FATE OF NON-REGULATED DBPS IN DISTRIBUTION SYSTEMS

David A. Reckhow (PI)

Department of Civil and Environmental Engineering
University of Massachusetts
Amherst, MA 01003

William Mitch (Co-PI)

Department of Chemical & Envir Engineering
Yale University
New Haven, CT

Chul Park (Co-PI)

Department of Civil and Environmental Engineering
University of Massachusetts
Amherst, MA 01003

In collaboration with:

CDM Consulting Engineers
210 25th Avenue North, Suite 1102
Nashville, TN 37203

Twelve Drinking Water Utilities
As named in the proposal

1. Objectives

The overall objective of this study is to develop models and new knowledge that helps in the prediction and understanding of key non-regulated DBPs; their expected concentrations, their degradation pathways, ways to accelerate their degradation, ways to minimize their formation.

Specific objectives of the proposed project are to:

1. Determine the rates of abiotic degradation of a group of non-regulated DBPs that is representative of some of the groups of greatest concern.
2. Determine degradation products of these compounds when possible

3. Determine impacts of various conditions and characteristics (e.g., pH, temperature, concentrations of reactive solutes) of the water on these degradation rates.
4. Develop kinetic models for degradation.
5. Develop similar models for DBP formation from the various drinking waters with their existing consortium of organic precursors
6. Evaluate the importance and impact of biodegradation in distribution systems for these compounds
7. Isolate and assess biodegradation from abiotic reactions with dissolved species, from abiotic reactions with particulate corrosion products in distribution systems.
8. Combine the knowledge gained into a set of mathematical models incorporating rate laws and rate constants that can be used to help predict formation and especially degradation of the key non-regulated DBPs

The final product of this research approach will be new knowledge and a set of modeling tools for the drinking water industry that will help them in understanding the impacts of water quality, distribution system management and even treatment on their formation, decomposition and therefore concentrations at the consumer's tap.

2. Work Plan

The proposed work will be organized into four major tasks.

I. Final selection of target DBPs
II. Laboratory Studies
    a. Initial Testing with Utility Waters
    b. Investigation of stability in water
    c. Reactions with reduced solutes
    d. Rates of formation under various disinfection scenarios
III. Field studies
    a. Chemical analysis of target compounds
    b. Biological degradation tests with DS solids
IV. Synthesis
    a. Development of Full Kinetic Models
    b. Recommendations for Future Research
    c. Recommendations regarding DBP Control

Task I: Final selection of target DBPs.

In this first task, we will finalize our list of target DBPs. This will be done quickly upon execution of the contract.

This will involve a multi-step evaluation of the target list presented below.

First, we recognized that with many hundreds of possible DBPs, we can only select a small subset. Therefore, a set of clear criteria must be established before finalizing a target list. In this regard, we are especially interested in those DBPs that have the following properties

- Known to occur in distribution systems, or at least known to be produced upon disinfection of natural waters
- Known or probable human toxicity
- Structures that are likely to impart diverse chemical and biological behavior; not necessarily characteristic of the currently regulated THMs and HAAs
- Compounds with readily available analytical methods or those that likely to be susceptible to analysis by existing methods

Each compound on the list need not satisfy each of the criteria, but we have tried to make selections with these criteria in mind. Some of the compounds on our preliminary list are shown in Table 7, below.

Table 7: Initial List of Proposed Target Compounds

Candidate Compound	Group	Methods	Location for Analysis
NDMA	Nitrosamines	Munch & Bassett, 2004	Yale
Dimethyl nitramine	Nitramines	Munch & Bassett, 2004	Yale
MX	Halocyclopentenoic Acids	From 12 city survey[2]	UMass
Chloroiodoacetic Acid	Iodoacids	Modification 12 city method[2]	UMass
Bromochloroacetamide	Haloamides	Modification 12 city method[2]	UMass
N-Chloro-1,1-Dichloroacetamide	N-chloroamides,	LC/MS method under development[1]	UMass
2,6-dichloro-1,4-benzoquinone	Haloquinones	LC/MS method under development[1]	UMass

[1]Methods currently under development as part of WRF project #4089

[2]Several methods have been tested in Weinberg at al.,2002 and used at UMass with minor modifications

The value of this work to the drinking water industry is highly dependent on the compounds selected for study. While two of the PIs (Reckhow & Mitch) have an excellent understanding of the current state of knowledge of emerging, non-regulated DBPs, we feel that such an important decision should not be made until all important additional sources are fully tapped.

1. **Literature and one-on-one discussions with active researchers** (June, 2010): There are several groups looking actively at non-regulated DBPs, as well as some who are exploring new methods for trace contaminants in water. The PIs will

conduct a short, but intensive survey of the latest information regarding candidate compounds for this study. This will include review of the most recent literature (including presentations), along with follow-up phone calls with the other researchers and possible a site visit or two.

