MODELING MICROORGANISM TRANSPORT IN RIVERBANK FILTRATION SYSTEMS

By

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ABSTRACT

Groundwater flow and microorganism (*Cryptosporidium parvum*, *Escherichia coli* and MS2) transport was simulated for a Riverbank Filtration (RBF) System in the Rio Grande de Manati region of Puerto Rico. MODFLOW 2000, a 3D saturated flow model, was used to simulate groundwater flow from the river to the wells in the riverbank. RT3D, a multi-species reactive model, was used to simulate microorganism transport. Both models required several parameters: (i) hydro-geological parameters were taken from previous research done in the study area, (ii) transport parameters (attachment coefficient and linear partitioning coefficient) were estimated based on sticking efficiency values reported in the literature. Colloid Filtration Theory was used for the estimation of the transport parameters. From the estimated parameters it was determined that microorganisms would show greater mass transfer from the aqueous to the solid phase at lower porosities. A 3-D grid was built to represent the study area. Groundwater flow output from MODFLOW 2000 showed a discrepancy of only 0.08% between inflow and outflow. MODFLOW 2000 generated inflow and outflow values matched values obtained in an earlier study at the same site, using MODFLOW 96. This indicated that the model's mass balance calculations were very good. RT3D used the flow results, obtained with MODFLOW 2000, to build the transport model. The river water microorganism load was set to a constant level of 100 microorganisms/L. On the basis of a 1000-days' simulation for *C. parvum* and *E. coli*, it was shown that the RBF system could provide safer water to the Rio Grande de Manati region. However, the virus analogue MS2 would reach the well after 900 days. Simulations also demonstrated that *C. parvum*'s removal would be more effective, compared to that of *E. coli* or MS2.

Four different scenarios — varying aquifer porosity, pumping rates, number of wells, and intermittent pumping — were simulated to evaluate their effect on microorganism transport. Porosity and pumping rates were positively related to travel distances, and negatively related to log removal rates. The number of wells and intermittent pumping did not have a direct effect on microorganism transport.

RÉSUMÉ

L'écoulement d'eaux souterraines et le transport de microorganismes (*Cryptosporidium parvum*, *Escherichia coli* and MS2) furent simulés pour un système de filtration de berge (FDB) situé dans la région de Manati de Rio Grande, au Porto Rico. Le modèle tridimensionnel d'écoulement en milieu saturé MODFLOW servit à simuler le ruissellement souterrain allant de la rivière vers des puits creusés dans la berge. RT3D, un modèle réactif plurispécifique servit à simuler le transport de microorganismes. Ensemble, les deux modèles exigèrent plusieurs paramètres: (i) les paramètres hydrogéologiques provinrent d'une étude précédente au même site, (ii) les paramètres de transport (coefficients d'attachement et de partitionnement linéaire) furent basés sur des valeurs d'efficacité d'adhésion rapportées dans la littérature. La théorie de filtration des colloïdes servit a l'évaluation des paramètres de transport. À partir de ces paramètres on peut prévoir qu'à des porosités moins élevées les microorganismes montreront un transfert de masse plus élevée entre la phase aqueuse et solide. Une grille tridimensionnelle fut établie pour représenter le secteur d'étude. Avec MODFLOW 2000, une différence de 0.08% exista entre l'apport et la sortie d'eaux de ruissellement souterraines. Les apports et sorties d'eau prédites par MODFLOW 2000 concordèrent très bien avec ceux obtenus lors d'une étude préalable au même site, indiquant l'exactitude des calculs de bilan massique du modèle. RT3D fonda son modèle de transport sur les valeurs de ruissellement souterrain calculé par MODFLOW. La charge microbienne de l'eau riveraine fut établie à un niveau constant de 100 microorganismes/L d'eau. Une simulation de 1000 jours pour *C. parvum* and *E. coli*, montra qu'un système FDB pouvait fournir une eau plus saine à région de Rio Grande de Manati. Cependant, l'analogue de virus, MS2, se rendrait au puits après 900 jours. Les simulations démontrèrent également que l'enlèvement de *C. parvum* serait plus efficace que celui de *Escherichia coli* ou de MS2.

Quatre scénarios différents furent simulés —variations en porosité, taux de pompage, nombre de puits et pompage intermittent — afin d'évaluer leur effet sur le transport de microorganismes. La porosité et le taux de pompage furent clairement liés a la distance parcourue, et inversement au taux logarithmique d'élimination. Le nombre de puits et le pompage intermittent n'eurent aucun effet direct sur le transport de microorganismes.

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Abbreviations

C is the aqueous-phase concentration of the specie [ML^{-3}]

C_0 bulk (influent) microbe concentration [ML^{-3}]

$\widetilde{C}$ solid-phase concentration of the species [either MM^{-1} or ML^{-3}]

C_{riv} hydraulic conductance of the stream-aquifer interconnection [L^2T^{-1}]

C_s concentration of source/sink [ML^{-3}]

d_c diameter of the spherical collector [L]

D_{ij} hydrodynamic dispersion coefficient [$L^2\ T^{-1}$]

DOS days of simulation [T]

ε soil porosity

h potentiometric head [L]

Δh change in head over a time interval of Δt [LT^{-1}]

k_{att} first order mass transfer rate between the dissolved and the sorbed phases, also referred as k_{att} [T^{-1}]

Kd linear partitioning or distribution coefficient for the sorbed phase [L^3M^{-1}]

K hydraulic conductivity of the streambed material [LT^{-1}]

L length of the stream [L]

M distance of flow or thickness of the streambed layer [L]

m total number of aqueous-phase (mobile) species

n total number of species (colloids)

N_A attraction number; represents combined influence of van der Waals attraction forces and fluid velocity on colloid deposition rate due to interception,

N_G gravity number; the ratio of Stokes colloid settling velocity to fluid's approach velocity,

N_{gr} gravitational number, representing the ratio of colloid's gravitational potential when located one colloid radius from the collector to the colloid's thermal energy

N_{Pe} Peclet number characterizing the ratio of convective transport to diffusive transport,

N_R aspect ratio,

N_{vdW} van der Waals number characterizing the ratio of van der Waals interaction energy to the colloid's thermal energy.

q_s volumetric flux of water per unit volume of aquifer representing sources and sinks [T^{-1}]

Q_i flow rate into the cell [L^3T^{-1}]

$\tilde{r}_c$ rate of all reactions that occur in the aqueous phase [$MM^{-1}\ T^{-1}$ or $ML^3\ T^{-1}$]

R_{bot} river bottom elevation [L]

S_s specific storage of the porous material [L]

t time [T]

t_o duration of microorganism injection [T]

ΔV volume of the cell [L^3]

v pore velocity [LT^{-1}]

W stream width [L]

X distance [L]

X_i distance along the respective Cartesian coordinate axis, [L]

X_{ij} distance along the respective Cartesian coordinate axis, [L]

Symbols

α microbe attachment (collision) efficiency

ρ bulk density of the soil matrix [ML^{-3}]

η experimental single-collector removal efficiency

η_0 single-collector contact efficiency (SCCE)

ε porosity

ρ_p microorganism density [ML^{-3}]

ρ_f fluid density [ML^{-3}]

μ fluid viscosity [$ML^{-1}T$]

CHAPTER I – INTRODUCTION

1.1. BACKGROUND

Disproportionate population growth, modern agricultural practices and substantial industrialization, have led to the contamination of fresh water resources all around the world. Surface water pollution arises from both point and non-point sources. While point-source pollution, such as direct waste-water discharge into a river can be effectively reduced or prevented by proper management; by contrast, non-point source pollution, such as agricultural runoff remains a potential risk. Even lower levels of pollutants in large volumes of runoff water can accumulate and present a greater load in water bodies.

Fertilizers, nutrients, pesticides and microorganisms can be found in fresh water sources. Microorganismal contamination is a major concern. Moreover the risk of waterborne diseases is high when pathogens are spread through water supply systems. Even at low population levels — less than 1 organism per litre of water — such pathogens can be harmful to an at-risk segment of the population, e.g., children and immune-compromised individuals (Ray, Melin et al. 2003). The main symptom of the presence of pathogens in poor quality water is diarrhoea. It causes 1.8 million deaths every year (WHO, 2004). Microorganism pollution involves diverse groups of pathogens that can have different and complex survival mechanisms, which usually helps extend their presence and propagation in the environment.

Water treatment methods involve chemical and physical treatments. Chemical treatment refers to the use of a chemical substance to eliminate or kill impurities and microorganisms present in raw water. Chlorination is the most common, simple and economical chemical treatment (Johnson 2005). However, chlorine, in reacting with certain components of raw water, is suspected of forming by-products toxic to humans (Christman 1998; Johnson 2005); thus its use is being controlled. Additionally, chlorine cannot assure effectively eliminate certain forms of pathogens. For example, *Cryptosporidium parvum* oocysts are highly resistant to chlorine disinfection (Environmental Protection Agency 2006). Therefore, pre-treatments are necessary.

Classic filtration and riverbank filtration systems (RBF) are included in the category of physical treatments. These physical treatments are usually used as pre-treatment processes to minimize the presence of suspended colloids or microbes in water. Essentially, the colloids or microorganisms are “trapped” by a filter that can be soil or a mesh.

Having been implemented for several years now, RBF has proven to be a natural, cost-effective water purification system. It is based on the natural or induced transport of water from a river, through the bank's alluvial sediments, via wells situated in the riverbed (Weiss, Bouwer et al. 2005). An RBF system helps improve water quality through three different processes: physical, chemical, and biological. To some degree, it provides several water quality enhancement functions, including color and odour enhancement, turbidity control, organic contaminant reduction and microorganism removal.

Several studies have acknowledged the effectiveness of RBF in pathogen removal (Berger 2002; Bhattacharjee, Ryan et al. 2002; Tufenkji, Ryan et al. 2002; Gollnitz, Clancy et al. 2003; Ray, Melin et al. 2003; Ahmed 2005; Foppen and Schijven 2006). However, pertinent information is lacking when it comes to the design of efficient RBF systems.

Several parameters, such as water quantity, quality, and soil properties, are needed to properly evaluate whether the system meets established standards. System performance can be evaluated by pilot studies; however, such studies are labour intensive, expensive and time consuming. Alternatively, such testing can be accomplished via modeling. Simulation programs are useful tools for attempting to reproduce the behaviour of natural systems. Moreover, they help understand how different processes are affected when one or more variables are changed. This allows the estimation of a variety of different scenarios.

Several models describing ground-water flow and contaminant transport are available; e.g., MODFLOW and RT3D. MODFLOW has become a world wide standard for ground water flow modelling. MODFLOW is a 3D, cell-centered, finite difference, saturated flow model that can perform steady-state and transient analysis of flow with a wide range of boundary conditions and input options. Comparatively, RT3D is a multi-

species reactive model that incorporates the mechanisms of advection, dispersion and an alternative chemical reaction package. In Groundwater Modeling System (GMS), the two models are used in conjunction; MODFLOW simulates the flow and RT3D uses the flow field for microorganism transport simulation.

1.2. OBJECTIVES

The main objective of this study was to simulate ground-water flow and microorganism transport in a Riverbank Filtration System using MODFLOW and RT3D models. The specific objectives were:

1. To simulate water flow in a River Bank Filtration System using the updated, 2000 version of MODFLOW.
2. To simulate the transport of *C. parvum*, *E. coli* and bacteriophage MS2 in a RBF system; and
3. To determine the impact of certain key parameters, such as the optimal well-to-river distance, soil porosity, pumping rates, number of wells and intermittent operational strategies on the performance of a RBF system using MODFLOW 2000 and RT3D.

1.3. SCOPE OF STUDY

MODFLOW 2000 has the ability to solve various ground-water flow problems. It can simulate confined and/or unconfined layers and the flow from external stresses, like the flow from the river towards a well. However, due to the limited availability of water-level data the ground-water flow model was not calibrated. Instead the results were compared to those of a previous study. Precipitation data was not available, thus the recharge package in the model was not considered. MODFLOW has the ability to handle changes in porosity, hydraulic conductivity and starting heads within the aquifer; however the pertinent data was not available, so mean parameters values were used.

MODFLOW was used to simulate the ground-water flow of the Rio Grande de Manatí River to the Manatí aquifer, Puerto Rico. Since, the Manatí aquifer has an irregular geometry, a one-layer numerical model was used in order to obtain a better approximation of the draw downs and flow paths. Hydrological data for the river (riverbed elevation, stage, hydraulic conductivity) and for the aquifer (head, porosity, hydraulic conductivity) were taken from Torres-Gonzales *et al*., (2000). Specific hydrological measurements, like vertical, longitudinal and lateral dispersion, were not available; hence the dispersion package was not used in the simulation.

The RT3D model was used in the simulation of the transport of *C. parvum, E.coli* and MS2 in a computer-generated Riverbank filtration system for the Rio Grande de Manatí Area. The hydrological data from the river and the aquifer were taken from the MODFLOW simulation. The transport parameters (attachment coefficient and linear partitioning coefficient) were calculated using a predictive equation. The single collector contact efficiency (SCCE or η_0) (Tufenkji and Elimelech 2004) was based on Colloid Filtration Theory. However, the applicability of the Colloid Filtration Theory to heterogeneous and natural sediments has not been tested. The input parameters used for the SCCE calculation were taken from soil column studies. Therefore, actual tests are needed to confirm these parameters, before deriving management criteria from the results obtained in this study. For viruses, the specific information required for the SCCE estimation was not available; thus reported surrogate (MS2) data was used. The results of the simulations were not corroborated by field trials; hence the applicability of these results should be validated.

1.4. THESIS ORGANIZATION

The present study is presented in traditional thesis format. This thesis is organized in five Chapters and one Appendix. The first Chapter gives a general background on fresh water pollution and attenuation processes used for its prevention and control, followed by the objectives of this research and the scope of the present study.

In the second Chapter a general literature review, which covers the topics of fresh water pollution, microorganismal pollution, microorganism transport and riverbank filtration systems; and finally the simulation models used in this research are briefly described.

The third chapter describes the methodology used and the details of different management scenarios tested. The fourth Chapter describes the results obtained in this study. A summary of this study and the main conclusions derived from it are given in the fifth chapter. Finally, in the Appendix, the input data and the output of this study are given.

CHAPTER II - LITERATURE REVIEW

"Access to safe drinking-water is essential to health, a basic human right and a component of effective policy for health protection" (WHO 2006). However, pollution is severely affecting water resources around the world. Fresh water pollution is of major concern as fresh water represents our most accessible source for consumption. Pollution comes in several forms: chemicals, organic materials, and microorganisms. Microorganismal pollution poses a greater risk to water resources because of the difficulties in its detection and, most importantly, the potential health hazards that can ensue. Therefore, a systematic approach to its prevention or reduction must be a major concern in ensuring safe drinking water.

In this Chapter, river water pollution originated by microorganisms, actual regulations and water quality standards are reviewed. Theories that explain the transport and fate of microorganisms in porous media are then summarized. There follows a description of the advantages, limitations and investigations of River Bank Filtration (RBF) Systems. Finally a commentary on the mathematical models employed in the assessment of RBF systems, including the models used in this research is presented.

2.1. RIVER WATER POLLUTION FROM MICROORGANISMS

The most common source for river water microorganismal pollution is human and animal fæces, which are frequently not properly treated before disposal (Carey, Lee et al. 2004; Pachepsky, Sadeghi et al. 2006). In populated and industrialized areas, waste-water discharge to rivers is an important source of microorganismal pollution. On the other hand, in rural areas agriculture activities represent a potential source of microorganismal pollution. Dorner *et al* (2006), through hydrologic modeling of pathogen fate and transport compared three probable non-point sources of contamination: overland flow, subsurface flow to tile drainage systems and in-stream routing. The study concluded that the most probable sources of contamination were the tile drainage systems. However, overland flow is of concern because, when it occurs, the microbial load is the highest. Fortunately, the model predicted that the probability of such an event

to occur was low (Dorner, Anderson et al. 2006). Microorganismal pollution also originates from point sources, for example discharge of waste water treatment plants, sewer overflows, slaughterhouses or animal feedlots (Kim, Choi et al. 2005).

Polluted freshwater can contain different microorganisms, including potential pathogens such as protozoa, bacteria, viruses or helminths (Table 2.1). These pathogens are usually transmitted through a fæcal-oral route, i.e., they replicate in a host, the host sheds contaminated fæces, and they enter the water body and a new host is infected after ingesting the contaminated water (US EPA 2006).

Table 2.1: List of most frequently found water-borne pathogens

Group	Water-borne Pathogen
Protozoa	*Cryptosporidium parvum* *Giardia lambia*
Bacteria	*Escherichia coli* (several strains) *Vibrio cholerae* *Salmonella typhi* *Legionella* spp.
Virus	Enteroviruses (Coxsackieviruses, Poliovirus, etc.) Hepatitis A and E virus Rotavirus

Adapted from (US EPA 2006)

The impact of pathogens on water supply management varies (Table 2.2) and the range of loads found in fresh water sources is wide (Table 2.3). Pathogens can cause diseases even at low load levels (ENSR International 2005). However, some pathogens can have different infective doses depending upon the health status of the host. Risk groups include people with locally or generally impaired immune defence mechanisms, such as elders or children, patients with extensive burns or wounds and people on immunosuppressive therapy or those with acquired immunodeficiency syndrome (AIDS) (WHO 2006).

Table 2.2: Waterborne pathogens and their significance in water supplies

Pathogen	Health significance	Persistence in water supplies	Resistance to chlorine	Relative infectivity	Important animal source
C. parvum	High	Long	High	High	Yes
E. coli – Pathogenic[1]	High	Moderate	Low	Low	Yes
Virus – Hepatitis A	High	Long	Moderate	High	No

[1] Includes enteropathogenic, enterotoxigenic and enteroinvasive;
Adapted from WHO, 2006

Table 2.3: Reported high levels (per litre) of pathogens in fresh water sources

Pathogen or indicator group	Lakes and reservoirs	Impacted rivers and streams	Wilderness rivers and streams	Groundwater
E. coli (counts/L)	10 000 – 1 000 000	30 000 – 1 000 000	6000 – 30 000	0 – 1000
C. parvum (counts/L)	4 – 290	2 – 480	2 – 240	0 – 1
Viruses *(counts/L)*	1 – 10	30 – 60	0 – 30	0 – 2

Adapted from (WHO 2006)

Organizations like the United Nations Environmental Program (UNEP), the World Health Organization (WHO) or governmental agencies have established criteria of maximum allowable loads of microorganisms in fresh water sources (Table 2.4). Even though levels of pathogens in water are monitored and regulated in many countries, outbreaks continue to happen (Carey, Lee et al. 2004; Kim, Choi et al. 2005). Major outbreaks are summarized in Table 2.5. A broad range of microorganisms are present in water and most are difficult to identify, either because detection techniques are time-consuming, or too sophisticated for use by technicians. A simple method to detect pathogens in fresh water is the use of indicator organisms, which are easily detected and identified. Indicator organisms include fæcal coliforms, enterococci or streptococci (ENSR International 2005).

Table 2.4: Maximum allowable pathogen loads in drinking water and required log removal levels

Pathogen	Max. allowable load in drinking water	Required log removal	Country
Cryptosporidium	TT [a] 2.6×10^{-5}	1 – 5.5 6.4 to 7.5	USA+ The Netherlands*
E. coli (generic)	5% [b]	-	USA+
Viruses (enteric)	TT [c] 1.8×10^{-7}	4 5 to 7	USA+ The Netherlands*

TT: Treatment Technique assuring (a) 2 log removal (c) 4 log removal (b) no more than 5.0% samples total coliform-positive in a month
Adapted from (Ray, Melin et al. 2003; US EPA 2003; US EPA 2006)

Table 2.5: Major outbreaks caused by microorganisms

Location, year	Number of cases	Microorganism	Pathogen load found	Postulated source of contamination
Milwaukee, Wisconsin, USA, 1993	403,000	*C. parvum*	Max 0.13 oocysts/L found in ice made at the time of the outbreak.	Deficient filtration system
Carrollton County, Georgia, USA, 1987	13,000	*C. parvum*	Mean of 0.63 oocysts/L found in the distribution system (40% infective).	Operational procedures
Walkerton, Ontario, Canada, 2000	2,000	*E coli* O157:H7	Not reported.	Improper operational procedures

Adapted from (Carey, Lee et al. 2004; Dorner, Anderson et al. 2006)

In this research three microorganisms groups: Protozoa, Bacteria and Viruses were chosen. Several pathogens are related to water-borne diseases; however, because of their role in major outbreaks, *C. parvum* and *E. coli* were selected as representatives of the Protozoa and Bacteria, respectively. Because of lack of enteric virus information

required for transport simulations, the bacteriophage MS2 was chosen. MS2 is often used as a virus tracer due to its similarities in transport behaviour with enteric viruses (Collins, Cronin et al. 2006).

2.1.1 Cryptosporidium parvum

C. parvum is an enteric and obligate protozoa, which infects the gastrointestinal tract of animals and humans, causing cryptosporidiosis. This protozoan parasite has a complex life cycle. However the oocyst stage is the one of concern due to its resistance to conventional water treatment methods, its prolonged survival and its low infectious dose (as low as 1-10 oocysts per individual), and because it is the propagation phase commonly found in the environment (Nasser, Huberman et al. 2003; Carey, Lee et al. 2004; Tufenkji and Elimelech 2005).

C. parvum causes gastroenteritis, mostly to young and immune compromised adults. The most frequent route of transmission is the oral-fæcal route, and human and animal fæces are the common source of contamination. Nasser *et al* (2003) reported shedding rates of 2.8×10^6 oocysts/day in the case of infected humans and 4.3×10^8 oocyst/day for infected calves. *C. parvum* has been found in 67–80% of untreated wastewater samples, at concentrations of up to 256 oocysts/L (Nasser, Huberman et al. 2003). A study of six reclamation facilities in the USA showed that 40% of samples were positive for *C. parvum* with a mean of 0.07 oocysts/L of treated wastewater (Carey, Lee et al. 2004). Thus, treated wastewater can also be a source of contamination. However, pre-treatment methods can improve quality of treated water.

The US National Academy of Science reports a 1 log inactivation at 100 and 180 days that corresponds to an inactivation rate coefficient of 0.023 and 0.013 day^{-1}, respectively for *C. parvum*. For this reason, they questioned the travel time of 60 days, recommended in the Netherlands and Germany, and suggested that a duration of 180 days or more might be required, when inactivation is the main mechanism for removal (Ray, Melin et al. 2003). However, several studies had shown that filtration is the main removal mechanism for *C. parvum*, and 60 to 70% of the recovery can be found between the first 30 mm of soil columns (Nasser, Huberman et al. 2003).

2.1.2 Escherichia coli

E. coli is a thermo-tolerant coliform bacterium that causes gastrointestinal infections. It has a low dose of infection (10-100 cells per individual) and has a good resistance to acidic conditions. Although its origin is human and animal fæces, it is a very cosmopolitan bacterium that can be found in insects, food, vegetables, and water. It can be easily transmitted via person-to-person contact (Jones, Campbell et al. 2002). Its consistently presence in warm-blooded animal fæces and its easy and quick detection, makes it one of the preferred indicators for fæcal contamination (Foppen and Schijven 2006). *E. coli* can be found in cattle fæces at levels which vary from 2.0×10^2 to 8.7×10^4 cfu (colony forming units) per gram of excreta (Jones, Campbell et al. 2002). Hæmorrhagic *E. coli* was found in l–25% of clinically healthy cattle in the US and UK (Ferguson, de Roda Husman et al. 2003). In sewage water, total coliforms, *E. coli* or enterococci can be found in concentrations of 10,000 to more than 10,000,000 cells per 100 mL (Ray, Melin et al. 2003).

Within 250 serotypes of *E. coli* identified, only a third are known to cause infection to human or animals. In fact, only *E. coli* O157:H7 and a few other serotypes are known to be pathogenic. Annual costs related to complications associated to *E. coli* infections are estimated to be US$ 400-900 million in the USA and £30 million in the UK (Jones, Campbell et al. 2002). RBF could decrease the levels of such pathogens in surface waters, reducing outbreaks, and having positive financial consequences.

Several factors affect the survival rate of this pathogen: temperature, humidity, pH, organic matter, predation, etc. The inactivation rate usually is very low; at groundwater temperature it was estimated to be 0.04 to 0.73 per day (Ray, Melin et al. 2003; Foppen and Schijven 2006). In manure, under controlled conditions, it persisted for more than 30 days, and under the fluctuating environmental conditions of a manure pile the survival time was extended to 21 months (Jones, Campbell et al. 2002). Thus, its presence in fresh water could be persistent, and its removal from drinking water is very important.

2.1.3 Bacteriophague MS2

In the U.S. the causative organisms of almost 50% of waterborne outbreaks between 1989 and 1996 were not identified, but findings suggested that they were related to viruses (Ferguson, de Roda Husman et al. 2003). The fæcal-oral route is the most common source of transmission; several human pathogenic viruses are excreted in contaminated fæces and then easily transmitted via water. Thus, domestic sewage generally contains some enteric viruses. Several illnesses are related to virus infections, including paralysis, meningitis, hepatitis, myocarditis and gastroenteritis.

Because of the lack of data on enteric virus transport parameters, a surrogate is used in study virus transport. Chemical substances and microbial tracers are used successfully to trace groundwater flow and mimic colloid transport, respectively. Microbial tracers become the perfect surrogate for virus transport, because they share many characteristics, including chemical composition, surface properties, charge and size. Some of the bacteriophages used as virus surrogates include MS2, PRD1 and ϕX174 (Collins, Cronin et al. 2006).

MS2 is an icosahedral f-specific bacteriophage (virus that infects bacteria) with a mean diameter of 27 nm and an isoelectric point of 3.5. MS2 is a very conservative tracer for enteric virus transport; the adsorption of MS2 in the majority of soil types is relatively low compared to other viruses (Collins, Cronin et al. 2006). Moreover, MS2 shows relatively high persistence during subsurface transport (Schijven, Medema et al. 2000). Studies on clay loam soil columns showed that MS2 shared similar removal rates with Hepatitis A virus, Poliovirus 1 and Echovirus 1 (Collins, Cronin et al. 2006). Thus MS2 appears to be a suitable surrogate for virus transport studies.

Virus transport has not been widely studied. However studies have shown that inactivation rate and adsorption are the major processes involved in virus removal in saturated porous media. Additionally, temperature, adsorption and soil microbial activity are the main factors affecting its inactivation (Schijven and Hassanizadeh 2000; Ray, Melin et al. 2003). A study with deep well injection reported that most of the reduction in MS2 was accomplished within the first 8 m of soil passage (Schijven, Medema et al.

2000). Thus, the study demonstrated the effectiveness of passage through soil as a valuable barrier against viruses.

2.2. SURFACE AND SUB-SURFACE TRANSPORT MECHANISMS FOR MICROORGANISMS

Microorganisms are transported as free cells or attached to other colloids, such as soil particles or manure. Advection, dispersion, diffusion and adsorption are the processes that affect the microorganism transport at this level. In addition to these four processes, colloids are subject to removal by physical mechanisms (Keller and Auset 2007). Removal of microorganisms in porous media can be divided in two major steps: transport and attachment (LeChevallier and Kwok-Keung 2004; McCarthy and McKay 2004).

2.2.1 Transport of microorganisms:

This step becomes the precursor to the attachment process and is defined as the transport of the colloid (microorganism) from the bulk fluid (aqueous media) to the mineral grain (porous media). Three different mechanisms are identified:

i. Interception: this mechanism is affected by the size of the microorganism, which flowing through the aqueous media following the streamline and can be intercepted by a grain of the porous media.
ii. Sedimentation: microorganisms of greater density than the fluid density, flow by gravity and make contact with the granular media.
iii. Diffusion: thermal energy induces random motion and contact with the media results.

Given these three mechanisms, transportation rates can be calculated as functions of physical properties of the colloid, porous and aqueous media, including colloid diameter, grain size and flow velocity. Three water filtration models had been developed, in order to simulate this process. Tufenjkji and Elimelech (2004) developed

the most accurate of these, which includes parameters such as the influence of hydrodynamic and van der Waals interactions.

2.2.2 Attachment to the porous media

Attachment is designated as the most important process in the removal of contaminants in the subsurface environment. For successful removal to occur, the microbe should contact the grain and attach to it (LeChevallier and Kwok-Keung 2004). The sticking efficiency is the factor used to represent the fraction of successful contacts that end in attachment. Theoretically sticking efficiency should vary between 0 (no contacts resulting in attachment) to 1 (all contacts resulted in attachment). Microbial transport, attachment or adhesion to porous media can be affected by several factors, for example:

- In sandy soils with relatively high pH, electrostatic repulsion inhibits MS2 attachment, and the values of collision efficiencies tend to be smaller (Schijven, Medema et al. 2000).
- *C. parvum's* adhesion to inorganic surfaces may be promoted by the glycoprotein found in its outer walls (Pachepsky, Sadeghi et al. 2006)
- Manure colloids may enhance the transport of manure-borne pathogens in soils, as seen with *E. coli*. (Pachepsky, Sadeghi et al. 2006)

The attachment process can occur under equilibrium or non-equilibrium conditions. Equilibrium sorption causes instantaneous reactions and it can be described by linear isotherms. A disadvantage of the equilibrium sorption theory includes the unlimited amount of sorption, which means that the number of available sorption sites is not limited. Non-equilibrium or Kinetic sorption occurs when the sorption process is slower than the ground-water flow (Zheng and Bennett 1995; Wagenet and Chen 1998). Extraction wells can cause non-equilibrium conditions when the water flow velocity is increased.

Shijven *et al*., 2000 showed that equilibrium adsorption and kinetic adsorption may yield similar results (Pachepsky, Sadeghi et al. 2006; Tufenkji 2006). Other results showed that equilibrium adsorption might not be the major contributor or even may not

contribute at all to microbial removal from aqueous phase (Bhattacharjee, Ryan et al. 2002; Tufenkji 2006). Brusseau *et al* 1991 reported that remediation in aquifers and soils were inhibited by non-equilibrium processes. Indeed, laboratory studies with *C. parvum* oocysts showed their removal to be controlled by non-equilibrium sorption rather than equilibrium sorption. Even though findings regarding equilibrium *vs.* non-equilibrium sorption are not quite conclusive, it is clear that non-equilibrium sorption has a significant impact on the transport and fate of pollutants in porous media.

2.3. RIVERBANK FILTRATION SYSTEMS

Riverbank filtration (RBF) can be defined as the natural or induced transport of water from the river to the aquifer, via the riverbed or bank. This system was initially reported in the 1800s in United Kingdom, and is now widely used in Europe, principally in Germany, were 63% of fresh water sources are from groundwater and 15.3% from RBF and groundwater recharge (Ray, Melin et al. 2003). In The Netherlands, 39% of surface water is treated using RBF and/or dune recharge (Ray, Melin et al. 2003).

The transport of water in RBF can be improved by placing extraction wells in the riverbank. These wells create a difference in the head between the river and the aquifer, inducing water transport (Ray, Melin et al. 2003). In Germany the distance between the well and the riverbank is of roughly 50—250 m, with only one exception were the distance was 20 m (Ray, Melin et al. 2003).

Through RBF the diverse material travelling in the river water (like microorganisms, chemicals, solids or organic matter) infiltrates to the porous media. They may be adsorbed when they make contact with the sediment; as a result the filtration process is achieved. Literature reports highest removal rates under slow groundwater velocity, in granular porous aquifers (sand or gravel) and under no detachment scenarios (Berger 2002; Ray, Melin et al. 2003). In fact, the most suitable aquifers to set up a RBF system are the aquifers composed of granular materials, such as gravel, sand and weakly cemented rock. The groundwater flows through narrow fractures in the solid bedrock, or through the small openings that act as a filter removing any suspended colloid.

In order to guarantee microorganism removal by inactivation, Germany and The Netherlands proposed a minimum of 50 to 60 days of water travel time for RBF sites or groundwater abstraction wells (Schijven *et al*., 2000; Ray *et al*., 2003; Hijnen *et al*., 2005). However some authors suggest that these travel times are insufficient, due to the high persistence of some microorganisms like *C. parvum* and viruses (Schijven and Hassanizadeh 2000).

The efficiency of a RBF depends on its ability to reduce or remove any contaminant from the river water to at least maximum allowable concentrations; consequently to ensure their maximum effectiveness, these facilities must be properly designed and operated. To properly design a RBF several parameters that may affect its performance in terms of final quality and quantity of water extracted must be considered (Berger 2002; Ray, Melin et al. 2003):

- Different removal processes, including inactivation and attachment of microbes
- Climatic conditions, seasonality of river flow
- Aquifer physical properties
- Initial river water quality
- Flow velocity
- Types of wells (vertical, horizontal, etc.)
- Distance between well(s) and riverbed (setback distance)
- Continuous or intermittent operation of wells (pumping periods)

The grain-size-distribution of the riverbed material must also be considered, in order to avoid potential areas of erosion and of final deposition of this material (Ray, Melin et al. 2003).

2.3.1 Advantages and Limitations of RBF Systems

RBF systems help improve water quality through three different processes: physical, chemical and biological, displaying multiple advantages like:

- color and odour enhancement
- turbidity control
- organic contaminant reduction

- microorganism removal
- Reduction of water treatment costs

However, RBF can fail under certain circumstances:

- River floods: An organic mat usually is developed at the river/aquifer interface. When the river floods this organic mat may be washed away and the performance of the RBF decreases (Ray, Melin et al. 2003).
- Riverbed Clogging: presence of suspended solids or organic matter can create layers that reduce or eliminate the permeability of the riverbed, causing reductions in the water yield. Nevertheless, scenarios of high river stage or flooding can "clean" these semi or impermeable layers (Ray, Melin et al. 2003).

Although RBF is a well-established filtration system, literature reports cryptosporidiosis outbreaks related to this systems (Ray, Melin et al. 2003). Thus, RBF has advantages as well as limitations that cannot be ignored, and more studies need to be done in order to understand the complex mechanism of microorganism removal.

2.3.2 Experience with RBF Systems

Although the advantages of RBF systems are well known, few studies had been done to confirm these.

The Central Wyoming Regional Water System in Casper, Wyoming operates several wells in the banks of the North Platte River. The system includes vertical wells, infiltration galleries and horizontal collector wells. In 1991, the USEPA granted a conditional approval, considering the system as an alternative filtration technology with 99% (2 log) reduction (Gollnitz, Clancy et al. 2003; Ray, Melin et al. 2003; Energy Laboratories Inc. 2004).

In 2002, a full-scale 2 year study was also done on the Ohio River. Intensive water quality measurements found *Cryptosporidium* and *Giardia* in the well water; although the effectiveness of the system was measured with indicators. Turbidity reduction within the 0.6 m of filtration reached 1 ntu (nanometric turbidity unit). The aerobic-spore reduction at 0.6 and 15.2 m of filtration reached 1.7 and 3.8 log-reductions, respectively (Gollnitz, Clancy et al. 2003).

Gollnitz *et al*. (2003) reported a multifaceted study at the Charles M. Bolton (CMB) groundwater system at the Greater Cincinnati Water Works (GCWW). River-to-well distances ranged from 15 to 247 m. Microbiological samples were taken from 1991 to 2002 and the sampling included *Cryptosporidium* and *Giardia*. The preliminary study showed that 33% of the samples were positive for *Giardia* and 16% were positive for *Cryptosporidium*, with mean concentrations of 16 cysts/100 L and 2 oocysts/100 L, respectively. Analyses made from 1999 to 2002 showed 39% and 11% positive samples for *Giardia* and *Cryptosporidium*, respectively, with a mean load of 50/100 L for Giardia and 4/100 L for *Cryptosporidium*. Neither *Giardia* nor *Cryptosporidium* were detected in groundwater samples during the study. The reduction for *Cryptosporidium* and *Giardia* was 3.7 and 3.6-log, respectively. Although the reduction for *Cryptosporidium* was high the study concluded that the water needed additional treatment, because of higher initial levels of *Cryptosporidium* in the raw water (0.11 oocysts/L) (Gollnitz, Clancy et al. 2003).

Weiss and Bouwer (2005) conducted a 1-year study in three rivers (Ohio, Missouri and Wabash) in the U.S. Samples were taken from five wells located at 27, 30, 37 and 122 m from the river. Microbial analysis included: coliforms, *Giardia* and *Cryptosporidium*. Aerobic and anaerobic-forming bacteria and bacteriophages were also measured. Even though *Cryptosporidium* and *Giardia* were found in the river waters, they were never found in the extraction wells. Reductions for bacteria, bacteriophages, total coliforms and turbidity were: 0.4-4.9, >2.1->3.2, 5.1-6.1 and 2.2-3.3 logs respectively (Weiss, Bouwer et al. 2005).

Even though these studies showed that RBF is an effective system, proper criteria for RBF design are needed. Modeling can be a useful tool for RBF design. Although several parameters that control microorganism transport need to be estimated, several models and theories that describe microbial transport have been developed

2.4. MATHEMATICAL MODELING FOR RBF SYSTEMS

"Mathematical models rely on quantification of relationships between specific parameters and variables to simulate the effects of natural processes" (Keeley 1989). Mathematical models are non-physical (abstract) and are helpful in finding functional

dependencies between causes and effects that might occur in real situations. Mathematical modeling helps with a fast solutions, and allow unlimited modifications for multiple scenario analysis (Keeley 1989). The field studies done so far are described in the following paragraphs.

The characterization of a RBF system in El Paso, Texas, included the obtention of hydrostatigraphic and hydrogeologic data and the use of artificial tracer trials (bromide tests) (Ahmed 2005). In this study, ground-water flow and microorganism transport were simulated with MODFLOW and MT3DMS. The selected distance between the streams and well was 18 m. Carboxylated micro-spheres of 1 and 6-10 μm were used to mimic the occurrence of bacteria and protozoa, however their appearance was episodic or very rare, reaching 6-log removals for both sizes of micro-spheres. In the case of *E. coli*, they reported its presence in the river water at levels ranging from 1-26.4 MPN/100 ml, but at the RBF extraction well the concentrations were below detection limits. A transport simulation of micro-spheres could not be done because of their sporadic appearance at the pumping wells. As a result only the bromide test results were simulated.

