Title: EDC/PPCP Benchmarking And Monitoring Strategies for Drinking Water Utilities
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Scope of Work

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Endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs) encompass hundreds of trace contaminants that have been detected in raw and treated drinking waters. Water utilities have expressed concern over these compounds and many have initiated expensive monitoring programs. Unfortunately, the choice of compounds to monitor has frequently been made in a haphazard way and without careful consideration of local conditions. In addition, the selection of monitoring sites and frequency has often been done without regard to the way in which monitoring data would be used, or the unique features of these compounds, including source types, loading dynamics, and behavior in the environment.

Therefore, the goal of this study is to develop a watershed-level protocol for addressing EDC/PPCP monitoring needs, utilizing a combination of statistical tools, GIS and spatial analysis, and analytical sampling of indicator and surrogate compounds. During the initial tasks, the Project Team will develop a general protocol for designing a sampling campaign using 1) Geographic Information Systems (GIS) and spatial analysis tools with available land use and other GIS layers to identify potential EDC and PPCP sources in a watershed, and to find optimal sampling locations; and 2) statistical analysis of existing data, in conjunction with GIS-based information on potential sources in the watershed, to determine a rational set of representative indicator compounds (a few EDC/PPCP compounds as indicative of the others) and surrogate parameters (conventional water quality parameters highly correlated with EDC/PPCP compounds), and to find optimal sampling frequency. These two tasks will use publicly available historical data from at least five watersheds (Lake Mead/Colorado River; Croton and Cat/Del systems, NY; South Platte River, CO; Cape Fear River Basin, NC; and the Merrimack River, MA) and perform an *a posteriori* analysis of the data sets. Once the generalized protocol is developed, it will be applied to two distinctly different watersheds (the South Platte, CO and Merrimack River Basins, MA) and their associated water utilities as a proof of concept. The protocols developed and validated during this study will assist drinking water utilities, individually or as a consortium, in utilizing limited resources intelligently to address the issue of EDCs and PPCPs in a cost effective manner, setting up a network of sampling locations throughout a watershed along with timing criteria for sample collection to achieve maximum benefit of the sampling performed. The principal product of this research will be a detailed, comprehensive, and well-tested list of protocols and strategies that can be used by a utility wishing to implement their own EDC/PPCP monitoring program.

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1.0 Project Description

1.1 Background

Statement of the Problem

Continued population growth and expansion is placing heavy burdens on our nation's water supplies, both in terms of quality and quantity. Water utilities are often forced to cope with adversely impacted water quality within watersheds along with examining innovative ways to stretch water supplies to ensure their ability to meet the demand for safe, clean drinking water. Changing land use patterns, urbanization, and population growth all play a role in increasing the loading of trace contaminants from municipal, agricultural, and industrial sources into new and existing surface and ground water supplies. Concomitant with the search for additional sources of drinking water, many utilities are turning to lower quality waters with more point and non-point source influence. Furthermore, as surface water flows are altered due to climate change, the percentage of wastewater and other inputs will also change and may adversely impact the quality of drinking water available to a utility (Benotti, Stanford, et al. 2010; Kolpin, Skopec, et al. 2004). Thus, the potential for trace contaminants to enter drinking water is high and is likely to continue increasing despite advances in water treatment processes (Benotti, Trenholm, et al. 2009; Snyder, Trenholm, et al. 2008; Snyder, Wert, et al. 2007a).

In recent years the public has been made acutely aware of the presence of pharmaceuticals and personal care products (PPCPs) and endocrine disrupting compounds (EDCs) in drinking water through popular press articles (Donn, Mendoza, et al. 2008a, b, c; Duhigg 2009; EWG 2009; Naidenko 2009), yet little assistance or context has been provided as to how to interpret those results. Although the presence of EDCs and PPCPs has been recognized in water for more than 40 years (Tabek and Bunch, 1970, Tabek et al, 1981, Ahern and Briggs, 1989, Stumm-Zollinger and Fair 1965), only recently has the issue come to the foreground of public debate. Numerous studies have identified trace contaminants in drinking water supplies from municipal, agricultural, and industrial inputs and have linked the presence of those compounds to adverse impacts on wildlife species (Ahel, Molnar, et al. 2000; Brion, Tyler, et al. 2004; Cicmanec, Staats, et al. 2003; Gibson, Smith, et al. 2005; Guillette, Crain, et al. 2000; Kolodziej and Sedlak 2007; Lerch and Blanchard 2003; Snow, Bartelt-Hunt, et al. 2008; Snyder, Villeneuve, et al. 2001; Stanford and Weinberg 2010; Voutsa, Hartmann, et al. 2006). These studies combined with popular press headlines such as "Traces of Drugs Found in Las Vegas Wash" (*Las Vegas Sun*, Oct. 16, 2000), "Male Fish Growing Eggs Found in Potomac: Sewage, Hormone Pollution May be the Cause" (*MSNBC*, Dec. 21, 2004), and "Testicles Shrinking in Las Vegas Bay", (*Southwest Hydrology*, March/April 2007) have heightened the public's fear over the presence of trace levels of contaminants in drinking water.

To exacerbate the issue further, proactive utilities working to stay ahead of the issue by sampling for EDCs, PPCPs, and other trace contaminants in their source and finished drinking waters have been "punished" by rebukes from groups such as Environmental Working Group (EWG 2009). While the 2009 Environmental Working Group study attempted to be "fair" in its ranking system for the "best" and "worst" utilities in the U.S., an enormous amount of bias was present in the study simply due to the types of compounds utilities examined in their *voluntary* occurrence studies. For example, of the thousands of potential trace organic contaminants that could be found in surface waters, were a utility to have chosen to sample for a suite of compounds that were either rarely detected in other studies, extremely well-removed during conventional drinking water treatment, or expected to be present only under certain land use patterns, then their results would have shown a low frequency of detection. On the other hand, were a utility to have chosen to sample for frequently-detected compounds and/or compounds that were less amenable to removal during treatment processes then that utility would have had a high frequency of detection. Thus, the simple act of choosing the compounds to look for in water can have enormous public perception implications yet provide little relevant information regarding risk.

Nearly all of the studies to date have focused on organic wastewater contaminants as the primary EDCs/PPCPs of interest, with the underlying assumption of these studies being that the chemicals of concern come from point-source municipal wastewater treatment facilities (WWTPs). However, recognizing that significant sources of EDCs/PPCPs may include non-point sources such as agriculture (confined animal feed operations (CAFOs) and crop-based farming) and urban/suburban runoff (Jjemba, 2008), these sources must be recognized in a comprehensive approach to developing a watershed specific EDC and PPCP analyte list. As an example, Figure 1 shows a box diagram for identifying point and nonpoint sources from residential, commercial, agricultural and industrial land uses. A generic representation such as that shown in Figure 1 can be organized and quantified for any watershed using geographic information systems (GIS) software.

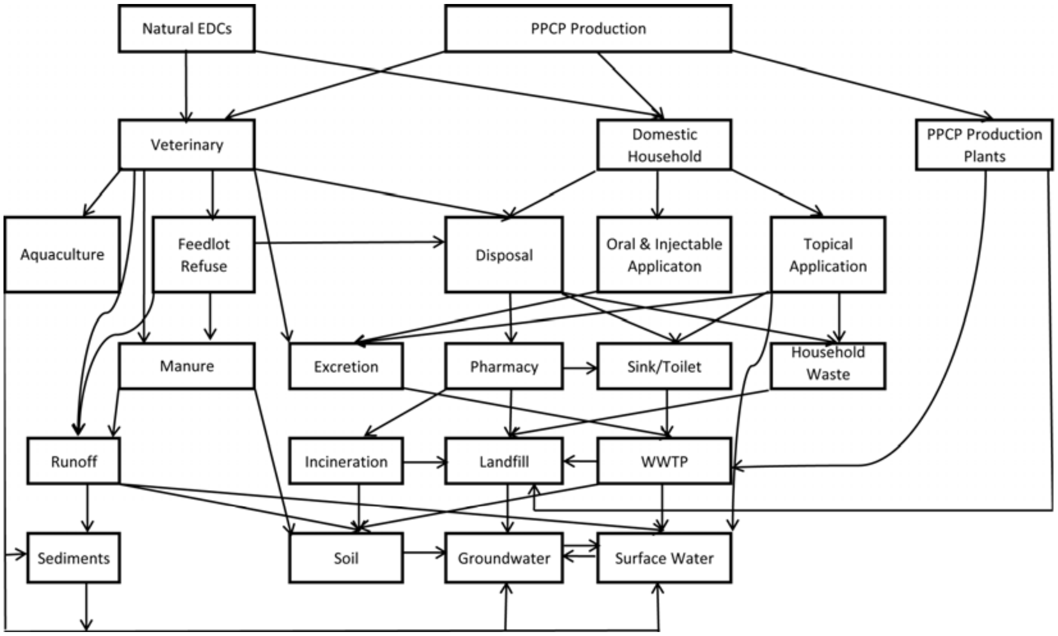


Figure 1 Typical pathways of EDC/PPCP pollution in surface water resources (Jjemba, 2008)

Therefore, in designing a systematic testing program to evaluate the presence or potential presence of trace contaminants in a drinking water supply, one must incorporate a thorough understand of the variables: Sources of contaminants, land use, watershed inputs, contaminant frequency distributions, temporal/seasonal variations, impact of drought, analytical methodologies, sample handling techniques, and interpreting data within a human health-based context. Additionally, utility managers and the scientific community must be cognizant of the significant financial burden that accompanies trace-level monitoring campaigns. Thus, this team will outline in this scope an approach to providing utilities with the information necessary to design and implement an informative and beneficial sampling campaign, while minimizing cost. The approach outlined will incorporate the plethora of published and/or publicly available data for meta-analysis while also designing and implementing two distinct sampling campaigns as a demonstration of the suggested approach.

Project Hypotheses

As a basis for framing the suggested project tasks and study objectives, and for providing a basis for later evaluation, the following hypotheses are proposed:

- Geographic Information Systems (GIS) and spatial analysis tools can be utilized to identify potential EDC and PPCP sources in a watershed. This information can be used to identify hotspots in the watershed and elucidate spatial variations EDC/PPCP impact.

- Statistical analysis of existing data can be used to determine a rational set of representative "indicator" compounds and surrogate parameters, which can be regularly analyzed for at particular locations to assess occurrence and to quantify the level of EDC/PPCP pollution at particular locations throughout a particular watershed.

- The protocols and tools developed can be successfully implemented in an intensive sampling campaign to determine extent, impact, and temporal, hydrologic, and spatial variability of EDC/PPCP pollution in two watersheds, differing greatly in hydrology, land use, and "watershed protection".

- A further demonstration of the applicability of the protocol with regard to frequency and location of sampling, reporting limits, and selection of analytes can be realized through *a posteriori* analysis of historical EDC/PPCP data sets from five major watersheds, thereby providing broader data set for statistical analysis without incurring the substantial costs of additional monitoring programs.

1.2 Research Approach

1.2.1 Overview of the Approach

Central to the development of any sampling design is a clear understanding of the utilities' objectives for conducting a sampling program. Although rarely articulated, sampling objectives are essential to help inform the spatial and temporal components of the design. While some utilities have only sampled EDCs/PPCPs at their intakes, others have engaged in broader watershed sampling campaigns. Reasons for sampling locations beyond the current intake include:

1. An interest in identifying major sources of EDCs/PPCPs that could impact the raw water
2. The desire for better information on which water sources or intakes should be used

3. The need to plan for possible future changes in the watershed (loadings, hydrology) that might result in long-term increases in EDC/PPCP concentrations
4. An interest in developing an early-warning system to prepare for short-term increases in EDC/PPCP concentrations.