2. **Written summary of target DBPs with pros and cons** (late June 2010). This will be a short and highly focused summary of the findings from #1.
3. **Conference call or Web-based PAC Meeting** (~1 week after distribution of the target DBP summary). This will give us a chance to discuss the final candidate list of target DBPs with the PAC, and arrived at a finalized list.

Task II: Laboratory Studies

Laboratory studies require that the research laboratories have pure solutions of the target compounds at known concentrations. The preferred source would be a commercial chemical supplier that can provide the compounds in high purity. In some cases it may be necessary to prepare the compounds in the laboratory just prior to testing (e.g.,. N-halo species). Under these circumstances, reasonable attempt must be made to assure the reaction stoichiometry and product yield. In some cases, it may be necessary to contract for synthesis of one or more of the target compounds.

Sub-task IIa: Initial Testing

The purpose of this work is to determine the tendency of the various utility waters to form each of the target DBPs. This information is essential to final development of later experiments and field tests and for re-evaluation of the target compound list and field sites.

Finished water will be shipped from each of the participating utilities and treated in the UMass laboratory with chlorine or chloramines at doses close to those used by the full-scale plant. These samples will be allowed to react for periods of time ranging from 30 minutes to 1 week. Samples will then be analyzed for all target DBPs by the appropriate methods. Note that this will require that one set of samples be quenched and rushed to Yale University (90 min by car) for analysis of the target compounds assigned to Bill Mitch's team.

Should one of the target compounds not appear in any of the test waters above its MDL, it will be necessary to re-evaluate the selection of that compound or the field sites. The action to be taken will depend on the known formation chemistry of that particular compound. In some cases we will be able to propose other waters that are more likely to have the appropriate precursors or chemistry. In other cases we may not. A decision will then be made as to whether a new site should be added to the study or a new target compound as a substitute for the one that failed to form.

Sub-task IIb: Stability in water.

Both Reckhow and Mitch have extensive experience with kinetic investigations of DBP degradation reactions (see background section). Studies as part of task IIb will follow standard practices for such kinetics testing. Reactions will be conducted in lightly buffered waters (10 mM total buffer) using several types of buffers, to help distinguish general from specific acid/base catalysis. A range of target pHs will be investigated from about 5 to 11, and ionic strength will be kept low and constant. All samples will be held at a pre-determined controlled temperature, and shielded from light. Reactions will be followed for timeframes resulting in 2 log decomposition or extending for 7 days, whichever is shorter. Analysis of residual compound will be conducted immediately or the samples will be stabilized (change in pH, refrigeration) and analyzed within accepted holding times. Runs at several temperatures will be made in these investigations to determine temperature model parameters (e.g., activation energies and pre-exponential factors).

To be more specific; we propose to use phosphate and carbonate (maybe borate at higher pH) as candidate buffers (see figure A, below). We'd like to look at several pHs (e.g., 5, 6, 7, 8, 9, 10, 11) and several temperatures (5, 20 & 35°C). To keep the experimental work under control, we'd propose an orthogonal design where we'd look at all 5 pHs at 20C and look at all three temperatures at pH 7. Samples would be collected at different reaction times (e.g., 9 total, plus one control) and analyzed as soon as possible. Figure A shows just a set of example reaction times. The actual reaction times would be tailored to the speed of the reaction. This makes a total of 90 experimental runs for each compound or set of compounds. Its may be possible to run multiple target compounds at the same time (same initial solution). However this may not be practical given the necessity of rapid chemical analysis. Data would be handled in accordance with standard integral method of kinetic analysis. Rate laws and rate constants would be determined from least square regression of standard kinetic linearizations. Data points would be weighted based on the relative standard deviation of the analytical method at the particular concentration level. Because we'd be running so many tests at different reaction times, we were hoping to use these as a proxy for exact laboratory replicates (e.g., experimental uncertainty would be incorporated into the error term in the rate constant.

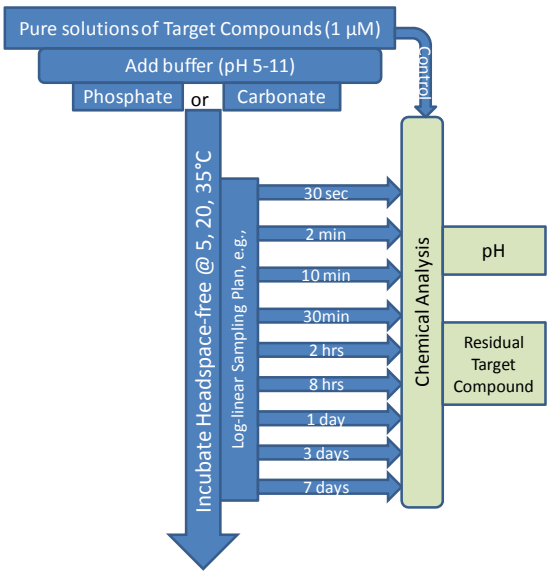


Figure A. Proposed Experimental Design for Task IIb Studies

Sub-task IIc: Reactions with reduced Solutes.

