Table 2-13. Major Storage Facilities Located within 8 km (5 mi) of the Radioisotope Production Facility Site

Storage facility	Product	Volume (gal)	Distance from RPF		Direction
			km	mi	
Magellan Pipeline Company Breakout Tanks	[Proprietary Information]	[Proprietary Information]	1.6	1	Southeast
Ferrellgas	[Proprietary Information]	[Proprietary Information]	8	5	North

RPF = Radioisotope Production Facility.

2.2.2 Air Traffic

2.2.2.1 Airports

There are three airports and three helicopter ports located within 16 km (10 mi) of the proposed RPF site. These airports are identified in in Figure 2-30. The nearest airport is the Columbia Regional Airport approximately 10.5 km (6.5 mi) south of the RPF site. The Columbia Regional Airport is used by commercial and privately owned aircraft. The airport is situated on approximately 0.532 ha (1,314 acre) and is owned and operated by the City of Columbia. This airport is the only public use airport located in Boone County for which records are kept.

For the 12-month period ending October 31, 2013, the airport had 16,610 aircraft operations for an average of 26/day that were 81 percent general aviation, 2 percent military, 16 percent air taxi, and 1 percent air carrier.

Two small private airports are located within 16 km (10 mi) of the RPF site. These airports include the Cedar Creek Airport, approximately 9.7 km (6 mi) east of the RPF site, and the Sugar Branch Airport, 16 km (10 mi) to the west of the RPF site. Operations data for these airports is not available.

Three helicopter ports are located with 16 km (10 mi) of the RPF site. These heliports support hospital operations and include the University Hospitals and Clinics heliport located 6 km (3.7 mi) northwest, MU heliport located 6 km (3.7 mi) northwest, and Boone Hospital Center heliport located 6.3 km (3.9 mi) northwest. No operations data are available for these heliports.

Based on NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors - Format and Content*, sites located between 8 km (5 mi) and 16 km (10 mi) from an existing or projected commercial or military airport with more than approximately 200 d^2 (where d is the distance in kilometers from the airport to the RPF site) commercial or military aircraft movements per year. The number of aircraft movements per year for the three heliports are not recorded. However, if it is assumed that on average these heliports support five operations or less a day (1,825/year), they are under the 200 d^2 (7,200) limit.

For the Columbia Regional Airport:

$$200\ d^2 = 200(10.4)^2 = 21,632$$

Based on this requirement, the Columbia Regional Airport does not need to be further evaluated. The guidance also requires that special consideration needs to be given to facilities sited within the trajectory of a runway of any airport. The RPF site is not located within a trajectory of a runway of the airport.

2.2.2.2 Airways

There are seven federal airways located within 16 km (10 mi) of the RPF site. These airways are identified in Figure 2-30. NUREG-1537 calls for the evaluation of frequency and type of aircraft movement, flight patterns, local meteorology, and topography. NUREG-0800, *Standard Review Plan*, Section 3.5.1.6, "Aircraft Hazards," was used to evaluate airways near the RPF site. NUREG-0800 indicates that an evaluation is not required when the nearest edge of the airway is greater than 3.2 km (2 mi) from the facility. Four of the seven airways (J24, J181, V12, and V63) fall within 3.2 km (2 mi) of the proposed RPF site (Table 2-14).

Table 2-14. Federal Designated Airways within 16 km (10 mi) of the Radioisotope Production Facility Site

Airway	Distanced from airway centerline to RPF		Airway width		Distance from airway edge to RPF	
	km	mi	km	mi	km	mi
J24	17.3	10.75	Not specified	Not specified	Within	Within
J181	4.8	3	Not specified	Not specified	Within	Within
V12	6.8	4.25	14.8	9.2	Within	Within
V44	11.2	7	14.8	9.2	3.5	4.0
V63	0.40	0.25	14.8	9.2	Within	Within
V175	19.3	12	14.8	9.2	2.2	2.5
V178/V239	11.2	7	14.8	9.2	2.6	3

RPF = Radioisotope Production Facility.

The hazards associated with these airways are evaluated in Section 2.2.2.5. Figure 2-30 identifies the centerline of federal airways within 10 mi (16 km) of the RPF site.

2.2.2.3 Military Airports and Training Routes

There are no military airports or training routes located within 16 km (10 mi) of the RPF site.

2.2.2.4 Approach and Holding Patterns

According to air traffic control at the Columbia Regional Airport, the controllers do not typical hold any traffic. However, if traffic is held, the aircraft are typically within their designated airspace, 8 km (5 mi) (Figure 2-29). The hazards associated with these airways are evaluated in Section 2.2.2.5.

2.2.2.5 Evaluation of Aircraft Hazard

NUREG-0800, Section 3.5.1.6, provides a methodology for determining the probability of an aircraft crash into a facility from airways. However, the approach requires knowledge of the number of flights per year along the airway. Because this information is not available for the flight paths near the RPF, DOE-STD-3014-96, *Accident Analysis for Aircraft Crash into Hazardous Facilities*, was used.

This method uses crash rates for non-airport operations. The following formula from the DOE standard was used.

$$F_j = N_j \times P_j \times f_j(x, y) \times A_j$$

Where:

F_j	=	Crash impact frequency
j	=	Each type of aircraft suggested in DOE-STD-3014-96
N_jP_j	=	Expected number of in-flight crashes per year
$f_j(x,y)$	=	Probability, given a crash, that the crash occurs in a 1-mi^2 area surrounding the facility
A_j	=	Effective plant area.

DOE-STD-3014-96 provides estimated $N_jP_jf_j(x,y)$ values for general and commercial aviation, and the average continental U.S. (CONUS) values were used. The effective area, A_j, for each aircraft category is determined by two components; the aircraft crashing into the facility either by skidding or by flying directly into it. The effective area is calculated based on an aircraft skidding or flying into the facility in the direction that produces the largest area (i.e., crashing in a direction perpendicular to the largest diagonal of the building). The following formula was used to calculating the skid and fly-in areas of an aircraft crashing into the facility.

$$A_{eff} = A_f + A_s$$

Where:

$$A_f = (WS + R) \times H \times cot\phi + \frac{(2 \times L \times W \times WS)}{R} + L \times W$$

and:

$$A_s = (WS + R) \times S$$

Where:

A_f	=	Effective fly-in area
As	=	Effective skid area
WS	=	Aircraft wingspan
R	=	Length of the diagonal of the facility = $\sqrt{L^2 + W^2}$
H	=	Facility height, facility-specific
cotΦ	=	Mean of the cotangent of the aircraft impact angle
L	=	Length of facility, facility-specific
W	=	Width of facility, facility-specific
S	=	Aircraft skid distance (mean value).

DOE-STD-3014-96 notes that in calculating an effective area, the analyst needs to be cognizant of the "critical areas" of the facility. The critical areas are locations in a facility that contain hazardous material and/or locations that, once impacted by a crash, can lead to cascading failures (e.g., a fire, collapse, and/or explosion that would impact the hazardous material). The critical areas of the RPF are considered to be the hot cell and waste management areas.

The critical areas dimensions are estimated at 30.5 × 24 m (100 × 80 ft), which provides a diagonal (R) of 39 m (128 ft). The facility height (H) of 13.7 m (45 ft) was used. DOE-STD-3014-96 provides estimates for aircraft wingspan, mean of the cotangent of the aircraft impact angle, and skid distance for five different aircraft types. The most conservative values were used in cases where there where more than one available for the specific aircraft. These values, along with the calculated effective plant area, are summarized in Table 2-15.

Table 2-15. Effective Area Input Values and Calculated Effective Plant Area

Aircraft	[a]Average CONUS values $N_iP_if_i(x,y)$	[a]Wing span WS (ft)	[a]cotΦ	Skid distance S (ft)	Effective plant area A_j (mi^2)	Non-airport crash frequency F_j
Air carrier	4E-7	98	10.2	1440	0.01569	6.27E-09
Air taxi	1E-6	59	10.2	1440	0.01303	1.30E-08
Large military	2E-7	223	9.7	[b]780	0.01561	3.12E-09
Small military	4E-6	78	10.4	[c]447	0.00705	2.82E-08
General aviation airplanes	2E-4	73	8.2	60	0.00338	6.77E-07

Source: EDF-3124-0015, 2014, *Evaluation of Aircraft Hazards*, Rev. 0, Portage, Inc., Idaho Falls, Idaho, August 16, 2014.

[a] DOE-STD-3014-96, 2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*, U.S. Department of Energy, Washington, D.C.

[b] Takeoff

[c] Landing

CONUS = continental United States.

The crash impact probabilities from airways for the five aircraft types are added to determine the overall probability for small and large aircraft. The resulting probability is 7.28E-07.

NUREG-1537 does not provide acceptance criteria to be used to evaluate the aircraft accident probability presented by nearby airways. However, NUREG-0800 does provide criteria for assessment of aircraft accidents. For aircraft accidents, NUREG-0800, Section 3.5.1.6, states that "Aircraft accidents that could lead to radiological consequences in excess of the exposure guidelines of 10 CFR 100 with a probability of occurrence greater than an order of magnitude of 10^{-7} per year should be considered in the design of the plant." The calculated crash impact probabilities from airways for all five aircraft types is less than an order of magnitude of 10^{-7} per year. Therefore, no future analysis is required.

2.2.3 Analysis of Potential Accidents at Facilities

On the basis of the information provided in Sections 2.2.1 and 0, the potential accidents to be considered as design-basis events and the potential effects of those accidents on the facility, in terms of design parameters (e.g., overpressure, missile energies) or physical phenomena (e.g., impact, flammable or toxic clouds), were identified in accordance with:

- 10 CFR 20, "Standards for Protection Against Radiation"
- 10 CFR 50.34, "Contents of Applications; Technical Information"
- Regulatory Guide 1.78, *Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release* (NRC, 2001)
- Regulatory Guide 1.91, *Evaluations of Explosions Postulated to Occur at Nearby Facilities and on Transportation Routes Near Nuclear Power Plants* (NRC, 2013)
- Regulatory Guide 1.206, *Combined License Applications for Nuclear Power Plants* (NRC, 2007)
- Regulatory Guide 4.7, *General Site Suitability Criteria for Nuclear Power Stations* (NRC, 1998)
- NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors - Format and Content.*

- NUREG-0800, *Standard Review Plan*
- *Handbook of Chemical Hazard Analysis Procedures* (FEMA, 1989)
- NUREG-1520, *Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility*
- NUREG-1805, *Fire Dynamics Tools (FDT^s) – Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program*
- NUREG/CR-6624, *Recommendations for Revision of Regulatory Guide 1.78*

The events are discussed in the following subsections.

2.2.3.1 Determination of Design-Basis Events

NUREG-1520, *Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility*, defines an external event as being not credible "if the event has a frequency of occurrence that can conservatively be estimated as less than once in a million years (10^{-6})." Design-basis events external to the NWMI RPF are defined as those accidents that have a probability of radiological release to the public $1x10^{-6}$ year, or greater, with the potential consequences serious enough to affect the safety of the plant to the extent that the guidelines in 10 CFR 50.34 could be exceeded.

The following accident categories were considered in selecting design-basis events: explosions, flammable vapor clouds (delayed ignition), toxic chemicals, and fires. The postulated accidents that would result in a chemical release were analyzed at the following locations:

- Nearby transportation routes such as U.S. Highway 63 and nearby natural gas pipelines
- Nearby chemical and fuel storage facilities.

2.2.3.1.1 Explosions

The impacts associated with accidents that involve high explosives, munitions, chemicals, and liquid or gaseous fuels stored or used by facilities near the proposed RPF were evaluated to analyze the structural response to blast pressures. This analysis included the evaluation of explosions from nearby railways, highways, or facilities and the resulting blast pressure on critical plant structures to ensure that such an explosion would not adversely affect the RPF's operation or safe shutdown.

The Regulatory Guide 1.91 and its recommended 6.9 kilopascal (kPa) (1 pound per square inch [lb/in^2]) value of peak positive incident overpressure was used to provide guidance in defining the allowable (i.e., standoff) and actual distances of hazardous chemicals transported or stored. This value is considered. Analyses that result in pressure below 6.9 kilopascal (kPa) (1 lb/in^2) are not expected to result in significant damage. The guide defines this standoff distance by the correlation of R > kW1/3, where R is the distance in feet from an explosion comprised of W pounds of trinitrotoluene (TNT), and a constant value k. NUREG 1805, Fire Dynamics Tools (FDTs) – Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program was used to define the TNT mass equivalent (W). This guide compares the heat of combustion of the chemical is to the heat of combustion of TNT.

In some cases, the result using the NUREG 1805 methods returned standoff distances greater than the actual distance of the analyzed incident to the RPF. In those cases, a probabilistic analysis was used to show that the rate of exposure to the overpressure in excess of 6.9 kPa (1 lb/in^2) is less than 1×10^6 per year using conservative assumptions.

The conservative assumptions included an explosion yield factor, the estimation of the available combustion energy released during an explosion, of 100 percent. This accounts for an in-vessel confined explosion and is considered to be conservative because a 100 percent yield factor is not achievable. Another conservative assumption used was that for liquids at atmospheric conditions, the storage tank was assumed to contain vapors at the upper explosive limit. Because the upper explosive limit produces the maximum explosive mass and liquid vapor explodes, not the liquid, this is considered conservative. These assumptions are consistent with those used in Chapter 15 of NUREG 1805.

For compressed or liquefied gases (i.e., propane, hydrogen), the entire contents of the storage vessel were assumed to be between the upper and lower explosive limits. An instantaneous depressurization of the vessel would result in vapor concentrations all within the explosive range at varying pressures and temperatures some of which would be below explosive limits. Therefore assuming the entire contents is with the explosive limits is considered conservative.

For unconfined explosions of propane, methane, or hydrogen, the yield factor of 3 percent from the Handbook of Chemical Hazard Analysis Procedures (FEMA, 1989) was used.

Pipelines

A stationary pipeline explosion is bounded by the delayed ignition explosion of that pipeline due to the wind is assumed to blow the release towards the RPF with a constant mass release rate from the pipeline that results in a much larger total explosive mass. Thus, the distance from the point of the explosion to the NWMI RPF is therefore much smaller for flammable vapor clouds than for pipeline explosions at the release point.

Waterway Traffic

There are no navigable waterways within 8 km (5 mi) of the RPF.

Highways

Hazardous materials with explosive potential that may possibly be transported on U.S. Highway 63 is shown in Table 2-16 (EDF-3124-0016, *Analysis of Potential Accidents at Facilities*) include [Proprietary Information]. The remaining chemicals identified in Table 2-16 are nonexplosive. The maximum quantity of the identified chemicals assumed to be transported on the highway was 22,679 kg (50,000 lb) per Regulatory Guide 1.91 (NRC, 2013). The volume of hydrogen was assumed to be 1,496 kg (3,300 lb) on a single truck per 49 CFR 173.318, "Cryogenic Liquids in Cargo Tanks."

Table 2-16 provides the results of the analysis using the TNT equivalency methodologies described in within this section. For all chemicals analyzed, the minimum separation distances (i.e., safe standoff distances) are less than the shortest distance (0.4 km [0.25 mi]) to a safety-related RPF structure from any point on U.S. Highway 63. The peak incident pressure is 6.9 kPa (1 lb/in.^{2}) at a distance greater than the shortest distance from U.S. Highway 63 to a safety-related RPF structure of 0.4 km (0.25 mi).

Table 2-16. Distance from the Radioisotope Production Facility where the Peak Incident Pressure is 6.9 kPa (1 lb/in.^{2}) from an Explosion on U.S. Highway 63

Hazardous material	Quantity		Acceptable distance peak incident pressure is 6.9 kPa (1 lb/in.^{2})	
	kg	lb	km	mi
Ammonia	22,680	50,000	0.27	0.17
Diesel	22,680	50,000	0.1	0.06
Gasoline	22,680	50,000	0.1	0.06
Glycol ether PM	22,680	50,000	0.1	0.06
Hydrogen	1,497	3,300	0.21	0.13
JP-4 aviation fuel	22,680	50,000	0.1	0.06
Methyl ethyl ketone	22,680	50,000	0.1	0.06
Petroleum naphtha	22,680	50,000	0.1	0.06
Propane	22,680	50,000	0.34	0.21
Toluene (32-8413)	22,680	50,000	0.1	0.06

Source: EDF-3124-0016, 2014, *Analysis of Potential Accidents at Facilities*, Rev. 1, Portage, Inc., Idaho Falls, Idaho, November 3, 2014.

A boiling liquid expanding vapor explosion (BLEVE) is an explosion caused by the rupture of a vessel containing a pressurized liquid above its boiling point (Roberts, 2000). A BLEVE overpressure for the propane tank was analyzed in detail. The 22,680 kg (50,000 lb) propane tank, i.e., 45,425 liter (L) (12-thousand gallon [kgal]), was assumed to fail at 55 degrees Celsius (°C) (320 lb/in.^{2} absolute). The entire contents of the tank (e.g., gas and liquid) were assumed to be involved in the BLEVE. The acceptable distance to 6.9 kPa (1 lb/in.^{2}) overpressure is 0.21 km (0.13 mi). The shortest distance to a safety-related RPF structure from any point on U.S. Highway 63 is 0.4 km (0.25 mi).

A BLEVE overpressure for the hydrogen tank was also analyzed in detail. The 1,497 kg (3,300 lb) propane tank (i.e., 45,425 L [12 kgal]) was assumed to fail at -240°C (183 lb/in.^{2} absolute), the point before the hydrogen becomes supercritical. The entire contents of the tank (e.g., gas and liquid) were assumed to be involved in the BLEVE. The acceptable distance to 6.9 kPa (1 lb/in.^{2}) overpressure is 0.08 km (0.05 mi). The shortest distance to a safety-related RPF structure from any point on U.S. Highway 63 is 0.4 km (0.25 mi).

Based on the above, an explosion involving potentially transported hazardous materials on U.S. Highway 63, would not adversely affect operation of the RPF. The results of the highway explosion analyses are provided in Table 2-16 (EDF-3124-0016).

2.2.3.1.2 Nearby Facilities

Analysis identified six off-site facilities that have explosive chemicals that are identified as the bounding instances of explosion analysis. The hazardous materials stored at nearby facilities that were identified for further analysis with regard to explosive potential are identified in Table 2-17.

Table 2-17. Analysis of Hazardous Chemicals Stored Within 8 km (5 mi) of the Radioisotope Production Facility

Hazardous material	Company	Distance		Mass		Acceptable distance (1 lb/in.^{2})	
		km	mi	kg	lb	km	mi
[Proprietary Information]	3M Company	>8	>5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Schwan's Home Service Inc.	3.2	2	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Gates Power Transmissions Materials Center	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Gates Power Transmissions Materials Center	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	MU South Farm	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	MU South Farm	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	MU South Farm	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Ryder Transportation	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Magellan Pipeline Company	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Magellan Pipeline Company	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

Source: EDF-3124-0016, 2014, *Analysis of Potential Accidents at Facilities*, Rev. 1, Portage, Inc., Idaho Falls, Idaho, November 3, 2014.

[a] Actual tank mass provided by owner was used.

[b] [Proprietary Information].