The goal of this projecct is to develop a watershed-level protocol for addressing EDC/PPCP monitoring needs, utilizing a combination of statistical tools, GIS and spatial analysis, and analytical sampling of indicator and surrogate compounds. During the initial tasks outlined below the Project Team will develop a general protocol for designing a sampling campaign including QA/QC procedures suggested by the Water Research Foundation Project 4167 team, sampling objectives as expressed by the impacted water utilities, use of available land use data, use of historical data when available, and information about the hydrology of the watershed. Once the generalized protocol is developed, it will be applied to two distinctly different watersheds (the South Platte, CO and Merrimack River Basins, MA) and their associated water utilities during a one-year monitoring study as a proof of concept. Furthermore, to maximize the research efforts while minimizing costs, the Project Team will use publicly available historical data from at least five watersheds (Lake Mead/Colorado River; Croton and Cat/Del systems, NY; South Platte River, CO; Cape Fear River Basin, NC; and the Merrimack River, MA) and perform an *a posteriori* analysis of the data sets, applying the general protocols as possible in order to determine what impact, if any, sampling strategy may have on data interpretation (i.e., QA/QC cannot be modified *ex post facto*; sampling locations, sampling frequency, and reporting limits (to a limited extent) can be modified during meta-analysis). The protocols developed and validated during this study will assist drinking water utilities, individually or as a consortium, to utilize limited resources intelligently to address the issue of EDCs and PPCPs in a cost effective manner, setting up a network of sampling locations throughout a watershed to achieve maximum benefit of the sampling performed. To achieve the goals, the project is divided into five main tasks outlined below.

1. **Literature Review, Communication with Water Research Foundation Project # 4167 Team, Finalization of Detailed Quality Assurance Plan**

2. **Development of Watershed Monitoring Program Protocols:** The developed protocol will combine the use of GIS data, historical data, and spatial analysis to outline how to choose a reasonable list of surrogate and indicator compounds and “intelligent sampling locations” in a particular watershed to evaluate the impact of EDCs and PPCPs within that watershed.

    a. **Collect Available Geographic/Land Use and Historical Monitoring Data**

    b. **Define Data Features Useful for Determining Susceptibility of a Watershed to EDC/PPCP Contamination**

    c. **Define Data Features Useful for Determining Sampling Locations**

    d. **Define Selection Criteria for a Short List of Analytes to Include in Monitoring Program**

3. **Retrospective Analysis of Historical Data from Five Case Studies:** The Project Team will evaluate the protocol through an analysis of five case studies to be performed in watersheds carefully chosen to observe differences in hydrology, land use, development and "watershed protection".
4. **Implementation of Watershed EDC/PPCP Sampling Protocol:** Using the protocols developed in Task 2 and in conjunction with recommendations from the Foundation's 4167 Round Robin study, two watersheds from Task 3 will be monitored for one year as a demonstration of concept while also providing a benchmark data set from which future studies can be compared.
5. **Synthesis of Results and Preparation of Final Report and Guidelines/ Recommendations for Utilities**

1.2.2 Project Tasks

A detailed description of each of the proposed tasks is provided below:

Task 1: Literature Review, Communication with Water Research Foundation Project # 4167 Team, Finalization of Detailed Quality Assurance Plan

The initial phase of the project will include an expansion of the already extensive literature review performed by the Project Team and continued investigation into other sources of data regarding EDC/PPCP occurrence from sources such as USGS and the US EPA. We have and will continue to pay special attention to data that can help bridge the gap between spatial information on contaminant sources to surface water concentrations. For point sources, this includes information on EDCs/PPCPs in municipal and industrial effluent and others such as hospitals and landfills that may discharge directly to the environment or into municipal systems. For the non-point sources, this includes similar data on home septic systems, urban storm water, agricultural operations, CAFOs, etc. We are also looking to incorporate treatment removal efficiency, export factors, zones of influence, and attenuation factors that can further assist the spatial analysis work.

Another key component of this first task will be to establish a means of communication with the Water Research Foundation and Southern Nevada Water Authority so that any additional findings or recommendations from Project #4167 can be incorporated into the sampling protocols. The literature reviewed will be summarized for the final report and will be used to the development of the full set of protocols to be used for this study.

Task 2: Development of Watershed Monitoring Program Protocols.

Subtask 2-a: Collect Available Geographic/Land Use and Historical Monitoring Data

As stated in the RFP and verified through our preliminary literature review, a plethora of data currently exists regarding EDCs and PPCPs in many watersheds throughout the United States. Although many of these studies may be subject to site selection bias and limited numbers of samples in individual watersheds, as well as variability in analyte lists, analytical methodologies, and quality assurance procedures, the available datasets can be analyzed *a posteriori* and utilized to better inform future sampling and analysis strategies. The project team has already identified several sources of publicly available EDC/PPCP occurrence data at the watershed scale, including studies performed by USGS and individual utilities. In addition, GIS layers identifying land use and locations of potential point and non-point sources of EDCs and PPCPs are readily available for the public in most cases. Table 1 describes the minimum amount of EDC/PPCP data publicly available in all 5 of the watersheds to be examined, as well as an overview of the GIS layers which were easily accessed in a cursory search.

Table 1 Description of available preliminary data identified to date

Watershed	EDC/PPCP sampling Efforts	GIS Layers
Lake Mead Basin	EDCs, PPCPs, Others, Traditional WW markers, Conductivity, TOC; data from at least 2003 for Lake Mead, and Upper and Lower CO River	Land use, watershed boundary, water bodies, hospitals and health centers, soil, census
Cat-Del and/or Croton	NYC DEP and NY Department of Health studies examining EDCs and PPCPs in NYC reservoirs.	Land use and land cover, watershed boundary, soil, stormwater outfalls, ortho imagery, digital elevation model
Merrimack (MA)	USGS & MA DEP study, 1 year of data from multiple locations; additional data avaible from other sources	Land use and land cover, watersheds and drainage basins, soils, stormwater outfalls, USGS data collection station, stream-gaging station, public water supplies, hospitals and health centers, ortho imagery, digital elevation model, census
Cape Fear River Basin	USGS Study, 2 years of data, On-going data collection may be available	Land cover, hydrology, watersheds, water bodies, ortho and aerial images, elevation, census
South Platte	Many years of monitoring data by utiliites in the watershed (Aurora, Denver, Thornton, Boulder)	Land cover, water bodies, hospitals, census

Subtask 2-b: Define Data Features Useful for Determining Susceptibility of a Watershed to EDC/PPCP Contamination

A GIS protocol will be developed to identify EDC and PPCP sources in the watersheds using GIS layers outlining land use, point source outfalls such as WWTPs, hospitals, NPDES permit locations; and locations of drinking water treatment facility (WTP) intakes. Land use information provides spatial distribution of potential sources of EDCs and PPCPs that are discharged to surface waters and that may be specific to the watershed (e.g., veterinary antibiotics and/or growth promoters could be expected from confined animal feeding operation sites but not from industrial inputs). The information will be used to identify potential nonpoint sources such as runoff from agricultural areas, farm animal operations, industrial areas, and urban/suburban areas.

An integration of the available literature regarding sources of contaminants to watersheds and available GIS data will allow the Project Team to define the data features that may indicate potential for contamination of each watershed. Furthermore, this information will be used to develop a table of data features that a utility can reference during GIS analysis for determining potential hot spots and types of contaminants to monitor. Figure 2 shows an example of a preliminary GIS analysis for the Las Vegas Wash and Lake Mead Watersheds in Southern Nevada. The resulting GIS map explicitly shows potential sources such as land use and locations of hospitals, septic tanks and WWTPs in the watersheds and definitive conclusions can be drawn that the major contributors are point sources that are clustered in urban setting. The result of preliminary GIS analysis also shows a low percentage (less than 1%) of agricultural area in this watershed, excluding the need of monitoring agricultural chemicals in the water. Such preliminary results highlight the power of GIS modeling to find locations of concern and their spatial distribution, which can be used to prioritize hotspots in the watershed. Further analysis will require additional information such as whether or not the hospitals and industries in the watershed have their own wastewater treatment facilities, which will be critical point sources in addition to municipal WWTPs.

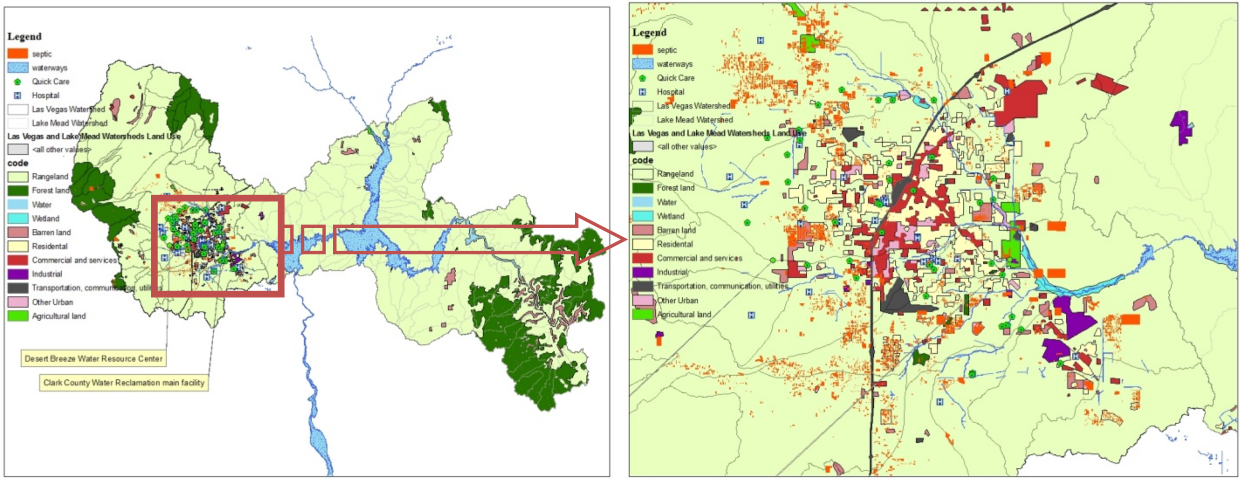


Figure 2 Potential sources of EDCs and PPCPs in Las Vegas and Lake Mead Watersheds

Subtask 2-c: Define Data Features Useful for Determining Sampling Locations

Implementing effective monitoring strategies requires developing a systematic approach for defining monitoring locations. From a drinking water utility's perspective, the water quality parameters which drive operational decisions and capital investments are those at the drinking water intake. While a spatially-diffuse watershed monitoring program provides interesting data, it may or may not provide the most useful information regarding EDCs/PPCPs and other contaminants at the intake. Furthermore, by targeting areas likely to have high concentrations of contaminants, the overall data set may be biased and not be indicative of water quality closer to the intake. Thus, a combined approach is necessary: Spatial analysis will be employed to select optimal monitoring locations for EDCs and PPCPs based on the sampling objectives. In most cases, the optimal monitoring locations will be a combination of points strategically positioned downgradient from known inputs to provide maximum spatial resolution of sources and concentration gradients. By combining approaches, the diurnal and seasonal fluctuations observed in other studies (e.g., Martinovic *et al*, 2008) may "normalize" or become muted during downstream transport due to the number of source inputs, the transformations that can occur, and removal to stationary phases (e.g., sediments). Furthermore, meta-analysis of the data will indicate the relative importance of sampling locations and whether that selection biases results away from actual concentrations observed at drinking water treatment plant intakes. Thus, the strategy provided here will be one that provides a protocol for defining sampling locations within a watershed but that focuses the meta-analysis of the data on the relationships in the watershed with those at the intake.

For selecting the optimal monitoring locations for EDCs and PPCPs, we propose two subtasks: 1) proximity analysis and hotspot analysis and 2) cost-effectiveness analysis.

First, the proximity of the sources to the surface waters and the intake of WTP will be examined using GIS models and spatial analysis. Those sources directly adjacent to surface waters are likely to have a greater impact whereas some nonpoint sources in remote areas can be attenuated by clay soils or vegetative buffer zones (Strobl, 2006). Also point sources especially wastewater outfalls located in close proximity to drinking water intakes will be of intense interest (van der Linden, 2008) and could be a potential "hot spot" in a watershed.