A limited set of tests will be run with dissolved inorganic species, containing reduced forms of iron, sulfur and nitrogen. The preferred reducing agents to be tested are: ferrous iron, sulfite, and nitrite. While there are many types of reduced substances present in distribution systems, it was felt that further investigations with other types, including pipe corrosion solids, should be deferred to a follow-up project if warranted. These will first be done at 20C, pH 7 and reduced species concentrations of 0.1 mM. Of course, dissolved oxygen will have to be purged from all samples prior to testing. If substantial degradation is seen, then the testing will be extended to other conditions (pH, concentrations, temperature).

Experiments in sub-task IIc would be quite similar to II b but with the following departures. We would use a single pH with a single buffer (selection based on the IIb results). We would purge with nitrogen to remove oxygen. To do this we'd want to pre-purge the aqueous buffer and dilution water in order to minimize volatilization of the target compounds. A control would be collected and analyzed to determine the extent of loss during purge. Then we would add the selected reduced organic (only one per experiment) and follow the loss, if any, with time. We would also want to measure the final concentration of the reduced inorganic compound, expecting that there would be some oxidative loss. We propose that additional experiments be conducted if substantial degradation is observed. This would include tests with varying reduced inorganic concentrations, varying pHs and possibly variable temperatures.

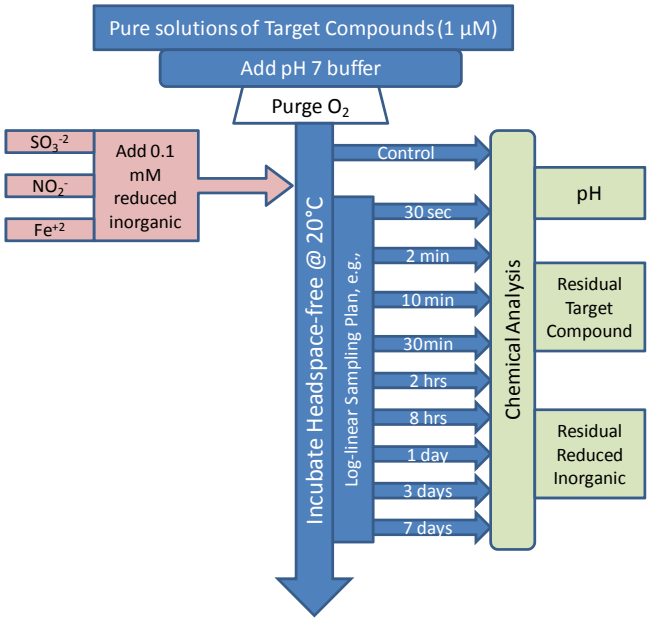


Figure B. Proposed Experimental Design for Task IIc Studies

Sub-task IId: Rates of Formation

A small group of utilities (ideally 3-4) will be selected for testing of formation kinetics for each of the target compounds. Water from the selected utilities will be chlorinated or chloraminated (depending on what is done in full scale) and allowed to react for a period of time from 30 minutes to 1 week. The samples will be held at controlled temperatures between 5C and 25C. Samples will be collected and analyzed over the 1 week period at a frequency that allows accurate determination of formation rates. Given the experience with THM and HAA formation kinetics, it is expected that these will have to be modeled in an empirical fashion. This is because it is unlikely that a formation of any of the target compounds will be attributable to a single identifiable precursor.

The task IId utilities will be treated with chlorine or chloramines to get adequate data on target compound formation to calibrate a formation model. Chlorine or chloramine doses would be selected based on what is actually used in the plant (total dose, if applied at multiple locations). We would look at a narrower range of temperatures as compared to the IIb studies. We would also need to monitor chlorine residual (free and combined). We also propose to measure THMs and HAAs as a benchmark with which to compare the target compound formation.

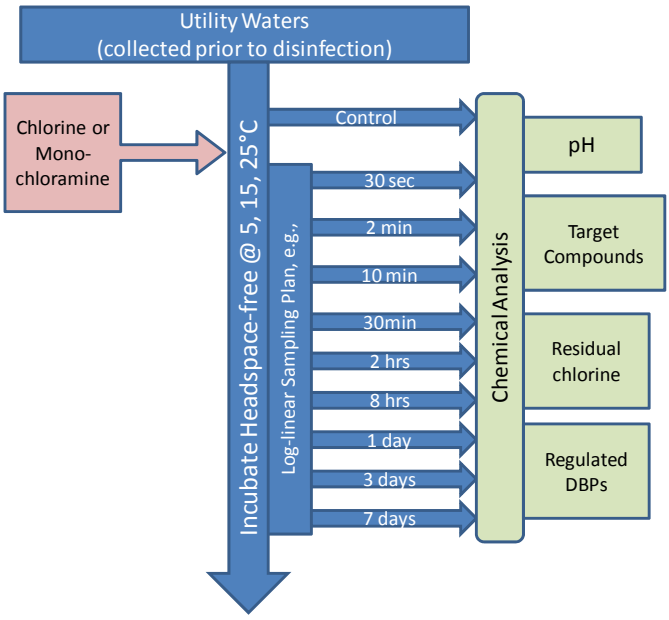


Figure C. Proposed Experimental Design for Task IId Studies

Task III: Field Studies.

