An-Najah National University

Faculty of Graduate Studies

General Characterization of Groundwater Aquifer in Al-Faria Catchment by Using a Tracer-based Methodology

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Dedication

I dedicate this thesis to my beloved mother and father, my sisters, and my friends.

Acknowledgments

First of all, praise be to Allah for helping me to bring this work into being. I would like to express my sincere gratitude to Dr. Marwan Haddad for his supervision, guidance and constructive advice. Special thanks also go to my defense committee: Dr. Sameer Shadeed, Dr. Abdel Fattah Al-Mallah, and Dr. Fathi Anayah.

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

General Characterization of Groundwater Aquifer in Al-Faria Catchment by Using a Tracer-based Methodology

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تم الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم لنيل أي درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name:	**اسم الطالب:**
Signature	**التوقيع:**
Date:	**التاريخ:**

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General Characterization of Groundwater Aquifer in Al-Faria Catchment Using a Tracer-based Methodology

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Abstract

Groundwater is the most dependable water resource in Palestine. Characterising groundwater is the primary tool towards its integrated management. Al-Faria catchment is considered an indispensable groundwater resource in the north-eastern part of the West Bank, Palestine, since it supplies domestic inhabitants, their livestock, and the agricultural lands with needed amounts of water. The quality of groundwater in the catchment is affected by the untreated wastewater disposal and the runoff from the adjacent agricultural lands. This research aims at gaining a better understanding of groundwater hydraulic properties in Al-Faria catchment. It paves the way for further future research which aims to study the interaction between surface water and groundwater. A single-well injection withdrawal tracer test using Uranine tracer was applied to determine the seepage velocity and the effective porosity of the unconfined Neogene sub-aquifer. Data were obtained by conducting two tracer experiment tests during the wet and the dry seasons of 2012/2013. Breakthrough curves that show the recovered tracer concentration over time were constructed for each experiment. The main difference between the two tracer-based conducted tests on the selected wells was the existence of non-uniform pumping rates from nearby wells. The breakthrough curve for the wet season showed a progressive recovery of tracer with the highest peak reached after 54 minutes of pumping. The breakthrough curve for the dry season showed three and almost equal successive peaks at the 18th, 26th, and 36th minutes of pumping. Results showed high values of seepage velocity in the tested sub-aquifer. The calculated seepage velocity and the effective porosity of the tested well in the wet season were 9.2 meter/day and 4.3% respectively. The test in the dry season gave no clear results for the tested properties. The effect of the non-uniform pumping rates from the nearby wells of the tested well in the dry season caused the tracer to disperse into different directions with different gradients. The applied test was more efficient when conducted in the wet season; this result can be attributed to the intensive pumping of the many adjacent wells in the catchment which cannot be easily controlled.

Finally, this research served as a preliminary work which paves the way for further groundwater tracer tests in the catchment; it should be stated that there is no previous experience in using the technique of single well injection withdrawal in this catchment.

Chapter One

Introduction

1.1 Background

Tracer testing has been introduced as one of the most effective tools in quantifying groundwater movement. It can be defined as the injection of a conservative material into the subsurface in order to simulate the flow and storage properties of the aquifer or to identify groundwater pathways. Tracer testing provides real data about groundwater behaviour that can be used to delineate drainage basins, identify groundwater flow paths, and groundwater velocities, dispersion, and storage (Hall, 1996). In addition, it can be used to check water exchange between rivers and groundwater in what is called surface water/groundwater interactions (Goldscheider et al., 2008).

The tracer tests were used in Al-Faria catchment, which lies within the Eastern Aquifer Basin, one of the three major groundwater aquifers forming West Bank groundwater resources. The nature of Eastern aquifer attributes by dolomite and limestones (TAHAL, 1963). Wells in Al-Faria catchment are drilled in four sub-aquifers. These sub-aquifers are Eocene, Cenomanian, Neogene and Pleistocene.

Many studies were conducted in Al-Faria catchment to study the hydrology of the catchment. Those studies made it one of the rich data catchment in the country. But unfortunately, not many researches were conducted in the catchment to study hydrogeological characteristics. In 1999, Dr. Ghanem finished his PhD research about “Hydrogeology and Hydrochemistry of the

Faria Drainage Basin/West Bank”. Ghanem’s research was one of the primary resources which informed this study. Many data about the catchment’s agricultural wells, pumping tests, and hydraulic conductivity data are obtained from this thesis. In addition, column experiment was conducted in a trial to check hydraulic conductivity of unsaturated soil of Neogen sub-aquifer.

Finally, The thesis focused on using tracer tests to check hydraulic properties of Neogene sub-aquifer. The significance of this study lies in the fact that there were no previous tracer researches done in the catchment to test the properties of groundwater using tracer technology. Many important results were obtained about the catchment’s suitability for such kinds of tests.

1.2 Research Motivations

This research is motivated by the following:

1. Lack of reliable data for hydraulic properties of groundwater in Al-Faria catchment. No tangible experimental data are available up to the date this research was conducted.
2. No previous experiences are available about using tracer applications in the catchment, especially for the purpose of investigating groundwater movement in the aquifers.
3. This research provides a good basis for conducting such tracer experiments in the future at Al-Faria catchment.

1.3 Goal and Objectives

The goal of this research is to collect scientifically sound evidence that can be used to characterize the hydraulic properties of groundwater available in the Neogene sub-aquifer in Al-Faria catchment.

In light of the above, the following objectives were achieved in the study:

- Groundwater characteristics (seepage velocity and effective porosity) were evaluated for two agricultural wells in the Neogene sub-aquifer using SWIW tracer test.
- Column experiment was done to get hydraulic conductivity of the Neogene unsaturated soil.

1.4 Research Methodology

. The main bulk of the research was geared towards conducting a SWIW tracer test is applied. The test has an advantage of using the same well for injection and monitoring. It can achieve the objectives of the research with less anticipated problems. The initial research procedure was modified due to technical difficulties and the unexpected costs of the proposed tracer test. The difficulties of the initial proposals are summarized in Section (5.3). Figure (1.3) shows the methodology which was followed in this research.

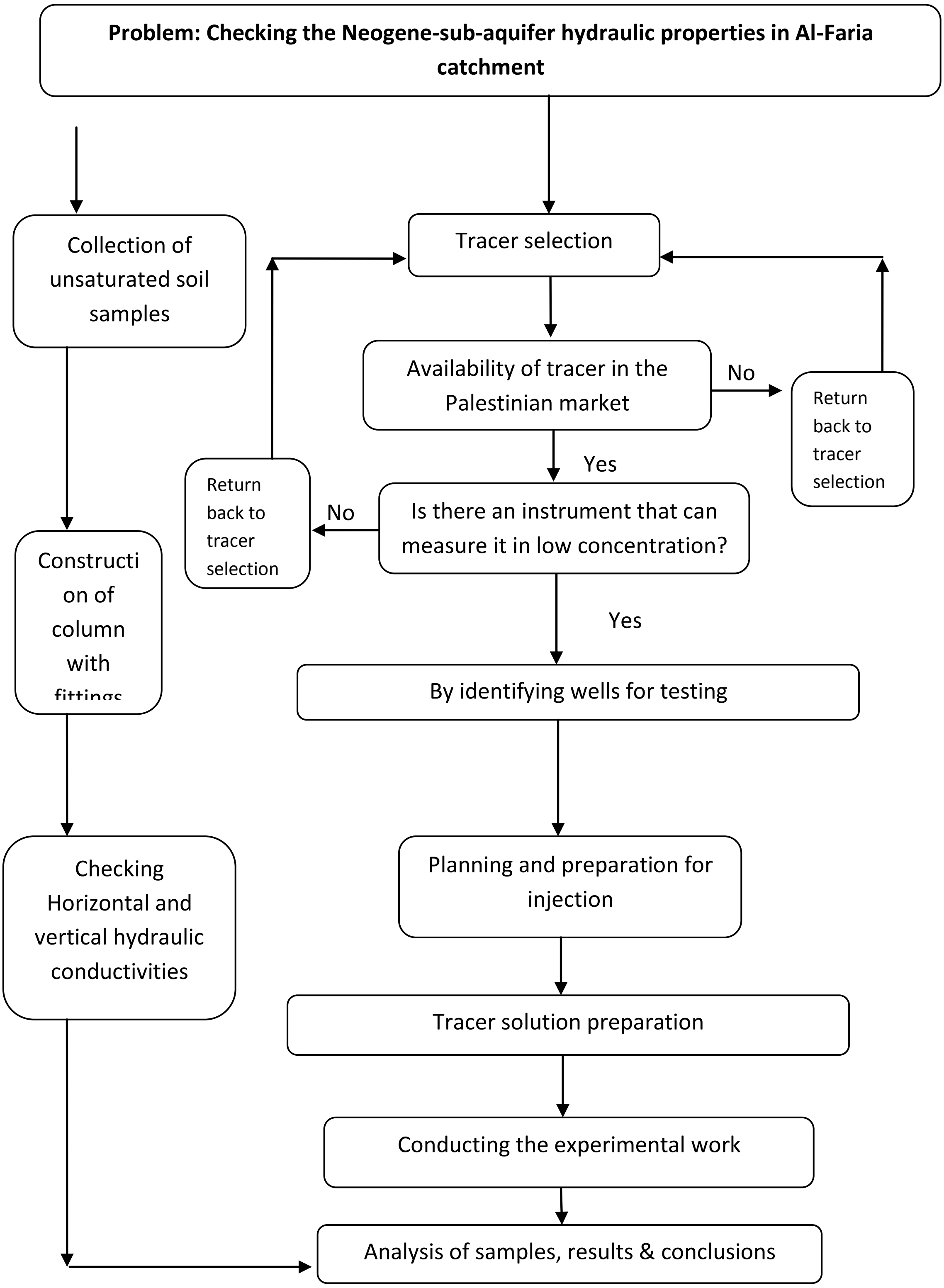


Figure 1.1: The research methodology

Chapter Two

Literature review

2.1 Artificial Tracers

Artificial tracers are widely used in groundwater tracer tests. They obtain information about groundwater pathways, seepage velocity, diffusivity and effective porosity. The main benefits from using the artificial tracers are the following:

1. Tracing the groundwater to check pathways and the connectivity of springs with recharge areas.
2. Determining the hydraulic parameters of aquifers such as groundwater seepage velocity.
3. Providing useful information for better management of groundwater resources and for enhancing pollution protection.

