REMEDIATION OF SEPTIC FIELDS THROUGH FLOW REDUCTION TECHNIQUES

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Executive Summary

Introduction

When faced with wastewater treatment problems private, commercial, and government agencies must have economically efficient options. Septic system failure in Nova Scotia and in other provinces is an expensive problem and is receiving more attention as water courses and groundwater systems become compromised by these pollution sources. Septic field malfunctions often stem directly from hydraulic overloading and the inability of the soil to adequately treat and mobilize septic wastewater. In Nova Scotia, the high annual rainfall (1200 mm/year) and impermeable soils serve to aggravate the problem of septic field breakouts and surface water pollution. This study was directed to the application of water reduction techniques in the remediation of existing septic beds that experience failure through hydraulic overloading.

Objectives

The primary objectives of this study are to:

- Determine the effectiveness of water conservation as a remedial measure for a failing septic-bed system by examining the effects of flow reduction on net loads to the system and the effects of net load reduction on system performance.
- Using mathematical water balance calculations extrapolate the results from the experimental system to possible situations in other areas of Canada.

Methodology

Low permeability soils and a high groundwater table at Waverley in N.S. resulted in one complete replacement of a disposal bed, for a multi unit residential property, and a continuing condition of high ponded effluent levels within that bed. This lead to occasional effluent breakouts and septic-tank pumping during wet seasonal periods.

A water meter was placed on the building water inlet and a detailed water use audit was conducted. Retrofitting all the units within the complex with low flow shower heads, sink aerators, low flow toilets, and the installation of a pressure reducing valve on the building water inlet reduced the hydraulic loading on the disposal bed by approximately 50% from initial water use levels. Field piezometric level observations, water usage values, and climatic data were used to construct a mathematical water balance model showing the relationship between hydraulic loading and disposal field performance.

Discussion

The ability of the water use audit to accurately predict the effects of the implementation of the water conservation measures points to the power of this technique for use in other situations.

The water balance model accurately represented the response of the disposal field ponding levels to measured hydraulic variations. The model was then used to simulate pre-conservation loading rates. The water balance model offers the promise of a useful tool for design and analysis of disposal field performance:

- it adequately represented the performance of two systems that are subjected to substantially different hydraulic loads.
- it provided a means to evaluate effects of water conservation methods on system performance.
- it demonstrates the role of system storage in disposal field performance.

The permeability of the clogging mat in the Waverley system has decreased significantly over time. These results indicate that the rate of decline in permeability is a function of loading rate. They also suggest that the rapid decline in the permeability of the Waverley system will result in problems that have been delayed, but not prevented , by water conservation measures.

Conclusions

Water conservation is an inexpensive technique to prevent, or at the least postpone, costly disposal bed replacement and can be used by private, commercial, or government agencies faced with failing on-site disposal systems. These measures can significantly reduce the hydraulic load on an on-site disposal system, resulting in lower levels of effluent ponding and groundwater mounding below the disposal bed in tight soils.

Hydraulic overloading is the major cause of on-site disposal system failure. Reducing the hydraulic load can significantly improve the performance of the disposal bed.

In an area of high annual precipitation, wastewater contributions to the on-site system are significantly greater than those from natural hydraulic loading on the disposal field, and therefore will have a significant impact on system performance.

The water balance model developed in this study reproduced measured field levels and indicates that without conservation, this system would be flooded.

Declining permeability, reduced by high organic loads, is expected to produce future problems at this site.

«Assainissement des champs d'évacuation par réduction du débit»

RÉSUMÉ

Introduction

Lorsqu'ils font face à des problèmes d'épuration des eaux usées, les établissements commerciaux, les gouvernements et les particuliers doivent pouvoir disposer de solutions efficientes. En Nouvelle-Écosse et dans d'autres provinces, la défaillance des installations septiques est un problème onéreux qui reçoit de plus en plus d'attention à mesure que les cours d'eau et que la nappe phréatique sont menacés par cette forme de pollution. Souvent, la défaillance des champs septiques découle directement de la surcharge hydraulique et de l'incapacité du sol à traiter et à mobiliser correctement les eaux d'égout septiques. En Nouvelle-Écosse, le taux annuel élevé de précipitations (1 200 mm) et l'imperméabilité des sols aggravent le problème de débordement des champs septiques et de pollution des eaux de ruissellement. La présente étude vise à déterminer si les techniques de réduction du débit d'eau peuvent contribuer à assainir les champs d'évacuation existants qui ne peuvent jouer leur rôle à cause de la surcharge hydraulique.

Objectifs

L'étude a pour objectifs principaux :

o de déterminer l'efficacité de l'économie de l'eau pour remédier à la défaillance des champs d'évacuation en examinant les effets de la réduction du débit sur les charges nettes imposées à l'installation de même que les effets de la réduction de la charge nette sur la performance de l'installation;

o d'extrapoler, au moyen du calcul mathématique du bilan hydrologique, les résultats tirés d'une installation expérimentale afin d'établir si cette solution pourrait s'appliquer à d'autres régions canadiennes.

Méthode

Les sols peu perméables et la surface élevée de la nappe phréatique à Waverley, en Nouvelle-Écosse, a entraîné le remplacement complet du champ d'évacuation d'un collectif d'habitation et des niveaux d'accumulation d'effluent constamment élevés à l'intérieur de ce champ. Cette situation a donné lieu à d'occasionnels débordements de l'effluent et a rendu nécessaire le pompage de la fosse septique en période de précipitations abondantes.

On a placé un compteur d'eau sur la prise d'eau et vérifié la consommation de façon détaillée. En dotant tous les appartements de l'ensemble de pommes de douche à débit réduit, d'aérateurs de robinet, de toilettes économes en eau et en posant un robinet réducteur de pression sur la prise d'eau de l'immeuble, on a pu réduire la charge hydraulique du champ d'évacuation d'environ 50 p. 100 par rapport à l'utilisation initiale. Des observations du niveau piézométrique sur le terrain, les valeurs relatives à la consommation d'eau et des données climatiques ont servi à réaliser un modèle du bilan hydrologique montrant la relation entre la charge hydraulique et la performance du champ d'évacuation.

Commentaire

Comme la vérification de la consommation d'eau permet de prévoir avec précision les effets des mesures d'économie de l'eau, cette technique s'avère très utile pour d'autres situations.

Le modèle du bilan hydrologique a représenté de façon précise la réaction des niveaux d'accumulation du champ d'évacuation par rapport aux variations mesurées de la charge hydraulique. Le modèle a ensuite servi à simuler les taux de charge existant avant la mise en place des mesures d'économie de l'eau. Le modèle du bilan hydrologique se révèle très prometteur pour la conception et l'analyse de la performance des champs d'évacuation, car :

- il a correctement modélisé la performance de deux installations soumises à des charges hydrauliques présentant des différences substantielles;
- il a servi à évaluer les effets des mesures d'économie de l'eau sur la performance de l'installation;
- il a démontré le rôle de la rétention au sein de l'installation pour ce qui est de la performance du champ d'évacuation.

La perméabilité de la couche bactérienne de l'installation de Waverley a diminué considérablement avec le temps. Les résultats révèlent que le taux de diminution de la perméabilité est fonction du taux de charge. Ils indiquent également que la diminution rapide de la perméabilité de l'installation de Waverley va entraîner des problèmes qui avaient jusqu'alors été différés, mais non réglés, par les mesures d'économie de l'eau.

Conclusions

Pour les commerces, les gouvernements et les particuliers qui font face à des problèmes d'épuration des eaux usées, l'économie de l'eau est une technique peu coûteuse permettant de prévenir, ou du moins de retarder, le remplacement onéreux d'un champ d'évacuation. Ces mesures peuvent réduire sensiblement la charge hydraulique d'une installation locale d'épuration, ce qui entraîne une diminution de l'accumulation d'effluent et de la surélévation de la nappe phréatique sous le champ d'évacuation dans les sols imperméables.

La surcharge hydraulique est la principale cause de défaillance des champs d'évacuation locaux. En diminuant la charge hydraulique, on arrive à améliorer considérablement la performance du champ.

Dans les régions à fortes précipitations annuelles, la présence d'eaux usées dans les installations d'épuration locales est beaucoup plus importante que celle de la charge hydraulique naturelle du champ d'évacuation; elles ont donc un impact significatif sur la performance de l'installation.

Le modèle du bilan hydrologique mis au point dans la cadre de cette étude a reproduit les niveaux mesurés dans les champs et indique que sans économie d'eau, cette installation serait inondée.

La réduction de la perméabilité, au moyen de charges organiques élevées, entraînera vraisemblablement des problèmes à cet endroit.