Participating Utilities

A total of 12-13 utilities have been selected for participation in this study (Table 8). They have been selected in an effort to capture the full range of disinfection scenarios found in the US. With only one exception, all of the selected utilities have well developed and calibrated

distribution system hydraulic/residence time models. Also, several have well calibrated water quality models, and have experience with coupon studies.

Table 8. Participating Utilities

Primary/Residual Disinfectant	Utility #1	Utility #2	Utility #3
Free Cl2/Free Cl2	Charleston, SC	Wyoming, MI	
Chlorine Dioxide/Free Cl2	Knoxville, TN		
Free Cl2/Chloramine	San Francisco, CA	EBMUD	Pineallas, FL
Ozone/Free Cl2	Monroe, MI		
Ozone/Chloramine	Ann Arbor, MI	Contra Costa, CA	Raleigh, NC[1]
MIOX	Anderson, SC		
UV/Chlorine	Cincinnati, OH		
Chloramine/Chloramine	Minneapolis, MN		

Sample Collection

These 12-13 participating utilities will be our primary source of treated water, and distribution system solids and biofilms for subsequent analysis and testing. We will make use of two sampling approaches:

- Collection of distribution system water samples at multiple locations in the systems representing a range of water ages, and water qualities
- Collection of scoured solids at locations exhibiting HAA degradation
- Harvesting of coupons and excavated pipe from key locations near points of known HAA degradation

Collection sites will be based on areas of known or suspected HAA loss. This work is timed to make good use of Initial Distribution System Evaluation (IDSE) data in locating the most promising sites.

In prior work, we have used HAA/THM ratios to find areas of high probability for HAA degradation. Some sample data from Norwood, MA are shown below (Figure 6). In this particular case, we have plotted the HAA5/THM ratio for two distribution system locations in rank order, and expressed as a percentile. The town hall site shows a typical distribution based on variable concentrations of both DBPs, but it does not show the distinctive loss of HAAs. The Pier 1 site does show a substantial HAA loss for about 50% of the samples. This site also has lower chlorine residuals during periods of HAA loss. In addition, other commonly measured parameters can be brought to bear on this assessment. These may include microbial parameters (e.g., HPC), chemical parameters (e.g., nitrate), or physical (e.g., temperature). In many systems, DHAA/THM ratios are more sensitive than the bulk HAA5/THM ratio. Nevertheless, for this particular system (chloramine residual, MWRA source), a mass ratio of about 0.3 seems to be the threshold for HAA degradation. This type of threshold is common, but it is site specific. We

[1] Not yet formally added; Raleigh practices an annual free chlorine burn; so it also occupies the ozone/free chlorine box

proposed to use existing and newly-collected data (e.g., with the IDSE) to identify the best collection sites in our fourteen participating utilities.

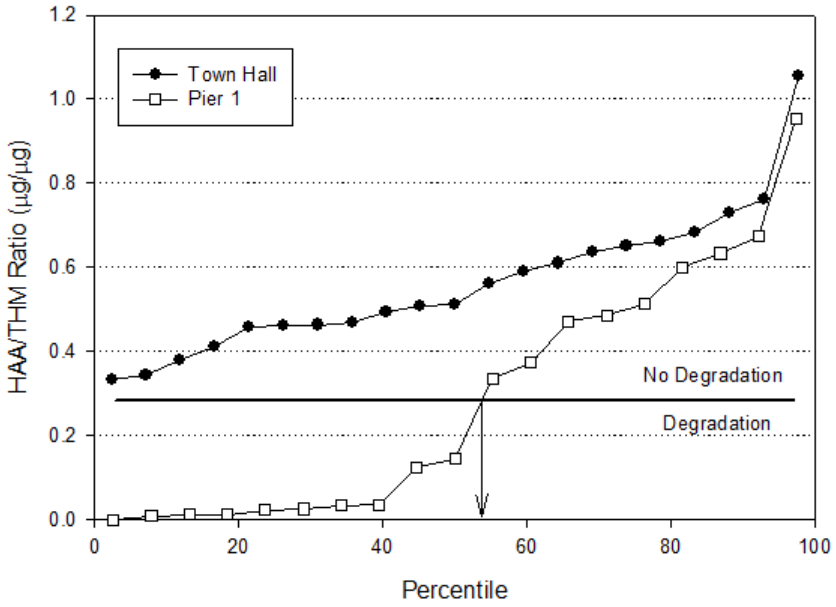


Figure 6. Ratios of haloacetic acids (HAA5) to trihalomethanes for two sampling locations in Norwood, MA (Castellon and Reckhow, 2006; report to NCI).

Sub-task IIIa: Chemical analysis of field samples.

