Another Day at the Beach

Marc Böhlen
Department of Media Study
University at Buffalo
marcbohlen@acm.org

Brian Clark
Department of Media Study
University at Buffalo
brianlarsonclark@gmail.com

Luge Yang
Department of Biostatistics
University at Buffalo
lugeyang@gmail.com

Jordan Dalton
Department of Media Study
University at Buffalo
jordan.a.dalton@gmail.com

Joe Atkinson
Department of Civil. Structural and Environmental Engineering
University at Buffalo
atkinson@buffalo.edu

Davide Blersch
Department of Civil. Structural and Environmental Engineering
University at Buffalo
dblersch@buffalo.edu

CHI'13, April 27 – May 2, 2013, Paris, France.

Abstract
We present a new approach to monitoring public recreational beach waters and describe a prototype system that collects data from sensors and from people and combines them to create a novel metric of water resource quality and appreciation. We present an evaluation of the system and consider some consequences for IT-enabled monitoring of shared resources in general.

Author Keywords
Urban Informatics; Participatory Sensing; Sustainable IT; Environmentality; Public Computational Media; Numeracy

ACM Classification Keywords
H.1.2 User/Machine Systems: Human information processing. H.5.3 Group and Organization Interfaces: Collaborative computing. J.5 Arts and Humanities: Performing arts. K.4.1 Public Policy Issues: Computer-related health issues

General Terms
Experimentation

Introduction
The GlassBottomFloat project (GBF) (www.glassbottomfloat.org) is an attempt to formulate

in concept and in practice a new approach to monitoring shared public resources. In particular, the project focuses on the monitoring of public recreational water resources such as beaches. The project is invested in considering the affordances and limitations of information technologies for the purpose of monitoring resources with the explicit participation of people, and is in that respect related to many other established, ongoing and recent endeavors such as participatory design [2], urban informatics [9], citizen sensing [10], participatory sensing [3, 11], participatory science [12], DIY pollution monitoring [4], street science [5], and sustainable IT [6, 7, 10].

What our project adds is, first, an alternative to the standard risk-centric-monitoring / sustainability philosophy; second, a formal framework for combining sensor data with crowd-sourced, interview-based subjective data; third, an evaluation of a prototype system with statistically significant data; fourth, an expanded interaction model including varied numeracy strategies and event-bootstrapped data and idea sharing approaches; and fifth, an account of the successes and failings of our experiment and observations on limitations of participatory monitoring.

A previous publication focused on the technical design of the system [1], while this text focuses on the environment experience approach and the methods chosen to enable it.

Being at the beach

While GBF considers expanding the role of computing in the monitoring of the recreational resources, it is principally invested in a more speculative attempt to 'reformat' monitoring of the commons. From the onset of the project, the goal was to imagine how a keen observer of the outdoors, such as *W.G. Seebald*, might appreciate an environmental monitoring effort. The project is hence not geared primarily toward improving currently existing monitoring efforts, but rather imagining future monitoring scenarios and inventing a technical framework to move towards that vision.

How is the water today?

From the perspective of the GBF initiative, the most pressing problem in environmental monitoring is not the lack of IT or the limited sophistication of the data management procedures. Rather, the most pressing problem is the failure to imagine a monitoring practice outside of risk management, and hence the failure to create a formal basis for engagement with the environment that is not based exclusively on fear of infection and illness. There can be no doubt that from the current state of affairs and a practical perspective, the concern for clean water and risk aversion is of paramount importance in industrial and post-industrial landscapes alike. GBF's approach in no way negates this; rather it places the need for hygiene second to the enjoyment of and appreciation of the commons, hoping to tentatively contribute to an alternate concept of resource monitoring that can take local needs, preferences and beliefs into account; an approach that can scale across cultures, and possibly to new forms of committment; to a future when the cleanliness of water might not be the exclusive concern of beach monitoring.

The following sections describe our approach in designing the GBF system.

Not your average DIY data collector

GBF was in operation (and under continuous development) over several years at two beaches in Western New York: Woodlawn Beach (2008) and Beaver Island (2009, 2010 and 2012).

Figure 1: GBF buoy at Beaver Island, Buffalo, NY

As is typical for environmental monitoring systems, GBF collected data, lots of data. Data collection occurred on two fronts: sensor data from a suite of distributed environmental sensors, and human experiential data collected in short interviews. We built a robot-buoy [Fig. 1] with state-of-the-art environmental sensing centered around the YSI-6600V2 sonde. The battery operated buoy, also capable of collecting weather, sonar and GPS data, could operate for a full day, and the data collection could be remotely controlled from the beach.

