Camera Group A – Groundwater report

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Introduction

The WHO/UNICEF 2000 Global Water Supply and Sanitation Assessment stated that only 47% of the population of rural areas in Africa, 62% in Latin America, and 75% in Asia have access to safe water. The predominant source of safe water in many of these rural areas is shallow groundwater. However, increasing global concern over the safety of these water supplies has arisen due to the increased detection of toxic organic chemicals and high levels of pathogenic microorganisms. Globally, the assurance of microbial safe water has been the priority. In the groundwater sector, this has however historically been assured through reliance on good engineering practice and safe distance from fecal sources.

A wide range of measurable characteristics, compounds or constituents can be found in water and may affect its quality. They fall into several categories:

- Physical
- Microbial
- Chemical, including
- Inorganic chemical.
- Organic compounds.
- Pesticides
- Radiological.

Appearance, taste and odor are useful indicators of quality because they are generally the characteristics by which the public judges water quality. However, water that is turbid or colored, or has an objectionable taste or odor, may not be unsafe to drink. Conversely, the absence of any unpleasant qualities does not guarantee that water is safe. The safety of water in public health terms is determined by its microbial, physical, chemical and radiological quality; of these, microbial quality is usually the most important. The ground water model presented in this case study discusses pathogen and

other chemical exposure from contaminated water sources and the minimization of pathogen exposure.

Ground water contamination case summary

<u>Situation:</u>

A hydrological investigation was requested on December 1st, 2001 in a hamlet community, located in the vicinity of the Ottawa, Ontario area, by two local families (identified as home 41 and 42). The families complained of a water quality problem related to a manure odor coming from their private water well and made suggestion that the water quality problem may be associated with the adjacent barnyard of home 50. No illnesses were reported in home 41 or 42.

<u>Homeowner 50:</u>

Lot 50 is a farm that is located directly north of homeowners 38-42. This homeowner has operated a barnyard /feedlot operation since 1990 that houses approximately 75 cattle on site. A shallow dug private well supply at this location supplies water to cattle.
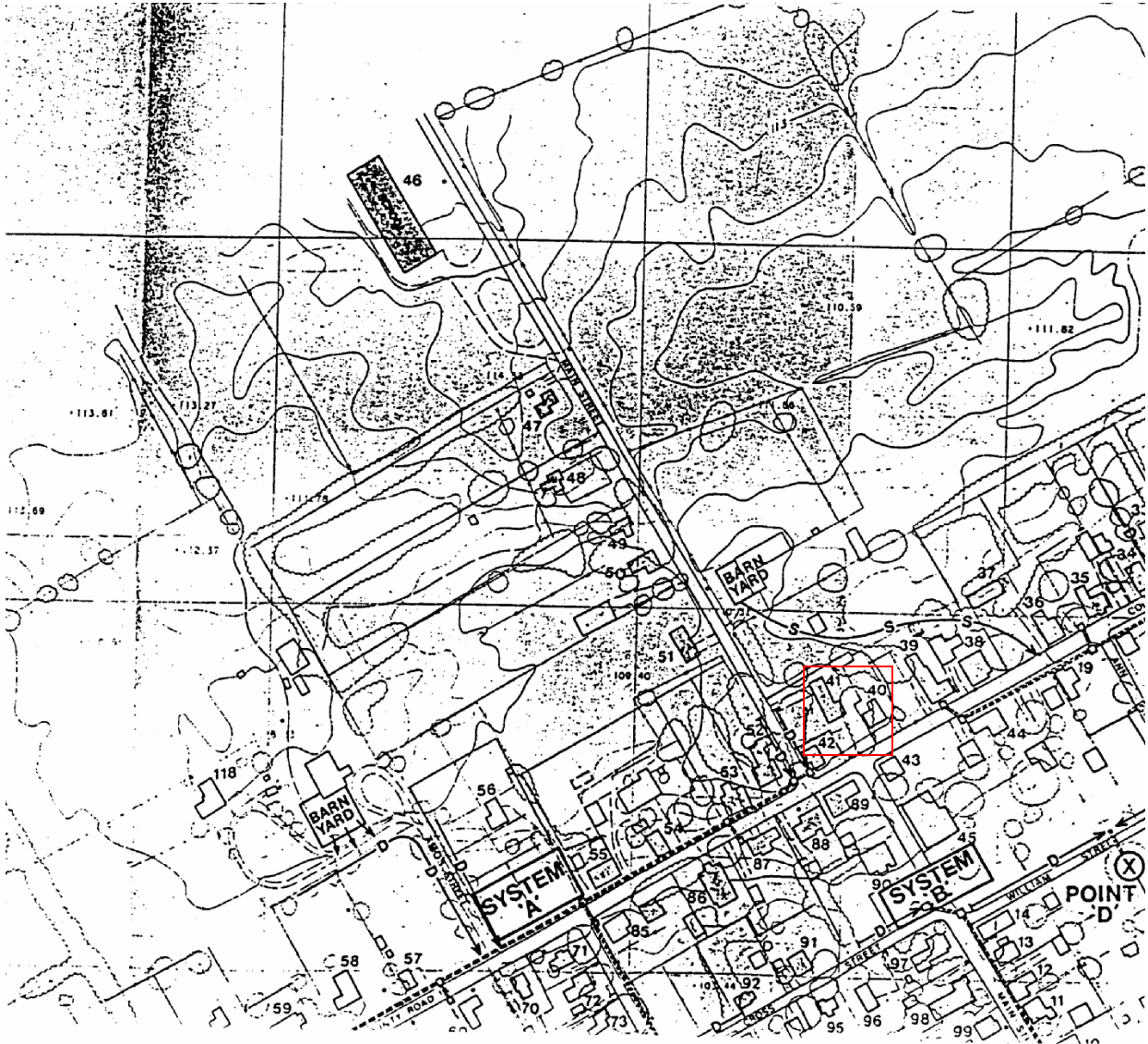
<u>Homeowner 42:</u>