[c] [Proprietary Information].

[d] [Proprietary Information].

MU = University of Missouri

A conservative analysis using TNT equivalency methods, as described in Section 2.2.3.1, was used to determine standoff distances for the storage of the identified hazardous materials. Table 2-17 provides the results of the analysis (EDF-3124-0016). The analysis showed that a [Proprietary Information]. The nearest tank of propane is approximately [Proprietary Information] from the RPF. However, the propane at this location is stored in multiple tanks, the largest of which is [Proprietary Information].

The results using this methodology indicate that the minimum separation distances (i.e., safe standoff distances) are less than the shortest distance from an RPF safety-related area to the storage location of the identified chemicals. Therefore, an explosion of any of these chemicals would not adversely affect operation of the RPF.

Railways

The only railroad within the 8 km (5 mi) radius of the RPF is the COLT Transload, which provides service for the Columbia Municipal Power Plant and a commercial lumber facility to the north of downtown Columbia. This rail line dead-ends approximately 7.2 km (4.5 mi) from the RPF. A review of the Tier II facilities did not identify any facilities with potentially hazardous chemicals near the rail line within 8 km (5 mi) radius of the RPF.

Explosion-Related Impacts Affecting Design

Regulatory Guide 1.91 cites 6.9 kPa (1 lb/in.^{2}) is considered a conservative value of peak positive incident overpressure, below which no significant damage would be expected. Thus, facility is acceptable when the calculated rate of occurrence of severe consequences from any external accident is less than 1×10^{-6} occurrences per year, and reasonable qualitative arguments can demonstrate that the realistic probability is lower. The RPF safety-related areas are designed to withstand a peak positive overpressure of at least 6.9 kPa (1 lb/in.^{2}) without loss of function/significant damage, as shown in Table 2-16 and Table 2-17. As a result, postulated explosion event scenarios will not result in severe consequences.

On-Site Diesel Fuel Tank

The RPF will have a 3,785 L (1-kgal) tank of diesel fuel within 9.1 m (30 ft) of the building. A tank containing 3,785 L (1 kgal) of diesel fuel is acceptable at a distance of 49.1 m (161 ft). Therefore, the on-site diesel explosion is analyzed using a probabilistic analysis. The total probability of a significant explosion is estimated using the probability of a spill and the conditional probability of an explosion given a spill.

The probability of a large release from a single-walled stationary tank at a fixed facility is 1×10^{-5} spills per year, and the probability of a spill from a double-walled stationary tank is 1×10^{-6} spills per year (FEMA, 1989). The rate of explosions per spill from diesel tanks is very low. A report on ignition probabilities for oil and gas (OGP, 2010) states that for releases of "combustible liquids stored at ambient pressure and at temperatures below their flash point from onshore outdoor storage area" tanks, the ignition probability is at most 0.24 percent. Combined with the single-walled tank spill probability, the frequency of an ignition is 2.4×10^{-8} ignitions per year, significantly less than the acceptance criteria.

2.2.3.1.3 Flammable Vapor Clouds (Delayed Ignition)

When a flammable chemical (e.g., liquid or gaseous state) is released into the atmosphere and forms a vapor cloud, the chemical disperses as it travels downwind. The portions of the vapor cloud where the concentration is within the flammable range, between the lower and upper flammability limits, may burn if the cloud encounters an ignition source. Deflagration or a detonation of the vapor cloud is determined by the pace of the flame through the vapor cloud. If the cloud burns fast enough to create a detonation, an explosive force is generated.

Chemicals were evaluated to ascertain which hazardous materials had the potential to form a flammable vapor cloud or vapor cloud explosion. The chemicals identified within flammability range, the Areal Locations of Hazardous Atmospheres (ALOHA) air dispersion computer model was used (ALOHA, 2008).

ALOHA was used to determine:

- The distances where the vapor cloud may exist between the upper explosion limit and the lower explosion limit (LEL), presenting the possibility of ignition and potential thermal radiation effects.
- Model the worst-case accidental vapor cloud explosion, including the standoff distances and overpressure effects at the nearest RPF safety-related area – worst-case scenario was assumed to be ignition by detonation was chosen for the ignition source with the standoff distance measured as the distance from the spill site to the location where the pressure wave is at 6.9 kPa (1 lb/in.^{2}) overpressure.

Conservative assumptions were used in both ALOHA analyses with regard to meteorological inputs and identified scenarios. The following meteorological assumptions were used as inputs to the ALOHA model:

- Pasquill Stability Class F (stable), with a wind speed of 1 meter per second (m/sec) (3.3 ft/sec)
- Ambient temperature of 27°C (81 degrees Fahrenheit [°F])
- Relative humidity 50 percent
- Cloud cover 50 percent
- Atmospheric pressure of 1 atmosphere.

Pasquill Stability Class F was selected based on local weather data. Class F represents the 5 percent worst-case weather conditions at the RPF site. For each of the identified liquid chemicals, the entire contents of the vessel were conservatively assumed to have leaked, forming a 1 centimeter (cm) (0.4-inch [in.]) thick puddle. For gaseous chemicals, the entire contents were released instantaneously as a gas. This provides a significant surface area to maximize evaporation and the formation of a vapor cloud in the case of liquid releases, and maximizes the peak concentration in the case of gas releases.

Pipelines

There are two natural gas transmission pipelines within 8 km (5 mi) of the proposed RPF. These pipelines include the Southern Star Central Gas Pipeline, Inc., located 1.6 km (1 mi), and the Ameren natural gas transmission pipeline located approximately 6.0 km (3.75 mi) from the RPF site.

Transmission pipelines are made of steel and generally operate at pressures ranging from 344 kPa (500 lb/in.^{2}) to 9,652 kPa (1,400 lb/in.^{2}) gauge. Pipelines can measure anywhere from 15.25 cm (6 in.) to 122 cm (48 in.) in diameter (ANL/EVS/TM/08-5, *Natural Gas Pipeline Technology Overview*).

The Southern Star natural gas pipeline is [Proprietary Information] in diameter. A conservative analysis was performed using the ALOHA model. The highest typical transmission pipeline pressure of 9,652 kPa (1400 lb/in.^{2}) was assumed. The pipeline was modeled as a complete break, with a constant source of natural gas available to the break. The distance to the LEL from the Southern Star natural gas pipeline is [Proprietary Information], which is less than the distance of [Proprietary Information] to the RPF. Because the concentration of natural gas is below the LEL at the RPF, a delayed flammable vapor cloud ignition cannot occur at the facility, and therefore, there will be no explosive overpressure (EDF-3124-0016).

The Ameren natural gas pipeline diameter is not known at this time. A conservative analysis was performed using the ALOHA model. The highest typical transmission pipeline pressure of 9,652 kPa (1,400 lb/in.^{2}) was assumed, along with the largest typical transmission pipeline diameter of 122 cm (48 in). The pipeline was modeled as a complete break, with a constant source of natural gas available to the break. The distance to the LEL from the Ameren natural gas pipeline is 3.5 km (2.2 mi), which is less than the distance of 6.0 km (3.75 mi) to the RPF site. Because the concentration of natural gas is below the LEL at the RPF, a delayed flammable vapor cloud ignition cannot occur at the facility, and therefore, there will be no explosive overpressure.

Waterway Traffic

There are no navigable waterways within 8 km (5 mi) of the RPF.

Highways

The hazardous materials potentially transported on U.S. Highway 63 that were identified for further analysis are diesel, gasoline, JP-4, petroleum naphtha, toluene, glycol ether PM, methyl ethyl ketone, hydrogen, propane, and ammonia. The remaining chemicals are nonexplosive. The closest RPF safety-related area is located approximately 0.40 km (0.25 mi) from U.S. Highway 63.

Consistent with Regulatory Guide 1.91, the tanker trucks are conservatively estimated, at most, to carry and release 22,680 kg (50,000 lb) of the identified chemical. The largest amount of hydrogen on a truck that was analyzed was 1,496 kg (3,300 lb). The analyzed effects of flammable vapor clouds and vapor cloud explosions from external sources are summarized in Table 2-18 (EDF-3124-0016).

The hydrogen releases from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis. Accident data were taken from NUREG/CR-6624, *Recommendations for Revision of Regulatory Guide 1.78*, and FEMA (1989). The accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill. When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release. The analysis showed that a 30 percent release of hydrogen resulted in a distance to the LEL of 0.79 km (0.49 mi). The accident analysis showed that a 10 percent release of hydrogen resulted in a distance to the LEL of 0.53 km (0.33 mi) (EDF-3124-0016).

Table 2-18. Flammable Vapor Cloud Explosion Analysis for U.S. Highway 63

Hazardous material	Quantity		Acceptable distance (LEL)		[a]Probability
	kg	lb	km	mi	
Ammonia	22,680	50,000	0.93	0.58	1.9×10^{-8}
Diesel	22,680	50,000	0.35	0.22	-
Gasoline	22,680	50,000	0.35	0.22	-
Glycol ether PM	22,680	50,000	0.06	0.04	-
Hydrogen	1,497	3,300	1.24	0.77	2.5×10^{-8}
JP-4 aviation fuel	22,680	50,000	0.35	0.22	-
Methyl ethyl ketone	22,680	50,000	0.19	0.12	-
Petroleum naphtha	22,680	50,000	0.35	0.22	-
Propane	22,680	50,000	1.37	0.85	2.7×10^{-8}
Toluene (32-8413)	22,680	50,000	0.13	0.08	-

Source: EDF-3124-0016, 2014, *Analysis of Potential Accidents at Facilities*, Rev. 1, Portage, Inc., Idaho Falls, Idaho, November 3, 2014.

[a] Probability only calculated for chemicals with acceptable distances greater than 0.4 km (0.25 mi).

LEL = lower explosion limit.

The probability of an explosion from a hydrogen truck accident is 1.6×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill × 0.2 ignition probability). The probability of this accident within 1.24 km (0.77 mi) of the RPF (i.e., 0.96 km [1.54 mi] total for U.S. Highway 63) would be 2.5×10^{-8} for a complete release scenario to meet the LEL.

The propane releases from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis. Accident data were taken from NUREG/CR-6624 and FEMA (1989). The accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill. When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release. The analysis showed that a 30 percent release of propane resulted in a distance to the LEL of 0.87 km (0.54 mi). The accident analysis showed that a 10 percent release of propane resulted in a distance to the LEL of 0.58 km (0.36 mi). The probability of an explosion from a propane truck accident is 1.6×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill × 0.2 ignition probability). The probability of this accident within 1.4 km (0.85 mi) of the RPF (e.g., 2.7 km [1.7 mi] total for U.S. Highway 63) would be 2.7×10^{-8} for a complete release scenario to meet the LEL.

The ammonia releases from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis. Accident data were taken from NUREG/CR-6624 and FEMA (1989). The accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill. When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release. The analysis showed that a 30 percent release of ammonia resulted in a distance to the LEL of 0.6 km (0.37 mi). The accident analysis showed that a 10 percent release of ammonia resulted in a distance to the LEL of 0.4 km (0.25 mi). The probability of an explosion from a propane truck accident is 1.6×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill × 0.2 ignition probability). The probability of this accident within 0.93 km (0.58 mi) of the RPF (e.g., 1.9 km [1.2 mi] total for U.S. Highway 63) would be 1.9×10^{-8} for a complete release scenario to meet the LEL.

Nearby Facilities

There are eight off-site facilities that have explosive chemicals identified as the bounding instances of explosion analysis. The hazardous materials stored at nearby facilities that were identified for further analysis with regard to explosive potential are identified in Table 2-19. The methodology presented previously in this section was used for determining the standoff distance for vapor cloud ignition and delayed vapor cloud explosion. A conservative analysis using TNT equivalency methods, as described earlier in this section, was used to determine standoff distances for the storage of the identified hazardous materials.

The distance to the LEL for the propane tank containing [Proprietary Information] of propane corresponds to more than [Proprietary Information]. The nearest tank of propane is approximately 3.2 km (2 mi) from the RPF. However, the propane at this location is stored in multiple tanks, the largest of which is [Proprietary Information]. The maximum content of a propane tank to meet the LEL at [Proprietary Information]. Flammable vapor clouds and vapor cloud explosions from external sources are summarized in Table 2-19 (EDF-3124-0016).

Table 2-19. Flammable Vapor Clouds and Vapor Cloud Explosions from External Sources (2 pages)

Hazardous material	Company	Distance		Mass		Acceptable distance (LEL)	
		km	mi	kg	lb	km	mi
[Proprietary Information]	Plasma Motor Fuels LLC	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	3M Company	>8	>5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Schwan's Home Service Inc.	3.2	2	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Gates Power Transmissions Materials Center	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Gates Power Transmissions Materials Center	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	MU South Farm	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	MU South Farm	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	MU South Farm	1.6	1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Ryder Transportation	2.4	1.5	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Magellan Pipeline Company	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
[Proprietary Information]	Magellan Pipeline Company	1.7	1.1	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

Source: EDF-3124-0016, 2014, *Analysis of Potential Accidents at Facilities*, Rev. 1, Portage, Inc., Idaho Falls, Idaho, November 3, 2014.

[a] Actual tank mass used.

[b] The maximum area of a spill in ALOHA is 31,400 square meters (m^2) – the inventory exceeds this value from a spill – therefore, 31,400 m^2 was used.

[c] [Proprietary Information].

[d] [Proprietary Information].

[e] [Proprietary Information].

ALOHA = Areal Locations of Hazardous Atmospheres.
LEL = lower explosion limit.
MU = University of Missouri.

Flammable Vapor Cloud (Delayed Ignition) Related Impacts Affecting the Design

Regulatory Guide 1.91 cites 6.9 kPa (1 lb/in.^{2}) is considered a conservative value of peak positive incident overpressure, below which no significant damage would be expected. Thus, facility is acceptable when the calculated rate of occurrence of severe consequences from any external accident is less than 1×10^{-6} occurrences per year, and reasonable qualitative arguments can demonstrate that the realistic probability is lower. The RPF safety-related areas are designed to withstand a peak positive overpressure of at least 6.9 kPa (1 lb/in.^{2}) without loss of function/significant damage, as shown in Table 2-16 and Table 2-17. As a result, postulated explosion event scenarios will not result in severe consequences.

2.2.3.1.4 Toxic Chemicals Impacts Affecting Design

Accidents involving the release of toxic chemicals from nearby mobile and stationary sources were considered. Toxic chemicals known to be present in the vicinity of the proposed RPF site or to be frequently transported in the vicinity were evaluated.

The potential hazardous materials transported on U.S. Highway 63 were evaluated to ascertain which hazardous materials should be analyzed with respect to their potential to form a toxic vapor cloud following an accidental release. The ALOHA air dispersion model was used to predict the concentrations of toxic chemical clouds as they disperse downwind for all facilities and sources.

The maximum distance a cloud can travel before it disperses enough to fall below the immediately dangerous to life and health (IDLH) concentration in the vapor cloud was determined using ALOHA. The ALOHA model was also used to predict the concentration of the chemical in the control room following a chemical release to ensure that, under worst-case scenarios, control room operators will have sufficient time to take appropriate action.

The IDLH is defined by the National Institute of Occupational Safety and Health as a situation that poses a threat of exposure that is likely to cause death or immediate or delayed permanent adverse health effects, or one that could prevent escape from such an environment. The IDLHs determined by the National Institute of Occupational Safety and Health are established such that workers are able to escape such environments without suffering permanent health damage.

Conservative meteorological assumptions were used: F (stable) stability class with a wind speed of 1 m/sec, ambient temperature of 25°C, relative humidity of 50 percent, cloud cover of 50 percent, and atmospheric pressure of one atmosphere. A Pasquill stability category "F" and a wind speed of 1 m/sec typically represent the worst 5 percent of meteorological conditions observed at a majority of nuclear plant sites. For each of the identified chemicals, the entire contents of the vessel are conservatively assumed to have leaked, forming a one-centimeter-thick puddle.

Review of the chemicals at nearby facilities did not contain any toxic materials that would be greater than those located on U.S. Highway 63; therefore, only toxic chemicals on U.S. Highway 63 were considered in the analysis. The toxic chemicals considered in the analysis were ammonia, chlorine, and sulfur dioxide.

- The distance to the IDHL for an ammonia release from a truck on U.S. Highway 63 is 9.7 km (6 mi). This is greater than the distance from U.S. Highway 63 to the RPF of 0.40 km (0.25 mi).
- The distance to the IDHL for a chlorine release from a truck on U.S. Highway 63 is 1.8 km (1.1 mi). This is greater than the distance from U.S. Highway 63 to the RPF of 0.40 km (0.25 mi).
- The distance to the IDHL for a sulfur dioxide release from a truck on U.S. Highway 63 is 3.1 km (1.9 mi). This is greater than the distance from U.S. Highway 63 to the RPF of 0.40 km (0.25 mi).

The ammonia releases from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis. Accident data were taken from NUREG/CR-6624 and FEMA (1989). The accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill. When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release. The accident analysis showed that a 30 percent release of ammonia resulted in a distance to the IDHL of 5.3 km (3.3 mi). The accident analysis showed that a 10 percent release of ammonia resulted in a distance to the IDHL of 3.1 km (1.9 mi). The probability of a spill from an ammonia truck accident is 8×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill). The probability of this accident within 9.7 km (6 mi) of the NWMI RPF (i.e., 19 km [12 mi] total for U.S. Highway 63) would be 9.6×10^{-7} for a complete release scenario to meet the IDLH (EDF-3124-0016).

The chlorine releases from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis. Accident data were taken from NUREG/CR-6624 and FEMA (1989). The accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill. When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release. The accident analysis showed that a 30 percent release of chlorine resulted in a distance to the IDHL of 1.2 km (0.73 mi). The accident analysis showed that a 10 percent release of chlorine resulted in a distance to the IDHL of 0.8 km (0.52 mi). The probability of a spill from a chlorine truck accident is 8×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill). The probability of this accident within 9.7 km (6 mi) of the RPF (i.e., 19 km [12 mi] total for U.S. Highway 63) would be 9.6×10^{-7} for a complete release scenario to meet the IDLH (EDF-3124-0016).

The sulfur dioxide releases from a truck on U.S. Highway 63 were analyzed using a probabilistic analysis. Accident data were taken from NUREG/CR-6624 and FEMA (1989). The accident frequency used was 2×10^{-6} accidents per truck mile, where 20 percent of accidents result in a spill. When a spill occurs, 20 percent of the spills are between 10 and 30 percent of the contents, and 20 percent of spills are complete release. The accident analysis showed that a 30 percent release of sulfur dioxide resulted in a distance to the IDHL of 1.8 km (1.1 mi). The accident analysis showed that a 10 percent release of sulfur dioxide resulted in a distance to the IDHL of 1.1 km (0.66 mi). The probability of a spill from a chlorine truck accident is 8×10^{-8} per truck mile (e.g., 2×10^{-6} accidents per truck mile × 0.2 spills/accident × 0.2 spills greater than 10 percent/spill). The probability of this accident within 9.7 km (6 mi) of the RPF (i.e., 19 km [12 mi] total for U.S. Highway 63) would be 9.6×10^{-7} for a complete release scenario to meet the IDLH.

