APPENDIX D

EXPERIMENTAL PROTOCOL

Field equipment was selected and procedures were developed to obtain a field test protocol that could be used to simultaneously measure sewer headspace ventilation and all parameters that influence it with sufficient accuracy that the results could be used for a variety of purposes including as input data for ventilation models and designing odor control systems. The protocol was structured so that a subject sewer reach could be fully characterized, with unknown variables eliminated. This document provides a description of the protocol including a description of equipment and apparatus and a general step-by-step procedure that can be adapted to specific sites.

D.1 Apparatus and Equipment

Belowground instruments need to be robust and able to tolerate the humid and potentially corrosive conditions inside a municipal sewer. Aboveground apparatus needs to be constructed so that it is sufficiently portable that multiple locations can be tested with the same apparatus, and can be taken down at the end of each sampling day.

Analytical equipment was selected to allow sufficient portability, response time, accuracy, and logging capability. Figures D-1 and D-2 show schematic diagrams of belowground apparatus and aboveground apparatus, respectively. Table D-1 lists the equipment and relevant specifications.

D.2 General Procedure

At each sampling site the following steps were completed to obtain field measurements:

1. Review site drawings and inspection videos, where available, to identify blockages, lateral tie-ins, or other structures that would affect the experiments. Select locations that have no blockages or lateral tie-ins between the upstream and downstream boundaries of the selected subject component.

2. Leak test sample trains. Test all data loggers and software.

3. Test carbon monoxide sensors against a known test gas concentration.

4. Install wastewater flow or depth meter. Where wastewater depth (and not flow) is measured, complete wastewater tracer measurements using tennis balls. Do this by dropping tennis balls in the upstream manhole and timing their travel time to the downstream manhole. Tennis balls are good for a liquid tracer because they float but are heavy enough not to be significantly slowed down by air drag, they are easy to spot in the wastewater and they are not likely to damage pumps or other downstream equipment. Take one depth measurement by hand to initialize meter. Download and review flow data from at least one diurnal cycle. Measure invert to ground level distance.

