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COOLING TECHNOLOGY INSTITUTE

AEP'S EXPERIENCE WITH POLYESTER FRP STRUCTURE COOLING TOWERS

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AEP EXPERIENCE WITH PULTRUDED POLYESTER FIBERGLASS STRUCTURE FOR COOLING TOWERS

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ABSTRACT

There are a total of 15 hyperbolic and 30 mechanical draft cooling towers on the AEP system. These towers utilize a cross-flow or counter-flow thermal transfer design, and almost all of the cross-flow towers are treated wood structures.

AEP replaced four cross-flow mechanical draft towers during the period of 2008 through May 2010, and a counter-flow mechanical draft tower was built for a new unit in 2009. All five of these new towers used polyester fiberglass structure from the same pultruder and were designed and constructed by a single cooling tower company. These five towers are the first fiberglass structure cooling towers on the AEP system which have been placed in-service.

Failed or cracked fiberglass columns were found in four towers and surface blisters were noticed in two of the new towers after 2 to 18 months of operation. This paper will summarize where the failures, cracks and blisters occurred, along with steps AEP is following up on to minimize cracks and blisters in future fiberglass cooling towers.

BACKGROUND

AEP is one of the largest electric utilities in the United States, delivering electricity to more than 5 million customers in 11 states. AEP ranks among the nation's largest generators of electricity, owning more than 38,000 megawatts (MW) of generating capacity in the U.S., with individual unit ratings ranging from 25 MW to 1300 MW.

AEP merged with Central South West Corporation in 2000, and the system is geographically designated as an eastern and western generating fleet. The eastern fleet currently has generating units in Indiana, Kentucky, Michigan, Ohio, Virginia and West Virginia, while the western fleet's generating units are located in Arkansas, Louisiana, Oklahoma and Texas.

FAILED FIBERGLASS COLUMNS AND BEARING PADS

Cross-Flow Cooling Tower No. 1

A new 14 cell, fiberglass structure, cross-flow, mechanical draft tower was completed in May 2008. Figure 1 represents the cross-flow structure for the tower and shows the ~ 40 ft columns (supplied in a single length with no splices) which support the 60" to 30" hot water distribution pipe on top of the hot water deck. There are six transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The 3-1/2" pipe columns rest on elevated concrete piers which are at eye level. All of the fiberglass columns were originally designed to sit on a fiberglass/neoprene bearing pad.

This unit had an outage in December 2009 and the cold water basin was drained so the new tower could be inspected. During the outage, approximately 90% of the fiberglass bearing pads had failed under the 3-1/2" pipe columns, and a total of 55 pipe columns (out of 168) had cracked at the bearing pads. Photo 1 represents the worse case failure found in the tower, while Photo 2 represents several of the typical failure modes found after 18 months of operation. Almost 60% of the failures were under the 60" hot water pipe in Cells 1 through 5, while the other 40% were spread out under the smaller pipes in Cells 6 through 14. The fiberglass bearing pads were replaced by the cooling tower contractor with 304 stainless pads under the high load columns. Below is a summary of how much was cut-off the 55 pipe columns above the bearing pads to remove the cracks in December 2009:

- 2 columns had 6 ft cut-off and a new 6 ft column section spliced in
- 1 column had 4 ft cut-off and a new 4 ft column section spliced in
- 14 columns had 3 ft cut-off and a new 3 ft column section spliced in
- 12 columns had 2 ft cut-off and a new 2 ft column section spliced in
- 26 columns had 1 ft cut-off and a new 1 ft column section spliced in

Photo 1 – Over tightened bolt at failed 3-1/2" pipe column

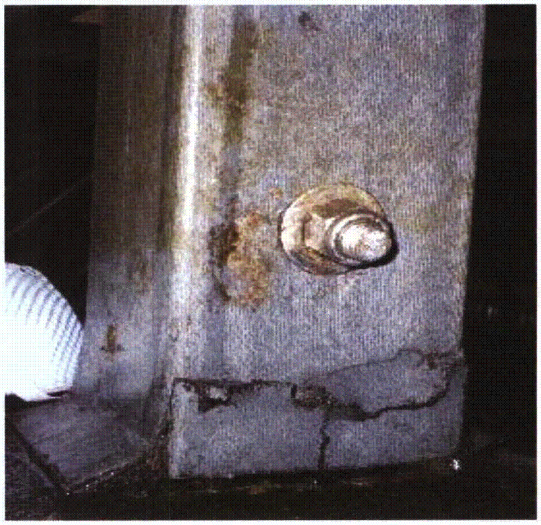

Photo 2 – Failed 3-1/2" pipe column with bottom shearing and mushrooming

There was not enough time during the December 2009 outage to chase out all of the cracks, so 11 pipe columns were left in-place with internal cracks at "horseshoe" reinforcement folds as shown in Photo 3.

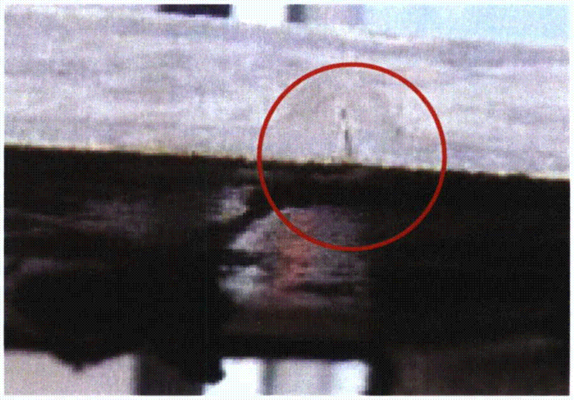

Photo 3 – Internally cracked pipe column at "horseshoe" fold of reinforcement material

This unit had another outage in September/October 2010 and the cold water basin was drained. A total of 35 pipe columns (not found with cracks in Dec. 2009) were now found with cracks or faces starting to shear, and 12 of these columns had 1.5" to 10" cut-off and a stainless steel shim or pedestal installed. A total of 29 of the previous 55 splice repaired pipe columns had the splice removed and a stainless pedestal installed. As a result, 90 (or 54%) of the 168 pipe columns exhibit damage at the bearing pad after 28 months of operation. Below is a summary of what was found and repaired in the fall of 2010:

- 23 columns (not exhibiting problems in Dec. 2009) had small cracks or were starting to mushroom at the stainless pads. These were left as-is and will be monitored.
- 11 columns (not exhibiting problems in Dec. 2009) had 1.5" cut-off and a stainless block (or shim) installed
- 1 column (not exhibiting problems in Dec. 2009) had 10" cut-off and a stainless pedestal installed
- 26 columns (repaired with a splice in Dec. 2009) had 1 ft stainless pedestals installed
- 3 columns (repaired with a splice in Dec. 2009) had 3 ft stainless pedestals installed

Cross-Flow Cooling Tower No. 2

Another new 12 cell, fiberglass structure, cross-flow, mechanical draft tower was completed in May 2008. Figure 2 represents the cross-flow structure for the tower and shows the ~ 48 ft columns (supplied in a single length with no splices) which support the 66" to 30" hot water distribution pipe on top of the hot water deck. There are six transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The 4" and 3-1/2" pipe columns rest on the cold water basin floor. All of the fiberglass columns were originally designed to sit on a fiberglass/neoprene bearing pad.

During a several day outage in March 2010, approximately 75%+ of the fiberglass bearing pads had failed under the pipe columns and a total of 35 highly loaded columns (out of 164) had cracked at the bearing pads and were repaired. A total of twelve 4" columns failed while twenty-three of the 3-1/2" columns failed. Photo 5 represents the worse case failure found in the tower after 22 months of operation. Roughly 35% of the failures were in Cells 1 through 4 under the 66" or 60" hot water pipe, while the other 65% were spread out under the smaller pipes in Cells 5 through 12. The fiberglass bearing pads were replaced by the cooling tower contractor with 304 stainless pads under the high load columns. Below is a summary of how much was cut-off the 35 highly loaded columns (e.g. pipe, motor or gearbox) to remove the cracks in March 2010:

- 10 columns had 17" cut off the bottom and stainless steel pedestals installed
- 25 columns had 1" to 3" cut off and stainless steel blocks (or shim) installed

This unit had another outage in October/November 2010 and the cold water basin was drained. A total of 53 columns (not repaired in March 2010) were found with damage at the stainless steel bearing pad (e.g. cracks, mushrooming or faces starting to shear [Photo 4]), and 19 of these columns had 1" to 17" cut-off and a stainless steel shim or pedestal installed. As a result, 88 (or 54%) of the 164 highly loaded columns have cracked after 28 months of operation. Below is a summary of what was found and repaired in November 2010:

- 34 columns (not repaired in March 2010) had small cracks or were starting to mushroom at the stainless pads. These were left as-is and will be monitored.
- 11 columns (not repaired in March 2010) had 1" to 2" cut-off and a stainless block (or shim) installed
- 8 columns (not repaired in March 2010) had 6" to 17" cut-off and a stainless pedestal installed
- 6 columns (previously repaired in March 2010) had additional column material cut-off and a higher stainless steel pedestal or additional shim plates installed.

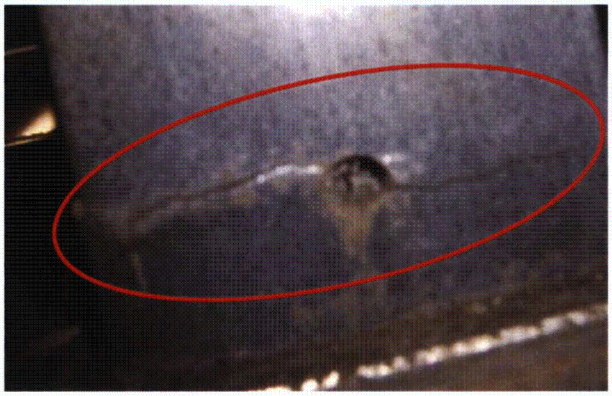

Photo 4 – Pipe column starting to shear along face

Photo 5 – Failed pipe column at FRP bearing pad

Cross-Flow Cooling Tower No. 3

A new 14 cell, fiberglass structure, cross-flow, mechanical draft tower was completed in May 2009. Figure 1 represents the cross-flow structure for the tower and shows the ~ 40 ft columns (supplied in a single length with no splices) which support the 60" to 30" hot water distribution pipe on top of the hot water deck. There are six transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The

3-1/2" pipe columns rest on elevated concrete piers which are at eye level. All of the fiberglass columns were originally designed to sit on a fiberglass/neoprene bearing pad.

During an outage in February/March 2010, approximately 90% of the fiberglass bearing pads had failed under the pipe columns and a total of 39 pipe columns (out of 168) had cracked at the bearing pads. Photos 6 and 7 represent the typical failure found in the tower after just 8 months of operation. Roughly 35% of the failures were under the 60" hot water pipe in Cells 1 through 5, while the other 65% were spread out under the smaller pipes in Cells 6 through 14. The fiberglass bearing pads were replaced by the cooling tower contractor with 304 stainless pads under the high load columns. Below is a summary of how much was cut-off the 39 pipe columns to remove the cracks in February/March 2010:

- 11 pipe columns had 18" cut of the bottom and stainless steel pedestals installed
- 28 pipe columns had 2" to 3" cut off the bottom and grout pads installed

Photo 6 – Cracked 3-1/2' pipe column under a bolt hole

Photo 7 – Cracked 3-1/2" pipe column at corner

Counter-Flow Cooling Tower

A new 10 cell, back-to-back, fiberglass structure, counter-flow, mechanical draft tower was constructed in 2009 and commissioned in early 2010. The columns are constructed of three separate pieces with two levels of splice blocks (designated by the red arrows in Photo 8). The four-bolt splice connections are comprised of a positioning tube inside of the column ends and flat plate on opposite sides. There are eight transverse bays in each cell with the transverse bents spaced every 6 ft, longitudinal bents spaced every 6 ft, and vertical elevations of 6 ft. The 3" and 4" columns rest on the cold water basin. All of the fiberglass columns were originally designed to sit on a fiberglass/neoprene bearing pad. Two 30" hot water distribution pipes enter each of the west side cells to supply water to the east and west back-to-back cells.

During a short March 2010 start-up outage the fiberglass bearing pads were replaced by the cooling tower contractor with 304 stainless pads under the high load columns (3,000 lbs or higher). During this outage a total of 10 highly loaded 3" columns were found cracked where they rest on the bearing pads. It is reported that none of the removed fiberglass plates exhibited any damage or cracks. Three of the 18 ft high 3" columns were replaced, while the other seven had 1" or 2" cut off the bottom and 304 stainless steel blocks installed under the columns. Photo 9 shows several cracks in a 3" column where it rests on the bearing pad.

Photo 8 – Photo of counter-flow tower with column splice elevations shown by red arrows.

Another short start-up outage occurred in May 2010 and the following 3" columns were replaced or repaired;

- 23 columns had cracks at the lower splice and the bottom section was replaced. Photo 10 shows cracks which were typically found at the column edges of the lower splice.
- 8 columns had cracks where the column sits on the bearing plate and were cut short by 1" or 2" and stainless steel blocks installed under the columns.

This unit had another outage in November 2010 and the cold water basin was drained. A total of two 3" columns (not exhibiting cracks in May 2010) now had cracks at the stainless steel bearing pad and both columns had roughly 2" cut-off and a stainless steel shim installed. Two additional 3" columns (not inspected in May 2010) were found with cracks at the lower splice joint, and both of those lower columns were replaced in November 2010.

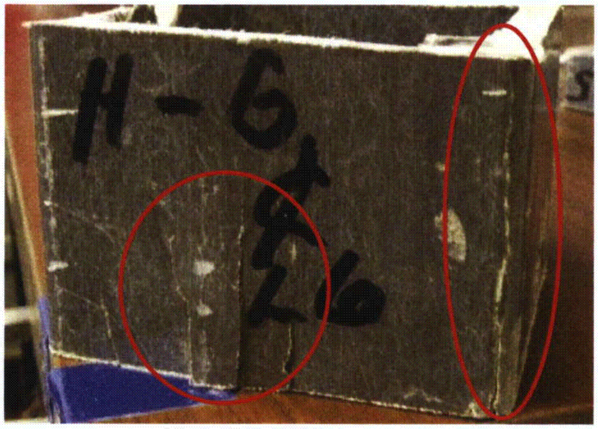

Photo 9 – Cracked column at fiberglass bearing pad

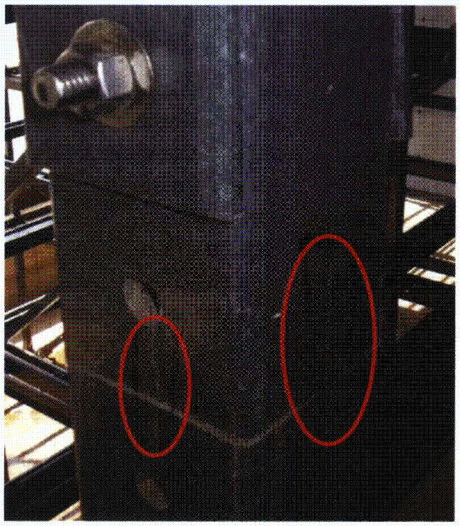

Photo 10 – Cracks at lower splice

Summary of Failed Columns

From a collection of failed column sections pulled from the structures, 80% of the cracks originated from the exterior surface while 20% originated on the interior surface. It was also observed that 70% of the cracks were located on the corners and roughly 30% of the cracks occurred on the face of the column. The failed pipe columns occur throughout the entire length of the tower, with about half of the failures occurring under columns supporting 66" or 60" pipes and the other half of the failures occurring under columns supporting 54" to 30" pipes, motors or fan gearboxes.

A handful of failed fiberglass bearing pads were found during construction and replaced on the cross-flow tower Nos. 1 and 2. It was originally thought debris had been trapped under the bearing pad, or the pedestal surface was not smooth and caused a stress concentration. In hindsight, those bearing pad failures during construction were a warning as to what would happen after the towers were placed in-service.

Below is a summary of the possible failure mechanisms which are causing the cracks in the fiberglass columns.

- The shear capacity of fiberglass is 4,500 psi, so in order to maintain a 3 to 1 safety margin then the highest shear load should be 1,500 psi or less. The calculated applied compressive stress along the seating surface of a 4" x ¼" column (loaded to 13,043 lbs) and a 3-1/2" x ¼" column (loaded to 11,416 lbs) is 3,478 psi and 3,512 psi, respectively.

- Failed column and bearing pad assemblies indicate the column cut into the fiberglass bearing pad (like a cookie cutter), which then caused the bearing pad to become inserted into the column and impose an internal force which overstressed the corners (Reference Photos 11 and 12). The FRP/neoprene bearing pads have been replaced under the high load columns in all the towers with 304 stainless/neoprene bearing pads.

Photo 11 – Failed FRP bearing pad under pipe column

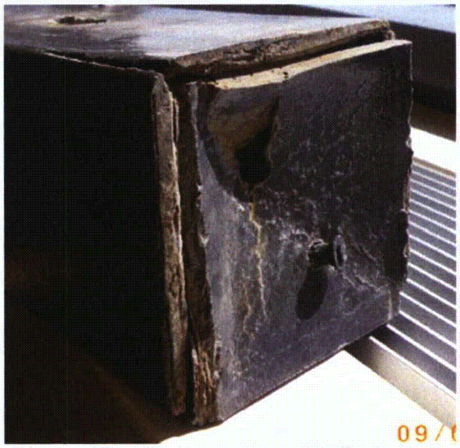

Photo 12 – Bottom view of failed pipe column & pad pushed into column

- Several bolts on the stainless steel anchor clips were over tightened which drew in the bolted surface of the column. Cracks due to over tightening would occur on the interior surface and not be visible during construction inspections.

- If a bolt can not be inserted through all the drilled bolt holes by hand, then construction personnel may pound the bolt through the holes versus threading it through. Bolts pounded through the bolt hole (on the back surface of the column) can fail the surface surrounding the bolt hole by tearing out a chunk. This would typically be covered over by a splice joint or horizontal girt, so it would only be caught by watching construction or randomly disassembling several joints after the tower is constructed.

- The counter-flow tower was "stick built" with 18 ft to 20 ft long columns like wood towers. One of the cooling tower design companies believe if the drilled hole location (in relation to the column end cut) is not within the fabrication tolerances of CTI STD-152 (2002), Table 2.4-1, then a column may crack. The CTI tolerance is +/- 1/16" for hole locations on all shapes less than 30 ft.

- It is also postulated that the use of hammers, rubber mallets or individuals kicking the column ends into position may cause micro-cracks (which are not visible to the naked eye) and then develop into visible cracks once the tower is placed into service.

- There are a number of column failures (e.g. vertical cracks starting from a column edge along the face or corner) which do not appear to fall under any of the above failure mechanisms, so it appears there may be one or more failure mechanisms which have not yet been identified.

CTI Standard STD-152 (2002), paragraph 2.3.2 currently states, "When bolting hollow members such as square tubes, no cracking of the hollow member should be allowed. If a crack is present, the member has failed and the member should be replaced." However, this standard is presently being revised and the new standard may allow some level of cracks and may put the burden on the owner's engineer (not the cooling tower design company) to define what is acceptable or reduces the risk of failure.

SURFACE BLISTERS

Surface blisters were found on two of the cross-flow towers after 18 months of operation. Approximately 20% of the columns in the cross-flow tower No. 2 had dime-size surface blisters which were usually on one face and linear as shown in Photo 13. Roughly 15% of the columns in the cross-flow tower No. 1 had pea-size surface blisters which were on multiple faces and located randomly. These blisters are located throughout the entire length of the towers and from the submerged cold water basin up to the fan deck. Almost all of the pipe saddle side plates (3/4" thick pultruded fiberglass) exhibited thumb-size surface blisters along the submerged area of the hot water deck as shown in Photo 14.

The make-up water sources for the cross-flow towers Nos. 1, 2, 3 and 4 are a fresh water lake or river. AEP feeds 93% concentrated sulfuric acid continuously into the make-up water to control pH, and shock feeds 12.5% concentrated bleach hypochlorite once or twice daily (up to 50 minutes per event) to control biological growth. Buckman Bulab 7126 (1 ppm) or Bulab 7045 (5 ppm) is fed continuously to control scale and act as a dispersant year round, along with Buckman Bellacide 325 several times each week (in 5 gallon doses) at tower Nos. 2 and 4 during the summer months to control algae.

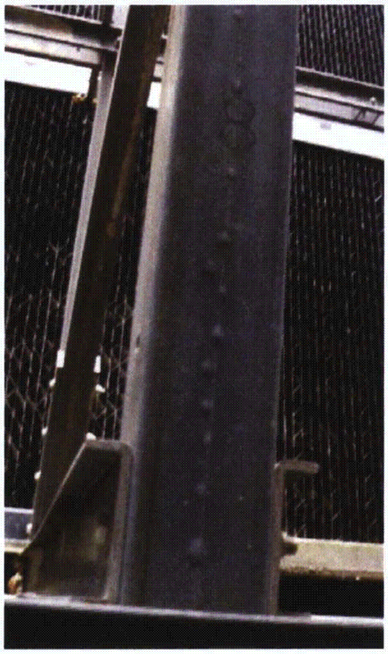

Photo 13 – Blistered Column

Photo 14 – Blistered Pipe Saddle Side Plate

The blisters on a 3-1/2" column under the fan in Cell 8 of the cross-flow tower No. 2 were photographed in Nov. 2009 (Photo 13) and March 2010, and the photos show that the number of blisters increased over that 4 month period.

Several blisters were pricked on the cross-flow tower No. 2 in Nov. 2009 and a honey colored liquid with an acetone odor was collected which ranged from 7 to 8 pH. Laboratory analysis of the liquid found fluoride (3.75 mg/L), phosphate (22.8 mg/L), chloride (84 mg/L), nitrate (121 mg/L), and sulfate (215 mg/L). An IC chromatogram found two peaks of organic acids, two peaks of potentially phosphonated or sulfonated compounds and five other peaks which could not be identified. The pultruder nor the cooling tower contractor have performed a forensic examination of the blistered columns or pipe saddle side plates.

For the period of May 2008 through November 2009, AEP collected all available temperatures, pH and chemistry data for the circulating water systems on cross-flow towers Nos. 1 and 2. AEP's analysis of the above data indicates both towers were operated within the parameters of the specified water condition limits (i.e. less than 125°F, pH range of 6.5 to 9.0, free available chlorine of less than 1.1 ppm or chlorides of less than 450 ppm).

AEP also sent a mass e-mail in early 2010 to approximately 100 individuals associated with utility sized cooling towers asking whether anyone had experienced blisters on pultruded polyester fiberglass shapes. One instance was reported in isolated cells of a cooling tower at a refinery in 2005/06 which was attributed to water chemistry upsets, but specifics were not available. Responses were obtained from 25 individuals and, except for the above instance, no one had experienced blisters. Many utilities stated they were treating the circulating water systems similar to AEP's treatment procedure. Several people offered an opinion that the blisters were due to fabrication problems versus a water chemistry induced issue.

No definitive conclusions have been reached on the blister situation or whether the blisters will affect the long term structural integrity of the pultrusions. AEP is in the process of monitoring the blisters, collecting more samples for analysis, and has set-up a laboratory experiment at AEP's Dolan Lab (near Columbus, Ohio).

AEP FREEZE/THAW TESTS ON PULTRUDED FIBERGLASS

At AEP's Dolan Lab in mid 2009, a total of 16 small sections (3/8" x 1") were obtained from 3" x ½" flat strips, 3" x ¼" flat strips and ¼" thick tube (column). Eight of the samples exhibited internal porosity while the other eight samples did not exhibit any visual defects. All the samples were measured and photographed with an electron microscope prior to any testing and after testing.

It was detemined that soaking each sample in ~ 70°F water for a half hour provided a saturated sample. The weight difference between the dry and saturated samples was roughly 1% to 2%.

Two groups of the saturated samples were frozen and then either fan dried or placed in an oven maintained at 115°F until all moisture was driven out of the samples. The other two groups of saturated samples were not frozen, but were either fan dried or oven dried at 115°F. The process for all four conditions was repeated eight times before each sample was again viewed and documented via an electron microscope.

A total of 83 defects were documented in the 16 samples, but not all defects were measured. The defects increased in size under all four of the conditions, but it appears more changes occurred when the samples were subjected to a 115°F temperature which is the upper design operating temperature of the cross-flow cooling towers.

It was observed that changes in the length or width of the cracks or voids occurred after the first cycle. It was also observed that two column sections (with no visual defects prior to testing) developed cracks after the soak/freeze/air dry cycling. The electron microscope does not have the capability of providing light or measuring depth into the photograph.

This data raises concerns about the expected life of saturated FRP components subjected to freezing and/or 115°F conditions, and whether exposed ends (from cutting, drilling, etc.) need to be coated.

AEP LESSONS LEARNED

Based upon the above pultruded fiberglass structural failures, surface blisters, testing and recent lessons learned on five new fiberglass cooling towers, below is AEP's current design philosophy for new fiberglass structure cooling towers.

New fiberglass towers shall comply with CTI STD-137 "Fiberglass Pultruded Structural Products for Use in Cooling Towers", and CTI STD-152 "Structural Design of FRP Components". All exceptions to these standards must be detailed in writing at the time of bid.

Minimum design stresses, water immersion correction factor and temperature correction factor, etc. are to comply with CTI STD-137. The structure's design basis is to incorporate the cooling tower contractor's published construction tolerances (i.e. column plumbness, cut end squareness, cross-sectional thickness, enlarged bolt holes, drilling tolerances, etc.). As a result, the reduction of a structural member's load carrying capacity due to the contractor's published construction tolerances shall not be covered by (or included in) the CTI service factors.

Any visually cracked structural member shall be replaced (at the expense of the cooling tower contractor) during construction and throughout the entire length of the warranty period. Any closed structural members (columns) which exhibit the surfaces being drawn together because of over tightened bolts shall be replaced (at the expense of the cooling tower contractor) even if no visual cracks are on the external surface. Contractor shall provide construction details to preclude over-tightening of bolts (e.g. use of torque wrenches, helical washers, lock nuts, etc.).

All fiberglass structural components are to be pultruded reinforced fiberglass with thermosetting resin and UV inhibitors throughout the cross-section. All fiberglass components are to be delivered to the plant site in a finished condition, so that no field applied resins are required.

A minimum of a 0.010 inch thick veil is required on the surfaces of all structural components (i.e. columns, diagonals, girts, handrails, etc.), and the veil is to incorporate proper UV inhibitors for long term exposure to ambient conditions. CTI STD-137 (09) states a 0.007 inch thick veil is standard.

All glass products shall be boron free. The glass products shall be Type E or Type E-CR (corrosion resistant).

Fiberglass bearing pads are unacceptable. All columns are to have full bearing contact to the cold water basin (with no gaps between the column and concrete) prior to tower completion. All column splice joints are to have full bearing contact between column ends.

The cooling tower company is responsible to provide all shop and field quality control and quality assurance requirements on all material, and set aside material not meeting this specification. Owner's engineer will spot audit the material and reject all material not meeting this specification (even if it has been installed). The following visual acceptance criteria will be used during construction and the entire warranty period. The visual acceptance criteria for all fiberglass pultruded products shall comply with ASTM D-4385-08, Visual Acceptance Level III, except for the columns which will have stricter requirements as noted below:

- Presence of any defects in excess of the following definitions shall be cause for rejection. Repairs will not be considered for these defects.
- Blister – Accept to Level I requirements, which does not allow blisters.
- Folded reinforcement – Folded near-surface reinforcement is not permitted along the straight edges if it exceeds 20% of the cross sectional thickness.

- Insufficient cure – Accept to Level II requirements, which does not allow insufficient cure. This will be tested in the shop and field via a Barcol hardness tester, and all values must exceed 45.

- Internal porosity – Accept to Level II requirements.

- Internal shrinkage cracks – No more than two (2) internal shrinkage cracks on each face of a cut end. All internal shrinkage cracks are defined as oriented perpendicular to the internal ply or reinforcement. If an internal shrinkage crack penetrates any internal ply or reinforcement, then it is defined as a crack and the piece is rejected. Any cracks oriented parallel to the internal ply or reinforcement will be defined as a delamination and rejected.

- Resin-rich areas – Accept if material reduction thickness is not over 10% and the area width is 1/8" or less. May be continuous in length, but not more than one area on a face. Resin-rich areas on opposing surfaces are not permitted. Must satisfy dimensional requirements.

The stated thickness of the pultruded shapes shall not deviate by more than 10% of the nominal thickness.

All holes are to be drilled and shall not exhibit "splinters" or "gouges" on the backside. No punched holes are acceptable.

The fiberglass pipe joints shall comply with CTI STD-154 for "Cooling Tower Filament Wound Fiberglass Piping Systems". Specifically, all joint wraps shall have a minimum thickness equal to the pipe thickness, and the overall wrap length shall be 26 times the pipe wall thickness and tapered at both ends to provide a smooth transition. In addition, all wrapped joints are to be performed by a qualified and certified technician.

CONCLUSIONS

The cooling tower contractor has been responsive in performing warranty repairs to these cooling towers, and we are continuing to work with the cooling tower contractor to identify all of the failure mechanisms.

There are no current national standards which completely covers the design, fabrication and construction of fiberglass cooling towers. The individual owner/buyer needs to become extremely knowledgeable about pultruded fiberglass before the specification is submitted for bidding so the final product is acceptable to the owner for a 30 year operating life. AEP has offered several clarifications in this paper in relation to current CTI Standards with the expectation that a better pultruded product can be specified, provided and constructed.

It appears that all the failure mechanisms for pultruded products are not completely understood, and the pultruders, cooling tower contractors and tower owners will need to work together to comprehend why column bottoms are cracking/failing and what can cause surface blisters.

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APPENDICES

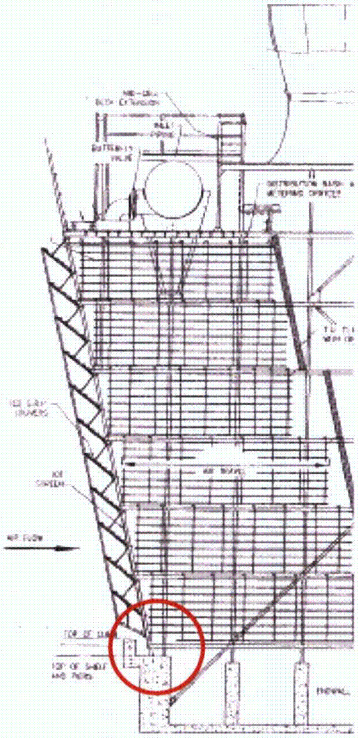

Figure 1 – Transverse Cross Section of a Cross-Flow Cooling Tower
3-1/2" Pipe Column Sits on Elevated Concrete Pier

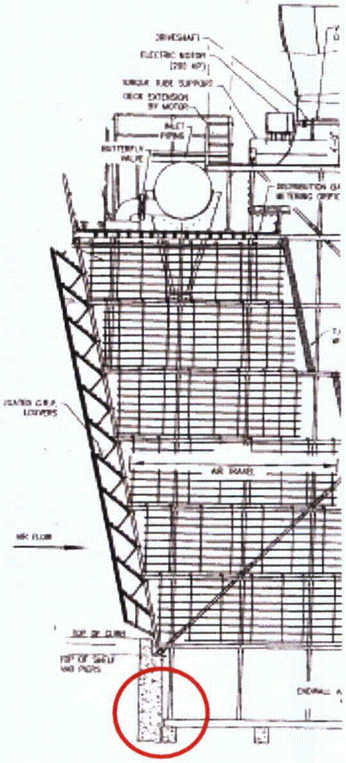

Figure 1 – Transverse Cross Section of a Cross-Flow Cooling Tower
4" & 3-1/2" Pipe Columns Sit on Cold Water Basin Floor

PAPER NO: **TP09-25**
CATEGORY: **LEGIONELLA**

COOLING TECHNOLOGY INSTITUTE

A SYSTEMATIC REVIEW OF BIOCIDES USED IN COOLING TOWERS FOR THE PREVENTION AND CONTROL OF *LEGIONELLA* spp. CONTAMINATION

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Abstract

Introduction: The use of biocides is very important for controlling *Legionella* contamination in evaporative cooling systems. This study is a systematic review of research studies that evaluated the effectiveness of biocides in evaporative cooling systems for *Legionella* control.

Methods: Published journal articles, dating from 1980-2008, were included if theses studies were field test of biocides against *Legionella* in operating cooling systems or tests preformed in a model cooling system that was spiked with *Legionella* spp. or used actual cooling water collected from an operating cooling system.

Results: Of the 52 journals produced from the systematic review, 20 articles meet the inclusion criteria. The types of biocide studies included 9 articles that tested only chemical biocides, 3 articles that tested only non-chemical biocides, and 8 articles that compared chemical and non-chemical biocides.

Discussion: The common end point for most of these studies was the measured reduction in the *Legionella* count in the cooling water after the addition of the biocide. There were not many studies conducted on the same kinds of biocides. When the same biocides were tested in more than one study, the results rarely agreed. Also, scientific statistics were rarely applied to the outcomes in many of these studies.

Future Research: Biocides need more field testing in order to generate better scientific evidence as to their effectiveness against *Legionella* spp. in operating evaporative cooling systems.

Introduction

Legionella is a family of bacteria that causes Legionnaires' disease and Pontiac fever, collectively known as legionellosis. Many outbreaks of legionellosis have been attributed to infected evaporative cooling systems including the first recorded outbreak at the Bellevue-Stratford hotel in Philadelphia, PA in 1979 (Respiratory infection- Pennsylania.1997). The Center for Disease Control and Prevention estimates 10,000 to more than 100,000 cases occur each year with a case-fatality rate of 8% (Hicks et al., 2007; Sheldon, Kerbel, Witherall, & Millar, 2000). Since the first recorded outbreak of legionellosis, an effort has been made to establish the best maintenance practices in evaporative cooling systems to control *Legionella* contamination and prevent further legionellosis outbreaks. Evaporative cooling systems operate at a pH range of 6.8 to 9.2, a temperature range of 25°C to 45°C which provides optimal growing conditions for *Legionella* species (spp.) (Bartram, Chartier, Lee, Pond, & Surman-Lee, 2007). Biocides are only one small part of controlling the *Legionella* contamination. The objective of this study was to do a systematic review of journal articles that investigated the efficiency of biocides to reduce the *Legionella* population in evaporative cooling systems.

Methods

A systematic review was conducted of journal articles published from 1980 to 2008. The journal articles were found using the following search engines: PubMed, PubMed Central, Ovid Medline, Google, Google Scholar, Highwire Press, Academic Universe, and Springerlink. Key words used to locate these journals included: "*Legionella* and biocides", "biocides and cooling towers", "biocides and cooling water", "*Legionella* and cooling towers", "biocides and *Legionella* and cooling towers", and Legionnaires' disease prevention". Also, the bibliographies of any relevant published literature were also searched for other pertinent articles. All study designs will be included as long as they meet the other inclusion criteria. The inclusion criteria consists of published studies that contain the following information: biocides used against *Legionella* in cooling towers, experiments performed in a cooling tower or model cooling system, uses *Legionella* bacteria isolated from the water of an operating cooling system or the water from an operating cooling system, the studies must be written in English, and are readily available. Journals not in English, not readily available, studies preformed with tap water infused with *Legionella* species from the American Type Culture Collection (ATCC) cell bank were eliminated from the study. Study papers presented at conferences were included as long as they met the inclusion criteria. These references were organized using Refworks©.

Results

The journal search produced 489 papers. Of these, only 52 were relevant to *Legionella* control in evaporative cooling systems. Applying the inclusion criteria produced 20 papers. The study types of these papers incorporated 16 experimental studies, 3 cross-sectional studies and one cost-effectiveness analysis. The types of biocides studied were as follows: 9 articles that tested only chemical biocides, 3 articles that tested only non-chemical biocides, and 8 articles that compared chemical versus non-chemical biocides. Tables 1 through 3 provide a brief summary of each article by displaying the study design, sample size and description, the location where the study was conducted, the type of biocides studied, and the results of each study.

Chemical Biocides

Table 1 describes the articles that only studied chemical biocides. The majority of these studies were conducted in the US, 2 were conducted in the UK, one in South Australia, and one in Spain. Three of these studies were conducted in a lab setting. One of these lab studies used

Legionella species isolated from cooling water and tested 8 different biocides, both alone and in combination (Garcia & Pelaz, 2008). The other two used *Legionella* species from ATCC in water samples collected from cooling towers and tested one biocide each (McCoy, Wireman, & Lashen, 1986; McCoy & Wireman, 1989). The endpoints of these studies were the fastest and most significant bacterial count reduction at different concentrations of biocide and pH. Four of the chemical biocide studies were long term field trials of biocides in cooling towers (Bentham & Broadbent, 1995; Fliermans & Harvey, 1984; Prince et al., 2002). Two of these studies collected water samples before biocide treatment within a 2 week to 5 month period, and then collected water samples after the biocide treatment for an additional 4-5 months. The other two studies randomly selected 14 or 16 cooling towers to treatment or control groups. Both trials lasted for 4 weeks with water samples taken from twice a week to every two weeks. The remaining two studies were cross-sectional studies. The first study gathered 2590 water samples from 1000 cooling towers in nine US states and reviewed the prevalence of *Legionella* and high *Legionella* counts in cooling towers utilizing eight different biocides both singly and in combination (Miller & Koebel, 2006). The other cross-sectional study simply reviewed the prevalence of biocide use among refinery and power plant cooling systems (Veil, Rice, & Raivel, 1997).

Non-Chemical Biocides

Table 2 describes the articles that only tested non-chemical biocides. Non-chemical biocide studies were reported in 3 articles. Two of them used an experimental study design and one was a cross-sectional study. Among these studies, one was conducted in the US, one in Finland, and one in South Australia. Two of these articles were long term field trials: one testing the e-disinfector (electrolytic disinfection) and the other testing ultra-violet irradiation (Forstmeier, Wozny, Buss, & Tolle, 2005; Kusnetsov et al., 1994). The UV-lamp field trial lasted for 33 days while the e-disinfector field trial lasted for 7 weeks. In both of these trials, before treatment and after treatment water samples were taken and the *Legionella* counts were compared. The remaining article was a cross-sectional study that collected 13 water samples from a single cooling tower over an unspecified period of months. The goal of this study was to establish correlations between *Legionella* growth and one or more of the following variables: alkalinity, pH and certain dissolved minerals.

Chemical versus Non-Chemical

The last category of articles includes studies that compared chemical biocides to non-chemical biocides in controlling *Legionella* populations (See Table 3). The majority of these studies were conducted in the US, but one was conducted in Finland and another in Japan. Five of these studies were side-by-side field trials comparing conventional chemical treatments to the non-chemical treatments where the cooling towers were randomized to one treatment per tower (Bisbee, 2003; Kitzman, Mazaiara, Padgett, Blumenschein, & Smith, 2003; Kusnetsov, Tulkki, Ahonen, & Martikainen, 1997; Pope, Eichler, Coates, Kramer, & Soracco, 1984; Yamamoto, Ezaki, Ikedo, & Yabuuchi, 1991). The study time frames for these field trials ranged from 4 months to 2 years. The water samples were taken from as little as once per month to as much as 5 times per week. Two other studies gave one treatment for a length of time and then began the second treatment for another period of time (Gilpin et al., 1985; McGrane & Ditzler, 1994). Each study time frame for the alternating treatments ranged from 2 hr to 2 months per treatment. Gilpin *et al.* also conducted a cross-sectional study on one cooling tower where water samples were collected every 2-3 days for 2 months. The goal of this survey was to monitor the *Legionella* population in this cooling tower which was under chemical treatment (Gilpin et al., 1985). The remaining article was a cost-effectiveness analysis for chemical and non-chemical treatments (Envirometrics Staff, 2004). The goal of this article was to identify the most useful and cost-effective biocides used in cooling towers.

General Results

For some biocides, a consensus on their overall effectiveness against *Legionella* and other heterotropic species simply does not exist. Bromo-chloro-dimethylhydantoin (BCD) was used in three studies, however there is a not consensus among these studies for BCD (Bentham & Broadbent, 1995; Fliermans & Harvey, 1984; McCoy & Wireman, 1989). Two studies reported that BCD is effective and one reported that it is not effective in reducing *Legionella* counts. 2-bromo-2-nitro-propane-1,3-diol (BNPD) was used in three studies (Bentham & Broadbent, 1995; Kusnetsov et al., 1997; Yamamoto et al., 1991). One study reported BNDP to be ineffective, one reported that it is only temporary effective, and a third study reported that it was effective at reducing *Legionella* in cooling water. Chlorine was used in four studies as a comparison group in the form of sodium hypochlorite or calcium hypochlorite although Veil *et al.* found it to be the most prevalent among biocides used in power plants and refineries (Envirometrics Staff, 2004; Garcia & Pelaz, 2008; Gilpin et al., 1985; McGrane & Ditzler, 1994; Veil et al., 1997). These studies found that chlorine was effective in reducing the *Legionella* count to 1000CFU/mL or less, but it was ineffective in reducing the total bacterial count. Five studies used the non-oxidizing biocide iosthiozolone in which two of these studies claim that it is effective and three which claim that iosthiozolone is ineffective for controlling *Legionella* and THC (Garcia & Pelaz, 2008; Kitzman et al., 2003; McCoy et al., 1986; Prince et al., 2002; Yamamoto et al., 1991). Pulse-power system disinfection and ozone were used in three studies each. PPS and ozone were individually compared to chemical treatments and found to be more effective than the chemical biocides (Bisbee, 2003; Kitzman et al., 2003; McGrane & Ditzler, 1994; Pope et al., 1984). However, the UV irradiation was found to be effective in one study and ineffective in three studies due to the fact that the basin was not subjected to the UV-light and thus was able to harbor the proliferating *Legionella* (Kusnetsov et al., 1994; Yamamoto et al., 1991). Miller *et al.* reported that all of the cooling towers included in their study harbored *Legionella* regardless of the type of chemical biocides used (Miller & Koebel, 2006). The most consistent feature of all the articles was that they all used the standard *Legionella* culture test.

Discussion

The studies included in this review revealed many different study designs and study lengths. The common endpoint was basically the reduction of *Legionella* species and, for some, total heterotrophic species counts (THC) during the time allowed. The study designs varied from laboratory experiments to randomized field trials to cross-sectional studies. For the laboratory studies, the study length ranged from 1hr to 24hrs. Also the number of biocides studied ranged from one, at varying pH levels, to 8, including all combinations of the 8 biocides. The randomized field trials also varied in length, frequency of sampling, and the use of different biocides. The frequency of the sampling has recently been proven to be a critical issue. Bentham and Broadbent in 2000 showed that the sampling of 28 cooling towers twice a week for sixteen weeks yielded means of less than 100 CFU/mL for most of the cooling towers, but the standard deviations were typically three times the means. These results show that the level of *Legionella* in cooling water is constantly in flux (Bentham, 2000). These data question the accuracy of sampling for *Legionella* once a week as a measure of the effectiveness of the biocides.

Of the articles included in this study, only a few of them used any actual statistics to report their data and instead reported only observational data. The "before and after" studies could have used a paired t-test to evaluate whether or not the reduction in the *Legionella* counts was truly significant.

The studies also varied types of biocides used. Very few of the articles incorporated the same biocides and the results often varied greatly. Many variables in the field can affect the efficiency of the various types of biocides. Some of these include: the turbidity of the make-up water, the pH must be in the correct range, the use of other chemicals (i.e. anti-corrosion agents and biodispersants), the total amount of dissolved solids, the amounts of dissolved organic chemicals, and even the season (Prince et al., 2002). Other factors for controlling *Legionella* growth include removal of organic and inorganic materials and deposits that can harbor *Legionella* as well as other bacterium and promote their growth (Cooling Technology Institute, 2008). *Legionella spp.* have the virus-like ability to reproduce inside of protozoa and amoebae (Atlas, 1999; Barbaree, Fields, Feeley, Gorman, & Martin, 1986). So biocides that did not significantly reduce the THC, allow for the rapid re-colonization of *Legionella*. Most of these studies only focused on the *Legionella* count but not the THC. Srikanth and Berk have found that some non-oxidizing biocides actually stimulate the growth of amoebae in cooling towers, and amoebae containing *Legionella* may adapt to these biocides (Atlas, 1999; Srikanth & Berk, 1993; Srikanth & Berk, 1994). Moreover, most of these studies included an initial cleaning phase followed by either continuous or slug doses of biocide without any additional treatments.

Future Research

Although *Legionella* species are ubiquitous in evaporative cooling systems and nearly impossible to eliminate totally, the level of contamination can be controlled to a benign state (Bentham, 2000). Deciding which biocides are well suited to this task is difficult since there is limited field research available. There are many biocides that are commercially available, but few of them have been field tested by unbiased parties or compared to other biocides to assess their efficiency. Some biocides, such as chlorine dioxide, have been found to be effective in potable water systems, but this system has not been fully applied or studied in cooling towers (Envirometrics Staff, 2004). According to Yu, many cooling system guidelines recommend conscientious maintenance to prevent *Legionella* proliferation, yet there is little data to support "the claim that maintenance minimizes colonization by *Legionella* and that control measures are useful in preventing outbreaks of Legionnaires' disease from cooling towers" (Yu, 2008). Clearly, this field of research is still wide open. Science has only begun to understand the best practices for *Legionella* control and prevention. More scientific evidence is needed to back up claims that one water treatment program is better than another. In the future, well designed scientific studies need to be conducted in order to establish what the best practices for *Legionella* control truly are.

Table 1: Chemical Biocides

Author/ Date	Study Design	Biocides/ dosage	Sample Description/ Location	Results
Bentham and Broadbent (1995) (Bentham & Broadbent, 1995)	Experimental	CPTE and BNPD at 200ppm, BCD[1] at 350g –slug dose	16 cooling towers in South Australia maintained to Australia's Standard, 15-300kW	1. Mean time to non-detection ±SD days 2. Mean time to reduction ±SD days CPTE: un-detection 5.4 ± 4.1d, reduction=13.8±13.0d BCD: un-detection=5.5 ± 5.3d, reduction=19.0±11.0d BNPD: *Legionella* counts not reduced
Garcia and Pelaz (2008) (Garcia & Pelaz, 2008)	Experimental	A. sodium hypochlorite B. Hydrogen peroxide/silver nitrate C. Didcyldimethylammonium chloride D. Benzalkonium chloride E. Ammonium salts & tributyltetradecylphosphium choloride F. THPS[4] G. DBNPA[4] H. Heterocyclic ketone chloromethylisothiazolone	*Legionella* from cooling towers (6), hotels (2), spa (1), & cruise ship (1) associated w/ outbreaks. Cultures were suspended in hard water and biocides added signally and in combination. Conducted in Spain.	G at 1ppm, A at 1ppm, H at 4ppm, and F at 16ppm induced MBE[2]. A and G produced the best FBE[3]. *Legionella* showed resistance to A, B, D, and F after 7 days. H, F, and B were dose depended. All of the disinfectants showed a bactericidal effect.
Flierman and Harvey (1984) (Fliermans & Harvey, 1984)	Experimental	No treatment for 4 months BCD[1] 0.2-0.5pmm continuous for 4 months. Sampling once per month.	One cooling tower: cooled 1000gal/min, pH6-7.5, temperature 27.5°C in South Carolina.	No effect at 0.2-0.5ppm, 1.5-2.1ppm continuous feed did not reduce the *Legionella* counts either.
Kurtz, JB *et al.* (1982) (Kutz, Bartlett, Newton, White, & Jones, 1982)	Experimental	1. Quaternary ammonium compound dimethyl-didecyl ammonium chloride (QAC/TBTO) 2. CPTE 3. sodium di-chlor-isocynurate (SCL) All biocides to maintain a free chlorine level of 0.5-2.0ppm for at least 4hr.	14 cooling towers randomly selected to one of 3 treatment groups or 2 control groups in London.	The doses and frequency used for QAC/TBTO and SCL were ineffective in reducing *Legionella* counts. CPTE only temporarily reduce the *Legionella* count below the detectable level.
McCoy, Wireman, and Lashen (1986) (McCoy et al., 1986)	Experimental	Methlychloro/methylisothiazolone various dosages	Cooling tower water w/o biocide present, pure *Legionella* cultures. Conducted in Michigan.	99% killed 6hr at 1.07ppm and 3hr at 3.13ppm at pH8.0 99% killed 6hr at 2.23ppm and 3hr at 9.43ppm at pH6.7 4x reduction w/ 24hr at 0.35ppm at any pH.

Table 1: Chemical Biocides, continued

Author/ Date	Study Design	Biocides/ dosage	Sample Description/ Location	Results
McCoy, and Wireman (1989) (McCoy & Wireman, 1989)	Experimental	BCD[1] 0.3-0.4ppm of FRC[5]	Cooling tower water w/o biocide present, pure *Legionella* cultures. Conducted in Michigan.	>99.99% reduction in viability in 10 and 20 min at pH6.0 and 0.5-1.8ppm, At pH8.5, >99.99% reduction in 20min at ≥1.0ppm.
Miller, RD and Koebel, DA (2006) (Miller & Koebel, 2006)	Cross-Sectional	1. Bromine 2. Quaternary ammonium compounds (QAC) 3. Carbamate 4. Isothiazolone 5. Glutaraldehyde 6. Hydrogen peroxide 7. DBNPA[4] 8. THPS[4] 28 different combinations were studied.	From 1998-2004 1,000 cooling towers in the US were sampled for *Legionella* prior to slug-fed doses of biocides. Total of 2590 water samples were collected from these towers.	Percent of cooling towers found with detectable *Legionella* counts (>10CFU/mL) and high counts (>1,000CFU/mL), respectively: count ± 95% CI 1. Bromine= 16 ±3%, 3 ±1%, n=572 2. QAC= 14±3%, 2 ±1%, n=484 3. Carbamate= 12±2%, 2±1%, n=929 4. Isothiazolone=12±2%, 2±1%, n=1224 5. Glutaraldehyde=15±2%, 2±1%; n=843 6. Hydrogen peroxide= 14±4%, 5±2, n=294 7. DBNPA[5]= 28±11%, 5±4%, n=61 8. THPS[5]= 7±2%, 1±1%, n=397
Prince, EL *et al.* (2002) (Prince et al., 2002)	Experimental	First, Bromine for 2 weeks Then Aqualox: "an aqueous solution of mixed oxidants generated on-site by electrolysis of a dilute saline solution in a proprietary electrochemical cell" pg. 243 for 5 months Isothiazolone was added monthly for biofilm control during entire study.	Tower 1: metal construction, make-up water from potable water mains. Tower 2: fiber-glass construction, make-up water from low-grade, non-potable source. Both previously treated with BCD 0.5-2ppm. Conducted in UK.	*Legionella* ssp. counts 1900-4000 CFU/L during pre-study, and none were detected during Aqualox-treatment in the 5 months of the study. Total viable count (TVC) during pre-treatment gave a mean of 10^5 CFU/mL, but after the Aqualox treatment, the mean fell to less than 10^3 CFU/mL. Isothiazolone showed no evidence of a significant TVC reduction in either tower. The free oxidant was between 0.3-1.0ppm for both towers.
Veil, JA *et al.* (1997) (Veil et al., 1997)	Cross-sectional	Studied which biocides were used most frequently in power plants and refineries	US: 67 power plants and 15 refineries	Power plants: n=67 Chlorine (n=53) the most prevalent, 7 plants don't use any biocides, 33 use oxidizing only, 6 use only non-oxidizing, and 21 use a combination of both. Refineries: n=15 Chlorine n=10 and bromine n=7. 2 plants use only one biocide, 8 plants use 2 kinds of biocides, and 5 plants use 3 different biocides.

[1] Chlorinated phenolic thioether (CPTE), 2-bromo-2-nitro-propane-1,3-diol (BNPD), bromo-chloro-dimethylhydantoin (BCD)

[2] Minimal bactericidal effect (MBE): The lowest concentration of the disinfectant able to induce bactericidal effect in all of the strains within 24 hours.

[3] Fastest bactericidal effect (FBE): The lowest concentration of the disinfectant able to induce bactericidal effect in all of the strains within 1 hour.

[4] 2-2-dibromo-3-nitropropionamide (DBNPA), tetra-(hydroxymethyl)phosphonium sulfate (THPS)

[5] Free residual chlorine

Table 2: Non-chemical biocides Only

Author/ Date	**Study Design**	**Biocides/ dosage**	**Sample Description/ Location**	**Results**
Forstmeier, M *et al.* (2005) (Forstmeier et al., 2005)	Experimental	E-disinfector: disinfects by hydroxyl radicals and produces a controlled free chlorine level without the additional of chemicals. Pg 762	One cooling tower over 2 months in South Australia.	Free chlorine level was maintained at 1.9mg/L so corrosion is reduced at this free chlorine level. TBC[1] were maintained <10^5CFU/mL, and *Legionella* counts were <10 CFU/mL[2].
Kusnetsov, JM *et al.* (1994) (Kusnetsov et al., 1994)	Experimental	Ultra-violet irradiation 13.8W per lamp (2 lamps total) at 253nm wavelength for 33days. Sampling occurred before and after the UV lamps.	A cooling system for telecommunication appliances. Conducted in Finland.	Field test of UV-radiator was not as efficient as in lab tests due to the stable concentration in the reservoir water, biofilm and sediment in the basin and the reactivation of damaged cells. Also build-up of debris to the UV-lamp surfaces.
States, SJ *et al.* (1987) (States et al., 1987)	Cross-sectional	Alkalinity pH Dissolved minerals (particularly Mn)	13 Water samples collected from a cooling tower basin in Pennsylvania.	Alkalinity ($P \leq 0.005$) and pH (≤ 0.01) were positively correlated with *Legionella* growth. Mn ($P=0.01$) was positively correlated with *Legionella* growth but less than alkalinity and pH.

[1] Total bacteria count (TBC)

[2] *Legionella* counts <10 CFU/mL are below the detectable amount for the test.

Table 3: Chemical versus non-chemical biocides

Author/ Date	Study Design	Biocides/ dosage	Sample Description/ Location	Results
Bisbee, D (2003) (Bisbee, 2003)	Experimental	Pulse-powered system (PPS) vs. chemical treatment	Two 239-ton cooling towers one with each biocide for one year in California.	PPS produced total bacterial levels of 1,000CFU/mL, reduced water usage by 68% over the chemically treated system.
Envirometrics Staff (2004) (Envirometrics Staff, 2004)	Cost-effectiveness analysis	Chlorine (Sodium Hypochlorite) Chloramine Chlorine dioxide Copper-sliver Ozone Ultraviolet light Pulsed Power systems	Review of other US studies.	Ozone, copper-sliver and pulsed power systems appear to be the most useful and cost-effective alternatives to chlorine for controlling *Legionella* contamination.
Glipin, RW *et al.* (1985) (Gilpin et al., 1985)	Experimental	Calcium hypochlorite Ultraviolet light Dodecylguanidine hypochloride and calcium hypochlorite-treatments used the surveyed cooling tower. Added on different days weekly	Evaporative condenser: First treated with chlorine for 10weeks then treated with UV-light for 6weeks with water samples taken 5 times per week. Cooling tower survey: sampled at 2-3 day intervals for 2 months. In Pennsylvania.	Evaporative Condenser: Before UV =1.1 x10^3CFU/mL *Legionella* After UV = 0.2 x10^3CFU/mL *Legionella* Reduction *P*=0.001 Cooling Tower survey (n=27) count ± SD TBC from pool water= 3.0x10^5±3.2x10^5CFU/mL TBC form slat surface=5.7x10^6±7.5x10^6CFU/mL *Legionella* count=59 ± 6.8CFU/mL
Kitzman, KA *et al.* (2003) (Kitzman et al., 2003)	Experimental	Chemical treatment (CT): alternating isothiazolone and glutaraldehyde Pulse power system (PPS) Hydrodynamic Cavitation (HDC)	3 side-by-side but independent cooling towers in South Carolina, one tower per treatment for six months.	Mean Planktonic bacterial count: (max level <1x10^5) CT=1.27x10^6CFU/mL PPS=6.5x10^4CFU/mL HDC=9.55x10^4CFU/mL Mean Sessile bacterial count: (max level < 2.0x 10^5CFU/cm^2) CT=2.5x 10^6CFU/cm^2 PPS=5.9x 10^5CFU/cm^2 HDC=1.9x 10^5CFU/cm^2
Kusnetsov, JM *et al.* (1997) (Kusnetsov et al., 1997)	Experimental	Lower Temperature (< 20°C) Improved Water Quality using tap water PHMB[1] at 43mg/L BNPD at 65-190mg/L	5 cooling systems: A and B lowered temperature, C with improved water quality, D with PHMB and E with BNPD. Conducted in Finland for 2 years.	Lowering of the water temperature did decrease the Legionella counts below 1,000CFU/L, but not TBC. Changing to tap water was only temporally effective in reducing the Legionella count. Both BNPD and PHMB lowered both the *Legionella* and the TBC for only 3weeks
McGrane, WK *et al.* (1994) (McGrane & Ditzler, 1994)	Experimental	Sodium Hypochlorite: 1.0 ppm free chlorine for 2hr. Ozone: 0.1ppm for 2hr. Samples take at 0, 1, and 2hrs.	Model cooling tower with the known bacterial and amoeba ssp. added to the model system including *Legionella pneumophila* sp. 1. In Georgia.	TBC: Chlorine = from 4.65 x10^6 CFU/mL at 0hr to 3.11 x10^6 CFU/ml at 2hr. Ozone= from 1.4x10^7 CFU/mL at 0hr to 6x10^3 at 2hr. *Legionella*: Chlorine= from 5.8x10^5 CFU/mL at 0hr to 2.6x10^3CFU/mL at 2hr. Ozone= from 2.9x10^4CFU/mL at 0hr to 0 CFU/mL at 1 and 2hr.

