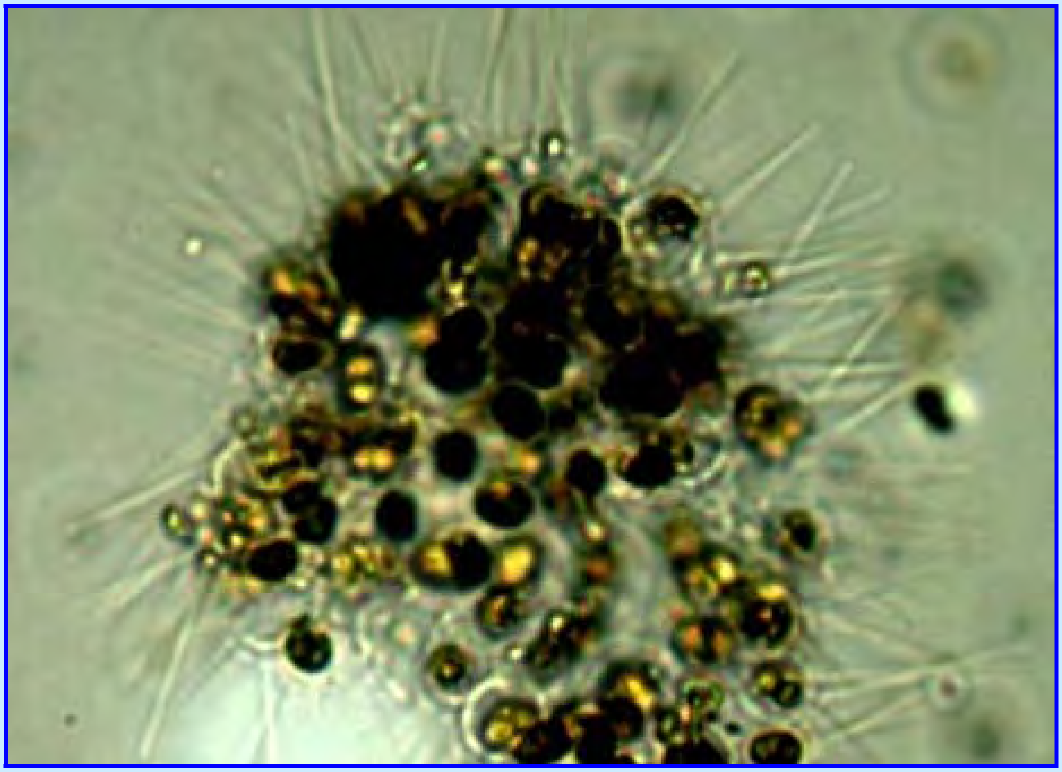
Response to an Increase in Metallic Taste Complaints in New York City Drinking Water

After Action Report

October 4 – December 21, 2009



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1. Executive Summary

On October 4, 2009, routine surveillance of the New York City 311 System[1] indicated an unusual increase in the number of complaints of metallic tasting water from City consumers. The Bureau of Water Supply (BWS) immediately began an investigation to identify the source of this taste problem. Initial actions, such as reviewing all current water quality data and collecting additional samples from areas reporting complaints, focused on confirming that the water was safe to drink and that only the taste of the water was impaired. The review of current water quality data indicated that all parameters were within normal ranges and confirmed that the water was safe to drink. Since the complaint calls arose from throughout all five boroughs of the New York City (NYC), the investigation focused on a system-wide or source water problem. A common cause of taste problems for water utilities is often related to treatment chemicals so BWS investigated and confirmed that all treatment operations were working properly. In addition, the quality and purity of the treatment chemicals themselves was confirmed. By October 7, 2009, the daily number of metallic taste complaints had risen to 26, representing a small portion of NYC residents but enough to be unusual and of concern. The NYC Water Supply provides water to many upstate communities in addition to NYC. The NYC Department of Environmental Protection (DEP) was informed by some of these communities that they were also receiving complaints from their consumers of metallic taste in the water. This information indicated that the source of the problem was further upstream from the distribution system and pointed to Kensico Reservoir as a likely source of the problem.

BWS contacted the Massachusetts Water Resource Authority (MWRA), as it was known that they had experienced similar taste problems in 2004 related to one of their source water reservoirs. MWRA confirmed that in 2004 they had received several complaints of metallic tasting water and ultimately determined the source of their problem to be an algal boom in one of their source reservoirs. They identified the golden-brown algae, *Chrysosphaerella* as the source of the taste problem. MWRA speculated that the disinfection process destroys the algae releasing a substance that imparts a metallic to the water.

DEP began to focus its investigation on algal concentrations within and exiting Kensico Reservoir. The algae *Chrysosphaerella* was identified as being present in the water leaving Kensico Reservoir and BWS implemented operational actions to mitigate the problem. On October 8, 2009, the Delaware Aqueduct was placed into a “by-pass” mode, routing Delaware water around Kensico Reservoir. The flow of Catskill water leaving Kensico was reduced. Following implementation of these actions, consumer taste complaints immediately began to decline in numbers. To keep apprised of the status of this taste problem, BWS Division of Watershed Water Quality Operations (WWQO) implemented an enhanced water quality monitoring program on Kensico Reservoir and Distribution Water Quality Science and Research tracked the number of 311 System complaints received daily.

Throughout this event, BWS notified regulatory agencies including the NYS DOH and NYC DOHMH of the status of this issue. Additionally, the DEP provided informational updates to NYC consumers through both the 311 System and the DEP internet web site.

By the beginning of November, concentrations of *Chrysosphaerella* in Kensico Reservoir began to show a significant decline. BWS developed and implemented a de-escalation plan with water

[1] 311 is New York City's online Web site and phone number for government information and non-emergency services.

quality and consumer complaint targets. After being in “by-pass” mode for 33 days the Delaware Aqueduct was slowly phased back to “reservoir” mode in a series of steps beginning on November 10, 2009. This slow blending of Delaware Aqueduct and Kensico Reservoir water allowed BWS to track consumer complaints while bringing Kensico Reservoir back in service. No increase in the number of taste complaints from City consumers was observed and on November 29, 2009, the Delaware System resumed normal operations with Kensico Reservoir fully online. BWS continued to monitor consumer complaints and on December 21, 2009, after meeting all targets of the de-escalation plan, ended all monitoring and surveillance related to the event.

Although drinking water taste and odor issues related to algal blooms are frequently observed by many water utilities throughout the country, such taste issues are rare to the NYC Water Supply. This incident was the first recorded occurrence of the algae *Chrysosphaerella* in the Water Supply. Because of its comprehensive 311 system, DEP was able to detect this issue immediately and through operational flexibility, BWS was able to manage the problem successfully. This resulted in little to no impact to drinking water consumers.

This report is intended to document DEP’s identification of this problem, investigation into the source of the problem, response to control the problem, communications to consumers and regulators, enhanced water supply monitoring and de-escalation to normal water supply operations. As this event was considered a “…significant unusual incident and/or monitoring [event]…”, this report will be submitted as a deliverable under section 5.1 of the 2007 NYC Filtration Avoidance Determination.

2. Description of Event

a. Timeline of Actions

The following is a chronological list of significant events and actions taken by BWS in response to an increase in complaints of metallic tasting drinking water. This timeline highlights the detection of complaints, the investigation into the source of the problem, BWS's management and control of the problem and finally, the determination that the problem had abated and the return of the Water Supply to normal operations.

Oct 4 - BWS monitoring of calls received by the City 311 Call Center realized a slight increase in the number of drinking water consumer taste complaint calls received (18 totals calls).

Oct 5 - Distribution Water Quality Operations (DWQO) collects additional samples in response to consumer taste complaints and begins an investigation into the cause of problem.
- Daily number of taste complaint calls increases to 32.

Oct 6 - DWQO continues to collect additional samples, all results to date are within normal ranges and meet all standards.
- DWQO begins to investigate the quality of treatment chemicals as a possible source.
- WWQO begins to implement an enhanced water quality monitoring program at watershed terminal reservoirs and keypoints.
- WWQO contacts MWRA to discuss a similar taste issue experienced in 2004.
- WWQO reviews recent source water phytoplankton data.
- The City of Yonkers notifies DEP that they are receiving consumer taste complaints. BWS contacts the Village of Greenburgh which indicates that they too are receiving taste complaints.
- BWS notifies NYSDOH of the situation.
- Daily number of taste complaint calls remains elevated at 27.

Oct 7 - WWQO provides an assessment of watershed water quality investigation.
- BWS believes that algae in Kensico Reservoir are the likely cause of metallic tasting water.
- Operations prepares to by-pass Kensico Reservoir to improve water quality.
- Daily number of taste complaint calls increases to 36.

Oct 8 - BWS begins by-pass of Kensico Reservoir with the Delaware Aqueduct and Catskill by-pass is considered, but decides to reduce the flow leaving Kensico.
- The alga *Chrysosphaerella* is confirmed by WWQO in samples from Kensico effluents.
- NYSDOH, NYC DOHMH and WCDOH are briefed on situation.
- Daily number of taste complaint calls remains at 36.

Oct 9 - Kensico by-pass operation completed, Delaware Aqueduct in "float" mode at West Branch and Kensico Reservoirs providing 90% Rondout water to distribution.
- Service Advisory posted on DEP web site informing consumers that the Water Supply is experiencing a taste issue and is taking action to control the problem.
- Daily number of taste complaint calls remains elevated at 35.

Oct 10- Consumer complaint calls reduces to 13.
- Water Quality begins internal daily reporting of taste complaints and water quality.

Oct 15- BWS begins weekly tracking of taste complaints received by outside communities.

Oct 28- Enhanced monitoring at Rondout and Ashokan Reservoirs completed, return to routine monitoring.

2. Description of Event

Nov 9 - All but one Kensico Reservoir survey sample results are <100 ASU/ml *Chrysosphaerella*.
- The daily number of consumer complaint calls is < 5 calls/day.

Nov 10- De-escalation of event begins.
- Delaware Aqueduct delivering 50% Kensico water.

Nov 19- Delaware Aqueduct delivering 75% Kensico water.

Nov 30- Delaware Aqueduct delivering 100% Kensico water. Water Supply returns to normal operations.

Dec 2 - Enhanced monitoring at Kensico ends, routine monitoring resumes.
- BWS continues to monitor and report consumer complaints daily.

Dec 21- Event declared ended, daily reporting discontinued and all monitoring and reporting resume to normal frequencies.

Dec 24- Weekly tracking of outside community taste complaints ends. No complaints reported in past three weeks.

3. Increase in Taste Complaints

a. In-City 311

On Sunday morning, October 4, 2009, while performing a routine query of the Hansen (V. 8) In-City 311 Call Center's drinking water quality complaints, an unusually high number of taste and odor complaints (QA) was observed. Thirteen water quality complaints were received with 11 of those complaints coded in the system as metallic taste and odor issues (QA3). Sixteen (16) water quality complaints were received from October 1-3, 2009 with 14 complaints specifically related to taste and odor issues. This increased volume of calls in addition to the proportion of those calls describing a metallic taste and odor issue was brought to the attention of BWS Division of Distribution Water Quality Operations (DWQO) supervisors and management on the morning of October 5th.

On Monday, October 5, 2009, the number of metallic taste calls increased to 19. These metallic taste complaints were mapped, and although there was no geographic clustering of complaints, Queens and Brooklyn, which receives water from City Tunnel 2 (Delaware System water), accounted for the majority of the calls (13 out of the 19 calls).

On Tuesday, October 6, 2009, there were 20 QA3 complaint calls reported. Although calls were received from all five boroughs, the majority of calls came from Queens, Brooklyn, and Staten Island. Therefore, DWQO's focus remained on City Tunnel 2 in distribution as the source of the problem. By October 7, 2009, consumer complaints increased to 26 and BWS's investigation indicated that Kensico Reservoir, and specifically the alga *Chrysosphaerella* was the likely source of the metallic taste. In response, on October 8, 2009 BWS began to by-pass Kensico Reservoir with the Delaware Aqueduct. The number of consumer complaints began to decline and by October 11, 2009, the daily number of calls was down to 3. Attachment 1 provides a table of daily NYC consumer complaints calls received by the 311 System.

b. Outside Communities

On October 6, 2009, DEP received notification from the Yonkers water utility that their consumers were complaining of metallic tasting water. Other outside communities receiving water from the NYC System were then contacted by DEP and it was discovered that similar complaints were also being received by the Greenburgh Consolidated water utility and the Westchester County Joint Water Works. This unusual rise in complaints corresponded with the rise in in-City complaints and indicated that the cause of the problem was in the source waters.

4. Investigation of Possible Causes

a. Distribution Water Quality

On Monday, October 5, 2009, DWQO began its investigation of metallic tasting water by collecting three hydrant samples in Queens corresponding to areas where the metallic taste complaints had been reported. During sample collection, water from all three sampling locations was tasted by the field person. A slight metallic taste and odor was noticed in two of the three samples. However, a very distinct metallic taste and odor was apparent from the hydrant sample collected at 242-29 89th Avenue in Bellerose, Queens.

On Tuesday, October 6, 2009, DWQO intensified its monitoring efforts to include nine more hydrant locations, three sites in each of the three boroughs (Queens, Brooklyn, and Staten Island). Routine samples for metals, chemistry and microbiological analyses were collected from 24 distribution sites throughout the five boroughs. Additionally, the three entry point sites representing water entering the distribution system from each of the three City Tunnels were sampled. Water quality results from analysis of the complaint hydrant locations and distribution monitoring sites collected on October 5 and 6, 2009, were all within the normal ranges.

i. Treatment Chemicals

Because many of the first complaint calls received through October 5, 2009, were primarily from locations that are delivered water from City Tunnel 2, DWQO speculated that treatment chemicals being added to City Tunnel 2 water might be causing the taste problem. Therefore, DWQO began a systematic investigation into the source and application of water treatment chemicals. Treatment chemicals applied to water in City Tunnel 2 water are chlorine, fluoride, phosphoric acid and caustic soda. Samples of the current chemical deliveries (caustic and phosphoric acids) were collected and sent to a DEP contract laboratory for analyses of quality and the certificates of quality were reviewed for the supply of chlorine. Since there had been no recent change in the phosphoric acid supply and the Kensico fluoride feed for the Delaware system had been off for several weeks, DWQO focused their attention on caustic soda. A new vendor, Kuehne Chemical Company, became the supplier as of October 1, 2009. DWQO proceeded to obtain the specification sheets from Kuehne Chemical Company to assess the quality of the caustic soda. A summary of the investigation of Water Supply treatment chemicals preformed is presented in Table 1.

4. Investigation of Possible Causes

Table 1 Investigation of Water Supply Treatment Chemicals

Treatment Chemical	Investigation	Conclusion
Chlorine Gas	Certificates of Analysis were reviewed. Changes in suppliers or shipments were investigated.	Certificates indicated acceptable quality and no changes in supplier was identified.
Caustic	Changes in suppliers or shipments were investigated. Samples were collected and shipped to a contract laboratory for analysis.	It was discovered that beginning October 1, 2009 DEP began receiving supply from a new vendor. Samples results indicated that the caustic met specifications and no contamination was identified.
Fluoride	Changes in the status and operation of the fluoride delivery system were investigated.	The fluoride system was operating correctly on the Catskill System, however the fluoride system had been off on the Delaware System for the previous two weeks.
Phosphoric Acid	Changes in suppliers or shipments were investigated. Samples were collected and shipped to a contract laboratory for analysis.	It was determined that no changes in the vendor, supply or delivery of phosphate had occurred. Sample results indicated that the phosphoric acid met specifications and no contamination was identified.

b. Source Water Quality

i. Keypoint Data

Raw Source water is monitored frequently by WWQO for compliance and surveillance purposes at the keypoints CATLEFF for the Catskill System and DEL18 for the Delaware System. Turbidity is sampled every four hours and analyzed at a certified laboratory. Fecal coliform samples are collected daily, along with other physical parameters, and phytoplankton samples are collected three times a week.

The 2009 data from the Source Water keypoints DEL18 and CATLEFF prior to October 7 contained four-hourly compliance turbidities averaging under 1 NTU, with only two values ≥2 NTU. Fecal coliform bacteria remained largely in the single-digits throughout the year with only 7 values >9 cfu/100mL. These were attributable to storm events or waterbird activity. A typical spring algal bloom with maximum concentrations ~700 ASU/mL had subsided by June and total phytoplankton concentrations were in the 200-300 ASU/mL range for both keypoint sites through September. In short, water quality was excellent and stable, and there was no indication of pending issues.

ii. Limnology Data

Routine limnological sampling of Kensico Reservoir indicated excellent water quality throughout the reservoir. The most recent survey prior to October 7, 2009, was conducted on September 22, 2009, and found turbidities between 0.4 and 1.4 NTU and fecal coliform bacteria only 1 or <1 cfu/100mL throughout the entire Reservoir. Phytoplankton concentrations were more varied as some areas of the reservoir (e.g., site 8) are isolated from the flows through the waterbody created by the Catskill and Delaware supplies. Phytoplankton concentrations in front of the Catskill and Delaware aqueduct effluents (sites 3BRK and 2BRK, respectively) ranged from 45 to 230 ASU/mL, which are considered low concentrations even for Kensico Reservoir.

By October 6, the in-City investigation of the metallic test problem had not identified a source, and attention began to focus on Kensico Reservoir. A special Reservoir survey was conducted by WWQO on October 7, 2009, with an emphasis on phytoplankton sampling. Prior to the collection phytoplankton samples, pH, DO and temperature were measured at 1 meter intervals through the water column at each site to identify the location of the thermocline. Phytoplankton samples were then collected at the thermocline and at one meter above and below the thermocline at selected sites. In addition, a review of the data from the previous survey (September 22, 2009) found spikes in dissolved oxygen at depths below 20 meters which suggested a layer of photosynthetic activity, so samples were collected at the depth of any apparent dissolved oxygen spike. One such layer was identified at a depth of 22 meters at site 6 and was sampled.

While WWQO field staff were collecting the Reservoir samples, BWS Management personnel were examining records of taste complaints in other water supplies and came across a report by the Massachusetts Water Resources Authority (MWRA) on taste complaints associated with a bloom of the algae *Chrysosphaerella*. Identification information regarding this specific alga was emailed to BWS microbiology staff as this alga had never been previously identified in the New York City water supply system.

Phytoplankton analysis by WWQO proceeded immediately once the samples were delivered to the laboratory. At first, microbiology staff did not identify anything unusual, but after reviewing the identification information provided, the microbiologists tentatively identified an alga that resembled *Chrysosphaerella*. Two days later, the identification was confirmed by MWRA staff (see section 4.d.).

c. Initial *Chrysosphaerella* Literature Review

As DEP began to realize that the algae *Chrysosphaerella* was the likely cause of the metallic taste complaints, a preliminary literature review on the life history of this algae was conducted by WWQO. A short life history document was prepared and provided to Water Quality management to aid in potential operational decisions. This document is included in this report as Attachment 2.

d. MWRA Communication

DEP was aware that the Massachusetts Water Resource Authority (MWRA) had experienced a similar incident of metallic taste complaints from consumers of their chlorinated drinking water in recent years. Since DEP was receiving numerous metallic taste complaints, WWQO staff contacted MWRA staff to discuss their previous experience with metallic taste issues, to confirm the identification of the potential algal organism causing the problem and to discuss chemical treatment options for controlling the suspected algae. MWRA's experience with metallic taste complaints indicted that the problem was strictly aesthetic and the water did not pose a health threat to consumers. A summary of these discussions with MWRA are presented below.

In early July 2004, MWRA and associated communities began receiving complaints of a metallic taste and odor to the drinking water (628 calls over the course of the month). As a result, MWRA and Massachusetts Department of Conservation and Recreation (DCR) staff conducted security and water quality checks of the system and found indications that an algal bloom was occurring in one of their source water reservoirs. The substantial bloom (>1500 ASU), observed at the Cosgrove intake in Wasschusett Reservoir, was of the golden-brown algae, *Chrysosphaerella*. MWRA suspected that chloramine disinfection interacted with the *Chrysosphaerella* and resulted in imparting a metallic taste to the water.

The algae were found predominantly in the metalimnion (~8m depth) of Wasschusett Reservoir at the boundary of the interflow of water coming from Quabbin Reservoir. The algal bloom event lasted through the month of July and consumer complaints generally dropped off in August. Several in-reservoir treatments with the algaecide copper sulfate were made to control this algae, however MWRA staff believe that the treatments were only marginally effective (D. Worden, personal communication). The ineffectiveness was attributed to the fact that the bloom was already in progress and was not treated at an early enough stage in the algae's population growth phase (B. Reilley, personal communication).

In July and August of 2005, MWRA experienced a second *Chrysosphaerella* bloom event; however, this event was not as severe and did not generate the same level of consumer complaints as the July 2004 event (B. Reilley, personal communication). To be proactive and prevent a significant bloom from developing, copper sulfate treatments were applied to the area in front to the intakes on Wasschusett Reservoir (3 day volume) on four occasions. It is important to note that MWRA's new Walnut Hill Water Treatment Plant was brought on-line in the spring of 2005. The treatment plant features ozone gas as its method of disinfection. MWRA has not received any metallic taste complaints from consumers since the treatment plant began operation.