We will conduct a series of tests from each of the participating utilities that has shown to harbor at least one of the target DBPs (as determined in sub-task IIa). Samples will be collected from a dozen sites across the distribution system for each utility. An attempt will be made to capture sites with a range of residence times, and water quality characteristics. The sites will be selected in collaboration with the utility personnel and with CDM engineers. In this selection process, we will make use of the calibrated hydraulic models, as well as all available water quality data for the utility.

Samples will be preserved on-site and shipped on ice by overnight carrier to UMass and Yale. Once at the two University labs, they will be analyzed for HAAs, THMs, TOX species (TOBr, TOCl, TOI) and target compounds. Using this information, we will be able to compare formation/degradation models with actual distribution system concentrations. This comparison will be done in the context of full models in Task IV.

The parallel analysis of regulated DBPs (especially HAAs) will help to provide a benchmark for biodegradation of non-regulated DBPs, thereby allowing utilities to tap into their large databases of HAAs and THMs to help in management of a larger array of DBPs. For example, we may find that certain compounds will be completely degraded at locations where DCAA is degraded. The analysis of TOX species is another unique feature of this research, as it will provide an assessment of overall dehalogenation reactions.

Sub-task IIIb: Use of field samples for biodegradation tests.

Following discussions with the participating utilities and analysis of their water quality data, we will select those that have distribution system locations with well documented HAA degradation. Samples from each of these locations will be collected in a fashion to maximize the capture of solids (e.g, high-velocity flushing). These samples will be rushed to UMass and used for the bench-scale biodegradation experiments.

The distribution system samples (with flushed solids) will be filtered in duplicate from identical aliquots of a single homogenized sample (Figure 7). This will result in two glass fiber filter disks with identical solid residues. One of the two will be subject to analysis of dry solids (TSS and metals) and fixed solids (allowing determination of VSS). The other will be cut in half for introduction into bottles 3 and 4. An azide solution will be added to bottle #4 as an abiotic control. Both bottles 3 and 4 will be filled with freshly-quenched plant effluent. This is intended to represent the water quality to which organisms in the distribution system samples were initially exposed in situ. The quenched plant effluent is prepared by holding the plant effluent in clean bottles for 24 hours, quenched with sodium thiosulfate at near quantitative doses. This water sample should contain the full suite of DBPs and other organic and inorganic nutrients as they exist throughout the system prior to any degradation. The suite of target compounds will then be added to this quenched sample. In addition to the abiotic control, there will also be a no-solids control (#6), prepared from the quenched plant effluent. To this we will add one half of a freshly-cleaned glass fiber filter. This is intended to show natural degradation and bottle/filter losses. Finally, scrapings from coupons or excavated pipe segments collected from the systems (where available) will be added to another bottle (#7) for assessment of biodegradation of attached biomass. In each case there will be some characterization of the transferred biomass using conventional methods (e.g., TOC, ATP, total proteins). Depending on the results, we may also make use of some molecular biology tools like RFLP (crude community analysis before cloning or sequence), SDS-PAGE, and enzymatic gel electrophoresis, all of which are used by one of the Co-PI's (Park). We are also prepared to measure biodegradable dissolved organic carbon (BDOC) and assimilable organic carbon (AOC) as an alternative surrogate to the HAAs for assessing the impact of biodegradation. While not a part of the core experimental design, the PI's recognize the importance of these widely accepted parameters, and they have used them as tools in several prior studies at UMass (e.g., Reckhow et al., 1992; Reckhow et al., 2006). See below for more details on these methods.

> *<u>Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) or 2D-PAGE</u>*
> *SDS-PAGE or 2D-PAGE can reveal profile of proteins and peptides (combined amino acids) that are present in water and biomass as well. Determining the protein pattern during the bioassay will allow us to investigate the fate of proteins in the incubation and to see if there are unique protein (enzyme) bands that emerge or disappear during the incubation. SDS-PAGE can also be directly applied to the solids (biomass) scoured from different distribution systems, which may allow us to detect whether there are common or unique protein (enzyme) bands in samples from systems exhibiting extensive HAA or DBP degradation. Once protein patterns are determined, the protein extracts or gels can be stored for later analysis. During this advanced proteomics analysis, we can identify what these proteins are (characteristics of proteins) and who are generating these proteins (source of proteins). For this project we do not plan to perform these identification processes but general protein fingerprinting by SDS-PAGE will still provide very useful microbial and protein data.*

Zymogramic (enzymatic) analysis *Zymography is similar with SDS-PAGE except for that this method is for selecting enzymatic proteins. The method is known to be very sensitive. We have already applied this method into wastewater treatment effluent and receiving waters and found it very useful in detecting various lytic enzymes in various water samples. We are planning to use this method for the project along with SDS-PAGE. Again, emerging enzyme bands and extracts can be saved for later analysis.*