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Remediation of Septic Fields Through Flow Reduction Techniques

by J.D. Mooers[1] and D.H. Waller[2]

Abstract

The objective of this study was to determine the impact of water conservation measures on a malfunctioning on-site wastewater disposal system, located at a 15 unit senior citizens complex. Low permeability soils and a high groundwater table at this site have resulted in one complete replacement of the disposal bed and a continuing condition of high ponded effluent levels within the bed, leading to occasional effluent breakouts and septic tank pumping during wet seasonal periods. Retrofitting all the units within the complex with low flow shower heads, sink aerators , low flow toilets, and the installation of a pressure reducing valve on the building water inlet has reduced the hydraulic loading on the disposal bed by approximately 50% over initial pre-conservation water usage. Field piezometric level observations, water usage values, and climatic data were used to construct a mathematical water balance showing the relationship between hydraulic loading and disposal field performance. The model, which reproduced measured field levels, indicates that without conservation the system would be flooded, but that declining permeability reduced by high organic loads is expected to produce future problems.

Introduction

Fiscal restraint programs by governments have resulted in resource scarcities in many areas, including the amount of money that municipalities have to spend on water projects. Accompanying this is an increased demand on the funds for the maintenance and upgrading of current facilities. When faced with water management or wastewater treatment problems, private, commercial or government agencies must have economically efficient options to allow the available funds to stretch as far as possible to ensure the maximum social benefit of this funding. Instead of replacing a problem on-site disposal field every few years, flow reduction is an economical solution that may prolong the life of a disposal field.

Septic field malfunctions often stem directly from hydraulic overloading, the inability of the soil to pass the inflowing load of septic tank effluent . In Nova Scotia, the high annual rainfall (1200 mm/year) and impermeable soils only serve to aggravate the problem of septic field breakouts and surface water pollution. Where systems fail the conventional options are replacement of the field where site size and other conditions permit , or central servicing. A third potential option is flow reduction to the disposal bed. The first of these three options, field replacement, is expensive and therefore undesirable,

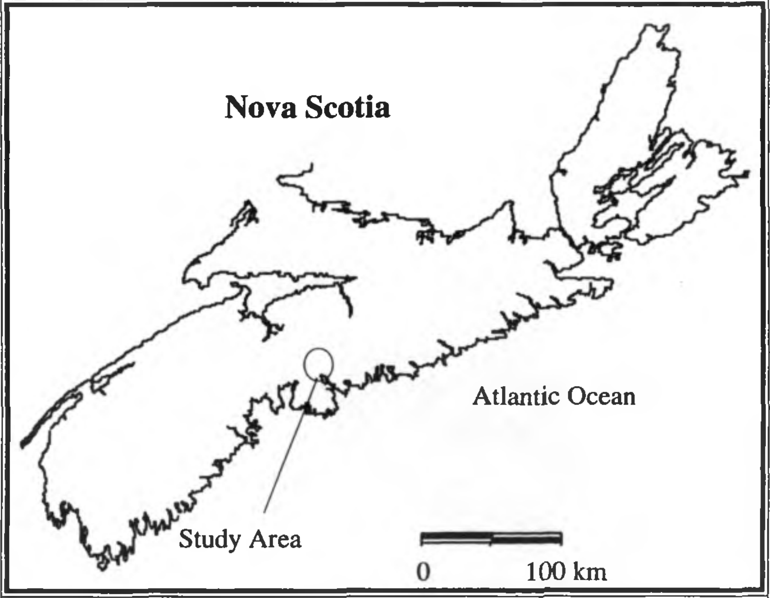

Figure 1. Study Location

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especially to the small home owner, as the cost of an on-site disposal system construction for a single dwelling can be several thousand dollars. Installing central servicing is only possible in areas with sufficient housing density to justify the expense. Such expenses are often deemed too high, and central collection and treatment may only transfer problems to a receiving water. If it were possible to leave the existing system in place and emphasize modifications to the hydraulic loading, it might be possible to return the field to a properly functioning system. This approach could provide substantial cost savings to any private, commercial or government agency faced with the problem of on-site disposal field failure.

This research was directed to the application of water reduction techniques in the remediation of existing septic beds that experience failure through hydraulic overloading. This research assessed the impacts of system performance by decreasing the net loads on a on-site waste disposal field through modifications of only the household inputs, and not other sources such as precipitation and groundwater. The chief objectives were to 1) determine the effectiveness of water conservation as a remedial measure for a failing system by examination of effects of flow reduction on net loads to the system, and the effects of the net load reduction on system performance; and 2) through the use of mathematical models to extrapolate the results from the Waverley system to other situations in Atlantic Canada and other areas of the country. This research also provides valuable water audit data, for multi-dwelling buildings, a necessity for water resource planning and management efforts.

The research field location is a 15 unit senior citizen housing complex, in Waverley, Nova Scotia, that has experienced a series of septic bed malfunctions due to excessive water inputs over the past several years. These problems were addressed by system modifications and measures to reduce water consumption. A good data base, and the interest of the responsible government agency, suggested that this site could yield a better understanding of the relationship of system performance to water demand.

System Characterization

On October 4, 1982 the Nova Scotia Department of Heath (NSDOH) issued a letter of approval setting out the proposed location and design of the sewage disposal system at the Waverley Senior Citizens complex. The project and sewage system were built by private contractors between the fall of 1983 and the fall of 1984, shortly after which the complex was occupied. By mid- 1985 there was flooding around the disposal field, and the septic tank was being pumped monthly. In October of 1986 the field was dug out and fully reconstructed. In January 1989 the system once again backed up into the building and effluent broke out along the south-east edge of the field. A complete history of the site is in Appendix 1.

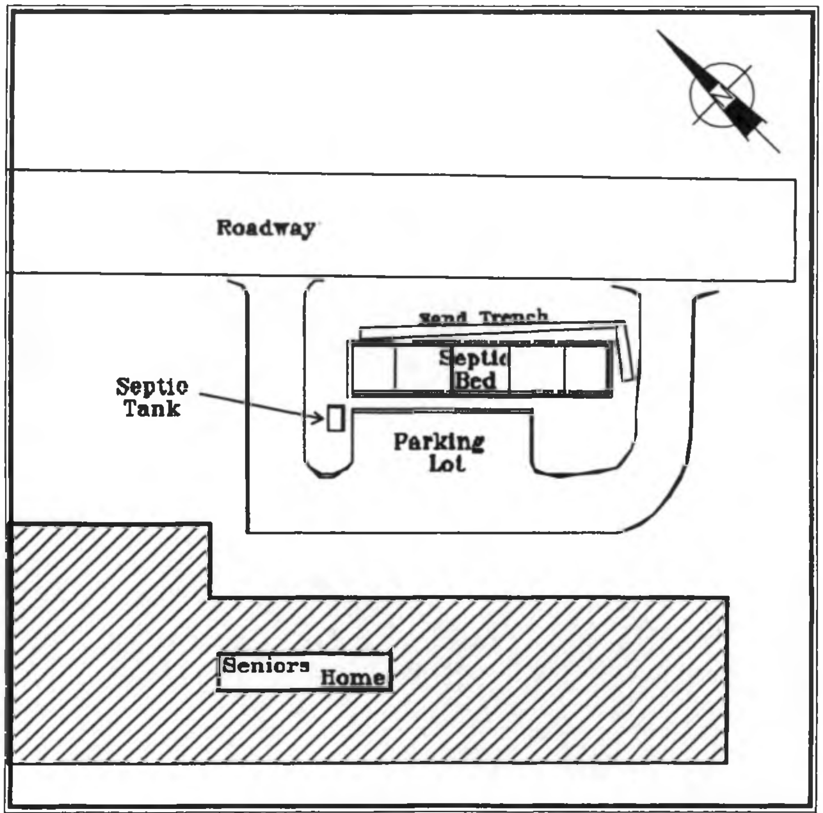

Figure 2. Disposal Field Layout

The Nova Scotia Department of Housing has maintained careful records of water usage and septic tank levels at the site from January 1989 to present. These records show that initial conservation efforts at the Waverley site resulted in the reduction of water consumption from roughly 1000 gal/day to approximately 700 gal/day. These conservation efforts included the installation of low-flow showerheads, placement of bricks in toilet tanks, sink aerators on the kitchen sinks, and installation of a pressure reducing valve on the building water inlet.

In their attempts to rectify the 1985 problems the NSDOH perceived the principle contributors to the field failure as:

- a very high seasonal water table that was not evident at the time of the soil test and that during critical periods was surcharging the field.

- the sewage disposal field itself upon subsequent examination was found to have defects making the majority of the field ineffective.
- measurement of water usage at the project indicated that water consumption was 50 percent higher than similar size projects elsewhere, thus putting a significantly higher load on the sewage system.
- the overall percolation rate of the soil in the location of the sewage field appeared to have been altered by excessive heavy vehicle traffic during the construction of the project or by some other means such as physical or biological clogging.

The water inlet to the building is connected to the Metropolitan Halifax water system. The wastewater disposal system consists of a 1000 gallon septic tank connected to an area bed disposal field (see Figures 2 and 3). The disposal bed is 95 by 25 feet. The field materials include 2 feet of gravel on which the disposal pipes are laid; the pipes are covered by a further 6 to 8 inches of gravel. The disposal field pipes form a rectangle 90 by 20 feet with four cross-pipes: two spaced 15 feet from each end of the rectangle and two 20 feet interior to these (Figure 3). The gravel is covered with geotextile, then 6 to 12 in. of clay, above which is a 2 to 3 inch layer of sod. Along the north and east side of the disposal bed is a sand filled trench approximately 9 feet deep.