2.2.3.1.5 Fires

Fires in adjacent industrial plants and storage facilities, oil and gas pipelines, and fires from transportation accidents were evaluated as events that could lead to high-heat fluxes. Three types of fires are analyzed for high-heat flux:

- BLEVE fireballs – Occurs when a tank containing a flammable liquefied gas bursts (e.g., similar to a BLEVE overpressure, the liquefied gas flashes which has a short duration)
- Pool fires – Occurs when a chemical that is liquid at standard conditions spills and catches fire
- Jet fires – Occurs when a pipeline ruptures or pressurized tank has a hole causing the continuous release of flammable gas

The limiting BLEVE fireball for the RPF is the rupture of a propane truck that contains 22,679 kg (50,000 lb) of liquefied propane and is 0.4 km (0.25 mi) from the RPF. ALOHA was used to calculate the heat flux and duration of the fireball. The results show that the heat flux on the RPF is 8.36 kilowatt (kW)/m^2 (2,650 British thermal units [BTU]/hr·square foot [ft^2]) and the duration of the fireball is 11 sec.

The American Concrete Institute has specified standards for short-term maximum bulk concrete temperatures of 177°C (350°F) following accidents (ACI 349-06, *Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-06) and Commentary*). NUREG/CR-3330, *Vulnerability of Nuclear Power Plant Structures to Large External Fires*, provides incident heat flux (kW/m^2) values and exposure times (hr) necessary for concrete to reach a temperature of 177°C (350°F). A heat flux of 15 kW/m^2 requires 11.6 hr of exposure for concrete to reach a temperature of 177°C (350°F), while a heat flux of 450 kW/m^2 requires 1.5 hr of exposure. Therefore, the heat flux from the propane BLEVE fireball will not impact the integrity of the RPF concrete structures (EDF-3124-0016).

The limiting pool fire would come from a gasoline truck on U.S. Highway 63. The truck contains 22,680 kg (50,000 lb) of gasoline and is 0.4 km (0.25 mi) from the RPF. The ALOHA model was used to calculate the heat flux for the pool fire. The results show that the maximum heat flux is 1.36 kW/m^2 (431.1 BTU/hr·ft^2) and the duration of the fireball is 60 sec. ACI 349-06 has specified standards for short-term maximum bulk concrete temperatures of 177°C (350°F) following accidents. Based on the NUREG/CR-3330 incident heat flux (kW/m^2) values and exposure times (hr) necessary for concrete to reach a temperature of 177°C (350°F) discussed above, the heat flux from the gasoline pool fire will not impact the integrity of the RPF concrete structures.

The Magellan pipeline was assumed to contain [Proprietary Information]. A conservative analysis was performed using the ALOHA model. The pipeline was assumed to be breached and spill the liquid contents in the soil, resulting in a liquid puddle that is [Proprietary Information]. The duration of the evaporating release was 1 hr. The total release of [Proprietary Information]. Based on the guidance used by the state of California (URS, 2007), which is a liquid flow rate of 2.13 m/sec (7 ft/sec) and the known pipeline diameter [Proprietary Information]. URS (2007) also provides guidance for the time of release, which is 15 min. The liquid flow rate, along with the 15-min release duration, would result in a total release of [Proprietary Information]. Therefore, a conservative release of [Proprietary Information]. was modeled in ALOHA based on the size of the release pool.

The distance to the LEL from the Magellan pipeline is 0.52 km (0.32 mi), which is less than the distance of 2.0 km (1.25 mi) to the proposed RPF site. Because the concentration of gasoline is below the LEL at the RPF, a delayed flammable vapor cloud ignition cannot occur at the facility and there will be no explosive overpressure.

There are two natural gas transmission pipelines within 8 km (5 mi) of the RPF. These pipelines include the Southern Star Central Gas Pipeline, Inc., located 1.6 km (1 mi) and the Ameren natural gas transmission pipeline located approximately 6.0 km (3.75 mi) from the RPF site. Transmission pipelines are made of steel and generally operate at pressures ranging from 344 kPa (500 lb/in.^{2}) to 9,652 kPa (1,400 lb/in.^{2}) gauge. Pipelines can measure anywhere from 15.25 cm (6 in.) to 122 cm (48 in.) in diameter (ANL/EVS/TM/08-5).

The Southern Star natural gas pipeline is [Proprietary Information]. A conservative jet fire analysis was performed using the ALOHA model. The highest typical transmission pipeline pressure of 9,652 kPa (1,400 lb/in.^{2}) was assumed. The pipeline was modeled as a complete break, with a constant source of natural gas available to the break. The modeling results show that the [Proprietary Information] at the RPF. This heat flux is negligible compared with the solar heat flux of approximately 1 kW/m^2 (0.088 BTU/ft^2). Therefore, the Southern Star pipeline jet fire is not considered a threat to the RPF.

The Ameren natural gas pipeline diameter is not known at this time. A conservative jet fire analysis was performed using the ALOHA model. The highest typical transmission pipeline pressure of 9,652 kPa (1400 lb/in.^{2}) was assumed along with the largest typical transmission pipeline diameter of 122 cm (48 in.). The pipeline was modeled as a complete break, with a constant source of natural gas available to the break. The modeling results show that the maximum heat flux is 0.076 kW/m^2 (0.0067 BTU/ft^2) at the RPF. This heat flux is negligible compared with the solar heat flux of approximately 1 kW/m^2 (0.088 BTU/ft^2). Therefore, the Ameren pipeline jet fire is not considered a threat to the RPF.

2.3 METEOROLOGY

2.3.1 General and Local Climate

The purpose of this climate analysis is to provide the information that supports the dispersion analysis of airborne releases from the proposed RPF site. Local dispersion climatology includes consideration of airflow and atmospheric turbulence. The following subsections address local topography, the source of local meteorological data, wind roses, and atmospheric stability distribution.

The proposed RPF site is located in central Missouri. The purpose of conducting a climate analysis is to understand the climate (a statistical description of weather) at the local project site within the context of the climate of the broader surrounding area.

Geomorphic, or physiographic, regions are broad-scale subdivisions of the nation that are based on terrain texture, rock type, geologic structure, and history. There are eight regions, subdivided into 25 provinces, and further subdivided to 85 sections within the U.S. (Fenneman, 1946). The characteristics and locations of these landforms influence local and regional climate and weather patterns.

The RPF site lies at the southern edge of the Central Lowlands physiographic province, within a few miles of the adjacent Ozark Plateau province, both of which lie within the larger Interior Plains physiographic region. The Central Lowlands includes most of the Corn Belt and lies within the heartland of America.

The RPF location places it in the Humid Continental-Warm Summer climatic zone. This type of climate has a characteristic long, warm summer with moderate relative humidity. The winters are cool to cold and mark a period of lower precipitation than during the remainder of the year. Because of its geographical location far inland, the region is subject to significant seasonal and daily temperature variations. Air masses moving over the state during the year include cold continental polar air from Canada, warm and humid maritime tropical air from the Gulf of Mexico and the Caribbean Sea, and dry eastward flowing air masses from the Rocky Mountains located to the west. Prolonged periods of extreme hot or cold temperatures are unusual (MU, 2006).

The general geostrophic airflow pattern and the prevailing jet stream track shuttle precipitation-producing mid-latitude cyclones (lows) across the state from west-to-east throughout the year. Consequently, precipitation events in all seasons move through from a westerly direction (MU, 2006).

Spring, summer, and early fall precipitation occurs in the form of rain and thunderstorms. Severe thunderstorms typically occur during the period from mid- to late-spring through early summer. Hail may be expected as a product of these storms. Wind speeds of up to 97 km/hr (60 mi/hr) or more may be experienced once or twice a year during a severe thunderstorm (MU, 2006).

Winter precipitation is generally light to moderate and occurs in the form of rain or snow, or a mixture of both, with an occasional, though infrequent, thunderstorm. Occasional heavy snowfall episodes do occur, but not often, and the accumulation does not last for any significant duration. Surface temperature conditions sometimes produce freezing rain or drizzle, although normally not more than a couple times each season.

The historical climate data within this section primarily came from National Oceanic and Atmospheric Administration (NOAA) High Plains Regional Climate Center's historical climate data summaries for Columbia reporting stations 231790 and 231791. MU also has a weather station at South Farm, less than 1.6 km (1 mi) away from the proposed site and approximately 6.4 km (4 mi) from Columbia. The weather station is used in conjunction with the school's agricultural program, and the weather data is available on the MU website. Simple searches and averages can be obtained through this database. Other sources, as needed, were used to augment NOAA data, particularly to better understand the immediate area around the proposed RPF site.

2.3.1.1 Temperature

Though temperatures reached a record high in 2012 of 41.7°C (107°F), in general, temperatures rarely exceed 38°C (100°F) in the summer and rarely fall below -18°C (0°F) in the winter. The mean maximum temperatures in Columbia, collected from the reporting station at the Columbia Regional Airport (Station 231791) over a 43-year period ranged from 2.8°C (37.2°F) in January to 31.4°C (88.5°F) in July. Daily temperatures during that period showed a wider variance, from -28.8°C (-20°F) in December to 44°C (111°F) in July. A summary of average and extreme temperature data for 1969 through 2012 is provided in Table 2-20 (WRCC, 2013a).

Table 2-20. Columbia, Missouri, Average and Extreme Monthly Climate, Historic Temperature Summary, 1969–2012

Measurement		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average max. temperature	°C	2.9	6.1	12.7	18.9	23.6	28.5	31.4	30.7	26.0	19.6	12.0	5.1	18.1
	°F	37.2	43.0	54.9	66.1	74.4	83.3	88.5	87.3	78.8	67.2	53.6	41.2	64.6
Average min. temperature	°C	-6.8	-4.3	1.2	6.8	12.1	17.0	19.6	18.4	13.7	7.4	1.5	-4.3	6.8
	°F	19.7	24.2	34.2	44.3	53.7	62.6	67.2	65.2	56.7	45.3	34.7	24.2	44.3
Daily extreme high	°C	23.3	27.8	29.4	32.2	33.3	[a]89	43.9	43.3	38.3	34.4	28.3	24.4	43.9
	°F	74.0	82.0	85.0	90.0	92.0	[a]107	111.0	110.0	101.0	94.0	83.0	76.0	111.0
Daily extreme low	°C	-28.3	-26.1	-20.6	-7.2	-1.7	4.4	8.9	5.6	0.0	-5.6	-17.8	-28.9	-28.9
	°F	-19.0	-15.0	-5.0	19.0	29.0	40.0	48.0	42.0	32.0	22.0	0.0	-20.0	-20.0
Average mean	°C	-1.9	0.9	6.9	12.9	17.8	22.8	25.4	24.6	19.9	13.5	6.7	0.4	12.5
	°F	28.5	33.6	44.5	55.2	64.1	73.0	77.8	76.3	67.8	56.3	44.1	32.7	54.5

Source: WRCC, 2013a, "Period of Record General Climate Summary – Temperature, 1969 to 2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?mo1791, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

[a] Occurred during 2008–2012 time period.

Average temperature data for the Columbia Missouri weather station was reviewed for the most recent five years that data were available (2008 to 2012). The lowest average temperature was -4.1°C (24.65°F), recorded in January 2010, and the highest average temperature was 29.5°C (85.06°F), recorded in July 2012. The five-year annual average temperature was 13.1°C (55.58°F). A five-year temperature summary is presented in Table 2-21 (WRCC, 2013b).

Table 2-21. Columbia, Missouri, Five-Year Temperature Summary, 2008–2012

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2008	°C	-0.6	-0.9	6.1	11.6	17.1	23.3	24.7	22.8	19.0	16.0	2.4	-1.1	12.2
	°F	31.0	30.3	42.9	52.9	62.8	73.9	76.4	73.0	66.3	60.9	36.3	30.1	54.0
2009	°C	-3.1	2.4	8.1	11.7	17.9	23.3	22.5	21.9	18.6	10.2	9.8	-1.1	11.8
	°F	26.5	36.3	46.5	53.1	64.2	73.9	72.5	71.4	65.5	50.3	49.6	30.0	53.3
2010	°C	-4.1	-2.7	7.4	16.1	18.0	24.6	25.6	25.5	19.8	14.8	7.6	-1.6	12.6
	°F	24.7	27.1	45.3	60.9	64.4	76.2	78.0	77.9	67.6	58.6	45.7	29.1	54.6
2011	°C	-3.9	-0.1	6.6	14.0	16.9	24.0	27.5	24.9	17.6	14.2	8.9	3.1	12.8
	°F	24.9	31.9	43.9	57.2	62.5	75.1	81.6	76.7	63.7	57.5	48.1	37.5	55.0
2012	°C	1.7	4.3	14.9	15.0	21.6	25.0	29.5	25.8	19.6	12.0	7.7	7.5	16.1
	°F	35.0	39.7	58.8	59.0	70.9	77.1	85.1	78.5	67.3	53.6	45.8	45.5	61.0
Mean	°C	-2.0	0.6	8.6	13.7	18.3	24.0	25.9	24.2	18.9	12.8	8.5	-0.2	13.1
	°F	28.4	33.1	47.5	56.6	64.9	75.3	78.7	75.5	66.1	55.0	47.3	31.7	55.6

Source: WRCC, 2013b, "Station Monthly Time Series, Columbia, Missouri, 2008-2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/wea_mnsimts.pl?laKCOU, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

The five-year average temperature, for the same time period, reported at the MU South Farm weather station was 12.3°C (54.2°F). The average minimum temperature was 6.9°C (44.5°F) and the average maximum temperature was 17.9°C (64.3°F) (MU, 2013).

2.3.1.2 Precipitation

According to the historical data from Station 231791, precipitation in the Columbia, Missouri area averages approximately 103.1 cm (40.6 in.) per year. Of that amount, the mean snowfall is 57.7 cm (22.7 in.) per year. The city has measurable amounts of precipitation 111 days/year. The maximum annual precipitation of 159 cm (62.49 in.) was measured in 1993, and the minimum annual precipitation of 60 cm (23.66 in.) was measured in 1980. On a monthly basis, rainfall amounts range from a high of 12.4 cm (4.89 in.) in May to a low of 4.62 cm (1.82 in.) in January (WRCC, 2013a).

According to the historical data from Station 231791, snow falls from November through April. During that period, a high of 16 cm (6.3 in.) was recorded in February 2011, and a low of 1.5 cm (0.6 in.) was recorded in 1980. A summary of average and extreme precipitation data for 1969 through 2012 is provided in Table 2-22 (WRCC, 2013a).

A recent five-year precipitation summary of the station data was obtained and reviewed. For each month during this time period, approximately 15 to 30 percent of the data was missing. Precipitation data from the MU South Farm weather station was also reviewed; however, the averages shown on the site were different than the Columbia weather station by a factor of five. Thus, the Columbia, Missouri weather station historical summary serves as the more complete picture of precipitation at the proposed RPF site.

Table 2-22. Columbia, Missouri, Average and Extreme Monthly Climate, Historic Precipitation Summary, 1969–2012

Measurement		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average total precipitation	cm	4.62	5.44	8.10	11.23	12.42	10.24	9.58	10.06	9.53	8.28	7.72	6.02	103.12
	in	1.82	2.14	3.19	4.42	4.89	4.03	3.77	3.96	3.75	3.26	3.04	2.37	40.60
High	cm	15.09	15.70	25.63	29.69	31.27	26.11	30.84	25.88	30.63	[a]27.9	26.47	17.68	158.72
	in	5.94	6.18	10.09	11.69	12.31	10.28	12.14	10.19	12.06	[a]10.99	10.42	6.96	62.49
Low	cm	0.13	0.28	1.98	2.26	[a]3.33	0.89	0.61	0.53	1.14	[a]0.91	1.07	1.22	60.10
	in	0.05	0.11	0.78	0.89	[a]1.31	0.35	0.24	0.21	0.45	[a]0.36	0.42	0.48	23.66
1-day max	cm	4.47	6.10	9.98	11.43	12.14	8.15	15.09	10.85	7.11	12.40	7.04	6.88	15.09
	in	1.76	2.40	3.93	4.50	4.78	3.21	5.94	4.27	2.80	4.88	2.77	2.71	5.94
Average total snowfall	cm	15.75	[a]16.00	7.37	1.52	0.00	0.00	0.00	0.00	0.00	0.00	4.57	12.70	57.66
	in	6.20	[a]6.3	2.90	0.60	0.00	0.00	0.00	0.00	0.00	0.00	1.80	5.00	22.70
High snowfall	cm	59.69	59.18	54.86	18.03	0.00	0.00	0.00	0.00	0.00	0.25	21.08	45.21	134.11
	in	23.50	23.30	21.60	7.10	0.00	0.00	0.00	0.00	0.00	0.10	8.30	17.80	52.80

Source: WRCC, 2013a, "Period of Record General Climate Summary – Temperature, 1969 to 2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?mo1791, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

[a] Occurred during 2008–2012 time period.

Hydrometeorological Report No 51, *Probable Maximum Precipitation Estimates, United States East of the 105th Meridian* (NOAA, 1978) provides probable maximum precipitation data for the U.S. east of the Rocky Mountains. Probable maximum precipitation values for a specific location are provided in Table 2-23 over ranges of time (6 to 72 hr) or ranges of geographic area (10 mi^2 to 20,000 mi^2).

Table 2-23. 72-Hour Probable Maximum Precipitation

Area	Precipitation (in.)				
	6-hr	12-hr	24-hr	48-hr	72-hr
10 mi^2	28	33	37	38.5	40
200 mi^2	20	24.5	26	29.5	33
1,000 mi^2	15	18.5	20.5	24	25.5
5,000 mi^2	9	12	14	17	19
10,000 mi^2	7	9.5	11.5	15	16.5
20,000 mi^2	5.1	7.5	9.5	12.5	14

2.3.1.3 Maximum Probable Snowpack

NUREG-1537, Part 1, Section 2.3.1, states that the snow load should be based on the 100-year return period snow accumulation. For MU facilities, the 2012 International Building Code (IBC) (IBC, 2012) has been levied as the required building code. The ground snow load is 20 lb/ft^2. To modify the snow load to be based on a 100-year return period, an importance factor of 1.2 is applied to the load determined using the nominal snow load (ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures*, Section C7.3.3). The nominal ice thickness is 2.54 cm (1 in.) concurrent with a 64.4 km/hr (40-mi/hr), 3-sec wind gust. To modify the ice load to be based on a 100-year return period, an importance factor of 1.25 is applied to the load determined using the nominal ice load (ASCE 7-10, Section C10.4.4).

2.3.1.4 Humidity

Average relative humidity data for the Columbia, Missouri weather station was reviewed for 2008 to 2012. The lowest average relative humidity was 51.89 percent, recorded in August 2012, and the highest average relative humidity was 82.13 percent, recorded in September 2008. The five-year annual average was 69.18 percent. The five-year relative humidity data is summarized in Table 2-24 (WRCC, 2013b).

