prairie du Chien Group as carbonate-dominated mixed carbonate siliciclastic sediments “deposited in and adjacent to shallow tropical seas that flooded most of the central North American craton during the Early Ordovician…[and] consists of sandy, silty and relatively pure dolomites and minor quartzarenites that underwent intermittent reworking by waves and unidirectional currents”. Smith et al. (1993) also state that “In the subsurface of the Michigan basin, dolomites of the Oneota Formation overlie silty-glauconitic dolomites of presumed Trempealeauan age, and are overlain by silty-sandy dolomites and dolomitic siltstone of the basal Shakopee [Foster] Formation”. The Shakopee is heterogeneous and consists of interbedded silty and sandy dolomites, with dolomitic siltstones, sandstones and shales. In the central Michigan Basin, Smith et al. (1993) state that the Shakopee is overlain by shales of varying thickness, that in turn are overlain by the St. Peter Sandstone. Milstein (1983) mapped the occurrence of the Prairie du Chien in the Michigan Basin, and showed that this formation is likely nearly absent in the CFL area, as verified by local well data (Section B.8.2.2).

#### B.8.1.3.3 Middle and Upper Ordovician Units (Injection Zone and Upper Confining Zone)

***St. Peter Sandstone/Glenwood Formation (Injection Zone)***

The St. Peter Sandstone occurs unconformably above the Prairie du Chien, and is present in northern portions of the Michigan Basin. The St. Peter is mapped as absent in southern Michigan. The Glenwood Shale is dolomitic and sandy shale that occurs in the northwestern portion of the Michigan Basin. It thins to the east and is a greenish-grey shale in central Michigan. It is persistent and mappable throughout the Basin but typically is no greater than 20 feet thick. WMU (1981) suggests that this unit may serve as a Confining Zone, as it is "thought to be a barrier to the movement of hydrocarbons from the Black River Group into the underlying Prairie du Chien and Cambrian units".

***Black River/Trenton Groups (Upper Confining Zone)***

The Black River Formation is composed of thick, undifferentiated dense brown/grey micritic limestones with cherty intervals and an altered volcanic ash layer called the Black River Shale. This shale is a thick yet distinctive bed, of limited extent, occurring in southern Michigan. Near outcrop, the Black River Formation may produce water from solution joints/fractures, but is "quite impermeable except where it has been dolomitized" in areas away from subcrop (WMU, 1981). The Trenton Formation consists of several hundred feet of light brown to brown limestone. It is 200-450 feet thick across the Michigan Basin. WMU (1981) states that "although the Trenton limestones are relatively impermeable, the possible presence of fractures and dolomitized zones could preclude its use as confining layer". The principle porosity zones are in areas of dolomitization. The Trenton-Black River Formation interval is approximately 700-800 feet thick in the Site area, based upon well logs, and was the subject of early oil exploration in the area. Figure B.8-14a is a structure contour map constructed on the top of the Trenton, Figure B.8-14b is an isopach thickness map of the Trenton, and Figure 8-14c is an isopach thickness map of the Black River. Note that Sumpter Field is a one-well Trenton field located northwest of the site; the single well produced oil for less than two years and was plugged and abandoned in 1947.

***Richmond Group/Utica Shale (Upper Confining Zone)***

The Richmond Group unconformably overlies the Trenton and Black River Formation. Regionally, it contains the Collingwood Shale and Utica Shale. The Collingwood can also be a shaly limestone but the formation is not reported to be present in southern portions of the State. The Trenton-Richmond Group (i.e., Utica Shale) stratigraphic boundary is "a widely recognized and traceable stratigraphic boundary throughout the basin, well-marked on both petrophysical and lithologic logs and also visible seismically. It is commonly used as a datum for structure contour maps and is assumed to be a chronostratigraphic surface" (WMU, 1981). Note that various authors disagree whether the Trenton-Utica contact is conformable.

The Utica Shale is upper Ordovician in age and records the influx of argillaceous mud into the depositional system. The Utica is a hard, dark gray to greenish black calcareous shale that is present throughout the Michigan Basin (WMU, 1981). Thickness varies from 140 to over 400 feet thick (Figure B.8-15), and it is identified in this figure as being approximately 300-350 feet thick in the site area based on regional information, although this thickness likely incorporations shales within the overlying Cincinnatian. WMU (1981) states that "the very low permeability of this rather thick shale coupled with the fact that it forms the seal on known hydrocarbon traps indicates that it is an excellent confining layer". The Utica Shale is the uppermost unit of the Upper Confining Zone.

The Upper Cincinnatian Group overlies the Utica shale. This Group consists of interbedded shales and carbonates, and is particularly shale-rich within the 200 or more feet that overlies the Utica Shale in the CFL area, based on well log data in the area.

***Clinton-Cataract Group***

The Clinton-Cataract Group occurs atop the Richmond Group, and consists of the upper Cabot Head Shale and lower Manitoulin Dolomite. The Cabot Head is composed of shale. The Manitoulin is buff to light brown dolomite, locally cherty with interbedded shale or shaly dolomite (Ells, 1967).

#### B.8.1.3.4 Silurian Units

Silurian units occur throughout Michigan and specifically in the Site area. The presence of low permeability units like shales and salts within the Silurian serve to impede vertical fluid movement.

***Niagara Group***

Matzkanin, et al. (1977) summarized the geology of the Niagara, stating "Niagara rocks in the subsurface are predominantly dolomites and limestones with scattered regional occurrences of cherty zones and thin shale beds. These rocks range in thickness from less than 100 feet in the basin interior to more than 1,000 feet at the basin margin… pinnacle reef complexes [occur] a few miles basin-ward from the thick carbonate bank. Reefs, reef associated sediments, and biostromes occur at various stratigraphic levels within the Salina-Niagara Group." Data presented in WMU (1981) suggest that the CFL is located in the carbonate bank area, and is upwards of 500 feet thick in the site area. Niagaran production from the Northville Field occurs over 20 miles north of the CFL location.

***Salina and Bass Island Groups***

WMU (1981) states that the Salina Group is a “thick sequence of carbonate, anhydrite, silt and shale” that is restricted in areal extent to the approximate location of the Niagara Formation. The unit grades upward from the Basal “A” member (A-1 Evaporite, A-1 Carbonate, A-2 Evaporite and A-2 Carbonate) through F member, and is composed of interbedded shales, limestones and salts. Data indicate that the Salina Group as a whole may be several hundred feet thick in the CFL area, although anhydrite rather than salts appears to be the primary evaporite (WMU, 1981).

The Bass Islands Group conformably overlies the Salina. The Bass Islands in the Michigan Basin generally consists of dense, buff dolomite and the upper part is sparsely oolitic. Lower in the section, gray argillaceous dolomites, shaley dolomites, and brown beds are present (Ells, 1967). WMU, (1981) states that the Bass Islands is described as a thick sequence of fine-grained dolomites that has floating anhydrite and celestite crystals, as well as some salt in central portions of the Michigan Basin. Regional data suggest the Bass Islands Group ranges from 0-750 feet thick in the Basin center, and is about 100-200 or more feet thick in the Site area.

#### B.8.1.3.5 Devonian – Mississippian Units

Devonian-aged units present in the area include the Bois Blanc Formation, Sylvania Sandstone, and Detroit River Group. Note that well data often identify the Dundee Formation as subcrop in the Wayne and Monroe County areas, but recent geologic data indicate that the Dundee is likely absent by erosion, with the Lucas Formation of the Detroit River Group being the youngest bedrock in the area exposed below the overlying glacial material.

***Detroit River Group***

WMU (1981) states that the Detroit River Group includes the Garden Island, Bois Blanc, Sylvania, Amherstburg, and Lucas Formations. The Detroit River Group as a whole is about 360 feet thick in the Site area. The Bois Blanc is composed of dolomite and cherty dolomites, with upper limestone-rich intervals. The Sylvania is sandstone, composed of well-rounded and sorted fine to medium grained quartzitic sandstone with thick chert and dolomitic intervals that is present in northwestern areas of the Basin. The Sylvania is identified in at least one local water well, and outcrops to the east of the Site. The Bois Blanc-Sylvania interval is approximately 100-150 feet thick near CFL based on regional data. The Amherstburg is a dark brown to black carbonaceous limestone that is present in most of the Michigan Basin. It is poorly bedded and dense, and may be present in the site area, although not specifically identified in local well data.

While the Detroit River includes the above formations, WMU (1981) indicates that it is “general practice” to only call that portion of the column between the top of the Amherstburg and Dundee the “Detroit River” and WMU (1981) states this portion of the column is sometimes referred to as the “Lucas Formation”. This portion of the column includes the Richfield Member, which is a sequence of interbedded limestone, dolomite and anhydrite with minor amounts of sand, a massive anhydrite unit, and the Horner Evaporite composed of interbedded anhydrite, limestone, and salt. The Lucas Formation is mapped as subcropping below the CFL area. Figure B.8-16 presents local bedrock below the site.

All units above the Detroit River are absent at the site due to erosion. Note that some geologic logs identify the occurrence of the Dundee Limestone, but state geologic maps indicate that the Lucas Formation (i.e., lower Detroit River) subcrops below overlying alluvium and glacial sediments in the Wayne and Monroe County areas.

#### B.8.1.3.6 Alluvium/Glacial Drift

Alluvium and glacial material cover the bedrock below the CFL area. Figure B.8-17 is a generalized regional isopach of the Glacial Drift showing that the Drift is approximately 50 feet thick at the Carleton Farms location in Wayne County. Alluvium plus glacial material thickness may range from 24 feet to over 74 feet locally. Alluvium generally consists of clay, silt, sand and gravel; glacial deposits occur below the alluvium, however most of the county is covered in lacustrine [lake] deposits composed primarily of clay and sand (Apple and Reeves, 2007). Figure B.8-18 presents a map of surficial deposits in the CFL area.

### B.8.1.4 Regional Hydrology

WMU (1981) provided an evaluation of regional groundwater systems in Michigan, and assigned Wayne and Monroe counties to the Southeast Southern Peninsula Region 1. According to this source, while most wells in these two counties produce from overlying alluvium and glacial material, upwards of 10% produce from bedrock units, including (where present) the Traverse, Dundee, Detroit River, and Sylvania Sandstone, as well as a few wells in deeper Silurian units such as the Bass Islands and Salina Group.

### B.8.1.5 Regional Seismicity

The CFL is in a USGS designated minor seismic risk area (USGS, 2017). The site area has a peak acceleration of 4-6 percent g (Figure B.8-19), with a 2% probability of exceedance in 50 years. Further, the 2018 one-year model prepared by USGS (earthquake.usgs.gov/hazards/induced/index.php#2018USGS) identified the state of Michigan as having a less than 1% probability of minor damage ground shaking, including induced seismicity events such as those that occur in Oklahoma and Kansas. The University of Michigan (2015) indicated that the most recent earthquake with a magnitude greater than 4.5 occurred more than 60 years ago on August 9, 1947 near the town of Coldwater. It damaged chimneys and cracked plaster over a large area of south-central Michigan and affected a total area of about 50,000 square miles, including points north to Muskegon and Saginaw and parts of Illinois, Indiana, and Wisconsin. Since 2008, four earthquakes have been detected in southern Michigan, including two in southern Michigan that includes one northeast of Union City and another south of Galesburg. Figure B.8-20 shows that over the past 100 years, 14 earthquakes have occurred regionally, typically with a magnitude of 3.5 or less have occurred regionally, with all occurring over 20 miles from the CFL area. See Section B.8.3.8 for additional information.

## B.8.2 Local Geologic Analysis

As shown on Figure B.4-1, summarized in Table B.4-1, and discussed in Section B.4, five wells partially penetrate the upper portion of the confining zone (Trenton and Utica Formations) within the AOR, but no wells fully penetrate through the Black River Formation to the injection interval within a two-mile radius around the CFL property boundary.

The nearest Class I wells penetrating to the Mt. Simon with well data, including test and core information and well logs, are two permitted and one plugged Class I Non-Hazardous Disposal wells owned by Environmental Geo-Technologies (EGT; previously Environmental Disposal Systems, Inc. [EDS]) in northern Wayne County. The two active wells are located in T3S R9E Section 12 (EPA Permit Nos. MI-163-1W-C010 for Well #1-12 and MI-163-1W-C011 for Well #2-12 issued in 2012). The plugged and abandoned well (EGT Well #1-20) is located in T3S R9E Section 20. Table B.8-1 summarizes pertinent information about these wells. The #1-12 and #2-12 wells are located approximately 11 miles northeast of the CFL site; well #1-20 is located approximately 7.5 miles northeast of the CFL site.

**Table B.8-1. Location of Nearby Mt. Simon Disposal Wells**

| Mt. Simon Well Location | Formal Well Name on Well Log | Well Name this Report |
|---|---|---|
| T3S R9E Sec 12 | Environmental Disposal Systems EDS 1-12 | EGT or EDS Well #1-12 |
| T3S R9E Sec 12 | Environmental Disposal Systems EDS 2-12 | EGT or EDS Well #2-12 |
| T3S R9E Sec 20 | Environmental Disposal Systems #1 | EGT or EDS Well #1-20 |

Figure B.8-21 presents a cross section constructed using Mt. Simon wells closest to the CFL area. Figure B.8-22 presents the Injection and Confining Zone generalized type log for the CFL site based upon EDS #1-12 well log data.

Local isopach and structure contour maps were generated for formations of interest in the Site area from available regional data. Maps were constructed based on a combination of well log picks and formation tops from the Michigan Department of Environmental Quality well database. Text discussion for units includes formation thickness and formation top information derived from wellsite geologist formation descriptions, but every value may not always directly correspond to the values presented on the associated structure contour and isopach maps. These small discrepancies are due to different methodologies for “picking” formations (i.e., during drilling vs. well logs). Significant differences between the data sources are identified and discussed in the text as appropriate, but minor variations of a few feet do not impact conclusions and are not explained further in subsequent sections of this document.

### B.8.2.1 Local Structural Geology

Regional structure contour maps are presented in Figures B.8-6, B.8-8, B.8-10, B.8-13, and B.8-14a. Local structure contour maps were constructed based on these maps with refinement using additional well data available from the EGT and other wells. Local maps are presented as they are discussed in subsequent sections. These maps were generally constructed using 50 foot contour intervals or alternates as appropriate for clarity of presentation. Consistent with regional characterization discussed in Section B.8.1, the analyses and mapping indicate that there are no major or mappable structural features within the Site area. Site-specific data also indicate that there are no mappable faults that transect the Injection Zone or Confining Zone locally within the AOR. That is, the Injection Zone and Confining Zone are laterally continuous, with no abrupt changes in thickness or lithology within a 5-mile radius of the Site. Structural analyses are dependent upon availability and accuracy of regional data as presented in the public record.

A local structure contour map was constructed at the top of the Mt. Simon using historical regional data presented in the EGLE tops database. Figure B.8-23 presents this surface. As shown in this figure, over the entire area the Mt. Simon dips approximately 60 feet per mile (approximately 0.65 degrees) to the northwest. Local dip direction is dependent upon formation but appears to be generally north-northwest, consistent in local and regional analyses. It should be noted that this surface does not correspond to the local stratigraphic top presented in Table B.8-2 because it was constructed using regional data that assumed a deeper Mt. Simon top than is currently identified.

### B.8.2.2 Local Stratigraphy

Table B.8-2 presents the estimated depths to formation tops. These depths are based on nearby oil and gas wells (with the deepest penetration extending to the Trenton Formation), as well as depths extrapolated from the local structural contour maps described in Section B.8.2, including the Mt. Simon wells at the EGT site (see Figure B.4-1). Table B.8-3 presents the formation thicknesses that are estimated from these data.

**Table B.8-2. Estimated Formation Tops at the Proposed CFL Well Locations**

| Formation | Est. Depth to Top, from GL (ft)* IW#1-36N | Est. Depth to Top, from GL (ft)* IW#2-36E |
|---|---|---|
| Ground Level (feet ASL) | 627 | 623 |
| Base of Alluvium/Glacial Material | 53 | 30 |
| Lucas Formation (Detroit River Group) | 53 | 30 |
| Sylvania Sandstone | 135 | 115 |
| Bois Blanc | 258 | 233 |
| Bass Island Group | 400 | 375 |
| Salina Group | 650 | 625 |
| Niagara Group | 1,122 | 1,097 |
| Clinton Group | 1,346 | 1,321 |
| Undifferentiated Upper Cincinnatian | 1,652 | 1,627 |
| Utica Shale | 2,227** | 2,198** |
| Trenton Formation | 2,357 | 2,323 |
| Black River Formation | 2,765 | 2,740 |
| Glenwood | 3,171 | 3,141 |
| Trempealeau Formation | 3,181 | 3,151 |
| Franconia/Dresbach Formation | 3,281 | 3,251 |
| Eau Claire Formation | 3,366 | 3,336 |
| Mt. Simon Sandstone | 3,527 | 3,502 |
| Precambrian Granite Wash | 3,807 | 3,782 |
| Precambrian basement | 3,827 | 3,802 |

*****Estimated depths at proposed well locations. All depths shall be determined and finalized during well installation.

** Utica top based on regional map information. Note that often the top is picked higher up the column into the Upper Cincinnatian, resulting in a thicker Utica shale unit.

**Table B.8-3. Estimated Formation Thickness at the Proposed CFL Well Locations**

| Formation | Est. Thickness (ft)* at IW#1-36N | Est. Thickness (ft)* at IW#2-36E |
|---|---|---|
| Alluvium/Glacial Drift | 53 | 30 |
| Lucas Formation (Detroit River Group) | 82 | 85 |
| Sylvania Sandstone | 123 | 123 |
| Bois Blanc | 142 | 142 |
| Bass Island Group | 250 | 250 |
| Salina Group | 472 | 472 |
| Niagara Group to Upper Cincinnatian | 530 | 530 |
| Undifferentiated Upper Cincinnatian | 575 | 575 |
| Utica Shale | 125 | 125 |
| Trenton Formation | 413 | 413 |
| Black River Formation | 406 | 401 |
| Glenwood | 10 | 10 |
| Trempealeau Formation | 100 | 100 |
| Franconia/Dresbach Formation | 85 | 85 |
| Eau Claire Formation | 161 | 166 |
| Mt. Simon Sandstone | 280 | 280 |
| Precambrian Granite Wash | 20 | 20 |
| Precambrian basement | Not applicable | Not applicable |

*Estimated thickness, both IW#1 and IW#2 locations. All thicknesses shall be determined and finalized during well installation. Note that formation thicknesses at each site are assumed roughly equivalent at this time, although actual thicknesses may vary.

The top of the Mt. Simon Sandstone is projected to be at approximately 3,527 ft BGL at IW#1-36N and 3,502 ft BGL at IW#2-36E, and is approximately 280-300 feet thick near the CFL site. The proposed Injection Zone consists of the Glenwood, Trempealeau, Franconia/Dresbach, Eau Claire, and Mt. Simon Formations; the overlying Trenton/Black River and Utica Shale compose the Upper Confining Zone. The proposed Injection Interval includes the Franconia/Dresbach through the Mt. Simon.

### B.8.2.2.1 Precambrian

The Precambrian Granite Wash was encountered at the EDS/EGT locations located approximately 7 to 11 miles northeast of CFL. This unit is described as quartz, clastics, and mineral fragments that are generally angular to very angular, tabular, and platey. The wash is orange/red with dark green tints, with some recrystalized quartz grains that are lighter/tan or cream in color. Chlorite, mica, black mineral fragments, and plagioclase fragments are present; it is described as having “no porosity”. Due to limited well control in the area, a local structure contour map of the top of the Precambrian basement was not constructed, but appears to occur at approximately 3,802 to 3,827 feet BGL near the site at the two proposed well locations (see Table B.8-2).

#### B.8.2.2.2 Cambrian (Injection Zone)

***Mt. Simon (Injection Interval)***

The Mt. Simon is a thick and ubiquitous sandstone sequence that is present above the Precambrian in the Site area. Figure B.8-23 is a structure contour map constructed at the top of the Mt. Simon, and Figure B.8-24 is a local isopach map of the Mt. Simon. These maps show that the Mt. Simon is present throughout the area, and is approximately 280 feet thick in the Site area, though inclusion of the granite wash in this interval may increase thickness by about 20 feet. Observed thicknesses at the EDS/EGT wells is approximately 335 feet. Farther to the west at the Pfizer wells, the Mt. Simon is approximately 650 feet thick.

Cores were taken from the Mt. Simon in the EDS/EGT Well #2-12; core data are summarized in Table B.8-4. Note that the upper Mt. Simon sample was located at the Eau Claire contact.

**Table B.8-4. Environmental Disposal Systems, Inc., EDS #2-12, Mt. Simon Core Data (12-12-01)**

| Depth | Porosity (Helium) | | Permeability ($K_{air}$) | |
|---|---|---|---|---|
| Top Depth: 4,127.0 ft.<br>Bottom Depth: 4,148.0 ft.<br>Number of Samples: 21 | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 4.8%<br>2.8%<br>8.6%<br>4.1% | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 1.10 md<br>0.01 md<br>8.03 md<br>0.09 md |
| Top Depth: 4,245.0 ft.<br>Bottom Depth: 4,258.0 ft<br>Number of Samples: 13 | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 10.4%<br>5.9%<br>13.7%<br>10.8% | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 25.3 md<br>0.01 md<br>208.0 md<br>7.99 md |

Core data indicate that the porosity in deeper Mt. Simon core ranges from 5.9 - 13.7%, while horizontal permeability to air ranges from 0.01 md to 208 md. Core is described as a grey to tan sandstone, fine to very fine grained, poorly cemented with dolomite. Core collected near or at the top of the Mt. Simon exhibit porosity ranging from 2.8 to 8.6%, with permeability ranging from 0.01 md to 8.03 md.

Historical reservoir testing and pressure falloff tests have been conducted at the EDS well #1-12, which are summarized in Table 8.4a (Petrotek, 2018). Permeability values from testing indicate a range of values from approximately 71 to 165 millidarcies (md). In addition, a pressure interference test was conducted between EDS #1-12 and #2-12 in June 2002 (Subsurface, 2002). This testing indicated that the reservoir encompasses two distinguishable hydraulic units, one with a permeability of 400 md and a thickness of 33 feet, and the other with a permeability of 63.4 md and a thickness of 190 feet. Based on this interference test, the total average permeability of these intervals is equal to approximately 113 md over a total thickness of 223 feet. Based on the results of these tests, an assumed permeability of 110 md over a thickness of 210 feet is conservatively assumed to represent the injection interval at the CFL wells.

**Table 8.4a. Historical Reservoir Testing, EGT Well #1-12**

| Well ID | Date | Gauge Depth (feet KB) | kh (md-ft) | k (md) | Skin | P* (psig) | Final Shut-in Pressure (psig) @ Gauge Depth |
|---|---|---|---|---|---|---|---|
| 1-12 | 2015 | 3,950 | 20,216 | 152 | 84 | 1,773 | 1,774.9 |
| 1-12 | 2016 | 3,950 | 22,225 | 165 | 41 | 1,755 | 1,761.3 |
| 1-12 | 2017 | 3,950 | 14,160 | 106 | 44 | 1,792 | 1,794.0 |
| 1-12 | 2018 | 3,950 | 9,488 | 71 | 37 | 1,804 | 1,796.7 |

Fluid samples from the Mt. Simon Sandstone were obtained by EDS via DST during drilling and completion of the EDS #2-12 well. The fluid sample TDS value was approximately 270,000 mg/L. Table B.8-5, below, presents water quality data obtained from the EDS #2-12 well.

**Table B.8-5. Environmental Disposal Systems, Inc., Mt. Simon Formation Brine Fluid Analysis, EDS #2-12 (12-12-01)**

| Analysis | Concentration | Units | Data Completed |
|---|---|---|---|
| Conductivity SM 2510-B | 16,200 | uS/cm | 12/17/01 |
| Magnesium EPA 242.1 FLAA | 2,900 | mg/L | 12/20/01 |
| Potassium EPA 258.1 FLAA | 1,910 | mg/L | 12/19/01 |
| Sodium EPA 273.1 FLAA | 39,400 | mg/L | 12/20/01 |
| Alkalinity (Bicarbonate) SM2320-B | 13 | mg/L | 12/20/01 |
| Alkalinity (Carbonate) SM2320-B | ND | mg/L | 12/20/01 |
| Chloride EPA 325.2 | 141,100 | mg/L | 12/31/01 |
| pH EPA 150.1 | 5.5 | s.u. | 12/19/01 |
| Residue, Filterable (TDS)/SM2540C | 270,100 | mg/L | 12/19/01 |
| Sulfate EPA 375.4 | 146 | mg/L | 01/03/02 |
| Sulfide SW846-9030A | N/D | mg/L | 01/03/02 |
| Temperature SM2550B | 20.6 | Degrees C | -- |

***Recent Reservoir Characteristic Analysis to Support CO2 Sequestration***

The Mt. Simon has recently been studied as a possible candidate formation for $CO_2$ injection and results of these analyses also provide information pertinent to fluid injection. Barnes et al. (2009) evaluated the sedimentary facies, lithology, and petrophysics of the Mt. Simon in western Michigan to further understand porosity and permeability development. These authors recognized that the Mt. Simon can be subdivided into three general units: a basal pink-red hematite-stained arkosic unit, central medium-coarse grained quartz sandstone with minor shale/glauconite, and upper transitional calcareous, argillaceous sandstone with fine-grained arkose interbeds that occurs conformably below the Eau Claire. However, extension of these lithofacies to the far east is difficult; see regional cross sections B.8-4 and B.8-5 which demonstrate that while the Mt. Simon is ubiquitous throughout Michigan, thickness and depositional characteristics are highly variable between western and eastern Michigan.

***Eau Claire Formation (Injection Interval)***

Regionally, the Eau Claire is highly variable from a compositional standpoint, consisting of fine grained sandstone with dolomitic cement in its lower half and siltstones, shales, and sandstone in the upper half. The entire thickness is glauconitic. The Eau Claire thickens to over 800 feet toward the center of the Michigan Basin (Figure B.8-9), and is approximately 160-190 or more feet thick in the CFL area. Note that the Eau Claire-Mt. Simon contact is highly gradational, therefore estimate of both Mt. Simon and Eau Claire thickness are estimates and vary depending on where that contact is selected.

The Eau Claire was cored in the EDS #1-12 and EDS #2-12 wells. Summary results of core analyses for the Eau Claire are presented in Tables B.8-6a and B.8-6b. Note that well EDS #1-12 is a directional well, therefore the core depths are not consistent with corrected formation tops at EDS #2-12. These data show that the sampled portion of the upper Eau Claire in EDS #1-12 exhibits a porosity ranging from 1.2-3.9%, with an average permeability $K_{air}$ of 0.10 md. The lower portion of the Eau Claire at EDS #1-12 exhibits a porosity ranging from 5.4% to 20.7%, with an average permeability of 13.3 md. The upper Eau Claire core is described as a dolomite with laminar bedding and slight anhydrite; the lower Eau Claire core is described as a fine to medium grained sandstone.

**Table B.8-6a. Environmental Disposal Systems, Inc., EDS #1-12, Eau Claire Core Data (1-28-02)**

| Depth | Porosity (Helium) | | Permeability ($K_{air}$) | |
|---|---|---|---|---|
| **Upper Eau Claire** | | | | |
| Top Depth: 3,060.0 ft.<br>Bottom Depth: 3,090.7 ft.<br>Number of Samples: 31 | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 2.1%<br>1.2%<br>3.9%<br>2.1% | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 0.10 md<br>0.01 md<br>0.66 md<br>0.04 md |
| **Lower Eau Claire** | | | | |
| Top Depth: 4,155.0 ft.<br>Bottom Depth: 4,187.3 ft<br>Number of Samples: 32 | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 10.8%<br>5.4%<br>20.7%<br>10.1% | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 13.3 md<br>0.06 md<br>73.0 md<br>5.91 md |

**Table B.8-6b. Environmental Disposal Systems, Inc., EDS #2-12, Lower Eau Claire Core Data (12-12-01)**

| Depth | Porosity (Helium) | | Permeability ($K_{air}$) | |
|---|---|---|---|---|
| Top Depth: 4,127.0 ft.<br>Bottom Depth: 4,148.0 ft.<br>Number of Samples: 21 | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 4.8%<br>2.8%<br>8.6%<br>4.1% | Arithmetic Average<br>Minimum<br>Maximum<br>Median | 1.10 md<br>0.01 md<br>8.03 md<br>0.09 md |

As shown on Figure B.8-25, regional data suggest the Eau Claire is approximately at least 180 feet thick in the Site area.

***Dresbach (Galesville) and Franconia (Injection Interval)***

The Dresbach is described as a sandstone that is clear to frosted; it is very fine to coarse grained with moderate to well-sorted subangular to rounded grains and trace glauconite. The Dresbach was not cored at either EDS well. Regional maps indicate this unit could be 50 feet thick, but local well data at the EDS locations combines the Franconia/Dresbach as a single interval that is approximately 50 feet thick in total. At EDS 2-12, the Franconia is described as a grey sandstone that is very fine grained with grey dolomite; it is also glauconitic and dolomitic at the base.

#### B.8.2.2.3 Ordovician (Injection Zone and Confining Zone)

In contrast to the deeper Cambrian units, units within the Ordovician are composed predominantly of carbonates, indicative of changes in the regional depositional systems. Ordovician units present at the Site are described below.

***Trempealeau Formation (Injection Zone)***

In western portion of Michigan, the Trempealeau is described as dolomite that is sandy at the base, with decreasing sand percentage up-section. The dolomites are light tan to tan and grey in color, with red/pink coloration and varying intercrystalline porosity. The units are variably described as fine to medium grained (sucrose to micritic), and may contain shale that is present in traces. Glauconite is also present. Figure B.8-12 is an isopach map of the Trempealeau, which shows that the interval to be 50-100 feet thick in the CFL area, which was verified by local data at the EDS wells, where the Trempealeau is approximately 120 feet thick.