The artificial tracer injection has a scale limitation on time and place and can produce information for specific part of the system within time of experiment. Normally, artificial tracers are commonly used in experiments that have a residence time not more than one year. They come in two main groups: solute tracers and fluorescent dyes tracers. Fluorescent dyes tracers are considered the most popular groundwater tracers. They are very similar in their behaviour in groundwater tracing to the ideal tracers. Ideal tracers and their properties will be discussed in Section 2.2. Table (2.1) depicts artificial tracers' classifications and a few examples for each group.

Table 2.1: List of artificial tracers and their groups (Leibundgut et al., 2009)

Artificial Tracers Groups					
Fluorescence tracers	Naphtionate	Pyranine	Uranine	Eosine	Rhodamines
Salts	Sodium/potassium chloride	Sodium/ potassium bromide	Lithium chloride	Potassium iodide	Sodium borate (borax)

Many groundwater resources refer to the ideal tracer. So, what is the ideal tracer? And does it exist? In fact, there is no such thing as an ideal tracer. But there are tracers which are described as ideal tracers due to their proximity to ideal tracers' properties. These properties will be discussed in Section 2.2.

2.2 Tracer Selection

The ideal tracers are those preservative, non-toxic materials which have physical and chemical structure that lets them to travel with groundwater in such a manner that allows for measuring the needed parameter of the test. They also have the advantage of low detection limit. Table (2.2) describes the specific characteristics of ideal tracers.

Table 2.2: Characteristics of ideal tracers (Weight, 2008)

Characteristic	**Ideality**
Toxicity	Non-toxic to the handlers, to the ecosystem, and to potential consumers of the traced water.
Solubility	Soluble in water with the resulting solution having approximately the same density as water
Physical features	Neutral in buoyancy and, in the case of particulate tracers, sufficiently small to avoid excessive losses by natural filtration.
Measurement	Unambiguously detectable in very small concentrations.

pH resistance	Resistant to adsorptive loss, cation exchange, photochemical decay, and quenching by natural effects such as pH change and temperature variation.
Cost	Available and reasonably inexpensive

Ideal tracer characteristics adequately meet the principal fluorescent tracer dyes as mentioned before in section 2.1. The advantages that make fluorescent tracer dyes close to ideal tracer behaviour are the following:

1- Simple analysis;

2- Low detection limit;

3- Small quantity of tracer needed in field experiment;

4- Preferred for linearity of calibration curve; and

5- Their toxicity is very low (some of them are non-toxic).

The fluorescent dyes are synthetic organic compounds that absorb light at specific wavelengths and emit fluorescence light at longer wavelengths. This optical property results in very low analytical detection limits. Table (2.3) provides additional information on fluorescent dyes.

Table 2.3: Fluorescent dyes information (Leibundgut et al., 2009).

Commercial name	**Compound class**	**Generic name**	**Chemical formula**
Naphthionate "Naphtionate Sodium-salt"	Aminonaphtalen-sulfonic acid	NA	$C_{10}H_8NNaO_3S$
Pyranine "D&C Green 8"	Anthraquinone	Solvent Green	$C_{16}H_7NaO_{10}S_3$
Uranine "Sodium-fluorescein, D&CYellow7"	Xanthene	Acid Yellow 73	$C_{20}H_{10}O_5Na_2$

Eosine "Eosine Yellow"	Xanthene	Acid Red 87	$C_{20}H_6Br_4NaO_5$
Amidorhodamine G	Xanthene	Acid Red 50	$C_{25}H_{25}N_2NaO_7S_2$
Sulforhodamine B	Xanthene	Acid Red 52	$C_{27}H_{29}N_2NaO_7S_2$
Rhodamine B	Xanthene	BasicViolet 10	$C_{28}H_{31}ClN_2O_3$
Rhodamine WT	Xanthene	Acid Red 388	$C_{29}H_{29}N_2NaO_5$

For many applications, the green fluorescent dye Uranine (Sodium fluorescein) is a preferred groundwater tracer, as it is highly soluble, inexpensive, toxicologically safe, and has an extremely low detection limit of ~0.005 μg/L (Leibundgut et al., 2009). The flourometer instrument can be used to measure Uranine dye with very low detection limits. This advantage makes it possible to use small quantities of dye and thus it decreases the cost of tracer test. Among other fluorescent dyes, Uranine has the best characteristics which make it close to the ideal tracer behaviour. Uranine reacts very sensitively to pH values below the neutral range. The best intensity measurements of Uranine were taken in pH range of 6.9-10.4 (Leibundgut et al., 2009).

The water samples taken from many agricultural wells in Al-Faria catchment between 2011 and 2013 show pH measurements above neutral (Shadeed et al., 2011). This limits the likelihood of the water acidity problem of Uranine in tracer tests. In addition, the fluorescent dyes have good solubility in water. Uranine and Eosine have the best solubility among the others.

However, Uranine has three main disadvantages: 1) fast and linear photolytic decay, 2) degrading in organic-rich environments, and 3) being undetectable in acidic water. Due to these disadvantages, Uranine is not selected for use to trace the Al-Faria stream which is rich in organics from the wastewater discharges. Additionally, the Uranine will experience photolytic decay in strong sun light. Thus, using the Uranine in tracing the groundwater in Al-Faria catchment will ignore the disadvantages of photolytic decay and organic-rich environment.

Following this study of the advantages, disadvantages and other relevant data about Fluorescent dyes, Uranine “Sodium fluorescein” ($C_{20}H_{10}Na_2O_5$; Acid Yellow 73; CAS number 518-47-8) was selected for a tracer. Uranine is an orange powder that turns to bright green and yellow colour when small quantities are mixed with water. Precaution is recommended when working with the powdered form of tracer because of skin and respiratory irritation. Uranine tracer is available in the Palestinian market as a powder with purity of 99%. Each 500 gram of Uranine tracer approximately cost $200. Table (2.4) shows a summary of all factors that were used to compare between fluorescent dyes.

Table 2.4: Summary of fluorescent tracers’ characteristics (Leibundgut et al. 2009).

Tracer	**Relative fluorescence yield**	**Detection limit (ppb)**	**Toxicity**	**Solubility (20 ºC)**	**Light sensitivity**
Naphthionate	18	0.2	Harmless	240	High
Pyranine	18	0.06	Harmless	350	High
Uranine	**100**	**0.001**	**Harmless**	300	High
Eosine	11.4	0.01	Harmless	300	Very high
Amidorhodamine G	32	0.005	High concentration	3	Low
Rhodamine B	9.5	0.02	Toxic	(3-20)	Low
Rhodamine WT	10	0.02	Toxic	(3-20)	Very low

Suforhodamine B	7	0.03	High concentration	10	Low

The fluorometer instrument can measure the Uranine by 0.01 mg/m^3 [Test is available in the Faculty of science at An-Najah National University]. Figure (2.1) shows one of the available measuring instruments in the University laboratories.

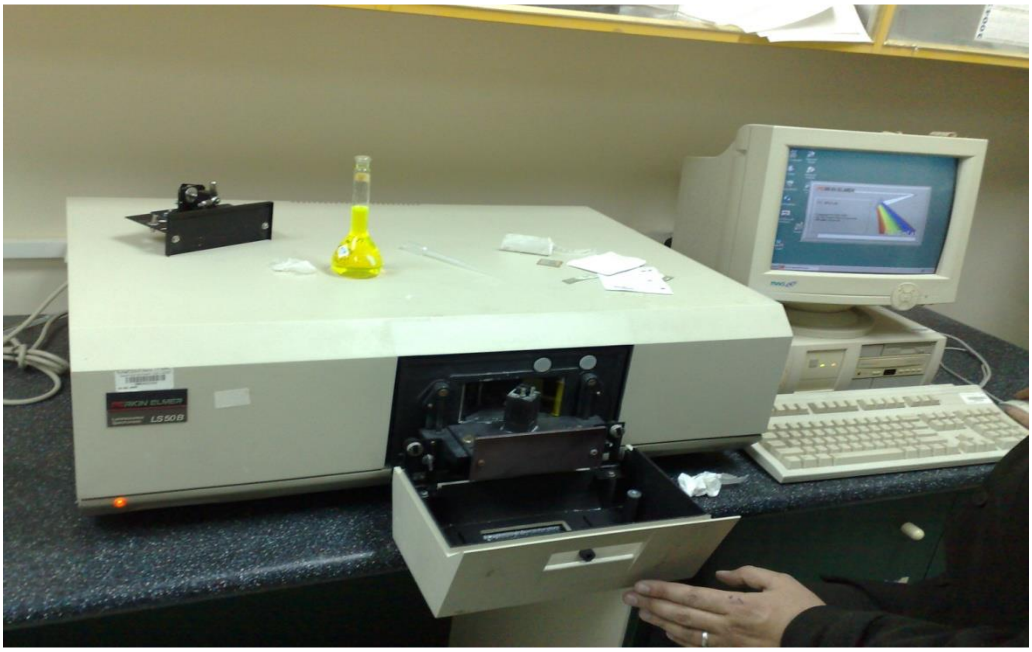


Figure 2.1: Fluorometer instrument in An-Najah National University laboratories

2.3 Uranine Preparation for Injection

In order to increase the solubility of Uranine, it should first be dissolved in alcohol (5 L alcohol/1kg Uranine); or in ammonia at (0.25 L ammonia/1kg Uranine), or in sodium hydroxide (NaOH). The optimal solution for dye testing is obtained if Uranine is dissolved in 7% NaOH with a 1:2 proportion. This means that when 10 kgs of Uranine are dissolved, a solution of 20 L is obtained. About 1.4 kg of solid NaOH should be added to 20 L of water (Milanović, 1981).

