MATHEMATICAL MODELLING OF CONTAMINANT TRANSPORT IN RIVERBANK FILTRATION SYSTEMS

SHAYMAA M MUSTAFA

UNIVERSITI TEKNOLOGI MALAYSIA

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To my beloved parents, the strong and first teachers
To my brother and sisters, lightening hope candles in my life
To my dear husband and children, the source of peace and love everyday
To my country Palestine, the place that I will always sacrifice for

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ABSTRACT

Analytical study of contaminant transport in riverbank filtration (RBF) systems is significant in providing a guide for managing and operating drinking water supplies from pumping wells. The pumping process and the distance of the pumping well from the river are two important factors for producing permissible drinking water from the system. Simulation of the impact of pumping rate and pumping time on contaminant transport based on analytical studies are not yet extensive. Thus, there is a lack of mathematical models for RBF systems to determine the shortest distance of the pumping well to the river, that produces quality water. This research aimed to provide a mathematical model based on advection dispersion equation and Green's function approach to determine the potential effects of pumping rate and pumping time, on one and two-dimensional contaminant transport models in RBF systems. The model would be able to show how the pumping time and pumping rate affect the contaminant concentration in RBF systems. By considering an inverse problem, the Green's function solution was applied to the problem in order to determine the shortest distance from the pumping well to the river, to increase the percentage of the quality of river water. This distance was computed when the contaminants were released from a few scenario which include a single polluted river and two polluted rivers. The distance evaluated was based on three simulated scenarios containing the varying pumping times, pumping rates and different initial concentrations from the river. The model was assessed using parameters related to nitrate (NO_3) compound obtained from RBF pilot project which had been conducted in Malaysia. The results confirmed the suitability of the proposed model in simulating the effect of pumping process on the quality of the produced water and in locating the pumping well. The proposed model is helpful in providing guide to manage the existing RBF systems as well as in establishing new sites.

ABSTRAK

Kajian analitik pengaliran bahan tercemar di dalam sistem penapisan tebing sungai (RBF) penting dalam menyediakan panduan pengurusan dan pengendalian bekalan air minuman dari telaga berpam. Proses pengepaman dan jarak dari telaga berpam ke tebing sungai adalah dua faktor penting untuk menghasilkan air minuman yang dibenarkan. Simulasi impak kadar dan masa pengepaman terhadap pengaliran bahan cemar berdasarkan kajian analitik belum begitu menyeluruh. Dengan itu terdapat kekurangan model matematik untuk sistem RBF bagi menentukan jarak terdekat telaga berpam dari tebing sungai yang menghasilkan air yang berkualiti. Justeru, kajian ini bertujuan untuk menyediakan satu model matematik berdasarkan persamaan penyebaran aliran lintang dan pendekatan fungsi Green dalam menentukan kesan terhadap potensi kadar dan masa pengepaman dengan model satu dan dua dimensi dalam sistem RBF. Model ini akan menunjukkan bagaimana masa dan kadar pengepaman memberi kesan kepada kepekatan bahan cemar dalam sistem RBF. Dengan mempertimbangkan masalah songsang, penyelesaian fungsi Green digunakan dalam masalah ini bagi menentukan jarak terdekat telaga berpam dari tebing sungai yang dapat menghasilkan kualiti air sungai berperatusan tinggi. Jarak ini dikira apabila bahan cemar dilepaskan dari beberapa senario, kepada satu sungai dan dua sungai yang tercemar. Jarak yang dinilai adalah berdasarkan tiga kes simulasi termasuk masa pengepaman yang berbeza-beza, kadar pengepaman dan tahap awal kepekatan air yang berbeza dari sungai. Model ini dinilai menggunakan parameter yang berkaitan dengan sebatian nitrat (NO_3) daripada projek RBF yang telah dijalankan di Malaysia. Keputusan ini mengesahkan kesesuaian model yang dicadangkan dalam mensimulasikan kesan proses pengepaman terhadap kualiti air yang dihasilkan dan penempatan lokasi telaga berpam. Model yang dicadangkan amat berguna untuk menyediakan panduan untuk mengurus sistem RBF sedia ada dan juga dalam membangunkan lokasi baru.

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LIST OF ABBREVIATIONS

ADE - Advection dispersion equation
AEM - Analytical element method
BEM - Boundary element method
BVP - Boundary value problem
DBPs - Disinfection by-products
DOM - Dissolved organic matter
DW1 - The first pumping well in the study area
DW2 - The second pumping well in the study area
EFT - Exponential Fourier Transform
FDM - Finite Difference Method
FEflow - Finite Element subsurface FLOW system
FEM - Finite Element Method
FEMLAB - Software based on MATLAB for solving PDE via FEM
FLexPDE - A finite element model builder and numerical solver
HP1 - HYDRUS-PHREEQC-1D
HYDRUS-1D - Water, heat, and solute movement in 1D simulator
LBM - Lattice Boltzmann Method
MODFLOW - Modelling Groundwater Flow and Pollution software
MT3DMS - Modular Transport Three Dimensional Model Simulator
MMP - Modified moment propagation
ODE - ordinary differential equation
PAT - Pump and treat system
PDE - Partial differential equation
PHREEQC - pH-Redox-Equilibrium Calculator
PF - Pumping function
RBF - Riverbank filtration system
RC - Radial collector
RMSE - Root Mean Square Error
RT3D - Reactive Transport Three Dimensional Model
SDR - Stream depletion rate

TCE	-	Trichloroethylene
TOC	-	Total organic compound
WHO	-	World Health Organization
1D	-	One dimensional contaminants transport
2D	-	Two dimensional contaminants transport
3D	-	Three dimensional contaminants transport

LIST OF SYMBOLS

a	-	Dispersivity
b	-	Ratio of free sedimentation segment length to grain radius
C	-	Solute concentration
C_s	-	The maximum limit of contaminant concentration
C_0	-	Initial concentration for $x = 0$
D	-	Diffusivity of mass transport
D_x	-	Diffusivity in x direction
D_y	-	Diffusivity in y direction
d	-	Thickness of the streambed
d_c	-	Average grain size
erfc	-	Complementary error function
G	-	source/sink
h	-	Head
K	-	Hydraulic conductivity
K_{att}	-	Microbial attachment rate
K_{det}	-	Microbial detachment rate
K_r	-	Hydraulic conductivity of the river
K_x	-	Hydraulic conductivity in x direction
K_y	-	Hydraulic conductivity in y direction
K_z	-	Hydraulic conductivity in z direction
L	-	Distance of the pumping well from the river edge
L_T	-	The total distance between tow rivers
m_{ads}	-	Total mass adsorbed due to microbial activity
m_{in}	-	Total mass of contaminants released from the river
m_0	-	Contaminants concentration at the pumping well
N	-	The constant recharge rate of contaminant
NO_3	-	Nitrate
Q	-	Constant pumping rate of the pumping well
Q_n	-	Mass flux normal to the boundary surface
Q_m	-	Mass flux

$Q_{m_{adv}}$ - advection flux

$Q_{m_{dsp}}$ - Diffusion flux

q - Stream depletion flow rate

q_n - Water flux normal to the boundary surface

$\frac{q}{Q}$ - The proportion of river water at the pumping well

R - Retardation factor

r_0 - Radius of influence

r_w - Radius of the main pumping well

S_x - Specific storage

Δs - Water drawdown in pumping well

Δs_1 - Water drawdown in DW1 well

Δs_2 - Water drawdown in DW2 well

T - Transmissivity

t_1 - Travelling time of contaminants

t_2 - Pumping time period

U - Darcy velocity

U_s - Settling velocity of bacteria

U_x - Darcy velocity in x direction

U_y - Darcy velocity in y direction

U_z - Darcy velocity in z direction

W - Well function

w_r - Width of the river

x_{min} - The shortest distance of the pumping well from river edge

x_{min_c} - The shortest distance at the case of clogging

$\delta(x)$ - Dirac delta function

λ - Stream bed leak coefficient

ρ - Water density

ρ_b - Bulk density

ρ_s - Density of bacteria

ϕ - The effective porosity

β - Degradation rate

ε - Empirical correction factor

α_s - Sticking factor

η_0 - Collision factor

ℓ_T - Laplace Transformation

ξ - Fourier transform variable

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Aquifers occupy around 2.5% of freshwater on earth and only, less than 1% of Earth’s water can be found in lakes, rivers, or atmosphere layers (Figure 1.1) (Environment and climate change Canada, 2013). Despite this small percentage, many countries depend heavily, or often exclusively, on the river water as a source of clean water for agriculture and drinking water supplies. (Pimentel *et al.*, 2004; Kallioras *et al.*, 2006; Schwarzenbach *et al.*, 2010; Arie *et al.*, 2012).

