RESEARCH REPORT

Validation of an Onsite Wastewater Risk Assessment Model

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Validation of an Onsite Wastewater Risk Assessment Model

Final Report

Submitted to:
Canada Mortgage and Housing Corporation

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January 18th, 2006

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EXECUTIVE SUMMARY

Failing onsite wastewater systems can pose a significant risk to public health and to the environment. An easy to use risk assessment model using readily available information would be a useful tool for regulators and can be used to prioritize onsite system re-inspection programs. Such a model has been developed and successfully applied to 19 villages within the City of Ottawa.

The model is comprised of a series of weighted risk factors applied to lot parcels in a GIS database. The factors were developed using existing data readily available to a municipality (soils, floodplain, parcel and building mapping, census data, aquifer vulnerability study, local hydro geological knowledge). The factors attempt to account for contaminant loading, contaminant pathways and operational life of onsite systems.

Data was collected from two field inspection campaigns and from replacement system records of the City of Ottawa to validate model parameters. The field inspection campaigns found no correlation between ground and surface water quality and indications of system malfunction; however, both system age and clay soils were found to be significant indicators of system failure. An analysis of onsite system replacement records indicates that system age is a determinant factor in hydraulic system failure, with the relative risk increasing by a factor of 5 for systems of 10-29 years and by a factor of 12 for systems 30 years and older. Soils also play an important role, with risk of failure generally increasing by a factor of 2 for systems installed in areas of impermeable soil.

The Risk Assessment Model was simplified and transformed to reflect our better understanding of the impact of system age and soil type on system failure rate. The revised Risk Model includes six factors: System Age, Soil, Lot Size, Depth to High Groundwater Table, Aquifer Conductivity, and Proximity to Surface Water.

RÉSUMÉ

La défaillance des installations d'assainissement autonomes peut présenter des risques importants pour la santé publique et pour l'environnement. Un modèle simple d'évaluation des risques mettant à contribution des renseignements faciles à obtenir constituerait un outil utile pour les organismes de réglementation et pourrait servir à établir l'ordre de priorité des programmes de réinspection des systèmes autonomes. Un tel modèle a été élaboré et appliqué avec succès dans 19 villages fusionnés à la ville d'Ottawa.

Le modèle comporte une série de facteurs de risque pondérés appliqués à des parcelles de terrain figurant dans une base de données d'un système d'information géographique (SIG). Les facteurs ont été mis au point à partir de données existantes qui sont facilement disponibles auprès des municipalités (les sols, une plaine inondable, les plans cadastraux et des bâtiments, les données de recensement, une étude de vulnérabilité de l'aquifère, les connaissances hydrogéologiques concernant la région). Les facteurs visent à représenter la charge des polluants, les voies de passage des polluants et la durée utile des installations autonomes.

Afin de valider les paramètres du modèle, une collecte de données a été effectuée dans le cadre de deux campagnes d'inspection sur le terrain et à partir des registres de la ville d'Ottawa concernant le remplacement des installations d'assainissement. Les inspections sur le terrain n'ont relevé aucune corrélation entre la qualité des eaux superficielles et souterraines et les indications de défaillance des installations; cependant, on a constaté que l'âge de ces systèmes et les sols argileux constituaient des indicateurs importants de la défaillance d'une installation. Une analyse des registres de remplacement des installations autonomes indique que l'âge d'un système est un facteur déterminant de la défaillance des installations hydrauliques, pour lesquelles le risque relatif est majoré par un facteur de 5 pour les installations de 10 à 29 ans et par un facteur de 12 pour celles de 30 ans et plus. Les sols jouent également un rôle important, étant donné que le risque de

défaillance est habituellement majoré par un facteur de 2 pour les systèmes installés dans des secteurs où le sol est imperméable.

Le modèle d'évaluation des risques a été simplifié et modifié en fonction de notre aptitude à mieux comprendre l'incidence qu'ont l'âge des installations et le type de sol sur le taux de défaillance des systèmes. Le modèle révisé d'évaluation des risques comporte six facteurs : l'âge de l'installation, le sol, les dimensions du terrain, la profondeur de la nappe phréatique, la conductivité de l'aquifère et la proximité des eaux superficielles.

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ACKNOWLEDGEMENTS

We would like to acknowledge the significant help of the Ottawa Septic System Office in providing access to their database and in particular the time and input of Terry Davidson, P.Eng., Manager of Septic System Approvals Office and Rosalind Kee. We would also like to thank Sarah Willie (Ottawa Septic System Office and Mississippi Valley Conservation Authority) for incorporating our research needs into her re-inspection program and for collecting water quality samples for us. Finally we would like to thank René Goulet of René Goulet Septic Tank Pumping for conducting a series of field inspections of onsite systems on our behalf.

We gratefully acknowledge the financial support of the Canada Mortgage and Housing Corporation, the City of Ottawa and the Eastern Ontario Water Resources Committee in funding this research project.

1.0 BACKGROUND AND INTRODUCTION

There is a growing acceptance that onsite wastewater systems form an integral and permanent part of the wastewater management infrastructure in rural areas. Traditionally, the maintenance of onsite systems (septic systems) was the responsibility of the home owner. With increasing development of non-centrally serviced areas and enhanced public concern for environmental protection and human health, local governments are taking a more active role in the management of onsite systems. A risk assessment model can provide a useful tool to help local governments develop rational management plans for decentralized systems. There are three types of risk which may be prioritized using models and addressed in a management plan: public health risk, ecological risk and financial risk (Jones et al., 2000).

Public health risk is a driving force behind most onsite system regulations. Contamination of drinking water by pathogens and nitrate are two major public health issues commonly related to onsite systems. Traditionally, prescriptive regulations attempt to assure sufficient depths of unsaturated soil and adequate horizontal separation distances between an onsite system and water supply wells or water bodies to protect public health from pathogen contamination. In Ontario, subdivision plans must ensure adequate dilution of nitrate through infiltration of precipitation and appropriate lot sizes. These regulations, coupled with system inspections at time of construction, attempt to minimize public health risks from onsite system effluent.

Ecological risk is a macro-level risk that considers the health of a watershed or an eco-system. This is often related to nutrient loading of surface water bodies and to cultural eutrophication. An evaluation of ecological risk must consider all sources of contamination including agricultural runoff, sewage plant discharges, industrial and storm water outfalls, and natural sources in addition to on-site systems.

The financial risks of onsite systems can be evaluated at both the community and the individual property scales. At the community scale, public health crises arising from contaminated communal water supplies or risks to tourism, fishing industries and to recreational water use from surface water contamination are all recent Canadian examples. At the scale of the individual property owner, system failure and its replacement cost, reduction in property value and alternative costs for a centralized system all represent significant financial risks for the individual owner.

Risk assessment methodologies have been developed to address one or more of these types of risk as they relate to onsite systems. The Onsite Wastewater Treatment Manual (USEPA, 2002) describes several model approaches including: a subjective vulnerability assessment, a probability analysis of water resources impact from wastewater discharges, contaminant transport modeling, and the DRASTIC model (Aller et al., 1987), which was developed by the USEPA to rate groundwater vulnerability using weighted factors of hydrogeologic settings. The factors included in the DRASTIC model are: depth to ground water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media, and hydraulic conductivity of the aquifer. The Risk Assessment System Handbook (Government of New South Wales, 2001) provides a comprehensive approach to risk assessment from onsite systems up to the watershed scale. Contaminant fate from onsite systems is well described in the Guidelines for Assessing the Risk to Groundwater from On-Site Sanitation (British Geological Survey, 2001).

All of the models listed above provide information to decision makers, enabling them to relate a risk of surface or groundwater pollution to mitigating actions such as mandating a higher level of technology or conducting more frequent inspections in high risk areas. Examples of high risk areas could include aquifer recharge zones, high density developments, village cores, waterfront areas, or areas with poor soils. A risk assessment model can be a useful management tool for regulatory authorities.