Homeowner 42's well located 1.2 meters south of the pasture field. Cattle's manure was located within 2 meters of homeowner 41's well. No water well record is available for this homeowner.

<u>Homeowner 41:</u>

This parcel is located immediately east of homeowner 42 and has a drilled well located at 15.2 meters and is completed into the Precambrain shield granite. The well is cased (with cement grout) from ground surface to 7 meters below ground surface. This homeowner has on site an ultraviolet light treatment unit to remove bacteria, but it was established through personal interview that the unit is not operational at all times. This parcel has an overburden that is approximately 3.0 meters thick. Both home 41 and 42's wells meet the provincial standard but not upgrade as most other families did. Water

samples were collected from home 41, 42, 50 and other nearby homeowner's wells. The laboratory results indicated sewage waste, cattle manure and/or naturally occurring soil bacterial as potential sources of contamination. Although no contamination record exists for homeowner 41 and 42's wells, both homeowners indicated long term (6-10 years) water quality problems related to manure odor.

Figure 1. Case study site map.

Site:

Land-use in this area is mixed and is comprised of both agricultural and small residential land-uses. Homeowners have private drinking water wells and private septic

tanks located on their properties that supply water and provide sewage disposal. Water well records indicate that the wells were originally constructed in the 1950's and that most are drilled wells. There were some wells no longer in use noted within the study area. The local topography slopes from north to south, and as such overland surface run-off flows from the north to the south draining into a swale, which leads to a creek that ultimately discharges into a lake. The overburden consists of till deposits comprising of boulders, cobbles sand and silt. Bedrock underlying the overburden material consists of Paleozoic limestone and shale formations in the study area. Water well records indicate that the bedrock is approximately 6-9 meters thick, below which Precambrian shield meta-volcanics and meta sediments. The bedrock in this area slopes from northwest to south east. Fracturing in the upper meter of the bedrock was reported. Three aquifers are located within the pore spaces of, sand and gravel overburden deposits, the upper fractured zone of the bedrock surface, fractures in the limestone bedrock and fractures in the Precambrian shield bedrock. Test well records indicated that these were located at 14.8, 19.8 and 20.4 meters below the land surface (overburden). Groundwater is created and recharged by precipitation events.

Case study water sampling data:

Water sampling from the wells of homeowner 41 and 42 both indicated evidence of bacteriological contamination as seen in Figure 2. Nitrite concentrations were also elevated beyond normal background level suggesting farming or other sewage related contamination as seen in figure 3. Water sampling was conducted regularly only after the compliant was filed in December (2 sampling points). Before the formal compliant was filed only one well water sample was taken per years for homeowner # 41; 1990, 1993, 1998 and homeowner # 42; 1990 and 1997.

How clean is clean drinking water: Canadian drinking water guidelines

The maximum acceptable concentration (MAC) for coliforms in drinking water is zero organisms detectable per 100 mL. Because coliforms are not uniformly distributed in water and are subject to considerable variation in enumeration, drinking water that full fills the following conditions is considered to be in compliance with the coliform MAC.

1. No sample should contain more than 10 total coliform organisms per 100 mL, none of which should be *Escherichia coli* or thermotolerant coliforms.