In 2009, MWRA and DCR developed an algal response plan (MWRA 2009). The plan establishes the criteria for enhanced monitoring and treatment (copper sulfate) for various algal genera. For *Chrysosphaerella*, enhanced reservoir monitoring begins when populations are greater than 75 ASU/mL and copper sulfate treatment is initiated when populations are greater than 100 ASU/mL. MWRA applies a target dose of 0.2 mg/L Cu for treatment of *Chrysosphaerella*. Application is made in-reservoir using a boat specially equipped with a mixing vat and diffuser pipe that can be deployed at the desired depth to apply copper sulfate. An area estimated to contain 1 BG of water (3-4 day supply) upstream of Cosgrove intake is generally treated.

i. Algae – *Chrysosphaerella*

Following discussions with MWRA, WWQO began scrutinizing water samples more closely to determine if *Chrysosphaerella* was present. Water samples are analyzed, by WWQO, for phytoplankton using the Sedgwick Rafter method (LAB 6140). An organism resembling *Chrysosphaerella* was found by WWQO laboratory staff in Kensico Reservoir keypoint and limnology samples.

Photographs of the suspected algal species were sent to MWRA for confirmation of DEP's identification. MWRA also uses the Sedwick-Rafter technique to analyze phytoplankton samples (Betsy Reilely, personal communication). Upon examination, MWRA verified that the organism that DEP identified was indeed *Chrysosphaerella*. Additionally, photos of the algae were also sent to the NYS-DOH Wadsworth Laboratory and they too confimed that the organism was *Chrysosphaerella*.

e. Problem Identification

BWS's initial investigation into taste complaints confirmed that the drinking water was potable. The fact the outside communities north of the City were receiving complaints of metallic tasting water, focused the investigation of the source of the problem to the source waters upstream of Hillview Reservoir. Since Yonkers withdraws water from the Catskill Aqueduct, Greenburgh withdraws from the Delaware Aqueduct, and Westchester County Joint Water Works draws water from the Rye Lake section of Kensico Reservoir, the investigation focused on Kensico Reservoir as the likely source of the problem.

It was speculated that an algal bloom within the Reservoir could be the source of the problem. Since Kensico Reservoir was the assumed source of the problem, BWS began by-pass operations of the Reservoir. The Delaware Aqueduct was placed in "float" mode at Shaft 17 thereby routing Rondout water directly to the distribution system. Water in the Catskill Aqueduct did not by-pass Kensico Reservoir but the flow leaving the reservoir was reduced.

To confirm that an algae bloom was the source of the problem, WWQO increased monitoring of phytoplankton at Kensico keypoints and reservoir monitoring sites. BWS also contacted the MWRA who had a similar metallic taste issues in the drinking water in 2004 and had identified the source of their metallic taste problem as the algae *Chrysosphaerella.* WWQO enhanced monitoring of Kensico Reservoir confirmed the presence of *Chrysosphaerella.* **This information, along with the reduction in in-City complaints following Kensico by-pass operations led to the conclusion that the source to the metallic taste in the drinking water was do to a bloom of the algae *Chrysosphaerella* in Kensico Reservoir.**

5. System Operational Responses and Actions

a. Disinfection Treatment Change

In response to the decision that the cause of the taste and odor problem was related to algae in the source water, on October 9, 2009 BWS slightly decreased the target chlorine dose from 0.6 to 0.4 ppm. It was assumed that this decrease would reduce the oxidation of the algae and the formation of taste and odor causing compounds. However, since the Kensico by-pass operation was also implemented at this time BWS was unable to determine if the chlorine dose reduction provided a benefit in the reduction of the formation of taste and odor causing compounds.

b. Kensico By-Pass

On October 8, 2009, BWS began implementation of a partial by-pass of Kensico Reservoir on the Delaware Aqueduct. By October 9, 2009, the Delaware by-pass tunnel at Shaft 17 was in 'float" mode with Shaft 9 at West Branch Reservoir also in "float" mode. Because of this operational configuration, about 90% of the water being delivered to Hillview Reservoir via the Delaware System was directly from Rondout Reservoir. This operation circumvented Delaware water around Kensico and West Branch Reservoirs, which improved the quality of the water being delivered to the City and resulted in a reduction in the number of consumer calls.

BWS also considered bypassing Kensico Reservoir with the Catskill System; however, this operation would have required that the Catskill bypass tunnel first be flushed before use. Flushing of the bypass, either out the blow off or back into the reservoir, would have required a 24-48 hour shutdown of the Catskill Aqueduct south of Kensico. In addition, turbidity levels leaving Ashokan were > 2.5 NTU. It was decided not to place the Catskill System on bypass but to reduce the effluent flow and monitor consumer complaints of taste issues. Taste complaints remained low and the Catskill System remained in "reservoir" mode for the duration of this event. It was speculated that since the Catskill water is routed through Hillview Reservoir it is provided additional time to aerate and mix following secondary chlorination, which may help reduce taste causing compounds.

c. Blending

After all water quality triggers described in the de-escalation plan had been reached, the Delaware Aqueduct at Kensico Reservoir was returned to "reservoir" from "by-pass" mode in steps. In each step, the blend of Kensico to West Branch water was increased until 100% Kensico water was being delivered to the Delaware Aqueduct below Kensico Reservoir. This blending operation allowed BWS to track water quality complaints to verify that metallic taste complaints did not increase as Kensico Reservoir was slowly brought back online.

5. System Operational Responses and Actions

Table 2 below lists the three steps implemented during the blending operation to bring Kensico Reservoir back online.

Table 2 Steps of the blending operation to bring Kensico Reservoir back online.

Step	Date	Blend
1	11/10/09	50% Kensico – 50% Delaware Aqueduct
2	11/19/09	75% Kensico – 25% Delaware Aqueduct
3	11/30/09	100% Kensico

d. Rondout/West Branch Tunnel Shutdown Operations

Because of DEP's management of the metallic taste event, DEP postponed a planned shutdown of the Rondout to West Branch Tunnel (RWBT). The shutdown, planned for October 17, 2009 was to install a new gate valve. However, the by-pass operations at Kensico required that the RWBT remain in service.

BWS re-evaluated the critical need to shutdown the RWBT to make repairs and the capabilities of the water supply system to support both the shutdown and the by-pass at Kensico Reservoir. System modeling indicated that a short, 9-day shutdown could be supported and on November 5, 2009, BWS proceeded with the shutdown. Since algal counts were declining in Kensico Reservoir, on November 10, 2009, BWS began blending operations at DEL17 to bring Kensico Reservoir slowly back online. The RWBT was placed back in service on November 14, 2009.

6. Water Quality Monitoring and Reporting

a. Implementation of Enhanced Monitoring

In response to metallic taste complaints by drinking water consumers and following the determination that the source of the taste problem was likely an increase in the concentration of the algae *Chrysosphaerella*, the Division of Watershed Water Quality Operations implemented an enhanced phytoplankton monitoring program.

i. Kensico Reservoir Keypoint Monitoring

Monitoring of the Kensico Reservoir effluents (DEL18, CATLEFF) and the Delaware Aqueduct influent at Kensico (DEL17) was increased to daily with a same day analysis turn-around-time (TAT). Phytoplankton samples at Kensico keypoints CATLEFF and DEL18 are normally are collected 3 days/week and DEL17 is normally collected once weekly, all with a one week TAT. This enhanced monitoring program began October 6, 2009 and continued through December 2, 2009.

To monitor the quality of the water entering Kensico, keypoint monitoring of the Rondout (RDRRCM) and Ashokan (EARCM) Reservoir effluents for phytoplankton was increased to daily with a same day TAT for analysis. Normally these samples are collected 3 days/week with a one week TAT. This enhanced monitoring program began October 6, 2009 and continued through October 28, 2009.

ii. Kensico, Rondout and Ashokan Reservoir Monitoring

Limnological surveys for phytoplankton in Kensico Reservoir were increased to weekly from October 6, 2009 through December 2, 2009 with next business day TAT pm sample analysis. Normally, phytoplankton surveys are conducted monthly with a one week TAT. In addition, weekly surveys were conducted at West Branch Reservoir for the month of October, but normal bi-weekly sampling was resumed based on the low occurrence of *Chrysosphaerella* observed.

Rondout Reservoir surveys were increased from bi-weekly to weekly from October 6, 2009 through November 9, 2009, with a next day TAT on results.

Table 3 Enhanced watershed water quality monitoring.

Site	Site Code	Enhanced Monitoring*	Routine Monitoring
Aqueduct Keypoint Monitoring			
Rondout Delaware Effluent	RDRR	7days/week	3 days/week
Kensico Delaware Influent	DEL17	7days/week	1 days/week
Kensico Delaware Effluent	DEL18	7days/week	3 days/week
Ashokan Catskill Effluent	EAR	7days/week	3 days/week
Kensico Catskill Effluent	CATLEFF	7days/week	3 days/week
Reservoir Monitoring			
Kensico	BRK 1-6	Weekly	bi-weekly
West Branch	CWB 1-3	Weekly	bi-weekly
Rondout	many	Weekly	bi-weekly

*Sample analysis time decreased to next day reporting of results.

iii. Occurrence of *Chrysosphaerella*

Chrysosphaerella was not observed in any West of Hudson keypoint or limnology samples collected from Ashokan Reservoir during this event. *Chrysosphaerella* was also not observed in any keypoint samples collected from Rondout Reservoir. However, the alga was found in low numbers (<100 ASU) in 4 out of 34 samples collected from the Rondout Reservoir in October. (Attachment 3)

After the first identification of *Chrysosphaerella* in samples collected from Kensico Reservoir on October 7, 2009, Kensico Laboratory's microbiology staff began to identify the alga regularly. Attachment 3 lists the concentrations of major groups of phytoplankton from Kensico keypoints CATLEFF, DEL18 and DEL17. Phytoplankton typically associated with taste and odor problems in treated water that were found in a raw water sample are listed, and the concentrations of *Chrysosphaerella* are shown in parentheses if the organism was countable. Daily sampling for phytoplankton at the DEL18 and CATLEFF keypoints found *Chrysosphaerella* present, if not always quantifiable, in all samples from October 7, 2009 through October 22, 2009. Note that the Delaware Aqueduct was placed in "float" mode on October 8, 2009. The Catskill Aqueduct was maintained on full "reservoir" mode and *Chrysosphaerella* appeared consistently in CATLEFF samples through November 1, 2009, typically at concentrations of 3-16 ASU/100ml.

WWQO Laboratories routinely reports total phytoplankton and the dominant genus only for keypoint samples. For reservoir samples the second most dominant genus is also recorded. *Chrysosphaerella* never achieved dominant genus counts in any keypoints samples, but a new recording field was created for this event to record the *Chrysosphaerella* concentrations observed in a sample. The field "GENOTH" or "other genus" was added to the Water Quality data set, as this information would not normally be recorded.

By November 2, 2009, *Chrysosphaerella* was not found in either Kensico effluent keypoint sample. Although it did appear sporadically again in a few full slide scans (see section 6.c.i), it did not appear in any countable quantities from November 12 through the cessation of daily keypoint sampling on December 2, 2009.

While *Chrysosphaerella* was never found to be the dominant organism in the keypoint samples, reservoir phytoplankton data indicate that by October 13, 2009, one week after it was first identified, *Chrysosphaerella* was the dominant alga in 13 of 22 samples (Attachment 4). Total phytoplankton concentrations were still well below the 2000 ASU/mL threshold that BWS traditionally associated with potential water quality issues.

The bar charts in Figure 2 and Figure 3 display *Chrysosphaerella* concentrations from each limnology sample collected, the sample date is displayed at the top of each chart. The bars are grouped by sampling site (see Figure 1 for a map of Kensico Reservoir with sampling sites) and the number below each bar lists the sample depth in meters. If no bar is displayed above a sample depth then the *Chrysosphaerella* concentration of the sample was zero. WWQO routinely collects phytoplankton samples at a depth of 3 meters at most sites, however, at sites 2 and 3 situated in front of the Delaware and Catskill aqueducts leaving Kensico Reservoir, respectively, samples are collected at two additional depths. The bar charts show the number of additional phytoplankton samples that were collected and analyzed by WWQO as part of the enhanced monitoring program in an effort to characterize the lateral and vertical distribution of the algae. While the time series (Figure 4) illustrates the decreasing concentrations of the algae over time, few other distribution signals emerge. Four of the seven samples with the highest concentration of the algae were collected from site 6, located in the middle of the Rye Lake section of Kensico Reservoir. Rye Lake is comprised entirely of Delaware Aqueduct water with negligible influences from local tributaries. The last sites with concentrations >100 ASU/100ml were 2 and 3, located in front of the aqueduct effluents. Generally, the algae appeared at multiple sites and depths and did not appear to have a preferred geographic or vertical location in Kensico Reservoir.

West Branch Reservoir, which is connected to the Delaware Aqueduct water between shafts DEL9 and DEL10, was sampled five times for phytoplankton between October 8, 2009 and November 10, 2009. *Chrysosphaerella* was detected in only two samples: once at site 2 on October 8, 2009 and once at site 3 on October 19, 2009. Sites 2 and 3 are located near shafts DEL9 and DEL10 respectively. These areas are typically influenced by the flow of the Delaware Aqueduct water into and out of West Branch Reservoir. Sites 1 and 4, which are not located adjacent to any aqueduct shaft buildings, never yielded any detections of *Chrysosphaerella*.

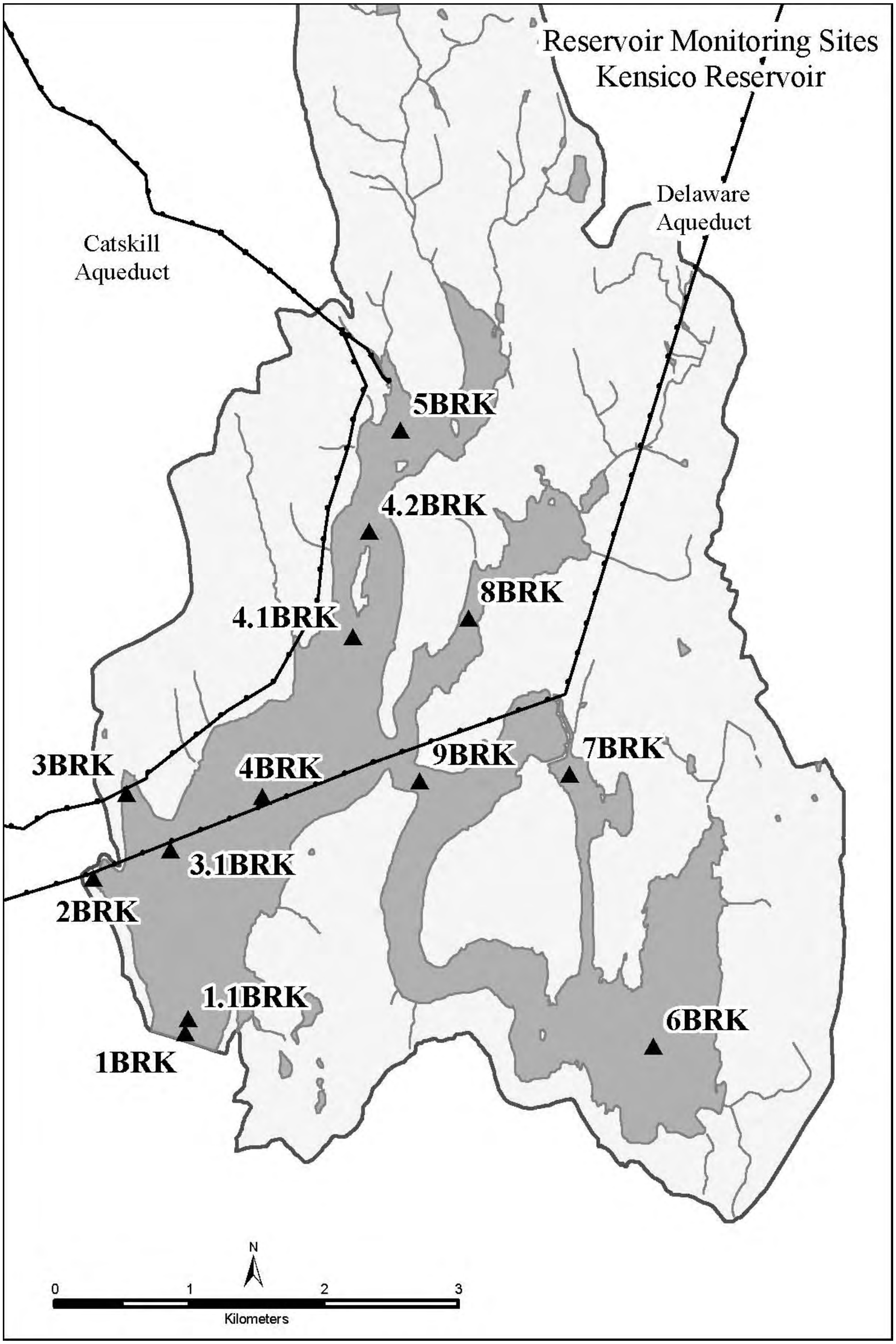


Figure 1 Map of Kensico Reservoir indicating reservoir monitoring sites.

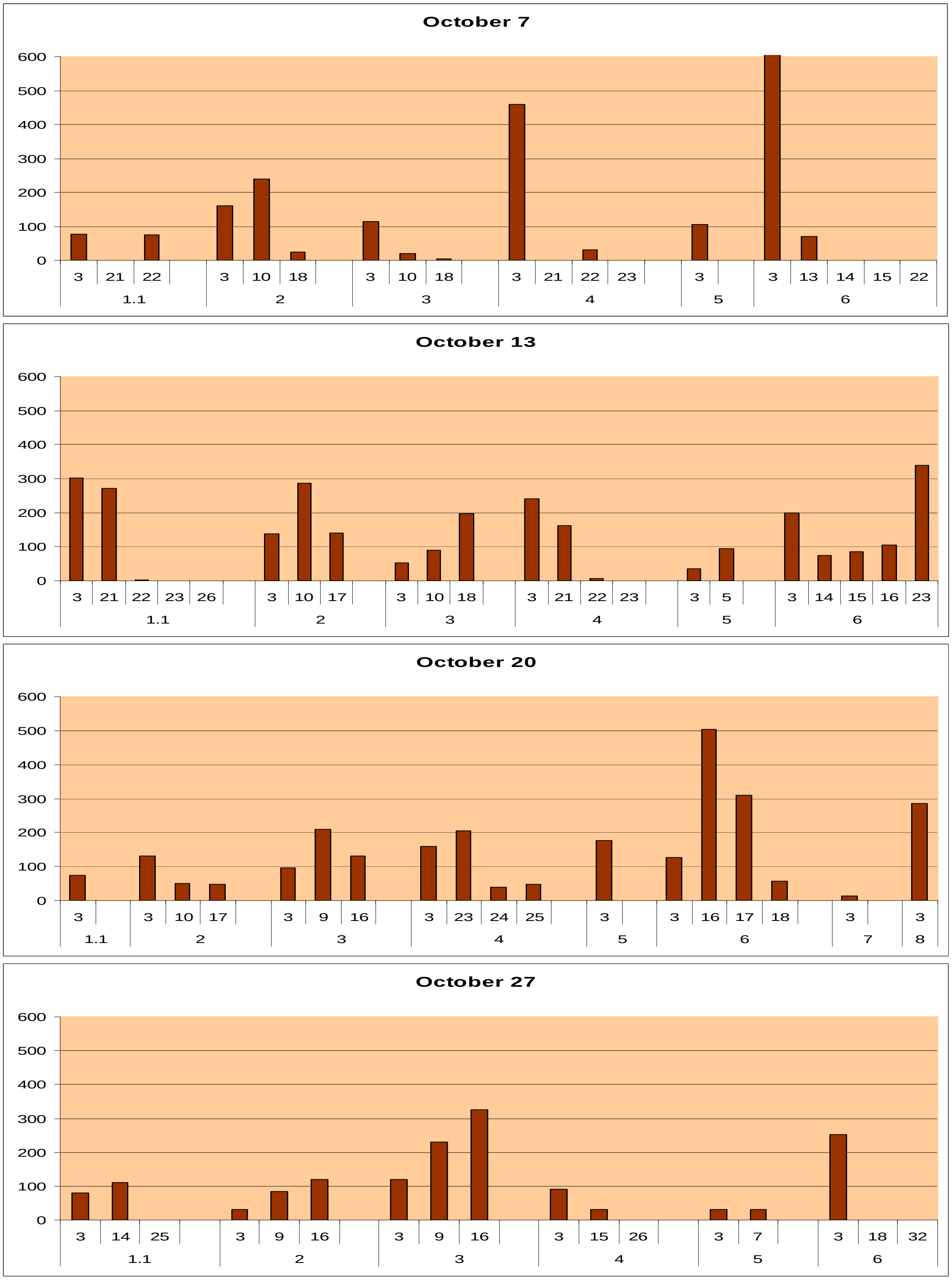


Figure 2 Counts (ASU/100ml) of *Chrysosphaerella* at Kensico Reservoir survey sites from October 7-27, 2009. Bars represent the value for each depth sampled at each site. No bar for a given depth indicates a value of zero.