The Prairie du Chien Group occurs above the Trempealeau, and is early Ordovician in age. It is present elsewhere in the state, but is absent below the CFL site.

***Glenwood Shale-St. Peter Sandstone Interval (Injection Zone)***

Regionally, the Glenwood-St. Peter Sandstone interval occurs above the Prairie du Chien interval and is up to 100 ft thick in western portions of the state. However, below the CFL, the unit is likely a very thin dolomite (less than 10 feet).

***Black River Formation - Trenton Formation (Confining Zone)***

The Black River Formation is ubiquitous in the Site area. It is composed of limestone that is described as light tan to grey and buff in color, and finely crystalline to chalky to micritic, with a few imbedded dolomite rhombs. Occasional shale intervals are described (although not present throughout). The Black River Group may also contain occasional sandstone intervals (described as white, quartizitic, and fine grained), as well as dolomite zones with traces of chert. The basal limestone is described as "pure" with little insoluble residue. In the CFL area, the Black River is described in the EDS wells as a thick, occasionally argillaceous dolomite that is typically dense. The Black River is approximately 400 feet thick at the EDS wells, and is expected to exhibit comparable thickness below CFL.

The overlying Trenton Formation is composed almost entirely of dolomites with some limestone intervals. Dolomite may be finely crystalline with scattered vugs and occasional carbonaceous partings. Dolomites may be brown to white, with limestones being grey to tank in color. In total, the Trenton-Black River is expected to be about 800 feet thick at CFL (Figure B.8-26).

Well log data at the EDS #1-20 well indicate that the average neutron porosity of the Trenton-Black River interval is generally 1-3%, noting that there may be more porous intervals. The Black River at EDS #1-20 exhibits a log porosity of approximately 2% throughout the entire interval, which is 454 feet thick (3,692-3,238 ft RKB). Regionally and where the Trenton-Black River is unfractured, porosity ranges from 2-5% and permeability of generally low (less than 10 mD, but lower than 0.01 mD) (Grammer, 2006).

It should be noted that the Trenton was pursued as a hydrocarbon producing zone to the north of the CFL site. Southeastern Michigan has several Trenton hydrocarbon producing fields, notably associated with structural features and hydrothermal dolomite development. As shown in Figure B.8-27, there are no significant structural features at the top of the Trenton in the CFL region, thus reducing the likelihood that this formation exhibits satisfactory reservoir characteristics and thus would not be pursued for hydrocarbon production. In fact, the single producing well in the nearby Sumpter field, the DeRoy 1 (T4S R8E Section 22), which was plugged and abandoned in 1947.

The Black River Formation is estimated to be approximately 400 or more feet thick at the Site, and the Trenton Formation is estimated to be approximately 400 feet. The thickness estimates are based on data obtained at the EDS well locations, as well as general information from nearby Trenton wells. However, these wells did not fully penetrate the Trenton Formation and typically total depths (TD) are 100-150 feet below the formation top. None of the wells within the 2-mile Area of Review are documented to have penetrated to the Black River, indicating that the lower 300-400 feet of the confining zone has not be penetrated by oil and gas wells within two miles of the proposed well locations. See Attachment B.4 for additional information.

***Utica Shale (Confining Zone)***

The Utica Shale is present throughout the Site area. The Utica Shale is described as a medium grey to grey-green shale with occasional brown shale partings; some well log cutting descriptions elsewhere in the state describe the shale as being blue-grey, muddy, and “gummy”. It is worth noting that the Utica Shale is in the lower Cincinnatian; locally, the upper Cincinnatian includes up to 235 feet or more of shales, that also offer upper confinement. Core was collected from this upper Cincinnatian Shale at the EDS No 2-12 well; Table B.8-7 presents this core information. As shown in Table B.8-7, porosity of the upper Cincinnatian ranges from 1.1-3.5%, and permeability varies from 0.01 md to 10.6 md.

**Table B.8-7. Environmental Disposal Systems, Inc., EDS #2-12, Upper Cincinnatian Core Data (12-12-01)**

| Depth | Porosity (Helium) | Permeability ($K_{air}$) |
|---|---|---|
| Top Depth: 2,505.0 ft.<br>Bottom Depth: 2,535.0 ft.<br>Number of Samples: 30 | Arithmetic Average 2.2%<br>Minimum 1.1%<br>Maximum 3.5%<br>Median 2.2% | Arithmetic Average 2.18 md<br>Minimum 0.01 md<br>Maximum 10.6 md<br>Median 1.41 md |

Sattler and Barnes (2018) noted that “The Utica Shale and Maquoketa Shale are considered to be the primary confining layers for Cambrian-Ordovician CO2 sequestration in the Midwest in the Michigan and Illinois Basins, respectively…” and “The Utica Shale is a notable confining zone in the region because of its widespread lateral continuity, dense mudrock lithology, and thickness in excess of 30 m.” Sattler (2015) evaluated Utica porosity and permeability measurement data obtained from core obtained from wells in nearby Lenawee and Jackson county; these are the closest wells in Sattler’s 2015 report to the proposed CFL well locations.

| Well | County | Utica Depth | Utica Porosity | Utica Permeability (orientation no defined; likely horizontal | Comment |
|---|---|---|---|---|---|
| Thompson 1-30 | Lenawee | 2,277 ft BGL | 0.77% | 0.003 mD | Similar depth to top of Utica at CFL |
| Arco-Conlkin 1-31 | Jackson | 3,696 ft BGL | 2.78% | 14.71 mD | Slightly deeper to top of Utica than at CFL |

The Utica-Trenton contact is abrupt, with the Utica deposited in an open marine environment (Sattler, 2015). Michigan core verifies the marine depositional setting, described as a sometimes fossiliferous grey to black mudstone with pyrite and calcareous lenses. Some vertical fractures were observed in core that were typically cemented with calcite or gypsum/anhydrite but fracturing was not described as laterally or vertically pervasive (Stattler, 2015). The Utica Shale gamma ray log response is typical of dense mudrock lithologies, and the response is generally consistent throughout the Michigan Basin although thickness may vary (Sattler, 2015).

The Utica shale is approximately 125-140 feet thick or more in the CFL area. Figure B.8-28 is an isopach of the Utica Shale, and Figure B.8-29 is a structure contour map constructed at the top of this shale.

#### B.8.2.2.4 Silurian, Devonian and Mississippian Units

Devonian and Mississippian-aged units are discussed in Sections B.8.1.3.4 and B.8.1.3.5 of this document. The units include the Undifferentiated Cincinnatian, Manitoulin Dolomite, Cabot Head Shale, Clinton Group, Niagara Group, Salina Group, Bass Islands Group, and Detroit River Group, with units above these absent by erosion at the CFL area. In total, this interval is estimated to be over 2,000 feet thick at the Site.

#### B.8.2.2.5 Alluvium and Glacial Material

Unconsolidated material of various origins and characteristics are present in the Site area. Figure B.8-17 shows the glacial clay/drift thickness to be approximately 50 feet, while Figure B.7-18 shows the total thicknesses of the overlying alluvium and till to not exceed 75 feet in the site area. Local data suggest that the total thickness of glacial clay will not exceed 53 feet at the selected CFL well locations (City Management Corporation, 1991).

### B.8.2.3 Local Seismic Activity

The Site occurs in a region where only minor occurrences of seismic activity have been detected (USGS, 2017). Figure B.8-19 shows that the Site area is located in an area with low peak acceleration. No damage from earthquakes is expected. Based on USGS records (https://earthquake.usgs.gov), only four earthquakes have been recorded in Michigan since 1974. Figure B.8-20 presents regional location of earthquakes in southern Michigan, and shows that the CFL site is approximately 75 miles from the closest Michigan earthquake that has occurred in the past 100 years. Table B.8-8 presents information about earthquakes presented in Figure B.8-20, noting that the closest earthquake to CFL was in Ontario over 15 miles away.

Induced seismicity related to human activity is a concern in localized areas elsewhere in the United States, in places such as Oklahoma and Kansas. The USGS recently published a document identifying the likely location of induced seismic events (Figure B.8-30). As shown in this figure, no areas in Michigan are identified as an area for potential induced seismic activity. Induced seismicity can sometimes be of concern in other areas where significant injection occurs near basement rock. In the case of the Mt. Simon, Class I disposal wells occur within the states of Michigan and Indiana, many of which have been in operation for decades and are completed throughout the Mt. Simon and at or near basement. None of the seismic events in Michigan or Indiana have been associated with Mt. Simon deep well injection activities.

**Table B.8-8. Earthquakes > 2.5 Magnitude, Southern Michigan Region, 1919-2019**

| Year | Month | Day | North Latitude | West Latitude | Magnitude | Location |
|---|---|---|---|---|---|---|
| 2018 | 4 | 20 | 42.1181 | -83.015 | 3.4 | 2km E of Amherstburg, Canada |
| 2017 | 5 | 14 | 42.136 | -82.41 | 2.6 | 18km ENE of Leamington, Canada |
| 2016 | 2 | 7 | 41.6503 | -82.8969 | 2.5 | 15km NNE of Port Clinton, Ohio |
| 2015 | 6 | 30 | 42.1464 | -85.0459 | 3.3 | 11km NE of Union City, Michigan |
| 2015* | 5 | 2 | 42.2357 | -85.4285 | 4.2 | 5km S of Galesburg, Michigan |
| 2015 | 2 | 16 | 45.0744 | -83.502 | 2.5 | Michigan |
| 2013 | 11 | 11 | 41.7999 | -87.8247 | 3.2 | 1km NW of Summit, Illinois |
| 2013 | 2 | 17 | 42.018 | -82.224 | 2.5 | southern Ontario, Canada |
| 2012 | 9 | 7 | 41.864 | -83.076 | 2.5 | Ohio |
| 2012 | 1 | 26 | 41.576 | -85.49 | 3 | Indiana |
| 2011 | 2 | 23 | 42.157 | -82.43 | 3 | southern Ontario, Canada |
| 2010 | 5 | 17 | 41.24 | -81.51 | 2.7 | Ohio |
| 2010 | 5 | 14 | 41.39 | -83.3 | 2.7 | Ohio |
| 2010 | 3 | 8 | 42.163 | -83.07 | 2.5 | Michigan |
| 2007 | 4 | 12 | 41.722 | -82.924 | 2.8 | Lake Erie, Ohio |
| 1994 | 9 | 2 | 42.798 | -84.604 | 3.5 | Michigan |
| 1984 | 1 | 14 | 41.645 | -83.427 | 2.5 | Ohio |
| 1980 | 8 | 20 | 41.941 | -83.01 | 3.2 | Ohio |
| 1976 | 2 | 2 | 41.96 | -82.67 | 3.4 | Ohio |
| 1974 | 9 | 29 | 41.238 | -83.361 | 3 | Ohio |
| 1947 | 8 | 10 | 41.928 | -85.004 | 4.6 | Indiana |

Source: National Earthquake Information Center
*University of Michigan, 2015

### B.8.2.4 Karst, Mines, and Other Features

Form EQ 7200-14 required the identification of faults, structural features, karst, mines and lost circulation zones within the Area of Review that can influence fluid migration, well competency, or induced seismicity. Faults and structural features were addressed in Sections B.8.1.2 and B.8.2.1.

The presence of karst is possible where carbonate beds are near surface with the potential for influx of water that would facilitate dissolution. Sinkholes have been identified in Monroe county where carbonate units occur near ground level, and both Wayne and Monroe County have been identified as areas where sinkholes are infrequent or likely infrequent (Michigan State University Extension, 2008). The possibility of carbonate dissolution features near surface, and particularly within the

Lucas that subcrops below the CFL, will be assessed during well installation.

Bedded salt is present in the shallow subsurface north of CFL, particularly near Detroit. Salt mine location is predicated by the occurrence of bedded salt near ground level, with the Salina Group the primary source of bedded salt. However, in the Carleton area, the Salina Group contains very little salt, and there is no information to indicate that salt mining (either dry or solution) occurs or has occurred within the AOR (http://geo.msu.edu/extra/geogmich/saltminingM.html). Further, there are no other known resources that are mined within the AOR.

### B.8.3 Conclusion

Data presented in this section indicate that the Site satisfies the geologic criteria for siting of Class I waste disposal wells by demonstrating that site stratigraphy, structure, hydrogeology and seismicity of the area meet these standards and criteria. Geologic properties are well defined, and as illustrated by geologic characterization and historic operation of neighboring wells, the Injection Interval has sufficient permeability, porosity, thickness and areal extent to accept injectate and prevent migration of fluids into USDWs. The Injection Zone, Injection Interval, and the Confining Zone are laterally continuous and free of transecting transmissive faults or fractures within the AOR. Further, the Injection Interval is separated from the top of the Confining Zone by sequences of permeable and less permeable strata that prevent vertical fluid movement. The Confining Zone is also separated from the base of the USDW by multiple sequences of permeable and less permeable strata that serve to prevent vertical fluid movement.

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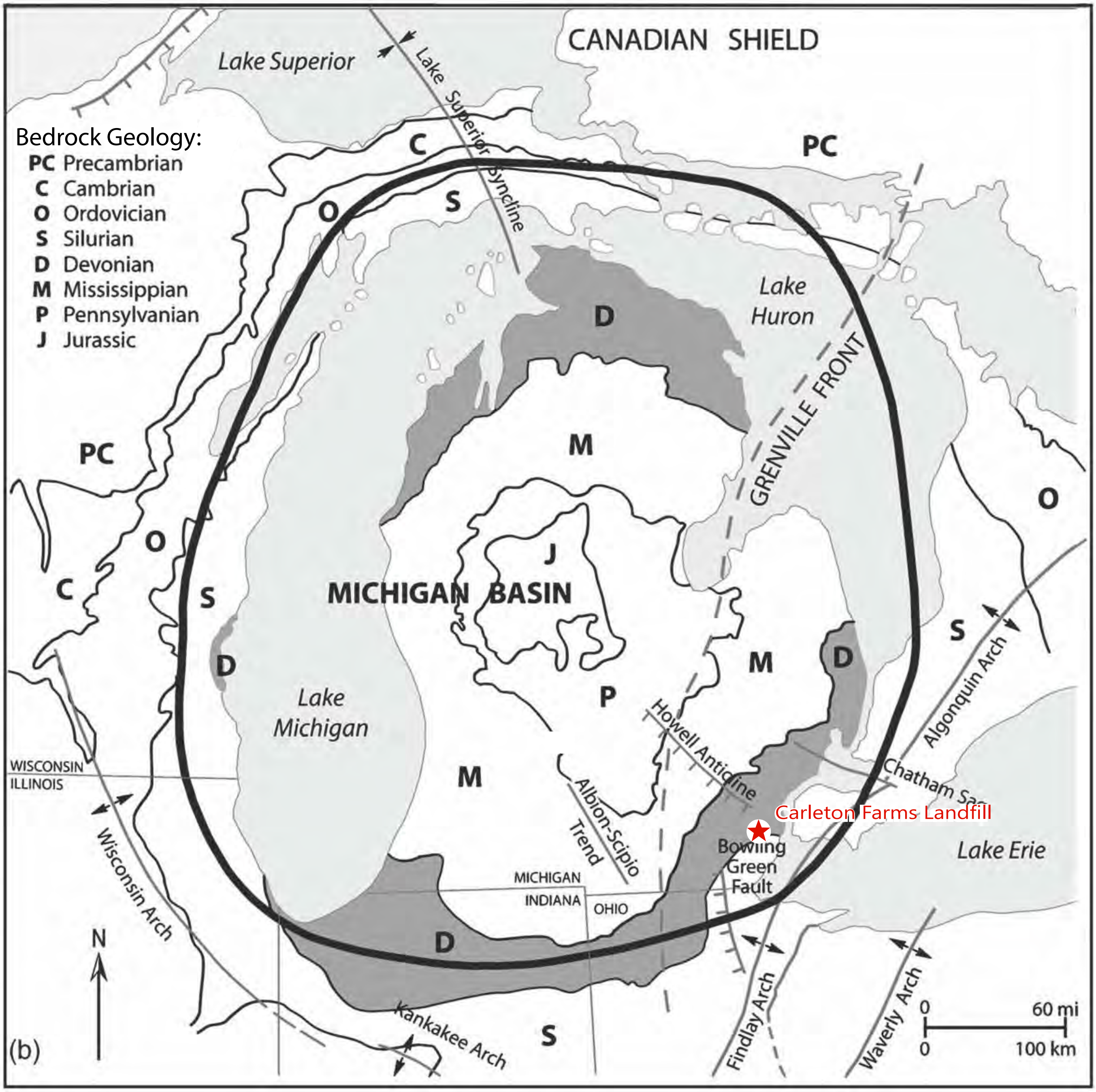


Modified from : Catacosinos et al., 1991

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Figure B.8-1
General Geology and Structural Features of the Michigan Basin
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| Scale: See Bar Scale | Date: September 2019 | |
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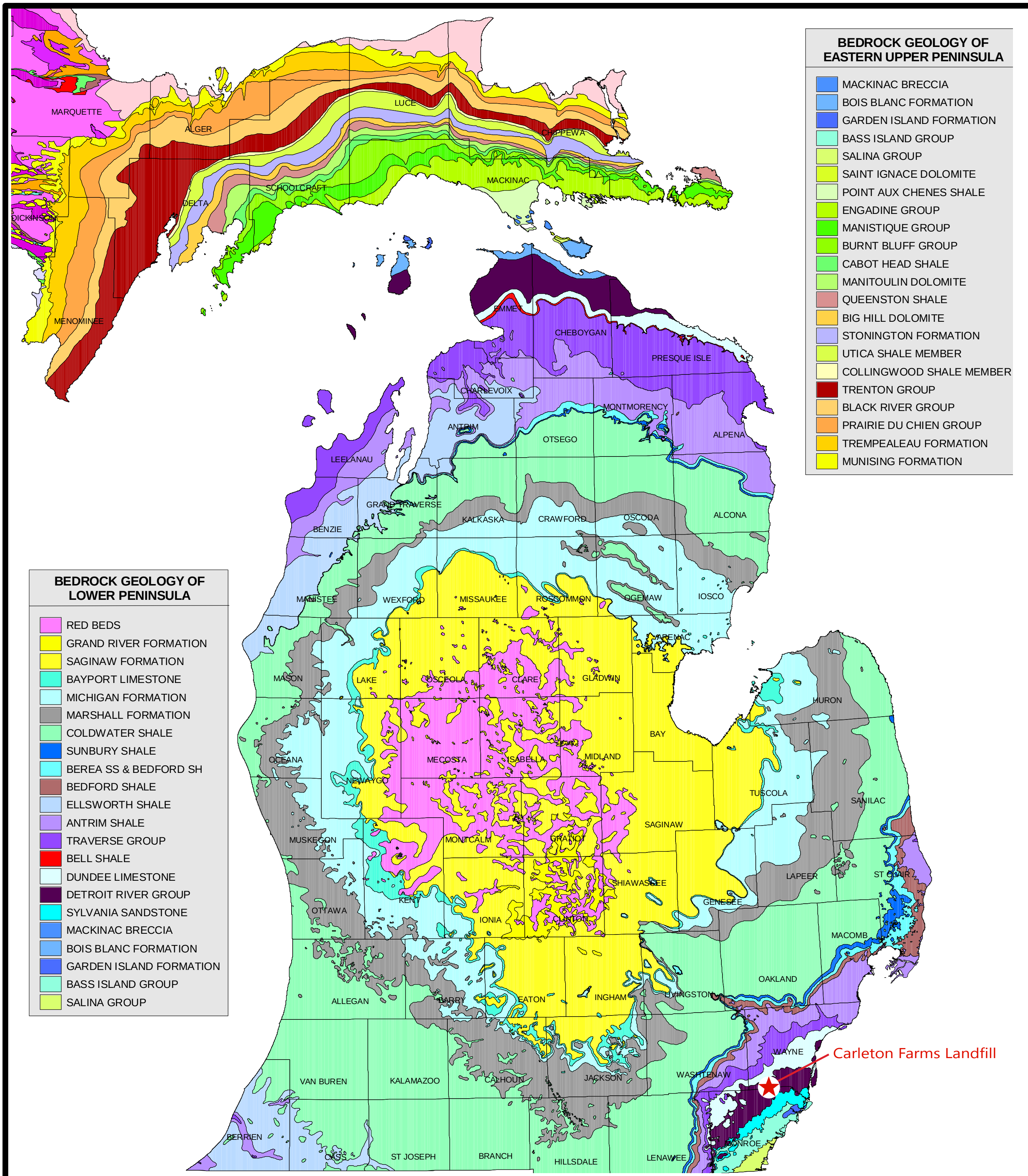


SOURCE

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
LAND AND MINERALS SERVICES DIVISION
RESOURCE MAPPING AND AERIAL PHOTOGRAPHY

Michigan Resource Information System
Part 609, Resource Inventory, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended.

Automated from "Bedrock Geology of Michigan," 1987, 1:500,000 scale, which was compiled from a variety of sources by the Michigan Department of Environmental Quality, Geological Survey Division.

Date: 11/12/99

0 20 40 Miles

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Figure B.8-2
Regional Bedrock Geology of Michigan

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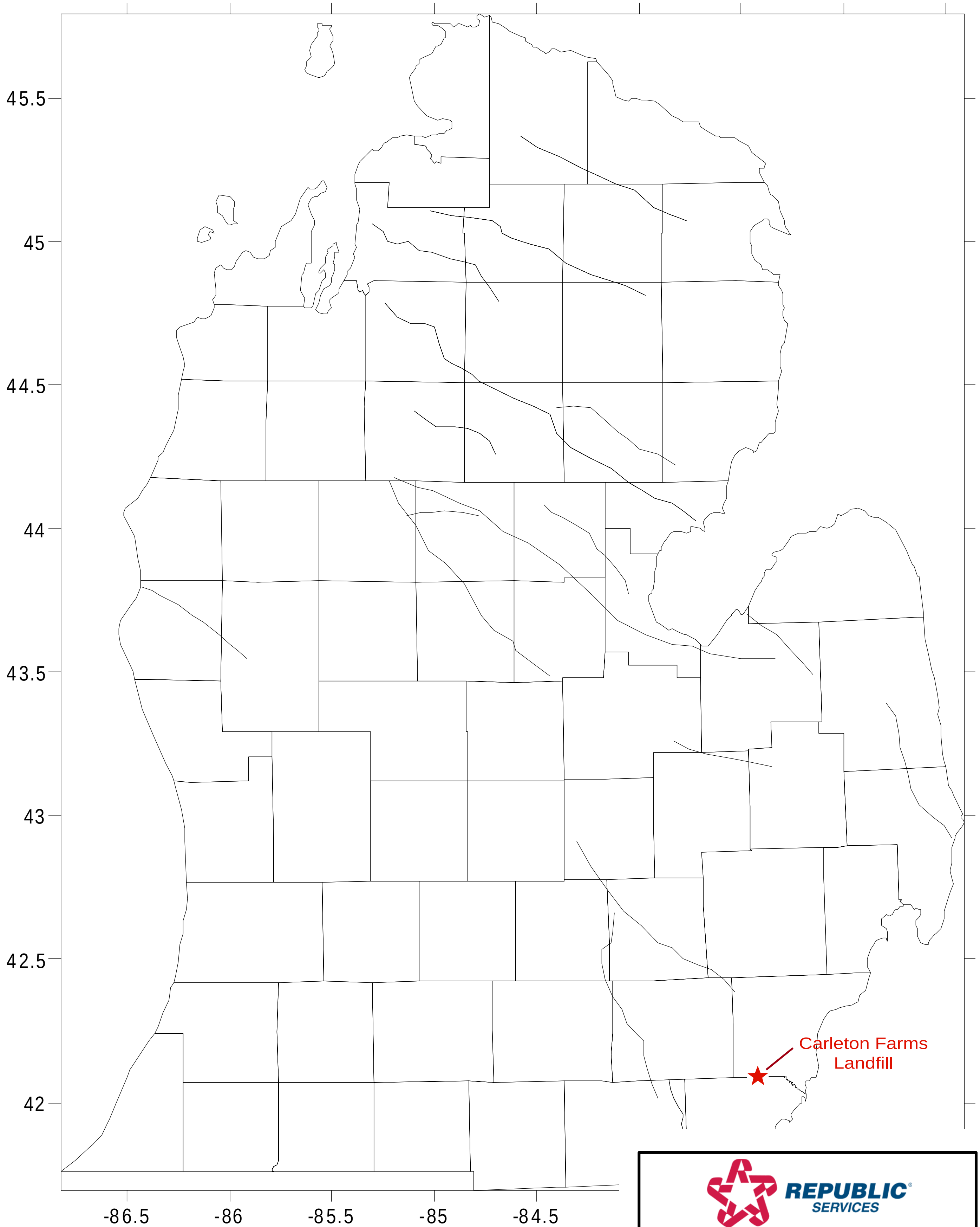


From: Wood and Harrison, 2002

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Figure B.8-3
Dundee Lineaments, Michigan Basin

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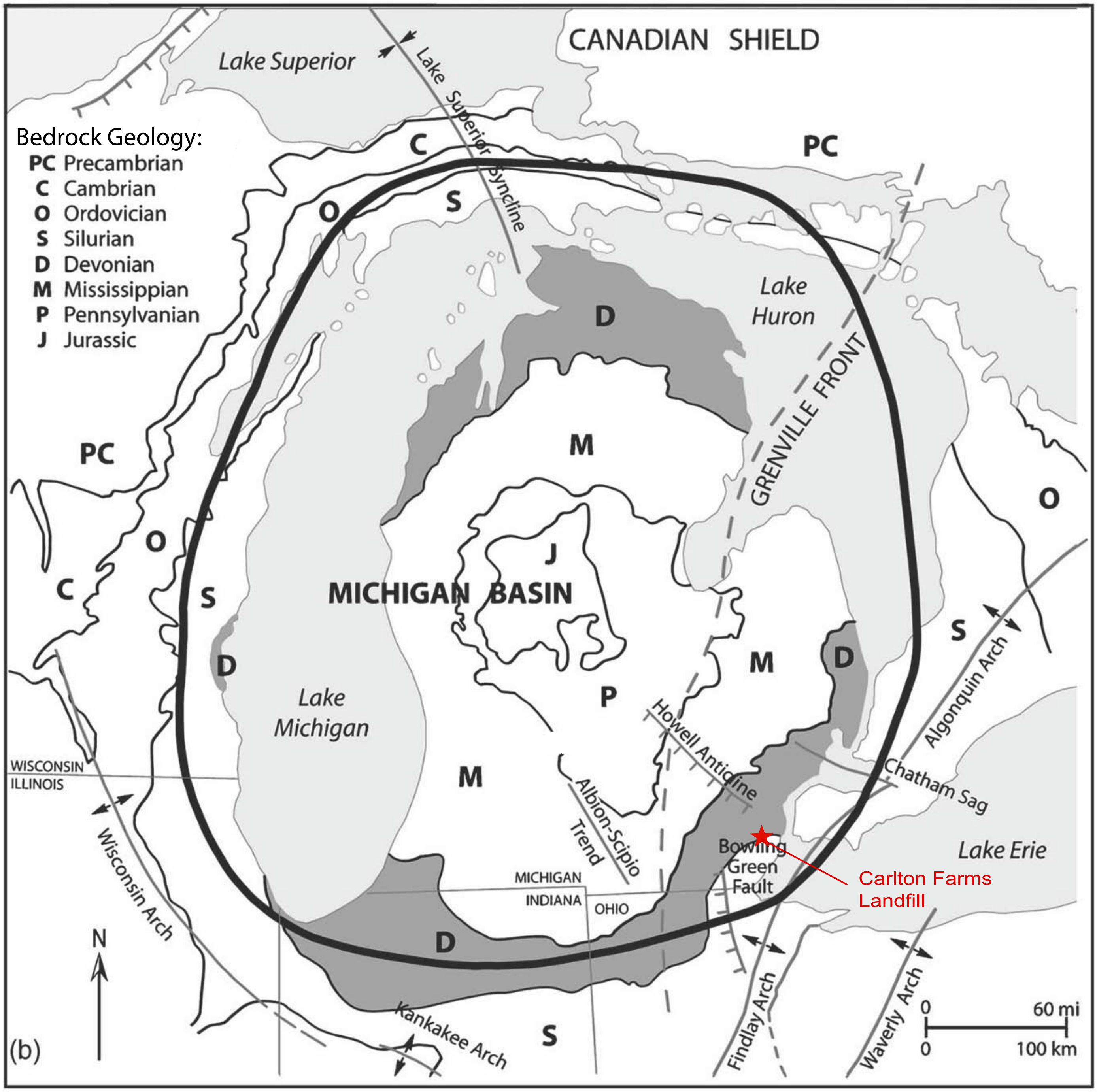


