# Cooling Tower Impact Analysis

*for a proposed*

# 750 MW Coal-Fired

# Mid-Michigan Energy Station

*prepared for*

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*prepared by*

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## *INTRODUCTION*

This report provides the results of an evaluation of the cooling water tower (CWT) impacts associated with the operation of linear mechanical-draft CWTs for a proposed 750 MW coal-fired Mid-Michigan Energy Station (Facility). The proposed Facility location is approximately two miles southeast of Midland, Michigan on the east bank of the Tittabawassee River. Figure 1 provides a site location map overlaid with the proposed Facility site plan. The proposed CWT would be a 20-cell wet evaporative cooling tower with plume abatement. The analysis examined the potential for fogging and icing impacts associated with ground fog and icing occurrences from the cooling tower plume.

## *SACTI MODEL DEFINITION, LIMITATIONS AND CONSERVATISM*

The CWT analysis was performed using the Seasonal/Annual Cooling Tower Impacts (SACTI) model, developed by researchers for the Electric Power Research Institute (EPRI). The SACTI model was developed especially for modeling utility CWTs. The model is widely recognized as being the most comprehensive and field validated CWT plume model available for modeling power plant CWT plumes. The Mid-Michigan analysis examined the potential impacts from both a non-plume abated and a plume-abated CWT. The original SACTI code did not include an algorithm to account for sensible heat added to the cooling tower plume by a hybrid CWT. TRC subsequently modified the code to incorporate plume abatement into the model. A discussion of the structure of the SACTI model and the modeling methodology employed by this analysis is included in the Appendix of this report.

SACTI is considered by the power industry to be the model of choice for calculating potential environmental impacts from a wet evaporative CWT. The SACTI model rigorously calculates the effects of the CWT condensed water plume for ground fogging, rime ice formation, elevated plume impacts and mineral deposition using actual (representative) meteorological data. While the model has been tested and validated using actual field conditions, it has certain limitations that cause it to provide conservative results. Namely, the model does not discern plume density, but rather if the plume water vapor content is greater than or less than the ambient saturation deficit. In this way, SACTI tabulates only the presence of a potential condensed plume regardless if the plume is barely saturated and evaporating. Similarly, SACTI tabulates a ground rime icing condition if there is a tabulated occurrence of a ground fog when the ambient temperature is below 32 $^{o}$F. Rime ice formation is a very complicated process and strongly affected by the supercooled liquid water density of the cooling tower plume, orientation of the object within the plume, wind speed, and ambient temperature to mention a few of the parameters. Essentially, SACTI only tabulates the conditions which may be conducive for rime ice formation, rather than actual formation of rime ice.