2. No consecutive sample from the same site should show the presence of coliform and other microorganisms.

3. There should be no human enteric viruses or viable protozoa (e.g., *Giardia*).

F**igure 2. Well water microbial data for # 41 and # 42.**
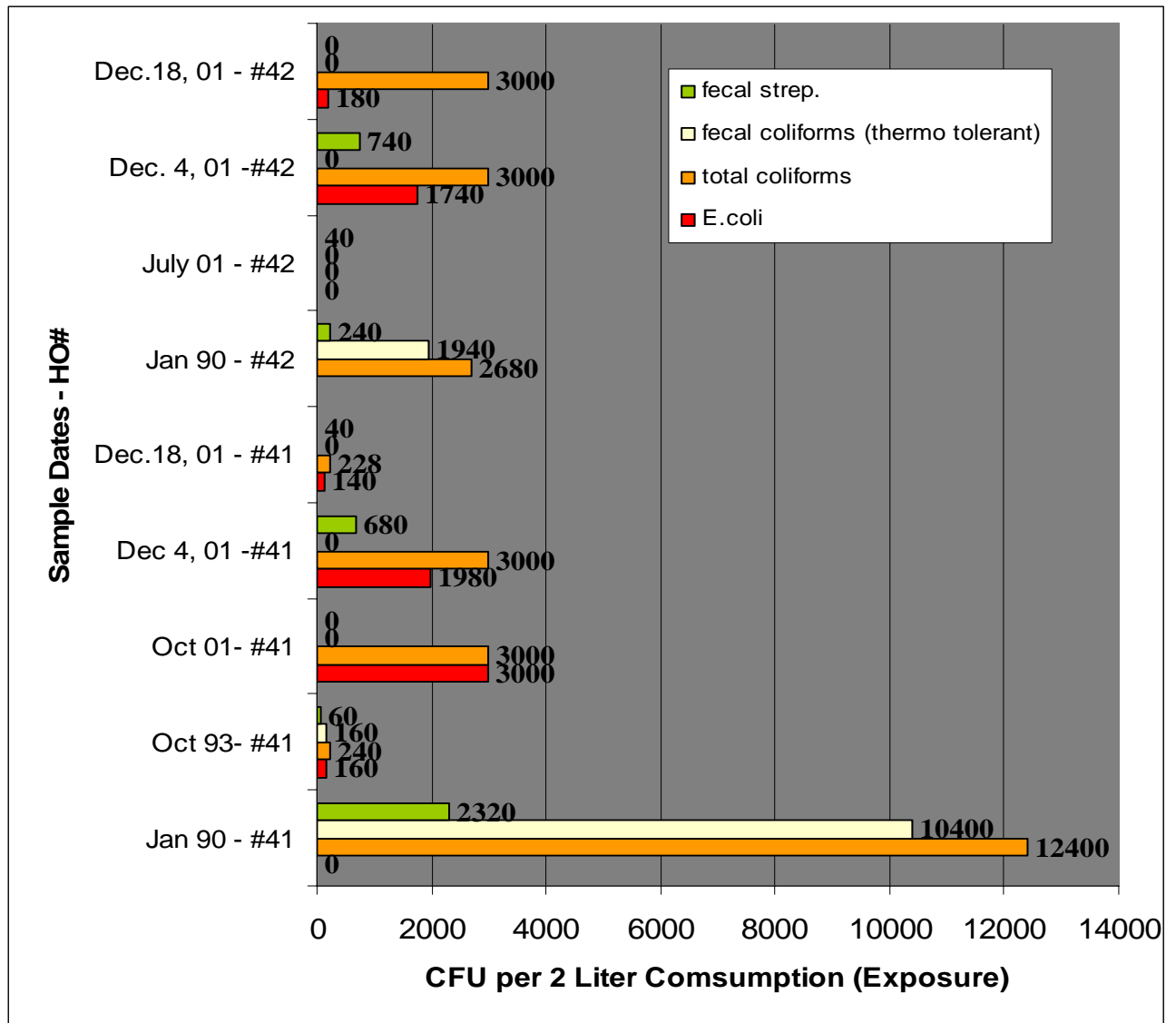
Figure 3. Well water nitrate, phosphorous and BOD levels for # 41 and # 42.
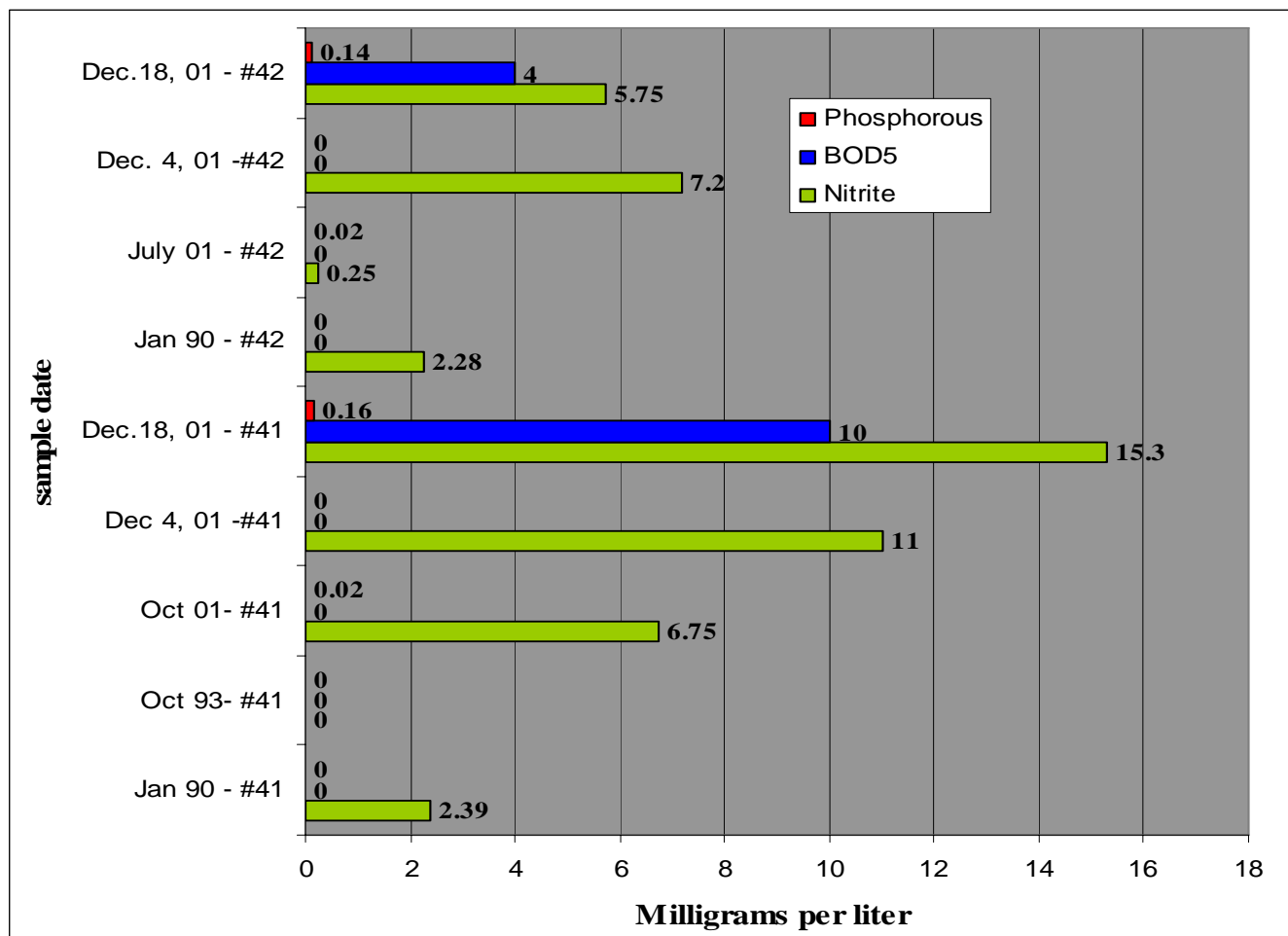
Risk Framework section