GIS spatial analysis provides different ways to evaluate proximity. Euclidean method is the simplest approach, although it might not be the most appropriate in this case. Instead, a flow path approach based on land use, slope, and soil type will be employed. This information can be combined with compound attenuation rates from the literature, based on the length of flow path and landscape characteristics. The information will be used to determine the relative importance of the identified sources which leads to the objective-dependent optimal monitoring points and frequency. The completion of this subtask will be a pre-requisite for the implementation of the watershed sampling campaign.

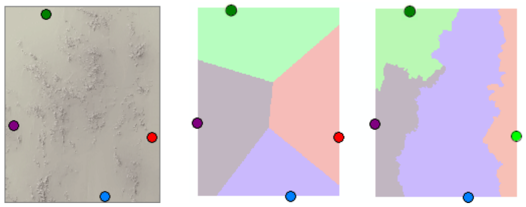
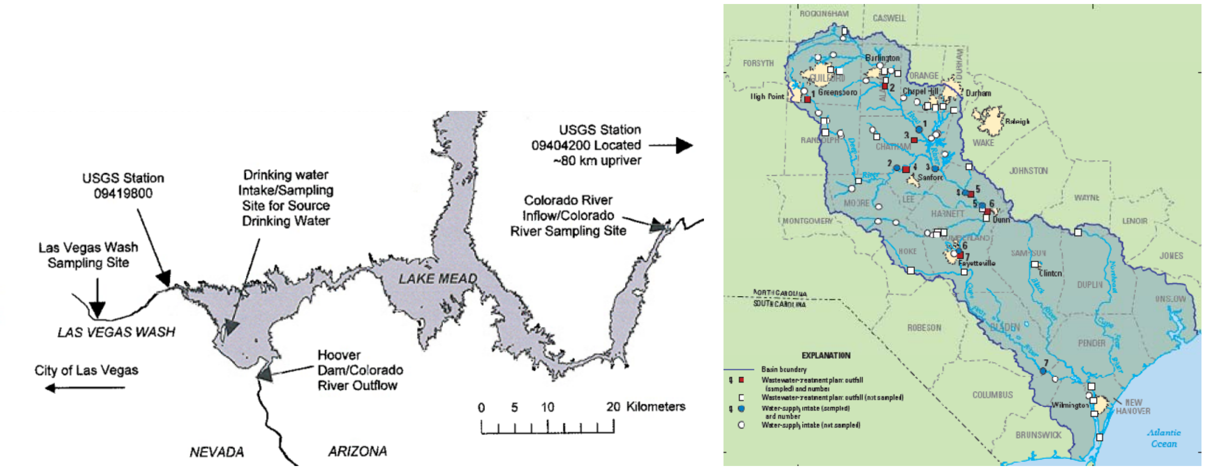

(a) (b) (c)

Figure 3 Examples of proximity analysis (a) a raster layer for distance calculation (b) Euclidean distance (c) Path distance (http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=709&pid=706&topicname=Proximity_analysis)

Second, these results will be used to examine the cost-effectiveness of monitoring locations and whether a more limited (and less expensive) approach to site selection would provide enough data to reach conclusions similar to those reached during an intensive monitoring campaign. While focusing monitoring on a limited number of hotspots could create a biased view of what actual DWTP influent concentrations will be, hot-spot monitoring might provide a view of "worse case scenarios" for which a utility may wish to prepare. On the other hand, limiting analysis to areas further downstream of hotspots and closer to intake structures may provide a more realistic representation of likely raw water quality. A meta-analysis of the data will therefore also include several exercises of "eliminating" sampling locations to determine what the impact, if any, there would have been on the data interpretation. Figure 4 shows an example of different types of waters and their monitoring locations. Our approach will assist in their decision making to select optimal monitoring locations at lower cost and for effective monitoring.



(a) (b)

Figure 4 Examples of monitoring sites, WWTPs and WTP intake in (a) Las Vegas Wash, NV (b) the Cape Fear River Basin, NC (Benotti, Stanford *et al.*, 2010; Ferrell, 2009)

Subtask 2-d Define Selection Criteria for a Short List of Analytes to Include in Monitoring Program

Protocol for determining baseline analytes: The selection of analytes for monitoring within a watershed must be a deliberate and well-designed process. There are thousands of potential contaminants that could end up in drinking water supplies, yet monitoring for each and every contaminant is costly, time consuming, beyond the means of most analytical laboratories, and of little use to regulators, operators, and the public. Thus, the need exists for a systematic process by which a utility (or group of utilities) can selectively monitor for contaminants which are relevant to their specific watershed, that have the potential to be found in finished drinking water, and are indicative of the types of inputs and the presence of other potential contaminants in the water. Furthermore, it would be naïve (and expensive) to assume that one list of target analytes could be developed and applied to all watersheds without regard to land use patterns, point source inputs, and non-point source inputs. As such, we will present a justification for a generalized analyte list that will then need to be adjusted on a per-watershed basis pending land use analysis by GIS. The finalized list for each watershed and expanded details of the selection process will be provided as one of the first deliverables of the research study.

Initially, a “menu” of possible analytes can be developed from several published reports regarding current monitoring requirements, occurrence and treatability of trace contaminants, and the selection of indicator and surrogate parameters (Drewes, J.E., *et al*, 2007; Snyder, S.A., *et al*, 2007; CDPH, 2008; Snyder, S., *et al*, 2008; Dickenson, E.R.V., *et al*, 2009). The analyte selection process has been described in detail in the two Snyder et al. reports (AwwaRF 2758 and AwwaRF 3085) and the Drewes et al. report (WRF-03-014), thus does not need to be “reinvented” for the sake of this study. However, relevant findings from the aforementioned reports can be used to further refine the proposed list.

Table 2 shows a summary of compounds found in finished drinking water from the AwwaRF 2758 and 3085 reports, their status with respect to the candidate contaminant lists (CCL), and the recommendations from 03-014 regarding potential tracers. The majority of compounds listed in Table 2 have the potential to be present in finished drinking water due to a lack of sufficient removal during drinking water treatment processes, thus represent a suite of potential analytes that could be considered of concern for a given watershed and drinking water utility. Furthermore, the Project Team would suggest that the list be limited, in most cases, to the compounds found in at least 20% of the drinking water samples since most of those compounds can serve as indicators of other sources of pollution. The Project Team also recommends including testosterone and 17β-estradiol as indicators of runoff from poultry, cattle, and swine farms (Finlay-Moore, *et al.*, 2000; Peterson, *et al.*, 2000; Hanselman, *et al.*, 2003). Several other indicators of runoff, agriculture, and industrial contaminant will also be considered from Table 2 including bisphenol-A, mecoprop, and linuron. If GIS land use analysis indicates significant industrial inputs, other contaminants could be considered on a case-by-case basis.

Table 2 Summary of drinking water detects for analytes in AwwaRF 2758 and 3085 and recommendations from WRF-03-014. ND = not detected/below reporting limit; N/A = not analyzed.

	AwwaRF 3085 Finished Water Frequency % Detection (n = 20)	AwwaRF 2758 Finished Water Frequency % Detection (n = 18)	Listed on CCL1, 2, or 3? Regulated?	Recommended Indicator? WRF-03-014
DEET	33	90	No	
Atrazine	83	75	Regulated	
Meprobamate	78	75	No	Yes
Dilantin	N/A	70	No	Yes
Ibuprofen	N/A	65	No	Yes
Iopromide	N/A	65	No	
Caffeine	N/A	60	No	
Phenytoin	56	N/A	No	
Carbamazepine	44	55	No	Yes
Atenolol	44	N/A	No	Yes
TCEP	39	35	No	Yes
Gemfibrozil	39	25	No	Yes
Metolachlor	33	20	CCL1, 2, 3	
TCPP (Fyrol PCF)	28	N/A	No	Yes
Sulfamethoxazole	22	5	No	Yes
Fluoxetine	11	ND	No	
Galaxolide	11	ND	No	
Linuron	11	ND	CCL1, 2	
Nonylphenol	11	N/A	No	
Progesterone	6	10	No	
Estrone	ND	10	CCL3	
Triclosan	6	5	No	Yes
Diazepam	6	ND	No	
BHT	6	N/A	No	
Bisphenol A	6	N/A	No	
Erythromycin	N/A	5	No	

Musk Ketone	N/A	5	No	
Naproxen	N/A	5	No	Yes
Oxybenzone	N/A	5	No	
Trimethoprim	N/A	5	No	Yes
Diclofenac	N/A	ND	No	Yes
Mecoprop	N/A	N/A	No	Yes
Salicylic Acid	N/A	N/A	No	Yes
TDCPP	N/A	N/A	No	Yes

While conducting EDC/PPCP sampling, the team will measure other water quality parameters relevant to drinking water utilities, to serve as surrogate parameters and tracers. These include total organic carbon (TOC), total nitrogen, total phosphorous, UV absorbance, hardness, and major anions, including ammonia, nitrate, nitrite, phosphate, sulfate and chloride. In addition, a set of tracers will be monitored. These are minor, yet highly stable (conservative) constituents that are present at disparate concentrations in different types of sources. The compounds proposed include boron, sucralose, and gadolinium. The first two are proposed as tracers of municipal and septic system effluents, the last one is an indicator of hospital wastes. Shifts in any of these parameters may serve to indicate a change in EDC/PPCP concentrations, and factor analysis will be performed to correlate surrogates and measured analytes to examine potential relationships. Also, the tracers will allow direct verification of the relative importance of residential wastewater and hospital wastes as determined by the spatial analysis.

Task 3: Retrospective Analysis of Historical Data from Five Case Studies

Using the tools outlined in Task 2, retrospective analysis of historical EDC/PPCP data and land use will be performed for five watersheds. As an outcome for this task, a set of recommendations for sampling locations, analytes, and reporting limits will be provided to partner utilities within the watershed, to assist in future planning of EDC/PPCP monitoring within their watershed. Deliverables to partnering case study utilities will include a report outlining these recommendations, including a discussion of the systematic processes undertaken by the project team for analysis of their data to arrive at the particular set of recommendations. Also included in the report will be a discussion of the potential of factor analysis for further reducing the number of analytes to a small set of "indicator compounds" specific to their watershed. Finally, guidance regarding risk associated with the detected levels of compounds in the watershed will be supplied by incorporating health-based reporting limits into the analysis. Descriptions of factor analysis and health-based reporting limits are included below.

Watershed Descriptions The five watersheds to be analyzed include the Lake Mead Basin and Colorado River serving partner utility Southern Nevada Water Authority (SNWA); the Croton and Cat/Del watersheds, serving partner utility New York City Department of Environmental Protection (NYC DEP); the South Platte River Basin, serving partner utilities Aurora CO, Boulder CO, Denver Water, and Thornton CO; the Merrimack watershed, overseen by partners Massachusetts Department of Environmental Protection (MADEP); and the Cape Fear River Basin. Each of the systems is described in detail below.

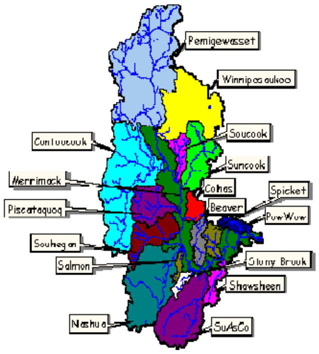
Case Study 1: *Lake Mead, Southern Nevada Water Authority* Lake Mead is arguably the most studied freshwater reservoir in the world. Extensive data sets are available that track spatial and temporal concentrations of organic and inorganic contaminants throughout the system. The extensive water quality monitoring reflects the importance of the resource. Nearly 30 million people rely on Lake Mead (or the Colorado River) for drinking water and/or agricultural use. Lake Mead is a sub-tropical, monomictic lake with approximately 97% of its inflow arriving from the Colorado River and 1.5% from the wastewater-dominated Las Vegas Wash. The city of Las Vegas, NV is unique in the Colorado River system in that it is the only major metropolitan area on the Colorado River, and as consequence, is the only major metropolitan area which returns treated wastewater to the system. The return of treated wastewater to Lake Mead is one of the largest water reuse practices in the US, and has contributed to a more sustainable use of this precious resource. At present, approximately 150,000 acre-feet of wastewater are returned to Lake Mead each year. However, any adverse effects on water quality associated with wastewater discharge potentially impact 30 million people and have direct implications for the potable water of Las Vegas and other cities downstream.