2.4 Injection Tools and Sampling Bottles

Many tools can be used in doing the tracer tests. They differ in their function and importance. The sample bottle type is considered as one of the important things in the tracer test. Due to the decay sensitivity of Uranine when it is exposed to light, a special type of bottles can be used to minimize the photosynthetic decay of Uranine. This type of bottles is produced from amber glass which has a dark brown colour. Amber glass bottles are reusable after good washing with alcohol solution. It is important to be sure that the bottles' tops have a tight seal screw. This type of bottles is better than the plastic ones which may adsorb tracer dye and disturb sample concentration. A sample of 50 mL volume is sufficient to do the analysis. The following items are the list of tools which can be used in tracer tests:

- Funnel
- Plastic pipe
- Amber glass sampling bottles (50 mL)
- Labels and timer
- Bags for saving and collecting samples
- Bucket and mixing stick
- Safety glasses to protect the eyes from the powder of the tracer dye

2.5 Tracer Injection Types

Slug and constant rate injection types are viewed as the main tracer injection mechanisms in tracer tests. These mechanisms depend on the purpose of the tracer experiment, and each one has its own applications.

The following is brief explanation for the main injection mechanisms.

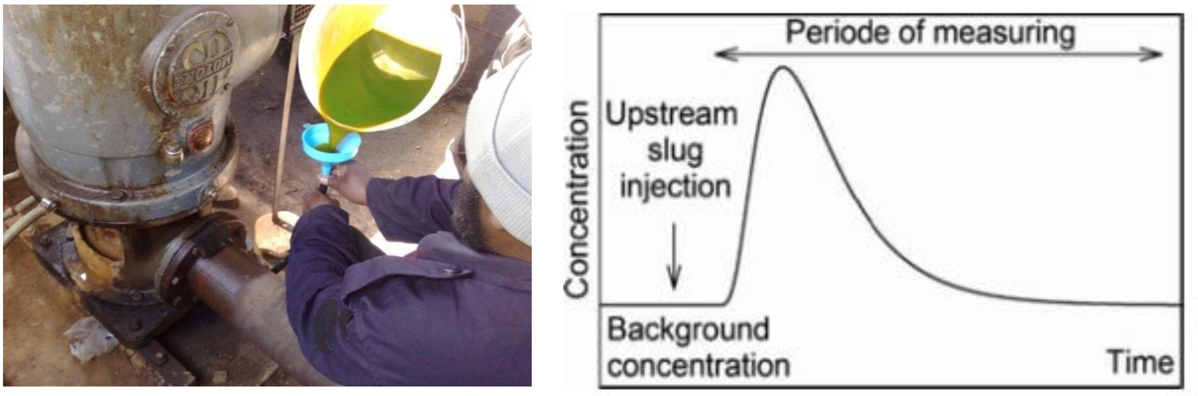
A) Slug Injection

It is a pulse injection of a known mass of tracer prepared as a concentrated solution added into a bulk system. Figure (2.2a) shows an example of a slug injection using Uranine tracer in an agricultural well in Al-Faria catchment.

This type of injection makes the tracer spread into the hydrologic system as a plume. The tracer pulse spreads due to vertical, lateral and longitudinal as well as turbulent mixing. The breakthrough curve of this type of injection usually depends on the longitudinal dispersion (Leibundgut et al., 2009). No special equipment for injection is needed when using the slug injection method provided that the tracer can be poured within streams and wells. Figure (2.2b) shows the typical breakthrough curve of a slug injection.

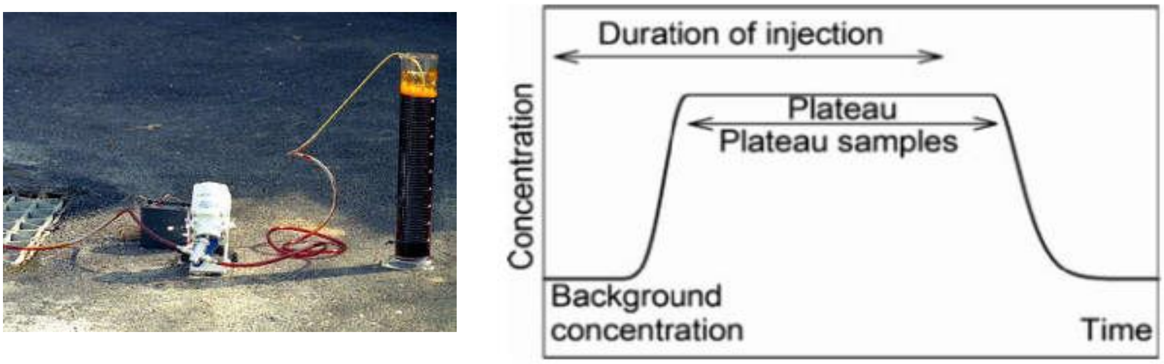
B) Constant Rate Injection

In this type of injection, the tracer solution will be injected to the field of experiment at a constant rate over a specific period. Constant rate injection is achieved by using a pump method as shown in Figure (2.2c). A General breakthrough curve which may result from this type of injection has the distinct shape shown in Figure (2.2d).



a) Slug injection of Uranine tracer into a well b) Expected breakthrough curve of slug

injection



c) Constant rate injection* d) Expected breakthrough curve of constant rate

injection

Figure (2.2): Applications of tracer injection types and expected breakthrough curve (Leibundgut et al., 2011)

(*http://www.turnerdesigns.com/newsletter/newsletter_1203_full.html)

2.6 Groundwater Tracer Experiments

The appropriate tracer test procedure is selected depending on the nature of the questions that remain unanswered after all other information has been collected about the hydrologic system. For example, if seepage velocity value is needed, then single-well tracer test can be performed. Therefore, the type of the tracer experiment that needs to be conducted depends on its objectives as depicted in Table (2.5).

Table 2.5: Main tracer experiments applications and objectives (Weight, 2008)

Test	Subcategory	Source duration	Information obtained	Hydraulic stress
Single well	Borehole dilution	Instantaneous	Flow direction, seepage velocity	Natural flow conditions
	Injection/pumping	Instantaneous	Seepage velocity, dispersion coefficient	Injection period precedes pumping period
Point source/ one sampling well	Natural flow	Instantaneous or continuous	Seepage velocity, dispersion coefficient	Natural flow conditions
	Diverging test	Instantaneous	Porosity, dispersion coefficient	Injection in the point source; sampling well is not pumped
	Conversion test	Instantaneous	Porosity, dispersion coefficient	Pumping from the sampling well; point source well is not stressed
	Recirculating test	continuous	Porosity, dispersion coefficient	Both wells are stressed.
Point source/ two sampling well	Recirculating tests	continuous	Porosity, dispersion coefficient, anisotropy	Injecting well receives pumped water or "clean" water from other source
Point source/ multiple sampling wells		continuous	Flow direction, seepage velocity, anisotropy	All wells are stressed
		Instantaneous	Flow direction, seepage velocity, anisotropy	Injecting well receives pumped water or "clean" water from other source Natural flow conditions

The most feasible test to conduct is the SWIW tracer test. This test has the advantage of using the same well for injection and monitoring. It can achieve the objectives of the research with less possible problems and in the most feasible way.

2.7 The Single Well Injection Withdrawal Tracer Test Procedure

The general procedure of single well injection withdrawal tracer test (SWIW) consists of the following phases:

1. Injection of tracer or (tracers) into groundwater formation through a borehole or a well as a pulse using the slug injection type.
2. Injection of a solution after tracer injection is stopped. This fluid is called the chaser; another tracer or normal water can be used as a chaser.
3. The waiting phase is meant to allow the tracer to spread as a ring due to longitudinal dispersion.
4. The recovery phase is when samples are retrieved to measure tracer breakthrough curve by running the pump of the borehole at constant rate.

The first phase in SWIW test is the slug injection of tracer solution into tested area through a borehole or a well. The second phase is injection of a chaser into the borehole or a well which allows the tracer to get out from the borehole into the geologic formation. It goes out taking a ring plume shape which spreads by dispersion toward natural groundwater flow path. Then, the waiting phase will start with no injection or withdrawal of water from the tested borehole. Tracer plume during this phase is lifted by natural groundwater flow and local hydraulic gradient. After the waiting phase is over, recovery phase will follow by starting up the borehole pump. Samples will be collected this phase and the breakthrough curve will appear through evaluation of hydraulic parameters of the tested area (Gustafsson et al., 2006). Figure (2.3) represents a general schematic tracer concentration which resulted during SWIW phases.

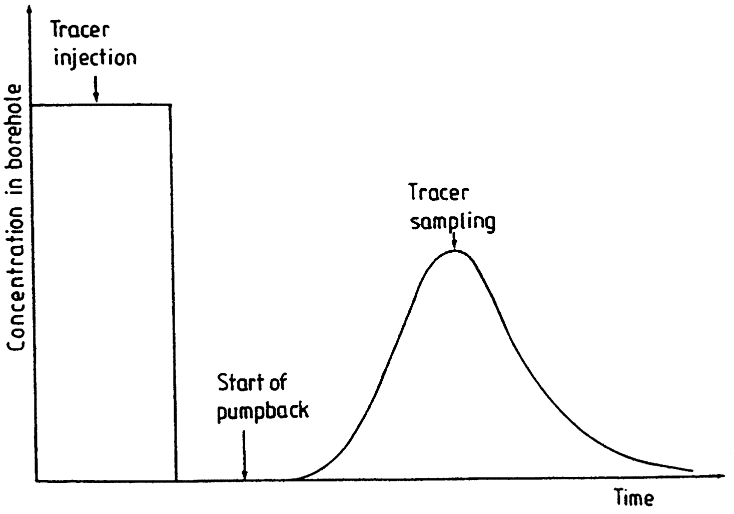


Figure (2.3): Schematic representation of tracer breakthrough curve in SWIW tracer tests (Andersson, 1995)

SWIW tracer test has the advantage of using only one well to make the injection and recovery of the tracer. This advantage makes the test more feasible than using multi- wells tracer test. The injected tracer in this type of tests experiences only a limited volume of the rock most adjacent to the tested borehole section. Multi-wells tests may give different types of information which are more relevant to flow paths over longer distances.