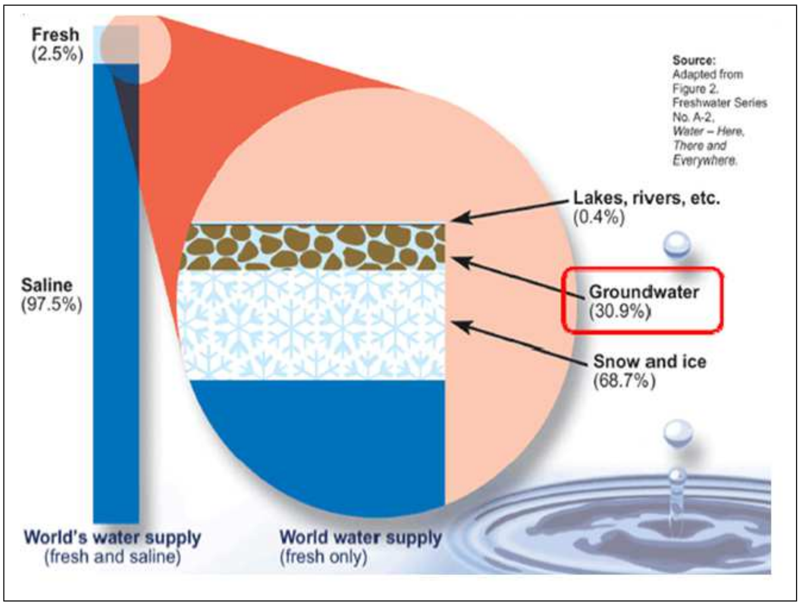

Figure 1.1: Groundwater and the world’s freshwater supply (Environment and climate change Canada, 2013)

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As a result of development and increasing of economic activities, the demand and the degree of contamination in raw water sources have significantly increased (Schwarzenbach *et al.*, 2010; Hogan, 2014; Juma *et al.*, 2014). The high demand of river water cannot be overcome by existing dams. In fact, building new dams is too expensive and causes negative impacts on the natural ecology. (Azhar, 2000). Additionally, the high levels of pollutants in river's water make it unsuitable for direct use, and affects the quantity of potable water supply, hence increases the river treatment cost. In the past decades, several water treatment plants in Malaysia have been closed as a result of high percentages of different kinds of pollutants in the rivers (Shamsuddin *et al.*, 2013). Moreover, the presence of contaminants in river water may cause detrimental effects on the environment, human health and crop productivity (Kan, 2009; Schwarzenbach *et al.*, 2010). Consequently, different diseases that can be fatal for individuals may occur. For example, the usage of agriculture fertilizers can cause contamination of river water by nitrates chemicals (Kowal and Polik, 1987). These compounds have harmful effects on human health, especially for infants, young children, elderly individuals, pregnant and nursing women (U.S. Environmental Protection Agency, 2009). For infants, the nitrate compounds can cause blue baby syndrome where the blood cannot properly carry oxygen (Comly, 1987; U.S. Environmental Protection Agency, 2009). This situation leads to infant death if there is no immediate medical attention. (Schwarzenbach *et al.*, 2010). Therefore, governments are making more efforts to solve surface water pollution problem and supplying healthy drinking water.

Most of river water treatment methods are generally based on pre-chlorination of river water before it is subjected to the treatment processes sequence (Singh *et al.*, 2010b). Chlorination is considered the most common, economical and simple chemical approach for river water treatment (Singh *et al.*, 2010b). However, chlorination of river water that is polluted by organics forms disinfection by-products (DBPs), thus its use is being controlled. Reducing or eliminating pre-chlorination and minimizing formation of DBPs by removing organics are regulatory requirements in developed countries. Riverbank filtration (RBF) is considered as one of the alternatives of the pre chlorination process that can be used to attenuate organic, microbial and other pollutants (Singh *et al.*, 2010b). Moreover, RBF is a sustainable approach for providing clean river's water and groundwater.

1.1.1 Riverbank filtration systems

A riverbank filtration system (RBF) is a natural technology for surface water treatment. Instead of using chemicals to treat water directly after obtaining it from the river, the infiltrated water can be extracted from one or a system of pumping wells adjacent to the stream (Hiscock and Grischek, 2002; Ray, 2002; Maliva and Missimer, 2012). RBF systems have the advantage of natural degradation of contaminants from river water during its passage through the aquifer. The contaminants are removed due to chemical, physical and biological processes that occur in riverbed sediments. The movement of water from the river to the surrounding aquifer can occur naturally or induced by using pumping wells. The pumping process lowers the pressure (head) in the aquifer and river bed sediments, which creates a difference in hydraulic gradients between surface water and the aquifer. This difference in the hydraulic head will induce the water to move from the river towards the pumping well. (Figure 1.2). The downward flow of water into the underlying aquifer caused by pumping process is called an induced infiltration or induced recharge (Maliva and Missimer, 2012).

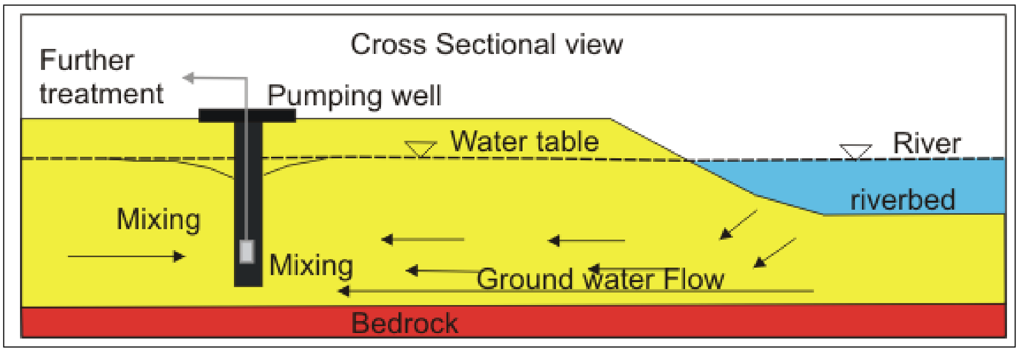

Figure 1.2: A simple river bank filtration system (modified from (Kim *et al.*, 2003))

The major advantage of RBF technology is that it can produce better quality of water with lower cost treatment than other river water treatment methods (Dalai and Jha, 2014). Using conventional river water treatment methods incur higher costs where it requires higher volumes of chemicals particularly with higher contaminant concentrations. Additionally, the volume of DBPs that is added to river water to eliminate microbial contamination is also high. On the other hand, reducing the pre-treatment requirements by using RBF technology lowers the operational costs (Maliva and Missimer, 2012; Dalai and Jha, 2014). Basically, RBF system can serve as the final treatment just before disinfection. However, sometimes additional treatment may be needed before water distributed. This can be determined according to the quality of the produced water. As a minimum, RBF systems can act as a pre-treatment step for drinking water production (Maliva and Missimer, 2012; Ray, 2002).

In general, RBF systems have no harmful effects on surrounding environments. This technique can reduce the concentrations of particulates (suspended solids, turbidity), pathogens, Gardai, dissolved organic carbon, and many (but not all) organic and inorganic compounds (Maliva and Missimer, 2012).