In Puerto Rico, a ground-water resource assessment was done in the Rio Grande de Manatí Area (Torres-Gonzales, Gomez-Gomez et al. 2002). MODFLOW was used for the ground-water flow simulation. Although extensive hydrological data was taken, the model could not be calibrated because of the limited water-level data collected. The MT3DMS model was used for the bacterial transport. The study was focused on the total transport of coliforms from the river to the extraction well, which was located 150 meters from the river. Surrogate or tracer assays were not conducted, and the results of the simulation could not be validated. However, the results showed a great effect of the porosity over the bacteria transport.

2.5. MATHEMATICAL MODELS

A number of mathematical models have been used to simulate flow and colloid's transport through porous media. MODFLOW is the most widely used among such groundwater models and RT3D is appropriate to simulate microorganism attenuation through saturated porous media.

2.5.1 MODFLOW

MODFLOW is a three-dimensional finite-difference ground-water model developed initially in 1984. Several versions are reported since then; in this study MODFLOW 2000 was used. MODFLOW-2000 simulates steady-state or transient flow in confined or/and unconfined aquifers. Parameters such as hydraulic conductivity, transmissivity or porosity can differ spatially. The ground-water flow equation is solved by the finite-approximation method in each block; within the block the medium properties are assumed to be uniform in order to solve the equation. The blocks or cells are grid units that can have different thicknesses and dimensions within the area of study. Several solvers can be assigned to solve a particular problem and the flow rate and cumulative-volume balances from each type of outflow or inflow are computed at each time step (McDonald and Harbaugh 1988).

2.4.1 RT3D

RT3D is a computer code developed in 1997 that solves the coupled partial differential equations that describe reactive-flow and transport of multiple mobile or immobile species in saturated ground-water systems. The transport equations are solved by a reaction operator-split numerical strategy. RT3D is an improved version of the U. S. EPA transport code, MT3D. RT3D uses the same routine for contaminant transport as MT3D. However, RT3D solves multiple-species transport with first-order reactions (Clement, Sun et al. 1998). In this study RT3D was selected because of its ability to simulate microorganism transport from liquid to solid phases, including sorption process.

2.5.2 CONCLUDING REMARKS

History shows that microbial pollution is of major concern in developing as well as developed countries. Short-term peaks of pathogen concentration are alarming, because small concentrations can considerably increase the risk of infections. Traditional detection techniques are usually costly and time consuming, and by the time the pathogen is detected, many people have been exposed to and an outbreak can have already occurred (WHO 2006). Thus, understanding the transport and fate of microorganisms in

porous media is important, and field studies are the best option. However, given the lack of funds and efficient detection techniques, the danger involving the use of pathogens in field studies and the need for efficient surrogates, field studies are not generally carried out. Therefore, theories that predict the transport of microorganisms and resultant simulation software are useful tools that can help calculate microorganism transport and assess the efficiency of attenuation mechanisms such as RBF systems.

CHAPTER III – METHODOLOGY

Chapter III describes the two models, MODFLOW and RT3D, selected for this research, focusing on their scope and their mathematical foundations. A description of the procedures for the model development is given next. A description of the study area and the input data is also provided, along with that of various scenarios selected for simulations are described.

Background

In this study two state-of-the-art mathematical models, MODFLOW and RT3D, were used to simulate groundwater flow and microbial transport in a RBF system. Recently a Groundwater Resource Assessment was carried out in the Rio Grande de Manati Alluvial Plain, Rio Arriba Saliente Area, Puerto Rico (Torres-Gonzales, Gomez-Gomez et al. 2002). Manati Assessment provided the hydrological data for the development of the groundwater model (MODFLOW). Data for the microorganism transport component of the study was not available; however, to the best of the author's knowledge, no measured data exists that could be used to support such a study. Therefore, some assumptions were made. The groundwater simulation results with MODFLOW 2000 were compared with those obtained in the Manati Assessment to assure that flow simulations were comparable to actual measured flows. RT3D was then used to simulate transport and fate of microorganisms.

Our research differed from the Manati Assessment in that:

i. The most recent version of MODFLOW (MODFLOW 2000) was used.
ii. The microorganism transport simulation was done with the reactive module RT3D, which, unlike MT3DMS, simulates the microorganism transport between the aqueous and solid phase.
iii. Since attachment is a major process in microorganism removal in porous media, the attachment coefficient (katt) was included in this simulation, in order to improve the microorganism transport simulation.

iv. The transport of *C. parvum, E. coli* and MS2 were investigated.

The present study was done in two steps:

- First, the most recent version of MODFLOW was validated with the original study data (Manati Assessment)
- Second, with the help of MODFLOW and RT3D, the effect of different parameters, deemed to have an important bearing on the functioning of RBF systems, or on the transport of *C. parvum*, *E. coli*, and MS2 were analyzed. The parameters evaluated were:
    i. Porosity
    ii. Number of extraction wells
    iii. Pumping rate
    iv. Effect of intermittent pumping

3.1. DESCRIPTION OF THE STUDY AREA

The study area is located on the north coast of Puerto Rico, in the Municipality of Manati, Rio Grande de Manati Valley, west of Barrio Rio Arriba Saliente (Latitude: 18°22'30"N, Longitude: 66°29'05"W), (Figure 3.1). The complete study area (Figure 3.2) covered 64 ha of the alluvial plain along a 0.8 km reach of the east bank of the Rio Grande de Manati. The extent of the alluvial deposits within the study area was 21 hectares (Torres-Gonzales, Gomez-Gomez et al. 2002).

Rio Grande de Manati River, having its origin in the volcanic highlands of Puerto Rico, drains the study area (Kelly, Roman-Mas et al. 1990). Mean-monthly discharge rates in the study area ranged from 0.40 to 68 m^3/s (1946-1998, gage station 50035000) and 1.41 to 105.7 m^3/s (1970-1998, gage station 50038100). During storm events the discharge could reach as high as 2831 m^3/s. The alluvial-plane surface ranges from about 29.9 m above mean sea level (AMSL) in the center and southern areas to about 28.3 m AMSL in the northern portions of the study area (Torres-Gonzales, Gomez-Gomez et al. 2002). The main activity around the area is agriculture, mainly the cultivation of hay for dairy cattle and for pasture. Mining of gravel is also very common; however this activity has caused a reduction in the altitude of the stream surface (approximate loss of 1.2 m). On average, the Rio Grande de Manatí receives 1.44 ML/yr of secondary-treated

wastewater discharge from the Ciales Wastewater facility, located 5 km upstream of the study area. Rio Grande de Manatí is also a source for 17 water filtration plants, located mainly upstream, with an uptake of 56.6 ML/day (Torres-Gonzales, Gomez-Gomez et al. 2002).

Groundwater provides the main supply of fresh water in this area. While agriculture is the main activity in the region, practices associated with it are the principal cause of the contamination of surrounding waterways. The unwanted presence of agrochemicals, microorganisms and salts is becoming common in freshwater sources. Consequently, authorities have been forced to close some wells that were not complying with USEPA potable water standards, creating a shortage in the freshwater supply. The alluvial deposits of Rio Grande de Manati River could become an excellent source of fresh water, solving the problem of fresh water supply. Therefore, authorities concluded that in order to evaluate the potential of the aquifer located in the Rio Arriba Saliente, a hydrologic investigation needed to be done (Torres-Gonzales, Gomez-Gomez et al. 2002).

The climate in the study area belongs to a humid-tropical environment, with a monthly mean temperature between 28 and 32°C and mean precipitation from 1.7 to 2.7 mm/month. The wettest months usually occur between September and December, as well a small period between April and May (Torres-Gonzales, Gomez-Gomez et al. 2002). Climatological details are summarized in Table 3.1.

3.2. INPUT DATA

3.5.1 Hydrological Data

The hydrological data for the study area was obtained from the United States Geological Service (USGS), Puerto Rico office. The data was supplied by Sigfredo Torres, one of the authors of Torres-Gonzales *et al* (2002).

The Manati Assessment concluded that the Rio Grande de Manati had a direct effect on hydrologic conditions in the study area and that it was indeed the principal source of recharge to the alluvial aquifer. A hydrogeologic survey was undertaken using

electric resistivity surveys (1974, 1988), employing a Schumberger electrode array. A preexisting programme in Fortran 77, Inverse.f77, was used to process the data. Subsurface stratigraphy, hydro-geologic properties and the direction of the ground-water flow were analyzed using 8 piezometers under pumping and non-pumping conditions. The piezometers were located across a depth range of 11.9 to 19.2 m, including, as a rule at least 3 to 4.6 m of aquifer. Areas with abundant gravel, pebble and cobble size gravel layers were noted and recorded when drilling boreholes for the piezometers, and indicated that the aquifer has good potential for water supply.

Table 3.1: Manati Monthly Climate Summary (SRCC 1971-2000)

MANATI 3 E, PUERTO RICO (665807)
Period of Record : 1/ 1/1948 to 12/31/2005

	Mean Max. Temp (°C)	Mean Min. Temp (°C)	Mean Total Precip. (mm)
Jan	28.17	18.83	18.2
Feb	28.33	18.56	12.7
Mar	29.28	18.83	11.7
Apr	29.72	19.78	20.0
May	30.72	20.89	26.2
Jun	31.72	21.83	13.9
Jul	31.44	22.17	17.8
Aug	31.61	22.28	1.87
Sep	31.56	21.89	2.17
Oct	31.22	21.39	2.35
Nov	29.89	20.67	2.71
Dec	28.72	19.56	2.44
Annual	30.22	20.56	23.57

Percent of possible observations for period of record: Max. Temp., 84.3%; Min. Temp., 84.1%; Precipitation, 87.3%; Snowfall, 83.9%; Snow Depth: 83.9%

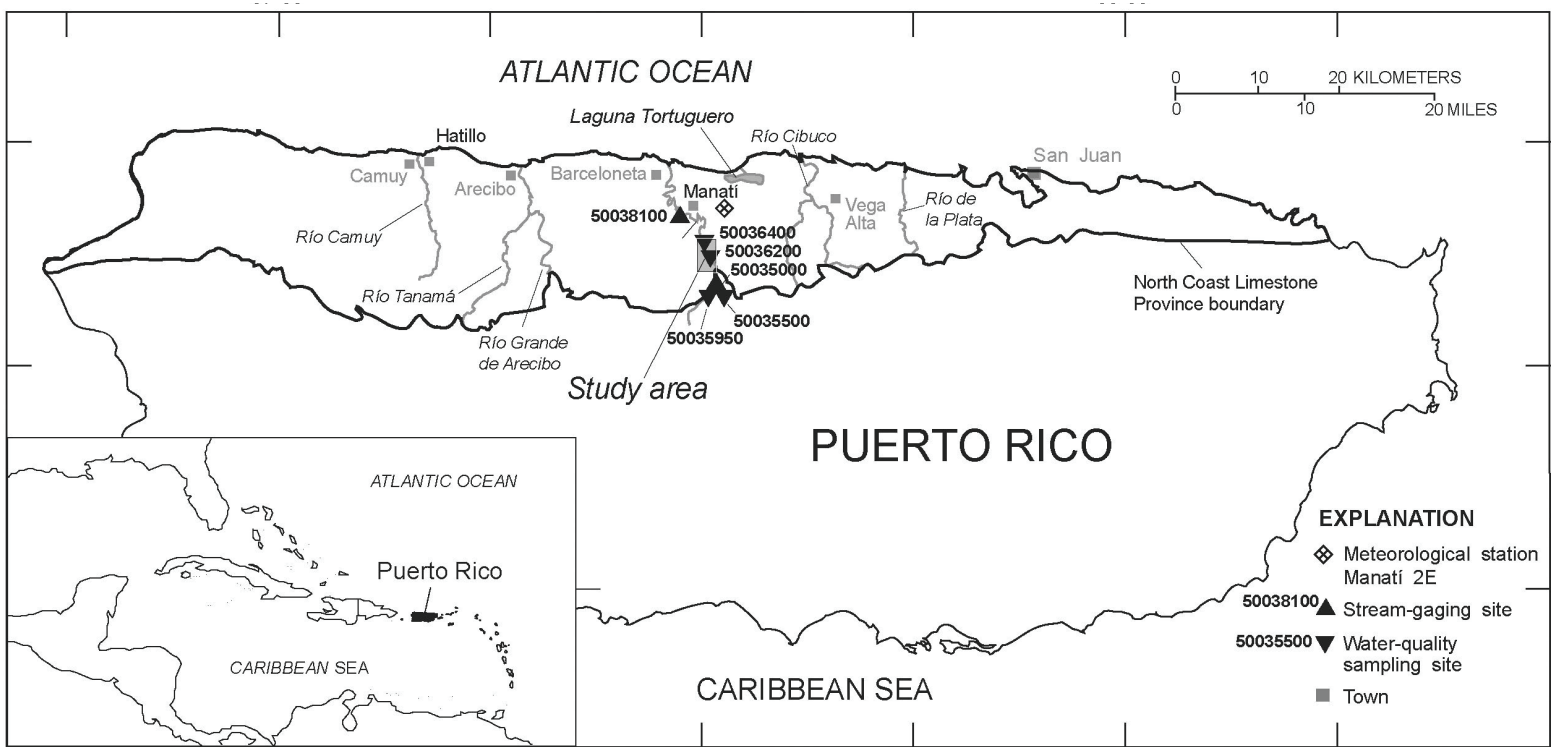


Fig. 3.1: Location of Municipality of Manati, Puerto Rico

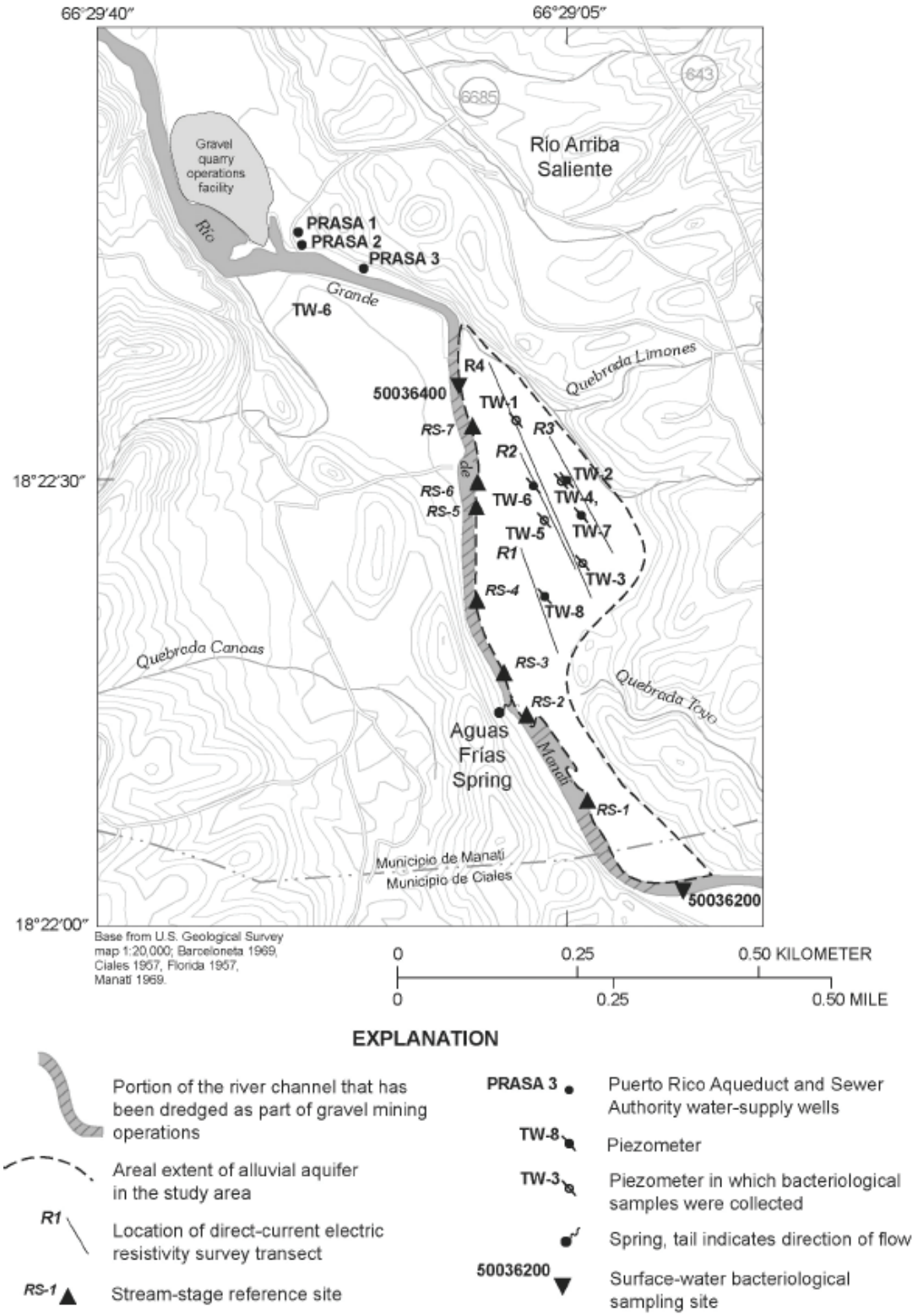


Figure 3.2: Rio Grande de Manati Study Area

Additionally, a potentiometric map for Rio Grande de Manatí was developed using the data obtained on seven different days, between March and July 1998. Daily flow ranged from 1.67 to 2.8 m^3/s. The hydrological data drawn from the Manati Assessment and used in the MODFLOW simulation included: river stage, riverbed elevation, riverbed hydraulic conductivity, aquifer hydraulic conductivity, aquifer depth, and porosity

3.5.2 Microbiological Data

The Manati Assessment (2002) collected surface and ground-water samples for bacteriological and chemical analyses according to procedures described in the USGS' National Field Manual (1997-1999) (Torres-Gonzales, Gomez-Gomez et al. 2002).

Groundwater samples were drawn from four different piezometers on July 1998 at three different occasions. Bacteriological and chemical analyses were performed. The results of chemical analyses of ground-water samples (piezometers TW-4), showed that the Rio Grande de Manatí complies with secondary drinking water standards.

The surface water samples were taken on 7 different occasions between March and July 1998, at each of three different sampling stations along the Rio Grande de Manatí. Almost all samples were taken after substantial periods of rainfall. These samples were analyzed for fæcal coliforms and fæcal streptococcus.

The Rio de Manati's water was classified as Class SD, meaning that the waters can be used as a raw source for the public water supply, propagation and preservation of desirable aquatic species, and primary and secondary contact recreation. Although, the maximum concentration of fæcal coliform and fæcal streptococcus allowed is 2,000 colonies per 100 mL, test results showed that 31% of samples from station 50035500 exceeded this limit (Table 3.2.).

Table 3.2: Results of bacteriological analysis (fæcal coliforms) of surface and ground-water samples from the Rio Grande de Manati, Puerto Rico

Source	Location	Date	Fæcal coliform colonies per 100 mL
Surface water	Upstream-Station 50035500	March, 1998	90
		April, 1998	710
		May, 1998	420
		July, 1998	200
	Upstream-Station 50036200	March, 1998	20
		April, 1998	610
		May, 1998	80
		July, 1998	280
	Downstream-Station 50036400	March, 1998	40
		April, 1998	750
		May, 1998	100
		July, 1998	330
Groundwater	TW-1	July, 1998	<1
	TW-3	July, 1998	<1
	TW-4	July, 1998	<1
	TW-5	July, 1998	<1

3.3. THE MODFLOW MODEL: GROUND-WATER SIMULATION

In this section, the hydrological and mathematical descriptions of the model used for the ground-water simulation are briefly presented.

3.1.1 Hydrological description

In MODFLOW, groundwater is defined as the water located in soils and geological formations that can be found beneath the water table under saturated conditions. The usual source of water recharge in aquifers is rainfall. The permeability of the aquifer allows rainfall to percolate or infiltrate. Rivers or streams are also a source for aquifer recharge. Under natural conditions, river flow from the river to the aquifer can either infiltrate from the river (when the water table is below the river bottom) or the river can be recharged by the aquifer (when the water table is above the river bottom).

However, water can be artificially pumped from the aquifer via extraction wells. The pumping action will induce horizontal hydraulic gradients towards the well, resulting in a decrease of the hydraulic head around the well, forming a cone of depression.

3.1.2 Mathematical description

MODFLOW is a modular finite-difference ground-water flow model, developed by the USGS (McDonald and Harbaugh 1988). The aquifer systems must meet the following requirements:

(a) Saturated flow conditions,

(b) Darcy's Law can be applied, and

(c) Constant water density

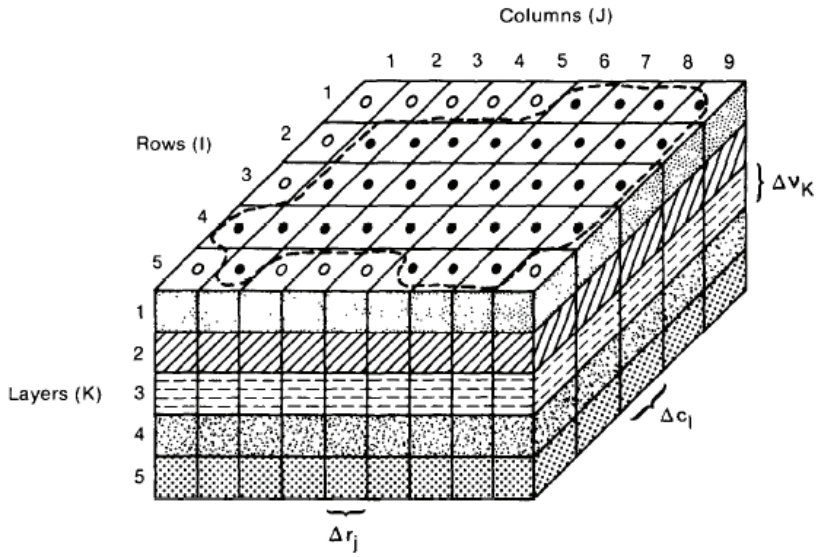
Under these circumstances, MODFLOW can simulate either steady state or transient flows using a wide variety of boundary conditions (confined aquifers, unconfined aquifers or confining units) and input options. The 3-dimensional movement of constant density groundwater through porous earth material may be described by the partial-differential equation:

$$\frac{\partial}{\partial X}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t} \qquad \{3.1\}$$

where:

h	is the potentiometric head (L),
t	is the time (T),
K_{xx}, K_{yy} and K_{zz}	are values of hydraulic conductivity along the x, y, and z coordinate axes, assumed to be parallel to the major axes of hydraulic conductivity (LT^{-1}),
S_s	is the specific storage of the porous material (L), and
W	is the volumetric flux per unit volume and represents sources or sinks of water (T^{-1})

The finite difference approximation was used to solve the groundwater flow. The flow region was subdivided into cells of uniform medium properties. An aquifer system can be simulated by spatial discretization through a system or mesh of blocks called cells (Fig 3.3). The locations are described in terms of rows, columns and layers (i, j, k).



---- Aquifer boundary,
● Active cell,
○ Inactive cell,
Δr_i Dimension of cell along the row direction "i" indicates the row number,
Δr_j Dimension of cell along the row direction "j" indicates the column number, and
Δr_k Dimension of cell along the row direction "k" indicates the layer number.

Fig 3.3: A discretized hypothetical aquifer system
(Adapted from MacDonald *et al*., 1998)

At each time step, MODFLOW calculates the head (ground water level) of every cell through the construction and solution of groundwater flow equations. MODFLOW also calculates the flow rate of every cell within the aquifer. These various processes are implemented through individual modules or packages (river package, well package, etc). These packages incorporate a particular hydrologic process or solution algorithm. Finally, MODFLOW calculates the general water budget, specifying the volume of inflow and outflows within the system (McDonald and Harbaugh 1988).

MODFLOW 2000 is an enhanced version of the USGS modular finite-difference ground-water flow model. MODFLOW 2000 allows definition of many data input quantities, using parameter values which can be applied to data input for many grid cells. Thus parameters make data input more user-friendly because of the multi-cell capability (Zheng, Hill et al. 2001). In MODFLOW 2000, the user can retain and limit the output files generated, allowing the user to specify the output to be saved. In MODFLOW 2000, redundant input parameters from the basic package were removed. In the Block Centered flow package, MODFLOW 2000 no longer reads any discretization data. Instead it uses the horizontal grid spacing, layer elevation and transient/steady-state data included in the global file. Thus, MODFLOW 2000 is a more efficient and user-friendly program (Harbaugh, Banta et al. 2000).

3.1.3 Building MODFLOW 2000 model for the study area

The following model building procedure was used to build the model for the study area.

3.1.3.1 Design of the 3D Grid

To develop the 1-layer model of the aquifer, a 3D finite difference grid was created. The grid measured 1051.56 m from north to south, and 487.68 m from west to east, covering a total area of 51.28 ha. The number of cells in each dimension for the Manati Assessment and the current simulation are given in Table 3.3.

Table 3.3: Grid values for Manati Assessment and Actual Simulation

Axis	Length (m)	Number of cells	
		Manati Assessment	Actual simulation
X	487.68	32	160
Y	1051.56	69	69
Z	30.48	1	1

3.1.3.2 Setting the boundary and initial conditions

The initial boundary conditions were defined by the IBOUND array. IBOUND identifies the activity of each cell so as to yield an appropriate solution of the flow equations (McDonald and Harbaugh 1988). In this array three options were available:

- IBOUND = 1, for active cells, when the head is variable (the head value is part of the simulation)
- IBOUND = -1, for cells that have a constant head
- IBOUND = 0, when the cell is inactive (the head value is not part of the simulation)

In this study the boundary conditions for the aquifer and the river were set as active (IBOUND = 1). The starting heads and the top elevation for this simulation were set as 30.48 m. The lowest elevation was set to 0 m.

The determination of the flow between the centers of adjacent cells (to and from the storage) was determined by the Block Centered Flow (BCF) array. The associated parameters used in this study are given in Table 3.4. The BCF array calculates the head at the center of each cell (node). Assuming constant density of groundwater, the equation for the balance of flow within the cell in this array is given by Equation 3.2 (McDonald and Harbaugh 1988).

$$\Sigma Q_i = \frac{\Delta h}{S_S - \Delta V} \qquad \{3.2\}$$

where:

Δh is the change in head over a time interval of Δt (LT^{-1})

Q_i is the flow rate into the cell (L^3T^{-1})

S_S is the specific storage, i.e, the volume of water that can be injected per unit of volume of the aquifer material per unit change in head (L^{-1})

ΔV is the volume of the cell (L^3)

Table 3.4: Block Centered Flow Parameters

Parameter	Value
Hydraulic conductivity	40.54 m/d
Type of layer	Unconfined
Wetting capability for dry cells	Not active

3.1.3.3 Building the local source/sink coverage

The Source/sink array includes several packages that help in the representation of local sources or sinks (rivers, general heads, wells, drains, etc) included in the area to be modeled. For this study, river and well packages were used.

Based on the head gradient, the river package simulates the flow between surface-water and groundwater systems (McDonald and Harbaugh 1988). In order to include the river package, the groundwater flow equation must be rewritten, adding terms representing the seepage to and from the surface for each cell affected by it. The flow between the stream and the groundwater is described by Equation 3.3.

$$Q_{riv} = \frac{K * L * W}{M}\left(H_{riv} - h_{i,j,k}\right) \qquad \{3.3\}$$

where:

Q_{riv} represents the flow between the stream and the aquifer (positive value if it is directed into the aquifer, L^3T^{-1}),

$h_{i,j,k}$ is the head at the node of the cell underlying the stream reach (L),

C_{riv} is the hydraulic conductance of the stream-aquifer interconnection (L^2T^{-1}),

H_{riv} is the head in the stream (L),

K is the hydraulic conductivity of the streambed material (LT^{-1}),

L represents the length of the stream (L),

M represents the distance of flow or thickness of the streambed layer (L),

R_{bot} is river bottom elevation (L), and

W represents the stream width (L),

In order to derive this equation, the following assumptions were made:

i. The measurable head loss between the aquifer and the stream is limited to those across the stream bed layer itself (the head loss is not significant between the bottom of the stream bed layer and the underlying model node)

ii. The underlying model cell remains fully saturated (the head in the cell will not drop below the streambed layer

In this study the parameters used for the calculation of the conductance of the river (C_{riv}) are given in Table 3.5.

Table 3.5: Initial input parameters used in the River Package

Parameter	Actual simulation
Riverbed hydraulic conductivity (K)	30.48 m/day
Stream length (L)	15.24 m
Stream width (W)	15.24 m
Stream thickness (M)	0.3048 m

The well package simulates the contribution or withdrawal of water from a well to the aquifer, in a specific time frame. The value of its contribution is defined by the pumping rate (McDonald and Harbaugh 1988). The parameters used in this package are given in Table 3.6.

Table 3.6: Initial input parameters used in the Well package

Location	Cell id (i,j,k)	Pumping rate
15 – 18 m from the river	27, 13, 1	2400 m^3/d

3.4. MICROORGANISM TRANSPORT:THE RT3D MODEL

In this section, the hydrological and mathematical description of the model, used for microorganism transport simulation, are briefly presented.

3.2.1 Transport of colloids

RT3D simulates the transport of colloids in saturated porous media. Microorganisms are considered bio-colloids. Infected living beings shed microorganisms to the environment in their fæces. Precipitation dissipates the infected fæces. Infiltration occurs and some microorganisms are transported to the soil along with water. Microorganisms are also transported with surface runoff, which could travel greater distances reaching a river. In the river, the microorganisms are mainly affected by two flow mechanisms: advection and dispersion. Given the right conditions, infiltration occurs and microorganisms are transported from the riverbed to the aquifer. Within the saturated porous media, microorganisms are affected by transport mechanisms of interception, sedimentation and diffusion. If the microorganism comes in contact with the porous media and attaches to it, the attachment process has occurred. The success of the microorganism removal process relies on the efficiency of the transport and attachment mechanisms.

3.2.2 Mathematical description

RT3D is a computer model that describes reactive-flow and transport of multiple mobile and/or immobile species in saturated groundwater systems through the solution of partial differential equations. RT3D is a generalized multi-species version of the transport code MT3D (USEPA). RT3D requires MODFLOW in order to compute the spatial and temporal variations in groundwater head distribution. For the transport of mobile species, RT3D includes terms for advection, dispersion, and equations for source/sink-mixing and a reaction term.

The implicit reaction solver makes RT3D a unique model useful for simulation of various types of chemical and microbial kinetics. The Rate Limited sorption (non equilibrium) reaction was used in this study. In a multi-dimensional saturated porous

media, the general macroscopic equations for the fate and transport of aqueous and solid-phase species are (Clement 1997):

$$\frac{\partial C_k}{\partial t} = \frac{\partial}{\partial Xi}\left(Dij \frac{\partial C_k}{\partial x_j} \right) - \frac{\partial}{\partial Xi}\left(ViC_k \right) + \frac{q_s}{\varepsilon}\left[Cs_k \right] + r_c \text{ , where } k = 1,2,...m \qquad \{3.7\}$$

$$\frac{d\widetilde{C}_{im}}{dt} = \widetilde{r}_c \text{ , where, } im = 1,2,...(n-m) \qquad \{3.8\}$$

where:

n is the total number of species (colloids),

m is the total number of aqueous-phase (mobile) species,

q_s is the volumetric flux of water per unit volume of aquifer representing sources and sinks [T^{-1}]

$\widetilde{r}_c$ represents the rate of all reactions that occur in the aqueous phase [either $MM^{-1}\ T^{-1}$ or $ML^3\ T^{-1}$ can be used]

$\widetilde{C}_{im}$ is the solid-phase concentration of the im^{th} species [either MM^{-1} (contaminant mass per unit mass of porous media) or ML^{-3} (contaminant mass per unit aqueous-phase volume)

C_k is the aqueous-phase concentration of the k^{th} species [ML^{-3}]

C_s is the concentration of source/sink [ML^{-3}]

D_{ij} is the hydrodynamic dispersion coefficient [$L^2\ T^{-1}$]

ε is the soil porosity

3.2.3 Building the transport model for the study area

The microorganism transport model was built in the following steps.

3.2.3.1 Setting the time steps or stress periods

The total simulation time is defined as the simulation period. The instance of simulation within which specified stress parameters are constant is defined as "time step or stress period". The simulation period was initially set at 1000 days.

3.2.3.2 Selection of packages governing microorganism transport

i. Advection package:

This feature allows simulation of the transport of contaminants at the same velocity as the groundwater. The equation for advection is as follows:

$$\frac{\partial C}{\partial t} = \frac{\partial(\theta v_i C)}{\partial X_i} \qquad \{3.9\}$$

where:

C is the aqueous-phase concentration [ML^{-3}],

X_i is the distance along the respective Cartesian coordinate axis, [L]

v is the pore velocity [LT^{-1}]

In the advection package, a solution scheme needs to be selected. The solution schemes include the standard finite-difference method, the particle tracking based Eulerian-Lagrangian methods or the Third-Order total-variation-diminishing (TVD) scheme. The standard finite-difference method was developed to be used in a fine grid, with scenarios involving large physical dispersion. The TDV solves the mass-conservative advection term without introducing excessive numerical dispersion and artificial oscillation (Zheng and Wang 1999). For this study, the TVD scheme was selected, since it is a more conservative scheme in terms of dispersion.

ii. Dispersion package:

Complementing advection, the dispersion package mimics the spreading of contaminants in the system. The calculation is based on mean groundwater velocity

vectors (Zheng and Wang 1999). The dispersion mechanism is described by the following equation (Eq. 3.10):

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial X_i}\left(D_{ij} \frac{\partial C}{\partial X_j} \right) \qquad \{3.10\}$$

where:

C is the aqueous-phase concentration [ML^{-3}],

X_{ij} is the distance along the respective Cartesian coordinate axis, [L]

D_{ij} is the hydrodynamic dispersion coefficient [$L^2\ T^{-1}$]

iii. Chemical reaction package: Non-equilibrium (rate-limited) sorption

Most contaminant transport models assume only equilibrium conditions between the solid and the liquid phase. However, when an external stress is affecting the aquifer, equilibrium conditions do not occur, and one must apply non-equilibrium kinetics. The rate-limited mass transfer approach simulates the sorption process of chemicals in porous media under non-equilibrium conditions (Clement, Sun et al. 1998). The extraction wells, included in this simulation, affect the normal ground-water flow conditions and the sorption process becomes slower than the velocity of groundwater flow. In such scenarios, the solute movement needs to be tracked in both mobile and immobile regions as follows (Clement and Jones 1998):

$$\frac{\partial C}{\partial t} + \frac{\rho \partial \widetilde{C}}{\varepsilon\, \partial t} = \frac{\partial}{\partial Xi}\left(Dij \frac{\partial [C]}{\partial X_j} \right) - \frac{\partial}{\partial Xi}(ViC) + \frac{qs}{\varepsilon} Cs \qquad \{3.12\}$$

$$\frac{dC}{dt} = -k_{att}\left(C - \frac{\widetilde{C}}{Kd} \right) \qquad \{3.13\}$$

$$\frac{d\widetilde{C}}{dt} = \frac{\varepsilon k_{att}}{\rho}\left(C - \frac{\widetilde{C}}{Kd} \right) \qquad \{3.14\}$$

where:

q_s is the volumetric flux of water per unit volume of aquifer representing sources and sinks [T^{-1}]

k_{att} is the first order mass transfer rate between the dissolved and the sorbed phases, also referred as k_{att} [T^{-1}]

Kd is the linear partitioning or distribution coefficient for the sorbed phase [L^3M^{-1}]

C is the aqueous-phase concentration of the specie [ML^{-3}]

$\widetilde{C}$ is the solid-phase concentration of the species [either MM^{-1} (contaminant mass per unit mass of porous media) or ML^{-3} (contaminant mass per unit aqueous-phase volume)]

ρ is the bulk density of the soil matrix [ML^{-3}]

Equations (3.12) and (3.13) are solved simultaneously, and the transport solution affected by non-equilibrium sorption is obtained. Studies have shown that as the mass transfer rate (k_{att}) increases, the sorption process becomes faster and the non-equilibrium sorption comes close to the equilibrium-controlled linear sorption. On the contrary, when the mass transfer rate (k_{att}) is small, the exchange between the solid and aqueous phase is slow and sorption becomes negligible (Zheng and Wang 1999). The theoretical background used for the calculation of the transport parameters is given in Section 3.3.

3.2.3.3 Setting the concentration conditions

The load condition of selected species (microorganisms) can be assigned to a desired set of cells. The condition of the load is given in the ICBUND array, and three options are available.

- ICBUND (+), for cells with variable load; hence the load varies with time.
- ICBUND (-), for cells that have a constant load,
- ICBUND (0), when the cell is inactive, as a result the load will not be considered or calculated.

In this study, the river cells were set as constant load, thus a negative ICBUND (-) was assigned. The values of initial load were given in the Starting Concentration array. The starting loads can be assigned independently at every cell on the grid in the aqueous or the solid phase. The subsequent loads are automatically calculated according to the reaction module selected. The hypothesis in this study was that the initial and only source of contamination was the river. The initial load of the river water was set to 100 microorganisms per litre of water for each of the three microorganisms evaluated. The initial ground-water load was set to zero. This allowed a more precise observation of the transport and spreading of the microorganism over the entire study area.

3.5. ESTIMATION OF TRANSPORT PARAMETERS

In this study, the Colloid Filtration Theory (CFT) was used to estimate the transport parameters needed for the simulation of microorganism transport. The CFT, which defines the removal of colloids from porous media, can be employed in models describing the transport of bacteria in groundwater (Harvey and Garabedian 1991). The CFT defines the mass transport process using the single-collector contact efficiency and the surface attachment by the sticking efficiency parameter (Tufenkji 2006).

3.3.1 Sticking efficiency (α)

The sticking efficiency parameter (α) is defined as the ratio of the number of collisions that result in attachment versus the total number of collisions. Essentially, α represents the probability those collisions will end in attachment (Tufenkji, Ryan et al. 2002; Tufenkji and Elimelech 2004; Tufenkji and Elimelech 2005). The sticking efficiency (α) reflects the net effect of repulsive and attraction forces between the colloid and the collector. The α value also depends on the surface characteristics of the colloid. Therefore, it is affected by factors like ionic strength, pH and organic carbon content (Yao, Habibian et al. 1971).