A risk assessment model for onsite systems was developed utilizing readily available sources of data to create a useful management and planning tool for use by regulatory authorities. The model was applied to 19 villages within the City of Ottawa, Ontario, Canada, with the purpose of prioritizing an inspection program of existing systems. A map of the City of Ottawa and the study villages is presented in Figure 1.

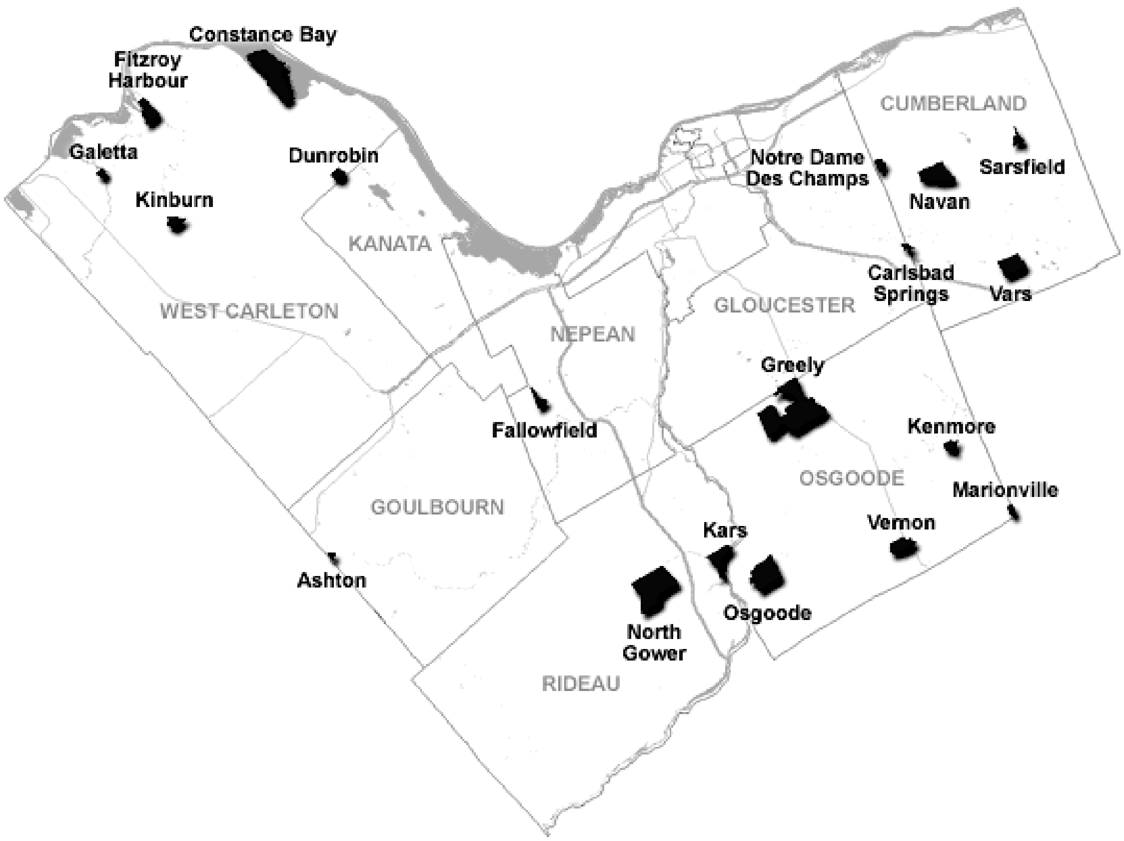

Figure 1. Map of the City of Ottawa with Study Area Villages

This report describes the initial development and application of a Risk Assessment Model to the City of Ottawa (Sections 2 and 3), the validation of Model parameters (Section 4) and the Revised Model (Section 5).

2.0 MODEL DEVELOPMENT

A risk assessment model was developed as part of an onsite system management plan for the City of Ottawa. The model will aid in the prioritization of a re-inspection program, as it is expected that it will take 10 years to inspect the approximately 30,000 existing onsite systems within the City. The model can ultimately be used as a tool to determine the level of on-going management required for an area based upon risk to human health or the environment. This model attempts to address risks related to system failure and water pollution.

The Risk Assessment Model developed in this study uses the same approach as the DRASTIC model (Aller et al., 1987), which attributes proportional weightings to a variety of risk factors. The Risk Assessment Model is comprised of factors accounting for contaminant loading, contaminant pathways, and age of systems.

Each risk factor is assigned a value of 0-5, with 0 representing no risk and 5 representing a very high risk. Each factor is assigned a corresponding weighting to account for its relative importance in the risk model. The weightings are described in Table 1 and are scaled such that the sum of all weightings is 100%. Each weighting is the product of an importance factor (out of 5) and a certainty factor (out of 5). The certainty factor accounts for the level of confidence in the data source. The sum of each risk factor multiplied by its weighting determines the risk model value [RISK = ∑ (RISK FACTOR X WEIGHTING)].

Table 1. Risk Assessment Model Factor Weighting

Risk Factor	Description	Importance (Rating)	Level of Certainty (Rating)	Weighting (% of total)
R_1-A	Soil Type – Permeable	5	3	11.3%
R_1-B	Soil Type - Impermeable	5	3	11.3%
R_2	Depth to Groundwater	4	3	9.0%
R_3	Aquifer Conductivity	2	2	3.0%
R_4	Population	4	5	15.0%
R_5	Drinking Water Vulnerability	4	3	9.0%
R_6	Lot Size	5	5	18.8%
R_7	System Age	5	3	11.3%
R_8	Proximity to Surface Water	3	5	11.3%

The model can be applied by village or by individual lot. A description of each risk factor follows.

<u>Risk Factors</u>

R_1 - Soil Type: The soil type is based upon surficial geology mapping. The type of soil reflects the hydraulic conductivity of systems built using *in-situ* soils as well as soils beneath systems constructed with imported sand. The various soil types were classified by hydraulic conductivity (K) as described in Table 2. The soil type factor was divided into two sub categories to reflect both increased risk of groundwater contamination by onsite systems (high K values) and risk of system clogging and surface break out of effluent (low K values). An area-weighted average was calculated for each village.

Table 2. Soil Hydraulic Conductivity

Estimated Soil Hydraulic Conductivity, K (cm/s)	Risk Rating	
	R_{1A}- Permeable Soils	R_{1B}- Impermeable Soils
$\leq 10^{-6}$	0	5
10^{-5}	0	3
10^{-4}	0.5	0.5
10^{-3}	3	0
$\geq 10^{-2}$	5	0

R_2 - Depth to Groundwater: The depth of the seasonal high water table is estimated for each village area based on a subjective assessment by a hydrogeologist with local knowledge. A seasonal high water table at a depth of greater than 5 m is considered to be of low risk while a seasonal water table of less than 1 m is considered to be of high risk, as described in Table 3.

Table 3. Depth to Groundwater

Estimated High Seasonal Water Table Depth (m)	Risk Rating
> 5	1
< 1	5

R_3 – Aquifer Conductivity: This factor was taken directly from an Aquifer Vulnerability Study conducted for the City (City of Ottawa, 2001). Aquifer conductivity refers to the hydraulic conductivity of the groundwater aquifer underlying the study area. Higher hydraulic conductivity increases the potential for pollution, as it facilitates the migration of contaminants through the aquifer. An area-weighted average was calculated for each village.

R4 - Population: This factor takes into account both total village population and population density (i.e. high population and high density results in a high risk). Population is generally a direct indication of pollution load to the groundwater. Table 4 describes the risk rating matrix for population.

Table 4. Population

Population Density (capita / ha)	Risk Rating Village Population (Capita) <300	 300-1000	 > 1000
< 9	1	2	3
9 - 12	2	3	4
>12	3	4	5

R_5 – Drinking Water Vulnerability: The source of drinking water for each village was identified by a hydrogeologist with local knowledge. If the overburden aquifer is used as a source for drinking water, or there is an anticipated hydraulic connection to the overburden aquifer, the source is considered to be high risk. If there is a significant isolation layer above the drinking water source aquifer, the source is considered to be low risk. Table 5 describes the drinking water vulnerability risk ratings.