Modified from : Catacosinos et al., 1991

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Figure B.8-3A
General Geology and Structural Features of the Michigan Basin
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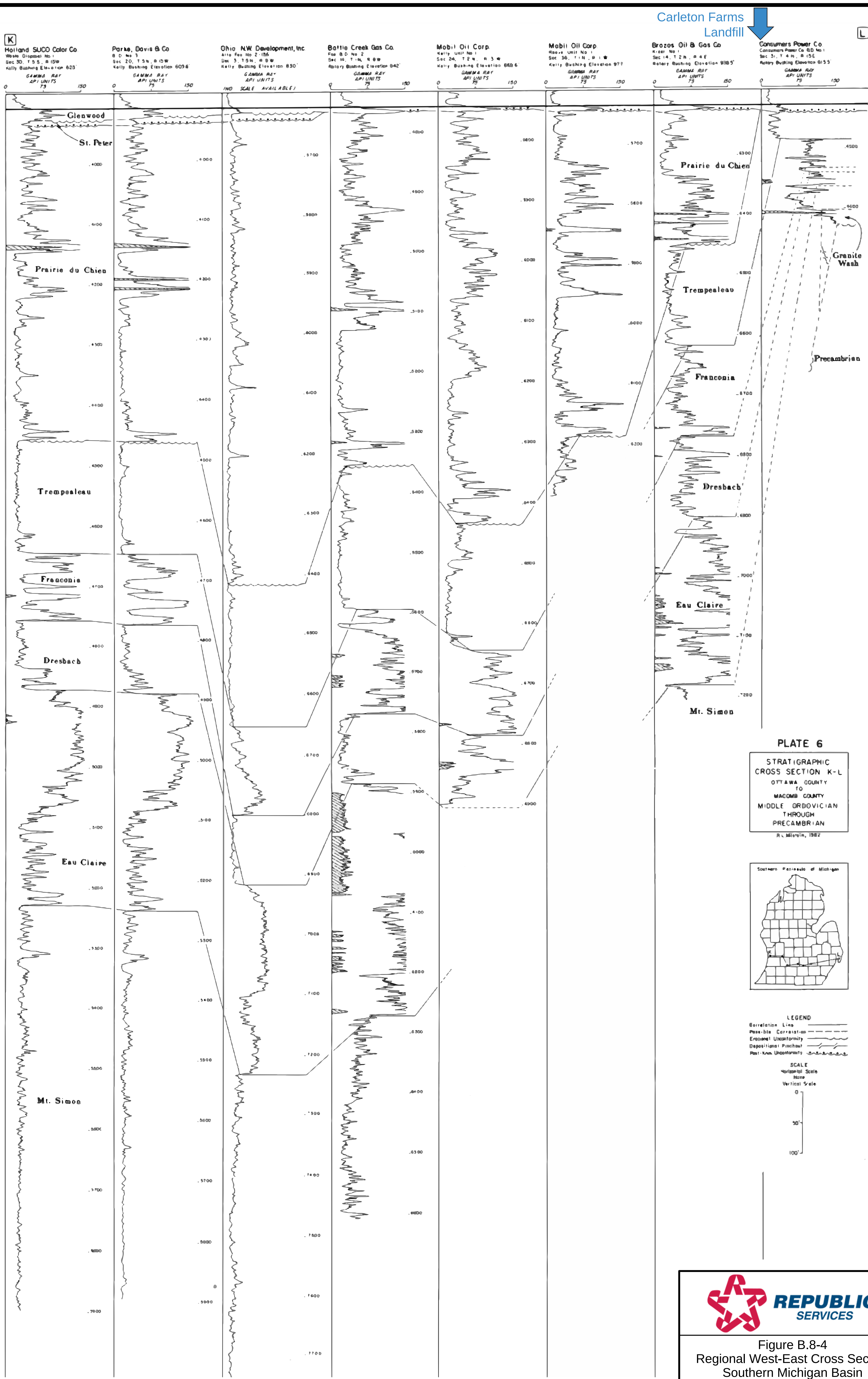


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Figure B.8-4
Regional West-East Cross Section
Southern Michigan Basin

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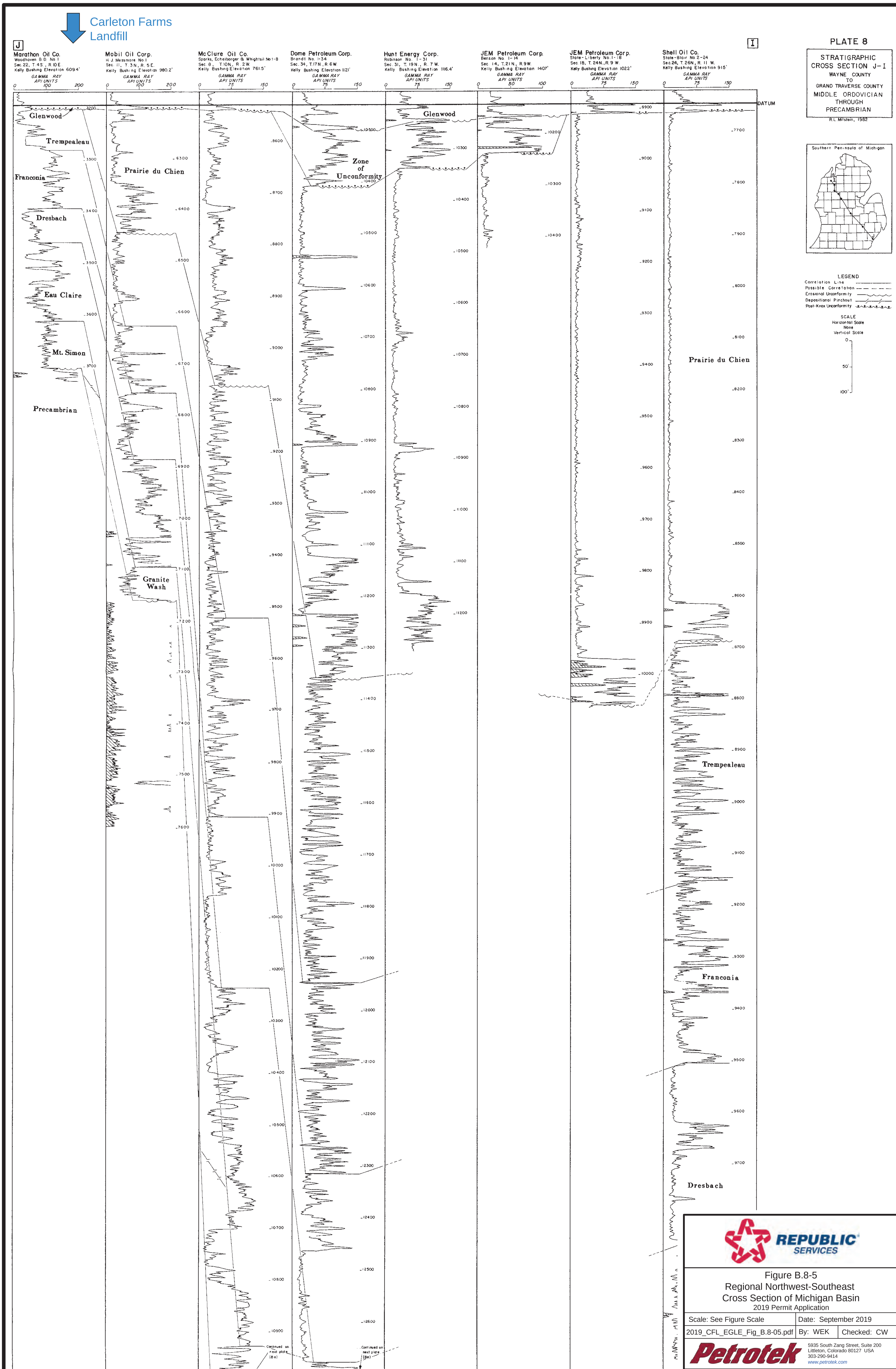


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Figure B.8-5
Regional Northwest-Southeast
Cross Section of Michigan Basin
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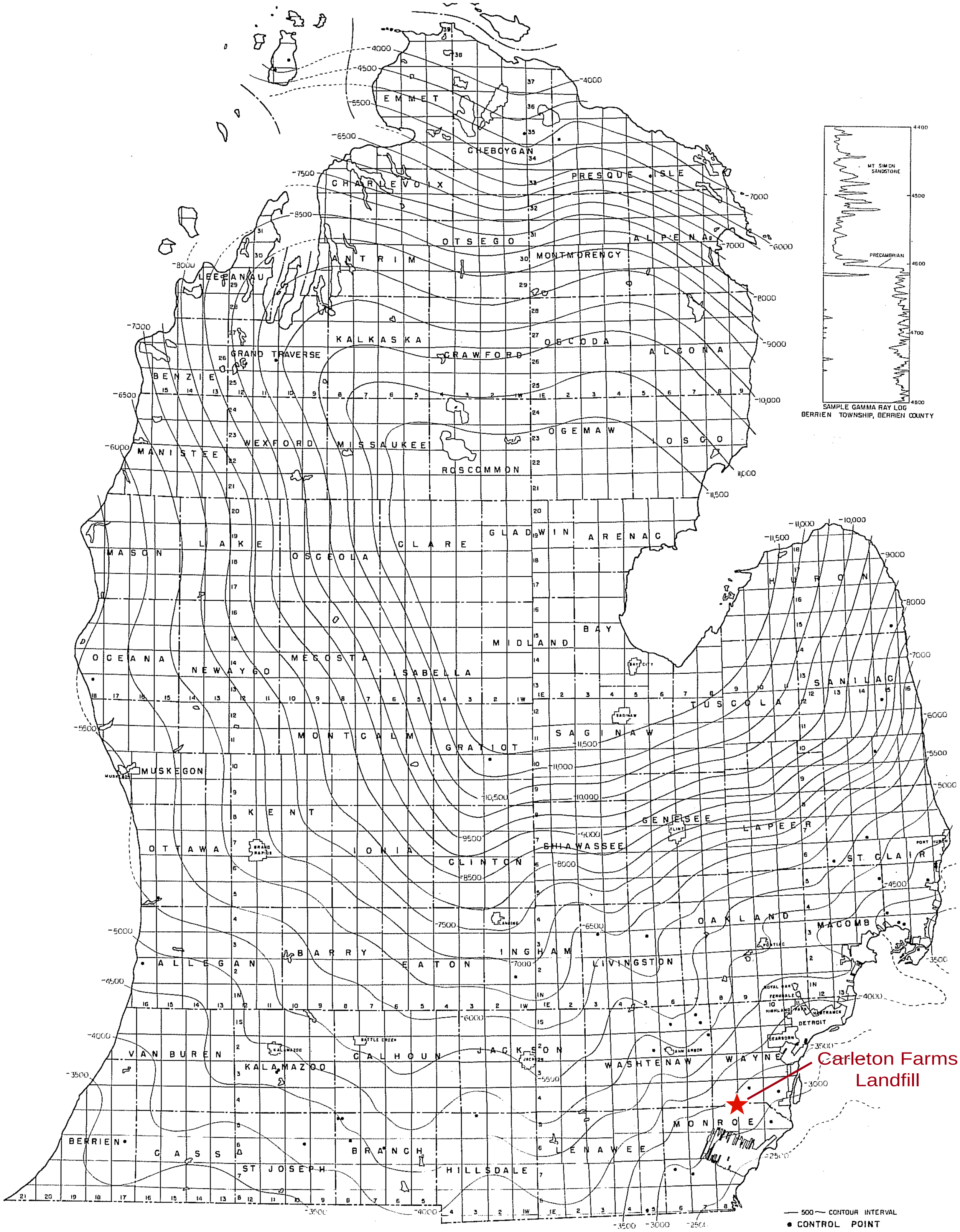


After: R. Milstein, 1988

Figure B.8-6
Precambrian Basement Structure
Contour Map, Michigan Basin
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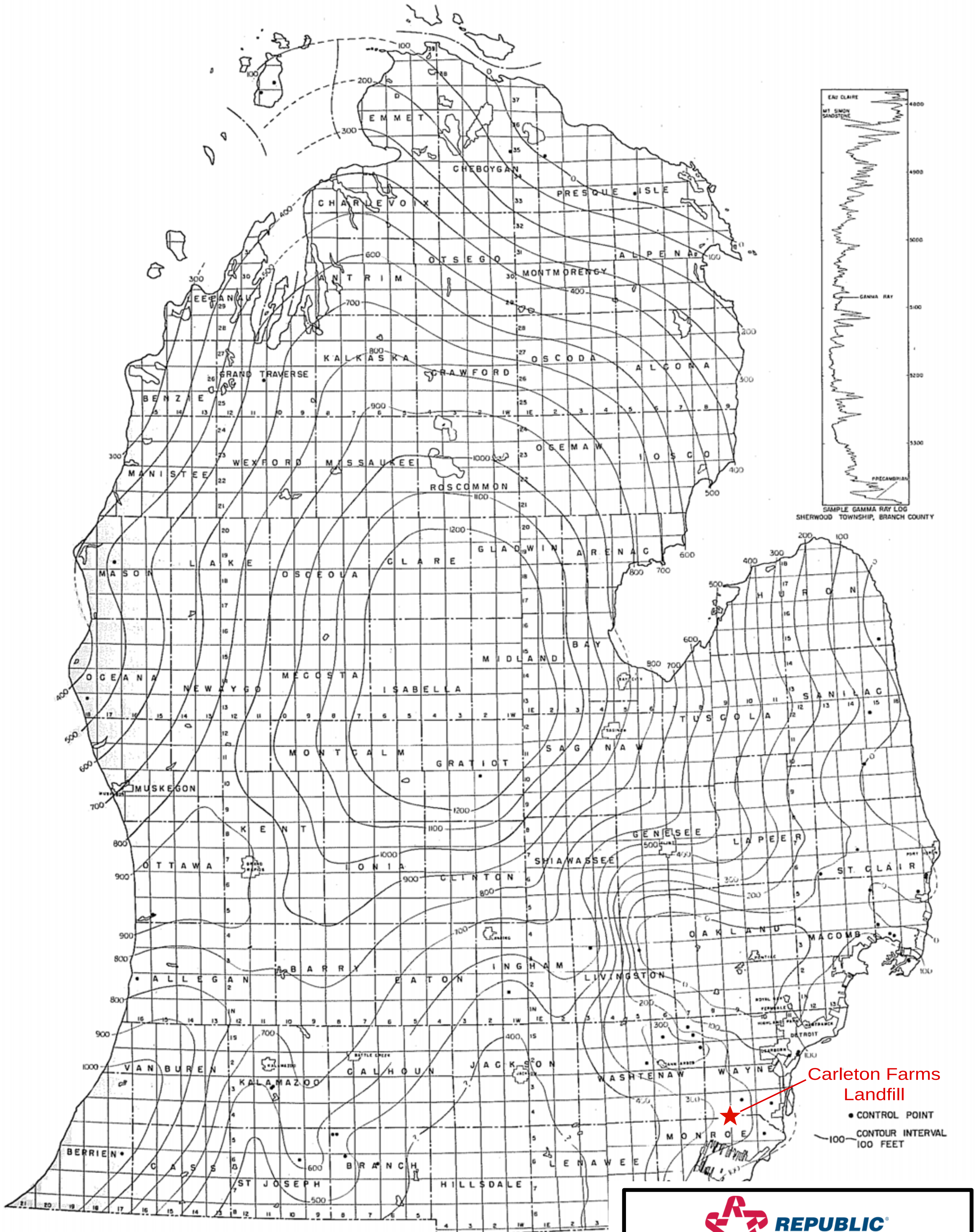


After: R. Milstein, 1988

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Figure B.8-7
Mt. Simon Sandstone Isopach Map, Michigan Basin
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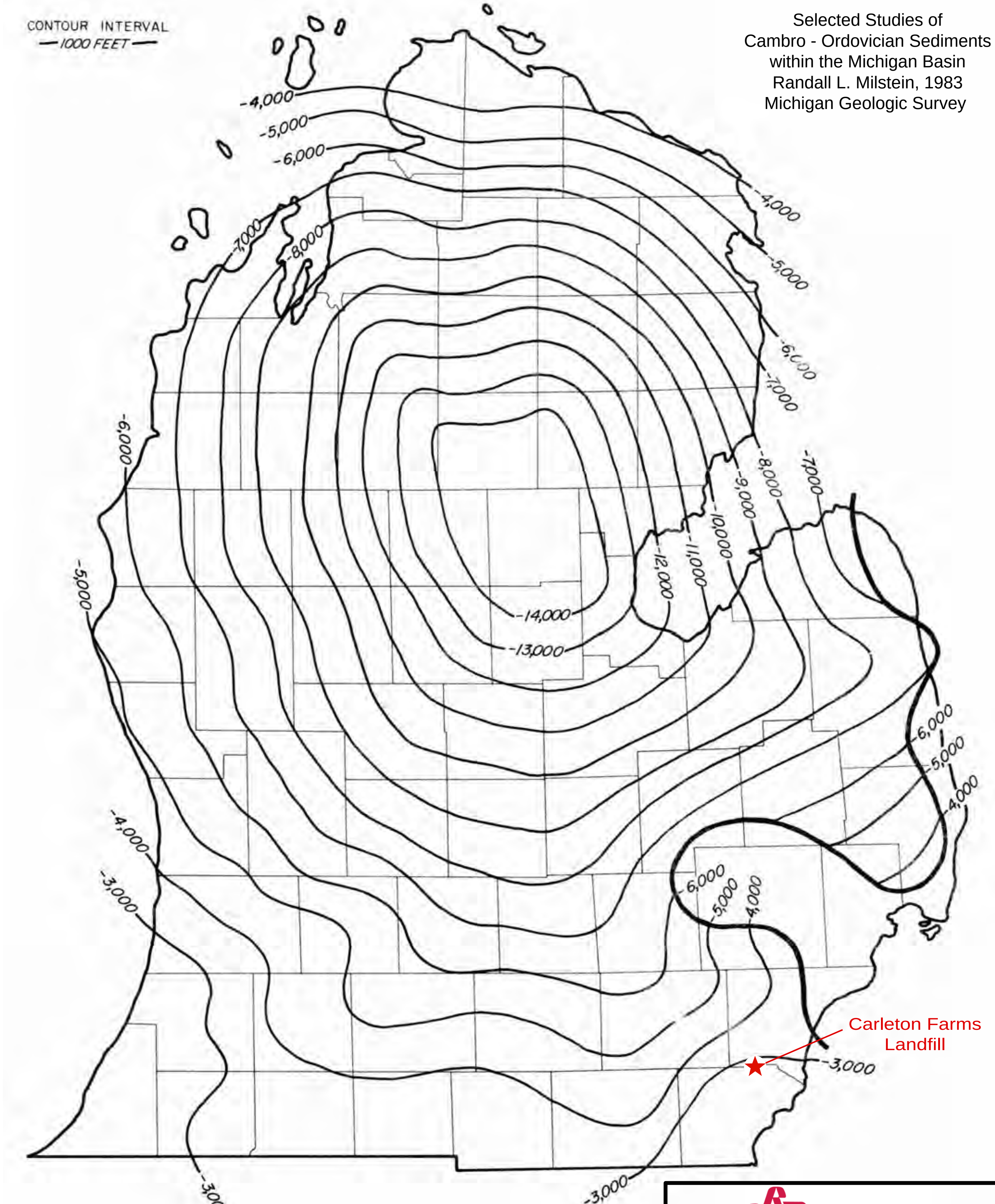


Figure B.8-8
Mt. Simon Sandstone Structure
Contour Map, Michigan Basin
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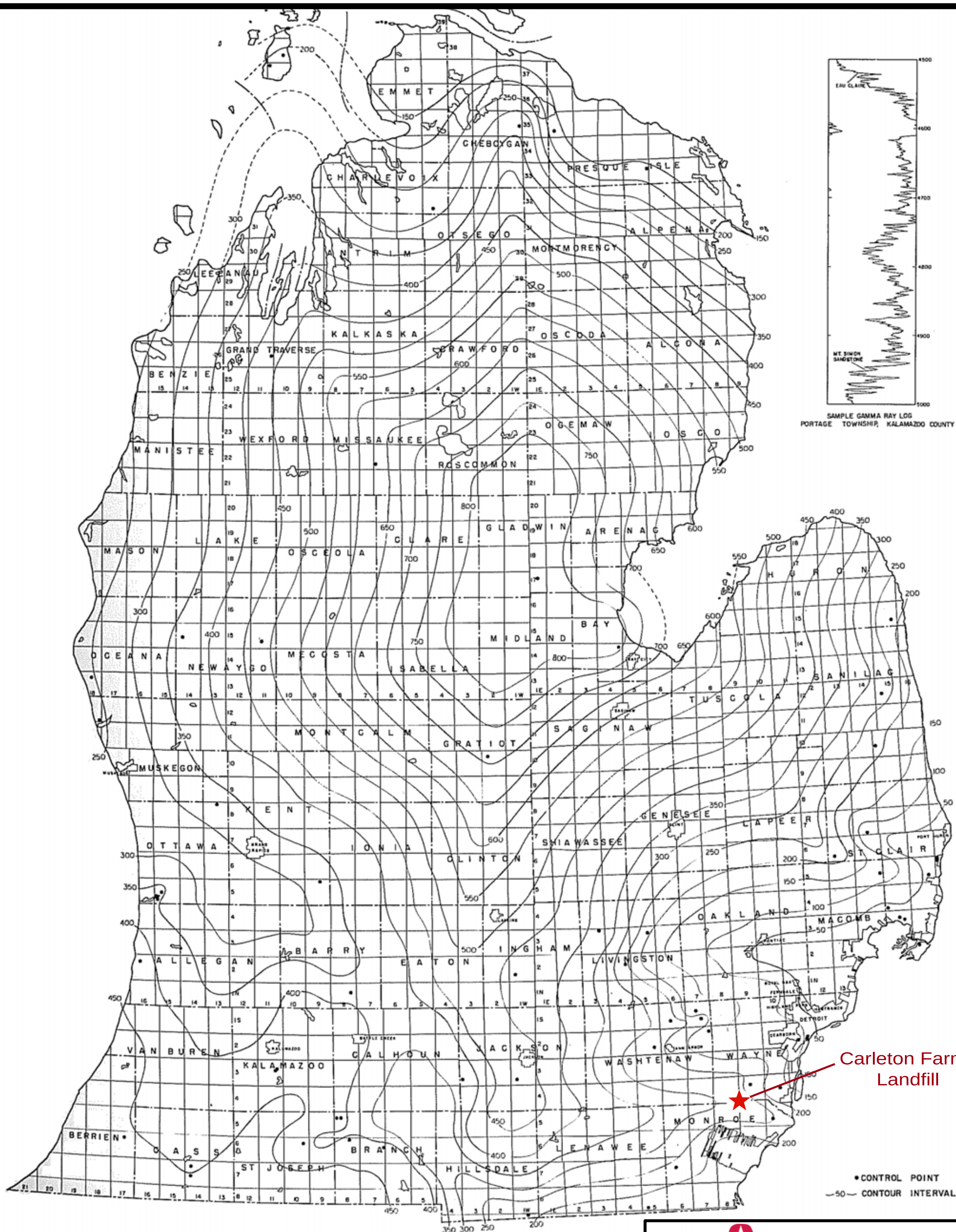


After: R. Milstein, 1988

Figure B.8-9
Eau Claire Formation Isopach Map, Michigan Basin
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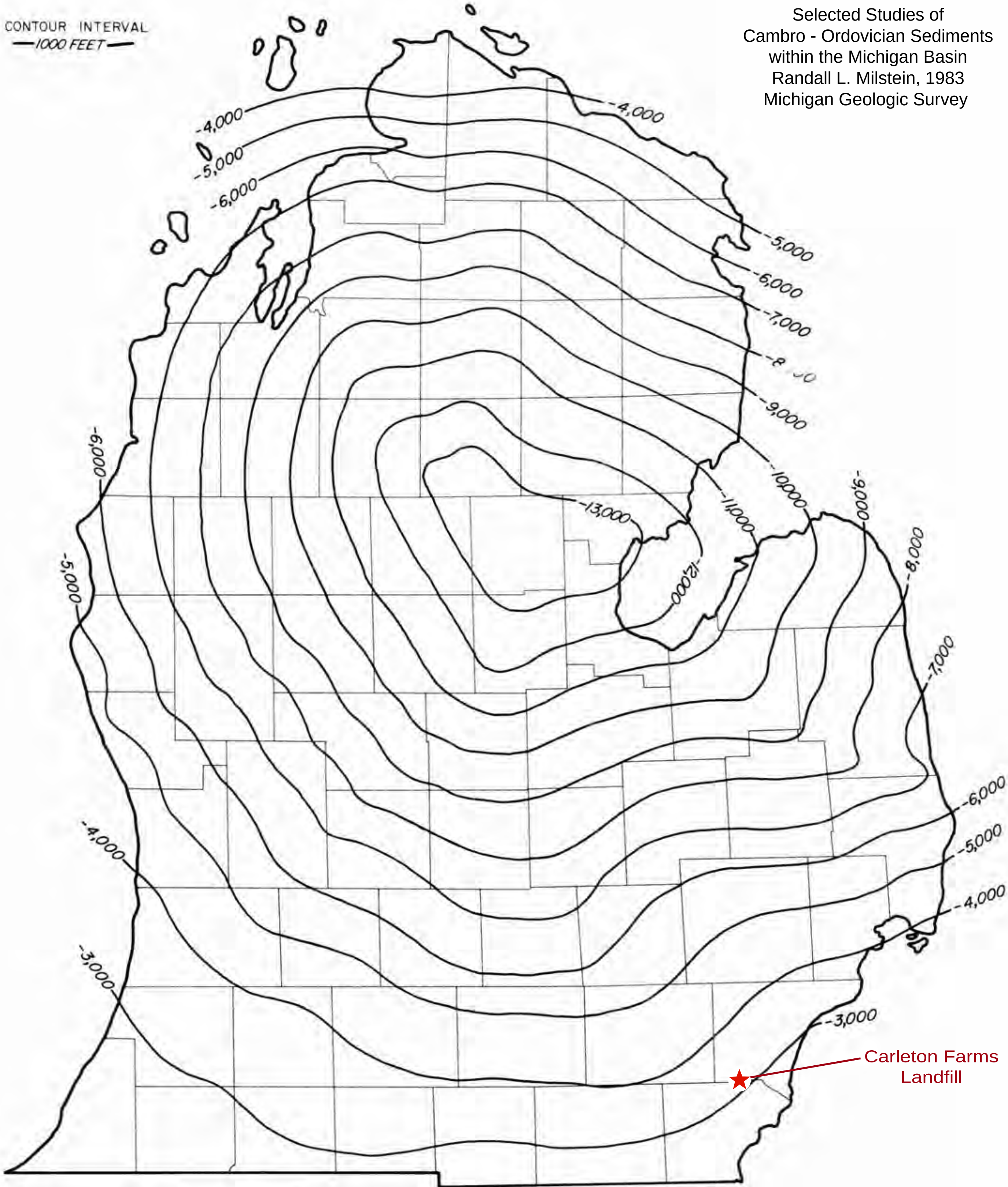


Figure B.8-10
Eau Claire Formation Structure
Contour Map, Michigan Basin
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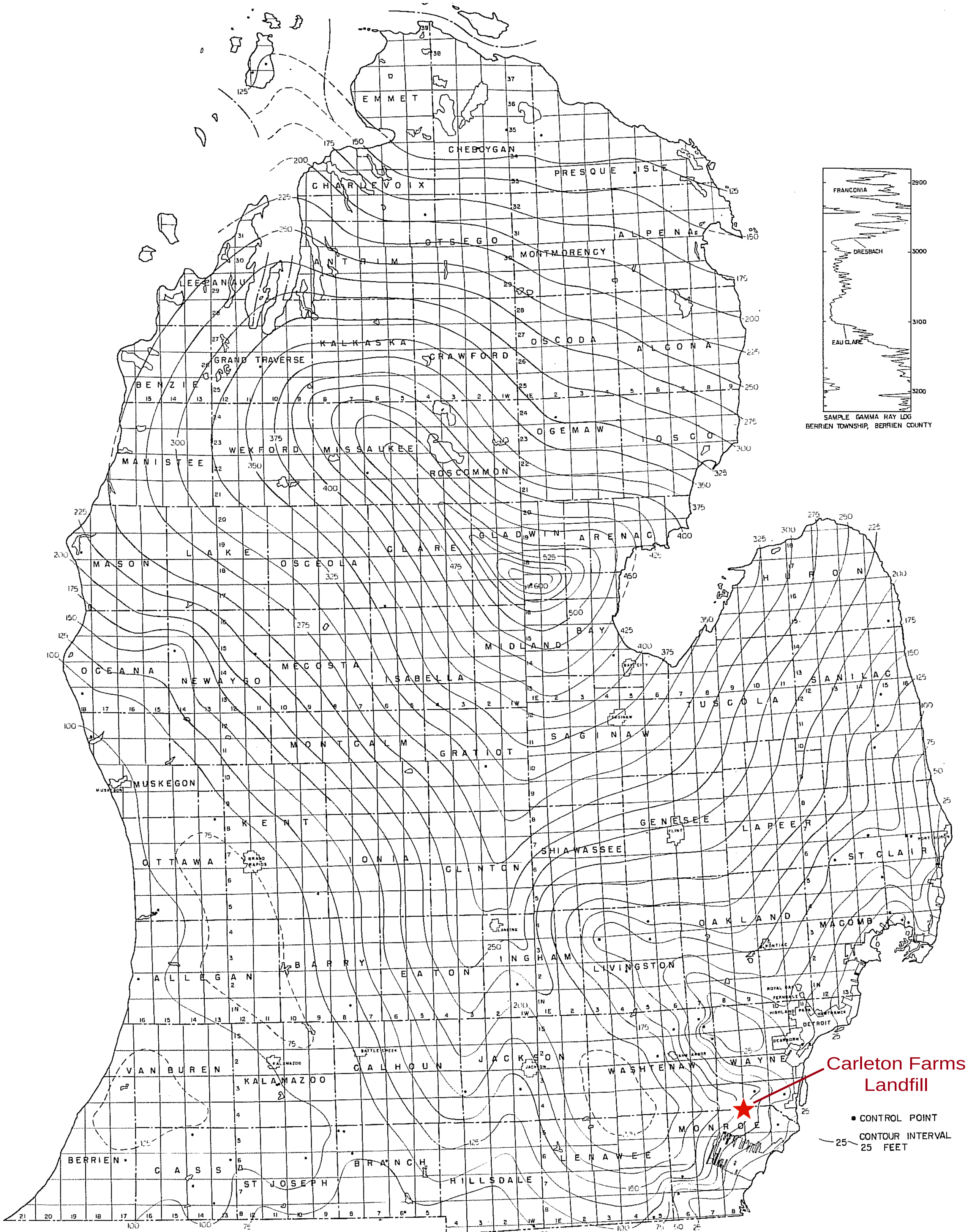