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Three flowcharts (Figures 4 to 6) were constructed to visually depict the framework proposed for assessing the risk of infection and complications (including death) from *E.coli* O157:H7 ingestion from contaminated groundwater. Figure 4 shows

the framework for the risk from bovine feces deposited on the ground surface and leaching *E.coli* O157:H7 (*E.coli*) into the soil matrix and eventually into the groundwater aquifer during a small to moderate rain event. There are actually three aquifers capable of transporting groundwater and thus the contaminants as well, however, it is known that site 41 (one of the complainants) is screening only the limestone aquifer, therefore, this is the one that will be considered in this framework structure.
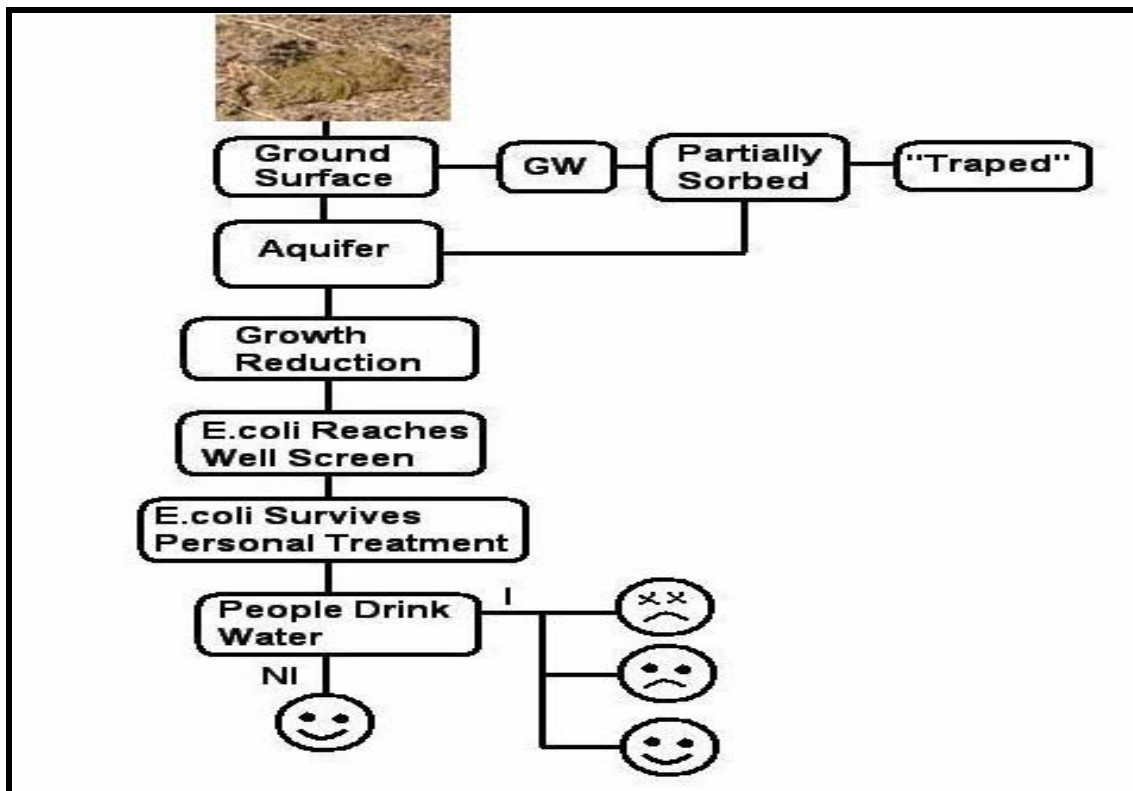

Figure 4. Proposed risk assessment framework for small to moderate rain events.

