Institut für Hydrologie
Albert-Ludwigs-Universität Freiburg im Breisgau

Using Tracer Techniques to Investigate Groundwater Recharge in the Mount Carmel Aquifer, Israel

Florian Winter

Diplomarbeit unter der Leitung von Prof. Dr. Ch. Leibundgut
Freiburg im Breisgau, Oktober 2006

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List of Abbreviations

λ .... Wavelength [nm]

C .... Concentration [mg/l]

M .... Injected Tracer Mass [g]

$masl$ .... meters above sea level

ppb .... parts per billion = μg/l

ppm .... parts per million = mg/l

Q .... Discharge [m^3/s]

R .... Restitution Rate [%]

t_0 .... Mean Transit Time [h]

EC .... Electrical Conductivity [μS/cm]

EMMA .... End Member Mixing Analysis

FFE .... First Flood Event

FSL .... Field Service Laboratory, Neve Yaa'r, Israel

IHF .... Institute of Hydrology, University of Freiburg

MCM .... Million Cubic Meters

MDM .... Multi Dispersion Model

NA .... Sodium-Naphtionate

SFE .... Second Flood Event

UA .... Uranine

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Summary

The aim of this study is to investigate groundwater recharge processes and rates for Nahal Oren in Mount Carmel, Israel, with emphasis on the localised recharge following ephemeral floods in the river system. The applied method combines artificial and environmental tracers. Sodium-Naphtionate and Uranine are applied to characterize indirect recharge from transmission losses, while Major Ions are used to estimate and quantify total groundwater recharge by means of the Chloride Mass Balance and an End Member Mixing Analysis as well as delineate direct and indirect recharge processes.

Nahal Oren is an ephemeral stream system that drains a catchment of 35 km^2 from the main watershed of Mt. Carmel to the west towards the Mediterranean Sea. It is characterized by a semi-arid climate with rainfall seasons in winter, the mean annual values range from 618 to 699.5 mm . The vegetation is a Mediterranean forest, composed mainly of pine, oak, Pistacia Lentiscus and associations. Runoff events occur every year, from December following high intense rainstorm events, or later in winter after the soil is well saturated. Two aquifers are known to exist in the study area (Judea Group Aquifer of Albian-Turonian age and Carmel Coast aquifer of Pleistocene age) and several wells are drilled into both aquifers to extract groundwater. The study reaches are situated in the lower Nahal Oren catchment.

The study included a stay of four months at the Department for Geography & Environmental Studies at the University of Haifa, Israel from January until April 2006. During this time two major experiments were carried out and data collection was complemented by additional measurements of static water levels, rainfall intensities, physical parameters, topographic heights and extensive fieldwork.

In total three injection pits have been dug into the alluvium near the wells Nahal Oren 3, 4 and 5. Each profile is surveyed and described with respect to stratigraphy, infiltration capacities, texture and preflow moisture. Two flood events occurred during the period of observation, referred to as the First Flood Event (FFE) and the Second Flood Event (SFE). They both lasted for about 2 days. 1 kg and 1.5 kg of Naphtionate were injected into the alluvial pits near well Nahal Oren 3 and 5, respectively, before the First Flood Event in a highly concentrated dilution. Before the Second Flood Event 1 kg of Naphtionate was injected into the soil pit near well Nahal Oren 4 and 100 g of Uranine was injected in each of 5 small pits into the alluvium from well Nahal Oren 3 upstream in interspace of about 40 m (500 g of Uranine total). Samples were taken during and after both flood events from wells Nahal Oren 1, 3, 4 and 5 for fluorescentic and major ions analysis. Simultaneously static water levels were taken from wells Nahal Oren 1, 2, 3, 4 and 5 manually. A CTD-DIVER probe was installed in the observation well Atlit 1 and recorded measurements of water level, temperature and electrical conductivity. Due to a malfunction of the hydrometric stations the hydrographs of both floods could not be recorded.

Water level changes are recorded in all of the monitored wells throughout the period of observation. Especially the rise in water levels after the flood events is significant and could be related to transmission losses and groundwater recharge processes. The static

water levels from the monitored wells indicate a groundwater gradient eastwards from well Nahal Oren 1. The detection of a reversed groundwater gradient does not verify the conceptual flow model described for the region in the winter months. This reverse gradient was supposed to evolve only in the summer months when extraction from the aquifer is highest.

The analysis of the fluorescentic dye tracers was carried out at the Institute of Hydrology, Freiburg. The positive detection of Naphtionate in well Nahal Oren 5 within hours after the FFE occurred indicates a fast vertical connection of the surface flow to the underlying aquifer. The restitution is calculated to 108.8 g. The Multi Dispersion Model (MDM) is applied, but should be regarded censoriously due to lack of runoff data. What seems remarkable though are the apparent short transit times through 100 m depth of unsaturated layer. Uranine and Naphtionate are not detected in the sampled wells Nahal Oren 1, 3 and 4, but still the possibility for a hydraulic connection between the surface flow and the underlying dolomite aquifer cannot be excluded

Data series of different sources for the same physical parameters or environmental tracer are compared with regard to their consistency and suitability for further interpretation. The data are obtained from in situ measurements, Field Service Lab in Neve Yaa'r and the Insitute for Hydrology, Freiburg, the latter are used in the methods applied.

The chemical composition, chloride concentrations and electrical conductivity are used to characterize the water types in the catchment and potential conceptual flow models in the area. The wells are assumed to tap the same aquifer and to be interconnected. The conceptual groundwater flow model can be validated from static water levels. These present conditions have so far been regarded to exist only during the summer, but appear to exist in the winter season as well.

The Chloride Mass Balance is used to calculate long-term groundwater recharge rates. Under the given conditions, limitations and presumptions valid in the area, a recharge rate of 62.7 mm or 2.19 MCM (Million Cubic Meters) can be computed for Nahal Oren catchment. Annual extraction from the wells exceeds this recharge rates in the years of 1991-2004, pointing toward an overuse of the resource, however the results of the Chloride Method should be verified.

An End Member Mixing Analysis (EMMA) is applied only for the period following the First Flood Event at well Nahal Oren 5. Surface flow and groundwater prior to the flood are defined as end members. Due to the detection of Naphtionate, the dilution of chloride and sulfate can be connected to an infiltrating water front from transmission losses. Other dilution observed in other events or wells cannot be determined and are therefore neglected. The use of chloride and sulfate as tracers results in minimal values of 127 and 160 m^3 absolute recharge, respectively, or 0.8 and 1% in proportions of the total runoff of this event. These are minimal values because discharge from the wells is just a fraction of recharged groundwater, others fractions seem to flow laterally.

Indirect recharge is likely to take place at location Nahal Oren 5, although the indications could not be found throughout the catchment. There are indications for an altered groundwater system with respect to flow directions and dynamics as well as chemical

composition in the Nahal Oren catchment. This altered groundwater system could be object to future studies.

Keywords:

groundwater recharge - transmission losses - flourescentic dye tracers - ephemeral - Mount Carmel - semi-arid

Zusammenfassung

Das Ziel dieser Arbeit ist es, die Prozesse der Grundwasserneubildung (GWNB) im Einzugsgebiet von Nahal Oren im Karmelgebirge, Israel, zu untersuchen. Dabei soll die lokale GWNB durch Infiltration von Abflussereignissen in ephemeren Gerinnen im Vordergrund stehen. Dazu wird eine Kombination von künstlichen und natürlichen Tracern angewendet. Natrium-Naphtionat und Uranin wird eingesetzt, um indirekte GWNB durch Transmission Losses zu charakterisieren. Die Analyse der Hauptionen des Wassers wird durchgeführt, um die gesamte GWNB-Rate mittels Chloridmethode und einer End Member Mixing Analyse abzuschätzen und zu quantifizieren, und um direkte und indirekte GWNB zu trennen.

Nahal Oren ist ein ephemeres Gerinnesystem, das ein mesoskaliges Einzugsgebiet von 35 km^2 von der Hauptwasserscheide des Karmelgebirges westwärts zum Mittelmeer hin entwässert. Es ist gekennzeichnet durch ein semi-arides Klima mit Winterniederschlägen, mit mittleren Jahressummen von 618 bis 699.5 mm. Die Vegetation besteht aus mediterranem Wald, Kiefer, Eiche, Pistazie und verwandten Arten. Abflussereignisse treten jedes Jahr auf, ab Dezember nach Niederschlagsereignissen von hoher Intensität oder später im Verlauf des Winters, wenn die Böden eine hohe Sättigung aufweisen. Im Versuchsgebiet existieren zwei Hauptaquifere, der Judea Group Aquifer aus der unteren bis mittleren Kreidezeit und der Küstenaquifer aus dem Pleistozän. Mehrere Brunnen zur Förderung von Grundwasser erschließen beide Aquifere. Versuchsgebiete für die vorliegende Studie wurden im unteren Einzugsgebiet ausgewiesen.

Im Zuge dieser Arbeit wurde einen 4-monatiger Aufenthalt am Department for Geography & Environmental Studies an der Universität Haifa in Israel ermöglicht. Während dieser Zeit wurden zwei Fluoreszenztracer-Experimente durchgeführt. Die Datenbeschaffung wurde komplettiert durch zusätzliche Messungen der Grundwasserspiegel, Niederschlagsintensitäten und physikalischen Parameter sowie ausgiebiger Geländearbeit.

Insgesamt wurden drei Injektionsstellen ausgewählt und Vertiefungen in das Alluvium des Wadis bei den Brunnen Nahal Oren 3, 4 und 5 gegraben. Jedes dieser Bodenprofile wurde vermessen und beschrieben bezüglich seiner Stratigraphie, Infiltrationskapazität, Korngrößenverteilung und Bodenfeuchtegehalt. Zwei Abflussereignisse wurden während der Untersuchungsperiode beobachtet und First Flood Event und Second Flood Event genannt. Beide dauerten jeweils ungefähr 2 Tage an. 1 kg beziehungsweise 1.5 kg Naphtionat wurden vor dem First Flood Event angelöst und in die Gruben im Alluvium nahe den Brunnen Nahal Oren 3 bzw. 5 injiziert. Vor dem Second Flood Event wurde 1 kg Naphtionat in die Grube nahe Brunnen Nahal Oren 4 eingespeist, und jeweils 100 g Uranin in eine von 5 kleinen Vertiefungen, von Brunnen Nahal Oren 3 stromaufwärts in Abständen von jeweils ca. 40 m (ingesamt 500 g Uranin). Grundwasserproben wurden während und nach den Abflussereignissen von den Brunnen Nahal Oren 1, 3, 4 und 5 gezogen: jeweils eine für die Fluroreszenzanalyse und eine für die Analyse der Hauptionen. Gleichzeitig wurden Grundwasserstände in den Brunnen Nahal Oren 1, 2, 3, 4 und 5 von Hand gemessen. Eine CTD-DIVER Sonde wurde in den Beobachtungsbrunnen Atlit 1 installiert und zeichnete Wasserstand, Temperatur und elektrische Leitfähigkeit des Grundwassers auf. Wegen eines Geräteausfalls konnten keine Abflussdaten und keine

Ganglinie von den Ereignissen an den hydrometrischen Stationen gemessen werden.

Änderungen der Grundwasserstände werden in allen beobachteten Brunnen während der gesamten Untersuchungszeit festgestellt. Gerade nach Abflussereignissen lässt sich ein deutlicher Anstieg festellen, der mit Transmission Losses und GWNB-Prozessen zusammenhängen könnte. Die beobachteten Grundwasserstände weisen auf einen ostwärts gerichteten Gradienten hin, ausgehend von Brunnen Nahal Oren 1. Dieser Feststellung eines umgekehrten Fließgradienten steht das Konzeptmodell, das für die Wintermonate beschrieben wird, gegenüber. Dieser inverse Fließgradient wurde nur für die Sommermonate beobachtet und beschrieben, wenn die Grundwasserentnahme aus dem Aquifer am höchsten ist.

Die Analyse der Fluoreszenztracer wurde am Institut für Hydrologie an der Universität Freiburg (IHF) durchgeführt. Der positive Nachweis von Naphtionat in Brunnen Nahal Oren 5 innerhalb weniger Stunden nach dem Abflussereignis FFE weist auf eine schnelle Verbindung des Oberflächenabflusses mit dem darunterliegenden Aquifer hin. Der Rückerhalt wird mit 108.8 g berechnet. Das Multi-Dispersions-Modell wird angewendet, sollte aber wegen fehlender Abflussdaten kritisch betrachtet werden. Der Nachweis kurzer Transportzeiten durch 100 m ungesättigter Zone ist allerdings bemerkenswert. An den Brunnen Nahal Oren 1, 3 und 4 konnte kein Uranin oder Naphtionat nachgewiesen werden; dies bedeutet jedoch nicht, dass man die Möglichkeit einer vertikalen hydraulischen Verbindung zum Dolomit-Aquifer verwerfen kann.

Die Datenreihen der physikalischen Parameter und der natürlichen Tracer von den verschiedenen Quellen werden hinsichtlich ihrer Konsistenz und ihrer Eignung zur weiteren Interpretation verglichen. Die Daten stammen aus In-Situ-Messungen, vom Field Service Laboratory in Neve Yaa'r, Israel, und von der Analyse am Institut für Hydrologie, Freiburg. Letztere werden für die weiteren Untersuchungen verwendet.

Die chemische Zusammensetzung, Chlorid-Konzentrationen und elektrische Leitfähigkeiten werden verwendet, um die Grundwassertypen im Einzugsgebiet zu charakterisieren und mögliche konzeptionelle Fließmodelle zu entwickeln. Die Brunnen erschließen denselben Aquifer und sind wahrscheinlich miteinander verbunden. Die Vorstellung des Grundwasserfließmodells kann aufgrund der Grundwasserstände verifiziert werden. Diese vorherrschenden Bedingungen wurden bisher nur im Sommer beobachtet, scheinen aber auch im Winter zu exisiteren.