*Discussion of Model Input Parameters*

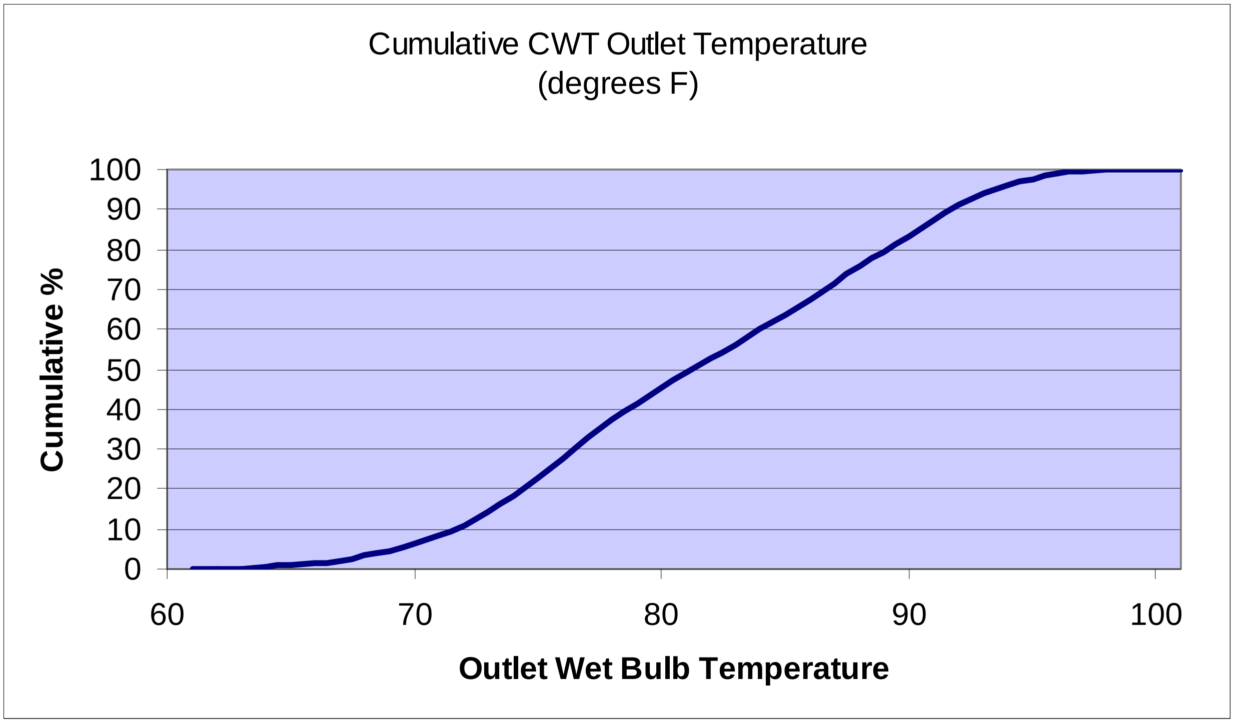
**Meteorology**

The model used ten years of hourly meteorological data (1997-2006) recorded at the MBS International Airport (MBS), Saginaw, Michigan airport. Mixing height data obtained from "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States", George Holzworth, EPA, 1972. Seasonal morning and afternoon mixing heights were used in combination with the MBS hourly meteorological data. These data are considered to be reasonably representative meteorological data to assess the potential CWT impacts for the proposed Facility. SACTI is a statistically based model that provides total hourly counts of ground fog and rime ice (among other parameters). As such the longer the meteorological period of record, a better estimate on the average number of hourly occurrences of fogging and/or icing will be made. Figure 2 shows a wind rose that presents a graphical distribution of the average wind speeds and direction for the six years of meteorological data. The directions represent from which the wind is blowing.