Many previous modelling studies had described 1D, 2D and 3D contaminant transport in aquifer (Pantelis, 1988; Doussan *et al.*, 1997; Neupauer and Wilson, 1999, 2001; Kim *et al.*, 2003; Kim, 2005; Massab *et al.*, 2006; Connell, 2007; Chen, 2010; Praveena and Aris, 2010; Singh *et al.*, 2010a; Chen *et al.*, 2012; Singh *et al.*, 2012; Malaguerra *et al.*, 2013; Singh, 2013; Chen *et al.*, 2015). Some of these studies were concerned about the effect of microbial activity on solute transport, but without considering the role of groundwater pumping (Doussan *et al.*, 1997; Kim *et al.*, 2003; Kim, 2005). Also, most of the models that described the impact of pumping process on solute transport were based on numerical modelling (Wail and Hatamleh, 2007; Belcher and Sweetkind, 2004; Ghoraba *et al.*, 2013; Yang *et al.*, 2011; Zhou and Li, 2011). Precisely, modelling groundwater flow and pollution software (MODFLOW) that was developed by McDonald and Harbaugh (1988) is the most used software by researchers for this purpose (Zhou and Li, 2011). Analytical models are considered as valuable tools for investigating solute transport in porous media and for verifying the numerical solutions due to its accuracy and simplicity (Leij and van Genuchten, 2000). Besides, Green's function approach can facilitate the analytical solution for 1D or 2D contaminant transport equation in uniform porous media with unsteady flow. This is due to its simplicity in solving multi-dimensional problems and flexibility in dealing with arbitrary initial and boundary conditions (Leij and van Genuchten, 2000). This method had been implemented previously by many researchers to investigate contaminant transport (Chen and Woodside, 1988; Adams and Viramontes, 1993; Leij *et al.*, 1993; Leij and van Genuchten, 2000; Park and Zhan, 2001). Some of these studies were concerned solely on contaminant transport without any adsorption or degradation (Chen and Woodside, 1988), while some other studies focused on natural contaminant movement without any effect of pumping well (Leij and van Genuchten, 2000; Park and Zhan, 2001). Furthermore, some researchers simulated the radial transport of pollutants towards a single, fully penetrating pumping well using Green's function method (Adams and Viramontes, 1993).

Managing and planning to establish new RBF projects has a wide variety of previous important decisions that should be taken before starting to establish the new site. One of these decisions is the RBF design selection that includes: the type of the aquifer, the well type and location. Regarding aquifer type, most of the RBF systems around the world (e.g. Canada, northern Europe and the northern United States) were established in confined aquifers (Maliva and Missimer, 2012) which is bounded both at the top and bottom by impervious or semi impervious layers, thus hydraulically isolated from other geological formations. This kind of aquifers is often preferred to bank filtrate so as to prevent contaminants seeping from the surface due to its disconnection with the surface (Malaguerra *et al.*, 2013). For the well type, a variety of different well technologies can be used in RBF systems including: vertical wells, horizontal or inclined wells and collector wells (Ranney collectors)(Maliva and Missimer, 2012) based on the hydrological properties of site and river, cost and the amount of infiltrated water needed to be supplied (Yeh and Chang, 2013). The radial collector well is a central well with horizontal sections of screened collector pipe called laterals and arranged radially to increase yield. The radial orientation of laterals in radial collector wells (RC) leads to unsteady groundwater flow inside the laterals. For calculating the location of pumping well, the three-dimensional finite-difference ground-water model is one of the most popular available techniques that can be used for this purpose. This technique is available in MODFLOW software which is widely used in such groundwater models to simulate steady-state or transient flow in confined or/and unconfined aquifers (McDonald and Harbaugh, 1988). However, MODFLOW was developed to capture the groundwater flow, not to determine the pumping well location. Therefore, it is required to develop an analytical model to determine the distance between the river and production well in order to get high percentage of infiltrating river water that satisfies the quality requirements of chemical contaminant concentration. Despite the strong relation between distance and contaminant concentration, most of the previous studies did not concerned about calculating the shortest distance of the pumping well from river edge. (Abdel-Fattah *et al.*, 2008; Shankar *et al.*, 2009; Orban *et al.*, 2010).

An improved understanding of contaminants behavior, and the factors controlling their transport in RBF systems, is important in planning and managing RBF sites. The pumping process is one of the crucial factors that could change subsurface water behavior. In particular, increasing the pumping rate leads to an increase in groundwater flow velocity. Consequently, the travelling time required by pollutants to reach the well may be decreased, which may raise the contamination in the area around the well. To assess the influence of pumping well on pollutant transport successfully, various means, such as mathematical modelling, are required. Despite the significance of Green's function method, most of the Green's function models in groundwater did not consider the effects of both pumping time and pumping rate on contaminant transport.

About the well location, it should be drilled within a suitable distance from the river. At this distance, the produced river water satisfies the quality requirements of contaminant removal which is sufficiently fresh for potable supplies. Depending on the two factors: the degree of contamination in the produced water and the expected river infiltration rate, the wells should be drilled within a suitable distance from the river. The values of these two factors will increase when the well is close to the river, accordingly starts to decline by increasing distance from the river (Dillon *et al.*, 2002). So, it is necessary to calculate the shortest location of the pumping well from the river to have potable water for public use. At this location, higher percentage of infiltrating river water can be obtained, at which the water drawdown inside the well is expected to be less.

The problem of determining the location of the well becomes more difficult if there is another polluted river on the opposite side. Any location for the well may not be adjacent to only one river, but sometimes it may be located between two polluted rivers. In this case, the well location should be adjusted in a suitable place between the river and the other pollution source. So, the previous analytical model is needed to be enhanced to specify the best location to drill the well between the two rivers. At this distance, the water produced from the well is expected to be with high quality and have a high percentage of infiltrating river water.

1.2 Research objectives

In this study, we used the Green's function approach and we extended the contaminant transport model which was based on the advection dispersion equation. The model was developed for different purposes:

1. To determine the effect of pumping well on one and two dimensional contaminant transport in RBF systems
2. To calculate the shortest distance of the pumping well from the river edge to produce water that satisfies the quality requirements of contaminant concentration.

3 To calculate the nearest location of the pumping well from river edge, taking into consideration the existence of other rivers in the opposite side.

Finally, the model was applied by using RBF pilot project parameters which had been conducted in Malaysia.

1.3 Research scope

The current study was concerned about three major RBF problems: one and two dimensional contaminant transport under the influence of pumping well, the shortest distance of the pumping well from the river edge, and; the shortest location of pumping well to the river edge by considering the existence of another polluted rivers. These problems were solved in this research by using the mathematical modelling techniques. The models were developed based on advection dispersion equation for solute transport and solved by using Green's function approach. The confined homogeneous and isotropic aquifer was chosen in our research, since it is preferred and common in RBF sites. Also, the study focused on the sandy and gravelly alluvial aquifer. This type of aquifer was common in RBF sites due to its ability to contain excessive amounts of water. The effects of initial contaminant concentration at the river and hydraulic conductivity on contaminant transport was also investigated. The models were applied and tested with data related to the nitrates NO_3 compound. Data were taken from the first RBF pilot project conducted in Malaysia (Shamsuddin *et al.*, 2013, 2014), because of the abundance of data from this site.

1.4 Research significance

RBF technique is one of the best solutions for surface water pollution, which provides better water quality with lower costs (Maliva and Missimer, 2012). By solving the first problem, it is then can be used to determine the effect of pumping process on contaminant transport. In particular, we can investigate to what extent the pumping rate and the pumping period affect the pumped water quality. Consequently, the pumping process can be managed carefully to produce water meet the quality requirements as long as possible.

Solving the second and third problem is helpful mainly in managing and building a new RBF site. It helps to decide locating the pumping well if there are one or two polluted rivers. This will lower the cost without losing time and efforts. This decision will be taken based on the quality degree of pumped water and the percentage of infiltrating river water. Based on our knowledge, there is no model developed before that can help to specify the well location.

Moreover, completing the objectives of this research can save a lot of effort and time that will consume in collecting data and monitoring water quality (Wexler, 1992). Also, this model can be verified by the industrial and engineering communities and be used for their relevant applications in groundwater systems.

1.5 Thesis organization

The present study was organized into eight Chapters and two Appendices. The first chapter gave a general background on: surface water pollution, types and sources of pollution, attenuation processes implemented for its control and prevention and RBF system. Also, it produced an overview of RBF system including its definition, efficiency, design, its importance comparable with other conventional water treatment approaches. This background was followed by the problem statements, objectives of this research, the scope of the present study and the significance of the research.

The second chapter was a general literature review. This review covers most of the previous mathematical models which were developed for RBF problems. This included the basic RBF subjects described by these models, main governing equations, different analytical and numerical solutions and comparison between these models.