The sticking efficiency parameter (α) cannot be accurately predicted (Tufenkji and Elimelech 2004). Therefore, the values of α must be estimated from experiments, that

are usually done in soil columns. (Schijven and Hassanizadeh 2000). Alternatively, values reported in literature could be used. For this study, values referred in experiments, that best fitted our study area, and its sand and gravel aquifer, were selected. These values are summarized in Table 3.7. According to these ranges of sticking efficiencies parameters, we designed a sub-scenario classification. Each sub-scenario was evaluated with both sticking efficiency values.

Table 3.7: Reported values for sticking efficiency parameter (α)

Microorganism	α		Soil Type	Experiment Type	Source
	min value	max value			
C. parvum	0.040	0.959	Sand/gravel	Soil column	(Hijnen, Brouwer-Hanzens et al. 2006)
E. coli	0.085	1.023	Sand/gravel	Soil column	(Hijnen, Brouwer-Hanzens et al. 2006)
MS2	0.003	0.021	Sand/gravel	Field study	(Hijnen, Brouwer-Hanzens et al. 2006)

3.3.2 Single-collector contact efficiency - SCCE (ηo)

Tufenkji and Elimelech (2004) described the most up-to-date equation for the single-collector contact efficiency (SCCE) for deposition in saturated porous media. This equation brings together the individual transport mechanisms of Brownian diffusion, interception and gravitational sedimentation with the influence of hydrodynamic and Van der Waals interactions. The equation is:

$$\eta_o = 2.4 A_s^{1/3} N_R^{-0.081} N_{Pe}^{-0.715} N_{vdW}^{0.052} + 0.55 A_s N_R^{1.675} N_A^{0.125} + 0.22 N_R^{-0.24} N_G^{1.11} N_{vdW}^{0.053} \quad \{3.16\}$$

where:

N_A is the attraction number; represents combined influence of van der Waals attraction forces and fluid velocity on colloid deposition rate due to interception,

N_G is the gravity number; the ratio of Stokes colloid settling velocity to fluid's approach velocity,

N_{gr} is the gravitational number, representing the ratio of colloid's gravitational potential when located one colloid radius from the collector to the colloid's thermal energy

N_{Pe} is the Peclet number characterizing the ratio of convective transport to diffusive transport,

N_R represents the aspect ratio, and

N_{vdW} is the van der Waals number characterizing the ratio of van der Waals interaction energy to the colloid's thermal energy.

Another term related to the single-collector contact efficiency (η_0) is the experimental single-collector removal efficiency (η), which represents the frequency at which colloids approaching strike the collector grain. Collision efficiency (α) also is defined in formula 3.17, that relates these two parameters (SCCE and η) (Tufenkji, Ryan et al. 2002; Tufenkji and Elimelech 2005).

$$\eta = \eta_0 * \alpha \qquad \{3.17\}$$

Under typical aquatic conditions, η_0 has a greater numerical value than η due to the repulsive colloidal interactions between collector and colloids (Tufenkji and Elimelech 2004). The parameters used for the calculation of the single collector contact efficiency are given in Tables 3.8, through 3.10.

Table 3.8: *C. parvum's* input parameters used for the calculation of the SSCE

Parameter				Unit
Porosity (ε)	0.28	0.35	0.40	-
Collector diameter (d_c)	0.50	0.50	0.50	mm
Fluid approach velocity (U)	9.84×10^{-5}	8.21×10^{-5}	7.19×10^{-5}	m/s
Microorganism density (ρ_p)	1050.00	1050.00	1050.00	kg/m^3
Fluid density (ρ_f)	1000.00	1000.00	1000.00	kg/m^3
Fluid viscosity (μ)	1.01×10^{-3}	1.01×10^{-3}	1.01×10^{-3}	kg/m s
Temperature (T)	293.00	293.00	293.00	K
Hamaker constant (A)	6.5×10^{-21}	6.5×10^{-21}	6.5×10^{-21}	J
Happel model parameter (A_s)	92.23	52.53	37.98	-
Microorganism size	4.50	4.50	4.50	(μm)

Table 3.9: *E. coli's* input parameters used for the calculation of the SCCE.

Parameter				Unit
Porosity (ε)	0.28	0.35	0.4	-
Collector diameter (d_c)	0.50	0.50	0.50	mm
Fluid approach velocity (U)	9.84×10^{-5}	8.21×10^{-5}	7.19×10^{-5}	m/s
Microorganism density (ρ_p)	1085.00	1085.00	1085.00	kg/m^3
Fluid density (ρ_f)	1000.00	1000.00	1000.00	kg/m^3
Fluid viscosity (μ)	1.01×10^{-3}	1.01×10^{-3}	1.01×10^{-3}	kg/m s
Temperature (T)	293.00	293.00	293.00	K
Hamaker constant (A)	6.2×10^{-21}	6.2×10^{-21}	6.2×10^{-21}	J
Happel model parameter (A_s)	92.23	52.53	37.98	-
Microorganism size	1.5	1.5	1.5	(μm)

Table 3.10: MS2's input parameters used for the calculation of the SCCE.

Parameter				Unit
Porosity (ε)	0.28	0.35	0.4	-
Collector diameter (d_c)	0.50	0.50	0.50	mm
Fluid approach velocity (U)	9.84×10^{-5}	8.21×10^{-5}	7.19×10^{-5}	m/s
Microorganism density (ρ_p)	1085.00	1085.00	1085.00	kg/m^3
Fluid density (ρ_f)	1000.00	1000.00	1000.00	kg/m^3
Fluid viscosity (μ)	1.01×10^{-3}	1.01×10^{-3}	1.01×10^{-3}	kg/m s
Temperature (T)	293.00	293.00	293.00	K
Hamaker constant (A)	6.2×10^{-21}	6.2×10^{-21}	6.2×10^{-21}	J
Happel model parameter (A_s)	92.23	52.53	37.98	-
Microorganism size	2.21×10^{-2}	2.21×10^{-2}	2.21×10^{-2}	(μm)

3.3.3 First order, mass-transfer rate parameter (ξ, k_{att}) [T^{-1}]

The mass-transfer rate parameter represents the rate of physical-chemical filtration. The mass-transfer rate parameter is equal to the particle attachment or particle deposition rate coefficient used in microorganism removal, and it is estimated by the CFT, based on fluid, sediment and the microorganism's properties.

$$k_{\text{att}} = \frac{3}{2}\frac{(1-\varepsilon)}{d_c\varepsilon}U\alpha\eta_0 \qquad \{3.18\}$$

where:

d_c is the diameter of the spherical collector (L),

U is the interstitial particle velocity (LT^{-1}), and

ε is the porosity of the porous medium

3.3.4 Linear partitioning coefficient or First-Order sorption constant (K_d) [LM^{-1}]

The linear partitioning coefficient, 1st order sorption constant or equilibrium constant, represents the ratio of concentration of the colloid in the two phases, aqueous and solid. Even though, it is preferable and highly recommended to determine the linear partitioning coefficient through batch partitioning experiments, this was not possible in the present study. So, the linear partitioning coefficient was calculated using the relationship between $\widetilde{C}_{(x)}$ and $C_{(x)}$ under equilibrium adsorption conditions:

$$\widetilde{C}_{(x)} = K_d\, C_{(x)} \qquad \{3.19\}$$

The classical Colloid Filtration Theory (CFT) was used next to calculate the concentration of bacteria in solid $\widetilde{C}_{(x)}$ and liquid phase $C_{(x)}$. Irreversible attachment of microbes, zero initial concentration of colloids, a steady state system and negligible hydrodynamic dispersion are assumed with this theory. (Tufenkji and Elimelech 2005; Tufenkji 2006). S(x) and C(x) are calculated using the following equations.

$$C_{(x)} = C_0 \exp\left[-\frac{k_{att}\, X}{V}\right] \qquad \{3.20\}$$

$$\widetilde{C}_{(x)} = \frac{t_o\, k_{att}\, \varepsilon\, C_o}{\rho b} \exp\left[-\frac{k_{att}\, X}{V}\right] \qquad \{3.21\}$$

where:

t_o is the duration of microorganism injection (T)

X is the distance (L)

3.6. GROUND-WATER FLOW MODELING FOT THE STUDY AREA

The MODFLOW model was constructed for the Rio Grande de Manati area, to assess the quantity of river water infiltrating from the river to the RBF system. The well

was positioned at 150 m from the river. Grid cells within the X axis were refined from 15 m to 3 m. The pumping rate used was 2400 m^3/d. Other input parameters such as hydraulic conductivity, river stage and riverbed elevation, were stated earlier.

3.7. ACCURACY ESTIMATION OF GROUND-WATER FLOW SIMULATIONS

The accuracy of the ground-water flow simulation results were estimated with the simulation results of the Manati Assessment. Cumulative volumes in river and wells were used as the parameters for this accuracy estimation.

3.8. MANAGEMENT SCENARIO ANALYSIS

The RT3D model was used to evaluate the effect of different transport parameters on the fate of three microorganisms. The scenarios simulated for each microorganism varied: (i) porosity, (ii) pumping rates (iii) number of wells and (iv) intermittent pumping.

3.8.1 Porosity

In this scenario, the effect of two porosities over microorganism transport was evaluated, and compared with the results obtained with the field-measured value of 0.275 for the study area. Porosities of 0.35 and 0.40 were chosen. This is because the Manati aquifer is mainly composed by sand and gravel, which have these respective values respectively (Gelhar, Welty et al. 1992). The sub-scenario classification, according to the porosity, is given in Table 3.11.

3.8.2 Pumping rates

Due to either population growth or increased industrial activities, demand for fresh water is always increasing. To satisfy water demand pumping rates must be increased. Therefore, in this scenario, the effect of pumping rates on microorganism transport was evaluated. Rio Grande de Manati river's base flow is usually greater than 1.08×10^5 m^3/d, thus a pumping rate of 2,400 m^3/d was possible (Torres-Gonzales,

Gomez-Gomez et al. 2002). For evaluation purposes, pumping rates of 1200 and 4800 m^3/d were chosen; they represent half and double the pumping rate applied in the Manati Study (2400 m^3/d). The details on sub-scenarios, according to the pumping rates used, are given in Table 3.11.

3.8.3 Number of Wells

The water flow rate must satisfy water requirements of the Rio Arriba Saliente and Pugnado Afuera population. The total population of this area is 15,000 habitants, and the mean water consumption in 1995 was 210 m^3 per person per year (Rico.com 2007; U.S.G.S 2007). Consequently, the population's water requirements were estimated at 8800 m^3/d. The Pumping rate was simulated in sub-scenarios G and H, with 4 and 6 wells respectively. The pumping rate selected for sub-scenario G (4 wells) was 2200 m^3/d per well, and 1460 m^3/d per well for sub-scenario H (6 wells). Both sub-scenarios yielded a total pumping rate of 8800 m^3/d. The details on sub-scenarios, according to the number of wells used, are given in Table 3.11.

3.8.4 Intermittent Pumping

Generally a greater number of wells are constructed than are actually required. This practice allows closing some wells for maintenance purposes without affecting the overall yield. The maximum number of wells that the Manati Aquifer can handle is 6, with 50 m between them. The simulation time of 1000 days was sub-divided in four periods of 250 days each. In the 1^{st} and 3^{rd} periods 6 wells were operating, while in the 2^{nd} and 4^{th} periods, two wells (W2 and W4) stopped pumping water from the aquifer. The total pumping rate in all periods was of 8800 m^3/d. Thus, the total pumping rate was divided within the working wells, yielding 1460 m^3/d per well for the 1^{st} and 3^{rd} period, and 2200 m^3/d per well for the 2^{nd} and 4^{th} period. This sub-scenario classification, according to the intermittent periods used, is given in Table 3.11.

Table 3.11: Sub-scenario classification according to the parameter evaluated

Scenario	Sub-scenario	Porosity	Time steps (TS)	Number of wells	Pumping rate per well (m^3/d)
Porosity	A1[a] A2[b]	0.275	1	1	2400
	B1[a] B2[b]	0.35	1	1	2400
	C1[a] C2[b]	0.4	1	1	2400
Pumping rate	D1[a] D2[b]	0.275	1	1	2400
	E1[a] E2[b]	0.275	1	1	1200
	F1[a] F2[b]	0.275	1	1	4800
Number of wells	G1[a] G2[b]	0.275	1	4	2400
	H1[a] H2[b]	0.275	1	6	1200
Intermittent pumping	K1[a] K2[b]	0.275	4	6 (1^{st} and 3^{rd} TS) 4 (2^{nd} and 4^{th} TS)	1460 2400

(a) minimum sticking efficiency [*C. parvum*: 0.04 ; *E. coli*: 0.085 ; MS2: 0.003]

(b) maximum sticking efficiency [*C. parvum*: 0.959 ; *E. coli*: 1.023; MS2: 0.021]

CHAPTER IV. - RESULTS AND DISCUSSION

Two simulation models, MODFLOW and RT3D, were chosen to simulate groundwater flow and microorganism transport. MODFLOW and RT3D required several parameters; some parameters were measurable, whereas some needed estimation. Aquifer hydraulic parameters were drawn from the Manati Assessment study (Torres-Gonzales, Gomez-Gomez et al. 2002), and used for the groundwater flow simulation. Transport parameters involved in microorganism removal (attachment coefficient and linear partitioning coefficient) were required for transport simulation using RT3D. Colloid Filtration Theory was used to estimate these parameters. Finally, these calculated parameters were used to build the reactive model for transport of *C. parvum, E. coli*, and MS2.

In this chapter the evaluation of the accuracy of the groundwater simulation, the estimation of η_0, k_{att}, K_d values, the initial transport simulation and finally the results of the different management scenarios for each microorganism are presented and discussed.

4.1. ACCURACY ESTIMATION OF GROUND-WATER FLOW SIMULATIONS

The hydrological data for the groundwater flow simulation was obtained from a previous study (Torres-Gonzales, Gomez-Gomez et al. 2002). The input data is detailed in section 3.1.3. The model was run for a period of 100 days. The aquifer was simulated with and without the well option. When implemented, wells were located 150 m from the river. The Manati study used MODFLOW 96 whereas this research was done with a recent version of the model, i.e. MODFLOW 2000. Thus the results of this study needed to be cross-checked.

For a natural aquifer scenario (no well), the contour lines of simulated water flow were perpendicular to the river (Figure 4.1), indicating that water flow within the aquifer ran parallel to the river. Water table measurements indicated that the Rio Grande de Manati was the main source of groundwater recharge, although rainfall was reported to also contribute during the wet months (Torres-Gonzales, Gomez-Gomez et al. 2002).

Throughout the year, the Rio Grande de Manati's daily discharge ranged from 3.4×10^4 to 9×10^6 m^3/d. The Rio Grande de Manati flows from south to north and the simulated mean head values ranged from 19.5 to 20.4 m, respectively. The calculated flow rate entering the aquifer along the southern river boundary was 380 m^3/d.

For an aquifer with pumping from an extraction well, the contour lines in the central and northern portions of the aquifer were completely reversed from their natural orientation (Figure 4.2). In these portions of the aquifer, contour lines were parallel to the river, indicating that in this area, the water flow ran perpendicular to the river. In the southern part of the simulated aquifer, the simulated contour lines were perpendicular to the river, indicating that the water flow ran parallel to the river. The simulated mean head values ranged from 16.75 to 20.33 m from north to south. The pumping action generated an increase of 2600 m^3/d of water entering the aquifer.

The 100-day water balance for the aquifer, with and without an extraction well, is given in Tables 4.2 and 4.1 respectively. The water balance obtained with MODFLOW 2000 was quite similar to that obtained with MODFLOW 1996, in the earlier study: the simulated balance discrepancies were 0.48% and 0.52%, respectively, for the natural aquifer (no extraction well) scenario, and 0.08% and 0.07%, respectively in the presence of the extraction well (Torres-Gonzales, Gomez-Gomez et al. 2002). The quantity of water entering the study area approximately equaled that pumped out. Thus it can be stated that the model's performance and the mass balance were satisfactory.

Table 4.1: Comparison of the volumetric budget at the end of the simulation for the natural aquifer (without extraction wells)

Package	Manati Assessment m^3/d	Actual Simulation m^3/d
River leakage	377.5	377.6
Total in	377.5	377.6
River leakage	379.4	379.4
Total out	379.4	379.4
In - out	-1.97	-1.82
Percent discrepancy	-0.52	-0.48

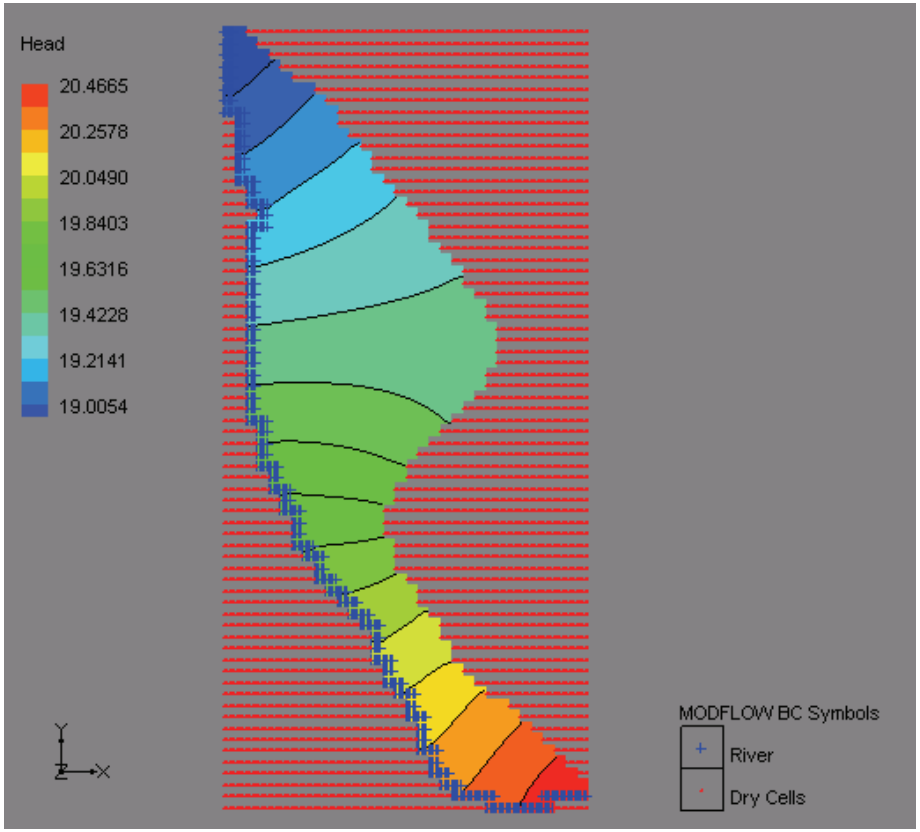


Fig 4.1: Ground water flow model, simulated head values for the natural aquifer without extraction well

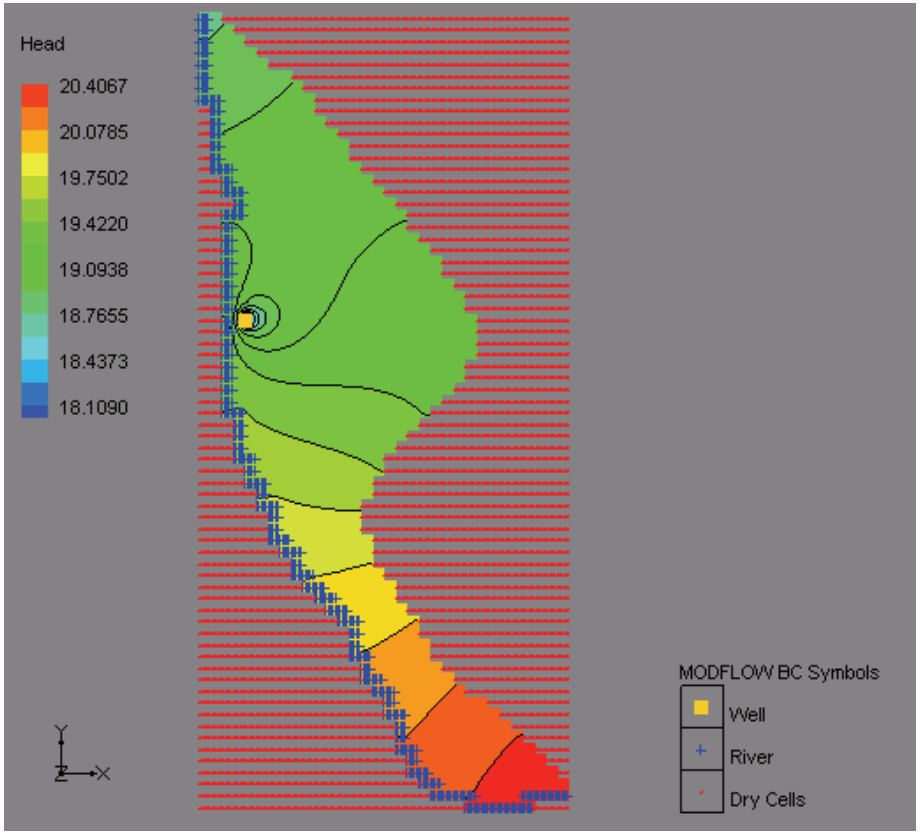


Fig 4.2: Ground water flow model, simulated head values for the aquifer including one extraction well

Table 4.2: Comparison of the volumetric budget at the end of the simulation for the aquifer with one extraction well

Package	Manati Assessment m^3/d	Actual Simulation m^3/d
River leakage	2603.1	2603.0
Wells	0.0	0.0
Total in	2603.1	2603.0
Wells	2446.6	2446.6
River leakage	158.4	158.4
Total out	2605.0	2605.0
In - out	-2	-2
Percent discrepancy	-0.07	-0.08

4.2. ESTIMATION OF MICROORGANISM TRANSPORT PARAMETERS

4.2.1. Single-collector contact efficiency - SCCE (η0)

According to the Colloid Filtration Theory, Single Collector Contact Efficiency (SCCE or η_0) represents the mass transport process in colloid transport and removal. The input data used for its computation is presented in Tables 3.8, 3.9 and 3.10. Equation 3.16 was used for its calculation. The calculated values of η_0 are presented in Table 4.3.

Table 4.3: Estimated values of η_0, k_{att} and K_d for different microorganisms at three different porosity levels

Microorganism	**Porosity**	η_0	k_{att} (d^{-1})		K_d (L/mg)	
			min	**max**	**min**	**max**
C. parvum	0.275	1.06×10^{-2}	28.37	680.21	4.88×10^{-3}	1.17×10^{-1}
	0.350	8.04×10^{-3}	12.71	304.62	2.78×10^{-3}	6.66×10^{-2}
	0.400	7.37×10^{-3}	8.24	197.48	2.06×10^{-3}	4.94×10^{-2}
E. coli	0.275	5.01×10^{-3}	29.15	350.88	5.01×10^{-3}	6.03×10^{-2}
	0.350	4.41×10^{-3}	14.82	178.42	3.24×10^{-3}	3.90×10^{-2}
	0.400	4.23×10^{-3}	10.07	121.15	2.52×10^{-3}	3.03×10^{-2}
MS2	0.275	9.17×10^{-2}	18.49	129.45	3.18×10^{-3}	2.22×10^{-2}
	0.35	8.65×10^{-2}	10.87	76.08	2.38×10^{-3}	1.66×10^{-2}
	0.40	8.55×10^{-2}	7.16	50.11	1.79×10^{-3}	1.25×10^{-2}

Porosity and microorganism diameter (particle size) are involved in the calculation of η_0. Throughout the calculation of η_0 (Eqn. 3.16), changes in porosity affected the Happel model parameter as well as transport by diffusion and interception; although the parameters for colloid filtration (aspect ratio, Peclet number, van der Waals number and gravitational number) were not affected. It is clear that η_0 was inversely proportional to the porosity, thus whenever the porosity raised, the value of η_0 decreased. Therefore, for all the microorganisms evaluated, the largest value of η_0 (for each microorganism) was obtained at a porosity of 0.275. These results indicate that for a porosity value of 0.275, microorganisms will exhibit a greater efficiency in contacting the porous media.

Different microorganisms are considered as biological colloids having different diameters (*C. parvum* 4.5 μm; *E. coli*: 1.5 μm and MS2: 0.02 μm). The colloid size (microorganism diameter) also takes part in the calculation of all transport parameters (diffusion, interception and gravity), and in almost all the dimensionless parameters governing colloid filtration, except the Van der Walls number. Simulated values of η_0 showed a negative correlation with colloid size up tothe breaking point of approximately 1 μm, and then η_0 values showed a positive correlation with the colloid size (Figure 4.3). Although the trend would be similar, the actual values for different microorganisms, depend on several factors like colloid's density, grain size, approach velocity, etc.. Thus, calculated values are slightly different than the values shown in Fig. 4.3. As expected, higher values of η_0 were obtained for microorganisms of lesser size: MS2 (0.02 μm) had the highest numerical value of η_0. *E.coli* had slightly higher η_0 values compared to *C. parvum*. This can be explained because, even though *C. parvum* is larger, its density is lesser than that of *E. coli*. Colloid density directly affects the gravitational number. Thus particles of lesser density show smaller gravitational number values, and when the gravitational number is diminished, gravitational sedimentation loses relevance. Therefore, the estimated values of η_0 suggest that, at the same porosity, MS2 will be more efficient in contacting the porous media.

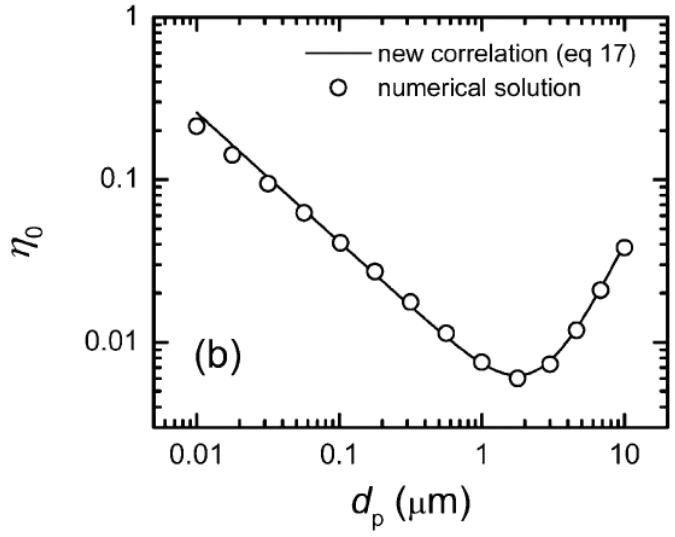


Fig. 4.3: Variation of estimated single collector contact efficiency (η_0) with colloid size (d_p), under riverbank filtration conditions.
Adapted from Tufenkji *et al*., 2004

Other parameters, like grain size (soil particle size), also affect η_0. Foppen *et al* (2006) reported that the reduction of grain size increased diffusion, interception and straining components in the η_0 (Foppen and Schijven 2006). Although only one aquifer was considered for all three microorganisms in this research, there is no effect of the grain size on the estimated η_0 for these three microorganisms.

4.2.2. Attachment coefficient (k_{att})

In order to simulate the microorganism transport with the RT3D model, the attachment coefficient (k_{att}) was calculated for porosities of 0.275, 0.350 and 0.400. Equation 3.18 was used for its determination; the input parameters being listed in Tables 3.8 through 3.10. The calculated values of k_{att} are presented in Table 4.3.

For each microorganism evaluated, k_{att} was inversely related to porosity, i.e., the highest values of k_{att} were observed at a porosity of 0.275. This indicates that at a porosity of 0.275, microorganisms will have greater removal rates due to attachment. Microorganism size also plays an important role in microorganism transport: microorganism size is proportional to k_{att} values. *C. parvum,* having the greatest size,

showed the greatest k_{att} values (Table 4.2). Thus it is expected that within the microorganisms evaluated and under the same porosity values, attachment would be greater for *C. parvum.*

Values of k_{att} for *C. parvum* for sandy soil have been reported to range from 50.4 to 125.28 d^{-1} (Bradford and Bettahar 2005). These values are within the range of the values estimated in this study. However, field values of k_{att} (0.8 – 4.1 d^{-1}) reported for MS2 (Schijven and Hassanizadeh 2000) were smaller than the values estimated in this study. Within these estimations, sticking efficiency was also included in k_{att}'s calculation and is directly correlated with it. Foppen et al (2006) attributed lower field values of sticking efficiency to the heterogeneity of the microbe population, preferential flow, or to the presence of compounds (inorganic compounds in waste water) that could be competing for the available attachment sites. Thus, the real adsorption capacities of MS2 might be over-estimated (Schijven and Hassanizadeh 2000).

4.2.3. Partitioning coefficient (K_d)

Another parameter required for the transport simulation is the partitioning coefficient (K_d). To calculate K_d, equilibrium adsorption of microbes to solid surfaces (linear adsorption isotherm) was assumed (Equation 3.19). Several calculations were done in order to obtain K_d, the details of which are outlined in Section 3.3.4. Estimated values of K_d are given in Table 4.3.

Values of K_d were inversely proportional to those of porosity. For all microorganisms tested, the highest K_d values were found at a porosity of 0.275, indicating that at a porosity of 0.275, microorganisms will be more effectively adsorbed to the porous media than at a lower porosity. Additionally, there was a positive correlation between K_d and microorganism size. The largest K_d value was found with *C. parvum* (1.17×10^{-1} L/mg) and the lowest for MS2 (1.66×10^{-2}). Thus under the same porosity conditions, *C. parvum* will be more effectively adsorbed to the porous media. To the best of the author's knowledge there are no studies which reports field values of K_d for the microorganisms evaluated; therefore K_d values could not be validated with published literature.

4.3. MICROORGANISM TRANSPORT SIMULATION THROUGH RBF SYSTEMS FOR THE RIO GRANDE DE MANATI AREA

The results from the groundwater simulation (MODFLOW) were used to build the microorganism transport simulation (RT3D). Manati Assessment's hydro-geological data was used in this simulation; details are given in Section 3.1.3. The well was located 15-18 m from the river. Usually, the maximum pumping rate for a well, located in aquifers with similar characteristics to Manati study area, is about 2400 m^3/d (Broughton 2006). Therefore, a pumping rate of 2400 m^3/d was applied. The simulation time was set to 1000 days to ascertain sustainability of the system.

The aqueous loads were calculated by the model with the previously estimated values of k_{att} and K_d. Removal of microorganisms through porous media at 0–3 m from the river is given in the Appendix, Table 6.1 - 6.6 (CD). At this distance and with the lowest attachment coefficient, the aqueous loads of *C. parvum, E. coli* and MS2 were 10.9, 10.5 and 18.7 microorganisms/L, respectively, at 100 days of simulation (DOS). With the highest attachment coefficient, the aqueous concentration levels of *C. parvum E. coli* and MS2 were 0.7, 0.78 and 2.11 microorganisms/L, respectively, at 100 DOS. Microorganisms with smaller values of these transport parameters showed higher loads in the aqueous phase due to the limited exchange between the aqueous and the solid phase. This trend was persistent at other DOS and is given in the Appendix, Table 6.1 - 6.6 (CD).

The transport simulation results for the lowest k_{att} value are given in Figures 4.4(a), 4.5(a) and 4.6(a). Only MS2 had reached the extraction well, at a load of 0.01 microorganisms/L after 800 DOS. At 900 DOS the concentration of MS2 was 0.03 microorganisms/L, although the permissible limit is 0.01 microorganisms/L. Therefore, the 4-log removal established by the (US EPA 2006), was not achieved. It may be noted that the simulation did not consider microorganism decay as this data was not available for the study area. So, with microorganism decay, our simulations may be considered as conservative (safer) estimations. If such results were obtained when having considered microorganism decay, then it would imply that some additional water treatment, like ozonation, would be needed. In the case of *C. parvum* and *E. coli*, these traveled a

maximum distance of 12 m from the river; thus they did not reach the well. This maximum distance was reached at 900 DOS and the load at 12 m from the river was <0.07 microorganisms/L. Again no decay rate was considered in these simulations. Despite this, *C. parvum* and *E. coli* did not reach the well. Thus, water filtered by the RBF system appears to be safe from these microorganisms.

The transport simulation results for the highest k_{att} value are given in Figures 4.4(b), 4.5(b) and 4.6(b). Under this scenario, the maximum distance traveled was 3-6 meters from the river for MS2 and 0–3 m from the river for *C. parvum* and *E. coli*. In this case, the microorganisms travelling in the porous media showed higher mass transfer rates between liquid and solid phase, thus complete removal was achieved ahead of reaching the well.

The removal levels [log(C/Co)] for the three microorganisms at 0-3 m from the river are given in Fig. 4.7. The highest log removal levels were achieved within the first 100 DOS. The greatest removal was seen in *C. parvum,* with values of 2.39 log and 0.96 log for the maximum and minimum attachment efficiencies, respectively. *E. coli* and MS2 log levels ranged from 2.11 – 0.98 and 1.68 - 0.78 log, respectively, for the maximum and minimum attachment efficiencies, respectively. This trend was persistent at other DOS [Appendix, Table 6.1 - 6.6 (CD)]. Thus, it appears that *C. parvum* removal in RBF systems would be more effective than that of *E. coli* and MS2.

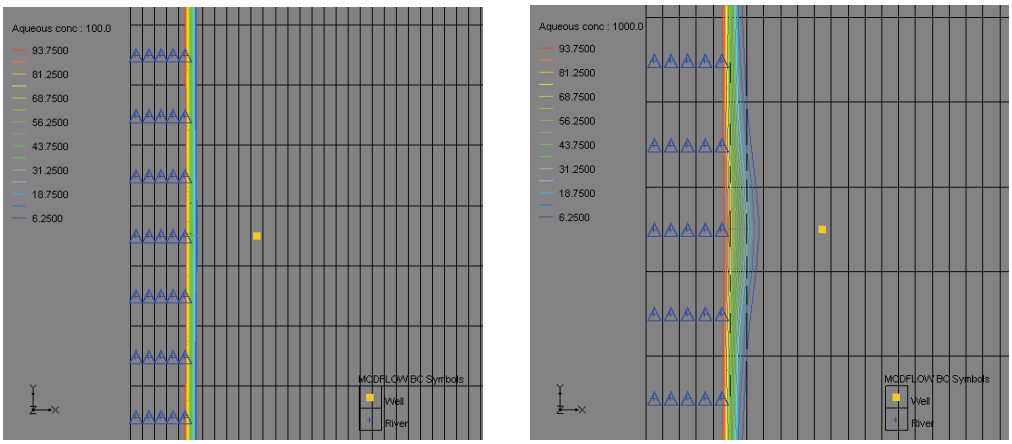


Figure 4.4: *C. parvum's* initial transport simulation (aqueous phase)

(a) 100 days (b) 1000 days

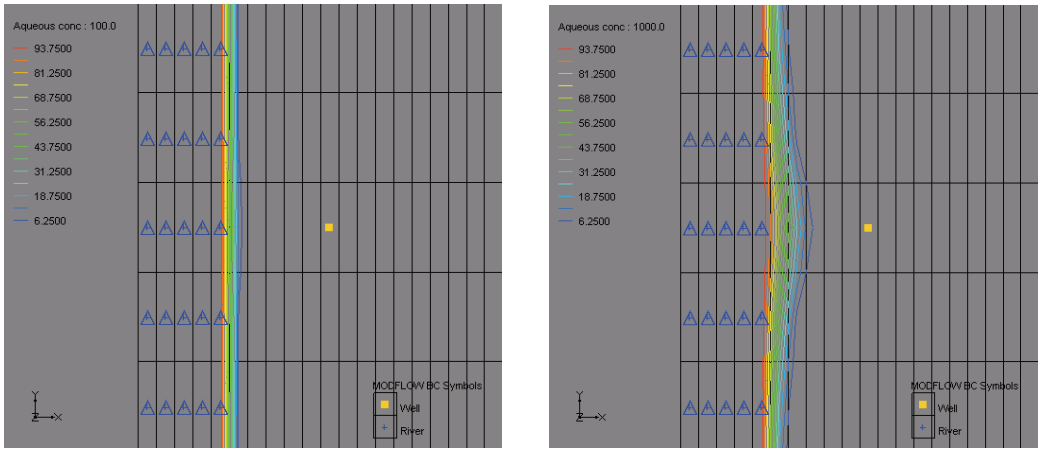


Figure 4.5: *E.coli's* initial transport simulation (aqueous phase)

(a) 100 days (b) 1000 days

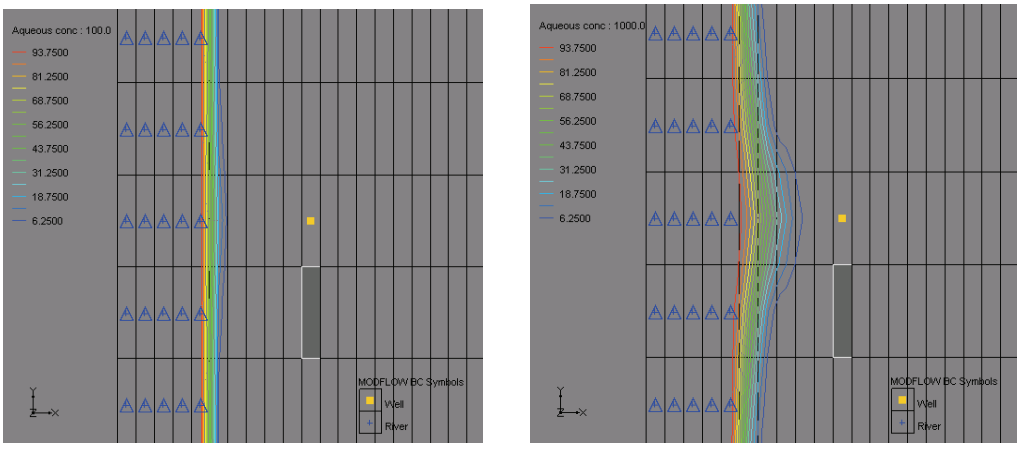


Figure 4.6: *MS2's* initial transport simulation (aqueous phase)

(a) 100 days (b) 1000 days

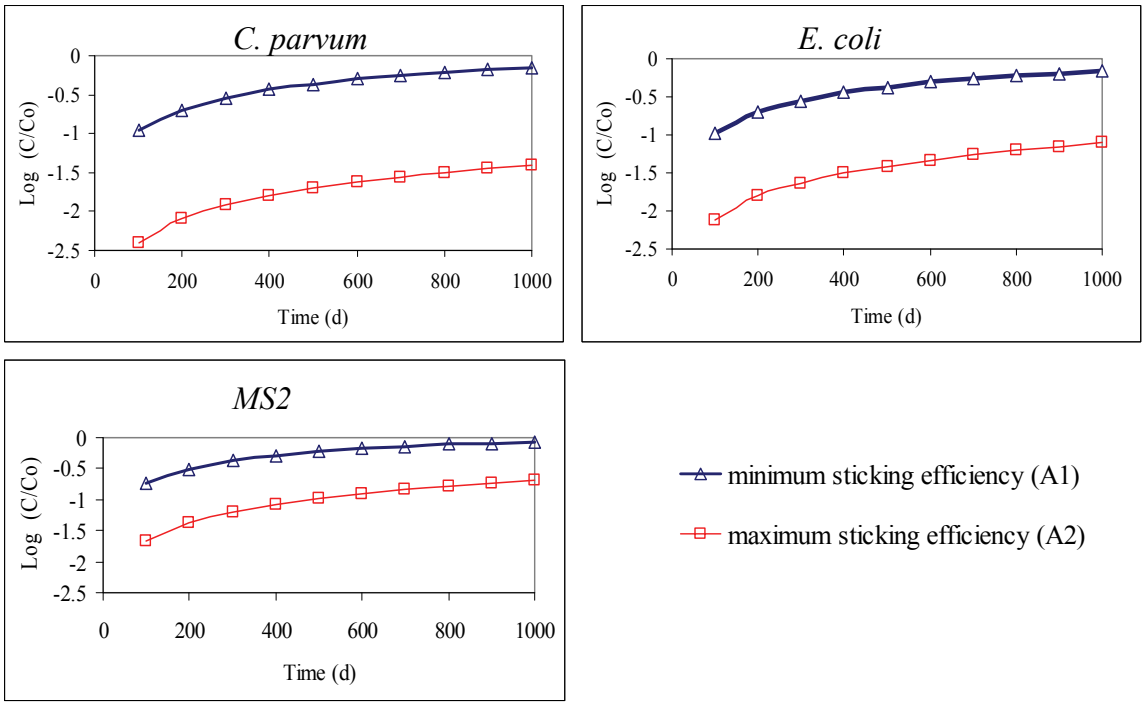


Fig 4.7: Log removal levels of *C. parvum, E. coli* and MS2 at Cell 1 (0-3 m from the river)

4.4. SCENARIO ANALYSIS

In this section, the results of different scenarios simulated for *C. parvum, E. coli* and MS2, are discussed. The estimated transport parameters, k_{att} and K_d, are given in Table 4.3. The input parameters needed for the hydro-geological processes (porosity and pumping rates) were changed according to the scenario tested (Table 3.11). The scenarios studied were: (i) porosity (scenarios A, B and C), (ii) pumping rates (scenarios D, E, F), (iii) number of wells (scenarios G, H) and (iv) intermittent pumping (scenario K). The results of microorganism transport were compared among these scenarios and also to results already obtained in the initial simulation for the Rio Grande de Manati area (Section 4.3).

