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A socio-ecological autopsy of the *E. coli* O157:H7 outbreak in Walkerton, Ontario, Canada

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Abstract

The socio-political context of modern environmental health disasters tends to be defined as being outside the scope of official public health and epidemiological investigations into the causes of such disasters. On the other hand, popular accounts of these disasters tend to focus exclusively on the role of particular individuals and/or political actors, while minimizing the role of ecological factors. It is argued that an exclusive focus on either set of causal factors gives an incomplete or distorted picture of the origins of an environmental health disaster. In this paper, a socio-ecological analysis is developed to demonstrate how the largest outbreak of waterborne *E. coli* O157:H7 in Canadian history was the emergent product of a complex interplay and intertwining of social and ecological processes. The socio-ecological autopsy approach that is developed here traces the social and ecological chain of events that ultimately led to the outbreak and demonstrates, in particular, the need for investigative analysis to focus on the socio-ecological "incubation" of an environmental health disaster. Drawing from both the social sciences (particularly, the sociology of disasters and organizational sociology), and from the ecological sciences (particularly disease ecology), the analysis developed here responds to the call for the application of a more transdisciplinary approach to the study of contemporary environmental health problems.

Keywords: Disease outbreaks; Environmental health; Disaster incubation; Agroecosystem, new and emerging diseases; *E. coli* O157:H7; Canada

Introduction

One of the fundamental principles of disease ecology states that society and the natural environment form a dynamic and complex system at equilibrium. Within this context, it is argued that human-induced stresses on this equilibrium, such as large-scale changes in land use, will induce effects that reverberate throughout the whole system and promote the emergence and diffusion of new diseases (McMichael, 2001; Cohen, 2000; Haggett, 1994). In analyzing how exactly such stresses on the natural environment impact on public health, researchers such as Pedersen (1996) and Barrett (2001) suggest the development of a broader framework in which to situate the relationship amongst health status, development and environmental change. In this light, Mayer (2000) calls for an approach based on a "political ecology of disease" that combines elements of traditional disease ecology with concepts from political economy. Similarly, the "ecosystem health" perspective supports this type of expanded focus but also emphasizes the need to incorporate longer temporal scales and higher levels of organization into the analysis of public health issues (see for example: Ullsten & Rapport, 2001; Rapport et al., 1998; Waltner-Toews & Wall, 1997). In essence, it has therefore been argued that the study of contemporary environmental health problems requires a more historically informed approach that goes beyond the immediate and localized ecological and social circumstances associated with the particular problem under investigation. In response, the present study employs a "socio-ecological" perspective to trace the causal links involved in a recent outbreak of *E. coli*

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O157:H7 in Walkerton, Ontario. The analysis will merge ecologically based theories of population health with concepts from organizational sociology and the social scientific research on disasters to demonstrate that the outbreak was not simply an anomalous event limited to one point in time and place, but the emergent product of an extended set of processes that evolved over time and through different geographic scales of involvement at the political-economic, social and biophysical levels.

The development of a distinctly socio-ecological approach for the present analysis was inspired by Klinenberg's (1999) *social* autopsy of the 1995 Chicago heat wave. Klinenberg's analysis focused on how certain socio-political conditions associated with an urban setting represented *structural causes* that played an integral role in the number and types of casualties that resulted from the extreme heat. Briefly, these structural causes included: patterns of marginalization related to the literal social isolation of poorer, mostly African–American seniors (many of whom were afraid to leave their inner city homes or leave their windows and doors open because of the threat of violence); the degradation of low-income housing conditions in certain parts of the city that resulted in an increased heat exposure for the many tenants who could not afford air-conditioning; as well as radical shifts in the local government that led to deficiencies in the administration of municipal public health programs and services during the emergency response. In essence, the analysis revealed how the mortality pattern of the heat wave reflected the structural (and spatial) inequalities found in the city's built environment.[1]

It should be noted however, that unlike the social autopsy analysis of an urban built environment, the analysis of the Walkerton tragedy must consider a *rural* environment—an area that is much more dependent on its natural ecology because of the central role that agriculture and the natural environment have in relation to the life and livelihood of residents in such areas. For this reason, the analysis of the Walkerton outbreak must consider the nature of the modern "agroecosystem"—that is, the complex of domesticated plants and animals, biotic and abiotic elements of the underlying soils, drainage networks, natural vegetation and wildlife as well as the human activities in the rural area (Conway, 1987; Waltner-Toews, 1996a). The agroecosystem concept is significant to the analysis of the Walkerton outbreak because it highlights the need to focus on processes unfolding at both the natural and social levels. The present analysis therefore extends the notion of social autopsy to include the consideration of the ecological processes occurring within the agroecosystem alongside the socio-political dimensions of such a system (hence, the adoption of the term *socio-ecological* analysis).

Each of the two separate but interrelated sets of causal factors dealt with in this analysis draw upon different types of literature. The research concerning the ecological dimensions of the outbreak were based on recent academic articles on agroecosystems and disease ecology (particularly those focusing on new and emerging diseases); while information about the socio-political dimensions were primarily drawn from the report of the Inquiry Commission[2] established to investigate the tragedy as well as the account documented by the journalist Perkel (2002). I had also attended several of the Inquiry hearing sessions in Walkerton and followed developments through local media reports and via the Inquiry Commission's Internet site. The orientation in data collection was directed towards the identification of underlying socio-political and ecological processes that formed the contextual backdrop to the outbreak. Generally, the focus therefore was on what organizational sociologist Turner (1976) refers to as the "*incubation phase*" of a disaster—that is, the pre-disaster period during which certain organizational processes and factors that inadvertently permit a disaster to occur are allowed to *accumulate unnoticed* (without action) until the actual disaster onset (although in the present case the incubation phase will also include ecological processes).