Die Chloridmethode wird angewendet, um GWNB-Raten im langjährigen Mittel zu berechnen. Unter den gegebenen Bedingungen und Einschränkungen im Einzugsgebiet kann die GWNB-Rate mit 62.7 mm bzw. 2.19 MCM (Millionen Kubikmeter) bestimmt werden. In den Jahren 1991-2004 überstieg die Grundwasserentnahme aus dem Aquifer diese Neubildungsrate in jedem Jahr, aber es wird empfohlen, die Ergebnisse der Chloridmethode nochmals zu verifizieren.

Eine End Member Mixing Analyse (EMMA) wird für die Zeit nach dem ersten Abflussereignis am Brunnen Nahal Oren 5 durchgeführt. Als End Member werden der Oberflächenabfluss und das Grundwasser im Zustand vor dem Abflussereignis bestimmt. Aufgrund des gleichzeitigen Nachweises von Naphtionat könnte die Verdünnung von Chlorid- und

Sulfat-Konzentrationen im Grundwasser mit einer infiltrierenden Wasserfront in Verbindung stehen. Die anderen Verdünnungseffekte in den anderen Brunnen können nicht eindeutig erklärt werden und werden daher vernachlässigt. Die Verwendung von Chlorid und Sulfat als natürliche Tracer ergibt eine minimale Neubildung von 127 bzw. 160 m^3, oder in Prozent, 0,8 bzw. 1% des gesamten Abflusses des Ereignisses. Diese Werte bezeichnen Minimalwerte der Neubildung, da das geförderte Grundwasser nur einen Teil des neugebildeten Grundwassers darstellt.

Die Ergebnisse weisen stark darauf hin, dass indirekte Neubildung zumindest am Brunnen Nahal Oren 5 stattfindet, kann aber nicht im ganzen Einzugsgebiet nachgewiesen werden. Es gibt Anzeichen für ein verändertes Grundwassersystem in Bezug auf Fließrichtungen und Dynamik, sowie auf chemische Zusammensetzung des Grundwassers im Einzugsgebiet Nahal Oren. Diese Veränderung des Grundwassersystems könnte Gegenstand zukünftiger Untersuchungen sein.

Chapter 1

Introduction

The investigation of hydrological processes has always been an important subject in dry arid and semi-arid areas. The main focus so far has been put on the assessment of replenishment of groundwater resources as it is often the only source of water. In semi-arid and arid regions the importance of groundwater recharge due to transmission losses increases with aridity ([Sorman & Abdulrazzak, 1993]).

In Israel, water is a relatively scarce and valuable commodity. Israel uses nearly all of its renewable water ressources throughout a single year. Therefore, in years of decreased precipitation resources might be exploited over the threshold of replenished water which causes groundwater tables to fall to a severe level and the salinity to rise. The Mt. Carmel Aquifer in the north-western part of Israel forms a separated unit of the Mountain Aquifer which is the second most important groundwater body in the area. In order to assess transmission losses in an ephemeral stream in the Mt. Carmel aquifer fluorescentic tracers are used to carry out experiments during two flood events following intense and heavy rainfall in the catchment.

1.1 Definitions

Groundwater recharge is generally defined as the infiltrating water which percolates to the groundwater table, forming an addition to the groundwater reservoir. A clear distinction should thus be made, both conceptually and for any modelling purposes, between the potential amount of water available for recharge from the soil zone and the actual recharge as defined above [Lerner et al, 1990].

Direct recharge is defined as water added to the groundwater reservoir in excess of soil moisture deficits and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone.
Indirect recharge results from percolation to the water table following runoff and localisation in joints, as ponding in low-lying areas and lakes, or through the beds of surface water courses. Two distinct categories of indirect recharge are thus evident: that associated with

surface water courses, and a second localised form resulting from horizontal surface concentration of water in the absence of well-defined channels [Lerner et al, 1990].

Transmission Losses are a phenomenon which is often observed in (semi-)arid catchments. It indicates the decrease of the flood volume and flood peak during runoff events due to high infiltration rates in ephemeral stream beds downstream.
The magnitude of transmission losses during a flood event is mainly dependent on hydrograph characteristics such as flood volume and duration and soil profile characteristics (e.g. [Sorman & Abdulrazzak, 1993])

1.2 Objectives

The objective of this study is to assess groundwater recharge processes and rates in the Nahal Oren catchment (Mt. Carmel Aquifer), with emphasis on the localised recharge following ephemeral floods in the river system. One way of linking the processes of transmission losses and groundwater recharge is to mark infiltrating runoff water during a flood in order to detect it later in the aquifer. The study was designe to combine artificial tracers (fluorescentic dye tracers) with environmental tracer methods (major ions, chloride method, End Member Mixing Analysis) and simultaneous groundwater level monitoring.

By using the results of the analysis and the application of a mathematical transport model assumptions can be made on:

- the hydraulic connection between the channel bed and the underlying aquifer
- transportation time through the unsaturated zone
- quantity of groundwater recharge in the area
- relevance of groundwater recharge from transmission losses
- vulnerability of the aquifer systems and potential hazards

1.3 State of the Art

A comprehensive and informative presentation of hydrological processes in arid and semiarid environments can be found in [Simmers, 2003]. It covers the most relevant processes in this study, from runoff generation to transmission losses and hydrochemical processes.

1.3.1 Groundwater Recharge in (semi-)arid areas

In [Lerner et al, 1990], the author presents a guide to understanding and estimating natural recharge. Different estimation methods and an overview of processes are shown and discussed.

[SORMAN & ABDULRAZZAK, 1993] found statistical regression equations for estimating groundwater recharge from transmission losses in an arid catchment on the Arabian peninsula. They classified different runoff events and observed various magnitudes of transmission losses resulting from similar runoff hydrographs due to soil and channel characteristics and antecedent conditions. Larger contributions to the recharge of the groundwater reservoir occur as a result of high initial moisture content accumulated from sequences of flood events and shallow depth to water table. The temporary hydraulic connection established between an ephemeral stream and the groundwater table depends on the flood duration.

[GREENBAUM ET AL, 2002] show that transmission losses and recharge in an alluvial aquifer in the Negev Desert, Israel, are related to the flood volume by a power decay function. They examine the long-term, event-based recharge of the aquifer by combining measured flood parameters and estimating long-term frequency of large floods with a paleoflood record of the catchment.

1.3.2 Artificial Tracers and Transmission Losses

There are only few studies on transmission losses with fluorescentic dye tracer aided experiments, both because of absorption processes of dye tracers in the unsaturated zone and because of the challenge of an accurate sampling schedule and finding accessible and representative sampling points.

[KÜLLS ET AL, 1995] use Sulforhodamine with its sorptiv quality during infiltration tests in dry channel alluvium in an arid region to investigate flow patterns which can control channel infiltration. The dye tracer test makes preferential flow in a downstream direction apparent and shows pipes above layers with a higher content of fines. Horizontal subsurface flow above inhibiting layers may cause a retardation of the saturation process, especially when the surface is highly permeable.

Three different artificial tracers (NaCl, Uranine and Sulphorhodamine) are used to study infiltration losses during an artificial flash flood by [LANGE ET AL, 1997]. The tracers have been injected after the breach of a water reservoir and have been detected both along the channel downstream in surface water samples and within the alluvium by using fluocapteurs which were placed in different depths into the alluvial body before the flood. They show different flow and infiltration paths along a reach of about 220 m and the dual role of the alluvium in a desert flash flood as both reducing the flood volume in the beginning but recontributing to the flow at the end of the flood when surface flow nearly ceases.

1.3.3 Nahal Oren Catchment

[WITTENBERG ET AL, 2004] compare two 12-year periods of runoff events in the Nahal Oren catchment. A classification of small and large floods is made by defining a threshold for peak discharge / flow volume. They conclude that large floods only originate after rainstorms of over 100 mm, and do rarely occur prior to december, whereas flow already originates after rainfall of 45-50 mm in recent years. This could be explained by the increasing uncertainty of the occurrence of large rainfall events and the decreasing length of dry spells.

In a current study [Arbel, not published] tries to estimate the spatial and temporal distribution of groundwater recharge in the Nahal Oren catchment, but focussing on the hillslope scale. Arbel is applying artificial tracers and monitoring natural tracers in caves and springs in different carbonatic lithologies in the area. This is intended to lead to an identification and quantification of direct and local recharge mechanisms.

Chapter 2

Methodology

2.1 Fluorescentic Dye Tracers

Nowadays the expectations to the investigation of substance migration have considerably risen the requirements to tracer tests with respect to their planning, execution and interpretation ([WGSHS, 2003]). It is therefore one of the most crucial tasks to select the most suitable tracer for a given object of investigation.
Dealing with groundwater recharge and therefore water flow through the unsaturated zone and to the groundwater table, the applied tracers have to satisfy the criteria of low sorptivity, good water solubility and must be toxicologically harmless. Therefore Uranine and Sodium-Naphtionate are the tracers of choice in this study.
The following descriptons of the fluorescentic dye tracers are based on the referring chapters in [Käss, 1998].

2.1.1 Uranine

Of all known substances, the fluorescein-anion has the strongest fluorescence and its properties as a tracer are unsurpassed. The sodium-salt of fluorescein, sold and known as Uranine, can be assumed as a quasi-ideal tracer in hydrogeological studies and is the most frequently used artificial tracer.

Uranine (Sodiumfluorescein, $C_{20}H_{10}Na_2O_5$, abbreviation: UA) forms dark-red, longish crystals in solid phase and does not fluoresce. Concentrated Uranine solutions are also dark-red and do not fluoresce until strongly diluted with water and dissociating into sodium cations and Uranine anions. The latter fluoresce in a green-yellowish luminance - the fluorescence maximum of Uranine lies at 512 nm wavelength - which is visible down to concentrations of about $10^{-8}\mu g/l$ under ideal conditions (see also Figure 2.1).

The quantum yield and therefore the intensity of the fluorescence is exceptionally high. Modern spectrofluorimeters (see below) have a detection limit of Uranine of $0.002\,\mu g/l = 2 \cdot 10^{-12}$. At very high concentrations over $10000\,\mu g/l$, the intensity of the fluorescence

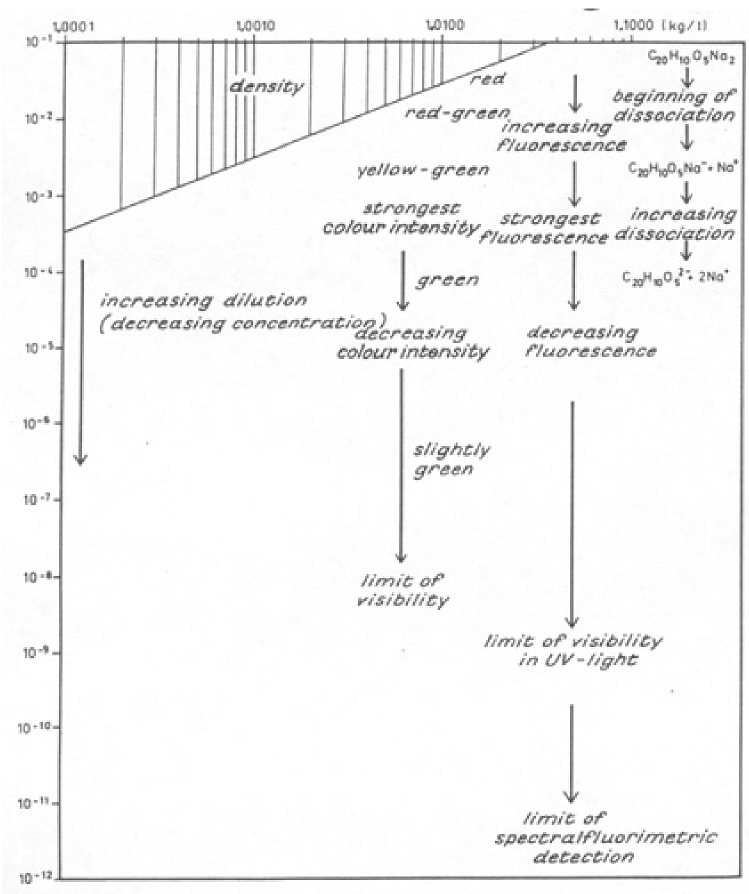


Figure 2.1: Visibility and Properties of Uranine in different concentrations ([Käss, 1998])

decreases in consequence of its individual light absorption and due to retrograde dissociation.

The intensity depends strongly upon the prevailing hydrogen ion concentration. The maximal fluorescence is reached at pH-values over 8.5, whereas at the neutrality point (pH 7) the intensity is only 80% of the maximal value. The more acidic the medium, the more Uranine-cations are present which have strong sorption properties. This is why in experiments in acidic groundwaters (pH-value < 5.5) Uranine should not be the chosen tracer, though the conversion of the Uranine-anion into the cation is reversible.
All substances that are transported with water undergo interactions with the solid state. The process of sorption takes place if a substance is bound to the solid phase without a chemical reaction. If the bond is so loose that the substance can become detached, the process is called desorption. There are reversible chemical reactions (ion exchange) and irreversible chemical processes where the dissolved substance is incorporated into the crystal lattice of the solid phase (absorption). Cationic dyes are more susceptible to sorption and ion exchange than anionic or electro-neutral dyes, since the solid material on the surface is negatively charged. Both dyes used in this study are anionic are not prone to either one of these processes. There are several studies to determine the sorption properties of fluorescent dyes with regards to their ability to serve as a tracer (e.g. adsorption coefficient ([Leibundgut 1974]), sieve coefficient ([Leibundgut & Lüthi 1976]),

saturation and sorption factor ([Leibundgut, 1981])).