Table 5. Drinking Water Vulnerability

Drinking Water Vulnerability	Risk Rating
Overburden aquifer used as a source for drinking water or anticipated hydraulic connection to the overburden aquifer	5
Significant isolation layer above the drinking water source	1

R_6 – Lot Size: Small lots often do not meet separation distances defined in the prescriptive code governing onsite systems in Ontario (OBC, 1997) and may pose a risk to drinking water safety and quality. The highest risk is assigned to lots of less than 0.1 ha (0.25 acres), while the lowest risk is assigned to lots of greater than 0.4 ha (1 acre). Table 6 describes the risk ratings for lot size. A village risk rating is calculated by taking an average for all lots.

Table 6. Lot Size

Lot Size	Risk Rating
0 - 0.1 ha	5
0.1 - 0.2 ha	4
0.2 - 0.4 ha	3
>0.4 ha	1

R_7 – System Age: Local experience has shown that the average operating life of an on-site system is about 25 years. Systems greater than 25 years old are assigned the highest risk rating, while systems less than 15 years old are assigned the lowest risk rating. The building age is used to represent the age of the onsite system, as onsite system records are incomplete and often do not have a municipal address. An average village risk rating was calculated based on the average rating for all homes in a village.

Table 7. System Age

Year of Construction	System Age (years)	Risk Rating
1992 – 2002	0-15	1
1977 - 1987	15-25	3
1812 – 1977	> 25	5

R_8 – Proximity to Surface Water: The one hundred year flood plain boundary was used to determine lots that were in close proximity to a water body. Each lot partially to fully within the floodplain is considered as high risk. All other lots are reported as no risk. Table 8 describes the risk ratings for proximity to surface water. The average village risk rating is calculated by taking an average rating for the lots in the village.

Table 8. Proximity to Surface Water

Part of lot within the floodplain	Risk Rating
Yes	5
No	0

3.0 MODEL APPLICATION AND SENSITIVITY ANALYSIS

The risk assessment model was applied to 19 villages within the City of Ottawa with the scores normalized to a value out of 100. The model analysis results are presented in Figure 2. Relative risk varies between 33 and 68 out of a possible 100 across the villages, with an average of 51.

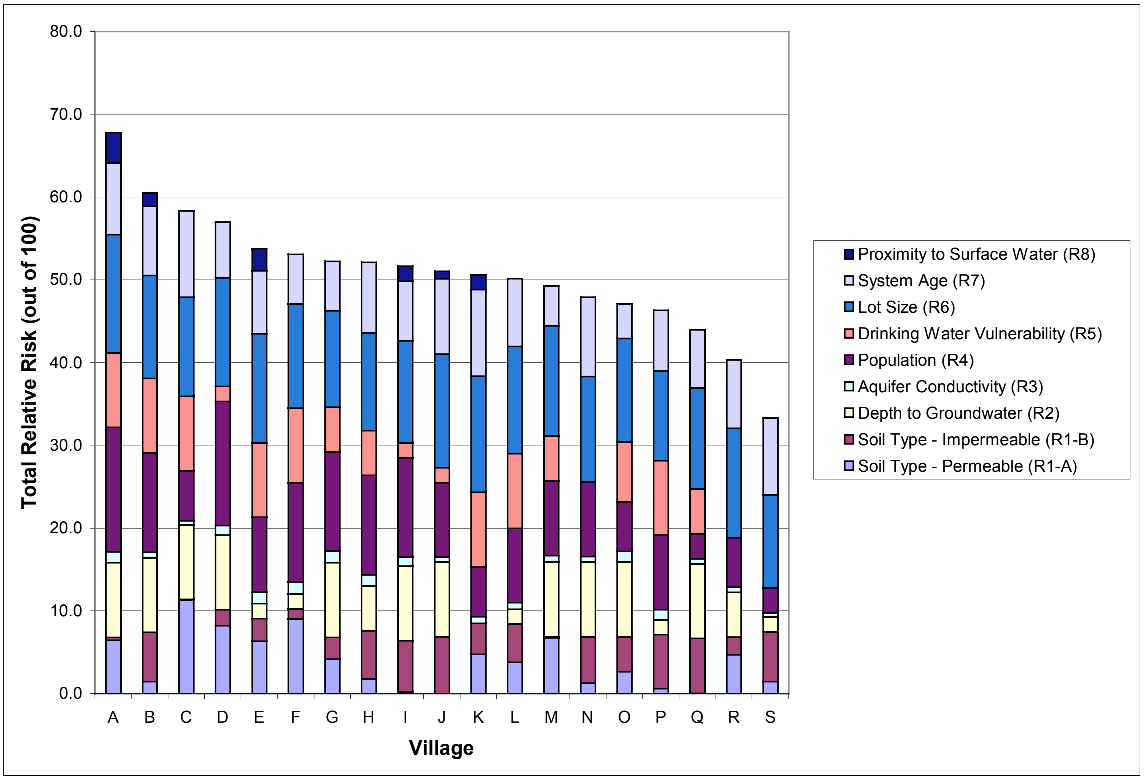

Figure 2. Risk Assessment Model Results for the City of Ottawa

The average risk values and variations for each factor are described in Table 9. The standard deviation of each factor measures the sensitivity of the factor's contribution to total risk. The model is most sensitive to the factors describing drinking water vulnerability (R_5), population (R_4) and depth to groundwater (R_2), with 2 standard deviations of 7.2, 7.1 and 7.0, respectively. The model is least sensitive to the factors describing aquifer conductivity (R_3), lot size (R_6) and proximity to surface water (R_8), with 2 standard deviations of 0.7, 1.8 and 2.2, respectively. The proximity to surface water factor (R_8) has the highest relative variation (340%) since only 6 of the 19 villages are along a river. Soil type factors (R_{1A}, R_{1B}) also have large variations (123 and 169%, respectively), indicating variable soil types in different villages. The lot size factor (R_6) and system age factor (R_7) have the smallest variations (14 and 45%, respectively), resulting from an even distribution of small and large lots and old and new systems across the different villages.

Table 9. Model Sensitivity Analysis

Factor	Description	Contribution to Total Risk (Avg. ± 2 SD)	Variation [1] (%)
R_1-A	Soil Type – Permeable	4.0 ± 6.7	169
R_1-B	Soil Type - Impermeable	3.9 ± 4.8	123
R_2	Depth to Groundwater	6.3 ± 7.0	113
R_3	Aquifer Conductivity	1.0 ± 0.7	72
R_4	Population	9.2 ± 7.1	77
R_5	Drinking Water Vulnerability	5.6 ± 7.2	129
R_6	Lot Size	12.8 ± 1.8	14
R_7	System Age	7.8 ± 3.5	45
R_8	Proximity to Surface Water	0.7 ± 2.2	340
Total		50.9 ± 14.9	29

[1] Variation = (2 Standard Deviations / Average) x 100

4.0 MODEL VALIDATION

Data on system malfunction or failure (from local knowledge, inspection reports, and replacement permits), along with groundwater quality data (nitrate, bacteria) and surface water quality data (bacteria, total phosphorus) have been used to validate model parameters.

4.1 Correlation with Local Knowledge

Personnel from the Ottawa Septic System Office (local regulatory authority) were surveyed concerning high risk factors causing system failure in each of the 19 villages evaluated in Ottawa. The risk factors identified included: lot size, system age, impermeable soils, shallow unconfined aquifer, systems in the floodplain and failing filter media bed systems. The number of high risk factors identified in each village was found to correlate well with total risk for that village (Correlation Coefficient = 0.67). This result indicates that the model reflects local knowledge.

4.2 Data Collection Methodology

Data was collected from three sources to validate the risk assessment model: two separate field data collection campaigns were undertaken during the summers of 2004 and 2005 and data was collected from historical records of replacement systems at the Ottawa Septic System Office.