After: R. Milstein, 1988

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Figure B.8-11a
Galesville (Dresbach)
Isopach Map, Michigan Basin
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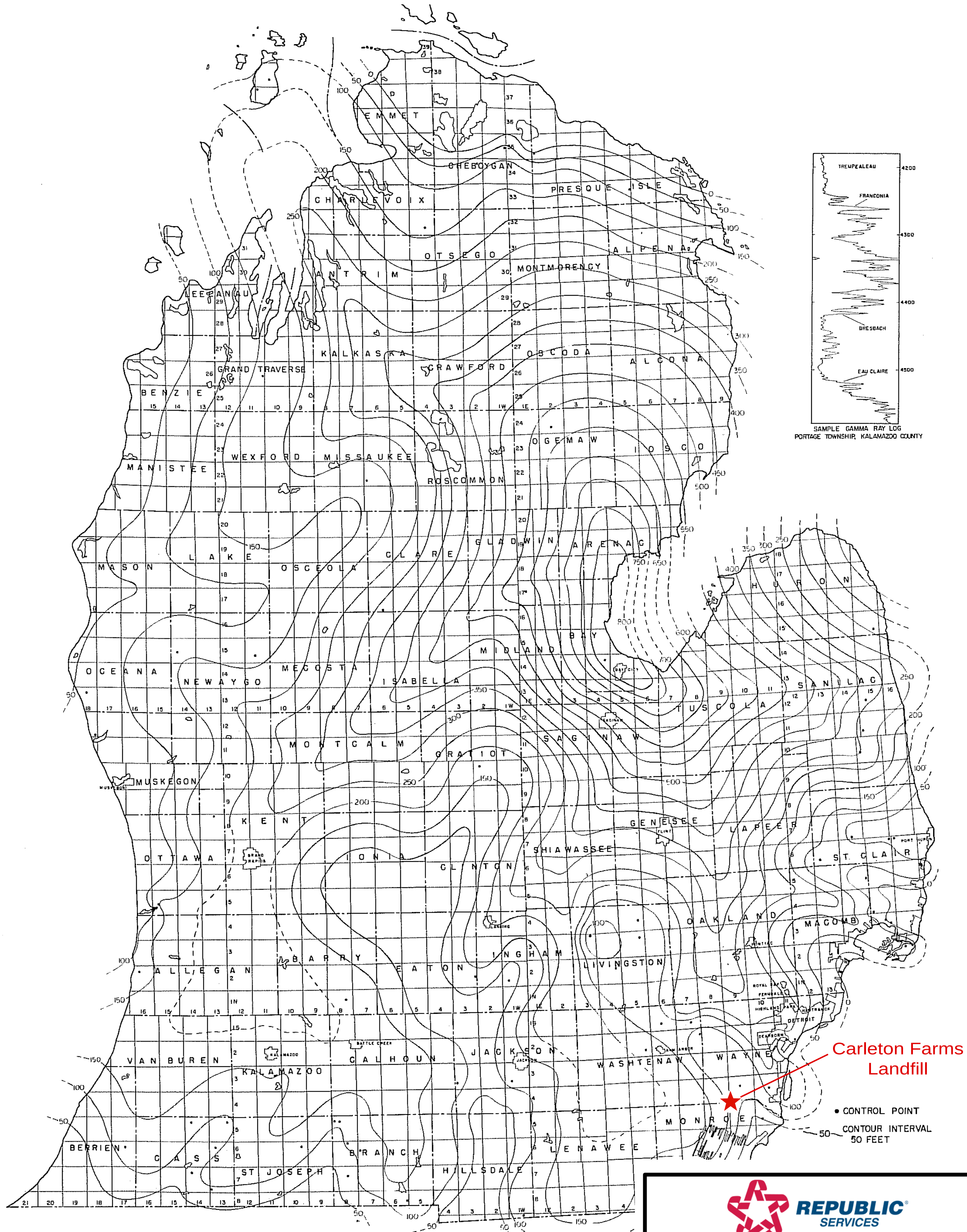


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Figure B.8-11b
Franconia Formation
Isopach Map, Michigan Basin

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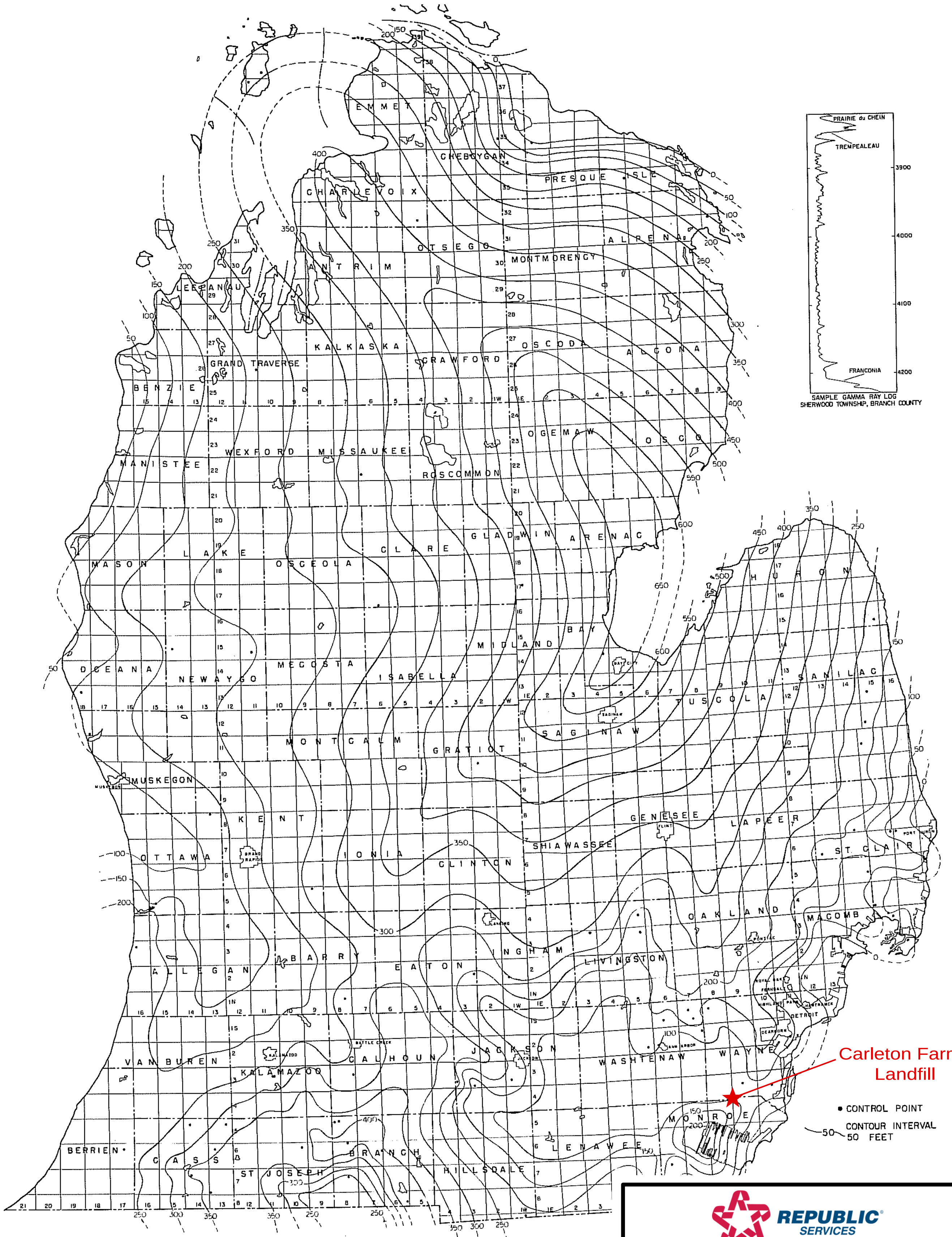
After: R. Milstein, 1988




After: R. Milstein, 1988

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Figure B.8-12
Trempealeau Formation Isopach Map, Michigan Basin
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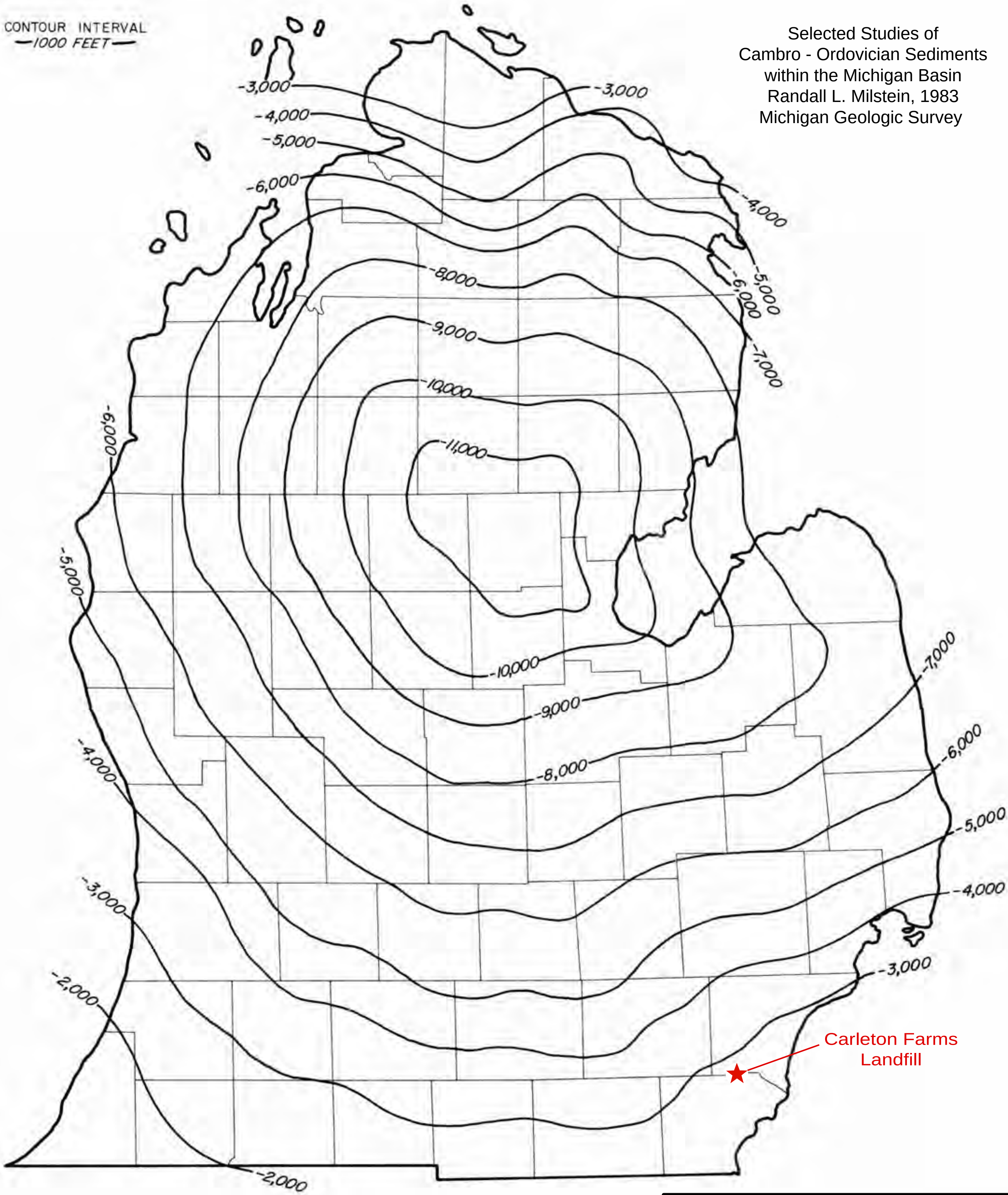


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Figure B.8-13
Trempealeau Formation Structure
Contour Map, Michigan Basin
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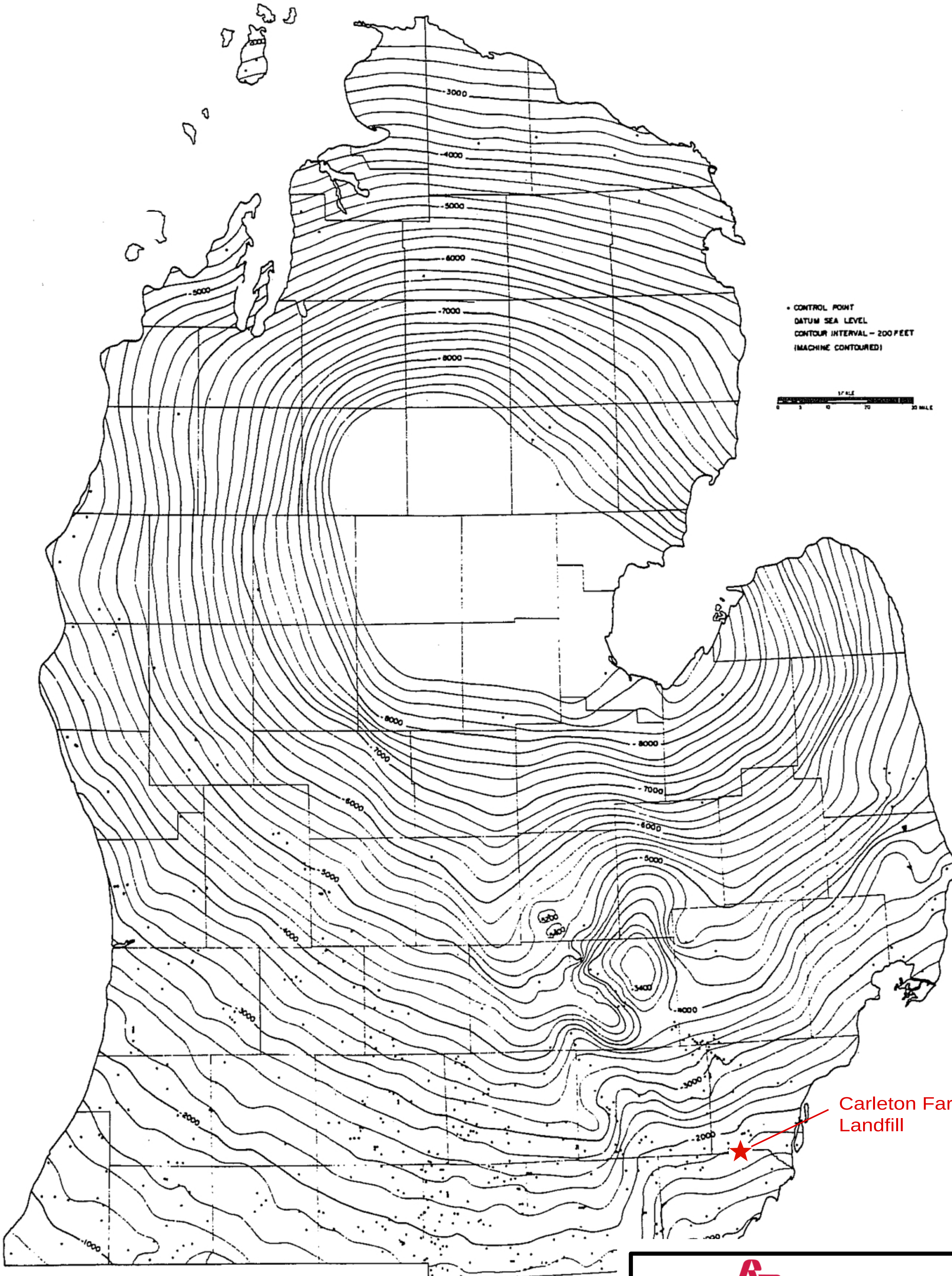


After:
Hinzi and Merrit in Stonehouse, 1969,
as presented in WMU, 1981

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Figure B.8-14a
Trenton Formation Structure
Contour Map, Michigan Basin

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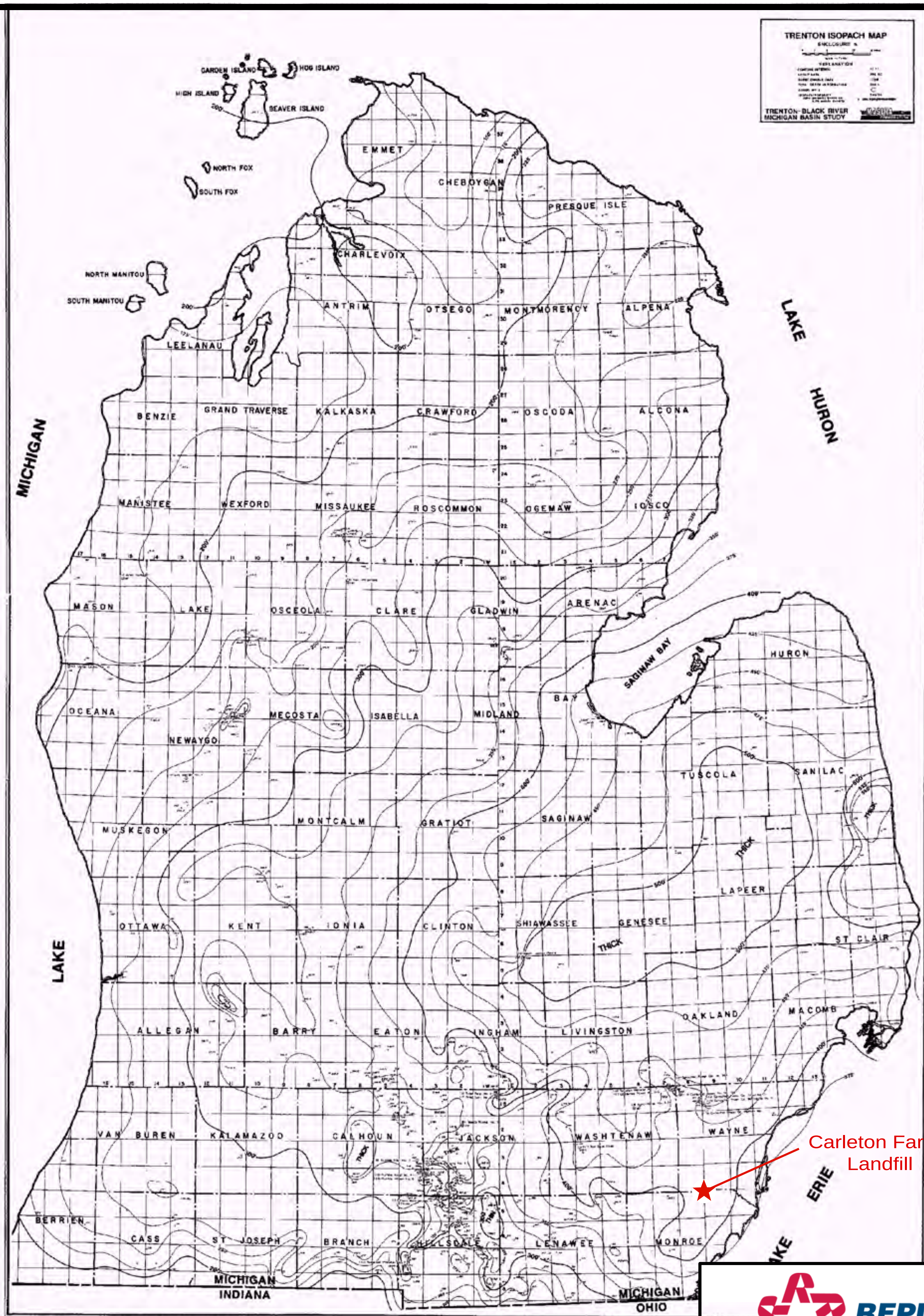


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Figure B.8-14b
Trenton Formation Isopach Map, Michigan Basin

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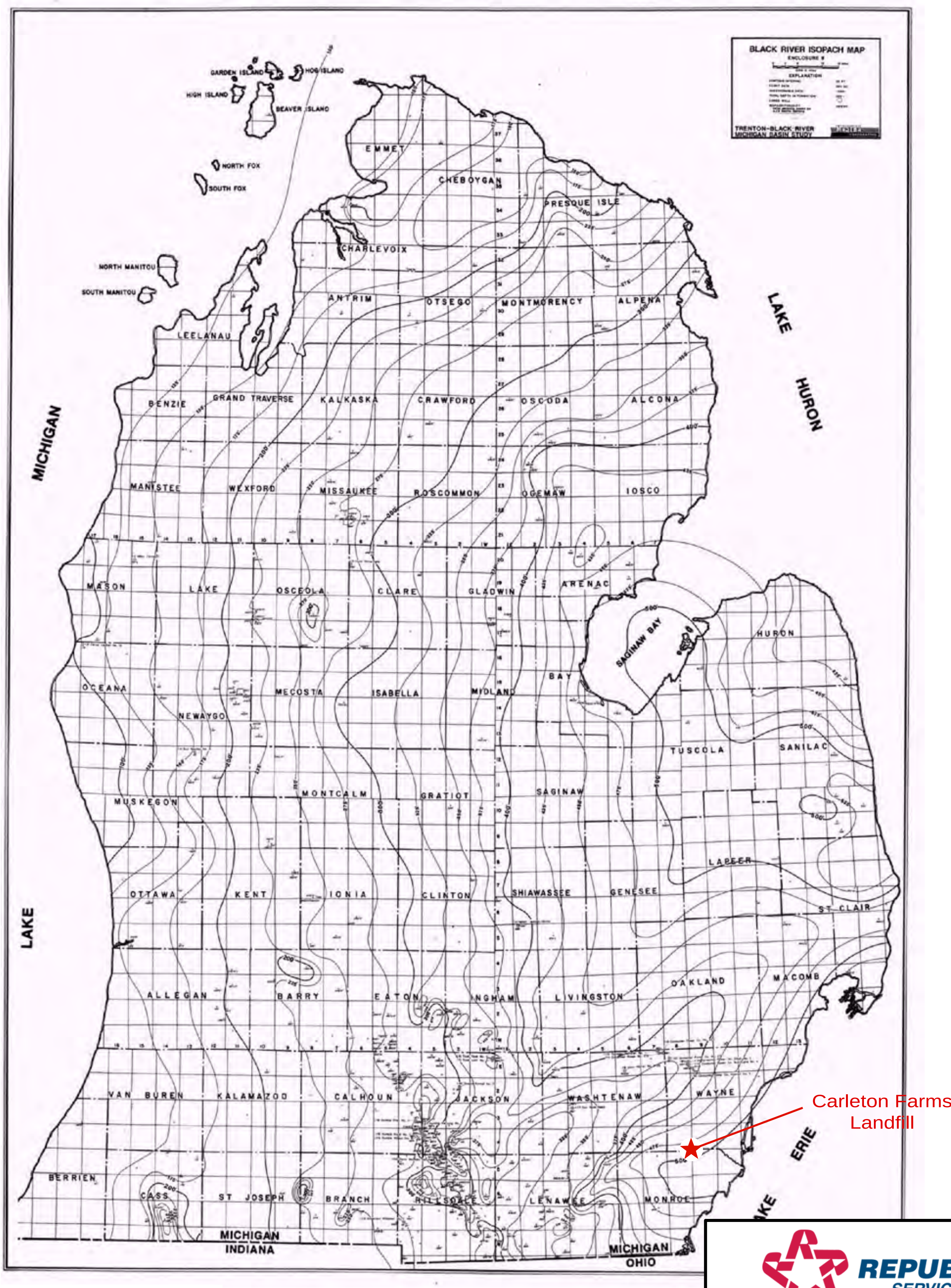


Figure B.8-14c
Black River Formation Isopach Map, Michigan Basin
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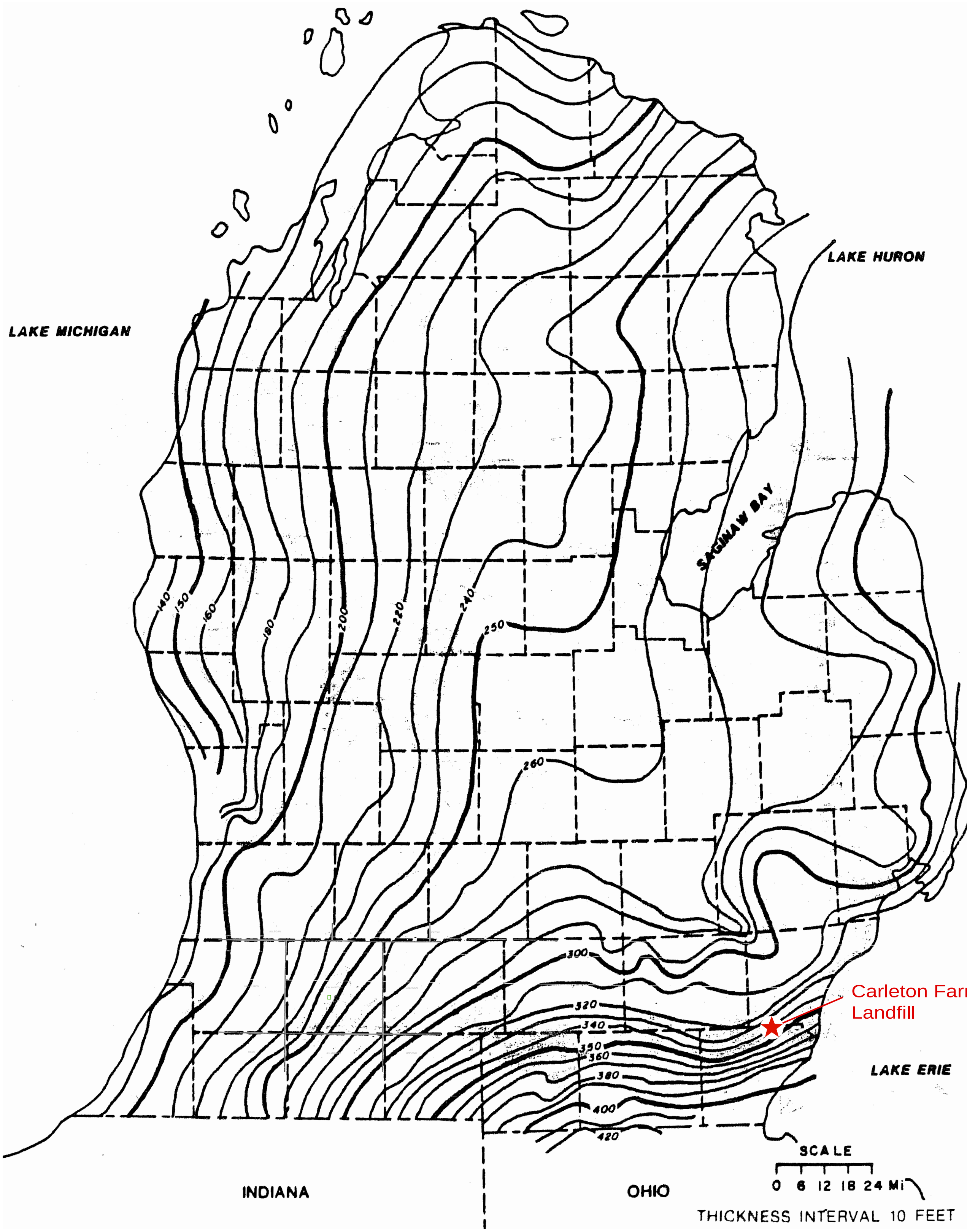


Nurmi, 1972 as presented in Envirocorp, 1991

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Figure B.8-15
Utica Shale Isopach Map,
Michigan Basin
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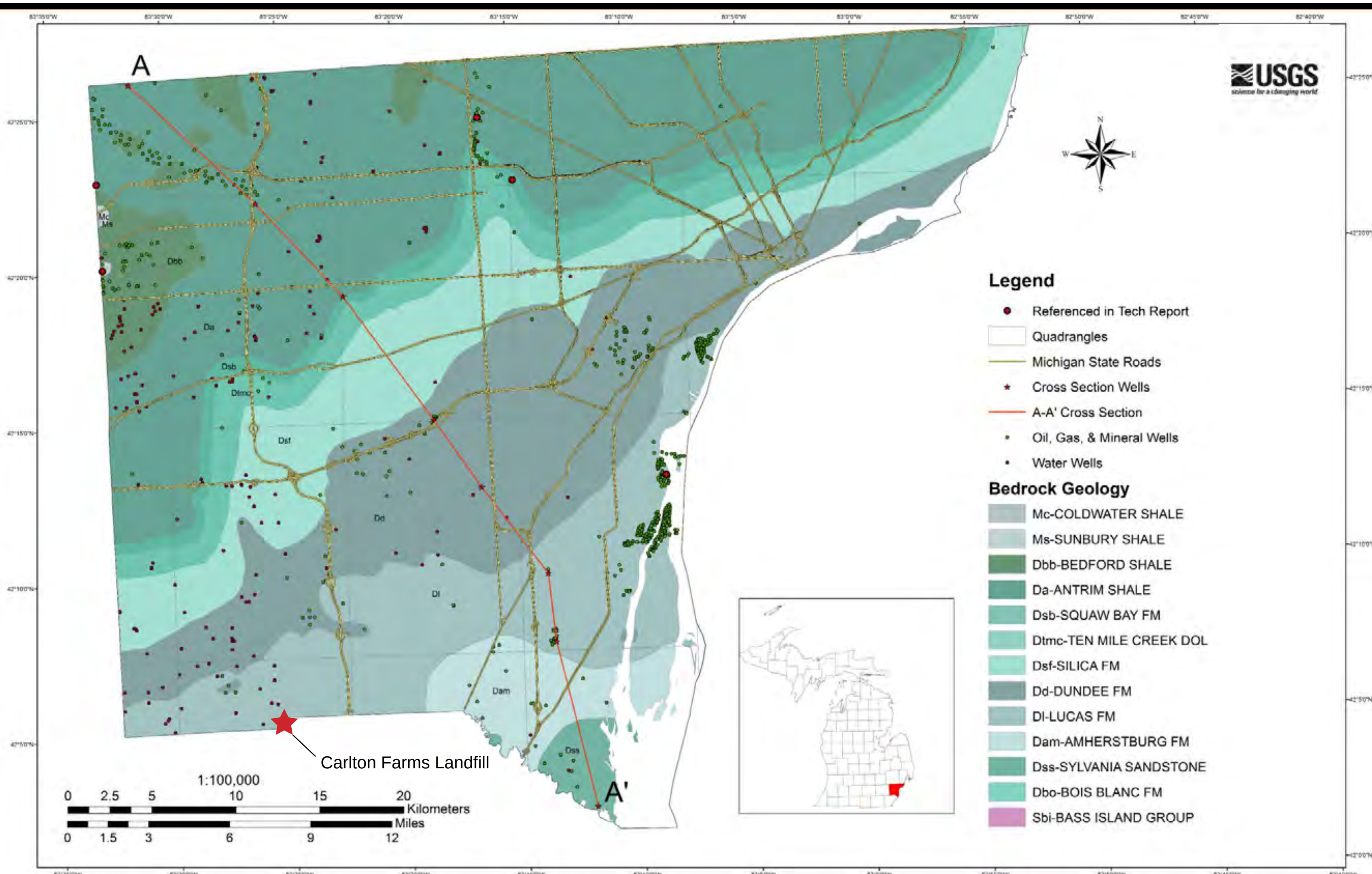