Table 2-24. Relative Humidity Data for Columbia, Missouri, 2008–2012

Year	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Oct (%)	Nov (%)	Dec (%)	Annual (%)
2008	60.51	72.02	66.68	64.85	69.49	71.40	74.38	78.87	82.13	77.52	65.87	71.48	71.18
2009	64.95	63.73	63.28	66.52	68.42	73.66	74.46	76.90	75.92	76.62	68.08	72.33	70.41
2010	75.69	73.42	70.33	61.24	74.71	76.64	79.19	75.19	76.17	58.65	64.86	72.85	71.58
2011	71.86	71.51	71.26	64.73	74.61	72.69	76.29	75.19	70.82	59.46	71.92	74.84	71.27
2012	64.05	63.72	63.58	65.03	61.33	54.89	52.96	51.89	69.64	66.76	62.25	70.91	61.46
Mean	67.41	68.88	67.03	64.47	69.71	69.86	71.46	71.61	74.94	65.37	66.78	72.88	69.18

Source: WRCC, 2013b, "Station Monthly Time Series, Columbia, Missouri, 2008-2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/wea_mnsimts.pl?laKCOU, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

2.3.1.5 Wind

Extreme wind speeds are uncommon in central Missouri. Wind that does occur is usually caused by pressure gradients and temperature contrasts present in the mid-latitude cyclones that pass through the state. These cyclones may spawn storms that produce high winds from gust fronts, microbursts, and tornadoes. Non-storm-related extreme winds are rare. Occasionally, cold high-pressure air filling in behind a front will cause high wind, especially in the winter when temperature contrasts are large.

Average wind speed data for the Columbia, Missouri weather station was reviewed for 2008 to 2012. The lowest mean wind speed was 8.8 km/hr (5.47 mi/hr) in August 2008 and the highest was 19.1 km/hr (11.87 mi/hr) recorded in December 2008. The five-year annual average was 14.25 km/hr (8.86 mi/hr). The five-year mean wind speed data is summarized in Table 2-25.

Table 2-25. Mean Wind Speed for Columbia, Missouri, from 2008–2012

Year	Rate	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2008	(km/hr)	18.85	17.03	16.96	17.53	15.76	13.97	11.28	8.80	10.01	11.59	14.32	19.10	14.93
	(mi/hr)	11.71	10.58	10.54	10.89	9.79	8.68	7.01	5.47	6.22	7.20	8.90	11.87	9.28
2009	(km/hr)	15.24	17.96	18.31	17.99	12.38	12.47	10.32	11.91	10.40	14.58	14.71	17.03	14.44
	(mi/hr)	9.47	11.16	11.38	11.18	7.69	7.75	6.41	7.40	6.46	9.06	9.14	10.58	8.97
2010	(km/hr)	13.74	13.73	15.96	17.06	12.79	11.43	10.06	9.88	12.17	16.30	14.73	13.41	13.10
	(mi/hr)	8.54	8.53	9.92	10.60	7.95	7.10	6.25	6.14	7.56	10.13	9.15	8.33	8.14
2011	(km/hr)	13.63	16.87	17.08	18.49	15.14	14.45	10.09	10.38	11.89	13.66	18.88	14.15	14.56
	(mi/hr)	8.47	10.48	10.61	11.49	9.41	8.98	6.27	6.45	7.39	8.49	11.73	8.79	9.05
2012	(km/hr)	16.98	15.64	16.53	15.19	13.42	13.68	10.56	11.35	11.57	13.79	14.97	14.18	13.97
	(mi/hr)	10.55	9.72	10.27	9.44	8.34	8.50	6.56	7.05	7.19	8.57	9.30	8.81	8.68
Mean	(km/hr)	15.69	16.24	16.96	17.25	13.90	13.20	10.46	10.46	11.20	14.08	15.92	16.25	14.26
	(mi/hr)	9.75	10.09	10.54	10.72	8.64	8.20	6.50	6.50	6.96	8.75	9.89	10.10	8.86

Source: WRCC, 2013b, "Station Monthly Time Series, Columbia, Missouri, 2008-2012, Station 231791 Columbia WSO AP," www.wrcc.dri.edu/cgi-bin/wea_mnsimts.pl?laKCOU, Western Regional Climate Center, Reno, Nevada, accessed August 2013.

Wind data from the MU South Farm weather station was also reviewed. The average shown on the site was different than the Columbia weather station by a factor of two. Thus, the Columbia weather station data serves as the more complete picture of wind activity at the proposed RPF site.

Two wind roses are presented to show the general historic wind flow patterns in the immediate area and the study area. Figure 2-31 shows the wind pattern as measured at MU South Farm, located immediately north of the proposed RPF site. This data is collected by MU. Figure 2-32 shows the wind patterns recorded at the Remote Automatic Weather Station (RAWS) in Columbia.

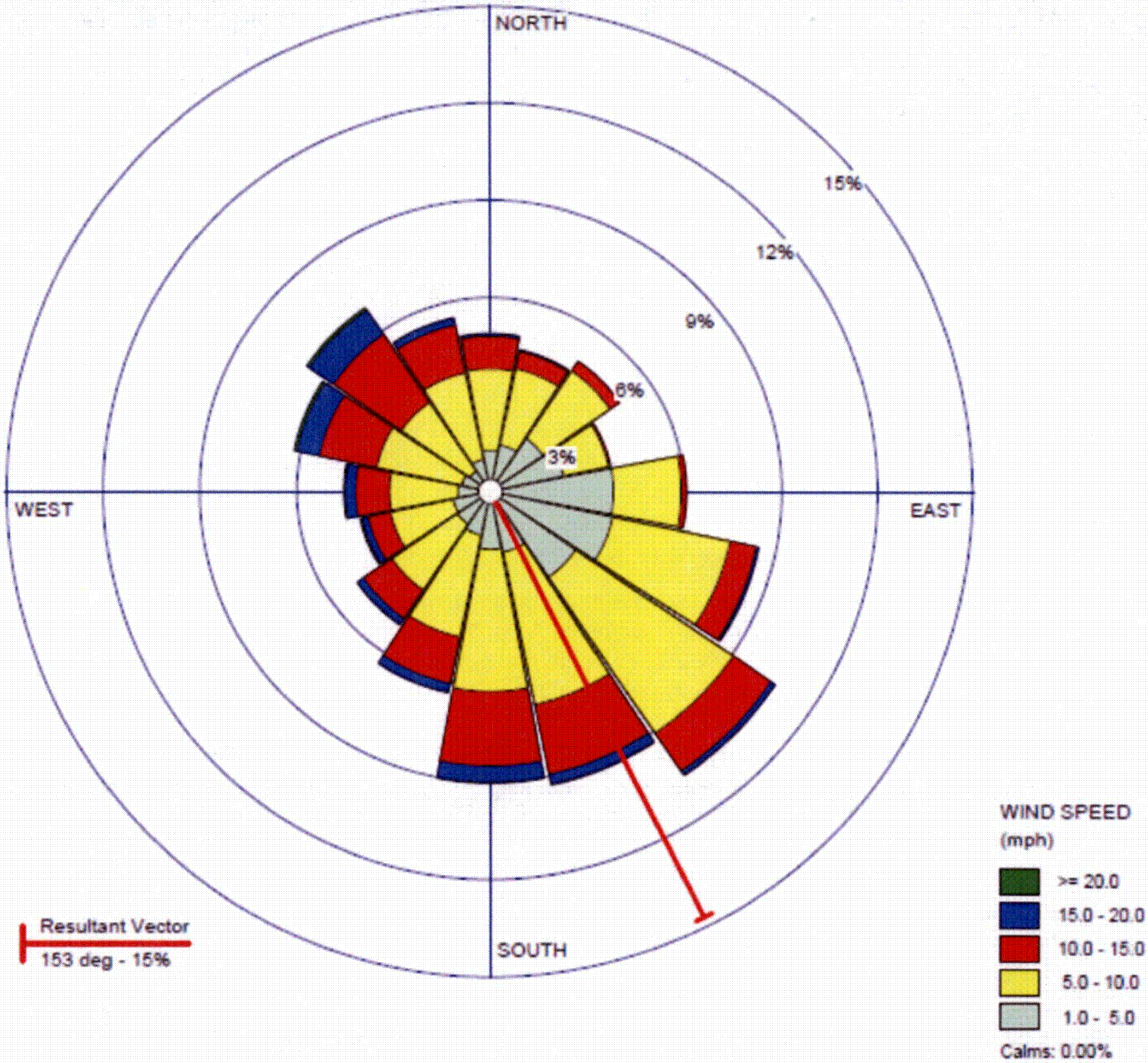


Figure 2-31. Wind Rose from South Farm, 2000–2010 (University of Missouri Agricultural Experiment Station)

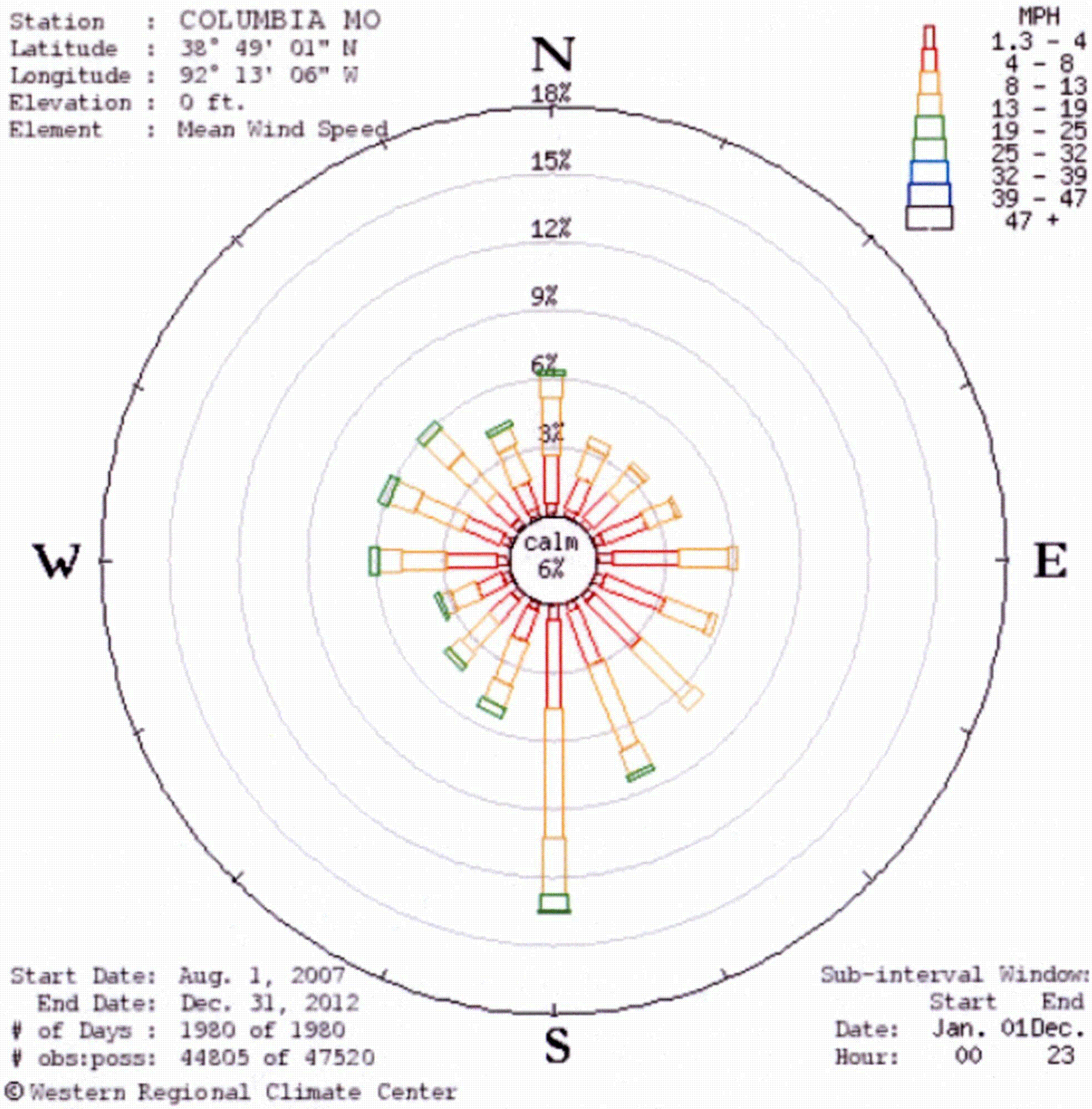


Figure 2-32. Wind Rose from Automatic Weather Station, Columbia, Missouri, 2007-2012 (Western Regional Climate Center)

Both wind roses show that the prevailing surface wind direction is from the south. The MU South Farm wind rose shows a total average wind speed of 11.3 km/hr (7 mi/hr), while the Columbia wind rose shows a total average speed of 14.16 km/hr (8.8 mi/hr). Both wind roses show that the average frequency of higher speed winds falls into the 24 to 40 km/hr (15 to 25-mi/hr) range.

2.3.1.6 100-Year Return Wind Speed

NUREG-1537, Part 1, Section 2.3.1, states that the wind load should be based on the 100-year return period wind speed. For MU facilities, IBC (2012) has been levied as the required building code. The basic wind speed for Category III and IV facilities is 193.1 km/hr (120 mi/hr). An evaluation of the effective return period for the basic wind speeds for Category III and IV facilities determined that the effective return period is 1,700 years (3 percent in 50 years, or 5.7 percent in 100 years) (ASCE 7-10, Section C26.5.1). Note that an event with a 100-year return period has a 63 percent chance of occurring at least once in a 100-year period.

2.3.1.7 Extreme Weather

The heartland of the country has the distinction of also being known as "tornado alley," a non-meteorological term that references the area where 90 percent of tornadoes have occurred as a result of the mixing of cold, dry air from Canada and the Rocky Mountains, with warm, moist air from the Gulf of Mexico and hot, dry air from the Sonoran Desert. This area exhibits a lot of atmospheric instability, heavy precipitation, and many intense thunderstorms.

Tornados are extreme wind speed events that are classified according to the Enhanced Fujita Tornado Intensity Scale (EF scale). The scale matches wind speeds to the severity of damaged caused by a tornado. The process involves determining the degree of damage according to a predefined damage scale of 28 indicators. The observed damage is associated with estimated wind speeds during the storm, and an EF scale number is assigned. Measuring tornadoes from EF-1 to EF-5, the scale uses more specific structural damage guidelines than the original Fujita scale (F scale), which was established in 1971. Table 2-26 shows the F and EF scales.

Table 2-26. Fujita Scale and Enhanced Fujita Scales Used to Determine Tornado Intensity

F number	F scale				EF number	EF scale	
	Fastest 1/4-mi		3-sec gust			3-sec gust	
	(km/hr)	(mi/hr)	(km/hr)	(mi/hr)		(km/hr)	(mi/hr)
0	64 -116	40–72	72-126	45–78	0	105-137	65-85
1	117 – 180	73–112	127-188	79–117	1	138-177	86–110
2	182- 253	113–157	189-259	118–161	2	178-217	111–135
3	254- 333	158–207	260-336	162–209	3	218-265	136–165
4	334- 418	208–260	337-420	210–261	4	266-322	166–200
5	419 – 512	261–318	421-510	262–317	5	Over 322	Over 200

EF scale = enhanced Fujita tornado intensity scale.
F scale = Fujita tornado intensity scale.

2.3.2 Site Meteorology

Conservative assumptions were used, in both the Radiological Safety Analysis Computer (RSAC) code to support 10 CFR 100.11, "Determination of Exclusion Area, Low Population Zone, and Population Center Distance," analyses and the ALOHA air dispersion model to support the preliminary safety analysis report with regard to meteorological inputs and identified scenarios.

The RSAC code, Version 6.2, was used to determine if the dose rate requirements in 10 CFR 100.11 would drive the required size of the exclusion area boundary for the NWMI RPF. 10 CFR 100.11 requires that an exclusion area be sized so that an individual located at any point on its boundary for 2 hr immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 roentgen equivalent in man (rem).

In the preliminary safety analysis report, design-basis events and the potential effects of those accidents on the facility, in terms of design parameters (e.g., overpressure, missile energies) or physical phenomena (e.g., impact, flammable or toxic clouds) were identified in accordance with 10 CFR 20, 10 CFR 50.34, Regulatory Guide 1.78, Regulatory Guide 1.91, Regulatory Guide 1.206, Regulatory Guide 4.7, and NUREG-1537.

Design-basis events, external to the proposed RPF, are defined as those accidents that have a probability of radiological release to the public on the order of magnitude of 1E-07 per year, or greater, with the potential consequences serious enough to affect the safety of the plant to the extent that the guidelines in 10 CFR 50.34 could be exceeded.

Chemicals were evaluated to ascertain which hazardous materials had the potential to form a flammable vapor cloud or vapor cloud explosion. For those chemicals with an identified flammability range, the ALOHA air dispersion model was used to determine the distances where the vapor cloud may exist between the upper explosion limit and the LEL, presenting the possibility of ignition and potential thermal radiation effects (ALOHA, 2008).

Conservative meteorological assumptions were used in both the RSAC and ALOHA analyses. Conservative Pasquill stability classes, including F and G, along with a wind speeds of 1 to 2 m/sec were assumed for the analyses. Site-specific meteorological measurements were not necessary to complete these bounding analyses.

Table 2-27 provides a tabulation of the distance from the exhaust stacks where airborne releases might be expected to points on the fence and site boundaries in each of the 16 compass directions to support dispersion analyses of airborne releases.

Table 2-27. Distances From Exhaust Stacks to Fence and Site Boundaries

Compass direction	Fence line		Site boundary	
	m	ft	m	ft
North	29	94	76	250
North Northeast	70	231	76	250
Northeast	82	269	86	281
East Northeast	103	338	110	363
East	76	250	84	275
East Southeast	65	213	69	225
Southeast	65	213	69	225
South Southeast	72	238	76	250
South	110	363	118	388
South Southwest	95	313	156	513
Southwest	80	263	149	488
West Southwest	42	138	112	369
West	23	75	65	213
West Northwest	19	63	57	188
Northwest	19	63	57	188
North Northwest	19	63	76	250

Regional Data Sources

Meteorological measurements would be available for use in responding to accidental radiological releases, other emergencies, and any other routine purposes that require access to meteorological information during the licensing period. That meteorological information would be obtained for local government weather monitoring stations that observe wind and other surface meteorological parameters on an hourly basis.

When needed during an emergency, real-time hourly surface meteorological measurements of wind direction, wind speed, air temperature, and weather type would be accessed by NWMI through Government data sources. Access would be attempted during the emergency in the following sequence, until reliable data is obtained, as follows:

1. Internet access to hourly surface weather observations recorded at Station 231791, Columbia Regional Airport (w1.weather.gov/data/obhistory/KCOU.html).
2. Telephone access to an automated voice recording at (573) 499-1400 of the most recent hourly surface observations recorded at the Columbia Regional Airport.
3. If weather observations are not available from the station at the Columbia Regional Airport, weather information from another station with hourly meteorological data in the site climate region would be used. The following Missouri stations would be used as listed in order of increasing distance from Columbia:
   a. Jefferson City Memorial Airport: w1.weather.gov/data/obhistory/KJEF.html
   b. Kansas City International Airport: w1.weather.gov/data/obhistory/KMCI.html
   c. Sedalia Memorial Airport: w1.weather.gov/data/obhistory/KDMO.html
   d. Spirit of St. Louis Airport: w1.weather.gov/data/obhistory/KSUS.html

During normal operations, data would be obtained by internet access to hourly surface weather observations recorded at the Columbia Regional Airport at w1.weather.gov/data/obhistory/KCOU.html.