The trench was considered a safety measure to provide some filtration of effluent that did not receive proper treatment in the disposal bed, and as a possible conduit to a deeper more conductive layer.

Methodology

Prior to this study the site was surveyed and three shallow piezometers (4 feet) were installed in the locations shown on Figure 3. During the study the septic tank, piezometer levels, and the water meter, were monitored weekly. Relevant records from the Nova Scotia Department of Housing and the Department of Health were assembled and reviewed. A detailed audit of each unit was conducted to examine the fixtures, conservation measures, and the nature of water use within the building. During a two week detailed study a rain gauge was placed on site and precipitation levels were compared with those collected at the Halifax International Airport less than 10 kilometers away. Environment Canada daily climatic data for this station was collected for the period January 1989 to December 1991. A one week detailed study was conducted after implementation of further water conservation measures. Daily water quality samples were collected from the piezometers and septic tank during this period.

Information about low-water consumption fixtures was assembled and reviewed. In addition, a literature search of

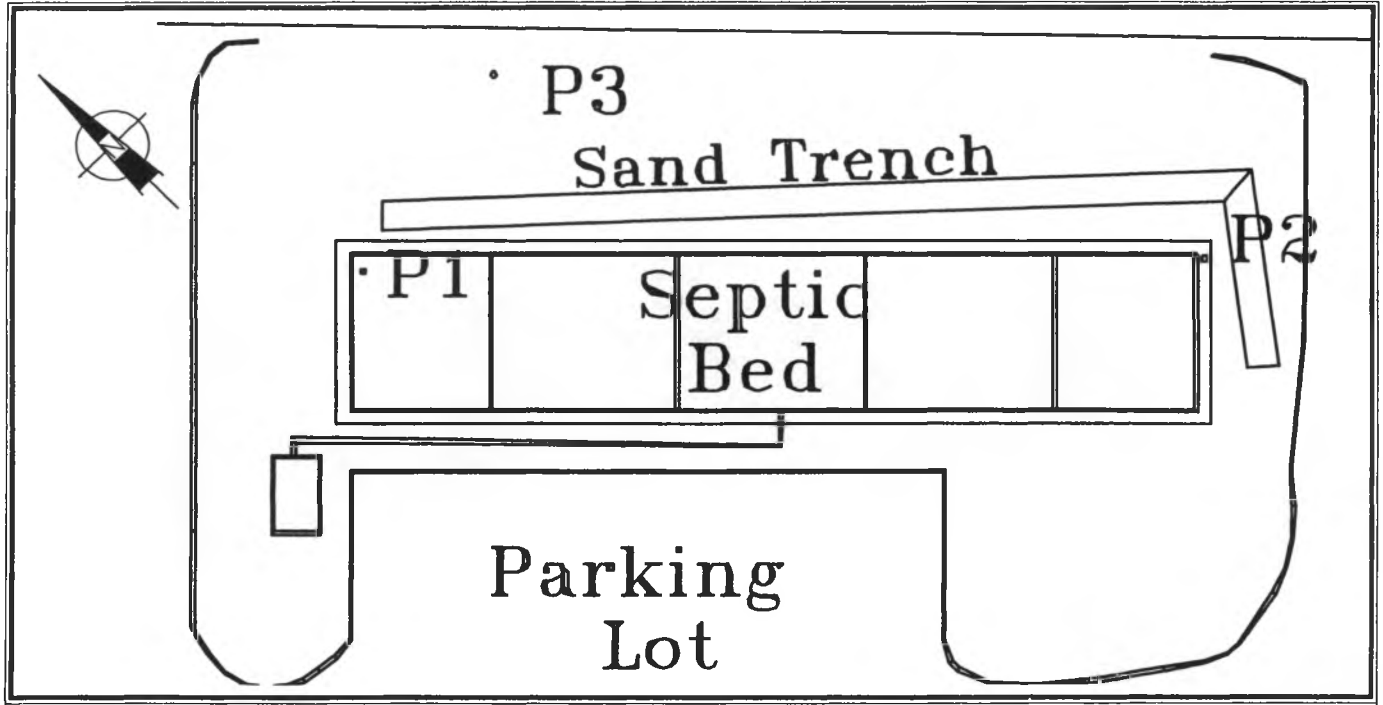

Figure 3. Piezometer Placement

water use data and multiple unit conservation projects was assembled, and is shown in Appendix 2.

The results of the system audit and the literature review of water conservation efforts were used to develop a proposal for the replacement of plumbing fixtures and fittings.

Water use, effluent level, and precipitation data from these analysis were used to develop a mathematical water balance model of the disposal system. The water balance was developed to establish the relationships between the measured system variables in order to predict the effects of changes to the system on performance.

Results

Water Use Audit

Table 1, based on the audit and the literature review, is an estimated allocation of daily water use within the building during the study period. Individual water use areas are discussed below.

1) Toilet Flow

The original toilets at the site used 3.5 imperial gallons per flush. With bricks in the toilet tanks this was reduced to 3.25 gallons per flush. This is less than the 5 to 7 gallons used by a conventional North American toilet, but it is more than currently available designs that use a smaller water reservoir and a specially-designed bowl to give the same flush power with water use per flush of 1.6 gallons.

2) Shower Heads / Sink Aerators

The site is equipped with low-flow shower heads that flow at a rate of 1.8 gal/min with both taps full open. Flow with the shower head removed is approximately 4.5 gal/min.

The kitchen sinks are equipped with aerators. Of the 15 units 5 were missing aerators at the initiation of this study. The measured rate of flow from an aerated faucet was 2.5 gal/min; unaerated flow was 4.5 gal/min.

3) Washing Machines

There are 2 washing machines, both coin operated Maytag commercial washers. These use 40.9 gal per load. Examination of the receipts from the coin box show an average of 1.1 washes/washer/day. This gives a total of 90 gal/day water use for clothes washing.

4) Total Water Use

The total water use at the site with bricks in the toilet tanks averaged 650 gals/day. After the removal of the bricks flow increased by approximately 100 gals/day.

Studies of water usage habits reveal that roughly 35% of indoor water used is for toilet flushing, 20% for bathing, and 22% for laundry (1981, Jarrett). This information was used to produce an estimated distribution of household water use at the study site, with bricks in the toilet tanks, as shown in Table 1.

Table 1. Pre-audit Interior Water Use

Toilet Flow	Shower/ Sink Flow	Washing Machine	**Total Flow**
Gal/Day	Gal/Day	Gal/Day	Gal/Day
260	300	90	**650**

Conservation Measures

The audit revealed that further water conservation measures could significantly reduce toilet and sink flow. A decision was made to replace the current toilets with 1.6 gallon per flush toilets, to replace the unreliable and broken kitchen sink aerators, and to add bathroom sink aerators. Installation of the low flow toilets was expected to reduce flush flow from roughly 360 gal/day to 160 gal/day. The expected flow reduction from the kitchen and bathroom sink aerators was approximately 50 gal/day. The total estimated post-conservation daily flow is summarized in Table 2.

Table 2. Post-conservation Interior Water Use

Toilet Flow	Shower/ Sink Flow	Washing Machine	**Total Flow**
Gal/Day	Gal/Day	Gal/Day	Gal/Day
160	250	90	**500**

The average total daily flow after the installation of the low-flow toilets, as measured from September 91 to January 92 was approximately 480 gal/day.

Wastewater Quality

The results of water quality sampling are shown in Table 3. The two piezometers within the disposal field, P1 and P2, show results consistent with the values for raw sewage measured in the septic tank. Piezometer P3, outside the field, shows reduced nitrate, phosphate, organic carbon, and total coliform levels.

Water Balance

Results of the water balance are presented in full in Appendix 3 and are summarized here.

The measured water balance variables included inflow to the building, also used as inflow to the septic system, septic tank levels, piezometric levels within the disposal field, and precipitation.

Simulated water levels in the Waverley system, based on clogging mat permeability values from the record period, adequately represent measured water levels when used with what are judged to be reasonable assumptions about values of other system variables . Application of the same relationships to another system, which was subject to substantially lower hydraulic loads, strengthens confidence in the model. Future application of data from other systems will confirm or modify opinions about the model's capabilities.

The model was used to simulate variations in system water levels at Waverley resulting from water usage corresponding to pre-conservation (1000 igpd), initial conservation average demand (670 igpd), and simulated effects of further conservation (520 igpd). Results are shown in Figure 4.

Discussion

Water Conservation

Initial conservation efforts at the Waverley site included a pressure reduction valve on the building water inlet, installation of aerators on the kitchen sinks, and placement of bricks in toilet tanks. This resulted in the reduction of water usage from approximately 900 gal/day down to 700 gal/day.