The diverse structural factors that informed the disaster incubation may be thought of in terms of "upstream" and "downstream" causes implicated in the processual development of the outbreak. The upstream category includes those factors that contributed to the *source* of the outbreak, while the downstream set refers to those factors that *permitted* or allowed the outbreak to occur once the upstream processes were already unfolding. To assist in the analysis of the various upstream and downstream processes, the following Socio-Ecological Matrix may prove useful (see Fig. 1). For each of the two dimensions (social and ecological), the matrix incorporates three levels of analysis (i.e. micro, meso, and macro). Mayer (2000) warns us, however, that the development of any political ecologically based interpretation of environmental health problems is challenging because it will involve the analysis of complex patterns of intersecting elements that are difficult to represent in a simple scheme. Bearing

[1] For other examples of social autopsies of disasters in the built environment, see Ali (2002a) and Beamish (2000).

[2] The independent Walkerton Inquiry Commission was established on June 12, 2000 and was headed by Justice Dennis O'Connor. The Commission consisted of a legal team and a research advisory panel that was comprised of technical and academic experts. Technical experts, local and provincial government officials were called to publicly testify and be questioned by the legal team from October 2000 to November 2001.

Downstream --- Upstream

	Micro Level	Meso Level	Macro Level
Ecological Dimension	1 Individual Water Well; Extreme Weather Event	2 Regionalized Factory Farm Setting	3 Evolution of New and (Re)Emerging Diseases; Processes of Global Climate Change
Social Dimension	4 Operator Failure; Individual Farmer	5 Public Utilities Company; Government Agencies (MOE, public health); Private Lab Testing	6 International Political Economy (Neoliberalism); Agribusiness

Fig. 1. The Socio-Ecological Matrix.

this in mind, rather than serving as a definitive scheme, the Socio-Ecological Matrix is meant only as a guide or template to help organize the research endeavor in a systematic fashion and to reveal those areas that may require further study and/or consultation from different disciplinary experts. Furthermore, it is hoped that the matrix will facilitate the identification of the *unintended consequences* of human interactions with the environment; especially those that can accumulate in an undetected manner—thereby raising the potential for disaster.

Although the matrix presents the different causal factors as discrete categories, it is important to note that in actuality, there is considerable overlap and interconnectivity between the various cells. For the sake of clarity in presentation the analysis considers the ecological and social dimensions separately but will consistently draw attention to the relevant interconnections throughout.

Background: the E. coli O157:H7 outbreak in Walkerton

On May 23–24, 2000, close to 160 people in the small farming community of Walkerton, Ontario (located about 180 km north-west of Toronto; population 4800) sought hospital treatment while another 500 residents called into hospitals complaining of similar ailments such as bloody diarrhea, vomiting, severe stomach cramps and fever (Bruce-Grey-Owen Sound Health Unit, 2000). Several days later, through the epidemiological efforts of the local health unit, the cause of the illnesses was determined to be the contamination of a drinking water well by cattle manure containing the deadly *E. coli* O157:H7 bacterial strain (and to a lesser extent, *Campbylobacter jejuni*). By the time of this determination, however, tragedy had already beset the rural community as more than 2300 became ill and seven people eventually succumbed to their illnesses (Bruce-Grey-Owen Sound Health Unit, 2000). The outbreak was the first and largest documented outbreak of *E. coli* O157:H7 infection associated with a municipal water supply in Canada and represented one of the worst public health tragedies faced in this country.

The ecological context of the Walkerton outbreak: the emergence of E. coli O157:H7

Initial accounts of the Walkerton outbreak tended to implicate localized environmental factors such as the geophysical features of the landscape near the contaminated well (i.e. shallow overburden containing highly fractured rock) or flooding from the extremely heavy rains falling in the area for several days preceding the outbreak. As will be explained in more detail, such downstream accounts (Cell 1 of the Socio-Ecological Matrix) are inadequate because they do not recognize the significance of the wider ecological context in disaster onset, especially in regard to the emergence of disease (Cells 2 and 3).

Illnesses due to *E. coli* O157:H7 infection were first recognized as a public health threat in the 1980s after the occurrence of several sporadic outbreaks caused by foodborne transmission.[3] The spread of this pathogen in North America during that period coincided with the importation of infected cattle from Argentina—where the rates of human infection were previously about three times higher than those found in North America

[3] Since *E. coli* O157:H7 is found in the intestines of cattle, the bacteria may become thoroughly mixed into meat products during the grinding process, hence foodborne outbreaks of *E. coli* O157:H7 are commonly referred to as bouts of ''Hamburger Disease'' by the popular press.