Case Study 2: *NYCDEP, NY* The Cat/Del and Croton systems are an enormous water source, serving approximately 9 million customers and providing 1.2 billion gallons per day to the greater NY city area. Water from four primary upstate watersheds is impounded in the Croton, Catskill and Delaware Systems which include 18 reservoirs and three controlled lakes, with a total available storage capacity of about 558 billion gallons. The three water systems were designed and built with various interconnections to increase flexibility by permitting exchange of water from one system to another. This feature helps to mitigate localized droughts and take advantage of excess water in any of the three systems. There is an extensive "watershed protection" program employed by NYCDEP, though several point source and non-point sources of contamination exist. Thus, NYCDEP is in the midst of an extensive EDC/PPCP monitoring campaign.

The Croton System normally provides approximately 10 to 12% of the City's daily water supply and can provide up to 25% during drought conditions. The Croton System consists of twelve reservoirs and three controlled lakes on the Croton River, its three branches and three other tributaries. The water flows from upstream reservoirs through natural streams to downstream reservoirs, terminating at the New Croton Reservoir. The watershed which supplies the Croton System has an area of 375 square miles. It lies almost entirely within New York State, centered approximately 45 miles north of lower Manhattan, with a small portion in the State of Connecticut. The watershed has been subjected to suburban-type development over the years and this has affected the quality of this water source. The water quality in the Croton system is generally quite good, however. It can be characterized as a low turbidity, moderately alkaline supply with low to moderate levels of natural organic matter. Although the water quality is relatively good, the NYCDEP entered into an enforceable Stipulation Agreement with the New York State Health Department (NYSDOH) to filter Croton water in order to comply with the Surface Water Treatment Rule. A 290 mgd dissolved air flotation/filtration/UV disinfection facility to treat Croton water is currently under construction.

The Catskill System watersheds occupy sparsely populated areas in the central and eastern portions of the Catskill Mountains and normally provide approximately 35% of the City's daily water supply. Water in the Catskill System comes from the watersheds of the Esopus and Schoharie Creeks, centered approximately 100 miles north of lower Manhattan and 35 miles west of Hudson River. Esopus Creek flows naturally into the Hudson River and a watershed area of 257 square miles is impounded by Ashokan Reservoir. Schoharie Creek drains into the Mohawk River and a watershed area of 314 square miles is impounded by Schoharie Reservoir. Most of the water from these two watersheds is stored in the Ashokan Reservoir and the balance in the Schoharie Reservoir. The Catskill system water is of excellent quality: very low in turbidity and natural organic matter, except during episodic storm events when the turbidity rises dramatically. However, the Catskill System was designed in a manner which allows for settling of the turbidity to occur as the water passes from the West Basin of Ashokan Reservoir to the East Basin of Ashokan Reservoir and into Kensico Reservoir. Alum is occasionally added to the Catskill water just prior to entering Kensico to aid the settling process during extreme storm events. For regulatory purposes, the Catskill System is combined with the Delaware System because both waters mix in the Kensico Reservoir north of New York City. The combined system is referred to as the Catskill/Delaware System.

Case Study 3: *South Platte River Basin* The South Platte River Basin has a drainage area of about 24,300 mi^2 (Dennehy, 1991). Originating in the mountains of central Colorado at the Continental Divide the river flows about 450 miles northeast across the Great Plains to its confluence with the North Platte River at North Platte, Nebraska. Altitude in the basin ranges from 14,286 ft at Mt. Lincoln on the Continental Divide to 2,750 ft. at the confluence of the South Platte and North Platte Rivers. The basin has a continental-type climate modified by topography, in which there are large temperature ranges and irregular seasonal and annual precipitation. Areas along the Continental Divide average 30 inches or more of precipitation annually, which includes snowfall in excess of 300 in. In contrast, the annual precipitation on the plains east of Denver, CO, and in the South Park area in the southwest part of the basin, ranges from 7 to 15 inches. The South Platte River Basin contains about 2.8 million people, over 95 percent of who live in Colorado. The basin contains the most concentrated population density in the Rocky Mountain region, located along the Front Range urban corridor in Colorado where the mountains meet the plains. Land use and land cover in the South Platte River Basin is divided into: 41% rangeland, 37% agricultural land, 16% forest land, 3% urban or built-up land, and 3% other land (Feagas *et al.*, 1983).



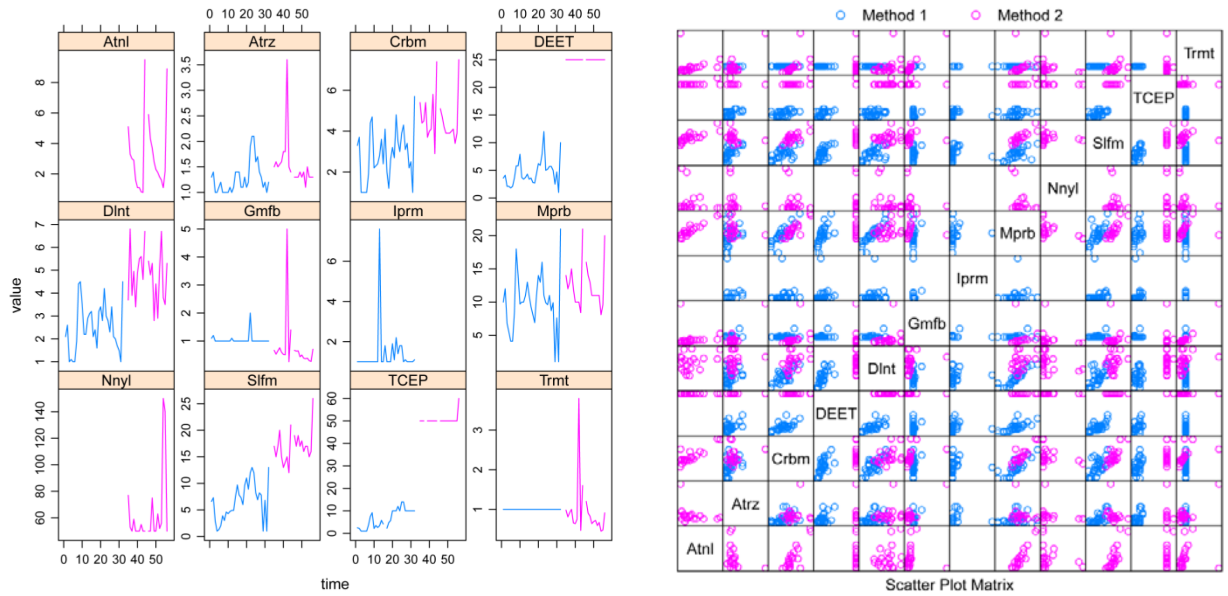
Case Study 4: *Merrimack Watershed, MA* The Merrimack River Watershed encompasses 5010 square miles within the states of New Hampshire and Massachusetts. It is the fourth largest watershed in New England. The Merrimack River is formed by the confluence of two major rivers, the Pemigewasset and Winnipesaukee, in Franklin, NH, and flows for 115 miles to the Atlantic Ocean. The watershed includes all or parts of approximately 200 communities with a total population of two million people. Elevations in the watershed range from sea level at the coast to about 300 feet at some of the inland hills. 78.8% of the Merrimack River watershed is comprised of the Forest/Rural open land use. In total, urban areas, including medium density residential, commercial, industrial, and urban open land use categories, combine for approximately 10.3% of the total watershed area. However, the major urban centers, such as the five sponsor communities, are more closely centered around the Merrimack River mainstem, which increases the potential pollutant impacts from these urbanized areas. The river receives an annual average of 43 inches of precipitation with the northern areas averaging slightly more (46 inches) and the southern areas slightly less (41 inches). Although precipitation is evenly distributed throughout the year, the water in snowfall is stored through the winter months for release during spring thaw.

Case Study 5: *Cape Fear Watershed, NC* The Cape Fear River basin is the largest river basin in North Carolina and is heavily urbanized in its headwaters where the cities of High Point, Greensboro, Burlington, Durham, and Raleigh are located. The Cape Fear River originates in the Piedmont Physiographic Province and flows through the Coastal Plain, ultimately terminating at the Atlantic Ocean. Characteristics of the river change along this route, with a general decrease in velocity and increases in depth and dissolved organic carbon concentration (Ferrell, 2009). Over 21% of the entire state's population resides in the Cape Fear River basin. About 35% of the streams in the Cape Fear River Basin are considered threatened and 18% are impaired by pollution. Land uses in the Cape Fear drainage area are quite diverse. In addition to the large urban populations that reside in such cities and towns as Wilmington and Greensboro, the basin includes one of the most concentrated turkey and hog production regions in the country. Two counties in the basin, Duplin and Sampson, produce more hogs than any other counties in the US. The Cape Fear River Basin experiences an average rainfall of 44 – 62 inches, and is particularly susceptible to hurricanes and tropical storms, which have caused flooding in all parts of the State (Zembruzski and others, 1991).

The Use of Factor Analysis for Identifying "Indicator" Compounds: Factor analysis is often applied when the goal is either to determine whether there is a common, underlying factor, or to display that factor so it can be interpreted. Here, our purpose is different. We want to characterize the extent to which compounds share a common factor so that we can use just a few of the compounds, or surrogate water quality parameters, as indicative of the others, and assess how accurately these indicators and surrogates represent EDC/PPCP concentrations. However, one must also bear in mind that relationships among the compounds can change over time.

Modern techniques such as dynamic and evolutionary factor analysis allow one to detect whether the factors, or the relationships between the factors and individual compounds, are changing. For example, Figure 5 shows twelve EDC and PPCP compounds from the Benotti, Stanford, and Snyder (2010) data set, selected because they had sufficient measurements above reporting limits and across analytical methods. Figure 5 (a) shows the measurements of each compound plotted as a time series. The x-axis is time (months) from 2003 through 2008. The method of chemical analysis changed at the end of 2005. The two methods are indicated by blue (old) and pink (new) data points. Figure 5 (a) has two points of interest. First, compounds such as Carbamazepine and Dilantin seem to have an increasing trend. But closer inspection reveals that the levels of those compounds are roughly stable for each analytic method, so the apparent trend might be due just to the change in method. Second, compounds such as Atenolol, Carbamazepine, and Meprobamate, seem to have a strong annual cycle, which peaks in winter. Sulfamethoxazole has a similar cycle, superimposed on an increasing trend. When several compounds have time-series that run roughly in parallel, it is often useful to model them through factor analysis. Such a statistical analysis, if it fits the data well, would suggest that not all compounds have to be monitored intensively; a small number of compounds or parameters would suffice for tracking the common factor. The other compounds could be monitored less frequently to see whether they still follow the common factor.

Figure 5 (b) is a scatterplot matrix that shows the values of each compound plotted against those of every other compound. Pink and blue again indicate the two analytic methods. When points are below detection limit, they are plotted at the detection limit. Figure 5 (b) shows clear relationships among several of the compounds, especially those that seem to share the common annual cycle seen in Figure 5 (a). Thus, Figure 5 (b) provides further evidence that one of those compounds can serve as a good indicator for the underlying common cycle. In particular, they do not all need to be monitored intensively. Factor analysis will also be employed to examine relationships between surrogate parameters as described in Task 2.d, and EDC/PPCP concentrations, to examine if changes in these parameters, which are cheaper and more regularly analyzed, can be indicative of changes in EDC/PPCP concentration.