In addition to the buoy, GBF encompassed a beach kiosk (a container office) located directly at the beach with an *Endetec B-16* biolab (http://www.endetec.com/en/products/) capable of detecting E. coli*,* the main indicator of contaminated beach waters, at the single coliform level. Table 1 lists the most important environmental parameters the GBF system collected:

Table 1: categories of sensor data

parameter	*units*	*meaning / interpretation*
turbidity	ntu	how clear is the water?
chlorophyll	ug/l	how much algae are present?
pH	H+	how acidic or basic is the water?
dissolved oxygen	mg/l	how much oxygen is there in the water?
water temperature	c	how warm is the water?
salinity	ppt	how high is the ionic content of the water? / how salty is the water?
total dissolved solids	mg/l	how high is the combined content of inorganic and organic substances in the water?
air temperature	C	how warm or cold is the air?
wind speed	m/s	how strong are the winds??
wind direction	deg	from which direction is the wind coming?
relative humidity	%	how humid is it?
barometric pressure	mmhg	how high or low is the atmospheric air pressure?
e.coli	colonies/mL	how much e.coli contamination is in the water?
total coliform	colonies/mL	what is the sum of all forms of coliforms in the water?
water depth	m	how deep is the water where the buoy is located?
gps location	lat/long	where is the buoy?

Crowd-sourcing the experience of being in the water

GBF wanted to know what people sensed and thought about the water they swam in. We collected an approximation of this soft knowledge by interviewing beach visitors. IRB certified interviewers performed 3-5 minute discussions with swimmers exiting the water, and recorded the responses in real-time with a custom-made mobile phone application directly to a remote database [Fig. 2].

We cast the question regarding the experiential water quality experience into the term the *swimming pleasure measure* (SPM), scaled between 1(worst) and 10(best).

Figure 2: Interviewing beach visitors

Furthermore, we differentiated between the experience of the beach and the water itself (spm_water_only) in order to filter out the influence of beach amenities on the actual being-in-the-water experience. The spm (spm_interview) values stem from interviews of swimmers immediately after exiting the water, still wet from the swimming experience. The spm_interview is the voice of the crowd describing the pleasure of being at the beach; spm_water_only is the voice of the crowd describing the pleasure of specifically being in the water. The scale of the spm (1 to 10) is chosen based on the ability of people of all linguistic and cultural backgrounds to relate experiences of the body to numerical scales of the body.

Table 2 summarizes the categories of data collected in the interviews.

Table 2: categories of survey data

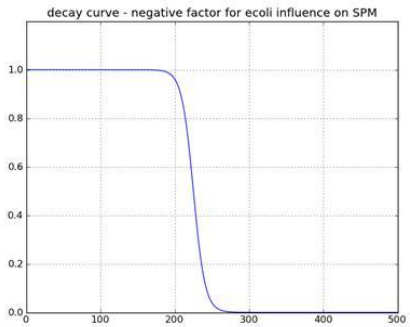
parameter	*units*	*meaning / interpretation*
spm_interview	1-10	what is the pleasure of being at the beach?
spm_water_only	1-10	what is the pleasure of being in the water?
spm_water_odor	n.a.	does the water have an unpleasant odor?
gender	m/f/unknown	observed
frequency	first time - regularly	how frequently does the visitor come to this beach?
residency	local/visitor	where does the visitor reside?
one word comment	text	what is most important for you at a beach?
comment	text	unstructured comments

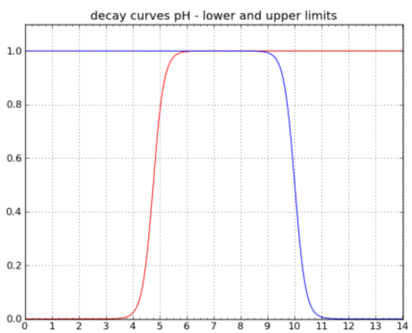
Towards a framework for post-risk resource management

GBF is invested in contributing to speculative approaches to environmental monitoring that are not solely risk-factor based. To this end, GBF developed a general approach to combining sensor data with human perceptual data (collected in interviews) and coined the term the *human computer resource percept*. The approach is described below.