There are other processes which are irreversible. Strong oxidizing agents destroy Uranine, especially the chemical agents used as desinfectants in water purification, but also chlorine dioxide and ozone. Uranine also decomposes when exposed to daylight, the reduction of fluorescence is described by an exponential decay. This photolysis prohibits the use of Uranine in surface water tracing tests (except for short-term tests), whereas in groundwater the tracer's sensitivity to light is of no great importance. The high light sensitivity does not affect the tracer test itself but is an inhibiting factor while sampling and storage of samples. Therefore samples taken from Uranine experiments should be stored in brown glass bottles.

Uranine has proven itself to be toxicologically harmless, neither it is on the list of cancerous substances, but also used in medical applications.

Thus Uranine is the first choice for groundwater tracer investigations. Its low detection limit, the moderate interaction with the aquifer, and its former successful application in karstic areas along with its inconvenience in surface flow tests contribute to its reputation of state-of-the-art in hydrological investigations.

2.1.2 Sodium-Naphtionate

Sodium-Naphtionate ($C_{10}H_8NNaO_3S$, abbreviation: NA) is a grey-pink powder which fluoresce in the blue range - the fluorescence maximum lies at 420 nm. The fluorescence intensity is only approximately 1/14 of Uranine's. A pronounced optical interference can occur as a consequence of optical impureness of the sample, which can significantly reduce its limit of detection with respect toother tracers. Although it has low sorption properties, since the fluorescence background is markedly higher than Uranine, almost twenty times the amount needs to be used in tracing tests. The fluorescence intensity is virtually constant between pH 4 and 9, towards lower pH-values it declines quickly, towards higher pH-values the intensity decreases rather slowly.

This tracer is best adapted for short distance tests and injections directly into the groundwater, whereas injections into the unsaturated zone are not recommended. Several field experiments have been carried out in porous aquifers, comparing the results of Uranine and Naphtionate. The tracer restitution is significantly smaller for Naphtionate, either suggesting an irreversible sorption or degradation of the Naphtionate. On the other hand, Naphtionate is found to have shorter transit times than Uranine.

A great advantage of using Sodium-Naphtionate in tracing tests is the invisibility at the sampling sites in the concentrations used. Under 1000 mg/l, it is virtually not organoleptically sensible. Like Uranine it decays in daylight, but not to the same extent. The tracer is well suited to be used along with Uranine without interference [Leibundgut & Wernli, 1988]. It has actually only an intermediate product in the dye synthesis, but it has proven itself in successful traces, also in karstic and fissured aquifers (e.g. [Leibundgut & Attinger, 1988]).

2.1.3 Analysis and Interpretation of Dye Tracer Experiments

Quantitative analysis of dye tracer experiments samples is carried out best by Spectrofluorimeters, instruments with two monochromators. A principal setup of a modern Spectrofluorimeter is shown in Figure 2.2. This setup allows to record both excitation and

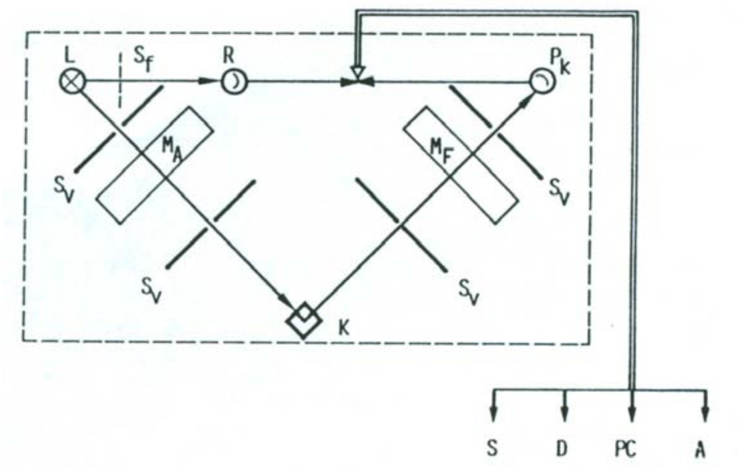


Figure 2.2: Principle setup of a modern spectrofluorimeter ([KÄSS, 1998]): L = light source, S_f = unchangeable slit, S_v = changeable slit, M_A = excitation monochromator, M_F = fluorescence monochromator, K = sample cuvette, P_k = photomultiplier, R = reference ray receiver, S = analog exit to recorder, D = digital exit to printer, PC = data processing and storage, A = exit to digital or analog display.

fluorescence spectra, and both the excitation and emission wavelengths can be selected to allow for optimal work.

The entrance and exit slits for both monochromators are quasi-continuously adjustable in half-width values of 5 to 25 nm or in increments of 0.1 nm, according to the instrument type, thereby allowing for an optimal energy flow. The sum of the entrance and exit slit width needs to be in any case smaller than $\triangle\lambda$, the difference of fluorescence and excitation wavelength.

All modern spectrofluorimeters are equipped with a programmable spectral sequence, where the beginning and end of the spectrum as well as speed of the spectral change (nm/min) can be selected. These commands can be carried out jointly or separately for the excitation as well as for the fluorescence monochromators. If both monochromators are moved simultaneously, the recording speed for both must be the same and the wavelength steps or wave number difference must remain constant. The latter method is called *synchroscan*. It is especially important for the identification of traces of fluorescence substances and for the detection and determination of two fluorescent dyes in one solution ([KÄSS, 1998]).

Evaluation and interpretion of dye tracer experiments suffers from a fundamental problem of large spatial patterns being superimposed by numerous small scale flow patterns ranging down to those at the grain surface of unconsolidated rocks or in the finest fissures of solid rock. These important large scale patterns must be separated from the less interesting small scale ones.

During the interpretation of a tracing test, it is only rarely possible to describe the spatial distributon of the tracer cloud in the underground for a specific point in time after the injection. Therefore the breakthrough curve of the tracer passage at a monitoring site has to be the base of evaluation. The application of a black-box-model to solve the inverse problem has already been successfully used in tracer tests in karstic areas. The description of the model is based on the ideas given in [Maloszewski et al, 1992], [Maloszewski 1994] and [Werner et al, 1997].

In fractured, karstified rocks there are different assumptions for interpreting tracer experiments: the tracer transport can be considered separately for each flow path and there are no interactions between the flow paths. Possible diffusion of tracer from the mobile water into the stagnant water in the micro-porous matrix and/or in temporarily nonactive parts of the karstic system is neglected. A conceptual model is shown in Figure 2.3. Under

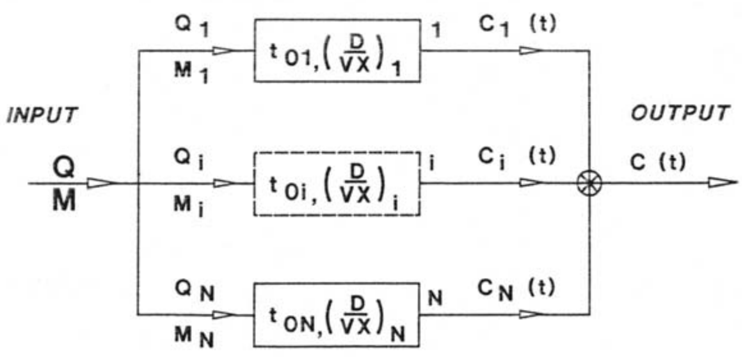


Figure 2.3: Conceptual Model of flow in karstified rocks (from [Maloszewski et al, 1992])

these assumptions on each parallel flow path the transport of an "ideal" (nonreactive) tracer is governed by a one dimensional dispersion model:

$$D_i \frac{\partial^2 C_i}{\partial x^2} + v_i \frac{\partial C_i}{\partial x} = \frac{\partial C_i}{\partial t} \tag{2.1}$$

where $C_i(x,t)$ is the concentration of tracer in water, v_i is the mean water velocity, and D_i is the dispersion coefficient for the i-th flow path. The molecular diffusion in water in the comparison to the hydrodynamic dispersion is negligible due to high water velocities. The dispersion coefficient is then

$$D_i = \alpha_i v_i, \tag{2.2}$$

where α_i is defined as the dispersivity on the i-th flow path. The model assumes that the whole mass of tracer, M, instantaneously injected in time $t = 0$ at the entrance to the system, is there well mixed and divided into N portions which immediately enter the N flow subsystems. This means that the tracer mass M_i entering each subsystem is proportional to the volumetric flow rate Q_i through that subsystem. All the flow paths meet again in the outflow from the system (spring) where instantaneous good mixing of the tracer takes place. This conceptual model has to be considered as a rough approximation of the reality. The number of possible flow subsystems N is one of the parameters to be fitted during its calibration. The flow distances, x_i, measured between the injection and detection site can be different for different flow paths and is not exactly known. Due to this fact it is always convenient to use as transport parameters: the mean transit time of water $t_0 = x/v$ and the dispersion parameter $D/vx = \alpha/x$. Assuming steady state flow conditions the mean transit time of water for the i-th flow path, t_{0i}, is simultaneously equal to the ratio of the volume of water V_i to the volumetric flow rate of water Q_i through the flow subsystem:

$$t_{0i} = x_i/v_i = V_i/Q_i \tag{2.3}$$

For an instantaneous injection described by the Dirac function the solution of equation (2.1) has the following form:

$$C_i(t) = \frac{M_i}{V_i} \frac{1}{\sqrt{4\pi(D/vx)_i(t/t_{0i})^3}} \cdot \exp\left[-\frac{(1-t/t_{0i})^2}{4(D/vx)_i(t/t_{0i})}\right] \tag{2.4}$$

where

$$(D/vx)_i = \alpha_i/x_i \tag{2.5}$$

is the dispersion parameter on the i-th flow path. The tracer concentration measured in the outflow from the system is the weighted mean concentration from all flow paths

$$C(t) = \sum_{i=1}^{N} \left[Q_i C_i(t)\right]/Q, \tag{2.6}$$

where $C_i(t)$ is the tracer output concentration at the end of the i-th flow path and Q is the total discharge measured simultaneously to the sum of partial flow rates:

$$Q = \sum_{i=1}^{N} Q_i. \tag{2.7}$$

It can be deduced from eq. (2.6) that the tracer concentration $C_i(t)$ at the end of the i-th flow path is diluted by other flow paths

$$C_{mi}(t) = Q_i C_i(t)/Q. \tag{2.8}$$

$C_{mi}(t)$ is now the tracer concentration from the i-th flow subsystem observed in the outflow from the whole system. Combining eq. (2.4) and (2.8) one obtains:

$$C_{mi}(t) = \frac{M_i}{Q} \frac{1}{t_{0i}\sqrt{4\pi(D/vx)_i(t/t_{0i})^3}} \cdot \exp\left[-\frac{(1-t/t_{0i})^2}{4(D/vx)_i(t/t_{0i})}\right]. \tag{2.9}$$

The total output concentration (eq. (2.6)) is the superposition of the partial concentrations, $C_{mi}(t)$

$$C(t) = \sum_{i=1}^{N} C_{mi}(t). \tag{2.10}$$

The theoretical tracer recovery R obtained in the outflow from the system is

$$R = Q \cdot \int_{0}^{\infty} C(t)dt, \tag{2.11}$$

whereas the partial tracer recoveries R_i observed at the end of each i-th flow path are calculated using the same equation but instead of Q and $C(t)$ one has to use Q_i and $C_i(t)$. By introducing eq. (2.8) into eq. (2.11) one obtains

$$R_i = Q \cdot \int_{0}^{\infty} C_{mi}(t) = M_i. \tag{2.12}$$

The mass of tracer injected into i-th flow path, M_i, can be then found using eq. (2.12) to the i-th tracer concentration curve measured in the outflow from the whole system. Theoretically the sum of all partial recoveries is equal to the total recovery and to the mass of tracer injected

$$R = \sum_{i=1}^{N} R_i = M. \tag{2.13}$$

The parameters for the flow model (eq. (2.9) and (2.10)) are the number of flow subsystems (N) and the parameters for each of the N flow paths. Each i-th flow path has its own mean transit time of water, t_{0i}, dispersion paramter, $(D/vx)_i$ and the flow rate, Q_i, represented by the tracer mass, M_i.

2.2 Groundwater Recharge Estimation

Estimation of groundwater recharge is often done by the help of environmental tracers. As [WGSHS, 2003] point out, the combination of natural and artificial tracers very often leads to a considerable gain in information.

2.2.1 Chloride Method

For an estimation of the mean average direct groundwater recharge the chloride method is a fair approximation to the long term average value. It has been applied by e.g. [Allison & Hughes, 1978], [Edmunds & Gaye, 1994] and [Schulz, 1972]; the description given here is based upon their publications.

Chloride is a conservative tracer, which indicates evaporation. The chloride method is based on the fact that precipitation contains chloride from sea salt aerosols. If the rainfall infiltrated immediately, without taking up additional solutes during overland flow, the chloride content in the soil depends on the amount of infiltrated rainfall only. During evaporation the concentration increases, and the increase is a measure of the evaporation. Chloride does not participate in water-rock ion exchange interactions, and once it enters the groundwater there is no process that can remove it. Together with rainfall data, and under the assumption of negligible runoff, recharge can be computed.

Chloride can reasonably be regarded as an inert element in the shallow hydrological cycle with its source derived from atmospheric deposition. Provided the inputs of rain (P) and chloride C_p are known, the average chloride concentration of interstitial water in an unsaturated zone profile (C_s) will, under steady-state conditions, be proportional to the concentration factor $P/(P-E)$ where P is the mean annual precipitation and E is evapotranspiration. The direct recharge R_d at a given location is given by

$$R_d = \frac{P \cdot (C_p + C_d)}{C_{si}} \tag{2.14}$$

where P is the long-term mean annual precipitation, C_p is the weighted mean concentration of chloride in rainfall, C_d id the amount of chloride in the dry deposition and C_{si} is the average concentration of chloride over interval i in interstitial water in the unsaturated zone.