The first field campaign targeted the re-inspection of septic systems on waterfront properties in the Tay Valley Township, which is located in Lanark County approximately 100 km south-west of Ottawa. This area was selected for two reasons: it represents a high risk area with close proximity to surface water (waterfront properties) and shallow depths to bedrock (generally less than 3 feet) and an onsite system re-inspection program was being undertaken during the summer of 2004 (Willie *et al*., 2005). A visual inspection of each leaching bed was conducted by a certified sewage system inspector. The inspection included a walk around the property to note obvious signs of problems affecting the operation of the sewage system including: a driveway or trees on the leaching bed, surface breakout of sewage, sewage odours, erosion of leaching bed side slopes, insufficient separation distances and the discharge of wastewater to the surface. Tanks were inspected by opening the inlet manhole and measuring the depth of sludge and scum using a NASCO "Sludge Judge" in the primary chamber of the tank. The sewage level inside the tank was also observed and the condition of the inlet baffle noted. Water samples were collected by the septic system inspectors from the tap (before any treatment device) and from the surface water along the shoreline at the closest distance from the leaching field at each property in bottles containing appropriate preservatives. Individual water quality results will remain confidential. Samples were stored in coolers with ice packs and couriered in coolers with ice packs to Collège d'Alfred within 24 hrs of sample collection. Samples were analysed at the ORWC water quality laboratory for nitrate, chloride and total phosphorus, while samples were analysed for *E.coli* at Accutest Laboratories in Ottawa. All analytical methods followed Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WEF, 1998).

The second field inspection was conducted as part of a study of the impact of water softener discharge on septic tanks (Kinsley *et al*, 2006). The field data was collected by René Goulet of Goulet Septic Tank Pumping. Mr. Goulet operates a septic pumping truck in Eastern Ontario, generally within the United Counties of Stormont, Dundas and Glengarry and the United Counties of Prescott and Russell (East of Ottawa between the Quebec and US borders). Ontario Rural Wastewater Centre (ORWC) Researchers accompanied Mr. Goulet for the first several sample events in order to develop and document a standardised sampling methodology. A survey form was filled out by Mr. Goulet and each homeowner to gather information on each system including: tank age, date of last pump-out, number of residents and bedrooms, type of septic system, soil type, and any history of bed failure or water quality problems. Participating homeowners and individual data will remain confidential. The size, material and condition of each tank as well as any signs of leaching bed failure were documented by Mr. Goulet. The sludge and scum depths were measured using a "Sludge Judge". A photograph was taken of the outlet baffle when corrosion was evident. The state of the leaching bed was evaluated in terms of the type of leaching bed (approved / not approved), any signs of surface breakout of effluent and water level above the outlet pipe in the septic tank.

The third source of data is the historical records of replacement systems at the Ottawa Septic System Office. Data from construction permit files for replacement systems installed within the past eight years was collected. Information in the database includes: system location, type of onsite technology which failed, soil type, depth to high groundwater and system age. The soil and high groundwater level data were taken from the test pit data reported in the files. The system age was sometimes written in the file, but often the age of the building was used to represent the system age. Information on individual systems will remain confidential.

4.3 Data Analysis

<u>Field Data Collection Campaign #1</u>

Data from the field inspections of the Tay Valley 2004 Re-inspection Program (n=110) with associated water quality data (n=48) are presented in Appendix A.

Table 10 describes the water quality results and Table 11 describes the re-inspection program results. The objective of this field study was to correlate water quality data to information obtained from the re-inspection program, particularly between signs of system failure and surface or groundwater contamination. Out of the 110 systems inspected, 31 systems were found to have a significant deficiency including: surface breakout, piping broken or sagging, root intrusion into tank, non-compliant grey water system, and privy full of sludge. There was corresponding water quality data for 13 of these 31 systems. From examination of this data it is clear that there was no significant correlation between any of the water quality indicators and results from the re-inspection program. Only 1 deficient system had an elevated well nitrate concentration (∃2.5 mg/L), two deficient systems had elevated TP concentrations (∃0.03 mg/L) and only one deficient system had an elevated Cl^- concentration (∃ 5 mg/L). The *E.coli* data indicated very little contamination with only two well samples positive for *E.coli* and only two surface water samples with *E.coli* ∃ 100 counts/100mL, which is the Ontario Provincial Water Quality Objective for Recreational Water Use (MOE, 1994).

Table 10. Water Quality Results – Tay Valley 2004 Re-Inspection Program

Parameter	Unit	Range	Well Water	Surface Water
			n	n
E.coli	counts/100mL	non detect	40	25
		1-99	2	18
		∃ 100	0	2
NO_3^--N	mg/L	0-2.49	37	47
		2.50-4.99	5	0
		5.00-7.49	3	0
		7.50-9.99	1	0
		∃ 10	0	1
Cl^-	mg/L	0-4.9	34	
		5.0-9.9	8	
		10.0-99.9	3	
		∃ 100	1	
TP	mg/L	0-0.009		4
		0.010-0.019		22
		0.020-0.029		11
		∃ 0.030		11

Generally the water quality observed in this study area was very good, with no nitrate concentrations found above the Ontario Drinking Water Standard of 10 mg/L NO_3^--N. Chloride concentrations were also extremely low, with 42 out of 47 samples below 10 mg/L. Total Phosphorus was the only contaminant measured which could be considered of concern, as 22 out of 48 samples were either at or exceeding the Ontario Provincial Water Quality Objective of 0.03 mg/L for rivers and 0.02 mg/L for lakes. The PWQO limits for Total Phosphorus are defined to avoid problems with excessive eutrophication.

Table 11. Tay Valley Re-inspection Program Results for 2004 (data provided by the Ottawa Septic System Office & Mississippi Valley Conservation Authority)

Type of System	n	No Problem Evident from Visual Inspection of Leaching Bed	Significant Deficiency (surface breakout, piping broken/sagging, root intrusion into tank, non-compliant grey water system, privy full)	Vegetation Growth on leaching bed / Stormwater drainage onto leaching bed	Insufficient Separation Distance from leaching bed to a well or water body	Tank Requiring Pumping
Filter Media / Trench / Unknown	101	72	17	6	1	5
Holding Tank	7	6			1	1
Grey Water Pit	15	4	8			
Privy	26	8	6			
Total	149	90	31	6	2	6

Results from this field study suggest that using water quality data as an indicator of onsite system performance is not feasible as no correlations were observed between system performance and ground or surface water quality. Once the effluent leaves the onsite system boundary (i.e. base of the absorption trench) the environmental factors of dilution, adsorption, attenuation, contaminant transport and the addition of other sources of pollution inputs can all play a role in reducing the reliability of environmental water quality results. However, the use and monitoring of groundwater nitrate, *E.coli* and perhaps chloride, as indicator of groundwater quality can provide important information to help develop a proactive management plan. The same may be said for total phosphorus and *E.coli* in surface waters. If a water quality problem is identified, then preventative and/or remedial action can be undertaken, which may include more active management of onsite systems or even the implementation of advanced onsite technologies to remove nitrate and/or phosphorus.

Field Data Collection Campaign #2

Data was collected from field inspections of leaching beds and septic tanks (n=75) as part of a 2005 Project "Impact of Water Softeners on Septic Tanks Field Evaluation Study". The data is presented in Appendix B.

The objective of the second field data collection campaign is to compare the prevalence of hydraulic failure of onsite systems (defined as a surface breakout or water level in the tank higher than the outlet pipe) to the risk assessment factors of soil type and age of system. Table 12 describes the results from the leaching bed and tank inspections.

Table 12. Onsite System Inspection Results (Source: Kinsley *et al*., 2005)

Parameter	**Units**	**Hydraulically Failed Systems**	**Sample Population**
Systems	Number	12	75
Persons	Number	3.0±1.4	3.1±1.3
Age	Years	28±10	21±9
Soil Type		9 clay 3 loam	22 clay 16 loam 28 sand 5 stony hardpan

Of the 75 systems evaluated, 12 were experiencing hydraulic failure; where failure is defined as surface breakout (2 systems) or water level in the tank higher than the outlet (10 systems). Nine of the twelve systems were installed in clay soils, representing 41% of the systems installed in clay soils compared with just 6% failure of systems in other soil types. The failed systems ranged in age from 10-40 years, with an average of 28 years compared with an average age of 20 years for functioning systems. It would appear that both soil type (clay) and system age (>20 years) are strong indicators of hydraulic failure.