Table 3: Chemical versus non-chemical biocides, continued

Author/ Date	**Study Design**	**Biocides/ dosage**	**Sample Description/ Location**	**Results**
Pope, D.H *et al.* (1984) (Pope et al., 1984)	Experimental	Ozone (0.33lb/day, conc. 0.6-1.8mg/L) Chemical treatment = 138ppm once / week of disodiumcyanodithiomido carbonate and potassium N-methyl dithiocarbamate.	2 cooling towers in NY. Tower A was the control (chemical treatment), and Tower B treated with ozone. Treatments were reversed after 2 months	TBC[2] Means: 1.7×10^5 cells/mL control and 4.4×10^2 cells/mL for the ozone tower, $P<0.0001$. Legionella Mean counts: $P<0.001$ reduction, 63% fewer in the ozone tower than the control tower.
Yamamoto, H. *et al.* (Yamamoto et al., 1991)	Experimental	1. initially cleaned w/ 3% hydrogen peroxide only, no additional biocides added 2. glutaraldehyde added once at 0.1% 3. continuous bronopol (BNPD) 4. continuous isothiazolone 5. UV lamp 110W w/ flow rate of $2.5m^3/h$ 6. UV lamp 60W w/ flow rate of $4m^3/h$ 7. UV lamp 40W w/ flow rate of $1.3m^3/h$	7 cooling towers (CT) <100 capacity ton with initial *Legionella* counts of 10-10^2CFU/100mL in Japan. One treatment per tower for 3-4 months.	CT 1: In 2 weeks, THC[3] increase from 10^4 to 10^7 CFU/mL & *Legionella* count 10^5 CFU/mL CT 2:THC & *Legionella* levels decreased when added but increase to initial level after 2 weeks. CT 3 & 4: THC results were similar to control (1) but *Legionella* growth was suppressed during 4 month study. CT 5, 6, &7: THC decreased from 1/10 to 1/100 of control (1) but *Legionella* counts reached 10^5 CFU/mL in 5 weeks. UV-sterilization did not include the basin area which allowed *Legionella* growth in the basin.

[1] Polyhexmethylene-bigluanidechloride (PHMB)
[2] Total Bacterial Count (TBC)
[3] Total Heterotropic bacterical Count (THC)

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CATEGORY: DRIFT

COOLING TOWER INSTITUTE

THE RELATIONSHIP BETWEEN SP AND HGBIK DRIFT MEASUREMENT RESULTS - NEW DATA CREATES A NEED FOR A SECOND LOOK

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Introduction

The CTI drift measurement code ATC-140 [1] specifies that isokinetic measurements be employed for cooling tower drift emissions measurements. The sensitive paper technique, an alternative method also referenced by the test code, provides additional information not supplied by the isokinetic test procedure. There have been few occasions, over the years when both the Sensitive Paper and HGBIK drift measurement techniques have been employed at the same location. This has allowed only periodic comparisons of the results of the two techniques. Both methods were employed at the same location during a recent test program. The results create an opportunity to revisit some of the traditionally held views of the expected relationships between the results of the two techniques. This paper compares the data supplied by each method as well as the drift rates measured by each. This paper also addresses issues relevant to the determination of the rate of the efflux from cooling towers of chemicals entrained in the drift.

Definition of Drift

There have historically been several definitions for drift including [2]:

1. the mass flux of cooling water droplets entrained from the fill and still present in liquid phase at the cooling tower exit;
2. the mass flux of liquid water at the cooling tower exit, including the recondensation droplets; and
3. the mass flux of cooling water entrained from the fill. The entrained water may be in either liquid or gaseous phase.

Drift Measurement Methodologies

Drift Measurement Methods for measuring drift can be divided into two groups:

1. sensitized surface methods; and
2. isokinetic methods.

In both methods, the sampling is conducted by traversing equal areas of the cooling tower fan stack exit plane. ATC-140 allows measurement to be conducted at any plane above the drift eliminators. The stack exit plane is the area most representative of emissions from the cooling tower. Only a limited number of field tests have been conducted comparing the results of the two methodologies, and this paper offers a new chance to revisit this issue.

Sensitized surface methods are direct methods for measuring drift. ESC's Sensitive Paper (SP) method is an example of a sensitized surface method, employing paper which "is chemically treated according to published procedures such that a droplet of water impinging on it will produce a stain whose size is related to the original droplet size and to the dynamics of its impingement. The relationship between the stain and the droplet size is obtained by calibrating the Sensitive Paper System by means of the vibrating orifice monodisperse water droplet generator over a range of droplet sizes and impingement velocities ranging from 2.5 m/s to 15 m/s. The paper is employed in machines which offer controlled exposure of the paper to the drift droplets and protect the paper before and after the exposure period." [3]

ESC's SP technique measures droplets with diameters as small as 10 µm to ones with diameters in excess of 1000 µm. Droplets are collected by impact with the sp. The efficiency of collection si dependant on the stack velocity and droplet diameter. Droplets above 50 microns in diameter are collected at near 100% efficiency, while droplets below 10 microns are collected below 10% efficiency. The ESC data reduction algorithm compensates for the lower collection efficiency for small droplets in the range of 10µm to 50µm. Both the number of droplets and the drift rate are determined at a measurement location as a function of bin sizes (droplet diameter ranges). The total drift rate at a measurement location is the sum of the drift rates of all the bin sizes at that location. The total drift rate of a fan stack is the sum of the total drift rates of all the measurement locations. The total drift rate of a cooling tower is the sum of the total drift rates of all fan stacks. The drift droplet size distribution can likewise be characterized for a measurement location, a fan stack, and a complete tower.

There are currently two main types of isokinetic systems in use for cooling tower testing [4]. One is a wet impinger type based on the EPA Stack Gas Sampling Method 13A. The other is the Heated Glass Bead Isokinetic (HGBIK) method. Both methods may use back-up filtering systems, but the approach to filter use may differ. Isokinetic methods are indirect methods for measuring drift. These methods measure the efflux of a chemical tracer in the circulating water and determine the equivalent drift by assuming that the chemical tracer's concentration in the cooling water is the same as in the drift droplets.

Mechanisms for Drift Droplet Generation

The two primary mechanisms for the generation of droplets within the cooling tower are [5,6]:

- mechanical generation; and
    - by a pressurized spray nozzle
    - via the turbulent breakup of a gravitationally supplied stream of water from an overhead distribution box
    - by impact with cooling tower fill
    - re-entrainment of previously collected droplets on the drift eliminators. This occurs when the collected drift does not properly drain from the drift eliminators.

- condensation of the saturated tower exhaust air.

The Cooling Tower Institute (CTI) is the recognized standard setting organization for the measurement of cooling tower drift. In CTI's Isokinetic Drift Test Code, ATC-140, June 1994 [4], it is stated that "There are two basic methods for drift measurement - Isokinetic (IK) for drift rate measurement and Sensitive Surface (SS) for drift droplet size characterization." The CTI code defines drift as droplets of circulating water which remain in the air passing through the drift eliminators. The code attempts to exclude condensed water droplets by specifying that a test be conducted under conditions in which there is no visible condensation on cooling tower surfaces.

Tower Description

The tower that was tested is a two cell counterflow cooling tower which was constructed in 1952. The cooling towers are of the coil shed type, in which the cooled water from the fill falls over a tube bundle containing the process fluid. Several modifications, including replacement of the fans and motors, have been done to the cooling tower since its original construction. Each cell contains two nominal 12 foot diameter fans, arranged parallel to the major axis of the cooling tower. The plenum area of each fan is isolated from the adjacent cell by a wall and is served by a separate water distribution system. Drift eliminators were of the wood slat type common in cooling towers of this vintage. The design water flow rate is 3000 gpm per cell. Drift measurements were made on the two fan stacks of one of the cells.

HGBIK Measurements

Selection of Chemical Tracer(s)

The HGIBK technique is dependent on the recovery of a chemical constituent of the circulating water. The selection criteria for chemical tracer compounds are:

- Stability - since the glass beads are heated to a high temperature, the tracer constituent must not be volatile or degrade at high temperatures.
- Concentration in circulating water - for reasonable collection intervals, the quantity of drift collect by the sampling apparatus will be very small. It is usually necessary to select a chemical tracer with a concentration of above 50 ppm in the circulating water in order to obtain a drift sample sufficiently above chemical analysis detection limits.
- Chemical analysis - there should be an accurate and cost efficient analysis for the tracer constituent.
- Concentration in ambient air - constituents present in the ambient air may interface with the drift analysis. High volume samplers may be used to detect the presence of tracer constituent in the ambient air. Note that there is no blank correction to the collected samples due to the influence of the ambient air.

On these bases, sodium, magnesium and calcium were selected as chemical tracers.

Drift Droplet Collection

The components of the Heated Glass Bead Isokinetic System (HGBIK or IK) are shown in Figures 1, 2 and 3. Prior to mobilization in the field, each of the sampling tubes (shown in Figure 2) was washed with warm, 10 percent by volume hydrochloric acid (HCl) and rinsed with distilled water to remove existing deposits. These tubes were then wrapped in plastic to prevent contamination during transport. Before the start of a test, the plastic was removed and the ground glass fitting of the sampling tube was clamped to the vacuum system. After installing the sampling tube, positive and negative electrical leads from a 110 VAC rheostat were connected to the heat assembly surrounding the tube. At this time, the appropriate back-up filter was also inserted in the vacuum system downstream from the glass beads. The tube was then affixed to the support structure (Figure 2.3) for positioning over the equal area points. Once in position, a current was applied to the heat assembly, resulting in the heating of the glass beads to a temperature above the boiling point of water. After heating was begun, the vacuum pumps were started and the appropriate flow rate through the rotameter was set using the regulating valve, with this flow being a function of the local updraft air velocity. The entire assembly was rotated in order to orient the tube parallel to the direction of the local exit air flow as revealed by the telltale. This angle was measured by an electronic sensing device which generates a resistive signal proportional to the angle of rotation. Sampling times were adjusted for the cosine of the airstream at each point. After satisfying the sampling interval for an individual point, the sampling tube was moved to the next point. When the last point of each traverse was completed, the power supplies to the heating assembly and the vacuum pumps were switched off. At the conclusion of the test, the sampling tube was disconnected from the receptacle and wrapped in plastic for transfer to the analysis laboratory. The associated backup filter was also removed at this time. One backup filter and tube were used for each fan stack. An IK tube blank and a backup filter procedural blank were collected before and after the tests.

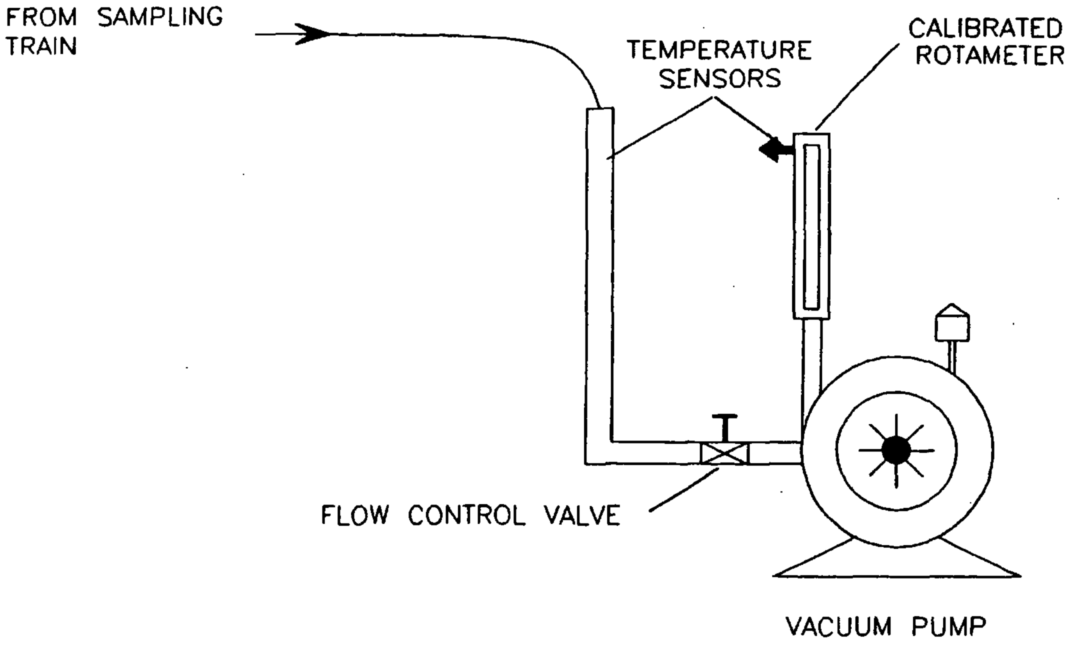


FIGURE 1

ESC HEATED GLASS BEAD SYSTEM

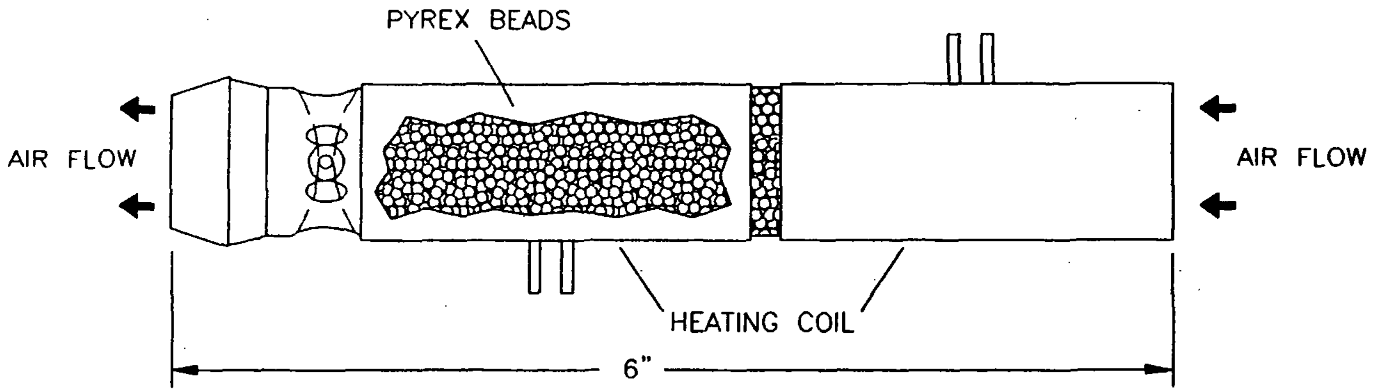


FIGURE 2

ESC HEATED GLASS BEAD SAMPLE TUBE

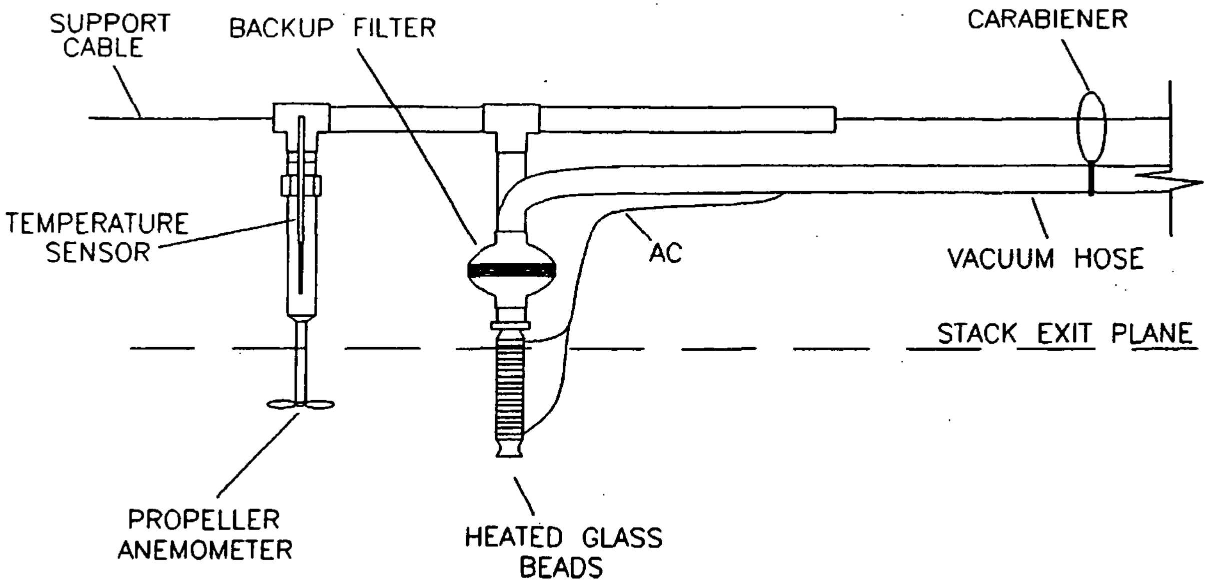


FIGURE 3

SAMPLING TRAIN SUPPORT

The laboratory recovered the collected sample masses at the conclusion of the tests. Collected sodium in the IK tubes was redissolved by washing each tube with two 15 ml rinses of a 10 percent solution of hydrochloric acid. This was followed by a single 15 ml distilled water rinse. The three rinses were composited in a 50 ml volumetric flask and 5 mls of distilled water was added to increase the total volume to 50 ml. The filters were analyzed by washing filters with concentrated hydrochloric acid and deionized water. The samples were then analyzed for trace elements by inductively coupled plasma techniques.

Updraft Air Velocity

In conjunction with the drift data, updraft air velocity was obtained at each sampling point. The local velocities were used to set the isokinetic flow rate and to compute the drift flux. Updraft air velocities were measured with a Gill propeller anemometer. Because the air in a cooling tower is not perpendicular to the fan stack exit plane, a tell-tale was attached to the anemometer to determine the direction and angle of flow. The anemometer was adjusted so that the propeller was perpendicular to the airstream before flow measurements were made.

Circulating Water Samples

Water samples were taken from the water flowing off the tube bundle before and after each traverse diameter. Each water sample bottle was labeled with the date, time and unique identification number. The water samples were analyzed to determine the concentrations of the trace elements that were used to calculate the drift fraction.

Circulating Water Flow Rate

Circulating water flow rate was calculated from pressure measurements made at the discharge of the pumps, using supplied pump curves.

The makeup flow stream was discharging into the water collection basin throughout the drift testing.

HGBIK Results and Analysis

The glass bead IK tubes and backup filters were analyzed for Ca, Mg and Na. Unexposed tubes and filters were analyzed for these elements in order to obtain blank values for the both the tube and filters. The net mass of each element was calculated by:

$$W_{net} = (W_{ik} - W_{ik,blank}) + (W_{filter} - W_{filter,blank})$$

where

W_{net} = the net mass of the tracer element collected, μg
W_{ik} = the mass of the tracer element collected on the test IK tube, μg
$W_{ik,blank}$ = the average mass of the tracer element on the IK blank tubes, μg
W_{filter} = the mass of the element collected on the test backup filter, μg
W_{filter} = the average mass of the tracer element collected on the blank backup filters, μg

The drift rate for each test, based on each of the selected elements, was calculated by:

$$D = \frac{100}{1000\frac{mg}{\mu g} \times 3.785\frac{\ell}{gal}} \times \frac{W_{net}}{C_{cw}\, T_{sampling}\, Q_{cw}}$$

where

D = drift rate, percent of circulating water flow

C_{cw} = circulating water concentration of element, mg/l

Q_{cw} = circulating water flow rate, gal/min

$T_{sampling}$ = sampling time, minutes

Based on the measured pump discharge pressure and basin levels, a water flow rate for stack A of 1390 gal/min was calculated. For stack B, the water flow rate was calculated to be 1510 gal/min.

Drift data from the isokinetic tests of stacks A and B are summarized in Table 1.

Table 1: Summary of Drift Data

	Drift Rate (Percent of CW Flow)			
	Ca	Mg	Na	Average
Test 1 Stack B	0.0100	0.0132	0.0130	0.0122
Test 2 Stack B	0.0074	0.0090	0.0089	0.0084
Test 3 Stack B	0.0084	0.0077	0.0073	0.0078
Average	0.0086	0.0100	0.0100	**0.0095**
Test 1 Stack A	0.0049	0.0051	0.0046	0.0049
Test 2 Stack A	0.0085	0.0110	0.0107	0.0101
Test 3 Stack A	0.0053	0.0061	0.0056	0.0057
Average	0.0062	0.0074	0.0070	**0.0069**

The drift rate for stack B was 0.0095 percent while that for stack A was 0.0069 percent of the respective water flow. The average drift rate for the two stacks tested was 0.0083 percent of the circulating water flow.

The total drift for the two fan stacks is therefore:

Stack A Drift = 1390 gpm x 0.000069
= 0.10 gpm
Stack B Drift = 1510 gpm x 0.000095
= 0.14 gpm .
Stacks A & B Drift = 0.24 gpm
or
Stacks A & B Drift = $\frac{0.24 \times 100}{(1510 + 1390)} = 0.0083\%$

The repeated tests yielded drift rates that varied by up to 30 percent from the average value. This variability is explained by variability of the emission rate across the fan stack. Much of the drift from cooling towers arises from small gaps in the drift eliminators and imperfections in the water distribution system. Such anomalies lead to high emission rates in local regions of the fan stack. Small variations in the wind speed and direction move the regions of high emission rates to different regions of the fan stack. Thus, the repeated tests may sample different proportions of these regions. The average drift rates based on each of the elements for both cells were within 10 percent of the average value. Since it is unlikely that contamination of the samples would contain three elements in the same proportion as the circulating water, contamination of the sampling tubes would seem to be ruled out as a source of the variation in the drift rate.

SP Measurements

Drift Droplet Collection

With the sensitive paper technique, sensitized papers are exposed at 16 equal area positions at the exit plane of the fan stack. The exposure is initiated by pulling a lanyard which opens a shutter mechanism exposing the sensitive paper to the drift. The exposure is terminated by releasing the lanyard. Exposures are timed with a stop watch. Drift droplets striking the paper produce blue stains which are sized and counted to determine the liquid drift flux.

Updraft Air Velocity

In conjunction with the drift data, updraft air velocity was obtained at each sampling point. The local velocities were used to calculate the impact velocity of the drift striking the SP. Updraft air velocities were measured with a Gill propeller anemometer. Because the air in a cooling tower is not perpendicular to the fan stack exit plan, a tell-tale was attached to the anemometer to determine the direction and angle of flow. The anemometer was adjusted so that the propeller was perpendicular to the airstream before flow measurements were made.

Circulating Water Flow Rate
Circulating water flow rate was calculated from pressure measurements made at the discharge of the pumps, using pump curves supplied by PG&E.

SP Results and Analysis
The Sensitive Paper (SP) System relies on droplet collection by inertial impaction on water-sensitive paper. The paper is chemically treated so that a droplet impinging on it will generate a well-defined dark blue stain on the pale yellow background of the paper. The size and shape of the stain are functions of the impingement dynamics, i.e., speed and angle, and of the original droplet diameter. If the technique is employed correctly, the stain will be circular, or nearly circular, in shape. The relationship between the stain and the droplet size was obtained by calibrating the SP System by means of a monodisperse water droplet generator over a range of droplet sizes and impaction velocities.

The processing of these exposed sensitive papers consisted of measuring the stain diameters by means of a microscope and a semi-automated Graf Pen digitizer linked to a personal computer which groups the counts of all stains by stain size ranges. Once the stain sizes are counted and grouped according to size, calibration curves for specific droplet sizes and impaction velocities are employed via computer programs to generate the original droplet sizes from which the stains were formed. In addition, a correction factor is applied to compensate for the collection efficiency of each droplet size range. This factor, which is important only for the droplets of less than approximately 50 μm, is computed by the procedures of Ranz and Wong.

Since the SP head is stationary, the paper collects those droplets which are transported to it by the updraft air flow. Large droplets in the updraft air do not move at the same speed as the air due to their settling velocities. Consequently, even if they were present in the same numbers as the small droplets, not as many would strike the sensitive paper surface during the sampling time. Therefore, the stationary SP head measures the droplet number flux directly. The droplet number flux is the number of droplets that cross a unit area per unit time. For a size range i and measurement position j, this can be written as:

$$\frac{\Delta N_{ij}}{A_s . t_s}$$

$$= \frac{\textit{number of droplets in size range } \Delta d_i}{(\textit{area of the sensitive paper}) \text{ x } (\textit{sampling time})}$$

The drift mass flux in the size range Δd_i is then:

$$\Delta f_{ij} = \frac{\Delta N_{ij}}{A_s \cdot t_s} \frac{\pi}{6} s_i d_i^3 \ (gm/m_2 \cdot s)$$

where s_i is the specific density (assumed here to be 1 gm/cm^3) of the droplet and d_i is the middle of droplet diameter size range Δd_i. The drift mass emission through the local area associated with the measurement point can then be found by multiplying the drift mass flux by the area. The total drift mass emission of the cell is then found by summation of the drift emission through these areas.

The results of the droplet size distribution measurements are summarized in Table 2 and illustrated in Figure 4.

The mass emission rates for each size range on stacks A and B were added to compute the overall droplet size distribution for the test cell. Most of the droplets larger than 500 microns, as well as one third of the mass emission rate for the cell occurred on two of the SP exposures on fan stack B. This indicates a highly localized source of the large droplets and is not unusual even for cooling towers in good repair. This could be a small gap in the drift eliminators or an area where water from a broken nozzle is spraying directly on the drift eliminators. The mass mean diameter of 252 microns is typical of a mechanical draft cooling towers with wooden drift eliminators in good condition.

The drift rate for the two stacks is therefore:

$$Stacks\ A\ \&\ B\ Drift = 1705 \frac{g}{\text{sec}} \times \frac{60\ \text{sec}}{\text{min}} \times \frac{lb}{454\ g} \frac{Ft^3}{62.4\ lb} \frac{7.48\ gal}{Ft^3}$$

$$= 0.27\ gpm$$

$$or \qquad = \frac{0.27 \times 100}{(1510 + 1390)} = 0.0093\%$$

Ambient Air Sampling
High volume samplers were continuously operated during the drift tests. Filters from these devices were analyzed for sodium, calcium and magnesium. Collected concentrations for sodium, calcium, and magnesium were below detection limits.

Discussion of Results

It is a historically held belief [4] that it is not possible to account for all of the drift by a drop size count. One study [7] found the ratio of IK to SP liquid mass emissions values varied between 1.3 to 6.2, with an average of 2.8. The conclusion that was presented at that time was that the evaporation in the fill may be more significant than previously recognized, and that would lead to the mineral concentration of the drift particles being higher than that of the circulating water. Shofner et al [8] described the ratio of IK to SP measured liquid mass emissions rates as typically on the order of 2 to 3. They attributed this to the following: (1) unscrubbed atmospheric pollution collected by the IK tubes leads to over prediction of apparent drift liquid mass; (2) the mineral concentration is greater in the drops than in the basin water due to evaporation in the fill, especially for small drops; and (3) there are acknowledged uncertainties in the particle-density-distribution measurements of smaller particle sizes (diameters of the order of 20 to 30μm and less).

For these tests, the drift rate computed for the SP test method was approximately 12% higher than the average drift rate produced by the HGBIK method. The distribution in the SP based drift tests both between trace elements and between test runs was comparable to the distribution of the isokinetic based drift test. This good agreement can be attributed to the lack of tracer elements in the ambient air.

The SP technique, does not evaluate drift emissions due to particles that are less than 10 microns in size. The uncertainties in the particle count of the smaller particles, however, must be very large before it would significantly alter the measured liquid mass emission rate. The potential for the SP technique to underestimate the liquid mass emission rate significantly is therefore much less than the IKs potential to overestimate the liquid mass emission rate significantly.

Another note of interest in the present report is that the ratio of minerals captured by the IK to the minerals present in the circulating water is consistent for the three tracer chemicals. It would therefore seem appropriate to calculate the mass emission of any non-volatile chemical using the measured ratio of another such chemical. This would be a valuable technique for determining the efflux of non-volatile chemicals which are present in the circulating water in very small concentrations.

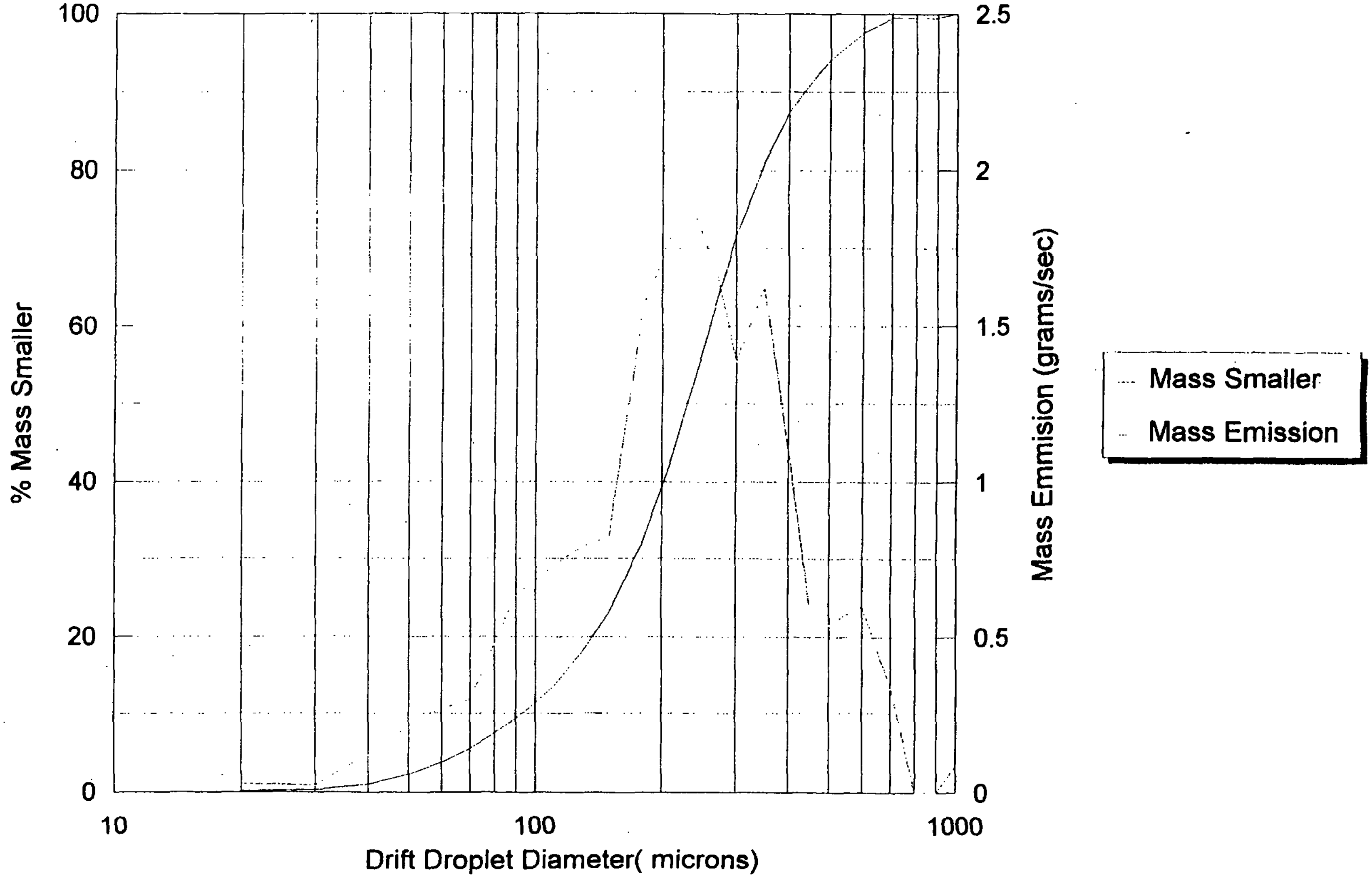
Table 2. Summary Drift Size Distribution for Stacks A and B

Bin	Lower Diameter microns	Upper Diameter microns	Mass Flux µg/m2/sec	Mass Emission g/sec	Mass % Smaller %
1	10	20	1222	0.026	0.15
2	20	30	1034	0.022	0.29
3	30	40	5585	0.121	0.99
4	40	50	9695	0.209	2.22
5	50	60	12350	0.267	3.79
6	60	70	13835	0.299	5.54
7	70	90	29300	0.633	9.25
8	90	110	33650	0.727	13.52
9	110	130	36550	0.789	18.15
10	130	150	38050	0.822	22.97
11	150	180	71800	1.551	32.07
12	180	210	82750	1.787	42.56
13	210	240	85850	1.854	53.43
14	240	270	77400	1.672	63.24
15	270	300	64200	1.387	71.38
16	300	350	75000	1.620	80.88
17	350	400	51100	1.104	87.36
18	400	450	27850	0.602	90.89
19	450	500	24910	0.538	94.04
20	500	600	27610	0.596	97.54
21	600	700	31300	0.338	99.52
22	700	800	0	0.000	99.52
23	800	900	0	0.000	99.52
24	900	1000	7500	0.081	100.00

Total Mass Flux	788500	µg/m²/sec
Mass Mean Diameter	**252**	microns
Mass Emission Rate	**17.05**	gram/sec

Figure 4 Summary Drift Droplet Size Distribution

Cooling Tower Stacks A and B



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Adopted Part 242, CO2 Budget Trading Program, Findings Statement and Final Supplemental Generic Environmental Impact Statement (SGEIS)
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6 NYCRR Parts 242 and 200 Regulatory Impact Statement

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Introduction

The Regional Greenhouse Gas Initiative (RGGI) is a cooperative, historic effort among New York and eight Participating States[1] and is the first mandatory, market-based carbon dioxide (CO_2) emissions reduction program in the United States. Since its inception in 2008, RGGI has utilized a market-based mechanism to cap and cost-effectively reduce emissions that cause climate change. Recently, New York along with the Participating States completed a comprehensive program review and announced a proposal to lower the regional emissions cap established under RGGI to 91 million tons in 2014, declining 2.5 percent a year through 2020.[2] Accordingly, New York and the Participating States committed to propose revisions, pursuant to state-specific regulatory processes, to their respective CO_2 Budget Trading Programs to further reduce CO_2 emissions from power plants in the region. To implement the updated RGGI program in New York State, the Department of Environmental Conservation (Department) proposes to revise 6 NYCRR Part 242, CO_2 Budget Trading Program (the Program) and 6 NYCRR Part 200, General Provisions.

The proposed Program revisions, which will cap regional CO_2 emissions at 91 million tons annually beginning in 2014, represent a nearly 45 percent reduction from the existing cap currently in place under the Program. After 2020, the cap will remain at 78 million tons annually. Further, to account for the existing private bank of CO_2 emissions allowances already acquired at auction, and to help create a binding cap, the proposed Program revisions provide two distinct budget adjustments. The First Control Period Interim Adjustment for Banked Allowances will reduce the budget for 100 percent of the first control period private bank of allowances (vintages 2009, 2010, and 2011) held by market participants after the first control period. The Second Control Period Interim Adjustment for Banked Allowances will reduce the budget for 100 percent of the surplus 2012 and 2013 vintage allowances held by market participants as of the end of 2013.

The proposed Program revisions also create the Cost Containment Reserve (CCR), which will help provide additional flexibility and cost containment for the Program. The CCR allowances will be triggered and released at auctions at $4/ton in 2014, $6/ton in 2015, $8/ton in 2016, and $10/ton in 2017. Each year after 2017, the CCR trigger price will increase by 2.5 percent. If the trigger price is reached, up to 10 million additional CCR allowances will be available for purchase at auction, except in 2014, when the reserve will be limited to five million allowances. The existing price triggers for expanding use of offsets and the one year compliance period extension will be eliminated in favor of the CCR.

Finally, the proposed Program revisions create an interim compliance obligation in part to align it with the annual compliance obligations under federal programs such as the Clean Air Interstate Rule and the Title IV *Acid Rain Program. This program revision also helps to address the potential for a budget source to avoid* its compliance obligation as a result of the business closing or falling into bankruptcy prior to the third year compliance obligation. In addition to demonstrating full compliance at the end of each three-year compliance period, regulated entities must now demonstrate that they are holding allowances equal to at least 50 percent of their emissions at the end of each of the first two years in each three year compliance period. The proposed Program revisions also include minor revisions such as setting the reserve price at $2.00 in 2014, to rise at 2.5 percent per year in subsequent years, updating all references, and deleting the early reduction allowance provisions. The majority of the proceeds from the sale of New York's allowances will continue to be dedicated to strategic energy or consumer benefits, such as energy efficiency and clean *energy technologies*.

The burning of fossil fuels to generate electricity is a major contributor to climate change because fossil-fuel generators emit large amounts of CO_2, the principal greenhouse gas (GHG). Overwhelming scientific evidence suggests that a warming climate poses a serious threat to the environmental resources and public health of New York State - the very same resources and public health the Legislature has charged the Department to preserve and protect. The warming climate threatens the health and well-being of the State's residents and citizens, the State's property, and the natural resources held in trust by the State, including, but not limited to, the State's air quality, water quality, marine and freshwater fisheries, salt and freshwater wetlands, surface and subsurface drinking water supplies, river and stream impoundment infrastructure, and forest species and wildlife habitats. Not only will the proposed Program revisions help to further counter the threat of a warming climate, they will also produce significant environmental co-benefits in the form of improved local air quality, and a more robust, diverse and clean energy supply in the State.

Statutory Authority

The statutory authority to revise the Program to reduce the CO_2 emissions cap, provide for the budget adjustments, add a cost containment reserve, and create an interim compliance obligation derives primarily from the Department's authority to use all available practical and reasonable methods to prevent and control air pollution, as set out in the Environmental Conservation Law (ECL) at Sections 1-0101, 1-0303, 3-0301, 19-0103, 19-0105, 19-0107, 19-0301, 19-0303, 19-0305, 71-2103, 71-2105.

Brief synopses of the statutory sections that grant the Department authority to promulgate these revisions to the Program and to prevent and control air pollution are outlined below.

ECL Section 1-0101. This section declares that it is a policy of New York State to conserve, improve and protect its natural resources and environment and control air pollution in order to enhance the health, safety and welfare of the people of New York State and their overall economic and social well-being. Section 1-0101 further expresses, among other things, that it is the policy of New York State to coordinate the State's environmental plans, functions, powers and programs with those of the federal government and other regions and manage air resources to the end that the State may fulfill its responsibility as trustee of the environment for present and future generations. This section supports the Department's efforts to work with other States in the region to address greenhouse gases in a coordinated fashion. This section further declares that the Department shall promote patterns of development and technology that minimize adverse impacts on the environment.

ECL Section 1-0303. This section defines the term "pollution." Pollution is defined as "the presence in the environment of conditions and or contaminants in quantities of characteristics which are or may be injurious to human, plant or animal life or to property or which unreasonably interfere with the comfortable enjoyment of life and property throughout such areas of the state as shall be affected thereby." The reduction in the CO_2 emissions cap and the budget adjustments will remove conditions and contaminants from the environment which are injurious to human, plant and animal life or to property throughout the State.

ECL Section 3-0301. This section empowers the Department to coordinate and develop programs to carry out the environmental policy of New York State set forth in section 1-0101. Section 3-0301 specifically empowers the Department to: provide for the prevention and abatement of air pollution; cooperate with officials and representatives of the federal government, other States and interstate agencies regarding problems affecting the environment of New York State; encourage and undertake scientific investigation and research on the ecological process, pollution prevention and abatement, and other areas essential to understanding and achievement of the environmental policy set forth in section 1-0101; monitor the environment to afford more effective and efficient control practices; identify changes in ecological systems and to warn of emergency conditions; enter into contracts with any person to do all things necessary or convenient to carry out the functions, powers and duties of the Department; and adopt such regulations as may be necessary, convenient or desirable to effectuate the environmental policy of the State. This section supports the Department's coordinated scientific and programmatic efforts to address greenhouse gases through the RGGI program.

ECL Section 19-0103. This section declares that it is the policy of New York State to maintain a reasonable degree of purity of air resources. In carrying out such policy, the Department is required to balance public health and welfare, the industrial development of the State, propagation and protection of flora and fauna, and the protection of personal property and other resources. To that end, the Department is required to use all available practical and reasonable methods to prevent and control air pollution in the State. The regulatory flexibility inherent in a cap-and-trade program that allows for interstate trading of emission allowances best enables the Department to balance the competing interests of the "protection of the public health and welfare" with continued "industrial development of the state" and "the protection of physical property and other resources," while also helping to ensure the continued reliability and adequacy of the state's electricity supply. By revising the Program to reduce the CO_2 emissions cap, provide for budget adjustments, add a cost containment reserve, and create interim compliance obligations, the Department is further able to balance these competing interests.

ECL Section 19-0105. This section declares that it is the purpose of Article 19 of the ECL to safeguard the air resources of New York State under a program which is consistent with the policy expressed in section 19-0103 and in accordance with other provisions of Article 19.

ECL Section 19-0107. This section defines the terms "air contaminant," "air pollution," and "air contamination source." "Air contaminant" is defined as "a dust, fume, gas, mist, odor, smoke, vapor, pollen, noise or any combination thereof." "Air pollution" is defined as "the presence in the outdoor atmosphere of one or more air contaminants in quantities, of characteristics and of a duration which are injurious to human, plant or animal life or to property or which unreasonably interfere with the comfortable enjoyment of life and property throughout the state or throughout such areas of the state as shall be affected thereby." The term "air contamination source" is defined as "any source at, from or by reason of which there is emitted into the atmosphere any air contaminant . . ." CO_2 is an "air contaminant" that causes "air pollution" as defined in the ECL because it is a gas that is present in the outdoor atmosphere in quantities that engenders and/or provokes climate change, which is injurious to life and property in New York State. Electric generating units are an "air contamination source" because they are responsible for approximately one-quarter of all CO_2 emissions in New York State. The Department's authority under the ECL to regulate CO_2 as an "air contaminant" was buttressed by the decision of the United States Supreme Court in Massachusetts v. Environmental Protection Agency, 127 S. Ct. 1438 (2007), that the United States Environmental Protection Agency ("EPA") has the authority to regulate CO_2 as an "air pollutant" under the Clean Air Act ("CAA"). Under the CAA, an "air pollutant" is defined as "any air pollutant agent or combination of agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air." 42 U.S.C. section 7602(g). The definitions of "air contaminant" and "air pollutant" under the ECL are broader than the definition of "air pollutant" under the CAA.

ECL Section 19-0301. This section declares that the Department has the power to promulgate regulations for preventing, controlling or prohibiting air pollution, and shall include in such regulations provisions prescribing the degree of air pollution that may be permitted and the extent to which "air contaminants" may *be emitted to the air by any "air contamination source" in any area of the State. The Department also has* the authority to cooperate with other states, interstate agencies, or international agencies with respect to the control of air pollution or air contamination. This section provides the Department with authority to revise the Program to reduce the CO_2 emissions cap and to provide for the budget adjustments.

ECL Section 19-0303. This section provides that the terms of any air pollution control regulation promulgated by the Department may differentiate between particular types and conditions of air pollution and air contamination sources. It supports the RGGI program in that cap-and-trade was identified as an effective manner or condition of regulation for the particular air pollutant and type of sources subject to the Program. In particular, fossil fuel-fired power plants that meet the 25 MW nameplate capacity applicability threshold were identified as a significant stationary emitter of CO_2 in New York State and the RGGI region, and thus are subject to the cap-and-trade program. At the same time, other types of sources of CO_2 emissions, including other existing stationary sources of CO_2, are not subject to the Program. Similarly, sources of other air pollutants may be subject to types of regulations other than a cap-and-trade program.

This section also requires the Department to include analysis in the RIS explaining state regulatory requirements that are more stringent than those found in the Clean Air Act or its implementing regulations. There is no CO_2 stationary source cap-and-trade program established by the Clean Air Act or its implementing regulations. Federal regulatory requirements governing sources of CO_2 emissions are discussed further in the Federal Standards section of this RIS, found on page 71. The Federal Standards section also explains how the Program and the proposed revisions would meet criteria in Section 19-0303 (4), if it was applicable to this rulemaking. Further, the cost-effectiveness of the Program and whether reasonably available alternatives exist is discussed at length in the Alternatives section of the RIS, found at page 67. The RIS thoroughly discusses the public health and environmental protection benefits of the Program and the proposed revisions in the Needs and Benefits section, found at page 14.

ECL Section 19-0305. This section authorizes the Department to enforce the codes, rules and regulations established in accordance with Article 19. Section 19-0305 also empowers the Department to conduct or cause to be conducted studies and research with respect to air pollution control, abatement or prevention.

ECL Section 71-2103 and Section 71-2105. These sections set forth the civil and criminal penalty structures for violations of Article 19. These sections provide authority to the Department to create the interim compliance obligation to better ensure compliance with the Program.

Although the Allowance Auction Program (21 NYCRR Part 507) will not be revised as part of this rulemaking, the statutory sections that grant NYSERDA authority to implement the Allowance Auction Program, which were outlined in the Regulatory Impact Statement accompanying such rulemaking, are briefly outlined below as background and context for the proposed Program revisions.

Public Authorities Law (PAL). *The proposed Program revisions are designed to allocate the* CO_2 allowances (including CCR allowances) to the Energy Efficiency and Clean Energy Technology (EE&CET) Account, which was created and will be administered by NYSERDA. NYSERDA will continue to administer the EE&CET Account so that CO_2 allowances will be sold in a transparent allowance auction or auctions and the proceeds of the auction or auctions will be used to promote and reward investments in energy efficiency, renewable or non-carbon emitting technologies, and/or innovative carbon emissions abatement technologies with significant carbon reducing potential.

The proposed Program revisions will create the Cost Containment Reserve (CCR) which will help provide additional flexibility and cost containment. NYSERDA will ensure that the CCR allowances will be triggered and released at auctions at $4/ton in 2014, $6/ton in 2015, $8/ton in 2016, and $10/ton in 2017. Each year after 2017 the CCR trigger price will increase by 2.5 percent. If the trigger price is reached, up to 10 million additional CCR allowances will be available for purchase at auction, except in 2014, when the reserve will be limited to five million allowances.

NYSERDA currently administers energy efficiency and clean technology programs funded by the EE&CET allocation pursuant to its authority under PAL Section 1854 and Title 9-A of Article 8 of the PAL, and will continue to do so under the proposed revisions to the Program. Section 1854 states that "the purposes of NYSERDA shall be to develop and implement new energy technologies consistent with economic, social and environmental objectives, to develop and encourage energy conservation technologies."

Title 9-A establishes the green jobs - green New York program for the purposes of promoting energy efficiency, energy conservation and the installation of clean energy technologies; reducing GHG emissions; supporting sustainable community development; creating green job opportunities, including opportunities for new entrants into the State's workforce, the long-term unemployed and displaced workers; and using innovative financing mechanisms to finance energy efficiency improvements through energy cost savings. The green jobs - green New York program is funded through appropriation from the RGGI allowance auction proceeds.

"Energy conservation technologies" are defined in PAL Section 1851(11) as "all methods of conserving energy, of improving the efficiency of energy utilization and of preserving and protecting the environment...in connection with the use of energy." PAL Section 1891(12) defines "qualified energy efficiency services" and provides a list of qualified measures that are eligible for funding under the Program.

NYSERDA's authority under PAL Section 1854 includes the following:

"1. Research, development and demonstration. To conduct, sponsor, assist and foster programs of research, development and demonstration in new energy technologies including but not limited to: energy conservation; production of power from new sources with emphasis on renewable energy sources such as solar, wind, bioconversion and solid waste; storage of energy with emphasis on inertial and battery storage; conversion and/or technological improvement of facilities now utilizing nuclear fission energy and fossil fuel energy technologies; transmission and distribution of power; and conversion of energy and improvements of efficiencies of such conversion, including the power after assessing and taking into account environmental considerations thereof, to establish, acquire, operate, develop and manage facilities therefor."

"2. The provision of services. To provide services required for the development and use of new energy technologies and related methods by the industrial, commercial, medical, scientific, public interest, educational and governmental organizations within the state, including the power to establish, acquire and develop facilities therefore not otherwise available within the state, and to operate and manage such facilities."

"11. To advise and assist the governor and legislature in the development and implementation of state policies relating to energy and energy resources."

"18. To provide for the deposit of all or a portion of the proceeds collected by the authority from the auction or sale of emissions allowances allocated by the department of environmental conservation to the authority pursuant to regulations adopted by the department of environmental conservation to a green jobs-green New York fund to be established in the custody of the commissioner of taxation and finance. The monies in such fund shall be available for the green jobs-green New York program pursuant to title nine-A of article eight of this chapter."

Although NYSERDA's Allowance Auction Program will not be revised as part of this rulemaking, this authority allows NYSERDA to continue to administer the EE&CET Account so that the proceeds of the auctions can be used to promote and reward investments in energy efficiency, renewable or non-carbon-emitting technologies, and/or innovative carbon emissions abatement technologies with significant carbon reduction potential and similar energy conservation technologies. The stated purposes of the EE&CET Account are consistent with NYSERDA's authority to conduct, sponsor and assist programs related to new energy technologies and qualified energy efficiency services and to provide services related to their development.

PAL Section 1855. The general powers that are relevant to NYSERDA's authority to administer the EE&CET Account to promote and reward investments in energy efficiency, renewable or non-carbon-emitting technologies, and/or innovative carbon emissions abatement technologies with significant carbon reduction potential, and to sell allowances (including CCR allowances) in a transparent auction are also set forth in PAL Section 1855. NYSERDA's authority under Sections 1854 and 1855 enables it to accept and sell the allowances and utilize the proceeds to promote and reward investments related to energy conservation technologies similar to the stated purposes of the EE&CET Account.

NYSERDA's authority to auction the CO_2 allowances and CCR allowances is enumerated in their powers:

"10. To enter into any contracts and to execute all instruments necessary or convenient for the exercise of its corporate powers and the fulfillment of its corporate purposes under this title."

"14. To accept any gifts or grants or loans of funds or property or financial or other aid in any form from the federal government or any agency or instrumentality thereof or from the state or from any other source and to comply, subject to the provisions of this title, with the terms and conditions thereof."

"17. To do all things necessary or convenient to carry out its corporate purposes and exercise the powers given and granted by this title."

Legislative Objectives

Through numerous legislative enactments, the Legislature has directed and empowered the Department to *promote the safety, health and welfare of the public, protect the State's natural environment, and also help* assure a safe, dependable and economical supply of energy to the people of the State. The warming climate represents an enormous environmental challenge for the State, because unabated, climate change will continue to have serious adverse impacts on the State's natural resources, public health and infrastructure. Power plants that burn fossil fuel emit significant quantities of CO_2, a chief contributor to the unnatural warming of our climate. New York power plants represent approximately one-fifth of all GHG emissions in the State.[3] In 2012, New York power plants subject to the Program emitted approximately 35 million tons of CO_2 into the atmosphere. By continuing to impose emissions limitations on fossil fuel-fired electric generating sources under a revised flexible cap-and-trade program, the Department is acting to preserve and protect the State's environment while maintaining a reliable supply of electricity. These air quality improvements will mitigate the impacts of climate change in New York, thereby contributing to public safety, health and welfare. The regulatory flexibility provided under the revisions to the Program, including the CCR and Offset provisions, helps to ensure continued reliability and adequacy of the State's electricity supply, assists in the furtherance of public health, and is necessary for continued industrial development and preservation of physical property.

The Department complied with Sections 202-a, 202-b and 202-bb of the State Administrative Procedures Act through an extensive Regional program review process that included public participation by all Participating States. New York coordinated an additional stakeholder process to gather input from the public within its borders. New York and the Participating States had committed to a comprehensive program review during the initial development of RGGI and agreed to evaluate: program success; program impacts; additional emissions reductions; imports and emissions leakage; and offsets. The Participating States initiated program review in the fall of 2010 with the announcement of the first stakeholder meeting, and concluded the process in February, 2013. The Participating States and RGGI Incorporated (RGGI, Inc.)[4] conducted more than a dozen stakeholder meetings and webinars during this period whereby they obtained public input on a number of program elements. Prior to each stakeholder meeting, agency staff and RGGI, Inc. distributed pertinent written material to the over 250 participants on the list serve and posted meeting documents on the RGGI, Inc. website. The stakeholder meetings were open to the public and all interested parties were encouraged to provide comment. All stakeholder comments were ultimately considered in the development of the Draft Updated Model Rule, which contained detailed regulatory text, and was released to the stakeholders for comment on November 20, 2012. On February 7, 2013, the Participating States released the final version of the Updated Model Rule, which contained additional updates based on stakeholder feedback received on the Draft Updated Model Rule.

New York conducted *an in-state stakeholder process designed* to provide updates on the status of the regional process and to afford additional opportunity for New York's stakeholders to provide comment. The Department held seven meetings and staff availability sessions in New York and, when possible, the Department sent list-serve notices to over 250 New York stakeholders announcing regional meetings and webinars. This included, for example, presentations by Department representatives, regarding RGGI program review and the proposed revisions to the Program, at the Business Council's[5] Spring Environmental Conference on April 18, 2013 and Annual Meeting in Bolton Landing on September 19, 2012.

Needs and Benefits

Introduction

Mitigating the impacts of a changing climate represents one of the most pressing environmental challenges for the State, the nation and the world. Extensive scientific data demonstrates the need for immediate worldwide action to reduce emissions from burning fossil fuels and supports the conclusion that great benefits will accrue if fossil fuel-fired emissions are reduced through programs like RGGI. This section outlines the Department's analysis of the need for the proposed Program revisions, principally the proposed reduction in the CO_2 emissions cap and budget adjustments, and discusses its considerable benefits.

First, this section explains the updated basic science of global climate change and the greenhouse effect and forcing effect that emissions of anthropogenic GHGs have on climate change. Second, this section explains the need for a binding CO_2 emissions cap and budget adjustments as illustrated by the most recent scientific findings and projected future impacts of climate warming on the region. Third, this section explains the Program benefits from the revisions to the Program including the substantial reduction of power plant emissions and the benefits of the CCR and Offsets programs. Finally, it explains the benefits associated with the auctioning of allowances, including CCR allowances, for purposes of energy efficiency and clean energy technologies.

The Greenhouse Effect and the Warming Climate

A naturally occurring greenhouse effect has regulated the earth's climate system for millions of years. Solar energy from the sun that reaches the surface of the earth is radiated back out into the atmosphere as long wave or infrared radiation. CO_2 and other naturally occurring GHGs trap heat in our atmosphere, maintaining the average temperature of the planet approximately 60°F higher than it normally would be. An enhanced greenhouse effect and associated climate change results as large quantities of anthropogenic GHGs, especially CO_2 from the burning of fossil fuels, are added to the atmosphere.

Since the mid-1700's, atmospheric concentrations of GHGs have increased substantially due to human activities such as fossil fuel use and land-use change. This is important because CO_2, as well as some other GHGs, persist in the atmosphere for hundreds of years and, thus, have a lasting effect on the climate. Today, atmospheric CO_2 concentrations have reached 400 parts per million --- nearly 40 percent higher than preindustrial levels, and according to ice core data, higher than at any point in the past 800,000 years.[6]

There is clear scientific consensus that anthropogenic emissions of CO_2 are contributing to the observed warming of the planet as presented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.[7] The large and persuasive body of research demonstrates through unequivocal evidence that the Earth's lower atmosphere, oceans, and land surfaces are warming; sea level is rising; and snow cover, mountain glaciers, and Arctic sea ice are shrinking. The Earth's climate is changing, with adverse consequences already well documented across the globe, in our nation and in the State. Extreme heat events are increasing and intense storms are occurring with greater frequency. Many of the observed climate changes are beyond what can be explained by natural variability of the climate.[8, 9]

In 2005, the United States National Academies of Science and the national academies of 10 other industrial nations reached a number of important conclusions about the need for government action to reduce emissions.[10] In response to scientific projections of likely severe climate impacts if global average temperatures rise more than approximately 3.6°F (2°C) above pre-industrial levels, the U.S. signed the 2009 Copenhagen Accords setting the target of limiting temperature increases to 2°C. The reduction of the emissions cap is further supported by a recent report analyzed by New York and the Participating States during Program review called "America's Climate Choices." This 2011 report by the National Academy of Sciences, recently emphasized again, the pressing need for action to reduce emissions and to limit the magnitude of climate change:

- Climate change poses significant risks for a broad range of human and natural systems;
- The faster emissions are reduced, the lower the risks posed by climate change. Each additional ton of GHG emitted commits us to further change and greater risks;
- It is imprudent to wait for unacceptable impacts to occur before taking action because the effects of GHG emissions do not fully manifest themselves for decades, and once manifested, many of these changes will persist for hundreds, even thousands of years; and
- The sooner that serious efforts to reduce GHG proceed, less pressure will be made for steeper (and thus likely more expensive) emission reductions later.[11]

Impacts from Emissions Already Observed in New York's Climate

The need for the reduction of CO_2 emissions is clearly supported by numerous direct impacts that have been observed in New York State.

- Temperature. Temperatures in New York State have risen during the twentieth century, with the greatest warming coming in recent decades - temperatures have risen by approximately 0.6°F per decade since 1970, with winter warming more than 1.1°F per decade.[12] This warming includes an increase in the number of extreme hot days (days at or above 90°F) and a decrease in the number of cold days (days at or below 32°F). New York experienced record high nighttime temperatures in the summer of 2010.[13]

- Sea level rise. Sea level in the coastal waters of New York State and up the Hudson River has been steadily rising over the 20th century, chiefly as a result of thermal expansion of ocean waters, melting of land ice and local changes in the height of land relative to the height of the continental land mass. Tide-gauge observations in New York indicate that rates of relative sea level rise were significantly greater than the global mean, ranging from 2.41 to 2.77 millimeters per year (0.9 to 1.1 inches per decade).[14]

Future Impacts from Emissions Predicted for New York's Climate

Predictions of future impacts associated with emissions in New York further support the need for a substantial reduction in the CO_2 emissions cap. 'Responding to Climate Change in New York State: The *ClimAID Integrated Assessment for Effective Climate Change Adaptation*' (ClimAID) *project examines* how sea level rise, changes in precipitation patterns, and more frequent severe weather conditions will affect New York's economy, environment, community life and human health. The project uses regionalized climate projections to develop adaptation recommendations and is a climate change preparedness resource for planners, policymakers, and the public.[15] The ClimAID project predicts the following:

- Air temperatures. Air temperatures are expected to rise across New York, by 1.5F° to 3°F by the 2020s, 3F° to 5.5°F by the 2050s, and 4F° to 9°F by the 2080s. By the end of the century, the greatest relative warming is projected for the northern regions of the State. The ranges in projected temperatures reflect potential future GHG emissions scenarios. The lower ends of the temperature ranges represent the projected outcome of lower emissions scenarios in which society dramatically reduces heat-trapping gas emissions and atmospheric GHG levels begin to stabilize. Likewise, the higher ends represent higher emissions scenarios in which emissions continue to increase and atmospheric GHG concentrations continue to rise. Sharp cuts in global emissions could result in smaller increases in temperatures, while a continuation of business as usual could result in increases greater than the highest projections.
- Precipitation. Annual average precipitation in New York is projected to increase by up to 5 percent by the *2020s, up to 10 percent by the 2050s and up to 15 percent by the 2080s, with the greatest increases in* the northern part of the State. The increased precipitation will not be evenly distributed over the course of the year; much of it is likely to occur during the winter months, while slightly reduced precipitation is possible for the late summer and early fall. The recent trend of increased heavy downpours and less light precipitation is expected to continue.
- Sea Level Rise. A recent study based upon 60 years of tide-gauge records indicates that the rate of increase for sea level rise along approximately 1000 km of the east coast of the United States, including New York, remains at approximately three to four times higher than the global average.[16] The New York State Sea Level Rise Task Force, charged by the State Legislature with assessing impacts to the State's coastlines from rising seas and recommending protective and adaptive measures, adopted the sea level rise values in Table 1 for two regions in New York. The projections for sea level rise represent the middle range of values from model-based probabilities (16 global climate models by three GHG emissions scenarios) rounded to the nearest inch. The projections for sea level rise with rapid ice-melt scenario assume acceleration of recent rates of ice melt in the Greenland and west Antarctic ice sheets.

