APPENDIX AVAILABLE ON REQUEST

Research Report 160

Personal and Ambient Exposures to Air Toxics in Camden, New Jersey

Paul J. Lioy et al.

Appendix F. GeoLogger Evaluation

Note: Appendices Available on the Web appear in a different order than in the original Investigators' Report. HEI has not changed these documents. Appendices were relettered as follows:

Appendix F was originally Appendix IV

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This document was reviewed by the HEI Health Review Committee but did not undergo the HEI scientific editing and production process.

Appendix IV. GeoLogger Evaluation

Background

Personal exposure is strongly affected by personal activities, which can lead to individualized contact with the sources of air pollutants (Bonanno et al. 2001; Zhang and Lioy 2002). In addition to monitoring the personal concentrations of target pollutants, it is important to collect activity and location information of study subjects during an exposure monitoring period to identify the potential sources and routes of exposure. Traditionally, time-activity questionnaires have been used to collect such information. However, the questionnaire method is inevitably based on subjects memory, thus some important exposure activities that may significantly contribute to the personal exposures may be missed (Freeman et al. 1999; Hubal et al. 2000).

Recently, global positioning system technology (GPS) has been used in exposure studies to provide more detailed and reliable personal time-location information (Elgethun et al. 2003; Phillips et al. 2005), GPS is a satellite-based technology composed of a system of satellites encircling earth and emitting a radio frequency detectable by GPS receivers. GPS receivers are designed to use this information and calculate coordinates of the receiver location ((Nuckols et al. 2004). They can record the trip or route to a location and the time that people spend at that location. This information can help researchers to evaluate the quality of time-activity data obtained from questionnaires, and aid in identifying trips or activities that a subject may miss in a recall questionnaire.

However, Phillips et al. (2005) and Elgethun et al. (2003) reported limitations of the GPS technology as a sole source of space–time data for an exposure assessment study. Both studies found the reception of the satellite signals to be adversely impacted by shielding from buildings of certain materials (e.g. concrete, steel) and to some extent vehicle body panels. Phillips et al. captured only about 30% of the total monitoring time attempted in 25 trials. Elgethun et al. reported reception efficiencies of 79% outdoors, 20% in homes, 12% in vehicles, and 6–9% in schools and businesses. Signal blockage and lost signals continue to be an issue with GPS today. Thus, the application of GPS technology in exposure assessment research requires further evaluation.

An evaluation of the GPS method to exposure measurement was conducted in this study. The Version 3.x GeoStats In-Vehicle GeoLogger™ (Geostats, Atlanta, GA) was suggested by the HEI because it can receive a good signal in indoor environments. The Geostats GeoLogger was first designed for vehicle use to track vehicle route, and was evaluated by DTLR New Horizons Program (Gleave, 2003) and Geostats company (Zmud and Wolf, 2004). Both reported good recording quality during their studies.

Evaluation Method

The Geostats GeoLogger system weighs about 1.75 lbs, including a GPS receiver, a data logger, an external rechargeable battery, and a small carry bag. The performance of the GeoLogger was evaluated both in the laboratory and in the field. The major parameters that can affect the performance of the Geologger were first tested for a 3-day period by field staff members. Included were signal reception under different environments (outdoor, indoor, in-vehicle), position precision, and battery performance. Three recording intervals and the "speed check" function were also tested to seek an optimal condition for field application. The 3-day test started early in the afternoon of the first day and ended in the morning of the third day. The participating staff members were required to carry the GeoLogger at all times during the testing period. They also kept detailed time-activity diaries. After the data was preliminary reviewed in one or two days, an interview would be arranged to clarify discrepancies between the time diary and the GeoLogger record.

During the field evaluation, the GeoLogger was placed in the front pouch of a backpack that held other personal sampling devices, with the GPS signal receiver hanging outside (Figure 2, main text). The backpack was carried by the subject during the 24-hr sampling period to track subjects' movements. Subjects were required to fill a time diary and finish time-activity questionnaire with the help of a field technician at the end of sampling. The questionnaire was used to log the time duration. It also provided descriptions of types of activities that the subject completed within three microenvironments (indoors, outdoors, and in-vehicle) during a 24-hour monitoring period.