The microorganism load at the river was set as 100 microorganisms/L, and the initial load in the aquifer was set as zero. Simulation results, for the three microorganisms, are given in the Appendix, Table 6.1 - 6.30 (CD). The microorganism

transport was evaluated according to the maximum traveled distance and the log-removal rates achieved.

For *C. parvum*, the National Primary Drinking Water Regulations classify source waters with levels of >3 oocysts/L as Bin 4. Bin 4 requires a 2.5 log removal for conventional filtration treatment processes (US EPA 2006). Thus, for the *C. parvum* transport simulation, a removal of 2.5 log or greater would be considered as safe. To the best of the author's knowledge, *E. coli* does not have a similar log removal rule for water filtration systems. However, its presence is continuously monitored and the maximum tolerable limit for potable water is zero. For evaluation purposes, a 2.5 log *E. coli* removal was considered as safe in this study. Wells located close to a potential virus source must accomplish a 4 log removal. If they do not fulfill this requirement, the aquifer will be considered "hydro-geologically sensitive" (Bhattacharjee, Ryan et al. 2002; US EPA 2006). Thus, for virus transport simulation a removal of 4 log was considered as safe.

4.4.1 SCENARIO 1: EFFECT OF AQUIFER POROSITY

The effect of three porosities on microorganism transport was evaluated. The transport of microorganisms under porosities of 0.35 and 0.40 was compared with that under a porosity of 0.275. The comparison was done on the basis of the maximum traveled distance and the loads transported. Additionally, log-removal is also discussed to evaluate the efficiency of microbial attenuation in aquifers with different porosities.

Several mechanisms, such as dispersion, advection and adsorption affect microorganism transport, thus loads in the aqueous phase generally decline while the water travels through a porous medium, irrespectively of its porosity values. This trend can be seen in Fig. 4.8 and 4.9, for the highest and lowest attachment coefficients, respectively. For the highest attachment coefficient, the maximum distances travelled by 1000 DOS for *C. parvum, E. coli* and MS2, under any porosity was 3-6 meters (Fig 4.8). In this case, microorganisms travelling in the porous media showed higher mass transfer rates between liquid and solid phase, thus complete removal was achieved before reaching the well, situated at 15–18 m from the river. For the lowest attachment coefficient, the maximum distance traveled after 1000 DOS was 15-18 m, under

porosities of 0.35 and 0.40. In the case of a porosity of 0.275 *C. parvum* and *E. coli* traveled a maximum distance of 9–12 m from the river; however MS2 travelled a maximum distance of 15–18 m. So, aquifer porosity is a determining factor for *C. parvum* and *E. coli*. For MS2, even at the lowest porosity used in this study, the risk of water pollution exists, so wells should be located further than the distance used in this study to be safe.

The microbial load at the well increased with time (Figure 4.10).. The travel times to reach the well were different for different porosities. For a porosity of 0.40, *C. parvum,* E. *coli* and MS2 reached the well after 300, 500 and 300 DOS, respectively. This is a much shorter period than that obtained under a porosity of 0.35, where these microorganisms reached the well after 600, 700 and 400 DOS, respectively. This is the effect of lower values of k_{att} and K_d obtained with higher porosities. Thus, at higher porosities there are chances that RBF might not be completely safe, and further treatment could be required.

The exchange between the aqueous and solid phase was lower under higher porosities, thus all microorganisms remained in the aqueous phase for longer time. Within the microorganisms evaluated, MS2 showed the least mass transfer between aqueous and solid phases, thus its transport was enhanced and the travel time to reach the well was shorter, compared to *C. parvum* and *E. coli*.

The efficiency of a filtration system is generally judged on the basis of log removal of microorganisms. Therefore, the fate and transport of microorganisms under consideration was further evaluated in light of log removal. Similar trends in log-removal were observed at different distances between the river and the well. However, numerically, log removal was different at different distances (Fig 4.11). Log removal being the lowest near the river, it is discussed at a greater length. Removal [(log C/Co)] levels within the first 0-3 meters between the river and the well are given in Fig. 4.11. Log-removal levels were inversely proportional to porosity. Consequently, at a porosity of 0.275 removal levels were greater than those under porosities of 0.35 or 0.40. Log removal decreased with distance; this was most evident at higher porosities, where log removal was almost negligible after 600 days (Appendix, Table 6.1-6.6). This trend can be seen in MS2 at three different porosity levels (Appendix, Table 6.1-6.6). Although the

log removal levels at different distances were always higher at the beginning of the simulation, results showed that even these higher levels were not enough to fulfill the log removal requirements for filtered water, for all three microorganisms at 0 – 3 meters from the river. Thus, the location of a well within 3 m from the river should not be considered.

Scenarios with high k_{att} values did not result in microorganisms reaching the well (Fig 4.8). However, at the lower $k_{att,}$ microorganisms reached the well, arriving, however, at different times. Loads reaching the well differed according to the porosity. Log removal rates at the well for the lower k_{att} are given in Fig 4.12. Log removal at porosities of 0.35 and 0.40 exceeded limits of 2.5 log removal for *C. parvum* at the well after 700 and 1000 DOS, respectively. Only under a porosity of 0.40 and 900 DOS and thereafter did *E. coli* no fall within acceptable limits of removal. As expected, MS2 reached the well under all three porosities tested. MS2 did not fail the 4 log removal criterion after 100, 500 and 800 DOS under porosities of 0.40, 0.35 and 0.275, respectively.

Finally, the best results were found with Manati's mean porosity of 0.27. As a consequence, for the design of a RBF system, lower aquifer porosity would be desirable.

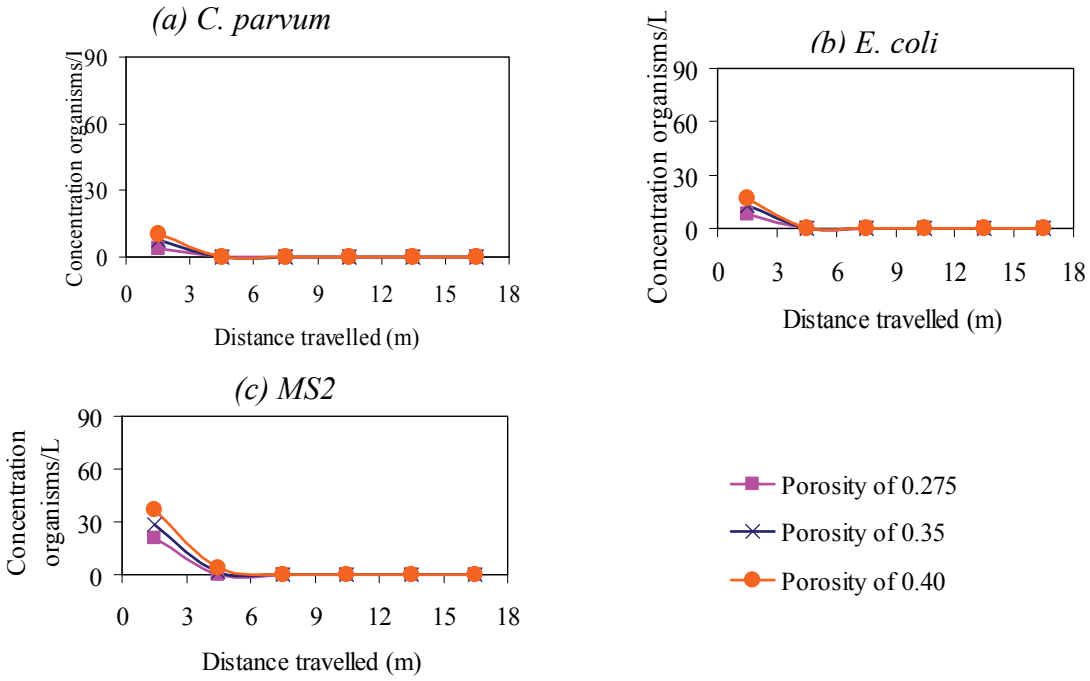


Fig 4.8: Effect of Porosity on *C. parvum, E. coli* and MS2 transport through the porous medium, under the higher $k_{att,}$ after 1000 days

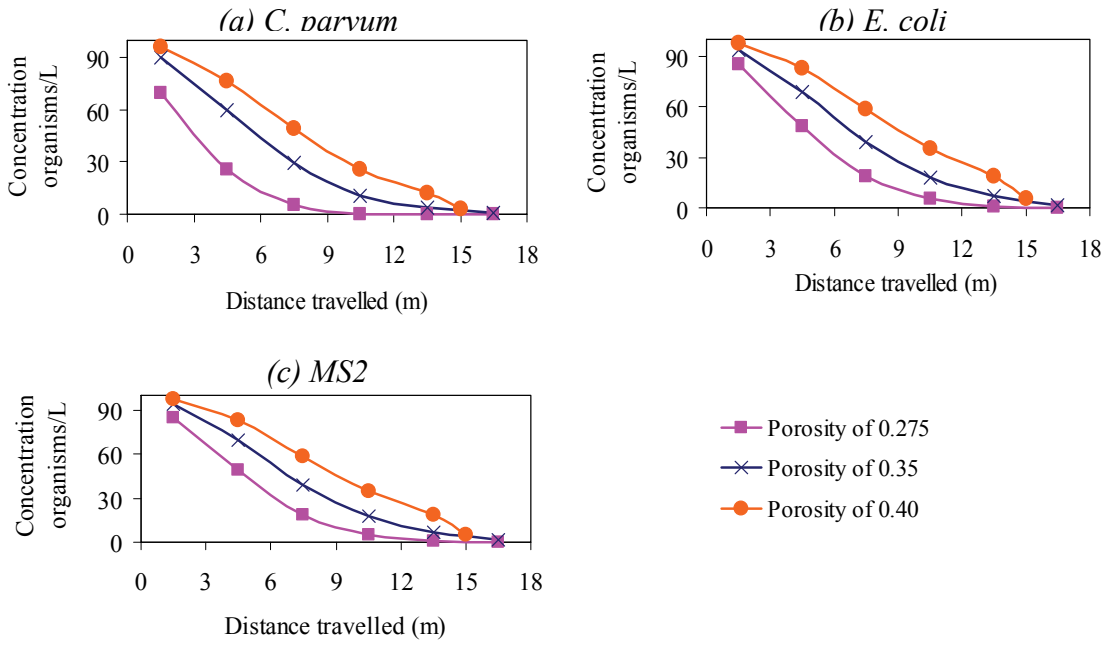


Fig 4.9: Effect of Porosity on *C. parvum, E. coli* and MS2 transport through the porous medium, under the lower $k_{att,}$ after 1000 days

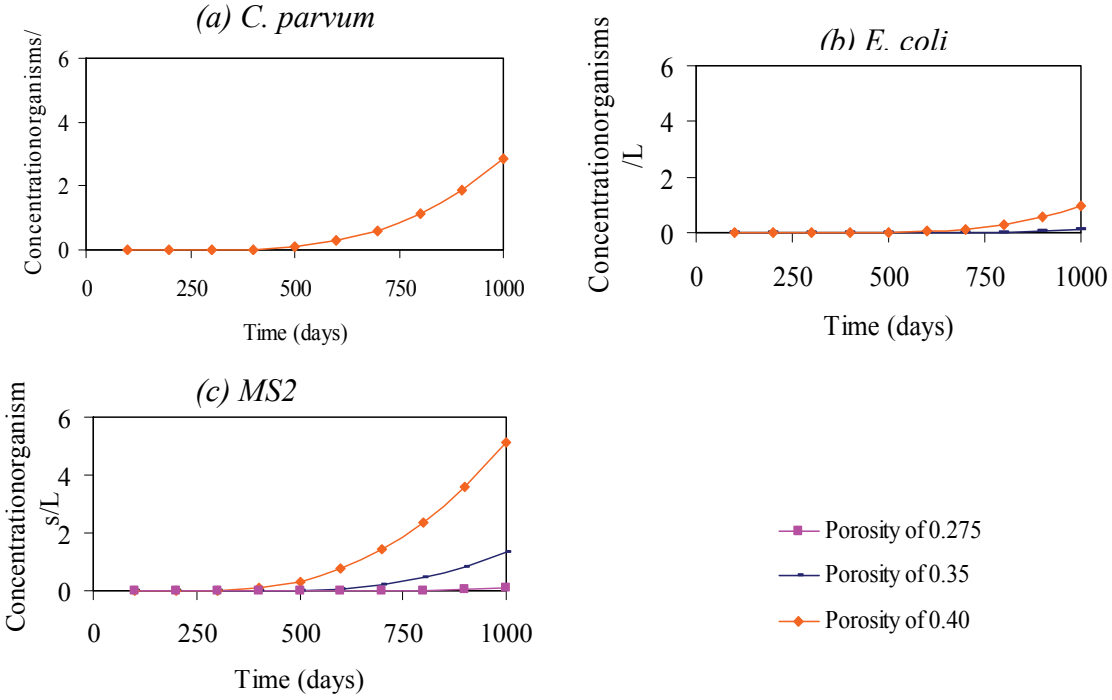


Fig. 4.10: Effect of porosity on microorganism loads at the extraction well, under the lower k_{att}, through simulation time (1000 days)

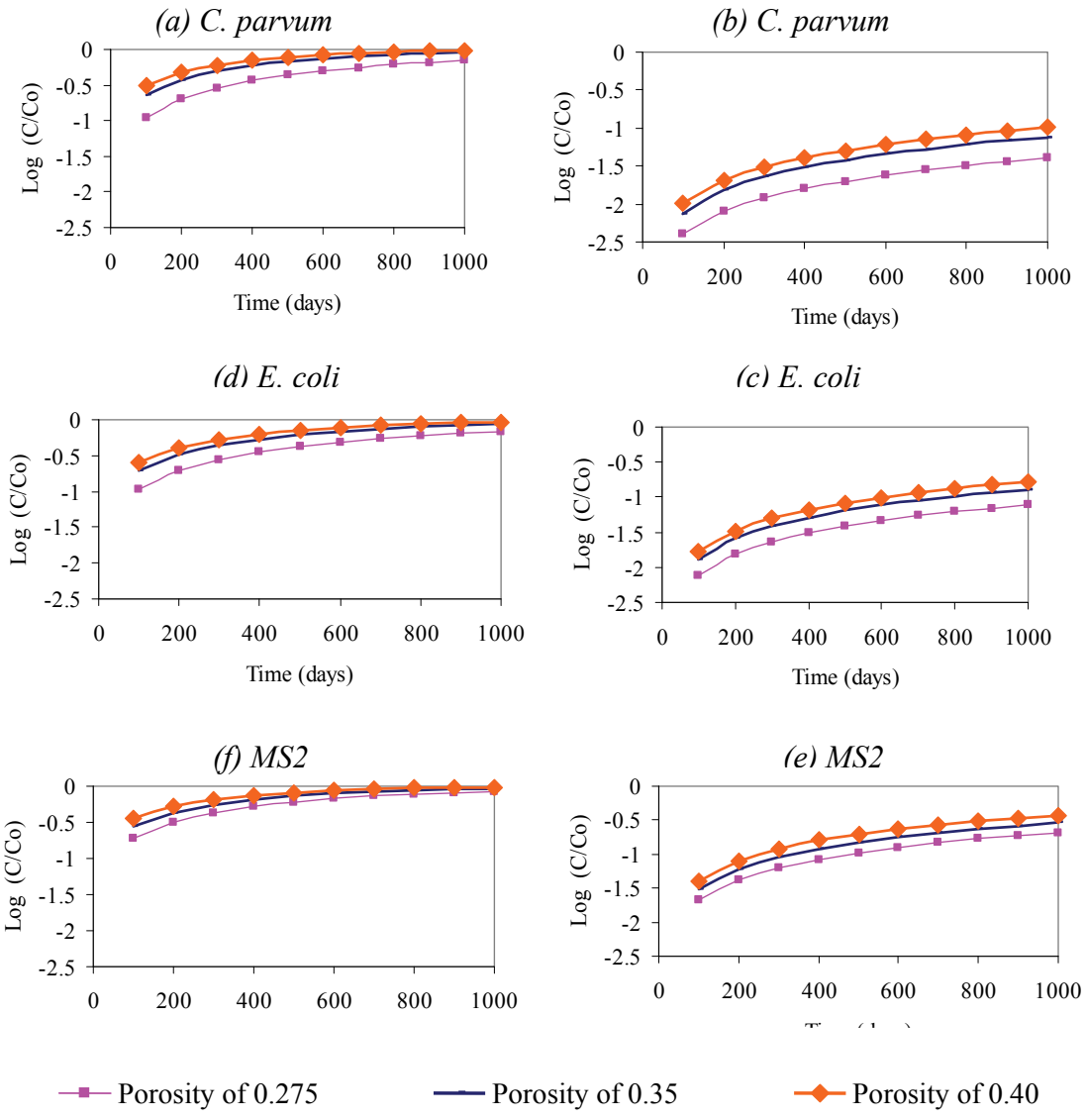


Fig 4.11: Scenario Porosity - Log removal (C/C_o) of *C. parvum, E. coli* and MS2 at Cell 1 (0-3 m from the river) for the lower and higher k_{att} values

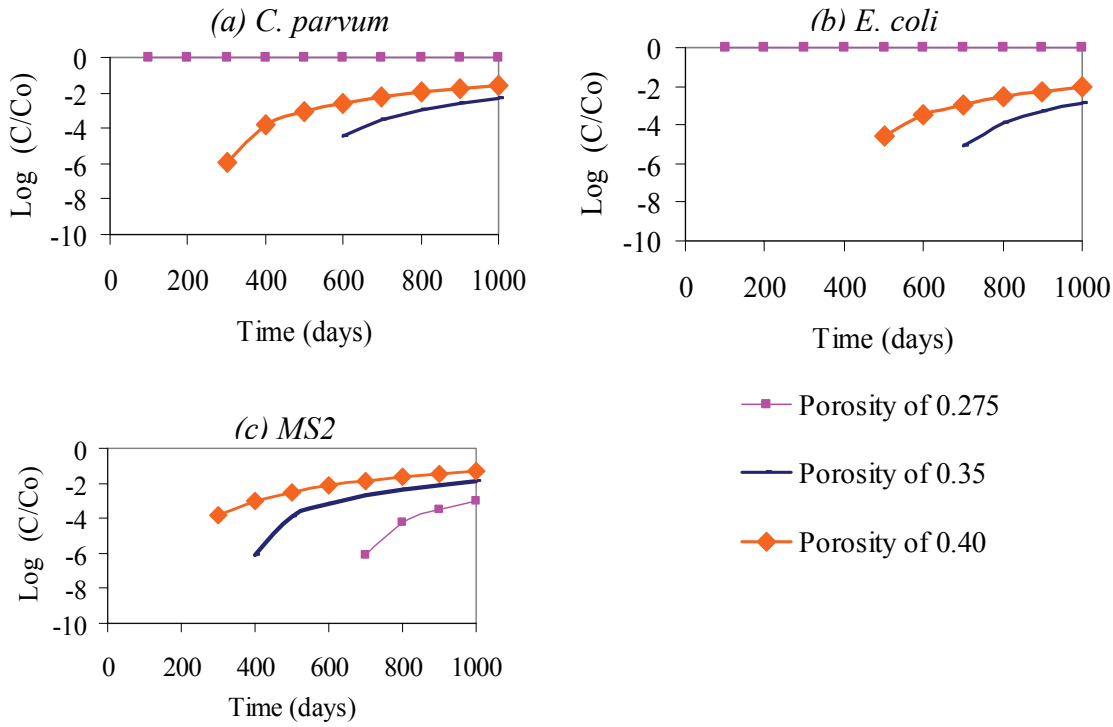


Fig 4.12: Scenario Porosity - Log removal (C/Co) of *C. parvum, E. coli* and MS2 at the extraction well (15-18 m from the river) for the lower k_{att}

4.4.2 SCENARIO 2: EFFECT OF PUMPING RATES

Pumping rates stimulate groundwater velocity and flow towards the well, thus possibly enhancing the transport of microorganisms to the well. In this scenario, the effect of two pumping rates, 1200 and 4800 m^3/d, on microorganism transport was assessed and compared with the suggested pumping rate for the study area, 2400 m^3/d.

The scenarios with higher pumping rates showed higher microorganism loads through all simulation times. Microorganism loads in the aqueous phase could only be attributed to the effect of pumping rates, since for each microorganism the values of the estimated transport parameters (k_{att} and K_d) remained constant.

Simulation results for microorganism transport through the porous media are given in Fig. 4.13 and 4.14, for the highest and lowest attachment coefficients, respectively. Microorganism loads decreased as they travelled through porous media. At

the highest attachment coefficient, the maximum distance travelled for all microorganisms, at all pumping rates, was 3–6 m from the river (Fig 4.13). The higher mass transfer rates would have prevented the transport of microorganisms to greater distances, thus their removal was achieved in shorter distances. For the lowest attachment coefficient, the maximum traveled distance under a pumping rate of 4800 m^3/d was 15–18 m from the river; thus they did reach the well after a certain time. So, a high pumping rate would enhance transport of microorganisms from the river to the well. In the case of the lower pumping rate of 1200 m^3/d, the maximum distance travelled was 6–9 m from the river, thus microorganisms did not reach the well. In the case of a pumping rate of 2400 m^3/d, *E. coli* and MS2 travelled a maximum distance of 9–12 m from the river, while *C. parvum* travelled a maximum distance of 12–15 m from the river. Therefore, maximum pumping rates of 2400 m^3/d can be safely applied for all microorganisms. Pumping rates of 4800 m^3/d or higher are not recommended, unless the well is located at a greater distance from the river.

Microorganism loads at the well are given in Fig. 4.15. The travel times for each to reach the well differed according to the pumping rate. At the maximum pumping rate of 4800 m^3/d, *E.coli* and *C. parvum* reached the well at 500 DOS, much slower than the 200 DOS it took MS2 to reach the well. Over 1000 DOS, under pumping rates of 1200 and 2400 m^3/d, microorganisms did not reach the well The travel times required to reach 3–6 m from the river were 100, 200 and 400 DOS for pumping rates of 4800, 2400 and 1200 m^3/d, respectively.

Log removal rates at 0-3 m from the river are given in Figure 4.16. Different pumping rates showed a similar trend in log removal rates, although the numerical values of log removal were different. Pumping rates are inversely related to log removal levels, i.e., log removal rates were lower at higher pumping rates. Higher pumping rates generated greater flow velocities and according to CFT, the collision efficiency decreases at higher flow velocities (McGechan and Lewis 2002). Consequently, for a pumping rate of 1200 m^3/d, the log removal rates were greater than those obtained at pumping rates of 2400 or 4800 m^3/d. At 0–3 m from the river, the requirement of 2.5 log removal for *C. parvum* and *E. coli* was only achieved for the first 100 simulation days, at the 1200 m^3/d pumping rate. For the 2400 and 4800 m^3/d pumping rates, sufficient log removal was

never achieved for all three microorganisms. Thus, the distance of 0–3 m from the river is not safe for extraction wells with pumping rates > 1200 m³/d.

The 1200 and 2400 m^3/d pumping rates did not result in the presence of *C. parvum* and *E. coli* at the well, thus they fulfilled the requirement of 2.5 log removal (Fig 4.17). MS2 met the requirements of 4 log removal for the pumping rate of 1200 m^3/d, but did not fulfill the required removal levels at pumping rates of 2400 m^3/d after 800 travel days. The pumping rate of 4800 m^3/d went beyond the acceptable limits of 2.5 log removal for *C. parvum* and *E. coli* after 500 simulation days. With a pumping rate of 4800 m^3/d, MS2 crossed the acceptable limit after 200 days, thus the log removal was not achieved for MS2 from this time onward. The results show that log removal levels were affected by the pumping rate and the pumping rate of 4800 m^3/d was not safe to RBF system at this site. Thus, depending upon the microorganism and log levels required, the results showed that the pumping rate on this site should not exceed 2400 m^3/d.

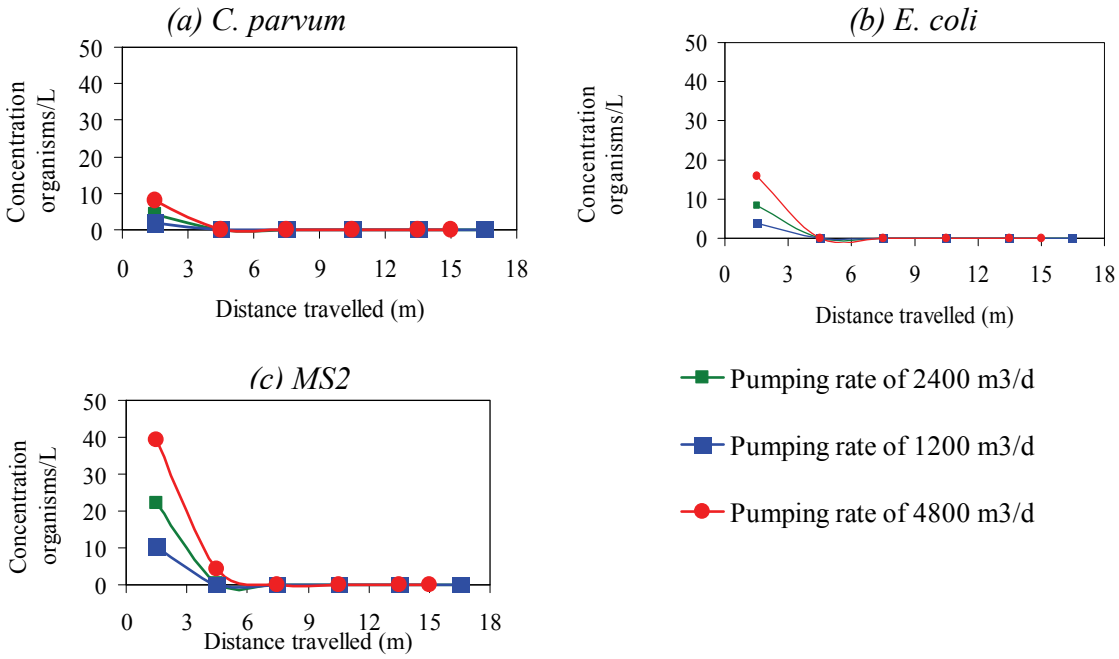


Fig 4.13: Pumping rate effect over *C. parvum, E. coli* and MS2 transport at different distances at the end of the simulation (1000 days) for the higher k_{att} value.

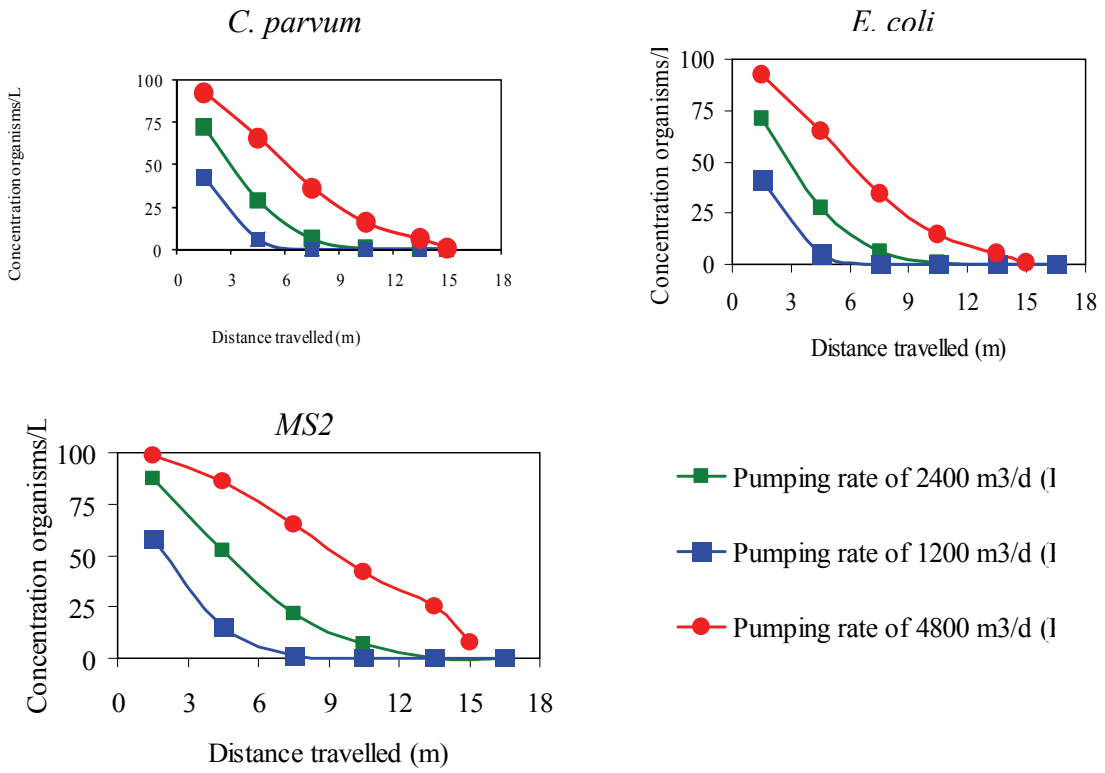


Fig 4.14: Pumping rate effect over *C. parvum, E. coli* and MS2 transport at different distances at the end of the simulation (1000 days) for the lower k_{att} value.

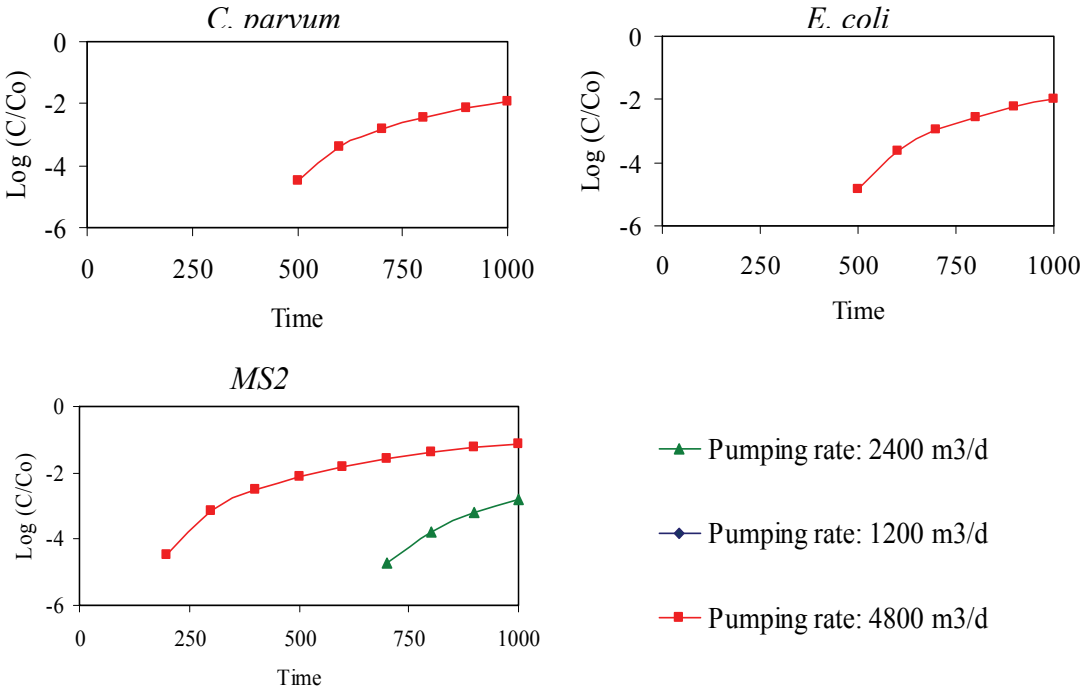


Fig. 4.15: Pumping rate effect over microorganism loads at the extraction well through simulation time (1000 days)

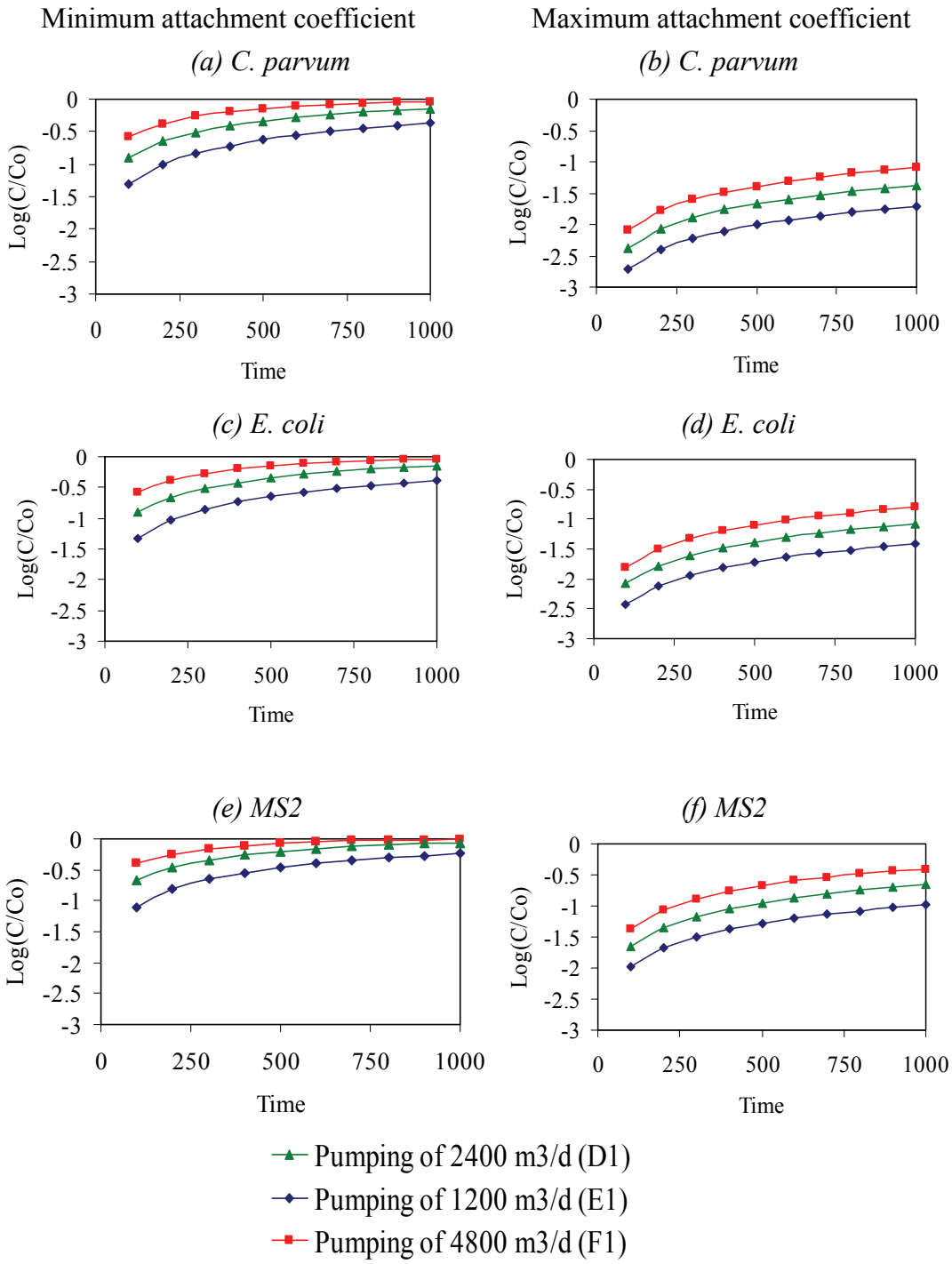


Fig 4.16: Pumping rate effect over Log removal (C/Co) of *C. parvum, E. coli* and MS2 at Cell 1 (0-3 m from the river)

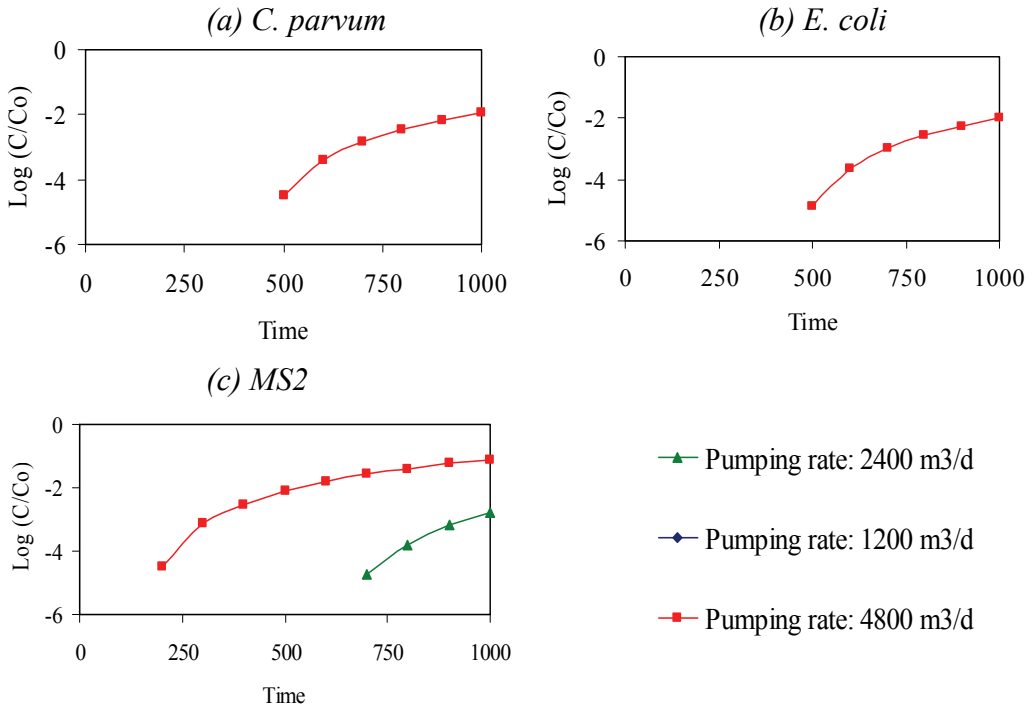


Fig 4.17: Pumping rate effect over Log removal (C/Co) of *C. parvum, E. coli* and MS2 at the extraction well (15-18 m from the river) for the lowest k_{att} value.