Table 1. Projected Sea Level Rise in Two Regions of New York

Lower Hudson Valley & Long Island	**2020s**	**2050s**	**2080s**
Sea level rise	2 to 5 in	7 to 12 in	12 to 23 in
Sea level rise with rapid ice-melt scenario	5 to 10 in	19 to 29 in	41 to 55 in
Mid-Hudson Valley & Capital Region	**2020s**	**2050s**	**2080s**
Sea level rise	1 to 4 in	5 to 9 in	8 to 18 in
Sea level rise with rapid ice-melt scenario	4 to 9 in	17 to 26 in	37 to 50 in

Source: New York State Sea Level Rise Task Force Report. December, 2010.[17]

- Changes in Extreme Events. Extreme climate events, such as heat waves and heavy rainstorms, significantly impact New York's communities and natural resources. Based on climate models, the ClimAID researchers developed probabilities of the future occurrence of extreme events in New York State. These results demonstrate that heat waves are expected to become more frequent and intense, heavy precipitation events are expected to become more frequent, and storm-related coastal flooding is expected to increase with rising sea levels.

Future Impacts from Emissions for New York State's Resource Sectors

The need for the significantly reduced CO_2 emissions cap and budget adjustments are further supported by the ClimAID Study[18] which enumerates a number of predictions specifically for New York's valued resources.

Water Resources

Rising air temperatures intensify the water cycle by driving increased evaporation and precipitation. The resulting altered patterns of precipitation include more rain falling in heavy events, often with longer dry periods in between. Heavy downpours have increased over the past 50 years and this trend is projected to continue, causing an increase in localized flash flooding in urban areas and hilly regions. Flooding has the potential to increase pollutants in the water supply and inundate wastewater treatment plants and other vulnerable development within floodplains. Less frequent summer rainfall is expected to result in additional, and possibly longer, summer dry periods, potentially impacting the ability of water supply systems to meet demands. Reduced summer flows on large rivers and lowered groundwater tables could lead to conflicts among competing water users. Increasing water temperatures in rivers and streams will affect aquatic health and reduce the capacity of streams to assimilate effluent from wastewater treatment plants.

Coastal Zones

High water levels, strong winds, and heavy precipitation resulting from strong coastal storms already cause billions of dollars in damage and disrupt transportation and power distribution systems. Sea level rise will lead to more frequent and extensive coastal flooding. Warming ocean waters raise sea level through thermal expansion and have the potential to strengthen the most powerful storms. Superstorm Sandy gained additional strength from unusually warm upper ocean temperatures in the North Atlantic. Sea level rise occurring in the New York City area increased the extent and magnitude of coastal flooding during Sandy with estimated costs of damage and loss in New York State exceeding 30 billion dollars.

Barrier islands are being dramatically altered by strong coastal storms, such as Hurricane Sandy, as ocean waters over wash dunes, create new inlets, and erode beaches. Sea level rise will greatly amplify risks to coastal populations and will lead to permanent inundation of low-lying areas, more frequent flooding by storm surges, and increased beach erosion. Loss of coastal wetlands reduces species diversity, including fish and shellfish populations. Some marine species, such as lobsters, are moving north from New York, while other species, such as the blue claw crab, are increasing in the warmer waters. Saltwater could reach farther up the Hudson River Estuary, potentially contaminating water supplies. Tides and storm surges may propagate farther, increasing flood risk both near and far from the coast. Sea level rise may also become the dominant stressor acting on vulnerable salt marshes.

Ecosystems

Within the next several decades, New York State is likely to see widespread shifts in species composition in the State's forests and other natural landscapes, with the loss of spruce-fir forests, alpine tundra and boreal plant communities. Climate change favors the expansion of some invasive species into New York, such as the aggressive weed, kudzu, and the insect pest, hemlock woolly adelgid. Some habitat and food generalists (such as white-tailed deer) may also benefit. A longer growing season and the potential fertilization effect of increasing CO_2 could increase the productivity of some hardwood tree species, provided growth is not limited by other factors such as drought or nutrient deficiency. CO_2 fertilization tends to preferentially increase the growth rate of fast growing species, which are often weeds and other invasive species. Lakes, streams, inland wetlands and associated aquatic species will be highly vulnerable to changes in the timing, supply, and intensity of rainfall and snowmelt, groundwater recharge and duration of ice cover. Increasing water temperatures will negatively affect brook trout and other native coldwater fish.

Agriculture

Increased summer heat stress will negatively affect cool-season crops and livestock unless farmers take adaptive measures such as shifting to more heat-tolerant crop varieties and improving cooling capacity of livestock facilities. Increased weed and pest pressure associated with longer growing seasons and warmer winters will be an increasingly important challenge. Water management will be a more serious challenge for New York farmers in the future due to increased frequency of heavy rainfall events, and more frequent and intense summer water deficits by mid-to late-century.

Public Health

Demand for health services and the need for public health surveillance and monitoring will increase as the climate continues to change. Heat-related illness and death are projected to increase, while cold-related deaths are projected to decrease. Increases in heat-related death, however, are projected to outweigh reductions in cold-related death. More intense precipitation and flooding along the coasts and rivers could lead to increased stress and mental health impacts, impaired ability to deliver public health and medical services, increased respiratory diseases such as asthma, and increased outbreaks of gastrointestinal diseases. Cardiovascular and respiratory-related illness and death will be affected by worsening air quality, including more smog, wildfires, pollens, and molds. Vector-borne diseases, such as those spread by mosquitoes and ticks ('e.g.', West Nile virus and Lyme disease), may expand or their distribution patterns may change, either of which may adversely affect additional populations. Water supply, recreational water quality, and food production will be at increased risk due to increased temperatures and changing precipitation patterns. Water- and food-borne diseases are likely to increase without mitigation and adaptation intervention.

Transportation

Over the next few decades, heat waves and heavy precipitation events are likely to increase transportation problems such as flooded streets and delays in mass transit. Coastal flooding will be more frequent and intense due to sea level rise. Major adaptations are likely to be needed, not only in the coastal zones, but also in the Hudson River Estuary all the way to Troy and Albany as sea level rise and storm surge propagate up the tide-controlled Hudson River. Materials used in transportation infrastructure, such as asphalt and train rails, are vulnerable to increased temperatures and frequency of extreme heat events. Air conditioning requirements in buses, trucks, and trains, and ventilation requirements for tunnels will increase.

Low-lying transportation systems such as subways and tunnels, especially in coastal and near-coastal areas, are at particular risk of flooding as a result of sea level rise, storm surge, and heavy precipitation events. Transportation systems are vulnerable to ice and snowstorms, although requirements for salting and snow removal may decrease as precipitation tends to occur more often as rain than snow. Freeze/thaw cycles that disturb roadbeds may increase in some regions as winter temperatures rise. Runways may need to be lengthened in some locations since hotter air provides less lift and hence requires higher speeds for takeoff. Newer, more powerful aircraft can reduce this potential impact. The Great Lakes may see a shorter season of winter ice cover, leading to a longer shipping season but lake levels may decrease due to increased evaporation. Reduced ice cover may result in an increase in "lake-effect" snow events, which cause various transportation problems.

New York State has the most days per year of freezing rain in the nation. This phenomenon affects air and ground transportation directly and indirectly through electric and communication outages. It is unknown how climate change will influence the frequency of freezing rain in the future.

Telecommunications

Communication service delivery is vulnerable to hurricanes, lightning, ice, snow, wind storms, and other extreme weather events, some of which are projected to change in frequency and/or intensity. The delivery of telecommunication services is sensitive to power outages, such as those resulting from the increased electrical demand associated with heat waves, which are expected to increase with climate change. Communication lines and other infrastructure are vulnerable to heavy precipitation events, flooding, and freezing rain. In coastal and near-coastal areas, sea level rise in combination with coastal storm surge flooding will be a considerable threat later this century.

Energy Sector

Impacts of climate change on energy demand are likely to be more significant than impacts on supply. Climate change will adversely affect system operations, increase the difficulty of ensuring adequate supply during peak demand periods, and exacerbate problematic conditions, such as the urban heat island effect. More frequent heat waves will cause an increase in the use of air conditioning, stressing power supplies and increasing peak demand loads. Increased air and water temperatures will decrease the efficiency of power plants as they decrease cooling capacity.

Coastal infrastructure is vulnerable to flooding as a result of sea level rise and coastal storms; hydropower is vulnerable to projected increases in summer drought. The availability and reliability of solar power systems are vulnerable to changes in cloud cover although this may be offset by advances in technology; wind power systems are similarly vulnerable to changes in wind speed and direction. Biomass energy availability depends on weather conditions during the growing season which will also be affected by a changing climate.

Transformers and distribution lines for both electric and gas supply, as was observed recently due to Superstorm Sandy, are vulnerable to extreme weather events, such as heat waves and flooding. Higher winter temperatures are expected to decrease winter heating demand, which will primarily affect natural gas markets, while increases in cooling demand will affect electricity markets; such changes will vary regionally. The indirect financial impacts of climate change may be greater than the direct impacts of climate change. These indirect impacts include those to investors and insurance companies as infrastructure becomes more vulnerable and those borne by consumers due to changing energy prices and the need to use more energy.

As outlined above, climate change is expected to impact New York's communities, economy and energy systems, affecting public health and safety, environment and natural resources, commerce and infrastructure. Consistent with its mission to protect the safety, health, and welfare of the public and the environmental resources of the State, the Department proposes the substantial reduction of the CO_2 emissions cap and budget adjustments, to address the specific potential harms identified and the overall nature and extent of threat of harm to the State from climate change.

Emissions from Power Plants in New York

The burning of fossil fuels in New York power plants is a major contributor to increased atmospheric concentrations of CO_2. In 2012, power plants in the State subject to the Program burned fossil fuels to produce approximately 35 million tons of CO_2 and significant amounts of other harmful pollutants that impact the health and welfare of New Yorkers. Since CO_2 emissions from the energy sector represent approximately one-fifth[19] of the State's total GHG emissions, any effort to curb the State's contribution to atmospheric concentrations of CO_2 must address CO_2 pollution from power plants.

In 1992, 154 nations, including the United States signed a treaty establishing the goal of stabilizing atmospheric GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. In response to scientific projections of likely severe climate impacts if global average temperatures rise more than approximately 3.6°F (2°C) above pre-industrial levels, the U.S. signed the 2009 Copenhagen CO_2 Accord[20] setting the target of limiting temperature increases to 2°C. As reported in 2007 by the IPCC, the best available scientific estimates indicate that there is an approximately 50 percent likelihood that the 2°C threshold will be exceeded when atmospheric CO_2 concentrations rise above 450 parts per million (ppm). Scientists project that stabilizing total atmospheric GHG concentrations (CO_2 plus the other long-lived GHGs, which include methane, nitrous oxide, ozone and several manmade fluorine-containing gases) at 450-500 ppm would provide a medium (approximately 50 percent) likelihood that warming will not exceed 2°C.

Scientific estimates of global emission levels required to maintain this concentration of atmospheric GHGs indicate that developed nations will need emission reductions of 80 percent from 1990 levels by mid-century. Given the considerable global CO_2 emissions already released to the atmosphere between 2000 and 2011, there is significant risk of exceeding the 2°C target unless decisive, global action is taken within this decade. The International Energy Agency's (IEA) 'World Energy Outlook Special Report 2013: Redrawing the Energy Climate Map' concludes the possibility of keeping the rise in global average temperature to 2°C now appears more remote than it was several years ago, but proposes near-term action to reduce emissions from the power sector and target energy efficiency measures in buildings, transportation and industry.

By modeling effective GHG emissions reduction, New York can encourage other states and nations to turn around the accumulation of heat-trapping GHG in the atmosphere. New York's acknowledged leadership position confers a unique opportunity to influence the ultimate costs the State and its citizens will bear from climate change.

Components of the Proposed Program Revisions

The reduction in the CO_2 emissions cap to current levels represents a critical step to combat the significant challenges presented by climate change and to advance sound energy policies that foster energy efficiency and energy independence.

The proposed Program revisions will cap regional emissions at 91 million tons annually beginning in 2014 and will reduce that level by 2.5 percent each year through 2020. This represents a nearly 45 percent reduction from the existing cap currently in place under the program. After 2020, the cap will remain at 78 million tons annually.

Further, to account for the existing private bank of CO_2 emissions allowances already acquired at auction, and to help create a binding cap, the proposed Program revisions provide two distinct budget (cap) adjustments. The First Control Period Interim Adjustment for Banked Allowances will reduce the budget for 100 percent of the first control period private bank of allowances (vintages 2009, 2010, and 2011) held by market participants after the first control period. The first adjustment will reduce New York's budget (the annual cap) by its portion of the regional cap (approximately 38.93 percent) in each allocation year over the seven year period 2014-2020. The Second Control Period Interim Adjustment for Banked Allowances will reduce the budget for 100 percent of the surplus 2012 and 2013 vintage allowances held by market participants as of the end of 2013. The second adjustment will reduce New York's budget (the annual cap) by its portion of the regional cap (approximately 38.93 percent) in each allocation year over the six year period 2015-2020.

To provide additional flexibility and cost containment the proposed Program revisions also create the Cost Containment Reserve (CCR). The CCR allowances will be triggered and released at auctions at $4/ton in 2014, $6/ton in 2015, $8/ton in 2016, and $10/ton in 2017. Each year after 2017 the CCR trigger price will increase by 2.5 percent. If the trigger price is reached, up to 10 million additional CCR allowances will be available for purchase at auction, except in 2014, when the reserve will be limited to five million allowances. The existing price triggers for expanding use of offsets and the one year compliance period extension will be eliminated in favor of the CCR.

As designed and implemented, the proposed reduction to the CO_2 emissions cap and budget adjustments will also achieve significant additional reductions outside of the power sector through reinvestment of auction proceeds for end-use energy efficiency and greenhouse gas emission reduction projects.

Finally, the proposed Program revisions create an interim compliance obligation in part to align it with the annual compliance obligations under federal programs such as the Clean Air Interstate Rule and the Title IV Acid Rain Program. This program revision also helps to address the potential for a budget source to avoid its compliance obligation as a result of the business closing or falling into bankruptcy prior to the third year compliance obligation. In addition to demonstrating full compliance at the end of each three-year compliance period, regulated entities must now demonstrate that they are holding allowances equal to at least 50 percent of their emissions at end of the first two years in each three year compliance period. The proposed Program amendments also include minor revisions such as setting the reserve price at $2.00 in 2014, to rise at 2.5 percent per year in subsequent years, updating all references, and deleting the early reduction allowance provisions. The majority of the proceeds from the sale of New York's allowances will be continue to be dedicated to strategic energy or consumer benefits, such as energy efficiency and clean energy technologies.

Benefits from the Proposed Program Revisions

Global action is needed to solve climate change, however renewed action in New York now will have local and Statewide benefits. Significant economic opportunities and environmental and health co-benefits such as reduced air pollution and improved public health are expected from programs that mitigate GHG emissions. First and foremost the reduction of the emissions cap and budget adjustments are projected to result in cumulative emission reductions, within the Participating States (2014 through 2020, including offsets), of 86 million tons of CO_2. In addition, the Program's mandatory, market-based carbon control mechanisms will remain unchanged and will continue to function properly and deliver positive economic benefits.[21, 22, 23, 24, 25]

In New York, auction proceeds will continue to support additional emission reductions through investments in energy efficiency, renewable and clean energy and innovative carbon-abatement technologies, as guided by the RGGI Operating Plan.[26] NYSERDA regulations established the Advisory Group of stakeholders, which will continue to represent a broad array of energy and environmental interests, to provide advice on how best to utilize auction proceeds to implement the goals of the Program of reducing CO_2 emissions in the most economically-efficient manner with the least cost to electricity consumers. The Operating Plan will continue to be reviewed and revised on an annual basis and the Advisory Group will convene to provide input.

The most recent version of the Operating Plan dated November 2012 estimates that the current investment of a portion of New York's proceeds in the Green Jobs - Green New York, Residential Energy Services, Municipal Water and Wastewater, and Industrial Process Improvement programs during a three year period will result in non-discounted lifetime savings of 1.9 million tons of CO_2 emissions and a non-discounted lifetime savings of $390 million on customer energy bills.

Projected benefits from the proposed revisions are detailed in a study by the Northeast States Coordinated Air Use Management (NESCAUM) that estimates the macroeconomic impacts of the program in the RGGI region. The study uses the Regional Economic Models, Inc. Policy Insight™ (REMI) model, a multi-state structural economic forecasting and policy analysis model that produces projections of employment, gross state product, and personal income.[27] The macroeconomic results reflect the potential impacts associated with the proposed revisions to the program (including the investment of auction proceeds in an estimated portfolio of energy efficiency, clean energy and carbon abatement programs). The study estimates that the cumulative changes in New York's Gross State Product and Personal Income associated with the proposed revisions to the program will be about $5.8 billion and $4.7 billion, respectively (2010 dollars, calculated as the present value of estimated annual changes over the period 2012 to 2040, discounted at three percent per year to account for the time-value of money). In the context of New York's total Gross State Product and total Personal Income these changes represent small but positive changes.

While the Operating Plan and macroeconomic modeling provide estimates of future benefits associated with the investment of projected auction proceeds in New York, NYSERDA will continue to prepare quarterly status reports that will include: a summary of program activities and implementation; an estimate of program benefits; and an accounting of program costs and expenditures associated with the actual receipt of proceeds through that point in time. The last quarterly progress report of the year also serves as an annual evaluation and status report. The annual report will also provide information on the geographic distribution of Program funding and benefits across the State.

The annual report for the quarter ending December 31, 2012 reflects benefits associated with spending through that date. The table below illustrates the estimated cumulative annual benefits (as of December 31, 2012) at the portfolio and program levels from all currently operational projects installed since the start of the existing Program. These metrics, prepared by NYSERDA Program evaluation and implementation staff, represent the State's best estimate of Program benefits to date and are adjusted over time as individual programs are evaluated and results are adjusted based on those evaluation studies.

Summary of Cumulative Portfolio Benefits through December 31, 2012[28]

Benefits	Results through December 31, 2012
Net Greenhouse Gas Emission Savings[1]1 (Annual Tons CO_{2e}[2])	56,764
Net Electricity Savings (Annual MWh)	16,895
Renewable Energy Generation (Annual MWh)	4,345
Net Natural Gas Savings (Annual MMBtu)	203,118
Net Fuel Oil Savings (Annual MMBtu)	337,096
Net Propane Savings (Annual MMBtu)	16,593
Net Steam Savings (Annal MMBtu)	15,969
Net Wood Savings (Annual MMBtu)	3,079
Net Kerosene Savings (Annual MMBtu)	1,026
Net Gasoline Savings (Annual MMBtu)	-
Net Residual Oil Savings (Annual MMBtu)	144
Net Diesel Savings (Annual MMBtu)	-
Total Fuel Savings (Annual MMBtu)	577,024
Annual Energy Bill Savings to Participating Customers ($ Million)	12.0

[1] These emission reductions are associated with both electric and fossil-fuel saving measures. Under a cap -and-trade system, the total number of emission allowances is determined by regulation. Regulated entities can purchase allowances and collectively emit up to the cap that is currently in place. Therefore, in the near term, electric efficiency projects may not decrease the overall amount of emissions going into the atmosphere. Nevertheless, electric efficiency projects will reduce end-users' responsibility or footprint associated with emissions from electricity production.

[2] CO_2e stands for carbon dioxide equivalent and describes the amount of CO_2 that would have the same global warming potential.

NYSERDA projects the discounted lifetime savings of the cumulative values in the table to result in approximate: fuel savings of 8.7 million MMBtu; electricity savings of 294,000 MWh; bill savings of $223 million; and CO_2 emission reductions of 753,000 tons. These annual values were converted to lifetime savings by applying a measure life assumption for each program that is based on the life of the longest-lived measure for that specific program. A five percent discount rate is applied to weight the impacts of the benefits over time.

The Program portfolio also results in non-energy benefits. For instance: Program funds were leveraged to obtain $100 million in Federal funding to support a New York based Photovoltaic (PV) Manufacturing Consortium; ten regional sustainability plans were created with the involvement of more than 2,500 New York stakeholders; and a series of technical analyses related to offshore wind development have been completed.

Complementary GHG Programs in New York

The Program and the proposed revisions to the Program, along with Greenhouse Gas Exhaust Emission Standards (6 NYCRR Part 218-8), CO_2 Performance Standards for Major Electric Generating Facilities (6 NYCRR Part 251), and the Renewable Portfolio Standard (RPS) are key components of New York's comprehensive GHG reduction policy. Working together, these programs benefit New York by reducing GHG emissions from the electricity generating sector and the motor vehicles sector, which are the two largest contributors of GHG emissions in New York State.

First, the Department adopted California GHG exhaust emission standards (6 NYCRR Subpart 218-8) for new motor vehicles to reduce emissions of GHGs, including most recently with amendments adopted in 2012. Section 177 of the Clean Air Act (42 United States Code Section 7507) permits states other than California to adopt motor vehicle emission standards, provided those standards are identical to California's standards. New York has chosen to adopt California's more stringent motor vehicle standards since the early 1990s, in order to obtain emission reductions from new motor vehicles not provided by Federal new motor vehicle standards.

Secondly, the Department promulgated CO_2 Performance Standards for Major Electric Generating Facilities (6 NYCRR Part 251) in 2012, which prevents new high carbon emitting sources in the power sector (like coal-fired plants without carbon capture and sequestration or another control technology) and establishes CO_2 emission standards for new major electric generating facilities. Part 251 also establishes CO_2 emission standards for the expansion of existing electric generating facilities that increase electrical output capacity by at least 25 MW. The Program and Part 251 work together - RGGI sets an overall cap on CO_2 emissions from all new and existing fossil fuel-fired sources 25 MW and larger, while Part 251 sets a specific source-level CO_2 emission limit on all new and expanding sources 25 MW or larger.

Finally, the primary objective of the RPS is to improve New York's environment and increase energy diversity in order to reduce reliance on fossil fueled energy sources within a competitive energy market. The RPS seeks to increase the amount of electricity purchased from renewable sources in New York to 30 percent by 2015. Eligible energy technologies include anaerobic digestion, biomass, fuel cells, hydroelectric, solar, tidal, and wind. The RPS features centralized procurement managed by NYSERDA which manages the RPS Program and solicits bids for renewable energy.

Climate change is a global problem and effective action at the national and international level is necessary in order to stabilize atmospheric GHG concentrations at acceptable levels. Notwithstanding this, action now at the State and regional level to reduce GHG emissions and to implement the revisions to the Program will benefit and reduce the risk of injury to New York and its citizens and residents from climate change. The risks of injury from a warming climate increases with the rate and magnitude of the warming, and in turn, the rate and magnitude of warming is primarily dependent upon the level of CO_2 emissions. The reductions in CO_2 emissions from power plants under the revisions to the Program contribute to a reduction in the risk of injury to New York and its citizens and residents from global climate change. In addition, by implementing the proposed revisions to the Program now, New York and the Participating States can:

- Reduce the long-term costs of addressing climate change. By acting now, states can avoid the need for more disruptive measures later.
- Position the region ahead of competitors. Taking early and continued action to reduce the region's carbon-intensity will create a competitive advantage relative to other parts of the country when action at the national and international level becomes unavoidable.
- Capture environmental co-benefits. Reducing power sector carbon emissions provides numerous environmental co-benefits, including reduced emissions of other pollutants associated with fossil-based electricity generation. Additional co-benefits will be realized through the offsets component of the program which encourages afforestation, reduced agricultural emissions, and reduced consumption of natural gas, propane, and home heating oil. Additionally, co-benefits will be realized by allocating almost 100 percent of the CO_2 allowances to the EE&CET account to be auctioned by NYSERDA and have the resulting proceeds utilized for the account's purposes.
- Drive new technology. By attaching tangible financial value to avoided carbon emissions, the proposed Program revisions provide a market incentive for developing and deploying new technologies that can increase fuel efficiency, utilize non-carbon resources (including renewable technologies such as wind and solar power), and reduce or eliminate carbon emissions from combustion sources. In addition, to the extent that the auctioning of allowances will spur additional investments in clean energy technologies, the auctions drive the deployment of new technologies in the State.
- Promote improved supply-side and demand-side efficiency. The proposed Program revisions create a direct incentive to reduce the fossil fuel inputs required to produce electricity through more efficient generating technologies. The Program's offsets provisions will continue to create incentives to promote improved demand-side efficiency, including not only more efficient technologies for reducing electricity consumption, but technologies for reducing primary energy consumption - both natural gas and home heating oil - in residential and commercial buildings. In addition, the allocation of offset allowances to create incentives for energy efficiency provides direct incentives for end-use and supply-side energy efficiency projects in the State.
- Improve the region's energy security and reduce its exposure to higher energy prices. By creating a market incentive for low-carbon and non-carbon electricity technologies and by promoting increased supply-side and demand-side efficiency, the proposed Program revisions reduce the Northeast's long-term exposure to high fossil fuel energy prices. Efficiency improvements and advances in new energy technology fostered by the proposed Program revisions can help buffer the region from the considerable economic risks associated with continued dependence on these fuels.
- *Stimulate economic development. The proposed Program revisions provide a positive stimulus for* economic growth in the region by creating incentives for new technologies that could be developed in-region, promoting a more efficient and cleaner electricity generating sector, prompting other activities

through its offsets program and improving efficiency. NYSERDA's investment of proceeds from the auctioning of allowances provides further economic benefits.

As outlined above, the revisions to the Program will provide numerous benefits and continue to position New York as a leader in innovative and progressive climate change policies. In the absence of a comprehensive federal program, New York must continue to monitor issues that may minimize or threaten the effectiveness of the Program such as the potential for emissions leakage.

Emissions Leakage

Emissions Leakage refers to a potential shift of electricity generation from capped sources subject to the Program, to higher-emitting sources not subject to the Program, in and outside of the State.[29] Emissions leakage is defined as the increase in CO_2 emissions outside the RGGI region that may "net out" (or partially eliminate) a portion of the emissions reductions made within the RGGI region. Emissions leakage is an important concept because electricity is routinely transmitted across regional boundaries to meet economic and reliability objectives.

The Department examined emissions leakage in the Final Generic Environmental Impact Statement for the existing Program, accepted on August 13, 2008, and has continued to evaluate the potential for emissions leakage since the Program's inception. New York and the Participating States examined leakage for CO_2 and other pollutants from the electric generating sector, such as NO_x and SO_2. However, since the federal action under the Clean Air Interstate Rule (CAIR) resulted in emissions caps for NO_x and SO_2, from the electric generating sector, emissions may shift, but will not increase as a result of the Program revisions.

Over the past few years, the RGGI Electricity Monitoring Staff Working Group (Staff Working Group) analyzed potential emissions leakage and issued two annual monitoring reports.[30, 31] These reports summarized data for electricity generation, electricity imports, and related CO_2 emissions for the Participating States from 2005 through 2010 and concluded that during the first two years of RGGI Program operation (2009 and 2010), there was no increase in CO_2 emissions or the CO_2 emission rate (pounds of CO_2 per megawatt hour, or lb CO_2/MWh) from non-RGGI electric generation serving load in the ten-state RGGI region. Thus, for that period, these reports found no evidence of emissions leakage caused by the existing Program.

In addition to the Electricity Monitoring reports issued by the Participating States, the New York ISO Inc., (NYISO) together with researchers at Rensselaer Polytechnic Institute (RPI), evaluated whether the Program's cost of compliance has resulted in emissions leakage. The NYISO and RPI developed econometric models to explain power transfers and CO_2 emissions from power plants in Pennsylvania from 2008 through 2010. While the models concluded that electrical loads, fuel costs, and non-emitting generation all have statistically significant impacts on emissions and power transfers, or both, the model was not able to show a statistically significant impact from the Program costs on either of the variables.[32] In other words, the report concludes that there is no evidence that the existing Program has caused emissions leakage.

Thus, according to the reports and studies conducted to date, no evidence of emissions leakage associated with the existing Program has been found. In order to estimate the amount of potential leakage associated with the proposed revisions to the Program including the cap reduction, the electricity sector modeling analysis estimated CO_2 emissions in and outside of the region. Cumulative CO_2 emissions reductions were compared between the RGGI region and the Eastern Interconnection[33] (which includes the RGGI region) plus the eastern Canadian provinces. Cumulative emission reductions within the Participating States (2014 through 2020, including offsets) are projected to be 86 million tons of CO_2. Over the same period, cumulative reductions in the entire Eastern Interconnect region are projected to be 28 million tons of CO_2. While the emissions leakage reports are being offered to guide New York and the region in making critical policy decisions, if monitoring indicates that leakage associated with the Program occurs and needs to be addressed, a number of states including New York,[34] are already moving to implement significant energy efficiency programs which help mitigate the effects of any emissions leakage.

Further, at the conclusion of Program review, the Participating States committed to engage in a collaborative effort informed by discussions with their respective ISOs to: identify and evaluate potential imports tracking tools; conduct further modeling to ascertain energy and price implications of any potential policy on emissions associated with imported electricity; and pursue additional legal research, leading to a workable, practicable, and legal mechanism to address emissions associated with imported electricity.

Benefits Associated with the Program Revisions with Respect to the Auction and Allocation of Allowances to Energy Efficiency and Clean Energy Technologies (EE & CET).[35]

Like the current Program, the proposed Program revisions require the Department and NYSERDA to continue to auction almost 100 percent of the allowances to ensure that the value of the cap-and-trade program inures to the consumers who pay for the Program, while at the same time allows for the rapid distribution of allowances into the marketplace where generators subject to the Program may purchase them. In further support of these goals, the auctions will continue to achieve, but will not be limited to, the following objectives: achieving fully transparent and efficient pricing of allowances; promoting a liquid allowance market by making entry and trading as easy and low-cost as possible; being open to participation by the categories of bidders determined by NYSERDA or its designee in consultation with the Auction Advisory Committee which meet the minimum financial requirements; monitoring for and guarding against the exercise of market power and market manipulation; being held as frequently as is needed to achieve design objectives; avoiding interference with existing allowance markets; aligning well with wholesale energy and capacity markets; and not acting as a barrier to efficient investment in relatively clean existing or new electricity generating sources.

NYSERDA's New York CO_2 Allowance Auction regulation, found at 21 NYCRR 507, establishes the rules for conducting auctions of CO_2 allowances to be administered by NYSERDA or its designee as part of the Program. This regulation is not proposed to be revised as part of this rulemaking, however, New York intends to continue to participate in uniform regional auctions for the allowances that it will be offering for sale. As part of the regional auction process, New York and the Participating States will continue to follow specific design elements for: reserve price; auction structure and format; allowance sale schedule; level of participation; treatment of unsold allowances; notice of auctions; monitoring; and auction results. Additional details and rules for each regional CO_2 allowance auction are provided in the Auction Notice issued by New York and the Participating States for each auction.

The Reserve Price is the minimum acceptable price for each CO_2 allowance in a specific auction. The reserve price at an auction is either the Minimum Reserve Price (MRP) or the Cost Containment Reserve (CCR)[36] trigger price, depending on the level of demand for allowances at the auction. Its use is important for mitigating the potential for auction prices to clear significantly below current market prices, due to tacit or explicit collusion, weak competition, or to maintain a minimum rate of progress in reducing emissions below business as usual.

The revisions to the Program provide that the MRP will be set at $2.00 in 2014 and increases by 2.5 percent each year. The CCR trigger prices are set at $4.00 in 2014, $6.00 in 2015, $8.00 in 2016, and $10.00 in 2017, rising by 2.5 percent each year thereafter in order to account for inflation.

Allowance Apportionment

Apportionment is the term used to describe the process by which the Participating States propose to distribute the regional emissions cap to individual state budgets. While there were a number of discussions surrounding apportionment during this Program review, it was agreed that a full review would not occur until the next Program review slated for 2016. Therefore, New York retains the same percentage of the regional cap established under the existing Program (approximately 38.93 percent). Notwithstanding this, in allocation years 2014, 2015, and 2016 only, New York is proposing to reduce its base budget from the amount that would otherwise result from this percentage by 200,000 allowances. Concurrently, the State of Rhode Island's base budget would increase by 200,000 allowances over that same time frame. New York is one of five RGGI states (also DE, MA, MD and VT) that has agreed to this temporary adjustment of their apportionment in order to provide more allowances to Rhode Island. When RGGI was initially established, allowances were apportioned among the states largely on the basis of emissions. While most RGGI states have experienced emissions from the affected source sector well below their portion of the regional cap between 2009 and 2012, emissions increases in Rhode Island have exceeded Rhode Island's apportioned percentage substantially in each year of the program. The temporary adjustment of allowances is intended to reduce Rhode Island's "shortfall" until the RGGI states have the opportunity for a thorough evaluation of the apportionment of allowances under the regional cap during the next program review planned for 2016. That evaluation will consider whether the apportionment formula should be changed and, if so, what criteria should govern that apportionment: emissions, electricity consumption, population etc.

It should be noted that this reduction does not change the State's percentage as it is applied to the interim adjustments or the cost containment reserve (CCR). Each of these will be based on the existing and continuing apportionment percentage of approximately 38.93 percent. In addition, the proposed rule eliminates the Reduction in the CO_2 Budget Trading Program base budget currently required under the limited exemption for units with an enforceable permit condition restricting the supply of the unit's annual electrical output to the electric grid to less than or equal to 10 percent of the annual gross generation from the unit. This will result in New York having more allowances to auction, despite the temporary reapportionment of some allowances to Rhode Island, than if it retained this provision.

Further, while this temporary reduction alters the cap trajectory for New York and Rhode Island relative to the 2.5 percent annual reduction for 2014, 2015 and 2016, it does not impact the regional cap trajectory. In other words, the regional emissions cap will decline by 2.5 percent each year from 2015 through 2020. In addition, in 2017, both states' base budgets realign to the existing apportionment percentages, and thus move back to the 2.5 percent trajectory based on calculating that trajectory from the starting year of 2014.

Allowance Set-Asides

The Department proposes to maintain the amount of CO_2 allowances allocated to the two existing set-aside accounts under the Program and proposes a modification to the existing voluntary renewable energy market set-aside to include eligible biomass, and minor clarifications to the long term contract (LTC) set-aside. Accordingly, the Department will allocate 700,000 and 1,500,000 tons to the voluntary renewable energy market and eligible biomass set-aside and long term contract set-aside accounts, respectively, from the CO_2 Budget Trading Program annual adjusted budget.

The Department proposes to modify the existing "voluntary renewable energy market set-aside" in subdivision 242-5.3(c) to include eligible biomass. This revision expands eligibility for retiring CO_2 allowances from the set-aside to include CO_2 budget sources that co-fire eligible biomass as a compliance mechanism. The Program currently allows CO_2 budget sources to deduct, as a compliance mechanism, CO_2 emissions attributable to the burning of eligible biomass from its CO_2 allowance compliance obligation. When this occurs, the amount of CO_2 emissions covered by the program decreases, meaning that demand for CO_2 allowances also decreases. Moreover, the amount of CO_2 allowances available to other CO_2 budget sources for compliance would correspondingly increase, potentially resulting in an "inflated" or over-allocated CO_2 emissions budget and regional CO_2 emissions cap. Thus, in order to help maintain the overall environmental integrity of the CO_2 emissions budget and regional CO_2 emissions cap, CO_2 allowances should also be retired from the Program if and when CO_2 emissions are exempted from the Program. Therefore, when a CO_2 budget source deducts CO_2 emissions from its compliance obligation as a result of co-firing eligible biomass, the Department proposes to also allow for the retirement of the corresponding number of CO_2 allowances from the set-aside.

The proposed revisions to the Program maintain the existing provisions for voluntary renewable energy purchases. A voluntary renewable energy purchase is a purchase of electricity from renewable energy generation or from renewable energy attribute credits by a retail electricity customer on a voluntary basis. Renewable energy includes electricity generated from biomass, wind, solar thermal, photovoltaic, geothermal, hydroelectric facilities certified by the Low Impact Hydropower Institute, wave and tidal action, and fuel cells powered by renewable fuels. The renewable energy generation or renewable energy attribute credits related to such purchases may not be used by the generator or purchaser to meet any regulatory mandate, such as an RPS. The Department will continue to retire allowances under the voluntary renewable energy market and eligible biomass set-aside for voluntary renewable energy purchases.

The 700,000 ton voluntary renewable energy market set-aside was calculated using information from the renewable energy market as it relates to the RPS with allowance for some market growth. Since the inception of the Program, this set-aside has been significantly under-subscribed and less than half of the annual 700,000 CO_2 allowance allocation has been retired each year on behalf of voluntary renewable energy purchases. The proposed expansion of eligibility in subdivision 242-5.3(c) increases the likelihood that the set-aside will be fully utilized. However, should the set-aside become over-subscribed, the Department maintains the proportional retirement provision in the set-aside, and any undistributed allowances from the set-aside may remain in the set-aside account for future retirement.

Under the proposed revisions to the Program, the LTC set-aside in subdivision 242-5.3(d) will continue to be available to CO_2 budget sources that can demonstrate, to the Department's satisfaction that: the LTC was entered into prior to March 2006; purchasing of allowances at auction or in the secondary market leads to substantial financial hardship because the LTC applicant is unable to pass on the cost of CO_2 allowances to the purchasing party under the conditions of the LTC; and the source's primary fuel is natural gas or the CO_2 budget source's CO_2 emission rate is no higher than 1100 lbs/MWhr. The proposed revisions to the LTC set-aside are intended to clarify the operation and administration of the set-aside, consistent with the Department's interpretation of subdivision 242-5.3(d) pursuant to Declaratory Ruling 19-18, which the Department issued on November 5, 2009.

Pursuant to the requirements in the regulation, each year the Department has reduced the quantity of allowances available for auction pursuant to the Reduction in the CO_2 Budget Trading Program base budget required under the "Behind-the Meter" provisions. This limited exemption for units with an enforceable permit condition restricting the supply of the unit's annual electrical output to the electric grid to less than or equal to 10 percent of the annual gross generation from the unit requires the Department to reduce the CO_2 Budget Trading Program base budget to remove the tons equal to the exempt unit's average annual emissions from the previous three calendar years. The Department is proposing to eliminate this provision because the regional cap, established under the program revisions, did not account for the emissions from these sources; therefore it is no longer necessary to subtract the emissions attributed to them from the base budget.

Summary of Needs and Benefits

New York's climate is changing, in part as a result of emissions from the burning of fossil fuels to generate electricity; reducing emissions now will help reduce the risk and magnitude of future climate change. The proposed revisions to the Program will reduce the emissions from New York power plants that cause and contribute to global climate change, while at the same time promote energy efficiency and clean renewable energy in the State. The EE & CET Allocation will ensure that electricity consumers in a deregulated market receive the maximum benefits from the revised Program at the least possible cost, and the investment of proceeds from the auction of allowances will provide further economic and environmental benefit.

Costs

Introduction

In addition to the needs analysis, the Department, NYSERDA and the New York State Department of Public Service (DPS) analyzed costs and impacts associated with compliance with the proposed revisions to the Program. This section explains NYSERDA's analysis and includes a summary of the Integrated Planning Model (IPM®) modeling conducted by ICF International (ICF). IPM® is a nationally recognized modeling tool used by the U.S. Environmental Protection Agency (EPA), state energy and environmental agencies, and private sector firms such as utilities and generation companies. This section also discusses the Department's analysis of the costs associated with State and local government compliance and impacts from the proposed revisions to the Program on the New York economy and customer bills.[37, 38]

Costs to the Regulated Sources and the Public

Reference Case v. Program Case

Modeling analysis and review was coordinated by RGGI Inc. and New York staff, and included input from energy and environmental representatives from the Participating States and each regional ISO. To estimate the potential impacts of the revisions to the Program, IPM® compared a future with the revisions to the Program (Program Case) to a Reference Case (business as usual scenario) that projects how the electricity system would look if the Program remained unchanged and proposed revisions were not implemented. The modeling assumptions and input data were developed through a stakeholder process with representatives from the electricity generation sector, business and industry, environmental advocates and consumer interest groups. Modeling results were then presented to stakeholders for review and comment throughout the development of the proposed revisions to the RGGI program.

Reference Case

Assumptions and sources of input data are specified in detail in the "RGGI DRAFT 2012 Reference Case and Sensitivity Analyses Assumptions."[39] Key assumptions and data include regional electricity demand, load shapes, transmission system capacities and limits, generation unit level operation and maintenance costs and performance characteristics, fuel prices, new capacity and emission control technology costs and performance characteristics, reserve margins and local reserve requirements, RPS requirements, national and state environmental regulations, and financial market assumptions. All estimates are based on 2010 dollars. Regional electricity demand growth projections, transmission capacities and limits, and near-term expected infrastructure additions/retirements were obtained from regional ISO sources. Long range Henry Hub natural gas prices (2020), based on forecast data from U.S. Energy Information Administration (EIA) were projected to be approximately $4.6/MMBtu (constant 2010 dollars).

A number of assumptions were used to develop the model, including: 1) the construction of new coal-fired plants was precluded to meet projected capacity shortfalls in the United States unless they include carbon capture; 2) new nuclear plant construction was limited to build outs at existing plant sites; 3) a national 3-pollutant policy (SO_2, NO_x and mercury) that approximates the Cross-state Air Pollution Rule (CSAPR) and the Mercury and Air Toxics Rule (MATS) is assumed; 4) RPS targets are assumed to be met in all states except New York; and 5) partial fulfillment of the RPS target is assumed in New York based upon New York ISO certainty criteria, capacity under RPS contract, and RPS funds currently approved for future solicitations (approximately $3 billion).

Under the Reference Case, generation from new gas-fired combined cycle units is projected to supply most of the growing electricity demand. Electric generation from gas-fired plants in New York is projected to increase by approximately 37 percent from 48,109 Gigawatt hours (GWh) in 2013 to 65,983 GWh in 2020. Generation from new renewable resources (primarily wind units) is projected to increase significantly, largely in response to RPS requirements. While nuclear generation is projected to decrease by about 35 percent between 2013 and 2020 due to the assumed retirement of the Indian Point units upon their respective license expiration, generation from coal-fired plants is projected to increase by about eight percent between 2013 and 2020. Finally, generation from existing oil/gas steam units is projected to decrease over time, as a result of displacement by lower-cost electricity from new gas-fired units. Additionally, net imports of electricity into New York are projected to rise from approximately 24,000 GWh in 2013 to approximately 26,800 GWh in 2016 before decreasing to about 23,000 in 2020. CO_2 emissions in the Reference Case, from sources in New York State subject to the Program, are projected to increase from approximately 34.6 million tons in 2013 to about 41.7 million tons in 2020. This increase is due primarily to increased generation from new and existing gas-fired power plants to meet projected load growth.

This generation data was based on the IPM Reference Case model runs and the table displayed below:

New York Reference Case Net Generation (in GWh)	2012	2013	2014	2015	2016	2018	2020
Combined Cycle	40,419	46,344	44,171	47,637	55,024	60,509	63,743
CT	2,146	1,765	2,249	2,165	2,365	2,265	2,240
Oil/Gas	12,198	11,696	11,689	11,568	11,476	11,184	10,960
Coal	5,127	5,956	6,834	6,052	6,585	4,861	6,419
Nuclear	42,450	42,450	35,229	35,369	27,516	27,516	27,516
'Conventional Generation Total'	102,340	108,212	100,172	102,791	102,966	106,335	110,878
Other - NUG/Cogen	1,863	1,863	1,875	1,881	1,884	1,884	1,887
Existing Conventional Hydro	27,082	27,275	27,251	27,540	27,471	27,540	27,532
Existing Renewables	5,457	5,444	5,444	5,457	5,500	5,464	5,444
'Other Generation Total'	34,402	34,582	34,571	34,878	34,855	34,888	34,864
Biomass: Direct Fire	-	-	433	738	738	738	738
Landfill Gas	35	35	393	483	483	483	483
Hydro	-	-	452	556	556	556	556
Onshore Wind	-	-	1,155	1,908	2,627	2,627	2,627
Offshore Wind	-	-	-	-	-	-	-
Solar	81	81	252	333	379	379	427
'New Renewable Generation Total'	116	116	2,685	4,017	4,781	4,781	4,830
Total GWh	136,858	142,910	137,428	141,686	142,602	146,004	150,572

This emissions data was based on the IPM Reference Case and the table displayed below:

Reference Case CO2 Emissions [Million Tons]	2012	2013	2014	2015	2016	2018	2020
MA	17	16	16	17	14	15	17
CT	6	7	7	7	7	7	7
ME	3	3	4	3	4	4	3
NH	2	3	2	2	2	2	2
RI	3	3	4	4	4	4	3
VT	0	0	0	0	0	0	0
NY	32	35	35	35	39	39	42
DE	4	3	4	4	5	5	5
MD	25	27	28	29	27	26	27
Total RGGI	93	96	100	102	101	102	105
Total Emissions at Affected Plants	91	93	97	100	99	99	103
Eastern Interconnect without RGGI	1,514	1,548	1,595	1,607	1,572	1,607	1,654
Total Eastern Interconnect	1,608	1,643	1,695	1,709	1,674	1,709	1,759
Total Canadian	102	98	95	97	100	101	104

Program Case

Interim Adjustment for Banked Allowances

Likewise, several assumptions were used to project impacts in the Program Case. For modeling purposes, the proposed CO_2 cap of 91 million tons, based on the approximate amount of current emissions in the RGGI region, was applied to sources subject to the Program in the Participating States. In order to account for the existing private bank of allowances and in order to help create a binding cap, the proposed revisions to the Program create provisions for two distinct budget adjustments.[40] In order to model the budget adjustments, the annual caps were adjusted in accordance with the model rule language and the assumption that the adjustment would account for the existing bank as well as 100 percent of the surplus (current cap and emissions) for 2013.

While the Program Case allows a limited number of emissions offsets to be purchased by affected generators and used for compliance by affected generators, the model assumes that it is not economically attractive for offset suppliers to sell their products in the RGGI market until prices reach $10 per allowance. This value is based on the reserve price under the California cap-and trade program which allows for the use of offset credits. As long as offset suppliers are able to sell similar products in the California market for prices higher than those in the RGGI market, offset suppliers would not be expected to sell into the RGGI market.

In order to obtain New York specific results, several components between the Program Case and the Reference Case are compared including generation mix, net electricity imports, changes in generation capacity, CO_2 emissions, CO_2 allowance prices, and wholesale and retail electricity price impacts. Electricity generation from gas-fired units in 2020 is about 1,576 GWh or 2.4 percent lower in the Program Case than in the Reference Case. Generation from coal-fired units in 2020 is about 2,376 GWh or 37 percent lower in the Program Case than in the Reference Case. Net imports into New York in 2020 are projected to be about 3,900 GWh or 17 percent higher in the Program Case than in the Reference Case. Relative to the Reference Case, total capacity additions through 2020 in the Program Case are the same (5,909 MW) as in the Reference Case. Coal capacity retirements through 2020 in the Reference Case are 408 MW while the estimated value for the Program Case is 466 MW.

This generation data was based on the differences between IPM Reference Case and IPM Program Case model runs and the tables displayed below:

New York Reference Case Net Generation (in GWh)	2012	2013	2014	2015	2016	2018	2020
CC	40,419	46,344	44,171	47,637	55,024	60,509	63,743
CT	2,146	1,765	2,249	2,165	2,365	2,265	2,240
Oil/Gas	12,198	11,696	11,689	11,568	11,476	11,184	10,960
Coal	5,127	5,956	6,834	6,052	6,585	4,861	6,419
Nuclear	42,450	42,450	35,229	35,369	27,516	27,516	27,516
'Conventional Generation Total'	102,340	108,212	100,172	102,791	102,966	106,335	110,878
Other - NUG/Cogen	1,863	1,863	1,875	1,881	1,884	1,884	1,887
Existing Conventional Hydro	27,082	27,275	27,251	27,540	27,471	27,540	27,532
Existing Renewables	5,457	5,444	5,444	5,457	5,500	5,464	5,444
'Other Generation Total'	34,402	34,582	34,571	34,878	34,855	34,888	34,864
Biomass: Direct Fire	-	-	433	738	738	738	738
Landfill Gas	35	35	393	483	483	483	483
Hydro	-	-	452	556	556	556	556
Onshore Wind	-	-	1,155	1,908	2,627	2,627	2,627
Offshore Wind	-	-	-	-	-	-	-
Solar	81	81	252	333	379	379	427
'New Renewable Generation Total'	116	116	2,685	4,017	4,781	4,781	4,830
Total GWh	136,858	142,910	137,428	141,686	142,602	146,004	150,572

New York Program Case Net Generation (in GWh)	2012	2013	2014	2015	2016	2018	2020

CC	40,392	46,335	43,696	46,972	53,823	58,554	61,862
CT	2,147	1,769	2,259	2,247	2,502	2,497	2,545
Oil/Gas	12,208	11,696	11,640	11,496	11,463	11,168	10,977
Coal	5,235	5,956	5,937	3,887	4,679	3,179	4,043
Nuclear	42,450	42,450	35,229	35,369	27,516	27,516	27,516
'Conventional Generation Total'	102,432	108,206	98,762	99,971	99,982	102,915	106,943
Other - NUG/Cogen	1,863	1,863	1,875	1,881	1,884	1,884	1,887
Existing Conventional Hydro	27,113	27,253	27,305	27,450	27,389	27,431	27,443
Existing Renewables	5,457	5,444	5,457	5,472	5,500	5,469	5,444
'Other Generation Total'	34,433	34,561	34,637	34,803	34,773	34,784	34,774
Biomass: Direct Fire	-	-	433	738	738	738	738
Landfill Gas	35	35	393	483	483	483	483
Hydro	-	-	452	556	556	556	556
Onshore Wind	-	-	1,155	1,908	2,627	2,627	2,627
Offshore Wind	-	-	-	-	-	-	-
Solar	81	81	252	333	379	379	427
'New Renewable Generation Total'	116	116	2,685	4,017	4,781	4,781	4,830
Total GWh	136,981	142,882	136,084	138,790	139,536	142,480	146,547

CO_2 emissions from New York generators in the Program Case are projected to be 3.2 million tons (eight percent) lower in 2020 than in the Reference Case. Over the 2014-2020 time period, cumulative CO_2 emission reductions from New York generators subject to the Program are projected to be 13 million tons in the Program Case as compared to the Reference Case. Although emissions from affected sources across the RGGI region are estimated to be 15 million tons (14.6 percent) lower under the Program Case than under the Reference Case in 2020, CO_2 emissions from the electricity sector in New York are projected to increase 4.9 million tons or 14.7 percent between 2014 and 2020. Principally, emissions in New York are projected to rise because the Indian Point nuclear units are assumed to retire when their current licenses expire in 2013 and 2015. The IPM model projects that the generation from these non-CO_2 emitting generators is likely to be replaced with fossil fuel-fired generation, at least in part. Nevertheless, CO_2 emission reductions over the 2014-2020 period from affected sources across the RGGI region are estimated to be 86 million tons in the Program Case compared to the Reference Case.

This emissions data was based on the differences between IPM Reference Case and IPM Program Case model runs and the tables displayed below:

Reference Case CO_2 Emissions [Million Tons]	**2012**	**2013**	**2014**	**2015**	**2016**	**2018**	**2020**
MA	17	16	16	17	14	15	17
CT	6	7	7	7	7	7	7
ME	3	3	4	3	4	4	3
NH	2	3	2	2	2	2	2
RI	3	3	4	4	4	4	3
VT	0	0	0	0	0	0	0
NY	32	35	35	35	39	39	42
DE	4	3	4	4	5	5	5
MD	25	27	28	29	27	26	27
Total RGGI	93	96	100	102	101	102	105
Total Emissions at Affected Plants	91	93	97	100	99	99	103
Eastern Interconnect without RGGI	1,514	1,548	1,595	1,607	1,572	1,607	1,654
Total Eastern Interconnect	1,608	1,643	1,695	1,709	1,674	1,709	1,759

Total Canadian	102	98	95	97	100	101	104

Program Case CO_2 Emissions [Million Tons]	**2012**	**2013**	**2014**	**2015**	**2016**	**2018**	**2020**
MA	17	15	15	15	13	14	16
CT	6	7	7	7	7	7	7
ME	3	3	4	4	4	3	3
NH	2	3	2	2	2	2	2
RI	3	4	4	4	4	4	4
VT	0	0	0	0	0	0	0
NY	32	35	34	33	36	36	38
DE	4	3	3	4	4	4	4
MD	25	27	23	23	22	17	17
Total RGGI	93	96	91	91	92	87	91
Total Emissions at Affected Plants	91	93	89	89	90	85	88
Eastern Interconnect without RGGI	1,514	1,548	1,601	1,613	1,579	1,616	1,662
Total Eastern Interconnect	1,608	1,643	1,692	1,704	1,671	1,704	1,753
Total Canadian	102	97	95	97	100	102	104

Under the Reference Case, without making any proposed Program revisions, CO_2 allowance prices are projected to remain at the minimum reserve price through 2020. Under the Program Case, CO_2 allowance prices (the cost of complying with RGGI) are projected to increase from approximately $6.02/ton (2010 *dollars) in 2014 to about $6.73/ton in 2016 and to about $8.41/ton in 2020. Approximately 17.6 million* allowances would be obtained by the marketplace between 2014 and 2020 from the Cost Containment Reserve (CCR), which would be triggered at $4/ton in 2014 and at $6/ton in 2015.[41] The acquisition of these additional allowances provides price dampening which is reflected in these estimated allowance prices.

This allowance price data was based on the IPM Reference Case and IPM Program Case model runs and the tables displayed below:

Reference Case Allowance Prices (2010$)	***2012***	***2013***	***2014***	***2015***	***2016***	***2018***	***2020***
NO_x Regional ($/ton)	450	450	450	450	450	450	450
SO_2 Regional Tier 1 ($/ton)	-	50	50	50	-	-	-
SO_2 Regional Tier 2 ($/ton)	-	50	50	50	-	-	-
Regional CO_2 ($/ton)	1.86	1.86	1.86	1.86	1.86	1.86	1.86

Program Case Allowance Prices (2010$)	**2012**	**2013**	**2014**	**2015**	**2016**	**2018**	**2020**
NO_x Regional ($/ton)	600	600	600	600	600	600	600
SO_2 Regional Tier 1 ($/ton)	-	6	6	7	-	-	-
SO_2 Regional Tier 2 ($/ton)	-	21	22	23	-	-	-
Regional CO_2 ($/ton)	1.86	1.86	6.02	6.37	6.73	7.52	8.41

Under the Program Case, New York's wholesale electricity prices (including both energy and capacity costs) are projected to be $1.64/MWh higher in 2016 and $2.12/MWh higher in 2020, than the Reference Case. RGGI is projected to increase wholesale electricity prices in New York State by about 3.0 percent in 2016 and 3.9 percent in 2020. For a typical New York residential customer (using 750 kWh per month), the projected increase in wholesale electricity prices in 2016 translates into a monthly retail bill increase of about 1.0 percent or $0.86. In 2020, the projected increase in wholesale electricity prices translates into a monthly residential retail bill increase of about 0.8 percent or $0.71. For commercial customers, the projected retail price impact of RGGI is about 1.1 percent in 2016 and 0.7 percent in 2020 ($7.87 and $5.00 per month, respectively). For industrial customers, the projected retail price impact of RGGI is about 1.7 percent in 2016 and 1.2 percent in 2020.

Alternative Bank Scenario

IPM projects electricity system operations and costs with perfect foresight, which means that there is certainty of knowledge of all future market outcomes, including allowance prices and the use of the private bank. In other words, IPM calculates when and whether it is cost-effective to make on-system emissions reductions at affected sources or to use allowances from the private bank. However, market participants may make decisions related to use of banked allowances for compliance on a shorter time horizon than projected by IPM using perfect foresight (i.e., due to uncertainty, market participants may be more likely to defer emissions reductions and rely more heavily on banked allowances in the short-term). In order to assess the use of the private bank during the short-term, an alternative usage scenario ("Alt Bank") was examined. Under the Alt Bank scenario, it is assumed that the marketplace would use the private bank of allowances at a rate roughly 40 percent faster than under the Program Case during the 2014-2017 timeframe. This scenario is not intended to be a prediction of market behavior; rather it is intended to provide a broader sense of potential market outcomes.

CO_2 emissions from New York generators are projected in the Alt Bank scenario to be 4.4 million tons (10.7 percent) lower in 2020 than Reference Case. The generators are assumed to use more of the private bank by 2017 under this scenario, therefore less allowances will be available for use in later years and more emissions reductions will occur during this timeframe. Emissions from affected sources across the RGGI region are estimated to be 81.6 million tons in 2020 under the Alt Bank scenario while they are projected to be 87.8 million tons under the Program Case.