The third chapter described the methodology used in this study, and the details of the analytical approaches implemented to achieve the research objectives. The fourth and fifth chapters presented the analytical models developed in this study to simulate the influence of pumping well on one and two-dimensional contaminant transport respectively. Also, the sensitivity analysis results for different pumping time, and rates were presented.

The sixth and seventh Chapters produced the theoretical calculations and the results of the developing models obtained to determine the shortest distance from pumping well to the river edge. In chapter 6, the distance was calculated when the river was the only source of contaminant while in chapter 7 we considered the existence of other sources. The conclusion and the future work of this study were given in the eighth chapter.

This thesis included two Appendices: Appendix A produced the derivation of the basic physical laws and equation implemented in this study. Appendix B showed the main papers that have been published /accepted/submitted in journals and presented in international conferences.

REFERENCES

Abdel-Fattah, A., Langford, R. and Schulze-Makuch, D. (2008). Applications of particle-tracking techniques to bank infiltration: a case study from El Paso, Texas, USA. *Environmental Geology*. 55(3), 505–515. ISSN 0943-0105. doi:10.1007/s00254-007-0996-z.

Adams, T. A. and Viramontes, R. C. (1993). *Analytical Modeling of Aquifer Decontamination by Pulsed Pumping When Contaminant Transport is Affected by Rate-Limited Sorption and Desorption*. Master's thesis. Air force institute of technology wright-patterson air force base, Ohio school of engineering, USA.

Akosman, C., Özdemİr, T. *et al.* (2010). Adsorption dynamics and equilibrium studies of nitrate onto various soils. *Fresenius Environmental Bulletin*. 19(10), 2246–2252.

Alhuri, Y., Ouazar, D. and Taik, A. (2011). Comparison between local and global Mesh-free methods for Ground-Water modeling. *International Journal of Computer Science Issues*. 8(2). ISSN 2333-9721.

Allan, F. M. and Elnajjar, E. (2012). The Role of Mathematical Modeling in Understanding the Groundwater Pollution. *International Journal of Thermal and Environmental Engineering*. 4(2), 171–176.

Alvarez, P. J. J. and Illman, W. A. (2005). *Fundamentals of Groundwater Flow and Contaminant Transport Processes*. John Wiley Sons, Inc., USA. ISBN 9780471738626. doi:10.1002/047173862X.ch4.

Ameli, A. A. (2014). *Semi-analytical methods for simulating the groundwater-surface water interface*. Ph.D. Thesis. University of Waterloo.

Anderson, E. I. (2005). Modeling groundwatersurface water interactions using the Dupuit approximation. *Advances in Water Resources*. 28(4), 315 – 327. ISSN 0309-1708. doi:http://dx.doi.org/10.1016/j.advwatres.2004.11.007.

Anderson, E. I. (2013). Stable pumping rates for horizontal wells in bank filtration systems. *Advances in Water Resources*. 54(0), 57 – 66. ISSN 0309-1708. doi:10.1016/j.advwatres.2012.12.012.

Aniszewski, A. (2009). Mathematical modeling and practical verification of groundwater and contaminant transport in a chosen natural aquifer. *Acta*

Geophysica. 57(2), 435–453. ISSN 1895-6572. doi:10.2478/s11600-008-0080-4.

Arie, D. R., Faycal, B., Andrea, S. P., Bernard, B., Ine, V., Sarah, M., Peter, S., Marco, P., Hector, Z., Vera, T., Alessandra, B. and Carlo, L. (2012). *Current water resources in Europe and Africa - Matching water supply and water demand*. Eur scientific and technical research reports. Joint research center, Institute for Environment and Sustainability, Italy. doi:10.2788/16108.

Ataie-Ashtiani, B. and Hosseini, S. (2005a). Error analysis of finite difference methods for two-dimensional advectiondispersionreaction equation. *Advances in Water Resources*. 28(8), 793 – 806. ISSN 0309-1708. doi:https://doi.org/10.1016/j.advwatres.2005.02.003.

Ataie-Ashtiani, B. and Hosseini, S. (2005b). Numerical errors of explicit finite difference approximation for two-dimensional solute transport equation with linear sorption. *Environmental Modelling and Software*. 20(7), 817–826.

Ataie-Ashtiani, B., Lockington, D. and Volker, R. (1999). Truncation errors in finite difference models for solute transport equation with first-order reaction. *Journal of contaminant hydrology*. 35(4), 409–428.

Avila, M. (2005). *Experiment and Modelling of the Competitive Sorption and Transport of Chlorinated Ethenes in Porous Media*. Cuvillier Verlag, Germany. ISBN 9783865376060.

Azhar, M. (2000). Managing Malaysian water resources development. *Jurnal Kesihatan Masyarakat*. 6(S), 40–58.

Baalousha, H. M. (2012). Drawdown and stream depletion induced by a nearby pumping well. *Journal of Hydrology*. 466467(0), 47 – 59. ISSN 0022-1694. doi:10.1016/j.jhydrol.2012.08.010.

Bakker, M. (2010). Hydraulic modeling of riverbank filtration systems with curved boundaries using analytic elements and series solutions. *Advances in Water Resources*. 33(8), 813–819.

Bakker, M., Kelson, V. A. and Luther, K. H. (2005). Multilayer Analytic Element Modeling of Radial Collector Wells. *Ground Water*. 43(6), 926–934. ISSN 1745-6584. doi:10.1111/j.1745-6584.2005.00116.x.

Banzhaf, S., Krein, A. and Scheytt, T. (2011). Investigative approaches to determine exchange processes in the hyporheic zone of a low permeability riverbank. *Hydrogeology Journal*. 19(3), 591–601.

Batu, V. (2005). *Applied Flow and Solute Transport Modeling in Aquifers: Fundamental Principles and Analytical and Numerical Methods*. (1st ed.). CRC

Press, Taylor and Francis group, USA.

Becker, B. P., Jansen, M., Sinaba, B. P. and Schüttrumpf, H. (2015). On the Modeling of Bank Storage in a Groundwater Model: The April, 1983, Flood Event in the Neuwieder Becken (Middle Rhine). *Water*. 7(3), 1173–1201.

Belcher, W. R. and Sweetkind, D. S. (2004). *Death Valley regional groundwater flow system, Nevada and California-Hydrogeologic framework and transient groundwater flow model*. Technical Report 5205. US Geological Survey,Scientific Investigations Report, USA.

Bender, C. M. and Orszag, S. A. (1999). *Advanced mathematical methods for scientists and engineers I*. Springer Science and Business Media.

Bergvall, M., Grip, H., Sjöström, J. and Laudon, H. (2011). Modeling subsurface transport in extensive glaciofluvial and littoral sediments to remediate a municipal drinking water aquifer. *Hydrology and Earth System Sciences*. 15(7), 2229–2244. doi:10.5194/hess-15-2229-2011.

Birch, S., Donahue, R., W Biggar, K. and C Sego, D. (2007). Prediction of flow rates for potable water supply from directionally drilled horizontal wells in river sediments. *Journal of Environmental Engineering and Science*. 6(2), 231–245.

Bischoff, H. (1981). An integral equation method to solve three dimensional confined flow to drainage systems. *Applied Mathematical Modelling*. 5(6), 399 – 404. ISSN 0307-904X. doi:10.1016/S0307-904X(81)80020-0.

Bishnoi, K., Kansal, M. L. and Mishra, G. (2016). Flow to a collector pipe laid under a stream bed. *ISH Journal of Hydraulic Engineering*. 22(1), 100–108. doi:10.1080/09715010.2015.1088410.

Bloetscher, F., Locke, N., VanAllen, T. and Muniz, A. (2014). A Managers Paradigm: Too Much Water and Limited Water Supplies. *Florida Water Resource Journal*. 64(5), 29–40.

Brunner, P., Simmons, C. T., Cook, P. G. and Therrien, R. (2010). Modeling Surface Water-Groundwater Interaction with MODFLOW: Some Considerations. *Ground Water*. 48, 174–180. doi:10.1111/j.1745-6584.2009.00644.x.

Butler Jr, J. J. (1997). *The design, performance, and analysis of slug tests*. CRC press.