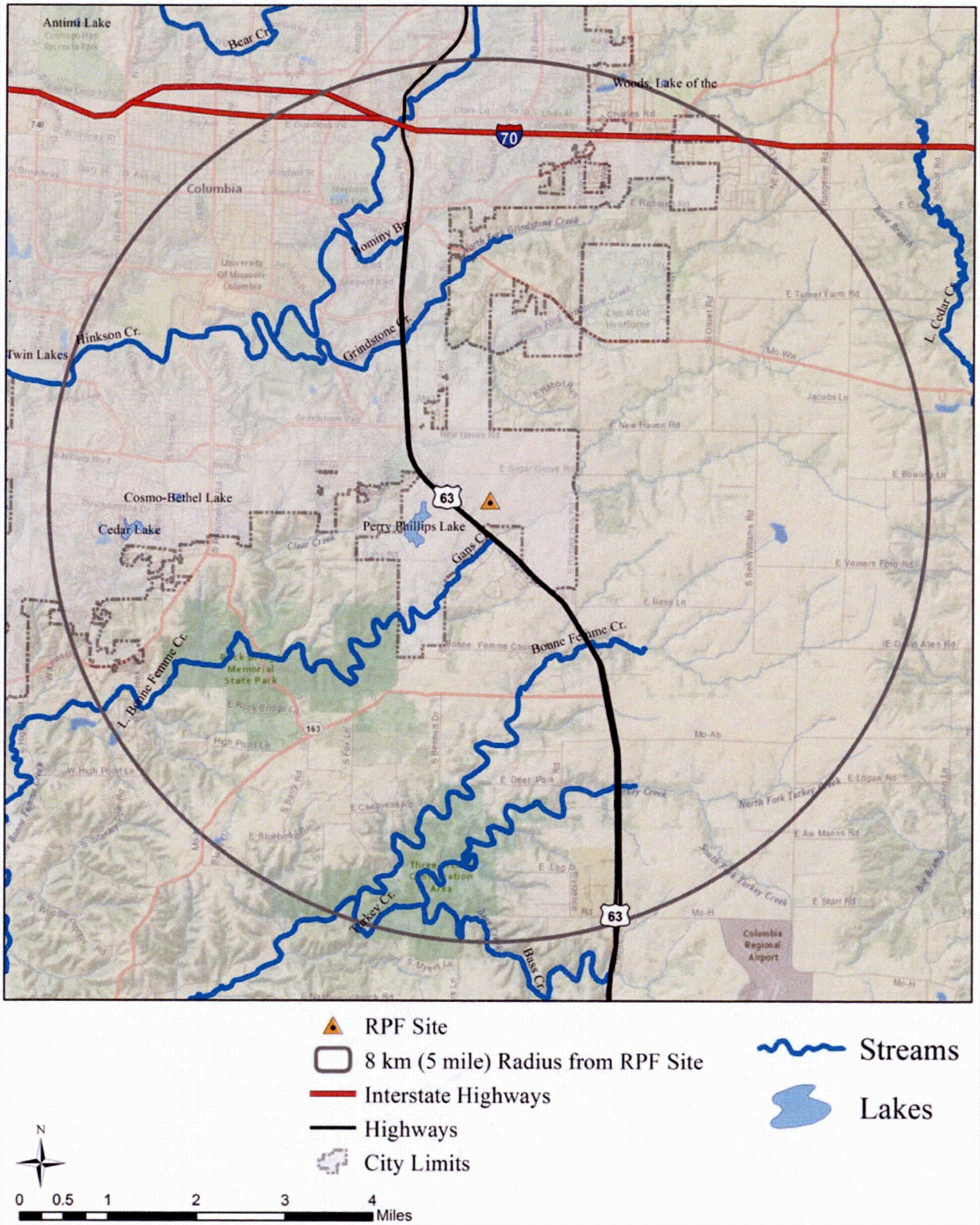
2.4 HYDROLOGY

2.4.1 Surface Water

Surface waters in central and southern Boone County drain into the Missouri River through a number of tributaries, including Bonne Femme, Cedar, Little Cedar, Hinkson, Jemerson, and Perche Creeks (Figure 2-33). The other major drainage feature in the county is a system of karst topography west and south of Columbia. Numerous sinkholes, some filled with water, overlie a complex network of caves and springs. Gans Creek, which drains Discovery Ridge and the proposed RPF site, is located within the Bonne Femme Watershed.

Bonne Femme Watershed

The Bonne Femme Watershed is comprised of two major sub-watersheds: the Bonne Femme and the Little Bonne Femme. Topographical contours of the land define the Bonne Femme Watershed, which encompasses approximately 241 square kilometers (km^2) (93 mi^2), approximately 15 percent of Boone County, including the proposed RPF site (BFSC, 2007). The RPF site is located within the northern portion of this watershed (Little Bonne Femme sub-watershed) and is approximately 0.4 km (0.25 mi) north of Gans Creek (Figure 2-34).



MDNR 2012 *Section 303d Listed Impaired Streams and Lakes*
[digital data]: ftp://msdis.missouri.edu/pub/Environment_Conservation/
MO_2012_Section_303d_Impaired_Lakes_shp.zip

Figure 2-33. Streams of Southern Boone County, Missouri

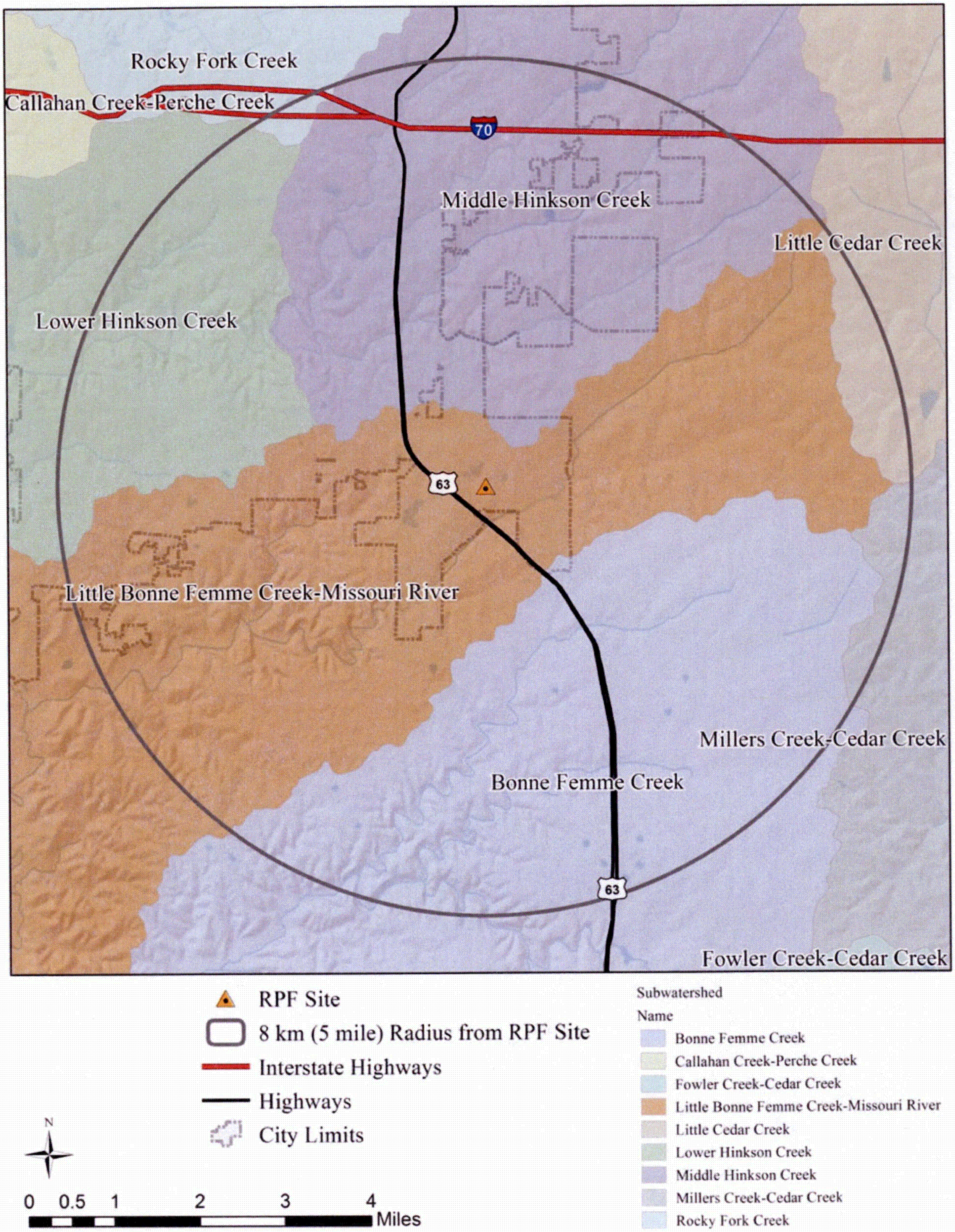


Figure 2-34. Map Showing Bonne Femme Watershed

Both the Bonne Femme and Little Bonne Femme creeks flow from east to west in a dendritic alignment into the Missouri River and are interconnected by the Devil's Icebox Cave Branch. Where Gans Creek meets Clear Creek, the Little Bonne Femme begins and flows south toward the Mayhan Branch. The Little Bonne Femme enters the Missouri River approximately 0.8 km (0.5 mi) south of this confluence. To the south, the Bonne Femme meets with the Fox Hollow Branch and then flows into the Missouri River (BFSC, 2007).

The most distinctive characteristic of the Bonne Femme Watershed is its karst topography. Within the karst terrain, the hydrology becomes complex because of losing and gaining sections of streams. Rough estimates show approximately 33 stream segments comprising approximately 37 km (23 mi) of losing streams (143 km [89 mi] of gaining stream) within the watershed. There are two main recharge areas tied to these losing and gaining sections of stream, including Devil's Ice Box recharge zone (3,397 ha [8,394 acres] of drainage), and Hunter's Cave recharge zone (3,330 ha [8,228 acres] of drainage) (BFSC, 2007).

A mixture of land uses occurs within the Bonne Femme watershed. The predominant land use accounting for 61.5 percent of the watershed is agricultural activities, including row crop productions, pasture, and range lands. Forested areas make up nearly one-third of the watershed, mainly within the central and western portion of the watershed. These forested areas also encompass most of the publicly owned lands, including Rock Bridge Memorial State Park and Three Creeks Conservation Area (BFSC, 2007).

2.4.2 Ground Water

Groundwater is the source of 74 percent of all rural domestic self-supplied water, 75 percent of all irrigation water, and 39 percent of all industrial self-supplied water, excluding water for thermoelectric power generation. The six principal aquifers in Missouri include:

- Major river valleys
- Alluvial (in southeastern Missouri)
- Wilcox and Claiborne
- McNairy
- Ozark
- Mississippian Aquifer (Kimmswick-Potosi)

The groundwater aquifer beneath the proposed RPF site is the Mississippian aquifer (also referred to as the Kimmswick-Potosi aquifer). Figure 2-35 is a map of the aquifer.

The Mississippian aquifer is the principal aquifer supplying groundwater to Boone County. The Mississippian aquifer consists of consolidated dolomite, limestone, and some sandstone beds that are generally confined. The Keokuk limestone and Burlington limestone are the principal water-yielding formations within this aquifer. Both formations consist of crystalline limestone and yield water primarily from solution cavities. In most places, the aquifer is overlain by a confining unit of Pennsylvanian shale and sandstone and glacial till. The aquifer is typically underlain by a confining unit of Mississippian shale. Recharge occurs primarily from precipitation infiltrating overlying aquifers. The top of this aquifer is approximately 548.6 m (1,800 ft) below-ground surface and is a primary source of water in seven counties north of the Missouri River (Miller and Appel, 1997).

In accordance with drillers' reports generated from 1987 to 2005, the estimated static water level in the area near the proposed site was approximately 198 m (650 ft) below-ground surface (MDNR, 2006). During previous investigations at Discovery Ridge, groundwater was observed at depths ranging from approximately 3.7–5.6 m (12–18.5 ft) below-ground surface.

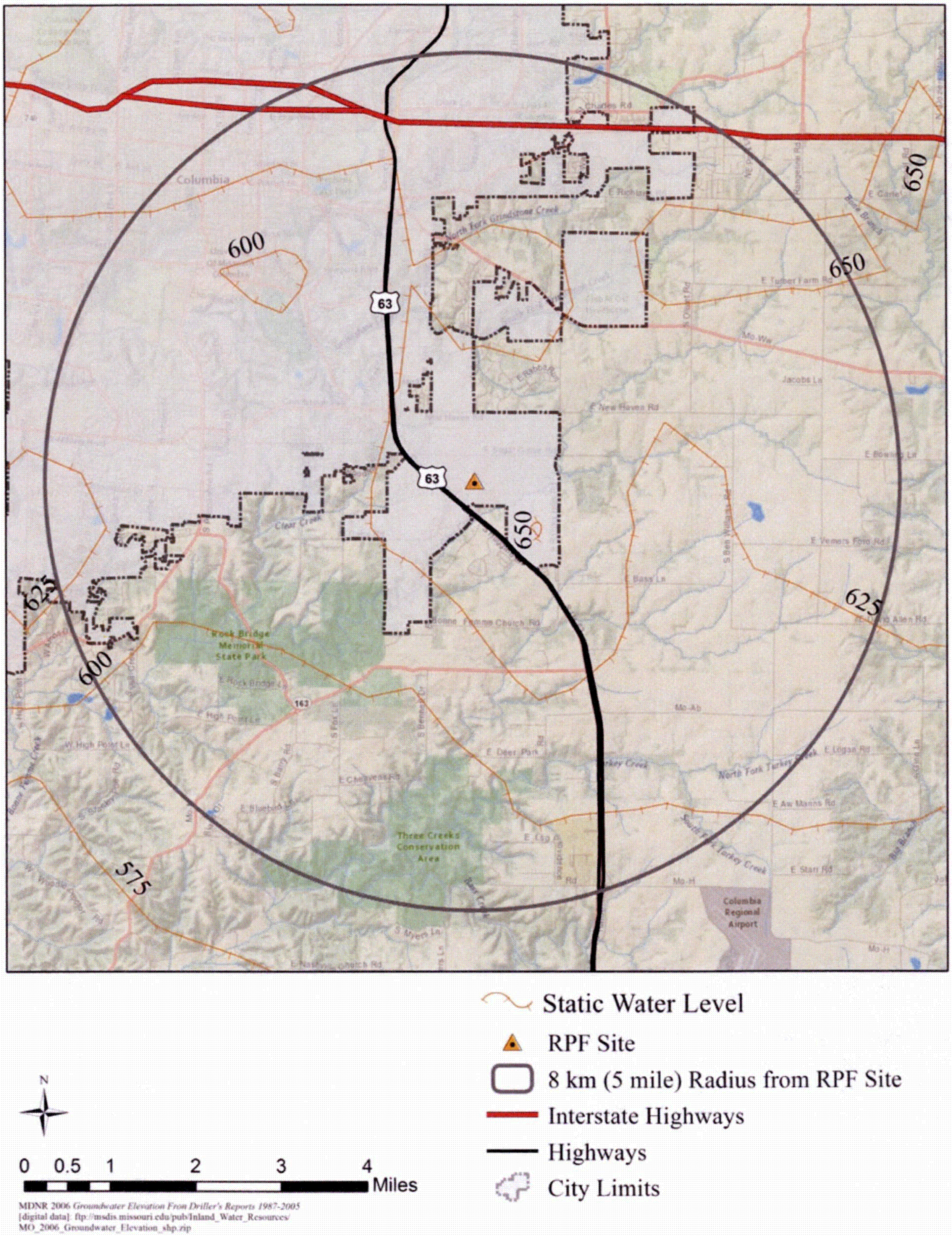


Figure 2-35. Aquifer Map

2.4.3 Floods

This subsection identifies the effects of potential floods on the proposed RPF site. Figure 2-36 provides the Federal Emergency Management Agency (FEMA) flood map of the area around the proposed RPF site. The site is located outside of the 500-year flood plain. The nearest FEMA flood zone A is located along Gans Creek located to the southeast of the site. The elevation of this zone is 242 m (795 ft). The RPF site elevation is 248 m (815 ft). There are no water impoundments or dams upstream of the RPF site on Gans Creek that could affect the facility.

There are also two ponds located near the RPF site within Discovery Ridge. These ponds include the 7.9 ha (19.6-acre) common grounds stormwater management pond located to the northwest of the site. The top of the dam for this pond is 246 m (807 ft), with the spillway at 245 m (804 ft). The second pond, currently approximately 4 ha (10 acres), is located to the northeast of the site. The elevation of the dam is approximately 244 m (801 ft). Failure of either of these two ponds would not likely affect the RPF because the elevation of the dams is lower than the elevation of the RPF.