This emissions data IPM Alt Bank Case model runs and the table displayed below:

91 Alt Bank CO_2 Emissions [Million Tons]	**2012**	**2013**	**2014**	**2015**	**2016**	**2018**	**2020**
MA	17	15	16	15	13	14	15
CT	6	7	7	7	7	7	7
ME	3	3	4	4	4	3	3
NH	2	3	2	2	2	2	2
RI	3	4	4	4	4	4	4
VT	0	0	0	0	0	0	0
NY	32	35	34	34	36	36	37
DE	4	3	4	4	4	4	3
MD	25	27	26	25	23	15	14
Total RGGI	94	96	96	95	93	85	84
Total Emissions at Affected Plants	92	93	94	92	90	82	82
Eastern Interconnect without RGGI	1,514	1,548	1,598	1,610	1,578	1,617	1,665
Total Eastern Interconnect	1,608	1,643	1,694	1,705	1,671	1,702	1,750
Total Canadian	102	97	95	97	100	102	105

CO_2 allowance prices under the Alt Bank scenario are projected to increase from approximately $3.60/ton (2010 dollars) in 2014 to about $6.57/ton in 2016 and about $10.21/ton in 2020. Prices are lower in the short-term under the Alt Bank scenario than under the Program Case because the former scenario assumes that more allowances from the private bank are being used for compliance in the short term. Similarly, prices are higher in 2020 under the Alt Bank scenario because the marketplace has fewer allowances left over in the private bank relative to the Reference Case, and therefore more on-system emissions reductions are required from compliance entities. In addition, it is estimated that approximately 10 million allowances would be obtained by the marketplace between 2014 and 2020 from the CCR. The acquisition of these additional allowances provides some price dampening which is reflected in these estimated allowance prices.

This allowance price data was based on IPM Alt Bank Case model runs and the table displayed below:

Alt Bank Allowance Prices (2010$)	**2012**	**2013**	**2014**	**2015**	**2016**	**2018**	**2020**
NO_x Regional ($/ton)	600	600	600	600	600	600	600
SO_2 Regional Tier 1 ($/ton)	-	6	6	7	-	-	-
SO_2 Regional Tier 2 ($/ton)	-	21	22	23	-	-	-
Regional CO_2 ($/ton)	1.86	1.86	3.60	5.14	6.57	8.00	10.21

Under the Alt Bank scenario, New York's wholesale electricity prices (including both energy and capacity costs) are projected to be $1.62/MWh higher in 2016 and $2.72/MWh higher in 2020, than the Reference Case. Wholesale electricity prices are estimated to increase by about 2.9 percent in 2016 and 4.9 percent in 2020 under the Alt Bank scenario relative to the Reference Case.

Sensitivity analyses were performed to develop bounds or collars around the Reference Case and Program Case projections. First, a Higher Emissions scenario that assumes higher natural gas prices and higher regional energy demand was evaluated. This scenario used natural gas prices from the Low Estimated Ultimate Recovery scenario in EIA's 2012 Annual Energy Outlook where Henry Hub natural gas prices are estimated to be $5.31/MMBtu in 2020. Demand in this case is assumed to be about three percent higher in the near-term and four percent higher in the longer-term than the Reference Case. Likewise, a Lower Emissions scenario was also developed that assumes lower natural gas prices, lower regional energy demand, and the continued operation of the Indian Point nuclear power plants through the timeframe of the study. This scenario used natural gas prices from the High Technically Recoverable Resources scenario in EIA's 2012 Annual Energy Outlook where Henry Hub natural gas prices are estimated to be $3.02/MMBtu in 2020. In this case, demand is assumed to be about three percent lower in the near-term and four percent lower in the longer-term than the Reference Case.

The modeling case that evaluated the potential impacts of the Updated Model Rule using the Higher Emissions assumptions was called the 91 Cap_Bank_Model Rule_High Case. Under this scenario, allowance prices are estimated to be $7.27/ton in 2014, $8.13/ton in 2016 and $10.15/ton in 2020. A sensitivity scenario was run to estimate the impacts of the Updated Model Rule with the Higher Emissions and Alt Bank assumptions. Under this 91 Cap Alt_Bank_Model_Rule_High Case, allowance prices are estimated to be about $4.62/ton in 2014, $$6.90/ton in 2016, and $16.44/ton in 2020.

In IPM, allowance prices would only be expected to rise above the minimum reserve price if the projected cumulative emissions over the time period exceed the cumulative cap level. When evaluating the impact of the Updated Model Rule using the Low Emissions scenario, emissions over the time period are projected to be 50 million tons less than the number of allowances available to the market (adjusted cap plus the emissions bank). Therefore, affected sources would not need to make any emission reductions and it is estimated that allowance prices would be at the minimum reserve price under this scenario. This scenario was not actually modeled; however, ICF staff provided the assessment of the scenario described in this paragraph.

A macro-economic impact study of the Program was also conducted at the direction of the Participating States through NESCAUM to estimate the potential impact of the Program on the economies of Participating States. The study used the REMI computer model. As mentioned above, the study concluded that the economic impacts of RGGI on the economies of the Participating States, including New York, were generally positive, albeit relatively small. For example, the cumulative changes in New York's Gross State Product and Personal Income associated with the proposed revisions to the Program will be about $5.8 billion and $4.7 billion, respectively (2010 dollars, calculated as the present value of estimated annual changes over the period 2012 to 2040, discounted at three percent per year to account for the time-value of money). The cumulative change in employment in New York associated with the Program will be about 80,500 job-years over the period 2012 to 2040. A job-year is equivalent to one person employed for one year.

Costs to State and Local Governments

In addition to the costs identified for regulated parties and the public, State and local governments will incur costs. The Jamestown Board of Public Utilities (JBPU), a municipally owned utility, owns and operates the S.A. Carlson Generating Station (SACGS). Emissions monitoring at SACGS currently meets the monitoring provisions of the Program, and no additional monitoring costs will be incurred under the proposed revisions to the Program. Notwithstanding this, just like any other owner or operator of any source subject to the Program, the JBPU will need to purchase CO_2 allowances equal to the number of tons of CO_2 emitted. The Department limited the analysis of control costs to the purchase of allowances to comply with the Program and assumed that the costs of allowances will be between $6.00 in 2014 and $9.00 in 2020 (in 2010 $) per ton for CO_2 under the Program Case. To estimate total costs for SACGS under the Program, the Department reviewed 2009 through 2012 emissions from Jamestown's affected unit. During that time period, Jamestown's emissions ranged from a low of 4,261 tons to a high of 117,311 tons. An estimate of compliance costs, based on these emissions values, indicates that purchasing allowances to cover emissions will result in estimated costs between a low of $25,600 and a potential high of $1 million annually. These costs will eventually be passed on to the consumers of electricity from the JBPU.

The JBPU has a range of compliance options and can utilize the flexibility inherent under the Program to comply. Since the program has a three year control period with the compliance obligation at the end of the control period, the emission peaks associated with electricity generation will be averaged out and more long term planning options will be available to SACGS. Although the Program revisions include an Interim

Control Period,[42] that will require JBPU to cover 50 percent of their emissions in each of the first two years of a three year control period, it is not anticipated that this interim requirement will significantly reduce the flexibility available to JBPU. The JBPU will also incur costs associated with the administration of the revised Program.

Department Costs

The Department will continue to incur staff costs associated with the implementation of the revised Program, including staff resources to review monitoring plans submitted by generators and to analyze data submitted to EPA to determine emissions and compliance obligations. Specifically, the Department requires sufficient staff to: review and process set-aside and offset applications; submit set-aside award requests for execution; modify permits and inspect generator facilities, including the continuous emission monitors; and analyze the Program's effectiveness. It should be noted, that the Department's costs are expected to remain unchanged as a result of the Program revisions.

NYSERDA will also continue to incur costs to administer and evaluate the use of auction proceeds from the Program and it will continue to convene an Advisory Group to provide guidance on how to best use auction proceeds and to assist with the development of the Operating Plan. The Plan is reviewed and revised on an annual basis by NYSERDA and an Advisory Group includes: 1) program selection criteria; 2) an anticipated schedule for implementation of the programs; 3) descriptions of the measurement, verification, and evaluation methods that will be used to judge the impacts and success of the programs; and 4) a quantification of NYSERDA's costs for administration and evaluation of the programs. It should be noted, that NYSERDA's administrative and evaluation rates are not expected to change as a result of the Program revisions. A significant portion of Program costs are allocated to the operation and administration of COATS and conducting allowance auctions. It is anticipated that these costs will not change in the future.

Local Government Mandates

This is not a mandate on local governments. The revised Program will continue to apply equally to any entity that owns or operates a subject source. Local governments have no additional compliance obligations as compared to other entities subject to the revised Program. The JBPU, a municipally owned public utility, owns and operates the SACGS. JBPU contains one combined cycle turbine at the SACGS that is currently subject to the Program and will remain subject to the revised Program; no other additional record keeping, reporting, or other requirements will be imposed on local governments.

Paperwork

Under the existing Program and the proposed revisions to the Program, the owners and operators of each source and each unit at the source shall retain the following documents for a period of 10 years from the date the document is created:

1. Account certificate of representation form;
2. Emissions monitoring information. CO_2 budget sources are required to report emissions and allowance transfers via electronic means which will minimize the paperwork burden on sources;
3. Copies of all reports, compliance certifications, and other submissions and all records made or required under the program;
4. Copies of all documents used to complete a permit application and any other submission under the program or to demonstrate compliance with the program;
5. Copies of all documents used to complete a consistency application and monitoring and verification report to demonstrate compliance with the offset provisions of the program; and
6. Copies of all documents required as part of an auction application.

For each control period in which one or more units at a source are subject to the CO_2 budget emission limitation, the CO_2 authorized account representative of the source shall submit to the Department, a compliance certification report for each source covering all such units. This must be submitted by the March 1st following the relevant control period for all units subject to the Program.

Duplication

The emissions monitoring and reporting requirements of the revised Program are unchanged from those of the existing Program, and are identical to those of the Title IV program and 6 NYCRR Parts 243, 244 and 245. Since these requirements are identical, monitoring and reporting done for the federal program can be used to comply with the monitoring and reporting requirements of the revised Program.

Alternatives

Alternatives Considered

No Action Alternative

The No Action alternative would leave the current Program in place and the Program cap and flexibility provisions within it would remain unchanged. During program review, the Department, along with DPS and NYSERDA, participated in a rigorous and comprehensive regional evaluation of the Program supported by an extensive regional stakeholder process that engaged the regulated community, environmental nonprofits, consumer and industry advocates, and other interested stakeholders. Through this process, which started in late 2010, the Department sought to ensure RGGI's continued success - effectively reducing CO_2 emissions while providing benefits to consumers and the State. Program review revealed:

- A significant excess supply of allowances relative to actual emission levels in the region, and
- The current cost control measures in the program, which are based upon expansion of the percentage of offset allowances allowable for compliance, would likely be ineffective in controlling costs if the emissions cap was made binding.

The excess supply of allowances or over-allocation was the result of a number of factors. As highlighted in a Draft White Paper prepared by NYSERDA,[43] a number of factors contributed to the observed decrease of CO_2 emissions from the RGGI region electricity sector from 2005 to 2009. The Draft White Paper identified three primary drivers of the decrease: 1) lower electricity load (due to weather; energy efficiency programs and customer-sited generation; and the economy); 2) fuel-switching from petroleum and coal to natural gas (due to relatively low natural gas prices); and 3) changes in available capacity mix (due to increased nuclear capacity availability and uprates; reduced available coal capacity; increased wind capacity; and increased use of hydro capacity).

Since the intent of the Program was and is to reduce CO_2 emissions from the electricity sector, the proposed revision to the Program recognize that over allocation of allowances reduces the effectiveness of the cap and minimizes the impact of the Program in achieving meaningful emission reductions. "Over allocation is a problem for program success and, in the design of future programs, designers should take precautions to avoid it. The environmental effectiveness of cap-and-trade regulation will really only be proven when programs create truly constrained allowance markets that force the maximally feasible emissions reductions that our environmental laws have so often required.[44] " Since the No Action alternative would leave the Program unchanged and would not address the issue of over allocation, it was not selected.

Modeling Different Cap Alternatives

The Department also considered different regional emissions cap levels as additional alternatives, rather than the 91 million ton regional emission cap that is proposed to be implemented under the revised Program. In order to determine the difference in the Program's impact under various scenarios and to support program review, the Participating States conducted REMI macroeconomic modeling, customer electricity bill analysis, and revised electricity sector modeling using the IPM. Comprehensive electricity sector modeling and economic analysis was considered to support evaluation of potential modifications to the Program. The most critical of these evaluations was the assessment of different cap levels to address over allocation of allowances. As discussed above, over allocation was influenced by a number of factors and was perhaps the most important issue addressed during program review.

First, different cap levels were assessed using the IPM model to determine their effectiveness in achieving emission reductions under the Program. CO_2 cap trajectories of 120 million tons, 115 million tons and 106 million tons were assessed starting in 2014. In each case, the cap declines from those levels at 2.5 percent per year through the modeled time horizon, or 2020. When the IPM Reference Case was updated in August 2012, projected emissions were significantly lower than previous modeling. Cumulatively, emissions dropped about 17 percent from the previous reference case and emissions at RGGI affected sources were projected to be only 91 million tons in 2012. Based on this updated information, an analysis of the March 2012 potential cap scenarios demonstrated that: the 115 and 120 cap levels and assumptions would result in prices remaining at the minimum reserve price; cumulatively, allowances would exceed emissions because emissions had fallen so significantly; the 106 cap level analysis indicated a need to address the projected private bank of allowances carried into 2014 and beyond. As a result of this, new modeling scenarios relative to the updated reference case of 106, 101, 97 and 91 million tons, with an adjustment for banked allowances, were subsequently evaluated.

Based on a review of all modeling iterations and after careful consideration, New York and the Participating States decided to propose to lower the regional CO_2 emissions cap to align the cap with current emissions levels, while accounting for allowances held by market participants in excess of the quantity needed to demonstrate compliance. Accordingly, New York and the Participating States selected and proposed a regional emissions cap in 2014 equal to 91 million tons declining 2.5 percent each year from 2015 through 2020.

The bank of allowances held by market participants is addressed with two interim adjustments for banked allowances. The first adjustment will be made over a seven-year period (2014-2020) for the first control period private bank of allowances and a second adjustment will be made over a six-year period (2015-2020) for the 2012 and 2013 private bank of allowances. These adjustments are necessary in order to account for the existing private bank of CO_2 emissions allowances already acquired at auction, and in order to help create a binding cap.

CCR, CCR Levels and Program Flexibility Alternatives

Flexibility provided under the Program maintains environmental integrity and provides compliance alternatives for regulated sources. As described above, compliance flexibility is inherent under a cap-and-trade program as compared to traditional command-and-control regulation. Under the existing Program, additional flexibility was provided through the expansion of allowable offset usage, the addition of international offsets and an extension of the compliance period. During program review, the Participating States recognized complexity associated with these provisions and their inability to provide immediate cost containment for the Program. Accordingly, the proposed revisions to the Program include a new CCR, which is a reserved quantity of allowances, in addition to the cap, that would only be available if defined allowance price triggers are exceeded. The CCR was chosen because the no action alternative of retaining the existing flexibility provisions would not have provided measurable cost control in an efficient, transparent and predictable manner.

During program review, the following two sets of price triggers were modeled with an annual CCR limit of 10 million allowances: (1) $5.00 in 2014, $7.00 from 2015 to 2017 and $10.00 from 2018 through 2020; and (2) $4.00 in 2014, $6.00 in 2015, $8.00 in 2016 and $10.00 from 2017 through 2020. The CCR allowances would be made available immediately in any auction in which demand for allowances at prices above the CCR trigger price exceeded the supply of allowances offered for sale in that auction prior to the addition of any CCR allowances. If the CCR is triggered, the CCR allowances will only be sold at or above the CCR trigger price. After careful consideration of these alternatives, the Department determined that the CCR will be equal to five million short tons in 2014 and 10 million short tons each year thereafter, and the CCR trigger prices will be $4.00 in 2014, $6.00 in 2015, $8.00 in 2016, and $10.00 in 2017. Each year after 2017, the CCR trigger price will increase by 2.5 percent.

In addition to the CCR, the existing flexibility provisions were reviewed. The proposed Program revisions retain the allowable offset usage percentage at 3.3 percent, and delete the existing offset price triggers that raise the allowable percentage of offsets and that allow the use of international CO_2 emission credit retirements. The offset price triggers and the potential extension of the control period to four years are replaced by the CCR mechanism, to provide measurable cost control in an efficient, transparent and predictable manner.

Federal Standards

In December 2009, EPA issued findings concluding that current and projected concentrations of GHGs in the atmosphere endanger the public health and welfare of current and future generations (the Endangerment Finding).[45] Following the Endangerment Finding, EPA has taken numerous additional actions under the Clean Air Act (Act) regarding the regulation of GHG emissions. As a result of these actions, according to EPA, GHGs became "subject to regulation" under the Act as of January 2, 2011. EPA promulgated a rule to tailor the major source applicability thresholds for GHG emissions for purposes of the Prevention of Significant Deterioration (PSD) and Title V programs under the Act (the "GHG Tailoring Rule"),[46] which the Department subsequently incorporated in its 6 NYCRR Parts 200, 201, and 231. PSD provisions establish preconstruction permitting requirements for new major stationary sources and major modifications at existing stationary sources. Most notably, PSD includes the requirement that applicable sources are subject to Best Available Control Technology (BACT) for GHGs.

EPA is currently committed, pursuant to a litigation settlement, to propose new source performance standards (NSPS) under section 111 of the Act for GHG emissions from power plants. This would include an NSPS for new sources pursuant to section 111(b) of the Act, as well as emission guidelines for required state regulation of GHG emissions from existing power plants under section 111(d) of the Act. In March 2012, EPA proposed a GHG NSPS for new power plants under section 111(b) of the Act. EPA has not finalized this proposal, nor has it proposed any emissions guidelines for existing sources under section 111 (d) of the Act. GHG NSPS for new or existing sources would likely apply to sources that are subject to the Program. The Department will continue to monitor the development of power plant GHG NSPS for both new and existing sources by EPA. If EPA ultimately adopts a GHG NSPS for new or existing sources, the Department will consider any necessary or appropriate action regarding the Program.

While stationary sources may be subject to Title V and PSD permitting requirements for GHGs under the Act, provided they meet or exceed the relevant applicability thresholds established by the GHG Tailoring Rule, there are currently no specific CO_2 emission standards for stationary sources in the federal regulations. In addition, PSD covers only new or modified sources. The proposed revisions to the Program are protective of public health and the environment in the absence of similar federal emission standards.

The potential adverse impact to global air quality and New York State's environment from CO_2 emissions necessitates that New York State take action now to minimize CO_2 emissions that contribute to climate change.

Due in part to the lack of a federal program, the Department has determined that fossil fuel-fired electricity generators must reduce emissions of CO_2 now. As explained above, the proposed revisions to the Program - including most notably the proposed reduction in the CO_2 emission cap - help to further this objective. Although national and international action is needed, the efforts undertaken by New York and the Participating States as part of revising the RGGI program will slow the rate and magnitude of climate change thereby reducing the risk of injury to the State and its citizens.

As an environmental leader, New York has participated in efforts to develop national emissions reduction programs for CO_2. The Department recognizes the benefits of a national program and will continue to participate on national and regional initiatives to encourage the development of such programs. In the event that a national market based trading program is developed, it will be rigorously reviewed for consistency with and timing of the Program.

Compliance Schedule

The proposed revisions to the Program do not change the applicability provisions of the current Program. Therefore, sources already subject to the current Program will remain subject to the proposed revisions to the Program. Moreover, pursuant to the proposed revisions, the second control period under the Program will remain from 2012-2014, with a CO_2 allowance transfer deadline of March 1, 2015. The revised Program will require affected sources and units to comply with the emission limitations of the Program beginning in 2014.

The proposed revisions to the Program create a modified compliance schedule called interim compliance periods which are defined as each of the first two years of a three-year control period. The first interim control period under the revised Program will be the year 2015. Accordingly, at the end of each control period, the owners and operators of each source subject to the Program shall hold a number of CO_2 allowances available for compliance deductions, as of the CO_2 allowance transfer deadline (midnight of March 1st or, if March 1st is not a business day, midnight of the first business day thereafter), in the source's compliance account that is not less than the total tons of CO_2 emissions for the control period less the CO_2 allowances deducted for the previous two interim control periods. In the first two calendar years of each three year control period (interim control period), the owners and operators of each source subject to the Program shall hold a number of CO_2 allowances available for compliance deductions, as of the CO_2 allowance transfer deadline (midnight of March 1st or, if March 1st is not a business day, midnight of the first business day thereafter), in the source's compliance account that is not less than 50 percent of the total tons of CO_2 emissions for that interim control period. A unit was subject to the control period requirement starting on the later of January 1, 2009 or the date the unit commences operation. A unit is subject to the interim control period requirements of the Program starting on the later of January 1, 2015 or date the unit commences operation.

For each control period in which a CO_2 budget source is subject to the Program, the CO_2 authorized account representative of the source must submit to the Department by the March 1st following the relevant control period, a compliance certification report for each source covering all such units. As noted above, the first CO_2 allowance transfer deadline under the proposed revisions to the Program will be March 1, 2015.

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[1] In addition to New York, the RGGI Participating States include: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, Rhode Island, and Vermont.

[2] The Participating States released the Updated Model Rule on February 7, 2013.

[3] " Patterns and Trends New York State Energy Profiles: 1996-2010," Final Report, April 2012.01http://www.nyserda.ny.gov/BusinessAreas/Energy-Data-and-Prices-Planning-and-Policy/Energy-Prices-Data-and-Reports/EA-Reports-and-Studies/Patterns-and-Trends.aspx?sc_database=web

[4] RGGI, Inc. is a 501(c)(3) non-profit corporation created to provide technical and administrative services to the Participating States.

[5] The Business Council of New York State, Inc., is the leading business organization in New York State, representing the interests of large and small firms throughout the state. Its membership is made up of thousands of member companies, as well as local chambers of commerce and professional and trade associations.

[6] National Research Council of the National Academies. Climate Change: Evidence, Impacts, and Choices. 2012. Available at http://nas-sites.org/americasclimatechoices/more-resources-on-climate-change/climate-

change-lines-of-evidence-booklet/.

[7] IPCC WGI Fourth Assessment Report, Climate Change 2007: The Physical Science Basis, February 2007, and available at: http://www.ipcc.ch.

[8] American Meteorological Society (AMS). Climate Change. An Information Statement of the American Meteorological Society. Adopted by AMS Council 20 August 2012.

[9] Hansen, J., Sato, M., Ruedy, R. 2012. 'Perception of climate change'. Proceedings from the National Academy of Sciences. www.pnas.org/cgi/doi/10.1073/pnas.1205276109. This study found that during the period from 1951-1980, extremely hot summers covered just 1 percent of Earth's land area. This had risen to 10 percent of the Earth's land area by the period from 1981-2010, and even higher during the 2006-2010 period. Based upon statistical analysis of global summertime temperatures, the authors concluded with a high degree of confidence, "extreme anomalies were a consequence of global warming because their likelihood in the absence of global warming was exceedingly small."

[10] Joint Science Academies' Statement: Global Response to Climate Change, issued June 7, 2005, and available at http://www.nationalacademies.org/onpi/06072005.pdf.

[11] The National Academy of Sciences. Committee on America's Climate Choices, Board on Atmospheric Sciences and Climate Division on Earth and Life Studies, National Research Council. 'America's Climate Choices Final Report'. 2011. http://americasclimatechoices.org/.

[12] Rosenzweig, C., W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn (Eds.) 2011. 'Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation'. New York State Energy Research and Development Authority (NYSERDA). http://www.nyserda.ny.gov/climaid

[13] Natural Resources Defense Council (NRDC). 'The Worst Summer Ever? Record Temperatures Heat Up the United States'. September 2010. NRDC. http://www.nrdc.org/globalwarming/hottestsummer/

[14] Titus, J.G. 'Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. Synthesis and Assessment Product 4.1'. U.S. Climate Change Science Program. 2009. http://www.epa.gov/climatechange/effects/coastal/sap4-1.html

[15] Rosenzweig, 'op.cit.'

[16] Sallenger, A.H., Doran, K.S., Howd, P.A. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. Nature Climate Change. Published online June 24, 2012. doi: 10.1038/NCLIMATE1597.

[17] "New York State Sea Level Rise Task Force Report to the Legislature," December 31, 2010. http://www.dec.ny.gov/docs/administration_pdf/slrtffinalrep.pdf. The 2013 New York City Panel on Climate Change (NPCC) Climate Risk Information Report provides updated sea-level rise projections. Using the latest models and information, the NPCC projects even greater sea level rise in the New York City area. http://www.nyc.gov/html/planyc2030/downloads/pdf/npcc_climate_risk_information_2013_report.pdf

[18] Rosenzweig, 'op.cit.'

[19] "Patterns and Trends New York State Energy Profiles: 1996-2010," Final Report, April 2012.01http://www.nyserda.ny.gov/BusinessAreas/Energy-Data-and-Prices-Planning-and-Policy/Energy-Prices-Data-and-Reports/EA-Reports-and-Studies/Patterns-and-Trends.aspx?sc_database=web

[20] Copenhagen Accord to the United Nations Framework Convention on Climate Change, Copenhagen Climate change Conference, December, 2009 http://unfccc.int/documentation/documents/advanced_search/items/6911.php?priref=600005735#beg

[21] Hibbard, P., Tierney, S., Okie, A., Darling, P. 'The Economic Impacts of the Regional Greenhouse Gas Initiative on Ten Northeast and Mid-Atlantic States (Review of the Use of RGGI Auction Proceeds from the First Three-Year Compliance Period)'. Analysis Group. November 15, 2011. http://www.analysisgroup.com/uploadedFiles/Publishing/Articles/Economic_Impact_RGGI_Report.pdf

[22] http://www.env-ne.org/public/resources/pdf/ENE_RGGI_Macroeconomic_Benefits_110915.pdf

[23] http://www.synapse-energy.com/Downloads/SynapseReport.2012-02.RAP.RGGI-Energy-Efficiency-Benefits.10-027A.pdf

[24] http://theenergycollective.com/wurzelmann/59328/rggi-s-benefits-costs-and-why-it-should-stay

[25] http://www.eany.org/images/Reports/rggi_success_apr2012.pdf

[26] New York State Energy and Research Development Authority (NYSERDA). 'Operating Plan for Investments in New York under the CO_2 Budget Trading Program and the CO_2 Allowance Auction Program'. NYSERDA. November 2012. http://www.nyserda.ny.gov/Energy-and-the-Environment/Regional-Greenhouse-Gas-Initiative/Auction-Proceeds.aspx

[27] "REMI Economic Impacts Analysis," by the Northeast States for Coordinated Air Use Management (NESCAUM), June 3, 2013.http://www.rggi.org/docs/ProgramReview/REMI%2091%20Cap%20Bank%

20MR_2013_06_03.pdf

[28] New York State Energy and Research Authority, "New Yorks RGGI-Funded Programs Status Report," Quarter Ending December 31, 2012. http://www.nyserda.ny.gov/Energy-and-the-Environment/Regional-Greenhouse-Gas-Initiative/Evaluations-of-Funds.aspx

[29] WRI White Paper: Greenhouse Gas Emissions Trading in the U.S. States: Observations and Lessons from the OTC NO_x Budget Program, A. Aulisi, A.E. Farrell, J. Pershing, S. VanDeveer. 2005.

[30] http://rggi.org/docs/Elec_monitoring_report_11_09_14.pdf

[31] http://rggi.org/docs/Market/Elec_Monitoring_Report_12_07_30_Final.pdf

[32] An Empirical Test for Inter-State Carbon-Dioxide Emissions Leakage Resulting from the Regional Greenhouse Gas Initiative, April 20, 2011. http://www.nyiso.com/public/webdocs/media_room/publications_presentations/Other_Reports/Other_Reports/ARCHIVE/Report_on_E

[33] The Eastern Interconnection (EI) includes the eastern two-thirds of the continental United States (excluding most of Texas and Florida). The Canadian portion includes Ontario east to the Maritime Provinces.

[34] CASE 07-M-0548 - Order Establishing Energy Efficiency Portfolio Standard and Approving Programs. (June 23, 2008) http://www3.dps.ny.gov/W/PSCWeb.nsf/ArticlesByTitle/06F2FEE55575BD8A852576E4006F9AF7?OpenDocument

[35] The Program is designed to allocate most of the CO_2 allowances to the EE&CET Account (the "EE & CET *Allocation"). The EE & CET Allocation is administered by NYSERDA, which currently administers similar* energy efficiency and clean energy technology programs, and allowances in the account are sold in transparent allowance auctions. This allocation achieves the emissions reduction goals of the Program and reduces impacts on consumers by promoting or rewarding investments in energy efficiency, renewable or non-carbon-emitting technologies, innovative carbon emissions abatement technologies with significant carbon reduction potential, and/or the administration of the Program.

[36] See discussion of Cost Containment Reserve provision on page 28.

[37] "REMI Economic Impacts Analysis," by the Northeast States for Coordinated Air Use Management (NESCAUM), dated May 29, 2013. http://www.dec.ny.gov/docs/administration_pdf/remi91cap2013.pdf

[38] "IPM Potential Scenario Customer Bill Analysis," by the Analysis Group, dated May 24, 2013. http://www.dec.ny.gov/docs/administration_pdf/custbillanaly2013.pdf

[39] The modeling assumptions document and the tabular results for each modeling run are located at http://www.rggi.org/design/program_review

[40] See discussion of the Interim Adjustment provisions on page 28.

[41] See discussion of Cost Containment Reserve provisions on page 28.

[42] See discussion of Interim Control Period provision on page 29.

[43] Relative Effects of Various Factors on RGGI Electricity Sector CO_2 Emissions: 2009 Compared to 2005, Draft White Paper, November 2, 2010. http://rggi.org/docs/Retrospective_Analysis_Draft_White_Paper.pdf

[44] The Overallocation Problem In Cap-And-Trade: Moving Toward Stringency, Lesley K. McAllister, 2009. http://www.columbiaenvironmentallaw.org/assets/pdfs/34.2/7._McAllister_34.2.pdf

[45] Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 FR 66496, December 15, 2009.

[46] Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule, 75 FR 31514, June 3, 2010.

REGIONAL GREENHOUSE GAS INITIATIVE

Memorandum of Understanding

WHEREAS, the States of Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont (the "Signatory States") each individually have a policy to conserve, improve, and protect their natural resources and environment in order to enhance the health, safety, and welfare of their residents consistent with continued overall economic growth and to maintain a safe and reliable electric power supply system; and

WHEREAS, there is a growing scientific consensus that the increase in anthropogenic emissions of greenhouse gases is enhancing the natural greenhouse effect resulting in changes in the Earth's climate; and

WHEREAS, climate change poses serious potential risks to human health and terrestrial and aquatic ecosystems globally and in the Signatory States including: more severe droughts and floods; atmospheric warming resulting in increased concentrations of ground-level ozone (smog) and associated adverse health effects; changes in forest composition as dominant plant species change; increases in habitat for disease-carrying insects like mosquitos and other vectors; increases in algal blooms that damage shellfish nurseries and can be toxic to humans; sea level rise that threatens coastal communities and infrastructure, saltwater contamination of drinking water and the destruction of coastal wetlands; increased incidence of storm surges and flooding of low-lying coastal areas which would lead to the erosion of beaches; and

WHEREAS, a carbon constraint on fossil fuel-fired electricity generation and the development of a CO_2 allowance trading mechanism will create a strong incentive for the creation, development, and deployment of more efficient fuel burning technologies and processes, as well as renewable energy supplies, demand-side management practices and actions to increase energy efficiency, and will lead to less dependence on the import of fossil fuels; and

WHEREAS, reducing our dependence on imported fossil fuels will enhance the region's economy by augmenting the region's energy security and by retaining energy spending and investments in the region; and

WHEREAS, the Signatory States wish to establish themselves and their industries as world leaders in the creation, development, and deployment of carbon emission control technologies, renewable energy supplies, and energy-efficient technologies, demand-side management practices, and increase the share of energy used within the Signatory States that is derived from secure and reliable supplies of energy; and

WHEREAS, climate change is occurring now, and continued delay in taking action to address the emissions that cause climate change will make any later necessary investments in mitigation and adaptive infrastructure much more difficult and costly; and

WHEREAS, to address global climate change and in order to do their fair share in addressing their contribution to this collective problem while preserving and enhancing the economic welfare of their residents, the Signatory States find it imperative to act together to control emissions of greenhouse gases, particularly carbon dioxide, into the Earth's atmosphere from within their region.

NOW THEREFORE, the Signatory States express their mutual understandings and commitments as follows:

1. OVERALL ENVIRONMENTAL GOAL

The Signatory States commit to propose for legislative and/or regulatory approval a CO_2 Budget Trading Program (the "Program") aimed at stabilizing and then reducing CO_2 emissions within the Signatory States, and implementing a regional CO_2 emissions budget and allowance trading program that will regulate CO_2 emissions from fossil fuel-fired electricity generating units having a rated capacity equal to or greater than 25 megawatts.

2. CO_2 BUDGET TRADING PROGRAM

A. Program Adoption. Each of the Signatory States commits to propose, for legislative and/or regulatory approval, the Program substantially as reflected in a Model Rule that will reflect the understandings and commitments of the states contained herein. The Program launch date will be January 1, 2009 as provided in 3.C. below.

B. Regional Emissions Cap. The regional base annual CO_2 emissions budget will be equal to 121,253,550 short tons.

C. State Emissions Caps. The regional base annual CO_2 emissions budget will be apportioned to the States so that each state's initial base annual CO_2 emissions budget is as follows:

Connecticut:	10,695,036 short tons
Delaware:	7,559,787 short tons
Maine:	5,948,902 short tons
New Hampshire:	8,620,460 short tons
New Jersey:	22,892,730 short tons
New York:	64,310,805 short tons
Vermont:	1,225,830 short tons

For the years 2009 through 2014, each state's base annual CO_2 emissions budget shall remain unchanged.

D. Scheduled Reductions. Beginning with the annual allocations for the year 2015, each state's base annual CO_2 emissions budget will decline by 2.5% per year so that each state's base annual emissions budget for 2018 will be 10% below its *initial base annual CO_2 emissions budget*.

E. Compliance Period and Safety Valve.

(1) Compliance Period. The compliance period shall be a minimum of three (3) years, unless extended after a Safety Valve Trigger Event (described below). A subject facility must have a sufficient number of allowances at the end of each compliance period to cover its emissions during that period.

(2) Safety Valve Trigger.

(a) Safety Valve Trigger. If, after the Market Settling Period (as defined below), the average regional spot price for CO_2 allowances equals or exceeds the Safety Valve Threshold (defined below) for a period of twelve months on a rolling average (a "Safety Valve Trigger Event"), then the compliance period may be extended by up to 3 one-year periods.

(b) Safety Valve Threshold. The Safety Valve Threshold shall be equal to $10.00 (2005$), as adjusted by the Consumer Price Index (CPI) plus 2% per year beginning January 1, 2006.

(c) Market Settling Period. The Market Settling Period is the first 14 months of each compliance period.

F. Offsets. The Program will provide for the award of offset allowances to sponsors of approved CO_2 (or CO_2 equivalent) emissions offset projects for reductions that are realized on or after the date of this MOU. Offset allowances may be used for compliance by units subject to the Program. Among the key features of the offset component of the Program are:

(1) General Requirements.

(a) Minimum Eligibility Requirements. At a minimum, eligible offsets shall consist of actions that are real, surplus, verifiable, permanent and enforceable.

(b) Initial Offset Types. The initial offset project types that may be approved by a Signatory State are: landfill gas (methane) capture and combustion; sulfur hexafluoride (SF_6) capture and recycling; afforestation (transition of land from non-forested to forested state); end-use efficiency for natural gas, propane and heating oil; methane capture from farming operations; and projects to reduce fugitive methane emissions from natural gas transmission and distribution. The measurement and verification protocols and certification processes will be consistent across the Signatory States and incorporated into each State's program.

(c) Additional Offset Types. The Signatory States agree to continue to cooperate on the development of additional offset categories and types, including other types of forestry projects, and grassland re-vegetation projects. Additional offset types will be added to the Program upon approval of the Signatory States.

(2) Initial Offsets Geography and Limits.

(a) Geographic Location of Offset Projects. Offset allowances may be awarded to projects located anywhere inside the United States, provided:

(1) allowances for projects located inside a Signatory State shall be awarded on the basis of one allowance for each CO_2-equivalent ton of certified reduction; and

(2) allowances for projects located outside the Signatory States shall be awarded one allowance for every two CO_2-equivalent tons of certified reduction.

(b) Limit on Offsets Use. In each compliance period, a source may cover up to 3.3% of its reported emissions with offset allowances.

(3) Offsets Trigger and Reset.

(a) Offsets Trigger. If, after the Market Settling Period (defined above), the average regional spot price for CO_2 allowances equals or exceeds $7.00 (2005$) per ton for a period of twelve months on a rolling average (an "Offsets Trigger Event"), then:

(1) offset allowances may be awarded to projects located anywhere in North America; and

(2) offset allowances will be awarded on the basis of one allowance for each CO_2-equivalent ton of certified reduction; and

(3) the percentage of offsets that a source may use to cover its emissions shall increase to 5.0% of its reported emissions for the compliance period in which the Offsets Trigger Event occurs.

(b) Offsets Reset. After an Offset Trigger Event, the limits on geography and use of offsets set forth in Section F.2. shall once again apply commencing at the start of the subsequent compliance period.

(4) Safety Valve Offsets Trigger and Reset.

(a) Safety Valve Offsets Trigger. If a Safety Valve Trigger Event has occurred twice in two consecutive 12-month periods (a "Safety Valve Offsets Trigger Event"), then:

(1) offset allowances may be awarded to projects located anywhere in North America or from international trading programs; and

(2) offset allowances may be awarded to projects located anywhere in North America or credits from international trading programs shall be awarded on the basis of one allowance for each CO_2-equivalent ton of certified reduction; and

(3) the percentage of offsets that a source may use to cover its emissions shall increase to 5.0% of its reported emissions for the first three years of the compliance period and 20% of its reported emissions for the period beginning with the fourth year of the compliance period and continuing through the end of the compliance period.

(b) Safety Valve Offsets Reset. After a Safety Valve Offsets Trigger Event, the limits on geography and use of offsets set forth in Section F.2. shall once again apply commencing at the start of the subsequent compliance period.

G. Allocations of Allowances. Each Signatory State may allocate allowances from its CO_2 emissions budget as determined appropriate by each Signatory State, provided:

(1) each Signatory State agrees that 25% of the allowances will be allocated for a consumer benefit or strategic energy purpose. Consumer benefit or strategic energy purposes include the use of the allowances to promote energy efficiency, to directly mitigate electricity ratepayer impacts, to promote renewable or non-carbon-emitting energy technologies, to stimulate or reward investment in the development of innovative carbon emissions abatement technologies with significant carbon reduction potential, and/or to fund administration of this Program; and

(2) the Signatory States recognize that, in order to provide regulatory certainty to covered sources, state-specific rules for allocations should be completed as far in advance of the launch of the Program as practicable.

H. Early Reduction Credits. Each Signatory State may grant early reduction credits for projects undertaken after the date this Memorandum is signed and prior to the launch of the Program as defined in 3.C. at facilities subject to the Program, which projects have the effect of reducing emissions from the facility by (a) an absolute reduction of emissions through emission rate improvements; or (b) permanently reducing utilization of one or more units at the facility.

I. Banking. The banking of allowances, offset allowances and early reduction credits will be allowed without limitation.

3. MODEL RULE FOR ESTABLISHMENT OF THE CO_2 BUDGET TRADING PROGRAM

A. Model Rule. The Signatory States are collectively developing a draft Model Rule to serve as the framework for the creation of necessary statutory and/or regulatory authority to establish the Program. The Signatory States will use their best efforts to collectively release this draft Model Rule within 90 days after the execution of this MOU for a 60-day public review and comment period. Comments received during this comment period shall be reviewed by the Signatory States, and revisions to the draft Model Rule will be considered. A revised Model Rule will be developed and released within 45 days of the close of the public comment period after consultation among the Signatory States.

B. Legislation and/or Rulemaking. Each Signatory State commits to seek to establish in statute and/or regulation the Program and have that State's component of the regional Program effective as soon as practicable but no later than December 31, 2008.

C. Launch of Program. The Signatory States intend that the first compliance period of the Program will commence January 1, 2009.

4. REGIONAL ORGANIZATION

In order to facilitate the ongoing administration of the Program, the Signatory States agree to create and maintain a regional organization ("RO") with a primary office in New York City. The RO will be a non-profit entity incorporated in New York and will operate pursuant to by-laws agreed upon by the Signatory States. The RO shall have an Executive Board comprised of two representatives from each Signatory State. The RO may employ staff and acquire and dispose of assets in order to perform its functions.

A. RO Functions. The RO will have the following functions:

(1) Deliberative Forum. Act as the forum for collective deliberation and action among the Signatory States in implementing the Program. The by-laws of the RO shall specify the process for deliberation and arriving at agreement to take collective action.

(2) Emissions and Allowance Tracking. Act on behalf of each of the Signatory States in developing, implementing and maintaining the system to receive and store reported emissions data from sources and track allowance accounts for the Program.

(3) Offsets Development. Provide technical support to the States for the development of new offset standards to be added to state rules.

(4) Offsets Implementation. Provide technical assistance to the States in reviewing and assessing applications for offsets projects. Such technical assistance may include the development of model guidance documents for use by the States for potential sponsors of offset projects. At the

request of any Signatory State, the RO may assist in the review of any application for the award of offsets credits.

(5) Limitation on Powers. The RO is a technical assistance organization only. The RO shall have no regulatory or enforcement authority with respect to the Program, and such authority is reserved to each Signatory State for the implementation of its rule.

B. Funding for the RO. The Signatory States agree that the RO shall be funded at least in part through payments from each Signatory State in proportion to the State's annual base CO2 Emissions Budget. The RO's budget shall be determined and approved by the RO's Executive Board.

5. ADDITION OR REMOVAL OF SIGNATORY STATES

A. New Signatory States.

(1) New Signatories. A Non-Signatory State may become a Signatory State by agreement of the Signatory States as reflected in an amendment to this MOU.

(2) Expansion. The Signatory States shall work together to encourage Non-Signatory States to become Signatory States and shall welcome expressions of interest from Non-Signatory States with a goal to expand the geographic reach of the Program.

(3) Massachusetts and Rhode Island. The Signatory States recognize the contributions of Massachusetts and Rhode Island to the design and development of the Program and the negotiation of this MOU. The Signatory States agree that Massachusetts and Rhode Island may become signatories to this MOU at any time prior to January 1, 2008, without any amendment to the terms of this MOU. In the event that authorized representatives of Massachusetts and/or Rhode Island execute this MOU before such date, they shall receive the following CO_2 emissions budgets:

Massachusetts:	26,660,204 short tons
Rhode Island:	2,659,239 short tons

In the event that Massachusetts and/or Rhode Island become Signatory States under this paragraph, then the regional emissions budget set forth in Section 2.B. of this MOU shall be increased to include the allowance budgets of Massachusetts and/or Rhode Island.

B. Withdrawal of a Signatory State. A Signatory State may, upon 30 days written notice, withdraw its agreement to this MOU and become a Non-Signatory State. In this event, the remaining Signatory States would execute measures to appropriately adjust allowance usage to account for the corresponding subtraction of units from the Program.

C. Removal of Signatory State. Removal of a Signatory State shall be handled in the by-laws of the Regional Organization.

6. PROGRAM MONITORING AND REVIEW

The Signatory States agree to monitor the progress of the Program on an ongoing basis.

A. Imports and Associated Emissions Leakage. The Signatory States recognize the potential that the Program may lead to increased electricity imports and associated emissions leakage. To address this potential, the Signatory States:

(1) agree to promptly, but no later than April 1, 2006, establish a multi-state working group consisting of representatives from the energy regulatory and environmental agencies in the Signatory States. The multi-state working group shall:

  (a) consider potential options for addressing leakage. Attention shall be paid not only to the potential effectiveness of a particular option to address leakage, but also to the potential impacts that option may have on energy prices, allowance prices, electric system reliability and on the economies of the RGGI states. In considering potential options, the working group shall consult with a panel of experts, stakeholders and representatives of the regional transmission organizations.

  (b) issue its findings and conclusions by December 2007.

(2) agree to consider, after taking into account the analyses and findings called for under Section 6(a)(1), what actions should be taken to address potential leakage prior to the launch of the program in January 2009.

(3) monitor electricity imports into the Signatory States on an ongoing basis commencing from the start of the program, and report the results of the monitoring on an annual basis beginning in 2010.

(4) immediately following the first three-year compliance period and at any time thereafter, determine whether and to what extent any increase in emissions

from electric generating units outside the Signatory States is attributable to the Program.

(5) if at any point after the launch of the program there is a determination that the Program has led to a significant increase in emissions from electric generating units outside the Signatory States, the Signatory States shall, after taking into account the analyses and findings called for under Section 6(a)(1), implement appropriate measures to mitigate such emissions.

(6) The Signatory States agree to pursue technically sound measures to prevent leakage from undermining the integrity of the Program.

B. Monitoring of Reliability Impacts. The Signatory States recognize the paramount importance of maintaining a reliable electrical system in the region, and are committed to monitoring the Program on an ongoing basis to ensure that the Program will not result in electricity supply interruptions.

C. Federal Program. When a federal program is proposed, the Signatory States will advocate for a federal program that rewards states that are first movers. If such a federal program is adopted, and it is determined to be comparable to this Program, the Signatory States will transition into the federal program.

D. Comprehensive 2012 Review. In 2012, the Signatory States will commence a comprehensive review of all components of the Program, including but not limited to:

(1) Program Success. The Signatory States will review whether the Program has been successful in meeting its goals.

(2) Program Impacts. The Signatory States will review the impacts of the Program as to price and system reliability.

(3) Additional Reductions. The Signatory States will consider whether additional reductions after 2018 should be implemented.

(4) Imports and Emissions Leakage. The Signatory States will consider the effectiveness of any measures put in place to control emissions leakage.

(5) Offsets. The Signatory States will evaluate the offsets component of the Program, with attention to price, availability, and environmental integrity, and recommend whether changes to the Program are warranted.

7. COMPLEMENTARY ENERGY POLICIES

Each state will maintain and, where feasible, expand energy policies to decrease the use of less efficient or relatively higher polluting generation while maintaining economic growth. These may include such measures as: end-use efficiency programs, demand response programs, distributed generation policies, electricity rate designs, appliance efficiency standards and building codes. Also, each state will maintain and, where feasible, expand programs that encourage development of non-carbon emitting electric generation and related technologies.

8. AMENDMENT

This MOU may be amended in writing upon the collective agreement of the authorized representatives of the Signatory States.

[Signatures on Next Page]

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the 20th day of December, 2005.

THE STATE OF CONNECTICUT

By: M. Jodi Rell

M. Jodi Rell
Governor

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the 20th day of December, 2005.

THE STATE OF DELAWARE

By: Ruth Ann Minner

Ruth Ann Minner
Governor

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the 30th day of December, 2005.

THE STATE OF MAINE

By: ____________________

John Elias Baldacci
Governor

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the 20th day of December, 2005.

STATE OF NEW HAMPSHIRE

By: ______________________

John Lynch
Governor

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the 20th day of December, 2005.

STATE OF NEW JERSEY

By: Richard J. Codey

Richard Codey
Governor

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the 20th day of December, 2005.

STATE OF NEW YORK

By:__________________________

George E. Pataki
Governor

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the 20th day of December, 2005.

STATE OF VERMONT

By:______________________

James Douglas
Governor

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the _______ day of ____________________, 20____.

COMMONWEALTH OF MASSACHUSETTS

By:________________________________
Its:

This Memorandum of Understanding on the Regional Greenhouse Gas Initiative signed as of the _______ day of ____________________, 20____.

STATE OF RHODE ISLAND &
PROVIDENCE PLANTATIONS

By:________________________
Its:

New York State ☰ State Agencies
Search all of NY.gov

DEPARTMENT OF
ENVIRONMENTAL CONSERVATION

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Animals, Plants, Aquatic Life
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Air
Air Quality Monitoring
2013 Monitoring Network Plan
Network Plan Part 13 - CO, NOx, Pb, PM, SO2, Ozone
Energy and Climate
Lands and Waters
Education
Permits and Licenses
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Network Plan Part 13 - CO, NOx, Pb, PM, SO2, Ozone

4. Criteria Contaminants

EPA is required to set National Ambient Air Quality Standards (NAAQS) for wide-spread pollutants from numerous and diverse sources considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against visibility impairment, damage to animals, crops, vegetation, and buildings. The Clean Air Act requires periodic review of the science upon which the standards are based and the standards themselves. Listed below are the NAAQS for six principal pollutants, which are called "criteria" pollutants.

Table 4.1 National Ambient Air Quality Standards

Pollutant	Primary Standards		Secondary Standards	
	Level	Averaging Times	Level	Averaging Times
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour$^{(1)}$	None	
	35 ppm (40 mg/m^3)	1-hour$^{(1)}$		
Lead	0.15 µg/m$^{3(2)}$	Rolling 3-month Average	Same as Primary	
Nitrogen Dioxide	53 ppb	Annual (Arithmetic Mean)	Same as Primary	
	100 ppb	1-hour$^{(3)}$	None	
Particulate Matter (PM10)	150 µg/m^3	24-hour$^{(4)}$	Same as Primary	
Particulate Matter (PM2.5)	12.0 µg/m^3	Annual$^{(5)}$ (Arith. Mean)	Same as Primary	
	35 µg/m^3	24-hour$^{(6)}$	Same as Primary	
Ozone	0.075 ppm (2008 std)	8-hour$^{(7)}$	Same as Primary	
	0.08 ppm (1997 std)	8-hour$^{(8)}$	Same as Primary	
	0.12 ppm	1-hour$^{(9)}$ Not applicable in NYS	Same as Primary	
Sulfur Oxides	75 ppb	1-hour$^{(10)}$	3-hour $^{(1)}$	0.5 ppm (1300 µg/m^3)

(1) Not to be exceeded more than once per year.

(2) Effective 1/12/2009, replaces the previous quarterly average value of 1.5µg/m^3.

(3) To attain this standard, the 3-year average of the 98th percentile of the daily maximum 1-hour average at each monitor within an area must not exceed 100 ppb (effective January 22, 2010).

(4) Not to be exceeded more than once per year on average over 3 years.

(5) To attain this standard, the 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed $12.0 \mu g/m^3$. Effective March 18, 2013.

(6) To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed $35 \mu g/m^3$(effective December 17, 2006).

(7) To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour *average ozone concentrations measured at each monitor within an area over each year must* not exceed 0.075 ppm (effective May 27, 2008).

(8) (a) To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.
(b) The 1997 standard-and the implementation rules for that standard-will remain in place for implementation purposes as EPA undertakes rulemaking to address the transition from the 1997 ozone standard to the 2008 ozone standard.
(c) EPA is in the process of reconsidering these standards (set in March 2008).

(9) (a) The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is < 1.
(b) As of June 15, 2005 EPA revoked the 1-hour ozone standard in all areas except the 8-hour ozone nonattainment Early Action Compact (EAC) Areas.

(10) Effective August 23, 2010. To attain this standard, the 3-year average of the 99th percentile of the daily maximum 1-hour average at each monitor within an area must not exceed 75 ppb.

4.1 Carbon Monoxide

Carbon monoxide, a colorless and odorless gas, is produced as a primary pollutant during the combustion of fossil and biomass fuels. Vegetation also can emit CO directly into the atmosphere as a metabolic by-product. Sources such as motor vehicles, non-road combustion engines or vehicles, and biomass burning can cause high concentrations of CO in the outdoor environment. Indoor sources include unvented, malfunctioning, or misused combustion appliances, combustion engines in garages or basements, and tobacco combustion. In both of these environments, CO is of direct concern because of the health effects that can result from human exposure to these high concentrations.

CO enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. The health threat from levels of CO sometimes found in the ambient air is most serious for those who suffer from cardiovascular disease such as angina pectoris. At much higher levels of exposure not commonly found in ambient air, CO can be poisonous, and even healthy individuals may be affected. Visual impairment, reduced work capacity, reduced manual dexterity, poor learning ability, and difficulty in performing complex tasks are all associated with exposure to elevated CO levels.

There are two primary NAAQS for ambient CO: a 1-hour average of 35 ppm and an 8-hour average of 9 ppm. These concentrations are not to be exceeded more than once per year. There currently are no secondary standards for CO.

Motor vehicle exhaust contributes about 60 percent of all CO emissions nationwide. High concentrations of CO generally occur in areas with heavy traffic congestion. Other sources of CO emissions include industrial processes, non-transportation fuel combustion, and natural sources such as wildfires. Peak CO concentrations typically occur during the colder months of the year when CO automotive emissions are greater and nighttime inversion conditions are more frequent.

Technological advancements in pollution control have brought about a downward trend for ambient CO concentrations over the past few decades. According to EPA estimates, annual CO emissions decreased from 197.3 million tons in 1970 to 89 million tons in 2005 nationally.

The number of monitors and concentration trends chart over the years in New York State are depicted in Figure 4.1. It clearly demonstrates that the current ambient levels of CO are well below the NAAQS, in spite of the continual increase in automobiles and vehicle-miles traveled in the State. As of 2002, all counties in the State have achieved attainment designation.

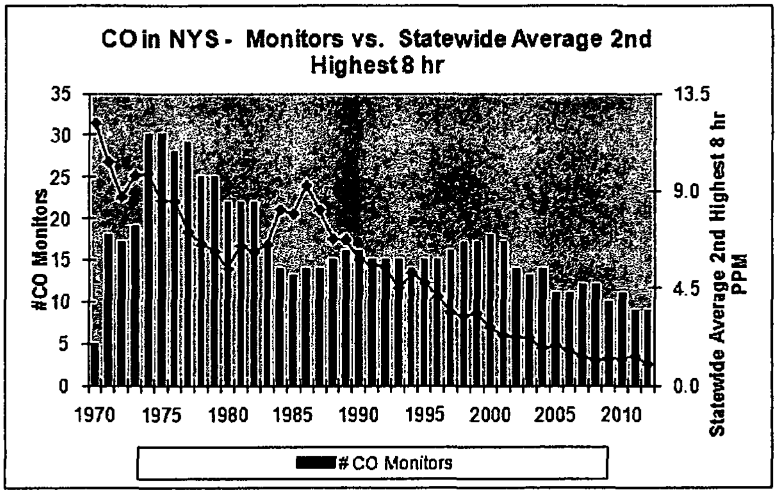


Figure 4.1 Carbon Monoxide Monitors and Concentration Trends

NYSDEC uses TEI Model 48C instruments that employ the NDIR gas filter correlation method for the continuous measurement of CO. Currently there are seven CO monitors in operation statewide as shown in Figure 4.2.

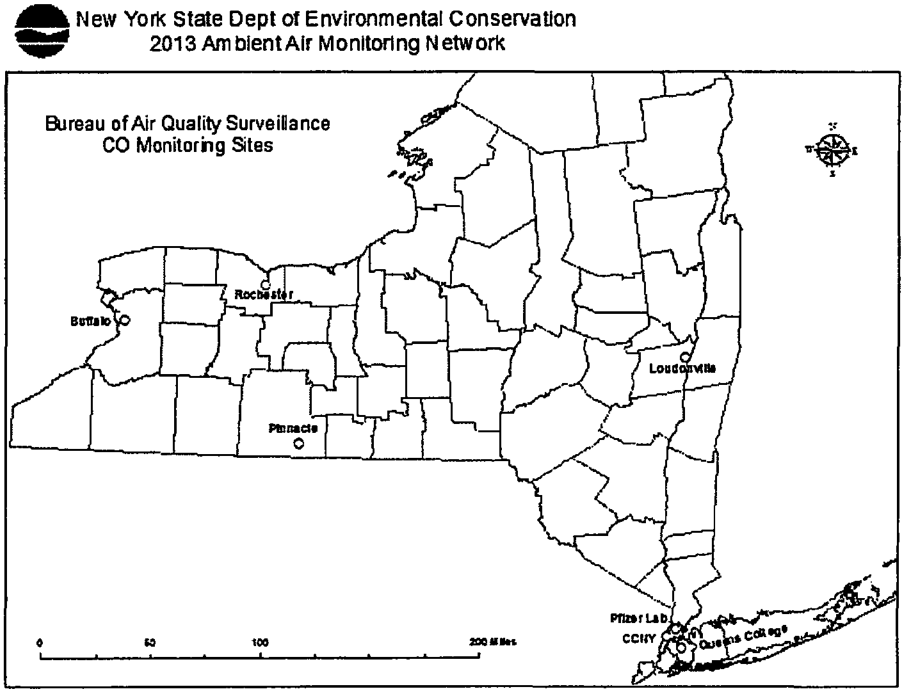


Figure 4.2 Location Map for Carbon Monoxide Monitoring Sites

4.2 Nitrogen Dioxide

Many chemical species of nitrogen oxides (NO_x) exist, but the air pollutant species of most interest from the point of view of human health is nitrogen dioxide (NO_2). Nitrogen dioxide is soluble in water, reddish-brown in color, and a strong oxidant.

Nitrogen dioxide is an important atmospheric trace gas, not only because of its health effects but also because (a) it absorbs visible solar radiation and contributes to impaired atmospheric visibility; (b) as an absorber of visible radiation it could have a potential direct role in global climate change if its concentrations were to become high enough; (c) it is, along with nitric oxide (NO), a chief regulator of the oxidizing capacity of the free troposphere by controlling the build-up and fate of radical species, including hydroxyl radicals; and (d) it plays a critical role in determining ozone (O_3) concentrations in the troposphere because the photolysis of nitrogen dioxide is the only key initiator of the photochemical formation of ozone, whether in polluted or unpolluted atmospheres.

Natural sources include intrusion of stratospheric nitrogen oxides, bacterial and volcanic action, and lightning. The major source of anthropogenic emissions of nitrogen oxides into the atmosphere is the combustion of fossil fuels in stationary sources (heating, power generation) and in motor vehicles (internal combustion engines).

In most ambient situations, nitric oxide is emitted and transformed into nitrogen dioxide in the atmosphere. Oxidation of nitric oxide by atmospheric oxidants such as ozone occurs rapidly, even at the low levels of reactants present in the atmosphere. Consequently, this reaction is regarded as the most important route for nitrogen dioxide production in the atmosphere.

Other contributions of nitrogen dioxide to the atmosphere come from specific non-combustion industrial processes, such as the manufacture of nitric acid, the use of explosives and welding.

Indoor sources include tobacco smoking and the use of gas-fired appliances and oil stoves.