(a) (b)

Figure 5 Preliminary statistical analysis results (a) Time series of selected EDCs and PPCPs (b) Correlations among different EDC and PPCP compounds

Guidance Regarding Risk: Incorporating Health Reporting Limits in Meta Analysis: In an effort to provide additional guidance regarding risk and data interpretation, several studies have recently been completed both in the US and abroad which examine the issue of *relevance* with respect to trace contaminant occurrence in drinking water (EPHC, NHMRC *et al*., 2008; Middleton, *et al*,. 2008; Snyder *et al*,. 2008; Snyder, Stanford *et al*., 2010). While the approaches have varied, each of the studies has included a component of human health-based risk guidelines for evaluating the presence of trace contaminants in drinking water. The terms have varied from "comparison values" (indicating only a cursory toxicological evaluation) to "drinking water effect levels" (DWELs) and "drinking water guidelines" (DWGs, indicating the completion of a full risk assessment) but the intent has been the same: the guidance value calculated from various sources/methods represents a threshold below which the risk to public health and the risk of observing any effect is expected to be minimal. Furthermore, observed concentrations of EDCs and PPCPs in drinking water have typically been several orders of magnitude less than the derived guideline values (Benotti *et al*., 2009; Snyder, *et al*,., 2008; Snyder, *et al*., 2007a), thus simply observing contaminants at parts per trillion concentrations and below does not imply risk by itself. Similarly, not observing a compound does not imply a lack of risk, though it is often interpreted as such (case in point, EWG 2009).

As an example of how health-based guideline values might be incorporated in a meta-analysis (and interpretation) of data, some recently-published data will be used as an example (Benotti, Stanford *et al*., 2010): In the published manuscript, data from 2003 to 2007 were presented that showed the impact of declining reservoir volume due to drought and climate change on the concentration of trace contaminants. The method reporting limits (MRLs) were typically 1 ng/L or less, depending on the method (methods changed during the study). Of the more than 60 compounds tracked during the monitoring, only a select few were detected across both analytical methods employed, thus only those compounds were reported (Table 3). If one considers the DWGs presented in the Australian Guidelines document (EPHC *et al.,* 2008) and the "comparison values" presented in the WateReuse Foundation report (WRF-05-005, Snyder, Stanford, *et al.,* 2010), then divide each of those by a factor of 100, a health-based reporting limit (HRL) can be derived (Table 3). By applying the lower (more conservative) HRL to the original data set such that any compounds detected at <HRL are not reported, an *a posteriori* analysis of the data and trends is possible (Figure 6). Based on a brief analysis of this data set, three observations are immediately apparent: First, the only compound left after applying the HRL is carbamazepine, a compound that has been suggested elsewhere as an appropriate indicator of wastewater influence (Drewes *et al*., 2007). Second, that *single* compound was able to exhibit the same overall trend as the sum of all contaminants used for the study. Third, only one compound was present at levels that would trigger further toxicological studies. The Project Team believes this is a critical observation that can be further explored during a meta-analysis of the five historical data sets and the two data sets that will be collected for this Project during Task 4.

Table 3 Method Reporting Limits and Health Reporting Limits (HRL) from Drinking Water Guidelines (DWG); HRL = DWG/100

	Method Reporting Limit (ng/L)	Australian DWG (ng/L)	DWG/100 (ng/L)	Snyder *et al.* Comparison Value (ng/L)	Snyder, *et al.* Comparison Value/100 (ng/L)
Atrazine	**1**	40000	**400**	3500	**35**
Carbamazepine	**1**	100000	**1000**	74	**0.74**
DEET	**1**	2500000	**25000**	n/a	**n/a**
Diazepam	**1**	2500	**25**	74	**0.74**
Diclofenac	**1**	2000	**20**	1600	**16**
Dilantin	**1**	n/a	**n/a**	n/a	**n/a**
Estradiol	**1**	175	**1.75**	0.91	**0.0091**
Estrone	**1**	30	**0.3**	0.2	**0.002**
Ethynylestradiol	**1**	1.5	**0.015**	0.34	**0.0034**
Fluoxetine	**1**	10000	**100**	3400	**34**
Gemfibrozil	**1**	600000	**6000**	11000	**110**
Meprobamate	**1**	45500	**455**	80000	**800**
Naproxen	**1**	220000	**2200**	45500	**455**
Progesterone	**1**	105000	**1050**	n/a	**n/a**
Sulfamethoxazole	**1**	35000	**350**	150000	**1500**
Testosterone	**1**	7000	**70**	n/a	**n/a**
Trimethoprim	**1**	70000	**700**	94500	**945**

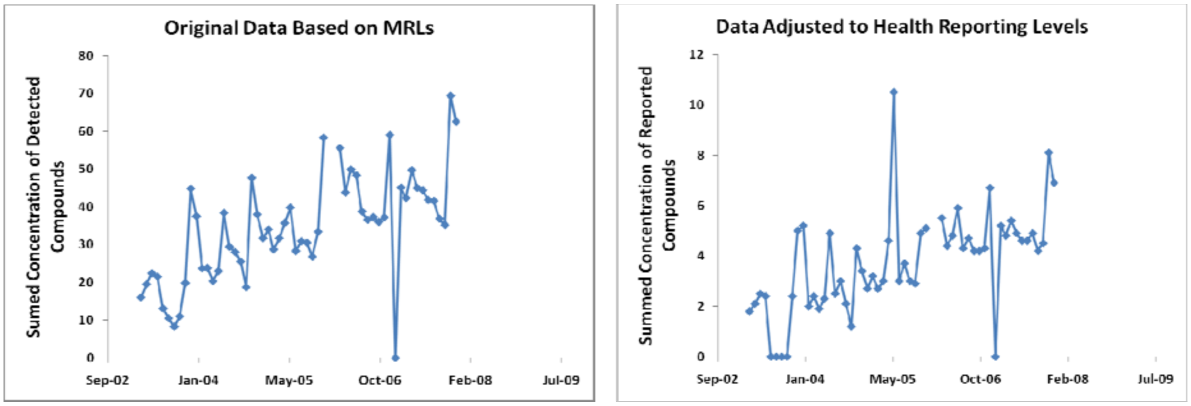


Figure 6 Original Data (Left) with Reported MRLs and Data Adjusted to HRLs (Right) from Table 1

Task 4: Implementation of Watershed EDC/PPCP Sampling Protocol

Using the protocols developed in Task 2 and in conjunction with recommendations from the Foundation’s 4167 Round Robin study, two watersheds will be monitored for one year as a demonstration of concept while also providing a benchmark data set from which future studies can be compared. For each watershed, the Project Team will use the results of Task 2 and 3 to identify a short list of indicator compounds and a few tracers which can be monitored regularly and can be used to give an indication of the magnitude and general source of contamination (i.e., agricultural, municipal, urban, industrial), and surrogate parameters to indicate a disruption in “normal” watershed activity which may justify further investigation. In addition, a subset of the newly collected samples will be subject to a broad-spectrum screening analysis for over 300 EDCs/PPCPs (Thurman lab; LC-TOF/MS method). For at least two watersheds, our monitoring data will be supplemented with data from sampling efforts which are already ongoing, funded by outside entities that have agreed to participate in our study, providing data from their efforts as “in-kind” contributions (see letters of support). This data will allow us the ability to compare directly our protocol recommendations with other sampling programs, providing a unique opportunity for the direct evaluation of the positive and negative aspects of the sampling protocol. Descriptions of analytical instrumentation, analytical methods, and sample handling and collection protocols to be utilized with this study are herein described. A detailed discussion of QA/QC procedures is provided in the QA/QC section of the document.

Sampling strategies need to consider the significance of temporal variability in EDC/PPCP concentrations (seasonal, weekly, daily, or even diurnal) and impacts of changing hydrologic conditions (drought, high flows, tides, stormwater contributions, etc). Monitoring results and associated risk management decisions may be strongly affected by such factors, which may be site specific. We anticipate collecting and analyzing 500 samples for EDCs/PPCPs over the 1-year monitoring period. About 250 samples would be collected from each of the two sites, with 20 samples every month on average from each. These include field replicates intended to clarify spatial-temporal variability from analytical uncertainty. Also among this group will be samples from major point sources such as wastewater treatment plant effluents. Attempts will be made to capture at least one major rain event such as a seasonal first flush. Details of the sampling design will be established with input from the PAC following analysis in Task 3.

Analytical instruments: The analytical equipment used at UMass for PPCP/EDC analysis was purchased by the Environmental Engineering group and is a collection of dedicated instruments under sole control of the PIs. Most PPCP/EDC work at UMass is done with a Waters Acquity UPLC coupled to a Waters Micromass Quattro Premier triple quadrupole mass spectrometer. The latter was acquired new in the summer of 2009. An integrated instrument (AquAnalysis) incorporating automated on-line SPE-LC/MS/MS has also been used for PPCP/EDC analysis at UMass. However, most front-end work on these compounds has been done with a more conventional off-line vacuum manifold SPE system. In late 2009, UMass acquired an FMS PowerPrep automated SPE instrument, an instrument which has provided much of the reproducibility described in other studies (Vanderford and Snyder, 2006; Trenholm *et al.*, 2006, 2008) We also have several new GC/MS systems that can be used for those compound most amenable to GC. These systems include a Varian 2200 ion trap GC/MS and a Waters Micromass time-of-flight GCT.

Analytical methods: The current UMass method for PPCP/EDC analysis is a hybrid of several published methods that are well regarded by experts in the field. No single published method could be used without some modification, due to differences in target analytes and instrumentation. First, the basis for the extraction and isolation protocol is EPA method 1694. Elements of Vanderford and Snyder's (2006) isotope dilution method were incorporated to help strengthen the method. Finally portions of Kasprzyk-Hordern *et al.,* (2008) were used for specifics of the UPLC solvent programs and MS instrument parameters. Final refinement regarding UPLC separation and MS settings (e.g., voltages, gas flows, temperatures) are performed through optimization with the UMass analytical equipment and using the actual analytes of interest. We have frequently used multiple LC/MS runs with the acid extract ESI+ compounds in an effort to maximize dwell time and S/N. We also use matrix-dependent higher SPE concentration factors as employed by Vanderford and Snyder (2006) and Trenholm *et al.* (2006, 2008).

Sample handling and collection protocols: Sample handling protocols generally follow those of EPA 1694 and include recommendations from the Water Research Foundation's Project 4167 (Round Robin). Amber borosilicate glass bottles are used for sample collection and storage. Ascorbic acid is used as a quenching agent instead of thiosulfate. Sodium azide at 1 g/L is used as a preservative and aqueous samples are held at 4 °C. Travel blanks and laboratory grade water blanks are included in each set of analyses. Preserved samples are extracted within 48 hours of receipt when possible, though hold times of up to 28 days may be acceptable based on the preliminary 4167 findings.

QA/QC procedures: Data quality objectives (DQOs) are in accordance with those listed in EPA 1694. Our QA/QC protocols are designed to meet the DQOs, and they follow those proscribed in EPA method 1694 with the following additions and clarifications. We normally follow two sets of parent-daughter transitions for each analyte instead of just one. This allows for separate calibration and quantification on both transitions. One is used as a primary upon which quantitation is normally based. The second is a confirmation for QC purposes.

The UMass laboratory uses an ultraperformance LC (Acquity UPLC) that makes use of smaller column packing providing higher chromatographic resolution than conventional HPLC. A complete set of aqueous standards (typically 5 concentration levels) are analyzed with each sample set. These are prepared entirely with water as a solvent, and span the range of concentrations of interest. Analyte and isotopic standard recovery are continuously monitored. Quantitation is performed with labeled versions of the analytes in almost all cases. When labeled compounds (or near analogs) cannot be obtained we use a labeled internal standard of the closest chemical properties as possible to the analyte. Matrix spike/recovery and laboratory grade water spike/recovery tests will be performed at regular intervals throughout the study to monitor the reproducibility of extraction and analytical methods.