Placing bricks in toilet tanks, to reduce flow volume, is not recommended as they can crack tanks or fragment and block plumbing causing expensive repairs. The daily water use at Waverley was roughly 650 gal/day, 40% of which, 260 gal/day, was for toilet flushing. Soon after the bricks were removed from the toilet tanks daily water use increased roughly 100 gal/day.

Table 3. Effluent Quality Results

Date	Well	N-TKN	NO_3+NO_2	N-NH_3	PO_4	pH	TOC	Total Coliforms
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	/100 ml
Apr/18/91	P1	-	<0.05	38.0	<0.01	-	43.0	250000
Apr/18/91	P2	-	<0.01	39.0	<0.01	-	41.0	300000
Apr/18/91	P3	-	<0.05	12.6	<0.05	-	2.9	0
May/9/91	P1	43	<0.05	32.0	7.1	6.82	53.0	>3000
May/9/91	P2	50	0.05	44.0	6.2	6.85	61.0	>3000
May/9/91	P3	15	<0.05	10.0	<0.01	6.48	3.3	0
May/31/91	P1	47	<0.05	40.0	2.9	7	20.1	-
May/31/91	P2	49	<0.05	44.0	3.3	7.1	20.8	-
May/31/91	P3	2.4	0.22	14.0	<0.01	7.2	2.4	-
May/31/91	Tank	49	<0.05	42.0	3.1	7.1	29.5	-
Oct/8/91	P1	41	0.11	39.7	4.4	7.2	15	1,020,000
Oct/8/91	P2	46	<0.05	45	5	7.3	17	2,600,000
Oct/8/91	P3	21	<0.05	20	0.01	6.7	3.1	1000
Oct/8/91	Tank	59	<0.05	50	5	7.2	59	6,200,000
Oct/15/91	P1	49	<0.05	44	4.2	6.96	13	550,000
Oct/15/91	P2	41	<0.05	38	4	6.91	15	50,000
Oct/15/91	P3	21	<0.05	21	.01	6.53	5.6	20,000
Oct/15/91	Tank	53	<0.05	44	4	7.55	530	13,000,000

Further measures proposed as a result of this project were the installation of low flow sink aerators, which are estimated to reduce flow further giving an estimated total flow reduction of 200 to 250 gal/day. It is clear comparing Tables 1 and 2 that the greatest conservation effect is due to toilet usage.

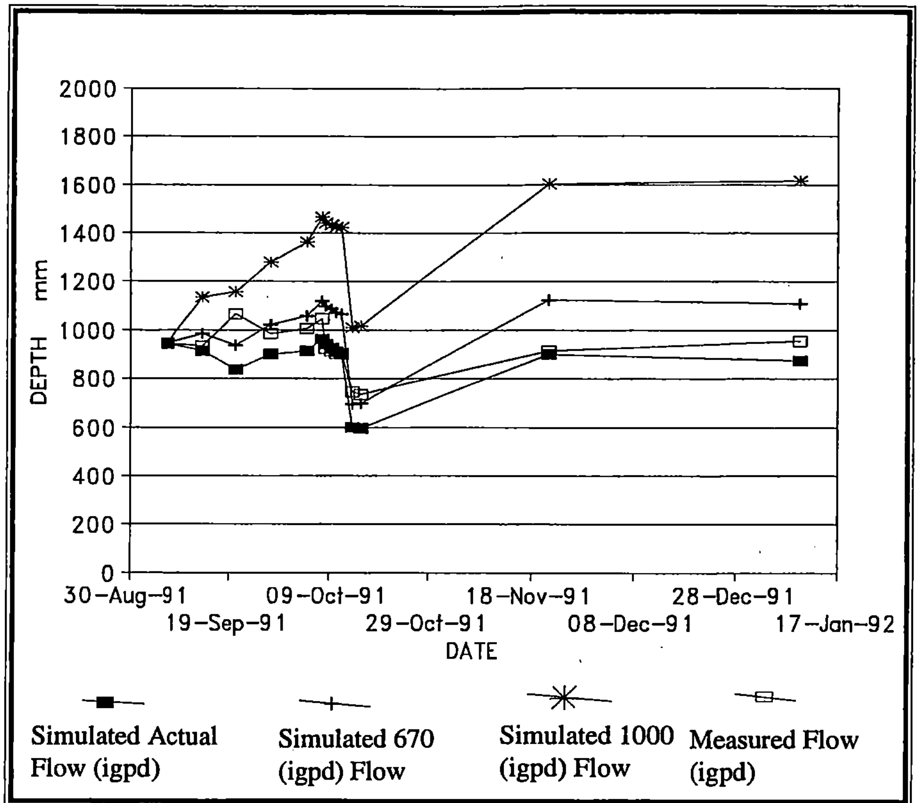

Figure 4. Effects of Water Conservation

Less expensive alternatives to low-flow toilets are plastic containers, which when placed in the toilet tank serve the same function as bricks, or flexible metal dams that retain part of the water during flushing. The former cost nothing and the latter about $4 per toilet, compared with the $175 per unit cost of a 1.6 gallon toilet. However, the toilets incorporate bowls that have been redesigned to be effectively cleansed by the smaller flow. The dams require periodic adjustment if they are to work effectively. If the plastic containers or dams are not effective, they can result in double flushing, which will eliminate any conservation gains.

The Nova Scotia Department of Housing in mid-September installed thirteen 1.6 gallon flush toilets at the Waverley site. Three of the low-flow toilets could not be installed due to space limitations in the units. The recommended low-flow sink aerators have yet to be installed at the site.

The ability of the audit to accurately predict the effects of the implementation of water conservation measures points to the power of this technique for use in other situations.

Water Balance

Figure 4 compares simulated water levels in the bed-- for the period September, 1991 to January, 1992-- for three simulated rates of water use: pre-conservation water demand; demand after initial conservation measures were employed; average demand after further conservation was implemented in September, and shows the measured levels. The simulation indicates that initial conservation measures would have reduced water levels by approximately 500 mm, and kept them just below ground levels in this period, and that the measures implemented in September reduced levels by a further 200 mm.

The information and discussion in Appendix 3 also indicates that the low permeability of the soil underlying the Waverley system may have resulted in continuous ponding in the bed, which is now producing a significant reduction in clogging mat permeability and may lead to system failure. Water conservation has delayed, but may not prevent, this result.

The simulation in Appendix 3 also indicates that pumping of the septic tank, which has been employed to reduce levels in the Waverley system, is effective in the short run but can be offset by effects of precipitation.

These results also demonstrate the importance, in the Waverley system, of the storage capacity represented by the area and depth of the disposal field.

The water balance model offers the promise of a useful tool for design and analysis of disposal field performance:

- it has adequately represented the performance of two systems that are subjected to substantially different hydraulic loads.
- it has provided a means to evaluate effects of water conservation methods on system performance.

- it demonstrates the role of system storage in disposal field performance.

The water balance model assumes that that flow from the system is controlled by the depth of water in the field and is not affected by groundwater levels below the bed. The model requires information about clogging mat permeability. More work is needed to evaluate the applicability of existing information about this subject, and to define the need for further research about clogging mat permeability and factors that control it.

The work reported here relates directly to a climatic and geologic region characterized by high precipitation, tight soils, and high groundwater levels. The Waverley system is subjected to high hydraulic loads resulting primarily from water usage. The system used for comparison has significantly smaller water use and a similar precipitation load. These conditions represent a range that suggests that the model can be usefully applied in other parts of Canada. Assuming that further experience validates the effectiveness of the water balance model, it offers the promise of a useful tool for the design and evaluation of on-site systems.

Water Quality

Figure 5, which is based on Table 3, illustrates relationships among sampling results for each parameter. The piezometers within the disposal field , P1 and P2, show results consistent with the values for raw sewage measured in the septic tank. Piezometer 3, outside the field, shows reduced nitrate, phosphate, organic carbon and coliform.

Water reaching Piezometer 3 has passed through the clogging mat, the sand filter, and the soil column, and has been diluted by ground water. The complete removal of bacteria is assumed to reflect die-off and filtration effects. It is difficult to assess the extent to which reductions in other parameters (on the order of 70% to 90%) are due to adsorption in the soil. Figure 5 also shows complete removal of phosphate from water reaching P3. There is no obvious explanation for low phosphate values in P1 and P2 on April 18. There is no indication of nitrification in samples obtained from Piezometer 3. The high organic carbon result obtained from the septic tank on October the 15th is believed to be the result of solids captured in the sampling process.