Restriction Fragment Length Polymorphism (RFLP) *RFLP is another molecular method that we can readily use for this project. RFLP is a culture independent method and it can reveal microbial composition in various water samples. Similar with SDS-PAGE and zymography, RFLP can provide community fingerprint in biomass collected from different water systems. Furthermore, tracking of changes in community structure during laboratory incubation would allow us to detect increases in important bacteria (possibly dehalogenating bacteria) that play a central role in breaking down some DBPs. Those microbial bands could be further submitted to sequencing for genus or species identification at the UMass Amherst Sequencing Facility. If we face sequence problems possibly due to a shorter DNA fraction from RFLP, we may have to adopt a different fingerprinting method following PCR, denaturing gradient gel electrophoresis (DGGE). At present, the PIs do not intend to use DGGE for the microbial analysis.*

Other biochemical methods for biodegradation study *Common parameters such as VSS/TSS, TOC, and COD will be determined through the biodegradation study. Other widely accepted parameters like AOC/BDOC will also be measured during the project. We will determine concentrations of protein-nitrogen, total nitrogen, NH_4-N, NO_3-N, NO_2-N, and organic nitrogen, which have been measured routinely for wastewater effluents and receiving waters in Park's lab. We also plan to measure total dehalogenase activity from solids from various distribution systems and also during the incubation. For this analysis, we will follow the methods that have already been established by other researchers (e.g., Slater et al., 1979, 1972).*

All of the bottles will be incubated at 20 C under aerobic conditions (mild agitation) for up to 14 days. Prior to incubation, all disinfectant residuals will be removed as previously described. Samples will be removed on a periodic basis so that residual HAAs may be determined. When significant changes in the HAAs are noted, additional testing will be conducted to see if there are changes in the target compounds. Other measurements will be made to allow for assessment of abiotic degradation (e.g., pH, dissolved reduced species).

In addition to the incubated experimental sets and controls, there will be two other "instantaneous" assessments; one from the filtered slurry of distribution system solids (#1), and one from the plant effluent (#5). Both of these are needed as baselines for assessing DBP loss and for generally characterizing the system water quality.

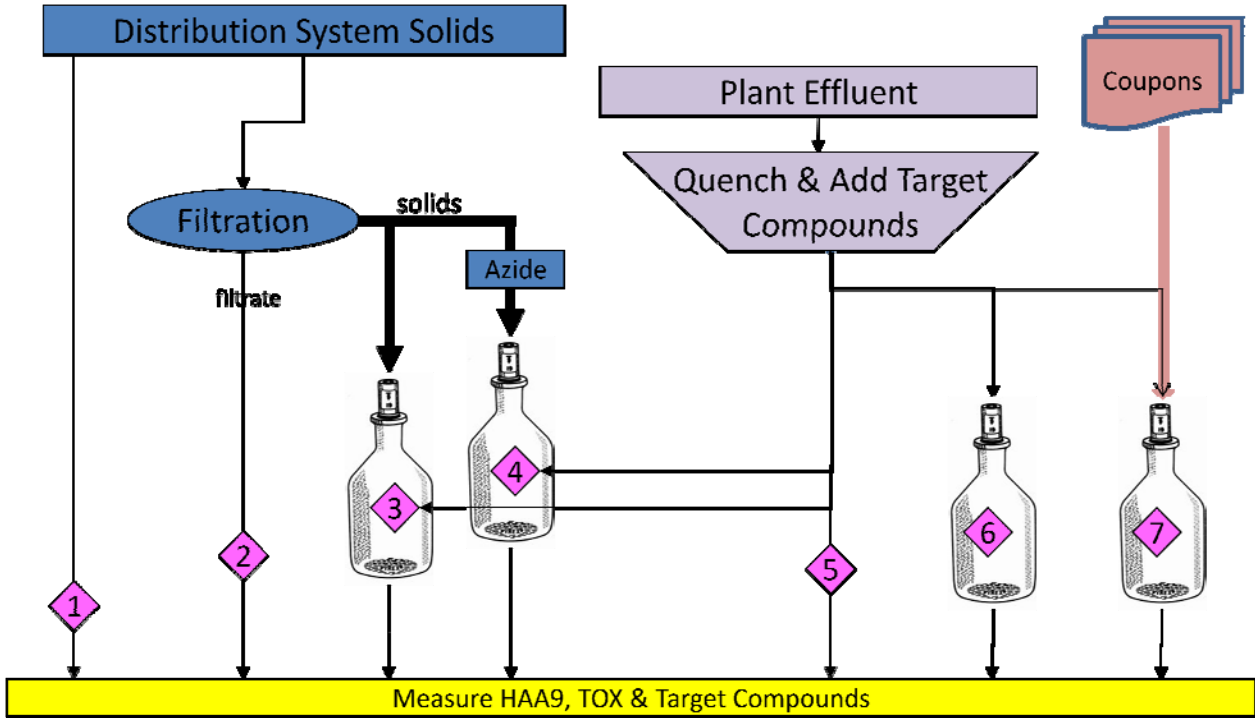


Figure 7. Experimental Design for biodegradation testing of bulk field samples

Task IV: Synthesis

Sub-task IVa: Development of Full Kinetic Models.