Nitrogen dioxide is the most widespread and commonly found nitrogen oxide and is a matter of public health concern. The most troubling health effects associated with short term exposures (i.e., less than 3 hours) to NO_x at or near the ambient NO_x concentrations seen in the United States include cough and increased changes in airway responsiveness and pulmonary function in individuals with preexisting respiratory illnesses, as well as increases in respiratory illnesses in children 5 to 12 years old.. Evidence suggests that long-term exposures to NO_x may lead to increased susceptibility to respiratory infection and may cause structural alterations in the lungs.

Atmospheric transformation of NO_x can lead to the formation of ozone and nitrogen-bearing particles (e.g., nitrates and nitric acid). As discussed in the ozone and particulate matter sections of this document, exposure to both PM and O_3 is associated with adverse health effects.

Nitrogen oxides contribute to a wide range of effects on public welfare and the environment, including global warming and stratospheric ozone depletion. Deposition of nitrogen can lead to fertilization, eutrophication, or acidification of terrestrial, wetland, and aquatic (e.g., fresh water bodies, estuaries, and coastal water) systems. These effects can alter competition between existing species, leading to changes in the number and type of species (composition) within a community. For example, eutrophic conditions in aquatic systems can produce explosive algae growth leading to a depletion of oxygen in the water and/or an increase in levels of toxins harmful to fish and other aquatic life.

The level for both the primary and secondary NAAQS for NO_2 is 0.053 ppm annual arithmetic average (mean), not to be exceeded. This past January EPA revised the NAAQS to include an hourly standard of 0.100 ppm. Figure 4.3 shows the number of monitoring sites and NO_2 concentration trends over the years. The current ambient levels of NO_2 observed in New York State are well below the NAAQS.

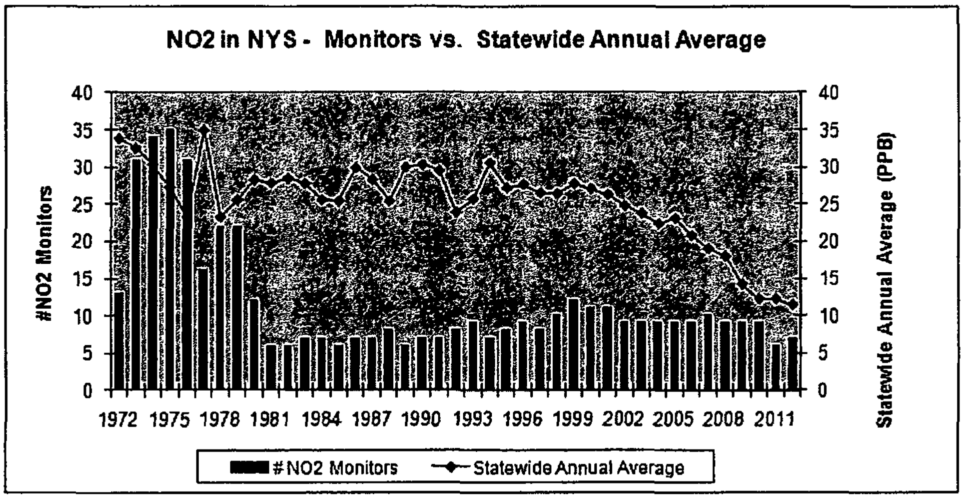


Figure 4.3 Nitrogen Dioxide Monitors and Concentration Trends

In New York, the TEI Model 42C instruments are deployed for continuous NO_2 measurements using the gas phase chemiluminescence method. Currently there are four NO_x monitoring sites statewide, and NO/NO_y monitors in Rochester, Pinnacle, and Queens College (both NO_2 and NO_y) as shown in Figure 4.4. NO/NO_y measurements are included within the NCore multi-pollutant site requirements and the PAMS program. These NO/NO_y measurements will produce conservative estimates for NO_2 that can be used to ensure tracking continued compliance with the NO_2 NAAQS. NO/NO_y monitors are used at these sites because it is important to collect data on total reactive nitrogen species for understanding O_3 photochemistry.

The EPA considered setting a secondary standard for NO_x and SO_x that would specifically target the impact of acidic deposition on wilderness areas. The EPA ultimately decided that there was not enough information at this time to tie specific water quality thresholds with ambient air concentrations. In the July 2011 final rule for NO_x and SO_x, the EPA stated that they would set up a monitoring program in sensitive areas to collect information to link water quality impacts to ambient air quality measurements. The NYSDEC is participating in this pilot monitoring program in the Adirondacks. Additional monitoring equipment has been installed at several sites to determine the concentrations of gasses and particles including ammonia. These data will be used in the future to inform the next review of the NO_x/SO_x standard.

New York State Dept of Environmental Conservation
2013 Ambient Air Monitoring Network

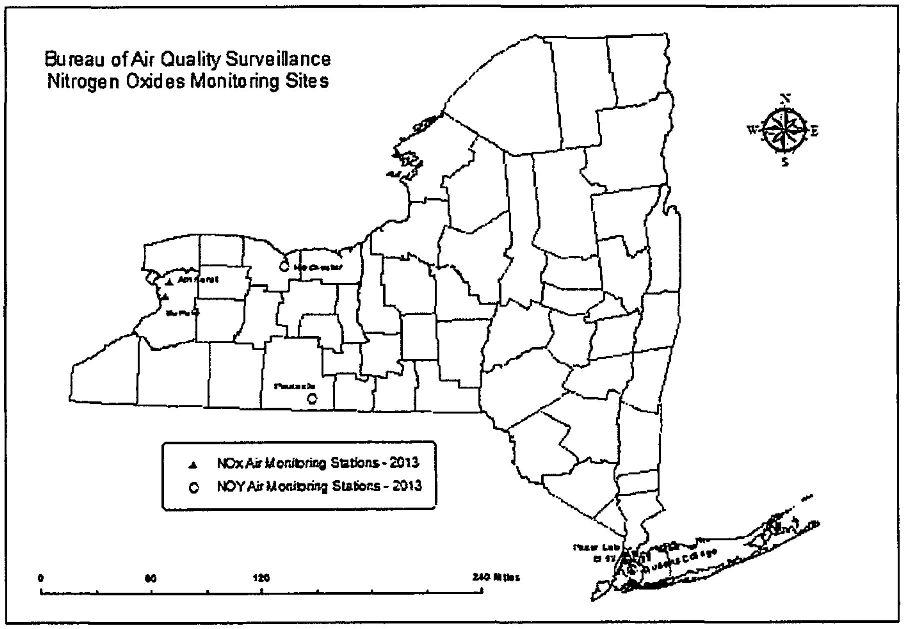


Figure 4.4 Location Map for Nitrogen Oxides Monitoring Sites

Although ambient NO_2 levels are not expected to contravene the NAAQS, monitoring is necessary due to it being an ozone precursor, and to track the effectiveness of emission reduction programs. Under the new NO_x rule that became effective January 22, 2010 each MSA with population larger than 500,000 will be required to operate a near-road monitor beginning in 2013. New York State will need to establish such a site in each of the following areas: Albany-Schenectady-Troy, Buffalo-Niagara Falls, Poughkeepsie-Newburgh-Middletown, Nassau-Suffolk, New York-White Plains, Rochester and Syracuse. One urban community wide monitor will be located in each of the three MSAs with population greater than 1 million: New York, Buffalo and Rochester. Furthermore, the Regional Administrators at their discretion, have the authority to require 40 additional sites nationwide in communities where susceptible and vulnerable populations are located. On March 7, 2013, EPA issued a final rule to revise the deadlines by which the near-road monitors within the NO2 monitoring network are to be operational. States and local agencies will begin operating the near-road component of the

NO2 network in phases between January 1, 2014 and January 1, 2017. This replaces the 2010 rule requirement that originally required all new NO2 monitors to begin operating on January 1, 2013. New York is working closely with EPA Region 2 to implement this rule. We have identified possible sites in New York and Buffalo and anticipate operation by 2014. We are actively pursuing a suitable site location in Rochester.

4.3 Lead

Elemental lead (Pb) possesses an array of useful physical and chemical properties, making it among the first metals to be extracted and used by humankind. It has a relatively low melting point (327.5°C), is a soft, malleable, and ductile metal, a poor electrical conductor, and is easily cast, rolled and extruded. Although sensitive to environmental acids, after exposure to environmental sulfuric acid (H_2SO_4), metallic Pb becomes impervious to corrosion due to weathering and submersion in water. This effect is due to the fact that Pb lead sulfate ($PbSO_4$), the relatively insoluble precipitate produced by reaction of Pb with H_2SO_4, forms a protective barrier against further chemical reactions. This aspect of its chemistry made Pb especially convenient for protective surface coatings (e.g. paint), roofing, containment of corrosive liquids, and (until the discovery of its adverse health effects), construction of water supply systems.

Pb will only exist in the vapor phase at or above 1750°C. Therefore, at ambient atmospheric temperatures, elemental Pb will deposit to surfaces or exist in the atmosphere as a component *of atmospheric aerosol.*

Exposure to lead occurs through ingestion of lead in food, water, soil, or dust and through inhalation. It accumulates in the blood, bones, and soft tissues. Lead can also adversely affect the kidneys, liver, nervous system, and other organs. Excessive exposure to lead may cause neurological impairments such as seizures, mental retardation, and/or behavioral disorders. Even at low doses, Pb exposure is associated with changes in fundamental enzymatic, energy transfer, and homeostatic mechanisms in the human body. Additionally, even low levels of Pb exposure may cause central nervous system damage in fetuses and children. Recent studies show that neurobehavioral changes may result from Pb exposure during the child's first years of life and that lead may be a factor in high blood pressure and subsequent heart disease.

Airborne lead can also have adverse impacts on the environment. Wild and domestic grazing animals may ingest lead that has deposited on plant or soil surfaces or that has been absorbed by plants through leaves or roots. Animals, however, do not appear to be more susceptible or more sensitive to adverse effects from lead than are humans. Therefore, the secondary standard for lead is identical to the primary standard.

In November of 2008 EPA published the final rule for the revision of the NAAQS for lead. The primary lead standard was revised to 0.15$\mu g/m^3$ in total suspended particles (Pb-TSP). The averaging time was changed to a rolling 3-month period with a maximum (not-to-be-exceeded) form, evaluated over a 3-year period. The revised secondary standard was set to be identical in all respects to the new primary standard. These new standards became effective on January 12, 2009, superseding the old standard of quarterly average concentration not to exceed 1.5$\mu g/m^3$. As part of the lead monitoring requirements, monitoring agencies are required to monitor ambient air near lead sources which are expected to or have been shown to have a potential to contribute to a 3-month average lead concentration in ambient air in excess of the level of the NAAQS. At a minimum, monitoring agencies must monitor near lead sources that emit 1.0 ton per year (tpy) or more. Monitoring is also required in each CBSA with a population equal to or greater than 500,000 people as determined by the latest available census figures. Revisions to the monitoring requirements pertaining to where State and local monitoring agencies would be required to conduct lead monitoring were finalized and became effective

January 26, 2011. The new regulations replaced the population oriented monitoring requirement with a requirement to add Pb monitors to the urban NCore monitors. The EPA also lowered the emission threshold from 1.0 tpy to 0.50 tpy for industrial sources of lead (e.g., lead smelters and foundries). However, the emission threshold for airports was maintained at 1.0 tpy. In addition, an airport monitoring study will be implemented to determine the need for monitoring of airports which emit less than 1.0 tpy of lead. Under this new rule lead monitoring is required for a minimum of one year at 15 additional airports that have been identified as having characteristics that could lead to ambient lead concentrations approaching or exceeding the lead NAAQS. Brookhaven and Republic airports in Suffolk County, New York have been designated as such. A 12-month monitoring study at Brookhaven Airport commenced concluded in October, 20121 and all data were submitted to AQS. The Republic Airport monitoring is expected to begin in the second quarter ofdid not start until October, 2012 due to protracted site lease negotiations.

Particulate lead samples are collected on glass fiber filters using a standard TSP high volume sampler which are subsequently analyzed by the laboratory using atomic absorption spectroscopy. Under the new rule, EPA is allowing Pb-PM_{10} in lieu of Pb-TSP where the maximum 3-month arithmetic mean Pb concentration is expected to be less than 0.10μg/m^3 (i.e., two thirds of the NAAQS) and where sources are not expected to emit ultra-coarse Pb. The population oriented Pb monitors at the NCore or NATTS sites are located away from known sources of Pb and will utilize Pb-PM_{10} samplers. Figure 4.5 depicts the number of monitoring sites and lead concentration trends for New York State over the years.

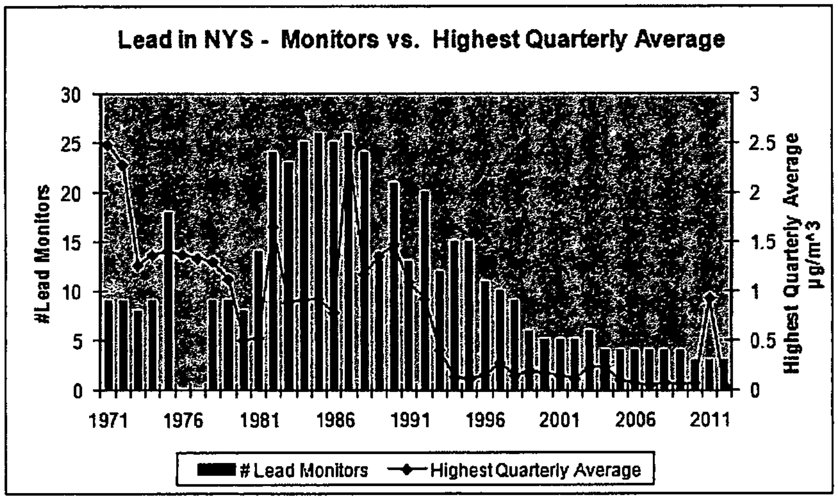


Figure 4.5 Lead Monitors and Concentration Trends

Currently there are four Pb-TSP monitors (one collocated) in operation in Middletown, where a lead acid battery recycling facility is located, and two urban CBSA monitors (low volume PM_{10}) at the NATTS sites in the Bronx and Rochester. The source oriented monitoring sites (AQS site ID # 36-071-3001, 36-071-3002, 36-071-3004) are in place as the facility has the potential to contribute to a 3-month average lead concentration in ambient air in excess of the level of the NAAQS. Routine data review showed that during the first quarter of 2011, there were a couple of sample dates that showed high levels of lead, which would lead to contravention of the new standard. Investigations at the facility led to enforcement actions although specific causes for the observed values were not discovered. Consequently an additional low volume PM10 sampler was put in place to collect daily filter samples for mass measurement and lead analysis using XRF in August 2011. The PM_{10} mass data collected at this site was low and mass determination was discontinued in November 2012. The highest 3 Month average PM_{10} lead concentration at this site was 0.021 µgPb/m^3 which is well below the standard..

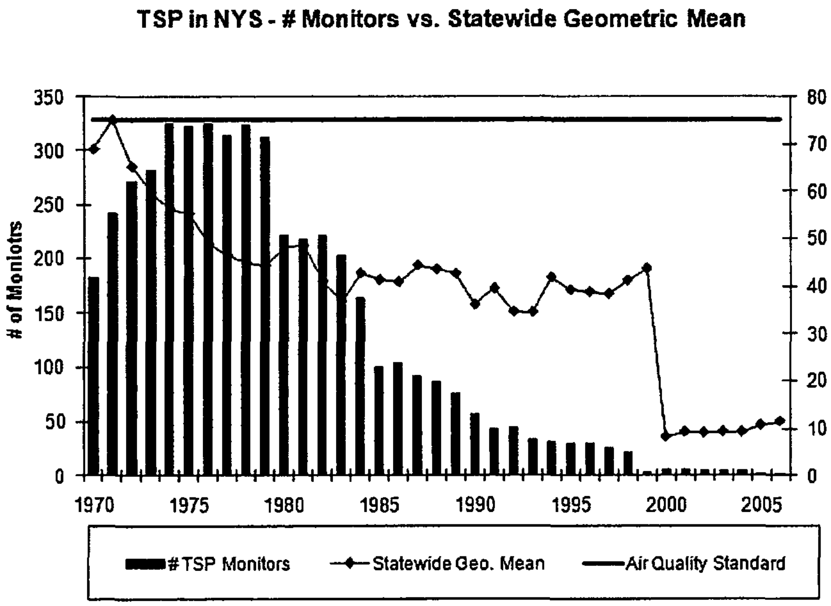
4.4 Particulate Matter

4.4.1 Total Suspended Particulate

Particulate matter is the generic term for a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes. Particles originate from a variety of anthropogenic stationary and mobile sources as well as natural sources. Particles may be emitted directly or formed in the atmosphere by transformations of gaseous emissions such as sulfur oxides, nitrogen oxides, and volatile organic compounds. The chemical and physical properties of PM vary greatly with time, location, meteorology, and source category, thus complicating the assessment of health and welfare effects.

EPA first established national ambient air quality standards for PM in 1971. The reference method specified for determining attainment of the original standards was the high-volume sampler, which collects PM up to a nominal size of 25 to 45 micrometers (µm), referred to as total suspended particles or TSP. The primary standards (measured by the indicator TSP) were 260µg/m^3 24-hour average, not to be exceeded more than once per year, and 75µg/m^3 annual geometric mean. The secondary standard was 150µg/m^3 24-hour average, not to be exceeded more than once per year. These standards were in place until 1987 when EPA changed the particle indicator from TSP to PM_{10}, the latter referring to particles with a mean aerodynamic diameter less than or equal to10 µm.

Figure 4.6 shows the number of monitoring sites and the composite annual geometric means ofTSP over the years. Trace metal analysis was also performed on the TSP filters until 1998. NYSDEC terminated the TSP sampling program when DOH could no longer provide laboratory analysis support.



4.6 Total Suspended Particulate Monitors and Concentration Trends

4.4.2 PM_{10}

In 1987 EPA revised the 1971 standards in order to protect against adverse health effects of inhalable airborne particles that can be deposited in the lower (thoracic) regions of the human respiratory tract, with PM_{10} as the indicator. EPA established identical primary and secondary PM_{10} standards for two averaging times: 150µg/m^3 (24-h average, with no more than one expected exceedance per year) and 50 µg/m^3 (expected annual arithmetic mean, averaged over three years). These standards remained in effect until 2002, when the courts finally upheld the 1997 revisions put forth by EPA as a result of the mandated periodic scientific review. After the most recent scientific review on PM, EPA issued the final rule in December, 2006 revising the $PM_{2.5}$ standards, at the same time revoking the PM_{10} annual standard while retaining the 24 hr standard at 150µg/m^3.

Wedding & Associates PM_{10} Critical Flow High Volume Sampler (WED PM_{10} sampler) were employed for the NYSDEC network. The quartz filters were collected and submitted to the Department of Health for laboratory analysis until 2005, when support services were terminated. Figure 4.7 shows the number of monitors and the composite annual arithmetic mean for PM_{10}.

Starting in 2004, the R&P Partisol 2025 samplers were used for manual PM_{10} collection by removing the $PM_{2.5}$ size selective inlet. The filter cartridges are submitted to RTI (EPA contract laboratory) for mass analysis.

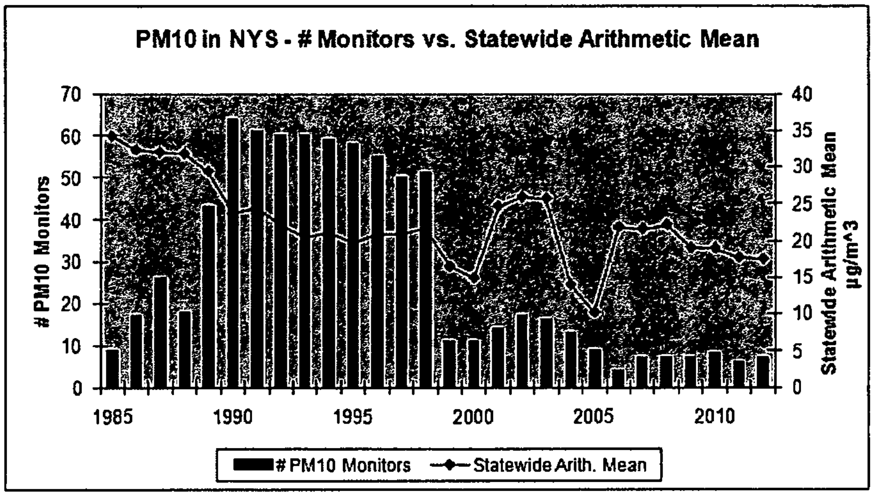


Figure 4.7 PM_{10} Monitors and Concentration Trends

Currently there are five such sites in operation, as shown in Figure 4.8.

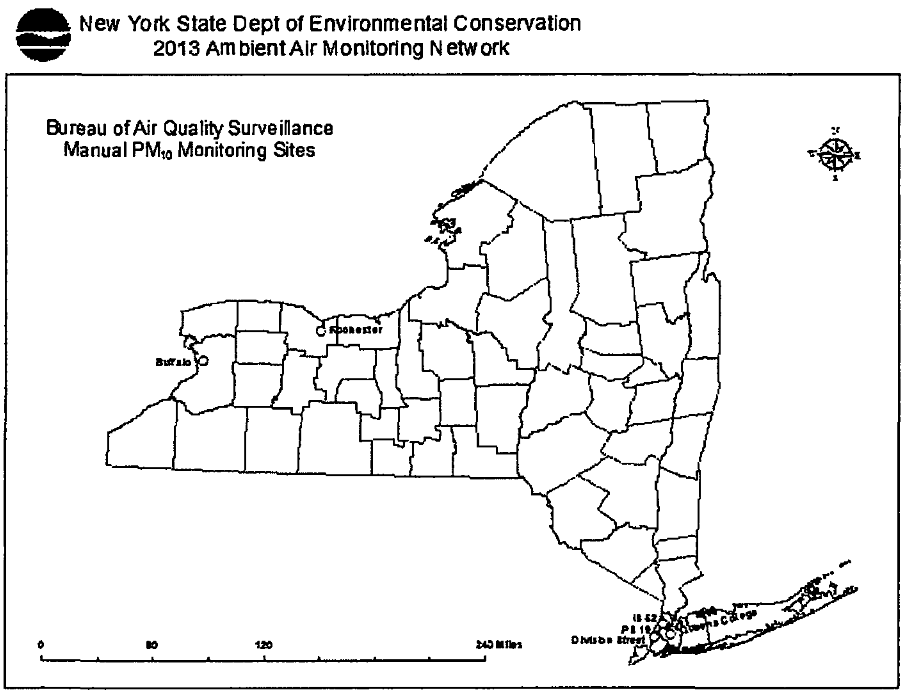


Figure 4.8 Location Map for PM_{10} Monitoring Sites

A continuous PM_{10} data are also obtained using Thermo Scientific 1405-DF instruments that simultaneously measure PM2.5, PM Coarse (PM10 - PM2.5) and PM10 mass concentrations at the IS 52, Queens College, and Pinnacle State Park sites.

4.4.3 $PM_{2.5}$

In July 1997, EPA Administrator promulgated significant revisions to the PM NAAQS, after taking into account scientific information and assessments presented by staff, Clean Air Scientific Advisory Committee advice and recommendations, and public comments. While it was determined that the PM NAAQS should continue to focus on particles less than or equal to 10 µm in diameter, it was also determined that the fine and coarse fractions of PM_{10} should be considered separately. New standards were added, using $PM_{2.5}$ as the indicator for fine particles; and PM_{10} standards were retained for the purpose of regulating coarse-fraction particles. Two new $PM_{2.5}$ standards were set: an annual standard of 15 µg/m^3, based on the 3-year average of annual arithmetic mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors; and a 24-h standard of 65 µg/m^3, based on the 3-year average of the 98th percentile of 24-h $PM_{2.5}$ concentrations at each population-oriented monitor within an area. To continue to address coarse-fraction particles, the annual PM_{10} standard was retained, and the form, but not the level, of the 24-h PM_{10} standard was revised to be based on the 99th percentile of 24-h PM_{10} concentrations at each monitor in an area. The secondary standards were revised by making them identical in all respects to the $PM_{2.5}$ and PM_{10} primary standards.

EPA lowered the NAAQS for PM in December of 2006 to provide increased protection of public health and welfare, respectively. EPA revised the level of the 24-hour $PM_{2.5}$ standard from 65 to 35 micrograms per cubic meter (µg/m^3) and retained the level of the annual $PM_{2.5}$ standard at 15 µg/m^3. With regard to PM_{10}, the 24-hour standard was retained, but the annual PM_{10} standard was revoked. On Dec. 14, 2012 EPA further strengthened the nation's air quality standards for fine particle pollution to by revising the primary annual $PM_{2.5}$ standard from 15 to 12 micrograms per cubic meter (µg/m3) and retaining the 24-hour fine particle standard of 35 µg/m^3. The new standards became effective on March 18, 2013.

The NYSDEC $PM_{2.5}$ monitoring network deploys a combination of filter based Federal Reference Method (FRM) samplers, continuous mass monitors, filter based speciation samplers and continuous speciation samplers. The data from the FRM samplers are used to determine if the State's air quality meets the National Ambient Air Quality Standards (NAAQS). The continuous mass sampler data are used for the reporting of near real-time air quality data for health related warnings and forecasts. The speciation filter sampler data are used to determine the chemical constituents that make up $PM_{2.5}$. The continuous speciation data are used to examine the short term fluctuations in the concentrations of individual species or components that make up $PM_{2.5}$.

PM Monitoring Objectives

The principal objective of the $PM_{2.5}$ monitoring network is to determine the exposure of the State's population to ambient $PM_{2.5}$. This objective is the primary focus of the FRM filter based samplers as well as for the continuous mass monitoring network. The protocols and equipment used for the FRM network are meticulously specified in the Code of Federal Regulations (CFR) to insure that the measurements are consistent from one State to another. The continuous mass monitoring instruments cannot accurately provide data for direct comparison with the NAAQS but these instruments actually provide the most useful data for population exposure. The continuous $PM_{2.5}$ data is updated every hour for near real-time health related warnings, $PM_{2.5}$ forecasts and updates as to current pollution concentrations.

The NYSDEC has attempted to adjust the $PM_{2.5}$ network in light of EPA expectations, updated regulations and prioritized funding. The FRM network consisted of 40 sites when it was fully established using the original design criteria from 1998. Since then the number of sites have been reduced because fewer sites were required to determine compliance with the Annual $PM_{2.5}$ NAAQS. The latest revisions to the Federal regulations have reduced the number of required monitors even further. These new requirements base the number of required monitors on population and the expected $PM_{2.5}$ concentration. The NYSDEC network exceeds these requirements in all areas that are expected to be near or above either the Annual or Daily $PM_{2.5}$ standard.

The other monitoring objectives for the $PM_{2.5}$ network include transport and background monitoring. Transport monitoring sites are sites that are situated so that the data are representative of the air masses moving into the State from areas upwind. These sites are important because the sources of $PM_{2.5}$ that are outside of New York can contribute to New York's $PM_{2.5}$ ambient concentration. Background monitoring sites are sites that are representative of $PM_{2.5}$ concentrations that are generally not related to specific sources but impact wide areas. The concentrations measured at these background sites generally represent the lowest expected $PM_{2.5}$ concentrations in New York State.

Monitoring Scale and Representativeness

The geography of New York State encompasses a lake shore to the west, plateaus and rolling hills in the center, mountains to the northeast and south and sea shores to the southeast. All of these areas have varying population densities and meteorology. The populations living in these areas are exposed to $PM_{2.5}$ that is generated locally as well as from $PM_{2.5}$ that is transported from areas outside of their region.

The actual design of the network is a compromise that minimizes the number of monitoring locations while ensuring that the measured concentrations for each area are indicative of actual population exposures. Each sampler is assigned a scale or "zone of representativeness" when it is installed. The scale determines how large a geographical area the resulting data will represent.

EPA has defined ambient monitoring scales as:

Microscale:	Represents (10 - 100 meters)
Middle Scale:	Represents (100 - 500 meters)
Neighborhood Scale:	Represents (500 meters - 4 km)
Urban Scale:	Represents (4 - 100 km)
Regional Scale:	Represents (100 to 1000 km)

The scale of the FRM monitoring sites that have population exposure as their objective is Neighborhood or Urban. The definitions of scale primarily serve to identify the site's sensitivity to individual sources. A monitoring site that is routinely impacted by a specific source has a much smaller "scale" than a site that only sees an effect from numerous widespread sources. The FRM sites in New York State are located in places that will likely have high concentrations and large monitoring scales. This ensures that the public is not exposed to higher ambient $PM_{2.5}$ concentrations than the concentrations from the FRM network reported for their area.

The $PM_{2.5}$ monitoring network works well for determining average ambient exposures for most of the State's population. The limitations of the network stem from the inability to monitor in smaller scales such as Middle and Microscale. An example of an urban microscale influence not addressed by the network would be $PM_{2.5}$ emissions from traffic in a street canyon. Certainly if New York residents spent much of their time in this type of confined area, then their exposure to ambient $PM_{2.5}$ would be considerably higher than that indicated by the closest neighborhood or urban scale monitor. Similarly, a person in a rural valley area subject to daily woodsmoke would also be exposed to higher $PM_{2.5}$ concentrations than those measured at the nearest Neighborhood or Urban scale monitor.

The $PM_{2.5}$ ambient monitoring network is also not able to determine the population's overall exposure to $PM_{2.5}$. Personal habits such as smoking and occupations such as mining, farming and construction can lead to much higher exposures to $PM_{2.5}$ than that of the majority of the population. Other factors such as widely varying indoor $PM_{2.5}$ concentrations can lead to uncertainty in overall $PM_{2.5}$ exposures.

$PM_{2.5}$ Monitoring Instrumentation

The filter based FRM samplers used in New York are the Model 2025 sequential samplers made by the Thermo Environmental Company (Franklin, MA). The sampler has been designated by EPA as a reference method instrument for $PM_{2.5}$ particle collection. The designation is: RFPS-0498-118.

Currently there are 19 FRM monitors in operation statewide, as shown in Figure 4.9.

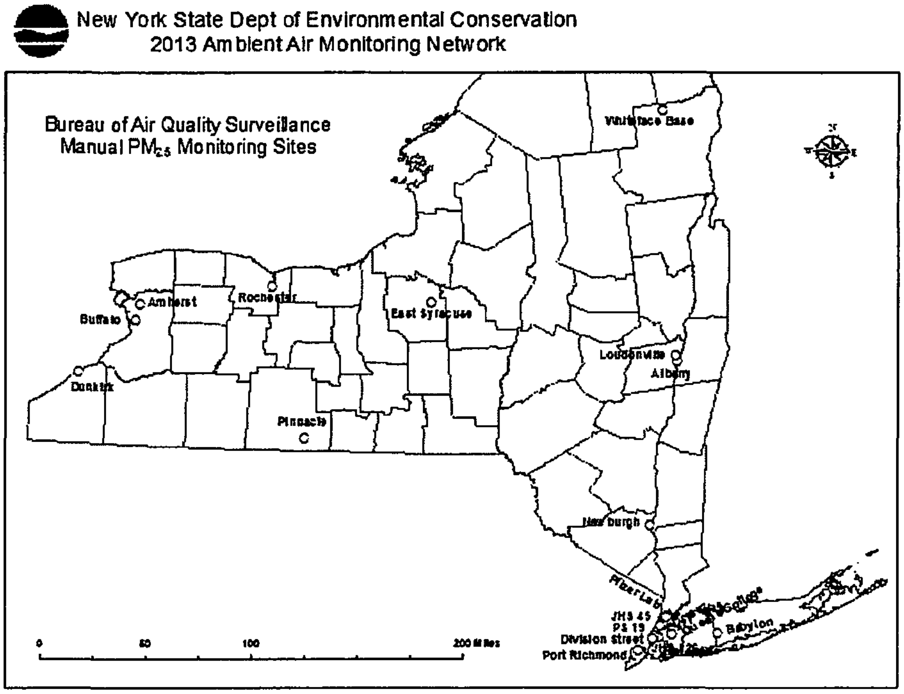


Figure 4.9 Site Location Map of Manual $PM_{2.5}$ (FRM) Monitoring Network

Figure 4.10 below shows the number of manual $PM_{2.5}$ monitoring sites and the composite annual arithmetic means in New York State since the network was implemented in 1998.

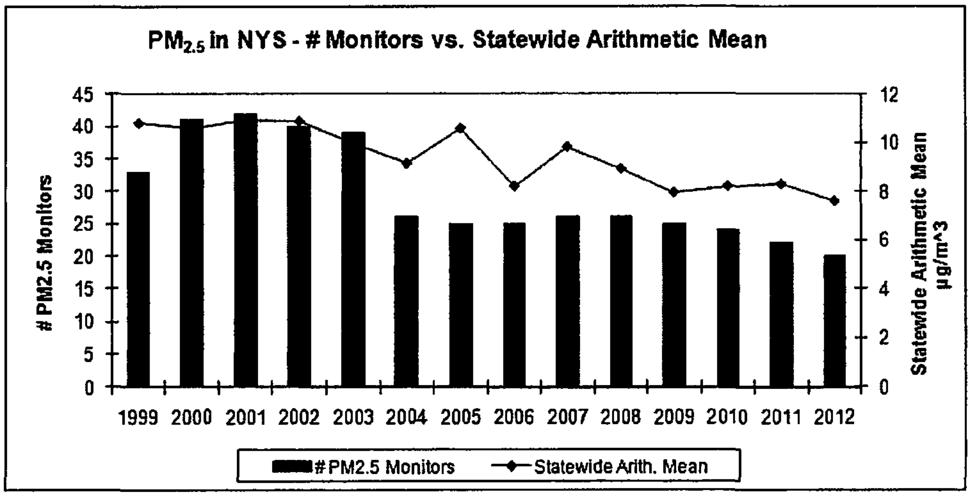


Figure 4.10 $PM_{2.5}$ Monitors and Concentration Trends

The continuous mass monitoring instruments used in New York are the TEOM 1400ab also made by the Thermo Environmental Company. These instruments have received designation by EPA for PM_{10} but not for $PM_{2.5}$. $PM_{2.5}$ is more difficult to measure than PM_{10} with automated samplers because $PM_{2.5}$ contains a higher fraction of volatile components. The heated measurement sensor for the TEOM reduces the amount of volatile mass measured as compared to filter based FRMs. The NYSDEC utilizes non-linear data adjustments to make the

TEOM data more comparable with the FRM data. The adjusted data are used for public reporting and forecasts of $PM_{2.5}$ concentrations.

The NYSDEC uses seven MetOne SuperSass and URG 3000N samplers for the collection of samples for the speciation of $PM_{2.5}$. The samplers collect 3 and 1 filter samples respectively every third day or sixth day for a period of 24 hours. The samples are then sent to an EPA contract laboratory for chemical analysis. There are over fifty species consisting of ions, metals and carbon species quantified by the analyses.

4.4.4 Continuous PM Monitoring

Continuous mass monitoring is performed primarily with a network of TEOM 1400ab instruments. In addition, there are three Thermo Scientific 1405-DF's deployed (IS 52, Queens College, and Pinnacle) to simultaneously measure PM2.5, PM Coarse (PM10 - PM2.5) and PM10 mass concentrations. This element of the $PM_{2.5}$ monitoring network provides the data used for public reporting purposes including; the NYSDEC website, the AIRNow website and for $PM_{2.5}$ forecasting. The data from the TEOMs are polled and reported every hour to insure that the public has access to the most recent air quality information.

The TEOM data are compared to the filter based FRM data on an annual basis. The comparison allows the analysts to create non-linear correction factors that modify the TEOM data to more closely resemble FRM data. This is necessary because FRM data is not available for near real-time public reporting purposes. EPA has recently recognized the value of these data adjustments and has created new method codes so this adjusted data can be submitted to the AQS database. The NYSDEC now submits TEOM data from each site in its original unadjusted format as well as the adjusted data to match more closely with the FRM.

There are 26 continuous $PM_{2.5}$ monitoring sites are depicted in Figure 4.11.

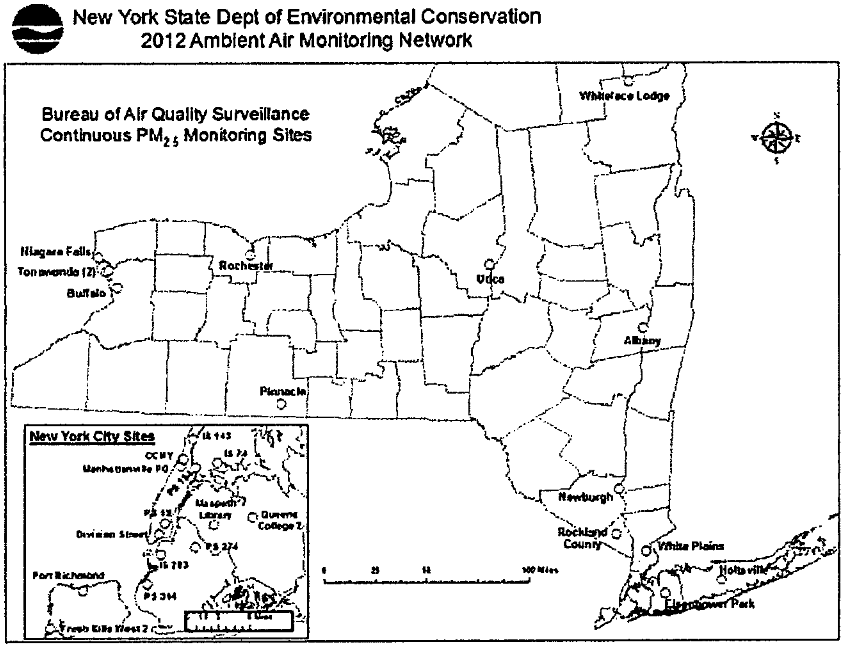


Figure 4.11 Site Location Map of Continuous $PM_{2.5}$ (TEOM) Monitoring Network

The NYSDEC also operates some of the newest continuous mass monitors which have undergone Federal Equivalent Method (FEM) designation. These instruments collect more of the volatile PM mass that the filter based FRM may or may not retain depending on the environmental conditions during and after the period in which the filter sample was collected. The Department has been evaluating the technological improvements that have led to the current PM2.5 continuous FEMs for more than 10 years. The Thermo Scientific 1405-DF FEM performed better than the other instruments in on-site deployments at urban and rural locations in the state. The Department purchased several of these but they have not operated reliably and have not produced data that compares acceptably with the FRM. The equipment manufacturer is aware of the issues and seems to be working towards resolutions of the problems. The Department will continue to rely on the FRM network to provide data for comparison with the ambient PM2.5 air quality standards. Currently there are three 1405-DF's deployed (IS 52, Queens College, and Pinnacle) to simultaneously measure PM2.5, PM Coarse (PM10 - PM2.5) and PM10 mass concentrations. The Department does not intend to use data collected by the FEMs for comparison to the NAAQS.

4.4.5 Speciation

Speciation monitoring is performed with a network of seven MetOne SuperSass samplers. There are eight sites in New York State operating with the Speciation Trends Network (CSN) sampling protocol. Five operate on a 1/3 day schedule and two operate on a 1/6 day schedule. All of these sites host collocated FRM and continuous mass monitoring instruments. A rural and an urban site also host collocated IMPROVE protocol samplers. The data from these sites is used to assist in the comparison between CSN and IMPROVE data sets. The goal of the urban installation will be to further relate the mostly rural IMPROVE network to the mostly urban CSN network.

In order to address inconsistencies in carbon sampling and analysis procedures used in urban CSN/SLAMS and rural IMPROVE programs, EPA determined that the URG sampler would be used at all CSN sites. The conversion was completed 2008 for all of the NY sites.

Figure 4.12 shows the seven CSN sites currently in operation.

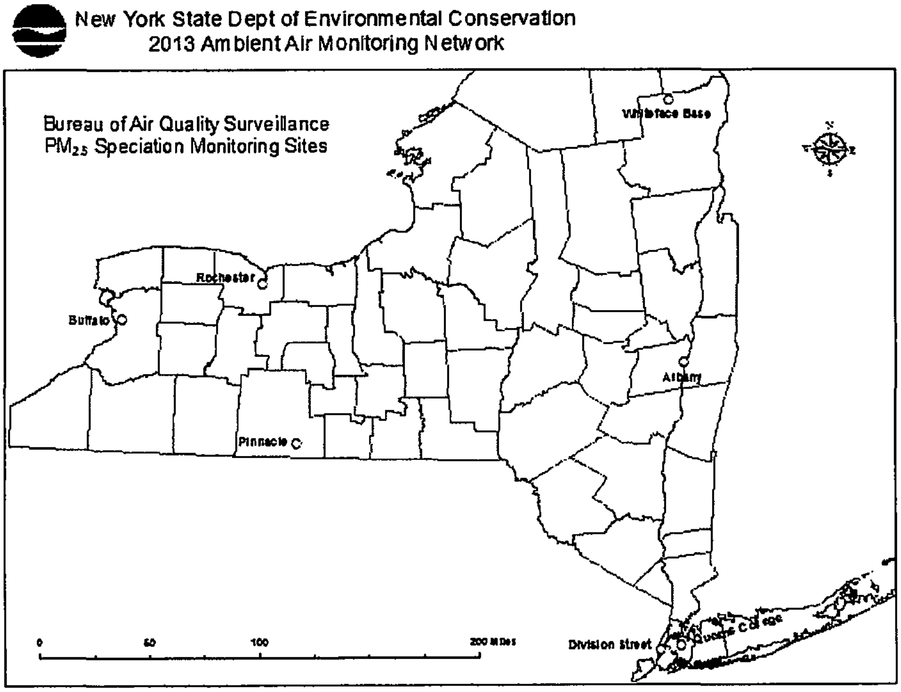


Figure 4.12 Location Map of Speciation Sampling Sites

4.4.6 Continuous Speciation

The NYSDEC recognizes the value of high temporal measurements (hourly or higher) of $PM_{2.5}$ species. This data is useful for the examination of pollutant trends (and temporal patterns) and can provide information necessary for identification of pollutant sources. This is critically important for areas facing non-attainment for the $PM_{2.5}$ NAAQS. Identifying seasonality of species is necessary to develop control strategies. Long term monitoring is vital to this effort because in addition to changes in source emissions, variations in meteorology also affect ambient pollutant concentrations (e.g. wetter than average conditions lead to a washout of pollutants and a lowering of ambient concentrations).

The NYSDEC continuous speciation program is expanding and currently includes monitoring at urban and rural locations. Sulfate, nitrate, organic carbon, elemental carbon and black carbon species data are collected at hourly or higher frequency. In this manner both the regional and inter-urban variability of these species are being investigated. The NYSDEC uses instruments to examine the species of $PM_{2.5}$ on a higher frequency than what is available from the filter based speciation sampling network. This continuous speciation data is useful in the examination of source strengths and the relationship between pollutant concentrations and meteorology. The operation of continuous speciation equipment is also less expensive than long term filter species measurements due to the high costs associated with filter lab analysis. Operation of continuous speciation in conjunction with 24-hr CSN sampling is beneficial in accounting for biases in measurements when a change to the CSN method occurs. This is demonstrated in the case of CSN carbon which was changed to the IMPROVE method in 2007. Long term collocated continuous carbon measurements prior to and following this change are being used to assess the bias between the old and the new carbon methods. This data will be important in determining the long term trends in $PM_{2.5}$ carbon species.

NYSDEC has been using the continuous speciation data in NYC to examine temporal patterns such as diurnal and day of week patterns of aerosol species related to source strengths and meteorology. For example elemental carbon, black carbon and primary pollutant NO_x in NYC track throughout the day with peak concentrations in the morning coincident with the early commute period. Mobile emissions in the early morning occur into a shallow boundary layer which concentrates pollutants near ground level. An elevation in boundary layer height during the day leads to a dispersion of pollutants and a less pronounced afternoon/evening peak. Concentrations of these species are also higher on weekdays compared to weekends indicating that local mobile emissions are a significant source of these species. During winter months organic carbon sometimes shows similar patterns to EC and NO_x reflecting the primary organic component most likely from mobile emissions. Throughout the year however organic carbon does not track the primary pollutants but is more correlated with $PM_{2.5}$ mass (and sulfate during summer months) indicating that there is a significant regional or non-local contribution to organic carbon measured in NYC. Our continuous speciation measurements also reveal temporal patterns in particle nitrate. In cooler months $PM_{2.5}$ nitrate has a broader peak than EC which appears later in the morning, consistent with photochemical and secondary aerosol production. During the warm season nitrate concentrations are significantly lower and the late morning nitrate peak (observed in winter) is not observed in the warm season because as temperatures rise during the day aerosol nitrate reverts back to its precursors (nitric acid and ammonia).

Continuous data can also be used to capture the full extent of regional or local plumes that would normally be missed by the 24-hr filter sampling network. It allows us to study plume events and how meteorology can affect measurements. One can also differentiate between plumes which are short term of a few hours long (e.g. plumes from oil boiler emissions) likely driven by carbon versus those that are more regionally driven by sulfate in summer. High temporal pollutant data is also beneficial for public health effect studies that often require resolving confounding factors.

Recently concerns have been raised regarding potential adverse health effects associated with residential wood burning. Wood smoke contains fine particulate matter which can cause short-term effects such as eye, nose, throat and lung irritation, coughing, sneezing, runny nose and shortness of breath. Exposure to PM2.5 also can affect lung function and worsen medical conditions such as asthma, allergies and heart disease. Long term exposure to fine PM may increase the risk from chronic bronchitis, reduce lung function and increase mortality from lung cancer and heart disease. In addition, wood smoke contains known human carcinogens including benzene, formaldehyde, dioxins and polycyclic aromatic hydrocarbons.

BAQS staff in collaboration with Clarkson University researchers were able to successfully characterize the ambient impact of residential wood combustion using dual wavelength (370 and 880 nm) aethalometer measurements in conjunction with filter measurements of levoglucosan and potassium, markers for wood smoke. The study, which was conducted from October 2009 to October 2010 in Rochester, showed that the wood smoke component of black carbon is most evident from October to March during the late evening hours on cold weekend nights. Residential wood combustion was estimated to contribute 17% to the PM2.5 mass during winter at the Rochester study site.

4.4.7 Additional Monitoring Initiatives

The NYSDEC has been active in additional research and monitoring beyond the mandated Federal requirements. Some of this work has been collaborative with goals ranging from collecting data with the newest technologies, to providing support for health studies to evaluating new monitoring instruments. Other projects undertaken by the NYSDEC such as adding additional monitoring after the World Trade Center attack or monitoring before and after the cap was installed on the Fresh Kills landfill could not have been undertaken by other Agencies.

4.4.7.1 PM2.5 Technology Assessment and Characterization Study-New York Supersite

The largest collaborative monitoring project undertaken by the NYSDEC and State University of New York's Atmospheric Science Research Center (SUNYA-ASRC) was the Supersite program known as PMTACS. The 5 year monitoring initiative leveraged resources from EPA, NYSERDA and the NYS Environmental Bond Act to obtain detailed highly resolved pollutant measurements from NYC, Whiteface Mountain and an upwind rural site south-west of Corning, NY. This monitoring project also involved participants from the NYSDOH, Penn State University, Aerodyne Research Inc. and Clarkson University. The project's website lists many of the program details: http://www.asrc.cestm.albany.edu/pmtacsny/index.html

Some of the instrument method development work initiated under this program has continued after the conclusion of the PMTACS program. This shared effort includes method development work on trace gas monitors, continuous organic carbon monitors, continuous particulate sulfate instruments, continuous particulate nitrate and ammonia instruments. All of these instruments will be needed as NYSDEC designs PM control strategies for non-attainment areas within New York State.

The current research undertaken by this collaboration involves small particle and precursor gas concentration measurements from rural and urban locations in NY State. NYSERDA has provided funds for this work which includes an intensive monitoring campaign over several weeks this summer in New York City. The past summer measurements in conjunction with some on-going measurements are being used to compare with data taken at an urban NYSDEC monitor and those from a mobile van traveling on nearby highways. These studies will help to determine the impacts of mobile sources at fixed neighborhood monitors.

4.4.7.2 Organic Carbon: Molecular Marker Characterization

The NYSDEC collaborated with Rutgers, Drexel, NESCAUM, NJDEP and CTDEP on a project called the Speciation of Organics for Apportionment of $PM_{2.5}$ in the New York City Area (SOAP). The field portion of the project was conducted from May 2002 to May 2003. It operated at four sites: Queens, NYC (high density urban residential); Elizabeth, NJ (adjacent to the NJ Turnpike); Westport, CT (downwind NYC); and a regional background site in Chester, NJ (upwind NYC). The study's chief objectives were to expand the chemical characterization of organic compounds and to estimate the source contributions of carbonaceous fine particles at urban and background monitoring sites.

This project continued at a site in NYC and a rural site in Addison, south-west of Corning, NY during 2005 to 2007. Sampling for this project has been completed. The data from this project will provide information about the significance of sources of organic carbon particulate in both urban and rural areas in New York. This type of information will be used to assess the potential viability of local and wide range $PM_{2.5}$ control strategies.

4.4.7.3 PM Coarse Monitoring

The NYSDEC is taking an active role in advance of an upcoming EPA directive to monitor for PM Coarse (PM_{10} - $PM_{2.5}$). Filter based monitoring was initiated in NYC and in Niagara Falls to determine approximate concentrations of PM Coarse. This information was used to assess PM Coarse elemental concentrations. The NYSDEC has also used this data to comment on the proposed PM Coarse standard and network design that were recently part of the draft CFR Parts 53 and 58. Filter based 1 day in 6 PM Coarse monitoring is also underway at the Rochester and IS52 NATTs sites and at the NCore site in Queens.

The NYSDEC has also supported the development of new automated near real-time PM instruments. The NYSDEC is evaluating the 1405-DF Federal Equivalent Method (FEM) PM Coarse instruments at 3 locations in New York State. Data from the filter based samplers already operating at the site will be used to evaluate the performance of these instruments. The benefit of this work for the NYSDEC is that if successful, the instruments can provide high frequency data that can also be used for comparison to the PM2.5 and PM10 NAAQS.

4.4.8 Air Pollution and Environmental Conditions

4.4.8.1 NYC Micro-scale Street Canyon Monitoring

The NYSDEC responded to a request by EPA to install 2 street level monitors in an urban area in NYC. The areas are known as canyons due to the tall buildings on either side of the street. The PM_{10} data collected at the one remaining site is used to evaluate the differences between data collected at very low elevations, close to high traffic roadways, and the monitors that are properly sited in the rest of the monitoring network.

4.4.8.2 Rochester PM Center Clarkson, Univ. of Rochester Medical Center

The NYSDEC collaborates with researchers from the University of Rochester Medical Center and Clarkson University who have been awarded a second PM health research grant from EPA. Their work focuses on the pathways and effects from PM pollution on the cardiovascular system. The NYSDEC provides data and support for a fine particle classifying instrument at a monitoring location near the University of Rochester.

4.4.8.3 Air Pollution Microscopy

In addition to performing toxics and acid deposition laboratory analyses, BAQS Monitoring Support Section at the Rensselaer facility operates a variety of analytical microscopes for particle analysis. These instruments include: Smiths Detection Inc. IlluminatIR Fourier Transform microscope; JEOL 6490LV Scanning Electron Microscope (SEM) with a Brucker Spirit Energy Dispersive Spectroscopy (EDS) System. Together with optical microscopes, staff can provide data on size, morphology, elemental, chemical, and other physical properties of particulate samples of size down to 1 µm in diameter. The information obtained is valuable for the understanding of source origin and provides important input for apportionment analysis.

Ultra fine particles (<0.1 µm), primarily generated from combustion processes, including stationary fossil-fuel electric power generation, industrial processes, boilers, and gasoline and diesel engines, are an important component of $PM_{2.5}$. Scientists are becoming increasingly more interested in these ultra fine or "Nano" size particles. Recently NYSDEC acquired a VEECO Nanoscope Multimode Atomic Force Microscope (AFM) for the analysis of these extremely small particles. With the addition of this new instrument, we are now able to look at particulate an order of magnitude smaller than what the Scanning Electron Microscope (300,000× mag vs. 3,000,000× mag) can provide. Whereas the SEM specializes in particles in the 2.5 micron range, the Nanoscope is currently analyzing particles in the 25-50 nanometer range. Particle size, surface texture and roughness are now available on such particles as diesel exhaust, wood smoke, and other products of combustion.

Recently NYSDEC acquired the Olympus LEXT Laser Confocal Microscope (LCM). It is designed to obtain images of ultrafine particles at ranges smaller than what can be seen with our Scanning Electron Microscope (SEM) and larger than what we can see with Atomic Force Microscope (AFM). It is the perfect fit between these two pieces of instrumentation and will complement both the AFM and SEM. Each method can "see" in the size range that the other cannot. The LCM works on particles between 500 nm and 200 microns, so it works in between the two.

The intended use of this instrument will provide information:

on the use of alternative fuels such as biodiesel and ethanol, as well as their use with different emission after-treatment strategies. Little to no information is currently available on the effect of such fuels on particle morphology.

to refine our methodologies for acquiring filter samples for microscopic examination and in performing these examinations. Future samples could potentially be taken both from direct mobile source emissions and also from ambient samplers deployed in the monitoring network.

to re-evaluate our earlier ultrafine particle measurements. For example, earlier results suggest the presence of a secondary small particle mode in biodiesel emissions (smaller particles pose greater risks of health effects). Microscopic examination could provide evidence to either support or dismiss this finding.

4.4.8.4 Ultrafine Particulate Monitoring

NYSDEC first began ultrafine particulate monitoring with the deployment of a TSI Model 3031 Ultrafine Particle Monitor (UPM) at Queens College in June of 2009. This instrument provides continuous measurements of size distribution and particle number concentrations of fine particles below1 micron, in the range from to 20 to 500 nanometers. The Queens College NCore site was selected for the UPM so as to complement a suite of parameters already being measured there. Concurrently a demo UPM unit on loan for one year from the manufacturer was installed at the Eisenhower Park location in Nassau County, which is expected to have a significant impact from mobile sources. Preliminary data suggest that the ultrafine particles are to a large extent regional in nature and less impacted by local mobile sources. The particle counts and size distributions for the two sites are similar, and also track the $PM_{2.5}$ profile in some cases. It is possible that the mobile signal is damped out due to the siting of the monitor, as the inlet probe height may not be optimal and there may be interference from nearby trees. In addition, a resource recovery facility located about ¼ mile west of the site, as well as other local sources (wood-fired pizza ovens, etc.) may influence the measurements. Alternate explanations may be that mobile ultrafine emissions are predominantly smaller than the 20 nanometer cut-off point or affect the measurements only on a short time scale. Data on particle size distribution and concentration will provide valuable information for the understanding of $PM_{2.5}$ formation mechanisms, as well as source apportionment determination.

It appears worthwhile to conduct short duration intensive studies in the future that simultaneously employ a suite of particle counting instruments including the Scanning Mobility Particle Sizer (SMPS), Fast Mobility Particle Sizer (FMPS), Condensation Particle Counter (CPC), and our UPM to further evaluate the mobile component. The new NO_x rule requiring the establishment of near-roadway monitors in populated areas starting in 2013 (see NO_2 Section) will afford an opportunity to collocate UPMs to further investigate the mobile contribution to the overall ultrafine concentration. The recent establishment of initial regulations intended to address ultrafine particle emissions from mobile sources (LEV-3 in California, Euro V-VII in the EU) is an early indicator of more extensive regulation of ultrafine particle emissions from mobile sources expected in the future, and suggests the potential emergence of regulations for ambient ultrafine particles as well.

In our Air Pollution Microscopy laboratory, three particle characterization techniques (Laser Scanning Confocal Microscopy, Scanning Electron Microscopy, and Atomic Force Microscopy) are used to investigate the morphology of real world ultrafine particles, such as those from mobile source emissions and other industrial sources. As an example, the changes in ultrafine particle morphology resulting from the use of two strategies for reducing diesel emissions, i.e., exhaust after-treatment and the use of alternative diesel fuels were studied. These activities complement the ambient monitoring data in understanding the formation, distribution and transport of ultrafine particulate.

4.5 Sulfur Dioxide

Sulfur dioxide (SO_2), a colorless, reactive gas, is produced during the burning of sulfur-containing fuels such as coal and oil, during metal smelting, and by other industrial processes. It belongs to a family of gases called sulfur oxides (SO_x). Major sources include power plants, industrial boilers, petroleum refineries, smelters, iron and steel mills. Generally, the highest concentrations of sulfur dioxide are found near large fuel combustion sources.

High concentrations of SO_2 can result in temporary breathing impairment for asthmatic children and adults who are active outdoors. Short-term exposures of asthmatic individuals to elevated SO_2 levels while at moderate exertion may result in reduced lung function that may be accompanied by symptoms such as wheezing, chest tightness, or shortness of breath. Other effects that have been associated with longer-term exposures to high concentrations of SO_2, in conjunction with high levels of PM, include respiratory illness, alterations in the lungs' defenses, and aggravation of existing cardiovascular disease. The subgroups of the population that may be affected under these conditions include individuals with cardiovascular disease or chronic lung disease, as well as children and the elderly.

Additionally, there are a variety of environmental concerns associated with high concentrations of SO_2. Because SO_2, along with NO_x, is a major precursor to acidic deposition (acid rain), it contributes to the acidification of soils, lakes, and streams and the associated adverse impacts on ecosystems. Sulfur dioxide exposure to vegetation can increase foliar injury, decrease plant growth and yield, and decrease the number and variety of plant species in a given community. Sulfur dioxide also is a major precursor to $PM_{2.5}$ (aerosols), which is of significant concern to human health, as well as a main pollutant that impairs visibility. Finally, SO_2 can accelerate the corrosion of natural and man-made materials (e.g., concrete and limestone) that are used in buildings and monuments, as well as paper, iron-containing metals, zinc, and other protective coatings.

Figure 4.13 shows the number of SO_2 monitors and the composite annual means in New York State over the years.