The Chloride Method is usually applied in the unsaturated soil zone between the groundwater table and the zero upward flux plane. However in an approximation and under certain limitations it can also be applied between surface and shallow groundwater, concerning the location of sampling ([Brunner et al, 2004]).

2.2.2 End Member Mixing Analysis

Attemps at identifying sources of storm runoff have involved hydrograph separation (or End Member Mixing Analysis - EMMA) using the chemical and isotopic mass balance equation:

$$Q_T C_T = Q_1 C_1 + Q_2 C_2 + \cdots + Q_n C_n \tag{2.15}$$

where $C_T, C_1, C_2, \cdots, C_n$ are the concentrations of solutes, electrical conductivity, pH, environmental stable and radio-isotopes of total storm runoff its assumed components. $Q_T, Q_1, Q_2, \cdots, Q_n$ are the corresponding discharge rates ([Ogunkoya & Jenkins, 1993]). Separating n fractions of the total discharge can be done by the use of $n-1$ tracers. Thus in theory almost unlimited components can be separated using the mass balance equation. Practically only the use of two or three component hydrograph separations are convenient, as there are conditions which have to be satisfied in the use of this method, and these include the following ([Ogunkoya & Jenkins, 1993]):

- the chemistry (solute and isotopic) of the waters from the various sources are distinguishable, i.e. each source has its own chemical identity
- the chemical identity is only changed during mixing in the system, there is spatial and temporal uniformity in the identity of each end-member

In nature there are usually not more than two or three end-members with constant concentration to be distinguished in their chemical composition.
The following part will show the relations for a two-component-separation. To identify the two end-member flows Q_1 and Q_2 from a observed flow Q_T, the concentrations C_1, C_2 and C_T must be known and measured, respectively (e.g. in [Kleissen et al, 1990]).

$$Q_T = Q_1 + Q_2 \tag{2.16}$$

$$Q_T C_T = Q_1 C_1 + Q_2 C_2 \tag{2.17}$$

This will lead to

$$Q_1 = Q_T \left[\frac{C_2 - C_T}{C_2 - C_1} \right] \tag{2.18}$$

and

$$Q_2 = Q_T \left[\frac{C_T - C_1}{C_2 - C_1} \right]. \tag{2.19}$$

With two components one may decide to use the highest and lowest observed values for the end-member concentrations, but choosing these values will lead to zero flow of one of the components during the periods that contain the extreme concentrations. However, in general Q_1/Q_2 is not sensitive to the assumed C_1, C_2, unless C_1 or $C_2 \approx C_T$ ([Kleissen et al, 1990]).

Chapter 3

Study Site

Mt. Carmel is a distinctive mountain ridge on the north-western coast of Israel, rising from the Mediterranean Sea to its highest peak at 546 masl (see Figure 3.1) and covering some 250 km^2.

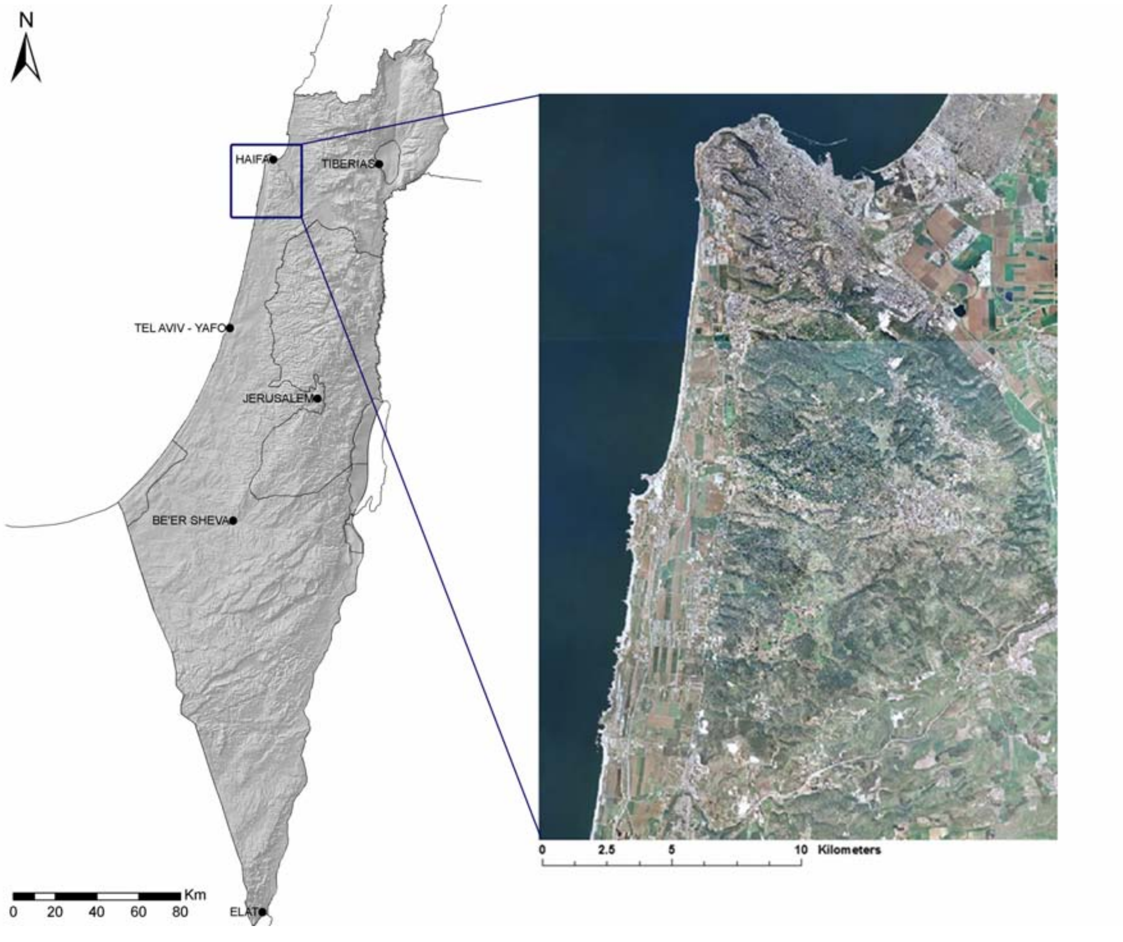


Figure 3.1: Area Map (after url2)

The area, characterised by its proximity to the sea and its sharp borders with the adjacent lowland, is triangular shaped and has clear morphological boundaries. It is bounded on the west by a sharp cliff line which is less pronounced in the north, and on the east by the big border fault. The upper Cretaceous carbonate rocks of Mt. Carmel are covered with shallow soils. The vegetation is a Mediterranean forest, composed mainly of a complex of pine (*Pinus halepensis*), oak (*Quercus calliprinos*), Pistacia Lentiscus and associations.

Nahal Oren is a mountainous, ephemeral stream system and is one of the biggest catchments in the Carmel mountain with a drainage area of 35 km^2. It drains from the main watershed to the west towards the Mediterranean and has a general gradient of 3 %. It has a bedrock channel with several alluvial sections in between and step pool morphology in general. The karstic nature of Nahal Oren catchment is well presented by a relatively low drainage density ([Wittenberg et al, 2004]). Its major tributary - Nahal Bustan (9 km^2 drainage area) joins the main Nahal Oren near the outlet from the Carmel mountain into the coastal plain. Figure 3.2 shows the catchment, as well as the distribution of wells, springs and gauging stations, which will be explained in detail in the experimental design section in chapter 4.

3.1 Climate

According to the Koeppen classification the climate of the study area is typical Mediterranean (Csa): rainy winters with hot and dry summers. Most rainstorms occur between November and March and are often convective during the autumn while winter precipitation (December – February) results from Eastern Mediterranean frontal systems. Mean annual precipitation increases from 550 mm at the coastal plain to 750 mm at the top. For the state of Israel, Jordan, and the West Bank, a mean annual distribution of rainfall is shown in Figure 3.3. One can see the climate gradient from the semi-arid north and north-west of the region to the arid deserts in the south of Israel and east of the Jordan river.

3.2 Geology

Mt. Carmel is a raised block, composed of Judea Group rocks (of Albian-Turonian age). It is delimited in the east and northeast by faults. On its southern boundary, Judea Group layers dip southwards below the Senonian and Eocene layers, which comprise the Menashe syncline. In the western Carmel, the cliffs that comprise the western boundary are reefs.

Mt. Carmel is characterised by severe and dense faulting, with abrupt lithofacies changes. Volcanic rocks are frequently encountered throughout the sedimentary succession. The various lithostratigraphic units of Mt. Carmel were deposited in marine environments that range from shallow to deep water. The Judea Group formations are composed principally of limestone and dolomite, with lesser amounts of interbedded chalk and marl. The Judea