In Figures 4 and 5 there are various sinks for the *E.coli* to be deposited as it infiltrates the ground surface and percolates towards the aquifer. The aquifer as mentioned afore is made of fractures limestone, and the water is obviously having an effect of dissolving this slightly since homeowner 41 has installed water softening treatment process. Since obviously some of the limestone is being eroded or dissolved as water flows through the aquifer this will also allow for a pH change slightly raising the pH from the carbonate (CO_3) being dissolved with the limestone ($CaCO_3$). This ph change will have an affect on the *E.coli* growth while traveling through the aquifer (increasing growth). *E.coli* concentration will increase at a faster rate when entering through infiltration and percolation (avoiding adsorption to the soil matrix). One of the

data gaps preventing a full quantitative analysis is the soil characteristics that would allow explanation of the absorption potential, allowing for the calculation of approximate concentrations that would be available to percolate into the aquifer.
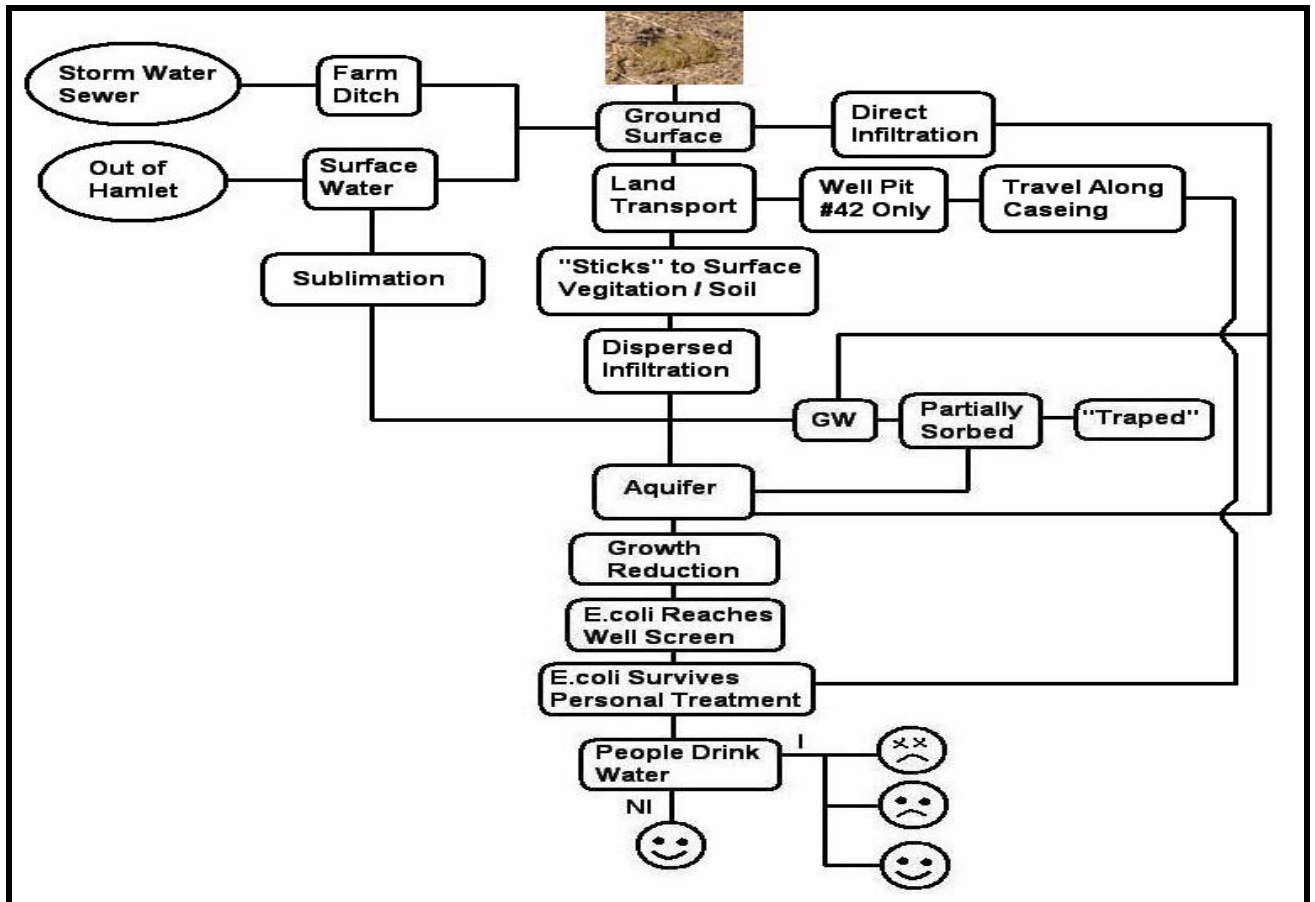
Figure 5. Proposed risk framework for large rain events.