Many researchers had successfully applied this test for confined and unconfined aquifers such as Hall et al. 1991. It is assumed that if the drawdown due to the recovery pumping rate is small compared to the aquifer thickness, then the error in results which is caused by applying the test to unconfined aquifers can be neglected and ignored due to their insignificant disturbance on the results. This depends on the ratio of water table drawdown with respect to the thickness of the tested aquifer.

2.8 SWIW Tracer Test's Problems

There are some factors which control the results and directly affect the success of SWIW tests. Most of these factors depend on the collected data of the tested aquifer. Those factors are summarized as follows:

1) Existing local hydraulic gradient (one of the most disturbing factors for SWIW)
2) Pumping test data
3) Heterogeneity of the tested aquifer

If the local hydraulic gradient is not well estimated, it may allow the pulse injected tracer to drift faraway from pump-back point. Also it could lead to wrong estimation of the time of waiting and recovery phases (Nordqvist, 2002).

The pumping test results are used directly in the equations of SWIW for estimation of seepage velocity and effective porosity. So it is important to get the updated pumping test data for the tested wells (Nordqvist, 2002).

The third factor is the heterogeneity of the tested aquifer. This factor appears when the aquifer thickness is not very well estimated and when it does highly varies from point to point. The aquifer thickness is used in calculating the effective porosity and seepage velocity for the tested well (Nordqvist, 2002).

2.9 Previous Studies

The SWIW test was first performed in the U.S. in 1971 (Deans, 1971). It was applied in many oil industry studies in order to estimate the residual oil saturation in the rock (Tomich et al., 1973). This SWIW technique has not been previously used in Al-Faria catchment. This section summarizes in Table (2.6) some of the important developments on using SWIW studies in hydrogeological tests.

Table 2.6: Main sources on SWIW tracer tests (Neretnieks, 2007)

Authors	Year	SWIW application
Mercado	1966	used SWIW tracer tests to evaluate porosity and dispersivities.
Borowczyk et al.	1967	
Bachmat et al.	1988	
Bear	1979	provided a relatively detailed discussion on the hydraulics of injection and withdrawal of fluid in a homogeneous single layer under an existing uniform hydraulic gradient.
Leap and Kaplan	1988	used SWIW to determine the existing hydraulic gradient.
Hall et al.	1991	used SWIW to determine effective porosity and dispersivity under an existing natural hydraulic gradient estimated from dilution measurements from recovery phase data.
Nagra /McNeish et al.	1990	
Snodgrass and Kitandis	1998	presented a method to evaluate first-order and zero-order reaction rates from SWIW test.
Haggerty et al.	2000a, 2000b, 2001	applied more elaborate models of rate-limited solute mass transfer to SWIW test tracer breakthrough data.

2.10 Hydraulic Conductivity and Effective Porosity in Al-Faria Catchment

Hydraulic conductivity and hydraulic gradient are very important groundwater parameters which are used in SWIW calculations for getting an estimation of seepage velocity and effective porosity. The effective porosity is always less than the total porosity of the soil but it may equal it in specific cases. It can be defined as the volume of water circulating in the soil with respect to total volume of soil.

After the pumping tests survey that had been done in Al-Faria catchment by Ghanem (1999), the hydraulic conductivity of the sub-aquifers in the catchment was accurately estimated. According to the survey results, Neogene sub-aquifer has a hydraulic conductivity value estimated at 28.4 m/d. Pleistocene shows values smaller than Neogene and it was estimated at 8 m/d. The Cenomenian sub-aquifers show a hydraulic conductivity ranging from 0.3 to 25.7 m/d. As for the effective porosity in the catchment, it has a low range that varies from 2% to 8%. These low values of effective porosity are affected by the natural rock formation in the area which is characterized by dolomite and limestone rocks (TAHAL 1963).

2.11 Management and Planning for Injection

The success of an artificial tracer experiment depends on careful planning. The management and planning step comes before conducting the experiment to overcome possible obstacles in performing the test. A formal request must conform to governorate laws and should abide by the existing legislation. Accordingly, a formal application will generally include (Leibundgut et al., 2009):

1- the characteristics of the injection, including logistical considerations such as access (keys, permits, etc.);
2- the necessary materials (tracer amount, bucket, funnel, tube, water for injection and/or flushing, water truck, keys for site access and to open wells, tools, instruments, the number and material of sampling bottles, water proof labeling pens, boxes, instructions, paperwork);
3- the expected tracer breakthrough curve and the maximum concentrations and the corresponding sampling intervals;
4- the sampling concept; and
5- the methods of analysis

Chapter Three

Study Area

3.1 Area Overview

Al-Faria catchment is located in the north-eastern part of West Bank, Palestine. The total area of the catchment is about 320 km^2. The catchment area can be divided into eight main land use types. These types of land use and their percentages are shown in Table (3.1).

Table 3.1: Main types of land use in Al-Faria catchment and their percentages (Dudeen, 2007)

Type of land use	Percentage (%)
Bare rocks	2.8
Built-up areas	4.7
Natural forests	0.9
Olive plantations	6.4
Agricultural areas	22.1
Scattered olive plantations	8.2
Natural grassy hill slopes	28.3
Sparsely vegetated hill slopes	26.6

Al-Faria catchment lies with respect to national coordinate system within latitudes of 160000 – 195000 m N, and longitudes of 175000 – 200000 m E. It lies with respect to international coordinate system within the latitude of 32° 2' - 32° 12' N, and the longitude of 35° 12'- 35° 35' E. Al-Faria catchment is located in the eastern groundwater basin (Ghanem, 1999). Figure (3.1) shows the location of Al-Faria catchment and the main groundwater basins in Palestine.

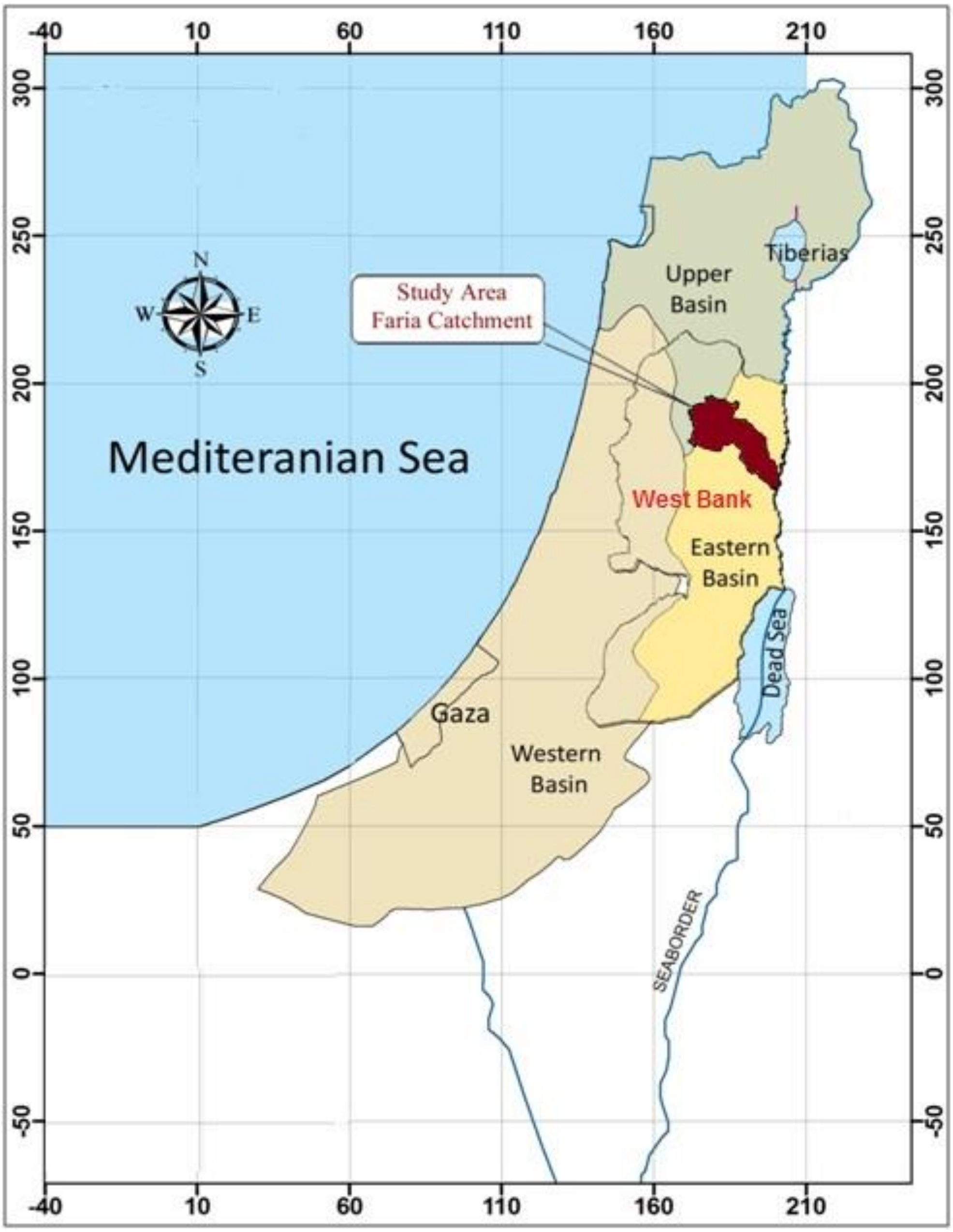


Figure 3.1: Location of Al-Faria catchment and the main groundwater basins in Palestine (PWA, 2011)

3.2 Tested Wells Locations and Information

The injection was done into two unconfined agricultural wells which are drilled into the Neogene sub-aquifer. According to the Palestinian Water Authority, these wells have the following ID numbers 18-18/031, and 18-

18/019. The wells had been selected to conduct the test for the following reasons: 1) owner permission to do the test, and 2) the availability of pumping test data. Table (3.2) and Figure (3.2) show related information about the tested wells and their location on an aerial map.