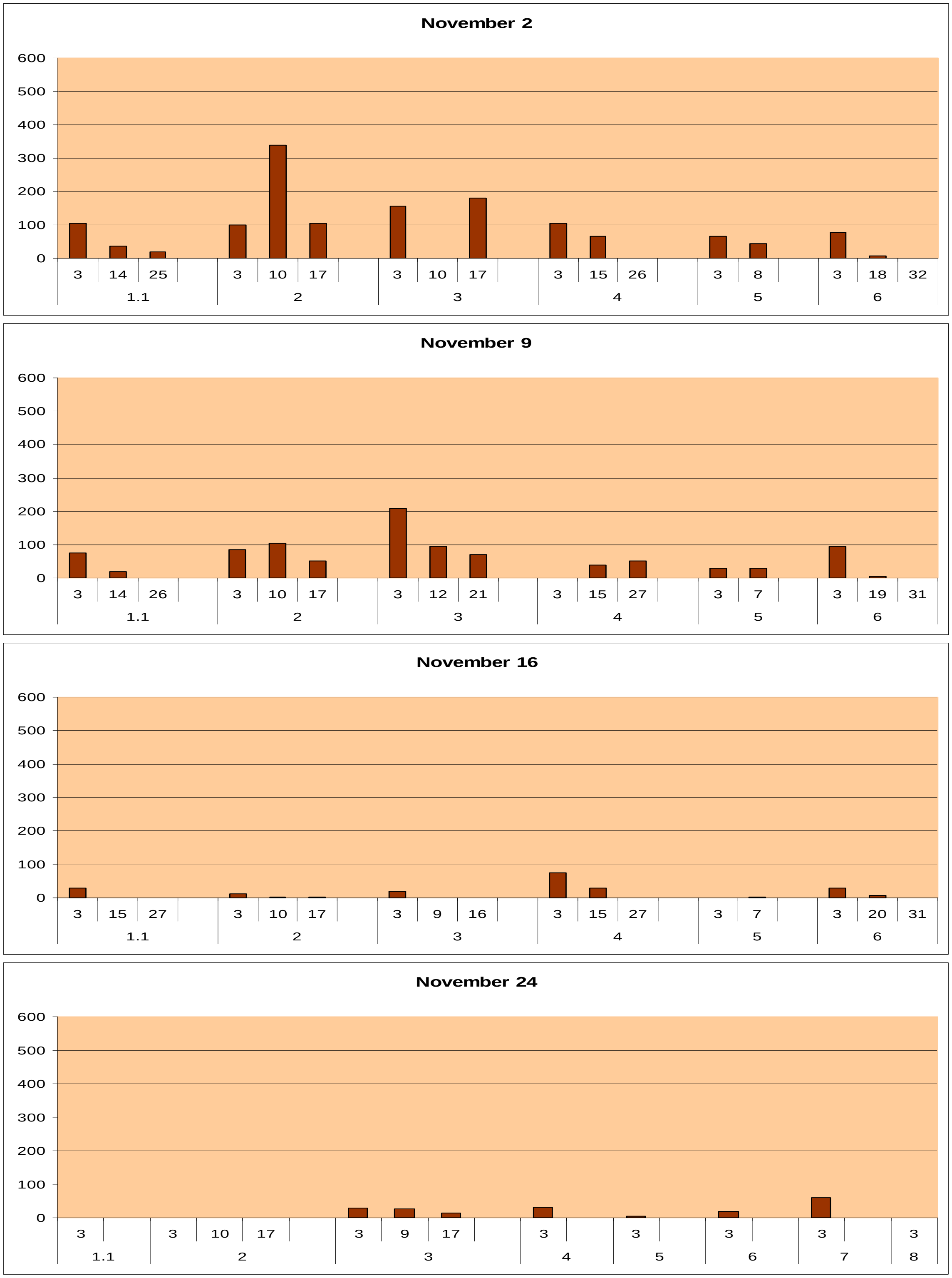
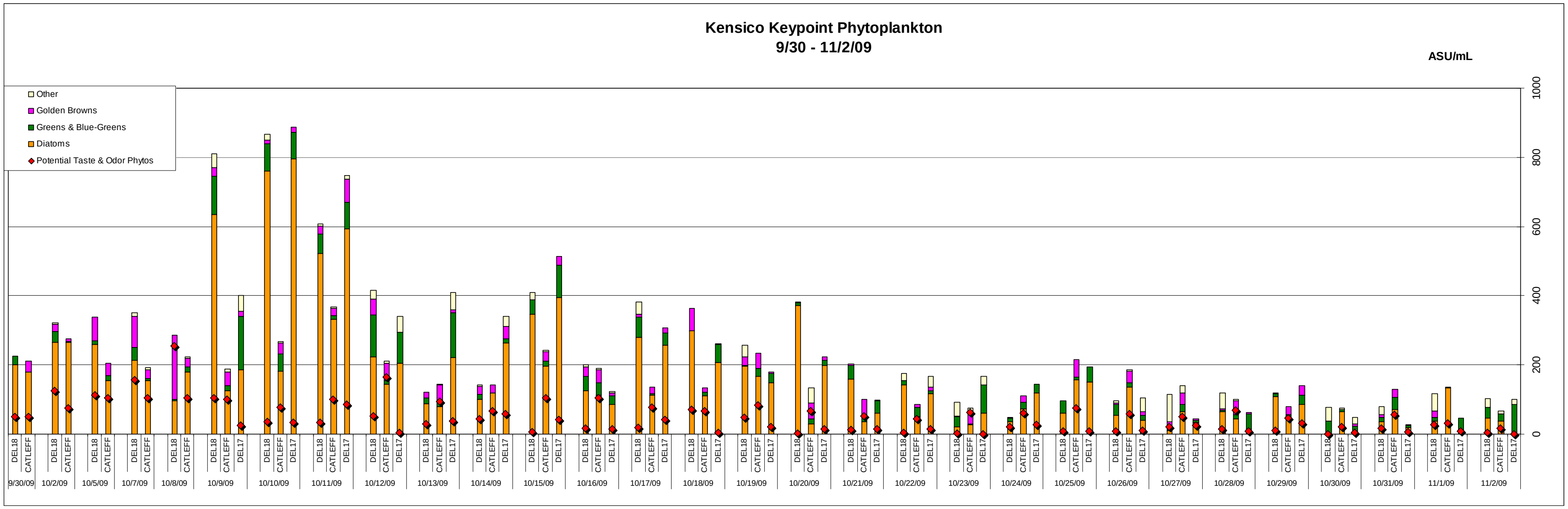


Figure 3 Counts (ASU/100ml) of *Chrysosphaerella* at Kensico Reservoir survey sites from November 2-24, 2009. Bars represent the value for each depth sampled at each site. No bar for a given depth indicates a value of zero.



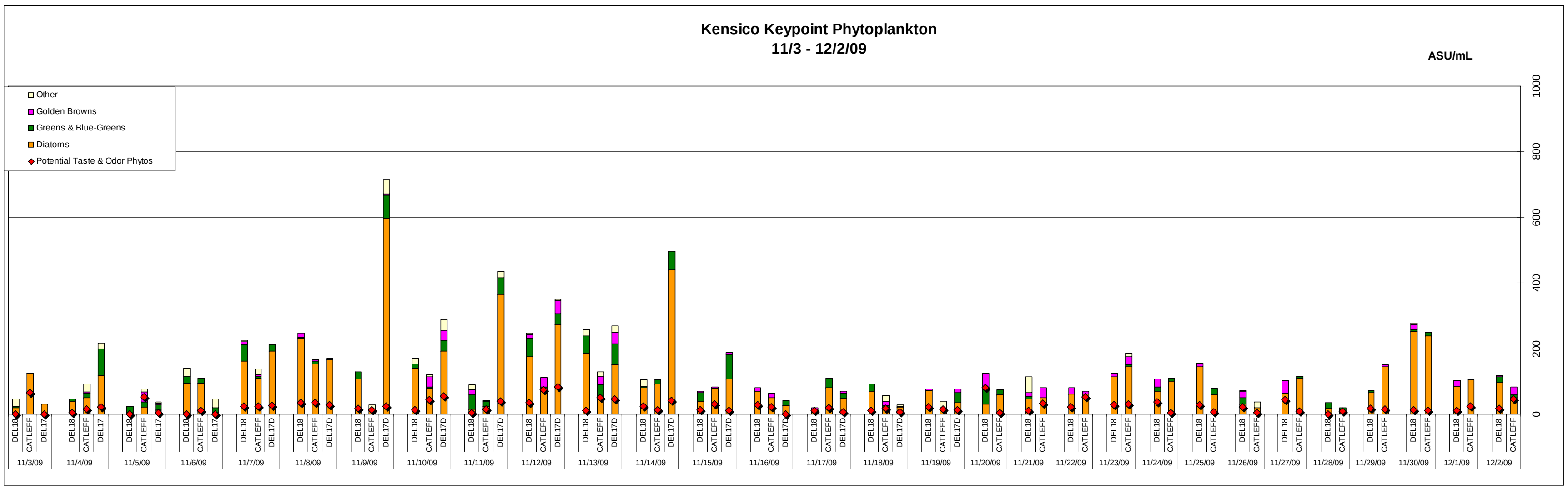


Figure 4 Phytoplankton counts (ASU/ml) at Kensico Reservoir aqueduct keypoints from September 30 to December 2, 2009. Note sample dates are displayed chronologically but only days when samples were collected are displayed.

b. Consumer Complaint Reporting

i. In-City

DEP has an automated system (Hanson) in place that receives and tracks calls received by NYC consumers reporting drinking water complaints to the New York City 311 System. On October 4, 2009, BWS began receiving a higher than normal number of consumer complaints (11) indicating a metallic or bitter taste (QA3) in the drinking water. Although this is a small fraction of the over 8,000,000 NYC water consumers, BWS managers were notified and an investigation into the source of the metallic taste began immediately. By October 7, 2009, the number of daily complaint calls had risen to 26 and BWS, suspecting that Kensico Reservoir was the source of the problem, placed the Delaware Aqueduct in by-pass mode circumventing the reservoir. Consumer complaint calls immediately began to decline and within a week, BWS was receiving less than 5 calls per day (Figure 5). BWS continued to monitor the number of water quality complaint calls on a daily basis and issued an internal BWS daily report on the number of complaint call received. A table of daily water quality complaint calls received throughout the entire event (October 1 – December 21, 2009) is included as Attachment 1.

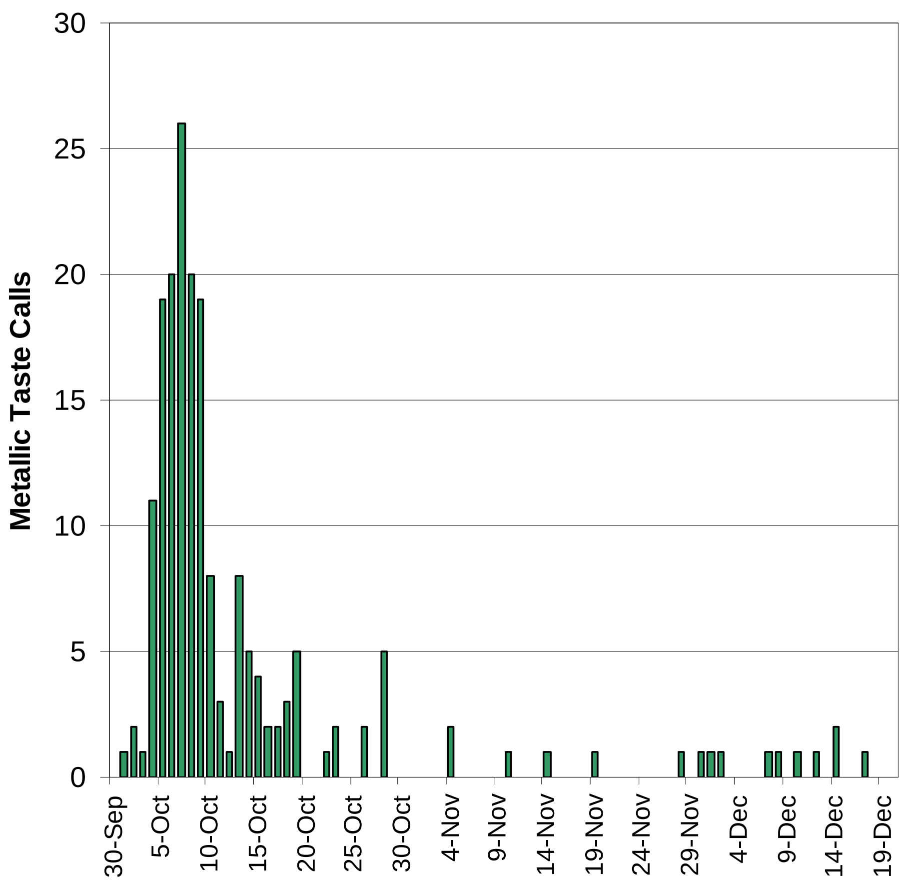


Figure 5 Daily number of NYC consumer metallic taste (QA3) complaint calls received.

ii. Outside Communities

On October 15, 2009, BWS began tracking customer complaint calls received by upstate communities who are served water from the Catskill System south of Kensico Reservoir. Some of these communities inquired about the cause of the metallic taste in the water being received from NYC and were informed that DEP's Water Quality Directorate was investigating the source of the problem. In the first weeks of the taste and odor event, complaint calls received by these communities were quite numerous and DEP requested and recorded the number of complaints from each of the communities on a daily basis. As the event progressed, the number complaints being received tapered off, and in response, the frequency of DEP's communication with the upstate communities decreased. On October 26, 2009, DEP reduced the frequency of requesting complaint totals from daily to Mondays and Fridays only.

One of the utilities served, United Water New Rochelle, set up an automatic "up front" recorded message for incoming complaint calls and therefore an accurate count of the total number of calls received was not kept and was not available.

The City of Yonkers received the highest number of complaint calls, numbering more than 50 on October 15, 2009, the first day that DEP began requesting information. By the end of DEP's surveillance of communities served, there were no reported taste and odor complaints from any of the communities. On December 24, 2009, DEP's tracking of customer complaint calls received by upstate communities was discontinued. Table 4, provides the dates that the communities were contacted and the number of taste and odor complaints reported.

Table 4 Summary of taste and odor complaints received by upstate communities supplied by Catskill Aqueduct below Kensico Reservoir.

	Greenburgh	Mt. Pleasant	Scarsdale	Sleepy Hollow	Tarrytown	UWNR	West. Co. #1&3	Yonkers
10/15/2009	NR	0	3	0	NR	NR	0	50
10/16/2009	NR	0	0	0	6	200 *	0	9
10/19/2009	10	0	1	0	0	NR	0	3
10/20/2009	0	1	0	1	1	NR	0	3
10/21/2009	0	1	0	0	0	NR	0	3
10/22/2009	0	0	0	0	0	NR	0	1
10/23/2009	0	0	2	0	1	NR	0	2
10/26/2009	0	0	0	0	1	NR	0	2
11/16/2009	0	0	0	0		NR	0	1
11/20/2009	0	0	1	NR	0	NR	0	0
11/23/2009	NR	0	0	NR	NR	NR	0	0
11/27/2009	NR	NR	NR	NR	NR	NR	NR	NR

	Greenburgh	Mt. Pleasant	Scarsdale	Sleepy Hollow	Tarrytown	UWNR	West. Co. #1&3	Yonkers
11/30/2009	0	NR	NR	0	NR	NR	0	1
12/11/2009	NR	0	NR	0	NR	NR	0	0
12/18/2009	0	0	0	NR	NR	NR	NR	NR
12/24/2009	NR	0	0	NR	NR	0	0	NR

Note: * = approximation only as this utility had set up an automatic header message for incoming calls.
NR = no response

c. Additional Water Quality Reporting

i. Watershed Water Quality Operations

In response to this event, WWQO modified its routine analytical procedure for analyzing phytoplankton samples. The modification required the analyst, when observing the sample under a microscope, to scan of the entire slide area for the presence of *Chrysosphaerella*. This "full scan" procedure was implemented for select sites and recorded as either present or absent in the full scan. Full scan procedures were performed at the following keypoint sites throughout the course of the event; Kensico effluents DEL18 and CATLEFF, Rondout effluent RDRRCM and Ashokan effluent EARCM. To assist in determining the extent of the problem in the Water Supply system, full scans were also performed on an as needed basis on reservoir influent sites at Kensico, West Branch, Rondout and Ashokan Reservoirs, elevation tap/gatehouse samples at Rondout, Ashokan, Pepacton, Neversink and Cannonsville Reservoirs and Delaware System effluents from Neversink, Pepacton and Cannonsville Reservoirs.

In addition to implementing a "full scan" procedure WWQO also modified how these data were recorded. Instead of simply recording the dominant genus present in a sample, WWQO tracked the counts of all organisms identified. This change allowed for the statistical evaluation of individual genus or class aggregation of algae (i.e., all golden browns seen). These modifications made DEP procedures generally equivalent to the procedures utilized by MWRA during their 2004 *Chrysosphaerella* bloom event (noting that MWRA utilized ten fields for counting rather than five).

To aid in the dissemination of information, data management procedures were also enhanced dramatically for this event. Daily e-mail updates of phytoplankton data results were provided by the Kensico Laboratory for sites DEL17, DEL18 and CATLEFF and by the Kingston Laboratory for sites RDRRCM and EARCM. Weekly updates were provided to the Director of Water Quality. WWQO maintained tracking tables and charts for Keypoints and Reservoir sites throughout the event.

ii. Distribution

Since the source of the taste problem was determined to be from a watershed source and since laboratory analysis was ineffective in identifying the taste causing compound, there was no increase in water quality monitoring in the distribution system in response to this event. However, routine daily water quality monitoring throughout the City continued.

d. Regulator Notification/Updates

On October 6, 2009, when DEP began to realize an increase in the number of drinking water taste complaints, the Director of Water Quality contacted NYC-DOHMH to apprise the Department of the issue. The NYS-DOH and WC-DOH were also notified of the issue and by October 8, 2009, DEP began providing these agencies with a daily update. As the number of complaints began to decline, communications with regulators became less frequent.

Although drinking water taste and odor issues are a concern, this event posed no public health risk and no water quality violations occurred. Updates to regulators were intended to keep regulators informed and to discuss DEP public notifications and communications related to this taste event.

e. Public Communication

i. DEP Response to Consumer Complaints

On Wednesday, October 7, 2009, DWQO contacted 37 311 system callers to address their metallic taste and odor concerns. DWQO staff normally contact 311 callers to address consumer complaints. Consumers were notified that DEP was aware of the problem; the problem was not localized; an investigation was under way; and based on the testing that had been done, the water was safe to drink.

On November 1, 2009, in response to a relatively high number of metallic taste and odor complaint calls recorded into the Hansen 311 system, DEP's Bureau of Communications and Intergovernmental Affairs (BCIA) implemented an automated phone call response system called Robocall. The Robocall System was used to respond to the more than 250 consumers who had called the 311 Call Center in the past month to report a metallic taste and odor to their drinking water. DWQO provided BCIA with a list of 250 names and telephone numbers to be contacted by Robocall.

ii. Web Announcement

The Agency took a proactive measure to notify the public of the unusual metallic taste of some drinking water and on October 9th posted a Service Advisory on the DEP website (http://www.nyc.gov/html/dep/html/advisories/metallic_water.shtml). The advisory explained the situation, indicated that the water was safe to drink, and instructed consumers to call 311 if they are experiencing a metallic taste in their water. In addition, a script was provided to 311 operators to provide any new callers, reporting a metallic taste to their water, with additional information. The script read as follows:

> "Over the past several days, DEP has received reports from individual consumers of metallic tasting water. We believe this is caused by the natural growth and biological degradation of certain algae in at least one of our reservoirs. Taste and odor issues caused by algae are not uncommon to water utilities nationwide; however, in the NYC system our source water protection programs have significantly reduced the frequency of algae related impacts on the water supply system over the last decade. We have done extensive testing and investigation of both our source waters in our upstate watersheds and in the City's distribution system and the water is safe to drink. We are continuing work to confirm the cause of this unusual taste and further investigate the situation. We are also adjusting water supply operations to address as quickly as possible this issue, which can be expected to run its course naturally as the weather gets colder. If you are experiencing metallic tasting water, please call 311."

f. Taste Testing

Due to the absence of any direct information regarding algae concentrations that lead to a disagreeable taste and odor in the drinking water, managers of the Water Quality Directorate undertook a subjective taste test investigation of raw Kensico Reservoir water chlorinated in the laboratory. Water samples were collected and chlorinated from three reservoir sites and the two effluent keypoints sites. Five Water Quality Managers participated in blind taste tests of water samples marked only as "A" to "E". The managers then recorded their estimation of the taste and the intensity of water from each sample. A brief description of the methodology used for this taste testing is provided as Attachment 5. These tests were conducted weekly for six weeks from October 20, 2009 to November 24, 2010.

The results of the taste testing indicated that the detection and perceived intensity of a metallic taste is subjective and experienced differently by different individuals. However, all subjects did perceive a metallic taste in many of samples. The concentration of *Chrysosphaerella* in the water samples varied from absent to 252 ASU/mL. While no clear threshold concentration at which a metallic taste can be detected was established, most participants did note a clear decrease in intensity as the algal concentrations began to decrease. Summary tables of the taste test results for each week are provided in Attachment 5.

7. De-Escalation of Event

a. De-Escalation Plan

During this taste and odor event, WWQO intensively monitored *Chrysosphaerella* levels in Kensico Reservoir and complaints of metallic tasting water from in-City consumers. To assist in the decision process to decide when to return the system to normal operations BWS developed a de-escalation plan. This plan identified both water quality and consumer complaint targets. Table 5 below lists the de-escalation targets presented in the plan. A copy of the De-escalation Plan developed for this event is included as Attachment 6.

Table 5 De-escalation Plan Sample targets for resuming normal operations.

Sample Type	Sample Targets
Kensico Reservoir Phytoplankton Sample	<100 ASU/100ml *Chrysosphaerella*
Kensico Effluent Keypoint	<15 ASU/100ml *Chrysosphaerella*
Consumer Compliant – metallic taste	< 2 Calls – 5 day average
Consumer Compliant – all taste	< 10 Calls – 5 day average

b. Decline in Phytoplankton Levels

To monitor in-reservoir levels of phytoplankton, and *Chrysosphaerella* in particular, during this event WWQO conducted weekly surveys of Kensico Reservoir. Concentrations of *Chrysosphaerella* observed are shown in Figure 2 and Figure 3 and the weekly phytoplankton results are provided in Attachment 4. By November 9, 2009, reservoir survey concentrations of *Chrysosphaerella* showed a noticeable reduction from levels seen at the beginning of the event in early October. *Chrysosphaerella* were still present at all sites, however at only one site was the concentration >100 ASU/100ml. Previous surveys consistently indicated concentrations of >100 ASU/100ml throughout the reservoir.