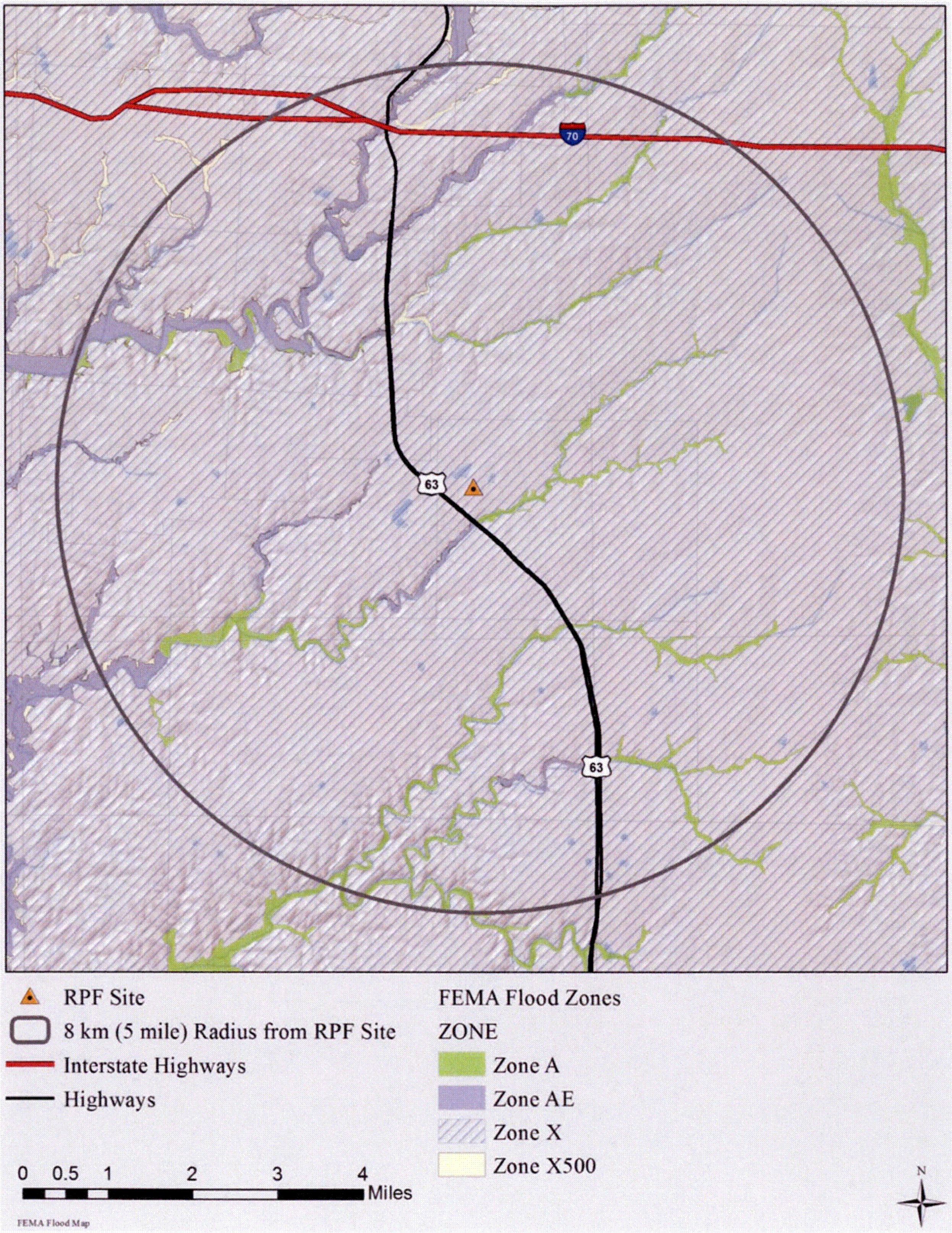


Figure 2-36. Federal Emergency Management Agency Flood Zones Around the Radioisotope Production Facility

2.5 GEOLOGY, SEISMOLOGY, AND GEOTECHNICAL ENGINEERING

This subsection provides summary descriptions of geomorphic provinces and their tectonic development, and the glacial history responsible for surface topography features found today in the state of Missouri. The descriptions are based on a review of relevant, readily available published reports and maps, and where available, records and unpublished reports from federal and state agencies. Information on the site characteristics has been acquired from these same sources and from site-specific investigations, including geotechnical field studies.

2.5.1 Regional Geology

2.5.1.1 Geomorphic Provinces

The state of Missouri is divided into three geomorphic provinces:

- Interior Plains Province, also referred to as the Central Lowland Province (northern Missouri, north of the Missouri River)
- Interior Highlands (central Missouri, south of the Missouri River)
- Atlantic Plains, also referred to as the Coastal Plains Province (the "boot heel" or southeastern corner of Missouri).

The proposed RPF site is located north of the Missouri River within the Interior Plains province. The Interior Plains are defined by the general texture of the surface terrain, rock type, and geologic structure. They are characterized by moderately dissected, glaciated, flat to rolling plains that slope gently toward the Missouri and Mississippi River valleys. Local relief is 6.1-50.3 m (20-165 ft). Drainage is dendritic, current geomorphic processes are fluvial erosion, transport and deposition, and minor mass wasting. Elevations range from 183-457 m (600-1,500 ft) above mean sea level, with the proposed RPF site averaging 245 m (805 ft) above mean sea level (USGS, 2013a).

2.5.1.1.1 Interior Plains Province

The Interior Plains Province is a vast region spread across the stable core (craton) of North America. This area formed when several small continents collided and welded together over a billion years ago, during the Precambrian Era. Precambrian metamorphic and igneous rocks now form the basement of the Interior Plains and make up the stable core of North America. Throughout the Paleozoic and Mesozoic Eras, the low lying Interior Plains remained relatively unaffected by mountain building and tectonic collisions in the western and eastern margins of the continent.

During the Mesozoic Era, the majority of the North American continental interior was above sea level, with two notable exceptions. The first occurring during the Jurassic Era (208-144 million years ago), when rising seas flooded the low lying areas of the continent and most of the Interior Plains were eventually submerged beneath the shallow Sundance Sea. The second exception occurred during the Cretaceous Period, when record high sea levels flooded the continental interior with shallow seas. During this time, the Interior Plains continued to receive deposits from the eroding Rocky Mountains to the west and Appalachian and Ouachita-Ozark Mountains to the east and south throughout the most recent Cenozoic Era. The flatness of the Interior Plains is a reflection of the platform of mostly flat-lying marine and stream deposits laid down in the Mesozoic and Cenozoic Eras. The overlying sedimentary rocks are composed mostly of limestone, sandstone, and shales (USGS, 2013a).

2.5.1.1.2 Interior Highlands Province

The southern portion of Missouri, south of the Missouri River, is located within the Interior Highlands Province. The Interior Highlands includes the Ozark and Ouachita Mountains of southern Missouri, Arkansas, and eastern Oklahoma. The rocky outcrops that make of the core of the Interior Highlands are Paleozoic age carbonates and other sedimentary rocks that were originally deposited on the sea floor. In the Ouachita Mountains, these ancient marine rocks are now contorted by folds and faults. The ancient, eroded mountains of the Interior Highlands stand surrounded by nearly flat-lying sedimentary rocks and deposits of the Interior and Atlantic Plains provinces.

The Interior Highlands consist of thick bedrock units of sandstone and shale, with lesser amounts of chert and novaculite (a fine-grained silica rock, like flint), deposited in a deep sea that covered the area from Late Cambrian through Early Pennsylvanian time. The area was then folded and faulted in such a manner that resistant beds of sandstone, chert, and novaculite now form long, sinuous mountain ridges that tower 152-457 m (500-1,500 ft) above adjacent valleys formed in easily eroded shale (USGS, 2013a).

2.5.1.1.3 Atlantic Plains Province

The Atlantic Plain Province is the flattest of all the provinces and stretches over 3,540 km (2,200 mi) in length from Cape Cod to the border of Mexico and southward another 1,609 km (1,000 mi) to the Yucatan Peninsula. The Atlantic Plains slope gently seaward from the Interior Highlands in a series of terraces. The gentle sloping continues far into the Atlantic and Gulf of Mexico, forming the continental shelf.

Eroded sediments from the Interior Highlands were carried east and southward by streams and gradually covered the faulted continental margin, burying it under a wedge of layered sedimentary and volcanic debris thousands of feet thick. The sedimentary rock layers that lie beneath much of the coastal plain and fringing continental shelf remain nearly horizontal or tilt gently toward the sea (USGS, 2013b).

2.5.1.2 Glacial History

> *"Recent studies of ice cores, stalagmites, and other temperature dating methods have concluded that there have been 30 sustained periods of frigid temperatures in the last 3 million years. Of the classical glacial periods, only two: pre-Illinoian (Nebraskan-Kansan) and Illinoian are now recognized as having left glacial deposits in the State of Missouri. The pre-Illinoian was the most severe. Amongst its legacy was the changing of the course of the Missouri River to its present location, the scouring and filling of Northern Missouri topography, and extensive outwash gravels left to the south of the present Missouri River. Although the Ozarks were not glaciated in the recent past, a cover of Pleistocene loess of varying thicknesses extends over all of the state except for the highest parts of the Ozark Mountains. Residuum, otherwise known as soil, clay, and rock fragments degrade from exposed and subsurface bedrock. Gravity and streams move this residuum, depositing it in sometimes graded layers."* (MDNR, 2013a)

In Boone County, the glacial till averages over 43 m (140 ft) thick in the northeastern portion of the county, and the loess material reaches a maximum depth of 6.1 m (20 ft) along the Missouri River Bluffs (Boone County, 2013).

2.5.1.3 Local Topography and Soils of Boone County

The topography of Boone County ranges from highly dissected hills to flat floodplains and nearly flat uplands. Elevations range from approximately 274.3 km (900 ft) above mean sea level along the northern boundary of Boone County to about 164.6 m (540 ft) above mean sea level in the southern tip of the county. Several areas of the county contain well developed cave and sinkhole formations.

Ordovician to middle Pennsylvania-aged dolomite, limestone, sandstone, coal, and shale deposits are visible throughout Boone County in geologic outcrops and roadcuts. The Mississippian-aged Burlington limestone is easily weathered by acidic groundwater and contains some unique natural resources of Boone County, including the most famous—Devil's Ice Box cave system, which is located approximately 2.4 km (1.5 mi) southwest of the proposed RPF site. There are numerous caves in Boone County and 418 documented sinkholes (Boone County, 2013)

Pennsylvanian aged deposits are overlaid by glacial till and loess. The soils of Boone County are included in parts of two major land resource areas: the Central Claypan Area and Central Mississippi Valley Wooded Slopes.

- **Central Claypan Area** – The Central Claypan Area soils were formed in glacial till and cover the northeastern and east-central portions of Boone County. Claypan soils display extreme variability within the soil profile and across the landscape; therefore, plant growth within these soils must contend with distinctively contrasting physical, chemical, and hydrologic properties at different soil depths. The depth to the claypan soils varies from approximately 10 cm (3.9 in.) on ridge tops up to 100 cm (39.4 in.) on backslopes. The soil horizons preceding the claypan are depleted of clay minerals, cations, and have a very low pH. The claypan horizon typically has an abrupt upper boundary with 100 percent more clay than the preceding horizon, and very low permeability.
- **Central Mississippi Valley Wooded Slopes** – This major land resource area consists of a dissected glacial till plain comprising rolling narrow ridge tops and hilly-to-steep ridge slopes. The small streams in this area have narrow valleys with steep gradients. The major rivers have nearly level broad floodplains, and the valley floors are tens of meters below the adjoining hilltops. Most of the soils within the central Mississippi valley wooded slopes area are found in silty loess or glacial till, are moderately to fine-grained in texture with a mixed mineralogy, and are well drained to moderately well-drained. These soils are typically observed on ridge tops and support forest flora (Boone County, 2013).

The proposed RPF site is located in a tectonically stable Interior Plains Province.

2.5.2 Site Geology

The stratigraphy of the geologic units that underlie the proposed RPF site and/or properties within a five-mile radius from the project site (Figure 2-37), are listed below from youngest to oldest:

- Quaternary Age Holocene Series (Qal)
- Pennsylvanian Age Desmoinesian Series Marmaton Group (Pm)
- Pennsylvanian Age Desmoinesian Series Cherokee Group (Pc)
- Mississippian Age Osagean Series Burlington Formation (Mo)
- Mississippian Age Kinderhookian Series (Mk)
- Late to Early Devonian aged (D)
- Early Ordovician Age Ibexian Series (Ojc)

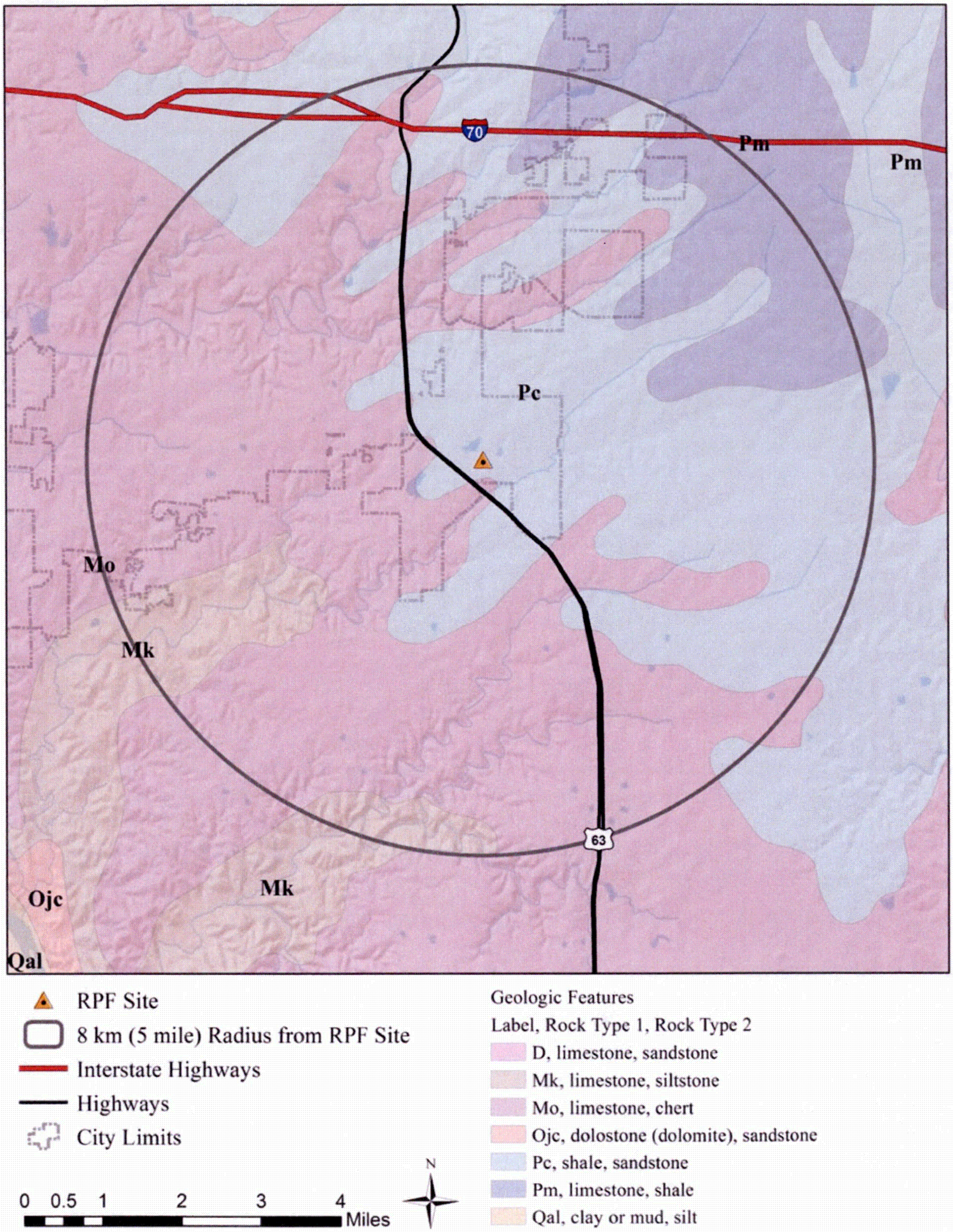


Figure 2-37. Geologic Features within an 8 km (5-mi) Radius of the Radioisotope Production Facility Site

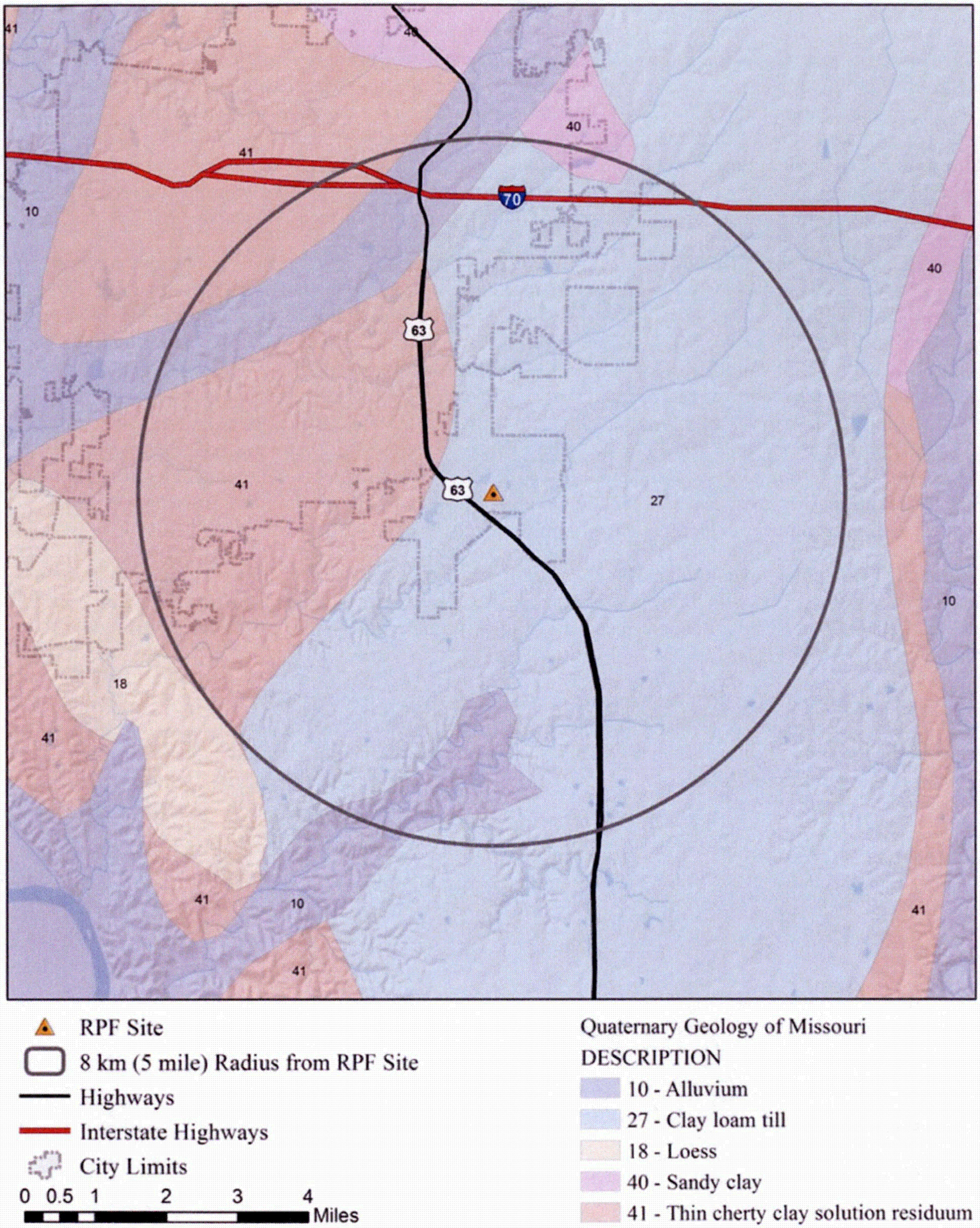
2.5.2.1 Quaternary Age Holocene Series (Qal)

The surface topography of the proposed RPF site and surrounding properties consists of Quaternary age bedrock overburden characterized by upland areas covered by a thin loess blanket and glacial drift. "Highly plastic clays that exhibit volume change with variations in moisture are commonly encountered near the ground surface" (Terracon, 2011). The surface topography of the proposed RPF site and surrounding properties consists of upland areas covered by a thin loess blanket and glacial drift. Previous investigations of Discovery Ridge noted that "Highly plastic clays that exhibit volume change with variations in moisture are commonly encountered near the ground surface" (Terracon, 2011).