4.4.3 SCENARIO 3: EFFECT OF NUMBER OF WELLS

In this scenario the effect of number of wells, 4-wells *vs.* 6-wells, on microorganism transport was evaluated (Fig. 4.18). The estimated yield for the aquifer was calculated as 8800 m^3/d, thus pumping rates of 2200 and 1460 m^3/d per well were applied for 4-wells and 6-wells scenarios, respectively. For all three microorganisms, trends were similar; therefore, only results for *C. parvum* are presented. The results for *E. coli* and MS2 are given in the Appendix, Fig. 6.17 through 6.24 (CD)

The simulation results on microorganism transport through porous media are given in Figures 4.19, for the high and low k_{att} values. Results showed that load decreased as raw water travelled through the porous media, irrespective of the number of wells used. With the highest attachment coefficient the maximum travelled distance, with a 4-well scenario, was 0–3 m from the river for *C. parvum*, *E. coli* and MS2. With 6-well scenario, the maximum distance traveled varied among the wells. Microorganisms

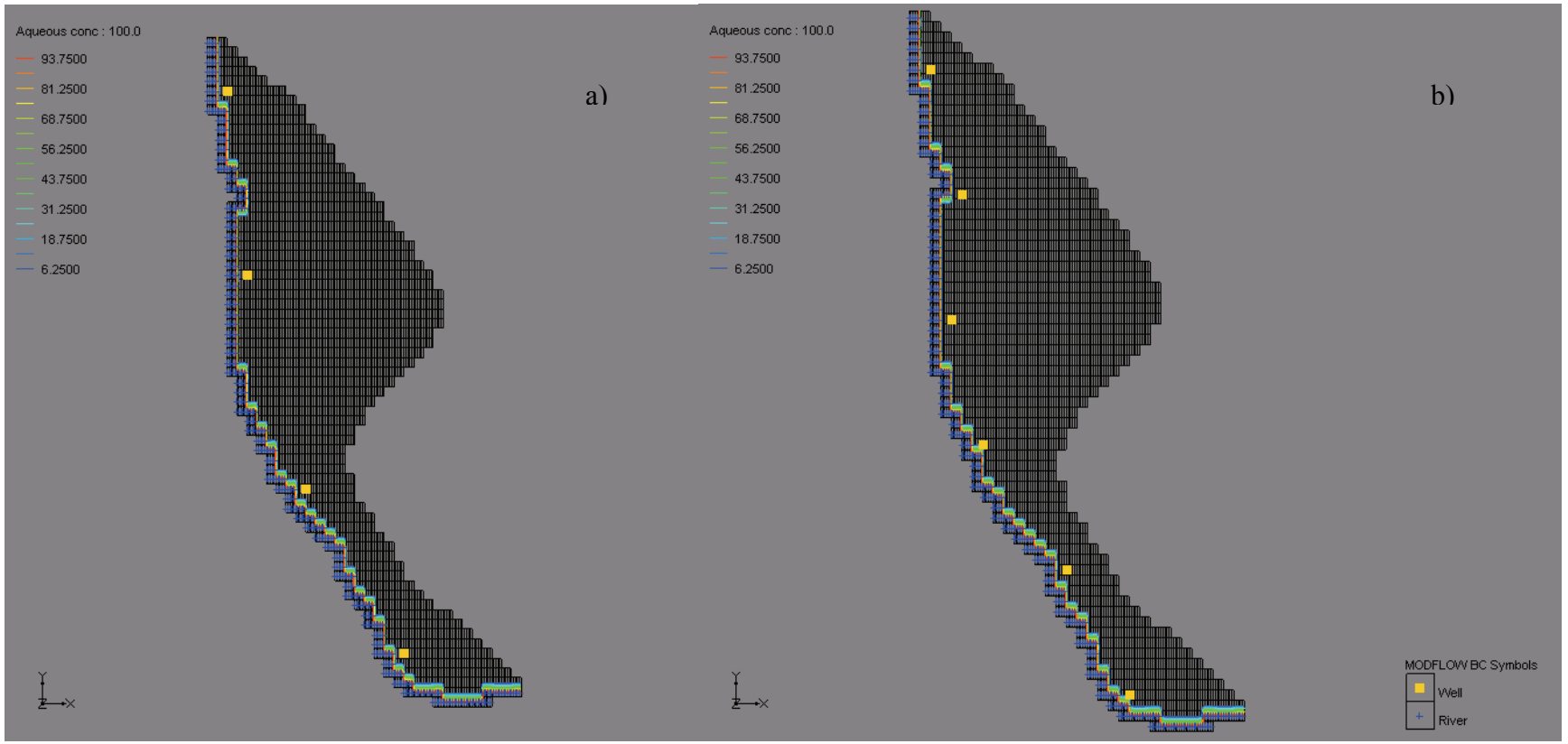


Fig. 4.18: Effect of number of wells on *C. parvum's* transport, Wells distribution, (a) Scenario 4-wells, (b) Scenario 6-wells, at 100 DOS

traveled a maximum distance of 0–3 m from the river to Wells 1, 2, 3 and 5; however, for wells 4 and 6 microorganisms travelled a maximum distance of 15–18 m from the river, reaching the well. This can be explained by the preferential location of wells 4 and 6, which were located in a river meander. Thus, in these two wells (4 and 6), water from the river was contributed to the wells from both directions (parallel: south to north; and perpendicular: west to east). The flow coming from the southerly direction was affected by contaminated river water; hence microorganism load in this area was higher. Finally, results showed that microorganisms travelled longer distances, particularly in the direction of natural groundwater flow (parallel to general direction of the river: south to north). By contrast, all the other four wells (1, 2, 3 and 5) were located parallel to the general direction of the river. The groundwater flow from this direction (parallel to the river) initially did not bear microorganisms, thus the microorganism concentration and the distance traveled in that area was lesser than that which occurred in the case of two wells (4 and 6).

For the lowest k_{att} value, microorganisms travelled a maximum distance of 9–12 m from the river under a 4-well scenario for *C. parvum* and *E. coli*, while, under the same conditions, MS2 traveled a maximum distance of 15–18 m from the river, thus reaching the well. Under the 6-well scenario, all microorganisms travelled a maximum distance of 15-18 m from the river at wells 4 and 6 (Fig. 4.20). Again, wells 4 and 6 received preferential flow from the river meander, thus they showed shorter travel times. For wells 1, 2, 3 and 5, microorganisms traveled a maximum distance of 6–9 m from the river for *C. parvum* and *E. coli;* and 12-15 m for MS2. Under the 4-well scenario, the distance traveled was 9–12 m from the river, but in the 6-well scenario, this distance was decreased to 6 – 9 m. This decrease in distance traveled resulted from the lower pumping rates applied under the 6-well scenario (1460 m^3/d), compared to the longer distance traveled under the 4-well scenario, at a higher pumping rate (2200 m^3/d).

At Cell 1 (0-3 meters from the river), log removal levels under the 4-well scenario were slightly lower, than under the 6-well scenario (Fig 4.21). This can be attributed to the greater flow caused by the greater pumping rates under the 4-well scenario (2200

m^3/d). Both scenarios (4 and 6-wells) did not meet the log removal criteria required for a RBF system for all three microorganisms. Thus, such close locations (0-3 m from the river) must not be considered for a RBF system. Although, microorganism transport was not studied for wells are located at distance of 0–3 m from the river, the mean velocity of water flow from river to well would be quite high. Thus, the movement of microorganisms would be greater than in the case of a well located at 15–18 m.

With the higher k_{att} value, the 4-well scenario did not show any microorganism presence at the well. Thus, the log removal requirement was met in this case. However, under the 6-wells scenario, microorganisms reached the well and failed removal requirement after 900 and 1000 DOS, respectively, for *C. parvum*, and *E. coli* (Fig 4.22). MS2 did not fulfill the requirement of 4 log removal at the well, exceeding the log removal limit after only 200 DOS. With the lowest attachment coefficient, *C. parvum* and *E. coli* did not reach the well, for either 4- or 6-well scenarios. Thus, again the 2.5 log removal level was fulfilled. However, MS2 did arrive to the well in both cases and the limits of 4 log removal were exceeded after 100 and 200 DOS, respectively.

In all scenarios the number of wells was not the crucial factor affecting the transport of microorganisms. The effect has more to do with the pumping rates used, which induced shorter travel times. Also, the location of the well was crucial: wells receiving preferential flow from the river, showed greater loads and shorter travel times. Thus, in these wells, the log removal was smaller. This highlights the importance of site selection for wells: wells should be located parallel to the river.

The 6-wells scenario was not appropriate for any of the microorganisms evaluated, because of the location of wells 4 and 6. The design for a RBF with 6 wells for the Manati area is not recommended, unless wells are placed farther from the river and additional treatment is applied. According to the log-removal results, the 4-well scenario did meet the removal requirements for *C. parvum* and *E. coli*, but not for MS2. It can be concluded that if the location of the wells is taken into account, the number of wells should not affect the transport behaviour of microorganisms through the porous medium.

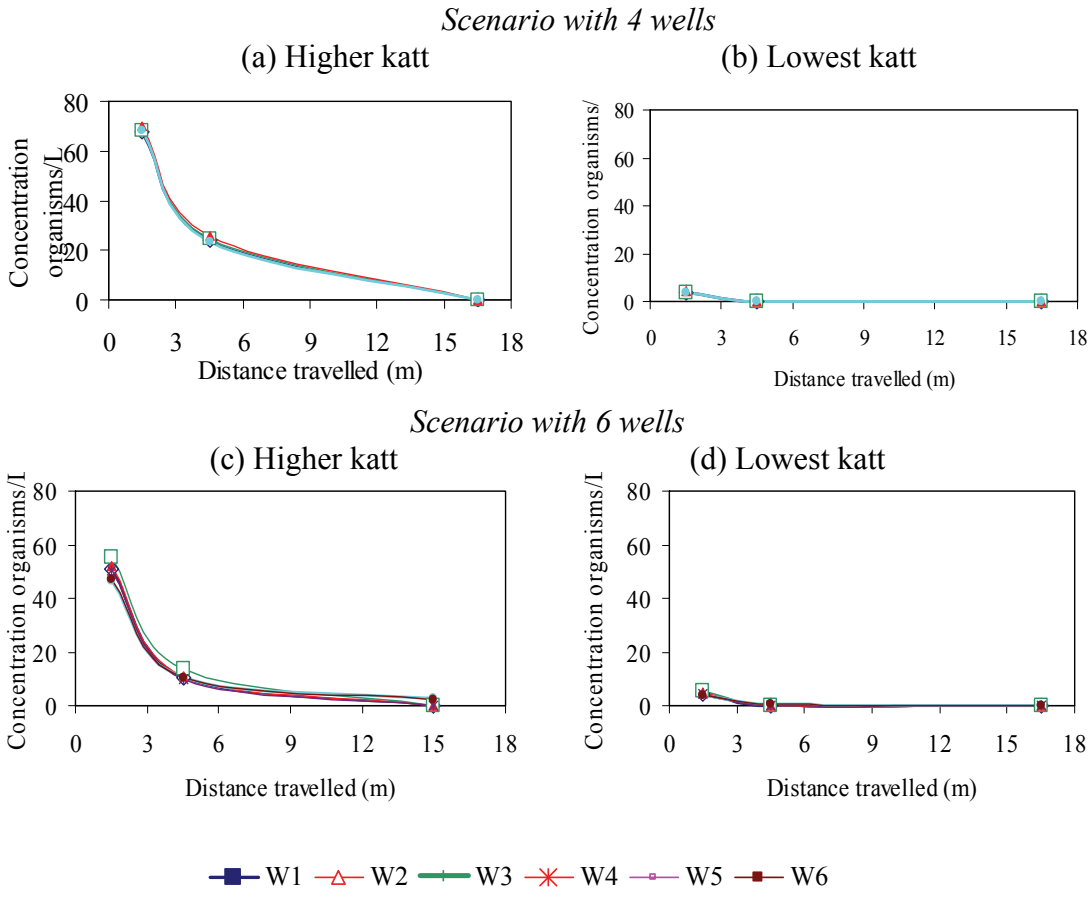


Fig 4.19: Effect of number of wells on *C. parvum* transport through porous media for the lowest and highest k_{att} values, at 1000 days

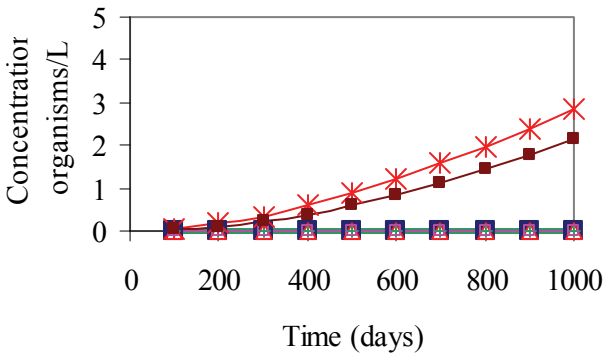


Fig. 4.20: *C. parvum* loads at the extraction well (15–18 m) through simulation time (1000 days)

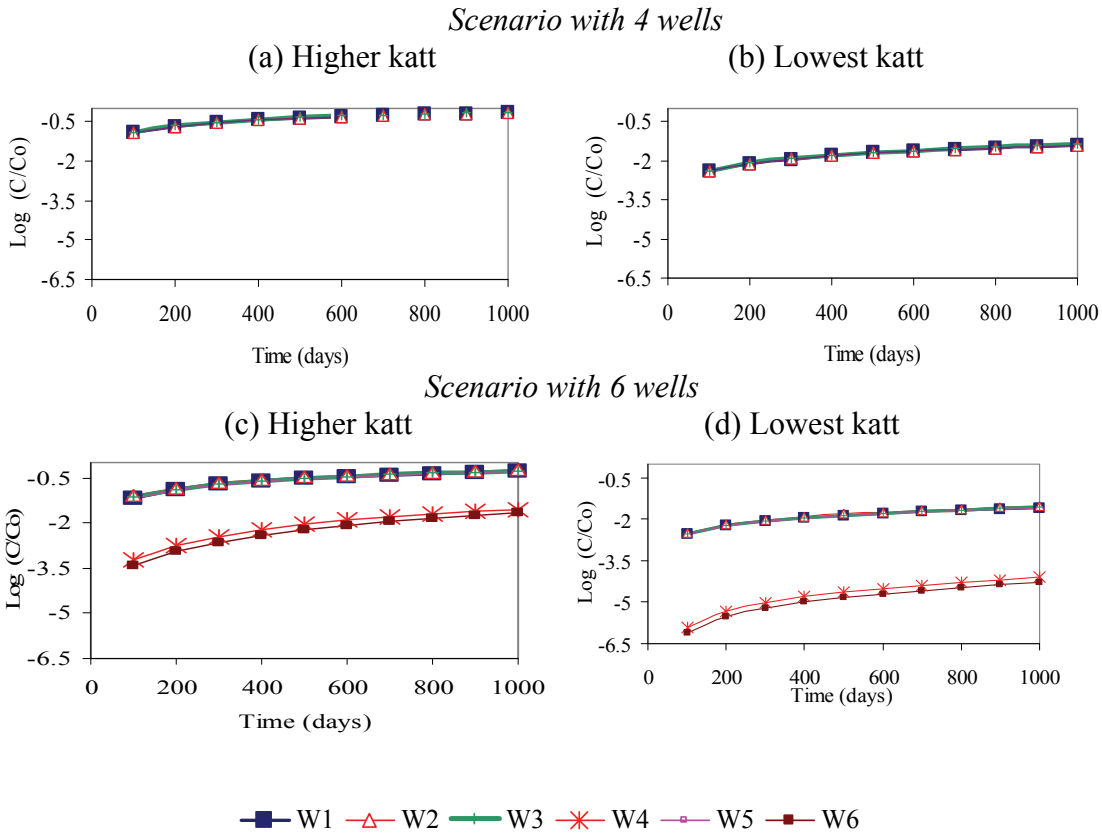


Fig 4.21: Effect of number of wells on log removal (C/Co) of *C. parvum* at Cell 1 (0-3 m from the river)

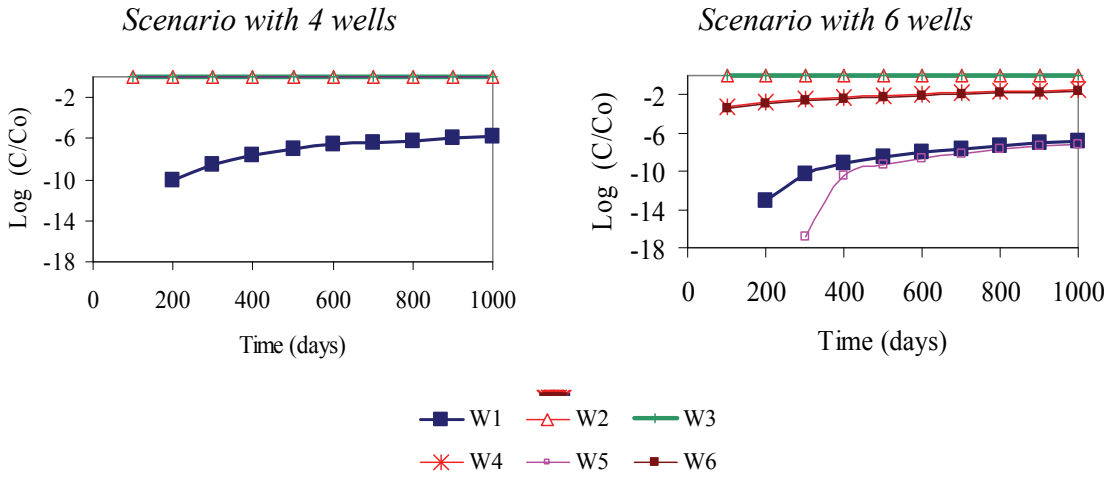


Fig 4.22: Effect of number of wells on log removal (C/Co) of *C. parvum* at theWell (15 - 18 m from the river), for the lower k_{att} value.

4.4.4 SCENARIO 4: INTERMITTENT PUMPING

In this scenario, the effect of intermittent pumping periods on microorganism transport was evaluated. A total pumping rate of 8800 m^3/d was used, distributed across 6 wells located in the study area (Fig. 4.23), yielding a pumping rate of 1460 m^3/d per well. For all three microorganisms, trends were similar; therefore, only results for *C. parvum* are presented. The results for *E. coli* and MS2 are given in the Appendix, Fig. 6.25 through 6.30 (CD).

The effect of intermittent pumping over microorganism transport through the porous media is shown in Figure 4.24. Wells 1, 3, 5 and 6 did not stop pumping, thus the microorganism load of the aqueous phase continuously increased over time, although the rate of increase was greater in the periods of greater pumping rate (2nd and 3rd period). However, in areas affected by pumping stoppages (wells 2 and 4), the concentration remained unchanged during stop intervals (2nd and 3rd) and later the concentration increased during the pumping periods (Fig 4.25).

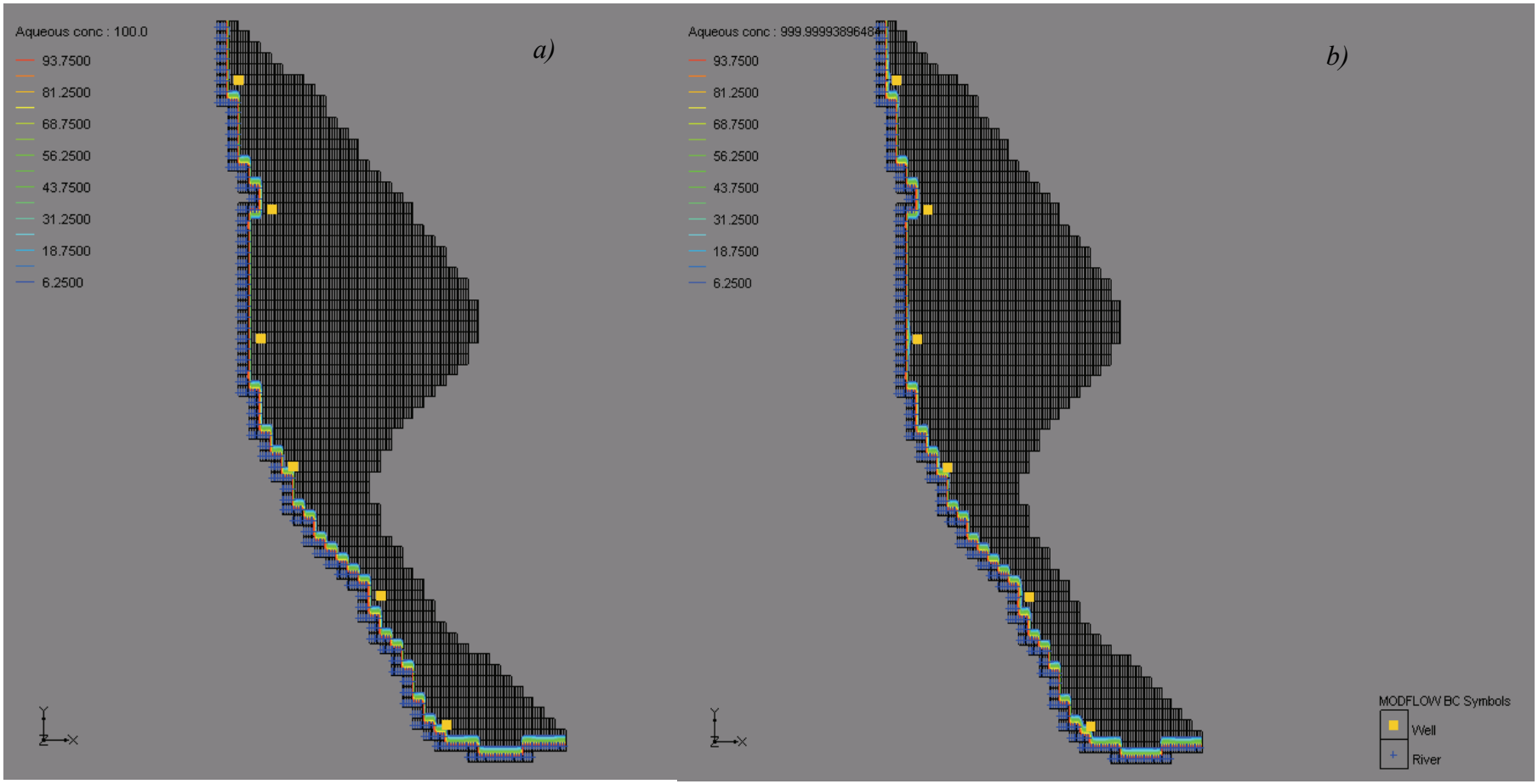


Fig. 4.23: Effect of intermittent pumping on *C. parvum's* transport, (a) 100 DOS (b) 1000 DOS, for the lowest katt

Higher flows induced by the pumping of an extraction well, enhanced microorganism transport in terms of greater loads and longer distances traveled. It should be noted that wells 4 and 6 were located in river meanders; therefore, greater microorganisms loads were found at these wells (Fig 4.25).

The results of the transport of microorganisms through porous media with the highest and lowest k_{att} values are shown in Figure 4.24. Under a high k_{att} value, microorganisms travelled a maximum distance of 0–3 m from the river at wells 1, 2, 3 and 5, whereas at wells 4 and 6, microorganisms were affected by the preferential location of the well and travelled a maximum distance of 15–18 m, and thus reached the well. Under a high k_{att} value stop periods did not affect the maximum traveled distance. Under the low k_{att} value, the microorganisms showed different travel times. For wells 1, 3 and 5, *C. parvum* and *E. coli* travelled a maximum distance of 6–9 meters. For well 2 a maximum distance of 3–6 m was traveled; while for wells 4 and 6, the travel distance was 15–18 m from the river. For *MS2*, a maximum travel distance of 6-9 m from the river was observed for wells 1, 3 and 5. For wells 2 and 3, maximum travel distance of 3-6 and 9–12 m from the river was simulated, respectively. For wells 4 and 6, microorganisms reached the well (15 – 18 m).

In general, well 2, which had stopping periods, showed less travel distance when compared to wells that were pumped continuously (1, 3 and 5). However, well 4 was not affected by this stop period due to its preferential location (river meander). Regardless of the intermittent periods applied, the location of the well was a crucial factor affecting the transport of microorganisms. Thus, areas such as those where wells 4 and 6 were located should not be used to install an extraction well unless the wells are located farther from the river.

The effect of stopping periods on log removal rates 0–3 m from the river is shown in Fig. 4.26. In the periods of continuously pumping the log removal levels decreased with time, whereas in the stopping periods, the log levels remained constant until pumping was resumed.

The simulation results at the well are given in Fig. 4.27. Under scenarios with a higher k_{att} value, microorganisms did not reach wells 1, 2, 3 and 5. Thus the log removal

level at these wells was achieved for all three microorganisms. Even though wells 4 and 6 showed the presence of microorganisms at the well, the load levels were acceptable, fulfilling the requirement for a 2.5 log removal of *C. parvum* and *E. coli*, and 4 log removal of MS2. At the lower k_{att} value, microorganisms arrived at the well at different times and concentrations. Wells 4 and 6 showed microorganisms at the well, and the log removal for *C. parvum* and *E. coli* was no longer achieved after 800 and 500 days, respectively. MS2 did not fulfill the requirement of 4 log removal in wells 4 and 6 at any time. *C. parvum*, *E. coli* and MS2 fulfilled the log removal criteria at wells 1, 2, 3 and 5. Irrespective of the intermittent periods applied, the location of wells 4 and 6 was in adequate; wells at these locations should be moved farther away from the river. The log removal trend did not change during continuous pumping, whereas it did change during stopping periods. Indeed, in stopping periods the log removal trend changed from variable to constant, as it can be seen for wells 2 and 4 (Fig. 4.26).

Shorter travel times and greater microorganism loads reaching the aquifer were seen in wells under continuous (*vs.* intermittent) pumping (wells 1, 3, 5 and 6). Again, enhancement of microorganism transport can be attributed to the higher pumping rates. We can conclude that intermittent pumping can promote microorganism transport, when the pumping rate is increased at wells working continuously. Thus, if intermittent pumping is needed, maximum pumping rate limits must be establishedin order to prevent a microorganism outbreak.

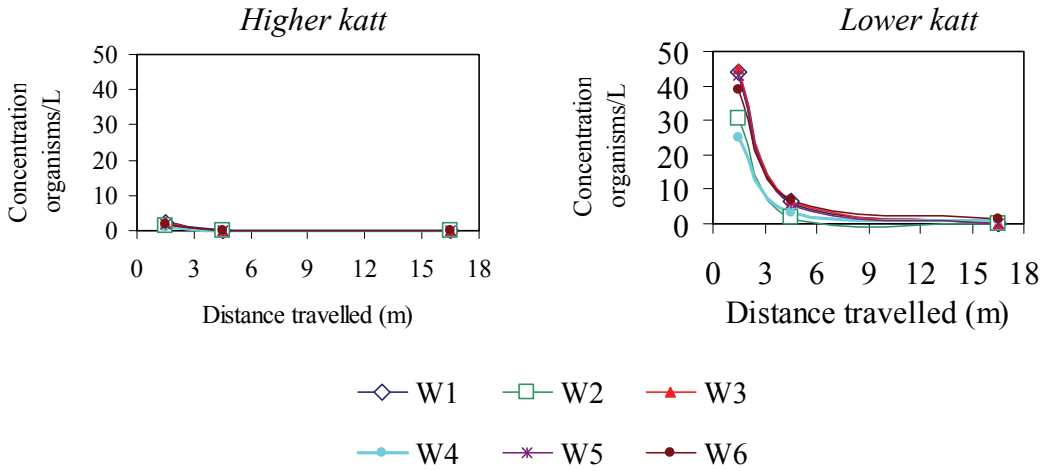


Fig 4.24: Effect of intermittent pumping on *C. parvum* transport through porous media for the highest and lowest k_{att} value, at 1000 days.

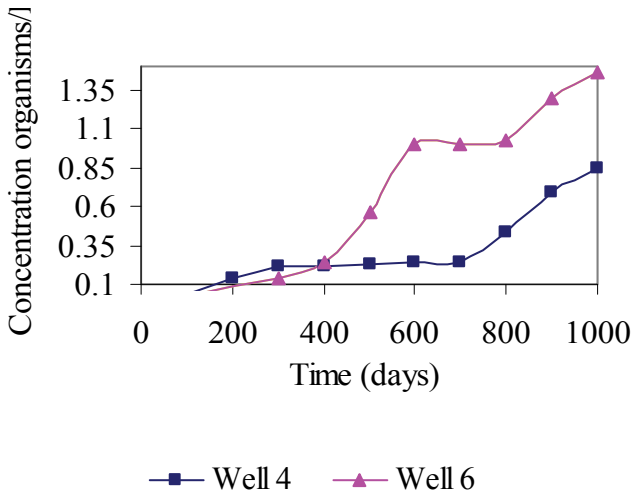


Fig. 4.25: Loads at the extraction well through simulation time (1000 days)

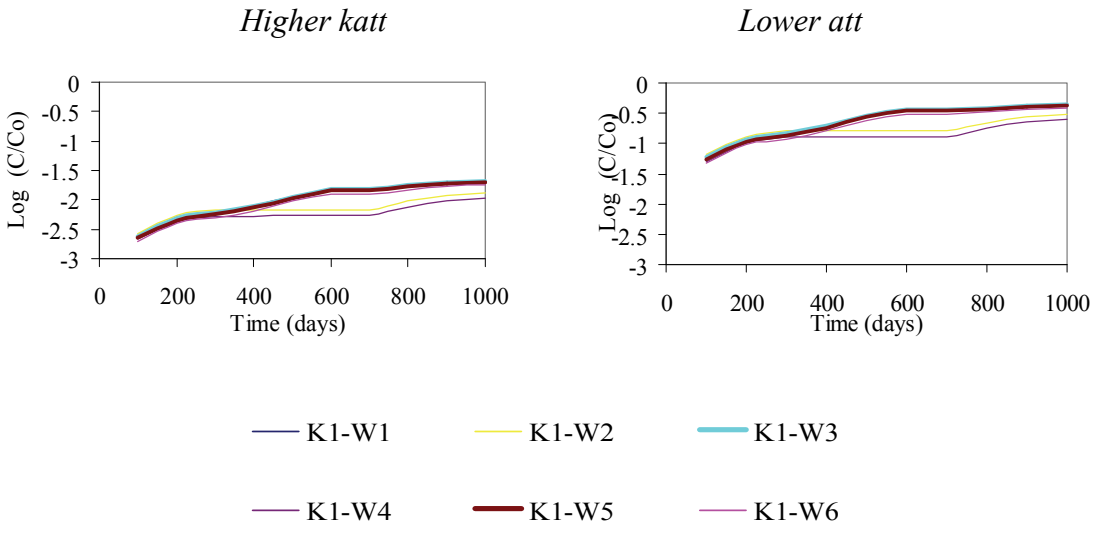


Fig 4.26: Effect of intermittent pumping on log removal (C/Co) of *C. parvum* at Cell 1 (0-3 m from the river)

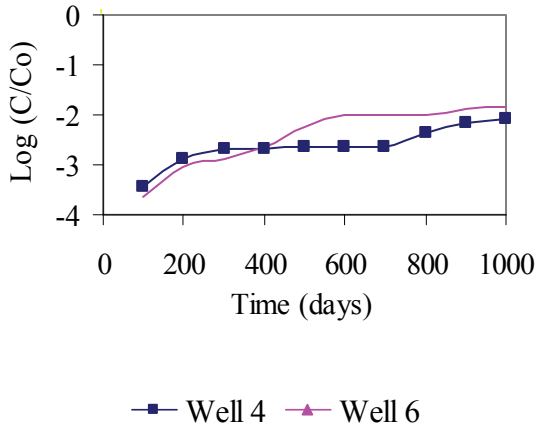


Fig 4.27: Effect of intermittent pumping on Log removal (C/Co) of *C. parvum* at the extraction well (15-18 m from the river), for the lowest k_{att} value

4.4.5 CONCLUDING REMARKS

Different scenarios for the Rio Grande de Manati Area were evaluated. Results showed that increase in porosity and pumping rates promoted microorganism transport. Porosity and pumping rates were positively correlated to microorganism travel distance and negatively related to travel times and log removal rates. In the case of a variable number of wells it was found that the number of wells was not the major factor affecting microorganism transport. Similar results were found for the intermittent pumping scenario. Finally, the results from this study showed that a River Bank Filtration System at Rio Grande de Manati should be located in areas were porosity does not exceed values of 0.275 and wells should not exceed pumping rates of 2400 m^3/d.

CHAPTER V – SUMMARY AND CONCLUSIONS

The main objective of this study was to simulate groundwater flow and microorganism transport in a RBF system. Thus, two models, i.e. MODFLOW 2000 and RT3D, were used. The simulation was run for the Rio Grande de Manati area, Puerto Rico.

This research started with the building of the conceptual model for the groundwater flow simulation. The flow results were validated with an earlier Manati study (Torres-Gonzales, Gomez-Gomez et al. 2002). Manati Assessment results and the results of the current simulation were quite similar. Flow results showed that the model's performance and the mass balance were satisfactory. The transport of *C. parvum, E. coli* and MS2 was simulated using RT3D.

For the microorganism transport simulation some parameters, such as attachment and linear partitioning coefficients, were required, and colloid filtration theory served in estimating these parameters. The transport model was also run for various scenarios involving different porosities, number of wells, pumping rates and intermittent pumping.

The following conclusions were drawn from this study:

- Simulation showed that porosity was positively correlated to microorganism travel distance; thus in scenarios with higher porosities, microorganisms travelled longer distances. The removal of microorganisms decreased with travelled distance and this decrease was more severe for higher porosities. Results also showed that the finer porous media yielded higher log removal levels.
- Higher pumping rates promoted transport in terms of microorganism load; thus higher levels of microorganisms were transported through porous media in sub-scenarios with higher pumping rates. Additionally, pumping rate was positively correlated to microorganism travel distance.

- The number of wells and the pump operation schedule, continuous or intermittent, did not have a direct effect on microorganism transport and removal. The benefit of having more wells is that the pumping rate can be decreased. As there was no marked effect of pumping schedule, intermittent pumping is preferable over continuous pumping. This is because when intermittent pumping is applied, the pause period can be used for well maintenance that is specially needed when clogging problem occurs.

The effectiveness of RBF systems depends on several factors like microorganism characteristics, soil properties (physical and chemical) and external stresses (like induced infiltration by an extraction well). RBF systems can be a useful natural filtration system to minimize microorganism contamination.