(McMichael, 2001, p. 112. Usually a harmless bacterial strain present in the intestines of cattle, it has been suggested the potentially lethal variant of *E. coli* O157:H7 probably evolved four decades ago in the Argentinian cattle reservoir when the harmless variant of the bacterium acquired a gene from the deadly *Shigella* bacterium through a viral agent, thus resulting in the lethal form (Heymann and Rodier, 1997). The resultant strain soon became prevalent in key cattle-growing regions throughout North America and most of the current knowledge of the epidemiology of *E. coli* O157:H7 has been obtained through the investigation of outbreaks and studies of the prevalence of this micro-organism in the bovine reservoir (Nikiforuk, 2000a).

One important factor that accounts for the pervasiveness of *E. coli* O157:H7 is the virulence exhibited by this particular pathogen—an emergent trait that may be linked to large-scale changes to ecological conditions (Cell 3). Whittam et al. (1998, p. 163) contend that if a new strain of bacteria is to become an infectious disease, it must first be able to survive the media though which it is transmitted to human beings. This is clearly an important issue in considering the circuitous ecological pathway through which *E. coli* O157:H7 was transmitted to Walkerton residents; as the pathogen traveled from the intestines of cattle, through the surface water pathways, through the soils into the ground water pathways and through the constructed drinking water system to be ultimately consumed by the unfortunate human victim. Notably, *E. coli* O157:H7 has been found to be particularly well adapted to survival in extreme environments because of its' resistance to acid, salt and chlorine. As such, the microbe is able to live in fresh water or seawater and has the ability to withstand freezing or temperatures as high as 160°F (Schlosser, 2002, p. 201). Consequently, such adaptability has meant that *E. coli* O157:H7 represents a particularly menacing public health threat because it can spread through different types of media. In this context, a critical trait in the emergence of *E. coli* O157:H7 as a foodborne and waterborne pathogen may have been the evolution of acid resistance.

According to Whittam, McGraw, and Reid (1998, p. 164), the acquired tolerance to highly acidic environments can contribute to the overall durability of a pathogen by allowing it to remain viable in the environment external to the animal host, particularly in different types of inhospitable conditions. In this connection, it has been suggested that the acidification of natural soils and waterways through acid rain has had the effect of selecting for enhanced durability of pathogens, thereby fostering the spread of durable mutants of pathogenic strains which may then have the potential to emerge as new waterborne and foodborne pathogens (Whittam et al., 1998, p. 164). Specifically, in the case of *E. coli* O157:H7, the acquisition of the acid tolerance trait may have allowed this particular pathogen to survive the extreme conditions involved in food processing (in the case of foodborne transmission), the extreme conditions related to the natural water pathways (in the case of waterborne transmission), while also allowing the pathogen to circumvent the host's gastric acid defenses. The key point of the "acid rain hypothesis" proposed by Whittam et al. (1998) is that *human-induced* changes to the natural environment (such as the acid rain which arises from the mixture of water vapor with industrial emissions of sulfur dioxide and oxides of nitrogen) may be creating new selective pressures that foster the emergence of new pathogens. Moreover, since acid rain often precipitates down in more remote/rural areas (and away from the urban centers that usually produce the industrial emissions), it would seem plausible that agroecosystems would exhibit the required acidic conditions that could have prompted the evolutionary emergence of *E. coli* O157:H7.

The role of human activity (particularly industrial activity) in the *creation* of the pathogenic strain is still not conclusive in the case of *E. coli* O157:H7. The role of human activity and social conditions in the *transmission* capacity and the infectivity of the pathogenic agents is better understood. As alluded to at the beginning of this paper, pathogens, human beings and agents of disease transmission are all elements of wider and extraordinarily complex ecosystems, and changes to one of these elements may have important ramifications for the spread of disease. With this understanding, it would be expected that changes to an agroecosystem by human activities such as factory farming, would lead to subtle but nonetheless significant alterations to the transmission of diseases—for example, by making a particular area more or less suitable as a reservoir for particular types of pathogens (Haggett, 1994). Morse (1993) uses the term *viral traffic* to refer to the movement of pathogenic agents between species and between individuals and he argues that the *outbreaks of "new" disease result from the alterations in viral traffic that are induced by changes in the ecological, economic and social environments* (see also, Mayer, 2000). In particular, such changes may facilitate "zoonotic transfer" where pathogens cross over from the animal reservoir to the human reservoir. For example, deforestation (a social practice) brings humans into increasing contact with pathogens that have not yet entered the human ecology (Price-Smith, 2002, p. 158; see also: Patz, Graczyk, Geller, & Vittor, 2000; Mayer, 2000; Regush, 2000; Wilson, 2001). With increased contact, a species crossover is more likely to occur, as was the case, for example, with the HIV and Ebola viruses (crossing from the primate reservoir) and *Faciparum malaria* (crossing from the avian reservoir). In the case of *E. coli* O157:H7, the viral traffic is intimately connected to the bovine reservoir and for this reason a more detailed consideration of the factory farming of livestock is necessary to understand some of the broader ecological impacts associated with this practice as they relate to the development of a pathogenic outbreak (Cell 2).