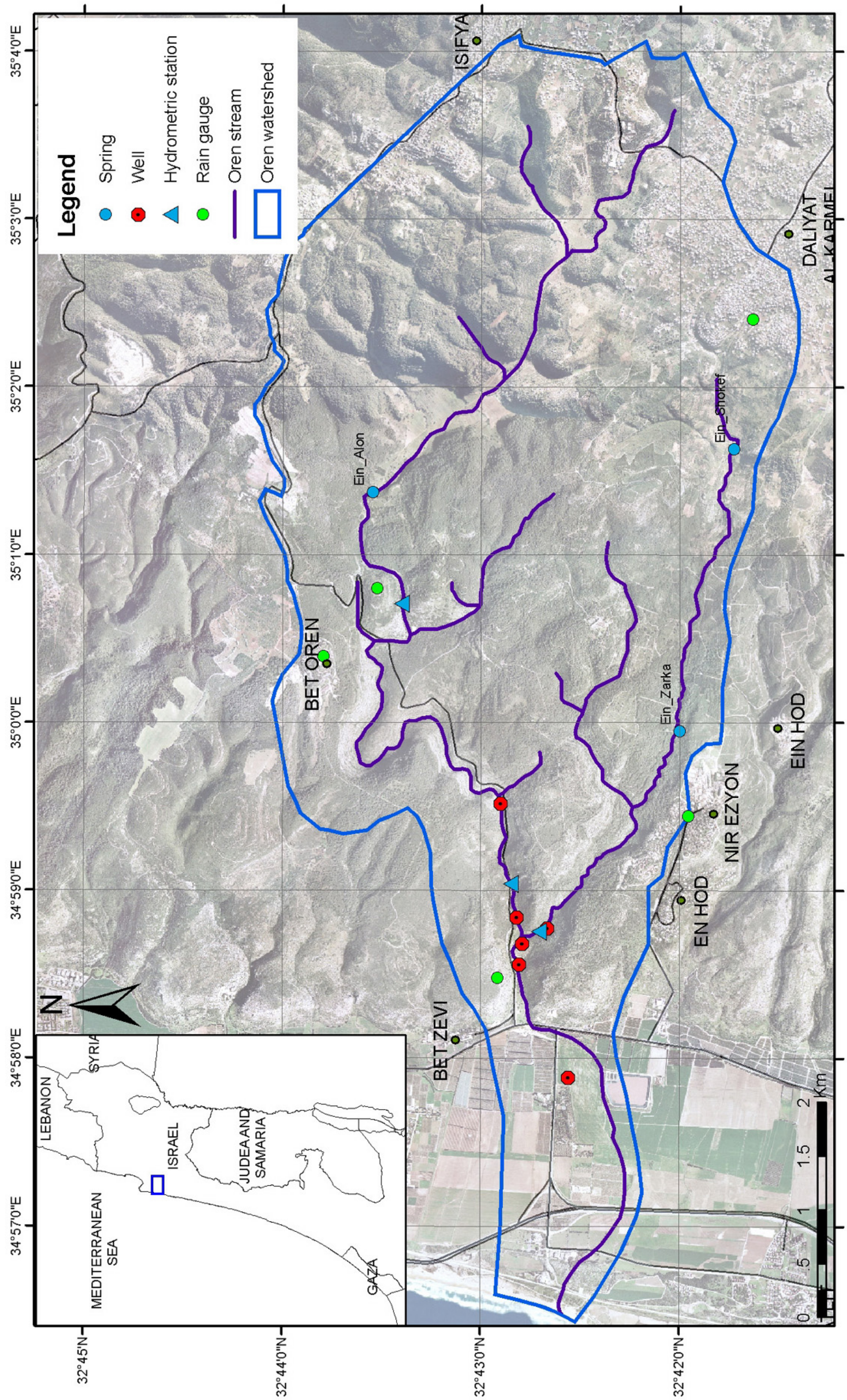


Figure 3.2: Nahal Oren Catchment

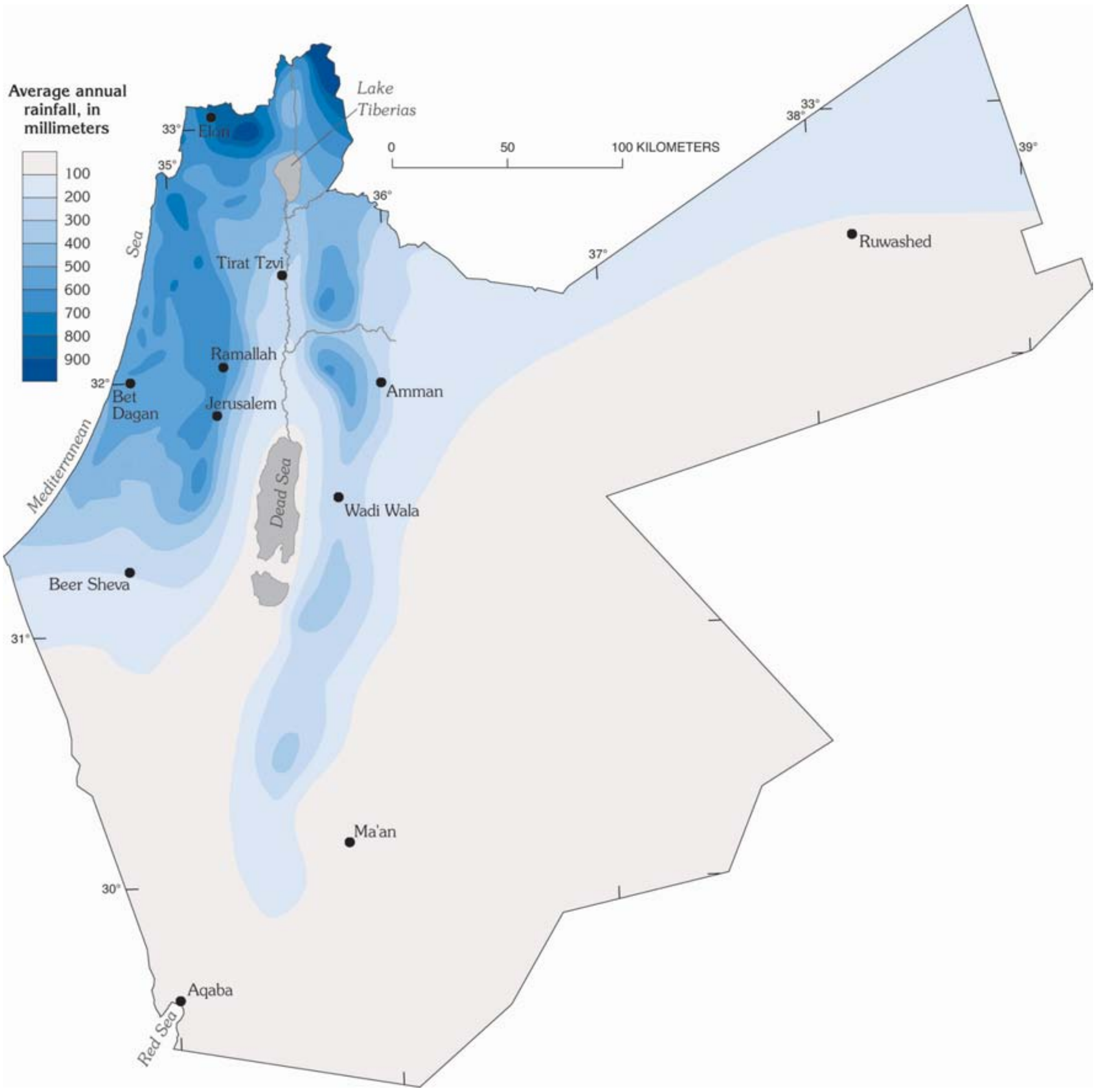


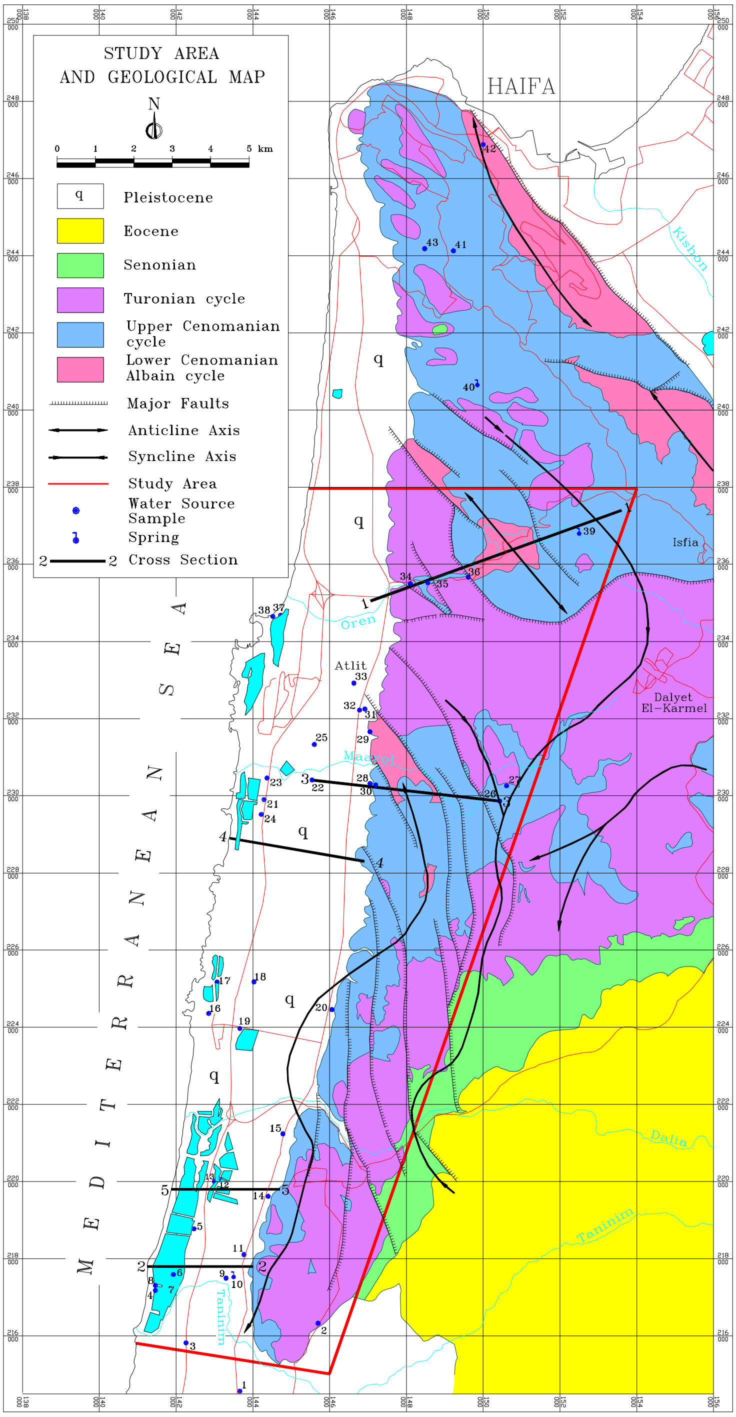
Figure 3.3: Mean Average Rainfall Map for Israel, West Bank and Jordan (from [URL1])

Group dolomites and limestones were deposited on a broad, shallow, partly restricted platform. The Talme Yafe Group marls, chalks and clays are a continental slope facies (Bein, 1974 in [Guttman, 1998]). These two groups interfinger at the western border of the study region. The transition zone, from a typical Judea Group facies to a typical Talme Yafe Group facies, occurs over a distance of only few kilometers. The stratigraphic cross-section of the Judea Group in Mt. Carmel can be devided and defined according to sedimentary cycles ([Guttman, 1998]):

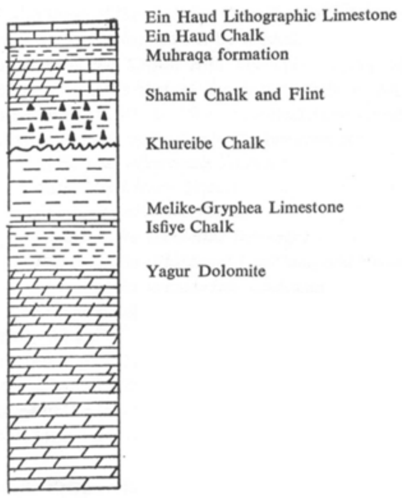
- **Albian-Lower Cenomanian:**
  This sequence is represented by the Yagur Formation. It is composed of dolomite and ruddiest reefs. The chalk facies of the Talme Yafe Group are located to the west of the Yagur Formations. Chalks were defined as belonging to the Talme Yafe Group, within the section of the Yagur Formation. The Yagur Formation is overlain by the Isafiya Formation, belonging to the Upper Cenomanian sequence.
- **Upper Cenomanian:**
  The Upper Cenomanian succession includes the chalk units in the section, and is comprised of the Isafiya, Khureibe and Shamir Formations. Basalt, tuffs, limestone and reefs appear within the chalk complex. This sequence differs from the sedimentary sequences below and above it in that it contains numerous facies changes. The many lithofacies changes stem from the different water depths under which the sediments were deposited.
- **Turonian:**
  The Turonian section is characterised predominantly limestone. It is conspicuous as it overlies the soft chalk layers of the Upper Cenomanian sequence. The Turonian rocks are mainly represented by the Mukhraqa Formation. In some places, marl beds belonging to the Ein Hod Formation and to the Daliya Formation. Within the Turonian section, various volcanic layers may be locally present.

Figure 3.4 summarizes the geological section in the northern Carmel including also a concept of the lithographic formations, a cross-section through the Nahal Oren catchment with some wells used in this study is shown in Figure 3.5. It should be mentioned that the study area in Figure 3.4a is not identical with the study area in this thesis, the Nahal Oren catchment is located around cross-section 1 (compare with Figures 3.2 and 3.7).

The Pleistocene section of the Carmel coast is relatively thin. At the eastern margins, it is about 20-25 m, increasing in thickness westwards. In general, the Pleistocene section thins from south to north and from west to east.
The Pleistocene section overlies the chalk and dolomite of the Judea Group (Michelson 1970 in [Guttman, 1998]). At its base it is predominantly dolomite near the foot of Mt. Carmel, and grades into chalks westwards. The stratigraphic section is composed of sand, calcareous sandstone and interbedded clay. Gravel may also be found along the river channels crossing the Carmel coast. The sand in the central section is covered with alluvial soils.



(a) Geological Structure in the Northern Carmel (from [GUTTMAN, 1998]). Note that the study site shown in this figure is not identical with the study site in this work. Nahal Oren catchment is located around cross-section 1.



(b) Stratigraphy and facies (from [KARCZ, 1959])

Figure 3.4: Geological Structure and Stratigraphy in the Northern Carmel

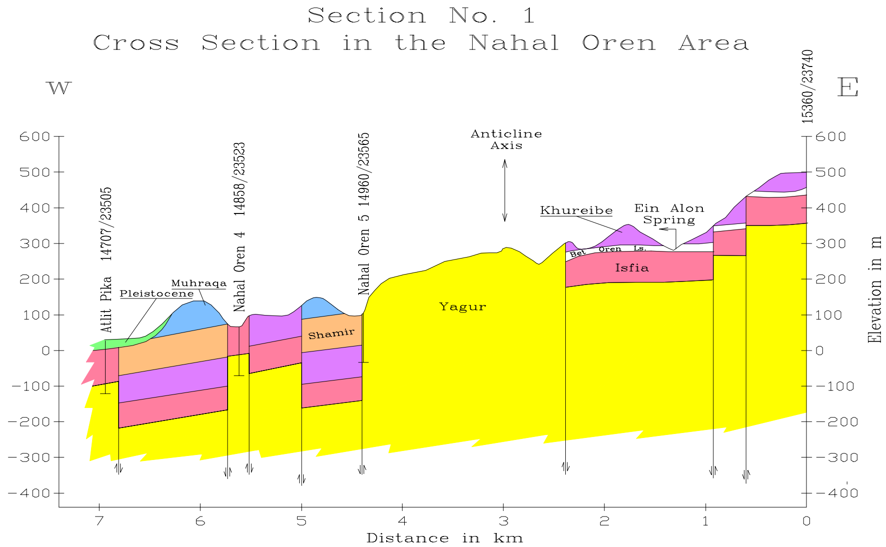


Figure 3.5: Geological Cross-Section in the Nahal Oren Area (from [Guttman, 1998])

3.3 Hydrology

3.3.1 Precipitation and Evaporation

There are a different rain gauging stations in and around the catchment which are operated by the Meteorological Survey of Israel: Atlit, Beit Oren and Nir Ezion. Other stations are operated by the Nature Reserve Authority and are located in adjacent catchments of Mt. Carmel: Nahal Mearot to the south, Hai-Bar and Carmel National Park to the north. They provide daily measurements of rainfall amounts. The rainfall station at the University of Haifa is operated by the Department for Geography & Environmental Studies and provides rainfall in various time-steps over the last 30 years (Figure 3.6).
The mean annual rainfall for the period of 1976-2004 is calculated to 717.9 mm. For the Beit Oren station the annual average is 699.5 mm, and analysis of the annual rainfall totals indicates no significant change from 1950-2000 ([Wittenberg et al, 2004]). At Nir Ezion station (in the lower part of Nahal Oren) the annual average is 618 mm ([Guttman, 1998]).
In addition to the official rain gauges, there are some more rainfall gauges under the supervision of [Arbel, not published]. One important station also for this study is situated near the confluence of Nahal Oren and Nahal Bustan on the ridge above the Oren Caves on the northern slope and is labeled *Oren Caves* in the following.

The potential evaporation in the area is in the range of 1500-1600 mm/year (Last, 1978 in [Guttman, 1998]).