<u>Historical Records of the Ottawa Septic System Office</u>

Data from onsite system replacement permit files at the Ottawa Septic System Office was compiled in order to analyse the effect of system age and soil type on system failure. Table 13 describes the data collected on replacement systems by year (n=308).

Table 13. Replacement Permits Analysed by Year

Year	Replacement Permits Analysed	Total Permits Issued
1998	19 (systems replaced with tertiary technologies)	269
1999	30 (systems replaced with tertiary technologies)	382
2000	21 (systems replaced with tertiary technologies)	410
2001	38 (systems replaced with tertiary technologies)	807
2002	60 (systems replaced with tertiary technologies)	997
2003	46 (2/3 of replacement systems)	867
2004	67 (all replacement systems)	844
2005	27 (all replacement systems)	463
Total	**308**	**5039**

The replacement system data is presented in Table 14. The data was divided into 10 year age intervals as well as into two soil groups consisting of good soils (sand) and poor soils (clay, silt, bedrock, till). The soil information was taken from the descriptions of the test pits provided in the permit reports.

Table 14. Age and Soil Type of Replacement Systems in Ottawa

Soil Type	**System Age (Years)**				
	1-9	**10-19**	**20-29**	**∃30**	**Total**
Sand	2	22	10	30	64
Clay/Silt/Bedrock/Till	3	48	16	100	167
Total	5	70	26	130	231

The proportion of system failure by age category for both sandy soils and poor soils was compared to the proportion of installed systems (housing stock) within that age category and is described in Figure 3. It is clear from the figure that the proportion of systems failing within the first 10 years of operation is much lower than the proportion of housing stock while the proportion of systems failing after 30 years of operation is much higher than the proportion of housing stock.

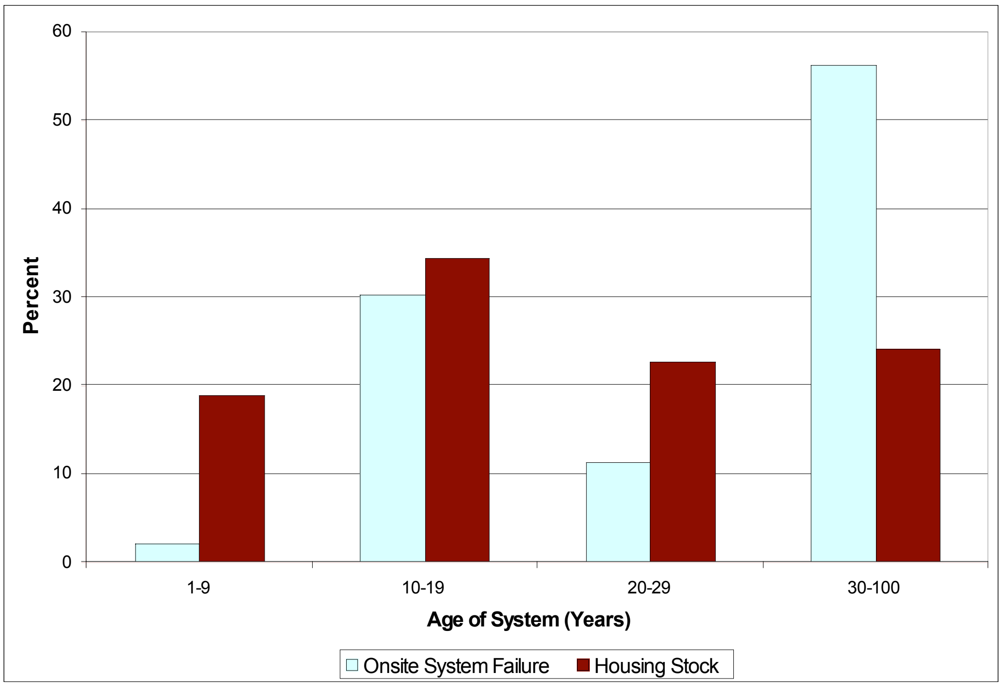

Figure 3. Age of Replacement Systems versus Housing Stock

Table 15 describes the relative risk of failure due to age and soil type. The relative risk is calculated as the proportion of failed systems divided by proportionate housing stock at each age interval (System Replacements (%) / Housing Stock (%)) normalised to the first age category.

Table 15. Relative Risk of Failure Due to Age and Soil Type

Age Category	Relative Risk		
	Sandy Soil (A)	Poor Soil (B)	Soil Effect (B/A)
1-9	1	1	1
10-19	6.1	9.1	1.5
20-29	4.2	7.6	1.8
∃30	12.2	27.8	2.3

The average percentage of sandy soils across 19 village residential areas in Ottawa was calculated to be 46 percent using surficial geology mapping. This means that the Soil Effect factor described in Table 15 is not influenced by the relative proportions of sandy to poor soils in dataset.

The relative risk of failure increases 12 fold for systems greater than 30 years old compared to systems less than 10 years old. Poor (impermeable) soils increase risk of failure by 1.5-2.3 times.

The rate of system replacement within Ottawa was calculated from data collated from 2003-2005 permits and is presented in Table 16. Replacement rates range from 0.03 – 0.39%. These rates clearly underestimate the rate of failure, as data from the field inspection campaigns showed 17-18% of systems with serious deficiencies requiring repair or replacement. However, the ratio of failure rates with each age category does provide a good measure of the relative risk of failure by age category and is similar to the calculation of relative risk presented in Table 15.

Table 16. System Replacement Rate

Soil Type	**System Age (Years)**				
	1-9	**10-19**	**20-29**	**∃30**	**Total**
# Replacement Systems (2003-2005)	4	45	18	61	128
# Systems Installed	5,654	10,350	6,781	7,215	30,000
Annual Replacement Rate (Systems/Year)	0.03	0.20	0.12	0.39	
Relative Risk of Failure (normalised to first age category)	1	7	4	13	

5.0 REVISED RISK ASSESSMENT MODEL

The field data and data from records of system replacement provide additional information on the risk of system failure due to age and soil type. The significant conclusions which can be drawn from the field inspection data are:

1. No correlations were drawn between water quality data (groundwater *E.coli*, NO_3, Cl^-; surface water *E.coli*, TP) and indications of system malfunction (surface breakout, piping broken/sagging, root intrusion into tank, non-compliant grey water system, privy full).
2. A significant proportion of systems inspected had a serious deficiency (17-18 percent)
3. Systems age and clay soils were both significant indicators of system failure.

The analysis of the septic system replacement data from the Ottawa Septic System Office indicated that system age and soil permeability are key factors in hydraulic system failure. The relative risk of failure increases by a factor of 5 for systems of 10-29 years and by a factor of 12 for systems 30 years and older while impermeable soils increased the risk of failure by a factor of 2.

The revised Risk Assessment Model is divided into two components. The first component is a Community Context to help relate the risks of onsite systems to water quality, water use and other sources of potential water contamination. The Community Context should help a municipality determine the scope of an onsite wastewater management program.

The second component is a simplified Risk Model consisting of six factors. The permeable soil factor was removed as groundwater transport of contaminants is captured in the aquifer conductivity factor, the population factor was removed as lot size provides an indirect measure of wastewater loading, and the drinking water vulnerability factor was moved to the Community Context component. The weighting of the system age factor (R_1) was set at 30% to reflect the high relative risk of system failure by age determined through the analysis of replacement systems. The soil factor (R_2) and lot size factor (R_3) were assigned 15% each, representing half of the weighting of the age factor. Factors affecting groundwater contaminant transport (R_4, R_5) were assigned a total weighting of 20% to equal the weighting of the factor affecting surface water pollution (R_6).