Factory farming and E. coli O157:H7

Employing some 640,000 people, agriculture and food production represents the province of Ontario's second largest industry (OMAFRA, 2000). Notably, since the end of the Second World War, agricultural livestock farming has become increasingly industrialized resulting in far fewer farms with more livestock per farm. Moreover, there has been a trend towards the concentration of single industry operations in particular geographic regions, for example, in certain areas of Alberta, South Carolina and Iowa. Walkerton itself is located in an region with intensive agricultural operations as it is surrounded by six rural counties that have the highest density of cattle and hogs in the province (Statistics Canada, 2001). Typically each feedlot may have as many as 25,000 cattle grazing in an outdoor area the size of a city block and this degree of intensification of livestock agriculture stands in stark contrast to the family farm enterprises of the past which tended to about 60 heads of cattle and 20 pigs.

Factory farming is associated with outbreaks of outbreaks of *E. coli* O157:H7 because of the voluminous amount of animal waste that is generated in these operations—one cow may produce as much waste as eight humans, while one pig produces as much as three humans (Nikiforuk, 2000b). To gain an appreciation of the magnitude involved, consider that a feedlot tending to 25,000 cows produces more than 50,000 tonnes of dung which is more than the fecal matter produced by 250,000 humans (Nikiforuk, 2000c), while a factory farming operation with 10,000 hogs will produce the equivalent waste of a city with 40,000 humans (Bell, 1998, p. 77). Although intensive livestock operations produce as much waste as small cities, they do not have the rural equivalent of an urban sewage treatment facility. The manure is simply collected and confined to piles stored in relatively small parcels of land—called manure storage lagoons—until it is spread on agricultural fields as fertilizer. Because of the excessive amount accumulated, it is common practice to apply the manure to farm fields at levels that cannot be naturally absorbed by the soil or the crop land base, thus resulting in excess nutrients being carried away in the natural surface water runoff (Bell, 1998).

With reference to southwestern Ontario's cattle country, the association of the incidence of gastrointestinal disease and areas of intensified agriculture has been known to federal scientists since at least 1994 (Michel et al., 1999; Valcour et al., 2002); and past studies had found that nearly a tenth of the well water sampled on Ontario farms were contaminated by bacterial strains similar to *E. coli* O157 (Nikiforuk, 2000a). Furthermore, in the aftermath of the Walkerton outbreak, the local health unit discovered that all but 2 of the 13 livestock farms located within a 4 km radius of the contaminated well had animal manure containing pathogens such as *Campylobacter* and *E. coli* O157:H7 (Bruce-Grey-Owen Sound Health Unit, 2000:iii).

The advent of factory farming essentially established the ecological setting for the proliferation and spread of virulent pathogens in two major ways. First, large feedlots provide pathogens with hospitable habitat-niches (Waltner-Toews, 2001). Thus, Schlosser observes that:

> Feedlots have become an extremely efficient mechanism for "recirculating the manure," which is unfortunate, since *E. coli* O157:H7 can replicate in cattle troughs and survive in manure for up to 90 days (2002:202).

Moreover, the crowded conditions in which factory farm animals live effectively allow various pathogens to travel from one animal to the next in a very expeditious manner in the bovine reservoir, thus dramatically altering the viral traffic and ultimately increasing the likelihood of human contact with these pathogens. Secondly, animals raised in close confinement are likely to experience stress; are vulnerable to the rapid spread of disease; and are deprived of the beneficial health effects that come from the natural exercise of grazing. As a result, cattle raised under such conditions exhibit a greater incidence of illness and for this reason it has become common practice for factory farm operations to mix feed with "maintenance doses" of antibiotics at increasingly higher rates (Khachatourians, 1999, 1998; McGeer, 1998; Conly, 2002). The indiscriminate use of antibiotics may encourage the spread of the virus that carries the gene to produce Shiga toxins to other microbes—as indicated by the finding that there are now at least 60 strains of *E. coli* that produce Shiga toxins (Schroeder, Meng, & Zhao, 2002).[4] It is hypothesized that virulent strains (such as *E. coli* O157:H7) are better able to survive long enough to develop antibiotic resistance (Schlosser, 2002, p. 221; Cohen, 2000; Threlfall et al., 2000; Schroeder et al., 2002).

In continuing to the macro-ecological analysis of the Walkerton tragedy (Cell 3), it will be useful to situate the outbreak in the context of disease ecology at the global

[4] Approximately half of all antibiotics manufactured in the United States are routed into animal feed and antibiotic industry has been aggressive in the promotion of such practices (WHO, 2000).

level. Medical ecologists (for example, McMichael, 2001; Haggett, 1994) have argued that large-scale environmental impacts—such as: global climate change, the disruption of freshwater supplies and the continued loss of ecostabilizing biodiversity—may in fact be contributing to the rise of a new class of emerging infectious diseases—that is, diseases whose incidence in humans have increased dramatically during the last two decades or diseases that are spreading to new geographical areas across the globe (Price-Smith, 2002, p. 2). Thus, McMichael (2001, p. 112) notes that over the past 25 years there has been a dramatic worldwide increase in the number of diseases belonging to this new class of disease, including: rotavirus, cryptosporidiosis, legionellossis, the Ebola virus, Lyme disease, hepatitis C, HIV/AIDS, and Hantavirus pulmonary syndrome (see also Garrett, 1994). As alluded to previously, *E. coli* O157:H7 fits into this class of emerging diseases as this pathogen was not found in the North American context 20 years ago; in fact, Whittam et al. (1998) go as far as to remark that the evolution of *E. coli* O157:H7 represents a model case of a new and emerging infectious disease (see also Heymann and Rodier, 1997; Armstrong, Hollingsworth, & Morris, 1996).