Table 6.1: Effect of porosity on *C. parvum*'s transport through porous media, low katt

			days	100	200	300	400	500	600	700	800	900	1000
Cp A1	Cell 1	0-3 m	oocysts/L	10.86	20.25	28.75	36.46	43.43	50.04	55.73	60.81	65.37	69.47
			log(C/Co)	-0.96	-0.69	-0.54	-0.44	-0.36	-0.30	-0.25	-0.22	-0.18	-0.16
	Cell 2	3-6 m	3-6 m	0.00	0.29	1.51	3.59	6.45	9.93	13.65	17.60	21.71	25.91
			log(C/Co)	*	-2.54	-1.82	-1.44	-1.19	-1.00	-0.86	-0.75	-0.66	-0.59
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.03	0.33	0.97	1.98	3.34	4.98
			log(C/Co)	*	*	*	*	-3.50	-2.48	-2.01	-1.70	-1.48	-1.30
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.30
			log(C/Co)	*	*	*	*	*	*	*	-5.02	-3.15	-2.53
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp B1	Cell 1	0-3 m	12-15 m	23.35	37.73	49.54	59.27	67.39	74.26	79.67	84.05	87.59	90.43
			log(C/Co)	-0.63	-0.42	-0.31	-0.23	-0.17	-0.13	-0.10	-0.08	-0.06	-0.04
	Cell 2	3-6 m	oocysts/L	0.78	4.82	10.76	17.64	25.09	32.86	40.33	47.43	54.07	60.17
			log(C/Co)	-2.11	-1.32	-0.97	-0.75	-0.60	-0.48	-0.39	-0.32	-0.27	-0.22
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.68	2.52	5.30	9.01	13.36	18.27	23.63	29.23
			log(C/Co)	*	-4.45	-2.17	-1.60	-1.28	-1.05	-0.87	-0.74	-0.63	-0.53
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.05	0.53	1.53	3.06	5.14	7.76	10.90
			log(C/Co)	*	*	*	-3.34	-2.28	-1.82	-1.51	-1.29	-1.11	-0.96
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.01	0.15	0.51	1.16	2.14	3.48
			log(C/Co)	*	*	*	*	-4.11	-2.84	-2.29	-1.94	-1.67	-1.46
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.26	0.50
			log(C/Co)	*	*	*	*	*	-4.40	-3.47	-2.95	-2.59	-2.31
Cp C1	Cell 1	0-3 m	12-15 m	31.53	47.76	60.47	70.35	77.98	83.94	88.36	91.67	94.14	95.97
			log(C/Co)	-0.50	-0.32	-0.22	-0.15	-0.11	-0.08	-0.05	-0.04	-0.03	-0.02
	Cell 2	3-6 m	oocysts/L	3.38	10.99	20.15	29.93	39.60	48.88	57.20	64.58	71.00	76.50
			log(C/Co)	-1.47	-0.96	-0.70	-0.52	-0.40	-0.31	-0.24	-0.19	-0.15	-0.12
	Cell 3	6-9 m	3-6 m	0.00	1.08	4.00	8.37	13.95	20.60	27.73	35.01	42.19	49.09
			log(C/Co)	*	-1.97	-1.40	-1.08	-0.86	-0.69	-0.56	-0.46	-0.37	-0.31
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.42	1.64	3.74	6.80	10.71	15.31	20.42	25.84
			log(C/Co)	*	-5.92	-2.37	-1.78	-1.43	-1.17	-0.97	-0.82	-0.69	-0.59
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.01	0.25	0.86	1.99	3.71	6.04	8.94	12.33
			log(C/Co)	*	*	-3.86	-2.61	-2.06	-1.70	-1.43	-1.22	-1.05	-0.91
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.02	0.09	0.28	0.61	1.13	1.87	2.84
			log(C/Co)	*	*	-5.92	-3.76	-3.03	-2.56	-2.22	-1.95	-1.73	-1.55

Cp: C. parvum

A1-A2: Porosity of 0.275; B1-B2: Porosity of 0.35; C1-C2: Porosity of 0.40

Table 6.2: Effect of porosity on *C. parvum*'s transport through porous media, high katt

				100	200	300	400	500	600	700	800	900	1000
Cp A2	Cell 1	0-3 m	oocysts/l	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00
			log(C/Co	-2.40	-2.10	-1.92	-1.80	-1.70	-1.62	-1.55	-1.49	-1.44	-1.40
	Cell 2	3-6 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
Cp B2	Cell 1	0-3 m	12-15 m	0.75	1.51	2.26	3.01	3.77	4.52	5.28	6.03	6.79	7.54
			log(C/Co	-2.12	-1.82	-1.65	-1.52	-1.42	-1.34	-1.28	-1.22	-1.17	-1.12
	Cell 2	3-6 m	oocysts/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
Cp C2	Cell 1	0-3 m	12-15 m	1.02	2.03	3.05	4.06	5.08	6.10	7.12	8.13	9.15	10.17
			log(C/Co	-1.99	-1.69	-1.52	-1.39	-1.29	-1.21	-1.15	-1.09	-1.04	-0.99
	Cell 2	3-6 m	oocysts/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co	*	*	*	*	*	*	*	*	*	*

Cp: C. parvum

A1-A2: Porosity of 0.275; B1-B2: Porosity of 0.35; C1-C2: Porosity of 0.40

Table 6.3: Effect of porosity on *E. coli*'s transport through porous media, low katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ec A1	Cell 1	0-3 m	oocysts/L	10.50	19.68	28.03	35.61	42.50	49.04	54.69	59.75	64.31	68.41
			log(C/Co)	-0.98	-0.71	-0.55	-0.45	-0.37	-0.31	-0.26	-0.22	-0.19	-0.16
	Cell 2	3-6 m	3-6 m	0.00	0.24	1.36	3.30	6.00	9.32	12.90	16.70	20.68	24.76
			log(C/Co)	*	-2.62	-1.87	-1.48	-1.22	-1.03	-0.89	-0.78	-0.68	-0.61
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.02	0.25	0.81	1.72	2.97	4.50
			log(C/Co)	*	*	*	*	-3.79	-2.59	-2.09	-1.76	-1.53	-1.35
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.21
			log(C/Co)	*	*	*	*	*	*	*	*	-3.38	-2.67
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec B1	Cell 1	0-3 m	12-15 m	19.58	32.78	43.91	53.33	61.41	68.46	74.20	78.97	82.96	86.28
			log(C/Co)	-0.71	-0.48	-0.36	-0.27	-0.21	-0.16	-0.13	-0.10	-0.08	-0.06
	Cell 2	3-6 m	oocysts/L	0.24	2.80	7.28	12.75	18.92	25.61	32.24	38.75	45.03	50.99
			log(C/Co)	-2.62	-1.55	-1.14	-0.89	-0.72	-0.59	-0.49	-0.41	-0.35	-0.29
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.11	0.99	2.74	5.24	8.37	12.03	16.14	20.63
			log(C/Co)	*	*	-2.96	-2.00	-1.56	-1.28	-1.08	-0.92	-0.79	-0.69
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.05	0.44	1.23	2.42	4.02	6.05
			log(C/Co)	*	*	*	*	-3.32	-2.36	-1.91	-1.62	-1.40	-1.22
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.31	0.74	1.41
			log(C/Co)	*	*	*	*	*	-5.00	-3.15	-2.51	-2.13	-1.85
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.14
			log(C/Co)	*	*	*	*	*	*	-5.06	-3.90	-3.27	-2.87
Ec C1	Cell 1	0-3 m	12-15 m	25.69	40.68	52.93	62.91	70.96	77.58	82.74	86.81	90.03	92.55
			log(C/Co)	-0.59	-0.39	-0.28	-0.20	-0.15	-0.11	-0.08	-0.06	-0.05	-0.03
	Cell 2	3-6 m	oocysts/L	1.36	6.48	13.36	21.22	29.46	37.80	45.68	53.02	59.73	65.77
			log(C/Co)	-1.87	-1.19	-0.87	-0.67	-0.53	-0.42	-0.34	-0.28	-0.22	-0.18
	Cell 3	6-9 m	3-6 m	0.00	0.10	1.41	3.95	7.54	12.10	17.32	23.10	29.19	35.35
			log(C/Co)	*	-3.00	-1.85	-1.40	-1.12	-0.92	-0.76	-0.64	-0.53	-0.45
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.30	1.19	2.70	4.86	7.67	11.08	14.98
			log(C/Co)	*	*	-5.04	-2.52	-1.93	-1.57	-1.31	-1.12	-0.96	-0.82
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.10	0.45	1.12	2.17	3.66	5.58
			log(C/Co)	*	*	*	-5.36	-2.98	-2.35	-1.95	-1.66	-1.44	-1.25
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.28	0.55	0.96
			log(C/Co)	*	*	*	*	-4.60	-3.50	-2.94	-2.56	-2.26	-2.02

Ec: E. coli

A1-A2: Porosity of 0.275; B1-B2: Porosity of 0.35; C1-C2: Porosity of 0.40

Table 6.4: Effect of porosity on *E. coli*'s transport through porous media, high katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ec A2	Cell 1	0-3 m	oocysts/L	0.78	1.55	2.33	3.11	3.88	4.66	5.44	6.22	6.99	7.77
			log(C/Co)	-2.11	-1.81	-1.63	-1.51	-1.41	-1.33	-1.26	-1.21	-1.16	-1.11
	Cell 2	3-6 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec B2	Cell 1	0-3 m	12-15 m	1.29	2.57	3.86	5.15	6.44	7.73	9.02	10.31	11.60	12.89
			log(C/Co)	-1.89	-1.59	-1.41	-1.29	-1.19	-1.11	-1.04	-0.99	-0.94	-0.89
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	-5.28
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec C2	Cell 1	0-3 m	12-15 m	1.66	3.31	4.97	6.63	8.29	9.95	11.61	13.27	14.91	16.52
			log(C/Co)	-1.78	-1.48	-1.30	-1.18	-1.08	-1.00	-0.94	-0.88	-0.83	-0.78
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08
			log(C/Co)	*	*	*	*	*	*	*	-4.59	-3.54	-3.08
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Ec: E. coli

A1-A2: Porosity of 0.275; B1-B2: Porosity of 0.35; C1-C2: Porosity of 0.40

Table 6.5: Effect of porosity on MS2's transport through porous media, low katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ms A1	Cell 1	0-3 m	oocysts/L	18.72	31.44	42.40	51.79	59.81	67.00	72.78	77.63	81.70	85.13
			log(C/Co)	-0.73	-0.50	-0.37	-0.29	-0.22	-0.17	-0.14	-0.11	-0.09	-0.07
	Cell 2	3-6 m	3-6 m	0.15	2.37	6.48	11.66	17.51	24.00	30.41	36.73	42.87	48.74
			log(C/Co)	-2.83	-1.63	-1.19	-0.93	-0.76	-0.62	-0.52	-0.43	-0.37	-0.31
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.04	0.73	2.24	4.55	7.42	10.83	14.67	18.92
			log(C/Co)	*	*	-3.40	-2.14	-1.65	-1.34	-1.13	-0.97	-0.83	-0.72
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.01	0.28	0.95	1.99	3.43	5.26
			log(C/Co)	*	*	*	*	-3.86	-2.55	-2.02	-1.70	-1.47	-1.28
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.21	0.57	1.14
			log(C/Co)	*	*	*	*	*	*	-3.47	-2.68	-2.25	-1.94
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.10
			log(C/Co)	*	*	*	*	*	*	-6.11	-4.22	-3.46	-3.00
Ms B1	Cell 1	0-3 m	12-15 m	27.60	43.05	55.37	65.22	73.16	79.64	84.59	88.44	91.43	93.74
			log(C/Co)	-0.56	-0.37	-0.26	-0.19	-0.14	-0.10	-0.07	-0.05	-0.04	-0.03
	Cell 2	3-6 m	oocysts/L	1.82	7.71	15.26	23.64	32.32	41.03	49.10	56.50	63.18	69.10
			log(C/Co)	-1.74	-1.11	-0.82	-0.63	-0.49	-0.39	-0.31	-0.25	-0.20	-0.16
	Cell 3	6-9 m	3-6 m	0.00	0.26	2.01	5.03	9.16	14.29	20.11	26.38	32.84	39.28
			log(C/Co)	*	-2.59	-1.70	-1.30	-1.04	-0.84	-0.70	-0.58	-0.48	-0.41
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.03	0.56	1.73	3.64	6.25	9.57	13.47	17.84
			log(C/Co)	*	*	-3.54	-2.25	-1.76	-1.44	-1.20	-1.02	-0.87	-0.75
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.02	0.23	0.74	1.66	3.02	4.87	7.20
			log(C/Co)	*	*	*	-3.76	-2.64	-2.13	-1.78	-1.52	-1.31	-1.14
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.01	0.07	0.20	0.44	0.82	1.36
			log(C/Co)	*	*	*	-6.07	-3.93	-3.17	-2.70	-2.36	-2.09	-1.87
Ms C1	Cell 1	0-3 m	12-15 m	35.87	52.75	65.53	75.13	82.26	87.63	91.46	94.21	96.17	97.54
			log(C/Co)	-0.45	-0.28	-0.18	-0.12	-0.08	-0.06	-0.04	-0.03	-0.02	-0.01
	Cell 2	3-6 m	oocysts/L	5.63	15.02	25.79	36.75	47.14	56.68	64.94	71.99	77.89	82.76
			log(C/Co)	-1.25	-0.82	-0.59	-0.43	-0.33	-0.25	-0.19	-0.14	-0.11	-0.08
	Cell 3	6-9 m	3-6 m	0.15	2.52	6.83	12.76	20.00	28.04	36.19	44.16	51.71	58.68
			log(C/Co)	-2.82	-1.60	-1.17	-0.89	-0.70	-0.55	-0.44	-0.36	-0.29	-0.23
	Cell 4	9-12 m	12-15 m	0.00	0.19	1.31	3.50	6.84	11.31	16.58	22.42	28.55	34.84
			log(C/Co)	*	-2.72	-1.88	-1.46	-1.16	-0.95	-0.78	-0.65	-0.54	-0.46
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.21	0.86	2.15	4.19	6.98	10.45	14.48	18.93
			log(C/Co)	*	-4.50	-2.69	-2.06	-1.67	-1.38	-1.16	-0.98	-0.84	-0.72
	Well	15 - 18 m	12-15 m	0.00	0.00	0.02	0.11	0.33	0.76	1.43	2.38	3.61	5.11
			log(C/Co)	*	*	-3.78	-2.97	-2.48	-2.12	-1.84	-1.62	-1.44	-1.29

Ms: MS2

A1-A2: Porosity of 0.275; B1-B2: Porosity of 0.35; C1-C2: Porosity of 0.40

Table 6.6: Effect of porosity on MS2's transport through porous media, high katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ms A2	Cell 1	0-3 m	oocysts/L	2.11	4.22	6.33	8.45	10.57	12.69	14.79	16.85	18.87	20.85
			log(C/Co)	-1.68	-1.37	-1.20	-1.07	-0.98	-0.90	-0.83	-0.77	-0.72	-0.68
	Cell 2	3-6 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.08	0.19	0.35
			log(C/Co)	*	*	*	*	*	*	-3.73	-3.08	-2.71	-2.46
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms B2	Cell 1	0-3 m	12-15 m	3.02	6.05	9.08	12.11	15.11	18.03	20.86	23.60	26.26	28.84
			log(C/Co)	-1.52	-1.22	-1.04	-0.92	-0.82	-0.74	-0.68	-0.63	-0.58	-0.54
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.03	0.16	0.38	0.69	1.08	1.56
			log(C/Co)	*	*	*	*	-3.47	-2.79	-2.42	-2.16	-1.97	-1.81
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms C2	Cell 1	0-3 m	12-15 m	4.02	8.04	12.07	16.04	19.85	23.52	27.04	30.41	33.65	36.76
			log(C/Co)	-1.40	-1.09	-0.92	-0.79	-0.70	-0.63	-0.57	-0.52	-0.47	-0.43
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.06	0.29	0.68	1.22	1.90	2.74	3.71
			log(C/Co)	*	*	*	-3.19	-2.54	-2.17	-1.91	-1.72	-1.56	-1.43
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Ms: MS2

A1-A2: Porosity of 0.275; B1-B2: Porosity of 0.35; C1-C2: Porosity of 0.40

Table 6.7: Effect of pumping rates on *C. parvum* 's transport through porous media, low katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Cp D1	Cell 1	0-3 m	oocysts/L	12.71	22.64	31.29	39.05	46.18	53.00	58.73	63.78	68.28	72.29
			log(C/Co)	-0.90	-0.65	-0.50	-0.41	-0.34	-0.28	-0.23	-0.20	-0.17	-0.14
	Cell 2	3-6 m	3-6 m	0.00	0.47	2.05	4.55	7.83	11.74	15.85	20.14	24.57	29.04
			log(C/Co)	*	-2.33	-1.69	-1.34	-1.11	-0.93	-0.80	-0.70	-0.61	-0.54
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.11	0.60	1.49	2.78	4.42	6.35
			log(C/Co)	*	*	*	*	-2.96	-2.22	-1.83	-1.56	-1.35	-1.20
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.56
			log(C/Co)	*	*	*	*	*	*	*	-3.52	-2.71	-2.25
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	-4.85
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp E1	Cell 1	0-3 m	12-15 m	4.85	9.61	14.38	18.97	23.34	27.51	31.48	35.27	38.87	42.29
			log(C/Co)	-1.31	-1.02	-0.84	-0.72	-0.63	-0.56	-0.50	-0.45	-0.41	-0.37
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.01	0.21	0.64	1.29	2.14	3.20	4.47	5.90
			log(C/Co)	*	*	-3.87	-2.67	-2.19	-1.89	-1.67	-1.49	-1.35	-1.23
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
			log(C/Co)	*	*	*	*	*	*	*	*	*	-3.66
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp F1	Cell 1	0-3 m	12-15 m	26.80	42.01	54.16	63.89	71.77	78.10	83.16	87.18	90.35	92.83
			log(C/Co)	-0.57	-0.38	-0.27	-0.19	-0.14	-0.11	-0.08	-0.06	-0.04	-0.03
	Cell 2	3-6 m	oocysts/L	1.41	6.82	13.96	21.92	30.21	38.41	46.26	53.57	60.25	66.25
			log(C/Co)	-1.85	-1.17	-0.86	-0.66	-0.52	-0.42	-0.33	-0.27	-0.22	-0.18
	Cell 3	6-9 m	3-6 m	0.00	0.08	1.45	4.19	7.95	12.58	17.96	23.86	30.02	36.23
			log(C/Co)	*	-3.10	-1.84	-1.38	-1.10	-0.90	-0.75	-0.62	-0.52	-0.44
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.29	1.29	2.93	5.24	8.23	11.82	15.88
			log(C/Co)	*	*	*	-2.54	-1.89	-1.53	-1.28	-1.08	-0.93	-0.80
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.11	0.52	1.29	2.48	4.14	6.25
			log(C/Co)	*	*	*	*	-2.97	-2.28	-1.89	-1.61	-1.38	-1.20
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.04	0.14	0.35	0.68	1.17
			log(C/Co)	*	*	*	*	-4.47	-3.42	-2.84	-2.46	-2.16	-1.93

Cp: C. parvum

D: Pumping rate of 2400 m3/d; E: Pumping rate of 1200 m3/d; F: Pumping rate of 4800 m3/d

Table 6.8: Effect of pumping rates on *C. parvum* 's transport through porous media, high katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Cp D2	Cell 1	0-3 m	oocysts/L	0.43	0.86	1.29	1.72	2.14	2.57	3.00	3.43	3.86	4.29
			log(C/Co)	-2.37	-2.07	-1.89	-1.77	-1.67	-1.59	-1.52	-1.46	-1.41	-1.37
	Cell 2	3-6 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp E2	Cell 1	0-3 m	12-15 m	0.20	0.40	0.59	0.79	0.99	1.19	1.39	1.58	1.78	1.98
			log(C/Co)	-2.70	-2.40	-2.23	-2.10	-2.00	-1.93	-1.86	-1.80	-1.75	-1.70
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp F2	Cell 1	0-3 m	12-15 m	0.82	1.63	2.45	3.27	4.08	4.90	5.72	6.54	7.36	8.18
			log(C/Co)	-2.09	-1.79	-1.61	-1.49	-1.39	-1.31	-1.24	-1.18	-1.13	-1.09
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Cp: C. parvum

D: Pumping rate of 2400 m3/d; E: Pumping rate of 1200 m3/d; F: Pumping rate of 4800 m3/d

Table 6.9: Effect of pumping rates on *E. coli*'s transport through porous media, low katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ec D1	Cell 1	0-3 m	oocysts/L	12.29	22.02	30.51	38.16	45.20	51.97	57.67	62.71	67.22	71.25
			log(C/Co)	-0.91	-0.66	-0.52	-0.42	-0.34	-0.28	-0.24	-0.20	-0.17	-0.15
	Cell 2	3-6 m	3-6 m	0.00	0.40	1.87	4.20	7.32	11.07	15.02	19.16	23.45	27.81
			log(C/Co)	*	-2.40	-1.73	-1.38	-1.14	-0.96	-0.82	-0.72	-0.63	-0.56
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.08	0.48	1.27	2.46	3.98	5.78
			log(C/Co)	*	*	*	*	-3.12	-2.32	-1.90	-1.61	-1.40	-1.24
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.44
			log(C/Co)	*	*	*	*	*	*	*	-3.85	-2.87	-2.36
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec E1	Cell 1	0-3 m	12-15 m	4.71	9.35	14.00	18.49	22.77	26.86	30.77	34.49	38.03	41.41
			log(C/Co)	-1.33	-1.03	-0.85	-0.73	-0.64	-0.57	-0.51	-0.46	-0.42	-0.38
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.01	0.18	0.57	1.17	1.97	2.96	4.15	5.51
			log(C/Co)	*	*	-4.10	-2.74	-2.24	-1.93	-1.71	-1.53	-1.38	-1.26
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
			log(C/Co)	*	*	*	*	*	*	*	*	*	-3.97
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec F1	Cell 1	0-3 m	12-15 m	26.07	41.12	53.19	62.91	70.82	77.21	82.35	86.46	89.72	92.30
			log(C/Co)	-0.58	-0.39	-0.27	-0.20	-0.15	-0.11	-0.08	-0.06	-0.05	-0.03
	Cell 2	3-6 m	oocysts/L	1.22	6.29	13.17	20.88	28.96	37.02	44.77	52.04	58.72	64.75
			log(C/Co)	-1.91	-1.20	-0.88	-0.68	-0.54	-0.43	-0.35	-0.28	-0.23	-0.19
	Cell 3	6-9 m	3-6 m	0.00	0.00	1.19	3.73	7.25	11.64	16.76	22.43	28.43	34.51
			log(C/Co)	*	*	-1.92	-1.43	-1.14	-0.93	-0.78	-0.65	-0.55	-0.46
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.19	1.05	2.53	4.65	7.42	10.79	14.64
			log(C/Co)	*	*	*	-2.73	-1.98	-1.60	-1.33	-1.13	-0.97	-0.83
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.07	0.40	1.06	2.11	3.61	5.54
			log(C/Co)	*	*	*	*	-3.17	-2.40	-1.98	-1.67	-1.44	-1.26
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.28	0.57	0.99
			log(C/Co)	*	*	*	*	-4.86	-3.63	-2.97	-2.56	-2.25	-2.00

Ec: E. coli

D: Pumping rate of 2400 m3/d; E: Pumping rate of 1200 m3/d; F: Pumping rate of 4800 m3/d

Table 6.10: Effect of pumping rates on *E. coli*'s transport through porous media, high katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ec D2	Cell 1	0-3 m	oocysts/L	0.83	1.66	2.50	3.33	4.16	4.99	5.83	6.66	7.50	8.33
			log(C/Co)	-2.08	-1.78	-1.60	-1.48	-1.38	-1.30	-1.23	-1.18	-1.13	-1.08
	Cell 2	3-6 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec E2	Cell 1	0-3 m	12-15 m	0.38	0.77	1.15	1.54	1.92	2.31	2.69	3.08	3.46	3.85
			log(C/Co)	-2.42	-2.11	-1.94	-1.81	-1.72	-1.64	-1.57	-1.51	-1.46	-1.42
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec F2	Cell 1	0-3 m	12-15 m	1.58	3.17	4.75	6.34	7.93	9.52	11.11	12.71	14.30	15.87
			log(C/Co)	-1.80	-1.50	-1.32	-1.20	-1.10	-1.02	-0.95	-0.90	-0.84	-0.80
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
			log(C/Co)	*	*	*	*	*	*	*	*	-4.51	-3.53
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Ec: E. coli

D: Pumping rate of 2400 m3/d; E: Pumping rate of 1200 m3/d; F: Pumping rate of 4800 m3/d

Table 6.11: Effect of pumping rates on MS2's transport through porous media, low kat

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ms D1	Cell 1	0-3 m	oocysts/L	21.42	34.56	45.54	54.83	62.82	69.90	75.52	80.16	84.03	87.22
			log(C/Co)	-0.67	-0.46	-0.34	-0.26	-0.20	-0.16	-0.12	-0.10	-0.08	-0.06
	Cell 2	3-6 m	3-6 m	0.26	3.14	7.96	13.67	20.04	26.98	33.75	40.35	46.68	52.65
			log(C/Co)	-2.59	-1.50	-1.10	-0.86	-0.70	-0.57	-0.47	-0.39	-0.33	-0.28
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.13	1.16	3.09	5.81	9.14	13.00	17.30	21.98
			log(C/Co)	*	*	-2.87	-1.94	-1.51	-1.24	-1.04	-0.89	-0.76	-0.66
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.07	0.53	1.43	2.75	4.51	6.69
			log(C/Co)	*	*	*	*	-3.13	-2.27	-1.84	-1.56	-1.35	-1.17
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.16
			log(C/Co)	*	*	*	*	*	*	-4.73	-3.79	-3.19	-2.79
Ms E1	Cell 1	0-3 m	12-15 m	7.99	15.29	22.19	28.59	34.52	40.03	45.13	49.84	54.20	58.22
			log(C/Co)	-1.10	-0.82	-0.65	-0.54	-0.46	-0.40	-0.35	-0.30	-0.27	-0.23
	Cell 2	3-6 m	oocysts/L	0.00	0.02	0.48	1.48	2.96	4.92	7.24	9.80	12.57	15.50
			log(C/Co)	*	-3.68	-2.31	-1.83	-1.53	-1.31	-1.14	-1.01	-0.90	-0.81
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.33	0.77	1.42
			log(C/Co)	*	*	*	*	*	-5.39	-3.09	-2.48	-2.11	-1.85
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms F1	Cell 1	0-3 m	12-15 m	39.54	56.70	69.22	78.35	84.99	89.77	93.17	95.56	97.20	98.32
			log(C/Co)	-0.40	-0.25	-0.16	-0.11	-0.07	-0.05	-0.03	-0.02	-0.01	-0.01
	Cell 2	3-6 m	oocysts/L	7.66	18.50	30.30	41.82	52.41	61.74	69.71	76.35	81.78	86.15
			log(C/Co)	-1.12	-0.73	-0.52	-0.38	-0.28	-0.21	-0.16	-0.12	-0.09	-0.06
	Cell 3	6-9 m	3-6 m	0.00	0.00	9.56	16.83	25.16	33.86	42.47	50.64	58.16	64.90
			log(C/Co)	*	*	-1.02	-0.77	-0.60	-0.47	-0.37	-0.30	-0.24	-0.19
	Cell 4	9-12 m	12-15 m	0.00	0.00	2.43	5.62	10.14	15.66	21.88	28.45	35.29	42.19
			log(C/Co)	*	*	-1.61	-1.25	-0.99	-0.81	-0.66	-0.55	-0.45	-0.37
	Cell 5	12-15 m	3-6 m	0.00	0.06	0.58	1.80	3.89	6.87	10.64	15.04	19.92	25.13
			log(C/Co)	*	-3.20	-2.24	-1.75	-1.41	-1.16	-0.97	-0.82	-0.70	-0.60
	Well	15 - 18 m	12-15 m	0.00	0.00	0.07	0.30	0.76	1.53	2.63	4.05	5.77	7.75
			log(C/Co)	*	-4.48	-3.14	-2.53	-2.12	-1.82	-1.58	-1.39	-1.24	-1.11

Ms: MS2

D: Pumping rate of 2400 m3/d; E: Pumping rate of 1200 m3/d; F: Pumping rate of 4800 m3/c

Table 6.12: Effect of pumping rates on MS2's transport through porous media, high katt

	Time (d)			100	200	300	400	500	600	700	800	900	1000
Ms D2	Cell 1	0-3 m	oocysts/L	2.26	4.52	6.79	9.05	11.32	13.59	15.81	17.98	20.10	22.18
			log(C/Co)	-1.65	-1.34	-1.17	-1.04	-0.95	-0.87	-0.80	-0.75	-0.70	-0.65
	Cell 2	3-6 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.16	0.31	0.52
			log(C/Co)	*	*	*	*	*	-4.27	-3.25	-2.80	-2.51	-2.29
	Cell 3	6-9 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms E2	Cell 1	0-3 m	12-15 m	1.04	2.09	3.13	4.18	5.22	6.27	7.32	8.37	9.41	10.46
			log(C/Co)	-1.98	-1.68	-1.50	-1.38	-1.28	-1.20	-1.14	-1.08	-1.03	-0.98
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	0 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms F2	Cell 1	0-3 m	12-15 m	4.36	8.74	13.11	17.37	21.45	25.36	29.10	32.68	36.11	39.38
			log(C/Co)	-1.36	-1.06	-0.88	-0.76	-0.67	-0.60	-0.54	-0.49	-0.44	-0.40
	Cell 2	3-6 m	oocysts/L	0.00	0.00	0.00	0.07	0.34	0.80	1.44	2.25	3.23	4.37
			log(C/Co)	*	*	*	-3.13	-2.46	-2.10	-1.84	-1.65	-1.49	-1.36
	Cell 3	6-9 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	3-6 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15 - 18 m	12-15 m	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Ms: MS2

D: Pumping rate of 2400 m3/d; E: Pumping rate of 1200 m3/d; F: Pumping rate of 4800 m3/d

Table 6.13: Effect of number of wells on *C. parvum* 's transport through porous media, low katt Scenario with 4 wells (G1)

				100	200	300	400	500	600	700	800	900	1000
Cp G1 w1	Cell 1	0-3 m	microorg/L	11.68	20.75	28.74	35.93	42.61	49.06	54.56	59.47	63.91	67.92
			log(C/Co)	-0.93	-0.68	-0.54	-0.44	-0.37	-0.31	-0.26	-0.23	-0.19	-0.17
	Cell 2	3-6 m	microorg/L	0.00	0.21	1.38	3.29	5.91	9.18	12.63	16.29	20.11	24.03
			log(C/Co)	*	-2.69	-1.86	-1.48	-1.23	-1.04	-0.90	-0.79	-0.70	-0.62
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.01	0.19	0.71	1.56	2.74	4.20
			log(C/Co)	*	*	*	*	-4.04	-2.71	-2.15	-1.81	-1.56	-1.38
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.15
			log(C/Co)	*	*	*	*	*	*	*	*	-3.61	-2.81
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	-10.05	-8.48	-7.65	-7.07	-6.60	-6.39	-6.19	-5.99	-5.79
Cp G1 w2	Cell 1	0-3 m	microorg/L	11.79	20.94	28.99	36.25	42.99	49.50	55.04	60.00	64.48	68.51
			log(C/Co)	-0.93	-0.68	-0.54	-0.44	-0.37	-0.31	-0.26	-0.22	-0.19	-0.16
	Cell 2	3-6 m	microorg/L	0.00	0.22	1.42	3.37	6.06	9.39	12.91	16.65	20.55	24.56
			log(C/Co)	*	-2.65	-1.85	-1.47	-1.22	-1.03	-0.89	-0.78	-0.69	-0.61
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.01	0.21	0.75	1.62	2.82	4.31
			log(C/Co)	*	*	*	*	-3.91	-2.68	-2.13	-1.79	-1.55	-1.37
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.16
			log(C/Co)	*	*	*	*	*	*	*	*	-3.59	-2.81
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp G1 w3	Cell 1	0-3 m	microorg/L	12.42	21.92	30.23	37.68	44.55	51.16	56.75	61.72	66.18	70.18
			log(C/Co)	-0.91	-0.66	-0.52	-0.42	-0.35	-0.29	-0.25	-0.21	-0.18	-0.15
	Cell 2	3-6 m	microorg/L	0.00	0.31	1.67	3.80	6.67	10.16	13.83	17.71	21.74	25.86
			log(C/Co)	*	-2.50	-1.78	-1.42	-1.18	-0.99	-0.86	-0.75	-0.66	-0.59
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.03	0.28	0.89	1.85	3.15	4.74
			log(C/Co)	*	*	*	*	-3.56	-2.55	-2.05	-1.73	-1.50	-1.32
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.19
			log(C/Co)	*	*	*	*	*	*	*	*	-3.42	-2.72
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp G1 w4	Cell 1	0-3 m	microorg/L	11.78	20.91	28.95	36.20	42.92	49.41	54.94	59.89	64.36	68.39
			log(C/Co)	-0.93	-0.68	-0.54	-0.44	-0.37	-0.31	-0.26	-0.22	-0.19	-0.17
	Cell 2	3-6 m	microorg/L	0.00	0.20	1.33	3.20	5.76	8.98	12.39	16.02	19.82	23.72
			log(C/Co)	*	-2.71	-1.87	-1.50	-1.24	-1.05	-0.91	-0.80	-0.70	-0.62
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.13	0.57	1.32	2.40	3.78
			log(C/Co)	*	*	*	*	-4.95	-2.87	-2.25	-1.88	-1.62	-1.42
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
			log(C/Co)	*	*	*	*	*	*	*	*	-4.81	-3.17
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Cp: C. parvum, w: well number

Table 6.14: Effect of number of wells on *C. parvum*'s transport through porous media, high katt Scenario with 4 wells (G2)

				100	200	300	400	500	600	700	800	900	1000
Cp G2 w1	Cell 1	0-3 m	microorg/L	0.38	0.77	1.15	1.53	1.91	2.30	2.68	3.06	3.44	3.83
			log(C/Co)	-2.42	-2.12	-1.94	-1.82	-1.72	-1.64	-1.57	-1.51	-1.46	-1.42
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp G2 w2	Cell 1	0-3 m	microorg/L	0.39	0.77	1.16	1.54	1.93	2.32	2.70	3.09	3.47	3.86
			log(C/Co)	-2.41	-2.11	-1.94	-1.81	-1.71	-1.64	-1.57	-1.51	-1.46	-1.41
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp G2 w3	Cell 1	0-3 m	microorg/L	0.41	0.81	1.22	1.63	2.04	2.44	2.85	3.26	3.67	4.07
			log(C/Co)	-2.39	-2.09	-1.91	-1.79	-1.69	-1.61	-1.54	-1.49	-1.44	-1.39
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp G2 w4	Cell 1	0-3 m	microorg/L	0.14	0.27	0.41	0.55	0.69	0.82	0.96	1.10	1.23	1.37
			log(C/Co)	-2.86	-2.56	-2.39	-2.26	-2.16	-2.08	-2.02	-1.96	-1.91	-1.86
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Cp: C. parvum, w: well number

Table 6.15: Effect of number of wells on *C. parvum*'s transport through porous media, low katt Scenario with 6 wells (H1)