Any future recommendations or findings from the Foundation's 4167 study will be incorporated into the study based on planned communication from the Foundation's Project Manager(s). Furthermore, the Project Team has partnered with the Center for Environmental Mass Spectrometry at the University of Colorado at Boulder (see Thurman letter) from the 4167 study to run occasional split samples and to analyze for additional compounds should the need arise based on land use analysis.

Protocols concerning the handling of non-detects will be established during task 4. The project team will consider at least four options: (a) use of 50% of the detection limit, (b) use of zero concentration, (c) multiple imputation, and (d) likelihood-based inference.

Task 5: Synthesis of Results and Preparation of Final Report and Guidance Document for Utilities

The conclusions from this project will provide the water industry with greatly needed information regarding a benchmark data set for watershed EDC/PPCP monitoring and a set of strategies for monitoring/benchmarking EDC/PPCP in their own watersheds. This task provides the Project Team with the time needed to complete the Draft Final Report and to include finalization of all deliverables.

The form for a utility guidance document will be established with input from the PAC and participating utilities. One possibility would be to present the guidance in the form of a process flow diagram to assist water utilities in getting an overall hand around the issue. The literature review should summarize what is known about EDC/PPCPs occurrence as well as why different investigators are finding some of the same compounds, but also different compounds (e.g., because they utilize different analytical methods). The report might also identify what are the significant inputs of EDCs/PPCPs from point sources, and from different land-use components, as best as can be determined from the literature and this (#4260) study. Another question to address is the significance of seasonality, The report could highlight "how to assess your WWTP" regarding inputs from pharmaceutical sources as well as based on different treatment technologies and different inputs. The report might also describe the various approaches used to estimate loadings from point and non-point sources based on discharge permits, land use, demographics etc. (e.g., with or without GIS), and the various sampling strategies that are used to estimate inputs (say for TMDL development). We believe that water utilities will be very interested in the performance of Method 1694 and 1698, and what analytes can be/not be detected. We also think that the conclusion is that there are multiple ways to design a sampling program, depending on the questions being asked.

1.3 Evaluation Criteria

An important aspect of this project in particular is the ability to evaluate the performance of the suggested protocol in a number of arenas. As outlined in the RFP, the applicability of these tools and protocols must be demonstrated "by designing and executing a sampling program on a minimum of two watersheds (for comparison)." As described in tasks 3 and 4, the project team is proposing preparation of the protocol for 5 case study utilities, and further performing and evaluating the protocol suggested sampling program for 2 of these studies. As in-kind support to the project, utilities within the watershed are donating data from sampling efforts which will be conducted in parallel to our sampling efforts, providing a unique opportunity for the direct evaluation of the positive and negative aspects of the sampling protocol. These case studies present an opportunity for evaluation for the suggested protocol, and will be analyzed using the following criteria:

1) Robustness of QA/QC methods and tools
2) Examine data veracity
3) Validity of recommended indicator compounds
4) Usefulness of Health-based Reporting Limits
5) Validity of suggested sampling location recommendations
6) Validity of suggested sampling frequency recommendations
7) Cost analysis of suggested protocol versus more conventional sampling effort.
8) Success in disseminating information to WateRF member utilities.

Robustness of QA/QC methods and tools. As a detailed quality assurance plan for the project is required as the first deliverable for this project, we have taken great care in identifying the QA/QC methods we will utilize for this project. However, the case studies present an opportunity to evaluate these methods, and incorporate any changes to the initial document which will lead to better QA/QC methodology in future studies. The project team will compare the QA/QC methods utilized in our study with those associated with the "in-kind" data as checks on the UMass QA/QC procedures, recognizing there will be inherent differences in analytical procedures and accounting for these differences in the analysis. The project team will also consider adding any future recommendations or findings from the Foundation's 4167 into the study based on planned communication from the Foundation's Project Manager(s) and through a partnership with the Center for Environmental Mass Spectrometry at the University of Colorado at Boulder from the 4167 study to run occasional split samples.

Examine data veracity. According to the RFP, the final report is to "examine data veracity, i.e., do the concentrations of materials make sense based on use patterns and point/nonpoint discharge concentrations". Our proposed methodology explicitly determines land-use patterns and point/nonpoint discharges, and as such provides an excellent opportunity to perform data veracity in a very quantitative manner.

Applicability of recommended indicator compounds Samples collected during the sampling portion of the project will be compared with "in-kind" data to evaluate the set of "indicator compounds" recommended by the project team resulting from the meta-analysis performed on previous data and the land-use evaluation. Factor analysis of the data can be utilized as outlined in Subtask 2.d to assess how accurately these indicators and surrogates represent EDC/PPCP concentrations.

Usefulness of Health-based Reporting Limits Similar to the examination of the applicability of the selected indicator compounds, a meta-analysis of the data will be used to examine the impact of reporting limits. Method reporting limits (MRLs) will be used throughout the study in accordance with standard practices but will be compared with the HRLs described in Task 3. By applying HRLs retrospectively, one will be able to determine what impact, if any, reporting limits may have on data interpretation. Furthermore, this analysis will point towards which compounds, if any, are present at *individual* concentrations at or above levels which may warrant additional toxicological/health risk assessment evaluation. This is an important point to consider due to the high costs associated with extremely low level monitoring of many analytes and due to the need to provide guidance to utilities about possible interpretations of the collected data.

Validity of suggested sampling location recommendations. As discussed in subtask 2.c, land-use analysis will be utilized to determine potential sampling locations, other than water utility intakes, which will be of use for determining impact of EDCs and PPCPs on a watershed. In addition,

Validity of suggested sampling frequency recommendations. Sampling will be performed by the project team at the utility water intakes on a monthly basis for the duration of the study period and rainfall event such as seasonal first flush. Utility provided data will be collected on the same schedule. However, meta-analysis of historical data will have yielded a sampling frequency, which may be less rigorous. The project team will analyze the data based on the recommendations to determine if the suggested sampling regiment will be sufficient for indicating general trends and worst-case concentrations of EDCs and PPCPs.

Cost analysis of suggested protocol versus conventional sampling effort. As one of the objectives outlined in the RFP is to maximize the useful information collected while minimizing strains on utilities resources, we anticipate that our protocol will suggest a minimum number of sampling locations which can be utilized to address watershed-wide EDC/PPCP concerns. To evaluate this criterion, a cost-analysis will be performed comparing the protocol suggested sampling effort with a conventional sampling effort, most likely that performed in conjunction with the "in-kind" data provided by utility partners. Variables such as numbers of sampling locations, frequency of sampling, and analytes will be evaluated within the constraints of maximizing information and minimizing cost of a yearlong sample effort.

Success in disseminating information to WateRF member utilities. The project team will utilize methods outlined in the draft project communication plan to disseminate this information to WateRF member utilities and AWWA member utilities in an effort to maximize impact of the study. Success in this criterion will result in widespread adoption of our proposed methodology to create a nation-wide network of utilities evaluating the impact of EDCs and PPCPs in their watersheds in a manner amenable to “generating datasets that are better characterized with respect to reliability and more amenable to future holistic analysis.

1.4 Technical Advisory Group

In an effort to integrate a broader spectrum of experience with EDCs/PPCPs, we have secured the informal assistance from the following 8 professionals. This group has ongoing work and special experience in this area and has promised to provide technical review services on the project.

1) Bill Becker, Hazen and Sawyer
2) Mark Bishop, Hazen and Sawyer
3) Beverly Stinson, AECOM
4) Jim Chaffee, AECOM
5) Ken Wagner, AECOM
6) Sam Perry, Washington State Department of Health
7) Steve Via, American Water Works Association
8) Eric Dickenson, Colorado School of Mines

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2.0 APPLICATIONS POTENTIAL

Utilities around the country are asking how they can most effectively monitor their raw waters and watersheds for EDCs and PPCPs. Given the laborious and sophisticated analysis required, the ever expanding analyte lists and the diffuse nature of their sources, the cost of this endeavor can quickly expand beyond reason. The proposed project will provide information that can help utilities make decisions on how to best use their resources to assess EDCs and PPCPs in their watersheds and raw waters.

To this end, the project team has recognized that there are ostensibly two main types of surface water source types: an isolated reservoir system serving a single large utility; and a "river" based reservoir system serving multiple drinking water utilities. Because of differences in ability to protect the systems, and the nature of the utilities drawing from the sources, each source type will be addressed applying a similar protocol with slight variations.

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

- A deeper understanding of the spatial, temporal distribution of EDCs and PPCPs in watersheds
- A detailed assessement of the differences in EDC/PPCP concentrations and distributions from five contrasting watersheds across the US
- Refined methodologies on the use of GIS data to assess likely EDC/PPCP concentrations
- Practical experience and data on the usefulness of some wastewater and runoff tracers in assessing EDC/PPCP sources and concentrations
- Insight into the interdependence of these parameters to aid with identification of sources for possible future source control
- A more complete understanding of EDC/PPCP behavior in natural systems

The principal products of the project will be monitoring tools with practical benefits to the water community. This information will be dissemminated through conference presentations, refereed publications, project reports, and a project website. Specifically, the products include:

- A short EDC/PPCP analyte list that includes compounds that reflect the complete body of EDC/PPCP compound of interest
- A set of EDC/PPCP monitoring protocols that include guidance on locations, sampling frequency, analyte selection, timing, and companion WQ parameters
- Guidance on use of tracers for helping to assess EDC/PPCP occurrence and sources
- Preliminary guidance on how to locate or characterize sources of EDCs and PPCPs in watersheds

For better implementation of the results of this work, we recommend that one or more workshops be held with utility managers to explain the protocols developed. These would allow for utilities who have not been directly involved in this research project to work with the experts in helping to apply the project results to their specific systems and needs.

3.0 QUALITY ASSURANCE / QUALITY CONTROL

In this section we list general QA/QC protocols used in the University of Massachusetts laboratories that will be participating in this research. Specific protocols or lab SOPs exist for each analyte or groups of analytes. Some of these specific features will be discussed below. For more information, the lead PI (Reckhow) may be contacted for a copy of the full laboratory SOP on any particular analyte or group of analytes.

Sampling Methods

Water samples will be collected according to the *Standard Methods for the Examination of Water and Wastewater* (APHA, 2000) wherever applicable. Details of sample analysis for conventional analytes are provided in Table 4. All samples collected in the laboratory and field will be labeled clearly and legibly with the following information:

- Parameter
- Preservative agent
- Laboratory analyzing sample
- Date / time of sample collection
- Facility or watershed where sample was collected
- Sample location within facility or watershed
- Sample number
- Replicate

Sample handling will utilize chain-of-custody forms to track sample handling. This will ensure that acceptable holding times are not exceeded, and allow reporting of sample conditions upon reception. The chain-of-custody forms will be filled out during sample collection, a copy of the chain-of-custody form will be filed with records on site, and the original chain-of-custody form will accompany the samples during transportation. Upon sample reception at the designated laboratory, the integrity of the sample containers will be assessed, the chain-of-custody forms will be completed, and the samples will be stored at 4 ºC in darkness or processed immediately. No chain-of-custody forms will be required for analyses conducted onsite.

QA/QC Procedure

For each batch of samples processed, the following steps are generally undertaken as part of Quality Assurance/Quality Control procedures and to assure defensibility of analytical results:

(a) Recovery of known additions:

The recovery of known additions will be part of regular analytical protocol. This will be used to assess matrix effects or the amount of interference. Note that isotope dilution methods are used to correct for matrix effects in the analysis of EDCs and PPCPs. The sum of duplicates and known additions will constitute at least 20% of the sample totals. The known addition will be between 1 and 10 times the ambient level. The procedure would not be used above the demonstrated linear range of the method. As part of this method, concentrated solutions will be used so that volume change in sample is negligible.