Table 3.2: General information about the tested wells (Ghanem, 1999)

Information	**First tested well**	**Second tested well**
Well ID number	18-18/031	18-18/019
Well location	Al-Nassariya	Beit Hasan
Drilling year	1970	1967
Aquifer type	Unconfined	Unconfined
Sub-aquifer	Neogene	Neogene
Pumping rate (m^3/hr)	65	45
Well depth	50	150
X coordinate	186410	181150
Y coordinate	183120	188730
Z coordinate	-29.155	-46.643

Figure 3.2: The locations of the tested wells in the study area (PWA, 2011)

3.3 Locations of Streams and Wells

Al-Faria catchment is divided with respect to runoff into three sub-catchments: (1) Badan, (2) Upper Faria, and (3) Malaqi. The upper Faria and the Badan contain most of the water springs in Al-Faria catchment and catch most of the rainwater falling within the catchment. Figure (3.4) shows Al-Faria sub-catchments (Shadeed, 2005).

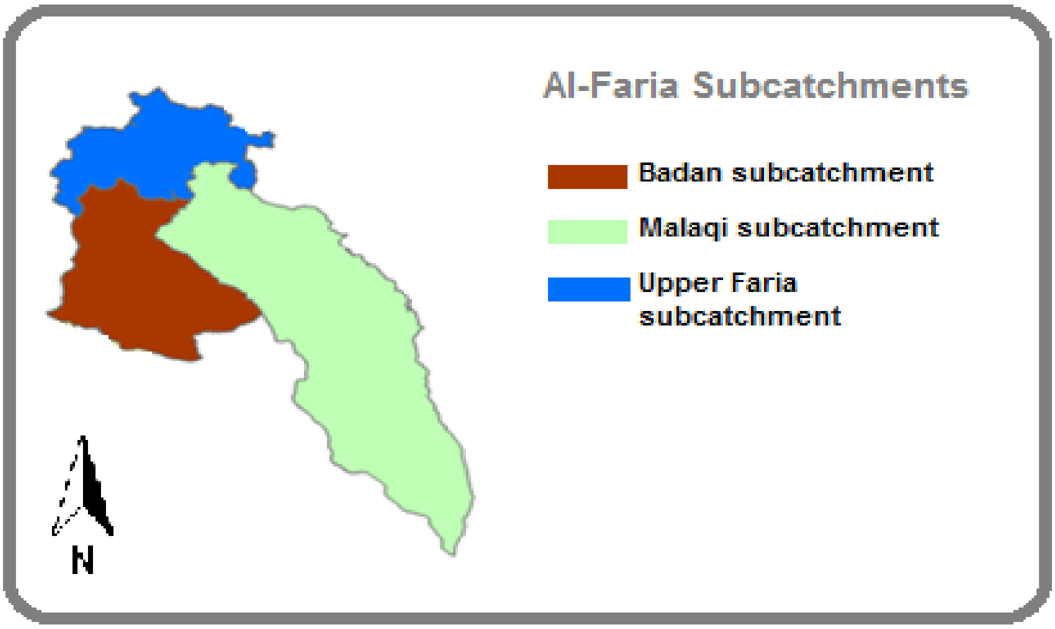


Figure 3.3: Al-Faria sub-catchments (Shadeed, 2005)

The contour elevations of Al-Faria catchment vary widely in elevations and steep slopes. The highest point in the catchment reaches (900) m above mean sea level at the Northwestern part of the catchment which is Nablus East mountains, while the lowest elevation is reached at (350) m below mean sea level at the Southeastern part near Jericho city and the Dead Sea. This variety of contour elevations creates three main drainage streams. The first stream flows from Nablus East and is called Wadi Sajour located in Badan sub-catchment. It consists of collected rainfall from mountainous parts of Nablus, and wastewater produced from Eastern sides of Nablus and its villages. The second one starts from the Upper Faria sub-catchment and is called Wadi Al-Batteikh. It consists of rainfall in the sub-catchment and wastewater of Faria refugee camp. These two streams connect together to form one stream starting in a place called Al-Malaqi bridge which is the starting point of the third sub-catchment "Malaqi" in Al-Faria catchment.

The third stream starts from Malaqi Bridge and ends in the Jordan Valley near the border between Palestine and the Kingdom of Jordan. Figure (3.5) shows the three main streams in Al-Faria catchment and the distribution of the wells in the area.

Nearly all groundwater wells in Al-Faria catchment are used for irrigation purposes. There are three main domestic wells in the catchment. Two of them are operated by Nablus municipality and the third one is operated by local council of Beit Dajan.

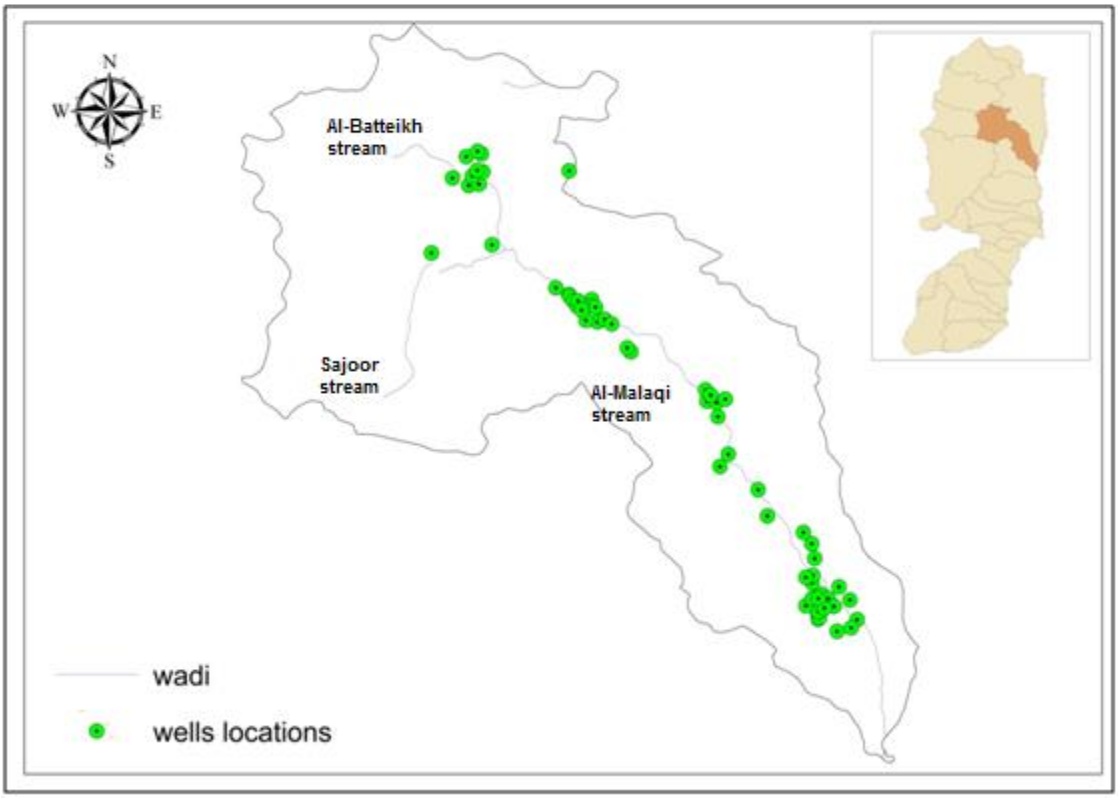


Figure 3.4: The three main streams in Al-Faria catchment and the distribution of wells (PWA, 2011)

3.4 Groundwater Basins

The west Bank is divided into three groundwater basins which are Western, Northeastern and Eastern (Figure 3.1). The dominant direction of the groundwater in the Northeastern basin is northeastwards. The dominant direction of groundwater in the Eastern basin is to the east and southeastern. The Western basin drains into the coastal part of Mediterranean Sea.

Al-Faria catchment is located in the Eastern basin. This basin has a great tectonic complexity. The Eastern basin drains groundwater from Neogene and Plistocene, and lower and upper Cenomanian sub-aquifers. The Cenomanian aquifer in the Eastern basin can be divided into shallow and deep lower Cenomanian sub-aquifers (Ghanem, 1999).

The source of water in the Eastern aquifer basin originates from the rainfall storms on the mountains East of Nablus. The points at which groundwater enters the aquifer basin are known as fissures, karstic feature, and joints of the mostly carbonate Ajlune group of late Cretaceous Age (Ghanem, 1999).

3.5 Aquifers System

The Eastern aquifer basin and its sub-aquifers are characterized as heterogeneous. Groundwater parameters change from point to point. The aquifer types in Al-Faria catchment consist of one upper unconfined and two lower confined sub-aquifer systems. Groundwater is found in formations of Plistocene to lower Cenomanian age, at varying depths reaching in some places to hundreds of meters. The unconfined sub-aquifers are Plistocene, Neogene, and Eocene, while the confined sub-aquifers are Touraniam and lower and Upper Cenomanian (Ghanem, 1999). Table (3.2) shows the various sub-aquifers names and gives additional information about their usages, depths and types.