The human computer resource percept and the swimming pleasure measure

The human computer resource percept (HCRP) combines human intuition expressed in language and sensor data processed by computers. The HCRP comprises three different modes of representing knowledge. First, it includes human perception and intuition (HRP); second, it includes the data from sensors (CRP); third, it includes, implicitly contained in





Figures 3 and 4: The decay function applied to E. coli and pH parameters.

the HRP, opinions and preferences. The HCRP's human input (see below) is a crowd-sourced daily summary (median operator M) of the current perceptions of beach visitors collected in interviews.

For recreational waters, a generally accepted quality indicator is the presence or absence of fecal contaminants. The most common microbial indicator of pathogens in fecal matter is E. coli. The inability of E. coli to grow in water, combined with its limited survival time in water environments, means that the detection of E. coli in a water system is a good indicator of recent fecal contamination [8]. For this reason, GBF uses the presence of E. coli (and other measures people cannot detect such as pH, see below) in its evaluation algorithm as a corrective factor that can override human opinion. The HCRP follows the mean of current beach visitors' opinions as long as the sensor data from the array of independent parameters are within acceptable (as defined by the EPA in this case) risk levels. Otherwise the HCRP uses the results from the sensors to 'tune' the human perceptions of the beach.

The HCRP divides sensory space into human- and sensor percepts. Sensing modalities included on the sensor side should not be perceptible by people. This distinction is not always obvious. The common water quality measure of turbidity (visual clarity of the water), for example, is allocated to the human, not the sensor perception side in the current version of the spm calculation even though our sensors can detect it. Dissolved oxygen (DO) and pH, on the other hand, are examples of parameters that sensors can record but people cannot. For this reason, they are allocated to the sensor side of the equation. However, while DO is an excellent measure of the ecological health of a body of water, our data seem to indicate that E. coli concentrations are inversely correlated with DO. Because of a lack of independence, dissolved oxygen is not included in the current implementation of the spm formula, and we include only E. coli and pH on the sensor side. When the E. coli count is below 235 coliform forming units and the pH is between 5 and 10, for example, these sensor measurements have no effect on the resultant spm [Figs 3,4] . If, however, they are found to be outside of these boundaries, their product (a cumulative factor less than one) reduces the value of the human-side spm result. The resultant metric is called the *spm_effective* (the effective swimming pleasure measure, also a single number between 1 and 10) and it is an application-specific implementation of the general HCRP. The following equations describe the relationship between the HCRP, HRP, CRP and the SPM:

$$\mathrm{HCRP} = \mathrm{HRP} * \Pi(\mathrm{CRP}(i))$$

$$\mathrm{spm\_effective} = M(\mathrm{spm}_{\mathrm{water\_only}}) * \Pi(F(\mathrm{E.coli}), F(\mathrm{pH}))$$

An important property of the current approach is the fact that the decay function F operates with ranges (set around defined thresholds) and transition regions as opposed to thresholds (see sidebar). The spm algorithm uses the product of a series of exponential decay functions (specifically in the form of the Boltzmann function) to implement this. The decay function acts mathematically more in tune with human descriptions and perceptions of outdoor conditions ("a bit more, somewhat less"...) than thresholds that impose binary boundaries.

The swimming pleasure measures (spm, spm_water_only, spm_effective) are an invention aimed at formalizing an inquiry into how people in body and mind (as biological sensor and as subjective arbitrator) perceive and experience publicly managed recreational waters, and how such a metric might compare with other parameters that are usually collected and evaluated by environmental monitoring systems.

Numeracy and data sharing strategies

Part of our research was invested in experimenting with novel ways of sharing data that are hard to 'grasp' for non-environmentalists. One of the approaches we tried was the real-time display of all data collected by sensors and interviewers. As soon as a new data point was available, it was posted to the web portal, suggesting to visitors that the system was 'alive' and full of potential for more data in the future.