				100	200	300	400	500	600	700	800	900	1000
Cp H1 w1	Cell 1	0-3 m	microorg/L	6.80	12.75	18.60	24.19	29.44	34.36	38.98	43.30	47.35	51.14
			log(C/Co)	-1.17	-0.89	-0.73	-0.62	-0.53	-0.46	-0.41	-0.36	-0.32	-0.29
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.18	0.74	1.66	2.92	4.50	6.35	8.39	10.58
			log(C/Co)	*	*	-2.75	-2.13	-1.78	-1.53	-1.35	-1.20	-1.08	-0.98
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.18	0.44
			log(C/Co)	*	*	*	*	*	*	*	-3.40	-2.74	-2.35
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	-13.02	-10.28	-9.24	-8.57	-8.08	-7.68	-7.35	-7.07	-6.83
Cp H1 w2	Cell 1	0-3 m	microorg/L	7.73	14.46	20.90	26.99	32.67	37.94	42.85	47.41	51.63	55.55
			log(C/Co)	-1.11	-0.84	-0.68	-0.57	-0.49	-0.42	-0.37	-0.32	-0.29	-0.26
	Cell 2	3-6 m	microorg/L	0.00	0.03	0.44	1.32	2.63	4.34	6.38	8.65	11.10	13.71
			log(C/Co)	*	-3.54	-2.36	-1.88	-1.58	-1.36	-1.20	-1.06	-0.95	-0.86
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.26	0.60	1.10
			log(C/Co)	*	*	*	*	*	-5.10	-3.17	-2.59	-2.23	-1.96
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp H1 w3	Cell 1	0-3 m	microorg/L	6.95	13.04	19.01	24.70	30.04	35.04	39.73	44.12	48.23	52.07
			log(C/Co)	-1.16	-0.88	-0.72	-0.61	-0.52	-0.46	-0.40	-0.36	-0.32	-0.28
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.21	0.83	1.82	3.16	4.84	6.77	8.90	11.19
			log(C/Co)	*	-5.75	-2.67	-2.08	-1.74	-1.50	-1.32	-1.17	-1.05	-0.95
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.24	0.54
			log(C/Co)	*	*	*	*	*	*	-4.89	-3.18	-2.62	-2.26
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp H1 w4	Cell 1	0-3 m	microorg/L	5.91	11.06	16.23	21.29	26.07	30.60	34.89	38.95	42.79	46.42
			log(C/Co)	-1.23	-0.96	-0.79	-0.67	-0.58	-0.51	-0.46	-0.41	-0.37	-0.33
	Cell 2	3-6 m	microorg/L	0.52	0.97	1.44	2.10	2.99	4.07	5.36	6.84	8.50	10.34
			log(C/Co)	-2.28	-2.01	-1.84	-1.68	-1.52	-1.39	-1.27	-1.17	-1.07	-0.99
	Cell 3	6-9 m	microorg/L	0.77	1.41	2.03	2.65	3.29	3.95	4.62	5.29	5.94	6.59
			log(C/Co)	-2.11	-1.85	-1.69	-1.58	-1.48	-1.40	-1.34	-1.28	-1.23	-1.18
	Cell 4	9-12 m	microorg/L	1.08	2.00	2.89	3.76	4.58	5.35	6.10	6.83	7.54	8.23
			log(C/Co)	-1.96	-1.70	-1.54	-1.43	-1.34	-1.27	-1.21	-1.17	-1.12	-1.08
	Cell 5	12-15 m	microorg/L	1.46	2.69	3.90	5.08	6.22	7.32	8.37	9.38	10.35	11.28
			log(C/Co)	-1.84	-1.57	-1.41	-1.29	-1.21	-1.14	-1.08	-1.03	-0.99	-0.95
	Well	15-18 m	microorg/L	0.06	0.18	0.35	0.59	0.87	1.20	1.57	1.96	2.39	2.84
			log(C/Co)	-3.23	-2.75	-2.46	-2.23	-2.06	-1.92	-1.81	-1.71	-1.62	-1.55
Cp H1 w5	Cell 1	0-3 m	microorg/L	6.61	12.40	18.13	23.62	28.78	33.63	38.19	42.47	46.48	50.25
			log(C/Co)	-1.18	-0.91	-0.74	-0.63	-0.54	-0.47	-0.42	-0.37	-0.33	-0.30
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.13	0.63	1.46	2.63	4.09	5.84	7.78	9.88
			log(C/Co)	*	*	-2.88	-2.20	-1.83	-1.58	-1.39	-1.23	-1.11	-1.01
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11	0.31
			log(C/Co)	*	*	*	*	*	-27.51	-25.90	-3.91	-2.97	-2.51
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	-16.92	-10.48	-9.34	-8.65	-8.14	-7.74	-7.41	-7.13
Cp H1 w6	Cell 1	0-3 m	microorg/L	6.00	11.22	16.46	21.56	26.38	30.95	35.28	39.38	43.25	46.91
			log(C/Co)	-1.22	-0.95	-0.78	-0.67	-0.58	-0.51	-0.45	-0.40	-0.36	-0.33
	Cell 2	3-6 m	microorg/L	0.50	0.94	1.39	2.05	2.94	4.03	5.32	6.79	8.45	10.29
			log(C/Co)	-2.30	-2.03	-1.86	-1.69	-1.53	-1.39	-1.27	-1.17	-1.07	-0.99
	Cell 3	6-9 m	microorg/L	0.74	1.36	1.96	2.56	3.17	3.82	4.47	5.11	5.75	6.38
			log(C/Co)	-2.13	-1.87	-1.71	-1.59	-1.50	-1.42	-1.35	-1.29	-1.24	-1.20
	Cell 4	9-12 m	microorg/L	1.04	1.92	2.78	3.62	4.41	5.16	5.88	6.58	7.27	7.95
			log(C/Co)	-1.98	-1.72	-1.56	-1.44	-1.36	-1.29	-1.23	-1.18	-1.14	-1.10
	Cell 5	12-15 m	microorg/L	1.40	2.59	3.75	4.90	6.01	7.08	8.10	9.09	10.03	10.94
			log(C/Co)	-1.85	-1.59	-1.43	-1.31	-1.22	-1.15	-1.09	-1.04	-1.00	-0.96
	Well	15-18 m	microorg/L	0.04	0.11	0.23	0.39	0.59	0.84	1.13	1.45	1.79	2.16
			log(C/Co)	-3.42	-2.95	-2.65	-2.41	-2.23	-2.07	-1.95	-1.84	-1.75	-1.67

Cp: C. parvum, w: well number

Table 6.16: Effect of number of wells on *C. parvum*'s transport through porous media, high katt Scenario with 6 wells (H2)

				100	200	300	400	500	600	700	800	900	1000
Cp H2 w1	Cell 1	0-3 m	microorg/L	0.30	0.58	0.85	1.11	1.36	1.62	1.87	2.13	2.38	2.64
			log(C/Co)	-2.53	-2.24	-2.07	-1.96	-1.87	-1.79	-1.73	-1.67	-1.62	-1.58
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp H2 w2	Cell 1	0-3 m	microorg/L	0.34	0.66	0.97	1.26	1.55	1.84	2.13	2.42	2.71	3.00
			log(C/Co)	-2.47	-2.18	-2.01	-1.90	-1.81	-1.74	-1.67	-1.62	-1.57	-1.52
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp H2 w3	Cell 1	0-3 m	microorg/L	0.30	0.59	0.87	1.13	1.39	1.65	1.91	2.18	2.44	2.70
			log(C/Co)	-2.52	-2.23	-2.06	-1.95	-1.86	-1.78	-1.72	-1.66	-1.61	-1.57
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp H2 w4	Cell 1	0-3 m	microorg/L	0.26	0.51	0.74	0.97	1.19	1.41	1.63	1.86	2.08	2.30
			log(C/Co)	-2.59	-2.30	-2.13	-2.02	-1.93	-1.85	-1.79	-1.73	-1.68	-1.64
	Cell 2	3-6 m	microorg/L	0.02	0.04	0.07	0.09	0.10	0.12	0.14	0.16	0.18	0.20
			log(C/Co)	-3.64	-3.35	-3.18	-3.07	-2.98	-2.90	-2.84	-2.79	-2.74	-2.69
	Cell 3	6-9 m	microorg/L	0.03	0.07	0.10	0.13	0.16	0.19	0.22	0.25	0.28	0.30
			log(C/Co)	-3.46	-3.17	-3.00	-2.89	-2.80	-2.73	-2.66	-2.61	-2.56	-2.52
	Cell 4	9-12 m	microorg/L	0.05	0.09	0.14	0.18	0.22	0.26	0.30	0.34	0.39	0.43
			log(C/Co)	-3.32	-3.03	-2.86	-2.75	-2.66	-2.58	-2.52	-2.46	-2.41	-2.37
	Cell 5	12-15 m	microorg/L	0.06	0.13	0.19	0.24	0.30	0.35	0.41	0.46	0.52	0.57
			log(C/Co)	-3.19	-2.90	-2.73	-2.62	-2.53	-2.45	-2.39	-2.33	-2.29	-2.24
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
			log(C/Co)	-5.90	-5.33	-5.01	-4.80	-4.64	-4.50	-4.38	-4.28	-4.18	-4.10
Cp H2 w5	Cell 1	0-3 m	microorg/L	0.29	0.56	0.83	1.08	1.32	1.57	1.82	2.07	2.32	2.57
			log(C/Co)	-2.54	-2.25	-2.08	-1.97	-1.88	-1.80	-1.74	-1.68	-1.63	-1.59
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp H2 w6	Cell 1	0-3 m	microorg/L	0.26	0.51	0.75	0.98	1.21	1.43	1.66	1.88	2.11	2.34
			log(C/Co)	-2.58	-2.29	-2.12	-2.01	-1.92	-1.84	-1.78	-1.72	-1.68	-1.63
	Cell 2	3-6 m	microorg/L	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.19
			log(C/Co)	-3.66	-3.37	-3.20	-3.09	-3.00	-2.92	-2.86	-2.80	-2.75	-2.71
	Cell 3	6-9 m	microorg/L	0.03	0.06	0.10	0.12	0.15	0.18	0.21	0.24	0.26	0.29
			log(C/Co)	-3.48	-3.19	-3.02	-2.91	-2.82	-2.74	-2.68	-2.63	-2.58	-2.53
	Cell 4	9-12 m	microorg/L	0.05	0.09	0.13	0.17	0.21	0.25	0.29	0.33	0.37	0.41
			log(C/Co)	-3.33	-3.04	-2.88	-2.76	-2.67	-2.60	-2.54	-2.48	-2.43	-2.39
	Cell 5	12-15 m	microorg/L	0.06	0.12	0.18	0.23	0.29	0.34	0.39	0.44	0.50	0.55
			log(C/Co)	-3.21	-2.92	-2.75	-2.63	-2.55	-2.47	-2.41	-2.35	-2.30	-2.26
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
			log(C/Co)	-6.10	-5.53	-5.21	-5.00	-4.83	-4.69	-4.58	-4.47	-4.38	-4.29

Cp: C. parvum, w: well number

Table 6.17: Effect of number of wells on *E. coli*'s transport through porous media, low katt Scenario with 4 wells (G1)

				100	200	300	400	500	600	700	800	900	1000
Ec G1 w1	Cell 1	0-3 m	microorg/L	11.30	20.18	28.01	35.09	41.68	48.07	53.53	58.42	62.86	66.86
			log(C/Co)	-0.95	-0.70	-0.55	-0.45	-0.38	-0.32	-0.27	-0.23	-0.20	-0.17
	Cell 2	3-6 m	microorg/L	0.00	0.16	1.24	3.02	5.50	8.61	11.93	15.46	19.15	22.95
			log(C/Co)	*	-2.79	-1.91	-1.52	-1.26	-1.06	-0.92	-0.81	-0.72	-0.64
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.14	0.58	1.34	2.42	3.77
			log(C/Co)	*	*	*	*	-4.60	-2.84	-2.23	-1.87	-1.62	-1.42
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11
			log(C/Co)	*	*	*	*	*	*	*	*	-3.99	-2.98
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	-10.25	-8.60	-7.75	-7.15	-6.68	-6.42	-6.24	-6.05	-5.85
Ec G1 w2	Cell 1	0-3 m	microorg/L	11.41	20.35	28.26	35.40	42.05	48.50	54.01	58.94	63.41	67.45
			log(C/Co)	-0.94	-0.69	-0.55	-0.45	-0.38	-0.31	-0.27	-0.23	-0.20	-0.17
	Cell 2	3-6 m	microorg/L	0.00	0.18	1.28	3.10	5.63	8.81	12.20	15.80	19.57	23.45
			log(C/Co)	*	-2.75	-1.89	-1.51	-1.25	-1.05	-0.91	-0.80	-0.71	-0.63
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.16	0.62	1.39	2.49	3.87
			log(C/Co)	*	*	*	*	-4.38	-2.80	-2.21	-1.86	-1.60	-1.41
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11
			log(C/Co)	*	*	*	*	*	*	*	*	-3.96	-2.97
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec G1 w3	Cell 1	0-3 m	microorg/L	12.01	21.32	29.48	36.81	43.60	50.15	55.71	60.66	65.12	69.13
			log(C/Co)	-0.92	-0.67	-0.53	-0.43	-0.36	-0.30	-0.25	-0.22	-0.19	-0.16
	Cell 2	3-6 m	microorg/L	0.00	0.26	1.51	3.51	6.22	9.57	13.09	16.83	20.73	24.72
			log(C/Co)	*	-2.58	-1.82	-1.45	-1.21	-1.02	-0.88	-0.77	-0.68	-0.61
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.01	0.21	0.75	1.60	2.79	4.27
			log(C/Co)	*	*	*	*	-3.85	-2.67	-2.13	-1.80	-1.55	-1.37
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14
			log(C/Co)	*	*	*	*	*	*	*	*	-3.72	-2.87
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec G1 w4	Cell 1	0-3 m	microorg/L	11.40	20.33	28.23	35.35	41.99	48.42	53.91	58.84	63.30	67.33
			log(C/Co)	-0.94	-0.69	-0.55	-0.45	-0.38	-0.31	-0.27	-0.23	-0.20	-0.17
	Cell 2	3-6 m	microorg/L	0.00	0.15	1.20	2.94	5.35	8.42	11.70	15.20	18.86	22.64
			log(C/Co)	*	-2.81	-1.92	-1.53	-1.27	-1.07	-0.93	-0.82	-0.72	-0.65
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.09	0.46	1.12	2.09	3.37
			log(C/Co)	*	*	*	*	*	-3.02	-2.34	-1.95	-1.68	-1.47
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
			log(C/Co)	*	*	*	*	*	*	*	*	*	-3.41
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Ec: E. coli, w: well number

Table 6.18: Effect of number of wells on *E. coli*'s transport through porous media, high katt Scenario with 4 wells (G2)

				100	200	300	400	500	600	700	800	900	1000
Ec G2 w1	Cell 1	0-3 m	microorg/L	0.74	1.48	2.23	2.97	3.71	4.46	5.20	5.94	6.69	7.43
			log(C/Co)	-2.13	-1.83	-1.65	-1.53	-1.43	-1.35	-1.28	-1.23	-1.17	-1.13
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec G2 w2	Cell 1	0-3 m	microorg/L	0.75	1.50	2.25	3.00	3.75	4.49	5.24	5.99	6.75	7.50
			log(C/Co)	-2.13	-1.82	-1.65	-1.52	-1.43	-1.35	-1.28	-1.22	-1.17	-1.13
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec G2 w3	Cell 1	0-3 m	microorg/L	0.79	1.58	2.37	3.16	3.95	4.74	5.53	6.32	7.11	7.90
			log(C/Co)	-2.10	-1.80	-1.62	-1.50	-1.40	-1.32	-1.26	-1.20	-1.15	-1.10
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec G2 w4	Cell 1	0-3 m	microorg/L	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
			log(C/Co)	-2.12	-1.82	-1.65	-1.52	-1.43	-1.35	-1.28	-1.22	-1.17	-1.12
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

Ec: E. coli, w: well number

Table 6.19: Effect of number of wells on *E. coli*'s transport through porous media, low katt Scenario with 6 wells (H1)

				100	200	300	400	500	600	700	800	900	1000
Ec H1 w1	Cell 1	0-3 m	microorg/l	6.63	12.43	18.14	23.63	28.78	33.62	38.16	42.43	46.43	50.18
			log(C/Co)	-1.18	-0.91	-0.74	-0.63	-0.54	-0.47	-0.42	-0.37	-0.33	-0.30
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.15	0.66	1.52	2.70	4.19	5.95	7.90	10.00
			log(C/Co)	*	*	-2.83	-2.18	-1.82	-1.57	-1.38	-1.23	-1.10	-1.00
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.36
			log(C/Co)	*	*	*	*	*	*	*	-3.63	-2.86	-2.44
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	-13.51	-10.40	-9.33	-8.65	-8.15	-7.75	-7.42	-7.14	-6.89
Ec H1 w2	Cell 1	0-3 m	microorg/l	7.54	14.10	20.40	26.38	31.95	37.15	41.98	46.49	50.67	54.56
			log(C/Co)	-1.12	-0.85	-0.69	-0.58	-0.50	-0.43	-0.38	-0.33	-0.30	-0.26
	Cell 2	3-6 m	microorg/l	0.00	0.02	0.39	1.20	2.43	4.05	5.99	8.15	10.51	13.02
			log(C/Co)	*	-3.69	-2.41	-1.92	-1.61	-1.39	-1.22	-1.09	-0.98	-0.89
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.21	0.50	0.95
			log(C/Co)	*	*	*	*	*	*	-3.33	-2.68	-2.30	-2.02
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec H1 w3	Cell 1	0-3 m	microorg/l	6.78	12.71	18.54	24.12	29.36	34.28	38.90	43.24	47.30	51.10
			log(C/Co)	-1.17	-0.90	-0.73	-0.62	-0.53	-0.46	-0.41	-0.36	-0.33	-0.29
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.18	0.75	1.67	2.93	4.51	6.35	8.39	10.58
			log(C/Co)	*	*	-2.74	-2.13	-1.78	-1.53	-1.35	-1.20	-1.08	-0.98
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.19	0.45
			log(C/Co)	*	*	*	*	*	*	*	-3.36	-2.72	-2.35
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec H1 w4	Cell 1	0-3 m	microorg/l	5.77	10.78	15.82	20.77	25.46	29.91	34.12	38.12	41.91	45.50
			log(C/Co)	-1.24	-0.97	-0.80	-0.68	-0.59	-0.52	-0.47	-0.42	-0.38	-0.34
	Cell 2	3-6 m	microorg/l	0.51	0.95	1.40	2.02	2.86	3.89	5.11	6.51	8.10	9.85
			log(C/Co)	-2.29	-2.02	-1.85	-1.69	-1.54	-1.41	-1.29	-1.19	-1.09	-1.01
	Cell 3	6-9 m	microorg/l	0.75	1.38	1.99	2.59	3.20	3.85	4.50	5.15	5.79	6.42
			log(C/Co)	-2.12	-1.86	-1.70	-1.59	-1.49	-1.41	-1.35	-1.29	-1.24	-1.19
	Cell 4	9-12 m	microorg/l	1.06	1.95	2.82	3.67	4.48	5.24	5.97	6.68	7.37	8.05
			log(C/Co)	-1.98	-1.71	-1.55	-1.44	-1.35	-1.28	-1.22	-1.18	-1.13	-1.09
	Cell 5	12-15 m	microorg/l	1.43	2.63	3.80	4.96	6.08	7.15	8.19	9.18	10.13	11.04
			log(C/Co)	-1.85	-1.58	-1.42	-1.30	-1.22	-1.15	-1.09	-1.04	-0.99	-0.96
	Well	15-18 m	microorg/l	0.06	0.17	0.33	0.56	0.83	1.15	1.50	1.88	2.29	2.72
			log(C/Co)	-3.25	-2.78	-2.48	-2.25	-2.08	-1.94	-1.82	-1.73	-1.64	-1.57
Ec H2 w5	Cell 1	0-3 m	microorg/l	6.45	12.09	17.68	23.06	28.13	32.89	37.38	41.60	45.57	49.30
			log(C/Co)	-1.19	-0.92	-0.75	-0.64	-0.55	-0.48	-0.43	-0.38	-0.34	-0.31
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.11	0.56	1.34	2.42	3.80	5.46	7.31	9.32
			log(C/Co)	*	*	-2.96	-2.25	-1.87	-1.62	-1.42	-1.26	-1.14	-1.03
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.25
			log(C/Co)	*	*	*	*	*	-27.98	-26.12	-4.34	-3.12	-2.61
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	-10.66	-9.46	-8.74	-8.23	-7.82	-7.49	-7.20
Ec H1 w6	Cell 1	0-3 m	microorg/l	5.86	10.94	16.04	21.04	25.77	30.26	34.51	38.54	42.36	45.98
			log(C/Co)	-1.23	-0.96	-0.79	-0.68	-0.59	-0.52	-0.46	-0.41	-0.37	-0.34
	Cell 2	3-6 m	microorg/l	0.49	0.91	1.35	1.97	2.81	3.85	5.07	6.47	8.05	9.79
			log(C/Co)	-2.31	-2.04	-1.87	-1.70	-1.55	-1.42	-1.30	-1.19	-1.09	-1.01
	Cell 3	6-9 m	microorg/l	0.72	1.33	1.91	2.50	3.09	3.72	4.35	4.98	5.60	6.22
			log(C/Co)	-2.14	-1.88	-1.72	-1.60	-1.51	-1.43	-1.36	-1.30	-1.25	-1.21
	Cell 4	9-12 m	microorg/l	1.02	1.88	2.71	3.53	4.31	5.04	5.75	6.44	7.11	7.77
			log(C/Co)	-1.99	-1.73	-1.57	-1.45	-1.37	-1.30	-1.24	-1.19	-1.15	-1.11
	Cell 5	12-15 m	microorg/l	1.37	2.53	3.66	4.78	5.87	6.91	7.92	8.89	9.81	10.71
			log(C/Co)	-1.86	-1.60	-1.44	-1.32	-1.23	-1.16	-1.10	-1.05	-1.01	-0.97
	Well	15-18 m	microorg/l	0.04	0.11	0.21	0.37	0.56	0.80	1.07	1.38	1.71	2.06
			log(C/Co)	-3.44	-2.97	-2.67	-2.43	-2.25	-2.10	-1.97	-1.86	-1.77	-1.69

Ec: E. coli, w: well number

Table 6.20: Effect of number of wells on *E. coli*'s transport through porous media, high katt Scenario with 6 wells (H2)

				100	200	300	400	500	600	700	800	900	1000
Ec H2 w1	Cell 1	0-3 m	microorg/l	0.66	1.17	1.66	2.16	2.65	3.15	3.64	4.14	4.64	5.13
			log(C/Co)	-2.18	-1.93	-1.78	-1.67	-1.58	-1.50	-1.44	-1.38	-1.33	-1.29
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec H2 w2	Cell 1	0-3 m	microorg/l	0.75	1.33	1.89	2.46	3.02	3.58	4.15	4.71	5.27	5.84
			log(C/Co)	-2.12	-1.87	-1.72	-1.61	-1.52	-1.45	-1.38	-1.33	-1.28	-1.23
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec H2 w3	Cell 1	0-3 m	microorg/l	0.68	1.20	1.70	2.21	2.71	3.22	3.73	4.23	4.74	5.25
			log(C/Co)	-2.17	-1.92	-1.77	-1.66	-1.57	-1.49	-1.43	-1.37	-1.32	-1.28
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec H2 w4	Cell 1	0-3 m	microorg/l	0.58	1.02	1.45	1.88	2.31	2.74	3.18	3.61	4.04	4.47
			log(C/Co)	-2.24	-1.99	-1.84	-1.73	-1.64	-1.56	-1.50	-1.44	-1.39	-1.35
	Cell 2	3-6 m	microorg/l	0.05	0.09	0.13	0.17	0.20	0.24	0.28	0.32	0.36	0.39
			log(C/Co)	-3.29	-3.04	-2.89	-2.78	-2.69	-2.62	-2.55	-2.50	-2.45	-2.40
	Cell 3	6-9 m	microorg/l	0.08	0.14	0.19	0.25	0.31	0.36	0.42	0.47	0.53	0.59
			log(C/Co)	-3.11	-2.87	-2.72	-2.60	-2.51	-2.44	-2.38	-2.32	-2.28	-2.23
	Cell 4	9-12 m	microorg/l	0.11	0.19	0.27	0.35	0.43	0.51	0.59	0.67	0.74	0.82
			log(C/Co)	-2.97	-2.72	-2.57	-2.46	-2.37	-2.29	-2.23	-2.18	-2.13	-2.08
	Cell 5	12-15 m	microorg/l	0.14	0.26	0.36	0.47	0.58	0.68	0.79	0.90	1.00	1.11
			log(C/Co)	-2.84	-2.59	-2.44	-2.33	-2.24	-2.17	-2.10	-2.05	-2.00	-1.96
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.03
			log(C/Co)	-5.15	-4.70	-4.43	-4.22	-4.06	-3.92	-3.81	-3.70	-3.61	-3.53
Ec H2 w5	Cell 1	0-3 m	microorg/l	0.64	1.14	1.62	2.10	2.58	3.06	3.55	4.03	4.51	4.99
			log(C/Co)	-2.19	-1.94	-1.79	-1.68	-1.59	-1.51	-1.45	-1.39	-1.35	-1.30
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec H2 w6	Cell 1	0-3 m	microorg/l	0.59	1.04	1.47	1.91	2.35	2.79	3.22	3.66	4.10	4.54
			log(C/Co)	-2.23	-1.98	-1.83	-1.72	-1.63	-1.55	-1.49	-1.44	-1.39	-1.34
	Cell 2	3-6 m	microorg/l	0.05	0.09	0.12	0.16	0.20	0.23	0.27	0.31	0.34	0.38
			log(C/Co)	-3.31	-3.06	-2.91	-2.80	-2.71	-2.63	-2.57	-2.52	-2.47	-2.42
	Cell 3	6-9 m	microorg/l	0.07	0.13	0.19	0.24	0.29	0.35	0.40	0.46	0.51	0.56
			log(C/Co)	-3.13	-2.88	-2.73	-2.62	-2.53	-2.46	-2.40	-2.34	-2.29	-2.25
	Cell 4	9-12 m	microorg/l	0.10	0.18	0.26	0.34	0.41	0.49	0.56	0.64	0.72	0.79
			log(C/Co)	-2.99	-2.74	-2.59	-2.47	-2.39	-2.31	-2.25	-2.19	-2.15	-2.10
	Cell 5	12-15 m	microorg/l	0.14	0.25	0.35	0.45	0.55	0.66	0.76	0.86	0.96	1.06
			log(C/Co)	-2.86	-2.61	-2.46	-2.35	-2.26	-2.18	-2.12	-2.07	-2.02	-1.97
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02
			log(C/Co)	-5.35	-4.89	-4.62	-4.42	-4.25	-4.12	-4.00	-3.90	-3.80	-3.72

Ec: E. coli, w: well number

Table 6.21: Effect of number of wells on MS2's transport through porous media, low katt
Scenario with 4 wells (G1)

				100	200	300	400	500	600	700	800	900	1000
Ms G1 w1	Cell 1	0-3 m	microorg/L	19.49	31.73	42.11	51.00	58.75	65.66	71.32	76.12	80.19	83.64
			log(C/Co)	-0.71	-0.50	-0.38	-0.29	-0.23	-0.18	-0.15	-0.12	-0.10	-0.08
	Cell 2	3-6 m	microorg/L	0.07	2.08	5.89	10.76	16.21	22.19	28.19	34.16	39.99	45.61
			log(C/Co)	-3.16	-1.68	-1.23	-0.97	-0.79	-0.65	-0.55	-0.47	-0.40	-0.34
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.01	0.46	1.72	3.72	6.30	9.36	12.84	16.68
			log(C/Co)	*	*	-3.97	-2.34	-1.77	-1.43	-1.20	-1.03	-0.89	-0.78
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.12	0.59	1.45	2.67	4.25
			log(C/Co)	*	*	*	*	-7.21	-2.91	-2.23	-1.84	-1.57	-1.37
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.32	0.77
			log(C/Co)	*	*	*	*	*	*	-4.14	-3.04	-2.49	-2.12
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06
			log(C/Co)	-9.44	-7.70	-6.84	-6.37	-6.18	-5.85	-5.36	-4.35	-3.72	-3.25
Ms G1 w2	Cell 1	0-3 m	microorg/L	19.67	32.00	42.48	51.45	59.27	66.22	71.92	76.75	80.83	84.28
			log(C/Co)	-0.71	-0.49	-0.37	-0.29	-0.23	-0.18	-0.14	-0.11	-0.09	-0.07
	Cell 2	3-6 m	microorg/L	0.08	2.15	6.03	11.00	16.57	22.67	28.81	34.92	40.89	46.64
			log(C/Co)	-3.11	-1.67	-1.22	-0.96	-0.78	-0.64	-0.54	-0.46	-0.39	-0.33
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.01	0.49	1.78	3.82	6.42	9.53	13.07	16.98
			log(C/Co)	*	*	-3.85	-2.31	-1.75	-1.42	-1.19	-1.02	-0.88	-0.77
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.12	0.59	1.44	2.66	4.22
			log(C/Co)	*	*	*	*	-6.16	-2.90	-2.23	-1.84	-1.58	-1.37
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.31	0.74
			log(C/Co)	*	*	*	*	*	*	-4.38	-3.06	-2.51	-2.13
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04
			log(C/Co)	*	*	*	*	*	*	*	-5.09	-3.98	-3.39
Ms G1 w3	Cell 1	0-3 m	microorg/L	20.63	33.31	44.02	53.10	60.96	67.89	73.53	78.25	82.23	85.56
			log(C/Co)	-0.69	-0.48	-0.36	-0.27	-0.21	-0.17	-0.13	-0.11	-0.08	-0.07
	Cell 2	3-6 m	microorg/L	0.12	2.47	6.64	11.82	17.61	23.90	30.17	36.38	42.41	48.16
			log(C/Co)	-2.93	-1.61	-1.18	-0.93	-0.75	-0.62	-0.52	-0.44	-0.37	-0.32
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.03	0.61	2.02	4.22	6.99	10.27	13.98	18.03
			log(C/Co)	*	*	-3.52	-2.22	-1.69	-1.37	-1.16	-0.99	-0.85	-0.74
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.16	0.69	1.62	2.93	4.62
			log(C/Co)	*	*	*	*	-4.73	-2.81	-2.16	-1.79	-1.53	-1.34
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10	0.34	0.80
			log(C/Co)	*	*	*	*	*	*	-4.05	-3.01	-2.47	-2.09
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06
			log(C/Co)	*	*	*	*	*	*	-5.71	-4.35	-3.70	-3.25
Ms G1 w4	Cell 1	0-3 m	microorg/L	6.98	12.03	17.03	21.93	26.64	31.27	35.57	39.65	43.55	47.25
			log(C/Co)	-1.16	-0.92	-0.77	-0.66	-0.57	-0.50	-0.45	-0.40	-0.36	-0.33
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.06	0.37	0.90	1.63	2.55	3.66	4.95
			log(C/Co)	*	*	*	-3.21	-2.43	-2.05	-1.79	-1.59	-1.44	-1.31
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

MS: MS2, w: well number

Table 6.22: Effect of number of wells on MS2's transport through porous media, high katt Scenario with 4 wells (G2)

				100	200	300	400	500	600	700	800	900	1000
Ms G2 w1	Cell 1	0-3 m	microorg/L	2.02	4.04	6.05	8.07	10.10	12.12	14.14	16.11	18.04	19.94
			log(C/Co)	-1.69	-1.39	-1.22	-1.09	-1.00	-0.92	-0.85	-0.79	-0.74	-0.70
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.15	0.29
			log(C/Co)	*	*	*	*	*	*	-3.99	-3.22	-2.82	-2.54
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	-12.37	-11.09	-10.35
Ms G2 w2	Cell 1	0-3 m	microorg/L	2.04	4.07	6.11	8.15	10.19	12.23	14.26	16.26	18.21	20.12
			log(C/Co)	-1.69	-1.39	-1.21	-1.09	-0.99	-0.91	-0.85	-0.79	-0.74	-0.70
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.16	0.30
			log(C/Co)	*	*	*	*	*	*	-3.89	-3.17	-2.78	-2.52
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms G2 w3	Cell 1	0-3 m	microorg/L	2.15	4.30	6.44	8.59	10.73	12.88	15.00	17.07	19.09	21.07
			log(C/Co)	-1.67	-1.37	-1.19	-1.07	-0.97	-0.89	-0.82	-0.77	-0.72	-0.68
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.23	0.39
			log(C/Co)	*	*	*	*	*	-5.30	-3.52	-2.98	-2.65	-2.41
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms G2 w4	Cell 1	0-3 m	microorg/L	0.72	1.45	2.17	2.89	3.61	4.34	5.06	5.78	6.50	7.22
			log(C/Co)	-2.14	-1.84	-1.66	-1.54	-1.44	-1.36	-1.30	-1.24	-1.19	-1.14
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*

MS: MS2, w: well number

Table 6.23: Effect of number of wells on MS2's transport through porous media, low katt
Scenario with 6 wells (H1)

				100	200	300	400	500	600	700	800	900	1000
Ms H1 w1	Cell 1	0-3 m	microorg/L	10.36	19.36	27.59	35.17	42.04	48.25	53.86	58.92	63.48	67.59
			log(C/Co)	-0.98	-0.71	-0.56	-0.45	-0.38	-0.32	-0.27	-0.23	-0.20	-0.17
	Cell 2	3-6 m	microorg/L	0.00	0.24	1.34	3.24	5.88	8.99	12.45	16.16	20.03	24.01
			log(C/Co)	*	-2.62	-1.87	-1.49	-1.23	-1.05	-0.90	-0.79	-0.70	-0.62
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.03	0.26	0.78	1.65	2.83	4.30
			log(C/Co)	*	*	*	*	-3.59	-2.59	-2.11	-1.78	-1.55	-1.37
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.22
			log(C/Co)	*	*	*	*	*	*	*	-6.42	-3.30	-2.66
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	-9.86	-8.67	-7.92	-7.39	-6.97	-6.62	-6.33	-6.07	-5.84
Ms H1 w2	Cell 1	0-3 m	microorg/L	11.78	21.72	30.66	38.79	46.06	52.54	58.32	63.46	68.03	72.08
			log(C/Co)	-0.93	-0.66	-0.51	-0.41	-0.34	-0.28	-0.23	-0.20	-0.17	-0.14
	Cell 2	3-6 m	microorg/L	0.00	0.54	2.17	4.76	8.05	11.81	15.90	20.21	24.65	29.15
			log(C/Co)	*	-2.27	-1.66	-1.32	-1.09	-0.93	-0.80	-0.69	-0.61	-0.54
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.01	0.21	0.75	1.67	2.96	4.58	6.51
			log(C/Co)	*	*	*	-4.07	-2.67	-2.13	-1.78	-1.53	-1.34	-1.19
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.29	0.67
			log(C/Co)	*	*	*	*	*	*	-4.60	-3.11	-2.54	-2.18
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
			log(C/Co)	*	*	*	*	*	*	*	*	*	-3.95
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms H1 w3	Cell 1	0-3 m	microorg/L	10.60	19.78	28.16	35.87	42.84	49.14	54.82	59.93	64.53	68.67
			log(C/Co)	-0.97	-0.70	-0.55	-0.45	-0.37	-0.31	-0.26	-0.22	-0.19	-0.16
	Cell 2	3-6 m	microorg/L	0.00	0.28	1.47	3.50	6.27	9.53	13.13	16.99	21.01	25.14
			log(C/Co)	*	-2.55	-1.83	-1.46	-1.20	-1.02	-0.88	-0.77	-0.68	-0.60
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.05	0.33	0.92	1.87	3.13	4.68
			log(C/Co)	*	*	*	*	-3.33	-2.48	-2.03	-1.73	-1.50	-1.33
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.27
			log(C/Co)	*	*	*	*	*	*	*	-4.60	-3.13	-2.57
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms H1 w4	Cell 1	0-3 m	microorg/L	9.00	16.91	24.39	31.36	37.77	43.66	49.07	54.02	58.55	62.69
			log(C/Co)	-1.05	-0.77	-0.61	-0.50	-0.42	-0.36	-0.31	-0.27	-0.23	-0.20
	Cell 2	3-6 m	microorg/L	0.79	1.52	2.67	4.32	6.44	8.99	11.95	15.17	18.56	22.07
			log(C/Co)	-2.10	-1.82	-1.57	-1.36	-1.19	-1.05	-0.92	-0.82	-0.73	-0.66
	Cell 3	6-9 m	microorg/L	1.16	2.11	3.06	4.08	5.10	6.11	7.10	8.18	9.40	10.75
			log(C/Co)	-1.94	-1.67	-1.51	-1.39	-1.29	-1.21	-1.15	-1.09	-1.03	-0.97
	Cell 4	9-12 m	microorg/L	1.63	3.00	4.29	5.48	6.62	7.71	8.76	9.79	10.82	11.87
			log(C/Co)	-1.79	-1.52	-1.37	-1.26	-1.18	-1.11	-1.06	-1.01	-0.97	-0.93
	Cell 5	12-15 m	microorg/L	2.20	4.05	5.82	7.51	9.09	10.57	11.96	13.27	14.50	15.65
			log(C/Co)	-1.66	-1.39	-1.24	-1.12	-1.04	-0.98	-0.92	-0.88	-0.84	-0.81
	Well	15-18 m	microorg/L	0.13	0.39	0.78	1.27	1.86	2.51	3.21	3.95	4.72	5.50
			log(C/Co)	-2.88	-2.41	-2.11	-1.89	-1.73	-1.60	-1.49	-1.40	-1.33	-1.26
Ms H1 w5	Cell 1	0-3 m	microorg/L	10.08	18.87	26.97	34.43	41.22	47.38	52.96	58.01	62.58	66.70
			log(C/Co)	-1.00	-0.72	-0.57	-0.46	-0.38	-0.32	-0.28	-0.24	-0.20	-0.18
	Cell 2	3-6 m	microorg/L	0.00	0.19	1.17	2.92	5.39	8.36	11.68	15.25	19.00	22.87
			log(C/Co)	*	-2.73	-1.93	-1.53	-1.27	-1.08	-0.93	-0.82	-0.72	-0.64
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.01	0.17	0.59	1.32	2.38	3.72
			log(C/Co)	*	*	*	-26.48	-4.27	-2.78	-2.23	-1.88	-1.62	-1.43
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11
			log(C/Co)	*	*	*	*	*	*	*	*	-3.93	-2.95
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	-12.26	-9.48	-8.44	-7.78	-7.29	-6.90	-6.58	-6.30	-6.06
Ms H1 w6	Cell 1	0-3 m	microorg/L	9.13	17.14	24.69	31.72	38.18	44.12	49.57	54.56	59.13	63.30
			log(C/Co)	-1.04	-0.77	-0.61	-0.50	-0.42	-0.36	-0.30	-0.26	-0.23	-0.20
	Cell 2	3-6 m	microorg/L	0.76	1.47	2.62	4.28	6.39	8.94	11.89	15.09	18.47	21.97
			log(C/Co)	-2.12	-1.83	-1.58	-1.37	-1.19	-1.05	-0.92	-0.82	-0.73	-0.66
	Cell 3	6-9 m	microorg/L	1.11	2.04	2.95	3.94	4.93	5.91	6.88	7.94	9.13	10.45
			log(C/Co)	-1.95	-1.69	-1.53	-1.40	-1.31	-1.23	-1.16	-1.10	-1.04	-0.98
	Cell 4	9-12 m	microorg/L	1.57	2.89	4.13	5.28	6.38	7.44	8.46	9.46	10.47	11.49
			log(C/Co)	-1.80	-1.54	-1.38	-1.28	-1.20	-1.13	-1.07	-1.02	-0.98	-0.94
	Cell 5	12-15 m	microorg/L	2.11	3.90	5.62	7.26	8.80	10.25	11.61	12.90	14.11	15.24
			log(C/Co)	-1.67	-1.41	-1.25	-1.14	-1.06	-0.99	-0.94	-0.89	-0.85	-0.82
	Well	15-18 m	microorg/L	0.08	0.25	0.52	0.90	1.36	1.89	2.47	3.08	3.73	4.40
			log(C/Co)	-3.08	-2.60	-2.28	-2.05	-1.87	-1.72	-1.61	-1.51	-1.43	-1.36

MS: MS2, w: well number

Table 6.24: Effect of number of wells on MS2's transport through porous media, high katt Scenario with 6 wells (H2)