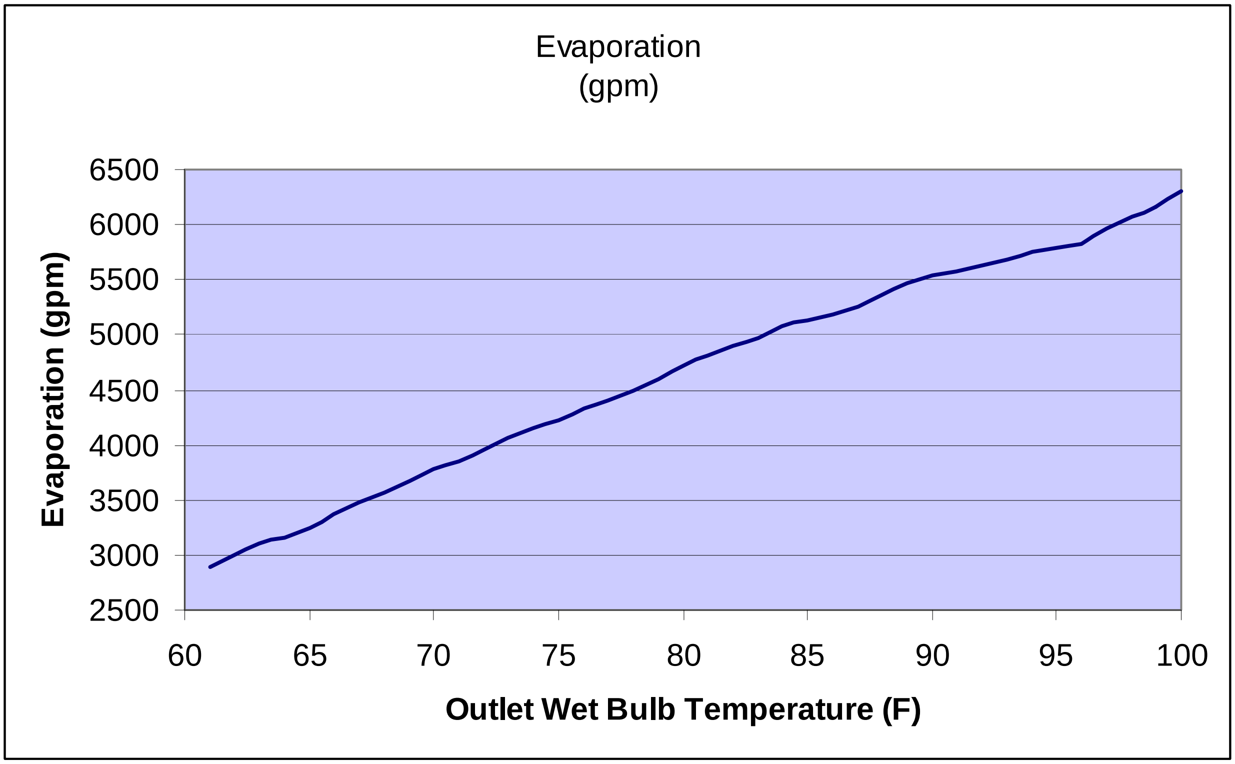
**Cooling Tower Parameters**

The CWT is proposed to be a 20-cell linear mechanical draft wet evaporative cooling tower. It is sized for a 102 $^{o}$F inlet water temperature, an 85 $^{o}$F return water temperature, a 17 $^{o}$F range and a 72 $^{o}$F wet bulb temperature with a 13 $^{o}$F wet bulb approach. The cooling tower operates by bringing the inlet air with a specific dry bulb and wet bulb temperature in contact with the circulating water. In order to minimize visible plume formation, the design will incorporate plume mitigation whereby a portion of the circulating water is directed through heating coils to warm the tower inlet air. Table 1 presents the physical dimensions and thermodynamic parameters of the proposed CTW.

The thermodynamics of the tower are such that the circulating water temperature and the outlet temperature (also called the outlet wet bulb temperature) approach equilibrium. The following figure illustrates the cumulative outlet wet bulb temperatures for the proposed tower based on the actual ten-years of hourly meteorological conditions recorded at MBS International Airport (1997-2006). As shown on this figure, the tower always operates between 60 and 100 $^{o}$F, with typical range between about 70 and 95 $^{o}$F.




The greater portion of the heat rejected by the CWT is through evaporation of the circulating water. During cooler ambient temperatures about 50 percent of the heat duty is rejected through evaporation with the remaining 50 percent through sensible heat transfer (warming of the cold air), while during hot ambient temperatures and high wet bulb conditions as much as 90 to 95 percent of the heat is rejected through evaporation. The following figure illustrates the amount of evaporation (in gallons per minute) for the proposed CWT based on the ten-years of actual hourly meteorological conditions recorded at MBS International Airport.




Under full heat duty conditions during the summer months, the typical evaporation from the cooling tower would be 5,000 to 6,000 gallons per minute, while during cooler months the evaporation would be 3,000 to 4,000 gpm. Even during the cooler months there is sufficient evaporated water to form a fairly dense visible plume once the outlet air cools upon contact and mixing with the cooler ambient air.

***Detailed Modeling Methodology***

The SACTI model calculated the probable frequency of occurrence of ground-level plume fogging and rime icing for the tower design location and orientation. In the case of plume fogging and icing the SACTI model provides results tabulated as total hours for the 10-year block of data. These values are divided by the number of years in the meteorological data set (in this case, ten) to determine the annual average. The modeling analysis included an assessment of a hybrid cooling tower where a portion of the hot inlet circulating water is diverted through dry coils within the tower to increase the dry bulb temperature of the cooling tower exhaust. The hybrid tower considered cases where 5 percent of the heat rejection would be through the dry coils. A detailed discussion of the SACTI model and hybrid tower algorithm is included in the Appendix of this report

***Methodology for Estimating Ground-Level Impacts***

The plume dispersion modeling program, known as MULT, assumes that fogging and icing potentially occurs during ten pre-defined meteorological scenarios. For the purpose of this study, ground "fogging" has conservatively been defined to occur for a given scenario when the plume is modeled to be in physical contact with the ground and/or the plume is below the height of the CWT. The area covered by the plume is then taken to be the area of fogging. Likewise, ground-level icing is conservatively assumed to occur when icing occurs during the five plume fogging scenarios for which the air temperature is less than freezing.