It is quite often the case that the role of the macro-ecological context in environmental health disasters tends to be overlooked because localized events are considered in isolation. As a result, the macro-ecological patterns that could readily be identified by considering the aggregation of events are usually missed. For example, in the case of Walkerton, the heavy rain preceding the outbreak (one of the worst rainstorms experienced in the areas for a decade) was usually conceived as a unique extreme weather anomaly that contributed to the disaster onset. However, it should be kept in mind that drastic events such as this heavy rainfall may prove to be part of a more general pattern. In this connection, Price-Smith (2002, pp. 148–154) contends that macro-ecological processes, such as global warming, would theoretically be expected to generate increased frequency and intensification of extreme weather events. He goes on to note that extreme weather events, such as hurricanes, have already been implicated in the recent emergence of new infectious diseases such as outbreaks of hantavirus in the southwestern US and the West Nile virus in New York state. In light of such findings, it is probably prudent to be vigilant about such trends and to maintain an upstream orientation to the study of new diseases.

In sum, the above discussion highlights the fact that the ecological conditions necessary for the Walkerton outbreak to occur were in place for some time. To understand why the outbreak occurred at this particular place and time requires a consideration of those social structural developments that inadvertently permitted the underlying broader ecological processes to converge, thereby allowing the outbreak to manifest itself. As will now be discussed, these structural developments are embedded in various levels of social organization—particularly bureaucratic and political economic settings (Cells 4 and 5).

The socio-political and economic context of the Walkerton outbreak

Edelstein (1988, p. 7) observes that technological disasters (such as chemical spills, industrial accidents, etc.) are commonly attributed to human shortcomings such as corporate greed or government corruption. Corroborating this finding, Tierney (1999, p. 227) notes that typically the search for the causes of such disasters tend not to be wide-ranging and are usually limited to the identification of two major types of causes—the failure of the relevant physical/technical systems or "human error" (i.e. operator failure). However, as we have already seen with respect to the micro-ecological level of analysis, the effect of this individualistic search for blame essentially diverts investigative attention away from the relevant *structurally* informed antecedents of the disaster—and this may suit certain political purposes. For example, the premier of the province consistently emphasized the view that the Walkerton tragedy was solely the result of the technical incompetence of the local public utilities commission (PUC) manager and not in any way related to recent changes to the regulatory frameworks governing water monitoring and public health (Perkel, 2002). To some extent this emphasis on operator failure was warranted given that the Walkerton PUC manager had for some time been engaged in several malfeasant activities such as: falsifying water monitoring entries in the daily operating records, inaccurately reporting the locations where microbiological samples were taken, failing to monitor chlorine residuals on a daily basis, and failing to add adequate doses of chlorine disinfectant to the water supply (Walkerton Inquiry, 2002). Clearly such individual practices did contribute to the disaster onset. However, broader systemic questions still remained as to how these derelict practices were allowed to continue unnoticed over an extended period of time, without the proper regulatory enforcement of government safeguards for the protection of water infrastructure. As will be discussed later, these questions are particularly pertinent in light of the general neo-liberal based trends of provincial governments in Canada to reduce overall funding and services to a whole range of programs related to social assistance, housing, education, municipal and health care (Glouberman, 2001; Knight, 1998; McBride, 2001).

Investigations into technological disaster often highlight the inadequacy of organizational intelligence to identify and act upon potentially dangerous but avoidable developments (Turner, 1976). As such, the Inquiry Commission found that a number of Ministry of Environment (MOE) programs and policies related to the regulation and oversight of municipal water systems were deficient (Walkerton Inquiry, 2002, p. 4). Amongst other factors, the Inquiry Commission found serious deficiencies in the approvals program (i.e. for a well to be approved as a source of drinking water); the inspection program; and the water operator certification and training programs. In addition, the Commission found that the Ministry emphasized voluntary abatement rather than mandatory abatement, which meant that procedures for the chlorination and monitoring of drinking water were to be followed on a voluntary basis. As such, violations of regulatory procedures related to water systems management were not met with legal sanctions.

It has been found that many recent outbreaks of *E. coli* O157:H7 have occurred in small water systems where financial resources preclude the use of sophisticated equipment and the highly trained personnel generally found in their larger city counterparts (Nadakavukaren, 2000, p. 602). Furthermore, the relatively sparse populations residing within rural areas generate a smaller tax revenue base (relative to urban areas)—as a result, less public funds are available for investment and improvement of local infrastructure and public works projects. In the case of the Walkerton municipality, such resource limitations were exacerbated because of the trickle-down effect of government imposed budget cuts to the Ministry of Environment (MOE) in 1996. Forced to work on a reduced budget, the MOE introduced certain changes related to the monitoring and oversight of drinking water supplies—changes that had significant impacts on the disaster incubation in Walkerton. First, whereas previously the MOE laboratories had conducted all routine drinking water tests for municipal water systems throughout the province, with the imposed budget restrictions, such testing was to be completed by private laboratories hired by the individual municipality. Consequently, the municipality was forced to assume the costs of this privatized testing (Perkel, 2002). In effect, this meant that the financial costs of monitoring a community's drinking water were "downloaded" from the provincial level to the municipality. Such additional imposed costs were particularly problematic for the Walkerton PUC. In competing with other small towns for new residents, businesses and industries, Walkerton was previously able to offer a major selling point—it had the cheapest water rates in the area (Perkel, 2002). This was despite the fact that the water side of the utility company was losing money, although the hydro-electricity side of the operation was generating adequate revenue (Perkel, 2002, p. 30). Thus, any additional financial costs associated with the water monitoring functions of the municipal utility company could not be readily assumed by the Walkerton PUC at that time.