Kinetic models for target compound degradation will be combined with the empirical kinetic models developed for target compound formation. While the formation model will be site-specific, the decomposition model should be transferrable. If biodegradation is observed, or anomalously high abiotic degradation (e.g., from abiotic, azide controls), there will be additional uncertainty in the final model.

Sub-task IVb: Recommendations for Future Research and DBP Control.

There is little doubt that this research project will generate some additional research questions, and clarify those that are most important to our greater understanding.

3. Applications Potential

This project will provide information on the conditions that influence degradation of non-regulated DBPs of concern in distribution systems, with the goal of aiding in the control of their

occurrence and concentrations.

The significant anticipated benefits of this project to the drinking water community include:

- A deeper understanding of physical and chemical parameters that control concentrations of hazardous non-regulated DBPs in distribution systems.
- Insight into the interdependence of these parameters to aid with new control strategies
- Degradation kinetics for these new DBPs, including impacts of pH, temperature, reduced inorganic species; all of which support modeling kinetics for DBPs in distribution systems
- Estimates of how prevalent biotic degradation of the non-regulated DBPs is in relation to abiotic degradation and in relation to biodegradation of HAAs
- A more complete understanding of DBP classes not yet subject to regulation

The principal products of the project will be engineering and operations knowledge with practical benefits to the water community:

- This project identifies factors that contribute to the chemical and biological degradation of a broad range of potentially hazardous DBPs
- This project will result in a series of kinetic models that can be used by utilities for the purpose of predicting locations and conditions where concentrations may be particularly high or particularly low.
- The models and new knowledge will help inform utilities considering changes in their disinfection processes and their distribution system management so that they can best control DBPs which still meeting other objectives

4. Management Plan

We have assembled a highly qualified and interdisciplinary research team that possesses a practical working knowledge of DBP chemistry, formation, decomposition, degradation and modeling.

Researcher	Expertise	Applied Questions within Project	Tasks*
David A. Reckhow PI	Aquatic Chemistry; WTPs	DBP measurements including breakdown metabolites; formation conditions (e.g. NOM load and rechlorination), formation potential	I, II, IIIa, IV
Chul Park, Co-PI	Environmental Microbiology	Microbial community composition, isolates and biofilms, enviro-kinetics, isolate-kinetics, model system study	IIIb
William Mitch, Co-PI	Nitrosamines, Nitramines, Kinetics	Biochemistry of enzymatic degradation of HAAs, breakdown products, inhibition, enyzme kinetics	I, II, IIIa

The project team will be organized on a functional basis, as illustrated in the organization chart below. The research collaboration will be facilitated through a suite of mechanisms including:

1. Monthly group meetings or bi-weekly meetings of specialized subgroups (PIs and students that currently work on related projects) on the UMass Amherst campus.
2. Quarterly meetings with Dr. Mitch and his students (or more frequent depending on the project period).
3. Periodic and final reports prepared by the Lead Investigator for each task.
4. Annual meetings of all team members at AWWA conferences.
5. Extensive use of phone and electronic communication.

Dave Reckhow will be the lead PI for this project and will be responsible for overall management and reporting. His primary area within the research team will be in analysis of target DBPs, directing tests for DBP formation and degradation, and developing kinetic models. He will supervise one doctoral level student in CEE to complete the studies and experiments described, as well as a laboratory staff person who will help with analysis by GC/MS and LC/MS. He will hold regular project meetings with the UMass team. He will be in regular contact with the Yale team. There will also be quarterly meetings between the two groups. This collaboration is especially effective because of the excellent working relationship between the PI and the co-PI s, and because of the phyical proximity of UMass and Yale.