Plume shadowing is computed directly in MULT from the modeled plume dimensions and the projections of these plumes on the ground. Plume shadowing events are only counted during the daylight hours, with changes in sunrise and sunset times adjusted for time of year, and are usually used to evaluate the potential for reduced crop yields in agricultural areas. Since visibility of the elevated plumes often is of more interest than plume shadowing (i.e. the agricultural areas were minimal within the study area), the focus of this analysis is on elevated plumes.

Mineral deposition is computed in MULT using the assumption that a portion of drift droplets falling from the plume will strike the ground, thereby depositing the dissolved minerals within the droplets. The mineral content in the circulating water included the dissolved minerals, plus other dissolved minerals and suspended solids. Current engineering assumptions indicate the makeup for the circulating water will undergo approximately 10 cycles of concentration, effectively concentrating the minerals (as calcium carbonate) in the circulating water to about 1,500 ppm. Based upon the Institute of Electrical and Electronic Engineers (IEEE) studies, the significant deposition threshold for electrical components (above which insulator failure is possible) is assumed to be 0.1 $mg/cm^2$/month of sodium chloride (NaCl).

While SACTI has the ability to identify frequency of elevated plumes and mineral deposition, impacts associated with plume shadowing and mineral deposition were not addressed in this analysis.

## **<u>MIDLAND CWT MODELED PLUME IMPACTS</u>**

The proposed Midland CWT was assessed to determine the potential icing and fogging impact upon the local area for the wet evaporative tower with 5% bypass plume abatement, design location and NE-SW orientation

### ***Midland CWT Plume Fogging and Icing Impacts Summary***

The proposed CWT was assessed to determine the potential mitigation of using a hybrid tower with a dry section. The amount of heat rejection through the dry coils during conditions conducive to plume formation was assumed to be 5 percent (of the total tower heat duty). This amount of heat rejection could be achieved by diverting 10% of the inlet circulating water through the coils since approximately half of the heat duty of the tower during cool weather is achieved by sensible heat transfer rather than evaporation.

Figures 3 and 4 illustrate the potential fogging and icing impacts associated with a 5 percent bypass plume abated (hybrid) tower. An average maximum of 4 hours per year of ground fogging is calculated to occur towards the southwest and towards the northeast and east of the CWT. This is a reduction of approximately 75% of the non-abated plume fogging hours. Similarly, the plume abatement substantially reduces the number of rime ice hours to less than 2 hours per year approximately 200-300 feet northeast and east of the CWT. Since TRC considers that the plume mitigation algorithm likely understates the amount of plume abatement achieved, it is possible that the fogging and icing impact are conservatively high, and the actual potential for adverse impacts due to plume fogging and rime ice formation is negligible.

## SUMMARY and CONCLUSION

The following provides a summary and various conclusions for the various SACTI modeled cases.

### Plume Ground Fogging

In general, the potential plume fogging impacts from the proposed plume abated CWT would only occur approximately 4 hours per year in any one direction, with the greatest number of plume hours towards the east (Figure 3). The extent of the plume abated ground fog impacts could extend several hundred feet towards the east. Considering that SACTI overstates the conditions when plumes are indicated to occur, such extended plumes may be very rare or may not occur at all. However, under inclement weather conditions such extended plumes may exacerbate existing poor visibility conditions.

### Plume Rime Icing

Of the estimated ground fogging hours, on average, approximately 2 hours at the location of the maximum rime ice impacts may occur when the air temperature is below freezing (Figure 4). Rime ice impacts may occur when the ground fog plume impinges upon the surface and the supercooled droplets freeze in contact. The plume abatement mitigates the formation of plumes and serves to reduce the potential number of hours rime ice conditions may occur.

In conclusion, the the proposed Facility’s CWT with plume abatement is anticipated to result in negligible plume fogging and icing impacts off of the facility property.