(b) Analysis of duplicates and split samples:

Duplicate samples will be processed on a routine basis. A duplicate sample is a sample that will be processed exactly as the original sample, including preparation and analysis. The duplicate samples will be used to determine precision. The sum of duplicates and known additions will constitute at least 20% of the number of samples. Approximately 10% of the samples will be split and shared between the UMass and Thurman labs for parallel analysis

(c) Analysis of reagent blanks and field blanks:

Reagent blanks will be analyzed whenever new reagents will be used or 5% of the sample load, whichever is greater. This will monitor purity of reagents and the overall procedural blank. A reagent blank will be run after any sample with a concentration greater than that of the highest standard or that might result in carryover from one sample to the next. Field blanks will accompany all field sampling campaigns. These typically constitute about 10% of the total number of field samples.

Table 4 Analysis – Container, Preservatives, Replicate Frequencies and Holding Times

Parameter	Collection Container	Preservative	Replicate Frequency	Maximum Sample Holding Time
PPCPs, EDCs, and organic tracer compounds	2-L amber borosilicate bottles with teflon lined screw caps	Sodium Azide, and Ascorbic acid if there is a disinfectant residual	1/10 samples analyzed in duplicate	Store at 4^0C, analyze within 2 days
Gadolinium and Boron	500-mL polyethylene	HNO_3	1/10 samples analyzed in duplicate	Store at 4^0C, analyze within 2 days
pH	Not Applicable	None	Single	Store at 4^0C, analyze within 1 day
Temperature	Not Applicable	None	Single	Analyzed immediately onsite
Turbidity	500-mL polyethylene bottle	None	Single	Store at 4^0C, analyze within 1 day
TOC and Total Nitrogen	125-mL borosilicate glass container	None	samples analyzed in duplicate	Store at 4^0C, start analyze within 1

				day
DOC	125-mL borosilicate glass container	None	One sample analyzed in triplicate	Store at 4^{0}C, start analyze within 1 day
Hardness	125 mL polyethylene bottle	None	1/10 samples analyzed in duplicate	Store at 4^{0}C, analyze within 14 days
Major Anions	125 mL polyethylene bottle	None	1/10 samples analyzed in duplicate	Store at 4^{0}C, analyze within 14 days

(d) Analysis of externally supplied standards:

As a minimum, externally supplied standards will be analyzed whenever analysis of known additions will not result in acceptable recovery, or once each analysis-day, whichever is greater. All attempts will be made to analyze laboratory control standards near sample ambient levels.

(e) Calibration with standards:

As a minimum, three different dilutions of the standard would be measured when an analysis is initiated (note: our practice is to use 8 for PPCP/EDC analysis). The standard curve would be verified each analysis-day by analyzing one or more standards within the linear range. Reportable analytical results would be those within the range of the standard dilutions used. Values above the highest standard would not be reported unless an initial demonstration of greater linear range has been made and the value is less than 1.5 times the highest standard. If a blank is subtracted, the result will be reported even if it turns out to be negative.

General sample collection and handling will be in accordance with the guidelines of Section 1060 of Standard Methods (APHA et al., 1995). Reagent grade chemicals or higher quality when needed will be used throughout the research. Milli-Q treatment of building RO water (purified by reverse osmosis, deionization, and carbon adsorption) will be used for preparation of reagents, sample blanks, and dilution water. Glassware used in the analyses will be thoroughly cleaned with a chromium-free sequence of detergent, oxidant and acid to prevent interferences from trace organics.

Analytical Procedures

Standard method protocols will be used to measure pH, conductivity, turbidity, alkalinity [APHA et al. 2006], TOC and AOC. Our methods for PPCP/EDCs generally follow those in EPA Method 1694 (see description below for more information on this) pH will be measured using a bench top Thermo-Orion pH meter. Turbidity will be measured using a bench top Hach Ratio turbidimeter. Conductivity will be measured using Thermo Orion Model 105 conductivity meter. TOC and DOC will be measured using a Shimadzu 5000 TOC analyzer. The precision, accuracy and method detection limits will be evaluated, and where there are existing methods, held within the control limits set forth in the accepted references (e.g.APHA et al., 2006; USEPA-EMSL, 1990; ASTM, 1994).

PPCPs and EDCs

The analytical equipment used at UMass for PPCP/EDC analysis was purchased by the Environmental Engineering group and is a collection of dedicated instruments under sole control of the PIs. Most PPCP/EDC work at UMass is done with a Waters Acquity UPLC coupled to a Waters Micromass Quattro Premier triple quadrupole mass spectrometer. The latter was acquired new in the summer of 2009. An integrated instrument (AquAnalysis) incorporating automated on-line SPE-LC/MS/MS has also been used for PPCP/EDC analysis at UMass. However, most front-end work on these compounds has been done with a more conventional off-line vacuum manifold SPE system. In late 2009, UMass acquired an FMS PowerPrep automated SPE instrument, an instrument which has provided much of the reproducibility described in other studies (Vanderford and Snyder, 2006; Trenholm et al., 2006, 2008) We also have several new GC/MS systems that can be used for those compound most amenable to GC. These systems include a Varian 2200 ion trap GC/MS and a Waters Micromass time-of-flight GCT.

The current UMass method for PPCP/EDC analysis is a hybrid of several published methods that are well regarded by experts in the field. No single published method could be used without some modification, due to differences in target analytes and instrumentation. First, the basis for the extraction and isolation protocol is EPA method 1694. Elements of Vanderford and Snyder's (2006) isotope dilution method were incorporated to help strengthen the method. Finally portions of Kasprzyk-Hordern et al., (2008) were used for specifics of the UPLC solvent programs and MS instrument parameters. Final refinement regarding UPLC separation and MS settings (e.g., voltages, gas flows, temperatures) are done through optimization with the UMass analytical equipment and using the actual analytes of interest. We have frequently used multiple LC/MS runs with the acid extract ESI+ compounds in an effort to maximize dwell time and S/N. We also use matrix-dependent higher SPE concentration factors as employed by Vanderford & Snyder (2006) and Trenholm et al. (2006, 2008). We are also accustomed to adopting new innovations as they become available. For example, we are currently working with a researcher from the NYS Department of Health to develop a derivatization method for enhanced detection of Bisphenol A and related compounds (e.g., estrogens) by positive electrospray-LC/MS (Xu and Spink, 2008).

Sample handling protocols generally follow those of EPA 1694 and include recommendations from the Water Research Foundation's Project 4167 (Round Robin). Amber borosilicate glass bottles are used for sample collection and storage . Ascorbic acid is used as a quenching agent instead of thiosulfate. Sodium azide at 1 g/L is used as a preservative and aqueous samples are held at 4 °C. Travel blanks and laboratory grade water blanks are included in each set of analyses. Preserved samples are extracted within 48 hours of receipt when possible, though hold times of up to 28 days may be acceptable based on the preliminary 4167 findings.

Data quality objectives (DQOs) are in accordance with those listed in EPA 1694. Our QA/QC protocols are designed to meet the DQOs, and they follow those proscribed in EPA method 1694 with the following additions and clarifications. We normally follow two sets of parent-daughter transitions for each analyte instead of just one. This allows for separate calibration and quantification on both transitions. One is used as a primary upon which quantitation is normally based. The second is a confirmation for QC purposes.

The UMass laboratory uses an ultraperformance LC (Acquity UPLC) that makes use of smaller column packing providing higher chromatographic resolution than conventional HPLC. A complete set of aqueous standards (typically 5 concentration levels) are run with each analytical set. These are prepared entirely with water as a solvent, and span the range of concentrations of interest. Analyte and isotopic standard recovery are continuously monitored. Quantitation is performed with labeled versions of the analytes in almost all cases. When labeled compounds (or near analogs) cannot be obtained we use a labeled internal standard of the closest chemical properties as possible to the analyte. Matrix spike/recovery and laboratory grade water spike/recovery tests will be performed at regular intervals throughout the study to monitor the reproducibility of extraction and analytical methods.

Any future recommendations or findings from the Foundation's 4167 study will be incorporated into the study based on planned communication from the Foundation's Project Manager(s). Furthermore, the Project Team has partnered with the Center for Environmental Mass Spectrometry at the University of Colorado at Boulder (see Thurman letter) from the 4167 study to run occasional split samples and to analyze for additional compounds should the need arise based on land use analysis.

Gadolinium and Boron

Analysis of Gadolinium (hospital waste tracer) and Boron (municipal wastewater treacer) will be done with a Perkin Elmer Elan 9000 DRC Inductively Coupled Plasma – Mass Spectrometer (ICP/MS). We will use the manufacturer's settings and instrument methodology. The detection limits for Gd and B in water are 0.0005 µg/L and 0.05 µg/L, respectively (ICP/MS with the Elan 9000). This Elan 9000 was purchased by the PI through an NSF MRI grant, and its use will be dedicated to this and related drinking water projects.

Major Anions and Cations

The major anions and cations will be measured at UMass with a newly-purchased Metrohm model 850 dual channel ion chromatograph. We will use the manufacturer's settings, columns and instrument methodology.

Data Reduction, Validation and Reporting

To ensure the accuracy and permanency of collected data, all manually-collected research data will be recorded with permanent ink in a bound notebook and all QC data (precision, accuracy) will be recorded in instrument log notebooks. Summary QC graphs and tables will be reviewed at least quarterly Concerns and conclusions will be reported to the Project Officer via the project reports.

All data will be subject to review by the principal investigators before release. The analysts involved will sign reports as well as all who review them. All signers attest that the data and associated information contained in the report are believed to be correct and that all quality assurance requirements have been fulfilled, unless exceptions are approved and noted. Careful and detailed laboratory records by each analyst will be maintained, including source of reagents, detailed procedures, instrument and conditions of analysis, failed experiments, etc. Data output will be archived.

The documentation required for the project will include the following:

- project log books
- raw data log sheets for onsite laboratory results
- raw data log sheets for onsite analytical instrument calibration
- raw data log sheets for onsite equipment calibration and verification
- laboratory chain-of-custody forms
- laboratory reports
- initialed and dated printouts of verified electronic data.

Data Delivery

Data delivery requirements are listed in Table 5.

Table 5 Data Delivery Requirements

Type of Data	Delivery Requirements
Outside laboratory analytical results	Reports of analytical results and QC results Copies of chain-of-custody forms
In-house Manual data	Original log book (copies for subcontractors)
In-house Electronic data	Spreadsheet format, similar in organization to raw data forms

Assessment and Response Actions

All calibration and QC data will be reviewed by the PIs and they will be responsible for assuring that all verifications and calibrations have been conducted on bench-scale equipment, pilot-scale equipment and analytical instruments at the beginning of the project. The graduate students and research associates working on this project will be responsible for ensuring that instrument systems are in control (i.e., they meet the acceptance criteria specified) and that QA objectives for method detection limit, precision, accuracy, and completeness are being met. If any QC data are outside of the acceptance criteria, the lead investigator on that task together with the PI (Dr. Reckhow) will investigate the cause of the discrepancy. If the discrepancy is due to an analytical problem, the sample will be re-analyzed or another sample will be collected and analyzed. If there is any other problem, the data will be flagged, another sample will be collected, or the steps outlined in the Corrective Action Plan in Table 4 will be implemented.

Precision

The precision of duplicate samples will be assessed by calculating the relative percent difference (RPD) according to:

$$RPD = \frac{|S - D|}{(S + D)/2} \times 100$$

where S is the sample concentration and D is the duplicate sample concentration

If calculated from three or more replicates, the precision will be determined using the relative standard deviation (RSD):

$$RSD = \frac{SD}{Average} \times 100\%$$

where SD is the standard deviation for the replicate samples.

Accuracy

For Measurements where matrix spikes are used, the accuracy will be evaluated by calculating the percent recovery (R):

$$R(\%) = \frac{S - U}{C_{SA}} \times 100\%$$

where S is the measured concentration in spiked sample, U is the measured concentration in the unspiked sample and C_{SA} is the calculated concentration of spike in the sample.

When a standard reference material (SRM) is used, the percent recovery is determined by:

$$R(\%) = \frac{C_m}{C_{SRM}} \times 100\%$$

where C_m is the measured concentration of SRM and C_{SRM} is the actual concentration of SRM.