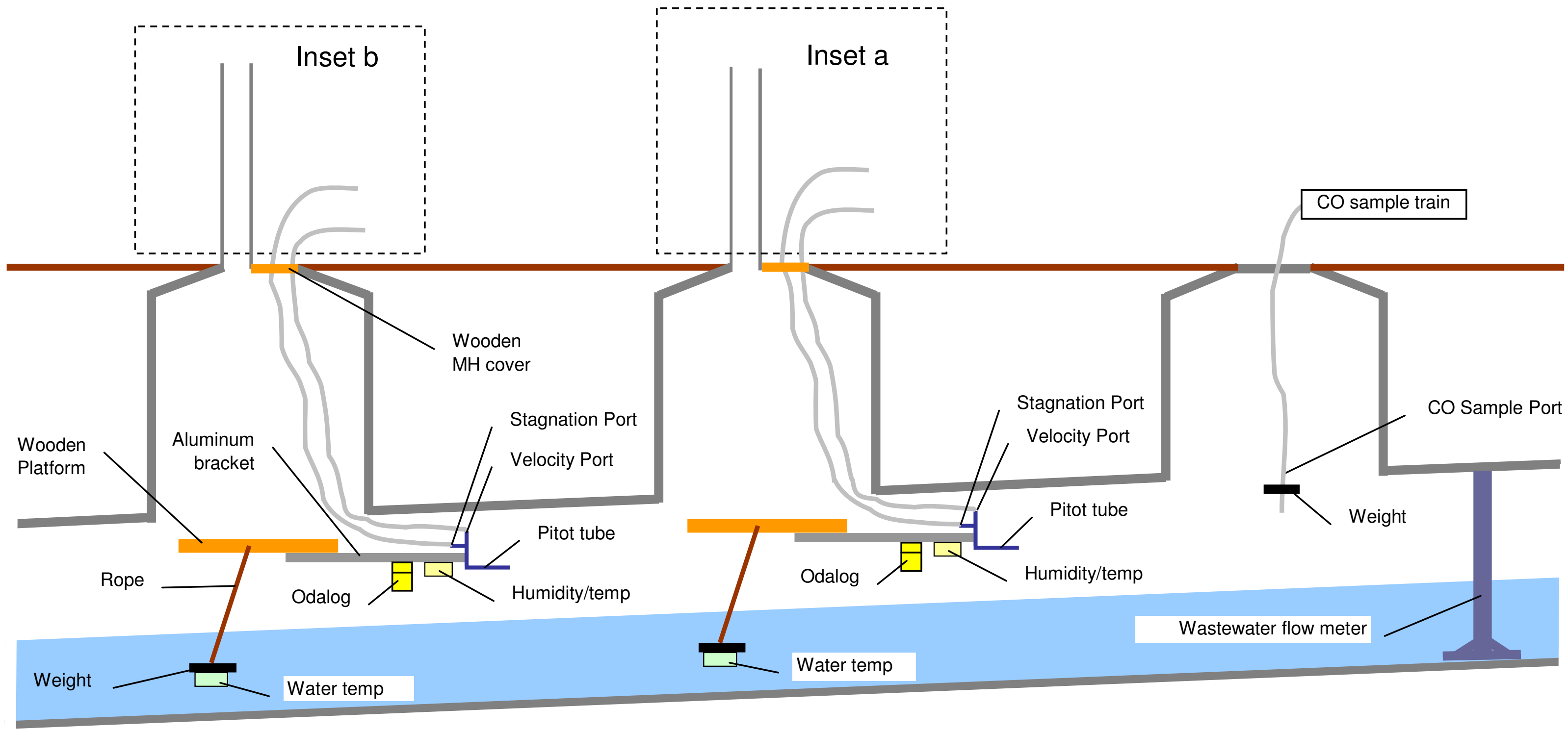

Figure D-1. Belowground Apparatus Diagram.

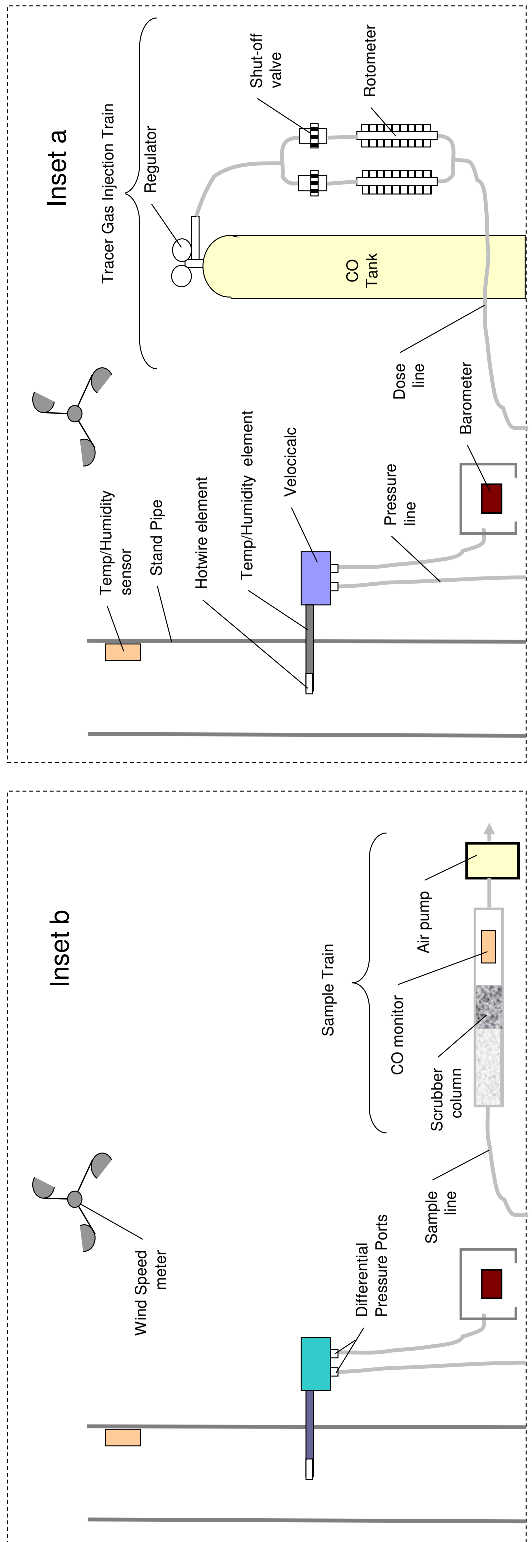

Figure D-2. Aboveground Apparatus Diagram Sample Train and Tracer Injection Train.