				100	200	300	400	500	600	700	800	900	1000
Ms H2 w1	Cell 1	0-3 m	microorg/l	1.77	3.04	4.32	5.67	7.02	8.37	9.72	11.06	12.41	13.76
			log(C/Co)	-1.75	-1.52	-1.36	-1.25	-1.15	-1.08	-1.01	-0.96	-0.91	-0.86
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	-4.37
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	-13.47	-12.17
Ms H2 w2	Cell 1	0-3 m	microorg/l	2.02	3.46	4.92	6.45	7.98	9.51	11.05	12.58	14.09	15.57
			log(C/Co)	-1.70	-1.46	-1.31	-1.19	-1.10	-1.02	-0.96	-0.90	-0.85	-0.81
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07
			log(C/Co)	*	*	*	*	*	*	*	-4.66	-3.61	-3.15
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms H2 w3	Cell 1	0-3 m	microorg/l	1.81	3.11	4.42	5.80	7.18	8.56	9.94	11.32	12.70	14.07
			log(C/Co)	-1.74	-1.51	-1.35	-1.24	-1.14	-1.07	-1.00	-0.95	-0.90	-0.85
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
			log(C/Co)	*	*	*	*	*	*	*	*	-7.62	-3.99
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms H2 w4	Cell 1	0-3 m	microorg/l	1.55	2.65	3.77	4.94	6.11	7.27	8.44	9.61	10.77	11.93
			log(C/Co)	-1.81	-1.58	-1.42	-1.31	-1.21	-1.14	-1.07	-1.02	-0.97	-0.92
	Cell 2	3-6 m	microorg/l	0.14	0.23	0.33	0.44	0.54	0.64	0.74	0.85	0.95	1.05
			log(C/Co)	-2.86	-2.63	-2.48	-2.36	-2.27	-2.19	-2.13	-2.07	-2.02	-1.98
	Cell 3	6-9 m	microorg/l	0.21	0.35	0.50	0.65	0.80	0.94	1.09	1.23	1.38	1.52
			log(C/Co)	-2.69	-2.46	-2.31	-2.19	-2.10	-2.03	-1.96	-1.91	-1.86	-1.82
	Cell 4	9-12 m	microorg/l	0.29	0.49	0.70	0.91	1.12	1.33	1.54	1.74	1.95	2.15
			log(C/Co)	-2.54	-2.31	-2.16	-2.04	-1.95	-1.88	-1.81	-1.76	-1.71	-1.67
	Cell 5	12-15 m	microorg/l	0.39	0.66	0.94	1.22	1.51	1.79	2.07	2.35	2.62	2.90
			log(C/Co)	-2.41	-2.18	-2.03	-1.91	-1.82	-1.75	-1.68	-1.63	-1.58	-1.54
	Well	15-18 m	microorg/l	0.00	0.01	0.02	0.04	0.06	0.08	0.10	0.13	0.16	0.19
			log(C/Co)	-4.30	-3.90	-3.64	-3.42	-3.25	-3.11	-2.99	-2.89	-2.79	-2.71
Ms H2 w5	Cell 1	0-3 m	microorg/l	1.72	2.96	4.21	5.52	6.83	8.14	9.45	10.76	12.07	13.39
			log(C/Co)	-1.76	-1.53	-1.38	-1.26	-1.17	-1.09	-1.02	-0.97	-0.92	-0.87
	Cell 2	3-6 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	-5.43
	Cell 3	6-9 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms H2 w6	Cell 1	0-3 m	microorg/l	1.57	2.69	3.83	5.01	6.20	7.38	8.57	9.75	10.93	12.11
			log(C/Co)	-1.80	-1.57	-1.42	-1.30	-1.21	-1.13	-1.07	-1.01	-0.96	-0.92
	Cell 2	3-6 m	microorg/l	0.13	0.22	0.32	0.42	0.52	0.62	0.71	0.81	0.91	1.01
			log(C/Co)	-2.88	-2.65	-2.50	-2.38	-2.29	-2.21	-2.15	-2.09	-2.04	-2.00
	Cell 3	6-9 m	microorg/l	0.20	0.34	0.48	0.62	0.76	0.91	1.05	1.19	1.32	1.46
			log(C/Co)	-2.71	-2.47	-2.32	-2.21	-2.12	-2.04	-1.98	-1.93	-1.88	-1.84
	Cell 4	9-12 m	microorg/l	0.28	0.47	0.67	0.87	1.08	1.28	1.48	1.68	1.87	2.07
			log(C/Co)	-2.56	-2.33	-2.18	-2.06	-1.97	-1.89	-1.83	-1.78	-1.73	-1.68
	Cell 5	12-15 m	microorg/l	0.37	0.63	0.90	1.17	1.45	1.72	1.99	2.26	2.52	2.79
			log(C/Co)	-2.43	-2.20	-2.05	-1.93	-1.84	-1.76	-1.70	-1.65	-1.60	-1.55
	Well	15-18 m	microorg/l	0.00	0.01	0.01	0.02	0.04	0.05	0.07	0.08	0.10	0.13
			log(C/Co)	-4.50	-4.09	-3.83	-3.62	-3.45	-3.31	-3.18	-3.08	-2.99	-2.90

MS: MS2, w: well number

Table 6.25: Effect of intermittent pumping on *C. parvum*'s transport through porous media, low katt

				100	200	300	400	500	600	700	800	900	1000
Cp K1 w1	Cell 1	0-3 m	microorg/L	5.71	11.42	14.27	18.94	28.23	35.61	35.62	37.76	41.96	44.06
			log(C/Co)	-1.24	-0.94	-0.85	-0.72	-0.55	-0.45	-0.45	-0.42	-0.38	-0.36
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.01	0.19	1.24	2.99	2.99	4.03	5.73	6.69
			log(C/Co)	*	*	-4.03	-2.72	-1.91	-1.52	-1.52	-1.39	-1.24	-1.17
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05
			log(C/Co)	*	*	*	*	*	*	*	*	-3.89	-3.32
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	-12.22	-9.26	-8.19	-8.19	-8.09	-7.70	-7.52
Cp K1 w2	Cell 1	0-3 m	microorg/L	6.51	13.00	16.17	16.16	16.18	16.20	16.20	22.13	27.71	30.50
			log(C/Co)	-1.19	-0.89	-0.79	-0.79	-0.79	-0.79	-0.79	-0.66	-0.56	-0.52
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.09	0.09	0.09	0.09	0.09	0.55	1.40	1.98
			log(C/Co)	*	-4.31	-3.04	-3.05	-3.05	-3.05	-3.05	-2.26	-1.85	-1.70
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	-11.70	-10.01	-9.58
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp K1 w3	Cell 1	0-3 m	microorg/L	5.87	11.75	14.68	19.35	28.65	36.05	36.06	38.29	42.58	44.73
			log(C/Co)	-1.23	-0.93	-0.83	-0.71	-0.54	-0.44	-0.44	-0.42	-0.37	-0.35
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.02	0.22	1.32	3.10	3.10	4.20	5.98	6.99
			log(C/Co)	*	*	-3.70	-2.65	-1.88	-1.51	-1.51	-1.38	-1.22	-1.16
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07
			log(C/Co)	*	*	*	*	*	*	*	*	-3.65	-3.18
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp K1 w4	Cell 1	0-3 m	microorg/L	5.09	10.14	12.66	12.70	12.81	12.91	12.91	17.85	22.62	25.02
			log(C/Co)	-1.29	-0.99	-0.90	-0.90	-0.89	-0.89	-0.89	-0.75	-0.65	-0.60
	Cell 2	3-6 m	microorg/L	0.54	1.07	1.33	1.36	1.41	1.46	1.46	1.99	2.74	3.21
			log(C/Co)	-2.27	-1.97	-1.88	-1.87	-1.85	-1.84	-1.84	-1.70	-1.56	-1.49
	Cell 3	6-9 m	microorg/L	0.75	1.46	1.81	1.83	1.90	1.96	1.96	2.60	3.26	3.60
			log(C/Co)	-2.13	-1.84	-1.74	-1.74	-1.72	-1.71	-1.71	-1.58	-1.49	-1.44
	Cell 4	9-12 m	microorg/L	1.00	1.97	2.44	2.48	2.58	2.66	2.66	3.55	4.44	4.88
			log(C/Co)	-2.00	-1.71	-1.61	-1.61	-1.59	-1.58	-1.58	-1.45	-1.35	-1.31
	Cell 5	12-15 m	microorg/L	1.28	2.52	3.13	3.18	3.28	3.37	3.37	4.54	5.70	6.30
			log(C/Co)	-1.89	-1.60	-1.50	-1.50	-1.48	-1.47	-1.47	-1.34	-1.24	-1.20
	Well	15-18 m	microorg/L	0.04	0.14	0.21	0.22	0.23	0.24	0.24	0.44	0.69	0.84
			log(C/Co)	-3.45	-2.86	-2.68	-2.67	-2.64	-2.62	-2.62	-2.36	-2.16	-2.08
Cp K1 w5	Cell 1	0-3 m	microorg/L	5.44	10.88	13.60	18.17	27.29	34.57	34.57	36.67	40.81	42.88
			log(C/Co)	-1.26	-0.96	-0.87	-0.74	-0.56	-0.46	-0.46	-0.44	-0.39	-0.37
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.13	1.02	2.59	2.59	3.53	5.08	5.97
			log(C/Co)	*	*	-5.59	-2.90	-1.99	-1.59	-1.59	-1.45	-1.29	-1.22
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
			log(C/Co)	*	*	*	*	*	*	*	*	*	-4.02
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	-10.71	-8.78	-8.78	-8.59	-8.10	-7.88
Cp K1 w6	Cell 1	0-3 m	microorg/L	4.81	9.58	11.95	16.02	24.30	31.00	31.00	32.98	36.84	38.79
			log(C/Co)	-1.32	-1.02	-0.92	-0.80	-0.61	-0.51	-0.51	-0.48	-0.43	-0.41
	Cell 2	3-6 m	microorg/L	0.53	1.05	1.31	1.71	2.87	4.34	4.34	5.09	6.36	7.07
			log(C/Co)	-2.28	-1.98	-1.88	-1.77	-1.54	-1.36	-1.36	-1.29	-1.20	-1.15
	Cell 3	6-9 m	microorg/L	0.72	1.41	1.74	2.26	3.34	4.34	4.34	4.72	5.38	5.72
			log(C/Co)	-2.14	-1.85	-1.76	-1.65	-1.48	-1.36	-1.36	-1.33	-1.27	-1.24
	Cell 4	9-12 m	microorg/L	0.96	1.88	2.34	3.06	4.51	5.68	5.68	6.06	6.77	7.13
			log(C/Co)	-2.02	-1.73	-1.63	-1.51	-1.35	-1.25	-1.25	-1.22	-1.17	-1.15
	Cell 5	12-15 m	microorg/L	1.22	2.41	3.00	3.94	5.89	7.49	7.49	8.02	8.99	9.48
			log(C/Co)	-1.91	-1.62	-1.52	-1.40	-1.23	-1.13	-1.13	-1.10	-1.05	-1.02
	Well	15-18 m	microorg/L	0.02	0.09	0.13	0.24	0.57	1.00	1.00	1.02	1.30	1.46
			log(C/Co)	-3.64	-3.06	-2.87	-2.62	-2.25	-2.00	-2.00	-1.99	-1.89	-1.84

Cp: C. parvum, w: well number

Table 6.26: Effect of intermittent pumping on *C. parvum* 's transport through porous media, high katt

				100	200	300	400	500	600	700	800	900	1000
Cp K2 w1	Cell 1	0-3 m	microorg/L	0.24	0.47	0.59	0.77	1.13	1.49	1.49	1.73	1.96	2.08
			log(C/Co)	-2.62	-2.32	-2.23	-2.11	-1.95	-1.83	-1.83	-1.76	-1.71	-1.68
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp K2 w2	Cell 1	0-3 m	microorg/L	0.27	0.54	0.68	0.68	0.68	0.68	0.68	0.94	1.21	1.34
			log(C/Co)	-2.57	-2.27	-2.17	-2.17	-2.17	-2.17	-2.17	-2.03	-1.92	-1.87
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp K2 w3	Cell 1	0-3 m	microorg/L	0.24	0.49	0.61	0.79	1.15	1.51	1.51	1.75	1.99	2.12
			log(C/Co)	-2.61	-2.31	-2.21	-2.10	-1.94	-1.82	-1.82	-1.76	-1.70	-1.67
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp K2 w4	Cell 1	0-3 m	microorg/L	0.21	0.42	0.53	0.53	0.54	0.54	0.54	0.75	0.96	1.07
			log(C/Co)	-2.67	-2.37	-2.28	-2.27	-2.27	-2.27	-2.27	-2.12	-2.02	-1.97
	Cell 2	3-6 m	microorg/L	0.02	0.04	0.06	0.06	0.06	0.06	0.06	0.08	0.10	0.11
			log(C/Co)	-3.65	-3.35	-3.25	-3.24	-3.23	-3.22	-3.22	-3.08	-2.98	-2.94
	Cell 3	6-9 m	microorg/L	0.03	0.06	0.08	0.08	0.08	0.08	0.08	0.12	0.15	0.16
			log(C/Co)	-3.50	-3.20	-3.10	-3.10	-3.08	-3.07	-3.07	-2.94	-2.83	-2.79
	Cell 4	9-12 m	microorg/L	0.04	0.08	0.11	0.11	0.11	0.11	0.11	0.16	0.20	0.22
			log(C/Co)	-3.37	-3.07	-2.98	-2.97	-2.96	-2.94	-2.94	-2.81	-2.70	-2.66
	Cell 5	12-15 m	microorg/L	0.05	0.11	0.14	0.14	0.14	0.14	0.14	0.20	0.25	0.28
			log(C/Co)	-3.27	-2.97	-2.87	-2.86	-2.85	-2.84	-2.84	-2.70	-2.60	-2.55
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	-6.20	-5.60	-5.40	-5.39	-5.37	-5.35	-5.35	-5.07	-4.86	-4.77
Cp K2 w5	Cell 1	0-3 m	microorg/L	0.23	0.45	0.57	0.74	1.09	1.43	1.44	1.66	1.89	2.01
			log(C/Co)	-2.65	-2.34	-2.25	-2.13	-1.96	-1.84	-1.84	-1.78	-1.72	-1.70
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Cp K2 w6	Cell 1	0-3 m	microorg/L	0.20	0.40	0.50	0.65	0.96	1.27	1.27	1.47	1.67	1.77
			log(C/Co)	-2.70	-2.40	-2.30	-2.18	-2.02	-1.90	-1.89	-1.83	-1.78	-1.75
	Cell 2	3-6 m	microorg/L	0.02	0.04	0.05	0.07	0.10	0.13	0.13	0.15	0.17	0.18
			log(C/Co)	-3.66	-3.36	-3.26	-3.15	-3.00	-2.88	-2.88	-2.82	-2.77	-2.74
	Cell 3	6-9 m	microorg/L	0.03	0.06	0.08	0.10	0.14	0.18	0.19	0.21	0.24	0.26
			log(C/Co)	-3.52	-3.21	-3.12	-3.01	-2.85	-2.73	-2.73	-2.67	-2.62	-2.59
	Cell 4	9-12 m	microorg/L	0.04	0.08	0.10	0.13	0.19	0.25	0.25	0.29	0.33	0.35
			log(C/Co)	-3.39	-3.09	-3.00	-2.89	-2.72	-2.61	-2.60	-2.54	-2.49	-2.46
	Cell 5	12-15 m	microorg/L	0.05	0.10	0.13	0.17	0.24	0.32	0.32	0.37	0.42	0.44
			log(C/Co)	-3.29	-2.99	-2.89	-2.78	-2.61	-2.50	-2.49	-2.43	-2.38	-2.35
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	-6.39	-5.79	-5.60	-5.37	-5.04	-4.80	-4.79	-4.67	-4.56	-4.51

Cp: C. parvum, w: well number

Table 6.27: Effect of intermittent pumping on *E. coli*'s transport through porous media, low katt

				100	200	300	400	500	600	700	800	900	1000
Ec K1 w1	Cell 1	0-3 m	microorg/L	5.56	11.12	13.90	18.43	27.51	34.85	34.86	36.95	41.09	43.15
			log(C/Co)	-1.25	-0.95	-0.86	-0.73	-0.56	-0.46	-0.46	-0.43	-0.39	-0.36
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.16	1.12	2.75	2.75	3.74	5.34	6.26
			log(C/Co)	*	*	-4.32	-2.80	-1.95	-1.56	-1.56	-1.43	-1.27	-1.20
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
			log(C/Co)	*	*	*	*	*	*	*	*	-4.34	-3.55
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	-12.85	-9.40	-8.29	-8.29	-8.18	-7.79	-7.60
Ec K1 w2	Cell 1	0-3 m	microorg/L	6.34	12.66	15.76	15.76	15.78	15.80	15.80	21.59	27.06	29.79
			log(C/Co)	-1.20	-0.90	-0.80	-0.80	-0.80	-0.80	-0.80	-0.67	-0.57	-0.53
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.07	0.07	0.07	0.07	0.07	0.49	1.28	1.82
			log(C/Co)	*	-4.69	-3.13	-3.14	-3.14	-3.14	-3.14	-2.31	-1.89	-1.74
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	-12.22	-10.11	-9.66
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec K1 w3	Cell 1	0-3 m	microorg/L	5.72	11.44	14.30	18.83	27.93	35.28	35.29	37.47	41.70	43.81
			log(C/Co)	-1.24	-0.94	-0.84	-0.73	-0.55	-0.45	-0.45	-0.43	-0.38	-0.36
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.01	0.19	1.18	2.85	2.85	3.90	5.58	6.54
			log(C/Co)	*	*	-3.89	-2.73	-1.93	-1.54	-1.54	-1.41	-1.25	-1.18
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04
			log(C/Co)	*	*	*	*	*	*	*	*	-3.97	-3.37
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec K1 w4	Cell 1	0-3 m	microorg/L	4.96	9.88	12.33	12.37	12.48	12.58	12.58	17.40	22.06	24.41
			log(C/Co)	-1.30	-1.01	-0.91	-0.91	-0.90	-0.90	-0.90	-0.76	-0.66	-0.61
	Cell 2	3-6 m	microorg/L	0.52	1.04	1.30	1.32	1.37	1.42	1.42	1.93	2.64	3.08
			log(C/Co)	-2.28	-1.98	-1.89	-1.88	-1.86	-1.85	-1.85	-1.71	-1.58	-1.51
	Cell 3	6-9 m	microorg/L	0.73	1.42	1.76	1.79	1.85	1.91	1.91	2.54	3.17	3.51
			log(C/Co)	-2.14	-1.85	-1.75	-1.75	-1.73	-1.72	-1.72	-1.60	-1.50	-1.46
	Cell 4	9-12 m	microorg/L	0.98	1.92	2.38	2.42	2.51	2.59	2.59	3.47	4.33	4.76
			log(C/Co)	-2.01	-1.72	-1.62	-1.62	-1.60	-1.59	-1.59	-1.46	-1.36	-1.32
	Cell 5	12-15 m	microorg/L	1.25	2.46	3.05	3.10	3.19	3.28	3.28	4.43	5.56	6.14
			log(C/Co)	-1.90	-1.61	-1.52	-1.51	-1.50	-1.48	-1.48	-1.35	-1.25	-1.21
	Well	15-18 m	microorg/L	0.03	0.13	0.20	0.21	0.22	0.23	0.23	0.41	0.65	0.80
			log(C/Co)	-3.47	-2.89	-2.70	-2.69	-2.66	-2.64	-2.64	-2.38	-2.18	-2.10
Ec K1 w5	Cell 1	0-3 m	microorg/L	5.30	10.59	13.24	17.68	26.60	33.82	33.83	35.88	39.95	41.99
			log(C/Co)	-1.28	-0.98	-0.88	-0.75	-0.58	-0.47	-0.47	-0.45	-0.40	-0.38
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.10	0.91	2.38	2.38	3.27	4.72	5.57
			log(C/Co)	*	*	*	-3.00	-2.04	-1.62	-1.62	-1.49	-1.33	-1.25
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	-4.57
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	-11.07	-8.91	-8.91	-8.71	-8.20	-7.97
Ec K1 w6	Cell 1	0-3 m	microorg/L	4.68	9.33	11.64	15.58	23.66	30.31	30.31	32.24	36.03	37.94
			log(C/Co)	-1.33	-1.03	-0.93	-0.81	-0.63	-0.52	-0.52	-0.49	-0.44	-0.42
	Cell 2	3-6 m	microorg/L	0.51	1.02	1.27	1.66	2.75	4.15	4.15	4.87	6.07	6.75
			log(C/Co)	-2.29	-1.99	-1.89	-1.78	-1.56	-1.38	-1.38	-1.31	-1.22	-1.17
	Cell 3	6-9 m	microorg/L	0.70	1.37	1.70	2.20	3.25	4.23	4.23	4.59	5.23	5.57
			log(C/Co)	-2.15	-1.86	-1.77	-1.66	-1.49	-1.37	-1.37	-1.34	-1.28	-1.25
	Cell 4	9-12 m	microorg/L	0.93	1.84	2.28	2.97	4.39	5.56	5.56	5.92	6.62	6.97
			log(C/Co)	-2.03	-1.74	-1.64	-1.53	-1.36	-1.26	-1.26	-1.23	-1.18	-1.16
	Cell 5	12-15 m	microorg/L	1.19	2.35	2.92	3.84	5.73	7.32	7.32	7.84	8.79	9.27
			log(C/Co)	-1.92	-1.63	-1.53	-1.42	-1.24	-1.14	-1.14	-1.11	-1.06	-1.03
	Well	15-18 m	microorg/L	0.02	0.08	0.13	0.23	0.54	0.95	0.95	0.97	1.23	1.39
			log(C/Co)	-3.67	-3.08	-2.89	-2.65	-2.27	-2.02	-2.02	-2.01	-1.91	-1.86

Ec: E. coli, w: well number

Table 6.28: Effect of intermittent pumping on *E. coli*'s transport through porous media, high katt

				100	200	300	400	500	600	700	800	900	1000
Ec K2 w1	Cell 1	0-3 m	microorg/L	0.46	0.92	1.15	1.50	2.19	2.90	2.91	3.35	3.81	4.05
			log(C/Co)	-2.34	-2.04	-1.94	-1.82	-1.66	-1.54	-1.54	-1.47	-1.42	-1.39
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec K2 w2	Cell 1	0-3 m	microorg/L	0.53	1.05	1.31	1.31	1.32	1.32	1.32	1.83	2.34	2.60
			log(C/Co)	-2.28	-1.98	-1.88	-1.88	-1.88	-1.88	-1.88	-1.74	-1.63	-1.59
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec K2 w3	Cell 1	0-3 m	microorg/L	0.47	0.95	1.18	1.53	2.23	2.94	2.94	3.40	3.87	4.11
			log(C/Co)	-2.32	-2.02	-1.93	-1.81	-1.65	-1.53	-1.53	-1.47	-1.41	-1.39
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec K2 w4	Cell 1	0-3 m	microorg/L	0.41	0.82	1.03	1.03	1.04	1.05	1.05	1.46	1.87	2.07
			log(C/Co)	-2.39	-2.08	-1.99	-1.99	-1.98	-1.98	-1.98	-1.84	-1.73	-1.68
	Cell 2	3-6 m	microorg/L	0.04	0.09	0.11	0.11	0.11	0.12	0.12	0.16	0.20	0.22
			log(C/Co)	-3.36	-3.06	-2.96	-2.96	-2.94	-2.93	-2.93	-2.80	-2.70	-2.65
	Cell 3	6-9 m	microorg/L	0.06	0.12	0.15	0.16	0.16	0.16	0.16	0.22	0.28	0.31
			log(C/Co)	-3.21	-2.91	-2.81	-2.81	-2.80	-2.78	-2.78	-2.65	-2.55	-2.50
	Cell 4	9-12 m	microorg/L	0.08	0.16	0.20	0.21	0.21	0.22	0.22	0.30	0.38	0.42
			log(C/Co)	-3.09	-2.79	-2.69	-2.68	-2.67	-2.66	-2.66	-2.52	-2.42	-2.37
	Cell 5	12-15 m	microorg/L	0.11	0.21	0.26	0.27	0.27	0.28	0.28	0.38	0.49	0.54
			log(C/Co)	-2.98	-2.68	-2.58	-2.58	-2.56	-2.55	-2.55	-2.41	-2.31	-2.27
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
			log(C/Co)	-5.62	-5.02	-4.83	-4.82	-4.80	-4.78	-4.78	-4.50	-4.29	-4.20
Ec K2 w5	Cell 1	0-3 m	microorg/L	0.44	0.88	1.10	1.43	2.11	2.79	2.80	3.23	3.67	3.90
			log(C/Co)	-2.36	-2.06	-1.96	-1.84	-1.68	-1.55	-1.55	-1.49	-1.44	-1.41
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ec K2 w6	Cell 1	0-3 m	microorg/L	0.39	0.78	0.97	1.27	1.86	2.47	2.48	2.85	3.24	3.44
			log(C/Co)	-2.41	-2.11	-2.01	-1.90	-1.73	-1.61	-1.61	-1.55	-1.49	-1.46
	Cell 2	3-6 m	microorg/L	0.04	0.09	0.11	0.14	0.19	0.25	0.26	0.29	0.33	0.35
			log(C/Co)	-3.37	-3.07	-2.97	-2.87	-2.71	-2.59	-2.59	-2.53	-2.48	-2.45
	Cell 3	6-9 m	microorg/L	0.06	0.12	0.15	0.19	0.27	0.36	0.36	0.41	0.47	0.49
			log(C/Co)	-3.23	-2.93	-2.83	-2.72	-2.56	-2.45	-2.45	-2.39	-2.33	-2.31
	Cell 4	9-12 m	microorg/L	0.08	0.16	0.20	0.25	0.37	0.48	0.48	0.55	0.63	0.67
			log(C/Co)	-3.11	-2.81	-2.71	-2.60	-2.44	-2.32	-2.32	-2.26	-2.20	-2.18
	Cell 5	12-15 m	microorg/L	0.10	0.20	0.25	0.32	0.47	0.62	0.62	0.71	0.81	0.86
			log(C/Co)	-3.00	-2.70	-2.60	-2.49	-2.33	-2.21	-2.21	-2.15	-2.09	-2.07
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
			log(C/Co)	-5.82	-5.22	-5.02	-4.79	-4.46	-4.22	-4.21	-4.10	-3.99	-3.94

Ec: E. coli, w: well number

Table 6.29: Effect of intermittent pumping on MS2's transport through porous media, low katt

				100	200	300	400	500	600	700	800	900	1000
Ms K1 w1	Cell 1	0-3 m	microorg/L	9.01	17.66	21.74	29.36	41.57	49.59	49.59	52.42	57.54	60.13
			log(C/Co)	-1.05	-0.75	-0.66	-0.53	-0.38	-0.30	-0.30	-0.28	-0.24	-0.22
	Cell 2	3-6 m	microorg/L	0.00	0.13	0.46	1.70	5.44	9.72	9.73	11.80	15.35	17.34
			log(C/Co)	*	-2.87	-2.34	-1.77	-1.26	-1.01	-1.01	-0.93	-0.81	-0.76
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.31	0.31	0.72	1.49	2.03
			log(C/Co)	*	*	*	*	-5.50	-2.52	-2.52	-2.14	-1.83	-1.69
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	-4.46
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	-11.39	-10.05	-8.61	-7.42	-6.81	-6.81	-6.73	-6.44	-6.29
Ms K1 w2	Cell 1	0-3 m	microorg/L	10.26	19.89	24.36	24.11	24.14	24.16	24.16	32.68	40.27	44.09
			log(C/Co)	-0.99	-0.70	-0.61	-0.62	-0.62	-0.62	-0.62	-0.49	-0.40	-0.36
	Cell 2	3-6 m	microorg/L	0.00	0.36	0.90	0.86	0.86	0.86	0.86	2.62	5.22	6.87
			log(C/Co)	*	-2.44	-2.05	-2.07	-2.06	-2.06	-2.06	-1.58	-1.28	-1.16
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07
			log(C/Co)	*	*	*	*	*	*	*	-10.16	-4.13	-3.18
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	-10.80
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms K1 w3	Cell 1	0-3 m	microorg/L	9.27	18.14	22.32	29.93	42.16	50.20	50.20	53.15	58.37	61.01
			log(C/Co)	-1.03	-0.74	-0.65	-0.52	-0.38	-0.30	-0.30	-0.27	-0.23	-0.21
	Cell 2	3-6 m	microorg/L	0.00	0.17	0.54	1.83	5.67	10.03	10.03	12.22	15.92	18.00
			log(C/Co)	*	-2.76	-2.26	-1.74	-1.25	-1.00	-1.00	-0.91	-0.80	-0.74
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.78	1.61	2.18
			log(C/Co)	*	*	*	*	-4.77	-2.48	-2.48	-2.11	-1.79	-1.66
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
			log(C/Co)	*	*	*	*	*	*	*	*	*	-4.18
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms K1 w4	Cell 1	0-3 m	microorg/L	8.01	15.72	19.45	19.32	19.49	19.63	19.63	26.93	33.62	37.04
			log(C/Co)	-1.10	-0.80	-0.71	-0.71	-0.71	-0.71	-0.71	-0.57	-0.47	-0.43
	Cell 2	3-6 m	microorg/L	0.84	1.66	2.17	2.18	2.27	2.33	2.33	3.71	5.53	6.68
			log(C/Co)	-2.07	-1.78	-1.66	-1.66	-1.64	-1.63	-1.63	-1.43	-1.26	-1.18
	Cell 3	6-9 m	microorg/L	1.16	2.22	2.73	2.76	2.86	2.94	2.94	3.97	5.07	5.67
			log(C/Co)	-1.94	-1.65	-1.56	-1.56	-1.54	-1.53	-1.53	-1.40	-1.29	-1.25
	Cell 4	9-12 m	microorg/L	1.56	3.00	3.69	3.73	3.87	3.99	3.99	5.30	6.53	7.17
			log(C/Co)	-1.81	-1.52	-1.43	-1.43	-1.41	-1.40	-1.40	-1.28	-1.19	-1.14
	Cell 5	12-15 m	microorg/L	2.00	3.86	4.75	4.78	4.94	5.06	5.06	6.84	8.53	9.40
			log(C/Co)	-1.70	-1.41	-1.32	-1.32	-1.31	-1.30	-1.30	-1.17	-1.07	-1.03
	Well	15-18 m	microorg/L	0.09	0.33	0.49	0.50	0.53	0.55	0.55	1.00	1.55	1.90
			log(C/Co)	-3.04	-2.49	-2.31	-2.30	-2.28	-2.26	-2.26	-2.00	-1.81	-1.72
Ms K1 w5	Cell 1	0-3 m	microorg/L	8.58	16.86	20.80	28.31	40.38	48.36	48.36	51.17	56.26	58.85
			log(C/Co)	-1.07	-0.77	-0.68	-0.55	-0.39	-0.32	-0.32	-0.29	-0.25	-0.23
	Cell 2	3-6 m	microorg/L	0.00	0.07	0.33	1.41	4.79	8.83	8.83	10.80	14.16	16.06
			log(C/Co)	*	-3.13	-2.49	-1.85	-1.32	-1.05	-1.05	-0.97	-0.85	-0.79
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.48	1.09	1.53
			log(C/Co)	*	*	*	*	*	-2.76	-2.76	-2.32	-1.96	-1.82
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	-9.63	-7.84	-7.08	-7.08	-6.98	-6.65	-6.48
Ms K1 w6	Cell 1	0-3 m	microorg/L	7.57	14.85	18.41	25.26	36.44	44.04	44.04	46.78	51.71	54.23
			log(C/Co)	-1.12	-0.83	-0.73	-0.60	-0.44	-0.36	-0.36	-0.33	-0.29	-0.27
	Cell 2	3-6 m	microorg/L	0.83	1.62	2.08	3.25	6.16	9.40	9.41	11.07	13.96	15.59
			log(C/Co)	-2.08	-1.79	-1.68	-1.49	-1.21	-1.03	-1.03	-0.96	-0.86	-0.81
	Cell 3	6-9 m	microorg/L	1.12	2.14	2.64	3.57	5.36	6.73	6.73	7.30	8.31	8.89
			log(C/Co)	-1.95	-1.67	-1.58	-1.45	-1.27	-1.17	-1.17	-1.14	-1.08	-1.05
	Cell 4	9-12 m	microorg/L	1.49	2.88	3.54	4.73	6.67	8.14	8.14	8.75	9.78	10.33
			log(C/Co)	-1.83	-1.54	-1.45	-1.33	-1.18	-1.09	-1.09	-1.06	-1.01	-0.99
	Cell 5	12-15 m	microorg/L	1.91	3.69	4.56	6.19	8.89	10.79	10.79	11.56	12.87	13.56
			log(C/Co)	-1.72	-1.43	-1.34	-1.21	-1.05	-0.97	-0.97	-0.94	-0.89	-0.87
	Well	15-18 m	microorg/L	0.06	0.21	0.32	0.61	1.40	2.17	2.17	2.29	2.87	3.20
			log(C/Co)	-3.24	-2.68	-2.50	-2.22	-1.85	-1.66	-1.66	-1.64	-1.54	-1.49

MS: MS2, w: well number

Table 6.30: Effect of intermittent pumping on MS2's transport through porous media, high katt

				100	200	300	400	500	600	700	800	900	1000
Ms K2 w1	Cell 1	0-3 m	microorg/L	1.25	2.50	3.13	4.07	5.96	8.34	8.34	9.11	10.37	11.00
			log(C/Co)	-1.90	-1.60	-1.50	-1.39	-1.22	-1.08	-1.08	-1.04	-0.98	-0.96
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms K2 w2	Cell 1	0-3 m	microorg/L	1.43	2.85	3.57	3.57	3.57	3.58	3.58	4.97	6.36	7.05
			log(C/Co)	-1.85	-1.54	-1.45	-1.45	-1.45	-1.45	-1.45	-1.30	-1.20	-1.15
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms K2 w3	Cell 1	0-3 m	microorg/L	1.29	2.57	3.22	4.16	6.06	8.44	8.44	9.24	10.54	11.18
			log(C/Co)	-1.89	-1.59	-1.49	-1.38	-1.22	-1.07	-1.07	-1.03	-0.98	-0.95
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms K2 w4	Cell 1	0-3 m	microorg/L	1.12	2.23	2.79	2.80	2.83	2.85	2.85	3.95	5.06	5.61
			log(C/Co)	-1.95	-1.65	-1.55	-1.55	-1.55	-1.54	-1.54	-1.40	-1.30	-1.25
	Cell 2	3-6 m	microorg/L	0.12	0.24	0.29	0.30	0.31	0.32	0.32	0.43	0.55	0.60
			log(C/Co)	-2.93	-2.63	-2.53	-2.52	-2.51	-2.49	-2.49	-2.36	-2.26	-2.22
	Cell 3	6-9 m	microorg/L	0.17	0.33	0.41	0.42	0.43	0.45	0.45	0.60	0.76	0.84
			log(C/Co)	-2.78	-2.48	-2.38	-2.38	-2.37	-2.35	-2.35	-2.22	-2.12	-2.08
	Cell 4	9-12 m	microorg/L	0.22	0.44	0.55	0.56	0.58	0.60	0.60	0.82	1.03	1.14
			log(C/Co)	-2.65	-2.35	-2.26	-2.25	-2.24	-2.22	-2.22	-2.09	-1.99	-1.94
	Cell 5	12-15 m	microorg/L	0.28	0.57	0.71	0.72	0.74	0.76	0.76	1.04	1.32	1.46
			log(C/Co)	-2.55	-2.25	-2.15	-2.14	-2.13	-2.12	-2.12	-1.98	-1.88	-1.84
	Well	15-18 m	microorg/L	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.05
			log(C/Co)	-4.76	-4.16	-3.97	-3.96	-3.94	-3.91	-3.91	-3.64	-3.43	-3.34
Ms K2 w5	Cell 1	0-3 m	microorg/L	1.19	2.38	2.98	3.89	5.73	8.03	8.03	8.77	9.99	10.59
			log(C/Co)	-1.92	-1.62	-1.53	-1.41	-1.24	-1.10	-1.10	-1.06	-1.00	-0.97
	Cell 2	3-6 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 3	6-9 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 4	9-12 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Cell 5	12-15 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
	Well	15-18 m	microorg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			log(C/Co)	*	*	*	*	*	*	*	*	*	*
Ms K2 w6	Cell 1	0-3 m	microorg/L	1.06	2.11	2.64	3.45	5.06	7.08	7.09	7.72	8.78	9.31
			log(C/Co)	-1.98	-1.68	-1.58	-1.46	-1.30	-1.15	-1.15	-1.11	-1.06	-1.03
	Cell 2	3-6 m	microorg/L	0.12	0.23	0.29	0.37	0.53	0.73	0.73	0.79	0.90	0.95
			log(C/Co)	-2.94	-2.64	-2.54	-2.43	-2.28	-2.14	-2.14	-2.10	-2.05	-2.02
	Cell 3	6-9 m	microorg/L	0.16	0.32	0.40	0.51	0.73	1.00	1.00	1.09	1.24	1.31
			log(C/Co)	-2.79	-2.50	-2.40	-2.29	-2.14	-2.00	-2.00	-1.96	-1.91	-1.88
	Cell 4	9-12 m	microorg/L	0.21	0.42	0.53	0.68	0.98	1.36	1.36	1.48	1.68	1.78
			log(C/Co)	-2.67	-2.37	-2.28	-2.17	-2.01	-1.87	-1.87	-1.83	-1.78	-1.75
	Cell 5	12-15 m	microorg/L	0.27	0.54	0.68	0.87	1.27	1.76	1.76	1.91	2.17	2.29
			log(C/Co)	-2.57	-2.27	-2.17	-2.06	-1.90	-1.76	-1.76	-1.72	-1.66	-1.64
	Well	15-18 m	microorg/L	0.00	0.00	0.01	0.01	0.02	0.05	0.05	0.06	0.07	0.08
			log(C/Co)	-4.95	-4.35	-4.16	-3.93	-3.60	-3.26	-3.26	-3.25	-3.14	-3.09

MS: MS2, w: well number

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