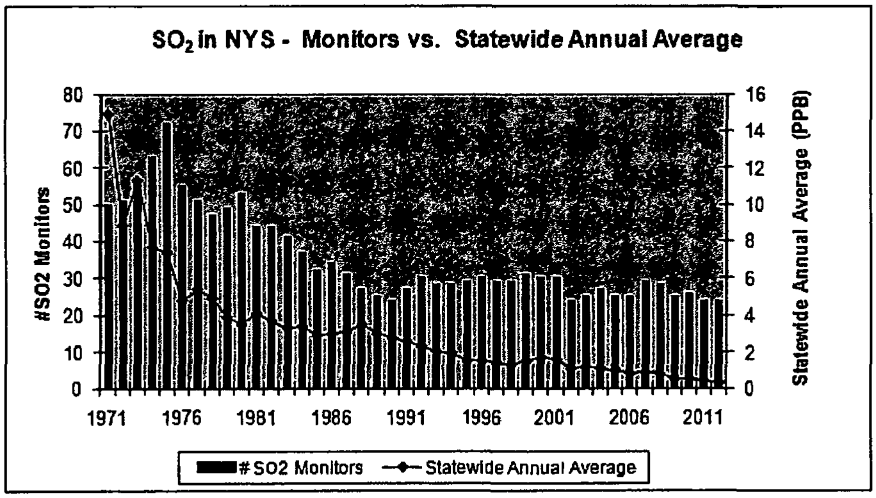


Figure 4.13 Sulfur Dioxide Monitors and Concentration Trends

Based on its most review of the air quality criteria for oxides of sulfur and the primary national ambient air quality standard (NAAQS) for oxides of sulfur as measured by sulfur dioxide (SO_2), EPA replaced the existing 24-hour and annual standards with a new short-term standard based on the 3-year average of the 99th percentile of the yearly distribution of 1-hour daily maximum SO_2 concentrations. EPA set the level of this new standard at 75 ppb, which became effective August 23, 2010. EPA is also establishing requirements for an SO_2 monitoring network. These new provisions require monitors in areas where there is an increased coincidence of population and SO_2 emissions. In order to do this, EPA developed a Population Weighted Emissions Index (PWEI) that uses population and emissions inventory data at the CBSA level to assign required monitoring for a given CBSA (with population and emissions being obvious relevant factors in prioritizing numbers of required monitors). The PWEI for a particular CBSA was proposed to be calculated by multiplying the population (using the latest Census Bureau estimates) of a CBSA by the total amount of SO_2 emissions in that CBSA. The CBSA SO_2 emission value would be in tons per year, and calculated by aggregating the county level emissions for each county in a CBSA. The PWEI values are being developed using the 2010 Census numbers. The final network design requires that any SO_2 monitors required in a particular CBSA as determined based on PWEI values shall satisfy the minimum monitoring requirements if they are sited at locations where they can meet any one or more of the monitoring objectives: Source-Oriented Monitoring, Highest Concentration, Population

Exposure, General Background, and Regional Transport. EPA is expected to provide additional guidance for the implementation of this rule.

There are 19 SO_2 monitors in operation currently, as shown in Figure 4.14. TEI Model 43C instruments using the pulsed fluorescence method are deployed in the network.

The EPA considered setting a secondary standard for NO_x and SO_x that would specifically target the impact of acidic deposition on wilderness areas. The EPA ultimately decided that there was not enough information at this time to tie specific water quality thresholds with ambient air concentrations. In the July 2011 final rule for NO_x and SO_x, the EPA stated that they would set up a monitoring program in sensitive areas to collect information to link water quality impacts to ambient air quality measurements. The NYSDEC is participating in this pilot monitoring program in the Adirondacks. Additional monitoring equipment has been installed at several sites to determine the concentrations of gasses and particles including ammonia. These data will be used in the future to inform the next review of the NO_x/SO_x standard.

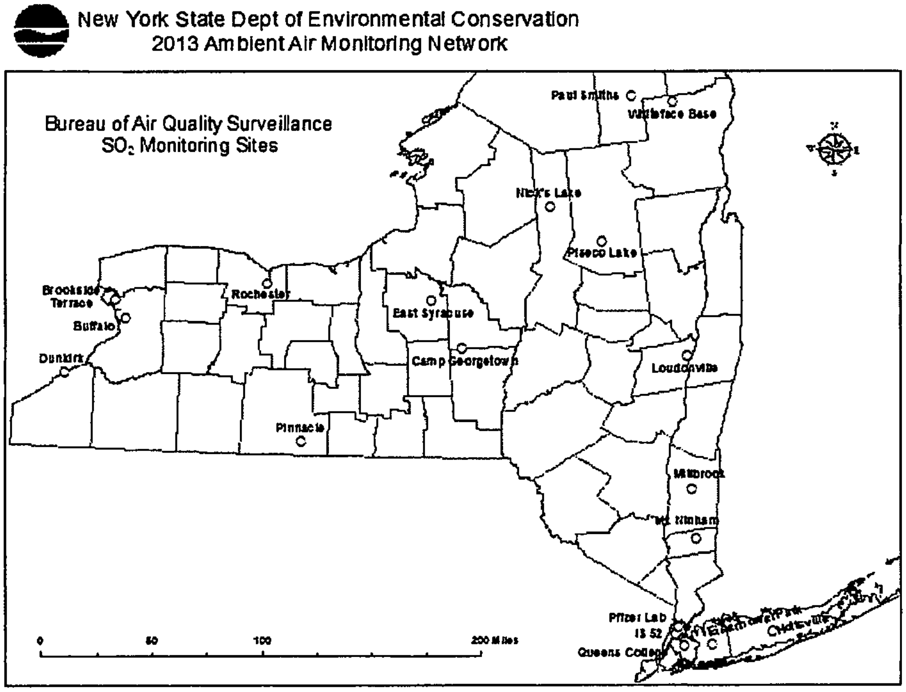


Figure 4.14 Location Map for Sulfur Dioxide Monitoring Sites

4.6 Ozone

Ozone is a molecule made up of three oxygen atoms (O_3), a very reactive gas, and even at low concentrations it is irritating and toxic. It occurs naturally in small amounts in the earth's upper atmosphere, and in the air of the lower atmosphere after a lightning storm. In the stratosphere, between 10km and 50km above the earth's surface it forms the Ozone Layer. This is an important protective layer which filters out most of the high energy ultra-violet radiation from the sun which would damage much of the life on earth. When ozone is present at ground level and in the troposphere (10-18 km above earth's surface) it is considered a pollutant and a greenhouse gas. Ozone is used both industrially and commercially due mainly to its reactivity. It is used as a clean way of purifying water both in industry and in the home in hot-tubs and fish tanks. It is also used to disinfect laundry both in hospitals and in the home.

Ground-level O_3 remains a pervasive pollution problem in the United States. Ozone is readily formed in the atmosphere by the reaction of volatile organic compounds (VOCs) and NO_x in the presence of heat and sunlight, which are most abundant in the summer. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, other industries, and natural (biogenic) sources. Nitrogen oxides (a precursor to ozone) are emitted from motor vehicles, power plants, and other sources of combustion, as well as natural sources including lightning and biological processes in soil. Changing weather patterns contribute to yearly differences in O_3 concentrations. Ozone and the precursor pollutants that cause O_3 also can be transported into an area from pollution sources located hundreds of miles upwind.

Ozone occurs naturally in the stratosphere and provides a protective layer high above the earth. However, at ground level, it is the prime ingredient of smog. Short-term (1- to 3-hour) and prolonged (6- to 8-hour) exposures to ambient O_3 concentrations have been linked to a number of health effects of concern. For example, increased hospital admissions and emergency room visits for respiratory causes have been associated with ambient O_3 exposures.

Exposures to O_3 result in lung inflammation, aggravate preexisting respiratory diseases such as asthma, and may make people more susceptible to respiratory infection. Other health effects attributed to short-term and prolonged exposures to O_3, generally while individuals are engaged in moderate or heavy exertion, include significant decreases in lung function and increased respiratory symptoms such as chest pain and cough. Children active outdoors during the summer when O_3 levels are at their highest are most at risk of experiencing such effects. Other at-risk groups include adults who are active outdoors, such as outdoor workers, and individuals with preexisting respiratory disorders such as asthma and chronic obstructive lung disease. Within each of these groups are individuals who are unusually sensitive to O_3. In addition, repeated long-term exposure to O_3 presents the possibility of irreversible changes in the lungs, which could lead to premature aging of the lungs and/or chronic respiratory illnesses.

Ozone also affects sensitive vegetation and ecosystems. Specifically, O_3 can lead to reductions in agricultural and commercial forest yields, reduced survivability of sensitive tree seedlings, and increased plant susceptibility to disease, pests, and other environmental stresses such as harsh weather. In long-lived species, these effects may become evident only after several years or even decades. As these species are out-competed by others, long-term effects on forest ecosystems and habitat quality for wildlife and endangered species become evident. Furthermore, O_3 injury to the foliage of trees and other plants can decrease the aesthetic value of ornamental species as well as the natural beauty of our national parks and recreation areas.

EPA initially established primary and secondary NAAQS for photochemical oxidants on April 30, 1971. Both primary and secondary standards were set at an hourly average of 0.08 parts per million (ppm), total photochemical oxidants, not to be exceeded more than one hour per year.

On February 8, 1979, EPA completed its first periodic review of the criteria and standards for O_3 and other photochemical oxidants and made significant revisions to the original standard: the level of the primary and secondary NAAQS was changed to 0.12 ppm; the indicator was changed to O_3; and the form of the standards was changed to be based on the expected number of days per calendar year with a maximum hourly average concentration above 0.12 ppm (i.e., attainment of the standard occurs when that number is equal to or less than one).

In July, 1997 EPA revised the primary and secondary O_3 standards on the basis of the then latest scientific evidence linking exposures to ambient O_3 to adverse health and welfare effects at levels allowed by the 1-hr average standards. The O_3 standards were revised by replacing *the existing primary 1-hr average standard with an 8-hr average* O_3 *standard set at a level of* 0.08 ppm. The form of the primary standard was changed to the annual fourth-highest daily maximum 8-hr average concentration, averaged over three years. The secondary O_3 standard was changed by making it identical in all respects to the revised primary standard. These standards were challenged in the courts and the litigation lasted until March, 2002 when the D.C. Circuit Court issued its final decision, finding the 1997 O_3 NAAQS to be "neither arbitrary nor capricious," and denying the remaining petitions for review. As of June 15, 2005 EPA revoked the 1-hour ozone standard in all areas except the fourteen 8-hour ozone nonattainment Early Action Compact (EAC) Areas (none in NY).

After the most recent review of the ozone NAAQS, EPA revised the 8 hr ozone standard (primary and secondary) to 0.075 ppm, which went into effect on May 27, 2008, at which time the 1-hr standard was revoked.

The number of ozone monitors and concentration trends for both the 1 hr, and 8 hr standards in New York State for the past three decades are shown in Figures 4.15 and 4.16, respectively.

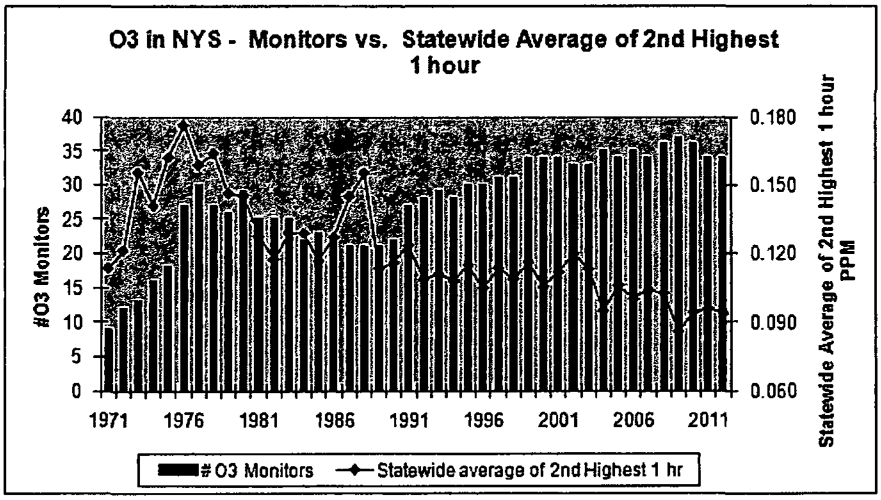


Figure 4.15 Ozone Monitors and 1 hr Concentration Trends

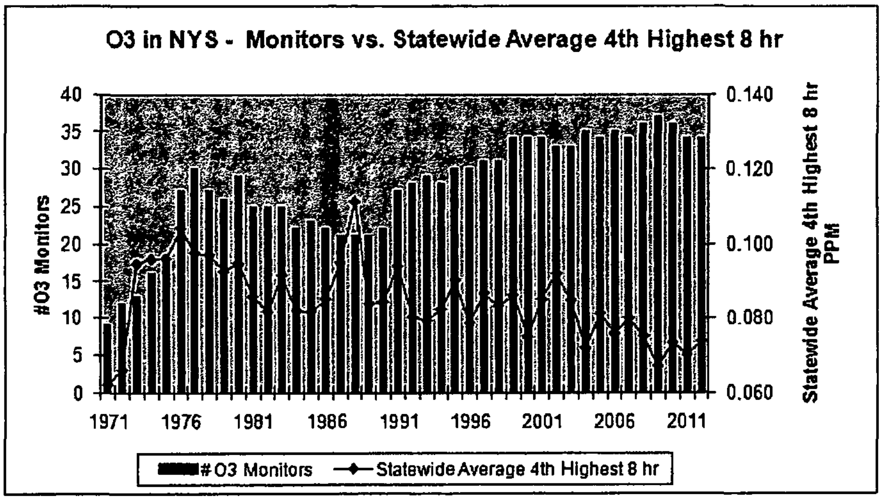


Figure 4.16 Ozone Monitors and 8 hr Concentration Trends

At present NYSDEC operates 29 TEI Model 49C ozone monitors statewide, which use the UV photometric method for detection. The site locations are depicted in Figure 4.17 below.

New York State Dept of Environmental Conservation
2013 Ambient Air Monitoring Network

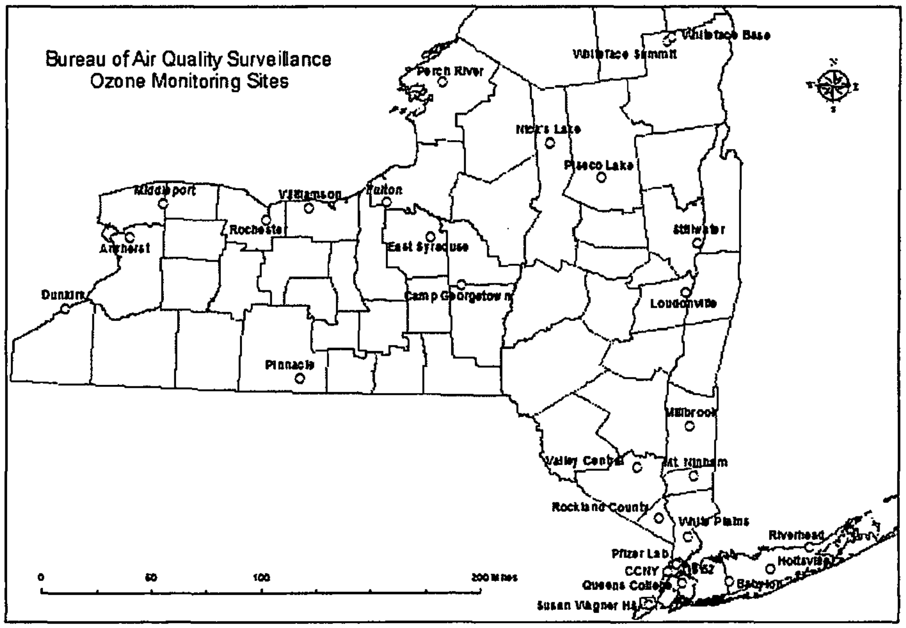


Figure 4.17 Location Map for Ozone Monitoring Sites

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COOLING TECHNOLOGY INSTITUTE

BEST PRACTICES FOR MINIMIZING DRIFT LOSS IN A COOLING TOWER

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Best Practices for Minimizing Drift Loss In a Cooling Tower

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Abstract:

There are many factors associated with the drift loss potential of a cooling tower. With the greater restrictions on drift emissions that are now required in many locales, it is important to know all of these factors to make sure that the drift loss of a tower is minimized. This paper will explore the various factors involved for both counterflow and crossflow cooling towers.

Introduction

In order to study the best practices for minimizing drift loss in a cooling tower it is important to understand exactly what "drift" is and the major factor in its containment, the drift eliminator. From the Cooling Technology Institute's (CTI) glossary of cooling tower definitions, drift is, "[W]ater lost from a cooling tower as liquid droplets entrained in the exhaust air. It is independent of water lost by evaporation. Units may be in lbs./hr. or percentage of circulating water flow. Drift eliminators control this loss from the tower."

Another way to define drift is: Drift is the spectrum of water droplets created by the aerodynamic forces acting on droplets and films within the cooling tower and discharged into the environment. Drift also contains the same chemicals and solids present in the circulating water. It is also important to note that drift is not the condensing water vapor normally emitted from cooling towers, since this is pure water. This visible condensed water vapor is known as the plume. (See Figures 1 & 2.)

There are various types of drift eliminators on the market today. The underlying mechanism of the method of drift removal for drift eliminators used in cooling towers is inertial impaction. Drift eliminators force the air and the entrained water droplets to make several directional changes as the moisture laden air passes through the drift eliminator. The system is a two-phase flow – gas and liquid. The liquid has more mass than the gas and thus has greater inertia and resistance to change in motion. Because of the water droplet's greater mass they deviate from the air streamlines and impact and collect against the surfaces of the drift eliminator. The collected drift water then drains back into the wet section of the cooling tower as its mass accumulates.

There are two main types of drift eliminators offered today, blade type eliminators and cellular type eliminators. (See Figures 3 & 4.) Blade type eliminators consist of waveform shaped blades that are commonly assembled into modules via means of spacers and/or caps. As the initial kind of drift eliminator, blade type eliminators initially offered drift removal efficiencies of 0.01-0.08% Water Flow (WF) for the early designs, and newer designs improved their removal efficiencies to 0.002-0.008% WF or better. The first cellular type drift eliminators were designed after blade type eliminators, and offered further improvements in drift removal efficiencies. Current state of the art eliminators can offer drift removal efficiencies from 0.002-0.0005% WF. Cellular type eliminators also offer benefits in field installation since they are more readily able to be trimmed or notched around penetrations to the drift eliminator plane. Another important factor in the development of drift eliminators is the use of a nesting design (Figure 5) in which adjacent eliminators with matching concave and convex edges are able to fit together and prevent drift droplets from bypassing the joint between the two eliminators.

Drift eliminators designed for use in cooling towers are optimized to work effectively within the general air velocity ranges of cooling towers, 2.0-3.6m/s (400-700FPM), and every eliminator has its own efficiency profile based on its unique design. Based on the inertial impaction theory of operation, at low velocities both the air and the drift droplets are able to pass through the eliminator due to the low inertial values of each. As the air velocity increases, the changes in direction have more impact on the drift droplets and they begin to collect on the eliminator surfaces. At the upper ranges of air velocities the air is able to re-entrain the accumulated drift water and strip it out of the eliminator, a phenomenon known as "breakthrough." (See Figure 6.)

Reasons to Eliminate Drift

Historically drift emissions of cooling towers have decreased as drift eliminator designs were refined due to continually evolving forces pushing for reduced drift rates. Towers manufactured in the 1970's typically had stated drift rates of 0.01% WF, while towers a decade later in the 1980's cut that in half to 0.005% WF. The turn of the century in 2000 yielded towers typically rated for 0.001% WF, and an ever increasing push today is for drift rates of 0.0005% WF.

There are several forces pushing the refinement of drift eliminator design and reductions in drift emission rates. One force is the nature of the drift that is emitted and its effect on that with which it comes into contact. As stated in its definition drift contains all of the chemicals and solids contained within the circulating water of the cooling tower. This includes dissolved solids such as salts and other chemicals from the process water, and it also includes any water treatment chemicals used to keep the cooling tower system functioning properly. Drift droplets are also large enough at 20-2000 microns to contain bacteria which may lead to illnesses, such as Legionnaire's Disease. Since drift droplets contain salts and other chemicals they can have a detrimental effect on surrounding flora and fauna. Drift droplets can also be highly corrosive to surrounding equipment and environs. Drift emissions from cooling towers have been known to spot and mar the paint finish of cars in nearby parking lots. They can also cause costly damage to surrounding equipment and buildings when the corrosive effects damage buildings and surrounding equipment.

Drift droplets can also cause early wear and erosion of fan blades since the droplets hammer at the leading edges of fan blades. Taken to its extreme the result could be a severe reduction in the efficiency of a fan's capability to move air and a serious concern for structural failure as shown in Figure 7.

Another factor pushing the reduction of drift emissions in the United States is the fact that the United States' Environmental Protection Agency (EPA) considers drift to be a regulated emission from a cooling tower, and the EPA is tightening regulations for PM-10 and PM-2.5 emissions. The EPA's PM-10 Standard covers particles 10 microns and smaller that, "are likely responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract." Particulate matter that is 10 microns and smaller in size is small enough to penetrate the lower regions of the respiratory tract but may not be able to be exhaled out. Under the Clean Air Act the EPA has a mandate to continue to refine and set new air quality standards, and the new standards for PM-2.5 emissions are being given to the various states for enforcement via the appropriate individual state environmental regulatory agencies.

General Tower Design Considerations

Adequate Plenum

-Induced Draft Counterflow Towers

In induced draft towers the plenum is the area of the tower between the drift eliminators and the fan. The plenum serves as an air transition and equalization chamber in which the air that moved through the fill and drift eliminators is compressed and is forced through the fan out into the surrounding atmosphere. Due to this transition if there is too little room between the drift eliminators and the fan, then the air velocity profile through the drift eliminators may vary widely yielding regions of velocities that exceed the design limits of the drift eliminator. This could yield two negative consequences: 1) the velocity in certain areas may exceed the breakthrough velocity of the eliminator in which case the expected drift rate would be void and 2) higher velocities generally increase the pressure drop across the eliminator which will decrease the thermal performance of the tower.

In a counterflow tower an historically accurate rule of thumb, as presented at the 1999 CTI Annual Conference Educational Seminar, for determining an adequate plenum is to have a percentage of fan coverage of at least 80%, where the percentage of fan coverage is defined as the circle projected onto the drift eliminator plane from a cone defined from a 45° angle from the fan cylinder opening. (See Figure 8 and Reference 4.)

A general velocity profile across the drift eliminator plane in a tower with an adequate plenum is shown in Figure 9. An adequate plenum allows a greater percentage of the drift eliminator plane to reflect the calculated average air velocity (Fan_{CFM}/A_{CELL}). An inadequate plenum forces the majority of the airflow to occur right under the fan cylinder and the resulting air velocities in that limited area can exceed the limits of the drift eliminator's optimum performance envelope.

-Induced Draft Crossflow Towers

Computational Fluid Dynamics (CFD) analysis of a variety of factory assembled induced draft crossflow towers shows that the plenum dimensions affect the velocity profile across the drift eliminator plane similar to the effect seen in counterflow towers. Figure 10 shows the basic set-up of a crossflow tower and the overall velocity vectors through the tower. Due to the different geometry involved in a crossflow tower with the drift eliminator sections extending in the vertical plane and the fan residing in a horizontal plane, in a double-flow crossflow tower the plenum dimensions can be represented by a ratio of the drift eliminator section height, referred to as "plenum height," divided by the horizontal distance between the opposing banks of drift eliminators at the mid-height of the drift eliminators, referred to as the "plenum width." This ratio will define a factor called the Plenum Ratio, (PR).

$$PR = H_P / W_P$$

H_P = Vertical Height of Plenum (at drift eliminators)
W_P = Width of Plenum (at mid-height of drift eliminators)

Based on the CFD analysis there is a relationship between the Plenum Ratio and the resulting ratio of the peak air velocity through the drift eliminators compared to the average air velocity through the drift eliminators, hence known as Velocity Ratio (VR).

$$VR = V_{PEAK} / V_{AVG}$$

V_{PEAK} = Peak air velocity through drift eliminators
V_{AVG} = Average velocity through drift eliminators

This relationship is shown in Figure 11. What makes this relationship important is that with a known average velocity and the plenum ratio defined by the tower geometry you can estimate what the peak velocity will be and then compare that to the breakthrough velocity of the drift eliminator in order to evaluate potential drift issues.

Another interesting facet of the CFD analysis is the visualizations that are possible of the air velocity profiles through the drift eliminator plane. Figures 12-16 show two different ways to view the information. Figures 12 and 13 show a three dimensional representation of two different towers. Figure 14 shows a general physical representation of the data contained in Figures 15 and 16 which show a grid format where the magnitudes of the velocities at discrete locations are highlighted by color coding. What is significant in the grid view is that the locations of velocities higher than 5m/s (1000FPM) are easily observed. The 5m/s (1000FPM) threshold is important because drift testing of an integral drift eliminator shows that the breakthrough velocity is slightly above that. Therefore 5m/s (1000FPM) is considered to be a conservative estimate of a velocity limitation for integral drift eliminators. As you can see between Figures 15 and 16, Figure 16 represents a tower with a much larger section of high velocities over the 5m/s (1000FPM) threshold. As such the tower represented by Figure 16 would have greater drift emissions than the tower represented by Figure 15 if only integral drift eliminators are used. The remedy is to change the drift eliminator to either a separate dedicated drift eliminator, which has better drift removal capabilities and better drainage, or a combination of both an integral drift eliminator and a separate dedicated drift eliminator for towers with the highest peak velocities and highest percentage of grid points over the 5m/s (1000FPM) threshold.

Drift eliminator support considerations

-Induced Draft Counterflow Towers

The placement and support of the drift eliminators also has an effect on the performance of the drift eliminators. In a counterflow tower there are two commonly used methods to support the drift eliminators. One method is to use the water distribution laterals as the drift eliminator supports. Another method is to provide an independent support system located above the water distribution headers and laterals designed specifically for the drift eliminators.

If the aim is to minimize drift loss from the tower, the preferred method is to follow the second method with the separate independent DE supports. The benefits for this method are realized by the increased distance the drift eliminators have from the spray nozzles. As separation from the nozzles increases, the likelihood of droplets from the nozzle being sprayed directly onto the drift eliminator decreases. If spray from the nozzles directly impacts the drift eliminators it is possible that the water may flood the eliminator and not allow it to function as designed yielding blocked airflow through the eliminator and/or water actually being sprayed through the eliminator. It is important to note that if an existing tower has the drift eliminators supported by the water distribution system, changing the drift supports to an independent system above the header and laterals will reduce the plenum at which point the Adequate Plenum factors above must be reviewed.

Case Study

Tower Type:	Induced Draft Counterflow tower
Original DE Supports Config.:	Water distribution system
Desired new DE Support Config:	Independent support system located 2.1m (7ft) above the top elevation of fill to allow workspace for maintenance crews

Cell Length	7.3m (24ft)	Cell Width	9.1m (30ft)
Fan Diameter	4.9m (16ft)	"Adequate Plenum"	1.7m (5.5ft)
Orig. Plenum Ht.:	1.7m (5.5ft)	Rev. Plenum Ht.:	0.7m (2ft)
Orig. Tower Capability:	100.0% *	Rev. Tower Capability:	93.6% *
Orig. Avg. DE Velocity:	2.95m/s (581 FPM)	Rev. Avg. DE Velocity:	5.07m/s (998FPM)

*Tower Capabilities based on the following standard nominal HVAC operating conditions:
35°C Hot Water – 29.4°C Cold Water @ 25.6° Wet bulb
(95°F Hot Water - 85°F Cold Water @ 78°F Wet bulb)

In this Case Study, the end user had a tower with poor water quality issues that needed weekly maintenance on the water distribution system and fill sections. Maintenance crews had to remove or shift around all of the drift eliminators every time that nozzles and laterals needed cleaned out. The crews would also pull up large pieces of scale and debris from the top fill section during this maintenance. With only a 0.9m (3ft) space between the fill and the drift eliminators the crews had to remove drift eliminators in order to be able to complete the weekly maintenance. In order to reduce the handling and wear on the drift eliminators and to allow for ease of movement for the crews, the end user sought to increase the distance from the top fill layer to the drift eliminators from 0.9m (3ft) to 2.1m (7ft). As shown in this Case Study, the unintended consequence of this change was a drastic reduction in the plenum which resulted in a

6.4% reduction in tower capacity and a drift problem due to resulting high velocities through the drift eliminators. With a calculated average air velocity of 5.07m/s (998 FPM) and the drift eliminators now being only 0.7m (2ft) from the fan inlet, the drift eliminators are now in the wake zone of the fan inlet and as such velocities are highly variable and the airflow is very turbulent. Various sections of the eliminators located under the annulus defined by the fan blade path experience velocities that exceed the breakthrough velocity of the drift eliminator with the water being stripped right out of the drift eliminators and out through the fan.

As illustrated in Case Study 1 due to the need to perform maintenance on the mechanical components of a cooling tower, many of which are only accessible from the plenum section of the tower, many tower operators make it a common practice to walk on the drift eliminators. This is against the recommendation of most drift eliminator manufacturers due to safety and performance concerns. Regarding safety concerns, drift eliminators are not designed to be a structural walking surface in a cooling tower, and the common air travel depths of approximately 133-152mm (5.25-6in) limit the loading and span capability of the part. Walking directly on a drift eliminator will also tend to bend the edges of the eliminator where a shoe or boot comes into contact with the drift eliminator. This deformation of the eliminator edge will change its performance altering the pressure drop and drift removal capability. Since maintenance of the mechanical components is required for the proper upkeep and performance of a cooling tower, it is highly suggested that towers be designed and built with actual dedicated walking surface structures for the purpose of performing said maintenance. If it is unavoidable to walk on the drift eliminators, at the very least, a layer of scaffolding planks long enough to extend beyond the drift eliminator supports be placed on top of the drift eliminators to protect the upper surface of the drift eliminator from foot traffic and to distribute the person's weight. Extreme care also must be taken by the maintenance personnel to step at the locations of the drift eliminator supports and not mid-span of the drift eliminators where they are weakest.

-Induced Draft Crossflow Towers

For towers with separate dedicated drift eliminators, most induced draft crossflow towers use some type of shelf or tray as the support for the drift eliminators. What is important to consider here is that the supports must be able to drain any collected water back into the "wet" section of the cooling tower. Since the drift eliminator shelves/trays act as a collection point for draining water, the DE supports should have drainage slots or holes to allow the water to move back into the wet/fill section of the tower.

For large industrial field erected towers it is also important that the drift eliminators be supported in multiple shorter height sections so that the water is able to drain from each section and not overload the drift eliminator. In general this is to mean that the drift eliminator panel heights match the tower structure heights. Thus for an 11m (36ft) tall tower with vertical bay spacing of 1.8m (6ft) it is better to have 6-1.8m (6ft) drift sections than 3-3.7m (12ft) sections. In this manner there is a reduced chance of the drift eliminator supports filling with water and allowing carryover through the drift eliminators.

In induced draft crossflow towers that utilize a splash fill it is important that the drift eliminators be installed far enough from the splash fill in order to prevent water from directly impinging on the drift eliminators. One guideline or rule of thumb to help prevent this is to make sure that the drift eliminators in the top bay (nearest the fan deck) be at least 305mm (12in) from the splash fill. An important consideration regarding this point is that a tower that changes from a splash fill orientation that was perpendicular to the airflow to an orientation parallel to the airflow will "breathe" better. This is generally a positive aspect from a thermal performance viewpoint since greater airflow yields more cooling, but from a drift elimination aspect it could have a detrimental effect. If the airflow is increased greatly, then the water flow through the fill section will be shifted more toward the drift eliminators. This shift could violate the distance from splash fill to drift eliminators guideline above, and the increased air velocities may exceed the design velocities of the drift eliminators.

Induced draft crossflow towers that use Integral Drift eliminators ("ID") should be supported per the fill manufacturer's recommendations. Towers that have multiple lifts of fill with ID should have seals and water diverters installed at each lift interface to ensure that the water draining from the integral drift eliminators of the upper lift is directed toward the center of the fill pack section of the lower lift. The goal is always to have proper water management with respect to the airflow and drift eliminator location.

Installation Details to "Finish the job"

Sealing the Drift Eliminator Plane

One of the most basic factors to consider when looking at a drift eliminator installation and getting the expected drift removal performance from the cooling tower is that all of the air and its entrained drift must be forced to transit through the drift eliminators. Since the air will always seek the path of least resistance, gaps between adjacent drift eliminator modules, drift eliminator modules and penetrating tower structures (support columns, cross-braces, transverse girts, etc.), drift eliminator modules and partition or end walls or tower casing must be avoided to maximize drift removal. One of the largest factors in minimizing drift is the quality of workmanship of the installer. Drift eliminator panels must be installed tightly side-to-side and end-to-end (if applicable). Drift eliminators need to be trimmed to within 1.6mm (1/16th in.) of any obstruction or penetration. At a minimum seals around any obstruction or penetration should also be placed on the "wet side" of the drift eliminators to prevent drift laden air from entering any gaps, and they can also be placed on the "dry side" of the drift eliminators to ensure complete blockage of any gaps. (See Figure 17.) The interface between the drift eliminators and any walls must also be sealed on the "wet side" of the drift eliminators to prevent bypass. Closed cell expanding foam may also be used to close any gaps not covered by other sealers.

Another important installation consideration for crossflow towers are seals and diverters at the water distribution level and the cold water basin. If not properly sealed, air can bypass the fill section and go above or below the fill taking with it some of the circulating water. Thus air seals should be placed at the air entering and air exiting side of the hot water basin to prevent this bypass. Seals that extend below the cold water basin operating waterline should also be installed. Water diverters should be placed on the underside of the hot water basin to prevent spray from the nozzles from directly impacting on either integral drift eliminators or separate dedicated drift eliminators. Water diverters should also be used at vertical fill section transitions to make sure the water is kept within the fill section which helps improve tower performance.

Drift Eliminator Directional Orientation

Many of the latest generation drift eliminators have specific directional installation orientations, and it is important to make sure the eliminators are installed correctly. In counterflow towers the highest efficiency eliminators on the market have drainage tips that allow the eliminator to drain the collected water better and help to reduce pressure drop through the drift eliminator. These drainage tips should be installed "down" in order for them to work appropriately. (See Figure 18.) In crossflow towers, many eliminators have a directional discharge helping to direct the exhaust air upward. (See Figure 19.) When combined with the usual angled installation of the drift eliminator plane into the airflow, commonly approximately 10deg from the vertical, this also yields a gravity-assisted drainage path for the collected water. If these eliminators are installed upside down, then any water collected in the drift eliminator will be forced out into the plenum via gravity, which is the exact opposite of the intended purpose of the drift eliminator.

Tower Operation Considerations

Drift elimination performance is also affected by different tower operation factors, especially those that influence the formation or size of droplets. One example of this is the water treatment program. Water treatment programs that include biodispersants, scale inhibitors, and some non-oxidizing biocides are surface-active (surfactant) and cause a reduction in the surface tension of the water. As surface tension decreases droplet sizes also decrease. Since drift eliminators are designed to be effective on typical drift droplets that measure 20-2000μ, a tower being treated with surfactants will have a greater quantity of smaller droplets that are able to pass unimpeded through a drift eliminator. It is for this reason that the latest revision of CTI Drift Test Code ATC-140 limits the surface tension of the circulating water to a minimum of 63 dynes/cm. For comparison pure water at a temperature of 48.9°C (120°F) has a surface tension of 68 dynes/cm. If the goal of a drift test is to measure the absolute lowest drift emissions from a tower, all surface-active treatments should be discontinued at least 72 hours prior to and during the testing period to ensure that the surfactant effects are minimized or removed. Please note that there could be other factors such as regulatory requirements or evaluative reasons for running a drift test that inhibit or preclude discontinuing surfactant use.

Another tower operation factor for pressurized water distribution systems is the water pressure. Higher pressure systems will yield smaller droplets, and as in the surface tension impact mentioned above, if the spray system is able to provide a fine enough mist due to high pressure levels, then the smaller droplets may be able to transit the drift eliminators. It is important to remember that specific nozzles are designed for specific operating pressures and changing the system pressure from its design point might yield unforeseen consequences.

Drift eliminators, the same as polymer fill products, must be conditioned during a "break in period" in order to achieve expected performance. Polymer materials have relatively low "surface energy" which causes water droplets to "bead up" instead of wetting out. The break in period provides an opportunity for a very thin layer of mineral scale to form, and this acts as a physical aid that allows the water film to become fully established. Therefore, just like new fill in a cooling tower that is going to be tested for thermal performance, it is important to let a tower operate under normal conditions for approximately 4-6 weeks before performing any drift tests in order to achieve expected performance from the drift eliminators.

Specifying Drift Eliminators

Since drift eliminators are the items used to control drift emissions from a cooling tower it is important to specify the proper eliminator. A proper drift eliminator specification will detail:

- Expected drift rate
- Material thickness and span requirements
- Material choice: If the material is a thermoplastic, specify that the material meets CTI STD-136, "Thermoplastic Materials Used for Film Fill, Splash Fill, Louvers and Drift Eliminators."
- Operating temperature
- Chemical composition of the bulk water
- Any other factors that might affect the drift eliminators.

Conclusions

As drift emissions become a greater concern to cooling tower owners and operators and to regulatory organizations, the practices associated with drift elimination will continue to rise in importance. These practices involve everything from tower design and drift eliminator design to installation and actual tower operations. Each aspect must be carefully planned and implemented in order to achieve the best drift removal possible. New tower designs need to incorporate adequate plenums to ensure that the drift eliminators experience airflow profiles across the entire drift eliminator plane that do not exceed the breakthrough velocities of the drift eliminators. Modifications to existing towers need to take into account the ramifications of changes to the original design of a tower and how they might affect drift performance. Water and airflow management concerns need to be addressed so that the circulating water is maintained within the fill section of the tower including water diverters and air/water seals at structural elements of the tower. The cooling tower operator must be vigilant about how he operates the tower and what water treatment protocols are followed. And after all of that is addressed, actual installation must be done by work crews that pay attention to detail, since all of the preceding work can be negated by a sloppy or poor installation. As one seasoned cooling tower industry individual explained once, "A piece of plywood makes a pretty darned good drift eliminator." However even the best piece of plywood, like the most efficient drift eliminator, will not prevent drift emissions if there are gaps surrounding it allowing the air to bypass it and escape the tower.

It is important to note that all guidelines and rules of thumb presented in this paper are suggested measures that, if followed, will help to minimize the drift loss from a tower. Specific situations with special conditions may exist that yield actual data from a drift test with a tower design or with installation practices that are in conflict with these guidelines. If this is the case, then the test data relevant to that specific design would supersede any guidelines or rules of thumb presented herein.

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6. Personal communications with Richard J. Aull.
7. Personal communications with Timothy E. Krell.
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Acknowledgements

The author would like to acknowledge the contributions of Mr. Richard J. Aull and Mr. Timothy E. Krell for their input and ideas during the process composing the section on the crossflow tower plenum analysis. Mr. Aull's experience and knowledge of a large variety of different crossflow towers helped guide the path, and Mr. Krell's work in the development and operation of the CFD models was critical to the understanding of the relationship presented in this paper.

Appendix I
Tables & Figures

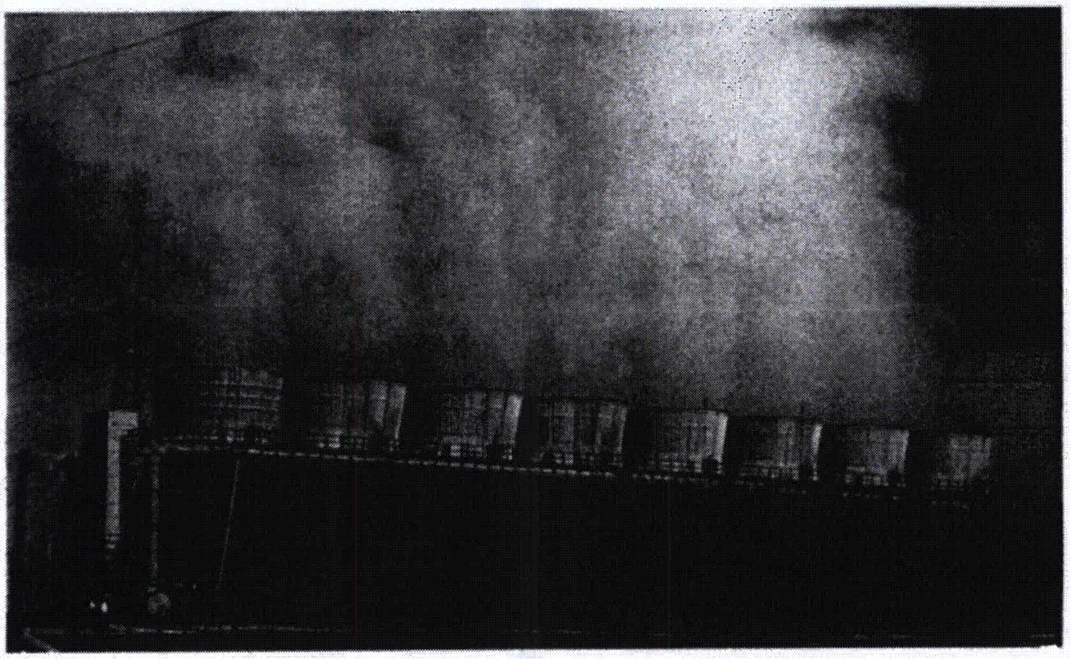


Figure 1: Cooling Tower Plume

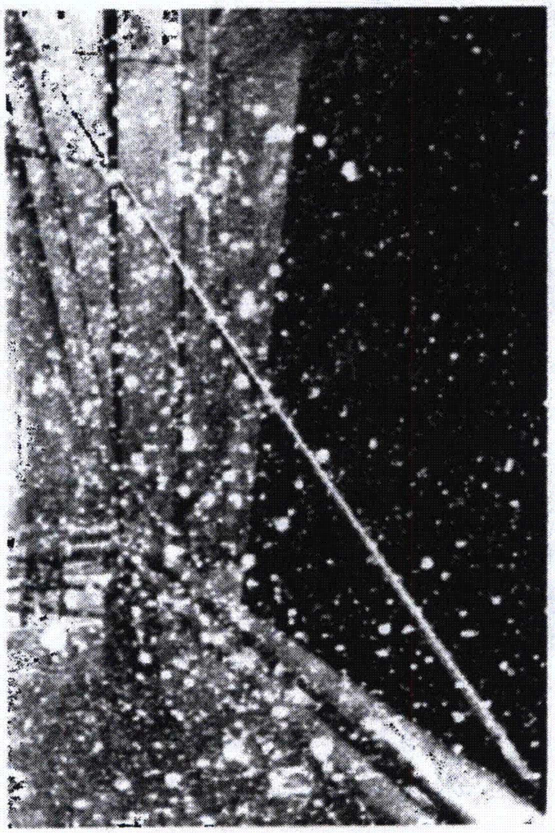


Figure 2: Cooling Tower Drift

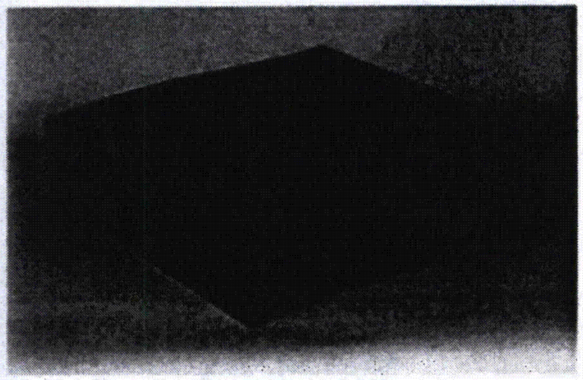


Figure 3: Blade Type Drift Eliminator

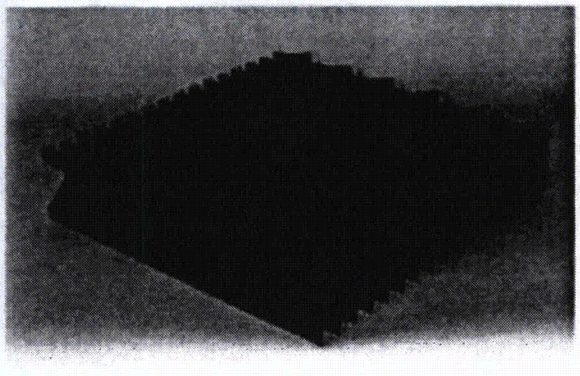


Figure 4: Cellular Type Drift Eliminator

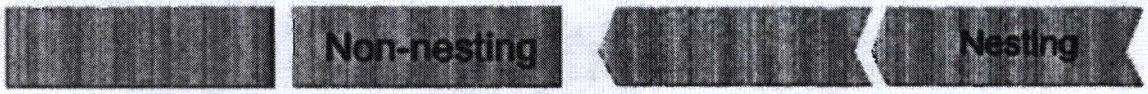


Figure 5: Non-nesting vs Nesting Eliminator Designs

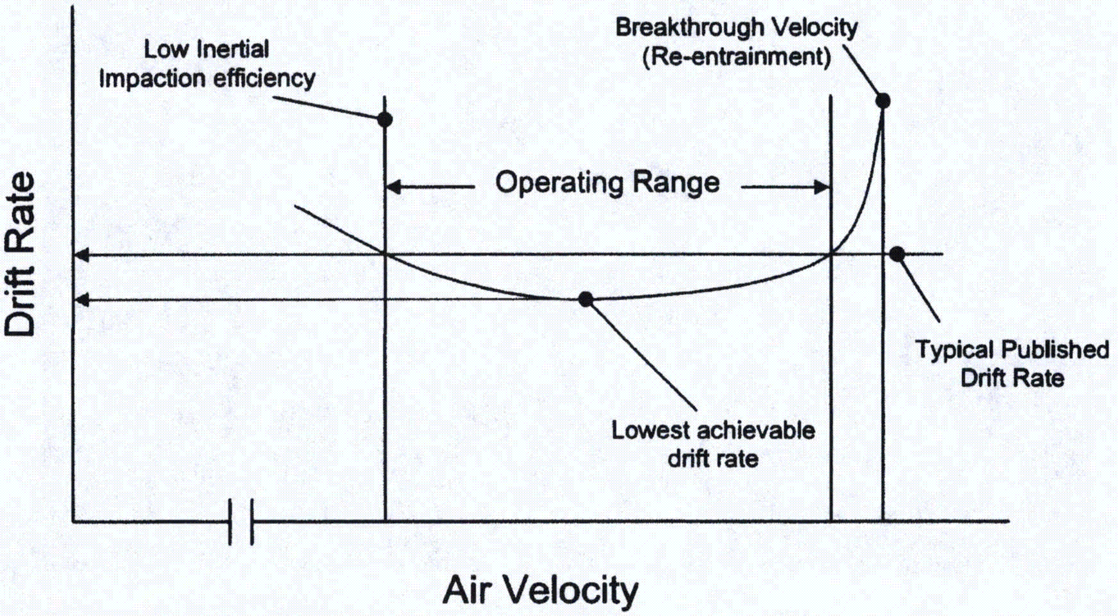


Figure 6: Generic Drift Eliminator – Drift Rate vs Air Velocity Profile

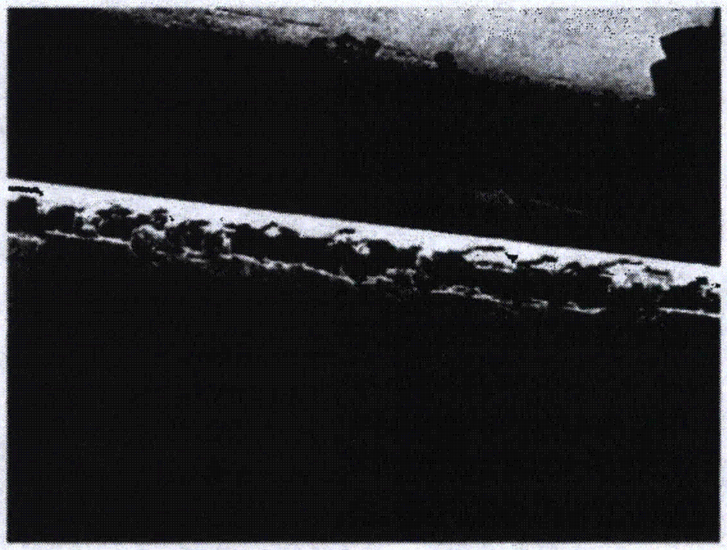
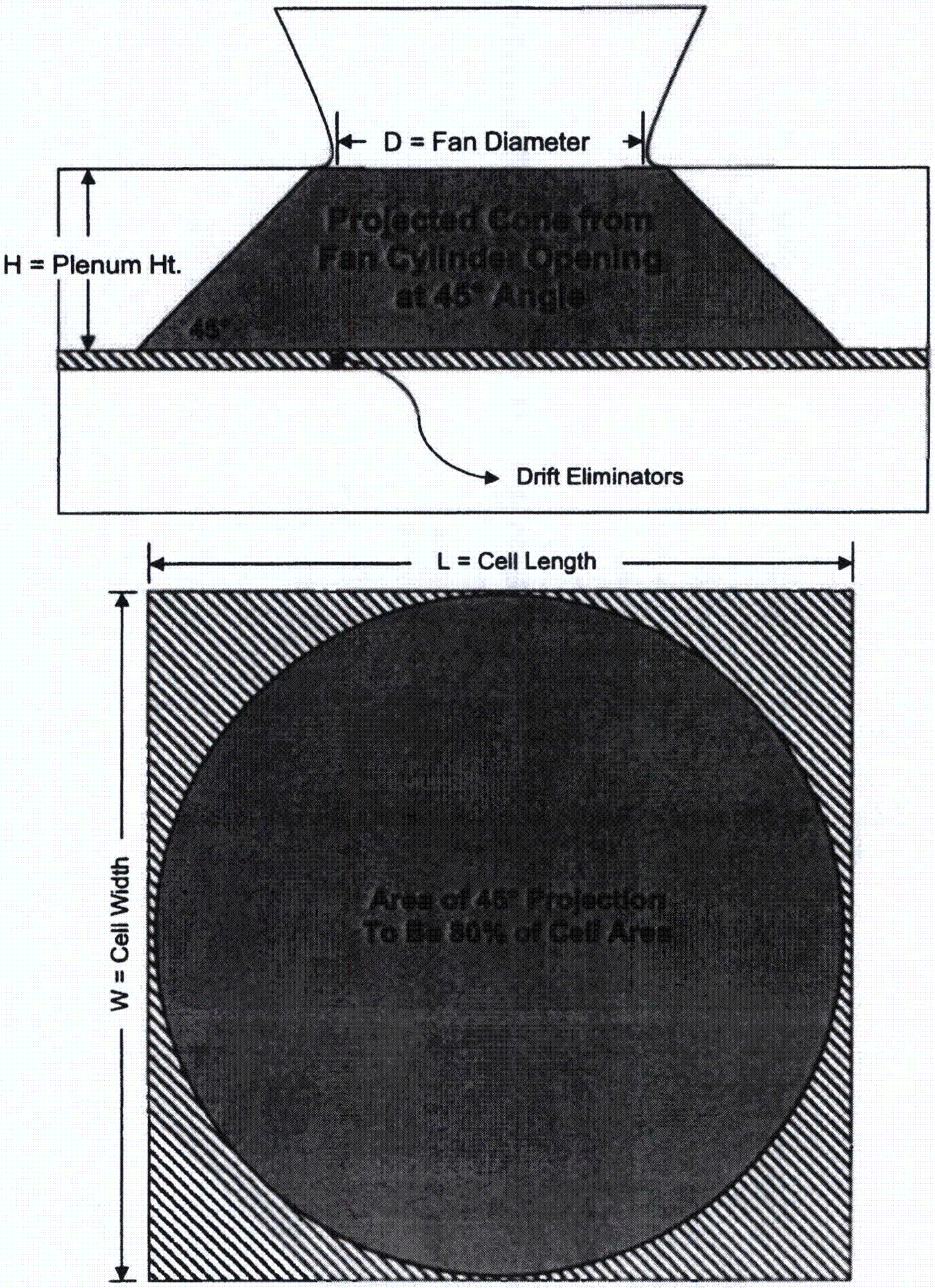


Figure 7: Severely Eroded Fan Blades



$$H = \sqrt{\left(\frac{0.8LW}{\pi}\right)} - \frac{D}{2}$$

Figure 8: Counterflow tower – Adequate Plenum Rule of Thumb

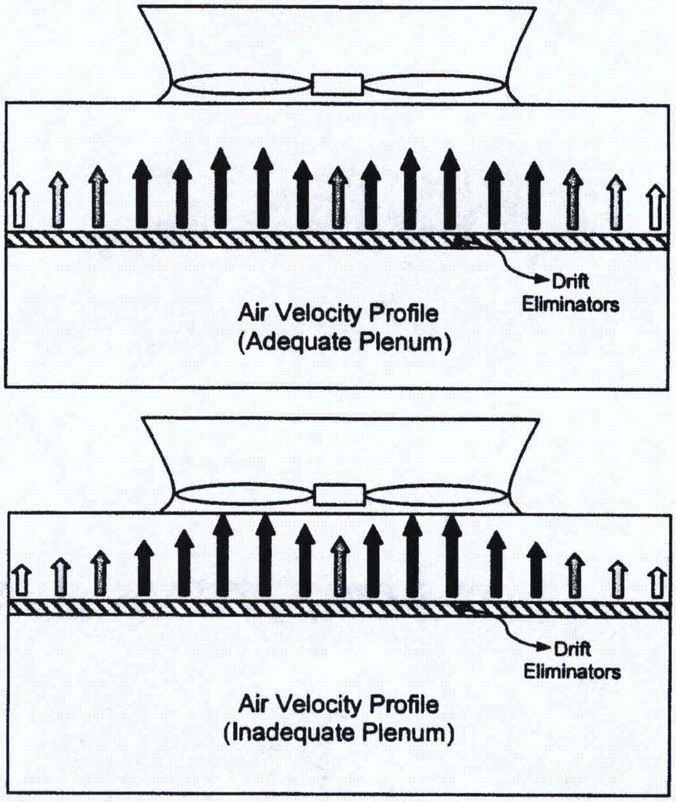


Figure 9: Adequate vs Inadequate Plenums Air Velocity Profiles (Counterflow towers)