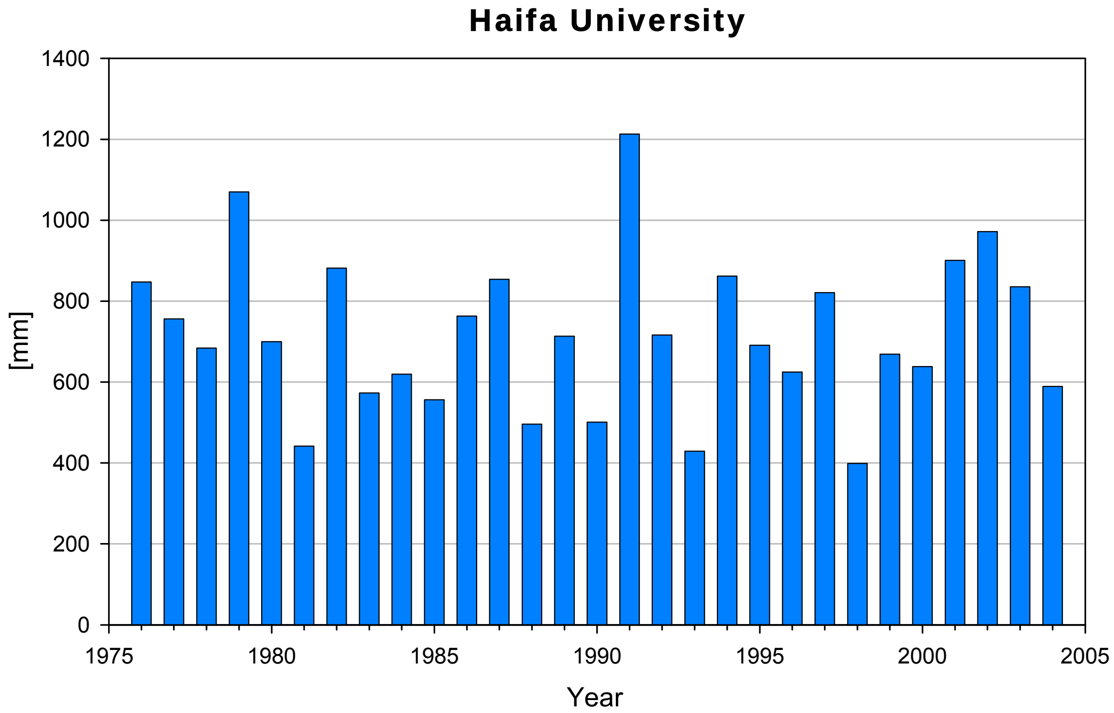


Figure 3.6: Annual rainfall totals for the period of 1976-2004 at Haifa University

3.3.2 Runoff

The ephemeral stream systems of Mt. Carmel experience sporadic flow events which occur usually in early December following high intense rainstorm events or later in the winter after the soil is well saturated. Flow generation depends largely on the cumulative rainfall since the beginning of the rain-season. Flows are commonly characterised by a rapid rise in water level, a peak discharge within a few hours, and a swift recession followed by a relatively long "tail". The typical lag time is generally a few hours, depending mostly on extent duration ranges between several hours to several days, where upon the channel returns to its previous dry condition. Only in some channels spring discharge sustains base flow which may last for a few days and up to a couple of weeks ([Wittenberg et al, 2004]).

There are three different hydrometric stations in the catchment which were already used in former studies ([Wittenberg et al, 2004], [Wittenberg & Greenbaum, 2005]). According to their location they are called *Pool*, *Bridge* and *Bustan* (see also Figure 3.7). Water balance investigations in a current study concentrate on the assessment of transmission losses between the Pool and the Bridge gauging station, whereas this study investigates the reaches between the Nahal Oren wells operated by Mekorot (see next subsection and chapter 4). Therefore the Pool discharge station is not regarded in this study as a flow recorded at this station is not representative for the lower Nahal Oren catchment.

Flood frequency analysis using Log Pearson III distribution in the Nahal Oren catchment indicated that the 5 year flood has a peak discharge of $5\,m^3s^{-1}$. The volume of such a

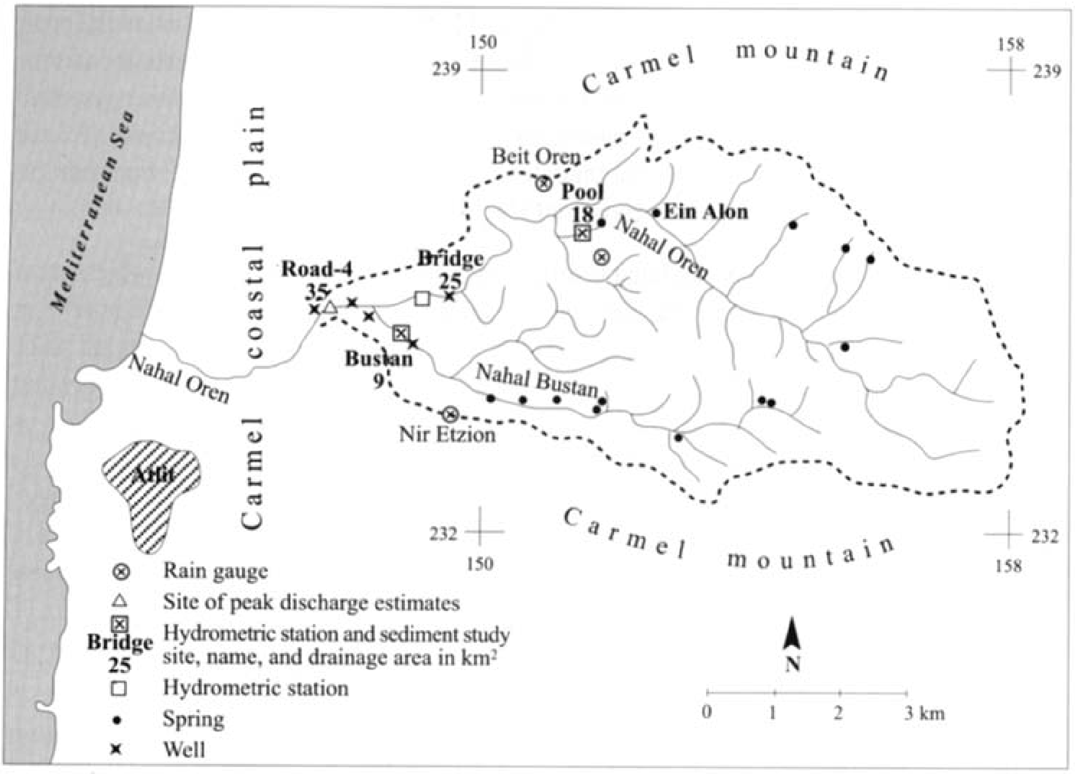


Figure 3.7: Nahal Oren Catchment (from [Wittenberg et al, 2004])

flood was estimated at $150{\cdot}10^3\,m^3$, by means of discharge-volume regression. Accordingly, flows with peak discharges larger that $5\,m^3s^{-1}$ and/or volumes of $150{\cdot}10^3\,m^3$ are defined here as *large* floods ([Wittenberg et al, 2004]).
The measured rainfall threshold for the initiation of a flow event ranges between 45 and 60 mm per rainstorm. These amounts generate low flows which usually decrease downstream and may even disappear due to transmission losses. However, large flows usually start following rainstorms of more than 100 mm, but may also occur in response to rainstorms of >70 mm during the end of winter (February) and the beginning of spring (March) due to high moisture content in the soil.
Magnitude and volume of floods are strongly related to rainfall intensities and seasonality, i.e. the duration of high-intensity rainfall needed for generating channel flow exceeds tens of minutes.

In the years of 2001-2003, 11 floods were recorded in total, 5 of which meet the criteria of being classified as large flood (see Table 3.1). The winter of 2001/02 - six flows, two of which were large flows - and the winter of 2002/03 - five flows, with three large events - were the years with the highest amounts of recorded floods in a surveyed period of 1991-2003. These winter were characterised by very high annual rainfall amounts - 126% and 135% of the average of 699.5 mm at the Beit Oren rainfall station. Peak discharges ranged from 3.3 to $17\,m^3s^{-1}$ and volumes ranged from 0.169 to 0.575 $10^6\,m^3$. The lack of flow events in years with similar precipitation amounts stems largely from the spatial distribution of rainfall within the basin.

Table 3.1: Hydrological characteristics of large floods and rainstorms in Nahal Oren (from [Wittenberg et al, 2004])

Date of Rainstorm	Peak Discharge [m^3/s]	Specific Peak Discharge [$m^3 s^{-1} km^{-2}$]	Volume [10^3 m^3]	Rainfall amount [mm]	Rainfall-runoff ration [%]
04.-06.12.2001	17.0	0.68	575	155.7	14.8
07.-10.01.2002	8.0	0.32	360	111.5	12.9
17.-20.12.2002	5.5	0.22	180	140.5	5.1
21.-22.02.2003	5.0	0.20	169	70.9	9.5
24.-27.03.2003	3.3	0.13	264.9	177.2	6.0

3.3.3 Groundwater

Two aquifers exist in the study area (Judea Group Aquifer of Albian-Turonian age and Carmel Coast aquifer of Pleistocene age), but only the Judea Group aquifer will be object to this study as all the wells sampled are drilled into the lithology of this aquifer.

The limestone and dolomite rocks of the Lower Albian-Cenomanian sedimentary sequence, the Upper Cenomanian dolomite rocks and the Turonian limestone and dolomite layer constitute the Judea Group aquifer at Mt. Carmel. Within the Judea Group of the Mt. Carmel there are layers of tuff, basalt and reef that can be considered to be local, small aquiferal units. The faults of Mt. Carmel (as shown in the cross-section in Figure 3.5) create hydraulic connection among the aquiferal horizons. In light of this, the Judea Group Aquifer in Mt. Carmel should be regarded as a single aquiferal unit ([Guttman, 1998]).

There are six wells in the area used in this study for different monitoring purposes: for the tracer experiments, for water level monitoring and for natural tracer sampling throughout the winter of 2005/06. The wells Nahal Oren 1, 2, 3, 4 and the observation well Atlit 1 are located at the foot of western Mt. Carmel along a north-south line of wells in other basins draining to the Mediterranean. Nahal Oren 5 is situated about 1.5 km east of Nahal Oren 1 and 2.6 km east of Atlit 1. All of the Nahal Oren wells are exploiting the Yagur formation (of Albian - Lower Cenomanian age), and the lack of significant drawdown among these wells are taken as evidence of hydrological connection throughout the Judea Group. Atlit 1 stopped pumping in 1992, and is drilled into the Isafiya formation of the Judea Group aquifer (see also drilling logs in Appendix).

As seen in Table 3.2, the discharge ranges from 100-370 m^3/hr. The transmissivity, as calculated from interference tests conducted in the Nahal Oren wells, reaches approximately 37000 m^2/day. The average hydraulic conductivity in the Judea Group aquifer is in the range of 100-200 m/day ([Guttman, 1998]).

Table 3.2: Wells in the Study Area - Capacities and Properties

	Capacity [m^3/h]	Discharge 2005 [MCM]	Depth [m]	Approx. Depth of Water Table [m]	Well Screen in
Nahal Oren 1	100-150	0.2766	117.70	44.5	Yagur Dolomite
Nahal Oren 2	350-370	0.8431	121.20	59.0	Yagur Dolomite
Nahal Oren 3	300-330	0.6200	159.60	57.2	Yagur Dolomite
Nahal Oren 4	~150	0.1884	129.00	62.1	Yagur Dolomite
Nahal Oren 5	300-350	0.5507	139.70	107.0	Yagur Dolomite
Atlit 1	-	-	~70	25.0	Isafiya Chalk and Limestone
total discharge 2005 :		**2.4788**			

The static groundwater levels in the wells of the Judea Group aquifer fluctuate sympathetically. This similarity indicates that in the western Mt. Carmel area the aquifer can be considered as one hydrological unit. The groundwater levels in the eastern wells are in most cases observed to be higher than those in wells located to the west. In other words, groundwater in the Judea Group aquifer flows generally in an east-west direction. During periods of massive pumping (principally during the summer months), groundwater levels in the eastern wells may at times, drop to below the level of that in the western wells at the foot of Mt. Carmel. This temporarily creates a reverse groundwater flow from west to east ([Guttman, 1998]).

Historical records evaluating the salinity show a general content of about 200 mg/l chloride in the Nahal Oren wells. In wells located further westward (like Atlit 1), a higher salinity of about 700-800 mg/l Cl^- can be expected because of the interaction with the Pleistocene aquifer. The salinity in the Judea Group aquifer is characterised by sharp seasonal fluctuations, ranging from tens to hundreds of mg/l per season, as well as a slow but continuous rise in salinity over the last 40 years. Moreover, there is a tendency for the salinity to rise during the summer pumping season. About 70-80% of the annual extraction takes place between May to October. During this period, a rise in salinity, of the order of tens to hundreds of mg/l over the winter values, may be discerned. In the winter, when pumping is reduced and natural replenishment occurs, there is a drop in the salinity to a level approaching that which prevailed before the summer increase ([Guttman, 1998]).

Figure 3.8 presents a correlation between the monthly volumes pumped and the salinity in well Nahal Oren 2. This pattern is found in all wells located along the Mt. Carmel foothills. This well has been taken to represent the aquifer as a whole in previous studies ([Guttman, 1998]), but unfortunately it has been shut down for maintenance during the period of this study and could only be used for taking static water levels.