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Figure B.8-16
Bedrock Geology of
Wayne County Michigan
2019 Feasibility

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(From Voice, Peter, undated, Revised Bedrock Map of Wayne County Michigan: An opportunity to Reassess the Natural Resources of Wayne County, Department of Geological and Environmental Sciences and the Michigan Geological Survey, Western Michigan University )

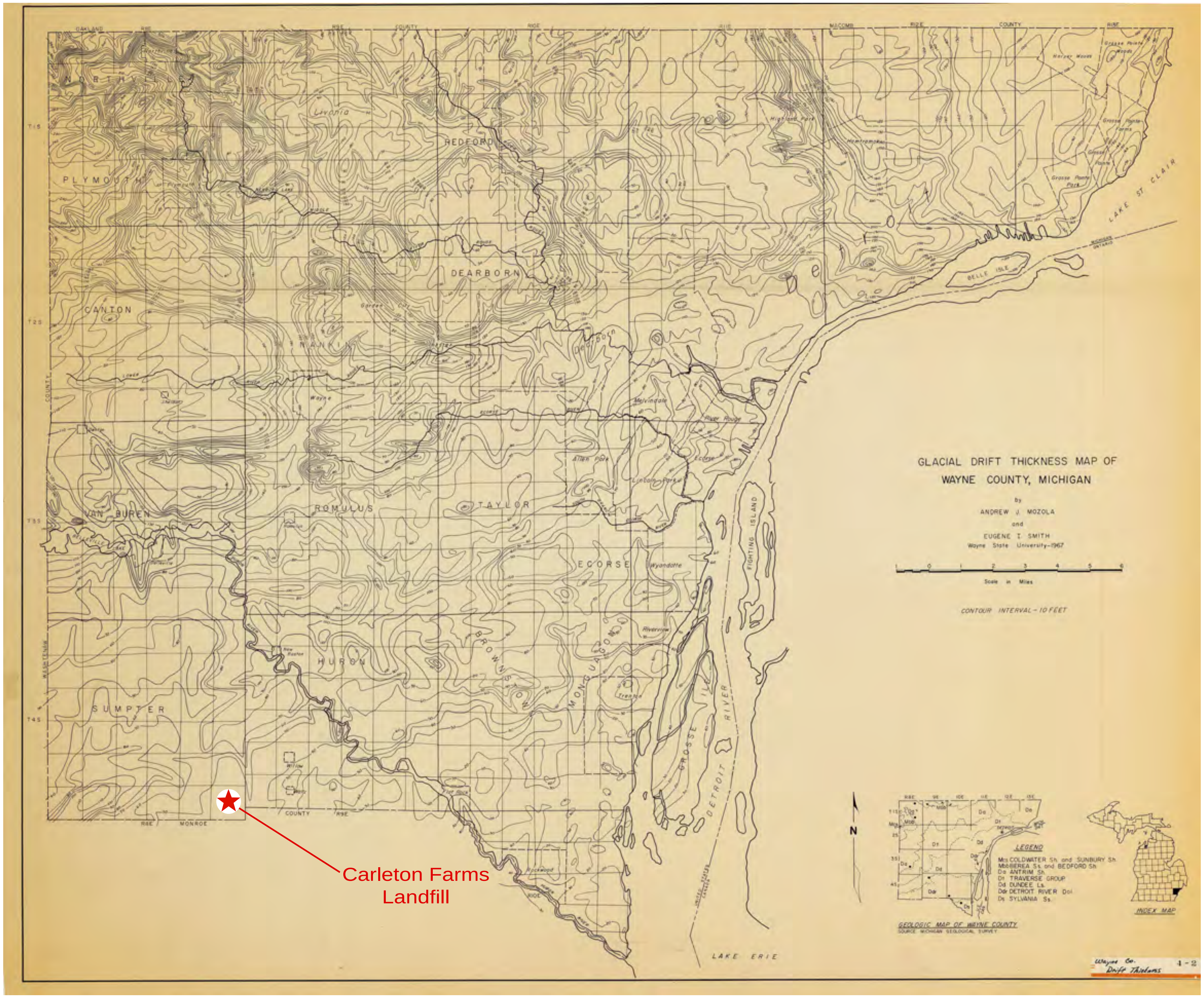


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Figure B.8-17
Glacial Drift Thickness Map of
Wayne County Michigan
2019 Permit Application

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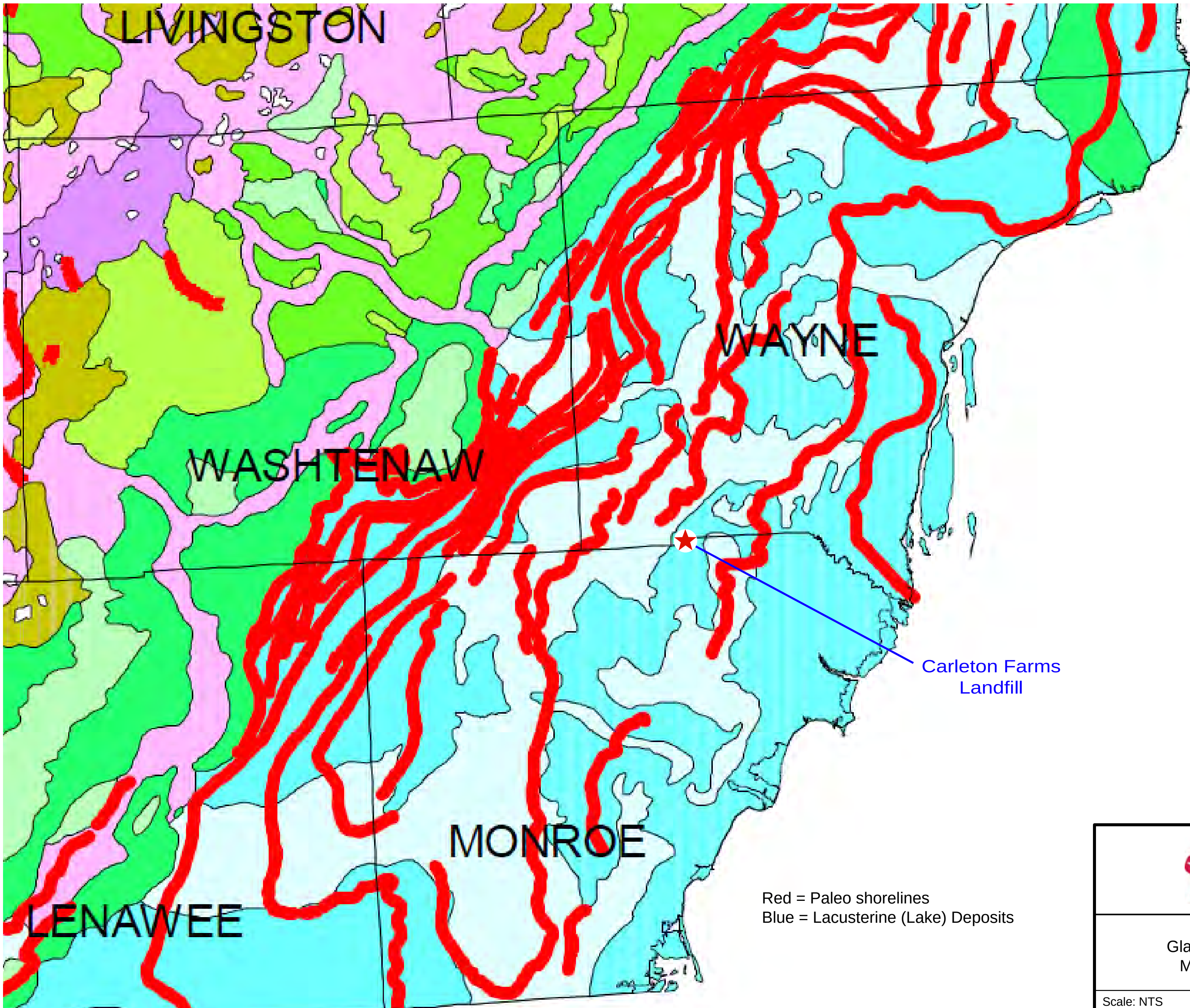


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Figure B.8-18
Glacial Geology of Wayne and Monroe Counties Michigan
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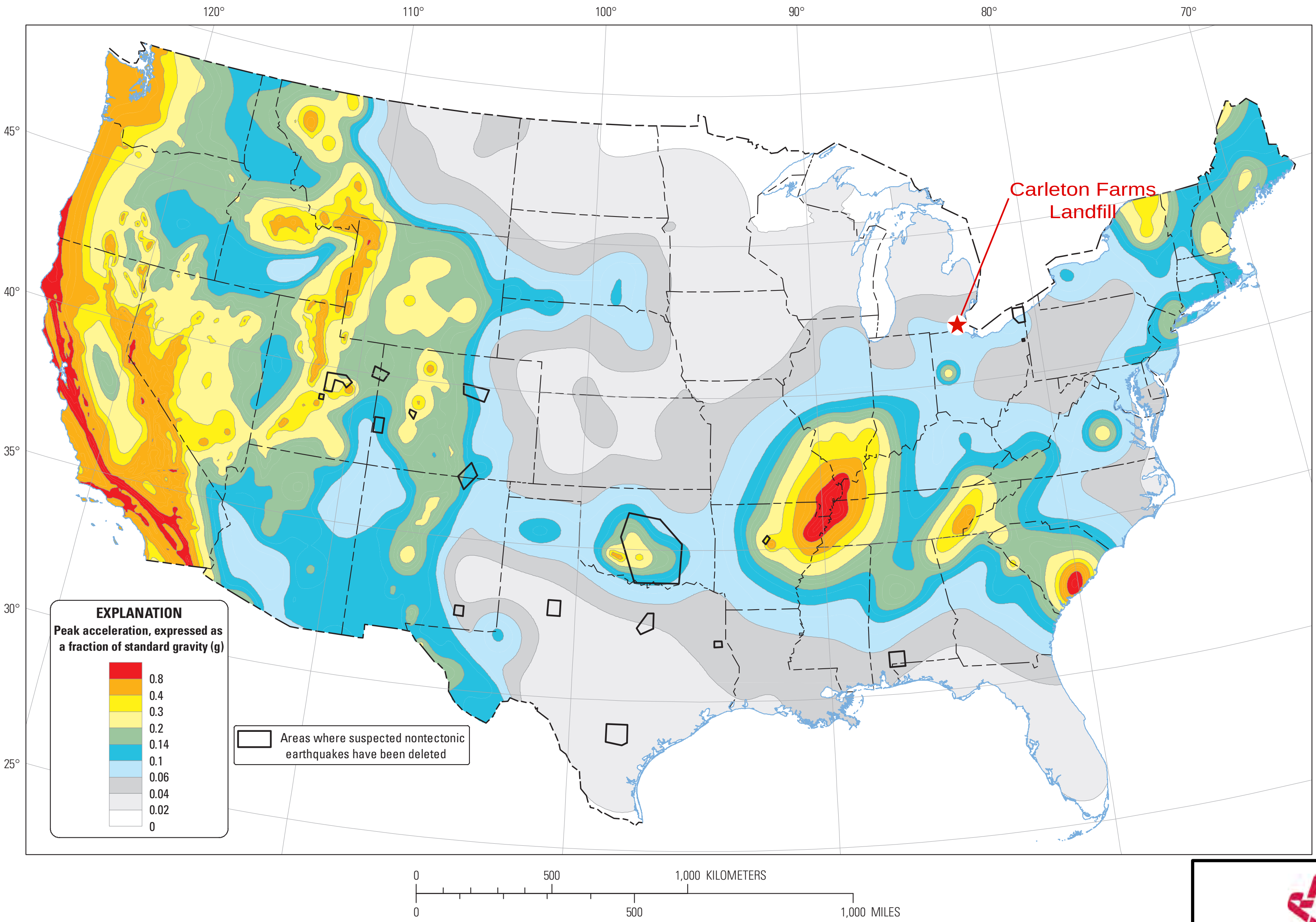
(From 1982 Quaternary Geology of Michigan, Michigan Department of Natural Resources)




**Two-percent probability of exceedance in 50 years map of peak ground acceleration**

(From Voice, Peter, undated, Revised Bedrock Map of Wayne County Michigan: An opportunity to Reassess the Natural Resources of Wayne County, Department of Geological and Environmental Sciences and the Michigan Geological Survey, Western Michigan University )

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Figure B.8-19
Peak Ground Acceleration,
2% Probability of Exceedance in 50 Years
2019 Feasibility

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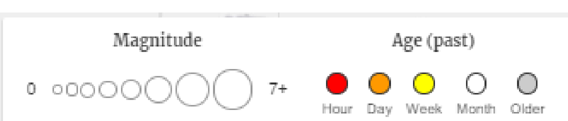


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Figure B.8-20
Location of Seismic Events
in Southern Michigan, 1919-2019
2019 Permit Application

| | | |
|---|---|---|
| Scale: See Bar Scale | Date: September 2019 | |
| 2019_CFL_EGLE_Fig_B.8-20.pdf | By: WEK | Checked: CW |

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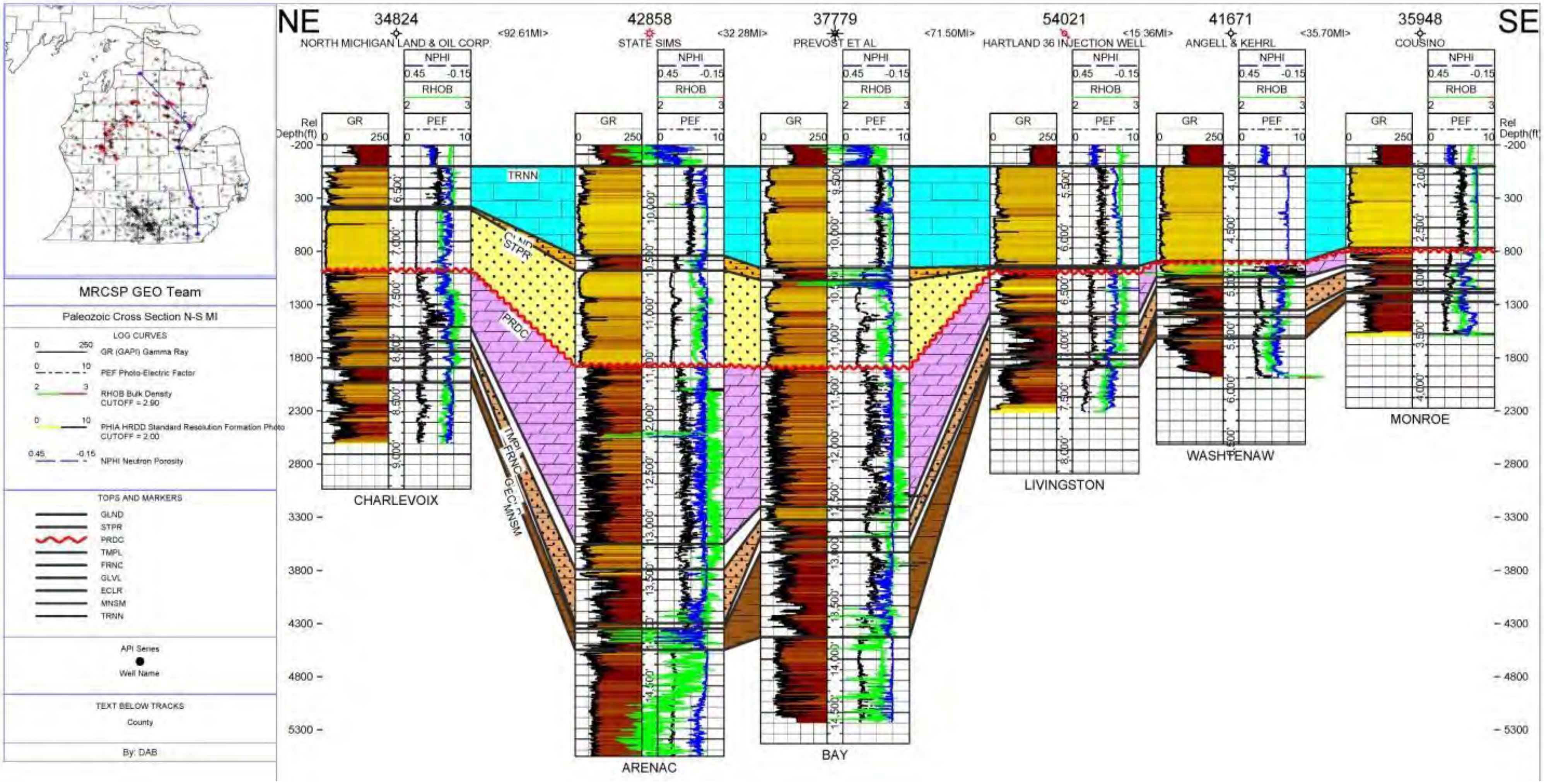


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Figure B.8-21
Local Cross Section

2019 Permit Application

| | | |
|---|---|---|
| Scale: NTS | Date: September 2019 | |
| 2019_CFL_EGLE_Fig_B.8-21.pdf | By: WEK | Checked: CW |

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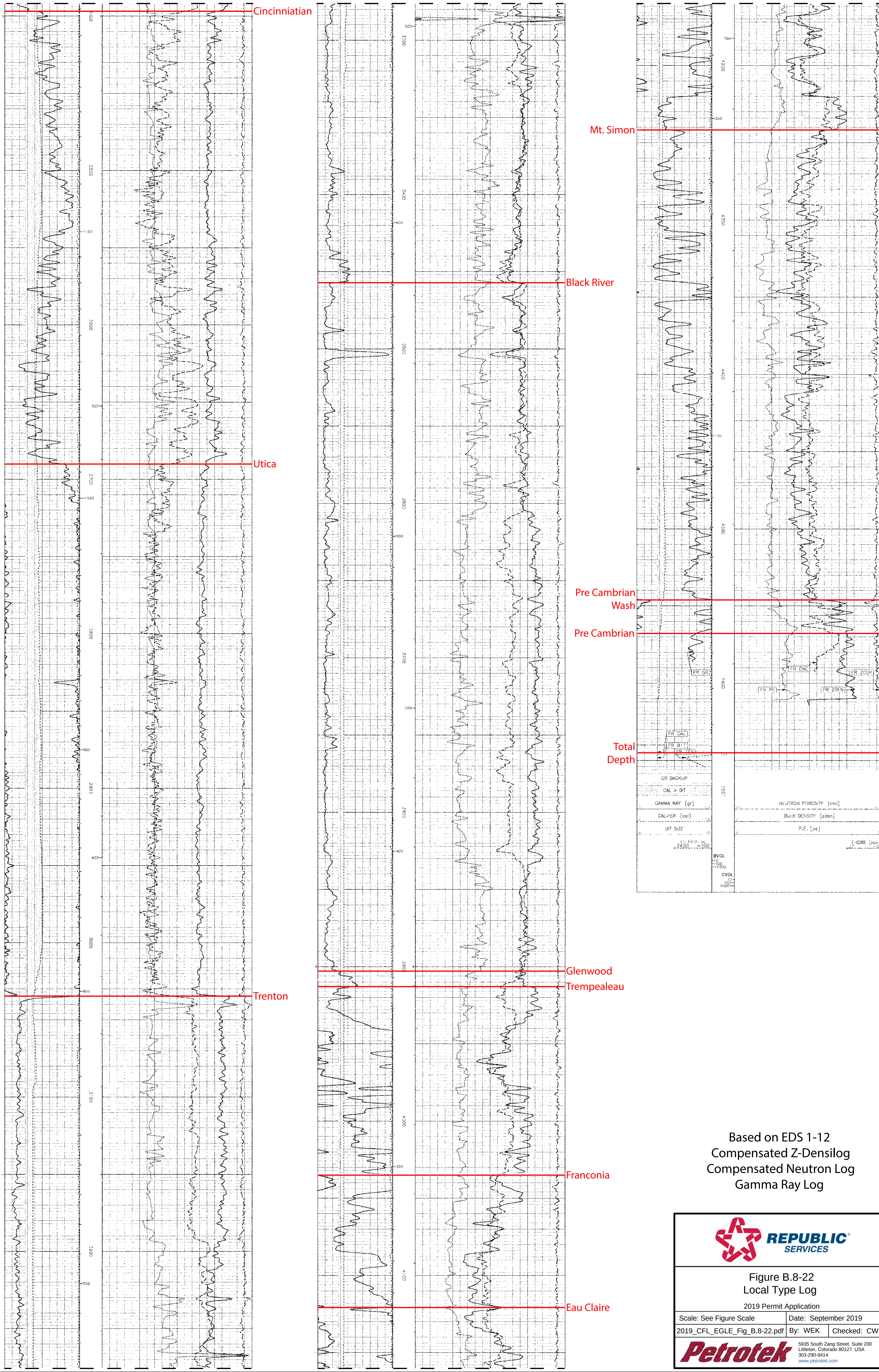


Based on EDS 1-12
Compensated Z-Densilog
Compensated Neutron Log
Gamma Ray Log

REPUBLIC SERVICES

Figure B.8-22
Local Type Log

2019 Permit Application

| Scale: See Figure Scale | Date: September 2019 | |
|---|---|---|
| 2019_CFL_EGLE_Fig_B.8-22.pdf | By: WEK | Checked: CW |

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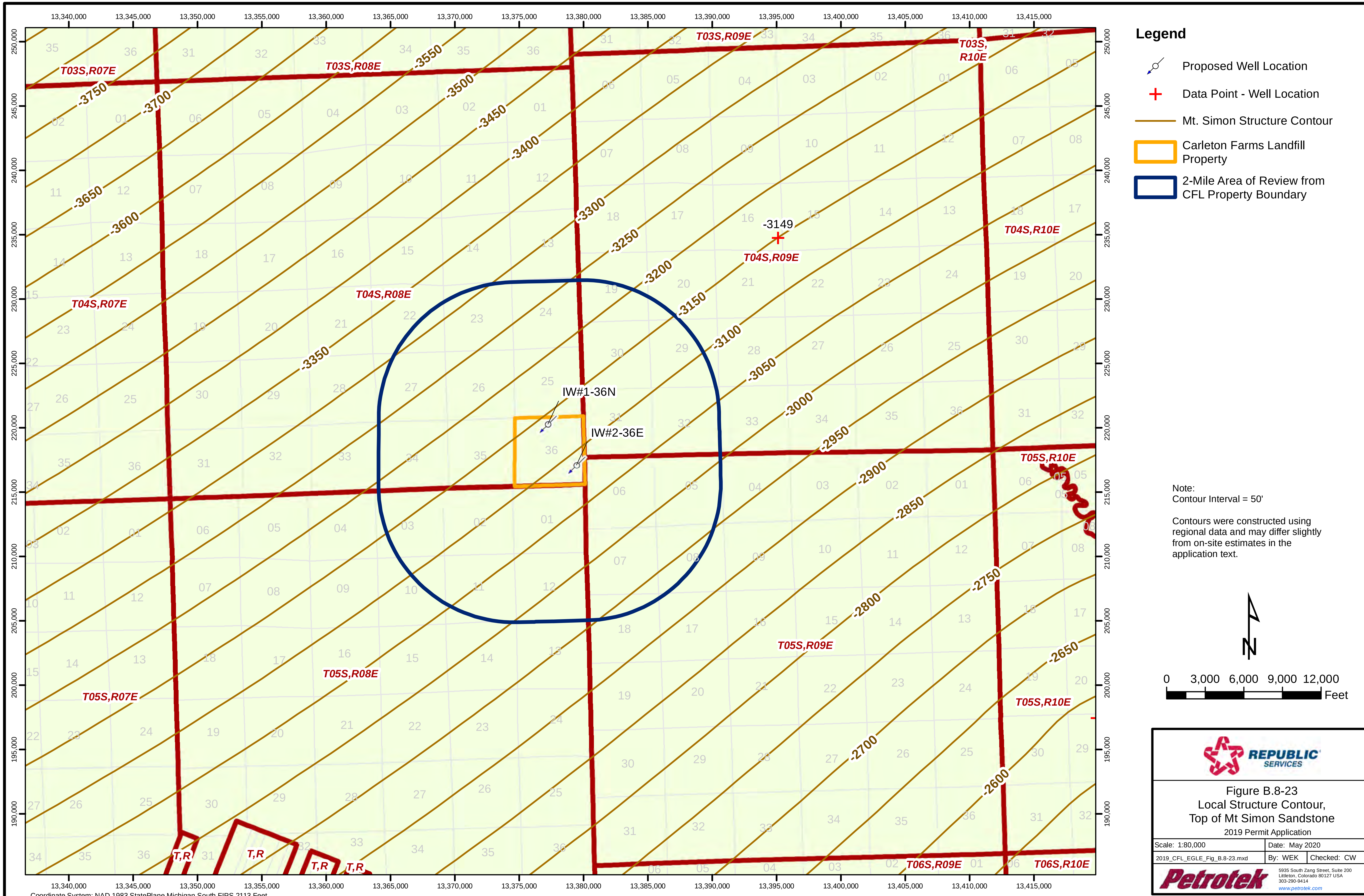


REPUBLIC SERVICES

Figure B.8-23
Local Structure Contour,
Top of Mt Simon Sandstone
2019 Permit Application

| Scale: 1:80,000 | Date: May 2020 | |
|---|---|---|
| 2019_CFL_EGLE_Fig_B.8-23.mxd | By: WEK | Checked: CW |

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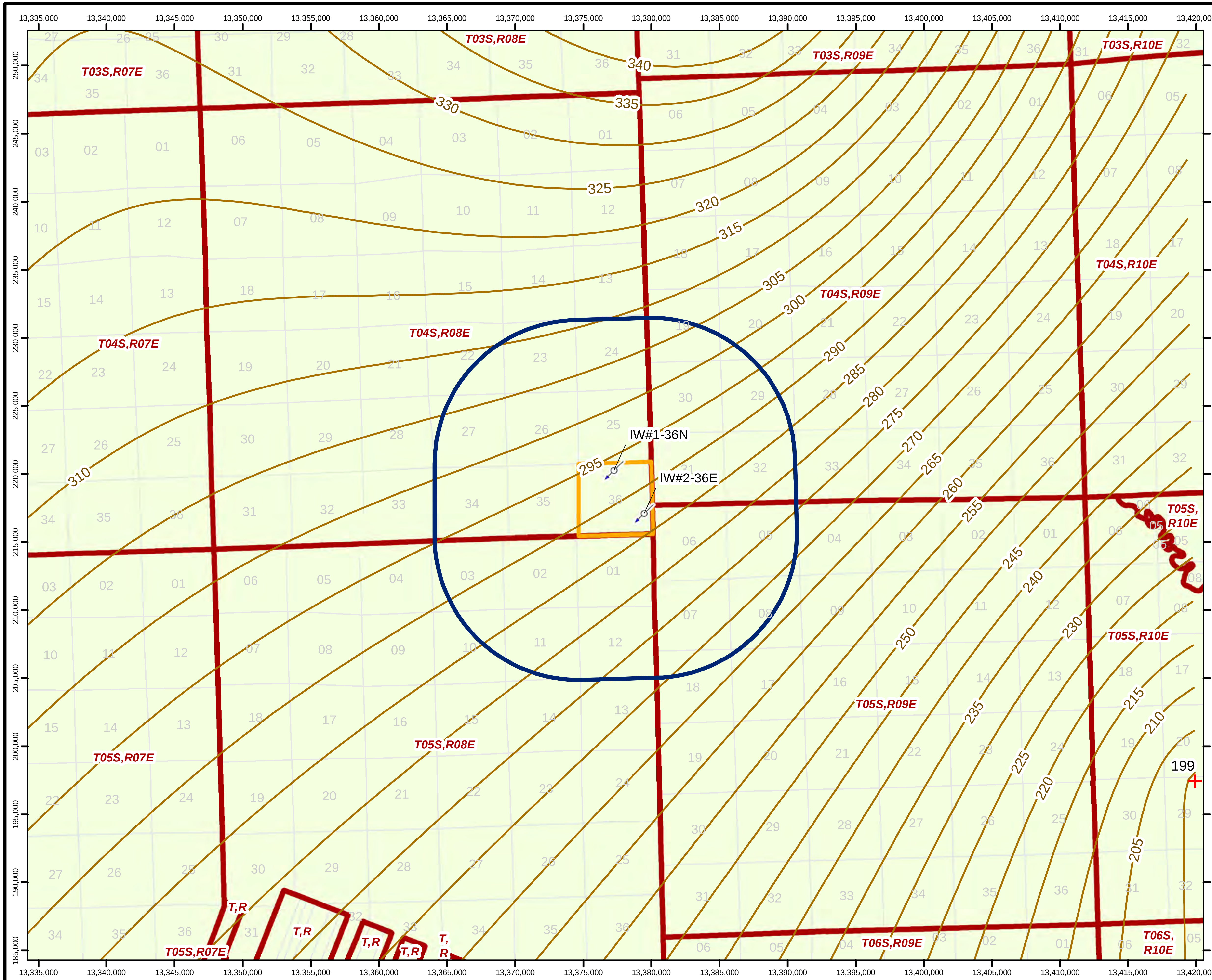


## Legend

- Proposed Well Location
- Data Point - Well Location
- Mt Simon Isopach Contour
- Carleton Farms Landfill Property
- 2-Mile Area of Review from CFL Property Boundary

Note:
Contour Interval = 5'

Isopach contours include thickness of Mt Simon formation and Granite Wash.