Buzek, F., Kadlecova, R., Jackova, I. and Lnenickova, Z. (2012). Nitrate transport in the unsaturated zone: a case study of the riverbank filtration system Karany, Czech Republic. *Hydrological Processes*. 26(5), 640–651. ISSN 1099-1085. doi:10.1002/hyp.8165.

Carslaw, H. S. and Jaeger, J. C. (1986). *Conduction of Heat in Solids*. (2nd ed.). Oxford University Press, Newyork.

Causon, D. M. and Mingham, C. G. (2010). *Introductory Finite Difference Methods for PDEs*. Ventus Publishing ApS, Denmark.

Chaudhari, N. M. *et al.* (1971). An improved numerical technique for solving multidimensional miscible displacement equations. *Society of Petroleum Engineers Journal*. 11(03), 277–284.

Chen, C., Wan, J. and Zhan, H. (2003). Theoretical and experimental studies of coupled seepage-pipe flow to a horizontal well. *Journal of Hydrology*. 281(12), 159 – 171. ISSN 0022-1694. doi:10.1016/S0022-1694(03)00207-5.

Chen, C.-S. and Woodside, G. D. (1988). Analytical solution for aquifer decontamination by pumping. *Water Resources Research*. 24(8), 1329–1338. doi: 10.1029/WR024i008p01329.

Chen, J.-S. (2010). Analytical model for fully three-dimensional radial dispersion in a finite-thickness aquifer. *Hydrological Processes*. 24(7), 934–945. ISSN 1099-1085. doi:10.1002/hyp.7541.

Chen, J.-S., Chen, J.-T., Liu, C.-W., Liang, C.-P. and Lin, C.-W. (2011). Analytical solutions to two-dimensional advectiondispersion equation in cylindrical coordinates in finite domain subject to first- and third-type inlet boundary conditions. *Journal of Hydrology*. 405(34), 522 – 531. ISSN 0022-1694. doi:10.1016/j.jhydrol.2011.06.002.

Chen, J.-S., Lai, K.-H., Liu, C.-W. and Ni, C.-F. (2012). A novel method for analytically solving multi-species advectivedispersive transport equations sequentially coupled with first-order decay reactions. *Journal of Hydrology*. 420-421, 191 – 204. ISSN 0022-1694. doi:10.1016/j.jhydrol.2011.12.001.

Chen, W.-B., Liu, W.-C., Hsu, M.-H. and Hwang, C.-C. (2015). Modeling investigation of suspended sediment transport in a tidal estuary using a three-dimensional model. *Applied Mathematical Modelling*. 39(9), 2570–2586.

Chen, Y., Xie, H., Ke, H. and Chen, R. (2009). An analytical solution for one-dimensional contaminant diffusion through multi-layered system and its applications. *Environmental Geology*. 58(5), 1083–1094. ISSN 0943-0105. doi: 10.1007/s00254-008-1587-3.

Chesnaux, R. and Allen, D. (2008). Groundwater travel times for unconfined island aquifers bounded by freshwater or seawater. *Hydrogeology Journal*. 16(3), 437–445.

Christensen, S., Zlotnik, V. A. and Tartakovsky, D. M. (2009). Optimal design of pumping tests in leaky aquifers for stream depletion analysis. *Journal of Hydrology*. 375(3-4), 554–565. doi:10.1016/j.jhydrol.2009.07.006.

Comly, H. H. (1987). Cyanosis in infants caused by nitrates in well water. *The journal of American Medical Association (JAMA)*. 257(20), 2788–2792.

Connell, L. (2007). Simple models for subsurface solute transport that combine unsaturated and saturated zone pathways. *Journal of Hydrology*. 332(34), 361 – 373. ISSN 0022-1694. doi:1016/j.jhydrol.2006.07.007.

Corapcioglu, M. Y. and Haridas, A. (1985). Microbial transport in soils and groundwater: A numerical model. *Advances in Water Resources*. 8(4), 188 – 200. ISSN 0309-1708. doi:10.1016/0309-1708(85)90063-6.

Dalai, C. and Jha, R. (2014). Review on Water Treatment Techniques Used for Riverbank Filtration. *International Journal of Civil Engineering Research*. 5(3), 221–226. ISSN 2278-3652.

Dash, R., Bhanu Prakash, E., Kumar, P., Mehrotra, I., Sandhu, C. and Grischek, T. (2010). River bank filtration in Haridwar, India: removal of turbidity, organics and bacteria. *Hydrogeology Journal*. 18(4), 973–983. ISSN 1431-2174. doi:10.1007/s10040-010-0574-4.

De Vet, W., Van Genuchten, C., Van Loosdrecht, M. and Van Dijk, J. (2010). Water quality and treatment of river bank filtrate. *Drinking Water Engineering and Science*. 3(1), 79–90.

Debrine, B. E. (1970). Electrolytic model study for collector wells under river beds. *Water Resources Research*. 6(3), 971–978.

Department of Standards Malaysia (2010). *Malaysian Standard: Drinking water-quality requirements*. Technical Report MS 2320:2010. Department of Standards Malaysia.

Dillon, P., Miller, M., Fallowfield, H. and Hutson, J. (2002). The potential of riverbank filtration for drinking water supplies in relation to microsystin removal in brackish aquifers. *Journal of Hydrology*. 266(34), 209 – 221. ISSN 0022-1694. doi:10.1016/S0022-1694(02)00166-X.

Doussan, C., Ledoux, E. and Detay, M. (1998). River-Groundwater Exchanges, Bank Filtration, and Groundwater Quality: Ammonium Behavior. *Journal of Environmental Quality*. 27(6), 1418–1427. doi:10.2134/jeq1998.00472425002700060019x.

Doussan, C., Poitevin, G., Ledoux, E. and Detay, M. (1997). River bank filtration: modelling of the changes in water chemistry with emphasis on nitrogen species.

Journal of Contaminant Hydrology. 25(12), 129 – 156. ISSN 0169-7722. doi: 10.1016/S0169-7722(96)00024-1.

Environment and climate change Canada (2013). *Water resources- Groundwater*.

Fallico, C. (2014). Reconsideration at field scale of the relationship between hydraulic conductivity and porosity: the case of a sandy aquifer in South Italy. *The Scientific World Journal*. 2014.

Faulkner, B. R., Olivas, Y., Ware, M. W., Roberts, M. G., Groves, J. F., Bates, K. S. and McCarty, S. L. (2010). Removal efficiencies and attachment coefficients for Cryptosporidium in sandy alluvial riverbank sediment. *Water Research*. 44(9), 2725 – 2734. ISSN 0043-1354. doi:10.1016/j.watres.2010.02.001.

Fetter, C. (1993). *Contaminant Hydrogeology*. Macmillan Publishing Company, Newyork. ISBN 9780023371356.

Fox, G. A., DuChateau, P. and Dumford, D. S. (2002). Analytical Model for Aquifer Response Incorporating Distributed Stream Leakage. *Ground Water*. 40(4), 378–384. ISSN 1745-6584. doi:10.1111/j.1745-6584.2002.tb02516.x.

Ghoraba, S., Zyedan, B. and Rashwan, I. (2013). Solute transport modeling of the groundwater for quaternary aquifer quality management in Middle Delta, Egypt. *Alexandria Engineering Journal*. 52(2), 197 – 207. ISSN 1110-0168. doi:10.1016/j.aej.2012.12.007.

Ghosh, N. C., Mishra, G. C., Sandhu, C. S. S., Grischek, T. and Singh, V. V. (2015). Interaction of Aquifer and River-Canal Network near Well Field. *Groundwater*. 53(5), 794–805. ISSN 1745-6584. doi:10.1111/gwat.12274.

Glover, R. E. and Balmer, G. G. (1954). River depletion resulting from pumping a well near a river. *Eos, Transactions American Geophysical Union*. 35(3), 468–470. ISSN 2324-9250. doi:10.1029/TR035i003p00468.

Griebling, S. A. and Neupauer, R. M. (2013). Adjoint modeling of stream depletion in groundwater-surface water systems. *Water Resources Research*. 49(8), 4971–4984. ISSN 1944-7973. doi:10.1002/wrcr.20385.