Table 3.3: General information of Al-Faria sub-aquifers (Ghanem, 1999)

Sub-aquifer	**Utilization**	**Type**
Pleistocene	Agriculture	Unconfined
Neogene	Agriculture	Unconfined
Eocene	Domestic	Unconfined
Touronian	Domestic	Confined
Upper and Lower Cenomenian	Domestic	Confined

Chapter Four

Materials and Methods

4.1 Introduction

This chapter discusses the theory and methods used to study the hydraulic properties of the Neogene sub-aquifer in Al-Faria catchment. Two SWIW tracer tests were performed to determine the seepage velocity and effective porosity. Also, a column test was used to estimate the hydraulic conductivity of the unsaturated soil of the sub-aquifer. The collected data from the tested wells, aquifer properties and the tests procedures are presented in this chapter.

4.2 SWIW Tracer Test Theory

Two SWIW tracer tests were performed on Al-Faria catchment to investigate seepage velocity and effective porosity of two agricultural wells in the Neogene sub-aquifer. The Uranine tracer solution was pulse injected in the test of both wells. But before discussing the data of tested wells and the designed tests, it is rather useful to explain the theory behind SWIW tests. It is described by Leap and Kaplan (1988) for laminar groundwater movement and derived from Darcy’s law. The following equations are used by Leap and Kaplan (1988) for calculating seepage velocity and effective porosity from the results of SWIW tracer tests.

$$V = \frac{Qt}{\pi h d^2 K I} \qquad (1)$$

$$n_e = \frac{\pi b K^2 I^2 d^2}{Qt} \qquad (2)$$

where:

Q	Pumping rate (m^3/hr)
h	Aquifer thickness (m)
K	Hydraulic conductivity (m/hr)
I	Hydraulic gradient (m/m)
t	Time elapsed from the start of pumping until the centre of mass of tracer is recovered (hr)
d	Time elapsed from the injection of tracer until the centre of mass of tracer is recovered (hr)
V	Seepage velocity of groundwater (m/hr)
n_e	Effective porosity (dimensionless)

4.3 Injection Preparation

The preparation for the injection in the tested wells was done was done in this manner:

1. The tracer mass was weighted in the lab and saved in a plastic bottle.
2. The quantity of alcohol needed to increase the solubility of the Uranine tracer was calculated and carried to the field in a plastic bottle.
3. The tracer mass and alcohol solution were mixed together in the field using extracted well water in a bucket to get homogenous solution.
4. A funnel with a plastic pipe was used to pour the mixed solution inside the well.
5. After the mixed solution injection is finished, extracted water from the same well was injected as a chaser solution.

The following picture shows the pulse injection mechanism of the mixed solution in well number 18-18/031.

Figure 4.1: The tools which were used in tracer injection in Al-Faria catchment

4.4 Chaser Injection

The chaser injection mechanism was done in the tested wells in two different ways. For the well no. 18-18/031, the chaser volume was approximately 240 L of water. This volume of water was injected gradually by a 20 L bucket, and then poured inside the well using the funnel. When the bucket was poured, the chaser injection stopped until the bucket was filled again with water. This step was repeated twelve times using the same bucket to complete the chaser injection.

But in well no. 18-18/019, the chaser injection was conducted by using a water tanker; the tanker was connected to a plastic pipe which reached to the well. The quantity of water which was injected as a chaser solution was not calculated, but the injection mechanism was repeated three minutes. It was not calculated because for cultural reasons; it was embarrassing to go on top of the farmer's roof to check the level of water in the tanker.

4.5 SWIW Tracer Test Phases' Times

The time step of the drift phase of SWIW test in Al-Faria catchment was estimated using the aquifer parameters from literature. Al-Faria catchment is characterized by limestone and dolomite aquifers, which have effective porosity ranges from 2% to 8%. If the local hydraulic gradient and the hydraulic conductivity in the well number 18-18/031 is 0.015 and 28.4 m/d respectively (Ghanem, 1999), so we can apply Darcy law to check the range of groundwater velocity within a unit area in this well as follows:

$$\mathrm{V} = \frac{\mathrm{q}}{\mathrm{n_e}} = \frac{\mathrm{KI/A}}{\mathrm{n_e}} = \frac{(28.4\ \mathrm{m/d})(0.015)/1\ \mathrm{m}^2}{2\%\ \text{minimum or}\ 8\%\ \text{maximum}}$$

Maximum groundwater velocity = 21 m/d

Minimum groundwater velocity = 5 m/d

If we take the average velocity of the previous results, we get to 13 m/d. This value was used to estimate the drift time phase to get to 2 to 3 meter drifting. The recommended optimal drift distance is 2 to 3 m (Hall, 1994). Therefore, the drift time phase can be calculated to achieve 3 m drifting will be the following:

Estimated drift time = Distance/Velocity = $\frac{(3\ \mathrm{m})}{(13\ \mathrm{m/d})}$ = 0.23 day = (5.5 hours)

For more safety, the drift time was estimated at 6 hours after the injection of tracer and chaser are finished.

As mentioned in the literature review section (2.4), SWIW tracer test has different phases. The following table summarizes the durations of SWIW tracer test phases which were used for both tested wells.

Table 4.1: SWIW phases times for both tested wells

Time	First hour				Second hour				Third hour				Forth hour				Fifth hour				Sixth hour				Seventh hour				Eighth hour			
Tracer injection phase	🟩																															
Chaser injection phase		🟥																														
Waiting phase duration			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩						
Recovery phase duration																											🟩	🟩	🟩	🟩	🟩	🟩

Notes:

1) Each hour in the table is divided into four quarters.
2) The red cell in the first hour is for chaser injection time and it is 15 minutes for well no. 18-18/031 and three minutes for the well no. 18-18/019.

4.6 Column Experiment

After finishing the core work of the research which was the SWIW tests, a soil column experiment was conducted to get the vertical and horizontal hydraulic conductivities of the unsaturated zone. Soil samples were taken from a specific site above groundwater table of Neogen sub-aquifer. Figure (4.3) shows the site of soil samples.

Figure 4.2: The location of the samples of soil which were used in the column experiment

The column was filled by well-mixed soil samples and then connected to a bucket, which had a level control instrument. This level controller adjusts the hydraulic gradient and makes the head of water inside the column constant. Any decrease of water in the control bucket is compensated for from another bucket. The column was exposed to specific hydraulic gradients within a specific time and the effluent water was collected in a graduated cylinder. The vertical and horizontal hydraulic conductivities were calculated by substituting the results in Darcy law equation. Figure (4.4) shows a schematic drawing which depicts the column experiment components.

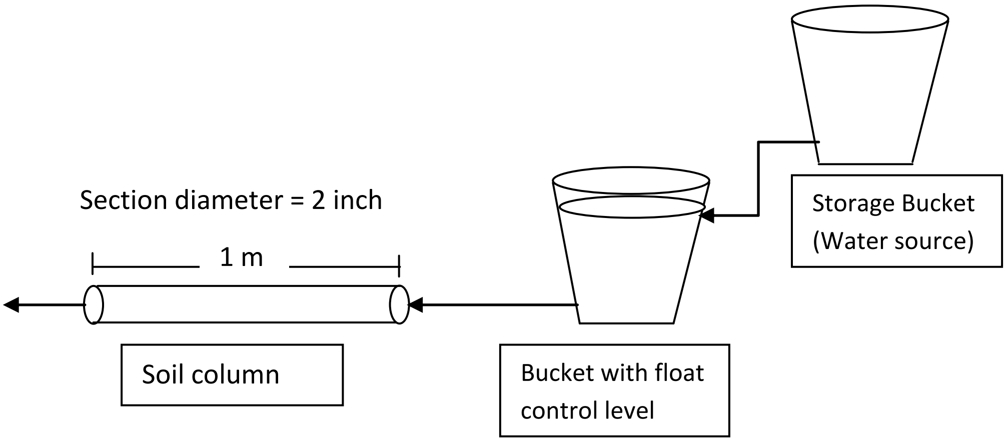


Figure 4.3: Schematic drawing of soil column experiment in horizontal way

Chapter Five

Results and Discussion

5.1 SWIW Tracer Tests results

Samples were collected in the recovery phase from both tested wells. The collected samples were measured in An-Najah National University laboratories by using different Fluorometer instrument types. The instruments were calibrated and prepared for measuring within Excitation/Emission wavelengths of 491 nm and 516 nm respectively. These values of wavelengths were used to adjust the instruments to highly detect the Uranine concentrations in the collected samples. Table (5.1) shows important information about the conducted tracer tests in both wells.

Table 5.1: Relative information of the designed SWIW tracer tests in the study area

Tested well number	**18-18/031**	**18-18/019**
Date of experiment	21/03/2012	23/8/2013
Uranine concentration which was used in the injection (g/L)	6	1
Uranine mass (g)	120	20
Measured samples	31	28
Recovery phase time (hr)	1.5	1.5
Sampling criteria	Sample every minute	Sample every three minutes
Instrument of measurement	Spectral laboratory Fluorometer	Aquafluor laboratory Fluorometer

Results of Uranine concentrations were used to draw the breakthrough curve of the test. Figures (5.1) and (5.2) show the breakthrough curves of both tested wells.