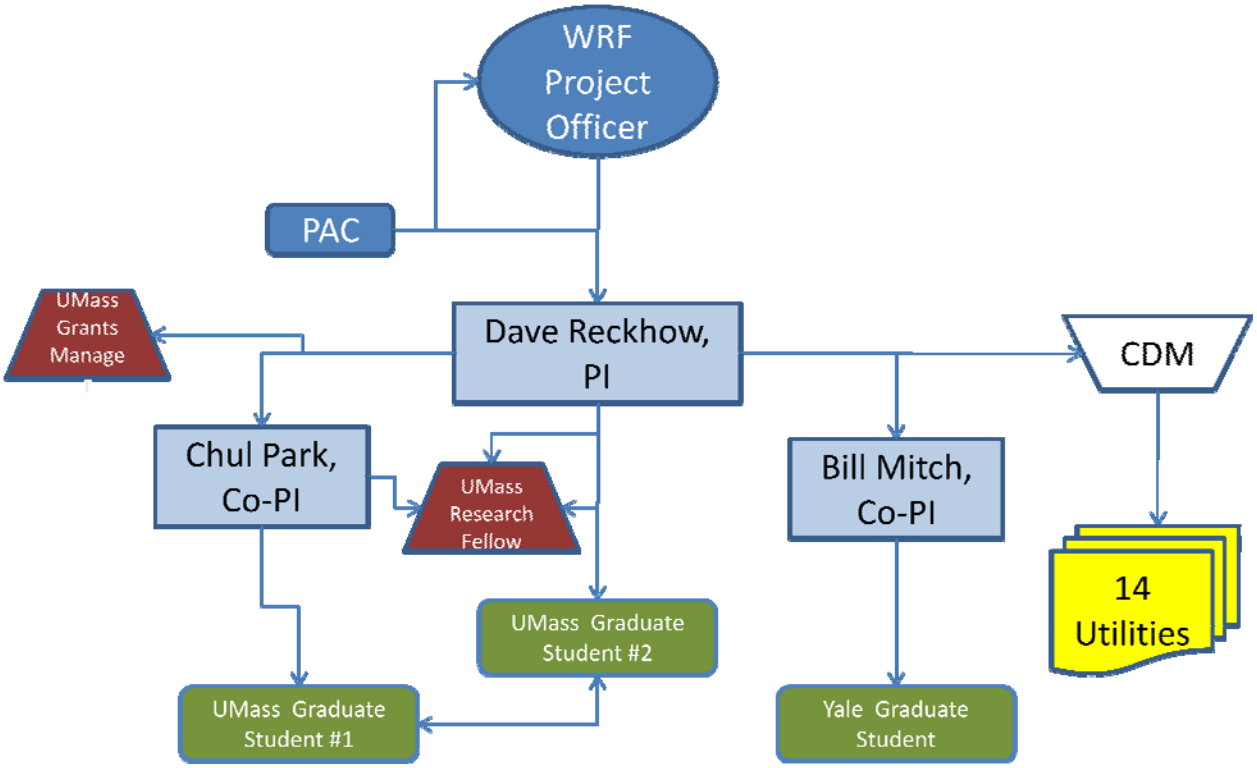
Chul Park will be responsible for all biodegradation testing and analysis. He will oversee a second graduate student in CEE to conduct this work.

William Mitch will oversee experiments related to the evaluation of the formation and degradation of nitrosamines and nitramines under conditions relevant to drinking water distribution systems. This responsibility includes the measurement of nitrosamines/nitramines. He will also oversee a graduate student. This work will be done at Yale University under subcontract with UMass. In addition, Dr. Mitch will aid in the preparation of a literature review, quarterly reports, and the draft final and final reports. Dr. Mitch will also help advise on other tasks. Dr. Mitch will commit ~10% of his time to the project.

CDM Engineers. CDM will be primarily responsible for coordinating the participating utilies, over the 2 year period of data collection. CDM will work with University of Massachusetts to develop a survey for distribution to Participating Utilities. The survey will allow specific information about each system to be collected including a description of water treatment process, determination of water age at distribution system sampling points, results of past monitoring for regulated and non-regulated DBPs, other water quality data at sampling points. This will be also used as an opportunity to obtain feedback on a recommend list of non-regulated DBPs for investigation in this project. CDM will summarize data from the survey and compile this information into a central database to track information that will allow researchers to correlate potential factors that affect DBP formation and degradation. CDM will provide technical review of reports, and assist in extracting water ages from distribution system hydraulic models. They will make us of Dr. Philip C. Singer who is under contract with CDM for additional technical oversight.

Utility Partners include utilities that have a strong interest in DBP control, and have well calibrated hydrualic models for their distribution systems. They are all contributing personnel time, assiting with shipping, and providing data on their systems.

The organizational chart below shows the key interrelationships and lines of communication between the various members of the project team.



5. SCHEDULE

	Year/Quarter →	2010				2011				2012	
#	Tasks	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd
1	Final Selection of Targen DBPs										
2a	Initial Testing of Utility Waters										
2b	Investigations of Stability in Water										
2c	Reactions with Reduced solutes										
2d	Formation Rates										
3a	Field Studies: Chemical Analysis										
3b	Field Studies: Biodegradation Testing										
4	Synthesis										
	Short Progress Reports										
	Full Progress Reports with Data										
	Final Report										

6. Supplemental Data on Participating Utilities

Table S1: List of Participating Utilities and Types of Disinfectants Used

City	State	Primary	Secondary	Source
Anderson	SC	MIOX		Lake Hartwell
Ann Arbor	MI	Ozone	Chloramines	Huron River
				Ground
Cincinnati	OH	UV	Free Cl_2	Ohio River
Contra Costa	CA	Ozone	Chloramines	Surface
EBMUD	CA	Free Cl_2	Chloramines	Mokelumne River watershed
		Ozone	Chloramines	surface
Knoxville	TN	ClO2	Free Cl_2	Tennessee River
				French Broad River
Minneapolis	MN	Chloramines	Chloramines	Mississippi River
Monroe	MI	Ozone	Free Cl_2	Lake Erie
Pinellas	FL	Free Cl_2	Chloramines	ground
				surface & desal
San Francisco	CA	Free Cl_2	Chloramines	Surface
		Ozone	Chloramines	Surface
Wyoming	MI	Free Cl_2	Free Cl_2	Lake Michigan
Charleston	SC	Chloramines	ClO2	Edisto River