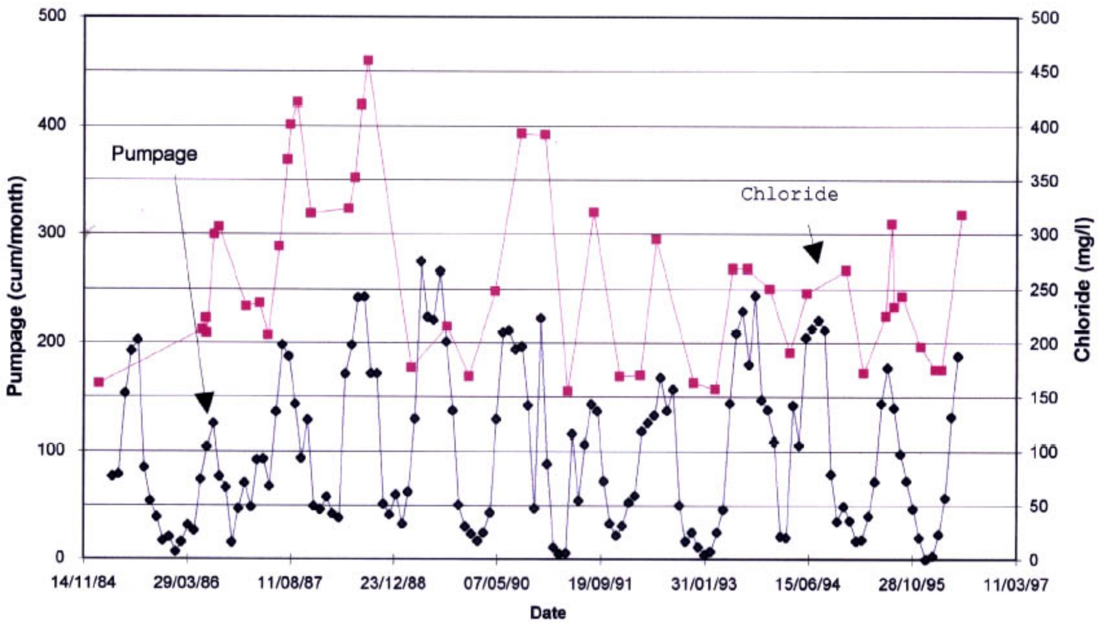


Figure 3.8: Pumping rates and Chloride concentrations in Nahal Oren 2 (from [Guttman, 1998])

The chemical composition of the aquifer in the Nahal Oren area has been analysed by [Guttman, 1998]. A Piper Diagram has been generated after the data given in his work, covers the period from 1951-1995) and is presented in Figure 3.9. The Ein Alon spring in the eastern side of the catchment (Figures 3.2 and 3.7) is of a Ca-Mg-HCO_3 water type. It represents the water in the recharge area of the Judea Group aquifer. The water from Atlit 1 in the western part of the catchment is of a Na-Ca-Cl-HCO_3 water type. These two locations can represent the two end-members in this area as their chemical compositions all form a line mainly in the anion section of the piper diagram. The chemical composition of the Nahal Oren wells between Ein Alon and Atlit 1 alter along this line and indicate the predominant flow path. The water from Nahal Oren 5 is of a Ca-Na-Mg-HCO_3 type, the water from Nahal Oren 1 of a Na-Ca-Mg-Cl-HCO_3 type. Hence the theoretical and predominant groundwater flow direction from east to west presented in [Guttman, 1998] could be verified for the historical data.

Groundwater ages are found to be less than 50 years using tritium and ^{14}C data, and it has been recharged since the 1960s ([Guttman, 1998]).

3.4 Conclusion

The Nahal Oren is an ephemeral stream system that drains a catchment area of 35 km^2. It is characterised by a semi-arid climate with rainfall seasons in winter ranging from 618 to 699.5 mm mean annual values. The vegetation is a Mediterranean forest, composed mainly of a complex of pine (*Pinus halepensis*), oak (*Quercus calliprinos*), Pistacia Lentiscus and associations. Runoff events occur every year, from December following high intense rainstorm events or later in the winter after the soil is well saturated. Two aquifers

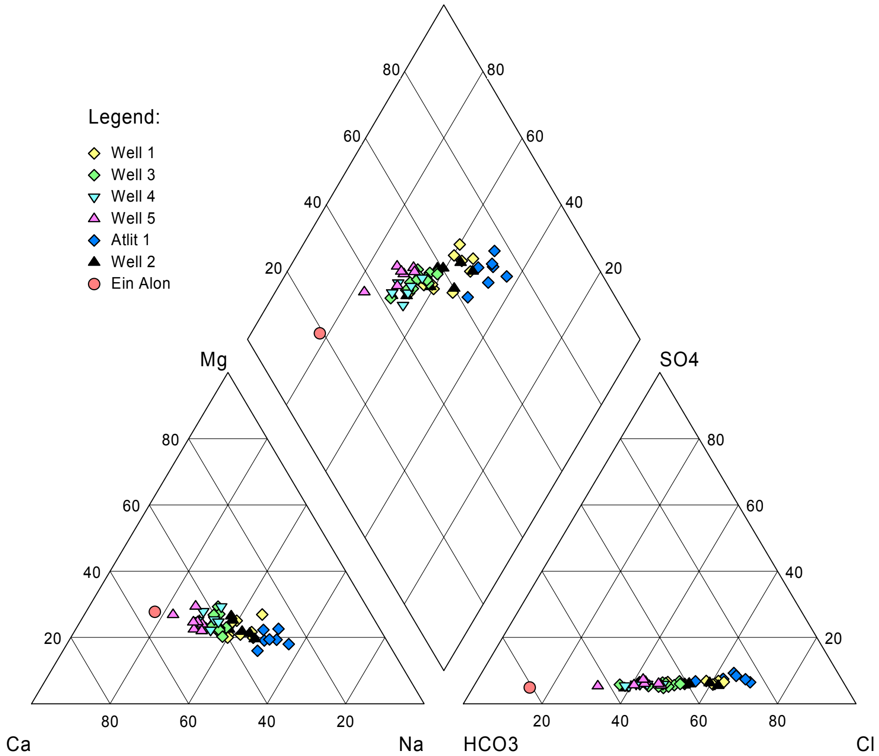


Figure 3.9: Piper Diagram from historical data (after [Guttman, 1998])

are known to exist in the study area (Judea Group Aquifer of Albian-Turonian age and Carmel Coast aquifer of Pleistocene age) and several wells are drilled into both aquifers to extract groundwater. Groundwater ages are found to be less than 50 years. A slow but continuous rise in chloride concentration in the groundwater of both aquifers has been recorded over the last 40 years.

In this study, the lower Nahal Oren catchment is object to several experiments using fluorescentic dye tracers to delineate transmission losses as a process of indirect groundwater recharge.

Figure 3.10: Nahal Oren from well Nahal Oren 5 upstream: The stream forms a narrow canyon into the Yagur dolomite formation (Beit Oren can be seen in the background).

Figure 3.11: Nahal Oren from the ridge above the Oren Caves: the wadi flows into the alluvial plain

Figure 3.12: The carbonatic cliffs of Mount Carmel at the outlet into the coastal plain westwards from well Nahal Oren 3

Chapter 4

Experimental Design and Data Collection

In this chapter, the setting and the implementation of the dye tracer experiments in the Nahal Oren catchment are explained as well as the additional data collection schemes and schedules. The preparations as well as the conduction of the experimental design are described and presented.

4.1 Experimental Design

The objectives of every tracer aided experiment in the field of hydrology are strongly connected to the choice of the tracers and the setting of the experiment as well as the declaration of representative study reaches and sampling points. The questions to be solved and the aims to be attained by the tracer test need to be defined ([WGSHS, 2003]). Every tracer experiment has to go through detailed preliminary investigations, and the use of fluorescentic dye tracers should be restricted to limited amounts in order to avoid interference with authorities and other third parties.

The aim of the tracer experiments in this study is the assessment of transmission losses contributing to groundwater recharge in the catchment. During a flood event in the ephemeral stream of Nahal Oren the infiltrating runoff has to be marked at the bottom of the unsaturated zone or when percolating water enters the bedrock. One way to achieve this is to inject the diluted dye directly into the runoff head during the flood. In this caseu the bulk of the tracer would be transported downstream with the surface runoff and the infiltrating fraction would be too little to detect; also the exact time of injection would be hard to estimate with respect to logistical problems. Another way is to dig deep pits into the alluvium over the entire cross section of the channel while the stream is dry, to inject the dye tracer prior to a flood into the bottom of the alluvial body in a diluted, but concentrated form ([WGSHS, 2003]) and cover the pits again with the alluvial soil. This way the tracer would be immobile until the alluvium is saturated from infiltrating loss of surface flow and the water would percolate down, entering the bedrock together with the dye tracer.

In the experimental design of this study it was planned to intensively sample groundwater from the time the first runoff occurs in Nahal Oren until the flood ceases, and also during dry conditions. Groundwater can be taken from the Nahal Oren wells operated by Mekorot, the national water supply company in Israel. Concurrently the static water level in the wells should be monitored before the well starts operating prior to taking groundwater samples. All the wells in this study are located on the river banks of Nahal Oren and Nahal Bustan, therefore only the vertical movement of the tracer can be considered in the interpretation of the experiment.

There has never been an experiment using dye tracers in the area; this study and the current work of [Arbel, not published] introduced this technique to the Nahal Oren catchment. Tracer experiments were carried out on different scales in the winter of 2005/06 to investigate groundwater recharge: [Arbel, not published] focusses on the slope and spring scale whereas this study takes the catchment scale into account. With the help of previous studies concerning transmission losses in the area the study reaches could be defined along the lower part of the Nahal Oren channel where the wells Nahal Oren 5, 3 and 1 are located from upstream to downstream and can be used for collecting groundwater samples (Figure 4.1). The hydrometric gauging station Bridge could provide discharge data from floods. Also in Nahal Bustan a study reach was defined, comprising of well Nahal Oren 4 and the gauging station Bustan (see also Figure 4.1). Well Nahal Oren 2 could only be used for monitoring static water levels as it was not in use during the period

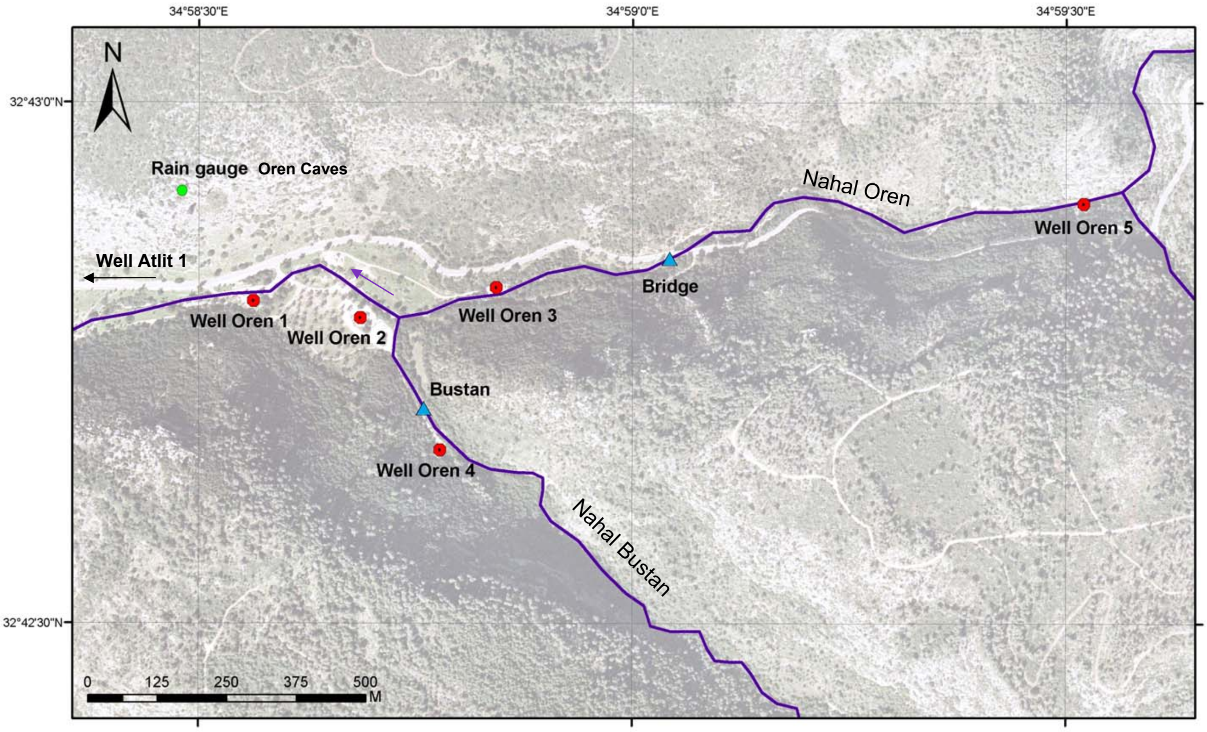


Figure 4.1: Location of the study reaches, wells, runoff and rainfall gauging stations

of investigation due to maintenance work. Precipitation and rainfall intensity has been measured above the Nahal Oren caves on a plateau on the mountain ridge of Mt. Carmel (also in Figure 4.1).

4.2 Study Reaches - Alluvial Properties and Pits

In order to estimate potential injection amounts of the dye tracers Naphtionate and Uranine, the alluvium of the study reaches in the Nahal Oren and Nahal Bustan stream system has to be investigated. It is also important to evaluate preflow moisture content of the alluvial soil to estimate lag times until the infiltrating runoff reaches the injected immobile tracer. Therefore it was decided to dig pits into the riverbed prior to floods, take representative soil samples and describe the alluvial properties of the profiles.

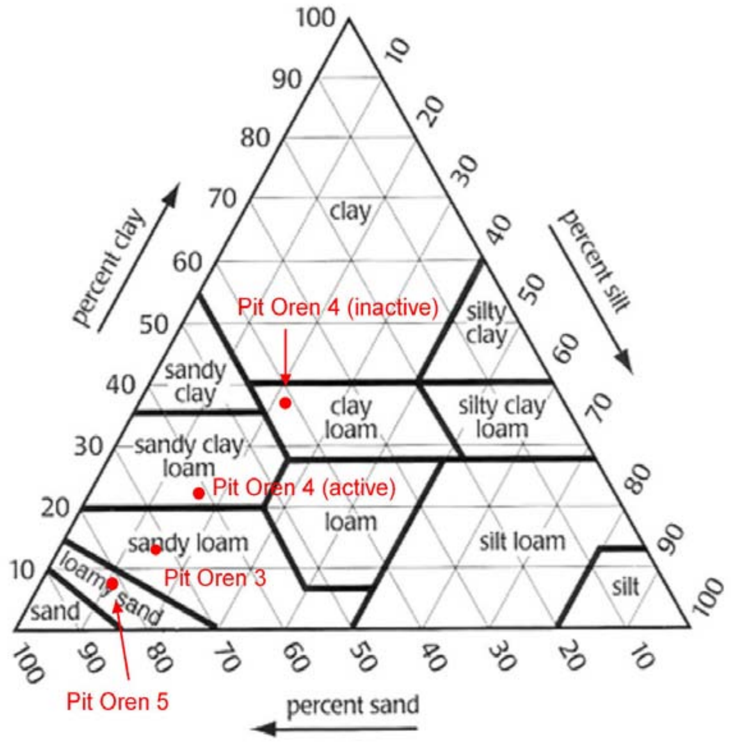


Figure 4.2: Texture Triangle of the alluvial pits near the Nahal Oren Wells

In total there are three big pits into the alluvium of the riverbed near the Wells Nahal Oren 3, 4 and 5. Each of these injection pits are described for its stratigraphy for the uppermost 70 - 100 cm. Soil samples from the most important sedimentary units from each pit have been taken prior to floods for texture and preflow moisture analysis. At each site, a cross section has been surveyed and the high water-marks are added to the cross sections. The texture analysis can be taken from Table 4.1 and from Figure 4.2. In all of the active layers of the alluvium there is a big fracture of grain sizes from 0.0063 - 2 mm. Grain sizes >2 mm have not been taken into account. Due to this high amount of sandy structures very high infiltration rates can be expected. Below detailed descriptions of the injection pits are given.