There is doubt as to the cause of the fecal contamination of the well water, since there are septic fields relatively near the water wells. So there is a relatively easy way of determining if there is septic contamination. This is a deterministic approach, if there is caffeine in the water sampled from the well, since cows do not use caffeine this could only be indicative of human fecal contamination. If there is caffeine present in the well water, then determining the drawdown from the well will show from the radius of the drawdown which if any septic tanks are within or near enough to that radius which is leaking or overflowing could cause human fecal contamination. For this reason a tracer study must be performed by sending the tracer through the waste plumbing system and

monitoring the pipeline to the septic tank, the septic tank and the pipeline to the drain field. If this tracer study does not show any leakage from the pipelines or the septic tank then the drain field should be examined (excavation) to determine if there is clogging allowing for fluid backup and a larger concentration in one point that the soil cannot assist in remediating nearly as well.

Should it be determined that the septic tank is within or near enough to the well drawdown radius then Figure 6 can be used to determine the framework for the risk assessment for contamination from the septic system in place. Figure 6 shows the possible movement of human fecal contamination from septic systems, along with the different sources and sinks in the control volume.
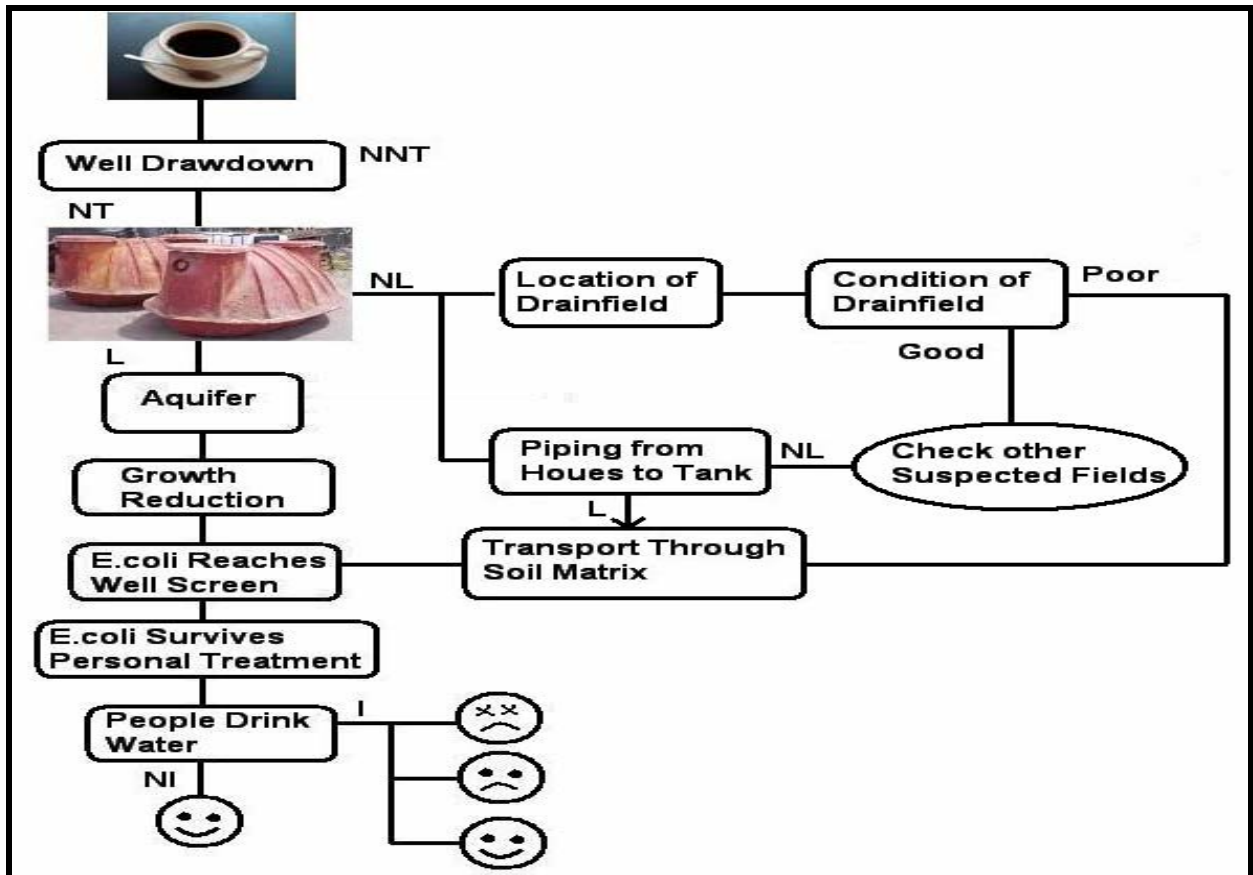

Figure 6. Proposed risk assessment framework for septic contamination.