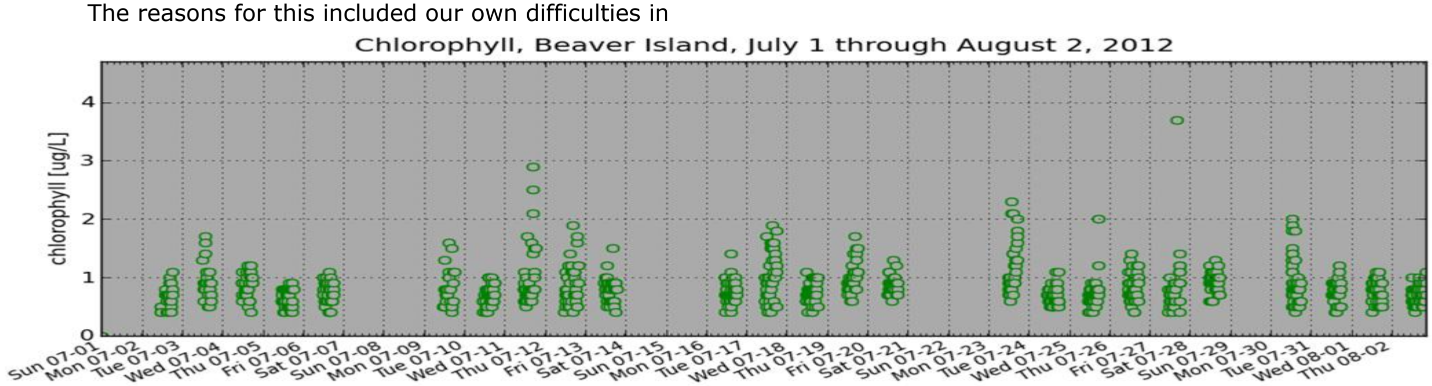
Our data management strategy let the data speak for itself, and offered context to those who seemed to desire it. The beach kiosk was always staffed with volunteers willing to explain the results to beach visitors. Furthermore, we implemented a 'bad data' policy centered on transparency, displaying all data. The reasons for this included our own difficulties in establishing the sources of some of the unusual data in real time. It is often only contextually (and hence after the fact) possible to decide what the causes of any particular 'bad data' might be. We also wanted to demonstrate to the beach visitors how things can go wrong and counter the myth of perfect data. This was one of the strategies we employed in the attempt to make our efforts believable [Fig 5].

Data analysis and interpretation

In order to see whether the proposed metric was effective we analyzed our spm_interview, spm and sensor data (containing for the Beaver Island location alone over 200 unique entries in 2010, and over 600 unique data entries in 2012) with different statistical tests [Table 3].

Surprisingly, analysis shows that no combination of our sensors from water chemistry; water biology and weather correlate significantly with the spm metric. While warm water and air were a given in our summer tests, wind, insolation, rain, turbidity and the non-perceivable parameters of chlorophyll, pH and E. coli were not.

Figure 5: completed figure of chlorophyll readings for the month of July, including some unusually high readings.



This suggests that the personal experience of the quality of the water while going for a swim is largely independent of how government agencies report on water quality. Additional analysis shows that the pleasure of being at the beach is, not surprisingly, significantly associated with the pleasurable experience of the water itself. Analysis also shows that there are significant differences between different beach visitor groups. For example, men and visitors (non-locals) were more likely to give higher spm scores. Teenagers were the most discerning beach visitors. They routinely offered lower spm scores.

Table 3: spm data analysis

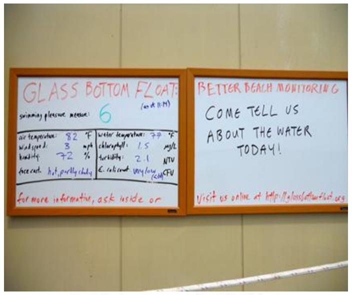
statement	test	evidence	year	sample size
there exists a positive relationship between spm and water odor	Kruskal-Wallis	p-value < 0.0001 p-value < 0.0001	2010 2012	N=203 N=664
visitors are more likely to give higher spm water scores than local residents	Wilcoxon rank sum	p-value = 0.0064	2010	N=32
men tend to give different spm water values than women;	Wilcoxon rank sum	p-value = 0.0193	2012	N=644
men are more likely to give higher spm water scores	Wilcox rank sum	p-value = 0.0193	2012	N=644
different age groups perceive the spm water differently;	Kruskal-Wallis	p-value = 0.0073	2010	N=200
teenagers are more likely to give lower spm water scores than adults	Kruskal-Wallis pairwise comparisons	p-value = 0.0008	2010	N=200
there is 95% confidence that 28% to 36% of people on the beach are concerned about the cleanness of the beach.	one sample normal test		2012	N=580