Figure 2-38 depicts the Quaternary age bedrock overburden at the proposed RPF site as clay loam till (No. 27). Clay loam till is also depicted on all adjacent properties to the north, east, south, and west. Additional Quaternary age deposits located within an 8 km (5-mi) radius of the proposed RPF site include alluvium (No. 10), loess (No. 18), sandy clay (No. 40), and thin, cherty clay solution residuum (No. 41). The surface topography of the proposed RPF site and surrounding properties consists of Quaternary age bedrock overburden characterized by upland areas covered by a thin loess blanket and glacial drift. "Highly plastic clays that exhibit volume change with variations in moisture are commonly encountered near the ground surface" (Terracon, 2011). The surface topography of the proposed RPF site and surrounding properties consists of upland areas covered by a thin loess blanket and glacial drift. Previous investigations of Discovery Ridge noted that "Highly plastic clays that exhibit volume change with variations in moisture are commonly encountered near the ground surface" (Terracon, 2011).

The typical Quaternary age groundcover found in Boone County consists of alluvial (stream-deposited) clays, sand, and gravels (with a few poorly consolidated sandstones); glacial tills (sand and well-sorted gravels); and eolian (windblown) clays and loess (an extremely fine "rock flour," which forms solid masses) (MDNR, 2013b).

These glacial deposits mantle the upland areas and consist of a heterogeneous mixture of clay, sand, and pebbles of diverse rock types. The deposits vary greatly in thickness and are as much as 42.7 m (140 ft) thick in the northern portion of Boone County. This material is relatively impermeable and supplies very little water to wells (MU, 2006).



USGS 1996. MO 1996 Quaternary Geology (SHP)
[digital data] ftp:msdis.missouri.edu/pub/Geological_Geophysical/MO_1996_Quaternary_Geology_shp.zip

Figure 2-38. Map of Missouri Quaternary Age Geology

2.5.2.2 Pennsylvanian Age Desmoinesian Series Marmaton Group (Pm) and Cherokee Group (Pc)

Pennsylvanian age strata (both Marmaton and Cherokee Groups) consists largely of clay and shale, with minor accounts of coal and thin, impure limestone beds. The total thickness may be as much as 33.5 m (110 ft). These beds produce only small quantities of water and are not used in this area as a source of supply. The water found in this unit is usually high in iron and sulfur content (MU, 2006).

Limestone and shale beds are generally thin and very widespread lateral units. Pennsylvanian deposits are quite extensive across Missouri, and they usually form thin- to medium-bedded layers of distinctive composition, called cyclothems. A cyclothem results when a sea transgresses and regresses very rapidly along a coastal area, and in a repeating pattern. Often, this pattern consists of a sandstone (beach), silty shale or siltstone (tidal), freshwater limestone (lagoon), underclay (terrestrial), coal (terrestrial swampy forest), shale (near shore tidal), limestone (shallow marine), and black shale (deep marine). This sequence can then repeat itself as the sea first regresses from the land, and then transgresses again (MDNR, 2013c).

2.5.2.3 Mississippian Age Osagean Series Burlington Formation (Mo)

The Mississippian age Burlington Formation stratum is the most extensively studied Mississippian age strata in Missouri. This crystalline, extremely fossiliferous limestone covers most of the state and extends into Iowa and Arkansas. Typical characteristics include white-to-gray, medium-to-coarsely grained layers of chert nodules, and a coarse-grained sedimentary structure called "styolites" formed from pressure solution. The pores in the styolites are often filled with chert or quartz deposits (MDNR, 2013d).

Burlington limestone is the principal limestone exposed in quarries, creek banks, and roadcuts near and around Columbia. This limestone is approximately 49 m (160 ft) thick in the Columbia area (but the thickness can vary) and may contain minor amounts of pyrite and limonite. Burlington limestone has historically been economically important as a limestone resource where exposed and as host rock for lead and zinc deposits in the presently inactive Tri-State mining district of Missouri, Kansas, and Oklahoma (MU, 2006).

Burlington limestone contains many shallow-drilled wells and yields sufficient quantities of relatively hard water for rural domestic supplies. The limestone is quite soluble and contains many caverns and solutions passages. Solution features, including caves and sinkholes, are commonly present in this formation (MU, 2006). Terracon Consultants, Inc. (Terracon) reported the following:

> *No caves or sinkholes are known to exist, or are published to exist within approximately 1 mi of the Discovery Ridge Research Park. However, several areas of known karst activity are present west and southwest of this project area and are in various stages of development. Site grading and drainage may alter site conditions and could possibly cause sinkholes in areas that have no history of this activity.* (Terracon, 2011)

2.5.2.4 Mississippian Age Kinderhookian Series Chouteau Limestone (Mk)

The Mississippian age Chouteau Limestone stratum is a very fine-grained carbonate and, for the most part, is an evenly bedded bluish gray limestone. The upper part is somewhat massive and high in magnesium. Chouteau limestone is relatively impermeable due to its fine texture, restricting the movement of water to joints and small fissures. This unit is a poor source of water but yields small quantities to a few wells (MU, 2006).

2.5.2.5 Late to Early Devonian Limestone (D)

Devonian limestone strata deposits greatly vary in lithology, and range from very fine-grained to coarsely textured beds. Some of the beds are slightly sandy. In some areas of Columbia, Missouri, the Devonian limestone beds are approximately 9 m (30 ft) thick; in other well locations, this limestone bed is completely absent. Devonian limestone is not a valuable water producer (MU, 2006).

2.5.2.6 Early Ordovician Age Ibexian Series Dolomites (Ojc)

Ordovician age deposits found in the Columbia area include the following, from youngest to oldest (MU, 2006):

- **St. Peter Sandstone** – This formation, which is a very important aquifer in eastern and northern Missouri, has no importance in the Columbia area. It is present only as localized masses in the depressions of older rocks.
- **Jefferson City Formation** – This predominantly dolomite formation averages approximately 122 m (400 ft) in thickness in the Columbia area, and wells drilled into it produce moderate quantities of relatively hard water. The formation probably has more rural domestic wells terminating in it than any other formation is this area.
- **Roubidoux Formation** – This formation consists of alternating sandstone and dolomite beds and averages approximately 30.5 m (100 ft) in thickness. The formation is a very dependable water producer.
- **Gasconade Formation** – This unit consists of mostly light-gray dolomite with sandstone (Gunter) at the base. The thickness is approximately 85.3 m (280 ft). This dolomite unit is very cavernous and contains many interconnected solution passages. The sandstone is approximately 4.6 m (15 ft) thick, is very permeable, has a wide aerial extent, and is a good source of water.

2.5.3 Onsite Soil Types

The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) Soil Survey Geographic database for Boone County (NRCS, 2012) lists the soil type beneath the proposed RPF site as the Mexico Silt Loam.

In 2011, Terracon completed a preliminary geotechnical investigation for the Discovery Ridge Certified Site Program, which included Lot 2 and Lots 5 through 18 of Discovery Ridge (Terracon, 2011). The proposed RPF site (Lot 15) is within the investigation area. The purpose of the investigation was to provide preliminary geotechnical recommendations concerning earthwork and the design and construction of foundations, floor slabs, and pavements for Discovery Ridge properties. As part of the study, nine soil borings (B-1 through B-9) were installed to depths ranging from 4–6 m (13–20 ft) below-ground surface to determine shallow subsurface soil geotechnical properties and shallow groundwater depth. Soil boring B-5 is nearest to the proposed RPF site, along the eastern boundary between Lots 14 and 15.

Discovery Ridge surface soils from 0.6–0.15 m (0.2–0.5 ft) below-ground surface were found to be brown, friable topsoil with significant amounts of organic matter. Subsurface soils from approximately 0.9–3.6 m (3–12 ft) below-ground surface were lean clay, lean-to-fat clay, and fat clay with moderate-to-high plasticity. Material beneath 3.6 m (12 ft) is listed only as limestone. Plasticity and liquid limit tests were completed for soils encountered from only four soil borings.

At the time of drilling, some of the soils displayed moisture levels greater their measured plastic limits. "Soils with moisture levels above their measured plastic limits may be prone to rutting and can develop unstable subgrade conditions during general construction operations" (Terracon, 2011). Moderate to high plasticity clays were observed at the site. Such soils are commonly referred to as "expansive" or "swelling" soils because they expand or swell as their moisture content increases. These soils in turn, contract or shrink as the moisture content decreases. Footings, floor slabs, and pavements supported on expansive soils often shift upward or downward causing possible distortion, cracking, or structural damage.

2.5.4 Seismicity

The most significant seismological feature in Missouri is the New Madrid Seismic Zone (NMSZ), located in the southeastern corner of the state and extending into parts of the contiguous states of Arkansas, Tennessee, Kentucky, and Illinois. The NMSZ is the most seismically active region in the U.S. east of the Rocky Mountains and is located approximately 483 km (300 mi) southeast of the proposed RPF site. During the winter of 1811–1812, the NMSZ was the location of some of the highest intensity seismic events ever noted in U.S. history. Hundreds of aftershocks, some severely damaging, continued for years.

Records show that since 1900, moderately damaging earthquakes have struck the NMSZ every few decades. Prehistoric earthquakes similar in size to those of 1811–1812 occurred in the middle 1400s and around 900 A.D. Strongly damaging earthquakes struck the southwestern end of the NMSZ near Marked Tree, Arkansas, in 1843 (magnitude 6.0), and the northeastern end near Charleston, Missouri, in 1895 (magnitude 6.6) (USGS, 2011a).

The NMSZ is made up of reactivated faults that formed when what is now North America began to split or rift apart approximately 500 million years ago. The resulting rift system died out before an ocean basin was formed, but a deep zone of weakness was created, referred to as the Reelfoot rift (USGS, 2011b). This fault system extends 241 km (150 mi) southward from Cairo, Illinois, through New Madrid and Caruthersville, Missouri, down through Blytheville, Arkansas, to Marked Tree, Arkansas. The Reelfoot rift dips into Kentucky near Fulton and into Tennessee near Reelfoot Lake, extending southeast into Dyersburg, Tennessee. The rift then crosses five state lines and crosses the Mississippi River in at least three places. The fault system is buried beneath as much as 8 km (5 mi) of sediment for much of the fault length and typically cannot be seen at the surface (USGS, 2011b).

Four of the largest faults are recognized as alignments of abundant small earthquakes, and movements along two of these faults dammed rivers and created lakes during the earthquakes of 1811–1812. A few more deeply buried faults were detected during oil and gas exploration, and a few small faults are known from geologic mapping (USGS, 2011b).

The remainder of the state, including the proposed RPF site located in central Missouri, is typical of the stable midcontinent U.S.

Earthquakes occur on faults within bedrock, usually several miles deep. According to the U.S. Geological Survey (USGS), earthquakes in the central and eastern U.S. typically are felt over a much broader region than in the western U.S. East of the Rocky Mountains, an earthquake can be felt over an area ten times larger than a similar magnitude earthquake on the west coast.

According to information from Missouri's State Emergency Management Agency Earthquake Program, some of the earthquakes measure at least 7.6 in magnitude and five of them measured 8.0 or greater. The 1811–1812 series changed the course of the Missouri River, and some shocks were felt as far away as Washington D.C. and Boston (MMRPC, 2010). The NMSZ has experienced numerous earthquakes since the 1811–1812 series, and at least 35 aftershocks of intensity V or greater that have been recorded in the state of Missouri since 1811. Numerous earthquakes originating outside of the state's boundaries have also affected Missouri. Table 2-28 summarizes the historical earthquakes that have affected the state of Missouri.

Table 2-28. Recorded Missouri Earthquake History (3 pages)

Date	Location	Magnitude	Recorded damage
12/16/1811 (1811–1812 series)	New Madrid Region, Missouri	7.7	Generated great waves on the Mississippi River causing major flooding, high river back cave-ins. Topographic changes affected an area of 78,000 to 130,000 km^2 (30,116 to 50,193 mi^2). Later geologic evidence indicated that the epicenter was likely in northeast Arkansas. The main shocks were felt over an area covering at least 5,180,000 km^2 (2,000,000 mi^2). Chimneys were knocked down in Cincinnati, Ohio, and bricks were reported to have fallen from chimneys in Georgia and South Carolina. The first shock was felt distinctively in Washington, D.C., 1,127 km (700 mi) away.
12/23/1812 (1811–1812 series)	New Madrid, Missouri	7.5	Second major shock more violent than the first.
2/7/1812 (1811–1812 series)	New Madrid, Missouri	7.7	Three main shocks reaching MMI of XII, the maximum on scale. Aftershocks continued to be felt for several years after the initial tremor. Historical accounts and later evidence indicate that the epicenter was close to the town of New Madrid, Missouri. This quake produced the largest liquefactions fields in the world.
1/4/1843	New Madrid, Missouri	Not listed	Cracked chimneys and walls in Memphis, Tennessee, and reportedly collapsed one building. The earth sank in some places near the town of New Madrid, Missouri, and an unverified report indicated that two hunters were drowned during the formation of a lake. The total felt area included at least 1,036,000 km^2 (400,000 mi^2).
4/24/1867	Eastern Kansas	Not listed	Reports indicated that an earthquake occurred in eastern Kansas and was felt as far eastward as Chicago, Illinois. It may have been noticeable in Columbia.
8/31/1886	Charleston, South Carolina	Not listed	An MMI of II earthquake recorded in St. Louis, Missouri, and was felt as far westward as Columbia. There were no reports of structural damage.

Table 2-28. Recorded Missouri Earthquake History (3 pages)

Date	Location	Magnitude	Recorded damage
10/31/1895	Charleston, Missouri	6.6	Largest earthquake to occur in the central Mississippi River valley since the 1811–1812 series. Structural damage and liquefaction phenomena were reported along a line from Bertrand, Missouri, in the west to Cairo, Illinois, to the east. Sand blows were observed in an area southwest of Charleston, Puxico, and Taylor, Missouri; Alton, and Cario, Illinois; Princeton, Indiana; and Paducah, Kentucky. The earthquake caused extensive damage (including downed chimneys, cracked walls, shattered windows, and broken plaster) to schools, churches, and private residences. Every building in the commercial area of Charleston was damaged. Cairo, Illinois, and Memphis, Tennessee, suffered significant damage. Near Charleston, 1.6 ha (4 acres) of ground sank and a lake formed. The shock was felt over all or portions of 24 states and in Canada. Ground shaking was recorded along the Ohio River Valley.
1903	New Madrid, Missouri	5.1	No information given.
4/9/1917	St. Genevieve/ St. Mary's Area, Missouri	Not listed	A sharp disturbance at St. Genevieve and St. Mary's, Missouri. According to the Daily Missourian, No. 187, dated April 9, 1917, the earthquake was not felt in Columbia. However, on the following day several people reported feeling the shock and attributed it to an explosion. No damage was reported in Columbia. Reportedly felt over a 518,000 km^2 (200,000 mi^2) area from Kansas to Ohio and Wisconsin to Mississippi.
5/1/1920	Missouri or Illinois	Not listed	This earthquake reportedly shook buildings across St. Louis. Two shocks were felt in Mt. Vernon, Illinois, and three were felt in Centralia, Illinois. The epicenter of this earthquake is unknown and is thought to have originated east of Columbia in Illinois. In the Evening Missourian, No. 207, dated May 1, 1920, the U.S. Weather Bureau reported that the shock was not felt in Columbia. However, in a later investigation a few people reported feeling a slight tremor.
8/19/1934	Rodney, Missouri	Listed as strong	At nearby Charleston, windows were broken and chimneys collapsed or were damaged. Similar effects were observed in Cairo, Mounds, and Mounds City, Illinois, and at Wickliffe, Kentucky. The area of destructive intensity included more than 596 km^2 (230 mi^2)
11/23/1939	Western Illinois	Not listed	An earthquake occurred near Red Bud, Illinois, and a reported MMI of II was recorded in Columbia, Missouri. The approximately distance from the epicenter to Columbia was 213 km (132 mi).

Table 2-28. Recorded Missouri Earthquake History (3 pages)

Date	Location	Magnitude	Recorded damage
3/3/1963	Near Menorkanut, Missouri	Not listed	MMI of III was recorded in Columbia. The approximately distance from the epicenter to Columbia was 317 km (197 mi).
10/21/1965	Eastern Missouri	Not listed	MMI of V in Columbia. The approximate distance from the epicenter to Columbia was 163 km) (101 mi).
11/9/1968	Wabash Valley Seismic Zone, southern Illinois	5.4	Strongest magnitude in central U.S. since the 1895 earthquake. Moderate damage to chimneys and walls at Hermann, St. Charles, St. Louis, and Sikeston, Missouri. Shaking was felt. Areas include all or portions of 23 states from Minnesota to Georgia and from Pennsylvania to Kansas, and in multi-story buildings in Boston, Massachusetts and southernmost Ontario, Canada.
1987	Wabash Valley Seismic Zone, near Olney, Richland County, SE Illinois	5.0	Chimneys and bricks fell, underground pipes were damaged, and sidewalks and streets cracked in at least four cities in Illinois, Indiana, and Kentucky. Shaking was felt in 17 states, from Pennsylvania to Kansas and from Alabama to Minnesota and southernmost Ontario, Canada.
2002	Wabash Valley Seismic Zone, Posey County, SW Indiana	4.6	Moderate earthquake caused chimney damage and cracked windows in and near Evansville, Indiana. Shaking was reported in seven states, including Missouri.

Sources:

USGS, 2013c, "Three Centuries of Earthquakes Poster," pubs.usgs.gov/imap/i-2812/i-2812.jpg, U.S. Geological Survey, Reston, Virginia, accessed July 23, 2013.

USGS, 2002, "Earthquakes in the Central United States 1699 -2002," pubs.usgs.gov/imap/i-2812/i-2812.jpg, U.S. Geological Survey, Reston, Virginia, June 18, 2002.

MU, 2006, *Missouri University Research Reactor (MURR) Safety Analysis Report*, MU Project# 000763, University of Missouri, Columbia, Missouri, August 18, 2006.

MMI = Modified Mercalli Intensity.

2.5.5 Maximum Earthquake Potential

In 2002, the USGS released the following projected hazards for Boone County, if an earthquake occurred along the NMSZ in the following 50 years (MMRPC, 2012):

- 25 to 40 percent chance of a magnitude 6.0 and greater earthquake
- 7 to 10 percent chance of a magnitude 7.5 to 8.0 earthquake.

According to the USGS, Boone County is one of the 47 counties in Missouri that would be severely impacted by a 7.6 magnitude earthquake with an epicenter on or near the NMSZ.

According to the *Boone County Hazard Mitigation Plan for 2010* (MMRPC, 2010), the Missouri State Emergency Management Agency has made projections of the highest earthquake intensities that would be experienced throughout the state of Missouri if various magnitude earthquakes occur along the NMSZ (Figure 2-39), as measured by the Modified Mercalli Intensity (MMI) scale. The pertinent information for Boone County is summarized in Table 2-29.