Contours were constructed using regional data and may differ slightly from on-site estimates in the application text.

N

0 3,000 6,000 9,000 12,000 Feet

REPUBLIC SERVICES

Figure B.8-24
Local Isopach Map,
Mt Simon Sandstone
2019 Permit Application

| Scale: 1:83,000 | Date: May 2020 | |
|---|---|---|
| 2019_CFL_EGLE_Fig_B.8-24.mxd | By: WEK | Checked: CW |

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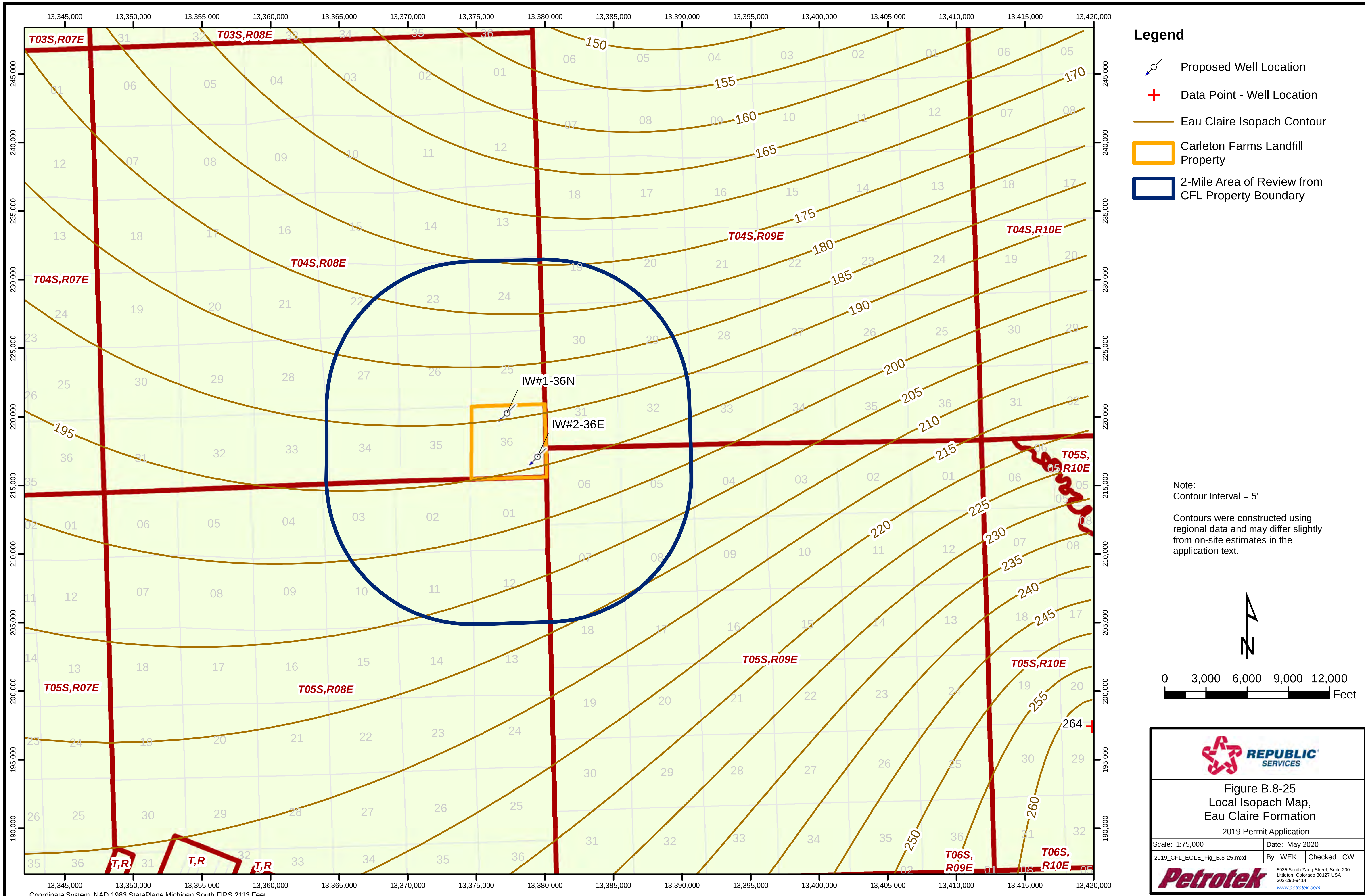
Legend
Proposed Well Location
Data Point - Well Location
Eau Claire Isopach Contour
Carleton Farms Landfill Property
2-Mile Area of Review from CFL Property Boundary
IW#1-36N
IW#2-36E
T03S,R07E
T03S,R08E
T04S,R07E
T04S,R08E
T04S,R09E
T04S,R10E
T05S,R07E
T05S,R08E
T05S,R09E
T05S,R10E
T06S, R09E
T06S, R10E
264
Note:
Contour Interval = 5'
Contours were constructed using regional data and may differ slightly from on-site estimates in the application text.
0 3,000 6,000 9,000 12,000 Feet
N
Coordinate System: NAD 1983 StatePlane Michigan South FIPS 2113 Feet
REPUBLIC SERVICES
Figure B.8-25
Local Isopach Map,
Eau Claire Formation
2019 Permit Application
Scale: 1:75,000
Date: May 2020
2019_CFL_EGLE_Fig_B.8-25.mxd
By: WEK
Checked: CW
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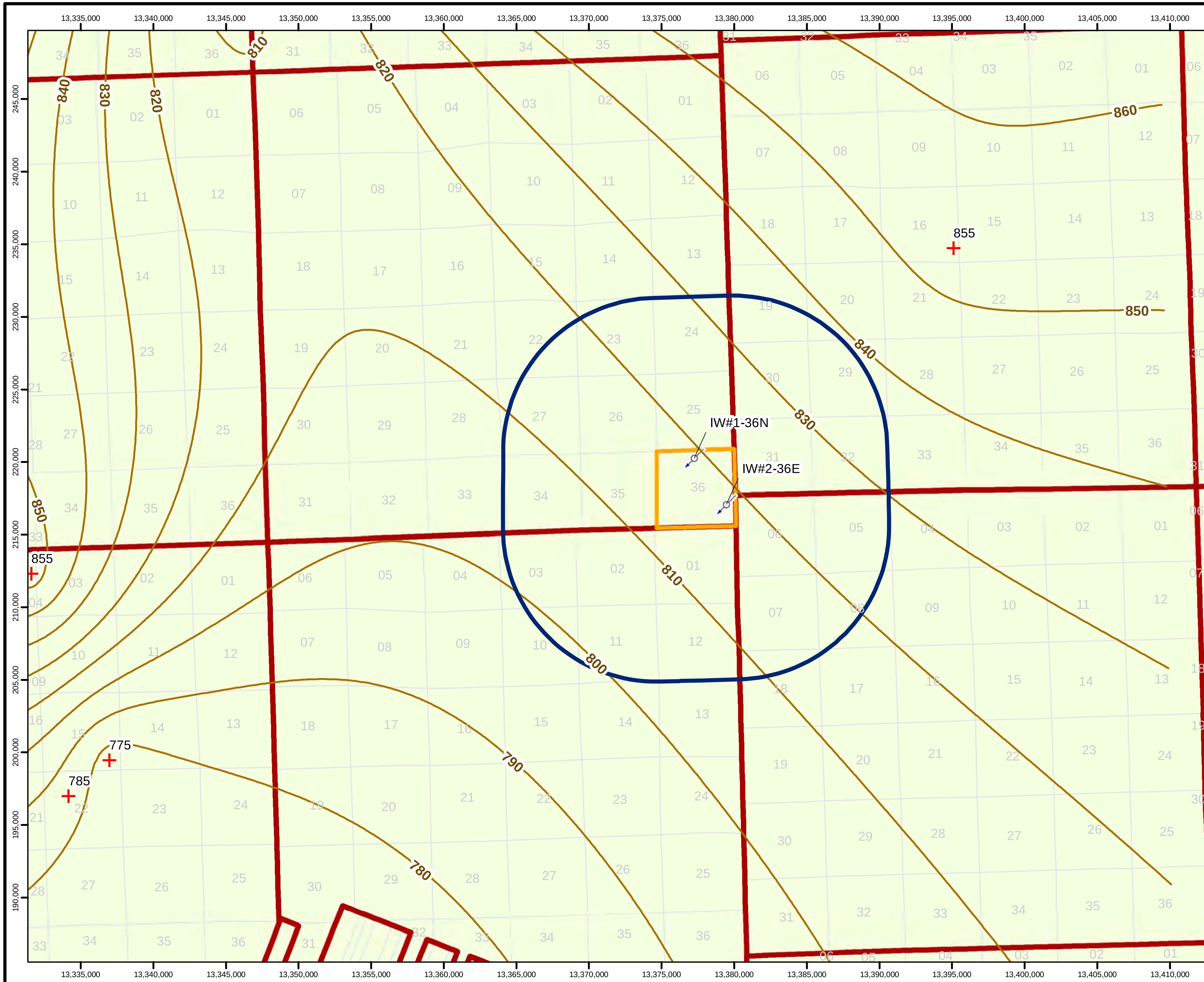


**Legend**

- Proposed Well Location
- Data Point - Well Location
- Trenton/Blackriver Structure Contour
- Carleton Farms Landfill Property
- 2-Mile Area of Review from CFL Property Boundary

Note:
Contour Interval = 10'

Contours were constructed using regional data and may differ slightly from on-site estimates in the application text.

N

0 3,000 6,000 9,000 12,000 Feet

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Figure B.8-26
Local Isopach Map,
Trenton/Black River Formations
2019 Permit Application

| | | |
|---|---|---|
| Scale: 1:78,000 | Date: May 2020 | |
| 2019_CFL_EGLE_Fig_B.8-26.mxd | By: WEK | Checked: CW |

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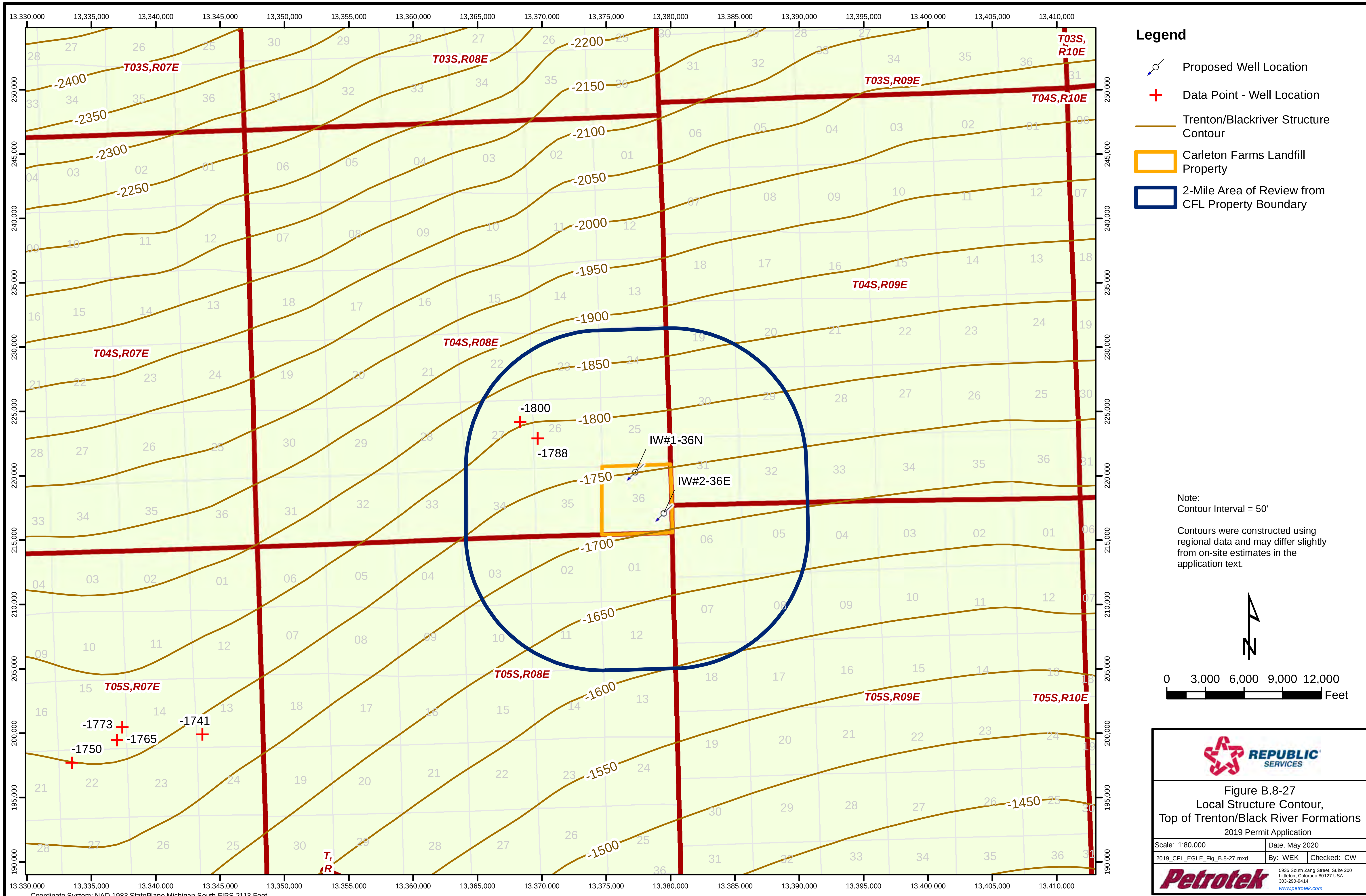
Legend
Proposed Well Location
Data Point - Well Location
Trenton/Blackriver Structure Contour
Carleton Farms Landfill Property
2-Mile Area of Review from CFL Property Boundary
Note:
Contour Interval = 50'
Contours were constructed using regional data and may differ slightly from on-site estimates in the application text.
IW#1-36N
IW#2-36E
-1800
-1788
-1773
-1765
-1750
-1741
-2400
-2350
-2300
-2250
-2200
-2150
-2100
-2050
-2000
-1950
-1900
-1850
-1800
-1750
-1700
-1650
-1600
-1550
-1500
-1450
T03S,R07E
T03S,R08E
T03S,R09E
T03S, R10E
T04S,R07E
T04S,R08E
T04S,R09E
T04S,R10E
T05S,R07E
T05S,R08E
T05S,R09E
T05S,R10E
0 3,000 6,000 9,000 12,000 Feet
N
Coordinate System: NAD 1983 StatePlane Michigan South FIPS 2113 Feet
REPUBLIC SERVICES
Figure B.8-27
Local Structure Contour,
Top of Trenton/Black River Formations
2019 Permit Application
Scale: 1:80,000
Date: May 2020
2019_CFL_EGLE_Fig_B.8-27.mxd
By: WEK
Checked: CW
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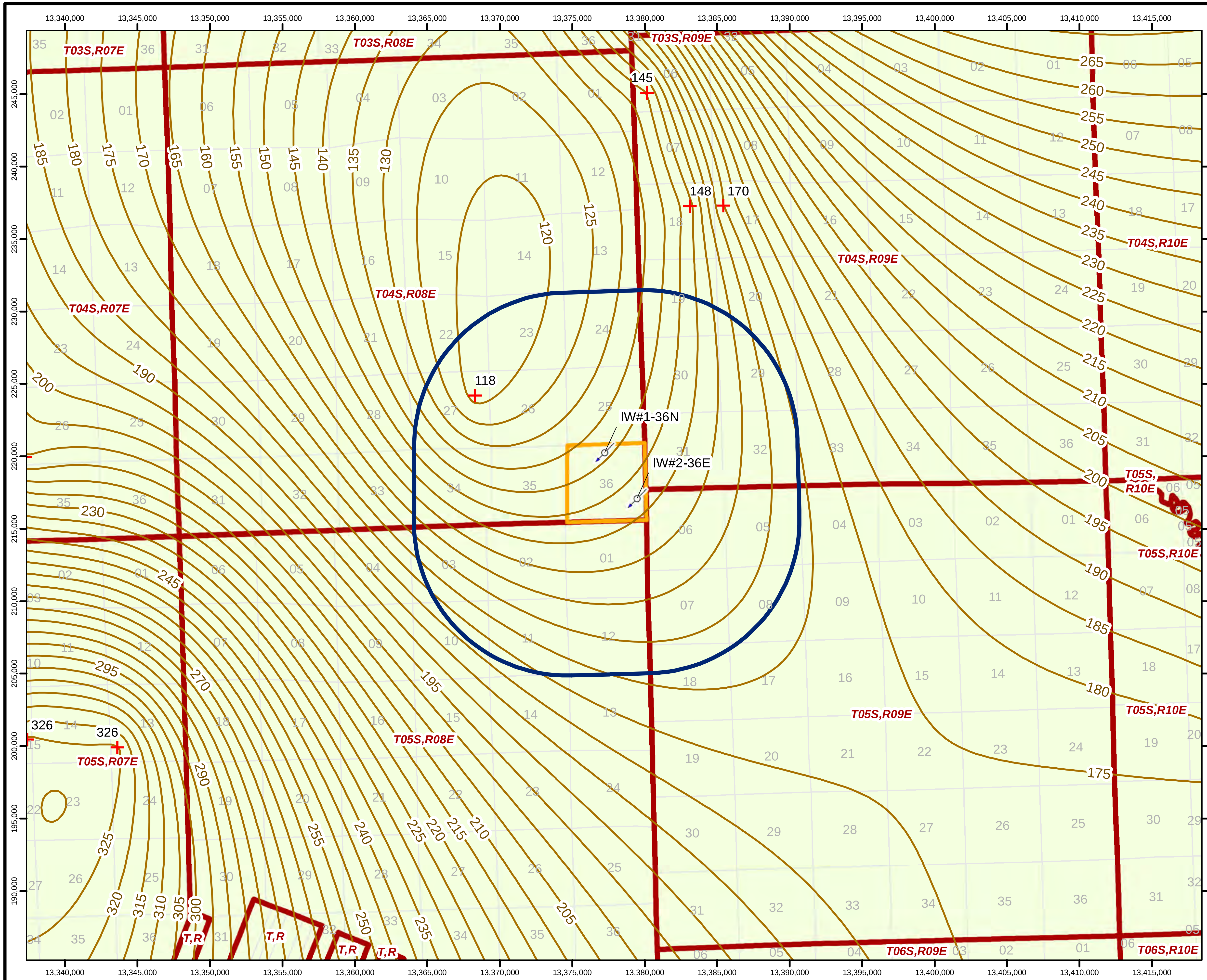


## Legend

- Proposed Well Location
- Data Point - Well Location
- Utica Isopach Contour
- Carleton Farms Landfill Property
- 2-Mile Area of Review from CFL Property Boundary

Note:
Contour Interval = 5'

Contours were constructed using regional data and may differ slightly from on-site estimates in the application text.

N

0 3,000 6,000 9,000 12,000 Feet

REPUBLIC SERVICES

Figure B.8-28
Local Isopach Map,
of the Utica Shale
2019 Permit Application

| Scale: 1:78,000 | Date: May 2020 | |
|---|---|---|
| 2019_CFL_EGLE_Fig_B.8-28.mxd | By: WEK | Checked: CW |

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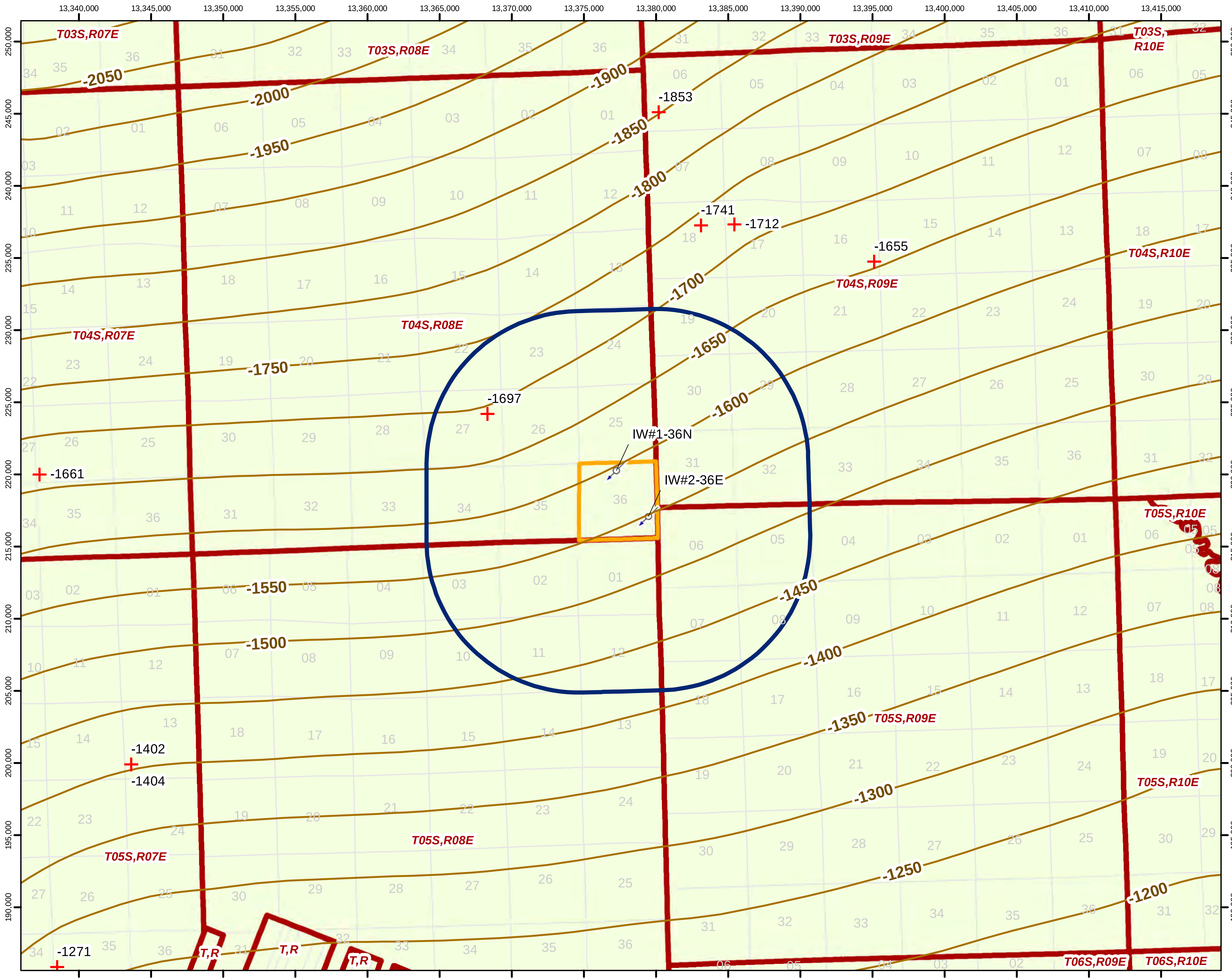


Coordinate System: NAD 1983 StatePlane Michigan South FIPS 2113 Feet

**Legend**

- Proposed Well Location
- Data Point - Well Location
- Utica Structure Contour
- Carleton Farms Landfill Property
- 2-Mile Area of Review from CFL Property Boundary

Note:
Contour Interval = 50'

Contours were constructed using regional data and may differ slightly from on-site estimates in the application text.

N

0 3,000 6,000 9,000 12,000 Feet

REPUBLIC SERVICES

Figure B.8-29
Local Structure Contour,
Top of the Utica Shale

2019 Permit Application

| | |
|---|---|
| Scale: 1:80,000 | Date: May 2020 |
| 2019_CFL_EGLE_Fig_B.8-29.mxd | By: WEK / Checked: CW |

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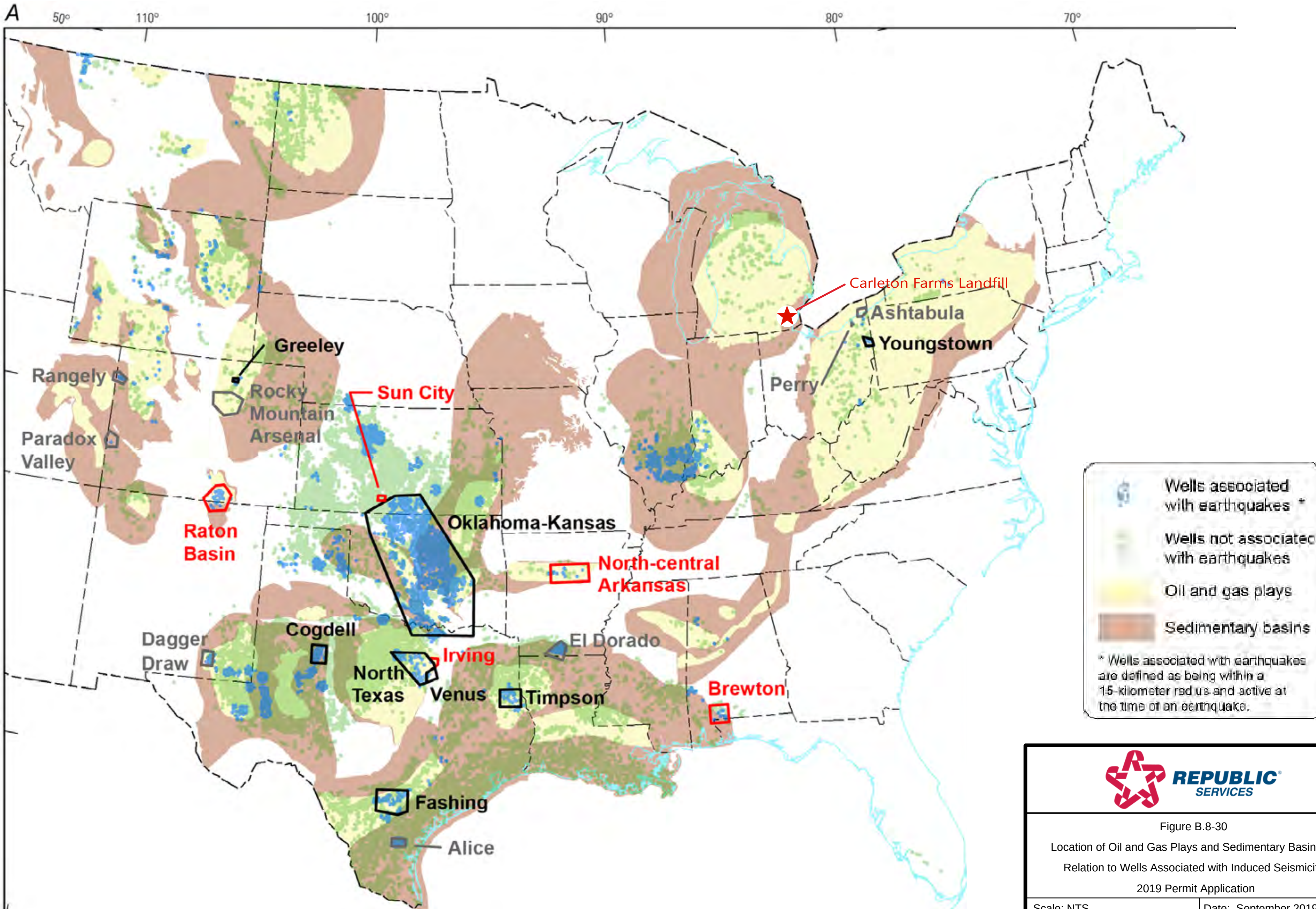


(USGS, 2016)

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Figure B.8-30

Location of Oil and Gas Plays and Sedimentary Basins in Relation to Wells Associated with Induced Seismicity

2019 Permit Application

| Scale: NTS | Date: September 2019 | |
|---|---|---|
| 2019_CFL_EGLE_Fig_B.8-30.pdf | By: WEK | Checked: CW |

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## B.9 Chemical, physical and bacteriological characterizations of the waste stream before and after treatment and/or filtration. Include a characterization of the compatibility of the injectate with the injection zone and the fluid in the injection zone along with a characterization of the potential for multiple waste streams to react in the well bore or in the injection zone.

### Injectate Characteristics

Carleton Farms Landfill (CFL) is an operating Type II municipal solid waste (MSW) Landfill and an MSW Incinerator Ash landfill. Wells IW#1-36N and IW#2-36E will inject non-hazardous fluids generated on-site from the leachate drainage system conveyed to the leachate storage system, wherein collection pipes from landfill cells drain leachate directly into a sump, and is pumped to either a lift station or directly to the existing above ground storage tanks. There is a 500,000 gallon storage tank near the proposed IW#1-36N location north of Cell 210 that receives leachate from MSW cells. There are two 80,000 gallon storage tanks near the proposed location for IW#2-36E well that receives leachate from the MSW as well as the Ash Cells (monofill). Leachate stored in the 500,000-gallon tank will be diverted to IW#1-36N and leachate from the two 80,000-gallon tanks will be diverted to IW#2-36E; however, wells could accept leachate from either or both tanks should either well be unavailable at any time (i.e., shut down for maintenance) or such operation is found necessary to optimize fluid disposal. Leachate received by above ground storage tanks is currently pumped to a truck loadout station for either on-site recirculation (if approved by appropriate agencies) or for off-site disposal. Historically, leachate is removed as necessary from tanks by a third-party hauler that can service the site as needed. Licensed industrial waste haulers have been used to collect and transport fluids for disposal at Clean Earth in Detroit Michigan, although other offsite non-hazardous liquid management facilities may be used.