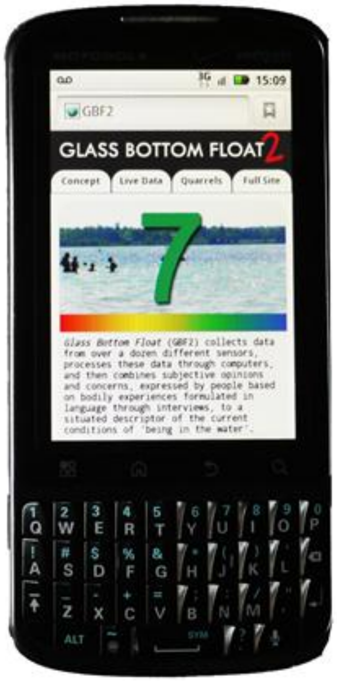
Most interesting however, is the evidence of a significant association between perceived water odor and the spm (spm and spm_water_only). This means that a significant conduit into the subjective experience of water quality and the pleasure of being at the beach and in the water is the water odor. While this might seem intuitive, it is an important result as the usual selection of physical water parameters for beach monitoring and environmental health of beach waters do not include water odor; it is not considered. Our data suggest that water odor is an important part of the pleasure of being at the beach and directly impacts people's intuitive perception of the health of a body of water.

New engagement strategies

Government agencies that collect water quality data are not visibly in action and disappear with their samples to the lab. Ubiquitous sensing need not result in the disappearance of those in charge of the sensing efforts. GBF placed a staffed mini-lab (the data kiosk) at the beach and allowed beach visitors unscripted observation of the water observers.

GBF also experimented with various data dissemination modalities. We combined ad hoc low-tech (hand scribbled signs) with high-tech (mobile media and the internet of things (https://cosm.com/feeds/68683)). We attempted to vary the depth of available information according to the affordances of the media and the sites of information consumption [Fig 6,7]. For example, we included on the mobile web some cursory information about our new beach quality metric, the swimming pleasure measure, reserving a full description for the desktop version of the website.





Figures 6 and 7: Data sharing strategies: scribbled notes and mobile media. The large number '7' is the then current effective swimming pleasure measure.

Furthermore, we considered event-based methods of information dissemination, including free public presentations that addressed a wide range of environmental monitoring topics, several of which the GBF effort was only indirectly related to. We called this feature the *Public Quarrels* series [Fig. 8]. They included weekly discussions, open to the public, between experts, activists and interested parties, often representing opposing positions (hence the term quarrels). The goal was to foster a slow-cooking but contentious 'idea factory' in which the novel monitoring efforts could be embedded and contextualized in unusual ways. We hoped for 'the unusual' to operate as a generator or attractor (not a spectacle). We timed the events to co-occur with the actual data collection – the sensors were in operation and undergraduate students were on the beach performing interviews as the *Public Quarrels* occurred. While it is difficult to assess success or failure of this aspect of the engagement strategy, it was apparent that the events left an impact on those who participated, with several visitors returning for multiple quarrel sessions.

Additional observations

Prior to 2012, our fecal contamination data were sourced from the state agency lab officially in charge of fecal contamination evaluation. In 2012 we incorporated a desktop bioincubator system to determine on site the E. coli concentration of the water at Beaver Island. Placing a bioincubator in a mobile lab at a public beach, collecting data more frequently than the official caretakers and making the data immediately available to the public was a novelty for beach visitors, beach management and operators alike. Without a doubt this intervention has disruptive potential.

Figure 8: One of the Public Quarrels at Beaver Island

GBF offered beach visitors an unusual amount of information on water conditions. In our discussions with beach visitors we found that while this increased their respect for our efforts, it also confused them to some degree. The fact that we had a staffed laboratory at the beach and were 'watching out' was perceived positively. We do know that the performative aspect of the various devices in action was an alien but fundamentally comforting addition to the beach landscape; it did not give the visitors the feeling that 'something was wrong with the water', but rather that 'something important was happening'.

We did not specifically ask how people felt about parameters they are not able to sense/detect versus those they could detect themselves. However, none of the 600+ 2012 visitors volunteered to comment on this

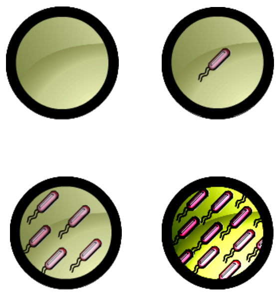


Figure 9: Sample of icons developed for the mobile phone denoting approximate E. coli levels: zero, low, medium (all below EPA mandated threshold) and high/dangerous level.

topic, leading us to imagine that it might not matter to them. But what we do know is that the data density acted for some visitors as a barrier. More than once we were asked to 'translate' the results to a simple "yes it is safe to swim" summary. The path we took to this (via the spm) was of secondary interest to them. When our they meant by and large 'clean water'. This we know because our survey asked visitors to pick one single word to describe a pleasurable swimming experience. The most frequent term used was "clean".