The GeoLogger™ has a longer cold start acquisition time than is specified by the manufacturer. After a GeoLogger is turned on, it requires approximately 40 minutes to 2 hours for the satellite system to locate the GeoLogger and log in data. Therefore, GeoLoggers were usually turned on two hours before sampling. After the laboratory evaluation and several field tests a complete Standard Operating Procedures (SOP) for GeoLogger use in the field has been developed.

Results of GeoLogger Evaluation

Overall Performance of GeoLogger

Ten tests having a 3-day test duration were conducted by the staff members of EOHSI. The data showed that GeoStats GeoLogger™ had remarkable performance to record vehicle traveling information. As shown in Figure IV-1, a geo-map for a large-scale travel tracking in suburban area, the GeoLogger record provided details of subject's traveling activities, such as, destination, route and time of each trip.

Figure IV-1 is a small-scale traveling geo-map with 20-second data log-in interval, which included driving, walking, and stopping. As summarized in Table IV-I, the GeoLogger recordings agreed with questionnaire information. Each point was labeled by real sampling time. The big loop in the center of this map was a walking track. As the subject reported in her diary, she finished lunch at the Campus Center and walked to a research building, then walked to another building and stayed there until late afternoon. The map showed continuous points recorded from 13:10-13:18 pm. The speed recorded was between 2.2 MPH and 3.2 MPH, which is normal walking speed.

It was critical to find a proper recording interval that could collect necessary information. Long data log-in intervals cannot catch enough information to represent a subject's activities. Short intervals were good for collecting more information, yet this effort used more electrical power and memory. Three recording intervals including 30s, 15s and 5s, were tested in lab evaluation. The track of 5s interval provided a clear subject path and had the most details. Compared to 5s, the interval of 30s sometimes could track the subject's route in micro-scale. The 15s interval catch the whole route and all the places the subject had stayed with less data points than 5s interval.

The "Speed Check" function of Version 3.x GeoStats GeoLogger™ was also tested. For the "Speed Check" on mode, GeoLogger automatically stops recording data at speed below 1 knot (1.15mph), which is good for vehicle-based use. The “speed check” mode function can make track-logs simpler and improve memory management. However, the setting of “Speed Check” may not apply to personal movement because the normal walking speed of a human is usually around 1~3mph. Walking at low speed may be skipped by “speed check”. Thus, “speed check” should be turned off during a community exposure study.

Most buildings tested in this study were one- or two-level wood- or brick- residence houses. Our test results showed that good signal was obtained from most of the residential buildings. There was also no blockage of the signal emitted in car. However, a signal was not recorded when subject entered a tall building, or drove under concrete-bridges.

Field Evaluation

The recording interval and speed check function were further evaluated in the field study. The recording intervals tested included 5, 20, and 30 seconds. The interval of 5 seconds was used at the beginning of the study, but it was found that this short interval consumed too much memory and power. Similar to the laboratory test results, the 30-second interval was too long and may miss some activity/location information. The interval of 20 second was found proper for this study. It greatly reduced the number of data points recorded and at the same time, provided sufficient data points to examine the activities/movements of the subjects.

“Speed check” mode was on at the beginning of the study to reduce the data points recorded during no movement. However, the cut point of speed check is 1.15 mph, which is similar to medium to low walking speed. Based on our observations, subjects in our study spent about 80% of time at home or in other indoor environments. Their speed was low, unless by car. When idling, GeoLogger stops recording because of “Speed check” function was on, i.e. it stops recording when the moving speed is lower than 1 mph. Many samples were found without or with only a few data points during the whole sampling period. Thus, in order to record subject activities, e.g. slow walking, the “speed check” mode was left on during the later sampling tests.