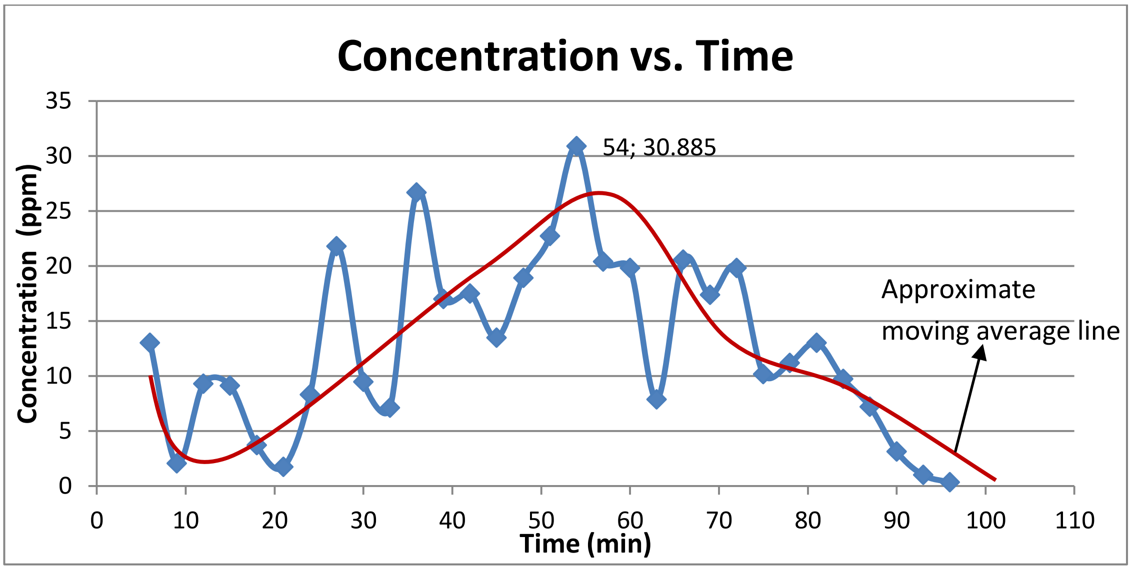


Figure 5.1: The breakthrough curve of the SWIW tracer test of tested well “18-18/031” (tested in winter season)

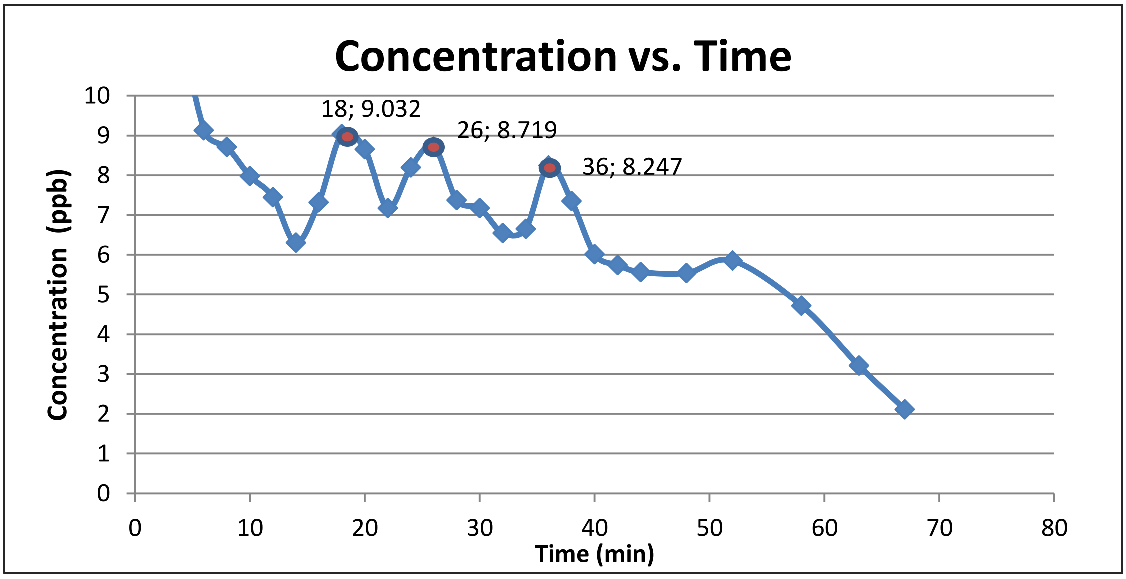


Figure 5.2: The breakthrough curve of the SWIW tracer test of tested well “18-18/019” (tested in summer season)

The SWIW tests were done at Al-Faria catchment in wet and dry seasons. The well number 18-18/031 was tested in the winter season and the well number 18-18/019 was tested in the summer season. The resulting breakthrough curve in the winter season showed relatively scattered values.

The scattering pattern was rising up to reach a certain point before it goes down again. However, the approximate moving average line, which appeared in red color in the winter breakthrough curve, formed an overall peak with a value of 30.8 mg/L after 54 minutes of recovery pumping. In the winter test, all nearby wells were not in operation.

The summer breakthrough curve had a smoother trend. In this curve, three proximate peaks appeared with the following values: 18 minutes; 9.03 ppb, 26 minutes; 8.72 ppb, and 36 minutes; 8.25 ppb. The reason for the three peaks was the non-uniform pumping rates of the different nearby wells. It affected the tracer solution to move with the natural groundwater gradient. Also, it caused the tracer plume to distribute and disperse into different directions due to the effect of forced non- uniform gradients of nearby wells.

The reason for the difference between the two breakthrough curves is that in the winter test the used chaser injection mechanism was intermittent (twelve water buckets over 15 minutes) the thing that caused more scattering in the winter breakthrough curve. Comparatively, in the summer test, the used chaser injection mechanism lasted three minutes (injection via a tanker). The scattering of recovered Uranine concentrations can be attributed to the higher concentration of injected Uranine concentration used in the winter test. The high concentration of injected Uranine may cause some Uranine solution to stick on the wells’ stone ring.

The results of the SWIW tracer test and pumping test data are necessary to calculate seepage velocity and effective porosity of the tested well. Table

(5.2) summarizes the necessary information needed to calculate the seepage velocity and the effective porosity for both tested wells.

Table (5.2): Aquifer and Pumping test data for both tested wells

Parameter	**Tested well 18-18/031**	**Tested well 18-18/019**
Pumping rate (Q) m^3/hour	65	45
Aquifer thickness (h) m	50*	Not measured
Hydraulic conductivity (K) m/hour	1.16**	0.15**
Transmisivity [(T)=Kh] m^2/d	Not measured	15.83**
Local hydraulic gradient (I) m/m	0.015**	0.015**
Elapsed time from the start of pumping until the peak of the Uranine is recovered (t) hour	0.9	0.3, 0.43, 0.6***
Elapsed time from the injection of tracer until the peak of the Uranine is recovered (d) hour	7.4	6.8, 7.23, 7.83***

*PWA (2011)

**Ghanem (1999)

***Tested well 18-18/019 has three closed distinguished peaks

The values of the seepage velocity and the effective porosity will be calculated by substituting the data of Table (5.2) into equations (1) and (2). Tables (5.3) and (5.4) summarize the main results of the SWIW tracer tests.

Table 5.3: Main results of the SWIW tracer test on the well number 18-18/031

Characteristic	**Value**
Seepage velocity (m/d)	9.2
Effective porosity	0.043

Table 5.4: Main results of the SWIW tracer test on the well number 18-18/019

Characteristic	First peak value	Second peak value	Third peak value
Seepage velocity (m/d)	9.4	13.0	17.2
Effective porosity	0.163	0.118	0.089

As mentioned in the literature review section (2.5), the local hydraulic gradient is one of the important parameters for calculating the results. If the local hydraulic gradient is not estimated very well, it may affect the results. Local hydraulic gradient in the tested area was borrowed from Ghanem (1999). It is recommended that researchers make several attempts to estimate the average local hydraulic gradient in the tested area before doing the test. However, it is extremely hard to do that because one needs to make sure that all wells are not in operation in the winter or summer so as not to affect the natural gradient. For seepage velocity calculation, pumping test data can neglect the effect of non well estimation of the aquifer thickness by using the transmissivity value when substituting in the equation. The available information which is substituted in the equations are different for both tested wells. Well number 18-18/031 has available information about the hydraulic conductivity and aquifer thickness, while well number 18-18/019 has available information on trasmissivity. The difference in the available data for the tested wells are shown in Tables (5.3) and (5.4), the seepage velocity of the well number 18-18/031 was calculated at 9.2 m/d, and for the well number 18-18/019, the seepage velocity was calculated at the three peaks . It was found that the first peak has the nearest seepage velocity value which equals to 9.4 m/d with high effective porosity values compared to the results for well number 18-18/031.

As mentioned in chapter 3 section (3.6), the geologic formation of Al-Faria catchment is marked by limestone and dolomite aquifers which have law values of effective porosity. The value ranges from 2% to 8% (TAHAL, 1963). The calculated effective porosity of the tested well (18-18/031) was 4.3%. However, the calculated effective porosity values for the three peaks in the tested well (18-18/019) were higher than the range of such aquifer. High effective porosity values are given while considering the aquifer thickness for the tested well (18-18/019) same as the aquifer thickness for the tested well (18-18/031). This assumption was made due to the lack of the exact aquifer thickness in the tested well (18-18/019). The resulting proximity of the tested well (18-18/031) to the theoretical values was considered as a good indication to the success of test. But the disparity in the results of the tested wells makes us question the dry season test results and gives enough incentive for further tracer tests.

One of the major problems that may face any experimenter in conduct such tests in Al-Faria catchment is the lacking of reliable data about the wells. Even the owners of the wells do not know about pumping rate capacity or the depth of their wells. The old data registered in the data bank of the Palestinian Water Authority should be updated. Many modifications were done to the wells, such as changing well pump, yet no updates are available. Tracer experiments in Al-Faria catchment need enough budget to perform pumping test for any intended future well test. Only financial compensation can convince the owners to allow such experiments and to stop pumping during test phases to prevent any disturbance to the groundwater natural gradient.

As shown in Table (5.2), the concentration of the Uranine which was used in the injection for the summer test was six times lower than the winter test. This was decided because of the different types of the fluorometer instruments that were used in analyzing tested samples. Spectral laboratory fluorometer instrument was used to analyze the Uranine concentrations of the winter test samples. It has the ability to measure a wide range of Uranine concentrations ranging from part per billion (ppb) to part per million (ppm). However, in the summer test, the Aquafluor fluorometer instrument, which has a range of measurement from 0 to 400 ppb, was used to analyze the Uranine concentrations in the samples. If the Uranine injected concentration in the summer test was the same as the concentration used in the winter test, then Aquafluor instrument cannot measure the recovered Uranine concentrations directly and need to make dilution for the samples to reach the available measuring range of the instrument. So the measuring technique using different instruments is considered as a source of uncertainty to the results.