Further impacts from the privatization of water management stemmed from the fact that the private environmental laboratories hired by the municipalities to do their testing were not government regulated. Consequently, there were no enforceable guidelines in place to govern the quality of the water testing nor did any standard requirements exist in regard to the qualifications or experience of laboratory personnel (Walkerton Inquiry, 2002). In addition, the provincial government made no provisions for the licensing, inspection, or auditing of the private laboratories that were hired by the municipalities to do their water testing. For example, the private laboratory hired by the Walkerton PUC was not accredited to test for bacteria. Nevertheless this private laboratory accepted and tested the water samples from the Walkerton utility company (Perkel, 2002, p. 52).

By implementing a policy of downsizing and privatization (despite protests from some ministry officials), the Inquiry found that the provincial MOE put less priority on its role in overseeing municipal water systems. Consequently, the number of inspections conducted by the MOE, the number of site visits and other contacts between MOE officials and municipal water officials, all decreased dramatically from 1996 onwards (Walkerton Inquiry, 2002).[5] A further ramification of the privatization of water testing involved the disruption of the regular and routine pattern of communication between the municipality, the MOE and the local Medical Officer of Health. Prior to privatization, government laboratories were legally required to report any adverse water test results to al1 three parties, and if necessary, the local Medical Officer of Health could issue an official "boil water" advisory. After privatization, however, the private laboratory testing facilities were not legally obliged to follow this reporting procedure. The private laboratory was only responsible for forwarding the results to their client—namely the municipal public utilities company. As a result, both the MOE and the Medical Officers of Health were effectively "left out of the loop." Such changes in the chain of communication may have contributed to an avoidable delay in the identification of *E. coli O157:H7* as a source of contamination during the emergency

[5] From 1994 to 2000, annual planned inspections for the Walkerton region decreased from 25 to 10; the number of annual actual site inspections decreased from 16 to 10; while the amount of employee resources expended on municipal water requirements decreased from 10.17% to 5.12% (on a province-wide scale, the number of inspections fell by 50%) (Walkerton Inquiry, 2002).

response phase of the Walkerton outbreak (Walkerton Inquiry, 2002).

The above review of developments at the meso-level of the Walkerton outbreak highlight the importance of incorporating the study of organizational processes in the analysis of an environmental health disaster—and it is at this level of analysis that organizational sociology and disaster research can perhaps make their most useful contributions. In this light, Turner (1976) explains how certain tendencies that occur within an organizational setting can contribute to the social foundation of a disaster. These tendencies include: rigidities in institutional beliefs, the neglect of outside complaints, the failure to comply with regulations, a tendency to minimize the emergent danger distracting decoy phenomena, and multiple information-handling difficulties, (see also Vaughan, 1996). From what has been reviewed thus far, it is clear that many of these tendencies were evident in the Walkerton case. One such example involves the Inquiry finding that the PUC manager repeatedly ignored Ministry warnings of high bacteria counts. The reasons for such neglect may be related to the institutional culture and system of informal norms that prevailed at the Walkerton PUC. Namely, the belief that the Ministry was being unnecessarily strict in their requirements for chlorine—an institutional view that was perhaps influenced by the fact that many citizens complained to the utilities company about the poor taste of the drinking water when chlorine was added (Perkel, 2002). It was apparent therefore that the monitoring of chlorine levels was not a priority for the utility. The development of such a view was likely to have also been influenced by the practices of the former PUC manager (who had trained the manager at the time of the Walkerton outbreak)—an individual found to have falsified the chlorine levels on water well logging sheets in order to keep the Ministry ''off his back'' (Perkel, 2002, p. 34).

Institutional inertia also prevailed on the Ministry side. For example, the MOE inspector involved in reviewing the Walkerton water monitoring records recommended on several occasions that the regional MOE office issue a legally binding order on the Walkerton PUC to raise their chlorine levels. Her requests were repeatedly rebuked because as Perkel notes:

> The culture that infused the Owen Sound office amounted to an unwillingness to rock the boat. Asking for voluntary compliance with guidelines had been for years the ministry's preferred method of dealing with problem waterworks. (2002:35)

In turn, this strategy of voluntary compliance could be attributed to a general government reluctance to impose costs or restrictions on businesses because of the view that such impositions would jeopardize opportunities for economic growth. Thus, Weale (1992; cited by Novek, 2003, p. 13) has found that widespread noncompliance with environmental guidelines is surprisingly common because monitoring and enforcement tend to lag behind the intent of regulatory policy. As a result, an ''implementation deficit'' develops and firms are able to carry out their ''business as usual'' until some indefinite point in the future.