Community Context
Water Quality Water Quality indicators of both groundwater and surface water can be used to justify or monitor the success of an onsite wastewater management strategy. Typical indicators for groundwater quality are nitrate and *E.coli*, while typical indicators of surface water quality are total phosphorus and *E.coli*. Suggested threshold limits which could be used to increase the scope or importance of a management plan could include: ➢ 0 *E.coli* for groundwater (Universal Drinking Water Standard) ➢ 100 *E.coli* for surface water (Ontario PWQO - Bathing) ➢ 0.01 mg/L TP for surface water (50% of Ontario PWQO to avoid eutrophication) ➢ 2.5 mg/L NO_3^--N (25% of Ontario Drinking Water Standard)
Water Use The uses of a water resource should be considered when defining the scope of an onsite wastewater management strategy. Typical water uses which could be influenced by onsite wastewater discharges include drinking water wells in a shallow or unconfined aquifer or surface water recreational uses including swimming, boating or sport fishing. Aquaculture is also an important water use in coastal areas.
Other Sources of Water Contamination Onsite wastewater systems are typically not the sole source of water quality impairment; therefore other non-point sources including agricultural runoff and point sources such as sewage outfall should be incorporated into any strategy aimed at improving water quality.

Onsite Wastewater Risk Assessment Model

The Risk Assessment Model developed in this study uses the same approach as the DRASTIC model (Aller et al., 1987), which attributes proportional weightings to a variety of risk factors. The Risk Assessment Model is comprised of factors accounting for contaminant loading, contaminant pathways, and age of systems.

Each risk factor is assigned a value of 0-5, with 0 representing no risk and 5 representing a very high risk. Each factor is assigned a corresponding weighting to account for its relative importance in the risk model. The weightings are described in Table 17. The sum of each risk factor multiplied by its weighting determines the risk model value [RISK = ∑ (RISK FACTOR X WEIGHTING)].

Table 17. Risk Assessment Model Factor Weighting

Risk Factor	Description	Weighting (% of total)
R_1	System Age	30%
R_2	Soil	15%
R_3	Lot Size	15%
R_4	Depth to High Ground Water Table	15%
R_5	Aquifer Conductivity	5%
R_6	Proximity to Surface Water	20%

The model can be applied by village or by individual lot. A description of each risk factor follows.

<u>Risk Factors</u>

R_1 – System Age: Relative risk of failure due to system age has been shown to increase from 1 to 5 to 12 times as the age of the system increases from 1-9 years to 10-29 years to 30 years and older. The building age can be used to represent the age of the onsite system when onsite system records are incomplete.

Table 18. System Age

System Age (years)	Risk Rating
0-9	0.4
10-29	2.1
∃ 30	5

R_2 - Soil Type: The soil type is based upon surficial geology mapping. The type of soil reflects the hydraulic conductivity of systems built using *in-situ* soils as well as soils beneath systems constructed with imported sand. The various soil types were classified by hydraulic conductivity (K) as described in Table 19. The soil type factor reflects the increased risk of system clogging and surface break out of effluent (low K values). An area-weighted average can be calculated or soil data from septic system records can be used for individual lots.

Table 19. Soil Hydraulic Conductivity

Estimated Soil Hydraulic Conductivity, K (cm/s)	R_2- Soil Impermeability
$\leq 10^{-6}$	5
10^{-5}	3
10^{-4}	0.5
10^{-3}	0
$\geq 10^{-2}$	0

R_3 – Lot Size: Lot size provides an indirect measure or wastewater loading to the groundwater. As well, small lots often do not meet regulatory separation distances and may pose a risk to drinking water safety and quality. The highest risk is assigned to lots of less than 0.1 ha (0.25 acres), while the lowest risk is assigned to lots of greater than 0.4 ha (1 acre). Table 20 describes the risk ratings for lot size.

Table 20. Lot Size

Lot Size	Risk Rating
0 - 0.1 ha	5
0.1 - 0.2 ha	4
0.2 - 0.4 ha	3
>0.4 ha	1

R_4 - Depth to High Groundwater Table: The depth of the seasonal high water table is estimated for area based on a subjective assessment by a hydrogeologist with local knowledge. A seasonal high water table at a depth of greater than 5 m is considered to be of low risk while a seasonal water table of less than 1 m is considered to be of high risk, as described in Table 21. Alternately, data from septic system inspection files can be used to provide a lot specific high water table value, although this information is often not available.

Table 21. Depth to High Groundwater Table

Estimated High Seasonal Water Table Depth (m)	Risk Rating
> 5	1
1-5	3
< 1	5

R_5 – Aquifer Conductivity: This factor can be taken directly from an Aquifer Vulnerability Study for the area of interest. These studies have been conducted for many municipalities. Aquifer conductivity refers to the hydraulic conductivity of the groundwater aquifer underlying the study area. Higher hydraulic conductivity increases the potential for pollution, as it facilitates the migration of contaminants through the aquifer.

R_6 – Proximity to Surface Water: The one hundred year flood plain boundary is used to determine lots that are in close proximity to a water body. Each lot partially to fully within the floodplain is considered as high risk. All other lots are reported as no risk. Table 22 describes the risk ratings for proximity to surface water.

Table 22. Proximity to Surface Water

Part of lot within the floodplain	Risk Rating
Yes	5
No	0

6.0 CONCLUSIONS

An onsite wastewater risk assessment model has been developed using readily available sources of information representative of system age, soil conditions, contaminant loading and contaminant transport. Data was collected from two field inspection campaigns and from replacement system records of the City of Ottawa in order to validate model parameters.

From the field inspection campaigns, the following can be concluded:

- No correlations were drawn between water quality data (groundwater *E.coli*, NO_3, Cl^-; surface water *E.coli*, TP) and indications of system malfunction (surface breakout, piping broken/sagging, root intrusion into tank, non-compliant grey water system, privy full).
- A significant proportion of systems inspected had a serious deficiency (17-18 percent)
- Systems age and clay soils were both significant indicators of system failure.

The analysis of the septic system replacement data from the Ottawa Septic System Office indicated that system age and soil permeability are key factors in hydraulic system failure. The relative risk of failure increases by a factor of 5 for systems of 10-29 years and by a factor of 12 for systems 30 years and older while impermeable soils increased the risk of failure by a factor of 2.

The Risk Assessment Model was simplified and transformed to reflect a better understanding of the impact of system age and soil type on system failure. The revised model has two components: a Community Context to describe water quality, water use and contaminant sources and a risk model consisting of 6 factors: System Age, Soil, Lot Size, Depth to HGWT, Aquifer Conductivity and Proximity to Surface Water.

7.0 TECHNOLOGY TRANSFER

To date three papers have been presented relating to this research study:

Kinsley, C. "Causes of Failure of Onsite Systems". In Proceedings of the 6th Annual Ontario Onsite Wastewater Conference and Exhibit. March 7-8th, 2005. Niagara Falls, Ontario

Kinsley, C., D. Joy, A. Campbell, D. Feniak, D. Branson , T. Albert, J. Sauriol. 2004. "A Risk Assessment Model for Onsite Systems Applied to the City of Ottawa, Canada" In Proceedings of the ASAE 10th National Symposium on Individual and Small Community Sewage Systems. March 21-24, Sacramento, California. pp. 44-51.

Kinsley, C. and Feniak, D. "Ottawa Onsite Wastewater Management Model". In Proceedings of the 5th Annual Ontario Onsite Wastewater Conference and Exhibit. March 8-9, 2004. Ottawa, Ontario.

A PDF version of the study findings will be posted on the ORWC website (www.orwc.uoguelph.ca).

8.0 REFERENCES

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Willie, S., Davidson, T., Coulthart-Dewey, K. 2005. Inspection of Existing Sewage Systems in Eastern Ontario. In Proceedings of the 6th Annual Ontario Onsite Wastewater Conference and Exhibit. March 7-8th, 2005. Niagara Falls, Ontario.