Grischek, T., Schoenheinz, D. and Ray, C. (2003). Siting and Design Issues for Riverbank Filtration Schemes. In Ray, C., Melin, G. and Linsky, R. (Eds.) *Riverbank Filtration*. (pp. 291–302). *Water Science and Technology Library*, vol. 43. Springer Netherlands. ISBN 978-1-4020-1133-7. doi:10.1007/0-306-48154-5_15.

Hantush, M. and Papadopulos, I. (1962). Flow of ground water to collector wells. *Journal of the Hydraulics Division*. 88(5), 221–244.

Harvey, R. W., Metge, D. W., Kinner, N. and Mayberry, N. (1997). Physiological

Considerations in Applying Laboratory-Determined Buoyant Densities to Predictions of Bacterial and Protozoan Transport in Groundwater: Results of In-Situ and Laboratory Tests. *Environmental Science and Technology*. 31(1), 289–295. doi: 10.1021/es960461d.

Heath, R. C. (1983). *Basic ground-water hydrology*. vol. 2220. US Geological Survey.

Hiscock, K. and Grischek, T. (2002). Attenuation of groundwater pollution by bank filtration. *Journal of Hydrology*. 266(34), 139 – 144. ISSN 0022-1694. doi:10.1016/S0022-1694(02)00158-0.

Hogan, C. (2014). *Water pollution*. Technical report. The encyclopedia of Earth.

Holzbecher, E. (2006). Calculating the effect of natural attenuation during bank filtration. *Computers Geosciences*. 32(9), 1451 – 1460. ISSN 0098-3004. doi: 10.1016/j.cageo.2006.01.009.

Hoppe-Jones, C., Oldham, G. and Drewes, J. E. (2010). Attenuation of total organic carbon and unregulated trace organic chemicals in U.S. riverbank filtration systems. *Water Research*. 44(15), 4643 – 4659. ISSN 0043-1354. doi:10.1016/j.watres.2010.06.022.

Horner, C., Holzbecher, E. and Ntzmann, G. (2007). A coupled transport and reaction model for long column experiments simulating bank filtration. *Hydrological Processes*. 21(8), 1015–1025. ISSN 1099-1085. doi:10.1002/hyp.6276.

Huang, C. S., Chen, J. J. and Yeh, H. D. (2016). Approximate analysis of three-dimensional groundwater flow toward a radial collector well in a finite-extent unconfined aquifer. *Hydrology and Earth System Sciences*. 20(1), 55–71.

Huang, C.-S., Chen, Y.-L. and Yeh, H.-D. (2011). A general analytical solution for flow to a single horizontal well by Fourier and Laplace transforms. *Advances in Water Resources*. 34(5), 640 – 648. ISSN 0309-1708. doi:10.1016/j.advwatres.2011.02.015.

Huang, J., Christ, J. A. and Goltz, M. N. (2008). An Assembly Model for Simulation of Large-Scale Ground Water Flow and Transport. *Ground Water*. 46(6), 882–892. ISSN 1745-6584. doi:10.1111/j.1745-6584.2008.00484.x.

Huisman, L. (1972). *Groundwater recovery*. (First american edition ed.). No. 978-0876910726 in Macmillan civil engineering hydraulics. Macmillan Press Ltd.,London.

Huisman, L. and Olsthoorn, T. (1984). *Artificial groundwater recharge*. *Pitman Research Notes in Mathematics Series*, vol. 7. Pitman Advanced Publishing Program, London.

Hunt, B. (1999). Unsteady Stream Depletion from Ground Water Pumping. *Ground Water*. 37(1), 98–102. ISSN 1745-6584. doi:10.1111/j.1745-6584.1999.tb00962.x.

Hunt, B. (2008). Stream Depletion for Streams and Aquifers with Finite Widths. *Journal of Hydrologic Engineering*. 13(2), 80–89. doi:10.1061/(ASCE) 1084-0699(2008)13:2(80).

Hunt, B. (2009). Stream Depletion in a Two-Layer Leaky Aquifer System. *Journal of Hydrologic Engineering*. 14(9), 895–903. doi:10.1061/(ASCE)HE.1943-5584. 0000063.

Intaraprasong, T. and Zhan, H. (2009). A general framework of streamaquifer interaction caused by variable stream stages. *Journal of Hydrology*. 373(12), 112 – 121. ISSN 0022-1694. doi:10.1016/j.jhydrol.2009.04.016.

Istok, J. D. and Dawson, K. J. (1991). *Aquifer testing: design and analysis of pumping and slug tests*. CRC Press.

Jenkins, C. T. (1968). Techniques for Computing Rate and Volume of Stream Depletion by Wellsa. *Ground Water*. 6(2), 37–46. ISSN 1745-6584. doi: 10.1111/j.1745-6584.1968.tb01641.x.

Juma, D. W., Wang, H. and Li, F. (2014). Impacts of population growth and economic development on water quality of a lake: case study of Lake Victoria Kenya water. *Environmental Science and Pollution Research*. 21(8), 5737–5746.

Kallioras, A., Pliakas, F. and Diamantis, I. (2006). The legislative framework and policy for the water resources management of transboundary rivers in Europe: the case of Nestos/Mesta River, between Greece and Bulgaria. *Environmental Science Policy*. 9(3), 291 – 301. ISSN 1462-9011. doi:10.1016/j.envsci.2005.12.001.

Kan, H. (2009). Environment and health in China: challenges and opportunities. *Environmental health perspectives*. 117(12), A530.

Kim, S.-B. (2005). Contaminant transport and biodegradation in saturated porous media: model development and simulation. *Hydrological Processes*. 19(20), 4069–4079. ISSN 1099-1085. doi:10.1002/hyp.5872.

Kim, S.-B. (2006). Numerical analysis of bacterial transport in saturated porous media. *Hydrological processes*. 20(5), 1177–1186.

Kim, S.-B., Corapcioglu, M. Y. and Kim, D.-J. (2003). Effect of dissolved organic matter and bacteria on contaminant transport in riverbank filtration. *Journal of Contaminant Hydrology*. 66(12), 1 – 23. ISSN 0169-7722. doi:10.1016/ S0169-7722(03)00025-1.

Kowal, A. and Polik, A. (1987). Nitrates in Groundwater. In De Waal, K. and

Van Den Brink, W. (Eds.) *Environmental Technology*. (pp. 604–609). Springer Netherlands. ISBN 978-94-010-8139-9. doi:10.1007/978-94-009-3663-8_73.

Kruseman, G. P., Ridder, N. A. *et al.* (1990). *Analysis and evaluation of pumping test data.* 47. International Institute for Land Reclamation and Improvement,The Netherlands.

Kuo, Y.-C., Huang, L.-H. and Tsai, T.-L. (2008). A hybrid three-dimensional computational model of groundwater solute transport in heterogeneous media. *Water Resources Research*. 44(3), n/a–n/a. ISSN 1944-7973. doi:10.1029/2007WR006084.

Lantz, R. *et al.* (1971). Quantitative evaluation of numerical diffusion (truncation error). *Society of Petroleum Engineers Journal*. 11(03), 315–320.

Leij, F. and van Genuchten, M. (2000). Analytical Modeling of Nonaqueous Phase Liquid Dissolution with Green's Functions. *Transport in Porous Media*. 38(1-2), 141–166. ISSN 0169-3913. doi:10.1023/A:1006611200487.

Leij, F. J., Priesack, E. and Schaap, M. G. (2000). Solute transport modeled with Green's functions with application to persistent solute sources. *Journal of Contaminant Hydrology*. 41(12), 155 – 173. ISSN 0169-7722. doi:10.1016/S0169-7722(99)00062-5.

Leij, F. J., Toride, N. and van Genuchten, M. T. (1993). Analytical solutions for non-equilibrium solute transport in three-dimensional porous media. *Journal of Hydrology*. 151(24), 193 – 228. ISSN 0022-1694. doi:10.1016/0022-1694(93)90236-3.

Lim, J.-W., Bae, G.-O. and Lee, K.-K. (2009). Groundwater vulnerability assessment by determining maximum contaminant loading limit in the vicinity of pumping wells. *Geosciences Journal*. 13(1), 79–85.

Lin, L., Yang, J.-Z., Zhang, B. and Zhu, Y. (2010). A simplified numerical model of 3-D groundwater and solute transport at large scale area. *Journal of Hydrodynamics, Ser. B*. 22(3), 319 – 328. ISSN 1001-6058. doi:10.1016/S1001-6058(09)60061-5.