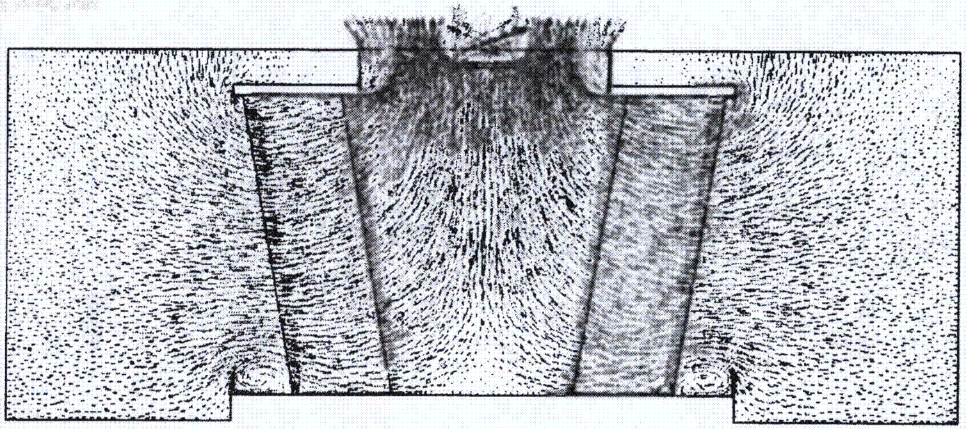


Figure 10: Basic Set-up of CFD Model – Crossflow Tower

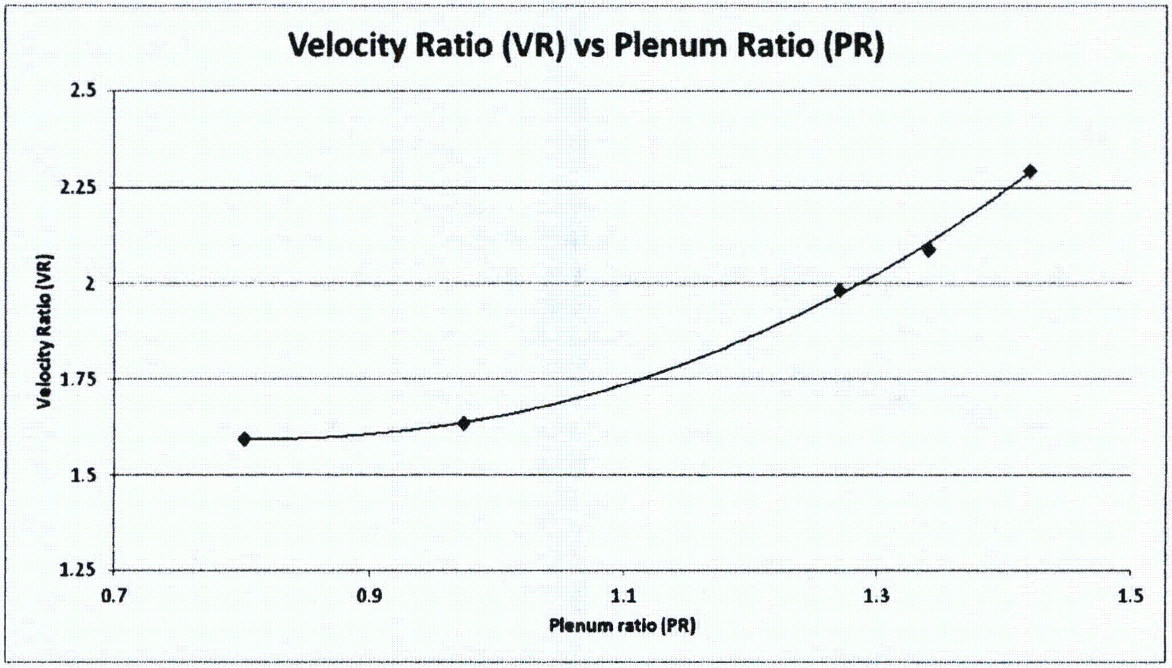


Figure 11: Crossflow Tower – Velocity Ratio vs Plenum Ratio

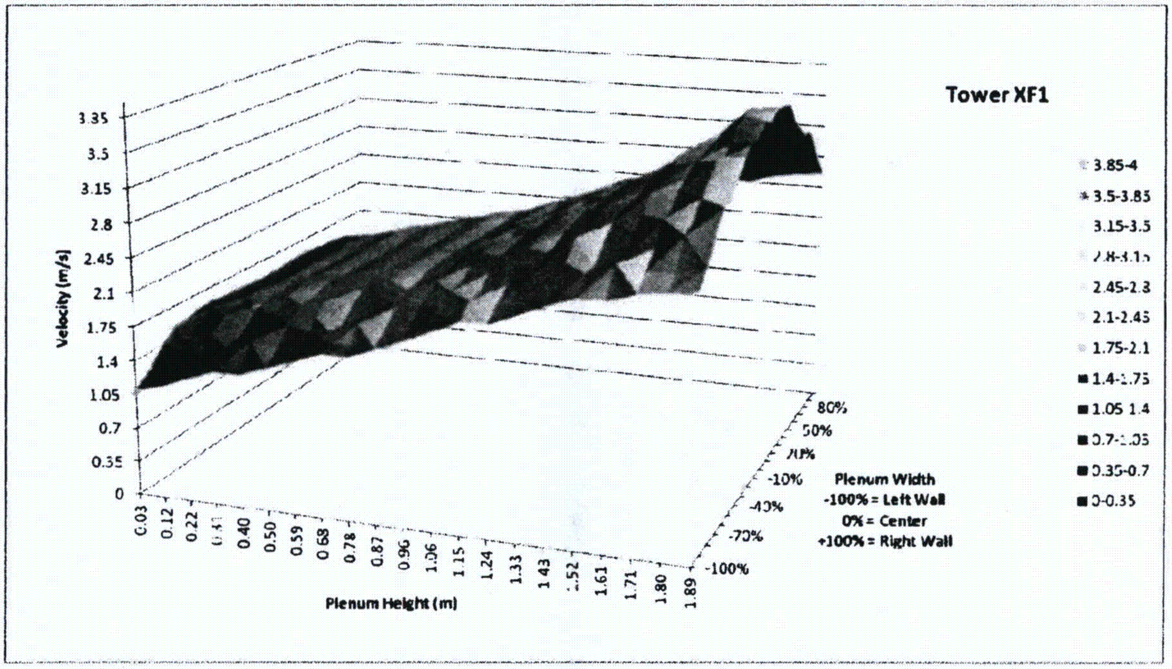


Figure 12: Crossflow Tower XF1 – 3D Velocity Profile

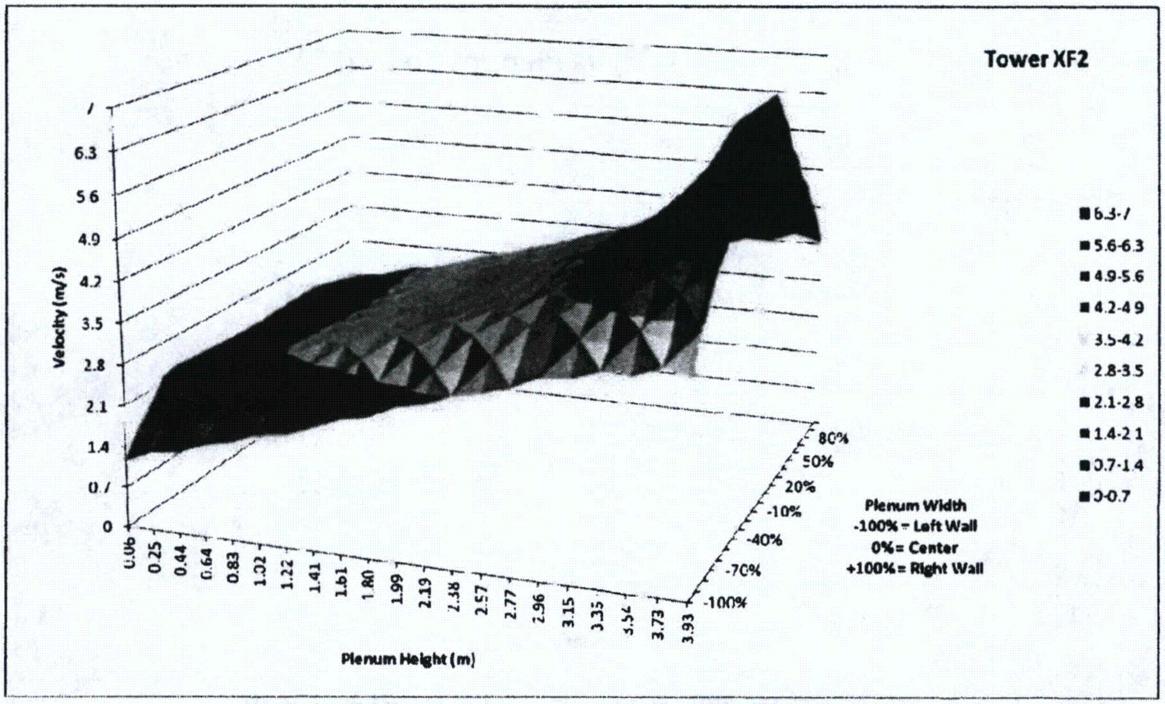


Figure 13: Crossflow Tower XF2 – 3D Velocity Profile

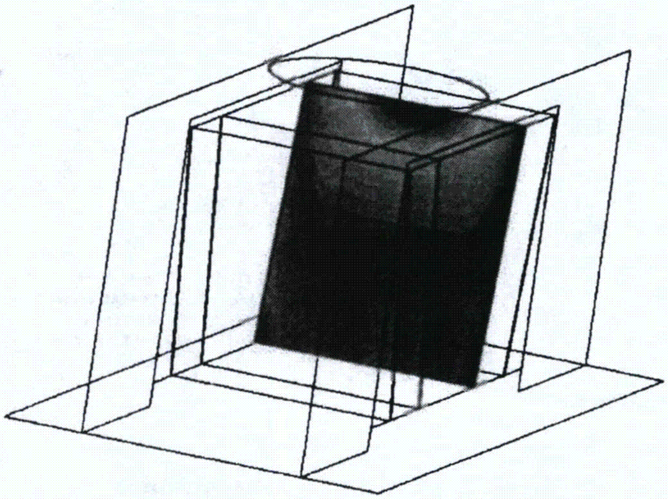


Figure 14: CFD DE Velocity Profile – Crossflow Tower

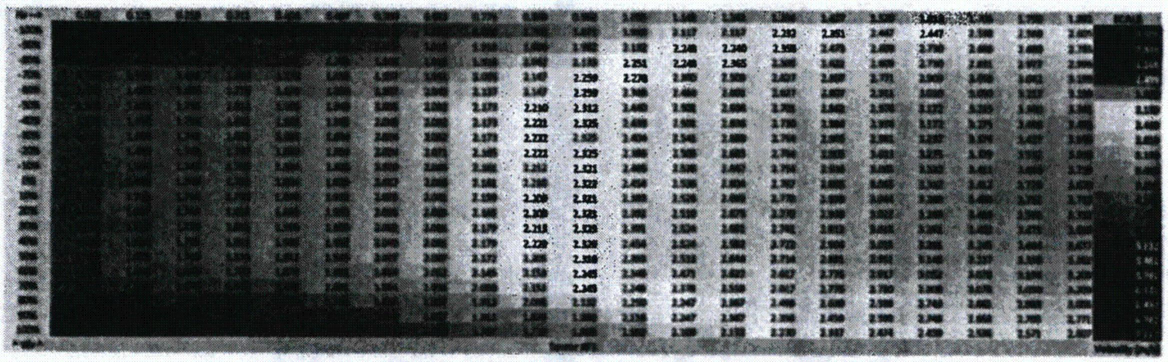


Figure 15: Crossflow Tower XF1 –Velocity Profile Grid

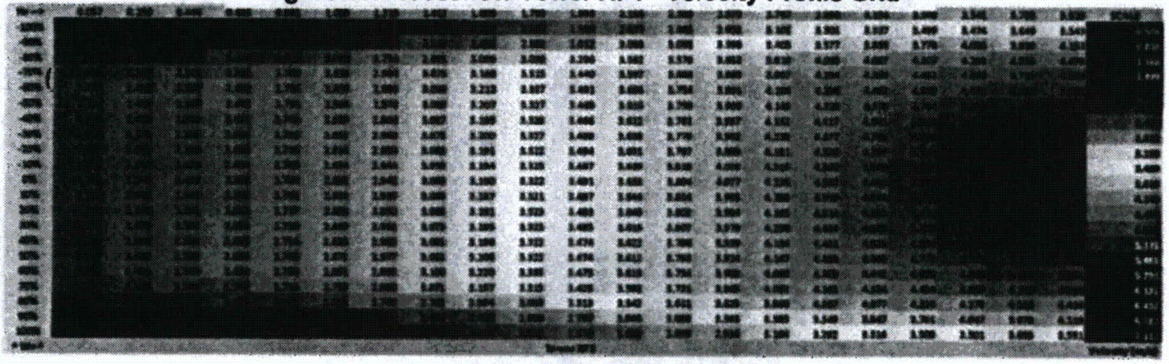


Figure 16: Crossflow Tower XF2 –Velocity Profile Grid

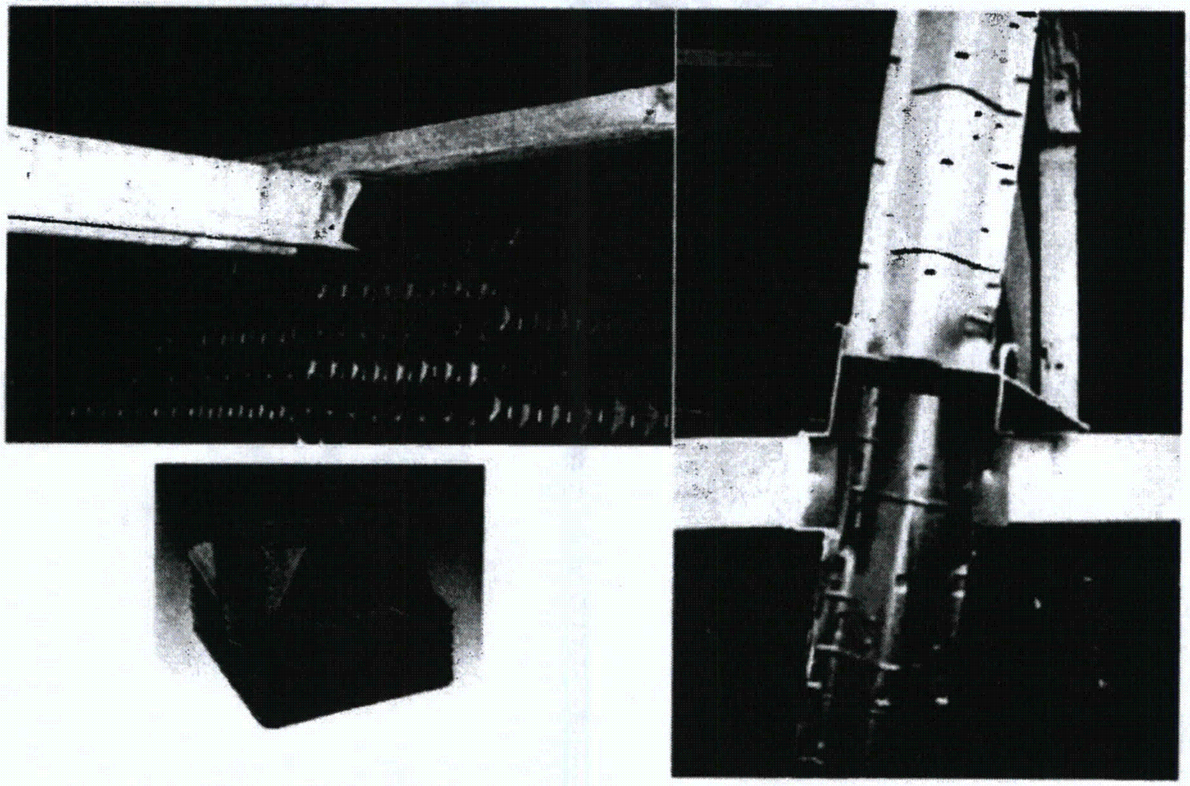


Figure 17: Sealing Methods for Structural Penetrations of Drift Eliminators

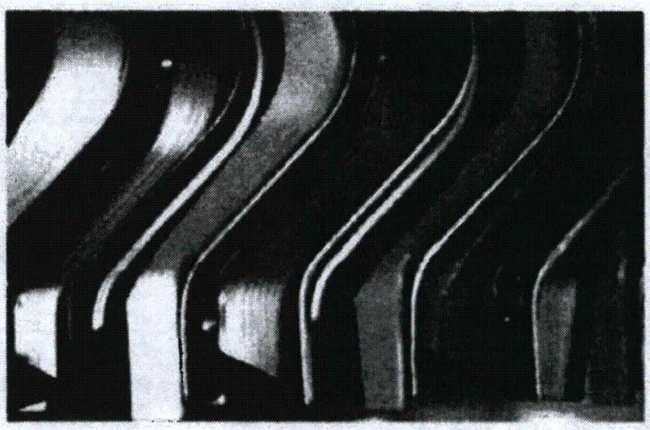


Figure 18: High Efficiency Eliminator Drainage Tips
(Counterflow towers)
Tips go "down" when installed

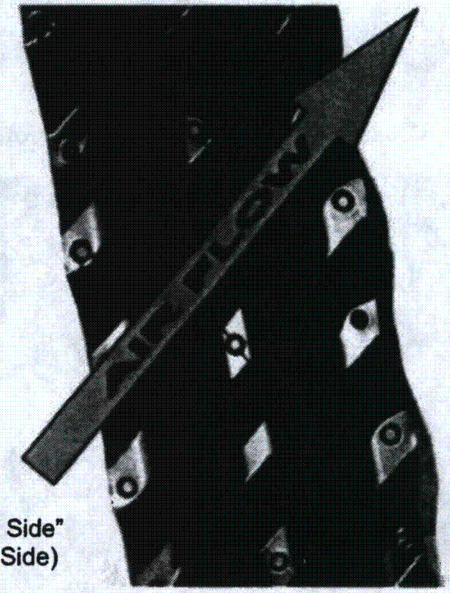
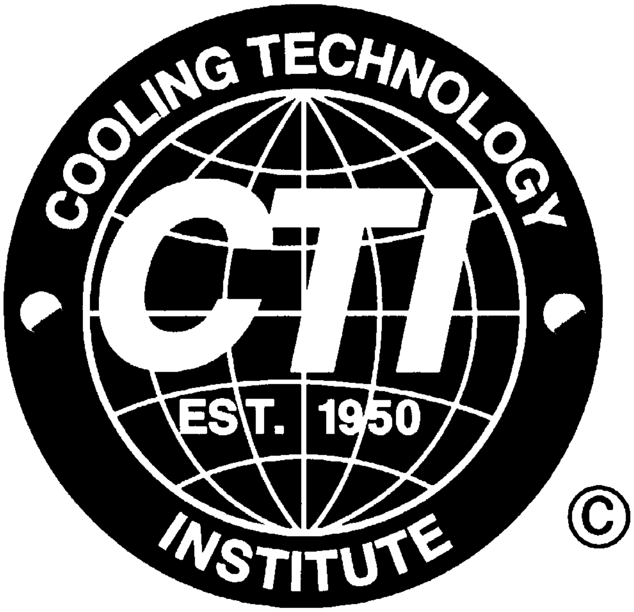


Figure 19: Crossflow Drift Eliminator
Proper Installation Orientation

COOLING TECHNOLOGY INSTITUTE

Isokinetic Drift Test Code



July 2011

ATC-140 (11)

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This document summarizes the best current state of knowledge regarding the specific subject. It represents a consensus of those individual members who have reviewed this document, its scope and provisions and is intended to aid all users or potential users of evaporative vapor condensers.

Approved by the CTI Executive Board.

This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2016.

Approved by the
CTI Executive Board

TABLE OF CONTENTS

Part I – Test Procedure

Section 1. Introduction

1.1 Scope. This code describes the measurement of drift emissions and\or determination of particulate matter from water-cooling towers using isokinetic methods.

1.2 Purpose. The purpose of the Code is to describe instrumentation and procedures for the testing and evaluation of drift from water-cooling towers.

1.2.1 Overview. In the operation of an evaporative cooling tower, moving air contacts water for heat transfer. The circulating water is distributed as droplets and films to maximize the surface area exposed to the air. In these processes, small water droplets are entrained in the air moving through the tower. Droplets that are not removed from the air stream are exhausted from the cooling tower into the environment. These droplets, which possess the same minerals (but not necessarily in the same concentrations) as the circulating water, are known as drift.

Cooling tower exit air contains water vapor, drift droplets, condensate droplets and particulate which originates in the ambient air but is unscrubbed by the cooling tower. The proportion of these constituents in the exit air are regulated by a number of factors including, but not limited to, drift eliminator design and installation, water distribution and fill system design, ambient psychrometric and wind conditions, circulating water chemistry, etc.

Cooling tower drift measurements are required for laboratory research and field measurement of drift emission rates. The impetus behind such measurements usually falls into one of four categories.

a) Drift contractual acceptance testing
b) Determination of compliance with regulatory requirements for drift or particulate matter.
c) Environmental impact assessment and modeling
d) Status testing on existing cooling towers.

If drift measurements are conducted to verify performance for contractual drift guarantees, it is emphasized that the guarantee basis is for drift only, and the guarantee is independent of the influence of ambient air constituents. Ambient air constituents that are drawn into the tower and then escape via the exit air stream may bias drift measurements. This requires that the drift measurement and calculation analysis method remain independent of significant influence of elements found in the inlet air stream. Background constituent levels cannot be subtracted from outlet levels since the scrubbing effect of the cooling tower is unknown. This is of particular importance when low levels of drift are measured.

1.2.2. There are two basic methods of drift measurement:

1. Isokinetic (IK) for drift rate measurement and
2. Sensitive Surface (SS) for drift droplet size characterization.

Each method yields specific information regarding the drift characteristics of the tower.

Highlights of the two methods are provided below:

ISOKINETIC METHODS (IK)

<u>POSITIVE ATTRIBUTES</u>

1. High collection efficiency on all droplet sizes.
2. Analysis for specific elements possible.
3. Provides integrated sample over exit area.

<u>NEGATIVE ATTRIBUTES</u>

1. Airborne elements may bias results.
2. Long sample times required for high efficiency drift eliminators or low mineral concentrations.

SENSITIZED SURFACE METHODS (SS)

<u>POSITIVE ATTRIBUTES</u>

1. Provides droplet size characteristics above 30 µm.
2. Not effected by airborne elements.
3. Provides relative indication of drift eliminator effectiveness.

<u>NEGATIVE ATTRIBUTES</u>

1. Poor collection efficiency on small droplets less than 30 µm.
2. Cannot distinguish between condensation and drift.
3. No droplet analysis for specific constituents.

1.2.3 This code describes a Heated Bead Isokinetic (HBIK) Drift Test Procedure. However, an alter-native Isokinetic Procedure with demonstrated performance may be utilized, if mutually agreed to by all parties.

The HBIK method is an isokinetic sampling method derived from applicable stack sampling procedures that have been modified to address the unique operating and environmental challenges associated with testing a cooling tower. These challenges include sampling a dilute pollutant in a saturated exhaust above a very large diameter fan stack. A composite sample of the exhausted metallic salts is collected from multiple sampling stations. The drift rate is a function of the ratio of the tracer element mass (tracer elements) to concentration of the tracer element in the circulating water.

1.2.4 The Sensitive Surface system most often used relies on droplet collection by inertial impaction on water sensitive paper. The paper is chemically treated so that a droplet impinging on it will generate a well-defined dark blue stain on the pale yellow background of the paper. The size and shape of the stain are functions of the impingement dynamics (i.e., speed and angle, and the original droplet diameter). If the technique is employed correctly, the stain will be circular, or nearly circular, in shape. The relationship between the stain and the droplet size is obtained by calibrating the SP system by means of a monodisperse water droplet generator over a range of droplet sizes and impaction velocities.

The processing of the exposed sensitive paper consists of evaluating the stain diameters, and grouping the counts of all stains by stain-size ranges. Once the stain sizes are counted and grouped according to size, calibration curves for specific droplet sizes and impaction velocities are employed via computer programs to generate the original droplet sizes from which the stains were formed. In addition, a correction factor is applied to compensate for the collection efficiency of each droplet size range. This factor, which is important only for droplets of less than approximately 30 microns, is computed by the procedures of Ranz and Wong.

1.3 **Flexibility.** It is recognized that the data limitations specified throughout this test procedure represent desired conditions which may not exist at the time the test is performed. In such cases, existing conditions may be used if mutually agreed upon prior to the test by authorized representatives of the manufacturer, the tower owner, and the CTI.

1.4 **Other Uses.** Although intended primarily for drift acceptance testing, all or parts of this Code may be used for other purposes, such as the determination of mineral mass emission.

1.5 **Impartial Testing Service.** The CTI Representative referred to in this Code shall be an impartial party to the test and shall have no connection with the manufacturer, the purchaser, or the Cooling Technology Institute, other than a contractual agreement with the latter. This Representative shall be sufficiently qualified to ensure that measurements and evaluations are made in accordance with the Code. The CTI Representative is hereinafter referred to as the CTI.

1.6 **Nomenclature.**
The symbols used in this Code are identified in Table 2.

Table 1
Nomenclature

Symbol	Definition	[SI]	[IP]	Section	Eq. #
A_N	Area of intake nozzle on isokinetic device	m^2	ft^2	4.1.3, 4.3, C-1,	6, 7, 12, 13
A_{SP}	Area of sampling plane	m^2	ft^2	4.3, C-1	12, 13
C_{Pitot}	Calibration coefficient of air velocity pressure Pitot tube	-	-	4.1.1	4
C_{STD}	Concentration of mineral emission	mg/L	g/ft^3	C-1	15
C_{TC}	Concentration of tracer element in circulating water	mg/L	ppm	4.3, C-1	12, 13
D_h	Hub diameter	m	ft	3.9.2	3
D_s	Stack diameter	m	ft	3.9.2	3
E_R	Emission rate	g/s	lb/hr	C-1	14, 15
hp_D	Design brake horsepower	kW	HP	2.3.5, C-2	1, 16, 17
hp_T	Tested brake horsepower	kW	HP	2.3.5, C-2	1, 16, 17
K	Coefficient = $\sqrt{2}$ [SI] or 1097 [IP]	-	-	4.1.1	4
K_0	Coefficient = 16.67 [SI] or 1 [IP]	-	-	4.1.3	6, 7
K_1	Coefficient = 10 [SI] or 37.854 [IP]	-	-	4.3, C-1	12, 13
K_7	Coefficient = 10^5 [SI] or 1.997×10^5 [IP]	-	-	C-1	14
K_8	Coefficient = 10^{-3} [SI] or 7.9366 [IP]	-	-	C-1	15
M	Number of sampling points on a single radius	-	-	3.9.2	3
m	Sampling point number	-	-	3.9.2	3
$M_{F,i}$	Mole fraction of dry gas	-	-	4.1.3	7, 8, 9
np	Number of sampling points	-	-	4.1.5, C-3	11, 18
$Q_{M,i}$	Measured sample volumetric flow rate	L/min	ft^3/min	4.1.3	7
$Q_{N,i}$	Sample volumetric flow rate	L/min	ft^3/min	4.1.3	6
Q_{STD}	Sample plane flow rate, dry standard conditions	L/s	ft^3/s	C-1	15
Q_{WT}	Water flow rate during test	L/s	gpm	4.3, C-1	12, 13, 14
$t_{1,i}$	Nominal sampling time	min	min	4.1.2	5
$t_{2,i}$	Actual sampling time adjusted for angularity of the flow	min	min	4.1.2 , 4.1.5, C-3	5, 11, 18
TDS	Total dissolved solids	mg/L	mg/L	C-1	14
t_E	Total equivalent sample time	s	min	4.3, C-1	12, 13
$U_{N,i}$	Sample velocity at nozzle inlet	m/min	ft/min	4.1.3, 4.1.4, 4.1.5, C-3	6, 7, 10, 11, 18
$U_{S,i}$	Air velocity	m/min	ft/min	4.1.1, 4.1.4, 4.1.5, C-3	4,10, 11, 18
V_{Cth}	Threshold velocity	m/s	ft/min	2.3.5, C-2	1, 2, 16, 17
$V_{D(avg)}$	Design average velocity	m/s	ft/min	2.3.5 C-2	1, 17
$V_{U(avg)}$	Measured average exit velocity	m/s	ft/min	2.3.5, C-2	2, 16
$\omega_{M,i}$	Specific humidity metering device	-	-	4.1.3	9
$\omega_{N,i}$	Specific humidity at the sampling plane	-	-	4.1.3	8, 9
W_T	Net weight of tracer	µg	µg	4.3, C-1	12, 13
X_m	Sample location, distance from wall	m	ft	3.9.2	3
$\Delta P_{s,i}$	Differential pressure (velocity pressure) at each sampling point	Pa	inH_2O	4.1.1	4
θ_i	Angle between flow direction and the normal to the sample plane	deg.	deg.	4.1.2	5
ρ	Air density	kg/m^3	lb/ft^3	4.1.1	4
ρ_{CW}	Density of the circulating water	kg/m^3	lb/ft^3	C-1	14
$\rho_{M,i}$	Density at measuring device	kg/m^3	lb/ft^3	4.1.3	7
$\rho_{N,i}$	Density at sample plane	kg/m^3	lb/ft^3	4.1.3	7

2.0 CONDITIONS OF TEST

2.1 **Conduct of Test.** Drift acceptance testing shall be conducted by the CTI in the presence of authorized representatives of the tower manufacturer and the tower purchaser, if they elect to attend. For acceptance testing, these representatives shall be given adequate notice to inspect the tower in advance, prepare it for the test and to attend the testing. In no case shall any directly involved party be barred from the test site.

2.2 **Condition of Equipment.** At the time of the test, the tower shall be in good operating condition. The Test shall be conducted under the following guidelines:

a) Acceptance test(s) shall be conducted within 24 months after structural completion of the tower or 18 months of operation, unless otherwise stipulated by mutual agreement of purchaser and manufacturer.

b) The cooling tower shall have been operated a minimum of 700 hours with a heat load, unless otherwise stipulated by mutual agreement of purchaser and manufacturer.

c) The water distribution system shall be in good repair and essentially clear and free of foreign materials which may impede the normal water flow.

d) Mechanical equipment, if involved, shall be in good working order. Fans shall be rotating in the correct direction, with proper orientation of leading and trailing edges. Axial fan blades shall be at a uniform angle. Centrifugal fans shall be free of foreign material and properly secured to the shafts.

e) Drift eliminators shall be essentially clear and free of algae and other deposits which may impede normal air flow.

f) Fill shall be essentially free of foreign materials such as oil, tar, scale, or algae which may impede or disrupt normal air or water flow.

g) Cross-flow towers shall be operated such that the level of water in the cold water basin level is at the recommended height to prevent air bypass beneath the fill.

h) Plume abated cooling towers shall have dry section inlet dampers in the closed position if present. If dampers are not present, by mutual consent of the test parties, the air inlets may be temporarily blocked to prevent ambient concentrations of tracer elements from entering the cooling tower.

2.3 **Operating Conditions.** The drift test of any cooling tower shall be conducted within the following limitations:

2.3.1 Requirements for drift testing of any tower shall include:

a) The temperature of the inlet air stream should remain above the freezing point of water.

b) The sampling area should be free from visible collection of condensation on surfaces.

c) The tower should be free of airborne foam at the sampling elevation.

d) The test period shall be free from any natural precipitation.

2.3.2 The circulating water flow rate shall be within ±10% of the design value.

2.3.3 The operating fan horsepower of mechanical draft towers, when corrected for air density, shall be within ±10% of the design value.

2.3.4 For contractual acceptance tests, the water surface tension shall not fall below the specified design basis surface tension value. If not specified contractually, for contractual acceptance tests, the surface tension of the circulation water shall not fall below 63 dynes/cm.

2.3.5 When the drift sampling is conducted at the exit plane of the fan stack, the average wind velocity shall be measured at the fan stack discharge elevation upwind of the test cell per paragraph 3.6.

The average allowable wind velocity shall not exceed 75% of the average exit velocity, based on the gross diameter of the fan stack being tested.

The average exit velocity can be determined using the manufacturer's data sheets, if available.

Alternately, the design average exit velocity can be calculated from the design fan air flow rate divided by the gross stack exit area or the stated average exit velocity.

If the manufacturer's nominal air velocity data is used, it must be corrected for the difference between the design airflow rate and the test airflow rate. The following equation can be used to determine the threshold velocity:

$$V_{Cth} = .75 * V_{D_{(avg)}} * \sqrt[3]{\frac{hp_T}{hp_D}} \qquad (1)$$

Where:

V_{Cth} = Threshold velocity, m/s (ft/min)

$V_{D(avg)}$ = Design average air velocity , m/s (ft/min)

hp_T = Tested brake horsepower, kW (HP)

hp_D = Design brake horsepower, kW (HP)

If the manufacturer's data is not available, the average exit velocity can be determined by measuring the air exit velocity at each of the local sampling stations during the first drift test traverse and calculating the average exit velocity.

$$V_{Cth} = .75 * V_{U_{(avg)}} \qquad (2)$$

Where:

$V_{U(avg)}$ = Average measured air velocity, m/s (ft.min)

Examples calculations of the evaluation of the wind speed threshold are included in appendix section C-2.

2.3.6 During normal operation of a cooling tower under heat load, it is common to observe some collection of condensation on the cooling tower structure and internal surfaces on the discharge side of the drift eliminators. Excess condensation on plenum surfaces can re-entrain salts and positively skew drift results. When conducting a drift test with a heat load, a certain amount of condensation droplets may be captured by the drift sampling train and influence the drift measurements. In order to minimize the potential influence of condensation, the drift tests may be conducted with little or no heat load. For mechanical draft tower tests conducted in cold weather, it is preferential to conduct a cooling tower emissions test in the absence of heat load. In the absence of heat load, the influences of condensation are minimized and drift tests may be more repeatable.

Due to the influence of wet-bulb temperature, dry-bulb temperature, and range on airflow for a natural draft tower, the following deviations from design conditions shall not be exceeded:

a) Wet-bulb..............±8.5°C (15°F)
b) Dry-bulb..............±14.0°C (25°F)
c) Range...................±20%

2.3.7 For multi-cell towers, one or more cells may be shut down, provided the circulating water flow to each operating cell is within the specified limits. (For the purposes of this Code, a "cell" is defined as the smallest subdivision of the tower, bounded by exterior walls and partition walls, which can function as an independent unit. Each cell may have one or more fans or stacks and one or more distribution systems). The water shall be distributed to all operating cells and/or parts of the tower as recommended by the manufacturer.

2.3.8 General Water Quality

2.3.8.1 The circulating water shall contain not more than 5 mg/L (ppm) oil, tar, or fatty substances as determined by the procedure outlined in Standard Methods for the Examination of Water and Wastewater, Current Edition published by APHA, AWWA and WEF.

2.3.8.2 Certain water treatment chemicals can significantly affect drift rate by reducing water surface tension. The direct effect of these surface acting agents (surfactants) is to increase the population of very small droplets that are produced by the nozzle spray and air-water interaction within the cooling tower. Many water treatment chemicals such as, bio-dispersants, scale inhibitors and some non-oxidizing biocides act as surfactants. Pure water at 50°C (122°F) has a surface tension of 68 dyne/cm[1]. To minimize small droplets becoming fluidized, the surface tension of the circulating water shall not fall below 63 dynes/cm (equivalent to pure water at 176F (80C) during the test.

The method for determining the surface tension shall be any of the following;

a) ASTM D1331 Standard Test Methods for Surface and Interfacial Tension of Solutions of Surface-Active Agents
b) ASTM D3825 Standard Test Method for Dynamic Surface Tension by the Fast-Bubble Technique
c) Bubble Tensiometer

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[1] Weast, R.C. (Ed.). Handbook of Chemistry and Physics, 61st ed. Boca Raton, Florida, CRC Press, p F-45, 1981

2.4 Constancy of Test Conditions.

For mechanical and natural draft towers, variations in operating conditions over the course of the sampling period shall be within the following limits:

2.4.1 Circulating water flow shall not vary by more than ±5% per hour.

2.4.2 The flow rate of any flow stream entering or leaving the cold water basin (e.g. Makeup or blowdown) must remain constant while measurements are being conducted. Side stream filters or reverse osmosis filters must not be activated while drift sampling unless the operation of the system is operated continuously.

2.4.3 The concentration of the tracer element(s) of each inlet water sample shall not vary more than 10% during each individual test. The variation shall be calculated as the difference between the maximum concentration and the minimum concentration divided by the average concentration.

2.4.4 To limit the variations in air flow for a natural draft cooling tower, changes in test conditions should be within the following limits:

2.4.4.1 Range shall not vary by more than ±5% per hour.

2.4.4.2 Instantaneous air temperature readings may fluctuate, but variations in the averages during the test period shall not exceed the following:

a) Wet-bulb...1°C per hour (2°F)
b) Dry-bulb...3°C per hour (5°F)

2.5 Number of Tests.

For acceptance testing, a minimum of two tests with results within ±25% of their average is required on each cell tested. Three tests may be beneficial in that an outlying test may be discarded to bring the average within ±25%. The tests may be conducted simultaneously or sequentially.

2.5.1 Number of Tested Cells. For towers consisting of five cells or less, a test of one cell is sufficient. A minimum of two cells shall be tested for towers consisting of more than five cells.

2.6 Frequency of Readings. Readings shall be taken at regular intervals and recorded in the units and to the number of significant figures shown in Table 3.

2.7 Test Accuracy. The overall tower drift rate test accuracy depends on the accuracy of chemical analysis and sampling techniques, the stability of test conditions, and for multi-cell towers, the number of cells tested and the quality and consistency of installation from cell to cell.

TABLE 2 Frequency of Readings and Units for Isokinetic Drift Tests

Measurement	**Minimum number**	**Unit**	**Record to nearest**
Exit air velocity or velocity pressure	Every sample point.	m/s, (ft/sec) or Pa, (inwg)	0.1 m/s, (0.1 ft/sec) or 2 Pa, (0.01 in.)
Exit air temperature	Every sample point.	°C, (°F)	0.5, (1.0)
Air Flow angle	Every sample point.	degrees	2
Isokinetic sample rate	Every sample point.	L/s, (ft3/sec)	0.05, (0.01)
Circulating water reference sample	Beginning, midpoint, and end of test		
Circulating water flow rate	1/hour*	L/s, (gpm)	0.05, (1)
Wind velocity	continuously	m/s, (mph)	0.5, (1)
Barometric pressure	1/test	kPa, (in. Hg)	0.2, (0.1)
Fan driver power input	1/test**	kW, (hp)	0.05, (0.1)
Wet-bulb temperature	1/hour***	°C, (°F)	0.05, (0.1)
Dry-bulb temperature	1/hour***	°C, (°F)	0.05, (0.1)
Cold water temperature	1/hour***	°C, (°F)	0.05, (0.1)
Hot water temperature	1/hour***	°C, (°F)	0.05, (0.1)

* If the valve alignment and number of operating pumps remains constant during the test, continuous monitoring of water flow rate is not required. If the flow rate to the test cell is controlled by an automated system, the system should be disabled during the testing. In rare cases, where the constancy of valve positions cannot be guaranteed, it may be necessary to continuously monitor the circulating water flow. If the flow stability is in question and a Pitot tube was used for water flow measurement, single center point readings of differential pressure may be used for monitoring the flow stability.

** If required (Mechanical Draft Towers)

*** If required (Natural Draft Towers)

3.0 INSTRUMENTS AND MEASUREMENTS

All air flow, water flow, temperature and power measuring devices shall be inspected and approved by CTI prior to the test. All instruments except for thermocouples shall have been calibrated before the test. Thermocouples shall undergo a functionality check prior to testing. All other instruments shall meet the calibration requirements specified in Table 4. Calibration must be traceable to the U.S. National Institute of Standards Technology (NIST), or derived from accepted values of natural physical constants.

Table 3 Minimum Calibration Frequencies

Instrument	Minimum Calibration Frequency
Anemometers	Yearly
Volumetric Sample Rate Device	Yearly
Dry Gas Meters	Yearly
Barometers	Yearly
Temperature sensors (excluding thermocouples)	Within 3 months prior to use
Water Flow Measurement Devices	Three years if undamaged
Electric Power Meters	Yearly
Wind Speed and Direction	Yearly

At the request and expense of the test purchaser, any and all instrumentation used on a test can be calibrated before and after a test. Flow sections built to ASME specifications may be physically inspected in lieu of calibration for conformance with manufacturer tolerance. The test agency shall have a written procedure for calibration of each instrument. The test agency shall maintain records showing the calibration history for each instrument and make them available upon request.

3.1 Water Flow Measurements

3.1.1 Water flow measurements may be made by any of the following devices. Any other CTI-approved methods of direct measurement may be used. The selection of method and location of measurement will depend upon the nature of the installation to be tested.

a) Pitot tube (traverse)
b) Orifice
c) Venturi
d) Magnetic flow meter
e) Flow nozzle
f) Turbine meter

3.1.2 The procedure for using any of the above shall be as described in one or more of the following sources:

a) Instrument manufacturer's instructions
b) CTI "Acceptance Test Code for Water Cooling Towers", ATC-105 (latest revision)
c) CTI "Standard for Water Flow Measurement" STD-146, (latest revision)
d) ASME "Supplements on Instruments and Apparatus," Part 5, Chapter 4 (latest revision)
e) ASME Power Test Code on "Hydraulic Prime Movers" (latest revision)

3.2 Water Temperature Measurements. At the time of this writing, the effect of heat load on drift from mechanical draft cooling towers has not been fully documented. Reference temperature measurements are optional for mechanical draft and required for natural draft towers. Measurements should be made with any of the instruments as described in ATC-105 (latest revision). Temperature-sensitive elements shall be located where the water will be thoroughly mixed.

3.2.1 Hot circulating water temperature measurement shall be made in the tower riser(s) or at the discharge of the inlet riser(s) into the flume or distribution system or at any place where the temperature of the water is well mixed and representative of the water temperature delivered to the test cell. If the inlet water flow is a mixture of two or more streams of different temperatures, complete mixing must be assured at the point of measurement or sufficient flow rate and temperature measurements shall be made to ensure an accurate weighted average hot water temperature.

3.2.2 Cold circulating water temperature measurements should preferably be made in a full-flowing bleed stream at the circulating pump discharge, and the average corrected for the energy added by the pump(s). If the measurement is made at a location where temperatures and velocities are not uniform over the stream cross-section, sufficient flow rate and temperature measurements shall be made to ensure an accurate weighted average cold water temperature.

3.3 Air Temperature Measurements

3.3.1 Inlet Wet-bulb Temperature. The measurement of inlet wet-bulb temperature is optional for mechanical draft and required for natural draft towers. For measurement of wet-bulb temperatures, a minimum of two instruments shall be used to ensure that the test average is within the required limits. Measurements shall be obtained using mechanically aspirated instruments, designed to meet the following requirements:

a) The indicator or recorder shall be graduated in increments of not more than 0.1°C (0.2°F).
b) The temperature-sensitive element shall be accurate to ±0.05°C (0.1°F).
c) The temperature-sensitive element shall be shielded from direct sunlight or from other significant sources of radiant heat. The shielding device shall be within 1°C (2°F) of the surrounding dry-bulb temperature.
d) The temperature-sensitive element shall be covered with a wick that is continuously fed from a reservoir of distilled water.
e) The temperature of the distilled water used to wet the wick shall be at approximately the wet-bulb temperature being measured. This may be obtained in practice by providing an adequate length of ventilated wick between the water supply and the temperature-sensitive element.
f) The wick shall fit snugly over the temperature-sensitive element and extend at least one inch past the element over the stem. It shall be kept clean while in use.
g) The air velocity over the temperature-sensitive element shall be maintained between 4.5 m/s (950 fpm) and 5.5 m/s (1050 fpm).

3.3.2 Inlet Dry-Bulb Temperature. The inlet dry-bulb temperature measurement is required for natural draft towers. For measurement of dry-bulb temperatures, a minimum of two instruments shall be used to ensure that the test average is within the required limits. Measurements shall be obtained using instruments designed to meet the following requirements:

a) The indicator or recorder shall be graduated in increments of not more than 0.1°C (0.2°F).
b) The temperature-sensitive element shall be accurate to ±0.05°C (0.1°F).

c) The temperature-sensitive element shall be shielded from direct sunlight or from other significant sources or radiant heat. The shielding device shall be within 0.1°C (0.2°F) of the surrounding dry-bulb temperature.

d) The air velocity over the temperature-sensitive element shall be maintained between 4.5 m/s (950 fpm) and 5.5 m/s (1050 fpm).

3.4 Barometric Pressure shall be measured near the sampling plane with a meteorological grade barometer accurate to within 0.03 KPa (0.1 inHg).

3.5 Sample Point Temperature Measurements. Sample point temperature measurements to determine air properties are required for all types of cooling towers covered in this code. The sample point temperature shall be measured at each station with instruments, meeting the following requirements:

a) The indicator or recorder shall be graduated in increments of not more than 0.5°C (1.0°F).

b) The temperature-sensitive element shall be accurate to ±1.3°C (2.4°F).

3.6 Wind Velocity (Speed and Direction). Wind velocity shall be measured with a meteorological type anemometer and wind vane, preferably remote reading and recording. Rotating cup anemometers with separate wind direction vane or combination self-aligning propeller and direction vane devices are readily available and acceptable.

For natural draft cooling towers, measurements shall be taken or correlated to a height equivalent to the top of the air inlet. Measurements shall be made in an open and unobstructed location, upwind of the tower and beyond the influence of the inlet air approach velocity. Care shall be taken to assure recorded wind speed and direction are representative of wind conditions affecting the tower. Placement of the wind measurement device shall be subject to mutual agreement by all parties to the test. Wind direction shall be recorded in compass degrees with the tower orientation and reference north clearly indicated.

For mechanical draft towers, the wind speed shall be measured upwind of the cell to be tested at an elevation 0.5 m (2 ft) higher than the fan stack discharge.

3.7 Fan Driver Power. For mechanical-draft and fan-assisted towers, fan power shall be determined as the density corrected power output from the motor or driver. In the case of electric motors, power input shall be determined by measurement of the voltage, current, and power factor, or by direct measurement of the kilowatt input. If motor input power is not directly measured at the motor, then a line loss correction shall be made, unless otherwise agreed upon by all parties. The output power is calculated from the product of the input power and the nominal fan motor efficiency. If not directly measured, base of the fan blades. This equation may also be used to estimates of the hot water temperature, cold water temperature, and entering air temperature shall be made in order to calculate and correct for the air density difference between the design and test point as specified in ATC-105.

3.8 Circulating Water Reference Sample. For tests conducted within one day, samples of the circulating water must be taken from the tower hot water inlet at the beginning, midpoint and end of each individual test. If tests are conducted over more than one day, samples shall be taken at the beginning and end of each day of sampling. Tests of less than one day are preferable because this reduces the chance for contamination. Sample preservation techniques should be implemented according to the requirements provided by the laboratory performing the analysis.

3.9 Drift Measurement Location. Sampling points must be made at the centroid of equal areas in any plane on the discharge side of the drift eliminators where reasonable access can be obtained. Possible measurement locations include the air flow exit plane of the cooling tower, beneath the fans in the stacks, or immediately downstream of the drift eliminators. The measurements are to be taken at a minimum of 24 equal area points in the sample plane.

3.9.1 For circular sample planes without hub effects, including natural draft towers, the sample locations will be based on the total area and located at the centroids of equal annular sample zones with a minimum of 4 radii and 6 points per radius. If additional locations are desired, the number of radii and/or the number of points per radius may be increased.

3.9.2 For circular sample planes with hub effects, the sample location will be based on the net area and located at the centroids of equal annular sample zones with a minimum of 4 radii and 6 points per radius. If additional locations are desired, the number of radii and/or the number of points per radius may be increased. For circular sampling planes the position of the sampling locations is calculated by:

$$X_m = \frac{D_s}{2} - \sqrt{\left[\left(\frac{2M - 2m + 1}{8M}\right)\left(D_s^2 - D_h^2\right)\right] + \left(\frac{D_h}{2}\right)^2} \quad (3)$$

Where;

X_m = sample location, distance from wall, m (ft)

D_s = stack diameter, m (ft)

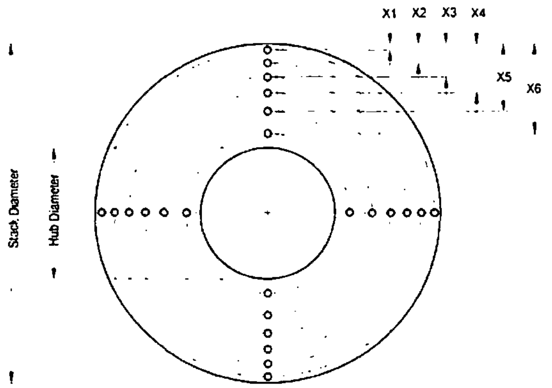
D_h = hub diameter, m (ft)

M = number of sampling points on a single radius

m = sampling point number

The hub diameter should be the larger diameter of the fan hub seal disk or the diameter of the circle described by the calculate the sample positions for circular sample planes without hub effects by setting the hub diameter equal to zero.

An illustration of a typical sampling grid follows:



Negative (toward the fan) velocities may occur at interior points at the fan discharge. If this occurs, no sampling shall be conducted at these points and these areas shall be subtracted from the total fan stack exit plane area. If initial 6-point fan traverses indicate a negative velocity at an interior point, then the number of sample points per radii should be increased with the objective of sampling six or more areas of positive flow.

3.9.2 For rectangular sample planes, the sample locations will be at the centroids of a matrix of equal area sample zones of similar length and width.

3.10 Drift Collection System.

3.10.1 Sample Point Velocity and Temperature. For isokinetic sampling, both the velocity and temperature measurements must be con-current with the drift sample collection. For velocity measurements, two types of instruments are commonly used. The potential advantages and limitations of each include:

a) Air Pitot tube. The air Pitot may be suited for velocity measurements in the cooling tower environment. Total and velocity pressure ports must be large enough in diameter to preclude plugging by water droplets which could cause erroneous results. Air Pitot tubes may be unsuitable for flow measurements at low air velocities due to difficulty in measuring the small differential pressure.

b) Propeller anemometer. The propeller anemometer may be suitable for velocity measurements in the cooling tower environment. When oriented into the air flow, velocity vectors are easily measured. Potential errors due to rapidly changing vectors are minimized by the cosine response of the instrument. Propeller anemometers are, however, influenced by the impact of water droplets and tend to over measure air flows in pulsing flow regimes such as found over cooling tower fans.

3.10.1.1 Sample plane without angular component. The air velocity and temperature must be measured at each sample location.

3.10.1.2 Sample plane with angular component. Air velocity, temperature and the angle of flow relative to the sampling plane must be measured at each sample location. Since flow angle can affect the drift results in field tests, the sampling technique must be adjusted to eliminate this bias.

Whenever angular flow is present, the probe must be aligned with the flow to insure isokinetic sampling. If the sample nozzle is oriented normal to the sample plane but not aligned with the airflow, the effective velocity through the nozzle opening is reduced by the cosine of the angle of deviation from normal direction. The sample flow rate will not be isokinetic. If the sample nozzle is aligned with the airflow but not oriented in the normal direction, the sample proportionality for the sample point will be compromised. Isokinetic and proportional sampling needs are both satisfied by orienting the sample probe into the direction of the airflow and adjusting the nominal base sampling time by the cosine of the angle of deviation from the normal direction.

When angular measurements are required, a protractor or inclinometer (accurate to 2°) must be mounted on the velocity measuring instrument. The velocity measuring instruments commonly used incorporate one of the following angle indicating devices:

a) Secondary Pitot tube. A Pitot tube mounted at right angles to the primary velocity measuring device.

b) Direction vane. A sail-like device mounted near the primary velocity measuring device on pivots that allow the sail to align itself with the air flow.

c) Tell-tail. A string or ribbon attached near the primary measuring device to indicate the air flow vector.

3.10.2 Isokinetic Sampling Train. This sampling method collects drift emissions by drawing a portion of the cooling tower exit airstream into a collection apparatus at the same speed and direction (isokinetically) as the local velocity in the cooling tower. The design of the sample shall be such that external surfaces of the nozzle are maintained hot enough to flash off water impinging on the outside surface. Materials of construction in contact with the sample shall not contain any elements or tracers that will be analyzed and shall be appropriate for any rinsing or handling requirements.

3.10.2.1 The primary collection media of the HBIK system consists of a specially configured nozzle-tube filled with tightly packed glass beads of approximately 6mm (1/4 inch) in diameter in a tube of 12 mm (1/2 inch) minimum inside diameter and a minimum of 100 mm (4 inches) long. A heating element and associated temperature control system are used to maintain the sample tube at a temperature sufficient to evaporate the water droplets. The temperature of the bead pack should be maintained above the boiling point of water at that location. Sufficient heating has occurred if the air temp is 5 degrees Celsius (10 degrees F) or above the stack temp at the local sampling station. The minerals or tracer entrained in the drift water droplets are deposited on the heated glass beads.

Other materials of construction are acceptable provided they are inert and do not contain leachable concentrations of the tracer elements used for the calculation of the drift rate or emitted mass.

3.10.2.2 The secondary collection media of the system is a filter assembly in series with the nozzle-tube. Its purpose is to collect any minerals or tracer which pass through the primary collection media. It is recommended that the filter assembly be attached to or placed as close to the nozzle as practical and oriented to minimize aerodynamic interference with the sample flow. Filters with one micron porosity are recommended. The filter media used should be free of or have very low concentrations of the minerals or tracers to be analyzed.

3.10.2.3 An inspection of the filter shall be made at the conclusion of the test to ensure its integrity. If the filter is damaged, the test shall be repeated.

3.10.3 Sample Gas Volume Control and Measurement. The final collection media outlet is connected via a vacuum tight line to a vacuum pump. The vacuum pump has control valves to set the desired sampling rate. The system contains a calibrated volumetric or flow rate device and both temperature measurement and sample gas path pressure measurement for correction of air density differences between the sample nozzle and flow measurement station.

3.11 Duration of Test. The duration of the test is governed by the expected drift rate, concentration of minerals or tracers, their relationship to the expected value of procedural blank and the detection limit of the analytical method(s). The test shall be sufficiently long to collect enough tracer mass on the IK tube to yield a sample which is a minimum of five (5) times the sample tube procedural blank or five (5) times the detection limit of the tracer element for the analytical equipment, whichever is greater.

3.12 Ambient Air Background Sample. An ambient air background sample shall be taken concurrently with the drift test to determine the concentration of potential tracer elements in the ambient air. Types of measurement devices in common use include suitable ambient air filter samplers or the isokinetic equipment sampling upwind from the tower. The ambient analysis is performed to determine the concentration of elements or tracers present in both the circulating water and ambient air stream. In order to minimize contamination of the ambient sample from the cooling tower, the ambient sampler should be placed between 5 meters and 15 meters from the tower inlet. The ambient sampler should be designed to prevent impingement from above so that drift droplets or tower blow through are not collected.

Because the calculated drift rate is a function of the tracer elements that are captured in the exhaust air stream, there is a potential drift emission rate impact (not mass emission rate impact) associated with the tracer elements in the ambient air that enter the cooling tower. The effect of ambient airborne elements on the calculated drift rate is a function of the scrubbing efficiency of the tower and the ratio of the element in the ambient to the concentration in the stack.

Review of available literature for comparable applications indicates that a scrubbing efficiency of approximately 90% is reasonable for most cooling tower applications. This means that the potential drift rate bias associated with collection of an unscrubbed ambient element used as a tracer is approximately 10% of the ratio of the ambient tracer concentration to the stack tracer concentration. In order to minimize the potential positive (higher value) bias in reported drift rate, the ratio of tracer element concentration in the fan stack to the concentration of the tracer in the ambient shall meet the requirements described in Section 4.2. For tracer elements that meet these criteria, the potential positive bias associated with the ambient tracers is approximately 2% of the reported drift rate. Because by definition "mass emission rate" includes all mass exiting the tower regardless of source, the presence of tracer elements in the ambient air does not present a positive bias in the reported mass emission rate.

In small towers or in test cells it may be cost effective to artificially introduce a tracer element into the circulating water that is not present in the ambient air. This method reduces the potential drift rate bias due to the stack sampling of unscrubbed ambient elements and can greatly shorten the sample time.

3.13 Typical Test Sequence. The typical sequence for a drift test is as follows:

a) Select sample plane and calculate sample locations.

b) Assemble drift sampling system and conduct pretest leak check.

c) Conduct water flow and fan horsepower measurements (if applicable) and initiate monitoring of required test parameters,

d) Collect circulating water sample.

e) Initiate isokinetic sampling and background measurement.

f) Collect intermediate circulating water sample(s).
g) Conclude isokinetic drift sampling of the selected sample plane.
h) Collect final circulating water sample at the conclusion of the test and terminate background sample measurement.
i) Perform post test leak check on drift sample system
j) Recover the drift samples from the sample collection system.
k) Prepare the drift samples, circulating water samples, water blanks, nozzle tube blanks, filter blanks, etc. for transport to the laboratory for analysis.

3.14 Leak Checks. A leak check of the system prior to the start of the sample collection is recommended. If during the sampling run, a component change becomes necessary, a leak check shall be conducted immediately before the change is made. After the component change is completed a leak check of the reassembled system is recommended. A leak check at the conclusion of each test is mandatory before disassembly of the system.

Pretest leak checks shall be conducted at a 50 kPa (15 in.-Hg) vacuum or the highest vacuum anticipated prior to sampling, whichever is less. Intermediate and post test leak checks shall be at a vacuum equal to or greater than that observed during sampling. If the leakage rate is less than 0.01 l/s (0.02 cfm) or 4% of the average sampling rate, whichever is less, the test results are acceptable without data corrections. If a higher leakage rate is observed, the sample volumes shall either be corrected or the sampling repeated. Equivalent criteria shall be employed with other gas flow measuring systems.

3.15 Sample Recovery.

The sampling apparatus should be moved to a clean area or laboratory for disassembly and recovery of the collected minerals or tracer from the system components.

The sample recovery techniques used should take into consideration the following:

a) Only ultra pure water and/or reagents should be used to rinse and recover the drift minerals or tracers from the sample apparatus components.
b) Multiple small volume rinses are preferred to a few large rinses.
c) The total rinse volume used should be minimized to avoid unnecessary dilution of the samples to be analyzed.
d) The use of ultrasonic cleaners may enhance sample recovery from the apparatus components, reduce rinse volume and speed recovery.
e) Filters should only be handled with clean tweezers or tongs.
f) Gloves or other protective clothing should be worn, as necessary, to protect against contaminating the samples.

For Samples recovered in the field, the following additional procedures should be followed

g) The recovered materials and rinses should transferred to pre-cleaned bottles for storage and transfer to the lab for analysis. (Cleaning should be in accordance with recognized protocols for the particular analysis to be used.)
h) Samples should be stabilized with appropriate reagents, as recommended, for the laboratory analysis procedure.
i) Blank or reference samples for the water, reagents and filters used should be prepared at the same time as the sample recovery.
j) Sample volumes must be accurately measured or weighed to provide data for later calculation.
k) Samples should be labeled and logged on a custody or transmittal sheet for transfer to a laboratory for analysis.

3.16 Sample Analysis. Several nationally recognized published reference documents are available for water sample preparation and analysis.

3.16.1 Listed in Appendix A are several preparation methods which are presented for information and reference purposes.

3.16.2 Typical Drift Sample Analysis Methods. Quantitative analysis of selected tracer elements in both the tower circulating water samples and the collected drift samples are performed by using appropriate analytical instruments. The instrument used must be standardized with one or more standard concentration solutions containing the required reference elements. After the standardization, the detection limit(s) are determined. The final detection limit for each element must account for the magnitude of any interferences from the other elements present in the sample.

4.0 CALCULATIONS

4.1 Calculation of Air Flow

4.1.1 Calculation of Sample Point Velocity. The air velocity at each sampling point is measured by an anemometer or Pitot tube oriented into the flow. To maintain isokinetic conditions, the inlet nozzle velocity of the sampling device is set to match the tower sample plane velocity as closely as possible.

If an anemometer is used, velocity in the flow direction is determined from the anemometer speed (including calibration corrections).

If a Pitot tube is used, velocity in the flow direction is calculated from:

$$U_{s,i} = K * C_{pitot} * \sqrt{\frac{\Delta P_{s,i}}{\rho}} \quad (4)$$

Where:

$U_{s.}$ = Air velocity m/s (ft/min)

C_{pitot} = Calibration coefficient of the air pitot tube, dimensionless

K = √2, for SI units (1097 fpm $(\text{lbm/ft}^3/\text{inwg})^{1/2}$ for I-P units)

ρ = Density of air at the sampling point kg/m^3, (lbm/ft^3)

$\Delta P_{s,i}$ = Differential pressure at each sampling point also called velocity pressure of the pitot when aligned in the air stream, Pa (inH_2O)

The density is a function of the barometric pressure, the stack temperature and stack gas composition. The composition of the stack gas is usually assumed to be saturated air.

4.1.2 Calculation of Sampling Time. If angular flow is present, the angle of the flow direction must be measured in addition to its velocity. The sample time at each point must then be adjusted from the nominal sample time. The adjustment is given by the following equation:

$$t_{2,i} = t_{1,i} * COS\ \theta_i \quad (5)$$

For each sample point:

$t_{2,i}$ = Actual sampling time with adjustment for the angularity of the flow angle, min

$t_{1,i}$ = Nominal sampling time, min

θ_i = angle between flow direction and the normal to the sample plane, degrees

4.1.3 Calculation of Sample Flow Rate. The sample velocity is determined for each point from the sample point volumetric flow rate,

$$U_{N,i} = K_0 \frac{Q_{N,i}}{A_N} \quad (6)$$

For each sample point, i:

$Q_{N,i}$ = Sample volumetric flow rate, L/min (ft^3/min)

A_N = Area of nozzle, m^2 (ft^2)

K_0 = 16.667 for SI units (1.0 for I-P units)

$U_{N,i}$ = Sample velocity at nozzle inlet, m/s (ft/min)

In most sample collection systems, the moisture is removed from the gas stream and the temperature at the sample gas volume control and measurement station differs from the sample temperature. Therefore, the sample volume at the flow measuring device must be corrected as given in the following equation:

$$U_{N,i} = \frac{Q_{M,i} K_0 \rho_{M,i}}{A_N \rho_{N,i}} M_{F,i} \quad (7)$$

For each sample point:

$Q_{M,i}$ = Measured sample volumetric flow rate, L/min (ft^3/min)

$\rho_{M,i}$ = density of air at the metering device

$\rho_{N,i}$ = density of air at the sampling plane

$M_{F,I}$ = correction factor depending on moisture removal system employed.