A total of 60 tests were conducted on 34 subjects during this study. Due to the battery problem during sampling, only 40 tests were valid for analysis. The tracking path obtained from one subject is presented in Figure IV-2. During this sampling period, a subject made several short trips within the neighborhood by walking, and a long trip to the shopping mall in downtown by bus, which agreed with the questionnaire information he/she provided. One outdoor trip in the early morning (4:02-4:46am) was not reported by subject but captured by GeoLogger. Similar to the laboratory evaluation results, the GeoLogger device has the ability to collect detailed spatial and temporal travel data. Preliminary analysis was performed to compare the activities, such as outdoor trip and time spent in different microenvironments, recorded by the Geologger and time-activity diary. The results showed that 15% of the Geologger records were in good agreement with the activities recorded in time-activity questionnaire, and 35% of the Geologger records provided more information (i.e. missing trips) than those recorded by questionnaires. For example, some subjects forgot to mention the short periods of time when they traveled in a vehicle. In addition, the time spent indoors was also often underestimated by the subjects.

Fifty percent (50%) of GeoLogger records missed part of the activities documented in the questionnaires. There was no signal loss in the homes tested because all the subjects live in one- or two-level brick-made apartments or row-houses. The loss of information by Geologger was primarily due to long “warm up” time, long interval time (30 seconds) tested at the beginning of the tests, loose connections during the sampling period, and a dead battery. Some were lost due to the sensitivity of this type of Geologger to low speed movement (< 1 mph). For example, one of the subjects had no data recorded during the period from 3 pm-11 pm, when the subject recorded in questionnaire that he was outdoors. It was found the data loss was due to the low moving speed of the subject during that period and the Geologger device could not capture the path.

The missing activities in questionnaires were primarily due to recall bias by subjects. During our pilot study, the follow-up interviews with staff members helped to make up several activity information that was missed by subjects. However, during field evaluation, the immediate follow-up interview with every subject was not performed. This is because it took time to process both Geologger and questionnaire data after sampling was completed. Also, the interview (or phone interview) was limited by the availability of the subject. Thus, the best recall time was missed which reduced the possibility of confirming or adding some activities that were missing in either database.

Based on the Geologger records and questionnaire information, we were also able to check the compliance with the sampling protocols by the subjects. It was found that no point was recorded by Geologger for several tests but subjects recorded several trips in questionnaire during the sampling period. Those measurements of air concentrations were considered invalid and were excluded for analysis.

Limitations of the GeoLogger Application

The GeoLogger evaluated in this study has been designed to record travel activities, thus, the position accuracy is 15-m RMS. During our tests, the position accuracy was about 25 m, greater than that reported in the product instruction manual. The information recorded by this Geologger can be used to determine if the subject had traveled by car, walked outdoors, and stayed at some places, however, the low resolution limits ability to differentiate indoor and outdoor position when the subject was at home. So far, the best position accuracy of GeoLoggers that have been reported is > 3.2 m (Elgethun et al, 2003). This resolution is much better than the Version 3.x GeoStats In-Vehicle GeoLogger^{TM}, but it is still not precise enough to always differentiate the boundary between indoor or outdoor environment sometimes.

Another limitation of the Geologger evaluated is the lag time after idling. The GeoLogger automatically stopped recording data when it was immobile, but it took about 10 min to reactivate GeoLogger so some movements after idling may have been missed. If the trip/movements were longer than 10 min, the time gap can be made up by the following track recorded and with the assistance of questionnaire information. To minimize the error in evaluation of subjects' activity, GeoLoggers should be improved to shorten the acquisition time.

Summary of GeoLogger Evaluation

This study evaluated the performance of GPS technology in an exposure study to present the advantage and limitation of application of GPS technology in future exposure assessment. The Geologger device provided an independent and objective approach to assessing the quality of time-activity data obtained from questionnaires. The information recorded can help researchers to make better estimates of exposure time and potential exposure sources during the monitoring period. Further, it can supplement the data by identifying missing activities that might significantly contribute to the personal exposures. By cross-checking the Geologger data with the time-activity logs, the quality of the time-activity data provided by the subjects through questionnaire format (i.e. time-activity log) can be better assessed.