We were not able to collect information on how people responded to the mobile phone interface and the icon strategy we developed [Fig. 9]. Most people we interviewed at the beach were not using mobile media at the beach. Moreover, the mobile interface was really designed for people thinking about coming to the beach, not those already at the beach. We believe that more time would be required to let the usefulness (and limitations) of the devised mobile access approach really sink in. Our project was active for only four weeks during the summer of 2012, and the mobile interface in its final version was available only in the second week.

While GBF did deliver interesting insights on several Island, the new proposed metric that combined crowd-sourced perceptions of the water together with sensor increased popularity, it should have been tied more closely to the water feature people in the post-industrial landscape of Buffalo really care about: cleanliness. However, we are convinced that the basic concept, the idea of combining soft human-side data with hard sensor side data has real potential.

Even beaches have glass ceilings

On at least one occasion, our system was able to detect a significant E. coli related water quality problem before the beach operators knew of it. Despite our immediate reactions (placing the information on the web, emailing AND calling the beach management) there was no response from beach management. Luckily, the condition persisted for less than 12 hours. But what this experience did tell us in no uncertain way is that no clever information collection and management system can be truly effective if it is not tied in to the decision and authority structure ultimately making decisions (in this case on whether to close the beach or not). The barriers to influencing the decision structure occurred on multiple levels. The first barrier was created by the new time scale imposed by the GBF measurement regime. Beach testing usually operates on at least a 24 hour cycle, and intermediate data, even important data, will go unanswered in this current paradigm. The second barrier was the novel and untested bio-incubator system, and the third barrier was the crowd-sourcing of subjective data.

Beaver Island beach management was very generous in supporting our experiment. However, we remained suspicious from the beginning as to whether the beach operators really took our results seriously – seriously enough to entrust us with recommending a beach closure. Now we know. Overall, GBF was perceived as too alien to (and too inexperienced in) the existing water evaluation culture.

Public computational media

Without a doubt computational media are changing the way we engage with the environment. One lesson from

GBF is that this change could be an opportunity not just for 'improvements', but fundamentally new ways of organizing the care of the commons and the public realm at large. Some of these reorganizations come with the scale of global information systems. Also, the established approach to sustainability can and should change. What might such an effort require? Certainly it cannot be driven by computational opportunities alone.

Acknowledgements
We thank the volunteers (Aubrey Beckinhausen, Geraldine Dambreville, Meghan Heintz) and the staff at Beaver Island State Park for their support. This project was supported in part by the Intel Labs University Research Office for the Biosensors in Everyday Life Program, and the University at Buffalo.

References
[1] Böhlen, M., Atkinson, J., (2010), Ambient Intelligence at the Beach, Web Intelligence and Intelligent Agent Technology, IEEE/WIC/ACM, 3 Sept. 2010, 361–364.

[2] Bødker, S. (1996). Creating conditions for participation: Conflicts and resources in systems design, Human Computer Interaction 11(3), 215-236

[3] Burke, J., Estrin, D., Hansen, M., Parker, A., Ramanathan, N., Reddy, S., Srivastava, M. (2006). Participatory Sensing. In the Proceedings of the International Workshop on World-Sensor-Web (WSW'2006), ACM.

[4] Citizen sensor - DIY pollution monitoring, http://www.citizensensor.cc/

[5] Corburn, J. (2006). Street Science, Community Knowledge and Environmental Health Justice, MIT Press.

[6] DiSalvo, C., Sengers, P., Brynjarsdóttir, H., (2010). Mapping the landscape of sustainable HCI. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10). ACM, 1975-1984.

[7] Dourish, P. (2010). HCI and environmental sustainability: the politics of design and the design of politics. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10). ACM, 1-10.

[8] Edberg, S. C., E. W. Rice, R. J. Karlin, and M. J. Allen. (2000.) Escherichia coli: the best biological drinking water indicator for public health protection. Symp. Ser. Soc. Appl. Microbiol. 29:106S–116S.

[9] Foth, M. (Ed.) (2009). Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City. Hershey, PA: Information Science Reference, IGI Global.

[10] Goodchild, M.F. (2007). Citizens as sensors: the world of volunteered geography. GeoJournal 69 (4): 211–221.

[11] Midden, C., McCalley, T., Ham, J., Zaalberg, R. (2008). Using persuasive technology to encourage sustainable behavior. Workshop on Pervasive Persuasive Technology and Environmental Sustainability.

[12] Moore, K. (2006). Powered by the people: Scientific authority in participatory science. In Frickel, S. and K. Moore (eds). The New Political Sociology of Science: Institutions, Networks, and Power. University of Wisconsin Press.