Lovanh, N., Zhang, Y.-K., Heathcote, R. C. and Alvarez, P. J. (2000). Guidelines to determine site-specific parameters for modeling the fate and transport of monoaromatic hydrocarbons in groundwater. *report submitted to the Iowa Comprehensive Petroleum Underground Storage Tank Fund Board, University of Iowa, Iowa City, Iowa.*

Malaguerra, F., Albrechtsen, H.-J. and Binning, P. J. (2013). Assessment of the contamination of drinking water supply wells by pesticides from surface water resources using a finite element reactive transport model and global sensitivity analysis techniques. *Journal of Hydrology*. 476(0), 321 – 331. ISSN 0022-1694. doi:10.1016/j.jhydrol.2012.11.010.

Maliva, R. and Missimer, T. (2012). Riverbank Filtration. In *Arid Lands Water Evaluation and Management*. (pp. 631–645). Environmental Science and Engineering. Springer Berlin Heidelberg. ISBN 978-3-642-29103-6. doi:10.1007/978-3-642-29104-3_24.

Massab, M., Cianci, R. and Paladino, O. (2006). Some analytical solutions for two-dimensional convectiondispersion equation in cylindrical geometry. *Environmental Modelling Software*. 21(5), 681 – 688. ISSN 1364-8152. doi:10.1016/j.envsoft.2004.12.003.

McDonald, M. and Harbaugh, A. (1988). *A modular three-dimensional finite-difference ground-water flow model*. Techniques of Water-Resources Investigations of the United States Geological Survey.

Meenal, M. and Eldho, T. (2012). Simulationoptimization model for groundwater contamination remediation using meshfree point collocation method and particle swarm optimization. *Sadhana*. 37(3), 351–369. ISSN 0256-2499. doi:10.1007/s12046-012-0086-0.

Mikołajków, J. (2010). Laboratory methods of estimating the retardation factor of migrating mineral nitrogen compounds in shallow groundwater. *Geological Quarterly*. 47(1), 91–96.

Morway, E. D., Niswonger, R. G., Langevin, C. D., Bailey, R. T. and Healy, R. W. (2013). Modeling Variably Saturated Subsurface Solute Transport with MODFLOW-UZF and MT3DMS. *Groundwater*. 51(2), 237–251. ISSN 1745-6584. doi:10.1111/j.1745-6584.2012.00971.x.

Müller, B., Scheytt, T., Zippel, M., Hannappel, S., Klein-Goedicke, J. and Duscher, K. (2011). A New Approach to Calculate EMEAs Predicted Environmental Concentration for Human Pharmaceuticals in Groundwater at Bank Filtration Sites. *Water, Air, Soil Pollution*. 217(1-4), 67–82. ISSN 0049-6979. doi:10.1007/s11270-010-0568-9.

Murphy, E. M. and Ginn, T. R. (2000). Modeling microbial processes in porous media. *Hydrogeology Journal*. 8(1), 142–158. ISSN 1431-2174. doi:10.1007/s100409900043.

Natarajan, N. and Kumar, G. S. (2011). Numerical modeling of bacteria facilitated contaminant transport in fractured porous media. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 387(13), 104 – 112. ISSN 0927-7757. doi:10.1016/j.colsurfa.2011.07.037.

Neupauer, R. M. and Wilson, J. L. (1999). Adjoint method for obtaining backward-in-time location and travel time probabilities of a conservative groundwater contaminant. *Water Resources Research*. 35(11), 3389–3398. ISSN 1944-7973. doi:10.1029/1999WR900190.

Neupauer, R. M. and Wilson, J. L. (2001). Adjoint-derived location and travel time probabilities for a multidimensional groundwater system. *Water Resources Research*. 37(6), 1657–1668.

Oosterbaan, R. and Nijland, H. (2006). Determining the Saturated Hydraulic Conductivity. In Ritzema, H. (Ed.) *Drainage principles and applications*. (pp. 283–294). 16. ILRI, chap. 12.

Orban, P., Brouyre, S., Batlle-Aguilar, J., Couturier, J., Goderniaux, P., Leroy, M., Maloszewski, P. and Dassargues, A. (2010). Regional transport modelling for nitrate trend assessment and forecasting in a chalk aquifer. *Journal of Contaminant Hydrology*. 118(12), 79 – 93. ISSN 0169-7722. doi:10.1016/j.jconhyd.2010.08.008.

Pantelis, G. (1988). A large-time saturated-unsaturated water and contaminant transport model in unconfined aquifers. *Applied Mathematical Modelling*. 12(4), 362–365.

Park, E. and Zhan, H. (2001). Analytical solutions of contaminant transport from finite one-, two-, and three-dimensional sources in a finite-thickness aquifer. *Journal of Contaminant Hydrology*. 53(12), 41 – 61. ISSN 0169-7722. doi:10.1016/S0169-7722(01)00136-X.

Patel, H., Eldho, T. and Rastogi, A. (2010). Simulation of Radial Collector Well in Shallow Alluvial Riverbed Aquifer Using Analytic Element Method. *Journal of Irrigation and Drainage Engineering*. 136(2), 107–119. doi:10.1061/(ASCE)IR.1943-4774.0000141.

Pimentel, D., Berger, B., Filiberto, D., Newton, M., Wolfe, B., Karabinakis, E., Clark, S., Poon, E., Abbett, E. and Nandagopal, S. (2004). Water Resources: Agricultural and Environmental Issues. *BioScience*. 54(10), 909–918. doi:10.1641/0006-3568(2004)054[0909:WRAAEI]2.0.CO;2.

Polomčić, D., Bajić, D. and Zarić, J. (2015). Determining the Groundwater Balance and Radius of Influence Using Hydrodynamic Modeling: Case Study of the Groundwater Source Šumice in Serbia. *Journal of Sustainable Development of Energy, Water and Environment Systems*. 3(3), 217–229.

Pozrikidis, C. (2002). *Boundary-element methods for Laplaces equation in two dimensions. A Practical Guide to Boundary Element Methods with the Software Library BEMLIB*. CRC Press, Taylor and Francis group, USA.

Praveena, S. M. and Aris, A. Z. (2010). Groundwater resources assessment using numerical model: A case study in low-lying coastal area. *International Journal of Environmental Science & Technology*. 7(1), 135–146.

Rao, S. S. (2005). *The Finite Element Method in Engineering*. (Fourth edition ed.). Burlington: Butterworth-Heinemann. ISBN 978-0-7506-7828-5. doi: 10.1016/B978-075067828-5/50000-7.

Ray, C. (2002). Conclusions and Recommendations of the NATO Advanced Research Workshop: Contaminant Biogeochemistry and Pathogen Removal Efficiency. In Ray, C. (Ed.) *Riverbank Filtration: Understanding Contaminant Biogeochemistry and Pathogen Removal*. (pp. 247–250). *NATO Science Series*, vol. 14. Springer Netherlands. ISBN 978-1-4020-0955-6. doi:10.1007/978-94-010-0479-4_13.

Razzak, A., Jinno, K., Hiroshiro, Y., Abdul Halim, M. and Oda, K. (2009). Mathematical modeling of biologically mediated redox processes of iron and arsenic release in groundwater. *Environmental Geology*. 58(3), 459–469. ISSN 0943-0105. doi:10.1007/s00254-008-1517-4.

Richard, B. and Gabriel, C. (2009). *Schaum's Outline of Differential Equations*, McGraw Hill Professional, Access Engineering, vol. 636, chap. 21: The Laplace Transform. (4th ed.), 178–242.

Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., von Gunten, U. and Wehrli, B. (2010). Global Water Pollution and Human Health. *Annual Review of Environment and Resources*. 35(1), 109–136. doi:10.1146/annurev-environ-100809-125342.

Sen, T. K., Das, D., Khilar, K. C. and Suraishkumar, G. (2005). Bacterial transport in porous media: New aspects of the mathematical model. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 260(13), 53 – 62. ISSN 0927-7757. doi:10.1016/j.colsurfa.2005.02.033.