Method Detection Limit (MDL)

To determine the MDL, at least seven replicates of a laboratory fortified blank at a concentration of three to five times the estimated instrument detection limit is analyzed through the entire analytical method. The MDL is calculated using the following equation:

MDL = (t) x (SD)

where t is the student's t value for 99 percent (t for 7 replicates = 3.14).

Completeness

Completeness is a measure of the amount of valid data obtained compared to the amount of samples collected. The degree of completeness is the number of acceptable analyzed samples divided by the number of samples collected, multiplied by 100. Completeness is defined by the following equation:

$$\%C = 100 \times \left(\frac{V}{T} \right)$$

where %C is the percent completeness, V is the number of measurements judged valid and T is the total number of measurements

The acceptable criteria for QA objectives are listed in Table 6. The acceptance criteria and corrective action plan for pilot-scale and bench-scale routine water quality parameters are summarized in Table 6.

Table 6 Acceptable Criteria for QA Objectives

Measurement	Reporting Units	MDL Goal	Precision (% RPD)[1]	Accuracy (%Recovery or % Bias)[2]	Completeness[3]
pH	pH units	0.1	± 10	90 – 110	90
TOC	mg/L	0.1	≤20	80 – 120	95
DOC	mg/L	0.1	≤20	80 – 120	95
PPCPs & EDCs	ng/L	0.1-10	≤25	75 - 125	95
Gd	ng/L	0.1	≤15	80 – 120	90
B	µg/L	0.05	≤15	80 – 120	90
Major Ions	mg/L	0.01-0.1	≤15	80 – 120	90

Notes:

1. Given as Relative Percent Difference (RPD) of laboratory duplicates
2. As percent recovery of matrix spike
3. Based on the number of valid measurements compared to total number of measurements

Table 7 Corrective Action Plan

Parameter	**Acceptance Criteria**	**Steps for Corrective Action**
Any duplicate analysis	See Table 6, Precision	Duplicates Check instrument calibration; re-calibrate instrument
Any method blank	See Table 6, Accuracy	Perform procedures specific to each analysis as determined by the laboratory performing the analysis

4.0 MANAGEMENT PLAN

The purpose of our Management and Communication Plan is to ensure effective communication between team members, timely implementation of project roles and responsibilities, and accountability for schedule maintenance and submission of deliverables for all project members. The Project's Principal Investigator, David Reckhow, will be responsible for this plan and will ensure regular communication and dissemination of data between team members. We have assembled highly qualified team of experts with experience in analytical techniques for detecting EDCs and PPCPs, GIS/spatial analysis, applications of statistical tools for ecological analyses, and utility experiences with EDCs and PPCPs. The team offers the foundation both the academic and practical professional experience to successfully conduct this research project. The research collaboration will be facilitated through: (1) weekly meetings of the UMass PIs, graduate RAs, analytical staff, and post-doctoral researchers, (2) monthly video conferences with the full research team, (3) meetings of team members at AWWA ACE, and (4) extensive use of phone and electronic communication.

David Reckhow (UMass) will be the PI and be responsible for overall project management and research communication. His primary area within the research team will be in supervising implementation of the watershed EDC/PPCP sampling protocol, analysis of target compounds, and collaborating all chemical analysis among UMass researchers and those outside of UMass. He will supervise one graduate student in CEE, as well as a laboratory staff (research associate) who will help with analysis by GC/MS and LC/MS. Dave has been on the Faculty of the University of Massachusetts since 1985, serving as Interim Department Head of CEE, Director of The Environmental Institute, and Director of the MA Water Resources Research Center. Prior to coming to UMass, he was a Post-Doctoral Research Associate with the Compagnie Générale des Eaux in Paris. Dave has degrees from Tufts University (BSCE), Stanford University (MSCE) and the University of North Carolina at Chapel Hill (PhD). His current research interests include general aquatic chemistry, chemical oxidation of organic compounds in water, coagulation processes, analysis of pollutants in water, and aquatic organic matter in natural systems and drinking waters. Dave has an active research program (including an ongoing WRF project on PPCPs), and he regularly serves as a consultant to engineering firms, and industrial and governmental groups.

Mi-Hyun Park (UMass) will be a co-PI and will lead GIS modeling for selecting monitoring locations and work with Dr. Michael Levine on statistical analysis to identify the relationships among sources and the EDCs and PPCPs in waters and to develop statistical tools for monitoring strategies. Prior to coming to UMass, she was working as an assistant researcher and post-doctoral researcher at UCLA. She has degrees from UCLA (Ph.D, Civil & Environmental Engineering) and Imperial College and KAIST (M.Scs, Computer Science and Civil & Environmental Engineering). Dr. Park has experience in GIS and remote sensing application to hotspot analysis for stormwater management and decision support systems. She has provided consulting services to municipalities, regulation agencies and industries and has published numerous peer-reviewed and presented conference papers on GIS, remote sensing application with artificial intelligence technique based on probabilistic and statistic approaches to nonpoint source pollution management.

Benjamin Stanford (Hazen and Sawyer) is the Director of Applied Research at Hazen and Sawyer in New York City. Dr. Stanford will serve as co-PI for the project, overseeing meta analysis of historical data, and serve as the main conduit of communication between the project team and several of the utility partners. Ben received a B.S. in Chemistry with honors from Warren Wilson College in Asheville, NC and a Ph.D. in Environmental Sciences and Engineering from the University of North Carolina at Chapel Hill. Ben's post-doctoral research was with Dr. Shane Snyder at the Southern Nevada Water Authority in Las Vegas. Ben's expertise is in environmental physical/organic chemistry and he has worked on multiple projects investigating the fate and transport of pharmaceuticals and endocrine disrupting compounds through drinking water treatment, wastewater treatment, and the environment.

Erik J. Rosenfeldt (Hazen and Sawyer, UMass) will be joining Hazen and Sawyer as a Senior Principal Engineer in Fairfax, VA in August, 2010. Currently an assistant professor at the University of Massachusetts, he will retain adjunct status with the department through the life of the project. Dr. Rosenfeldt will serve as co-PI for the project, and will oversee the integration of research efforts between the University of Massachusetts researchers and the utility/consulting/regulatory partners. Erik received his BS in Chemical Engineering from Washington University in St. Louis, and MS and PhD degrees in Civil and Environmental Engineering from Duke University. An expert in advanced physical/chemical treatment processes, Dr. Rosenfeldt's research has focused on utilizing these technologies for removing threats associate with EDCs and PPCPs from drinking water.

Michael Lavine (University of Massachusetts) is Professor of Statistics at the University of Massachusetts Amherst and will be a co-PI on the project. Lavine received a Ph.D. in statistics from the University of Minnesota in 1987, taught at Duke University for over 20 years, and recently moved to the Department of Mathematics and Statistics at UMass. He has collaborated with many Ecologists and Environmental Scientists, held an appointment in Duke's Nicholas School of Earth and Ocean Sciences, and is on the editorial board of *Ecology and Ecological Monographs* and *Environmental and Ecological Statistics*.

David Lipsky (New York City Department of Environmental Protection) is chief of the Distribution Water Quality Science and Research Division for New York City Department of Environmental Protection. He will serve as co-PI for the project, in charge of coordinating efforts of the project within the New York City Watershed, the water source for more than 9 million customers.

Alex Mofidi (AECOM) Mr. Mofidi is a Senior Process Engineer at AECOM. He will serve as co-PI for the project, serving as the main conduit of communication between the project team and several of the utility partners. He has 19 years experience evaluating and optimizing water treatment issues such as source and finished water quality, treatment optimization, operations training and management, and regulatory compliance. He is a past Purification manager for Metropolitan Water District of Southern California responsible for drinking water regulatory compliance for their five water treatment plants. He has BS and MS degrees in Civil Engineering, is currently appointed to the AWWA Disinfection Systems and Emerging Water Quality Issues Committees.

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6.0 SCHEDULE

The project timeline, shown in Figure 7, displays the proposed timeframe for the work. In general, the work will be divided into three main events. The first six months will be devoted to background data collection, Spatial analysis and GIS meta analysis for the two major case studies (Merrimack and South Platte), development of a watershed EDC/PPCP sampling protocol, including a detailed QA plan, which will be submitted as the project's first deliverable. The next year will be devoted to implementing the watershed EDC/PPCP sampling protocol for Merrimack and South Platte, in conjunction with utility partner driven EDC/PPCP data collection efforts, which have been donated to the project in the form of "in-kind" services. Concurrently, meta analysis will be performed on the remaining three case studies, to develop protocols addressing potential EDC/PPCP watershed sampling protocols. The final six months of the project will be devoted to data analysis, addressing the project defined evaluation criteria, and preparing reports for utility partners and WateRF. Throughout the project, quarterly progress reports will be provided to the PAC, and input will be solicited frequently from the Technical Advisory Group

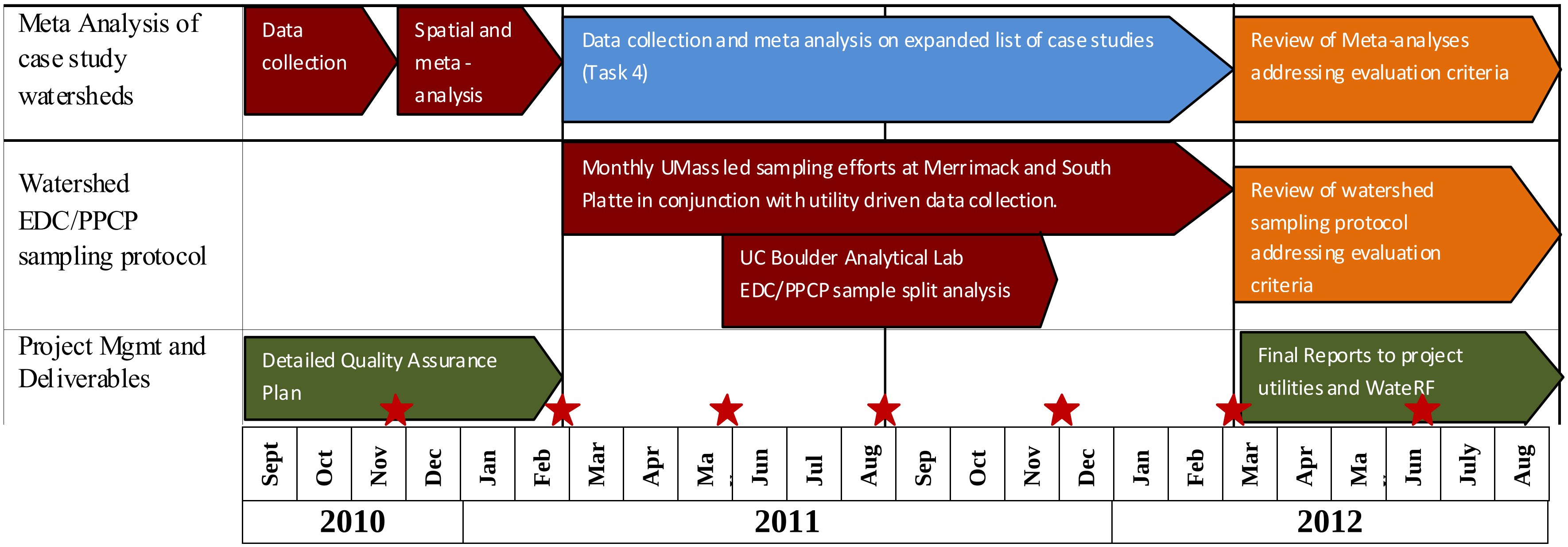

Figure 7: Project Schedule. Color coded as follows: Red = Implementation of watershed EDC/PPCP sampling protocol; Blue= Retrospective analysis of historical data from five case studies; Orange = Review to address evaluation criteria; Green = Preparation of Deliverables. Stars indicate quarterly progress report will be provided to the PAC and TAG for review and comment