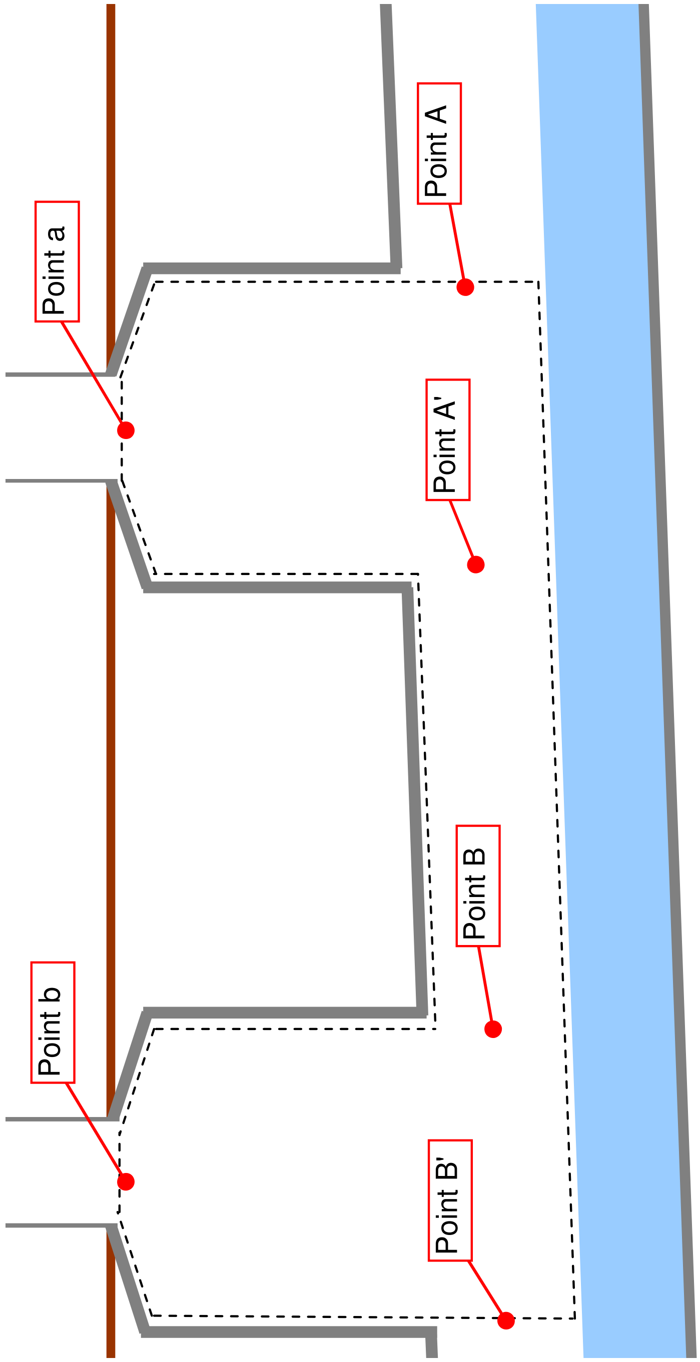

Figure D-3. Point Locations.