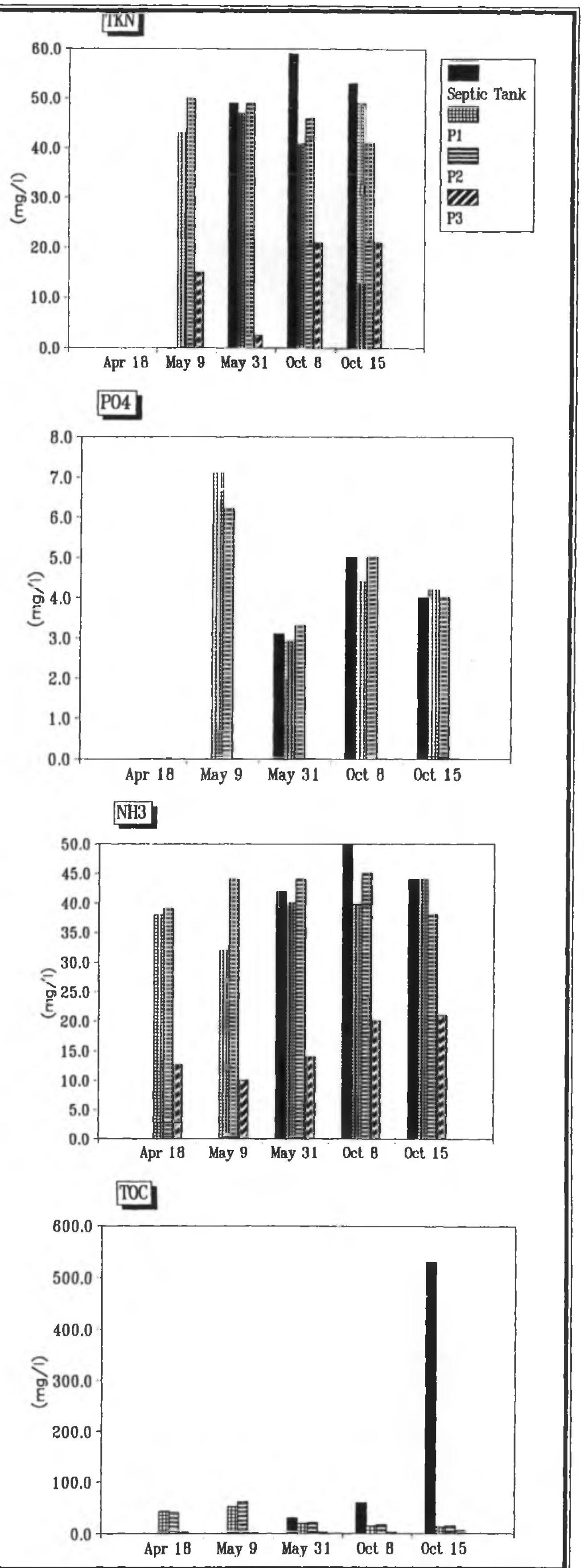

Figure 5. Chemical Quality

Conclusions

Private, commercial, or government agencies faced with failing on-site disposal systems can use water conservation as an inexpensive technique to prevent, or at the least postpone, costly disposal bed replacement. Water conservation measures can significantly reduce the hydraulic load on an on-site disposal system, resulting in lower levels of effluent ponding and groundwater mounding below the disposal bed in tight soils. As the major cause of on-site disposal system failure is hydraulic overloading, reducing the hydraulic load can significantly improve the performance of the disposal bed.

Even in an area of high annual precipitation, wastewater contributions to the on-site system are significantly greater than those from natural hydraulic loading on the disposal field, and therefore will have a significant impact on system performance.

The water balance model developed in this study appears to offer a useful tool for design and evaluation of on-site systems.

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Jarrett, A. R., et al ,1981, Alternative on-lot Trench Systems with Dosing and Water Conservation, Proceedings of the Third National Symposium on Individual and Small Community Sewage Treatment, ASAE, 1982 pp 150-159

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Appendix 1: Historical Site Information

September 1985

Evidence of excess underground water in the area of the field resulted in a decision to install a diverter drain around the rear of field to pick up roof water and surface water. The cost of this french drain system was approximately $9000.

November 1985

The septic tank was being pumped regularly at a cost of approximately $1500 a month.

May 1986

Excavation on site revealed a very high water table and, at a meeting with the Department of Health, the possibility of constructing a sewage treatment plant was discussed at an approximate cost of $25,000. In July the Department of Health indicated that they would not grant permission to allow sewage treatment plant outfall to enter the nearby recreational lake.

August 1986

Following evidence of flooding in the field exploratory excavations found that the septic field had several broken pipes, a reverse grade and was deeper than installation specifications recommended

October 9th, 1986

Work being done on drainage problems consisted of removing a "big 0" pipe and replacing it with 6" PVC pipe which started at the existing catch basin and ran along the driveway to the newly installed catch basin at the south corner of the parking lot

October 15th, 1986

The existing septic field dug out and removed. The field was fully reconstructed to proper specifications for approximately $17,000.Septic tank pumped. During the new installation, the septic tank was pumped several times. Assumedly, it was septic waste and not leakage from groundwater. The new field was covered with geotextile and then topsoil.

1987 - 1988

During 1987 - 1988, the problems with the sewage system appeared to recede and were limited to occasional nuisances of water leaching from the field. In February 1988 the complex was metered to determine water consumption, revealing a consumption rate 50% higher than similar sized projects.

December 21st, 1988

A problem occurred with the effluent breaking through the grass on top of the disposal field. A proposal was made to dig a trench around the field, and to fill it with clear stone and sand, and cover it with a geotextile.

December 22nd, 1988

The initial trench was started very close to the bed and quickly filled with water from the septic bed. A senior N.S. Dept. of Health engineer reviewed the situation and advised moving the trench farther away from the front of the bed, to remove sand barrier and to replace it with clear stone. The trench was filled with 1" clear stone, a geotextile laid down, and all was covered with sand to a depth of 1 ft.

December 23rd, 1988

The system appeared to be performing well.

December 30th, 1988

The Waverley home toilets would not flush on the first floor, and the tank was pumped.

January 3rd, 1989

The septic system was inspected revealing water in tank up to bottom of the chimney and breaking through the ground at the upper end of the trench that was dug in December of 1988.

January 6th, 1989

Inspection of the septic tank revealed water in the tank up to the lower end, i.e. the bottom of the chimney. There was water breaking through where the trench was dug near the south driveway. The water was frozen due to cold and was apparently effluent.

January 10th, 1989

Inspection of septic tank showed water above the bottom of the chimney. It was difficult to see the breakthrough effluent on the ground due to the frozen conditions. Concern regarding the water metering system was noted. Apparently, potential leakage was developing through the meter.

January 12th, 1989

Water flow monitoring continued. The tenants were requested not to use the water for half an hour and it appeared that there was a very small leakage.

January 13th, 1989

Breakthrough of effluent was still noted on the ground near the septic field.

January 16th, 1989

The level of the septic tank was down two inches from the previous reading. There was no effluent breaking through the ground.

January 17, 1989

The septic tank level was the same as the previous day, however, effluent was breaking through the ground.

January 23rd, 1989

Dye testing was conducted to determine the effluent breakout locations.. More sand was placed on top of these locations. The following day, breakouts were noticed on the ground and the driveway in the form of a coloured dye. Gauge monitoring showed that water usage at the complex was 1000 gallons over 24 hours

January 25th, 1989

Contemplation of low flow toilets was now underway, however, the decision was made to install bricks in the toilet tanks.

January 26, 1989

A pressure reducing valve (PRV) was installed on the water supply inlet.

January 27th, 1989

Shower heads were replaced with low-flow shower heads and bricks were placed in the water tanks of all toilets. The driveway continued to show septic effluent leakage. Throughout the month of February, septic effluent continued to intermittently pour over the driveway depending on water usage.

February 15, 1989

The water pressure was reduced with the PRV. The next day, following complaints about low pressure and problems with toilet flushing, the PRV was brought back up to its original setting.

February 21st, 1989

Septic tank water levels were very high, but there did not appear to be any effluent leakage on the driveway. The following day the effluent was leaking onto the driveway with bad odours noted. Once again, throughout February there were periods where water was intermittently flowing over the driveway from the bed.

March 15th, 1989

The water consumption over the 24 hour period was down to about 758 gallons. This represents the decrease due to shower heads, bricks in the toilets, and the pressure reducing valve.

May 1989

Evaluation of further trenching and lot grading was carried out, including the grading cost of filling the ditch between the field and the road with 1 in. clear stone . .

May 24th, 1989

Some cosmetic repairs were conducted at the site. A "big 0" pipe was installed in the ditch between the field and the road and covered with gravel. The septic tank was pumped and a clay barrier was installed along the back of the curb. A trench dug for the clay barrier filled in with water. This trench had a "big 0" pipe placed inside which was covered with 1-3" clear stone.

June 2nd, 1989

Fluorescent dye was placed in the system by the area Public Health Inspector and was recovered form the ditch on the opposite side of Faucheau Lane on June 5th. This test was repeated on June 28th but no dye was visually detected.

June 19th, 1990

Three shallow level piezometers were installed in the disposal bed. Further monitoring of the OSWDS has consisted of weekly monitoring of piezometer water levels, effluent levels in the septic tank, and the inflow water use meter.