However, the Version 3.x GeoStats In-Vehicle GeoLogger^{TM} has been designed for vehicle traveling. Personal activity tracking requires much higher resolution than vehicle traveling. Improvements are needed on the sensitivity for low speed so the slow movement by subject can be recorded. In addition, the precision and accuracy (< 1 m in distance) need to be improved so the data recorded by Geologger can distinguish indoor and outdoor environments. The information is critical for exposure assessment because the sources that subjects may encounter can be significantly different in these two microenvironments.

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Table IV-1. Example of the Cross-Verification of Questionnaire and Geologger record.

Time	Real Activity	Geologger Record	Comments for Cross Verification
12:13pm	Turned on geologger in office	No record	Missing info
12:16-12:18pm	Left office and walked to the parking lot	No record	Missing info
12:18-12:21pm	Drove to dinning hall	No record	Missing info
12:21-12:38pm	Walked around dinning hall	Little record, just 3 points	Missing info
12:38-1:07pm	Had lunch in dinning hall	No record	Missing info or stop recording when subject were idling
1:07-1:15pm	Walked on campus	recorded	Record from 12:53pm when the subject were idling
1:15-6:30pm	Sit in seminar	No record	stop recording when subject were idling
6:30-6:45pm	Walked to parking lot and waited there	Recorded	Agree
6:45-7:00pm	Drove to student dorm and wait in parking lot	Recorded	Agree
7:00-7:30pm	Drove to restaurant	Recorded	Agree
7:30-8:30pm	Had dinner	No record	stop recording when subject were idling
8:30-9:00pm	Drove back home	Recorded	agree
9:00-9:20pm	Stayed at home	No record	stop recording when subject were idling
9:20-9:50pm	Drove to a friend's home and drove back home	Recorded driving activity until 10pm	Subject misreported the time she arrived home based on the Geologger data and map.
10pm – the 2nd day morning	Stayed at home	Recording on and off	The Geologger wasn't moved.

Figure IV-1. The tracking path recorded by the GeoLogger for EOHSI staff member during lab evaluation. Recording started at around 13:08pm and ended at 18:51pm. A walking track was presented as closely connected dots in the figure. After resting in a building for the afternoon, another driving track was recorded as well. Details of the trip were explained in Table I.


0
100
200
400
Meters
NAD_1983_StatePlane_New_Jersey_FIPS_2900_Feet
N
W
E
S
18:43:08
18:42:46
18:44:27
18:45:07
18:50:06
18:44:47
18:49:06
18:47:06
18:49:27
18:48:26
18:49:46
18:50:26
18:42:27
18:42:21
18:41:26
18:50:46
18:41:57
18:51:46
18:41:06
18:51:06
18:51:26
18:40:47
13:11:09
13:10:51
13:09:03
13:07:21
13:10:01
13:18:42
18:29:06
13:05:41
18:29:07
13:05:01
13:18:20
18:37:27
12:54:22
18:40:29
13:18:01
18:38:30
18:29:40
13:17:50
13:12:21
12:53:42
13:12:41
12:53:23
18:40:07
13:17:19
13:13:00
13:17:00
13:16:20
13:13:21
13:16:40
13:13:40
13:15:01
13:14:01
18:40:01
13:15:47
Sample of points
Sample of points logged by GeoLogger in Busch Campus, during the test in Feb. 3, 2006