Table D-1. Equipment List

Parameter	Symbol	Units	Range	Resolution	Accuracy (±)	Logging Freq. (Sec)	Model	Make
Carbon Monoxide Flow	F_{CO}	L/min	0 to 0.5	0.01	5%	N/A	VF Visi-Float	Dwyer
			0 to 1.0	0.05	5%	N/A	VF Visi-Float	Dwyer
			1.0 to 10	0.5	5%	N/A	VF Visi-Float	Dwyer
Diff. Pressure	ΔP	Pa	-500 +500	1	2.5	1	Smart Reader Plus	ACR
CO Conc.	C	ppm	0 - 1000	0.5	6	10	EL-USB-CO	Lascar
Humidity	H	%	0 to 100	3.00%	2.5	1	Pro v2	HOBO
Temp.	T	°C	- 4 to 70	0.02	0.2	1		
Water Temp.	$T_{w,}$	°C	0 to 50	0.02	0.2	1	U22 Water Temp Pro v2	HOBO
Water Flow	F_w	m^3/s	To nearly full	0.001	2%		2150 (2110 depth only)	ISCO
Diff. Pressure	ΔP	Pa	-3700 to +3700	0.1	1	1	VelociCalc 9555	TSI
Humidity	H	%	0 - 95	0.1	3	1		
Temp.	T	°F	4 to 45	0.1	0.5	1		
Air Velocity	V	m/s	1 to 5	0.0033	3% or 0.01	1		
Bar Pressure	P_{bar}	Pa	68,950 to 124,100	1	2%	1	Barometric Pressure Smart Sensor	HOBO
Wind Speed	V_{wind}	m/s	0 to 45	0.38	1.1	60	Wind Speed Smart Sensor	HOBO
CO gas							99.5% purity	
Regulator							R-77-15	Trimline
Pitot tubes							Series 160	Dwyer
Air pumps		L/min	0.5 to 5				HFS-513	Gillian
Dreirite media							Calcium sulfate desiccant pellets	Dreirite
Smoke bombs							#2B or of comparable generation	Classic
Activated Carbon media							Sulfox 0.2	Jacobi

5. Smoke test reach to verify direction and approximate speed of airflow. Select a smoke generation device that generate smoke for at least one minute in sufficient density that it will be clearly visible after traveling the length of the subject sewer component being tested. Table D-1 provides an example smoke-generating device.
6. Set belowground data loggers, temperature and relative humidity sensors, and wastewater temperature meters to log at 1-minute intervals.
7. Assemble belowground apparatus and install at upstream and downstream headspaces with Pitot tube and data loggers located several feet upstream to avoid interference by in-gassing air. Hook up the pressure tube to the stagnation port of the Pitot tube and the tracer sample train tube (downstream manhole) or tracer dose tube (upstream manhole) to the velocity port. Use a steel weight and rope to tether the wastewater temperature sensor. Use previously logged wastewater depth data to locate equipment above the high-water level.
8. Set aboveground data loggers, wind speed meter, barometer, temperature and relative humidity meters, hotwire anemometer, differential pressure monitors, and carbon monoxide monitors to log at 1-minute intervals.
9. Assemble aboveground apparatus and install at the upstream and downstream manholes (same manholes where belowground equipment is installed). Use silicone or equivalent sealer to seal the wooden manhole cover edges and penetrations. Adjust the anemometer probe so that the element is located in the center of the stand pipe and the probe is perpendicular to the stand pipe. Install the Velocicalc® temperature/relative humidity meter to monitor ambient air and the Lascar® temperature/relative humidity meter to monitor air inside the stand pipe. Install carbon monoxide monitors to monitor ambient concentration. Mount wind speed meter at the height of the stand pipe opening. Install the barometer at ground level.
10. Install the sample train at the downstream manhole to pull air from the belowground velocity port, through a desiccant column, through an activated carbon column, and past the Lascar sensor. The sample air travel time within the sample train should be less than 1 minute. Use a second carbon monoxide sensor with a visual readout to monitor concentration in real time.
11. Install additional tracer sample trains in the manhole upstream of the subject reach and in manholes between (if any) the upstream and downstream ends of the subject reach. Additional sample train tubes should be suspended below the sewer crown. However, they need not be located upstream. All manholes with sample trains should be sealed so that the only place air can enter or exit is at points *a*, *b*, *A*, and *B'*. (See Figure D-3 for point locations.)
12. Provide spare sample pumps so that some pumps can be charging while others are deployed. Provide power to upstream and downstream locations using vehicles and cigarette-lighter inverters. Provide spare batteries for all powered equipment.
13. Assemble dosing apparatus. Set carbon monoxide tank regulator pressure low enough that there is no danger of causing leaks in the rotometer assembly and high enough that flow responds quickly to rotometer adjustments and remains steady. Approximately 3 to 5 pounds per square inch (psi) works best.