As necessary, gas condensate, storm water, surface water run-off, and/or fluids derived from or necessary for IW#1-36N and IW#2-36E operation and maintenance may also be injected. However, fluid from the leachate collection system is anticipated to constitute the majority of the total fluid volume.

Landfill leachate is generated when precipitation contacts the solid waste in the landfill's active disposal area. As this precipitation migrates downward through the waste mass, it dissolves soluble materials (or leaches) and mixes with other liquids contained within the waste or generated as part of the degradation process. Landfill leachate is comprised of approximately water, dissolved salts, and other inorganic and organic components. Injectate will also include landfill gas condensate. Table B.9-1 presents 2017-2019 summary analytical information for select municipal solid landfill cells and the Ash monofill. As shown in this table, while analytical concentrations may vary somewhat between the landfill cells, the composition of leachate from the municipal solid waste (MSW) landfill cells and Ash monofill is relatively comparable.

Under the Carleton Farms Landfill Operating License, total leachate volume is recorded on a monthly basis and water quality on a quarterly basis. Samples are collected on a quarterly basis, and analyzed for the parameters per the Landfill Operating License requirements.

Compatibility and plugging problems encountered due to injection of non-hazardous landfill leachate and gas condensate are possible due to particulate matter, which could cause decreased flow capacity. Screens or filters may be used to condition fluids if needed. Due to the composition of the fluid to be injected and landfill origin, periodic biocide treatments may be instituted as needed to prevent the establishment of bacterial plugging issues. Also, the possibility of inorganic precipitate within tubing, pipe, or the injection formation could require monitoring, so implementation of a system to prevent plugging or treat leachate may be required. Such solids, compatibility, or bacterial problems, if they do occur, would not be a containment issue, but would be an operations issue. If plugging occurred and was not remedied, the operator could reduce injection rates so that maximum pressure limits are not exceeded. To sustain rates if such a situation develops, periodic stimulations may be required, but would be accomplished within regulatory requirements.

**Table B.9-1. Leachate Chemical Characterization, Carleton Farms Landfill**

| Parameter | | Composite MSW Cells | | | Ash Monofill | | |
|---|---|---|---|---|---|---|---|
| | | Max | Min | Average | Max | Min | Average |
| TEMPERATURE, FIELD (C) | | 22.6 | 5.8 | 16.2 | 24.2 | 12.1 | 18.9 |
| Potassium (mg/L) | 7440-09-7 | 9900 | 127 | 5883 | 2990 | 261 | 1387 |
| Barium (mg/L) | 7440-39-3 | 20.8 | 0.112 | 7.8 | 2.56 | 0.288 | 0.94 |
| Nitrogen, Ammonia (mg/L) | 7664-41-7 | 1820 | 1.4 | 324 | 2180 | 323 | 1530 |
| Nitrogen, Total Inorganic (mg/L) | SAN-005 | 1820 | 2.2 | 324 | 2180 | 323 | 1530 |
| Antimony (mg/L) | 7440-36-0 | 0.0198 | 0.0058 | 0.011 | 0.0272 | 0.0114 | 0.0207 |
| Arsenic (mg/L) | 7440-38-2 | 0.109 | 0.02 | 0.07 | 0.265 | 0.228 | 0.25 |
| Beryllium (mg/L) | 7440-41-7 | <0.005 | <0.001 | 0.004 | <0.05 | <0.005 | 0.02 |
| Cadmium (mg/L) | 7440-43-9 | <0.001 | 0.00082 | 0.001 | <0.0077 | 0.0043 | 0.0055 |
| Chromium (mg/L) | 7440-47-3 | 0.0385 | <0.005 | 0.017 | 0.518 | <0.456 | 0.487 |
| Cobalt (mg/L) | 7440-48-4 | <0.05 | 0.0132 | 0.026 | 0.0513 | 0.036 | 0.044 |
| Copper (mg/L) | 7440-50-8 | 0.0319 | 0.0119 | 0.0195 | 0.0108 | 0.0069 | 0.0085 |
| Iron (mg/L) | 7439-89-6 | 61.6 | 4.23 | 24.6 | 21.7 | 5.14 | 11.1 |
| Lead (mg/L) | 7439-92-1 | <0.005 | 0.0027 | 0.004 | 0.0125 | 0.0065 | 0.0093 |
| Nickel (mg/L) | 7440-02-0 | 0.113 | 0.0625 | 0.089 | 0.481 | 0.436 | 452 |
| Selenium (mg/L) | 7782-49-2 | 0.0111 | 0.0067 | 0.0091 | 0.0115 | 0.0073 | 0.0097 |
| Silver (mg/L) | 7440-22-4 | <0.001 | <0.0002 | 0.001 | 0.0015 | <0.001 | 0.001 |
| Thallium (mg/L) | 7440-28-0 | <0.01 | <0.004 | 0.01 | <0.01 | <0.01 | 0.01 |
| Vanadium (mg/L) | 7440-62-2 | 0.0192 | <0.01 | 0.013 | 0.219 | 0.197 | 0.212 |
| Zinc (mg/L) | 7440-66-6 | <0.1 | 0.0528 | 0.0843 | 0.371 | 0.048 | 0.173 |
| Bromodichloromethane (ug/L) | 75-27-4 | <10* | <1 | 2 | <25* | <1 | 11 |
| Bromoform (ug/L) | 75-25-2 | <10* | <1 | 2 | <25* | <1 | 11 |
| Carbon Tetrachloride (ug/L) | 56-23-5 | <10* | <1 | 2 | <25* | <1 | 11 |
| Chlorobenzene (ug/L) | 108-90-7 | <10* | <1 | 2 | <25* | <1 | 11 |
| Chloroethane (ug/L) | 75-00-3 | <50* | <5 | 12 | <125* | <5 | 53 |

| Parameter | | Composite MSW Cells | | | Ash Monofill | | |
|---|---|---|---|---|---|---|---|
| | | Max | Min | Average | Max | Min | Average |
| Manganese (mg/L) | 7439-96-5 | 2.15 | 0.31 | 1.35 | 2.63 | 0.155 | 0.98 |
| | | | | | | | |
| Magnesium (mg/L) | 7439-95-4 | 24.8 | <5 | 13.9 | 144 | 84 | 105 |
| Mercury (mg/L) | 7439-97-6 | n/a | n/a | n/a | n/a | n/a | n/a |
| Sodium (mg/L) | 7440-23-5 | 18300 | 11300 | 15000 | 4760 | 4040 | 4493 |
| Bicarbonate Alkalinity (mg/L) | 71-52-3 | 4800 | 320 | 2073 | 12000 | 9000 | 10900 |
| Carbonate Alkalinity (mg/L) | SAN-001 | <10* | <10 | 10 | <10 | <10 | 10 |
| Phenolics (mg/L) | 64743-03-9 | 3.6 | 1.4 | 2.3 | 7.7 | 0.386 | 4 |
| TDS (mg/L) | SAN-006 | 106000 | 2940 | 64171 | 19900 | 18200 | 19300 |
| Sulfate (mg/L) | 14808-79-8 | <587 | <0.25 | 142 | 310 | 25.6 | 125 |
| COD (mg/L) | SAN-008 | 6130 | 3800 | 5040 | 12600 | 7320 | 9890 |
| NITROGEN, NITRATE-NITRITE (MG/L) | SAN-004 | 0.8 | <0.04 | 0.3 | 2.2 | 0.2 | 0.8 |
| PHOSPHORUS, TOTAL (MG/L) | 7723-14-0 | 14.4 | 14.4 | 14.4 | 13.4 | 13.4 | 13.4 |
| TOC (MG/L) | 7440-44-0 | 1940 | 5.2 | 588 | 4120 | 351 | 2364 |
| Conductivity (UMHOS/CM) | 10-34-4 | 45300 | 1326 | 16391 | 18910 | 1299 | 11730 |
| Boron (MG/L) | 7440-42-8 | 47 | 0.187 | 7 | 47 | 38.7 | 44 |
| CYANIDE, TOTAL (MG/L) | 57-12-5 | 0.007 | <0.005 | 0.006 | 0.14 | 0.028 | 0.07 |
| ETHYLBENZENE (UG/L) | 100-41-4 | <14.1* | <1 | 5 | <25 | 6.8 | 13 |
| CHLORIDE (MG/L) | n/a | 99400 | 1020 | 46656 | 31700 | 1240 | 9709 |
| CHLOROMETHANE (UG/L) | 74-87-3 | <50* | <5 | 12 | <125* | 5 | 53 |
| DIETHYL ETHER [ETHYL ETHER] (UG/L) | 60-29-7 | <50* | <5 | 16 | <50* | 25 | 42 |
| TETRAHYDROFURAN (UG/L) | 109-99-9 | 403 | <12.5 | 114.2 | 1880 | 107 | 1063 |
| Fluoride (ug/L) | n/a | <100000* | <1000 | 15244 | n/a | n/a | n/a |
| Chloroform (ug/L) | 67-66-3 | <10* | <1 | 2 | <25* | <1 | 11 |
| Dibromochloromethane (ug/L) | 124-48-1 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,2-Dichlorobenzene (ug/L) | 95-50-1 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,4-Dichlorobenzene (ug/L) | 106-46-7 | <10* | <1 | 2 | <25* | 3.4 | 11 |
| 1,1-Dichloroethane (ug/L) | 75-34-3 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,2-Dichloroethane (ug/L) | 107-06-2 | <10* | <1 | 2 | <25* | <1 | 11 |
| | | | | | | | |
| 1,1-Dichloroethene (ug/L) | 75-35-4 | <10* | <1 | 2 | <25* | <1 | 11 |
| cis-1,2-Dichloroethene (ug/L) | 156-59-2 | <10* | <1 | 2 | <25* | 1.2 | 11 |
| trans-1,2-Dichloroethene (ug/L) | 156-60-5 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,2-Dichloropropane (ug/L) | 78-87-5 | <10* | <1 | 2 | <25* | <1 | 11 |
| cis-1,3-Dichloropropene (ug/L) | 10061-01-5 | <10* | <1 | 2 | <25* | <1 | 11 |
| trans-1,3-Dichloropropene (ug/L) | 10061-02-6 | <10* | <1 | 2.4 | <25* | <1 | 11 |
| Bromomethane (ug/L) | 74-83-9 | <50 | <1 | 11 | <125* | <5 | 53 |
| Dibromomethane (ug/L) | 74-95-3 | <10* | <1 | 2 | <25* | <1 | 11 |
| Methylene Chloride (ug/L) | 75-09-2 | <50 | <1 | 11 | <25* | <5 | 53 |
| Iodomethane (ug/L) | 74-88-4 | <10* | <1 | 3 | <25* | <1 | 11 |
| 1,1,1,2-Tetrachloroethane (ug/L) | 630-20-6 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,1,2,2-Tetrachloroethane (ug/L) | 79-34-5 | <10* | <1 | 2 | <25* | <1 | 11 |

| Parameter | | Composite MSW Cells | | | Ash Monofill | | |
|---|---|---|---|---|---|---|---|
| | | Max | Min | Average | Max | Min | Average |
| Tetrachloroethene (ug/L) | 127-18-4 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,1,1-Trichloroethane (ug/L) | 71-55-6 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,1,2-Trichloroethane (ug/L) | 79-00-5 | <10* | <1 | 2 | <25* | <1 | 11 |
| Trichloroethene (ug/L) | 79-01-6 | <10* | <1 | 2 | <25* | <1 | 11 |
| Trichlorofluoromethane (ug/L) | 75-69-4 | <10* | <1 | 2 | <25* | <1 | 11 |
| 1,2,3-Trichloropropane (ug/L) | 96-18-4 | <10* | <1 | 2 | <25* | <1 | 11 |
| Vinyl chloride (ug/L) | 75-01-4 | <10* | <1 | 2 | <25* | <1 | 11 |
| Benzene (ug/L) | 71-43-2 | <10* | <1 | 3 | <25* | <4 | 11 |
| Styrene (ug/L) | 100-42-5 | <10* | <1 | 2 | <25* | <1 | 11 |
| Toluene (ug/L) | 108-88-3 | 18.7 | <1 | 7.4 | 61.8 | 10.3 | 23.7 |
| Acetone (ug/L) | 67-64-1 | 10200 | 574 | 3445 | 12200 | 3650 | 8817 |
| Acrylonitrile (ug/L) | 107-13-1 | <50* | <5 | 16 | <50* | <25* | 42 |
| Bromochloromethane (ug/L) | 74-97-5 | <10* | <1* | 3 | <10* | <5* | 8 |
| Carbon disulfide (ug/L) | 75-15-0 | <10* | <1* | 3 | <10* | <5* | 8 |
| 1,2-Dibromo-3-chloropropane (ug/L) | 96-12-8 | <50* | <5 | 16 | <50* | <25* | 42 |
| 1,2-Dibromoethane (ug/L) | 106-93-4 | <10* | <1* | 3 | <10* | <5* | 8 |
| | | | | | | | |
| Trans-1,4-Dichloro-2-butene (ug/L) | 110-57-6 | <50* | <5 | 16 | <50* | <25* | 42 |
| 2-Hexanone (ug/L) | 591-78-6 | <50* | <5 | 23 | <236* | 33.4 | 106 |
| Calcium (mg/L) | 7440-70-2 | 9240 | 31 | 4969 | 442 | 74.2 | 221 |
| 2-Butanone [MEK] (ug/L) | n/a | 5240 | 55.1 | 2648 | 7110 | 7110 | 7110 |
| 4-Methyl-2-pentanone [MIBK] (ug/L) | n/a | 91.7 | <5 | 54.8 | 108 | 90.6 | 99 |
| BOD, [5-Day] (mg/L) | n/a | 3880 | 1150 | 1883 | 7410 | 206 | 2272 |
| pH, Field (S.U.) | n/a | 9.72 | 5.94 | 7.82 | 8.65 | 7.13 | 7.92 |
| XYLENES, TOTAL (ug/L) | 1330-20-7 | <40.7* | <2 | 13.6 | <50* | <20 | 31.1 |
| METHYL ISOBUTYL KETONE (ug/L) | 108-10-1 | <50* | <50* | 50 | <50* | <50* | 50 |
| strontium (ug/L) | 7440-24-6 | 57800 | 57800 | 57800 | 2270 | 2270 | 2270 |
| Silica (ug/L) | n/a | 24700 | 24700 | 24700 | 32000 | 32000 | 32000 |
| Alkalinity, Total (ug/L) | n/a | 1100000 | 1100000 | 1100000 | 11700000 | 11700000 | 11700000 |
| 2-BUTANONE [MEK], TCLP (UG/L) | n/a | 651 | 306 | 479 | 5360 | 1620 | 3490 |
| *Elevated detection limit due to sample dilution | | | | | | | |

## B.10 Information to characterize the proposed injection zone, including:

- **A. The geological name of the stratum or strata making up the injection zone and the top and bottom depths of the injection zone.**
- **B. An isopach map showing thickness and areal extent of the injection zone**
- **C. Lithology, grain mineralogy and matrix cementing of the injection zone.**
- **D. Effective porosity of the injection zone including the method of determination.**
- **E. Vertical and horizontal permeability of the injection zone and the method used to determine permeability. Horizontal and vertical variations in permeability expected within the area of influence.**
- **F. The occurrence and extent of natural fractures and/or solution features within the area of influence.**
- **G. Chemical and physical characteristics of the fluids contained in the injection zone and fluid saturations.**
- **H. The anticipated bottom hole temperature and pressure of the injection zone and whether these quantities have been affected by past fluid injection or withdrawal.**
- **I. Formation fracture pressure, the method used to determine fracture pressure and the expected direction of fracture propagation.**
- **J. The vertical distance between the top of the injection zone from the base of the lowest fresh water strata.**
- **K. Other information the applicant believes will characterize the injection zone.**

Items A-C are detailed in Section B.8. Items D-K will be verified during drilling and testing of IW-1. Literature data available to characterize formations has been cited in previous sections. Available data are summarized below.

### A. The geological name of the stratum or strata making up the injection zone and the top and bottom depths of the injection zone.

The proposed injection zone includes the interval from (deepest to shallowest) the Mt. Simon Sandstone to the Glenwood Formation. CFL intends to complete the Franconia/Dresbach through the Mt. Simon Formation, which represents the injection interval. The table below provides estimated top/bottom depths in feet below ground level (BGL) for this interval at each proposed injection well.

**Estimated Formation Tops at the Proposed CFL Well Locations**

| Formation | Est. Depth to Top, from GL (ft)* IW#1-36N | Est. Depth to Top, from GL (ft)* IW#2-36E |
|---|---|---|
| Ground Level (feet ASL) | 627 | 623 |
| Base of Alluvium/Glacial Material | 53 | 30 |
| Lucas Formation (Detroit River Group) | 53 | 30 |
| Sylvania Sandstone | 135 | 110 |
| Bois Blanc | 258 | 233 |
| Bass Island Group | 400 | 375 |
| Salina Group | 650 | 625 |
| Niagara Group | 1,122 | 1,097 |
| Clinton Group | 1,346 | 1,321 |
| Undifferentiated Upper Cincinnatian | 1,652 | 1,627 |
| Utica Shale | 2,227** | 2,198** |
| Trenton Formation | 2,357 | 2,323 |
| Black River Formation | 2,765 | 2,740 |
| Glenwood | 3,171 | 3,141 |
| Trempealeau Formation | 3,181 | 3,151 |
| Franconia/Dresbach Formation | 3,281 | 3,251 |
| Eau Claire Formation | 3,366 | 3,336 |
| Mt. Simon Sandstone | 3,527 | 3,502 |
| Precambrian Granite Wash | 3,807 | 3,782 |
| Precambrian basement | 3,827 | 3,802 |

*Estimated depth at proposed IW-1 location; IW-2 will likely be shallower. All depths shall be determined and finalized during well installation.

** Utica top based on regional map information. Note that often the top is picked higher up the column into the Upper Cincinnatian, resulting in a thicker Utica shale unit.

## B. An isopach map showing thickness and areal extent of the injection zone

Figures B.8-7 and B.8-24 are regional and local isopach maps of the Mt. Simon Sandstone, respectively. Figures B.8-9 and B.8-25 are regional and local isopachs of the Eau Claire, respectively. Figures B.8-11a and B.8-11b are regional isopaches of the Galesville/Dresbach and Franconia Formations, respectively. Figure B.8-33 presents a local isopach of the Franconia Formation. Figures B.8-12 is a regional isopach of the Trempeleau Formation. In total, the injection zone from the base of the Mt. Simon to the base of the Black River is laterally pervasive and is approximately 650 feet thick in the CFL area.

It is noted that CFL only intends to use the Franconia/Dresbach through the Mt. Simon injection interval as an open hole completion for the proposed injection wells.

### C. Lithology, grain mineralogy and matrix cementing of the injection zone.

See Section B.8 for detailed lithologic information concerning the Injection Zone formations.

### D. Effective porosity of the injection zone including the method of determination.

See Section B.8 for detailed information concerning the effective porosity of the injection zone formations and method of determination. Core data available for the formations in the injection zone are presented in Section B.8.

The injection zone includes the Mt. Simon, Eau Claire, Franconia/Dresbach, Trempealeau, and Glenwood Formations. The Franconia/Dresbach to the Mt. Simon is the injection interval that will be completed, open hole, and into which injection will take place. The overlying formations constitute the remainder of the injection zone, and these formations offer arrestment capabilities. The following summarizes porosity information pertaining to the Formations of the Munsing Group and Trempealeau Formation, noting that the Mt. Simon information is also included in Section B.8.

<u>Injection Zone: Mt. Simon Porosity Range</u>

As indicated in Section B.8.2.2.2, the Mt. Simon injection interval is well characterized by local core data that present local porosity information. Cores were taken from the Mt. Simon at the nearby EDS well No. 2-12 from 4127-4148 ft and 4245-4258 ft. Mt. Simon porosity information obtained from theses core indicate that porosity averaged 4.8 and 10.4%, respectively, with maximum porosity within the lower interval of 13.7%, nothing that the lower (deeper) core is more representative of the Mt. Simon.

<u>Injection Zone: Eau Claire, Franconia/Dresbach, and Trempealeau Formations Porosity Ranges</u>

The following information addressed porosity of formations above the Mt. Simon within the Injection Zone.

<u>Eau Claire Porosity Range</u>: The Eau Claire was cored in the EDS #1-12 and EDS #2-12 wells (see Section B.8.2.2.2). Summary results of core analyses for the Eau Claire are presented in Tables B.8-6a and B.8-6b. Note that well EDS #1-12 is a directional well, therefore the core depths are not consistent with corrected formation tops at EDS #2-12. These data show that the sampled portion of the upper Eau Claire in EDS #1-12 exhibits a porosity ranging from 1.2-3.9%, with an average permeability $K_{air}$ of 0.10 md. The lower portion of the Eau Clair at EDS #1-12 exhibits a porosity ranging from 5.4% to 20.7%, with an average permeability of 13.3 md. The upper Eau Claire core is described as a dolomite with laminar bedding and slight anhydrite; the lower Eau Claire core is described as a fine to medium grained sandstone.

Additional information from core data is presented in Section B.8 in Tables B.8.6a and B.8.6b.

Franconia/Dresbach Porosity Range: The Franconia and Dresbach/Galesville are considered together. Wireline data from the EDS #1-12 well indicates this general interval exhibits neutron porosity varying from 9-14%, while the same interval at the EDS #1-20 well in T3S R9E Section 20 exhibited up to 15% neutron porosity over the total interval thickness of approximately 60 feet. It is expected that the interval may exhibit similar porosity in the CFL area.

Additional information from core data is presented in Section B.8 in Tables B.8.7a and B.8.7b.

Trempealeau Porosity Range: Wireline data from the EDS #1-20 well was evaluated to assess Trempealeau porosity in this well location. Based on the neutron porosity, the Trempealeau Formation exhibits porosity ranging from 6-10% in cleaner zones with less shale admix. Additional information for the Trempealeau is presented in Section B.8.

### E. Vertical and horizontal permeability of the injection zone and the method used to determine permeability. Horizontal and vertical variations in permeability expected within the area of influence.

Permeability data for the formations in the injection zone are provided in various tables in Section B.8.

### F. The occurrence and extent of natural fractures and/or solution features within the area of influence.

No solution features such as paleokarst are documented in the proposed injection zone at the proposed well location. See B.8 for additional information about injection zone lithologies and structural geology.

### G. Chemical and physical characteristics of the fluids contained in the injection zone and fluid saturations.

Fluid samples were obtained during drilling from the EDS Well No 2-12. These data indicate that the TDS concentrations in the Mt. Simon was 270,000 mg/L at this location; this is the closest Mt. Simon water quality data point to the CFL.

Additional information is provided in Sections B.7 and B.8.2.2.2.

### H. The anticipated bottom hole temperature and pressure of the injection zone and whether these quantities have been affected by past fluid injection or withdrawal.

The nearest wells that penetrate through the Mt. Simon Sandstone that have well data including well logs are the EDS Wells #1-20, #1-12, and #2-12. Well log data for the EDS well #1-20 indicates the bottomhole temperature at a measure Log TD of 4,490 RKB was 100 degrees F.

Reservoir pressure in the Mt. Simon Sandstone is estimated based on data from the EDS Wells #1-12 and #2-12 as presented in the No Migration Variance Petition (Subsurface, 2000). The original measured pressure at the EDS #1-12 well was 1,825 psi at 4,000 ft RKB (reservoir pressure gradient of 0.4577 psi/ft); the extrapolated pressure at well #2-12 at 4,265 ft RKB was 1983.5 psi (0.4665 psi/ft). Averaging these two values results in a reservoir pressure gradient of 0.462 psi/ft, which is utilized for reservoir characterization at the CFL site in this document. This value is consistent with regional data for the Mt. Simon in this portion of Michigan. Based on an estimated total depth of 3,827 ft BGL at IW#1-36N and a reservoir pressure gradient of 0.462 psi/ft in the Mt. Simon, estimated bottom hole pressure is estimated to be 1768 psi; estimated bottom hole pressure at the IW#2-36E well location is estimated to be approximately 1,756 psi (estimated total depth of 3,802 ft BGL).

### I. Formation fracture pressure, the method used to determine fracture pressure and the expected direction of fracture propagation.

Wells IW#1-36N and IW#2-36E will be designed for operation under positive pressure to be supplied by using an injection pump. Although no site specific data are available, two step-rate injection tests were conducted at the EDS #2-12 well on December 12 and 18, 2001. The results of the December 12 test indicated a fracture pressure gradient of 0.787 psi/ft. The test on December 18 indicated a fracture pressure gradient of 0.746 psi/ft. As a conservative approach, a fracture gradient of 0.74 psi/ft is assumed for calculations of maximum injection pressure.

Maximum wellhead injection pressure is calculated using the assumed formation fracture pressure and the specific gravity (SG) of the injectate. If a safety factor of 0.05 for the SG of the injectate (average SG expected to be between 1.00 to 1.06) is included, a maximum expected SG of 1.11 is assumed (1.06 + 0.05 = 1.11). Injection fluid is assumed to be comprised of this brine (SG = 1.11) that fills the tubing from the surface to the top of the injection zone. At IW#1-36N, this corresponds to a depth of 3,171 feet; at IW#2-36E this corresponds to a maximum depth of 3,141 feet. Maximum wellhead injection pressure at these two wells is calculated as follows (14.7 psi equals assumed atmospheric pressure):

- IW#1-36N: 3,171 ft * (0.74 psi/ft – (0.433 psi/ft * 1.11)) – 14.7 psi = 808 psi
- IW#2-36E: 3,141 ft * (0.74 psi/ft – (0.433 psi/ft * 1.11)) – 14.7 psi = 800 psi

These values are conservative since no allowances for tubing friction are included in this calculation. Average injection pressures are expected to be approximately 500 to 700 psi.

Note that the average specific gravity is expected to be in the 1.00 to 1.06 range. The maximum pressure exerted by injectate of a 1.06 specific gravity at the top of the injection zone (estimated to be 3,171 feet BGL [IW#1-36N] and 3,141 feet BGL [IW#2-36E]) is not likely to exceed 1,455 psi and 1,442 psi, respectively. Adding in the requested wellhead injection pressure for each well yields a total downhole pressure of 2,263 psi (IW#1-36N) and 2,242 psi (IW#2-36E), which is approximately 80 psi less than the calculated bottomhole fracture pressure of 2,347 psi at IW#1-36N (3,171 ft * 0.74 psi/ft) and 2,324 psi at IW#2-36E (3,141 ft * 0.74 psi/ft), which ignores friction losses, thus offering a conservative safety margin.

Note that CFL only intends to complete the two wells to the Franconia/Dresbach through the Mt. Simon Sandstone with a casing shoe at a depth of approximately 3,281 feet (IW#1-36N) and 3,251 feet (IW#1-36E). Therefore, calculations at the shallower depths of 3,171 and 3,141 feet, respectively, are conservative.

**J. The vertical distance between the top of the injection zone from the base of the lowest fresh water strata.**

As shown in the table above, the top of the Glenwood (top of the injection zone) is over 2,600 feet below the top of the Bass Islands. As CFL only intends to complete the wells to the top of the Franconia/Dresbach, the top of this interval is located almost 2,900 feet below the base of the USDW.

**K. Other information the applicant believes will characterize the injection zone.**

See Section B.8 for additional information.

## B.11 Information to characterize the proposed confining zone, including:

- **A. The geological name of the stratum or strata making up the confining zone and the top and bottom depths of the confining zone.**
- **B. An isopach map showing thickness and areal extent of the confining zone**
- **C. Lithology, grain mineralogy and matrix cementing of the confining zone.**
- **D. Effective porosity of the confining zone including the method of determination.**
- **E. Vertical and horizontal permeability of the confining zone and the method used to determine permeability. Horizontal and vertical variations in permeability expected within the area of influence.**
- **F. The occurrence and extent of natural fractures and/or solution features within the area of influence.**
- **G. Chemical and physical characteristics of the fluids contained in the confining zone and fluid saturations.**
- **H. Formation fracture pressure, the method used to determine fracture pressure and the expected direction of fracture propagation.**
- **I. The vertical distance between the top of the confining zone from the base of the lowest fresh water strata.**
- **J. Other information the applicant believes will characterize the confining zone.**

Items A-C are detailed in Section B.8. Items D-J will be verified during drilling and testing of the IW-1 well. Literature data available to characterize formations has been cited in previous sections. Available data are summarized below.

### A. The geological name of the stratum or strata making up the confining zone and the top and bottom depths of the confining zone.

The proposed confining zone is the Utica Shale, Trenton, and Black River Formations. The table below provides estimated top/bottom depths in feet below ground level (BGL) for these formations.

**Estimated Formation Tops at the Proposed CFL Well Locations**

| Formation | Est. Depth to Top, from GL (ft)* IW#1-36N | Est. Depth to Top, from GL (ft)* IW#2-36E |
|---|---|---|
| Ground Level (feet ASL) | 627 | 623 |
| Base of Alluvium/Glacial Material | 53 | 30 |
| Lucas Formation (Detroit River Group) | 53 | 30 |
| Sylvania Sandstone | 135 | 110 |
| Bois Blanc | 258 | 233 |
| Bass Island Group | 400 | 375 |
| Salina Group | 650 | 625 |
| Niagara Group | 1,122 | 1,097 |
| Clinton Group | 1,346 | 1,321 |
| Undifferentiated Upper Cincinnatian | 1,652 | 1,627 |
| Utica Shale | 2,227** | 2,198** |
| Trenton Formation | 2,357 | 2,323 |
| Black River Formation | 2,765 | 2,740 |
| Glenwood | 3,171 | 3,141 |
| Trempealeau Formation | 3,181 | 3,151 |
| Franconia/Dresbach Formation | 3,281 | 3,251 |
| Eau Claire Formation | 3,366 | 3,336 |
| Mt. Simon Sandstone | 3,527 | 3,502 |
| Precambrian Granite Wash | 3,807 | 3,782 |
| Precambrian basement | 3,827 | 3,802 |

*Estimated depth at proposed IW-1 location; IW-2 will likely be shallower. All depths shall be determined and finalized during well installation.