For a system including a desiccant (producing dry air),

$$M_{F,i} = (1 + \omega_{N,i}) \quad (8)$$

and for systems removing only condensed water,

$$M_{F,i} = \frac{1 + \omega_{N,i}}{1 + \omega_{M,i}} \quad (9)$$

Where:

$\omega_{N,i}$ = specific humidity at the sampling plane

$\omega_{M,i}$ = specific humidity metering device

In most cases the air at the sampling location can be assumed to be saturated. For systems removing only condensed water, the air at the metering location will be saturated. The density of dry and saturated air and the specific humidity of saturated air can be found in standard psychrometric tables such as that found in CTI ATC-105.

4.1.4 Monitoring of Sample Flow. The local isokinetic percentage is calculated by

$$IK\%_i = 100 \frac{U_{N,i}}{U_{S,i}} \quad (10)$$

The volumetric flow rate at each sampling point should be set so that the isokinetic percentage is as close as possible to 100 percent.

4.1.5 Determination of Overall Isokinetic Percentage. The overall isokinetic percentage is determined by

$$IK\% = 100\frac{\sum\limits_{i=1,np} U_{N,i} t_{2,i}}{\sum\limits_{i=1,np} U_{S,i} t_{2,i}} \qquad (11)$$

Where:

np = total number of sampling points.

If the test is more than ± 10% from 100% isokinetic the test should be rerun.

4.1.6 Determination of Bead Pack Tracer Mass. The amount of tracer mass collected on the bead pack is corrected for the amount of the tracer element (e.g. sodium, calcium or magnesium mass) that is present on a "field blank" bead pack. A field blank bead pack is a bead pack that is taken into the field and handled in the same manner as a bead pack that is used for testing, but it is not exposed at the fan stack. The objective of a field blank is to determine the amount of tracer element that is inherent in the handling and analysis of the test bead pack. The corrected elemental test mass is the mass of each element that is collected in the test bead pack minus the elemental mass present in the field blank.

4.1.7 Determination of Filter or Back-up Media Mass. The amount of tracer mass collected on the back up filter or water filled impingers downstream of the bead pack is corrected for the amount of the tracer element (e.g. sodium, calcium or magnesium mass) present in a "field blank" filter or water solutions that are used to make the back up impinger solutions. A field blank filter is a filter that is handled in the same manner as a filter that is used in a test, but the filter is not exposed at the fan stack. The objective of a field blank is to determine the amount of tracer element that is inherent in filter materials or that is introduced in the handling and analysis of the test filters. The corrected elemental test mass is the mass of each element that is collected in the test filter minus the elemental mass present in the field blank.

4.1.8 Determination of Net Tracer Mass. The net tracer mass is the total elemental tracer mass collected in both the heated bead pack and back up media after the bead pack and back up media are corrected for field blanks.

4.2 Selection of Tracer Elements. Tracers that are used for the calculation of drift should meet the following criteria:

a) The sample mass in the test bead pack should be at least 5 times the reported detection limit for the candidate tracer.

b) The sample mass in the test bead pack should be at least 5 times the bead pack blank for the candidate tracer.

c) The ambient concentration of the tracer element should be less than 20% of the stack concentration.

d) The CTI test representative will evaluate the individual test runs and choose the most representative tracer elements and analyses. The test representative may discard outlying test results.

If several tracers meet the selection criteria for analysis, the results are presented in tabular format for comparison and averaged to present an overall drift rate.

4.3 Calculation of Drift Emission Rate. The following equation is used to calculate the drift results:

$$\%Drift = K_1 * \frac{A_{SP}}{A_N} * \frac{W_T}{Q_{WT} * t_E * C_{TC}} \qquad (12)$$

Where:

A_N = Nozzle area, m^2 (ft^2)

A_{SP} = Sample plane area, m^2 (ft^2)

C_{TC} = Circulating Water tracer concentration, mg/L (ppm)

K_1 = 10 for SI units (37.854 for I-P units)

Q_{WT} = Water flow rate during test, L/s (gpm)

t_E = Total equivalent sample time, sec, (min)

W_T = Net weight of tracer, µg

5.0 REPORT OF RESULTS

5.1 Scope. The report of the test shall include:

a) Calculated drift rate.

b) The data required by this test procedure.

c) Any deviations from this procedure.

d) A description of the cooling tower with its orientation and principle dimensions.

e) A sketch of the installation which shows the location where water flow and fan power (if required) were measured.

f) A sketch showing location of drift sampling points.

g) Other required measurements.

5.2 **Test Forms.** The test observations shall be entered on a CTI Form (or equal), which shall include original data sheets which should be authenticated by the signatures of the attending representatives of the manufacturer, the purchaser, and the CTI.

5.3 **Distribution.** Upon completion of an acceptance test, one copy of the test forms and subsequent test report shall be distributed to tower owner and the tower manufacturer or their designated representative. The original is retained by the CTI.

5.4 **Security.** Information on any acceptance test will be available only to the tower owner, the tower manufacturer or their designated representatives, and the CTI. Such information will not be accessible to CTI members.

5.5 **Potential Test Influences.** Inconsistencies may result due to the following considerations which should be discussed in the test report in the event that they existed during testing.

a) Condensation collecting in the tower may pick up minerals or tracers deposited in the plenum. If this condensation is collected in the collection apparatus the measured drift rate will be artificially high.

b) Air flow and/or circulating water flow rates, which differ significantly from design, can influence the tower drift rate.

c) Improper distribution of air and/or water can have a negative impact on the performance of the drift eliminators.

d) Cross-flow towers should have the cold water basin level at the recommended height to prevent air bypass.

e) If foam in the cooling tower is collected in the sampler, the measured drift rate will be artificially high.

f) Surface tension fluctuation of the cooling tower water during the test or between tests.

APPENDIX A
Examples of Typical Sample Preparation Methods

ACIDIFICATION AND DILUTION

This is the simplest procedure used to prepare surface and ground water samples for analysis by flame atomic absorption spectroscopy (FLAA) or by inductively coupled argon plasma spectroscopy (ICP). At the time of analysis the sample is diluted, if necessary, and acidified with nitric acid to obtain approximately a 10% nitric acid sample matrix.

METHOD 3005

Method 3005 is an acid digestion procedure used to prepare surface and ground water samples for analysis by flame atomic absorption spectroscopy (FLAA) or by inductively coupled argon plasma spectroscopy (ICP).

For total recoverable metals the entire sample is acidified at the time of collection with nitric acid. At the time of analysis the sample is heated with acid and substantially reduced in volume. The digestate is filtered and diluted to volume, and is then ready for analysis.

For dissolved metals the sample is filtered four a 0.5 mm filter at the time of collection and the liquid phase is then acidified at the time of collection with nitric acid. At the time of analysis the sample is heated with acid and substantially reduced in volume. The digestate is filtered (if necessary) to volume, and is then ready for analysis.

METHOD 3010

Method 3010 is a digestion procedure that is used for the preparation of aqueous samples, EP and mobility-procedure extracts, and wastes that contain suspended solids for analysis, by flame atomic absorption spectroscopy (FLAA) or by inductively coupled argon plasma spectroscopy (ICP).

A mixture of nitric acid and the material to be analyzed is refluxed in a covered Griffin beaker. This step is repeated with additional portions of nitric acid until the digestate is light in color or until its color has stabilized. After the digestate has been brought to a low volume, it is refluxed with hydrochloric acid and brought up to volume.

METHOD 3050

Method 3050 is an acid digestion procedure used to prepare sediments, sludges, and soil samples for analysis by flame or furnace atomic absorption spectrosocopy (FLAA and GFAA, respectively) or by inductively coupled argo plasma spectroscopy (ICP).

A representative sample is digested in nitric acid and hydrogen peroxide. The digestate is then refluxed with either nitric acid or hydrochloric acid. Dilute hydrochloric acid is used as the final reflux acid for (1) the ICP analysis of As and Se, and (2) the flame AA or ICP analysis of Al, Ba, Ca, Dc, Cr, Co, Cu, Fe, Mo, Pb, Ni, K, Na, T1, V, and Zn. Dilute nitric acid is employed as the final dilution acid for the furnace AA analysis of As, Be, Cd, Cr, Co, Pb, Mo, Se, T1, and V.

APPENDIX B
Examples of Typical Laboratory Analysis Methods

METHOD 6010

Method 6010 describes the procedures for inductively coupled argon plasma spectrosocopy (ICP) in determining elements including metals in solution. This method is applicable to a large number of metals and wastes. All matrices, including ground water, aqueous samples, EP extracts, industrial wastes, soils, sludges, sediments and other solid wastes, require digestion prior to analysis.

ICP is used for the simultaneous or sequential, multi-elemental determination of elements by measuring the element-emitted light with optical spectrometry. Samples are nebulized and the resulting emission spectra are produced by a radio-frequency inductively coupled plasma. The spectra are dispersed by a grating spectrometer, and the intensities of the lines are monitored by photomultiplier tubes. Background correction is required for trace element determination. In direct-aspiration atomic absorption spectroscopy, a sample is aspirated and atomized in a flame. A light beam from a hollow cathode lamp or an electrodeless discharge lamp is directed through the flame into a monochromator and onto a detector that measures the amount of absorbed light. Absorption depends upon the presence of free unexcited ground-state atoms in the flame. Because the wavelength of the light beam is characteristic of only the metal being determined, the light energy absorbed by the flame is a measure of the concentration of that metal in the sample. This principle is the basis of atomic absorption.

METHOD 7000 AND 7191

Method 7000 is used for the determination of metals in drinking surface and saline waters and domestic and industrial wastes by Atomic Absorption. While drinking water free of particulate matter may be analyzed directly, ground water, other aqueous samples, EP extracts, industrial wastes, soils, sludges, sediments, and other solid wastes require digestion prior to analysis. Method 7191 is a modification of Method 7000 that is specific for chromium by Atomic Absorption using the furnace technique.

In direct-aspiration atomic absorption spectroscopy, a sample is aspirated and atomized in a flame. A light beam from a hollow cathode lamp or an electrodeless discharge lamp is directed through the flame into a monochromator, and onto a detector that measures the amount of absorbed light. Absorption depends upon the presence of free unexcited ground-state atoms in the flame. Because the wavelength of the light beam is characteristic of only the metal being determined, the light energy absorbed by the flame is a measure of the concentration of that metal in the sample. This principle is the basis of atomic absorption.

When using the furnace technique in conjunction with an atomic absorption spectrophotometer, a representative aliquot of the sample is placed in the graphite tube in the furnace, evaporated to dryness, charred, and atomized. As a greater percentage of available analyte atoms is vaporized and disassociated for absorption in the tube rather than the flame, the use of smaller sample volumes or detection of lower concentrations of elements is possible. The principle is essentially the same as with direct aspiration atomic absorption, except that a furnace, rather than a flame is used to atomize the sample.

NEUTRON ACTIVATION ANALYSIS

Neutron activation analysis (NAA) is a highly selective and sensitive analytical method capable of measuring trace amounts of many elements. NAA is performed by first irradiating a sample with neutrons to produce radioactive isotopes of the stable elements present in the sample, then selectively measuring the activated products using techniques such as gamma-ray spectroscopy or specific radiochemical separation procedures. NAA may be applied to relatively small samples of solids or liquids since it is independent of the chemical form of the elements and requires a minimum of pre-analysis preparation or chemistry, thus minimizing reagent or laboratory contamination.

APPENDIX C
Equations for Isokinetic Sampling and Drift Calculations Using Volumetric Flow Measurement Methods

C-1 Equations for Calculating Drift Rate and Other Emission Parameters

The following equation determines the drift rate as a percent of the circulating water flow rate which is the primary purpose of the test code.

$$\%Drift = K_1 * \frac{A_{SP}}{A_N} * \frac{W_T}{Q_{WT} * t_E * C_{TC}} \qquad (13)$$

Where:

A_N = Nozzle area, m^2 (ft^2)
A_{SP} = Sample plane area, m^2 (ft^2)
C_{TC} = Circulating Water tracer concentration, mg/L
K_1 = 10 for SI units (37.854 for I-P units)
Q_{WT} = Water flow rate during test, L/s (gpm)
t_E = Total equivalent sample time, s (min)
W_T = Net weight of tracer, μg

If the total mineral concentration of the circulating water flow is measured during the test in addition to the tracer concentration, the overall mass flux of the cooling tower can also be determined.

$$E_R = K_7 * \%Drift * Q_{WT} * \rho_{CW} * TDS \qquad (14)$$

Where:

E_R = Emission rate, g/s (lb/hr)
K_7 = 10^5 for SI units (1.997×10^5 for I-P units)
TDS = Total dissolved solids mg/L

$$C_{STD} = K_8 * \frac{E_R}{Q_{STD}} \qquad (15)$$

Where:

C_{STD} = Concentration of mineral emission, mg/L (g/ft^3)
K_8 = 10^{-3} for SI units (7.9366 for I-P units)
Q_{STD} = Sample plane flow rate, dry standard conditions, L/s (ft^3/s)

C-2 Threshold Wind Velocity

Examples to illustrate the calculation of the acceptable wind velocity or threshold velocity are provided below.

Example: High BHP

32 ft diameter stack at the exit plane, 1,500,000 cfm, 1865 fpm average exit velocity

If the measured fan motor output power is 185 hp and the design fan motor output power is 200 then the corrected threshold velocity would equal:

$$V_{Cth} = .75 * V_{U_{(avg)}} * \sqrt[3]{\frac{hp_T}{hp_D}} = .75 * 1865 * \sqrt[3]{\frac{185}{200}} = 1363\, fpm = 15.4\, mph \tag{16}$$

Example: Low BHP

32 ft diameter stack at the exit, 1,000,000 cfm, 1244 fpm average exit velocity

If the measured fan motor power is 92 bhp and the design fan motor output power is 100 bhp then the corrected threshold velocity would equal:

$$V_{Cth} = .75 * V_{D_{avg}} * \sqrt[3]{\frac{hp_T}{hp_D}} = .75 * 1244 * \sqrt[3]{\frac{92}{100}} = 1209\, fpm = 10.3\, mph \tag{17}$$

C-3 Equations for Overall Test Isokinetic Calculations (Flow Rate Based)

The following equations can be used to calculate the isokinetic sampling velocity for each sampling station:

At the conclusion of the test, the overall isokinetic sampling percentage can be calculated by:

$$IK\% = 100 \frac{\sum_{i=1,np} U_{N,i} t_{2,i}}{\sum_{i=1,np} U_{S,i} t_{2,i}} \tag{18}$$

Where

$U_{N,I}$ = Velocity of air entering the sampling nozzle, m/s (ft/min)

$Us_{,i}$ = Velocity of air at sampling point i, m/s (ft/min)

$t_{2,i}$ = Sampling time at sampling point, i, min

np_i = Number of sampling points

C.4-3 Drift Rate Example

C-4.3.1 Flow Rate Based Example

HGBIK Stack Data Spreadsheet

CTI Sample Data Set

BP in Hg	IK Tube Diam in	Basetime min	Tube Area ft^2	S-Type Pitot Coef Cp	Orifice Discharge Coefficient C_D
29.66	0.73	18	0.00291	0.845	1.520

Sampling Station	Time	Stack Temp F	Orifice Temp F	Stack Velocity DP Inwg	Orifice Static Press Inch Hg Vac	Orifice DP Inches H2O	Avg Angle Deg	Time min	IK Ratio %
1	11:08:08	99.0	74.2	0.33	7	1.3	39	14.0	101%
2	11:22:07	99.9	75.0	0.38	8	1.5	29	15.7	98%
3	11:37:52	99.8	75.9	0.48	11	2.3	23	16.6	101%
4	11:54:26	100.8	78.0	0.55	13	3	20	16.9	101%
5	12:11:20	102.0	78.9	0.48	11	2.3	21	16.8	100%
6	12:28:09	102.8	81.6	0.11	4	0.37	45	12.7	99%
STOP	12:40:52								
1	12:58:32	100.6	79.3	0.43	10	2	38	14.2	101%
2	13:12:43	103.3	82.3	0.52	12	2.6	28	15.9	100%
3	13:28:37	103.4	82.8	0.62	15	4	18	17.1	103%
4	13:45:44	103.1	82.8	0.66	16	4.3	17	17.2	100%
5	14:02:57	102.9	84.1	0.5	12	2.6	23	16.6	101%
6	14:19:31	103.3	86.2	0.08	3	0.26	45	12.7	98%
STOP	14:32:14								
1	15:07:14	103.8	85.4	0.45	10	2	32	15.3	99%
2	15:22:30	104.8	86.1	0.55	12	2.8	6	17.9	100%
3	15:40:24	103.4	85.1	0.5	11	2.4	13	17.5	100%
4	15:57:56	103.5	85.6	0.58	13	3.1	14	17.5	100%
5	16:15:24	103.6	85.3	0.37	9	1.6	20	16.9	100%
6	16:32:19	103.9	86.0	0.06	2	0.2	45	12.7	101%
STOP	16:45:02								
1	17:06:03	101.2	86.2	0.41	10	1.7	45	12.7	95%
2	17:18:47	103.5	85.5	0.55	12	2.8	36	14.6	100%
3	17:33:20	103.7	84.3	0.66	16	4.4	22	16.7	101%
4	17:50:02	103.5	82.2	0.66	16	4.4	25	16.3	101%
5	18:06:20	102.9	83.3	0.45	11	2.2	18	17.1	101%
6	18:23:27	103.5	83.8	0.05	1	0.15	45	12.7	98%
STOP	18:36:11								100.2%

Total Sample Time
374.4

ATC-140 Drift Calcuation Spreadsheet
CTI Sample Data Set

Glass Bead	Sample ID		Ca	Mg
Sample	12	μ g	130	46
Bead Blank 1	13	μ g	0	0
Bead Blank 2	14	μ g	6	0
Bead Blank 3	15	μ g	13	0
Average Blank		μ g	6.3	0.0
Corrected Bead		μ g	127	46
Bead RDL			5	5

Back Up Filter	18	μ g	27	5
Filter Blank 1	19	μ g	12	0
Filter Blank 2	20	μ g	9	0
Filter Blank 3	21	μ g	17	0
Average Blank		μ g	12.7	0.0
Corrected Filter		μ g	16.5	5
Filter RDL			5	5

Net Mass Stack	μ g	143.5	51

Water Sample				
Sample 1	07	μ g/ml	210	64
Sample 2	08	μ g/ml	230	71
Sample 3	09	μ g/ml	180	56
		Avg	206.7	63.7

Nozzle Area	Stack Area
m^2	m^2
0.0002708	78.10
Waterflow Rate	Total Time
l/sec	sec
765.00	22464

Bead Ratio to RDL	
26.0	9.2
Bead Ratio to Blank	
43.3	NA

Ratio of Ambient to Stack	
19%	12%

	Drift Rate
Ca	**Mg**
0.0012%	**0.0013%**
Valid RDL Ratio	Valid RDL Ratio
Valid Bead\Blank	Valid Bead\Blank

CTI Sample Data Set

Stack Concentration			
		Ca	Mg
Collected Mass	microgram	127.0	46.0
Sample Time	min	374.4	374.4
Volumetric Flow	acfm	6.59	6.59
	m^3/min	0.187	0.187
Ratio of Nozzle to Stack			
Sampled Volume	m^3	69.9	69.9
Concentration	**µg/m^3**	**1.817**	**0.658**

Ambient Concentration			
		Ca	Mg
HiVol Filter	µ g	110	22
Filter Blank	µ g	12.7	0
Corrected Filter	µ g	97.3	22
Sample Time		695	695
Volumetric Flow	acfm	14	14
	m^3/min	0.397	0.397
Sampled Volume	m^3	276	276
Concentration	**µg/m^3**	**0.353**	**0.080**

Ratio of Ambient to Stack Conc	**19%**	**12%**

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United States
Environmental Protection
Agency

Health Risk and Exposure Assessment for Ozone

Second External Review Draft

Executive Summary

DISCLAIMER

This draft document has been prepared by staff from the Risk and Benefits Group, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. Any findings and conclusions are those of the authors and do not necessarily reflect the views of the Agency. This draft document is being circulated to facilitate discussion with the Clean Air Scientific Advisory Committee to inform the EPA's consideration of the ozone National Ambient Air Quality Standards.

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February 2014

Health Risk and Exposure Assessment for Ozone

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Executive Summary

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Health and Environmental Impacts Division
Risk and Benefits Group
Research Triangle Park, North Carolina 27711

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Executive Summary

Introduction

As part of the review of the ozone National Ambient Air Quality Standards (NAAQS), EPA has prepared this Risk and Exposure Assessment (REA) to provide estimates of exposures to O3 and resulting mortality and morbidity health risks. The health effects evaluated in this REA are based on the findings of the O3 ISA (U.S. EPA, 2012) that short term O3 exposures are causally related to respiratory effects, and likely causally related to cardiovascular effects, and that long term O3 exposures are likely causally related to respiratory effects. The assessment evaluated total exposures and risks associated with the full range of observed O3 concentrations. In addition, the REA estimated the incremental changes in exposures and risks between just meeting the existing standard of 75 ppb and just meeting potential alternative standard levels of 70, 65, and 60 ppb using the form and averaging time of the existing standard, which is the annual 4th highest daily maximum 8-hour O3 concentration, averaged over three consecutive years. The results of the REA help to inform the O3 Policy Assessment (PA) in considering the adequacy of the existing O3 standards, and potential risk reductions associated with potential alternative levels of the standard.

As described in the conceptual framework and scope in Chapters 2 and 3, respectively, the health REA discusses air quality considerations (Chapter 4) and evaluates exposures and lung function risk in 15 urban case study areas (Chapters 5 and 6, respectively) and risks based on application of results of epidemiology studies in a subset of 12 urban case study areas (Chapter 7) . In addition, to place the urban area analyses in a broader context, the assessment estimated the national burden of mortality associated with recent O3 levels, and evaluated the representativeness of the urban areas in characterizing O3 exposures and risks across the U.S. (Chapter 8). To further facilitate interpretation of the results of the exposure and risk assessment, Chapter 9 provides a synthesis of the various results, focusing on comparing and contrasting those results to identify common patterns, or important differences. It also includes an overall integrated characterization of exposure and risk in the context of key policy relevant questions.

Conceptual Framework and Scope

The REA provides information to answer key policy-relevant risk questions with regards to evaluation of the adequacy of the existing standards and evaluation of potential alternative standards such as:

"To what extent do risk and/or exposure analyses suggest that exposures of concern for O_3-related health effects are likely to occur with existing ambient levels of O_3 or with levels that just meet the O_3 standard?

To what extent do alternative standards, taking together levels, averaging times and forms, reduce estimated exposures and risks of concern attributable to O_3 and other photochemical oxidants, and what are the uncertainties associated with the estimated exposure and risk reductions?"
In answering these questions, the REA evaluates total exposures and risks associated with the full range of observed O_3 concentrations, as well as the incremental changes in exposures and risks for just meeting the existing standard and just meeting several alternative standards. With regard to selecting alternative levels for the 8-hour O_3 standards for evaluation in the quantitative risk assessment, we base the range of levels on the evaluations of the evidence provided in the first draft PA, which received support from the CASAC in their advisory letter on the first draft PA. The

first draft PA recommended evaluation of 8-hour maximum concentrations in the range of 60 to 70 ppb, with possible consideration of levels somewhat below 60 ppb.

O_3 concentrations from 2006-2010 are used in estimating exposures and risks for the 15 urban case study areas. Because of the year-to-year variability in O_3 concentrations, the assessment evaluates scenarios for meeting the existing and potential alternative standards based on multiple years of O_3 data to better capture the high degree of variability in meteorological conditions, as well as reflecting years with higher and lower emissions of O_3 precursors. The 15 urban case study areas were selected to be generally representative of U.S. populations, geographic areas, climates, and different O_3 and co-pollutant levels. These urban case study areas include Atlanta, GA; Baltimore, MD; Boston, MA; Chicago, IL; Cleveland, OH; Dallas, TX; Denver, CO; Detroit, MI; Houston, TX; Los Angeles, CA; New York, NY; Philadelphia, PA; Sacramento, CA; St. Louis, MO; and Washington, D.C.

We have identified the following goals for the urban area exposure and risk assessments: (1) to provide estimates of the percent of people in the general population and in at-risk populations and lifestages with O_3 exposures above health-based benchmark levels; (2) to provide estimates of the percent of people in the general population and in at-risk populations and lifestages with impaired lung function (defined based on decrements in FEV1) resulting from exposures to O_3; (3) to provide estimates of the potential magnitude of premature mortality associated with both short-term and long-term O_3 exposures, and selected morbidity health effects associated with short-term O_3 exposures; (4) to evaluate the influence of various inputs and assumptions on risk estimates to the extent possible given available methods and data; (5) to gain insights into the spatial and temporal distribution of risks associated with O_3 concentrations just meeting existing and alternative standards, patterns of risk reduction associated with meeting alternative standards relative to the existing standard, and uncertainties in the estimates of risk and risk reductions.

In working towards these goals, we follow a conceptual framework, shown in the figure below, comprised of air quality characterization, review of relevant scientific evidence on health effects, modeling of exposure, modeling of risk, and risk characterization. As shown in this framework, modeling of personal exposure and estimation of risks, which rely on personal exposure estimates, are implemented using the Air Pollution Exposure model (APEX)[1] (U.S. EPA, 2012a,b). Modeling of population level risks for endpoints based on application of results of epidemiological studies is implemented using the environmental Benefits Mapping and Analysis Program (BenMAP)[2], a peer reviewed software tool for estimating risks and impacts associated with changes in ambient air quality (U.S. EPA, 2013). The overall characterization of risk draws from the results of the exposure assessment and both types of risk assessment.

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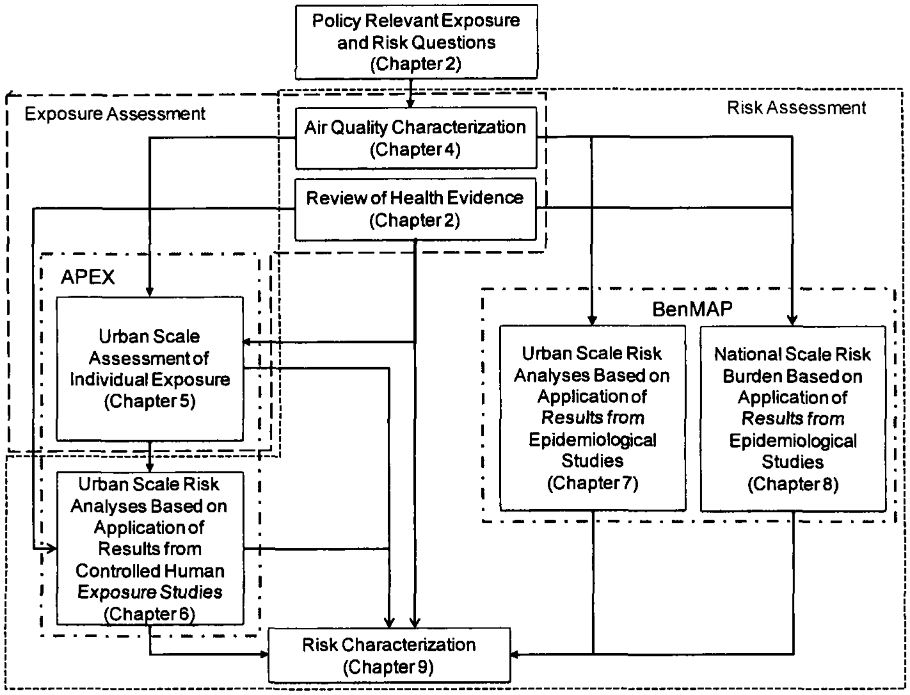
[1] APEX is available for download at http://www.epa.gov/ttn/fera/human_apex.html

[2] BenMAP is available for download at http://www.epa.gov/air/benmap/



Air Quality Considerations

In this analysis, we employed a photochemical model-based adjustment methodology (Simon et al, 2012) to estimate the change in observed hourly O3 concentrations at a given set of monitoring sites resulting from across-the-board reductions in U.S. anthropogenic NOx and/or VOC emissions. This information was then used to adjust recent O3 concentrations (2006-2010) in the 15 case study areas to reflect just meeting the existing standard of 75 ppb and just meeting potential alternative standard levels of 70, 65, and 60 ppb. Because the form of the existing O3 standard is based on the 3-year average of the 4th highest daily 8-hour maximum, we simulate just meeting the standard for two periods, 2006-2008 and 2008-2010.

The use of the model-based adjustment methodology is an example of how we have brought improvements into this review that better represent current scientific understanding. The model-based adjustment methodology represents a substantial improvement over the quadratic rollback method used to adjust O3 concentrations in past reviews. For example, while the quadratic rollback was a purely mathematical technique which attempted to reproduce the distribution of observed O3 concentrations just meeting various standards, the new methodology uses photochemical modeling to simulate the response in O3 concentrations due to changes in precursor emissions based on current understanding of atmospheric chemistry and transport. Second, quadratic rollback used the same mathematical formula to adjust concentrations at all monitors within each urban case study area for all hours, while model-based adjustment methodology allows the adjustments to vary both spatially across each case study area and temporally across hours of the day and across seasons. Finally, quadratic rollback was designed to only allow decreases in O3 concentrations, while the model-based adjustment methodology allows both increases and decreases in O3 concentrations, which more accurately reflects the scientific understanding that increases in O3 concentrations may occur in response to reductions in NOx emissions in some situations, such as in urban areas with a large amount of NOx emissions.

Several general trends are evident in the changes in O3 patterns across the case study areas and across the different standards under consideration. In all 15 case study areas, peak O3 concentrations tended to decrease while the lowest O3 concentrations tended to increase as the concentrations were adjusted to meet the existing and potential alternative standards. In addition, high and mid-range O3 concentrations generally decreased in rural and suburban portions of the case study areas, while O3 response to NOx reductions was more varied within urban core areas. In particular, while the annual 4th highest daily maximum 8-hour concentrations generally decreased in the urban core of the case study areas in response to reductions in NOx emissions, the seasonal mean of the daily maximum 8-hour O3 concentrations did not change significantly, though it did exhibit some increases or decreases in the various case study areas as the distribution of O3 was further adjusted to meet lower potential alternative standards.

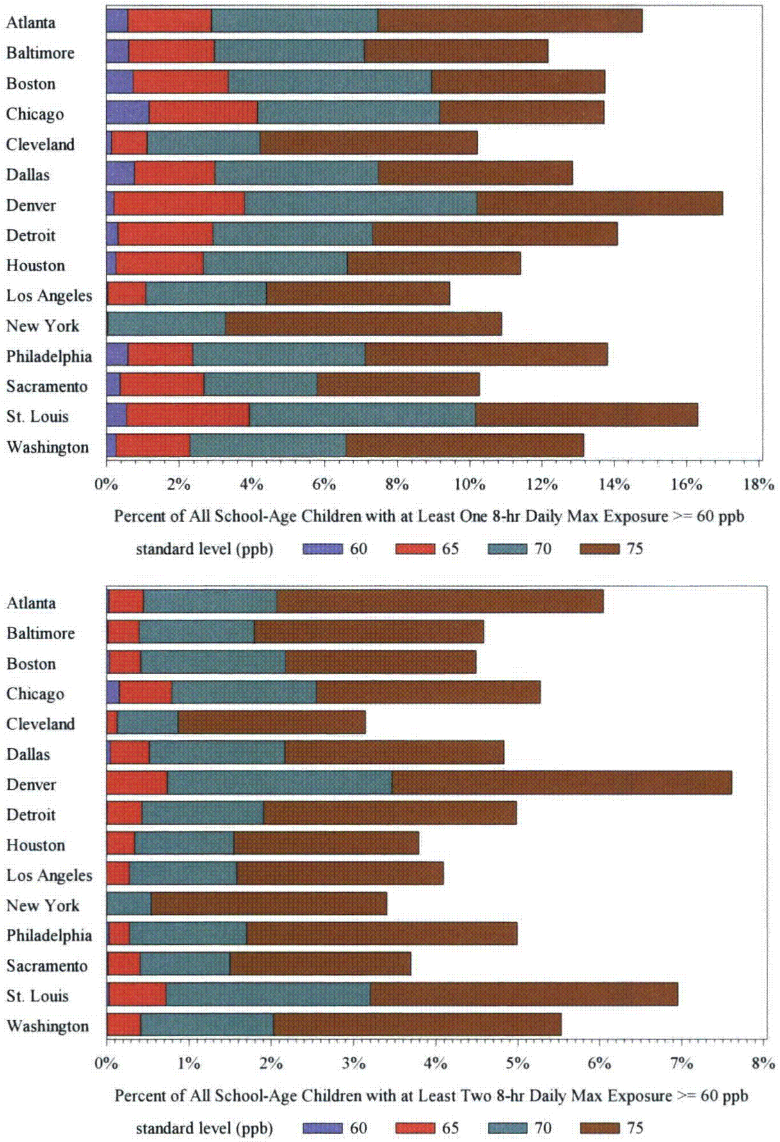
The adjustments to O3 to reflect just meeting existing and potential alternative standards are conducted by decreasing only emissions of anthropogenic NOx and VOC within the U.S. As such, the estimated changes in exposure and risk, based on these air quality changes, are solely attributable to changes in U.S. emissions.

Human Exposure Modeling

The population exposure assessment evaluated exposures to O3 using the APEX exposure model which uses time-activity diary and anthropometric data coupled with local meteorology, population demographics, and O3 concentrations to estimate the percent of study groups above exposure benchmarks. The analyses examined exposure to O3 for the general population, all school-aged children (ages 5-18), asthmatic school-aged children (ages 5-18), asthmatic adults (ages > 18), and older persons (ages 65 and older), with a focus on populations engaged in moderate or greater exertion, for example, children engaged in outdoor recreational activities. Exposure is assessed in the 15 urban case study areas for recent O3 (2006-2010) and for O3 adjusted to just meet existing and potential alternative standards for two design value periods (2006-2008 and 2008-2010). The analysis provided estimates of the percent of several populations of interest exposed to concentrations above three health-relevant 8-hour average O3 exposure benchmarks: 60, 70, and 80 ppb. These benchmarks were selected so as to provide some perspective on the public health impacts of O3-related health effects that have been demonstrated in human clinical and toxicological studies, but cannot currently be evaluated in quantitative risk assessments, such as lung inflammation and increased airway responsiveness. The ISA includes studies showing significant effects at each of these benchmark levels (U.S. EPA, 2012).

The analysis found that children are the population of greatest concern for O3 exposures due to the greater amount of time they spend outdoors engaged in moderate or higher exertion activities and the fact that children have the highest percent of exposures of concern of any of the at-risk populations. As a result, we focus on the results for children in this discussion.

The two figures below show the average across 2006-2010 of the percentage of school-aged children experiencing 8-hour exposure greater than 60 ppb for at least one exposure (top) and for at least two exposures (bottom) per year. Based on this information, no more than 26 percent of any



Average percent increases in percent of all school-age children exposed at or above 60 ppb-8hr for each study area over all years, for at least one exposure (left) and for at least two exposures (right) per year.

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

study group in any study area was exposed at least once at or above the 60 ppb-8hr benchmark, when meeting the existing standard. When meeting a standard level of 70 ppb, less than 20 percent of any study group in any study area was exposed at least once at or above the 60 ppb-8hr exposure benchmark. Meeting a standard level of 65 ppb is estimated to reduce the percent of persons at or above an exposure benchmark of 60 ppb-8hr to 10 percent or less of any study group and study area.

For the exposure benchmark of 70 ppb-8hr, less than 10 percent of any study group, including all school-age children, in any study area, was exposed at least once at or above the exposure benchmark when meeting the existing standard. For the highest exposure benchmark of 80 ppb-8hr, less than 1 percent of any study group in any study area was exposed at least once at or above the exposure benchmark when meeting the existing standard. These percentages are even smaller when meeting the lower alterative standard levels.

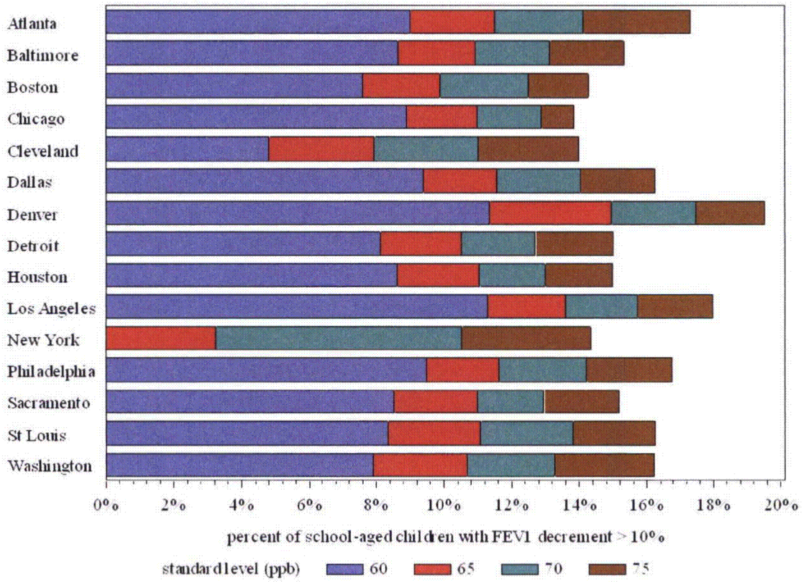
For two or more exceedances at the 60 ppb-8hr benchmark, less than 15 percent of any study group in any study area experience 8-hour exposure greater than 60 ppb-8hr when meeting the existing standard. There were no persons estimated to experience any multi-day exposures at or above 80 ppb-8hr for any study group in any study area, while 2.2 percent or less of persons were estimated to experience two or more exposures at or above 70 ppb-8hr, when meeting the existing standard or any of the alternative standard levels.

In addition, the exposure assessment also identified the specific microenvironments and activities that contribute most to exposure and evaluated at what times and how long individuals were in key microenvironments and were engaged in key activities, with a focus on persons experiencing the highest daily maximum 8-hour exposure within each study area. That analysis found that: (1) Children are an important exposure population subgroup, largely as a result of the combination of high levels of outdoor time and engagement in moderate or high exertion level activities. (2) Persons spending a large portion of their time outdoors during afternoon hours experienced the highest 8-hour O3 exposure concentrations given that O3 concentrations in other microenvironments were simulated to be lower than ambient concentrations. (3) Highly exposed children on average spend half of their outdoor time engaged in moderate or greater exertion levels, such as in sporting activities. Highly exposed adults also spent their outdoor time engaged in moderate or greater exertion levels though on average, not as frequently as children.

Health Risks Based on Controlled Human Exposure Studies

This analysis uses the estimates of exposure from APEX, combined with results from controlled human exposure studies, to estimate the number and percent of at-risk populations (all children, children with asthma, adults aged 18-35, adults aged 36-55, and outdoor workers) experiencing selected decrements in lung function. The analysis focuses on estimates of the percent of each at-risk population experiencing a reduction in lung function for three different levels of impact: 10, 15, and 20 percent decrements in FEV1. These levels of impact were selected based on the literature discussing the adversity associated with increasing lung function decrements (US EPA, 2012, Section 6.2.1.1; Henderson, 2006). Lung function decrements of 10 percent and 15 percent in FEV1 are considered moderate decrements; 10 percent is considered potentially adverse for people with lung disease, while a 15 percent is potentially adverse for active healthy people. A 20 percent decrement in FEV1 is considered a large decrement that is potentially adverse for healthy people and can potentially cause more serious effects in people with lung disease.

Two models were used to estimate lung function risks. One model was based on application of a population level exposure-response (E-R) function consistent with the approach used in the previous O3 review, and the other model was based on application of an individual level risk function (the McDonnell-Stewart-Smith (MSS) model), which is being introduced in this review. The main differences between the two models are that the MSS model includes responses for a wider range of exposure protocols (under different levels of exertion, lengths of exposures, and patterns of exposure concentrations) than the exposure-response model of previous reviews. Both models have a logistic form and are less sensitive to changes at very low concentrations of O3 than to higher O3 concentrations. As a result, the models show very few FEV1 responses > 10% when ambient concentrations are below 20 ppb and very few FEV1 responses > 15% when ambient concentrations are below 40 ppb. Because the individual level E-R function approach allows for a more complete estimate of risk, we focus on the results of the MSS model for this discussion.



Average percent increases in percent of all school-age children with FEV1 decrement ≥ 10 percent in each study area over all years

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

Lung function risks were estimated for each of the 15 urban case study areas for recent air quality (2006-2010) and for air quality adjusted to just meet existing and alternative standards for two design value periods (2006-2008 and 2008-2010). As with the exposure assessment, we focus on lung function decrements in children as they are the populations likely to have the greatest percentage at risk due to higher levels of exposure and greater levels of exertion. The figure above shows the risks just meeting the existing and potential alternative standard levels, where risk is taken to be the average value for each study area (over all years) of the percent of school-aged children with FEV1 decrement of 10 percent or greater. This figure shows that there are significant decreases in incremental risk for all 15 cities in the progression from the level of the existing standard, 75 ppb to the alternative standard levels of 70, 65, and 60 ppb. The risks in this figure for Washington, DC, for example, are about 16.3 percent for the existing standard level of 75 ppb and about13.3 percent for the alternative standard level of 70 ppb. The length of the brown bar is the incremental risk reduction (3 percent) in going from the existing standard of 75 ppb to the 70 ppb alternative standard. The pattern of reductions for lung function decrements larger than 15 and 20 percent are similar.

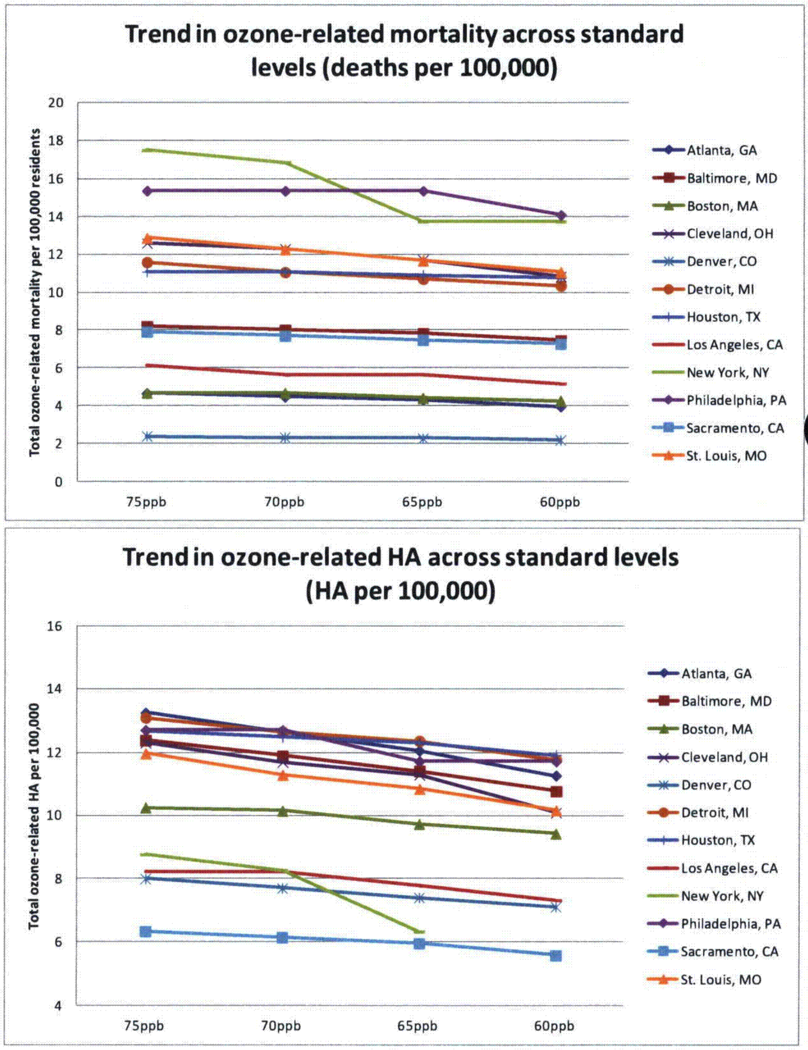
Health Risks Based on Application of Results of Epidemiological Studies

The epidemiology-based risk assessment evaluated mortality and morbidity risks from short-term exposures, as well as mortality risks from long-term exposures to O3, by applying concentration-response (C-R) functions derived from epidemiology studies. Most of the endpoints evaluated in epidemiology studies are for the entire study population. Because most mortality and hospitalizations occur in older persons, the risk estimates for this portion of the analysis are thus more focused in adults rather than children, and thus differ in focus compared to the human exposure and lung function risk assessments. The analysis included both a set of urban area case studies and a national-scale assessment.

The urban case study analyses evaluated mortality and morbidity risks, including emergency department (ED) visits, hospitalizations, and respiratory symptoms associated with recent O3 concentrations (2006-2010) and with O3 concentrations adjusted to just meet the existing and alternative O3 standards. Mortality and hospital admissions (HA) were evaluated in 12 urban areas (a subset of the 15 urban areas evaluated in the exposure and lung function risk assessments), while ED visits and respiratory symptoms were evaluated in a subset of areas with supporting epidemiology studies. The 12 urban areas were: Atlanta, GA; Baltimore, MD; Boston, MA; Cleveland, OH; Denver, CO; Detroit, MI; Houston, TX; Los Angeles, CA; New York, NY; Philadelphia, PA; Sacramento, CA; and St. Louis, MO. The urban case study analyses focus on risk estimates for the middle year of each three-year attainment simulation period (2006-2008 and 2008-2010) in order to provide estimates of risk for a year with generally higher O3 levels (2007) and a year with generally lower O3 levels (2009).

In previous reviews, O3 risks were estimated for the portion of total O3 attributable to North American anthropogenic sources (referred to in previous O3 reviews as "policy relevant background"). In contrast, this assessment provides risk estimates for the urban areas for O3 concentrations down to zero, reflecting the lack of evidence for a detectable threshold in the C-R functions (ISA, 2012), and the understanding that U.S. populations may experience health risks associated with O3 resulting from emissions from all sources, both natural and anthropogenic, and within and outside the U.S.

The two figures to the right show the results of the mortality (top) and respiratory hospital admissions (bottom) risk assessments for all 12 urban areas associated with short-term exposure to O3, showing the effect on the incidence per 100,000 population just meeting the existing 75 ppb standard and potential alternative O3 standards of 70, 65, and 60 ppb in 2007. The overall trend across urban areas is small decreases in mortality and morbidity risk as air quality is adjusted to just meet incrementally lower standard levels. In New York, there are somewhat greater decreases, reflecting the relatively large emission reductions used to adjust air quality to just meet the 65 ppb alternative standard, and the substantial change in the distribution of O3 concentrations that resulted. Risks vary substantially across urban areas; however, the general pattern of reductions across the alternative

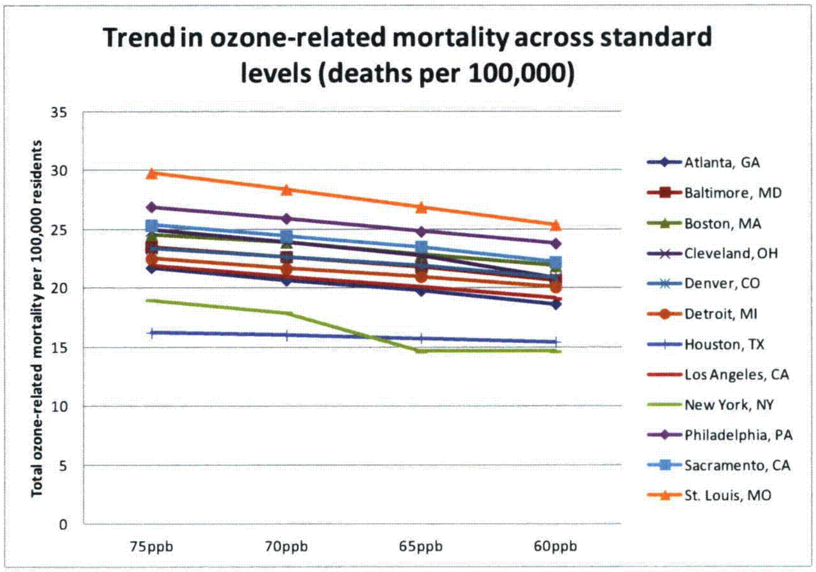


Impacts of just meeting existing and alternative standard levels on short-term mortality risk per 100,000 population (top) and on respiratory hospital admissions risk per 100,000 population for 2007 (bottom)

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

standards is similar between urban areas. Risks are generally slightly lower in 2009 relative to 2007; though the patterns of reductions are very similar between the two years. On average, compared with meeting the existing standard, mortality and respiratory hospitalization risks decrease by 5% or less for a level of 70 ppb, 10% or less for a level of 65 ppb, and 15% or less for a level of 60 ppb. Larger risk reductions are estimated on days with higher O3.

We also evaluated mortality risks in the 12 urban areas associated with long-term O3 exposures (based on the April to September average of the peak daily one-hour maximum concentrations). The figure below shows the results of long-term mortality risk assessments for all 12 urban areas, showing the effect on the incidence per 100,000 population just meeting the existing standard and potential alternative O3 standard levels of 70, 65, and 60 ppb in 2007. Risks from long-term exposures after just meeting the existing standard are substantially greater than risks from short-term exposures, ranging from 16 to 20 percent of respiratory mortality across urban areas. However, the percent reductions in risks are similar to those for mortality from short-term exposures, e.g., less than 10 percent reduction in risk relative to just meeting the existing standard in most areas when just meeting the 70 ppb and 65 ppb alternative standards, and less than 20 percent reductions when just meeting the 60 ppb alternative standard level.



Impacts of just meeting existing and alternative standard levels on long-term mortality risk per 100,000 population for 2007

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

Mortality and morbidity risks generally do not show large responses to meeting existing or alternative levels of the standard for several reasons. First, these risks are based on C-R functions that are approximately linear along the full range of concentrations, and therefore reflect the impact of changes in O3 along the complete range of 8-hour average O3 concentrations. This includes days with low baseline O3 concentrations that are predicted to have increases in O3 concentrations, as well as days with higher starting O3 concentrations that are predicted to have decreases in O3 concentrations as a result of just meeting existing and potential alternative standards. Second, these risks reflect changes in the urban-area wide monitor average, which will not be as responsive to air quality adjustments as the design value monitor, and which includes monitors with both decreases and increases in 8-hour concentrations. Third, the days and locations with predicted increases in O3 concentrations (generally those with low to midrange starting O3 concentrations) resulting from just meeting the existing or alternative standard levels generally are frequent enough to offset days and locations with predicted decreases in O3. The focus of the epidemiological studies on urban area-wide average O3 concentrations, and the lack of thresholds coupled with the linear nature of the C-R functions mean that in this analysis, the impact of a peak-based standard (which seeks to reduce peak concentrations regardless of effects on low or mean concentrations) on estimates of mortality and morbidity risks based on results of those studies is relatively small. However, we are not able to draw strong conclusions about the results across urban areas, because of the limited number of urban areas represented for most of the endpoints.

The national-scale epidemiology-based risk assessment evaluated only mortality associated with recent O3 concentrations across the entire U.S for 2006-2008. The national-scale assessment is a complement to the urban scale analysis, providing both a broader assessment of O3-related health risks across the U.S. It demonstrates that there are O3 risks across the U.S, not just in urban areas, even though the O3 levels in many areas were lower than the existing standard level. We estimated 15,000 premature O3-related non-accidental deaths (all ages) annually associated with short-term exposure to recent O3 levels across the continental U.S. for 2007, May-September. For long-term mortality, we estimated 45,000 premature O3-related adult (age 30 and older) respiratory deaths annually for 2007, April-September. While we did not assess the changes in risk at a national level associated with just meeting existing and potential alternative standards, just meeting existing and potential alternative standards would likely reduce O3 concentrations both in areas that are not meeting those standards and in locations surrounding those areas, leading to risk reductions that are not captured by the urban scale analysis.

Representativeness of Exposure and Risk Results

As part of this assessment, we conducted several analyses to determine the extent to which our selected urban areas represent: (1) the highest mortality and morbidity risk areas in the U.S.; and (2) the types of patterns of O3 air quality changes that we estimate would be experienced by the overall U.S. population in response to emissions reductions that would decrease peak O3 concentrations to meet the existing standard or lower alternative O3 standard levels.

We selected urban areas for the exposure and risk analyses based on criteria that included O3 levels, at-risk populations, and related factors that were designed to ensure we captured areas and populations likely to experience high O3 exposures and risks. Based on the comparisons of distributions of risk characteristics, the selected urban case study areas represent urban areas that are among the most populated in the U.S., have relatively high peak O3 levels, and capture well the range of city-specific mortality risk effect estimates. The analyses found that the O3 mortality risk for short-term O3 exposures in the 12 urban study areas are representative of the full distribution of U.S. O3-related mortality, representing both high end and low end risk counties. For the long-term exposure related mortality risk metric, the 12 urban study areas are representative of the central portion of the distribution of risks across all U.S. counties, however, the selected 12 urban areas do not capture the very highest (greater than 98th percentile) or lowest (less than 25th percentile) ends of the national distribution of long-term exposure-related O3-related risk.

While we selected urban areas to represent those populations likely to experience elevated risks from O3 exposure, we did not include amongst the selection criteria the responsiveness of O3 in the urban area to decreases in O3 precursor emissions that would be needed to just meet existing or potential alternative standards. The additional analyses we conducted suggest that many of the urban case study areas may show O3 responses that are typical of other large urban areas in the U.S., but may not represent the response of O3 in other populated areas of the U.S. These other areas, including suburban areas, smaller urban areas, and rural areas, would be more likely than our urban case study areas to experience area-wide average decreases in mean O3 concentrations and, therefore, decreases in mortality and morbidity risks, as O3 standards are met. Even though large urban areas have high population density, the majority of the U.S. population lives outside of these types of urban core areas, and thus, a large proportion of the population is likely to experience greater mortality and morbidity risk reductions in response to reductions in 8-hour O3 concentrations than are predicted by our modeling in the 12 selected urban case study areas.

Because our selection strategy for risk modeling was focused on identifying areas with high risk, we tended to select large urban population centers. This strategy was largely successful in including urban areas in the upper end of the O3 risk distribution. However, this also led to an overrepresentation of the populations living in locations where we estimate increasing mean seasonal O3 would occur in response to decreases in O3 precursor emissions that would be needed to just meet existing or alternative standards. The implication of this is that our estimates of mortality and morbidity risk reductions for the selected urban areas should not be seen as representative of potential risk reductions for most of the U.S. population, and are likely to understate the average risk reduction that would be experienced across the population.

Synthesis

To facilitate interpretation of the results of the exposure and risk assessment, this assessment provides a synthesis of the various results, focusing on comparing and contrasting those results to identify common patterns, or important differences. Consistent with the available evidence, we estimated exposures relative to several health-based exposure benchmarks, lung function risks based on a threshold exposure-response model of lung function decrements, and mortality and morbidity risks based on non-threshold C-R functions. These three different analyses result in differing sensitivities of results to changes in O3. Because the three metrics are affected differently by changes in O3 at low concentration levels, it is important to understand these changes in O3 at low concentrations in interpreting differences in the results across metrics.

The exposure benchmark analysis is the least sensitive to changes in O3 in the lower part of the distribution of starting O3 concentrations, because the lowest of the exposure benchmarks is at 60 ppb, above the portion of the distribution of starting O3 concentrations where we saw increases. Since the modeled exposures will always be less than or equal to the monitor concentrations, a benchmark of exposure at 60 ppb is above the range of O3 concentrations where the model-based adjustment approach estimates increases in concentrations. Thus, this metric is most reflective of the decreases in O3 at high concentrations that are expected to result from just meeting the existing and potential alternative standards.

The lung function risk analysis is less sensitive than the mortality and morbidity risk assessments to changes at very low concentrations of O3, because the risk function is logistic and shows little response at lower O3 dose rates that tend to occur when ambient concentrations are lower (generally less than 20 ppb for the 10 percent FEV1 decrement and generally less than 40 ppb for the 15 percent FEV1 decrement). However, because there are still some increases that occur in the 50 to 60 ppb range where the estimated risk is more responsive, there may be some reduction in the net risk decrease.

The mortality and morbidity risk assessment is the analysis that is most sensitive to the increases in O3 in the lower part of the distribution of starting O3 concentrations that we estimated would occur as the existing and alternative standards are met in some urban areas. Mean O3 concentrations for the urban areas change little between air quality scenarios for meeting the existing and alternative standards, because mean concentrations reflect both the increases in O3 at lower concentrations and the decreases in O3 occurring on days with high O3 concentrations. This leads to small net changes in mortality and morbidity risk estimates for many of the urban case study areas. However, both the net change in risk and the distribution of risk across the range of O3 concentrations may be relevant in considering the degree of additional protection provided by just meeting existing and alternative standards.

In conclusion, we have estimated that exposures and risks remain after just meeting the existing standards and that that in many cases, just meeting potential alternative standard levels results in reductions in those exposures and risks. Meeting potential alternative standards has larger impacts on metrics that are not sensitive to changes in lower O3 concentrations. When meeting the 70, 65, and 60 ppb alternative standards, the percent of children experiencing exposures above the 60 ppb health benchmark falls to less than 20 percent, less than 10 percent, and less than 3 percent in the worst O3 year for all 15 case study urban areas, respectively. Lung function risk also drops considerably as lower standards are met. When meeting the 70, 65, and 60 ppb alternative standards, the percent of children with lung function decrements greater than or equal to 10 percent in the worst year falls to less than 21 percent, less than 18 percent, and less than 14 percent in the worst O3 year for all 15 case study urban areas, respectively. Mortality and respiratory hospitalization risks decrease by 5% or less for a level of 70 ppb, 10% or less for a level of 65 ppb, and 15% or less for a level of 60 ppb. These smaller changes in the mortality and morbidity risks, relative to the exposures and lung function risk reductions, reflect the impact of increasing O3 on low concentration days, and the non-threshold nature of the C-R function. Larger mortality and morbidity risk reductions are estimated on days with higher baseline O3 concentrations.

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