At the lower portion of Figures 4, 5 and 6 at the cell "People Drink Water" in here lies the possibility for a quantitative risk assessment that will allow the answer to setback distance from the pasture land. Dose response data could be obtained for infection as

well as death and debilitating conditions that can occur from *E.coli* O157:H7 exposure (hemolytic uremic syndrome, renal failure, brain damage, etc.). From this data and knowing that infection of *E.coli* O157:H7 can be modeled by the beta Poisson dose response model ($\alpha = 0.49$, $N_{50} = 596,000$) (Haas et.al. 2000) a bootstrap simulation can be performed to allow for a distribution of α and N_{50} values for a plot of the risk to infection to be plotted within confidence intervals found from the bootstrap analysis. This, however, was not performed since the R code to perform the bootstrap simulations was not able to be trouble-shooted and debugged in time for the submission of this project.

However a risk assessment performed as described would inform the decision makers of the risk of infection at a given dose. Then choosing a risk that the homeowner is willing to take on can be used to determine a dose of *E.coli* that would be tolerable (preferably 0). Then given information on the water treatment system's (personal UV treatment for site 41 is the only one known) efficacy for *E.coli* and the amount of *E.coli* entering that portion of the overall control system being known, it can be determined how far if at all the well should be setback from the pastureland or the septic fields depending on which one is the source of the contamination.

Missing Data

Several pieces of important information were needed to complete this risk assessment. Examples of problem areas were: the infectious dose of *E .coli* in various literature ranged from 10-100 to 10^5, there were no transport studies of microbes through limestone etc. In this assessment we calculated the data standard deviation of *E.coli* in well water samples to be 1133^2. The standard deviation was too large or variable to model an average daily dose. As a result the average amount of *E. coli* # 41 (no disinfection) received was calculated as an average consumption of 2 liters per day, with the highest exposure being around 12,400 microbes as see in Figure 2. However, what percentage of that intake would be pathogenic *E. coli?* As result of the above example and other unavailable data the model could not be mathematical completed see the table below. Therefore a recommendation of well distance from contamination sources and a dose exposure estimate could not be made. However, there are a number of recommendations that would work in this case.

1. Perform a tracer study on the septic system to determine if there is a fault in this system
2. Test the well water for *Giardia*, and *Camphylobacter* since these are indicative of bovine waste.
3. If it is determined the septic system is at fault, and if any part of the septic system is failing or leaking repair these components or replace the system.
4. Instead of moving the well and the large costs associated with this, determine the cost effectiveness of entrenching a sand barrier around the well to slow the transport and partially filter the microorganisms.
5. Investigate farm subsidies grants for the farmer to move the pastureland farther from the hamlet to mitigate risks from him.

Table 1. Missing information.

Data needed	Data value determined from literature	Data Gap	Method of determination if not known
Amount of E. coli in cow manure	**1)** 10^6 E.coli per of cow manure gram (4). **2)** Cows excrete about 15 pounds of feces per day.	none	…
E. coli 0157:H7prevelance in cow feces.	**1**) Highest in July (44.7) & Aug. (42.1) (12). **2)** None in Dec.,March & April (12) **3)** E.coli 0157 in 1 -1.5 % of cattle (11).	Study only conduced 1 year w/ limited data points. (poor quality study)	…
Amount of E.coli 0157 in sewage from septic tank.	**1)** 10^5-10^7 fecal coliforms in sewage. (4) **2)** Human feces has 10^9-10^{12} E.coli per gram **3)** Humans excrete 150 g - to 300 g of feces per day (Gerba)	How many E. coli 0157 in sewage?	Obtain sample from septic tank
Amount of E.coli in soil and persistance in soil and /or leaching into lower limestone soil depths.	**1)** Initial titer of E.coli from manure (10^6) persists in sandy loam soils for up to 60 days (4).	No data microbial data for limestone stone persistance or transport.	Monitoring well(s) for groundwater samples
Effects of weather conditions on sewage/ cow manure movement throught ground water or soil.	E.coli is highest in the water table after major rain and melting snow events (8).	…	…

Temperature of soil.	**1)** Estimated groundwater Temp.range 10-12°C. (Dr. Medema) **2)** E.coli survives longer in cooler temperature. **3)** Soil - 100 days at 4C and 60 days at 20 (1)	Exact soil temperature	Soil testing
Temperature of groundwater.	**1)** E.coli survives longer in cooler temp. **2)** water -12 days at 4C and 8 days at 20C. (1) .	Measured ground water temperature	CPT
Soil pH	**1)** Estimate soil pH from 7.7 to 5.9 (limestone soil).	Exact soil pH	
E. coli growth rate in low pH	Lower pH =slower growth rate 1) growth time at 7.0 pH =40 min. (13) 2) growth time at 5.0pH = 140 min.(13)	More data points for growth in lower pH. (poor quality study)	
Hydraulic conductivity of aquifer	Not known	value	CPT
Residence time of aquifer	Not known	value	CPT
Permiability of soil matrix	Not known	value	Permiameter
Adsorbance of soil matrix	Not known	value	Soil testing
UV treatment efficacy	3 log removal (depending on time of exposure and unit efficiency (2)	Need data	Literature
Infection dose response model	Beta Poisson modeled (alpha = 0.49, N50=596,000) (Haas, et.al. (2000))	Need data	Literature
Mortality dose response model	not analyzed	Need data	Literature and Dose response analysis
Degenerative illness as a result of infection dose response model	No reliable data found	Need data	Literature
Ground surface roughness	Ground surface not sufficiently described	Need data	Literature
Wellpit roughness	Well pit has some growth on it but of unknown type therefore cannot	Need data	Literature
Well caseing roughness	Dependant on caseing material	Material unknown	Manufacturer