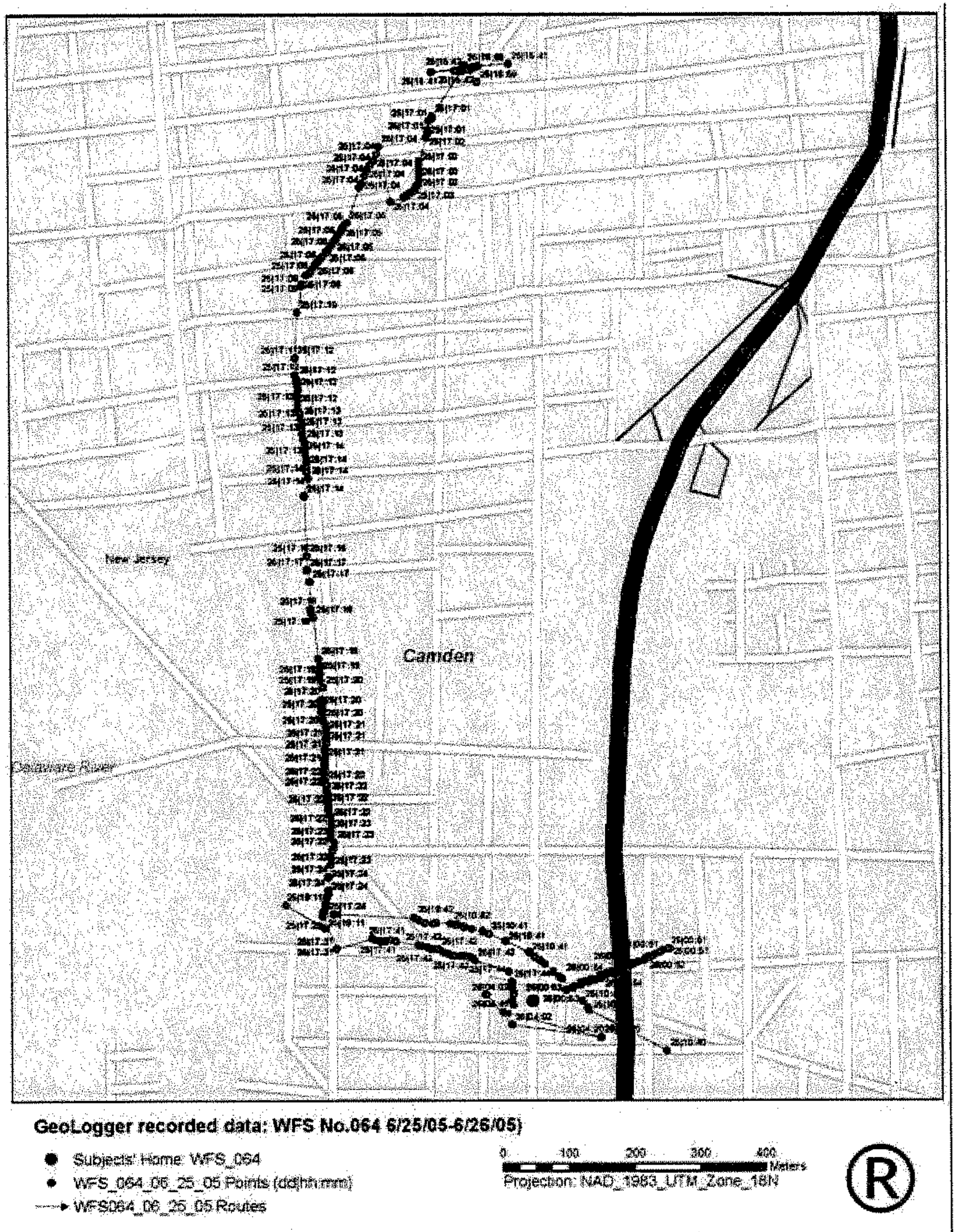

Figure IV-2. The tracking path recorded by the GeoLogger for subject WFS-064 during sampling period 6/25/2005-6/26/2005.

GeoLogger recorded data: WFS No.064 6/25/05-6/26/05)

- Subjects' Home: WFS_064
- WFS_064_06_25_05 Points (dd|hh:mm)
- → WFS064_06_25_05 Routes

0 100 200 300 400 Meters

Projection: NAD_1983_UTM_Zone_18N

N W E S