Finally, warnings signs may be also be missed because institutional actors become distracted by other problems. For example, the government imposed deregulation of the electricity market created addition problems that the Walkerton utility had to address. To meet a government deadline, utilities companies in Ontario had 2 years to come up with their own plans to deal with the restructuring. Consequently, the Walkerton PUC manager was forced to set aside activities related to the everyday workings of the PUC related to water monitoring and attend an endless number of meetings that dealt with issues stemming from the deregulation of electricity (Perkel, 2002, p. 41).

The organizational processes reviewed above did not occur in a vacuum since organizations themselves are embedded in a larger social context. As such, the day-to-day activities of organizations will be influenced by wider social forces, such as the international political economic processes that encourage the adoption of neo-liberal policies based on privatization, deregulation and downsizing. Furthermore, these international political-economic forces will have significant impacts on the biophysical environment by influencing the nature, type and scale of economic activities that are pursued at the local level.

The international political economic context of the Walkerton outbreak

According to Bebbington and Batterbury (2001), any explanations of the modern transformation of the rural environment must take into account the dynamics of international agribusiness. This is because transnational market forces can impact the landscape of an agroecosystem by directly and non-directly influencing the land use decisions made by rural communities. For this reason, an understanding of the macro-social context of the Walkerton outbreak (Cell 6) will require a consideration of how the local land use practice of factory farming is related to the globalized capitalist system.

The rapid emergence of intensified livestock operations in the North American context was fueled by several developments at the national and international levels. First, to meet the demands of the burgeoning fast food industry, new large-scale methods of raising cattle were required. In light of the post-war success of industries based on the assembly line (i.e. Fordism), it is not surprising that agribusiness soon applied mass production techniques to livestock farming. Ritzer (1996) notes that Fordist practices are based on the guiding principles of efficiency, calculability, predictability and control; and all of these can be found in large factory farm operations (as well as in the associated meatpacking firms).

Second, the movement towards intensified livestock operations was supported by government efforts to create a market for surplus grain (Schlosser, 2002). Shortly after the Second World War, farmers started to feed grain to their cattle, and as a result, the animals were no longer free to roam and graze on large parcels of land (such practice would be considered as inefficient in accordance to Fordist principles). To further encourage grain-feeding, government subsidies ensured that grain prices were kept low. As a result, the practice of feeding grain to a large number of animals confined to a relatively small enclosed area soon became the standard practice of the beef industry.

Third, during the 1980s, the remaining smaller scale family farms were facing a profitability crisis as declining commodity prices, land price collapses, and increased global competition and trade wars were threatening their survival (Hall, 1998)—thus further establishing the economic conditions necessary for the domination of cattle farming by industrialized livestock operations. Furthermore, this period of time witnessed the rise of an increasingly globalized neo-liberal agenda that furthered the interests of large-scale factory farms. Thus, Novek (2003) notes that provincial governments in Canada had actively promoted the expansion of intensified livestock operations for some time, while exhibiting a reluctance to impose regulatory restrictions on farmers due to the associated financial costs.

In sum, by promoting the switch from traditional livestock farming to factory farming, international agribusiness and the pursuit of a neo-liberal political agenda have combined to exert significant upstream influences in the creation of the ecological conditions necessary for the emergence of such pathogens as *E. coli* O157:H7 in rural communities. Thus, Waltner-Toews (1996b, p.180) notes that:

> We have created unprecedented evolutionary opportunities for microorganisms, and they have been quick to take advantage of them… [T]hrough specific economic incentives given to agriculture we have created opportunities for a wide range of agents to have catastrophic effects on human, animal and ecosystem health. The particular agent is less important than the ecological niche it fills. (1999b:180)

The final sections of this paper discuss some of the general implications that can be drawn form the socio-ecological analysis of the Walkerton outbreak.

The emergence of the rural health penalty

The socio-ecological analysis of the Walkerton outbreak gives some credence to Pedersen's (1996) contention that large scale structural determinants, such as globalization, climate change, and stresses on terrestrial ecosystems, are interacting with micro-scale determinants of the local milieu to produce significant changes in the ecology of disease. In addition, as alluded to at the beginning of this paper, the need to recognize these interconnections between the social and ecological settings, as well as between the different scales (i.e. micro, meso, macro), presents unique problems for conventional disease ecology and draws attention to the limitations of current methods used to study environmental health problems. In this connection, Wilson (2001, p. 287) observes that conventional epidemiological analyses tend to be inadequate in the study of modern environmental health problems because they describe existing patterns of disease exclusively in terms of person, place and time. In particular, traditional epidemiological approaches tend to adopt a downstream orientation. As a result, they are apt to miss important features of the temporal or spatial scale over which ecological changes influence the evolution and transmission of pathogenic agents. In responding to this inadequacy of approach, Wilson proposes a strategy of *eco-epidemiological* surveillance—that is, epidemiological studies geared to long-term data gathering with a "renewed commitment to and respect for naturalistic observations … aimed at understanding mechanisms and processes of environmental influences on infectious disease" (2001:317). For example, as relevant to the present case, eco-epidemiological surveillance could involve the development of techniques for the careful monitoring of the environmental impacts of factory farming. At the same, with the use of a socio-ecological matrix, the eco-epidemiological surveillance approach could trace these impacts to changes in those social, economic and health policies related to agroecosystems. Such a technique would be especially useful in the identification and response to possible threats in rural regions as these areas are not commonly subject to public scrutiny—a point which will now be addressed in further detail.