Camara project: Ground water Protection Questions

1) *What hazard are associated with animal waste?*

When contaminants from animal waste seep into underground sources of drinking water the amount of nitrate in the ground water supply can reach unhealthy levels. Infants up to three months of age are particularly susceptible to high nitrate levels and may develop Blue Baby Syndrome (methemoglobinemia) an often fatal blood disorder.Microbes associated with animal waste are e.coli, cryto, giardia, listeria, salmonella, Mycobacterium paratuberculousis. *A. butzleri and Campylobacteraceae* strains has been isolated in different breeding animals and is present in a great variety of retail meats, including chicken, beef, pork, and lamb, with a high prevalence in poultry.

2) *How does one estimate the risk if ground water contamination from these pathogens?*

    By using the following steps:
        a) Estimating the inactivation kinetics of pathogens in soil and fecal matrices.
        Below are known factors influencing pathogen kinetics in soil.
            1) 10^6 *E. coli* in gram of cow manure and $10^{9\text{-}12}$ gram of human feces
            (septic tank) (5).
            2) When mixed with soil manure inoculation of *E.coli* is consistent (6).
            3) There is a 3 fold increase in die-off rate if *E.coli* is in ground water with
            a decreasing pH (7).
        b) Characterization of the particle sizes with which pathogens are transported.
            1) Bacteria size ranges from 0.02 – 200 um.
        c) Characterization of pathogen properties and watershed – specific features that
        affect terrestrial transport and attenuation.
            1) Limestone substrate
        d) The inactivation and sedimentation of pathogens during the initial introduction
        into the aquatic environment.
            1) See risk assessment profile (temp and pH of soil etc).

3) *What type of water treatment is needed to insure public health protection?*

    Water treatment needed to inactive microbes thereby protecting the public include: chlorine (gas, hypochlorine, chlorine dioxide) UVlight, ozone, and ultrafiltration. USEPA specifies a 99.99% (4 log) inactivation of viruses, 99% Cryptosporium and other protozoans

    Canada has only guidelines for drinking water or private well water treatment. As a result the best management practices employed by utilities or in response to EPA regulation are listed below (K). These practices help to protect public health.
        a) Source water protection barriers :

Approved source water protection or wellhead protection program with minimum setback distances specified from microbial contamination and hydrological criteria used for well sitting. Well head monitoring is also required.
b) Well and water-system integrity barriers. Sanitary survey and corrections required.
c) Operations and system- maintenance barriers.
Well and pump disinfection. Periodic flushing of distribution system. Disinfection of new/repaired water mains. Cross connection control programs. Requirements for certification of operators.
d) Disinfection requirements for water treatment include: Specified disinfection C x T values. Microbial kill/reduction values. Specified minimum disinfectant or chlorine residual in distribution system.

- Feedlots: the following can be used to protect the public health: divert off from feedlots area, minimize runoff by reshaping the area, collect and treat runoff, line manure pits, and collect and treat pit effluent.

4) How clean should groundwater be and can this be monitored?

Compliance monitoring to ensure treatment technology reliably achieves 4-log

a) **Source water monitoring** to **Periodic sanitary surveys** of systems requiring the evaluation of eight elements and the identification of significant deficiencies;
b) **Hydrogeologic sensitivity assessments** to identify wells sensitive to microbial fecal contamination;
c) test for the presence of fecal indicators *(E. coli*, enterococci, or coliphage) in the ground water sample. There are two monitoring provisions:
    1. Routine monitoring for systems that do not provide 4-log treatment (inactivation or removal of viruses) and draw water from sensitive wells;
    2. Triggered monitoring for systems that do not provide 4-log treatment and have a total-coliform positive sample under Total Coliform Rule.
d) **Corrective action** is required for any system with a significant deficiency or source water fecal contamination. The system must implement one or more of the following correction action options:
    o Correct the significant deficiency,
    o Eliminate the source of contamination,
    o Provide an alternate source of water, or
    o Provide treatment which achieves at 4-log inactivation or removal of viruses.
e) inactivation or removal of viruses.

5) How can what we do at the community level assist with individual choices about well protection and home water treatment?

Community organizations can educate the well owner in addition to offering government incentives to maintain proper well functioning and sanitation. In addition we can draft and put in place health education and legislation, wash hand, disinfection, cook and well control sewage system.

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