Uranine recovery in both tests were calculated and found that they are faraway from the injected mass in the tests. They were about 508 g and 0.11 g for wet test and dry test respectively. The recovered mass in both tests are not reasonable if compared to the injected ones. This was because lack of enough samples which made a gap between samples' time intervals.

5.2 Column Experiment Results

One meter long pipe with two inches diameter was filled by disturbed unsaturated soil taken from a site three meters above the Neogene groundwater table. Three trials were done with different hydraulic gradients to check vertical and horizontal hydraulic conductivities. Effluent water was collected and its volume was measured for each trial for the duration of four hours. Table (5.5) and (5.6) show the results of both horizontal and vertical column trials.

Table 5.5: Column experiment results of horizontal conductivity

Items	**Trial 1**	**Trial 2**	**Trial 3**
Hydraulic gradient	1.85	2.5	3.12
The collected water volume (mL)	52	81	133
Flow rate, Q (mL/hr)	13	20.25	33.25
Hydraulic conductivity, K (m/d)	0.0833	0.0960	0.126
Average hydraulic conductivity (m/d)	0.102		

Table 5.6: Column experiment results of vertical conductivity

Items	**Trial 1**	**Trial 2**	**Trial 3**
Hydraulic gradient	2	2.5	3.2
The collected water volume (mL)	89	121	166
Flow rate, Q (mL/hr)	22.3	30.2	41.5
Hydraulic conductivity, K (m/d)	0.1318	0.1434	0.1536
Average hydraulic conductivity (m/d)	0.143		

The relationship between Darcy fluxes and hydraulic gradients showed that horizontal hydraulic conductivity “as an average value of the trials” was estimated at 0.102 m/d, whereas the vertical hydraulic conductivity was estimated to be 0.143 m/d. The resulting hydraulic conductivities are very low if they were to be compared with hydraulic conductivity of well number 18-18/031. Low non- representative values of hydraulic conductivities resulting from the column experiment were due to disturbing the soil structure which changed the real porosity of the soil samples. Porosity of the soil inside the column was changed when the soil mixture from the collected samples was filled out. Soil sample grain size had a fine texture and low permeability. This experiment is considered as a failure and can neither describe the hydraulic conductivity nor the porosity of the unsaturated zone. It is recommended to do the experiment in the site location where the soil samples were collected. By doing the experiment in the field, less disturbance for soil structure would happen.

Another suggested experiment is to check the hydraulic parameters of the unsaturated zone near well number 18-18/031. There was a big excavation three meters away from the well, with a depth of eight meters and a diameter of approximately five meters. By saturating this excavation with tracer solution, then collecting water samples from the well, the collected samples will describe the transfer of the tracer from the unsaturated zone to the water table through known forced gradient. The height of the unsaturated zone can be calculated easily by subtracting the well depth to water and the depth of the excavation. It will provide valuable information about the dispersion parameter.

Finally, relating the groundwater and unsaturated zone hydraulic parameters together will give a solid ground to start further research in the field of surface water/groundwater interactions in the study area.

5.3 Difficulties

It became apparent that the research procedure needed to be modified to overcome logistical and cultural difficulties. This section summarizes the main difficulties which may face conducting tracer tests in the study area. Those difficulties are:

1. It is difficult to take permissions from responsible authorities to conduct such tests due to political complications in the area of experiment.
2. If no permissions are taken from the responsible authorities, it is difficult to make the tracer test nearby municipal wells and Israeli settlements.
3. If the monitoring point (spring or well) is far away from the injection point by more than 10 meters, it will not be easy to convince the farmers in the area to make their wells out of operation for days. This is because they are selling water for irrigation purposes in the summer season, and they are using their wells as drinking water supply all year long.
4. If the pathway of the tracer is an objective of the tracer test, so it will need many efforts to get monitoring in different directions, and it will need enough staff and will take more than one student to do the task.

5. The tracer experimenter can put him/herself at risk as some farmers may claim that the tracer material affect their irrigated crops.
6. The owners of wells are often apprehensive from conducting such tests because they are used to seeing Israeli military engineering department every month taking water samples from their wells
7. The lack of reliable data in Al-Faria catchment and the lack of financial support were considered as main obstacles to conduct such tests.

Chapter Six

Conclusions and Recommendations

Based on the results of this research, the following are the main conclusions:

1. The SWIW tracer test proved to be applicable in Al-Faria catchment. The test provided sufficient information to calculate the seepage velocity and effective porosity in the study area of Al-Faria catchment.
2. The SWIW tracer test in the winter season was more efficient than the summer one; this is because of intensive pumping from surrounding wells during the summer season in the catchment which cannot be easily controlled.
3. Uranine tracer proved to be one of the efficient tools to conduct such tracer tests.
4. The chaser continuous injection method using low concentration of the injected tracer brought up smooth un-scattered breakthrough curve.
5. The effect of non-uniform pumping rates from the nearby wells of the tested well made the tracer disperse in different directions with different gradients. This showed in the breakthrough curve by giving multi proximate concentration peaks.
6. The soil column experiment failed to give a clear understanding about the hydraulic conductivity of the unsaturated zone soil. This

was because of the disturbed samples which changed the soil porosity.

Based on the findings of this research, the researcher can make the following recommendations:

- It is recommended future researchers use Uranine tracer in the future at Al-Faria catchment due to its various advantages and ease of measuring.
- This research documented a practical experience for using Uranine tracer and single well injection withdrawal tracer test and will be the key reference for other related researches in the future.
- It is suggested to do dual well tracer experiment between tested well (18/18-031) and (18/18-031A). This recommendation comes as a result of the proximity between the two wells which are only 50 meters apart and the available data outcomes from the experiment for the well (18/18/-031).
- Researchers should take every precautionary measure when planning for injection in Al-Faria agricultural wells because people there usually drink from these wells.
- It is recommended that researchers use in-situ fluorometer instrument type in the future tracer tests. It will provide easy and fast measuring for tracer concentrations.
- Financial resources are crucial to the success of such tracer hydrologic research. It may cost a lot for the pumping tests and the many soil test analysis.

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جامعة النجاح الوطنية

كلية الدراسات العليا

الخصائص العامة للمياه الجوفية في منطقة وادي الفارعة باستخدام تقنية تتبع المواد

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قدمت هذه الاطروحة استكمالا لمتطلبات نيل درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

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الملخص

تعتبر المياه الجوفية من المصادر المائية الهامه في فلسطين، فدراسة تلك المياه وخصائصها تعد من الأدوات التي يعتمد عليها في عمل ادارة مناسبة لها. تعد منطقة تغذية الفارعه التي تقع في الحوض الشمالي الشرقي بالضفه الغربيه من أهم المصادر الجوفيه في فلسطين حيث انها تزود مختلف القطاعات بالمياه سواء كانت للاحتياجات البشرية والزراعية والحيوانية. ان نوعية المياه الجوفية في منطقة تغذية الفارعة تأثرت بالمياه العادمة الغير معالجة و بالمواد الكيميائيه الناتجة عن الأنشطة الزراعية. الهدف من هذا البحث هو الحصول على أفضل مفهوم لخصائص المياه الجوفية الهيدرولوكية في منطقة تغذية الفارعه. ان هذه الدراسة سوف تمهد الطريق لأبحاث اخرى بالمستقبل تعنى بدراسة علاقة المياه السطحية ونوعيتها بنوعية المياه الجوفية. الطريقة التي استخدمت في هذا البحث لتحديد سرعة المياه الجوفيه والنفاذية الفعاله لحوض النيوجين الغير محصور هي تكنولوجيا حقن مادة اليورانااين في بئر وحيدة. ومن خلال استخدام هذه التكنولوجيا تم التوصل إلى نتائج للخصائص الهيدروليكية في بئرين مختلفين بفصلين مختلفين (التجربة الأولى في فصل الشتاء والثانية في فصل الصيف لعام (2013/2012) ومن ثم تم رسم منحنيات تبين العلاقة بين الوقت والتركيز للمادة المتتبعه المسترجعه في عملية الضخ لكل من التجربتين . كان من اهم الفروقات بين التجربتين في كلا البئرين هو وجود عمليات ضخ مختلفة وغير منتظمة من الآبار المجاورة. ان المنحنى الناتج من التجربة التي تمت في فصل الشتاء أظهر أعلى تركيز للمادة المتتبعه بعد 54 دقيقة من عملية الضخ و المنحنى الناتج من التجربة التي تمت في فصل الصيف أظهرت ثلاث قيم كبرى ومتتالية لتركيز المادة المتتبعة بأوقات متفاوته هي 18 دقيقة، 26 دقيقة، و36 دقيقة من عملية الضخ. أظهرت نتائج البحث قيم سرعة عالية للمياه الجوفية في الحوض الجوفي النيوجيني. ان التجربة التي تمت في فصل الشتاء أظهرت ان سرعة المياه الجوفية بها 9.2 متر في اليوم بنفاذية فعالة 4.3%. ان التجربة التي حصلت في فصل الصيف اظهرت نتائج غير صحيحة للخصائص المذكورة بفعل تأثر البئر بعمليات الضخ الغير منتظمة للآبار المجاورة، حيث

أثرت على انتشار المادة المتتبعة وجعلتها تنتشر باتجاهات مختلفة بفعل قوى ضخ متفاوته. ان القيام بالتجربة خلال فصل الشتاء كان اكثر فعالية من القيام بها في فصل الصيف وذلك بسبب عمليات الضخ الكثيفة التي تنتج من الآبار المجاورة والتي لا يستطيع التحكم بها بسهولة.

هذا البحث يستخدم كأداه ابتدائية تمهد الطريق لدراسة المياه الجوفية باستخدام تكنولوجيا المادة المتتبعه في منطقة تغذية الفارعة، علما أنه لا يوجد خبرة سابقة باستخدام طريقة البئر الوحيدة في المنطقة لدراسة المياه الجوفية وخصائصها.