Shamsuddin, M., Sulaiman, W., Suratman, S., Zakaria, M. and Samuding, K. (2013). Conjunctive use of surface water and groundwater via the bank infiltration method. *Arabian Journal of Geosciences*. 7(9), 3731–3753. ISSN 1866-7511. doi:10.1007/s12517-013-1036-9.

Shamsuddin, M. and Suratman, S. (2011). *Study On Groundwater Optimisation In Jenderam Hiller, Dengikil, Selangor*. Technical Report NAHRIM/PKG/2/2011. National Hydraulic Research Institute of Malaysia. doi:10.1007/s12517-013-1036-9.

Shamsuddin, M., Suratman, S., Zakaria, M., Aris, A. and Sulaiman, W. (2014). Particle tracking analysis of riveraquifer interaction via bank infiltration techniques. *Environmental Earth Sciences*. 72(8), 3129–3142. ISSN 1866-6280. doi:10.1007/s12665-014-3217-6.

Shankar, V., Eckert, P., Ojha, C. and Knig, C. M. (2009). Transient Three-dimensional Modeling of Riverbank Filtration at Grind Well Field, Germany. *Hydrogeology Journal 17.2*. 17(2), 321–26.

Singh, M., Ahamad, S. and Singh, V. (2012). Analytical Solution for One-Dimensional Solute Dispersion with Time-Dependent Source Concentration along Uniform Groundwater Flow in a Homogeneous Porous Formation. *Journal of Engineering Mechanics*. 138(8), 1045–1056. doi:10.1061/(ASCE)EM.1943-7889.0000384.

Singh, M., Mahato, N. and Kumar, P. (2011). Comparative Study of Analytical Solutions for Time-Dependent Solute Transport Along Unsteady Groundwater Flow in Semi-infinite Aquifer. *International Journal of Geosciences*. 2(4), 457–467. doi: 10.4236/ijg.2011.24048.

Singh, M., Singh, P. and Singh, V. (2010a). Analytical Solution for Two-Dimensional Solute Transport in Finite Aquifer with Time-Dependent Source Concentration. *Journal of Engineering Mechanics*. 136(10), 1309–1315. doi:10.1061/(ASCE)EM. 1943-7889.0000177.

Singh, P., Kumar, P., Mehrotra, I. and Grischek, T. (2010b). Impact of riverbank filtration on treatment of polluted river water. *Journal of Environmental Management*. 91(5), 1055 – 1062. ISSN 0301-4797. doi:10.1016/j.jenvman.2009. 11.013.

Singh, R. (2013). Advection diffusion equation models in near-surface geophysical and environmental sciences. *Journal of Indian Geophysical Union*. 17, 117–127.

Smedt, F. D. (2009). Groudwater Hydrology, course notes. *Free University Brussel, Brussel*.

Steward, D. R. and Jin, W. (2001). Gaining and losing sections of horizontal wells. *Water Resources Research*. 37(11), 2677–2685.

Strack, O. (1999). Principles of the analytic element method. *Journal of Hydrology*. 226(34), 128 – 138. ISSN 0022-1694. doi:10.1016/S0022-1694(99)00144-4.

Strack, O. D. (1995). A Dupuit-Forchheimer Model for three-dimensional flow with variable density. *Water Resources Research*. 31(12), 3007–3017.

Tan, Y. f. and Zhou, Z.-f. (2008). Simulation of solute transport in a parallel single fracture with LBM/MMP mixed method. *Journal of Hydrodynamics, Ser. B*. 20(3), 365 – 372. ISSN 1001-6058. doi:10.1016/S1001-6058(08)60069-4.

Thakur, A. K., Ojha, C. S. P., Singh, V. P., Gurjar, B. R. and Sandhu, C. (2013). Removal of Pathogens by River Bank Filtration at Haridwar, India. *Hydrological Processes*. 27(11), 1535–1542. ISSN 1099-1085. doi:10.1002/hyp.9301.

Theis, C. V. (1935). The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. *Transactions, American Geophysical Union*. 16, 519–524.

Theis, C. V. (1941). The effect of a well on the flow of a nearby stream. *Transactions, American Geophysical Union*. 22, 734–738. doi:10.1029/TR022i003p00734.

Tournoud, M.-G., Perrin, J.-L., Gimbert, F. and Picot, B. (2005). Spatial evolution of nitrogen and phosphorus loads along a small Mediterranean river: implication of bed sediments. *Hydrological Processes*. 19(18), 3581–3592. ISSN 1099-1085. doi:10.1002/hyp.5848.

Tufenkji, N. (2007). Modeling microbial transport in porous media: Traditional approaches and recent developments. *Advances in Water Resources*. 30(67), 1455 – 1469. ISSN 0309-1708. doi:10.1016/j.advwatres.2006.05.014.

U.S. Environmental Protection Agency (December 2009). *Water on Tap: What You Need to Know*. Technical report.

Wail, Y. A. E. S. and Hatamleh, R. I. (2007). Using Modflow and MT3D Groundwater Flow and Transport Models As a Management Tool for the Azraq Groundwater System. *Jordan Journal of Civil Engineering*. 1(2).

Wang, H., Han, R., Zhao, Y., Lu, W. and Zhang, Y. (2011). Stepwise superposition approximation approach for analytical solutions with non-zero initial concentration using existing solutions of zero initial concentration in contaminate transport. *Journal of Environmental Sciences*. 23(6), 923 – 930. ISSN 1001-0742. doi: 10.1016/S1001-0742(10)60486-X.

Wang, P., Pozdniakov, S. P. and Shestakov, V. M. (2015). Optimum experimental design of a monitoring network for parameter identification at riverbank well fields. *Journal of Hydrology*. 523, 531 – 541. ISSN 0022-1694. doi:10.1016/j.jhydrol.2015.02.004.

Wexler, E. J. (1992). *Analytical solutions for one-, two-, and three-dimensional solute transport in ground-water systems with uniform flow*. US Government Printing Office.

WHO (2008). *Guidelines for drinking-water quality: recommendations*. vol. 1. World Health Organization.

Wolfgang. Kuehn, U. M. (2000). Riverbank Filtration: An Overview. *American Water Works Association*. 92, 60–69.

Yang, Q., Lun, W. and Fang, Y. (2011). Numerical Modeling of Three Dimension Groundwater Flow in Tongliao (China). *Procedia Engineering*. 24, 638 – 642.

ISSN 1877-7058. doi:10.1016/j.proeng.2011.11.2709. International Conference on Advances in Engineering 2011.

Yeh, H.-D. and Chang, Y.-C. (2013). Recent advances in modeling of well hydraulics. *Advances in Water Resources*. 51(0), 27 – 51. ISSN 0309-1708. doi:10.1016/j.advwatres.2012.03.006.

Zhan, H. and Park, E. (2003). Horizontal well hydraulics in leaky aquifers. *Journal of Hydrology*. 281(12), 129 – 146. ISSN 0022-1694. doi:10.1016/S0022-1694(03)00205-1.

Zhan, H. and Zlotnik, V. A. (2002). Groundwater flow to a horizontal or slanted well in an unconfined aquifer. *Water Resources Research*. 38(7), 13–1–13–11. ISSN 1944-7973. doi:10.1029/2001WR000401.

Zheng, C. (1992). *MT3D: A modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems*. SS Papadopulos & Associates.

Zheng, C. and Bennett, G. (2002). *Applied Contaminant Transport Modeling: Theory and Practice*. (2nd ed.). Wiley. ISBN 978-0471384779.

Zhou, Y. and Li, W. (2011). A review of regional groundwater flow modeling. *Geoscience Frontiers*. 2(2), 205 – 214. ISSN 1674-9871. doi:10.1016/j.gsf.2011.03.003.

Zhu, Y., Shi, L., Yang, J., Wu, J. and Mao, D. (2013). Coupling methodology and application of a fully integrated model for contaminant transport in the subsurface system. *Journal of Hydrology*. 501(0), 56 – 72. ISSN 0022-1694. doi:10.1016/j.jhydrol.2013.07.038.

Zlotnik, V. and Tartakovsky, D. (2008). Stream Depletion by Groundwater Pumping in Leaky Aquifers. *Journal of Hydrologic Engineering*. 13(2), 43–50. doi:10.1061/(ASCE)1084-0699(2008)13:2(43).