The BWS De-Escalation Plan target for acceptable reservoir quality is <100 ASU/100ml of *Chrysosphaerella.* Since this target value is not based on actual past experience but on communications with other water utilities (MWA), BWS was uncertain if concentrations <100 ASU/100ml would impart a detectable taste to the drinking water. To address this concern, BWS brought Kensico Reservoir back online in steps, slowly "blending" Kensico Reservoir water into the Delaware Aqueduct. On November 10, 2009, BWS began to blending 50% reservoir water into the aqueduct. Phytoplankton concentration at reservoir effluent keypoints and in-City consumer calls were monitored daily throughout the blending process.

Total phytoplankton concentrations at reservoir effluent keypoints showed a slight increase, particularly at DEL17, when the blending operation began (Figure 4). But concentrations returned to low levels within a few days. Consumer complaint calls remained low, a good indication that the addition of Kensico water was not imparting a detectable metallic taste to the drinking water.

Kensico Reservoir surveys continued to show a decline in *Chrysosphaerella* concentrations and in their distribution throughout the reservoir in November. By the November 24 survey, *Chrysosphaerella* were not detected at 3 of 8 sample sites and average site concentrations were <60 ASU/100ml at all sites. On November 30, 2009, the blending operation was complete and Kensico Reservoir was fully online. At this time, routine bi-weekly reservoir monitoring and 3 day/week Kensico effluent keypoint monitoring for phytoplankton resumed.

c. Decline in Consumer Complaints

BWS tracked in-City consumer complaints from the beginning of this event through December 21, 2009, a week after Kensico Reservoir was back in service. Targets for consumer calls established in the De-escalation Plan are <10 calls/day for any taste complaint category (QA1 – QA5) and <2 calls/day for metallic taste complaints (QA2), both reported as a 5-day average. Figure 6 shows the 5-day averages for consumer complaint calls for the entire event period, October 1 – December 21, 2009. The 5-day average for all taste complaint calls declined to below the 10 calls/day target on October 14 and remained below this threshold for the rest of the event. The 5-day average for metallic taste complaints calls fell below the 2 calls/day target on October 22, 2009, and remained below this level for the remainder of the event.

To determine the metallic taste target BWS reviewed 8 years (2000-2008) of historic data on consumer calls. These data indicated that on average, DEP receives 0.36 calls/day from City consumers complaining of metallic tasting water, or about 1.8 calls every five days. This indicates that the <2 calls/day is a reasonable background condition for consumer complaint calls.

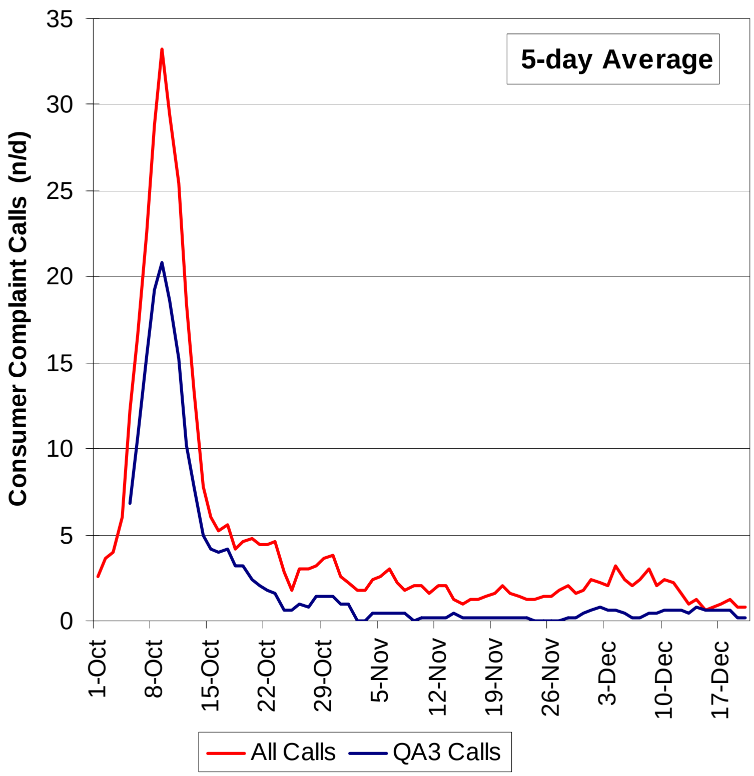


Figure 6 5-day averages for all drinking water taste compliant calls and only metallic taste complaint calls (QA3).

d. Return to Routine Operations

By the beginning of November, levels of *Chrysosphaerella* in Kensico Reservoir were declining. The De-escalation Plan target for reservoir concentrations was 100 ASU/100ml and the November 9, 2009 reservoir survey indicated that only one location, site BRK3, exceeded this concentration. At this time, the Delaware Aqueduct was by-passing Kensico Reservoir (in float mode) and delivering Rondout and West Branch water directly to Hillview. BWS had delayed a planned shutdown of the RWBT in October needed for infrastructure repairs. It was critical that the shutdown and repairs proceed placing an increased need that Kensico Reservoir be back online. On November 5, 2009, BWS began a 9 day shutdown of the RWBT.

With water quality improving and an increasing need to operate Kensico Reservoir, BWS began to bring the reservoir back online gradually, in steps. On November 10, 2009, BWS began delivering a blend of 50% Kensico water into the aqueduct while closely monitoring levels of *Chrysosphaerella* at the keypoints and in-City consumer complaints. Nine days later (November 19, 2009), BWS increased the blend to 75% Kensico water. And after another 11 days, on November 30, 2009, BWS began to operate Kensico in full “reservoir mode”, 100% Kensico water with no water by-passing Kensico Reservoir. Normal reservoir operations resumed and BWS continued to track consumer taste complaints to ensure the problem was no longer evident. No increase in *Chrysosphaerella* concentrations at reservoir keypoints was observed during the blending operation and there was no increase in the number of consumer calls.

8. Review of Ecology of *Chrysosphaerella*

To assist in managing this metallic taste event BWS realized that it needed a better understanding of the source organism. To meet this need, a brief review of the ecology of *Chrysosphaerella* was assembled. *Chrysosphaerella* belong to a group of phytoplankton known as Chrysophytes or golden-brown algae. Chrysophytes are mixotrophic, having the ability to obtain energy through photosynthesis and by ingestion of other microorganisms. The pigment content for Chrysophytes includes chlorophyll a, chlorophyll c3, violaxanthin and fucoxanthin. Ratios of these pigments can be used to differentiate the golden-browns from other algal groups (Schluter et al 2006). Their heterotrophic facet is enhanced by motility due to the presence of flagella. Some Chrysophytes have scales that contain silica (Lund and Lund 1995), and some species have the ability to mineralize iron and manganese. These metals appear as deposits on their scales (Wehr and Sheath 2003). The spores produced by Chrysophytes have siliceous coverings. Once the spores are in the sediments, they are available to the water column during future turnover events. When conditions are favorable, such as in early autumn, their numbers can increase again. The thick wall surrounding the cysts can be protective for several years before germination occurs (Kristiansen 2007). In general, the Chrysophytes are not easily dispersed from one water body to another, except for the cysts, which are hardier since they are less subject to desiccation than the vegetative cells (Kristiansen 2007).

Two species of *Chrysosphaerella* are commonly found in North America, *C. brevispina* and *C. longispina*. Differentiation of these two species requires the use of electron microscopy (Siver and Hamer 1989). Both species of *Chrysosphaerella* exist as colonial forms. Large colonial Chrysophytes can dominate during stratification (Sangren 1988), and were commonly found below the thermocline as short-lived, monospecific blooms (Paterson and Cummings 2004). The ability of Chrysophytes to thrive below the thermocline allows them to avoid UV radiation, reduce grazing pressure and provides proximity to nutrient-rich hypolimnetic water (Leavitt et al 1999).

C. longispina can occur through most of the growing season, and blooms can start in late summer to early fall and persist into winter while *C. brevispina* typically appears through winter. Various studies have been conducted on the conditions in which these Chrysophytes are found. In a study of Connecticut lakes, Siver and Hamer (1989) used cluster analysis to determine the optimal conditions for many taxa. The weighted means for several water quality indicators for *C. longispina* were: pH 6.0, specific conductivity 40 µS cm-1, temperature 14.8° C, and total phosphorus of 16 µg L-1. Additional studies on the specific conductivity showed that *C. longispina* occurred at an optimum of 56 µS cm-1 but tolerated 28 µS cm-1 (Siver 1993). *C. brevispina* occurred at an optimum of 91µS cm-1 but tolerated 57 µS cm-1. In a study of algal class response to total phosphorus (TP) levels, Watson et al (2003) found that Chrysophytes dominate in low TP waters. Similar conditions were found in boreal lakes in the Canadian Shield (Paterson and Cummings 2004).

Sediments provide an excellent record of the presence of scaled Chrysophytes over time. Paterson and Cummings (2004) investigated 50 boreal lakes and found that scaled Chrysophytes, including *Synura*, have increased substantially since pre-industrial times. On two of the lakes where they performed detailed stratigraphic sediment analysis, the abundance of colonial taxa began to rise in the 1930s to 1950s, and markedly increased in the last two decades. In other lakes where the cores constituted the record of millennia of deposition, the authors found that the recent increase in colonial Chrysophytes was unprecedented. They conclude that these rapid increases are likely the result of broad-scale, regional anthropogenic influences (e.g. climate change, ozone depletion and subsequent increase in UV radiation and acid deposition).

a. Occurrence in NYC Water Supply

As part of the investigation of this incident, BWS reviewed its water quality database for any past occurrences of *Chrysosphaerella* from all past reservoir and aqueduct keypoint sampling. In the >20 years of BWS phytoplankton samples reviewed, *Chrysosphaerella* had never been observed and recorded. The identification of *Chrysosphaerella* in Kensico Reservoir is the first reported occurrence of this alga in the NYC water. However, since this alga is ubiquitous throughout New York and Connecticut it is likely that is has been present in BWS reservoirs at low concentrations and not identified.

9. Review of Algae Related Taste and Odor Issues

a. Experience of Other Water Utilities

Although other water supply utilities have certainly experienced taste and odor issues related to Chrysophyte blooms, there appears to be little documented evidence of such events. In our literature search, there was only one well-documented Chrysophyte bloom of this particular genus associated with taste and odor complaints. This bloom occurred in 2004 in Boston's water supply and caused numerous complaints of a fishy odor and a metallic taste. References for this event include MWRA's Annual Report (2004) and communications with MWRA staff (B. Reilely and others, personal communication).

The 2004 bloom in Boston's water supply started after the July 4th weekend. MWRA began to receive complaints of a metallic taste in the water. Subsequent sampling showed that a bloom of >1400 ASU ml-1 of *Chrysosphaerella* was occurring in the metalimnion of Wachusett Reservoir. A cold water interflow from Quabbin Reservoir caused a sharp thermocline at a depth of 8 m. Water quality conditions at the depth of this bloom showed that dissolved oxygen was at 110% of saturation, the pH was 6.2 and the specific conductivity was approximately 73µS/cm.

Based on their findings, MWRA theorized that *Chrysosphaerella* inhabiting the Wachusett epilimnion migrated rapidly from the epilimnion to the bloom stratum in the few days prior to and during the July 4th weekend. This migration was assumed primarily an avoidance response to intensifying solar radiation and warming epilimnetic temperatures, and not attraction to nutritional resources. Accumulation at a depth of 7.5 meters indicated that this position in the thermocline provided *Chrysosphaerella* with the optimal combination of light intensity, food sources and cooler temperatures. These conditions have been documented as optimal for *Chrysosphaerella* by Siver and Hamer (1989).

The MWRA event was their first significant experience with *Chrysosphaerella* and the first occurrence of metallic taste and odor in their water supply. Only four much smaller blooms had been recorded in the 8 years prior to 2004. This was one of the most persistent algal related taste and odor episodes that the MWRA staff can remember. Copper sulfate application was largely ineffective, perhaps because it may have been applied too late in the growth cycle (B. Reilly, MWRA, personal communication). The bloom of *Chrysosphaerella* died off in early August and during the last two weeks of the bloom, the algal colonies showed detectable signs of senescence.

Despite the paucity of data specific to *Chrysosphaerella* blooms, some utilities have noted a general increase in the occurrence of other Chrysophytes in recent years. A bloom of *Uroglena* occurred in Seattle in 2003 which also caused a fishy odor and metallic taste. An Ohio water supply reservoir has had six problematic *Synura* blooms in the past two decades that caused taste and odor complaints. Philadelphia has had a history of *Synura* blooms and has an aggressive taste and odor program to address occurrences of this and other algae (Suffet et al 2008). MWRA of Boston has also had problems with *Synura* prior to the *Chrysosphaerella* bloom. Since there are similarities between these Chrysophytes, a summary of the water supply's experience is included.

The *Uroglena* bloom in Seattle was only mentioned briefly in links found during a web search, and was subsequently discussed with M. Joubert of Seattle Public Utilities (personal communication). Rather than paraphrase their description, a summary paragraph is excerpted from an e-mail exchange:

> "We had an extensive bloom in our Chester Morse watershed reservoir in 2003 (about July 1st) – biovolume got up to around 12 mm3/L and chla was about 15 ug/L where the *Uroglena* was concentrated at about 2 meters down during the day. At the same time, the biovolume was less than 1 mm^3/L at 15 meters. Our actual drinking water intake is many miles downstream (Cedar River) and is the outlet of our 11 billion gallon Lake Youngs (flushing rate 120 days). Even though it is many miles downstream and had been chlorinated, the water flowing into Lake Youngs had a rather strong fishy, metallic flavor from the Chester Morse *Uroglena*. However we did not get the fishy, metallic flavor coming out of Lake Youngs and going to our customers until Lake Youngs itself developed a minor *Uroglena* bloom (max biovolume 3 mm^3/L) at the first of August 2003. By this time, the bloom in Chester Morse was beginning to dissipate and the water coming down the Cedar River was tasting better than the water coming out of Lake Youngs so we began bypassing the lake. Our customers did get some fishy, metallic flavored water delivered to their taps but it was minimized considerably by our ability to bypass."

One possible explanation for the occurrence of the *Uroglena* bloom was that these events seemed to occur after a disturbance. They found that dredging or increased water levels may have been linked to the blooms, but could only speculate if the cause was resuspension of the spores or possible nutrient enrichment.

Seattle didn't have any treatment option at the time other than by-pass operations. They now have ozone which they stated obliterates off-flavors but may cause a slight plastic taste. M. Joubert suggested that selective withdrawal could be an option for NYC since *Chrysoshaerella* like *Uroglena* are motile and have a tendency to move within the water column. Since 2003 Seattle has had "some minor blooms in Chester Morse (max biovolume about 7 mm^3/L) and we have seen the *Uroglena* in Lake Youngs as well but always at less than 1 mm^3/L. Now having ozone, we do not worry about the fishy, metallic flavors – we just worry about plastic flavors".

Synura blooms are a well documented cause of a "cucumber" taste and odor in water supplies. In Youngstown Ohio, the Meander Creek Reservoir began having taste and odor problems in 1987 that were caused by *Synura petersenii*. These blooms have continued into 2009 and have been attributed to an improvement in water clarity as a result of a decrease in trophic conditions (Schroeder et al 2009). Philadelphia has had extensive experience with Synura blooms in the Delaware River. They attribute the taste and odor to an algal exudate, trans,2-cis,6-nonadienal, which has become part of their routine taste and odor chemical analysis (Suffet et al 2008). Treatment methods used by Philadelphia to address *Synura* blooms include a combination of powdered activated carbon, river water bypass and hydraulic changes in the distribution system.

As stated earlier, MWRA of Boston has also had problematic *Synura* blooms in the past. These blooms have been attributed to small-scale temperature gradients in the metalimnion of Wachusett Reservoir along with favorable light and nutrient availability (Worden 2003). Worden also stated that silica depletion in the water column following a spring diatom bloom may limit the growth of *Synura* later in the year. MWRA typically treats in the vicinity of their intake with copper sulfate to decrease levels of *Synura* and other taste and odor algae. They have established an action threshold of 20 ASU ml-1 for this alga.

b. Taste Causing Compounds

Taste and odor (T&O) issues are commonly encountered in public water supplies. Since taste and odor are inextricably linked, flavor is a common descriptor for the taste and odor sensation, and is the basis of flavor profile analysis (FPA) used by some utilities (Veolia 2007). The causes for T&O problems can include naturally produced compounds (e.g. geosmin from cyanobacteria), pollutants, physiochemical changes in the water source (e.g. anoxia), and changes caused by water treatment chemicals (e.g. chlorine). The taste causing compounds have been determined for many phytoplankton species, but not specifically for the metallic taste experienced during a *Chrysosphaerella* bloom.

Two prime examples of T&O compounds that impart an earthy, moldy flavor are geosmin and 2-methylisoborneol (MIB), typically found in cyanobacteria and actinomycetes. Odor threshold values have been established for these two compounds. A literature review shows that many additional T&O compounds are polyunsaturated fatty acid derivatives (PUFA) such as aldehydes and ketones. *Synura*, a *Chrysophyte*, has a cucumber odor that has been ascribed to trans, cis -2,6-nonadienal, a fatty acid aldehyde (Wee et al 1994). Dr. Susan Watson in Canada stated that the *Chrysophyte* algae are known to cause fishy odors from the breakdown of PUFAs (e.g. Watson et al. 2001, Stachwill et al. 2007, Watson et al. 2008). For example, “The Glenmore Reservoir and water treatment plant (GWTP) supplies drinking water to over 50% of the ca. 1 million consumers in Calgary (Alberta). Despite low nutrients and high raw water quality, the reservoir experiences periodic outbreaks of fishy/floral T/O, caused by *chrysophytes* and diatoms (*Uroglena americana, Dinobryon spp., Synura petersenii, Asterionella formosa*). These odours are produced by the unsaturated C7 - C1 0 alkenes 2,4-heptadienal, 2,4,7-octatriene, 2,4-decadienal and 2,4,7-decatrienal, generated during from the enzymatic breakdown of algal polyunsaturated fatty acids (PUFAs). The formation, persistence and stability of these compounds in both the raw water and treatment plant are not well understood (Satchwill et al. 2007). For the Glenmore Reservoir, Watson et al. (2001) found “Raw water odour was characteristically fishy, mainly caused by the VOCs 2,4,7-decatrienal, 2,4-heptadienal and 2,4-decadienal. Based on algal population and VOC dynamics, these compounds were attributed to *Dinobryon*. Trace amounts of 2,6-nonadienal (*S. petersenii*) and 1,3,5 and 1,3,6-octatriene (*A. formosa*) were also detected. It was concluded that 2,4,7-decatrienal was the major source of the raw water odour.” In another paper, Watson and Satchwill (2003) state “… the processes that influence the levels and dynamics of algal volatile organic compounds (AVOC) AVOC production are not well understood. There has been some success in linking AVOCs to individual taxa, but it is often difficult to predict taste and odour (T/O) outbreaks because algal communities show significant among- and within-species variation in AVOC production.” In a conversation with Dr. Watson, she stated that she doesn’t have a culture of *Chrysosphaerella* to work with, but would gladly take one. She did say that the heptadienals tend to resist breakdown even after chlorination.

9.

In addition to the PUFA compounds, other T&O compounds found in various phytoplankton groups include aromatics, terpenes, amines and organosulphur compounds (Watson et al 2001). As stated earlier, the cause of the metallic taste imparted by *Chrysosphaerella* has not been determined. It could be attributed to a combination of these compounds, or to an unidentified compound. There is also the possibility that another factor may be at play. Some *Chrysophytes* have the ability to mineralize iron and manganese from their surrounding water and deposit these metals on their scales (Wehr and Sheath 2003). Specific information on the content of these metals in the cells was not found during our literature search, but the potential for this mechanism to have a role in the flavor characteristics of these algae cannot be ruled out. Further elucidation of the compounds responsible for imparting a metallic taste would need to be performed before a positive link to a source could be determined.

c. Algae Treatment Options

Water supply experience with *Chrysosphaerella* blooms seems to be limited. The treatment options in the literature are those that are applicable to algae in general. Treatment can take place in a source water reservoir, or as part of the processes employed in a water treatment plant. Attachment 7 provides a summary table of reservoir management techniques that have been applied to control various algae.

In-Reservoir Treatment

One of the primary compounds used in many water supply reservoirs to treat algal blooms is copper sulfate. Massachusetts Water Resources Authority (MWRA) of Boston has direct experience with the use of copper sulfate in Wachusett Reservoir. In both 2004 and 2005, MWRA attempted to apply copper sulfate at the depths *Chrysosphaerella* were observed (usually at 7 to 9 m below the water surface). The application in 2004 was not successful. In 2005, they improved the application equipment. A schematic drawing of the boat, and the apparatus used at variable depths down to 8 m was provided to DEP. However, effective use of such a device requires close control of the depth of application of copper sulfate. The location of the application also needs to be closely monitored in order to effectively eliminate *Chrysosphaerella*.

Chrysophytes are usually susceptible to copper sulfate. A moderate recommended dose for most algae is 0.3 mg/L. In New York State, copper sulfate was classified as a restricted use pesticide in 1993 (NYSCRR 326.2(h)) and its use in water supplies has diminished in recent years as compared with surrounding states.