Social scientists have documented that certain areas of a city readily provide a setting for the collection of situations and circumstances, that under certain conditions, can have disastrous consequences for the health of human populations (see for example, Ali, 2002a,b; Couch and Kroll-Smith, 1991, 1985; Fitzpatrick and

Lagory, 2000, p. 10). In this context, the American College of Physicians have note that city-dwellers may be susceptible to an "urban health penalty"—the confluence of circumstances that lead to poor health in the inner city, and including those conditions related to poor nutrition, poverty, unemployment, deteriorating housing, violence and the loss of services (Link and Phelan, 1995; Fitzpatrick and Lagory, 2000, p. 8). The convergence of upstream and downstream factors that led to the disaster in Walkerton indicates that in the contemporary era we may be seeing the rise of an analog to the urban health penalty—namely the "rural health penalty". The rural health penalty is intimately connected to the changing social and biophysical conditions of the modern agroecosystem that increase the disaster potential of these areas. That is, the conditions of existence in relatively remote areas are perhaps leading to an increased vulnerability of rural residents to particular types of environmental health problems—for example, exposure to new and emerging diseases;[6] impacts of industrialized agriculture such as exposure to chemical pesticides and herbicides; as well as exposure to acid rain originating from industrial pollution from cities. The implication is that the rural setting will increasingly represent a new and important setting for the convergence of global social and ecological forces, thereby serving as the springboard for new types of environmental health disasters within modern society. This type of understanding of rural health problems is particularly important in light of the view expressed by the noted sociologist Erikson (1991) who notes that disasters:

> In a sense, are really no more than locations of unusual density, moments of unusual publicity, involving perils that are spread out more evenly over all the surfaces of the earth. An acute disaster offers us a distilled, concentrated look at something more chronic and widespread. (1991:27)

Erikson reminds us therefore, that environmental health disasters, such as the Walkerton outbreak, may very well represent warning signs of the existence of a broader, insidious trend occurring in rural regions—particularly in light of similar instances in the recent past, including a outbreak of *Cryptosporidium* in North Battleford, Saskatchewan where over 300 people became ill in April 2001 (CBC Online, 2001).

[6] It is worthwhile to note that not only are rural residents particularly vulnerable to infection by *E. coli* O157:H7, but, to a whole host of other new and emerging pathogens associated with food production in general and factory farming in particular. Thus, Waltner-Toews (2001, p. 19) notes that new epidemiological patterns of foodborne diseases are already in evidence with regard to: bovine spongiform encephalopathy, antibiotic-resistant bacteria and *Salmonella* DT 104.

The Walkerton outbreak and complex systems

As a final point of discussion it will be useful to consider the nature of complex systems and the relationship of these to disaster incubation and the socio-ecological approach in general. The multi-faceted development of the Walkerton outbreak essentially illustrates the "interactive complexity" of the contemporary socio-ecological system. That is, how disasters may arise when independent processes unfolding at different levels converge and interact with each other in unexpected ways (Perrow, 1984). Interactive complexity is characteristic to all complex systems where a multiplicity of events occurring at roughly the same time (but not necessarily in the same place) can converge to catalyze a disaster. In the case of Walkerton, these events included the many factors identified in the Socio-Ecological Matrix. The existence of multiple processes acting at different levels and scales makes it difficult to capture and effectively deal with the interactive complexity of a socio-ecological system. One way forward is to adopt an analytical approach that respects the whole and does not engage in an overly reductionist approach because as Glouberman warns:

> Attempts to simplify complex systems, like the supply of safe water, can increase the risk of disasters, because the simplification process often ignores events that might stabilize or destabilize the system. (2001:48)

Thus, Glouberman (2001, p. 48) notes that efforts such as streamlining the provincial system of water regulation and monitoring, or simplifying the reporting procedure for adverse water test results, essentially led to the increased potential for disaster to occur in Walkerton. For example, the loss of check points or stabilizing agents within the complex regulatory system is seen in regard to the strategy of voluntary compliance to water regulations. This is because the accepted practice of voluntary compliance led to the failure to establish a check point that would ensure that public safety regulations were met by the utilities company. A second example was the elimination of the requirement to report adverse water test results to the Ministry of Environment and the Medical Officer of Health. This omission essentially eliminated a key check point or stabilizing agent needed to ensure proper response in case of water contamination (Glouberman, 2001, p. 38).

In conclusion, perhaps at the very least, the lesson to be learned from the socio-ecological analysis of the Walkerton case is that in contemporary times we have changed the nature and character of our environment. Under these circumstances, greater vigilance and care is needed to identify and respond to the newly emerging health problems that emanate from the environmental changes. The analysis of these changes is particularly vexing in contemporary times because large scale changes in the Earth's environment are generating complex challenges that we can barely understand. As a consequence, Homer-Dixon (2001) notes that we may now be facing a pressing "ingenuity gap" in which a vacuum exists between the requirement for ingenuity and the supply of ingenuity (i.e. our delivery of ideas in response to these problems). By focusing on the identification and analysis of the wide-ranging institutional and biophysical factors that lead to the development of environmental health disasters, it is hoped that the adoption of a socio-ecological analysis will help unravel the complexity so that progress can be made towards closing the ingenuity gap—so that ultimately, preventative measures can be taken in the future.

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