APPENDIX A – TAY VALLEY RE-INSPECTION PROGRAM DATA

			OTHER SYSTEM		SEPTIC SYSTEM INFORMATION				Water Quality Data					
Inspection Number	Date Inspected	Property Use	Greywa	Privy	Tank Type	Date Issued	Bed Type	Problems (Wet, Veg, Erosion, Pipes, Surface, Tree, Other)	NO_3 (DW) mg	NO_3 (SW) mg	TP (SW) mg/l	Cl^- (DW) mg/l	E.coli (DW) ct	E.coli (SW) ct
1	22-Jul-04	Residential	No	No	Concrete	1998	Filter	Pump Out	1.4	1.6	0.02	1.9		20
2	21-Jul-04	Residential	No	No	Concrete	1987	Trench	Okay	8.5	1.5	0.03	2.7		<10
3	22-Jul-04	Residential	No	No	Concrete	1986	Filter	Okay	5.1	1.6	0.04	6.5	<10	110
4	23-Jul-04	Residential	No	No	Plastic	1989	Filter	Okay	1.8	1.4	0.05	5.4	<10	110
5	26-Jul-04	Seasonal	Yes	No	Holding	1980	Holding Tank	Okay	1.5	1.6	0.01	1.9	<10	<10
6	26-Jul-04	Seasonal	No	No	Concrete	1994	Filter	Okay	1.3	1.4	0.01	2.0	0	4
7	26-Jul-04	Seasonal	No	No	Concrete	1986	Filter	Okay	1.2	1.4	0.01	3.7	<10	<10
8	27-Jul-04	Seasonal	No	No	Concrete	1984	Filter	Okay	0.6	1.4	0.02	1.7	0	0
9	27-Jul-04	Seasonal	No	No	Plastic	1980	Trench	Okay	2.2	1.4	0.04	2.0	<10	10
10	3-Aug-04	Seasonal	No	Yes	Concrete	1990	Filter	Okay	1.8	0.9	0.01	2.0	<10	<10
11	3-Aug-04	Seasonal	No	No	Concrete	1984	Filter	Okay		0.9	0.02			<10
12	3-Aug-04	Seasonal	No	Yes	Holding	1987	Holding Tank	Okay	0.8	0.8	0.03	2.0	<10	<10
13	3-Aug-04	Seasonal	No	No	Concrete	1986	Filter	Okay	1.1	0.8	0.02	2.1	<10	<10
14	3-Aug-04	Seasonal	No	Yes	Unknown	1986	Filter	Okay	0.7	0.9	0.02	1.0	<10	10
15	4-Aug-04	Residential	No	No	Concrete	1986	Filter	Okay	1.0	0.7	0.02	3.4	<10	10
16	9-Aug-04	Residential	No	No	Concrete	2004	Filter	Okay	1.8	1.4	0.01	5.1	<10	<10
17	9-Aug-04	Residential	No	No	Concrete	Unknown	Filter	Okay	0.8	1.4	0.02	1.8	<10	<10
18	10-Aug-04	Seasonal	No	Yes	Concrete	1991	Filter	Okay	0.8			1.6	<10	<10
19	9-Aug-04	Seasonal	No	No	Fiberglass	1989	Filter	Pipes						
20	9-Aug-04	Seasonal	Yes	No	Plastic	1992	Filter	Okay	1.5	2.2	0.01	1.6	<10	<10
21	9-Aug-04	Residential	No	No	Plastic	1994	Filter	Okay	6.3	1.0	0.02	0.7	<10	<10
22	10-Aug-04	Residential	No	No	Plastic	1985	Filter	Okay	4.9	1.5	0.01	4.5	<10	<10
23	11-Aug-04	Residential	No	No	Concrete	1967	Filter	Pump Out		0.8	0.02			
24	11-Aug-04	Residential	No	No	Plastic	1989	Trench	Okay	1.0	1.0	0.03	1.7	30	<10
25	11-Aug-04	Residential	No	No	Concrete	1987	Filter	Wet	0.9	0.9	0.03	4.8	<10	40
26	12-Aug-04	Residential	No	Yes	Concrete	1984	Trench	Wet	1.8	0.7	0.03	0.7	<10	<10
27	17-Aug-04	Seasonal	No	No	Plastic	1996	Filter	Tree Growth	1.5	1.5	0.03	7.1	0	3
28	18-Aug-04	Seasonal	No	No	Concrete	1982	Filter	Okay	1.5	1.4	0.02	7.8	0	1
29	18-Aug-04	Seasonal	No	Yes	Concrete	1986	Filter	Okay	1.4	1.6	0.03	2.0	<10	<10
30	18-Aug-04	Seasonal	No	Yes	Concrete	1999	Filter	Okay	1.6	1.5	0.06	2.1	0	0
31	19-Aug-04	Seasonal	No	No	Concrete	1986	Filter	Okay	1.7	1.4	0.02	1.8	0	0

			OTHER SYSTEI		SEPTIC SYSTEM INFORMATION				Water Quality Data					
Inspection Number	Date Inspected	Property Use	Greywa	Privy	Tank Type	Date Issued	Bed Type	Problems (Wet, Veg, Erosion, Pipes, Surface, Tree, Other)	NO_3 (DW) mg	NO_3 (SW) mg	TP (SW) mg/l	Cl^- (DW) mg/l	E.coli (DW) ci	E.coli (SW) ct
32	18-Aug-04	Seasonal	No	No	Concrete	1986	Filter	Okay	2.5	1.6			0	0
33	24-Aug-04	Residential	No	No	Plastic	2001	Filter	Okay	4.9			5.6		
34	24-Aug-04	Residential	No	No	Concrete	1987	Filter	Wet	5.1			24.0	<10	
35	24-Aug-04	Residential	No	No	Concrete	1995	Filter	Lush Veg	1.3	1.8	0.03	44.8		
36	24-Aug-04	Seasonal	No	No	Plastic	1993	Filter	Okay	1.8			0.0		<10
37	24-Aug-04	Seasonal	Yes	Yes	Concrete	1995	Filter	Okay	1.9	1.7	0.02	1.0	<10	
38	24-Aug-04	Residential	No	No	Plastic	1993	Filter	Okay	1.4	1.8	0.01	6.2		
39	25-Aug-04	Residential	Yes	Yes	Concrete	1970	Filter	Okay					<10	
40	25-Aug-04	Seasonal	Yes	No	Concrete	1999	Trench	Lush Veg	1.2	1.1	0.01	0.0	<10	10
41	25-Aug-04	Seasonal	No	No	Concrete	1981	Filter	Lush Veg		1.4	0.02			<10
42	25-Aug-04	Seasonal	No	Yes	Concrete	Unknown	Filter	Okay	1.9			0.1	<10	
43	26-Aug-04	Seasonal	No	No	Plastic	1990	Filter	Lush Veg						
44	26-Aug-04	Seasonal	No	No	Concrete	2002	Filter	Okay						
45	26-Aug-04	Seasonal	No	No	Concrete	1990	Filter	Roots						
46	30-Aug-04	Seasonal	No	Yes	Unknown	Unknown	Filter	Okay						
47	30-Aug-04	Seasonal	Yes	Yes	Not Applicable	Unknown	Not Applicable	Okay		1.2	0.01			5
48	30-Aug-04	Residential	No	No	Concrete	Unknown	Filter	Okay	3.2	20.5	0.06	43.2	0	
49	30-Aug-04	Residential	No	Yes	Concrete	1996	Trench	Okay			0.02	231.3		
50	31-Aug-04	Seasonal	No	No	Holding	Unknown	Holding Tank	Okay	1.3	1.0	0.02	9.8	0	2
51	31-Aug-04	Residential	No	No	Unknown	Unknown	Filter	Okay	0.9	1.1	0.01	1.0	0	2
52	31-Aug-04	Seasonal	Yes	No	Unknown	Unknown	Filter	Okay		1.3	0.03			0
53	31-Aug-04	Seasonal	No	No	Concrete	1980	Filter	Okay	1.5	1.0	0.03	3.5	0	0
54	5-Oct-04	Seasonal	No	No	Concrete	1994	Filter	Wet						
55	31-Aug-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay						
56	31-Aug-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay	1.1	1.0	0.02	0.2	0	3
57	2-Sep-04	Seasonal	No	No	Unknown	Unknown	Unknown	Okay						
58	2-Sep-04	Seasonal	No	No	Concrete	1980	Filter	Okay						
59	2-Sep-04	Seasonal	No	No	Unknown	Unknown	Unknown	Okay						
60	2-Sep-04	Seasonal	No	Yes	Concrete	Unknown	Filter	Okay						
61	7-Sep-04	Seasonal	No	Yes	Concrete	1960	Filter	Okay						
62	7-Sep-04	Residential	No	No	Unknown	Unknown	Unknown	Response Required						