Chlorine has also been used to control algae. Two types of treatment include chlorination of inflowing water and reservoir application. Transfer of water from one basin to another requires end-point chlorination so that there is no residual when the tunnel water enters the downstream reservoir. Alternatively, dechlorination facilities can be used at the terminus of the tunnels. Reservoir application of chlorine is usually reserved for distribution or operational reservoirs. Los Angeles (MWDSC) regularly chlorinates some of its basins, such as Etiwanda, to control nuisance growths of algae (Taylor 2006). The Israeli National Water Carrier chlorinates Eshkol Reservoir (at a Cl_2 concentration of 0.2 mg L^{-1}) for the control of taste and odor producing algae such as *Dinobryon* and *Uroglena* (Porat et al 2008). In both of these cases, the impoundments have a short residence time and adequate circulation helps distribute the chlorine residual. In a deep reservoir such as Kensico, selectively applying chlorine at 8 m would be impractical.

Attachment 7 provides an extensive list of additional reservoir based control measures. Since phosphorus limitation may be advantageous to *Chrysophyte* populations, watershed phosphorus reduction measures are not considered a control measure. Circulation and destratification may help in decreasing the niche available to *Chrsyophytes,* but that may not be practical on a scale applicable to Kensico Reservoir. Dilution is certainly an operational strategy that can be applied to reduction of blooms. Drawdown and sediment removal strategies target nutritional release from the sediments and would not be beneficial in the case of *Chrysosphaerella* in Kensico. The limited removal of algal spores would not be worth the effort entailed in sediment removal. Dyes and surface covers are also not practical and mechanical removal is more applicable to algal mats, which are more typically found with blue-green algae. Selective withdrawal is a viable option for the NYC water supply system if the problem algae is restricted to certain depths, however this method does not address the source. Another control method is the use of precipitants to remove whole algal cells from the water column. Various types of clay have been used to form sinking particles with algal cells (Sengco 2005). Alum has also been used to drop out whole cells so that taste and odor compounds aren't released (Rashash, et al 1996). These precipitation strategies would only be practical for blooms that are treated in tunnels and aqueducts from upstream sources. Additional strategies provided in Attachment 7 include sonication, peroxides and biological control measures.

This preliminary review suggests that the most practical in-reservoir control option for DEP would be copper sulfate treatment. The use of a boat that is equipped to dispense a solution at depth appears to be the best alternative to control established *Chrysosphaerella* populations. According to the manufacturer's label, (Phelps Dodge 1999) copper sulfate can be applied by spraying a solution on the surface, injecting a solution at depth or by directly injecting a solution into flowing water. DEP does not currently have the necessary equipment to inject a solution at depth. Another option is treating incoming aqueducts with break-point chlorination to prevent upstream algal blooms from being transported to downstream reservoirs. De-chlorination would be performed at the aqueduct outfall. Alternatively, a flocculent such as alum could be used to remove incoming algal cells as the water enters a receiving reservoir.

<u>Water Treatment Options for Taste and Odor</u>
There are many commonly used water treatment methods to counter taste and odor problems resulting from various algae. These include chlorine, chlorine dioxide, potassium permanganate ($KMnO_4$), ozone and activated carbon. Lin (1977) provided a description of each method along with their advantages and disadvantages. Chlorine is by far the most common disinfectant as well as an agent for taste and odor control. The balancing point that must be achieved is minimizing the offending compounds without creating additional taste and odor. In his synoptic summary, Lin stated that control of *Synura* taste and odor was achievable by chlorinating just a few ppm above the "free available chlorine zone" (i.e. break-point chlorination). Chlorine can also be used in combination with $KMnO_4$ pretreatment and activated carbon, as is the case with Philadelphia's treatment of *Synura* blooms (Suffet et al 2008). Potassium permanganate has had wide use in the control of taste and odors in public water supplies. It has the advantage of being economical and practical to use. A solution of $KMnO_4$ is typically applied at the head of the plant as a preoxidant. Lin provided several examples where taste and odor were effectively reduced by potassium permanganate. Chlorine dioxide

is another potent oxidant but has limitations for large scale plants because of safety and instability.

Ozonation is a disinfection process that has wide application in addressing taste and odor issues in Europe and is becoming more common in the United States. It has the advantage of being a stronger oxidant than chlorine and being relatively inexpensive (Lin 1977). Lin also mentions that ozonation followed by chlorination has considerably reduced organoleptic taste and odor compounds. MWRA of Boston completed an ozonation plant on part of their system shortly after their *Chrysosphaerella* bloom in 2004. After the start of ozonation of the water, MWRA received no taste and odor complaints even though *Chrysosphaerella* levels were high (B. Reilely, MWRA, personal communication). Seattle has also had success treating part of their supply with ozonation to reduce a metallic taste from a bloom of *Uroglena* (M. Joubert, Seattle Public utilities, personal communication).

Activated carbon has been widely used for removal of taste and odor compounds in public water supplies. Carbon also has the advantage of removing other compounds, such as precursors for disinfection by-products. In general, molecules having higher molecular weight tend to adsorb better to carbon (Lin 1977). Lin also notes that activated carbon is very effective in minimizing the problems associated with algal metabolites.

In this review of water treatment options, ozonation combined with chlorine appears to be the most successful option in reducing taste and odor problems caused by algae. Ozonation was considered as a secondary disinfectant for the Catskill and Delaware Systems, but ultraviolet disinfection was ultimately selected. A review of the literature did not provide sufficient information on the combined effect of UV and chlorine on reducing taste and odor problems, particularly for *Chrysosphaerella*.

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NYC 311 Call Center Daily Calls
Drinking Water Quality Complaint Calls by QA Type

DATE	Chlorine QA1	Chemical QA2	Metallic QA3	Musty QA4	Sewer QA5	Total
01-Oct	2	2	1	0	0	5
02-Oct	0	1	2	2	1	6
03-Oct	0	1	1	1	2	5
04-Oct	0	1	11	0	1	13
05-Oct	2	1	19	6	4	32
06-Oct	0	2	20	4	1	27
07-Oct	1	2	26	5	2	36
08-Oct	4	2	20	8	2	36
09-Oct	0	2	19	9	5	35
10-Oct	0	2	8	0	3	13
11-Oct	0	1	3	2	1	7
12-Oct	0	0	1	0	0	1
13-Oct	0	0	8	3	0	11
14-Oct	0	2	5	0	0	7
15-Oct	0	0	4	0	0	4
16-Oct	0	0	2	1	0	3
17-Oct	0	1	2	0	0	3
18-Oct	0	0	3	0	1	4
19-Oct	3	1	5	0	0	9
20-Oct	1	1	0	1	2	5
21-Oct	0	1	0	0	0	1
22-Oct	0	0	1	1	1	3
23-Oct	1	2	2	0	0	5
24-Oct	0	0	0	0	0	0
25-Oct	0	0	0	0	0	0
26-Oct	1	3	2	1	0	7
27-Oct	2	0	0	0	1	3
28-Oct	0	1	5	0	0	6
29-Oct	0	1	0	1	0	2
30-Oct	0	1	0	0	0	1
31-Oct	0	0	0	0	1	1
01-Nov	0	1	0	0	0	1
02-Nov	0	1	0	2	1	4
03-Nov	1	1	0	0	0	2
04-Nov	1	0	2	1	0	4
05-Nov	2	0	0	0	0	2
06-Nov	0	1	0	1	1	3
07-Nov	0	0	0	0	0	0
08-Nov	0	0	0	0	0	0
09-Nov	1	2	0	1	1	5
10-Nov	0	0	1	0	1	2
11-Nov	0	0	0	1	0	1
12-Nov	0	1	0	0	1	2
13-Nov	0	0	0	0	0	0
14-Nov	0	0	1	0	0	1
15-Nov	0	1	0	0	0	1

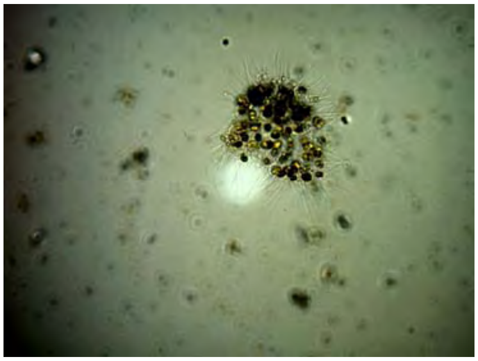
Attachment 1 NYC 311 Call Center Daily Calls

DATE	Chlorine QA1	Chemical QA2	Metallic QA3	Musty QA4	Sewer QA5	Total
16-Nov	0	1	0	1	0	2
17-Nov	2	0	0	0	0	2
18-Nov	1	0	0	0	0	1
19-Nov	0	0	1	0	1	2
20-Nov	1	1	0	0	1	3
21-Nov	0	0	0	0	0	0
22-Nov	0	1	0	0	0	1
23-Nov	0	0	0	0	0	0
24-Nov	1	0	0	1	0	2
25-Nov	2	0	0	2	0	4
26-Nov	0	0	0	0	0	0
27-Nov	1	1	0	0	1	3
28-Nov	0	0	1	0	0	1
29-Nov	0	0	0	0	0	0
30-Nov	0	2	1	0	2	5
01-Dec	1	1	1	0	0	3
02-Dec	0	0	1	0	1	2
03-Dec	0	0	0	0	0	0
04-Dec	2	2	0	1	1	6
05-Dec	0	1	0	0	0	1
06-Dec	1	0	0	0	0	1
07-Dec	1	1	1	0	1	4
08-Dec	1	0	1	0	1	3
09-Dec	0	1	0	0	0	1
10-Dec	1	0	1	1	0	3
11-Dec	0	0	0	0	0	0
12-Dec	0	0	1	0	0	1
13-Dec	0	0	0	0	0	0
14-Dec	0	0	2	0	0	2
15-Dec	0	0	0	0	0	0
16-Dec	1	0	0	0	0	1
17-Dec	1	0	1	0	0	2
18-Dec	0	1	0	0	0	1
19-Dec	0	0	0	0	0	0
20-Dec	0	0	0	0	0	0
21-Dec	0	0	0	0	0	0

Chrysosphaerella - Life History Info

Introduction

In early October, complaints about a metallic taste in NYC's drinking water supply rose to significant levels of concern. Through discussions with other water supplies it became apparent that the potential causal factor, in our case, may be a colonial, golden-brown, (silica-scaled chrysophyte) algae in the genus *Chrysosphaerella*; recently found in Kensico Reservoir. Only a few colonies of these algae may produce a very perceptible metallic flavor following chlorination.



This algae appears to be uncommon to NYC reservoirs, having not been reported as a dominant genera in any survey prior to 2009.

Chrysosphaerella, however, is common in many freshwater localities (Siver 1993).

In 1980 three colonial taxa were recognized in the genus *Chrysosphaerella* (*C. longispina* Laut., *C. brevispina* Korsh. emend. Harris and Bradley, and *C. multispina* Bradley). Two of the species, *C. longispina* and *C. brevispina*, are commonly found in freshwater habitats (Takahashi1978; Wee 1982). Siver (1989) found *C. longispina* common in Connecticut and Adirondack lakes. Wujek et al 2006 found *C. longispina* in many locations throughout NY, whereas *C.brevispina* was not. We suspect that *C. longispina* is the species of interest here in Kensico Reservoir, as well. Some environmental criteria for *Chrysosphaerella* are examined below to support this hypothesis.

pH & Conductivity

In Connecticut lakes, maximal distribution occurs between pH 5 & 7 (Siver 1993) *Chrysosphaerella longispina* was found primarily in acidic (pH 5-6.75) localities low in specific conductance (<70 µS cm-l).

Siver (1993b) found *C. brevispina* preferred specific conductivity in the 90-120 µS cm-l range.

Temperature

C. brevispina and *C. longispina* were found to be distributed primarily in winter and summer/autumn months, respectively (Siver 1993)

Chrysosphaerella longispina was found throughout the year in Connecticut lakes. Most commonly, populations of this taxon began growth during the late summer and early autumn months and often thrived into early winter. Harris & Bradley (1958) also reported *C. longispina* to occur primarily during the autumn.

Chrysosphaerella brevispina was found to be a true winter species, often beginning growth in late autumn or early winter, persisting through the winter and disappearing shortly after ice out

Because of its occurrence throughout the year, *C. longispina* was found over a wide temperature gradient. The weighted mean temperature at which this organism occurred was 13.3°C.

Siver (1989; 1993) calculated that *C. brevispina* occurred at a weighted mean temperature of 10°C. The published literature is in agreement with the findings of this study that C. brevispina is a cold water taxon.

Trophic State

Chrysosphaerella longispina was found primarily in oligotrophic and mesotrophic waterbodies. Whereas *C. brevispina* may prefer more eutrophic waters.

Current conditions

NYC's Kensico Reservoir waters closely match the specific water quality conditions mentioned above for *C. longispina*. The reservoir is mesotrophic. The table below shows typical water quality conditions in the reservoir. These data were collected near the dam in October. The depth of the thermocline in blue. Samples were collected at all four depths to elucidate the impact of thermal structure on Chrysosphaerella distribution.

Depth (m)	Temp(°C)	pH	DO(mg/L)	Cond(µS/cm)
21	13.8	6.5	7.3	68
22	10.8	6.2	7.2	70
23	8.9	6.2	7.7	71
24	7.9	6.2	8.3	72

MWRA experience

In 2004, MWRA and communities began to receive complaints of a metallic taste and odor in the water after the July 4th weekend. Staff completed a security and water quality scan of the system and determined that the cause was a substantial bloom (>500ASU/mL) of golden-brown algae called *Chrysosphaerella* at a depth of approximately 8 meters (in the metalimnion) of Wachusett Reservoir. The pH at this location and depth was 6.2 to 6.8. and specific conductivity was ~73 µS/cm .

Based on their findings MWRA theorized that *Chrysosphaerella* inhabiting the Wachusett epilimnion migrated rapidly from the epilimnion to the bloom stratum in the few days prior to and during the July 4th weekend. This migration was primarily an avoidance response to intensifying solar radiation and warming epilimnetic temperatures, and not attraction to nutritional resources. Aggregation at a depth of 7.5 meters indicates that this position in the thermocline provided *Chrysosphaerella* with the optimal combination of light intensity and cooler temperatures.

This event is MWRA's first significant experience with *Chrysosphaerella* (only four much smaller blooms have been recorded over the past 18 years) and the first occurrence of the metallic taste and odor. This was one of the most persistent algal related taste and odor episodes staff can remember. Copper sulfate application was largely ineffective. It was thought that the copper sulfate may have been applied too late in the growth cycle to be effective. *Chrysosphaerella* died off in early August

In the last two weeks of the bloom, *Chrysosphaerella* colonies often appeared unhealthy with individual dead cells present. Also during this time, the organism was frequently observed as colony fragments or as individual cells disassociated from a colony.

During the initial stage of "turnover", when the epilimnion mixed with the metalimnetic interflow in late October, diatoms (mostly *Asterionella*) started to increase in abundance

Conclusions & Predictions

- Based upon the pH, temperature, specific conductivity and life history characteristics of *C. longispina*, as described by various researchers, I believe that *C. longispina* is the specific organism of concern in the NYC Water Supply.
- Peak numbers reported from Kensico Reservoir keypoint analyses did not approach the levels observed by MWRA.
- I expect that low concentrations of *C. longispira* will continue to be observed into the late fall/early winter (Nov-Dec), following turnover and the decline in water temperature.
- At this time, a natural die-off of the chrysophyte will occur, and diatoms will then become dominant (possibly due to silica availability).
- It is likely that we will see *Chrysosphaerella* again in future years under similar conditions. Formation of resting cells, or cysts, provides a "seed bank" for future recruitment when conditions become favorable.

Attachment 3 Keypoint Pytoplankton Data

Kensico Keypoint Phytoplankton Data (ASU/mL)

Date	Site	Diatoms	Greens & Blue-Greens	Golden Browns	Other	Potential Taste & Odor Phytos	Potential Taste & Odor Phytos Found in Sample (ASU Chrysosphaerella only)	Total	Reported Genus	count	Chyrsosphaerella Count Full Scan
12/2/09	CATLEFF	50	10	22.5	0	45	Asterionella, Synedra, Synura, Dinobryon	82.5	Tabelleria	15	absent
	DEL18	95.5	17.5	5	0	18.5	Synedra, Dinobryon	118	Melosira	65	absent
12/1/09	CATLEFF	105	0	0	0	25	Asterionella	105	Melosira	65	present
	DEL18	85	0	17.5	0	10	Dinobryon	102.5	Melosira	75	absent
11/30/09	CATLEFF	238.75	11.25	0	0	10	Asterionella, Synedra	250	Melosira	210	absent
	DEL18	252.5	5	15	5	12.5	Synedra, Dinobryon	277.5	Melosira	180	absent
11/29/09	CATLEFF	145	0	6.25	0	16.25	Asterionella, Synedra, Mallomonas	151.25	Melosira	68	present
	DEL18	66.5	5	0	0	16.5	Asterionella, Synedra	71.5	Melosira	48	absent
11/28/09	CATLEFF	9	10	0	0	9	Asterionella	19	Ankistrodesmus	10	absent
	DEL18	18	16	0	0	0	none	34	Melosira	13	absent
11/27/09	CATLEFF	110.5	2.5	0	2	8.5	Asterionella, Synedra	115	Melosira	78	absent
	DEL18	63	0	40	0	43	Asterionella, Dinobryon	103	Fragilaria	60	absent
11/26/09	CATLEFF	20	0	0	17.5	5	Synedra	37.5	Chroomonas	18	absent
	DEL18	30	20	20	2.5	22.5	Synedra, Synura, Dinobryon	72.5	Stephanodiscus	15	absent
11/25/09	CATLEFF	58.75	17.5	2.5	0	6.25	Asterionella, Synedra, Dinobryon	78.75	Melosira	42	prsent
	DEL18	145.5	0	10	0	28	Asterionella, Synedra, Synura	155.5	Melosira	100	absent
11/24/09	CATLEFF	100	10	0	0	5	Synedra	110	Melosira	45	absent
	DEL18	70.5	12.5	25	0	38	Asterionella, Synedra, Synura, Dinobryon	108	Melosira	30	absent
11/23/09	CATLEFF	145	5	25	10	30	Synedra, Dinobryon	185	Melosira	95	absent
	DEL18	114.75	0	10	0	29.5	Asterionella, Synedra, Synura	124.75	Melosira	54	absent
11/22/09	CATLEFF	60.5	0	10	0	53	Asterionella, Synedra, Dinobryon	70.5	Synedra	30	absent
	DEL18	60.25	0	20	0	22.5	Synedra, Synura, Dinobryon	80.25	Melosira	49	absent
11/21/09	CATLEFF	49.5	0	32.5	0	32.5	Dinobryon	82	Melosira	46.5	absent
	DEL18	46	9	10	49	10	Dinobryon	114	Fragilaria	30	absent
11/20/09	CATLEFF	60	15	0	0	5	Asterionella	75	Melosira	50	absent
	DEL18	30	45	50	0	80	Synedra, Synura, Dinobryon, Mallomonas	125	Dinobryon	35	absent
11/19/09	DEL17D	35	31	10	0	12.5	Synedra, Dinobryon	76	Fragilaria	30	absent
	CATLEFF	15	0	5	20	15	Asterionella, Dinobryon	40	chroomonas	20	absent
	DEL18	72.5	0	5	0	22.5	Asterionella,Synedra, Mallomonas	77.5	Melosira	55	absent
11/18/09	DEL17D	22.5	2.5	0	2.5	6.25	Synedra	27.5	Fragilaria	10	absent
	CATLEFF	22.5	3.75	13.75	16.25	17.5	Asterionella,Synura, Dinobryon	56.25	Melosira	15	absent
	DEL18	70	21	0	0	10	Asterionella, Synedra	91	Tabellaria	28	absent
11/17/09	DEL17D	47.5	16.5	5	0	7.5	Synedra, Dinobryon	69	Melosira	37.5	absent
	CATLEFF	82	26.25	1.25	0	20.75	Asterionella,Synedra, Dinobryon	109.5	Melosira	32.5	absent
	DEL18	6.25	3.75	8.75	1.25	10	Synedra, Synura	20	Synura	8.75	absent
11/16/09	DEL17D	26.25	15	0	1.25	0	none	42.5	Melosira	15	absent
	CATLEFF	51.25	0	12.5	0	22.5	Synedra, Synura	63.75	Stephanodiscus	20	absent
	DEL18	70.25	0	10	0	29	Asterionella, Synedra, Synura	80.25	Melosira	23.75	absent
11/15/09	DEL17D	107.75	74.5	5	0	11	Synedra, Synura	187.25	Melosira	90.5	absent
	CATLEFF	79	0	5	0	31.5	Asterionella, Synedra, Dinobryon	84	Melosira	47.5	absent
	DEL18	38.5	26.25	5	0	13.5	Synedra, Dinobryon	69.75	Melosira	23.75	absent
11/14/09	DEL17D	438.75	58.75	0	0	40.5	Asterionella, Synedra	497.5	Melosira	330	absent
	CATLEFF	91.5	12.5	0	3.75	14	Asterionella, Synedra	107.75	Melosira	71	present
	DEL18	81	5	0	18.75	25	Synedra	104.75	Melosira	29	present
11/13/09	DEL17D	150	65	35	20	45	Asterionella, Synedra, Synura, Mallomonas	270	Melosira	90	absent
	CATLEFF	50	40	25	15	50	Asterionella, Synedra, Dinobryon	130	Microcystis	30	absent