**Table 1**
**Cooling Tower Operating Parameters**

| **Parameter** | **Plume Abatement with 5% bypass** |
|---|---|
| Tower Loading Case (worst case summer): | Full load |
| Tower Orientation and configuration | NE-SW 10x2 |
| Number of Cells: | 20 |
| Tower Height (top of fan) (meters): | 18.6 (61 ft) |
| Tower Length (meters): | 182.9 (600 ft) |
| Tower Width (meters): | 33.2 (109 ft) |
| Cell Diameter (meters): | 9.6 (31.5 ft) |
| Tower Effective Diameter[(1)] (meters): | 42.9 (140.9 ft) |
| Tower Heat Duty (MMBTU/hr): | 3,551 |
| Tower Heat Duty (wet section) (MWthermal): | 988 |
| Heat Duty Bypass (dry section) (MWthermal): | 52 |
| Tower Total Air Flow (ACFM): | 28,340,000 |
| Circulating Water (Total) (gpm) | 418,000 |
| Circulating water TDS % (as $CaCO_3$) | 1,354 ppm |
| Site Latitude (NAD27) (degrees): | 43.5761°N |
| Site Longitude (NAD27) (degrees): | 84.1949°W |

**Table 2**
**NE/SW Orientation**
**Cooling Tower Impacts**

| **Description** (units based on 10-years of hourly meteorology) | **Hybrid Evaporative Tower 5% bypass** | | |
|---|---|---|---|
| | Maximum Value | Direction of Plume towards | Distance from Tower (meters/feet) |
| Plume Ground Fogging | 4 (hrs/yr) | E | 150/500 |
| Rime Icing | 1.6 (hrs/yr) | E | 150/500 |