Appendix 2: Literature Review of Water Conservation Measures

Studies of water usage habits in North America reveal that a typical Canadian family of four uses about 10,000 litres of water per week indoors (Water,1990). Roughly 35% of this indoor water use is for toilet flushing, 20% for bathing, and 22% for laundry (1981, Jarrett). These activities account for approximately 75% of daily water usage (Macmillan,1990) and represent the greatest contributions to OSWDS. Healy and Laak (1973) found that 75% of all soil absorption systems failed due to hydraulic overloading as opposed to clogging, which indicates that there exists an opportunity to prevent and remedy the failure of OSWDS through water conservation techniques.. This potential has been explored by a number of authors. The majority of this research has focused on the potential for conservation while a smaller group has focused on the effects that a lower volume of more highly concentrated waste has on the disposal field.

Hampton et al (1984) conducted a study in Indiana in which the effluent from 13 homes, serviced by individual wells and OSWDS, was monitored before and after the installation of water conservation devices. In this study there was an increase in concentration of all effluent parameters measured a year after the installation of the water conservation equipment on all homes, however, two years after installation parameters measured were the same as or less than the initial values. The authors suggest that even though water conservation has lead to a higher concentration of pollutants the overall mass loading to the field is not increased due to improved septic tank treatment.

A similar study by Rubin et al (1981) examined the waste quality effects of effluent at the site of a small business. The business was constructed at a location that had very poor waste disposal soil characteristics. Extreme low flow toilets and faucets were installed. Flow monitoring indicated that the actual waste flow was 72% less than that calculated using standard usage/employee/day figures. The suspended solids and chemical oxygen demand (COD) values of the effluent from the septic tank showed slight improvement over conventional estimates of these parameters although the nitrogen values were higher. The authors suggest that an increased concentration of the effluent can be offset by increasing the size of the septic tank. This allows for a longer retention time, increasing the quantity of pollutants which will settle and decreasing the concentration of those which can be chemically or biologically reduced in the tank.

A study which focused only on the quantity of water which could be saved was conducted by Wilborn (1981) in a project to retrofit multi-housing projects with low-flow shower heads, faucets, and toilets. Results showed a water consumption reduction of between 68 to 102 gallons/unit/day down from a high of 251 gallons/unit/day. The savings in water costs were able to cover the implementation costs of the program in periods of 2 to 4 months. In another study involving multi-housing complexes Frank (1981) states that mass distribution of water savings devices has little effect without verification of installation, education of the device users, the performance of a leak check during installation, and a plan for on going preventative maintenance for the water system.

Many of the reports reviewed during the preparation of this report discussed the variability of the effectiveness of water conservation projects and studies. The main reason sited for the fluctuation of results is the degree to which the users of water conservation devices are willing or able to adopt water use habit changes (Baumann, 1981). Maximum water conservation is achieved not only through the passive use of low-flow hardware, it also involves the adoption of conservation habits by the users. The environmental and socio-economic conditions of water conservation participants, the price and availability of water, and the effectiveness of consumer education are all parameters which affect the amount of water conserved and are beyond the control of most studies to evaluate. Most authors note that the most effective conservation programs exists in areas with a perceived serious problem. When the public feels that water conservation measures will be effective in response to a known problem their cooperation will be greatest.

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Appendix 3 : An On-Site Water Balance Model

Objective

The objective in developing the model was to determine if formal relationships could be established between measured variables and system performance, which could be use to predict effects of changes in loadings or design variables.

Source of Data

Periodic measurements were available from the Waverley site over a period of 13 months. These included water demand, and water levels in the septic tank and in three piezometers in and around the disposal bed. Precipitation records were available from the Halifax International Airport, located about 10 km. from the site.

System Characteristics

It was assumed that the wastewater flow equaled total water demand. Water use for lawn watering, although not monitored or measured, was believed to be small.

Effects of precipitation were expected to be small. The existence of a clay layer beneath the soil over the bed was expected to isolate the system from these effects. Furthermore, it was expected that in the summer evapo-transpiration would exceed precipitation and that soil storage would modulate differences in these two rates.

Water levels and storage values were based on data from Piezometer 1 in the disposal bed (Figure A1) . Data from Piezometer 2 was not used because (a) most values of water elevation were similar to those in Piezometer 1, and (b) on some dates data was missing or recorded values were unreasonable, probably due to icing in winter.

Methodology

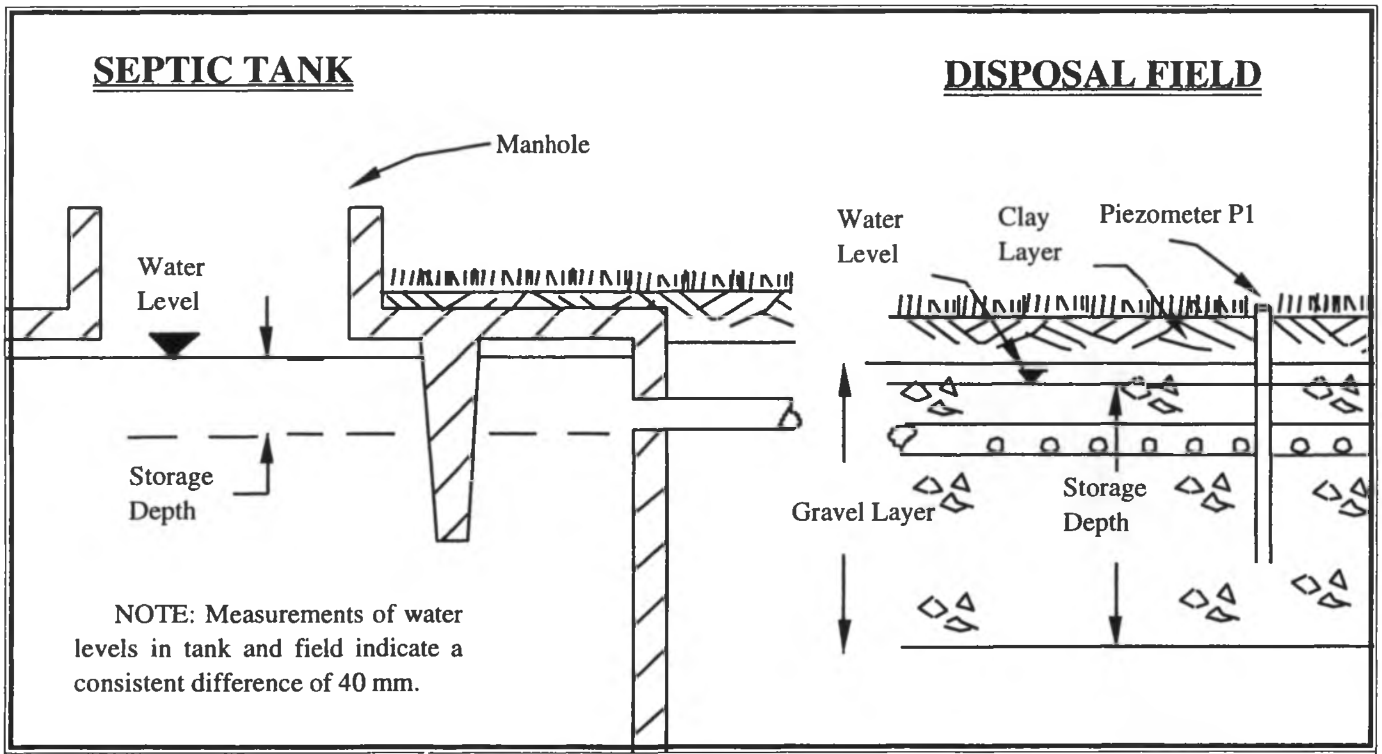
It was assumed that the hydraulics of the system could be described by the following relationships:

$$H2O + PPT*C - OUT = S2 - S1 \tag{1}$$

$$OUT=(QOUT1 + QOUT2)/2 \tag{2}$$

$$QOUT=K*H \tag{3}$$

$$S=H*PC \tag{4}$$



NOTE: Measurements of water levels in tank and field indicate a consistent difference of 40 mm.

Figure A1. Septic Tank and Disposal Field Layout

where
H2O = Water Demand = Sewage Flow in time DT, Igal.
PPT = Total precipitation in time DT, Igal.
C = Fraction of total precipitation reaching the bed.
OUT= Outflow volume from bed in time DT, Igal.
S= water storage volume occupied in bed at time T, Igal.
QOUT= rate of outflow from the bed, Igal/day.
K= permeability constant for clogging mat, Igal/day/mm.
H= water depth in bed, mm.
PC= storage constant, Igal/mm.

The storage constant included storage in the septic tank as well as the field, because depths in the field consistently exceeded the level of the tank outlet and tank and bed levels varied together. Unit storage in the tank was .71 Igal/mm; in the field it was 48.8 Igal/mm before correction for porosity. These values were summarized as:

$$PC=(.71+P*48.8) \tag{5}$$

where P = porosity as a fraction of gross volume.