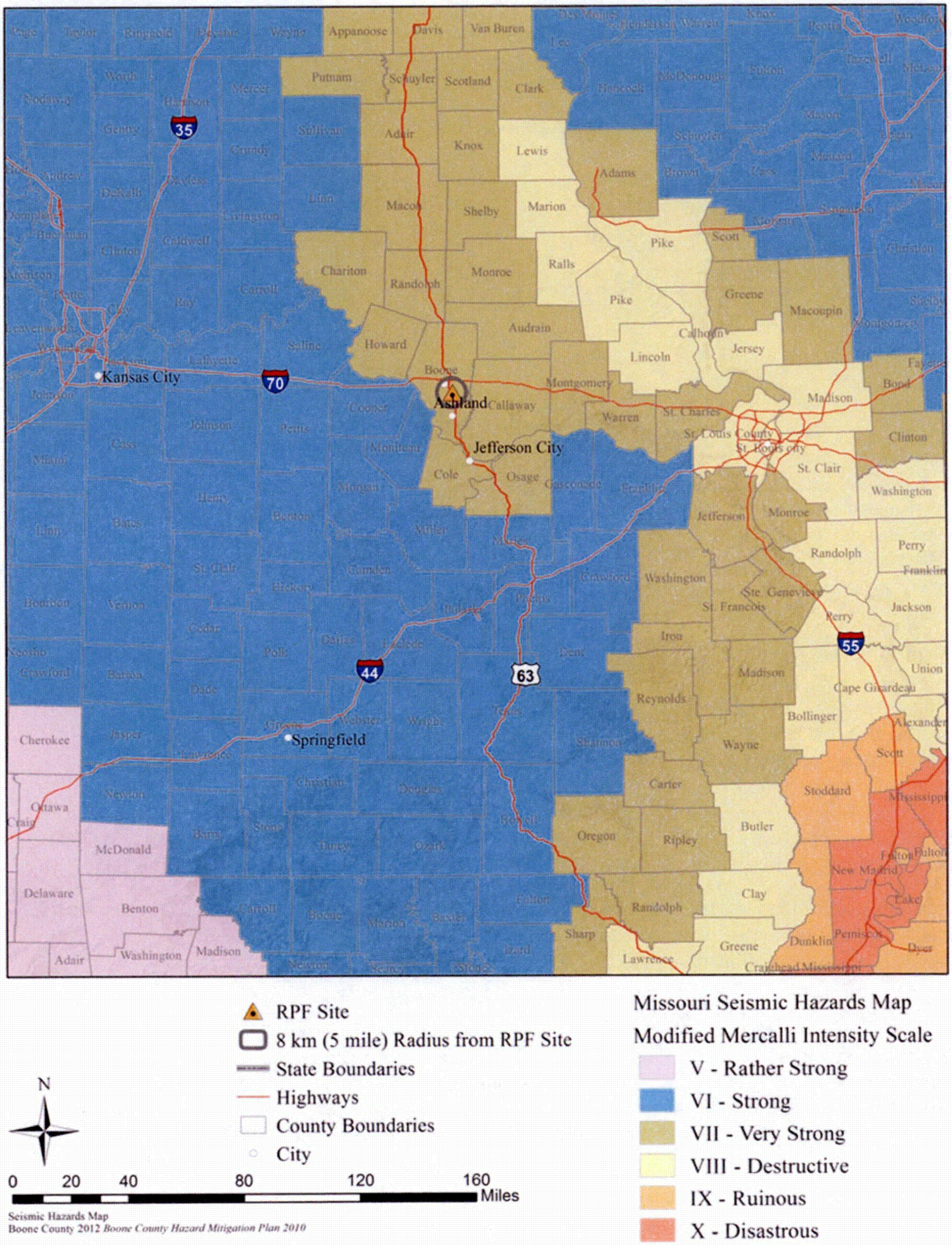


Figure 2-39. Hazard Mitigation Map

Table 2-29. Projected Earthquake Hazards for Boone County

Magnitude at NMSZ	Probability of occurrence (2002–2052)	Intensity in Boone County (MMI)	Expected damage
6.7	25–40%	VI, strong	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
7.6	7–10%	VII, very strong	Difficult to stand; significant damage to poorly or badly designed buildings, adobe houses, old walls, spires, and other; damage would be slight to moderate in well-built buildings; numerous broken windows; weak chimneys break at roof lines; cornices from towers and high buildings fall; loose bricks fall from buildings; heavy furniture is overturned and damaged; and some sand and gravel streambanks cave in.

Source: MMRPC, 2010, *Boone County Hazard Mitigation Plan*, www.mmrpc.org/the-region/boone-county, Mid-Missouri Regional Planning Commission, State of Missouri Emergency Management Agency, Ashland, Missouri, July 15, 2010.

MMI = Modified Mercalli Intensity.
NMSZ = New Madrid Seismic Zone.

The USGS National Seismic Hazard Maps display earthquake ground motions for various probability levels across the U.S. and are applied in seismic provisions of building codes, insurance rate structures, risk assessments, and other public policy. Updates to these maps incorporate new findings on earthquake ground shaking, faults, seismicity, and geodesy. The resulting maps are derived from seismic hazard curves calculated on a grid of sites across the U.S. that describe the frequency of exceeding a set of ground motions. In accordance with the 2008 USGS Scientific Investigation Map (No. 3195) (USGS, 2008), the proposed RPF site is within the third lowest earthquake hazard area with peak acceleration potentials of 2–3 (Petersen et al., 2011). This category indicates an estimated horizontal ground-shaking level between 8-in-100 to 16-in-100 chance of being exceeded in a 50-year period.

According to MMRPC (2010), the entire county is at risk for effects of an earthquake along the NMSZ. Areas near the Missouri River could be particularly vulnerable due to the soil or alluvium along river channels being susceptible to liquefaction from amplification waves.

2.5.6 Vibratory Ground Motion

NUREG-1537, Part 1, Section 3.4 requires that seismic design for non-power reactors should, at a minimum, be consistent with local building codes and other applicable standards. For MU facilities, the 2012 IBC has been levied as the required building code. Therefore, seismic design parameters for the proposed project are discussed in terms of the 2012 IBC and associated standards.

Seismic provisions in 2012 IBC, Chapter 16, Section 13, "Earthquake Loads," and ASCE 7-10, Chapter 11, are based on 5 percent damped spectral accelerations for a maximum-considered earthquake with a return period of 2,475 years (equivalent to a ground motion with a 2 percent probability of exceedance in 50 years). Spectral acceleration values for the maximum considered earthquake are for soil Site Class B (rock). The short- (S_S) and long- (S_1) period spectral accelerations for rock sites are provided by Boone County and are based on USGS (2009) data.

In the 2009 IBC, Site Class B soil conditions require modification for other soil site classes by the application of the site coefficients F_a (site coefficient for 0.2-sec period) and F_v (site coefficient for 1-sec period). Soil-modified S_S becomes S_{MS} (maximum-considered earthquake spectral response for 0.2 sec modified for soil Site Class) and soil-modified S_1 become S_{M1} (maximum-considered earthquake spectral response for 1-sec period modified for soil Site Class) where $S_{MS} = S_S \times F_a$ and $S_{M1} = S_1 \times F_v$ (Equations 16-36 and 16-37 in IBC, 2009). Boone County, Missouri indicates S_S and S1 values of 0.213 g-force (g) and 0.093 g, respectively (Fa and $F_v = 1$) for the site.

The Boone County site is a soil Site Class D site. When modified for a Site Class D site by application of the site coefficients F_a and F_v, S_{MS} and S_{M1} values of 0.341 g and 0.223 g, respectively ($F_a = 1.6$ and $F_v = 2.4$) are obtained. The S_{MS} and S_{M1} values represent the maximum-considered earthquake acceleration response spectral accelerations for the site, as modified for the site soil conditions. These modified spectral acceleration values are then multiplied by two-thirds to develop the design acceleration response spectrum values of S_{DS} (design spectral response acceleration coefficient at short periods) and S_{D1} (design spectral response acceleration coefficient for a 1-sec period), where $S_{DS} = S_{MS} \times 2/3$, and $S_{D1} = S_{M1} \times 2/3$ (Equations 16-38 and 16-39 in IBC, 2009). The S_{DS} and S_{D1} values are used to develop the design acceleration response spectrum suitable for structural analysis and design for the requirements of the IBC (2009) and ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures*. Key parameters for the development of seismic design ground motions are derived from the 2009 IBC and ASCE 7-05 seismic design procedures.

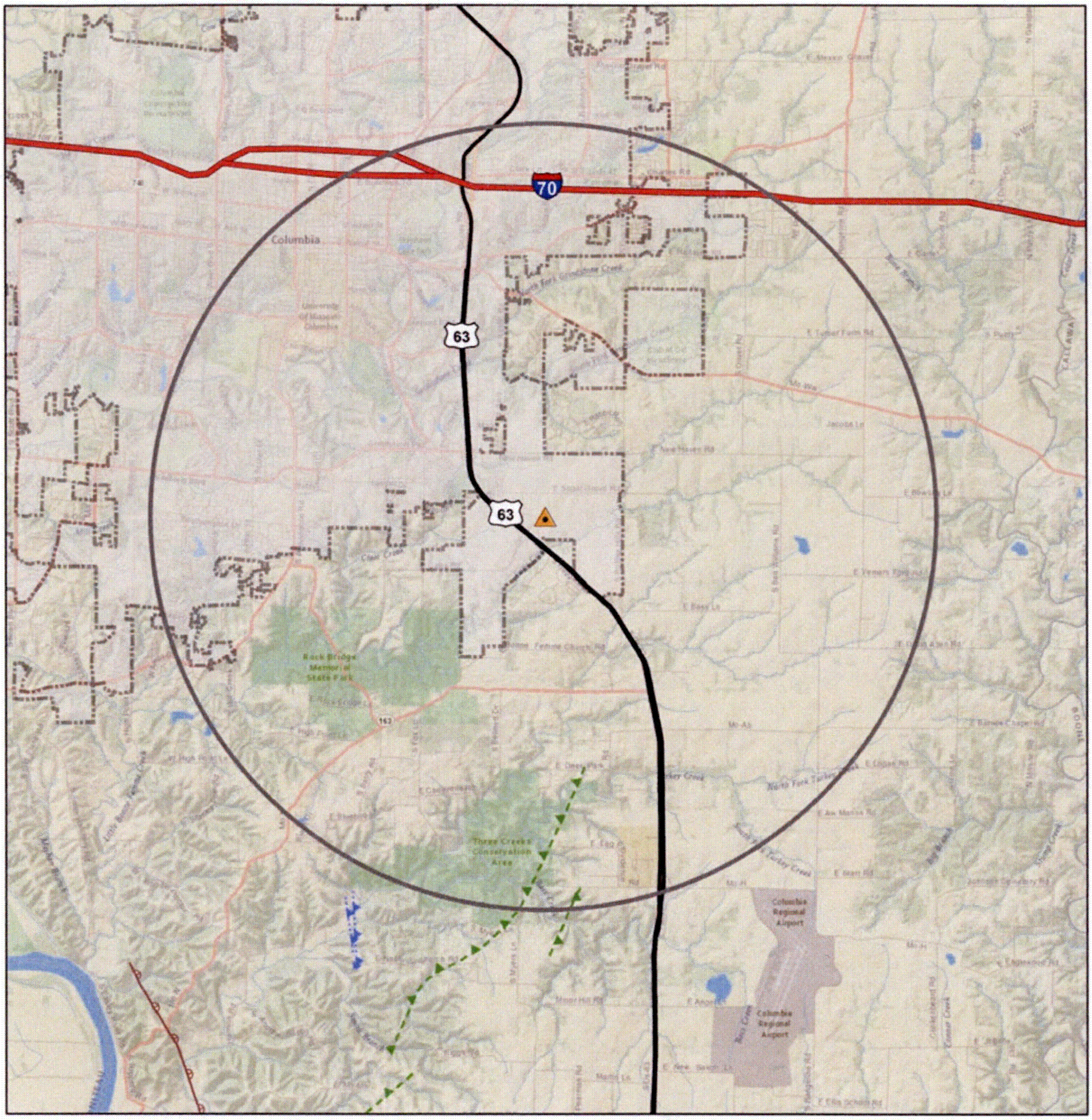
2.5.7 Surface Faulting

There is one major fault zone located within a five-mile radius of the proposed RPF site (Figure 2-40). The Fox Hallow Fault is located approximately 5.6 km (3.5 mi) southeast of the proposed RPF site. The Fox Hollow Fault is a small fault, striking northeast, and fades into a monocline at its two ends. The fault is reportedly a normal fault with a throw of approximately 37 m (120 ft) down to the southwest, and shows Mississippian-aged Chouteau limestone beds faulted against Ordovician-aged Jefferson Dolomite (Union Electric Company, 2008).

During the Union Electric Company study, the Fox Hollow fault was investigated at six waypoints where visual observations of the fault were made. These, plus other road cuts in the local area, were investigated for evidence of offsets and shears. No new roads have been cut or significant new development has occurred recently in the area.

At Waypoint 1, which is in Fox Hollow where the valley runs normal to the Fox Hollow Fault, the valley is heavily vegetated and reworked for agriculture. An outcrop of Jefferson Dolomite, about 91 m (300 ft) long, was observed on the north side of the valley. The Jefferson is dipping about 5 degrees to the west on the west flank or down-dipping of a monocline.

At the other waypoints along the fault alignment, the vegetation was heavy and the ground surface had been reworked for agriculture. No evidence of the fault was observed in any road cuts in the area, and no surface manifestation of the fault was observed at any of the waypoints.



RPF Site
8 km (5 mile) Radius from RPF Site
Interstate Highways
Highways
City Limits

0 0.5 1 2 3 4 Miles

Fault Structures
NAME
Bonne Femme Creek graben
Fox Hollow fault and monocline
Sapp monocline

MoDNR 2010. MO 2010 Tectonic Fault Structures (SHP)
MoDNR/DGLS/GSP [digital data]: ftp://msdis.missouri.edu/pub/
Geological_Geophysical/MO_2010_Tetonic_Fault_Structures_shp-.zip

Figure 2-40. Geologic Faults Map

The field investigation was expanded to the east of the fault along State Highway 63, which runs sub-parallel to the main feature and reportedly on the up-thrown side. Depending on the location, State Highway 63 runs about 4.8 to 5.6 km (3 to 3.5 mi) to the east of the feature. All road cuts along State Highway 63, and the east-west roads running from the fault to State Highway 63, were examined for offsets, abrupt changes in dip, and evidence of shearing. In each case, questionable features were linked to non-tectonic causes, primarily erosion or slumping associated with the road itself. Based on the Union Electric Company investigation, the fault was inactive at the time of their study.

2.5.8 Liquefaction Potential

Liquefaction is a process by which water-saturated sediment temporarily loses strength and acts as a fluid when exposed to strong seismic shaking. The shaking causes the grains to lose grain-to-grain contact, so the sediment tends to flow. Liquefaction most likely occurs in loose sandy soil with a shallow water table (which is common for areas around floodplains or bays). Liquefaction often leads to overpressured fluids that can erupt to the surface, forming features known as sand blows.

The 1811–1812 earthquakes caused ground subsidence by soil liquefaction across the Mississippi River flood plain and along tributaries to the Mississippi River over at least 15,000 km^2. Liquefaction along the Mississippi River Valley during the 1811-1812 earthquakes created one of the world's largest sand blown fields. According to the USGS, recent sand blows dot the landscape surrounding New Madrid, Missouri (USGS, 2011b).

The Association of Central United States Earthquake Consortium State Geologists (CUSEC) established regional maps identifying areas of higher and lower potential for amplification of earthquake ground motion by soils or liquefaction of the soils. The areas were defined on the basis of the geology of the upper 15 m (50 ft). Their map identifies the RPF area as an area of having lower potential for amplifying earthquake ground motions or liquefaction (CUSEC, 1999).

The Terracon (2011) preliminary geotechnical investigation for the Discovery Ridge Certified Site Program included Lot 2 and Lots 5 through 18 of the Discovery Ridge Research Park. The proposed RPF site (Lot 15) is located within Terracon's project area. As part of their study, Terracon installed nine soil borings (B-1 through B-9) to depths ranging from 4 to 6 m (13 to 20 ft) below-ground surface. Soil boring B-5 was drilled nearest to the proposed RPF site and was installed along the eastern boundary between Lots 14 and 15.

Soils – Terracon described the subsurface soils in soil boring B-5 as listed below:

- 6-9.1 cm (0.2-0.3 ft) below-ground surface; brown, friable topsoil with significant amounts of organic matter
- 9.1-91 cm (0.3-3.0 ft) below-ground surface; lean clay (CL), brown, stiff, water content 24 percent, dry unit weight 98 lb/ft^3, and unconfined strength 4,000 kilopounds per square foot (kip/ft^2)
- 0.9-2.4 m (3.0-8.0 ft) below-ground surface; fat clay (CH), gray with red, stiff, water content 31 percent, dry unit weight 91 lb/ft^3, and unconfined strength 4,000 kip/ft^2
- 2.4-3.7 m (8.0-12.0 ft) below-ground surface; fat clay (CH), reddish brown and light gray, trace sand and gravel, possible cobbles, stiff (glacial drift), water content 16 percent, dry unit weight 116 lb/ft^3, and unconfined strength 7,000 kip/ft^2
- 3.7-5.2 m (12.0-17 ft) below-ground surface; sandy lean to fat clay (CL-CH), reddish brown with light gray, trace gravel, possible cobbles, stiff (glacial drift), water content 21 percent, and unconfined strength 4,000 kip/ft^2.

- 5.2-6.1 m (17-20 ft) below-ground surface; fat clay (CH), reddish brown and light gray, trace sand and gravel, possible cobbles, very stiff (glacial drift), standard penetration test blow count = 19, water content 18 percent, and unconfined strength 7,500 kip/ft^2.

Laboratory testing indicated that the lean clay tested from soil boring B-5, 0.3-0.91 m (1-3 ft) below-ground surface, had a liquid limit of 31 percent, a plastic limit of 21 percent, and a plasticity index of 10 percent.

Groundwater level – Shallow groundwater encountered at the time of drilling in soil boring B-5 was at 5 m (16.5 ft) below-ground surface and the static water level stabilized at 3.7 m (12.0 ft) below-ground surface. Shallow groundwater was not encountered in soil boring B-6 (located on Lot 10) during the drilling operation, but later stabilized at 5.6 m (18.5 ft) below-ground surface.

Liquefaction potential – Based on the preliminary geotechnical study conducted by Terracon (2011), liquefaction of soils at the proposed RPF site cannot be determined. Contradictory information is listed below:

- In accordance with liquefaction potential screening techniques, cohesive soils with fines content greater than 30 percent and fines that are either classified as clays based on the Unified Soil Classification System or have a plasticity index greater than 30 percent with natural water contents lower than 90 percent, can be considered nonliquefiable. Soils logged in soil boring B-5 are listed as clays under the Unified Soil Classification System; however, the plasticity index is only 10 percent, with water contents ranging from 16 to 31 percent.
- Depth below-ground surface – A soil layer within 50 ft of the ground surface is more likely to liquefy than deeper layers.
- Soil penetration resistance – Soil layers with a normalized standard penetration test blow count less than 22 have been known to liquefy. The standard penetration test blow count listed for soil boring B-5 is 19. In accordance with the statement above, this would depict soils susceptible to liquefaction.

Additional geotechnical analysis will be conducted at the RPF site to determine the liquefaction potential of the soils onsite.

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