*Figure 1: Facility Proposed Location*

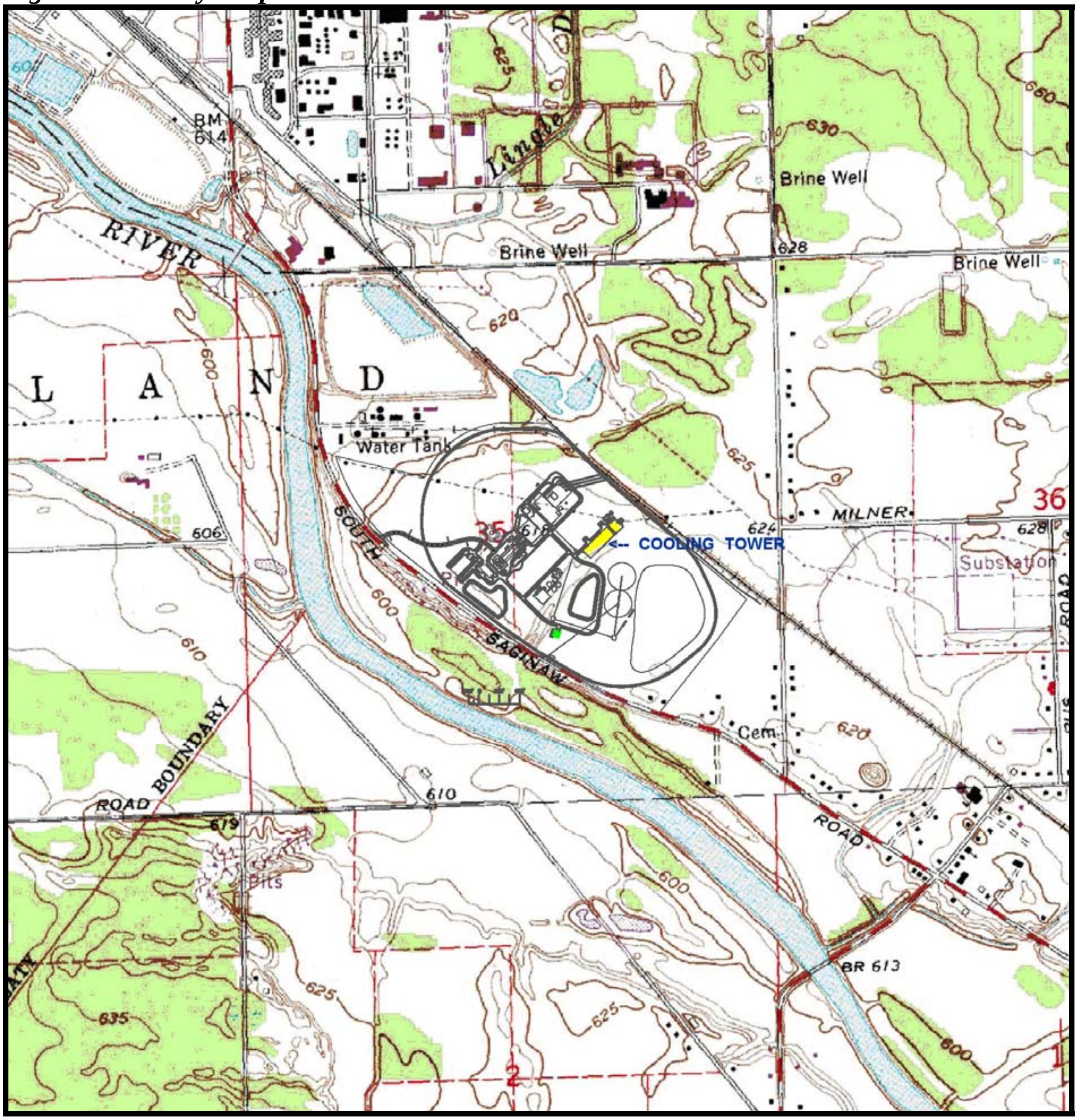
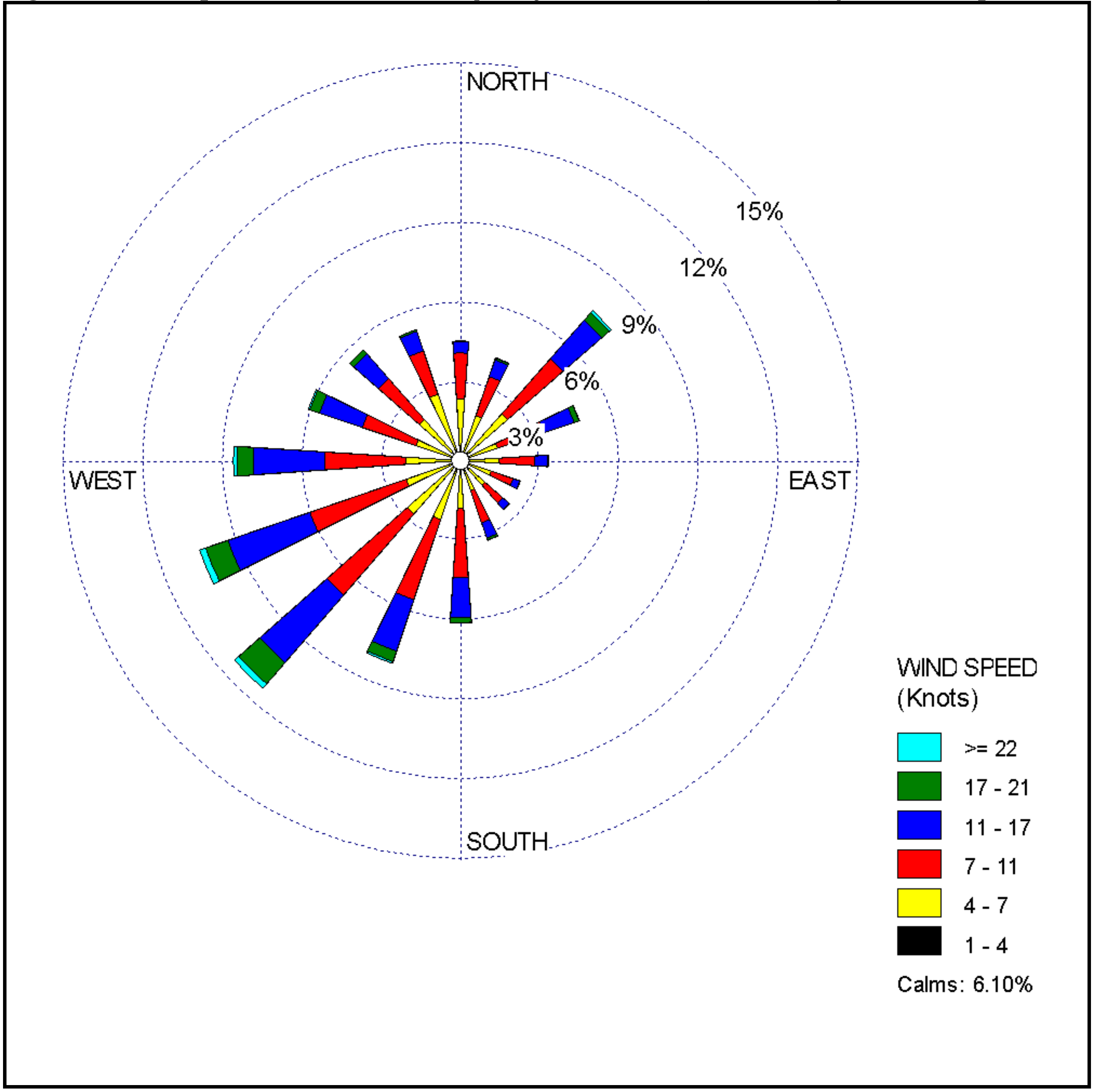