Attachment 3 Keypoint Pytoplankton Data

Date	Site	Diatoms	Greens & Blue-Greens	Golden Browns	Other	Potential Taste & Odor Phytos	Potential Taste & Odor Phytos Found in Sample (ASU Chrysosphaerella only)	Total	Reported Genus	count	Chyrsosphaerella Count Full Scan
	DEL18	185	52.5	0	20	10	Asterionella	257.5	Melosira	120	absent
	DEL17D	273.75	32.5	38.75	5	83.75	Asterionella, Synedra, Synura, Dinobryon, Mallomonas	350	Melosira	200	absent
11/12/09	CATLEFF	72.25	10	28.75	0	74.75	Asterionella, Synedra, Synura, Dinobryon, Mallomonas	111	Synedra	30	absent
	DEL18	175	57.5	10	5	35	Asterionella, Synedra, Mallomonas, Chrysosphaerella (5)	247.5	Melosira	110	present
	DEL17D	365	50	0	20	40	Asterionella, Synedra	435	Melosira	275	absent
11/11/09	CATLEFF	25	15	0	2.5	15	Asterionella, Synedra	42.5	Synedra, Cyclotella, Closteriopsis	E	present
	DEL18	15	45	15	15	5	Mallomonas	90	Gomphosphaerium	40	present
	DEL17D	193.25	31.75	30	33.75	54	Synedra, Synura	288.75	Melosira	148	absent
11/10/09	CATLEFF	79.75	3.75	30	6.25	43.5	Asterionella, Synedra, Dinobryon	119.75	Melosira	25	absent
	DEL18	140.25	12.75	0	17.5	12.5	Synedra	170.5	Melosira	91.5	absent
	DEL17D	597.5	70	5	42.5	25	Synedra	715	Melosira	370	absent
11/9/09	CATLEFF	12.5	0	0	15	12.5	Synedra	27.5	Croomonas	15	present
	DEL18	107	21.5	0	0	17	Asterionella, Synedra	128.5	Melosira	73	absent
	DEL17D	165.5	0	5	0	28	Asterionella, Synedra, Sinura	170.5	Melosira	68.75	absent
11/8/09	CATLEFF	153.25	8.75	5	0	35.5	Asterionella, Synedra, Dinobryon	167	Melosira	101.5	absent
	DEL18	231	2.5	13.75	0	34.25	Syndera, Synura, Dinobryon, Mallomonas	247.25	Melosira	165.5	absent
	DEL17D	191.75	20.5	0	0	25.25	Synedra	212.25	Melosira	156.5	absent
11/7/09	CATLEFF	108.5	7.5	3.75	18.75	24.75	Asterionella, Synedra, Synura, Dinobryon	138.5	Melosira	45	absent
	DEL18	162.5	50.75	8.75	3.75	23.75	Syndera, Synura	225.75	Melosira	140	absent
	DEL17	5	15	0	25	0	none	45	Spondylosium	20	absent
11/6/09	CATLEFF	95	15	0	0	10	Synedra	110	Melosira	75	absent
	DEL18	95	20	0	25	0	none	140	Melosira	95	absent
	DEL17	12.5	15	5	5	5	Dinobryon	37.5	Oscillatoria	15	absent
11/5/09	CATLEFF	22.5	15	30	10	52.5	Asterionella, Synedra, Dinobryon	77.5	Dinobryon	30	present
	DEL18	5	20	0	0	0	none	25	Ankistrodesmus	10	present
	DEL17	118.5	79.75	0	18.75	21	Synedra	217	Melosira	75	absent
11/4/09	CATLEFF	50	12.5	5	25	15	Asterionella, Synedra, Dinobryon	92.5	Melosira	25	absent
	DEL18	40	5	0	0	5	Synedra	45	Stephanodiscus	20	absent
	DEL17	30	0	0	0	0	none	30	Melosira	30	absent
11/3/09	CATLEFF	125	0	0	0	65	Asterionella, Synedra	125	Fragilaria	40	absent
	DEL18	20	5	0	20	0	none	45	Melosira	20	absent
	DEL17	0	85	0	15	0	none	100	Oscillatoria	60	absent
11/2/09	CATLEFF	37.5	20	0	10	17.5	Asterionella, Synedra	67.5	Melosira	20	absent
	DEL18	46.25	31	0	25	5	Synedra	102.25	Melosira	37.5	absent
	DEL17	11.5	34	0	0	9	Synedra	45.5	Aphanizomenon	29	absent
11/1/09	CATLEFF	134	2.5	0	0	31.5	Asterionella, Synedra	136.5	Fragilaria	62.5	present
	DEL18	37.5	10	20	50	27.5	Synedra, Dinobryon	117.5	Spondylosium	50	absent
	DEL17	18	7.5	2.5	0	5.5	Synedra, Synura	28	Fragilaria	10	absent
10/31/09	CATLEFF	70.5	35	23.75	0	56.75	Asterinella, Synedra, Synura, Dinobryon	129.25	Tabellaria	22.5	present
	DEL18	35	13.75	7.5	22.5	17.5	Asterinella, Synedra, Synura, Dinobryon	78.75	Fragilaria	25	absent
	DEL17	0	23.75	5	20	5	Synura	48.75	Spondylosium	15	present
10/30/09	CATLEFF	65	5	0	5	20	Synedra	75	Fragilaria/Synedra	20	present
	DEL18	0	37.5	0	40	0	none	77.5	Spondylosium	40	present
	DEL17	85	27	28.75	0	31.25	Synedra, Dinobryon, Mallomonas	140.75	Fragilaria	67.5	present
10/29/09	CATLEFF	51.25	5	22.5	0	45	Asterinella, Synedra, Synura, Dinobryon, Chrysosphaerella (12.5)	78.75	Melosira	22.5	present
	DEL18	108.75	7.5	2.5	0	10	Asterionella, Synedra, Synura	118.75	Fragilaria	97.5	absent
	DEL17	15	43	5	0	7.5	Synedra, Synura, Chrysosphaerella (2.5)	63	Aphanizomenon	40.5	present
10/28/09	CATLEFF	44.5	12.5	40	3.75	69.5	Asterinella, Synedra, Dinobryon, Chrysosphaerella (10)	100.75	Dinobryon	30	present
	DEL18	64	5	5	45	14	Synedra, Synura, Chrysosphaerella (2.5)	119	Fragilaria	55	present
	DEL17	33.75	5	5	0	25	Asterinella, Synedra, Dinobryon	43.75	Synedra	15	present

Attachment 3 Keypoint Pytoplankton Data

Date	Site	Diatoms	Greens & Blue-Greens	Golden Browns	Other	Potential Taste & Odor Phytos	Potential Taste & Odor Phytos Found in Sample (ASU Chrysosphaerella only)	Total	Reported Genus	count	Chyrsosphaerella Count Full Scan
10/27/09	CATLEFF	65	20	35	20	50	Asterinella, Synedra, Dinobryon, Mallomonas	140	Tabellieria	40	present
	DEL18	10	10	15	80	20	Asterionella, Dinobryon	115	Dinobryon	15	absent
	DEL17	38.75	15	10	41.25	10	Dinobryon	105	Fragilaria	27.5	present
10/26/09	CATLEFF	136.25	12.5	32.5	5	58.75	Asterinell, Synedra, Synura, Dinobryon	186.25	Fragilaria	67.5	present
	DEL18	53.75	32.5	3.75	5	7.5	Synedra, Synura, Chrysosphaerella (1)	95	Fragilaria	48.75	present
	DEL17	150.5	43.5	0	0	8	Synedra	194	Fragilaria	140	present
10/25/09	CATLEFF	156.75	7.5	50	0	75.5	Synedra, Dinobryon	214.25	Dinobryon	77.5	present
	DEL18	59.75	35.5	0	0	8.5	Synedra	95.25	Fragilaria/Oscillatoria	37.5	present
	DEL17	119.25	25	0	0	28	Asterionella, Synedra	144.25	Fragilaria	82.5	present
10/24/09	CATLEFF	73.5	17.5	18.75	0	61	Asterionella, Synedra, Synura, Mallomonas	109.75	Fragilaria	30	present
	DEL18	35.75	10	1.25	1.25	20.75	Asterionella, Synedra, Synura	48.25	Fragilaria	15	present
	DEL17	60	82.5	0	25	0	none	167.5	Fragilaria	55	absent
10/23/09	CATLEFF	26.25	2.5	38.75	7.5	62.5	Synedra, Micratinium, Synura, Dinobryon, Chrysosphaerella (6)	75	Dinobryon	28	present
	DEL18	20	30	2.5	40	2.5	Dinobryon	92.5	Fragilaria/Oscillatoria	20	absent
	DEL17	117.5	7.5	10	32.5	15	Synedra, Synura	167.5	Fragilaria	110	present
10/22/09	CATLEFF	50.5	27.5	7.5	0	43	Asterionella, Synedra, Chrysosphaerella (8)	85.5	Synedra	28	present
	DEL18	142.5	12.5	0	20	5	Synedra	175	Fragilaria	113	present
	DEL17	61.5	35	2.5	0	14	Synedra, Mallomonas	99	Fragilaria	35	present
10/21/09	CATLEFF	36	12.5	51.25	0	51.25	Dinobryon, Mallomonas, Chrysosphaerella (12)	99.75	Fragilaria	26	present
	DEL18	157.75	40	3.75	0	12.75	Asterionella, Synedra, Synura, Dinobryon,	201.5	Fragilaria	143	present
	DEL17	197.5	16.25	8.75	0	13.75	Synedra, Synura	222.5	Fragilaria	128	present
10/20/09	CATLEFF	30.25	13.75	45	45	66.5	Synedra, Dinobryon, Chrysosphaerella (4)	134	Dinobryon	45	present
	DEL18	370.75	10	1.25	0	1.25	Chrysospherella (1)	382	Fragilaria	323	present
	DEL17	149	25.5	5	0	21.5	Synedra, Synura	179.5	Fragilaria	130	present
10/19/09	CATLEFF	166	25	42.5	0	83.5	Asterionella, Synedra, Mallomonas, Chrysosphaerella (3)	233.5	Fragilaria	100	present
	DEL18	196.25	2.5	25	32.5	47.5	Asterionella, Synedra, Synura, Dinobryon	256.25	Fragilaria	88	present
	DEL17	206.25	52.5	0	2.5	5	Synedra	261.25	Fragilaria	190	present
10/18/09	CATLEFF	111.25	10	12.5	0	67.5	Asterionella, Synedra,Dinobryon, Chrysosphaerella (3)	133.75	Fragilaria	56	present
	DEL18	297.5	0	65	0	70	Synedra,Dinobryon, Chrysosphaerella (5)	362.5	Fragilaria	230	present
	DEL17	256.5	35	16.25	0	42.75	Asterionella, Synedra, Synura, Dinobryon, Mallomonas	307.75	Fragilaria	210	present
10/17/09	CATLEFF	112.75	5	17.5	0	76.5	Asterionella, Synedra, Synura, Dinobryon, Chrysosphaerella (5)	135.25	Synedra	45	present
	DEL18	280	57.5	8.75	35	18.75	Asterionella, Synedra, Synura, Dinobryon, Chrysosphaerella (1)	381.25	Fragilaria	220	present
	DEL17	85.5	25	7.5	5	14.25	Asterionella, Synudra	123	Fragilaria	48	present
10/16/09	CATLEFF	113.75	35.5	36.25	5	105	Asterionella, Synedra, Synura, Dinobryon, Mallomonas, Chrysosphaerella (13	190.5	Fragilaria	190	present
	DEL18	125	42.5	27.5	5	17.5	Synura, Dinobryon	200	Fragilaria	88	present
	DEL17	395	92.5	26.25	0	41.25	Asterionella, Synedra, Mallomonas, Chrysosphaerella (23)	513.75	Fragilaria	510	present
10/15/09	CATLEFF	197	14	27.5	3.75	104.5	Asterionella, Synedra, Synura, Dinobryon, Chrysosphaerella (8)	242.25	Fragilaria	110	present
	DEL18	346	41.5	1.25	20	7.25	Asterionella, Synura	408.75	Fragilaria	410	present
	DEL17	263.75	12.5	35	30	57.5	Asterionella, Synedra, Synura, Dinobryon	341.25	Fragilaria	240	present
10/14/09	CATLEFF	118.75	1.25	22.5	0	66.25	Synedra, Micractinium, Dinobryon	142.5	Fragilaria	75	present
	DEL18	100	15	23.75	3.75	43.75	Synedra, Synura	142.5	Fragilaria	80	present
	DEL17	221.25	130.5	7.5	50	37.5	Asterionella, Synedra, Mallomonas, Chrysosphaerella (1)	409.25	Fragilaria	190	present
10/13/09	CATLEFF	80	11.25	51.25	1.25	93.75	Asterionella, Synedra, Synura, Dinobryon, Chrysosphaerella (16)	143.75	Fragilaria	35	present
	DEL18	87.5	17.5	16.25	0	28.75	Asterionella, Synedra, Synura, Dinobryon, Chrysosphaerella (5)	121.25	Fragilaria	44	present
	DEL17	205	90	0	45	5	Asterionella	340	Fragilaria	195	present
10/12/09	CATLEFF	145	10	50	5	165	Asterionella, Synedra, Micractinium, Dinobryon	210	Synedra	105	present
	DEL18	222.5	122.5	45	25	52.5	Asterionella, Synedra, Mallomonas, Chrysosphaerella (12)	415	Fragilaria	215	present
	DEL17	592.5	77.5	67.5	10	85	Asterionella, Synedra, Synura, Dinobryon	747.5	Fragiliaria	540	absent
10/11/09	CATLEFF	331.75	10	21.25	3.75	99.25	Asterionella, Synedra, Synura, Dinobryon, Chrysosphaerella (6)	366.75	Fragiliaria	170	present
	DEL18	521	57.5	22.5	7.5	33.5	Asterionella, Synedra, Dinobryon, Chrysosphaerella (8)	608.5	Fragiliaria	490	present

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Date	Site	Diatoms	Greens & Blue-Greens	Golden Browns	Other	Potential Taste & Odor Phytos	Potential Taste & Odor Phytos Found in Sample (ASU Chrysosphaerella only)	Total	Reported Genus	count	Chyrsosphaerella Count Full Scan
10/10/09	DEL17	795.5	76.5	16.25	0	34.25	Asterionella, Synedra, Synura, Mallomonas, Chrysosphaerella (1)	888.25	Fragilaria	770	present
	CATLEFF	180.75	50	32.5	3.75	77	Asterionella, Synedra, Synura, Dinobryon	267	Fragilaria	85	present
	DEL18	759.5	79.75	10	16.25	36	Asterionella, Synedra, Dinobryon	865.5	Fragilaria	720	present
10/9/09	DEL17	185	155	15	45	25	Synedra, Dinobryon	400	Fragilaria	170	present
	CATLEFF	125	15	40	7.5	100	Asterionella, Synedra, Dinobryon	187.5	Fragilaria	65	present
	DEL18	635	110	25	40	105	Asterionella, Synedra, Dinobryon	810	Fragilaria	550	present
10/8/09	CATLEFF	180	15	25	2.5	105	Asterionella, Synedra, Dinobryon	222.5	Synedra	70	present
	DEL18	95	5	185	0	255	Asterionella, Synedra, Synura, Dinobryon, Chrysosphaerella (115)	285	Chrysosphaerella	120	present
10/7/09	CATLEFF	155	5	25	7.5	105	Asterionella, Synedra, Dinobryon, Mallmonas, Chrysosphaerella (5)	192.5	Fragilaria	75	
	DEL18	212.5	37.5	90	10	157.5	Asterionella, Synedra, Micractinium, Dinobryon, Mallomonas, Chrysosphaerella (45	350	Fragilaria	90	
10/5/09	CATLEFF	154.75	15	35	0	103.5	Asterionella, Synedra, Dinobryon	204.75	Synedra	50	
	DEL18	258.5	10	68.75	0	112.25	Asterionella, Synedra, Micractinium, Dinobryon, Mallomonas	337.25	Fragiliaria	210	
10/2/09	CATLEFF	265.5	2.5	7.5	0	75.5	Asterionella, Synedra, Dinobryon	275.5	Fragiliaria	180	
	DEL18	266	31.25	20	3.75	124.75	Asterionella, Synedra, Micractinium, Synura, Dinobryon	321	Fragiliaria	170	
9/30/09	CATLEFF	180	0	30	0	50	Asterionella, Synedra, Dinobryon	210	Fragiliaria	160	
	DEL18	200	25	0	0	50	Asterionella, Synedra	225	Fragiliaria	150	
9/28/09	CATLEFF	150	0	0	0	85	Asterionella, Synedra	150	Synedra	60	
	DEL18	340	5	25	5	60	Asterionella, Synedra, Micractinium, Dinobryon, Mallomonas	375	Fragiliaria	310	
9/25/09	CATLEFF	316	2.5	35	0	68.5	Asterionella, Synedra, Dinobryon	353.5	Fragiliaria	260	
	DEL18	174.5	5	20	0	79.5	Asterionella, Synedra, Dinobryon, Mallomonas	199.5	Fragiliaria	120	
9/23/09	CATLEFF	206	5	30	0	96	Asterionella, Synedra, Dinobryon	241	Fragiliaria	140	
	DEL18	209.75	15	12.5	40	93.5	Asterionella, Synedra, Micractinium, Dinobryon, Mallomonas	277.25	Fragiliaria	120	
9/21/09	CATLEFF	202.5	2.5	2.5	45	97.5	Asterionella, Synedra, Synura	252.5	Fragiliaria	88	
	DEL18	112.25	20	15	0	76	Asterionella, Synedra, Dinobryon	147.25	Synedra	32	
9/18/09	CATLEFF	344.5	0	7.5	0	29.5	Asterionella, Synedra, Synura, Dinobryon, Mallomonas	352	Fragiliaria	290	
	DEL18	300	30	8.75	0	83.75	Asterionella, Synedra, Dinobryon	338.75	Fragiliaria	220	
9/16	DEL18	35	5	25	0	53.75	Asterionella, Synedra, Synura, Dinobryon	65	Asterionella	26	
9/17	CATLEFF	193.75	22.5	32.5	50	56.25	Asterionella, Synedra, Synura, Dinobryon	298.75	Fragiliaria	130	
9/14/09	CATLEFF	75	60	10	0	25	Asterionella, Synedra, Dinobryon	145	Fragiliaria	60	
	DEL18	187.5	67.5	15	0	52.5	Asterionella, Synedra, Dinobryon	270	Fragiliaria	130	
9/11/09	CATLEFF	119.5	15	70	0	97	Asterionella, Synedra, Dinobryon	204.5	Dinobryon	70	
	DEL18	270.75	2.5	75	0	94.5	Asterionella, Synedra, Dinobryon	348.25	Fragiliaria	230	
9/9/09	CATLEFF	115	5	15	0	80	Asterionella, Synedra, Dinobryon	135	Fragiliaria	45	
	DEL18	80	25	165	45	195	Asterionella, Synedra, Dinobryon	315	Dinobryon	160	
9/7/09	CATLEFF	27.5	22.5	87.5	0	115	Synedra, Dinobryon	137.5	Dinobryon	88	
	DEL18	50	40	105	0	155	Synedra, Dinobryon	195	Dinobryon	110	
9/4/09	CATLEFF	53	7.5	37.5	0	75.5	Synedra, Dinobryon	98	Synedra	38	
	DEL18	186	15	37.5	0	103.5	Asterionella, Synedra, Dinobryon	238.5	Fragiliaria	120	
9/2/09	CATLEFF	73	0	75	0	108	Asterionella, Synedra, Dinobryon	148	Dinobryon	75	
	DEL18	162.25	7.5	60	0	93.5	Synedra, Dinobryon	229.75	Fragiliaria	85	

Attachment 3 Keypoint Phytoplankton Data

WOH Keypoint Phytoplankton Data (ASU/mL)

Date	Site	Diatoms	Greens & Blue-Greens	Golden Browns	Other	Potential Taste & Odor Phytos	Potential Taste & Odor Phtyos Found in Sample	Total	Reported Genus	Count	Chysosphaerella count full scan
11/27	RDRRCM	0	0	0	0	0		0			
	EARCM	81.6	0	0	0	25.5		81.6	Melosira	56	N/A
11/25	RDRRCM	0	0	0	0	0		0			
	EARCM	306	0	0	0	10.2	Synedra	306	Melosira	280	N/A
11/23	RDRRCM	10.2	0	5.1	0	5.1	Synedra	15.3	Cryptomonas	5	Absent
	EARCM	392.7	0	10.2	0	20.4	Synedra	402.9	Melosira	290	N/A
11/20	RDRRCM	15.3	0	0	0	0	None	15.3	Tabellaria	15	N/A
	EARCM	91.8	30.6	5.1	0	0	None	127.5	Melosira	92	N/A
11/18	RDRRCM	0	0	5.1	0	0	None	5.1	Cryptomonas	5	N/A
	EARCM	142.8	5.1	5.1	0	20.4	Synedra, Synura	153	Melosira	110	N/A
11/16	RDRRCM	0	35.7	10.2	0	0	None	45.9	Dictyosphaerium	15	N/A
	EARCM	117.3	0	15.3	0	25.5	Synedra, Dinobryon	132.6	Dinobryon	15	N/A
11/13	RDRRCM	0	0	0	0	0		Off Line			
	EARCM	25.5	0	30.6	0	25.5	Synura	56.1	Synura	26	N/A
11/12	RDRRCM	0	0	0	0	0		Off Line			
	EARCM	76.5	0	5.1	0	5.1	Synedra	81.6	Melosira	36	N/A
11/9	RDRRCM	0	0	0	0	0		Off Line			
	EARCM	182	20.8	0	0	0	None	202.8	Melosira	110	N/A
11/6	RDRRCM	0	0	0	0	0		0			
	EARCM	96.9	15.3	35.7	0	61.2	Synedra, Synura	147.9	Melosira	56	N/A
11/4	RDRRCM	0	0	10.2	0	0	None	10.2	Cryptomonas	10	Absent
	EARCM	78	15.6	15.6	0	26	Synedra	109.2	Melosira	52	Absent
11/2	RDRRCM	5.1	5.1	10.2	20.4	0	None	40.8	Snowella	20	Absent
	EARCM	260.1	25.5	96.9	0	107.1	Synedra, Synura, Dinobryon	382.5	Melosira	200	Absent
10/30	RDRRCM	0	10.2	0	0	0	None	10.2	Aphanizomenon	10	Absent
	EARCM	0	0	0	0	0	None	<5	None	<5	Absent
10/28	RDRRCM	0	0	10.2	0	0	None	10.2	Cryptomonas	10	Absent
	EARCM	142.8	25.5	35.7	0	51	Dibonryon, Micractinium	204	Tabellaria	140	Absent
10/27	RDRRCM	0	5.1	5.2	0	0	None	10.3	Cryptomonas	5	Absent
	EARCM	10.2	5.1	30.6	0	35.7	Synedra, Dinobryon	45.9	Dinobryon	31	Absent
10/26	RDRRCM	0	0	10.2	0	5.1	Dinobryon	10.2	Cryptomonas	5	Absent