			OTHER SYSTEI		SEPTIC SYSTEM INFORMATION				Water Quality Data					
Inspection Number	Date Inspected	Property Use	Greywa	Privy	Tank Type	Date Issued	Bed Type	Problems (Wet, Veg, Erosion, Pipes, Surface, Tree, Other)	NO_3 (DW) mg	NO_3 (SW) mg	TP (SW) mg/l	Cl^- (DW) mg/l	E.coli (DW) cl	E.coli (SW) ct
63	7-Sep-04	Residential	No	No	Concrete	1970	Filter	Okay		1.5	0.02			
64	7-Sep-04	Residential	No	No	Unknown	Unknown	Filter	Okay	2.2	1.2			0	82
65	7-Sep-04	Residential	No	No	Plastic	1997	Filter	Okay						
66	8-Sep-04	Residential	No	No	Concrete	1986	Filter	Okay						
67	8-Sep-04	Seasonal	No	No	Holding	Unknown	Holding Tank	Okay						
68	8-Sep-04	Residential	No	No	Unknown	Unknown	Unknown	Okay						
69	8-Sep-04	Seasonal	No	No	Holding	1981	Holding Tank	Okay						
70	8-Sep-04	Residential	No	Yes	Unknown	Unknown	Filter	Wet						
71	8-Aug-04	Residential	No	No	Unknown	Unknown	Unknown	Response Required						
72	13-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay						
73	13-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Tree Growth						
74	13-Sep-04	Seasonal	No	No	Fiberglass	1990	Filter	Tree Growth						
75	13-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay						
76	13-Sep-04	Seasonal	No	No	Plastic	1989	Filter	Okay						
77	14-Sep-04	Seasonal	Yes	No	Concrete	1987	Filter	Pipes					<10	20
78	14-Sep-04	Seasonal	Yes	No	Concrete	1997	Filter	Pipes						
79	14-Sep-04	Residential	No	No	Concrete	1993	Filter	Okay	4.0	1.4	0.00	0.4	15	10
80	15-Sep-04	Residential	Yes	Yes	Concrete	1993	Filter	Okay						
81	14-Sep-04	Seasonal	No	No	Concrete	Unknown	Filter	Roots			0.04	1.3		
82	14-Sep-04	Residential	No	Yes	Concrete	1991	Filter	Okay						
83	14-Sep-04	Seasonal	No	No	Concrete	Unknown	Filter	Okay						
84	15-Sep-04	Seasonal	Yes	Yes	Concrete	Unknown	Filter	Okay	1.9	1.5	0.00	2.4	0	0
85	16-Sep-04	Residential	No	No	Concrete	1995	Trench	Okay						
86	16-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay						
87	16-Sep-04	Seasonal	No	No	Concrete	1990	Filter	Okay	1.2	1.0	0.01	2.4	0	7
88	21-Sep-04	Seasonal	Yes	Yes	Holding	1984	Holding Tank	Pipes						
89	21-Sep-04	Seasonal	No	No	Concrete	1984	Filter	Okay						
90	21-Sep-04	Seasonal	No	Yes	Unknown	Unknown	Unknown	Okay						
91	21-Sep-04	Seasonal	No	Yes (Vau	Holding	Unknown	Holding Tank	Okay						
92	21-Sep-04	Residential	No	Yes	Holding	1984	Holding Tank	Okay						
93	21-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay						
94	21-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay						
95	21-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Erosion						
96	21-Sep-04	Seasonal	Yes	Yes	Unknown	Unknown	Unknown	Response Required						
97	22-Sep-04	Seasonal	No	No	Unknown	Unknown	Unknown	Response Required						
98	22-Sep-04	Seasonal	No	No	Unknown	Unknown	Filter	Okay						
99	22-Sep-04	Residential	No	No	Concrete	1995	Filter	Okay						
100	27-Sep-04	Residential	No	No	Concrete	Unknown	Unknown	Okay						
101	27-Sep-04	Residential	No	No	Concrete	1987	Trench	Okay						
102	27-Sep-04	Residential	No	No	Concrete	1986	Trench	Okay						
103	19-Aug-04	Seasonal	No	No	Concrete	1987	Filter	Okay		1.3	0.16			4
104	1-Oct-04	Residential	Yes	Yes	Unknown	Unknown	Unknown	Pipes						
105	1-Oct-04	Residential	No	No	Concrete	1990	Filter	Okay						
106	1-Oct-04	Seasonal	No	Yes	Unknown	Unknown	Unknown	Okay						
107	1-Oct-04	Seasonal	No	Yes	Fiberglass	1981	Filter	Okay						
108	4-Oct-04	Residential	No	No	Unknown	1986	Filter	Okay						
109	5-Oct-04	Residential	Yes	No	Plastic	2000	Filter	Okay						
110	4-Oct-04	Seasonal	No	No	Unknown	Unknown	Unknown	Okay						

APPENDIX B – WATER SOFTENER FIELD EVALUATION STUDY DATA

#	Problems	Failed	Soil Type	Age of System	# of People
1	Water level in tank higher than outlet	Y	clay	23	2
2	None		loam		2
3	No. Mantle of gravel at end		sand	23	5
4	None		loam	1	5
5	Water level in tank higher than outlet & water r	Y	clay	40	4
6	None		clay		2
7	None		sand	5	2
8	None		clay	30	2
9	None		clay	30	1
10	None		sand	17	2
11	Water level in tank higher than outlet	Y	clay	30	4
12	None		clay	27	4
13	Water level in tank higher than outlet	Y	clay	40	1
14	Mushy ground and water level in tank higher th	Y	clay		5
15	None		loam	30	2
16	Very sludgy	Y	loam		4
17	No - past due for being pumped		sand	9	2
18					4
19	No		sand	15	4
20	Toilets backing up; water level in tank higher th	Y	clay	37	3
21	Toilets backing up; blocked inlet pipe	Y	loam		3
22	No		sand	13	3
23	No		loam	25	2
24	No		sand		2
25	No		sand	12	3
26	No		loam	40	2
27	No problem except Outlo towd ot tank decomposing				3
28	No problem		loam	30	1
29	No		sand	20	2
30	water level in tank higher than outlet	Y	loam	20	2
31	No problem		sand	15	2
32	No problem		loam		4
33	No problem		stoney	25	3
34	No problem		loam		4
35	No problem		sand		6
36	No problem		stoney	25	5
37	No problem		stoney	25	4
38	No problem		stoney		5
39					

#	Problems	Failed	Soil Type	Age of System	# of People
40	No problem		loam		3
41	No problem		loam	20	3
42	No problem		clay	20	2.5
43	No problem		clay	5	5
44	No problem		sand		2
45	No problem		clay	32	3.5
46	No problem		clay		5
47	No		loam		3
48	No		sand		2
49	Water level in tank higher than outlet	Y	clay	15	1
50	No		sand		3
51	No		sand		4
52	Water level in tank higher than outlet	Y	clay		2
53	No		sand		2
54	No		clay	15	2
55	No		sand	27	3
56	No		sand	15	5
57	No		sand		2
58	No		clay	20	4
59	No		clay	30	3
60	No		sand	17	5
61	No		sand	18	5
62	Water level in tank higher than outlet	Y	clay	17	5
63	No		clay	18	3
64	No		sand	15	3
65	No		sand	7	4
66	No		loam	20	4
67	No		stoney	30	1
68	No		loam	30	5
69	No		sand	13	4
70	No		sand	12	3
71					
72	No		sand	12	2
73	No		sand	10	3
74	No		sand	23	3
75	No		clay	30	3
76	No		sand		1
77	No		sand		3