***Figure 2: Wind Speed and Direction Frequency Distribution (Windrose) for MBS Airport*** [(1)]




(1) Based on hourly observations from MBS International Airport (1997-2006)

Figure 3: Ground Fog Impacts Average Hours per year - 750MW Facility - 5% Bypass Hybrid Cooling Tower

Figure 4: Rime Ice Impacts Average Hours per year - 750MW Facility - 5% Bypass Hybrid Cooling Tower

## REFERENCES

EPA (1987). "On-site Meteorological Program Guidance for Regulatory Modeling Applications," U.S. Environmental Protection Agency, Office of Air & Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC-EPA450/4-87-013.

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Policastro, A.J., L. Coke, and M. Wastag (1984). User's Manual:-Cooling TowerPlume Prediction Code, Electric Power Research Institute, EPRI CS-3403-CCM, Palo Alto, CA.

Sauvageot, H. (1989). "Radar Measurements of Cooling Tower Drift," J.Appl. Meteor., Sept., Vol. 28, pp. 925-935.

**APPENDIX**
**SACTI Model Description**

The EPRI SACTI CWT model calculates the seasonal and annual impacts of CWT vapor plumes. Various environmental impacts simulated in the SACTI model include:

- plume-induced fogging and icing (during freezing conditions) downwind of the CWT,
- visible plume length and height,.
- elevated plumes and plume shadowing (the frequency and length of elevated plumes at a given location), and,
- deposition of minerals (salt) contained in CWT plume drift (water droplets entrained in the plume during plume exhaust),

The SACTI model is a multiple-source model that predicts CWT plume impacts from any number of identical natural draft, linear mechanical draft, or circular mechanical draft CWTs. The SACTI model was designed to provide predictions that can be used in the licensing of power plants with CWTs. The model developers validated the model with field and laboratory data in all situations where good quality data existed.

The seasonal/annual modeling methodology employed by the SACTI model is a parameterization scheme that reduces the available hourly meteorological data to between 20 and 50 categories (typically 35-45 plume categories are used) of unique meteorological conditions (from a CWT plume dispersion perspective). Potential ground fogging and icing cases are reduced to a predefined 10 categories, which are assumed by the model to be the result of aerodynamic downwash in the lee (downwind side) of the CWT. Plumes that are rapidly brought to the ground due to aerodynamic effects will always be lower in height than the tower. The elevated plumes will typically be at or higher than the height of the tower. Rime icing events are tabulated by SACTI when a ground fog event occurs while the ambient temperature is below freezing (32 $^{o}$F)

Each category is modeled separately and the modeling results of the category are assumed to apply for all occurrences of the category for the period for which modeling is performed. The number of specific categories for a given situation is dependent upon the CWT geometry, tower emission parameters, and the meteorological conditions experienced at the site. The categorization scheme used in the SACTI model allows a user to analyze multiple years of meteorological data without the need to model every hour of every year to determine plume impacts. The representative scenarios are assumed to apply for multiple hours, thereby greatly reducing computer execution time. As discussed earlier, however, because SACTI is a statistically based model, a large meteorological database is recommended to provide a large selection of meteorological conditions.

The SACTI model is composed of four separate programs: a meteorological preprocessing program (PREP); a plume dispersion program (MULT); a program to produce tabular summaries of the modeling results (TABLES); and a graphical postprocessor program (PAGE).

To begin a SACTI modeling analysis, the PREP program reads a sequential hourly meteorological data file and generates a set of meteorological scenarios that produce significant plume dispersion effects. The MULT program then computes the expected plume dispersion for each meteorological scenario developed by PREP. The output of the PREP program is a sequential hourly listing of the meteorological conditions and plume dispersion category for each hour of meteorological data processed. The output from the MULT program is a listing of the plume dispersion and fogging impact for each meteorological scenario (category) simulated.

The TABLES program combines the output of the PREP and MULT programs and produces a set of tabular frequency of occurrence listings of the various environmental effects produced by the CWT plume. The environmental effects computed by the TABLES program are the average of the individual impacts of each scenario model weighted by the number occurrences of that scenario in the input PREP data file.