Attachment 3 Keypoint Phytoplankton Data

Date	Site	Diatoms	Greens & Blue-Greens	Golden Browns	Other	Potential Taste & Odor Phytos	Potential Taste & Odor Phtyos Found in Sample	Total	Reported Genus	Count	Chysosphaerella count full scan
10/26	EARCM	5.1	0	0	0	5.1	Synedra	5.1	Synedra	5	Absent
10/23	RDRRCM	0	10.2	25.5	0	25.5	Dinobryon	35.7	Dinobryon	26	Absent
	EARCM	132.6	5.1	15.3	0	35.7	Synedra, Dinobryon	153	Melosira	31	Absent
10/22	RDRRCM	20.4	0	5.1	0	0	None	25.5	Rhizosolenia	15	Absent
	EARCM	5.1	0	25.5	0	25.5	Dinobryon	30.6	Dinobryon	26	Absent
10/21	RDRRCM	0	5.1	0	0	0	None	5.1	Apahizomenon	5	Absent
	EARCM	15.3	0	0	0	10.2	Synedra	15.3	Synedra	10	Absent
10/20	RDRRCM	0	0	0	0	0	None	<5	None	<5	Absent
	EARCM	0	10.2	0	5.1	0	None	15.3	Staurastrum	10	Absent
10/19	RDRRCM	10.2	0	0	0	10.2	Synedra	10.2	Synedra	10	Absent
	EARCM	25.5	35.7	5.1	0	25.5	Synedra	66.3	Anabaena	36	Absent
10/16	RDRRCM	5.1	15.3	10.2	0	10.2	Dynobryon	30.6	Dynobryon	15	Absent
	EARCM	40.8	15.3	5.1	0	30.6	Synedra	61.2	Synedra	31	Absent
10/15	RDRRCM	61.2	56.1	15.3	0	10.2		132.6	Aphanizomenon	26	Absent
	EARCM	5.1	25.5	25.5	0	30.6	Synedra, Dinobryon	56.1	Dinobryon	26	Absent
10/14	RDRRCM	36.4	10.4	5.2	0	10.4	Synedra	52	Rhizosolenia	16	Absent
	EARCM	35.7	10.2	20.4	0	56.1	Synedra, Synura	66.3	Synedra	36	Absent
10/13	RDRRCM	93.6	57.2	20.8	0	78	Asterionella, Synura, Micractinium	171.6	Fragilaria	52	Absent
	EARCM	51	20.4	30.6	0	56.1	Synedra, Dinobryon	102	Dinobryon	31	Absent
10/12	RDRRCM	86.7	35.7	0	0	5.1	Synedra	122.4	Fragilaria	77	Absent
	EARCM	132.6	61.2	10.2	0	30.6	Synedra, Dinobryon	204	Tabellaria	92	Absent
10/11	RDRRCM	260.1	35.7	0	0	0	None	295.8	Fragilaria	180	Absent
	EARCM	91.8	45.9	0	51	25.5	Synedra	188.7	Ceratium	51	Absent
10/10	RDRRCM	102	30.6	20.4	0	40.8	Asterionella, Synedra, Dinobryon	153	Fragilaria	71	Absent
	EARCM	127.5	25.5	40.8	0	71.4	Asterionella, Synedra, Synura, Dinobryon	193.8	Tabellaria	71	Absent
10/9	RDRRCM	86.7	10.2	10.2	0	20.4	Synedra, Dinobryon	107.1	Fragilaria	77	Absent
	EARCM	208	15.6	52	0	72.8	Synedra, Dinobryon	275.6	Tabellaria	140	Absent
10/8	RDRRCM	107.1	15.3	5.1	0	15.3	Asterionella, Synedra	127.5	Fragilaria	87	
	EARCM	0	0	0	0	0	No sample collected	0			
10/7	RDRRCM	20.4	5.1	0	0	5.1	Synedra	25.5	Fragilaria	10	
	EARCM	76.5	20.4	30.6	0	91.8	Asterionella, Synedra, Synura, Dinobryon	127.5	Synedra	56	
10/2	RDRRCM	66.3	25.5	10.2	5.1	0	None	107.1	Fragilaria	61	

Attachment 3 Keypoint Phytoplankton Data

Date	Site	Diatoms	Greens & Blue-Greens	Golden Browns	Other	Potential Taste & Odor Phytos	Potential Taste & Odor Phtyos Found in Sample	Total	Reported Genus	Count	Chysosphaerella count full scan
10/2	EARCM	158.1	25.5	0	0	137.7	Asterionella, Synedra	183.6	Synedra	130	
9/30	RDRRCM	168.3	0	0	0	0	None	168.3	Fragilaria	140	
	EARCM	127.5	20.4	15.3	0	117.3	Asterionella, Synedra, Dinobryon	163.2	Synedra	97	
9/28	RDRRCM	45.9	20.4	0	0	10.2	Asterionella	66.3	Fragilaria	36	
	EARCM	51	10.2	0	0	51	Asterionella, Synedra	61.2	Synedra	31	
9/25	RDRRCM	56.1	45.9	0	0	10.2	Asterionella	102	Aphanizomenon	46	
	EARCM	229.5	25.5	0	0	66.3	Asterionella, Synedra	255	Melosira	100	
9/23	RDRRCM	66.3	15.3	5.1	0	5.1	Synura	86.7	Fragilaria	66	
	EARCM	234.6	10.2	0	0	198.9	Asterionella, Synedra	244.8	Synedra	97	
9/21	RDRRCM	219.3	61.2	0	0	10.2	Asterionella	280.5	Fragilaria	210	
	EARCM	0	0	0	0	0	None	0	None		
9/18	RDRRCM	5.1	66.3	0	0	0	None	71.4	Staurastrum	61	
	EARCM	219.3	0	15.3	0	229.5	Asterionella, Synedra, Dinobryon, Mallomonas	234.6	Asterionella	130	
9/16	RDRRCM	83.2	0	31.2	0	31.2	Synura	114.4	Fragilaria	62	
	EARCM	137.7	51	30.6	0	127.5	Asterionella, Synedra, Dinobryon	219.3	Asterionella	56	
9/14	RDRRCM	56.1	30.6	0	0	0	None	86.7	Fragilaria	46	
	EARCM	204	40.8	20.4	0	76.5	Asterionella, Synedra, Dinobryon, Mallomonas	265.2	Melosira	66	
9/11	RDRRCM	295.8	0	0	0	5.1	Asterionella	295.8	Fragilaria	290	
	EARCM	45.9	20.4	0	0	45.9	Asterionella, Synedra	66.3	Synedra	31	
9/9	RDRRCM	62.4	0	0	0	0	None	62.4	Fragilaria	62	
	EARCM	173.4	25.5	5.1	0	30.6	Asterionella, Synedra	204	Melosira	77	
9/8	RDRRCM	61.2	5.1	0	0	0	None	66.3	Fragilaria	61	
	EARCM	107.1	20.4	0	0	20.4	Asterionella, Synedra	127.5	Tabellaria	66	
9/4	RDRRCM	81.6	0	0	0	0	None	81.6	Fragilaria	82	
	EARCM	102	10.2	5.1	0	40.8	Asterionella, Synedra, Dinobryon	117.3	Tabellaria	66	
9/2	RDRRCM	0	0	0	0	0	None	0	None	0	
	EARCM	223.6	5.2	41.6	0	98.8	Synedra, Dinobryon	270.4	Tabellaria	120	
8/31	RDRRCM	112.2	0	0	0	0	Nonr	112.2	Fragilaria	110	
	EARCM	130	15.6	20.8	0	52	Asterionella, Synedra, Dinobryon	166.4	Tabellaria	62.4	

Kensico Limnology Phytoplankton Data Averaged by Site

Date	Site	Diatoms	Greens & Blue-Greens	Other Golden Browns	Chrysosphaerella	Other	Total
10/7/2009	1.1BRK	55	1	29	51	1	138
10/7/2009	2BRK	158	9	107	142	2	417
10/7/2009	3BRK	112	5	68	47	20	251
10/7/2009	4BRK	58	12	18	123	30	241
10/7/2009	5BRK	62	29	63	105	9	267
10/7/2009	6BRK	295	16	64	139	1	514
10/13/2009	1.1BRK	117	6	11	116	259	509
10/13/2009	2BRK	107	2	95	188	6	398
10/13/2009	3BRK	244	5	54	113	2	418
10/13/2009	4BRK	50	0	69	103	4	226
10/13/2009	5BRK	139	30	20	65	0	254
10/13/2009	6BRK	109	20	49	161	1	340
10/20/2009	1.1BRK	79	10	18	74	5	185
10/20/2009	2BRK	82	22	98	76	13	291
10/20/2009	3BRK	221	28	67	145	27	487
10/20/2009	4BRK	52	16	33	113	0	214
10/20/2009	5BRK	89	25	41	176	0	331
10/20/2009	6BRK	60	21	78	250	0	409
10/20/2009	7BRK	79	8	55	13	0	154
10/20/2009	8BRK	38	9	125	285	6	463
10/27/2009	1.1BRK	83	16	38	63	13	215
10/27/2009	2BRK	39	5	30	79	1	154
10/27/2009	3BRK	39	12	131	225	8	415
10/27/2009	4BRK	44	3	30	40	2	119
10/27/2009	5BRK	71	4	39	30	0	144
10/27/2009	6BRK	60	1	32	84	0	178
11/2/2009	1.1BRK	50	5	51	54	8	168
11/2/2009	2BRK	21	3	103	182	3	313
11/2/2009	3BRK	32	3	88	112	11	246
11/2/2009	4BRK	70	4	24	57	2	156
11/2/2009	5BRK	41	19	15	55	0	130
11/2/2009	6BRK	70	5	76	28	0	180
11/9/2009	1.1BRK	58	0	43	32	7	140
11/9/2009	2BRK	35	10	43	80	12	180
11/9/2009	3BRK	67	7	33	125	0	232
11/9/2009	4BRK	55	15	48	30	9	158
11/9/2009	5BRK	187	22	24	30	0	263
11/9/2009	6BRK	44	5	130	33	2	214
11/16/2009	1.1BRK	32	5	108	10	2	157
11/16/2009	2BRK	57	11	30	5	1	104
11/16/2009	3BRK	118	13	42	7	6	186
11/16/2009	4BRK	71	1	68	35	2	177
11/16/2009	5BRK	120	3	23	1	0	146
11/16/2009	6BRK	103	2	115	13	6	239
11/24/2009	1.1BRK	155	25	15	0	0	195
11/24/2009	2BRK	95	10	60	0	11	176
11/24/2009	3BRK	78	11	52	24	0	165
11/24/2009	4BRK	66	0	68	33	0	166

Attachment 4 Limnology Phytoplankton Data

Date	Site	Diatoms	Greens & Blue-Greens	Other Golden Browns	Chrysosphaerella	Other	Total
11/24/2009	5BRK	226	0	10	5	0	241
11/24/2009	6BRK	80	75	375	20	25	575
11/24/2009	7BRK	73	20	60	60	30	243
11/24/2009	8BRK	10	20	0	0	0	30

Management Taste Test - *Chrysosphaerella* Event

10/19/09

I. Background

In early October 2009, NYC's 311 line began receiving complaints about a "metallic" taste in tap water in the distribution system. Investigation into system operations and treatment chemicals, along with subsequent complaints from customers in Westchester County led BWS to identify Kensico Reservoir itself as the likely source of the problem. Eventually, an algal genera that may be new to our reservoir system was isolated and identified: *Chrysosphaerella* spp. In consultation with the Massachusetts Water Resources Authority, we learned that blooms of this algae in relatively low numbers has correlated with taste and odor complaints. After Kensico and Kingston microbiology staff received notification of its potential presence and additional information about its morphology, concentrations as high as 115 ASU were found in Kensico effluent keypoints, and concentrations as high as 625 ASU were found in Kensico Reservoir.

The absence of any direct information regarding algae concentrations that lead to disagreeable taste and odor in the water supply prompted managers of the Water Quality directorate to undertake a brief and subjective investigation of the taste of raw Kensico Reservoir water after chlorination in the laboratory.

II. Study Method

Samples of raw water collected in dishwasher-cleaned 2L Nalgene PP from five locations will be "treated" by adding Chlorox® in sufficient quantity to result in a free chlorine residual of approximately 1.5 ppm. The sample sites will include: CATLEFF, DEL18, 2BRK3, 3BRK3 and 4BRK3. Kensico Laboratory staff will "dose" the samples and pour off five aliquots of each sample into 8 oz. PETE bottles previously containing Poland Spring® water and label each aliquot from the same source with the same letter designation, ultimately resulting in five "A" bottles from one sample, five "B" bottles from another sample and so on. The Supervisor of the Aqueduct Monitoring section will retain the record of which letter corresponded to which specific sample, but this information will not be revealed to the managers until after the taste test.

Samples will be collected on the morning of October 20, 2009, and are expected to be "treated" and separated into aliquots before 4:00 pm on the same day. All managers participating in the taste test are expected to have their aliquots in their possession late in the afternoon of October 20, and the first tasting will occur at 10:00 pm. Samples should be refrigerated, but taken out to warm at room temperature for 15 minutes prior to tasting. Subsequent tastings will occur at 10:00 am and 10:00 pm on the 21st.

Tasting will consist of drawing water from each bottle into the mouth, noting the flavor and odor of the sample, and spitting the water out. Tap water will be used to rinse between each test. Descriptors of the taste and/or odor of each aliquot will be noted in the appropriate section of the attached data sheet. On October 22, the data sheets will be emailed to the WWQO Deputy Chief of Compliance along with the sample identity of each aliquot for compilation into a results table.

The managers who have agreed to participate in this test are: Lori Emery, Salomé Freud, Andrew Bader, Dale Borchert and Charles Cutietta-Olson.

Management Taste Test Data Sheet:

Bottle Label	10:00 pm, Oct. 20	10:00 am, Oct. 21	10:00 pm, Oct. 21
A			
B			
C			
D			
E			

Management Taste Test Results Summary

Chrysosphaeraella Metallic Taste Complaint Event, 2009

10/22/2009

The following results are a tabulation of taste testing of several Kensico region samples. These samples were prepared to gather some data over a period of time and over a range of concentrations of Chrysosphaerella in order to evalutate taste. Results are presented in increasing phytoplankton concentration.

Sample (Bottle Label)	Chrysosphaerella concentration (ASU/mL)	Analysis 10:00 PM, 10/20/09	Analysis 10:00 AM, 10/21/09	Analysis 10:00 PM, 10/21/09	**Taste tests identifing "Metallic taste" as present and Summation Notes**
DEL18 (D)	Present only	Neutral (CCO) Neutral/Nothing (APB) Chlorine odor, ok taste (LJE) Negative (SF) No taste (DB)	Metallic aftertaste; musty (CCO) Neutral/Nothing (APB) Mild chlorine odor, ok taste (LJE) Negative (SF) No taste (DB)	Metallic aftertaste; musty (CCO) Neutral/Nothing (APB) Mild chlorine odor, ok taste (LJE) Negative (SF) No taste (DB)	**2/15** Generally, no taste
CATLEFF (C)	12.5	Neutral/chlorine (CCO) Slight Chlorinous to neutral (APB) Chlorine odor, metallic taste (LJE) Musty + (SF) No taste (DB)	Metallic aftertaste; musty (CCO) Slightly metallic (APB) Mild chlorine odor, metallic taste (1) (LJE) Musty (SF) No taste (DB)	Weak metallic; aftertaste (CCO) Slightly metallic/musty (APB) Mild chlorine odor, metallic taste (1) (LJE) Musty + (SF) No taste (DB)	**7/15** Minimal taste that could be perceived as musty or metallic; intensity generally accepted as slight
6 BRK 3 (E)	127.5	Strong aftertaste; Musty (CCO) Moderately metallic (APB) Chlorine odor, metallic taste (LJE) Metallic + (SF) Metallic aftertaste (DB)	Neutral/chlorine (CCO) Very metallic (APB) Mild chlorine, but metallic, odor: very metallic taste (4) (LJE) Metallic + (SF) Metallic aftertaste (DB)	Neutral (CCO) Very metallic (APB) Metallic odor, metallic taste (4) (LJE) Metallic + (SF) Metallic aftertaste (DB)	**12/15** Metallic taste; intensity ranged from mild to strong
2 BRK 2 (B)	130	Slight metaillic (CCO) Sligthly musty (APB) Chlorine odor, metallic taste (LJE) Metallic ++ (SF) Strong metallic aftertaste (DB)	Slight metaillic (CCO) Moderately metallic (APB) Mild chlorine odor, metallic taste (3) (LJE) Metallic + (SF) Strong metallic aftertaste (DB)	Musty (CCO) Moderately metallic (APB) Chlorine odor, metallic taste (3) (LJE) Metallic ++ (SF) Strong metallic aftertaste (DB)	**13/15** Taste identified as either musty or metallic: intensity ranged from mild to strong
4 BRK 3 (A)	160	Strong aftertaste; Musty (CCO) Slightly metallic (APB) Chlorine odor, metallic taste (LJE) Musty + (SF) Mild metallic aftertaste (DB)	Aftertaste; mild metallic (CCO) Moderately metallic (APB) Mild chlorine odor, metallic taste (2) (LJE) Musty ++ (SF) Metallic aftertaste (DB)	Strong metallic (CCO) Moderately metallic (APB) Chlorine odor, mild metallic taste (2) (LJE) Musty ++ (SF) Metallic aftertaste (DB)	**11/15** Taste identified as either musty or metallic: intensity ranged from mild to strong

Attachment 5 Taste Testing Results Summary

Management Taste Test Results, Study 2, Summary

Chrysosphaeraella Metallic Taste Complaint Event, 2009

10/29/2009

The following results are a tabulation of taste testing of several Kensico region samples. These samples were prepared to gather some data over a period of time and over a range of concentrations of Chrysosphaerella in order to evalutate taste. Results are presented in increasing phytoplankton concentration.

Sample (10/27/09) (Bottle Label)	Chrysosphaerella concentration (ASU/mL)	Analysis 12:00 PM, 10/28/09	Analysis 12:00 PM, 10/29/09	**Taste tests identifing "Metallic taste" as present and Summation Notes**
DEL18 (D)	Absent	No particular taste (CCO) Nothing – Neutral (APB) No Taste - normal (LJE) No Taste (SF) No Taste (DB)	Metallic aftertaste (CCO) Nothing – Neutral (APB) No Taste - normal (LJE) No Taste (SF) No Taste (DB)	**1/10** No Taste
CATLEFF (A)	Present (but not in a counting field)	Slight Metallic (CCO) Slight musty/metallic (APB) Metallic -1 (LJE) Metallic + (SF) Slight Metallic (DB)	No particluar taste (CCO) Slight metallic (APB) Mild metallic -1 (LJE) Metallic (SF) Slight Metallic (DB)	**9/10** Metallic taste; intensity ranged from none to slight
2 BRK 3 (E)	31	Metallic bite (CCO) Slight metallic (APB) Metallic – 4 (LJE) Metallic + (SF) No Taste (DB)	Strong metallic aftertaste (CCO) Moderately metallic (APB) Metallic – 4 (LJE) Metallic (SF) No Taste (DB)	**8/10** Metallic taste; intensity ranged from none to strong
4 BRK 3 (B)	90	Metallic (stronger than A) (CCO) Moderately metallic (APB) Metallic – 2 (LJE) Metallic (SF) Slight Metallic (DB)	No particular taste (CCO) Slight metallic (APB) Metallic – 2 (LJE) Metallic (SF) Metallic (DB)	**9/10** Metallic taste; intensity ranged from none to moderate
6 BRK 3 (C)	252	No particular taste (CCO) Very Metallic (APB) Metallic – 3 (LJE) Metallic (SF) Slight Metallic (DB)	Metallic aftertaste (CCO) Very Metallic (APB) Metallic – 3 (LJE) Metallic + (SF) Slight Metallic (DB)	**9/10** Metallic taste; intensity ranged from none to very metallic

CCO noted that all bottles possessed a pretty strong chlorine odor.

SF tasted unchlorinated reservoir water and noted no taste.

Notably, compared to last week the musty taste designation diminshed and most testers felt the intensity of metallic tastes were lower.