** Utica top based on regional map information. Note that often the top is picked higher up the column into the Upper Cincinnatian, resulting in a thicker Utica shale unit.

### A. An isopach map showing thickness and areal extent of the confining zone

Figure B.8-15 is a regional isopach and Figure B.8-28 is a local isopach of the Utica Shale. Figure B-26 is a local isopach of the Trenton/Black River Formations. Based on these data, the estimated thickness of the Utica Shale and Trenton/Black River interval is at least approximately 900 feet and the interval is aerially extensive across the state.

### B. Lithology, grain mineralogy and matrix cementing of the confining zone.

See Section B.8 for detailed lithologic information concerning the Confining Zone formation.

### C. Effective porosity of the confining zone including the method of determination.

The Utica Shale is composed primarily of silty claystone deposited in a marine environment (Sattler, 2015). Western Michigan University (WMU,1981) reported porosity from cores collected and evaluated for the Consumers Power Company (Mirant Zeeland) Brine Disposal Well No 139 T4N, R15E, as being 1.5-4%. Sattler and Barnes (2018) noted that “The Utica Shale and Maquoketa Shale are considered to be the primary confining layers for Cambrian-Ordovician CO2 sequestration in the Midwest in the Michigan and Illinois Basins, respectively…” and “The Utica Shale is a notable confining zone in the region because of its widespread lateral continuity, dense mudrock lithology, and thickness in excess of 30 m.” Sattler evaluated Utica porosity and permeability measurement data obtained from core obtained from wells in nearby Lenawee and Jackson county, which showed the Utica porosity to be between 0.77% and 2.78% based on core analysis, and permeability to be 0.003 mD-14.71 mD, nothing that the permeability data are horizontal, not vertical values.

The Black River/Trenton occurs immediately below the Utica Shale. Well log data at the EDS #1-20 well indicate that the average neutron porosity of the Trenton-Black River interval is generally 1-3%, noting that there may be more porous intervals. The Black River at EDS #1-20 exhibits a log porosity of approximately 2% throughout the entire interval, which is 454 feet thick (3,692-3,238 ft RKB). Regionally and where the Trenton-Black River is unfractured, porosity ranges from 2-5% and permeability of generally low (less than 10 mD, but lower than 0.01 mD) (Grammer, 2006).

### D. Vertical and horizontal permeability of the confining zone and the method used to determine permeability. Horizontal and vertical variations in permeability expected within the area of influence.

As indicated under item B.11-D above, core data are available for the Utica Shale are available at various locations throughout the state (Briggs, 1968, Stattler, 2015). These data indicate that Utica Shale permeabilities of less than 0.5-2.5 md were reported for the “a location in southeastern Michigan” while Utica Shale permeabilities varied from 0.003-89.42 md elsewhere in the state. The Trenton Group at the Warner-Lambert Well No. 5 (T5N R15W Sec 20) was cored, and exhibited a horizontal brine permeability as low as $5.166 \times 10^{-6}$ md and vertical core plug permeability to injectate as low as $5.2 \times 10^{-6}$ md. Where unfractured and not an oil or gas reservoir as is likely the case at CFL, the Trenton and Black River likely exhibit similar permeabilities.

**E. The occurrence and extent of natural fractures and/or solution features within the area of influence.**

No solution features such as paleokarst are documented in the confining zone (i.e., Utica, Trenton/Black River) at the proposed well locations. See Section B.8 for additional information about confining zone lithologies and characteristics, as well as the occurrence of karst and solution features at the bedrock-alluvium/glacial clay contact.

The Trenton produces oil and gas elsewhere in southeastern Michigan in associated with known fault zones or structural trends (e.g. Cohee, 1945; Davies and Smith, 2006). Grammer (2006) concluded that structural mapping and log analysis of the Trenton/Black River suggest a close spatial relationship between dolomite and regional scale faulting, which is associated with major Trenton/Black River hydrocarbon producing fields like Albion/Scipio which occurs in Hillsdale, Jackson, and Calhoun counties, and Northville field that occurs in northwestern Wayne county. Geologic maps constructed at the top of the Trenton in the CFL area (Figure B-27) and Utica Shale (B-28) show no indication of structural features that would contribute to porosity development in the Trenton/Black River. It should be noted that even in areas where such features occur, the Utica Shale serves as a vertical cap for oil or gas migration.

**F. Chemical and physical characteristics of the fluids contained in the confining zone and fluid saturations.**

Data specific to the Utica Shale in the CFL area are not available. However, A search of the USGS Produced Waters Geochemical Database (USGS 2019) identified a water quality value for the Trenton Formation in Sumpter Township, corresponding to the well located in T4S R8E Section 22, which was abandoned in 1947. The Trenton Formation at this location yielded a water quality of 210,000 ppm TDS, indicating that the confining zone in the CFL area far exceeds 10,000 ppm TDS. Note that while no local Utica water quality data were identified, WMU (1981) states that the Utica Shale is not an aquifer, due to lower permeability and porosity, and water quality is likely comparable to that of the underlying Trenton/Black River.

**G. Formation fracture pressure, the method used to determine fracture pressure and the expected direction of fracture propagation.**

Wells IW#1-36N and IW#2-36E will be designed for operation under positive pressure to be supplied by using an injection pump. Although no site specific data are available, two step-rate injection tests were conducted at the EDS #2-12 well on December 12 and 18, 2001. The results of the December 12 test indicated a fracture pressure gradient of 0.787 psi/ft. The test on December 18 indicated a fracture pressure gradient of 0.746 psi/ft. As a conservative approach, a fracture gradient of 0.74 psi/ft is assumed for calculations of maximum injection pressure.

Maximum wellhead injection pressure is calculated using the assumed formation fracture pressure and the specific gravity (SG) of the injectate. If a safety factor of 0.05 for the SG of the injectate (average SG expected to be between 1.00 to 1.06) is included, a maximum expected SG of 1.11 is assumed (1.06 + 0.05 = 1.10). Injection fluid is assumed to be comprised of this brine (SG = 1.11) that fills the tubing from the surface to the top of the injection zone. At IW#1-36N, this corresponds to a depth of 3,171 feet; at IW#2-36E this corresponds to a maximum depth of 3,141 feet. Maximum wellhead injection pressure at these two wells is calculated as follows (14.7 psi equals assumed atmospheric pressure):

- IW#1-36N: 3,171 ft * (0.74 psi/ft – (0.433 psi/ft * 1.11)) – 14.7 psi = 808 psi
- IW#2-36E: 3,141 ft * (0.74 psi/ft – (0.433 psi/ft * 1.11)) – 14.7 psi = 800 psi

These values are conservative since no allowances for tubing friction are included in this calculation. Average injection pressures are expected to be approximately 500 to 700 psi.

Note that the average specific gravity is expected to be in the 1.00 to 1.06 range. The maximum pressure exerted by injectate of a 1.06 specific gravity at the top of the injection zone (estimated to be 3,171 feet BGL [IW#1-36N] and 3,141 feet BGL [IW#2-36E]) is not likely to exceed 1,455 psi and 1,442 psi, respectively. Adding in the requested wellhead injection pressure for each well yields a total downhole pressure of 2,263 psi (IW#1-36N) and 2,242 psi (IW#2-36E), which is approximately 80 psi less than the calculated bottomhole fracture pressure of 2,347 psi at IW#1-36N (3,171 ft * 0.74 psi/ft) and 2,324 psi at IW#2-36E (3,141 ft * 0.74 psi/ft), which ignores friction losses, thus offering a conservative safety margin.

Note that CFL only intends to complete the two wells to the Franconia/Dresbach through the Mt. Simon Sandstone with a casing shoe at a depth of approximately 3,281 feet (IW#1-36N) and 3,251 feet (IW#1-36E). Therefore, calculations at the shallower depths of 3,171 and 3,141 feet, respectively, are conservative.

### H. The vertical distance between the top of the confining zone from the base of the lowest fresh water strata.

As shown in the table above, the top of the Utica Shale (top of the confining zone) is over 1,800 feet below the base of the Bois Blanc, which is conservatively assigned as the lowermost USDW in the CFL area.

### J. Other information the applicant believes will characterize the confining zone.

See Section B.8 for additional information.

## REFERENCES

Cohee, George V, 1945. “Geology and Oil and Gas Possibilities of Trenton and Black River Limestones of the Michigan Basin, Michigan and Adjacent Areas. USGS Oil and Gas Investigations Preliminary Chart 11

Davies, Graham R. and Langorne B. Smith Jr. “Structurally controlled hydrothermal dolomite reservoir facies: An overview.” AAPG Bulletin, V. 90, no. 11 (November 2006), pp. 1641–1690.

Grammer, Michael G., 2006, Phase II (Year 2) Summary of Research – Establishing the Relationship Between Fracture-Related Dolomite and Primary Rock Fabric on Distribution of Reservoirs in the Michigan Basin, Department of Energy Topical Report DE-FC26-04NT15513.

## B.12 Information demonstrating injection of liquids into the proposed zone will not exceed the fracture pressure gradient and information showing injection into the proposed geological strata will not initiate fractures through the confining zone. Information showing the anticipated dispersion, diffusion and/or displacement of injected fluids and behavior of transient pressure gradients in the injection zone during and following injection.

### Maximum Injection Pressure

Wells IW#1-36N and IW#2-36E will be designed for operation under positive pressure to be supplied by using an injection pump. Although no site specific data are available, two step-rate injection tests were conducted at the EDS #2-12 well on December 12 and 18, 2001. The results of the December 12 test indicated a fracture pressure gradient of 0.787 psi/ft. The test on December 18 indicated a fracture pressure gradient of 0.746 psi/ft. As a conservative approach, a fracture gradient of 0.74 psi/ft is assumed for calculations of maximum injection pressure.

Maximum wellhead injection pressure is calculated using the assumed formation fracture pressure and the specific gravity (SG) of the injectate. If a safety factor of 0.05 for the SG of the injectate (average SG expected to be between 1.00 to 1.06) is included, a maximum expected SG of 1.11 is assumed (1.06 + 0.05 = 1.11). Injection fluid is assumed to be comprised of this brine (SG = 1.11) that fills the tubing from the surface to the top of the injection zone. At IW#1-36N, this corresponds to a depth of 3,171 feet; at IW#2-36E this corresponds to a maximum depth of 3,141 feet. Maximum wellhead injection pressure at these two wells is calculated as follows (14.7 psi equals assumed atmospheric pressure):

- IW#1-36N: 3,171 ft * (0.74 psi/ft – (0.433 psi/ft * 1.11)) – 14.7 psi = 808 psi
- IW#2-36E: 3,141 ft * (0.74 psi/ft – (0.433 psi/ft * 1.11)) – 14.7 psi = 800 psi

These values are conservative since no allowances for tubing friction are included in this calculation. Average injection pressures are expected to be approximately 500 to 700 psi.

Note that the average specific gravity is expected to be in the 1.00 to 1.06 range. The maximum pressure exerted by injectate of a 1.06 specific gravity at the top of the injection zone (estimated to be 3,171 feet BGL [IW#1-36N] and 3,141 feet BGL [IW#2-36E]) is not likely to exceed 1,455 psi and 1,442 psi, respectively. Adding in the requested wellhead injection pressure for each well yields a total downhole pressure of 2,263 psi (IW#1-36N) and 2,242 psi (IW#2-36E), which is approximately 80 psi less than the calculated bottomhole fracture pressure of 2,347 psi at IW#1-36N (3,171 ft * 0.74 psi/ft) and 2,324 psi at IW#2-36E (3,141 ft * 0.74 psi/ft), which ignores friction losses, thus offering a conservative safety margin.

Note that CFL only intends to complete the two wells to the Franconia/Dresbach through the Mt. Simon Sandstone with a casing shoe at a depth of approximately 3,281 feet (IW#1-36N) and 3,251 feet (IW#1-36E). Therefore, calculations at the shallower depths of 3,171 and 3,141 feet, respectively, are conservative.

**Average Rates, Volumes and Pressures**

The range of injection rates and pressures is expected to fluctuate depending on the demands of the system along with variables related to the well and reservoir conditions. Operational injection rates are expected to average approximately 70 gpm per well (combined average from two wells of 140 gpm), with a maximum rate of 80 gpm per well, for a combined maximum injection rate of 160 gpm. The estimated annual volume is not expected to exceed 84,096,000 gallons/year, with an average daily volume of 201,600 gallons (140 gpm) and maximum expected daily volume of 230,400 gallons (160 gpm). Table B.12-1 presents representative historic leachate generation information that reflects anticipated injectate volumes.

**Table B.12-1. Annual Leachate Volumes, Carleton Farms Landfill, 2014-2019**

| Year | Volume (gallons) |
|---|---|
| 2014 | 19,188,796 |
| 2015 | 20,270,182 |
| 2016 | 30,385,240 |
| 2017 | 35,949,955 |
| 2018 | 62,181,290 |
| 2019* | 36,553,412 / 72,000,000 |

* 2019 volumes from data thru July; 72,000,000 annual volume is projected estimate for the year.

The wells are to be operated, and operating data will be reported, according to the requirements presented in Table B.12-2.

**Table B12-2. Operating, Monitoring, and Reporting Requirements, CFL IW#1-36N and IW#2-36E**

| Characteristic | Value | Minimum Monitoring Frequency [2] | Minimum Reporting Frequency |
|---|---|---|---|
| Injection Rate (Maximum); Per Well | 80 gallons/min | Continuous | Monthly |
| Injection Rate (Maximum); Combined | 160 gallons/min | Continuous | Monthly |
| Injection Rate (Average); Per Well | 70 gallons/min | Continuous | Monthly |
| Injection Rate (Average); Combined | 140 gallons/min | Continuous | Monthly |
| Cumulative Estimated Annual Volume, Both Wells | 73,584,000 gallons/year | Continuous | Monthly |
| Injection Pressure (maximum); IW#1-36N | 822 psig | Continuous | Monthly |

| | | | |
|---|---|---|---|
| Injection Pressure (maximum); IW#2-36E | 814 psig | Continuous | Monthly |
| Injection Pressure (average); both wells | 500 - 700 psig | Continuous | Monthly |
| Annulus Pressure | 100 psig min. | Continuous | Monthly |
| Annulus/Tubing Pressure Differential | 100 psig min. | Continuous | Monthly |
| Sight Glass Level | Visible | Daily, when operated | Monthly |
| Annulus Fluid Addition Or Removal | None | Monthly | Monthly |
| Chemical Composition of Injected Fluids[1] | None | Monthly | Monthly |
| Physical Characteristics of Injected Fluids[1] | Non-hazardous | Monthly | Monthly |

[1] As specified in the Waste Analysis Plan, see Attachment C (CD-ROM)
[2] Continuous is to be defined as a value recorded not less than once every five (5) minutes

## Impact of Injection

There are five wells that penetrate into the confining zone, but none of these wells was drilled through the base of the confining zone into the uppermost injection zone within the two-mile AOR. The nearest wells that penetrate the injection zone and injection interval are the two Class I non-hazardous wells at the EDS facility, located approximately 11 miles northeast of the CFL facility.

The Franconia/Dresbach through Mt. Simon injection interval will be tested to verify capacity upon well installation. Until data are obtained during installation of the well, estimates of formation properties have been assigned based on regional data associated with the closest wells to the Mt. Simon being the EDS wells in Romulus, MI (Wells #1-12 [UIC Permit MI-163-1W-C010], #2-12 [UIC Permit MI-163-1W-C011], and #1-20 [plugged and abandoned; previous UIC Permit MI-163-1W-006]) and projected operational parameters, to generate an estimate of the fluid front for the two proposed CFL wells. Standard equations for the volume of a porous cylinder can be used with the following parameters to generate an estimate for a simplistic piston-like displacement fluid front radius. Based on parameters determined at the EDS wells, the following conservative formation characteristics and injectate volumes were assumed:

- 210 foot net thickness in the injection interval, which is estimated to have a gross thickness of approximately 650 feet at both wells
- 840,960,000 gallons of injectate at each well, estimated based on twenty years of continuous injection at a rate of 42,048,000 gallons per year (80 gpm)

The following formula was used to estimate the radius of fluid displacement at each well:

$$\text{Radius} = (\text{volume} / \pi * \Phi * h)^{1/2}$$
$$= [(840{,}960{,}000 \text{ gal} * \text{ft}^3/7.48 \text{ gal}) / \pi * 0.11 * 210]^{1/2}$$
$$= 1{,}245 \text{ ft}$$

As an estimate for illustrative purposes, this calculation yields a piston-like, 100 percent injected fluid front radial distance of approximately 1,245 feet from each well (see Figure B.6-3). Although dispersion will play a role in spreading this plume over a slightly larger area, even a relatively large dispersivity combined with a low cut-off boundary concentration would likely yield a plume that reaches a radial distance of just under ¼-mile from the well. This is much smaller than the two-mile AOR radius for which artificial penetrations were identified and evaluated.

Compatibility problems encountered due to injection of non-hazardous landfill leachate and gas condensate are possible due to injection of particulate matter that could cause decreased flow capacity. Screens or filters may be used to condition fluids if needed. Due to the composition of the fluid to be injected and landfill origin, periodic biocide treatments may be instituted as needed to prevent the establishment of bacterial plugging issues. Also, it is possible that the concentration of iron within injectate could lead to precipitation issues within tubing, pipe, or the formation, so implementation of a system to prevent plugging or treat iron may be required. Such solids, compatibility, or bacterial problems, if they do occur, would not be a containment issue, but would be an operations issue. If plugging occurred and was not remedied, the operator could reduce injection rates so that maximum pressure limits are not exceeded. To sustain rates if such a situation develops, periodic stimulations may be required, but would be accomplished within regulatory requirements.

## B.13 Proposed operating data including all of the following data:

**A. The anticipated daily injection rates and pressures.**
**B. The types of fluids to be injected.**
**C. A plan for conducting mechanical integrity tests.**

**A and B**. As noted in Section B.12, continuous injection at an average rate of 70 gpm per well (140 gpm combined; equivalent to 201,600 gallons per day) is projected. This is equivalent to an injection volume from two wells of approximately 73,584,000 gallons per year. At the maxiumum permitted injection rate of 160 gpm (80 gpm per well), injection volume is equivalent to not more than 80,096,000 gallons per year. As noted on Table B.12-2, average injection pressure is estimated to be approximately 500 to 700 psig with a maximum injection pressure of not more than 822 psig at IW#1-36N and 814 psig at IW#2-36E. The injectate will be non-hazardous fluids generated on-site from landfill leachate and gas condensate collection systems. As necessary, storm water, surface water run-off, and/or fluids derived from or necessary for disposal well operation and maintenance may also be injected. See Item B.9 and B.12 for additional information pertaining to daily injection rates/pressure and the types of fluids to be injected.

**C.** Annual Part I mechanical integrity testing for IW#1-36N and IW#2-36N will include reservoir monitoring as specified by permit requirements in addition to static annulus pressure testing. CFL will provide the agency a minimum of 30 days notice prior to annual testing. Although test procedures or methods may be changed based on approval by EGLE staff, the following procedure will be used for the first such testing performed:

1. Conduct Wellsite Safety Meeting
    a. Prior to commencement of field activities, conduct safety meeting with contractors and personnel to be involved with field services and MIT testing. Ensure that all safety procedures are understood and review days' work activities.
2. Conduct Reservoir (Fall-Off or Static) Pressure Test
    a. For fall-off, record data regarding test well injection at typical operating conditions (constant rate). Rate versus time data will be recorded during the injection period. Cumulative injection volume will also be recorded. Continue injection for a minimum of approximately 8 hours. Note that significant rate variations may yield poor quality data or require more complicated analysis techniques.
    b. Rig-up pressure gauge and run in well to a depth likely not to exceed approximately 3,300 feet or other depth approved by EGLE.
    c. For pressure transient fall-off, obtain final stabilized injection pressure for a minimum of 1 hour. For static test, collect a minimum of two pressure/temperature readings at depth. Ensure that the gauge temperature readings have also stabilized.
    d. After gauge recordings are stable, cease injection and monitor pressure fall-off. Continue monitoring pressure for a minimum of 8 hours or until a

valid observation of fall-off curve is observed. For a static gradient survey, the well will be shut-in for a minimum of 48 hours before testing. Wellbore pressure gradients will be obtained to establish fluid gradient and bottomhole pressure data will be collected for a minimum of 4 hours for static testing.

   e. Stop test data acquisition, rig-down and release equipment.

3. Annulus Pressure Test
   a. Stabilize well pressure and temperature.
   b. As practical, arrangements will be made for a representative from EGLE to be present to witness testing.
   c. Install ball valve or similar type “bleed” valve on annulus gate valve. Pressurize annulus to a minimum of 100 psig above maximum permitted operating pressure and shut-in valve. Install certified gauge on “bleed” type valve. The annulus may need to be pressurized and bled off several times to ensure an absence of air.
   d. Monitor and record pressure for 1 hour. Pressure may not fluctuate more than 3% during the one-hour test.
   e. Lower the annulus pressure to normal operating pressure at the end of the test.

Part II mechanical integrity testing to be conducted every 5 years, as required by EGLE, is detailed in Sections A.11 and A.14 and is not repeated herein.

**B.14 For a proposed disposal well to dispose of waste products into a zone that would likely constitute a producing oil or gas pool or natural brine pool, a list of all offset operators and certification that the person making application for a well has notified all offset operators of the person's intention by certified mail. If within 21 days after the mailing date an offset operator files a substantive objection with the supervisor, then the application shall not be granted without a hearing pursuant to part 12 of these rules. A hearing may also be scheduled by the supervisor to determine the need or desirability of granting permission for the proposed well.**

Production from the Franconia/Dresbach through the Mt. Simon interval has not been identified in the vicinity of the proposed disposal well. There are also no deep wells within the vicinity of the CFL that penetrate to or produce from zones below the Black River Formation, which is the lowermost interval of proposed upper confining zone. Therefore, a list of offset operators is not required.

## B.15 A proposed plugging and abandonment plan

The following is the proposed plan for plugging and abandonment of the proposed IW#1-36N and IW#2-36N wells. Note that procedures for plugging will be the same for both wells, though there is minor variations in depths and cement volumes based on minor differences in projected depths.

**CFL IW#1-36N and IW#2-36E PLUGGING AND ABANDONMENT PLAN**

1. Notify regulatory agencies a minimum of 30 days prior to commencement of plugging operations.
2. Prepare well and location for plugging. Move in and rig up well servicing rig, pipe racks and tanks.
3. Install a test gauge on the annulus to perform a static annulus pressure test. Ensure that the annulus is fluid filled and that the well has been shut-in for a minimum of 24 hours. Pressurize annulus and isolate from the annulus system. Monitor annular pressure for one hour.
4. Displace tubing with kill brine as needed to control wellhead pressure. Dismantle wellhead and install blow-out preventer. Displace annulus with kill brine as needed to control pressure. Brine compatibility with cement to be used will be verified.
5. Remove injection tubing and packer. If packer will not unseat, proceed with fishing operations as needed to remove packer from hole or obtain approval to set retainer above packer and pump cement through retainer and abandoned packer.
6. Make up mechanical retainer on workstring and trip in hole. Set cement retainer at top of injection interval just above historical packer setting depth. Test cement retainer to 500 psig.
7. Move in cement and cementing equipment.
8. Displace hole below retainer with Class “A” cement. Unsting from retainer and spot 50 additional sacks (sx) on top of retainer. Cement volume has been calculated based on the following volumes for IW#1-36N and IW#2-36E:

   IW#1-36N
   - 6-1/8” hole from 3,281 ft BGL to a projected depth of 3,827 ft BGL, at 0.2046 $ft^3/ft$ = 112 $ft^3$, or 95 sx Class “A” cement
   - 7” casing from surface to 3,281 ft GL, at 0.2148 $ft^3/ft$ = 705 $ft^3$, or 597 sx Class “A” cement

   IW#2-36E
   - 6-1/8” hole from 3,251 ft BGL to a projected depth of 3,802 ft BGL, at 0.2046 $ft^3/ft$ = 107 $ft^3$, or 90 sx Class “A” cement
   - 7” casing from surface to 3,251ft GL, at 0.2148 $ft^3/ft$ = 698 $ft^3$, or 592 sx Class “A” cement

Therefore, the total volume of the plugs is estimated to be 817 $ft^3$, which is equivalent to 692 sx of Class "A" cement with a yield of 1.18 $ft^3$/sack for IW#1-36N. For IW#2-36E, the total volume is estimated to be 805 $ft^3$, which is equivalent to 682 sx of Class "A" cement with a yield of 1.18 $ft^3$/sack. If wellbore fill is present, this volume may have to be reduced or squeezed into the openhole of the injection interval.

9. Once cement has been tagged on top of the retainer, spot successive, continuous balanced cement plugs in 500' intervals from top of cement retainer to surface (6 intervals required). Cement to be API Class 'A' with not more than 4% bentonite. If neat Class 'A' cement is pumped it will have the following slurry properties.
    - Water ratio – 5.2 gallons per sack
    - Slurry weight – 15.60 pounds per gallon
    - Slurry volume – 1.18 $ft^3$/sack

   An estimated 547 sacks, or 645 $ft^3$, of slurry will be required above the retainer for IW#1-36N; for IW#2-36E, an estimated 542 sacks, or 640 $ft^3$, will be required.
10. Remove BOP and wellhead equipment.
11. Cut off wellhead approximately 4 feet BGL and weld cap with permanent marker on casing.
12. Rig down and move out all equipment.
13. Prepare and file USEPA and EGLE Plugging Reports.

The steel plate will be inscribed with the disposal well identification information and the date of plugging. Federal and State representatives will have been invited to witness the plugging and sign the plug and abandonment form.

## B.16 Identify the source or sources of proposed injected fluids. Identify if injected fluids will be considered hazardous or non-hazardous as defined by Part 111, Hazardous Waste Management, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (NREPA)

See Section B.9 for information about waste sources and waste chemistry. As stated in Section B.9, non-hazardous landfill leachate and gas condensate will be injected in the proposed IW#1-36N and IW#2-36E injection wells. Injection of fluids generated on-site will provide an environmentally safe management option that does not require off-site transport with associated traffic, potential for fluid spillage, and other issues. CFL believes Class I authorization will provide the most environmentally safe option for management of on-site generated fluids into formations deeply isolated from overlying USDWs. This will safely, cost effectively, and efficiently manage non-hazardous fluids via injection while minimizing the risks associated with transporting such wastes substantial distances to utilize other fluid management methods.

### B.17 Whether the well is to be a multisource commercial hazardous waste disposal well.

This well permit application request is for single source non-hazardous wells, not multisource commercial hazardous waste disposal wells.

## B.18 Additional information required for an application for a permit to drill and operate a storage well or to convert a previously drilled well to such a well:

**For an application to drill storage well or to convert a previously drilled well to a storage well, also submit the following information in addition to that submitted in the previous section for a disposal well. In the previous sections instructions, replace the term ‘disposal’ with ‘storage’ and ‘waste’ with ‘stored product.’**

1. **The name and chemical formula of the product to be stored, and a characterization of the physical, chemical, and hazardous or toxic properties of the product.**
2. **The anticipated vertical and horizontal dimensions and volume of the completed underground storage cavity.**
3. **The anticipated operating life of the underground storage cavity.**
4. **The method to be used to create the underground storage cavity.**
5. **The name of the geological stratum in which the underground storage cavity will be created.**
6. **A schematic diagram of the well bore showing the proposed arrangement and specifications of the down hole well equipment.**
7. **If the underground storage cavity is to be formed by solution mining bedded salt, then all of the following information shall be included:**
8. **The plan for disposal of brine produced during solution mining of the underground storage cavity and for the operating life of the underground storage cavity.**
9. **The expected starting and ending dates of the solution mining.**
10. **The range of anticipated operating pressures of the underground storage cavity.**
11. **The anticipated range of operating injection pressure.**
12. **The proposed method of displacing stored product.**
13. **A plan for testing the mechanical integrity of the underground storage cavity as provided in R 299.2392 and R 299.2393.**

N/A. This application is not being submitted for a permit to drill and operate a storage well or to convert a previously drilled well to such a well.

## B.19 Additional information required for an application for a permit to drill and operate a well for the production of artificial brine or to convert a previously drilled well to such a well:

**For an application to drill and operate a brine well for production of artificial brine or to convert a previously drilled well to a well for production of artificial brine, submit in addition to the information in the first section, all of the following proposed information:**

1. **If the well will be drilled into an existing cavern, the number of wells in the cavern, the present extent of the cavern, and the purpose of the proposed well.**
2. **The name of the geological stratum or strata to be mined, the top and bottom depths of the mined zone, the gross and net mineable thickness, and the mineral or minerals to be recovered by solution mining.**
3. **An isopach map showing thickness and areal extent of the strata to be mined.**
4. **A sketch showing the extent of the planned mine area.**
5. **The geological strata to be left in place for roof support.**
6. **A diagram showing the well bore with the proposed casing program and its relationship to the stratum or strata to be mined.**
7. **A plan for conducting subsidence monitoring as required in R 299.2407 or a rationale for not conducting subsidence monitoring.**

N/A. This application is not being submitted for a permit to drill and operate a well for the production of artificial brine or to convert a previously drilled well to such a well.

**A public hearing may be scheduled by the Supervisor of Mineral Wells to take public comment on the proposed well. If such a hearing is scheduled, the applicant will be responsible for the scheduling and preparation and publication of the notice.**

**Please collate the above documents into a set and mail the original and two copies of the application (total of 3 sets) plus 3 additional copies of form EQP 7200-1 to:**

**Department of Environment, Great Lakes and Energy**
**Office of Geological Survey**
**P.O. Box 30256**
**Lansing, Michigan 48909**

The above documents have been collated and appropriate numbers of document and form copies have been sent to the above address.