The post-processing program PAGE produces computer page plots of the output from the TABLES program. Only the first three programs were needed for this analysis. Graphical post-processing was performed using a separate graphics package, rather than the PAGE program.

The SACTI-PREP model generates five scenarios that are assumed to produce CWT plume icing and fogging, and five additional scenarios that produce CWT plume fogging only. Because plume fogging and icing occur during plume downwash conditions, and downwash is assumed to be different for circular and linear CWTs of the same size, the icing and fogging scenarios for these two tower types are different. These ten scenarios are independent of individual tower or plume geometry characteristics, except that plumes from natural draft CWTs are assumed not to produce ground level fogging and icing.

An additional number of scenarios are also developed that are functions of the meteorological conditions occurring in the input meteorological data. These scenarios depend upon observed wind speed, dry bulb and dew point temperatures, atmospheric stability, and other meteorological factors, in addition to specific CWT parameters. These scenarios can vary with the specific CWT modeled and are used to estimate the potential for icing and fogging impacts. A total of 10 downwash (fogging and icing scenarios) and 9 plume scenarios were used by SACTI for the Midland Generating Station CWT analysis for the non-abated scenario while 10 downwash and 35 plume cases were selected by the preprocessor for the 5 percent bypass abatement scenario.

Mineral deposition is simulated by SACTI by calculating the amount of liquid water that is emitted by the tower through drift (liquid water droplets that are entrained in the exhaust flow). The drift contains dissolved minerals, predominately calcium carbonate with fresh water for makeup, and any anti-scaling agents used to treat the circulating water. The drift droplets are modeled as a tilted plume, causing deposition of the droplets in the immediate vicinity of the tower. If sufficiently heavy, the mineral deposition will manifest itself as a white film on surfaces, and can be particularly noticeable on vehicles (i.e. windshield and windows), that may be parked adjacent to the tower for any extended period of time (days or weeks). Normally, such deposition is not an issue unless the circulating water contains a high concentration of sodium chloride (NaCl). Mineral deposition was not addressed for the Midland Generating Station CWT analysis.

**TRC Plume Abatement Algorithm**

In order to account for plume abatement in a hybrid linear mechanical draft cooling tower, TRC added additional code to the SACTI PREP program. To simulate the plume abatement operation of the tower, the amount of plume abatement is input as a percent of the total heat rejection of the cooling tower that is achieved by the dry section of the tower. In practice, this is accomplished by diverting a portion of the hot circulating water through radiator coils constructed either on the inlet sides of the tower or internally in the tower. The size of the coils and amount of circulating water determines the amount of heat rejection by the dry section. The increase in inlet air temperature is caused by inlet air being drawn through the dry coils. The dry section is typically designed to provide a certain amount of dry bulb temperature increase of the outlet exhaust air. This increase in temperature can reduce the relative humidity of the exhaust to below 100 percent resulting in a mitigation or elimination of the visible plume.

While only a portion of the inlet air may pass through the dry coils, the assumption is made that the warmer air will rapidly mix with the balance of inlet air, thus the entire mass of inlet air is used in the delta-T calculation. The formula used is:

$$\text{Delta-T } (°\text{F}) = 1/C_p \times \text{hybrid heat rejection / total pounds air flow}$$

where:

$C_p$ = Specific heat capacity of dry air; 0.24 BTU/(lb × °F)

Hybrid heat rejection is total heat rejection (MMBtu/hr) times percent of dry cooling.

The heat capacity of air does vary slightly with temperature, however for this calculation $C_p$ is assumed constant over the relatively narrow operating temperature range of the cooling tower (where most evaporative cooling towers operate with a circulating water range between 65 and 95 $^{o}$F). This method conservatively simulates plume abatement since it not only accounts for the reduced heat load to the wet section, the sensible heat added to the inlet air by the dry section is also included. The typical dry bulb temperature increase is 5 to 30 $^{o}$F, depending on the amount of plume abatement designed. Additionally, plume abatement is typically not used at warmer temperatures since the cooling efficiency of the dry coils decreases as the ambient air temperature approaches the inlet cooling water temperature. The station operators will either reduce the amount of cooling water diverted to the dry coils, or turn off the dry section completely.