Management Taste Test Results, Study 3, Summary

Chrysosphaeraella Metallic Taste Complaint Event, 2009

11/4/2009, rev 2 **Corrected bottle lable designations**

The following results are a tabulation of taste testing of several Kensico region samples. These samples were prepared to gather some data over a period of time and over a range of concentrations of Chrysosphaerella in order to evalutate taste. Results are presented in increasing phytoplankton concentration.

Sample (11/2/09) (Bottle Label)	Chrysosphaerella concentration (ASU/mL)	Analysis 12:00 PM, 11/3/09	Analysis 12:00 PM, 11/4/09	**Taste tests identifing "Metallic taste" as present and Summation Notes**
DEL18 (A)	Absent	Faint metallic aftertaste (CCO) Nothing (APB) None (LJE) No taste (SF)	Slight metallic aftertaste (CCO) Nothing (APB) None (LJE) No taste (SF)	**2/8** Generally no taste
CATLEFF (C)	Absent	Neutral (CCO) Slightly metallic (APB) Very mild metallic - 1 (LJE) Metallic (-) (SF)	Slight metallic aftertaste (CCO) Slightly metallic (APB) Very mild metallic - 1 (LJE) Metallic (-) (SF)	**7/8** Metallic taste; intensity ranged from none to slightly metallic
6 BRK 3 (B)	78	Metallic aftertaste (stronger than A) (CCO) Moderately metallic (APB) Mild metallic - 3 (LJE) Musty (SF)	Metallic bite (CCO) Moderately metallic (APB) Mild metallic - 3 (LJE) Musty (SF)	**6/8** Metallic taste; intensity ranged from none to biting
2 BRK 3 (E)	100	Metallic aftertaste(stronger than D) (CCO) Slightly metallic (APB) Metallic – 4 (LJE) Metallic (SF)	Metallic bite (CCO) Slightly/Moderately metallic (APB) Metallic - 4 (LJE) Metallic (SF)	**8/8** Metallic taste; intensity ranged from none to strong
4 BRK 3 (D)	105	Metallic aftertaste (CCO) Slightly metallic (APB) Very mild metallic - 2 (LJE) Metallic (+) (SF)	Neutral (CCO) Slightly metallic (APB) Very mild metallic - 2 (LJE) Metallic (SF)	**7/8** Metallic taste; intensity ranged from none to strong

Management Taste Test Results, Study 4, Summary

Chrysosphaeraella Metallic Taste Complaint Event, 2009

11/12/2009

The following results are a tabulation of taste testing of several Kensico region samples. These samples were prepared to gather some data over a period of time and over a range of concentrations of Chrysosphaerella in order to evalutate taste. Results are presented in increasing phytoplankton concentration.

Sample (11/9/09) (Bottle Label)	Chrysosphaerella concentration (ASU/mL)	Analysis 12:00 PM, 11/10/09	Analysis 12:00 PM, 11/11/09	**Taste tests identifing "Metallic taste" as present and Summation Notes**
DEL18 (E)	Absent	Neutral (CCO) Slightly metallic (APB) Mild metallic (LJE) No taste/Flat (SF) Slight metallic (DB)	Neutral (1) (CCO) Slightly metallic (APB) Very mild metallic (LJE) No taste (SF) No Taste (DB)	**5/10** Metallic taste; intensity ranged from none to slight
CATLEFF (B)	Present	Slight metallic (CCO) Slightly metallic /none (APB) Very mild metallic (LJE) Metallic mild (SF) No Taste (DB)	Slight metallic (4) (CCO) None (APB) Very mild metallic (LJE) No taste (SF) No Taste (DB)	**6/10** Metallic taste; intensity ranged from none to slight
4 BRK 3 (A)	<5 (not scanned)	Metallic bite (CCO) Slightly metallic (APB) Very mild metallic (LJE) Metallic mild (SF) No Taste (DB)	Slight metallic (3) (CCO) Slightly metallic (APB) Very mild metallic (LJE) Metallic (SF) No Taste (DB)	**8/10** Metallic taste; intensity ranged from none to biting.
2 BRK 3 (D)	85	Neutral, slight metallic aftertaste (CCO) Slightly metallic (APB) Metallic (LJE) Metallic (SF) Slight metallic (DB)	Neutral (2) (CCO) Slightly metallic (APB) Metallic (LJE) Metallic mild (SF) Slight metallic (DB)	**9/10** Metallic taste; intensity ranged from slight to strong
6 BRK 3 (C)	95	Neutral (CCO) Slightly metallic (APB) Metallic (LJE) Metallic (SF) Slight metallic (DB)	Metallic (5) (CCO) Moderately metallic (APB) Metallic (LJE) Metallic (SF) Slight metallic (DB)	**9/10** Metallic taste; intensity ranged from none to present

CCO rankings: 1=most neutral, 5=most metallic

CCO Note – A, D, E virtually indistinguishable

APB Note – A, D, E Just a hint of "flavor"

Management Taste Test Results, Study 5, Summary

Chrysosphaeraella Metallic Taste Complaint Event, 2009

11/19/2009

The following results are a tabulation of taste testing of several Kensico region samples. These samples were prepared to gather some data over a period of time and over a range of concentrations of Chrysosphaerella in order to evalutate taste. Results are presented in increasing phytoplankton concentration.

Sample (11/16/09) (Bottle Label)	Chrysosphaerella concentration (ASU/mL)	Analysis 12:00 PM, 11/18/09	Analysis 12:00 PM, 11/19/09	**Taste tests identifing "Metallic taste" as present and Summation Notes**
DEL18 (B)	Absent	2 - (CCO) Nothing (APB) Very slight metalic taste (BEST) (SS) Very slight metallic (LJE)	5 - (CCO) Nothing (APB) No taste (SS) Normal (LJE)	**3/8** Metallic taste intensity ranged from none to most
CATLEFF (E)	Absent	3 - (CCO) Nothing (APB) Slight metallic taste (SS) Slight metallic (LJE)	1 - (CCO) Nothing (APB) Very slight metallic aftertaste (SS) Very slight metallic (LJE)	**4/8** Metallic taste intensity ranged from none to slight
2 BRK 3 (A)	12.5	1 - (CCO) Slightly metallic (APB) Slight metallic aftertaste (SS) Very slight – hard to distinquish metallic (LJE)	2 - (CCO) Slightly metallic (APB) Very slight metallic aftertaste (SS) Normal (LJE)	**5/8** Metallic taste intensity ranged from none to slight
6 BRK 3 (D)	30	5 - (CCO) Slightly metallic (APB) Metallic taste (WORST) (SS) Slight metallic (LJE)	3 - (CCO) Slightly metallic (APB) Metallic taste (SS) Slight metallic (LJE)	**7/8** Metallic taste intensity ranged from slight to most or worst
4 BRK 3 (C)	75	4 - (CCO) Slightly metallic (APB) Slight metallic aftertaste (SS) Slight metallic (LJE)	4 - (CCO) Slightly metallic (APB) Slight metallic aftertaste (SS) Very slight metallic (LJE)	**8/8** Metallic taste intensity ranged from very slight to metallic.

SS=Steven Schindler

LJE - Very slight = hard to distinquish

CCO ranked 1=most neutral to 5= most metallic (where 1-3 can be considered neutral and 4-5 can be considered metallic), on day 1 A=B=E and C=D, on day 2 B=C=D were only slightly different from A=E.

DB and SF did not participate in this round.

Management Taste Test Results, Study 6, Summary

Chrysosphaeraella Metallic Taste Complaint Event, 2009

11/30/2009

The following results are a tabulation of taste testing of several Kensico region samples. These samples were prepared to gather some data over a period of time and over a range of concentrations of Chrysosphaerella in order to evalutate taste. Results are presented in increasing phytoplankton concentration.

Sample (11/23/09) (Bottle Label)	Chrysosphaerella concentration * From 11/24/09 samples (ASU/mL)	Analysis 6:00 PM, 11/24/09	Analysis 6:00 PM, 11/25/09	**Taste tests identifing "Metallic taste" as present and Summation Notes**
DEL 18 (E)	Absent	Neutral - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 9:30AM on 11/25	Neutral - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 2:30PM on 11/25	**0/0** No metallic taste
CATLEFF (D)	Absent	Slight metallic - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 9:30AM on 11/25	Metallic - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 2:30PM on 11/25	**2/8** Metallic taste intensity ranged from none to present
2 BRK 3 (B)	Present	Neutral - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 9:30AM on 11/25	Neutral - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 2:30PM on 11/25	**0/0** No metallic taste
6 BRK 3 (A)	20	Metallic - (CCO) Slightly metallic - (APB) Very slight metallic - (SS) Very slight metallic - (LJE) @ 9:30AM on 11/25	Slight metallic - (CCO) Slightly metallic - (APB) Very slight metallic – (SS) Very slight metallic - (LJE) @ 2:30PM on 11/25	**8/8** Metallic taste intensity ranged from very slight to present
4 BRK 3 (C)	32.5	Neutral - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 9:30AM on 11/25	Neutral - (CCO) Nothing - (APB) No metallic taste - (SS) None - (LJE) @ 2:30PM on 11/25	**0/0** No metallic taste

DB and SF did not participate in this round.

***Chrysosphaerella* Event De-escalation Plan** October 22, 2009

1) Background
    a. The algae *Chrysosphaerella* is believed to be the cause of metallic taste and odor complaints within the City's distribution system. Limnological surveys of Kensico Reservoir have indicated that *Chrysosphaerella* is present throughout the reservoir and is currently the dominant phytoplankton genus at most locations. *Chrysosphaerella* has been documented as causing metallic taste complaints in other water supply systems, including Massachusetts Water Resources Authority (MWRA) in 2004.

2) Current Monitoring
    a. Water Quality – Kensico effluent keypoint samples (DEL18, CATLEFF) are being monitored daily to determine the concentration of *Chrysosphaerella.* In addition, the Delaware influent to Kensico (DEL17) is being monitored daily and the Rondout effluent keypoint (RDRRCM) and the Ashokan Reservoir keypoint (EARCM) are being monitored 5 days/week. Limnological surveys of Kensico, Rondout, and West Branch reservoirs are being performed weekly.
    b. Complaints – water quality complaints from in-City drinking water consumers received through 311 (coded QA) are being monitored and reported daily. Consumer complaints received by outside communities who draw water off the City's water supply system at or below the Kensico Reservoir are being reported daily.

3) Current Operations
    a. The Delaware System is on "float" mode of both West Branch and Kensico Reservoirs. As a result, approximately 90% of the Delaware water being distributed to the City via the Delaware aqueduct is from Rondout Reservoir. The Catskill System is currently drawing water directly from Kensico Reservoir. The Delaware System is on by-pass mode at Hillview Reservoir and is delivering water directly to the Distribution System via Tunnels 2 and 3. The Catskill System is on reservoir mode at Hillview and is delivering water to the Distribution System via Tunnel 1.

4) De-escalation
    a. Returning to normal reservoir operational mode at Kensico will be based on de-escalation triggers for water quality and complaints as outlined below. All trigger levels should be considered estimates, as decisions to change operational mode may be dependent on other contributing factors (e.g. need for implementing the Rondout-West Branch Tunnel shutdown, other operational needs).
    b. Water Quality Triggers
        i. Limnological Results – based on information obtained from MWRA we have established a *Chrysosphaerella* trigger level of 100 ASU/mL as the concentration

that is acceptable within Kensico Reservoir. *Chrysosphaerella* concentrations must be below 100 ASU/mL at all sites in Kensico before returning to normal operations at Kensico is considered. Concentrations in the Limnological survey of 10/13/09 indicated that *Chrysosphaerella* was present at concentrations of 200-300 ASU/mL at many sites, so 100 ASU/mL would also indicate that a significant decreasing trend of *Chrysosphaerella* concentrations had occurred.

ii. Keypoint Results - concentrations of *Chrysosphaerella* in the Kensico effluent samples provide information on the water being delivered to the Catskill and Delaware Aqueducts. Prior to putting the Delaware System on float mode at Kensico *Chrysosphaerella* concentrations were as high as 100 ASU/mL in the Kensico effluents. Since the operational changes were made the concentrations have been generally under 20 ASU/mL and complaints have dropped significantly. Based on this information and the fact that MWRA has established a level of concern at 15 ASU/mL following the event at MWRA, DEP will use <15 ASU/mL for a running 5 day average as the trigger for the Kensico effluent keypoint samples.

1. Management Taste Test Five Managers from the Water Quality Directorate participated in a blind taste test of source water to assist in determining:
    a. At what levels *Chrysophaerella* present a metallic taste problem
    b. Whether Kensico can return to reservoir mode on the Delaware Aqueduct without exacerbating the taste complaint situation.
2. Based on the taste test it was realized that the detection of a metallic taste was inconsistent between testers and no clear threshold concentration was identified. Therefore the <15 ASU/mL trigger could not be supported or refuted by this simple taste test.

c. Complaint Triggers

i. City's QA Complaints – during the first week of the event (Oct 5-Oct 9) 311 metallic taste complaints (QA3) averaged approximately 20 calls per day. DEP's baseline for QA3 calls is less than 1 call/day, however we routinely experience 3 calls per day pertaining to other characteristics of taste. Since some people characterize taste differently, calls coming in may be delayed, and as the public's attention to this matter is heightened, we expect to receive a few QA3 calls for some time. Based on this information we will use a trigger level of < 2 QA3 and <10 QA total call for a running 5 day average as a trigger for defining a reduction in complaints sufficient to resume normal operations.

ii. Outside Communities – we have received some calls from the outside communities that receive Kensico water. Since these communities are receiving water directly from Kensico, complaints within their systems are an indication of what we may expect when we begin to deliver Kensico water directly into the City's distribution system via the Delaware Aqueduct. DEP does not have information regarding the accuracy of the outside community complaints, and as such, we will use this information only as a guide in making a decision to de-escalate. If the general number of complaints is not increasing, then de-escalation can be considered.

d. Operations
   i. Kensico Delaware System – when all of the above triggers have been reached we will return to the normal Delaware System operational mode at Kensico in steps. This will allow DEP to track water quality complaints during the operation to verify that a return of the metallic complaint issue does not occur. Each step will be held for 2 days and complaint triggers will be monitored before proceeding to the next step. The steps will be as follows:
      1. Adjust Delaware System flows to achieve approximately 33% Kensico reservoir flow.
      2. Adjust Delaware System flows to achieve approximately 67% Kensico reservoir flow.
      3. Return to full reservoir flow of the Delaware System at Kensico.
   ii. Kensico Catskill System - once the Delaware System has returned to normal operation with no complaint triggers, then routine operation of the Catskill System can resume.

Attachment 7. Management Options for Control of Algae. (Adapted from Wagner 2001).

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
IN-LAKE PHYSICAL CONTROLS			
1) Circulation and De-stratification	♦ Use of water or air to keep water in motion ♦ Intended to prevent or break stratification ♦ Generally driven by mechanical or pneumatic force	♦ Reduces surface build-up of algal scums ♦ May disrupt growth of blue-green algae ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ May reduce internal loading of phosphorus	♦ May spread localized impacts ♦ May lower oxygen levels in shallow water ♦ May promote downstream impacts
2) Dilution and Flushing	♦ Addition of water of better quality can dilute nutrients ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up ♦ May have continuous or periodic additions	♦ Dilution reduces nutrient concentrations without altering load ♦ Flushing minimizes detention; response to pollutants may be reduced	♦ Diverts water from other uses ♦ Flushing may wash desirable zooplankton from lake ♦ Use of poorer quality water increases loads ♦ Possible downstream impacts
3) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments ♦ Duration of exposure and degree of dewatering of exposed areas are important ♦ Discharge of a large portion of lake water with nutrients at the highest level	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ May provide rooted plant control as well ♦ Long-term, low-cost approach to managing internal load	♦ Possible impacts on non-target resources ♦ Possible impairment of water supply ♦ Alteration of downstream flows and winter water level ♦ May result in greater nutrient availability if flushing inadequate ♦ Usually a very slow way to lower

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
	of the year can result in a net loss of nutrients from the lake. ♦ Refill by lower nutrient water from a well-managed watershed, or just high spring flushing, can reset the lake to a lower nutrient level. ♦ Algae are affected mainly by reduction in available nutrients.		internal loading (10-30 year timeframe typical)
4) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability	♦ Can control algae if internal recycling is main nutrient source ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with recreation or other uses during dredging
5) Light-limiting Dyes and Surface Covers	♦ Creates light limitation	♦ Creates light limit on algal growth without high turbidity or great depth ♦ May achieve some control of rooted plants as well	♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
6) Mechanical Removal	♦ Filtering of pumped water ♦ Collection of floating scums or mats with booms, nets, or other devices ♦ Continuous or multiple applications per year usually needed	♦ Algae and associated nutrients can be removed from system ♦ Surface collection can be applied as needed ♦ May remove floating debris ♦ Collected algae dry to minimal volume	♦ Filtration requires high backwash and sludge handling capability for use with high algal densities ♦ Labor and/or capital intensive ♦ Variable collection efficiency ♦ Possible impacts on non-target aquatic life
7)Selective Withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels ♦ May be pumped or utilize passive head differential	♦ Removes targeted water from lake efficiently ♦ Complements other techniques such as drawdown or aeration ♦ May prevent anoxia and phosphorus build up in bottom water ♦ May remove initial phase of algal blooms which start in deep water ♦ May create coldwater conditions downstream	♦ Possible downstream impacts of poor water quality ♦ May eliminate colder thermal layer that supports certain fish ♦ May promote mixing of remaining poor quality bottom water with surface waters ♦ May cause unintended drawdown if inflows do not match withdrawal
8) Sonication	♦ Sound waves disrupt algal cells	♦ Supposedly affects only algae (new technique) ♦ Applicable in localized areas	♦ Uncertain effects on non-target organisms ♦ May release cellular toxins or other undesirable contents into water column

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
IN-LAKE CHEMICAL CONTROLS			
9) Algaecides	♦ Liquid or pelletized algaecides applied to target area ♦ Algae killed by direct toxicity or metabolic interference ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid elimination of algae from water column, normally with increased water clarity ♦ May result in net movement of nutrients to bottom of lake	♦ Possible toxicity to non-target species ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity ♦ Possible recycling of nutrients
9a) Forms of Copper	♦ Cellular toxicant, suggested disruption of photosynthesis, nitrogen metabolism, and membrane transport ♦ Applied as wide variety of liquid or granular formulations, often in conjunction with chelators, polymers, surfactants or herbicides	♦ Effective and rapid control of many algae species ♦ Approved for use in most water supplies	♦ Possible toxicity to aquatic fauna ♦ Ineffective at colder temperatures ♦ Accumulation of copper in system ♦ Resistance by certain green and blue-green nuisance species ♦ Rupturing of cells releases nutrients and toxins
9b) Oxidants (mostly peroxides)	♦ Disrupts most cellular functions, tends to attack membranes ♦ Applied most often as a liquid.	♦ Potential selectivity against blue-greens ♦ Moderate control of thick algal mats, used where copper alone is ineffective ♦ Rapid action	♦ Older formulations tended to have high toxicity to some aquatic fauna ♦ Limited field experience with new formulations

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
10) Settling Agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too ♦ Lime, alum or polymers applied, usually as a liquid or slurry ♦ Creates a floc with algae and other suspended particles ♦ Floc settles to bottom of lake ♦ Re-application typically necessary at least once/yr	♦ Removes algae and increases water clarity without lysing most cells ♦ Reduces nutrient recycling if floc sufficient ♦ Removes non-algal particles as well as algae ♦ May reduce dissolved phosphorus levels at the same time	♦ Possible impacts on aquatic fauna ♦ Possible fluctuations in water chemistry during treatment ♦ Resuspension of floc possible in shallow, well-mixed waters ♦ Promotes increased sediment accumulation
IN-LAKE BIOLOGICAL CONTROLS			
16) Enhanced Grazing	♦ Manipulation of biological components of system to achieve grazing control over algae ♦ Typically involves alteration of fish community to promote growth of large herbivorous zooplankton, or stocking with phytophagous fish	♦ May increase water clarity by changes in algal biomass or cell size distribution without reduction of nutrient levels ♦ Can convert unwanted biomass into desirable form (fish) ♦ Harnesses natural processes to produce desired conditions	♦ May involve introduction of exotic species ♦ Effects may not be controllable or lasting ♦ May foster shifts in algal composition to even less desirable forms
16.a) Herbivorous Fish	♦ Stocking of fish that eat algae	♦ Converts algae directly into potentially harvestable fish ♦ Grazing pressure can be adjusted through stocking rate	♦ Typically requires introduction of non-native species ♦ Difficult to control over long term ♦ Smaller algal forms may be benefited and bloom

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
16.b) Herbivorous Zooplankton	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton ♦ May involve stocking piscivores or removing planktivores ♦ May also involve stocking zooplankton or establishing refugia	♦ Converts algae indirectly into harvestable fish ♦ Zooplankton response to increasing algae can be rapid ♦ May be accomplished without introduction of non-native species ♦ Generally compatible with most fishery management goals	♦ Highly variable response expected; temporal and spatial variability may be high ♦ Requires careful monitoring and management action on 1-5 yr basis ♦ Larger or toxic algal forms may be benefited and bloom
18) Pathogens	♦ Addition of inoculum to initiate attack on algal cells ♦ May involve fungi, bacteria or viruses	♦ May create lakewide “epidemic” and reduction of algal biomass ♦ May provide sustained control through cycles ♦ Can be highly specific to algal group or genera	♦ Largely experimental approach at this time ♦ May promote resistant nuisance forms ♦ May cause high oxygen demand or release of toxins by lysed algal cells ♦ Effects on non-target organisms uncertain