The preceding relationships can be combined to produce

$$K=2*(H2O+PPT*C*48.8*P-PC*(H2-H1)\,/\,(DT*(H1+H2)) \tag{6}$$

and

$$H2=(H20+PTT*C*48.8*P+H1*(PC-K*DT/2)\,/\,(PC+K*DT/2) \tag{7}$$

Known values of the other terms were used to solve for values of K for each time increment, and the mean value was derived for the period of record. The mean value was then used to calculate H2 values.

Calculations

Water levels in the system were simulated for the period June 26, 1990 through August 2, 1991. Calculations were carried out in a spreadsheet, for time steps corresponding to the frequency of data collection (one day to one week). They were repeated, for comparison, in daily time steps ; in this case daily sewage flows were assumed to be uniform between data collection dates, and piezometer levels were interpolated between measured values.

To determine how precipitation might contribute water to the system, a water balance relationship was defined for the soil layer over the bed, and calculations were carried out for the year, assuming that the specific retention of the soil layer would define soil storage.

To determine effects of the clay layer on isolating the disposal field from the soil layer, calculations were repeated using different values of the percentage of precipitation reaching the field in the October-April period.

As an independent check of the validity of the water balance developed for the Waverley system, data from an earlier study at another site were used to determine if the model could reliably predict changes in field levels based on available physical and climatic data. The Scotch Village system was monitored from 1981 to 1985(1). Monitoring results were compared with results of simulations based on the water balance equations developed for the Waverley system.

To estimate potential effects of water conservation measures on system behavior, simulations of the Waverley system were repeated based on average water use values corresponding to pre-conservation, the current average usage, and estimated reduced usage.

Results

Initial simulations of levels in the disposal field, which were based on the period June 26, 1990 - August 2, 1991, gave acceptable agreement (based on visual comparison) with measured levels, using the following parameter values: porosity= 0.25; fraction of winter precipitation reaching field= 0.4; permeability of clogging mat= 0.016 mm/day/mm of depth over the mat.

Results of the soil water balance calculation indicated that in the period May through September no water would have been available for accretion from soil to the disposal bed. In the period October through April excess water would be available for ground water accretion. This comparison was based on simulation time steps equal to sampling intervals. It was repeated based on a daily simulation time step, and simulated results were virtually identical to those shown.

When additional data became available, the simulation was extended through January 9, 1992. The simulated water levels were significantly lower than measured values, which increased despite the initiation of successful conservation measures on September 6, 1991, and pumping out of the septic tank on October 12. Consideration of available information led to the conclusion that groundwater mounding beneath the bed could not account for reduced

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(1) Waller, D.H., 1975, "Monitoring of an On-Site Disposal System, Scotch Village, Nova Scotia", final report to Nova Scotia Department of Health, CWRS Internal Data Report.

discharge rates. Re-examination of the calculated permeability of the clogging mat, from which an average value had been derived, indicated that the permeability of the clogging mat decreased over time (Figure A2; 1 IGPD= 0.02 mm/day/mm).

When the simulation was repeated using K values from the regression shown in Figure A2, an acceptable fit was obtained-Figure A3. The simulated values reproduce the effect of pumping the tank, which lowered the water level in the bed; daily measurements that might have verified the minimum level are not available because the pumpout was not planned or anticipated.

Results of the Scotch Village simulation are shown in Figure A4. The simulated result assumed a field porosity of 0.3, no summer precipitation entering the bed, and 70 % of winter precipitation entering the system. The figure is based on a clogging mat permeability of 0.07 mm/day/mm.

Figure A5 compares water levels in the Waverley field, based on three levels of water use, with observed values in the period since conservation measures were initiated on September 6, 1991. The greatest water use corresponds to the usage prior to conservation measures initiated in 1989. The value of 678 IGPD is the average prior to September 6, 1991. The lowest value is based on the average water demand after September 6. These results indicate that if no conservation measures had been used water levels in the field would have been above ground level for most of the period since September , 1991, and that levels would have closely approached ground level if the additional measures had not been adopted in September.

Discussion

It appears clear that the behavior of the Waverley system is determined primarily by the hydraulic load imposed by water use in the building. Total water demand in the study period, most of which reached the bed, totaled 309,254 Igal; in the same period precipitation, much of which did not reach the field, totaled 65,177 Igal. Water level reductions predicted as the result of conservation measures, as shown in Figure A5, are significant in terms of elimination of surface discharges from this system. Values of parameters determined for the Waverley and the Scotch Village systems are consistent with differences in these systems:

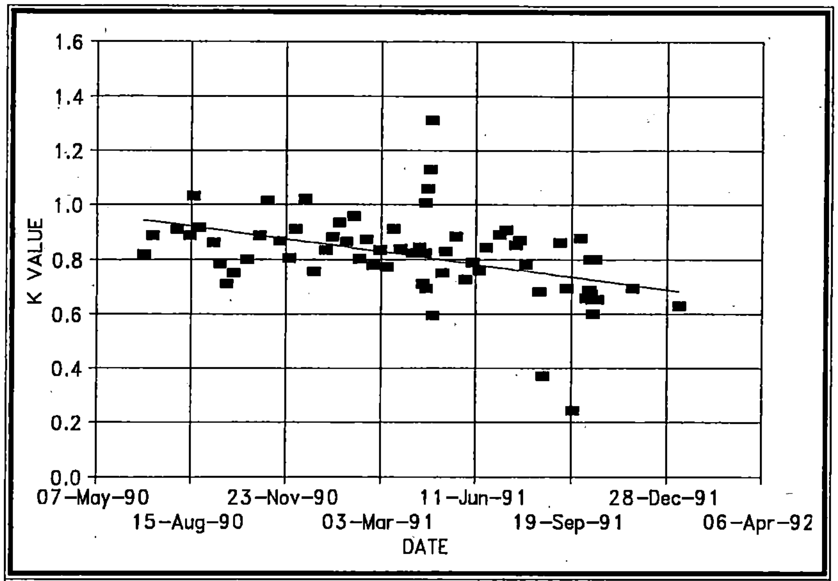

Figure A2. Variation of K Value Over Time

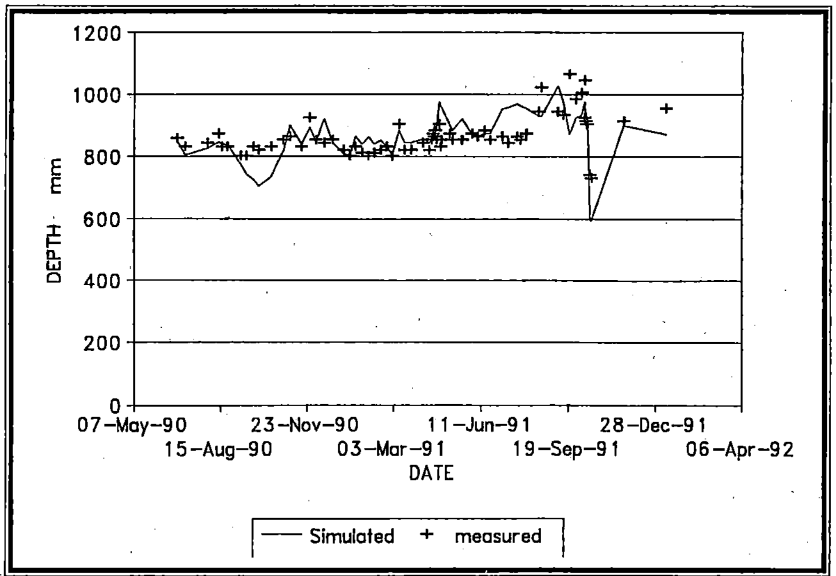

Figure A3. Simulated Water Levels in Disposal Field

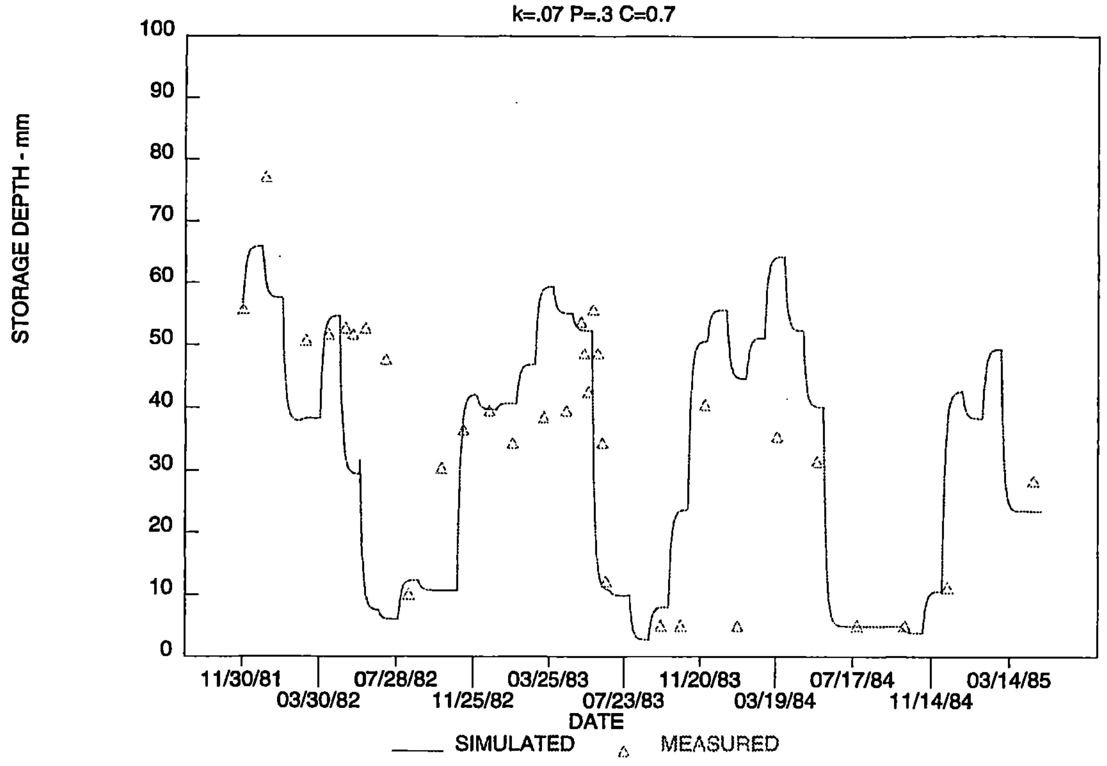

Figure A4. Scotch Village Water Balance Results

- Results suggest that in the winter months less than half of precipitation falling on the field surface at Waverley reaches the bed. At Scotch Village, where the bed is not covered by a clay layer, the calculated percentage is 70 percent.
- The hydraulic load on the Waverley system from water use is much larger than that on the Scotch Village system. The total precipitation on each system is similar, but the amount reaching the bed at Waverley is less because of the clay layer. Because the water use effect predominates, the total load on the Waverley system, as shown by Table A1, is 4 times greater. The net precipitation shown in Table A1 is based on the fraction reaching the bed in winter, to indicate relative loads in the period when loads are greatest.

Table. A1

HYDRAULIC LOADS AT WAVERLEY AND SCOTCH VILLAGE

(mm/day)

	WATER DEMAND	TOTAL PRECIP.	NET PRECIP.	TOTAL
WAVERLEY (current water use)	9.9	2.8	1.1	11.0
SCOTCH VILLAGE	0.7	2.8	2.0	2.7

- The estimated permeability of the clogging mat at Waverley, expressed as mm/day/mm of depth, is 0.018; the comparable value for Scotch Village is 0.07. Both systems are underlain by glacial till, and the groundwater table in each case, as indicated by piezometer readings, remained below the bottom of the field. The lower value at Waverley is probably not surprising, given the significantly greater organic load associated with hydraulic loads on this system.
- The permeability of the clogging mat in the Waverley system has decreased significantly over time. Simulation of the Scotch Village system, which is loaded at a significantly lower rate, indicates that the permeability of the mat did not change significantly over the four year observation period. These results indicate that the rate of decline in permeability is a function of loading rate. They also suggest that the rapid

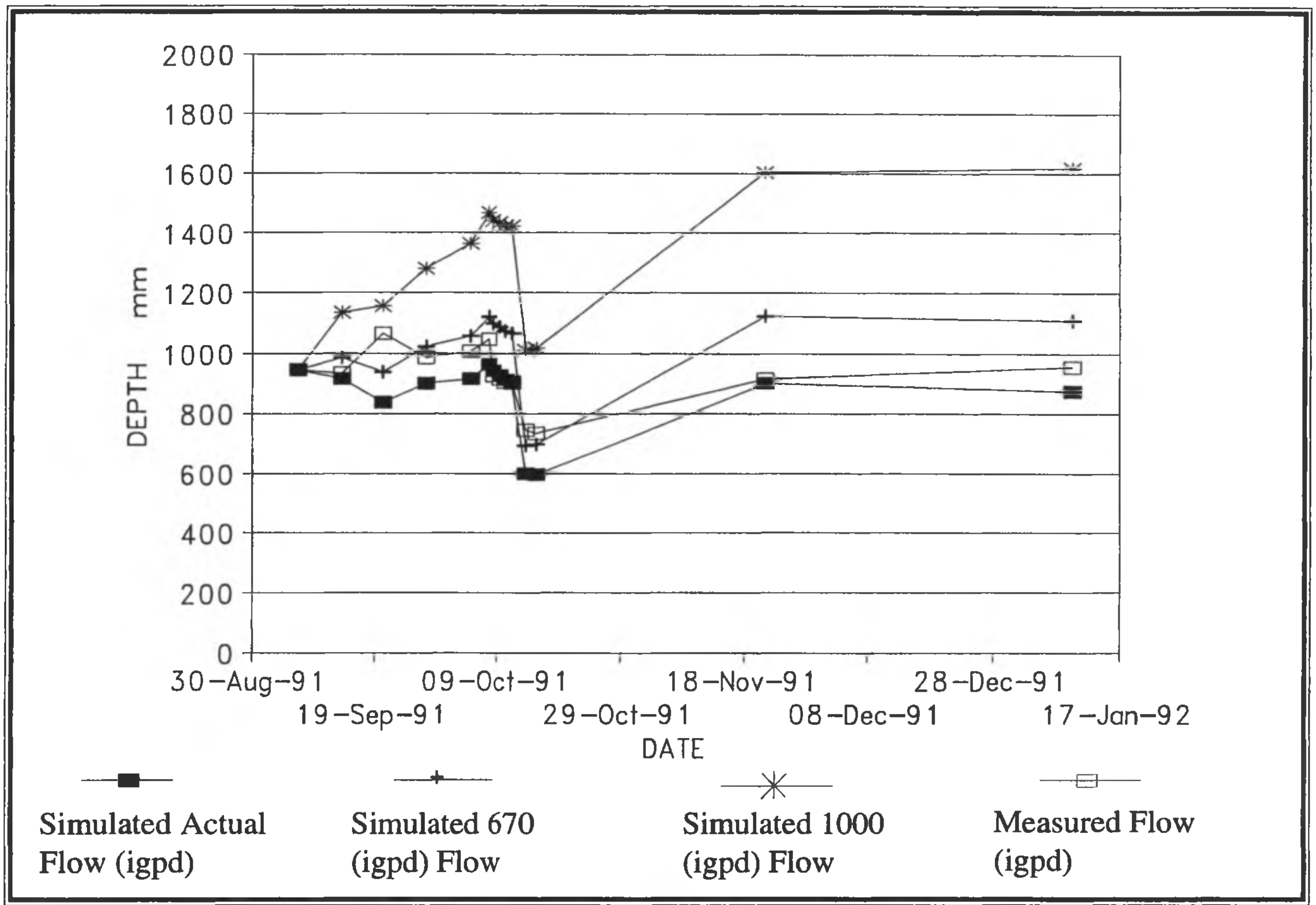

Figure A5. Effects of Water Conservation

decline in the permeability of the Waverley system will result in problems that have been delayed, but not prevented , by water conservation measures.

Figure A5 suggests that pumping of the septic tank at Waverley produced only a short term reduction in water level in the field; precipitation in the succeeding period contributed to a rapid restoration of water levels.

Comparison of hydraulic loadings on the Waverley system with the design rate in the Nova Scotia Department of Health Guidelines[1] indicates the system is not overloaded if the soil in which the system is installed falls within the permeability limits on which the Guidelines are based. The Guidelines are based on a hydraulic loading rate of 0.667 IGPD/FT^2, which corresponds to a soil permeability of 30.5 mm/day if no ponding over the soil surface is assumed. The current hydraulic loading on the Waverley disposal field from the sewage system is 9.9 mm/day, i.e., the Guideline requirement is satisfied.

However, the Guideline loading rate assumes that the soil permeability is equal to or greater than that of a silty clay. No measurements are available to establish the permeability of the soil under the Waverley system, but descriptions of conditions prior to installation of the septic tank system suggests that it was installed in clay, which could have a permeability in the range of 1 mm/day.

If this is true, the hydraulic loading rate has exceeded the capacity of the soil to accept the effluent without ponding, and the disposal system has operated in a permanently flooded condition. This would be expected to result in anaerobic conditions in the bed, and in reduction in clogging mat permeability that would aggravate the flooding problem.

Based on available information it appears that, even with conservation measures, the hydraulic loads on this system exceed the permeability of the underlying soil, and /or that

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[1] Nova Scotia Department of Health and Fitness, 1988, On-SIte Sewage Disposal Systems, Technical Guidelines, P.O. Box 488, Halifax, N.S., Canada

the loading rate prior to water conservation resulted in ponding that has established an anaerobic, and hydraulically inefficient, clogging mat.

Conclusion

The water balance model adequately represents the response of an on-site disposal field to hydraulic loads. Data from other systems will help to verify or modify this conclusion.