Table 4.1: Texture analysis of the pits near the Nahal Oren Wells

Location	Clay (%)	Silt (%)	Sand (%)	Texture
Pit Oren 3 (active layer)	13.0	14.0	73.0	sandy loam
Pit Oren 5 (active layer)	9.0	10.0	81.0	loamy sand
Pit Oren 4 (active layer)	21.0	18.0	61.0	sandy clay loam
Pit Oren 4 (inactive layer)	37.0	22.0	41.0	clay loam

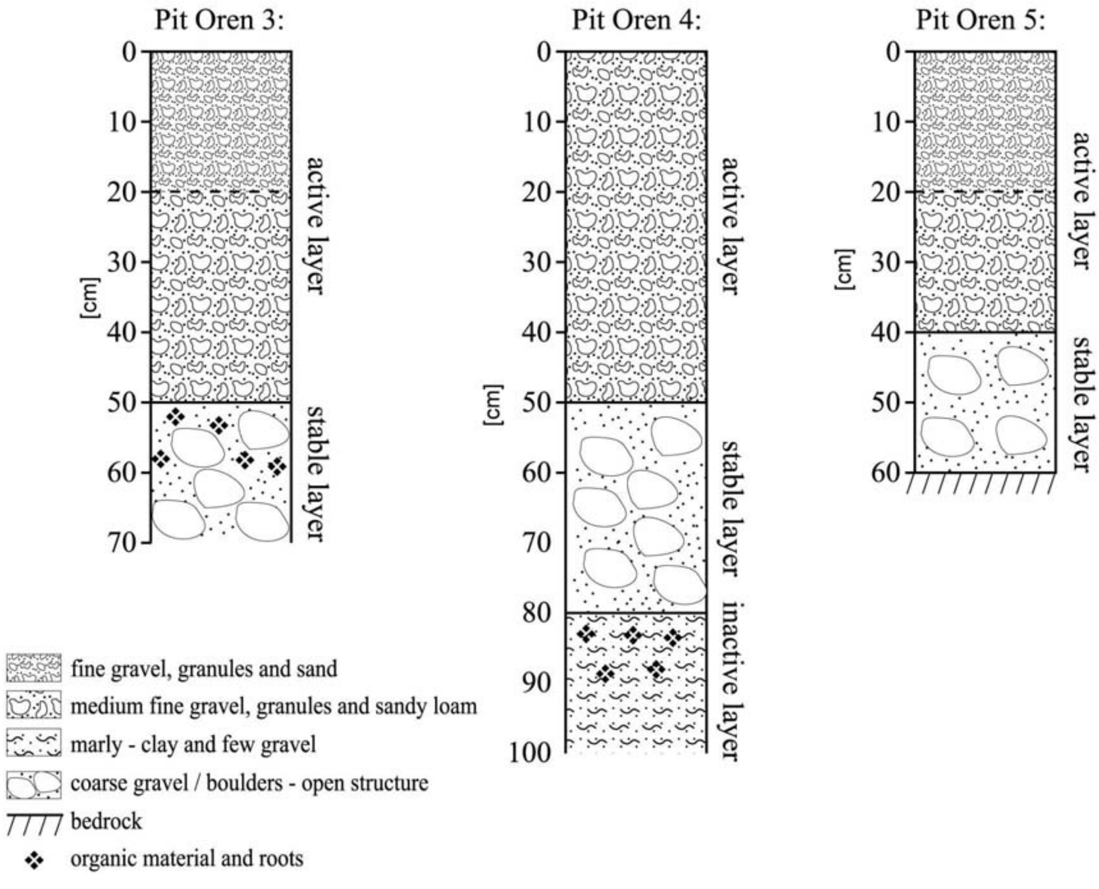


Figure 4.3: Stratigraphy of pits near wells Nahal Oren 3, 4 and 5

Pit Oren 3, which is placed into the middle of the wadi into the alluvial channel about 15 m upstream from Well Nahal Oren 3, is 2.20 m wide and 0.7 m deep (Figure 4.4). It shows no layering in the upper 50 cm, round pebbles of chalky limestone and angled dolomite gravel are deposited with amounts of fine material between it. Open structures (see Figure 4.5) are found to occur in this layer, thus the infiltration is assumed to be increased. Also the sandy fraction accounts for 73% of the soil matrix. In the lower 20 cm of the pit there are round pebbles, cobble, organic material and wood, which indicates

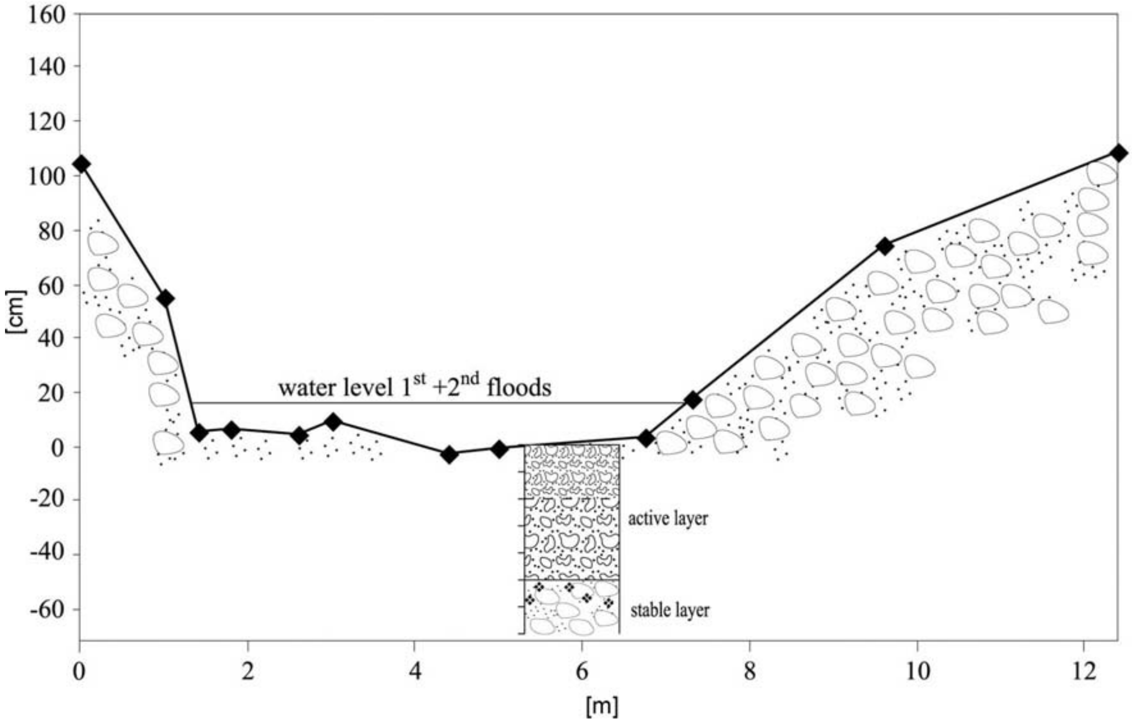


Figure 4.4: Cross Section and Stratigraphy at Pit Oren 3

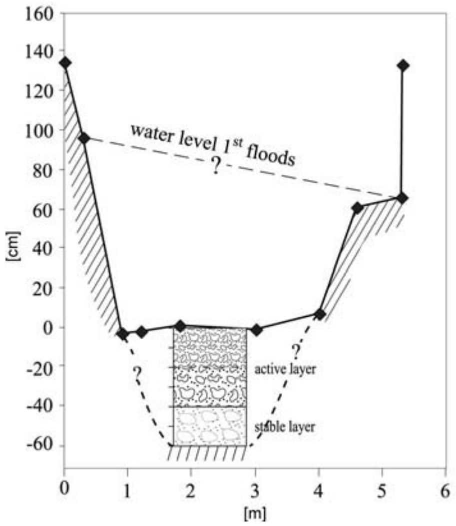
(a) Alluvial Profile of Pit Oren 3

(b) Open Structures at Pit Oren 3

Figure 4.5: Pit Oren 3

a stable layer of the alluvium. The sample for texture analysis is taken from the upper (active) layer and is classified as sandy loam. The alluvium at Well Nahal Oren 3 is thicker as the wadi opens up to the plain outlet of the stream system. The bedrock could not be reached in this injection pit.

Pit Oren 5 covers the entire cross-section about 20 m upstream from Well Nahal Oren 5 where the cliffs of the Mt. Carmel limestone form a narrow canyon. Compared to the other pits this one has been dug into the bedrock channel which is quite outstanding. It is only 60 cm deep, but reaches the bedrock after this depth (Figure 4.6). In the lower 20 cm big boulders are found which indicates again a stable layer. The upper 40 cm consist of very coarse sand and gravel, with loose and open structures, thus very high infiltration rates are assumed here. The texture analysis of the also shows the loamy sand structure. In this injection pit it was attempted to inject the tracer directly onto the bedrock surface. During a flood it was intended that the transmission losses take up the tracer immediately, enter the bedrock's lithological layers and does not have to infiltrate through the alluvial layer.

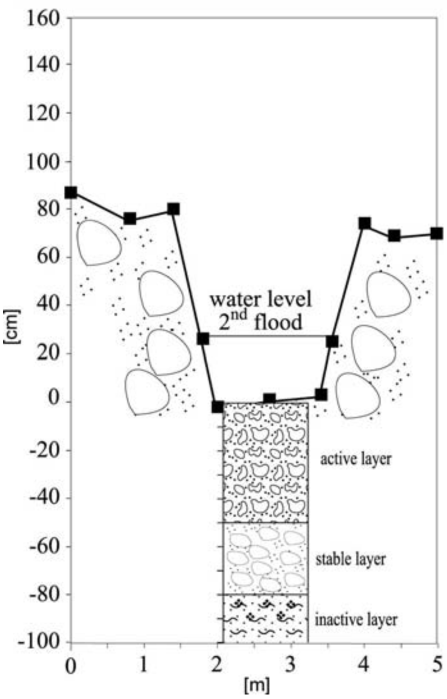


(a) Cross Section

(b) Nahal Oren at Pit Oren 5

Figure 4.6: Pit Oren 5

Pit Oren 4 also covers the entire cross-section about 20 m upstream of Well Nahal Oren 4, where the wadi is bounded by big boulders at both sides of the stream bed. Like at Well Nahal Oren 3, the pit has been dug into the alluvial channel. It is 1.70 m wide and 100 cm deep (Figure 4.7). Two different layers could be defined, with different texture and different hydrological preferences. The active layer in the upper 80 cm consists mainly of gravel and sandy matrix with patches of fine material. At a depth of 50 - 80 cm cobble and small boulders can be found with sandy structures in between. The inactive layer in the lower 20 cm has a reddish colour, which derives from a high fraction of marl and clay (Table 4.1). It is likely to experience decreased infiltration in this layer which probably accounts for having more frequent floods in Nahal Bustan than in Nahal Oren.



(a) Cross Section

(b) Picture of Pit Oren 4

Figure 4.7: Pit Oren 4

The water content in the alluvium accounts for the day before the investigated floods, is determined gravimetric and is summarised in Table 4.2. The low values of 10.5-17.4% weight water content assure that the injected tracers were immobile until the saturation process finished due to intense rainstorms on the 25.01.06 and 09.02.06 and the consequent runoff and infiltration on the 26./27.01.06 and 09./10.02.06.

Table 4.2: Weight Water Content in the Alluvium prior to flood

Location	Weight Water Content (%)
Pit Oren 3 (active layer)	11.5
Pit Oren 5 (active layer)	10.5
Pit Oren 4 (active layer)	17.4
Pit Oren 4 (inactive layer)	17.0

4.2.1 The First Flood Event on 26./27.01.06

In the rainy season of 2005/06 there had already been a flood on Christmas Eve, but the flood which occurred on the 26./27.01.06 was the first one for which a tracer aided experiment could be prepared. Therefore this flood is labeled the First Flood Event (FFE) in the following.

The heavy and intense rainfalls on the 25.01.06 induced a flood in the Nahal Oren river system which lasted from approximately 9:00 on the 26.01.06 until 22:00 the day after. More precise times and duration of the runoff event could have only been taken from the discharge data of the Bridge hydrometric station, but due to a malfunction of the data logger no runoff data was recorded from this station. The peak runoff was estimated by high water marks later on to about 0.6 m^3/s at the Bridge, and the duration to about 37 h. From historical data ([Greenbaum & Wittenberg, 2006]) the total discharge volume is derived from a linear regression of flood peak discharge vs. volumes for flood durations of 2 days. This way a total runoff volume of 16,000 m^3 can be assumed.

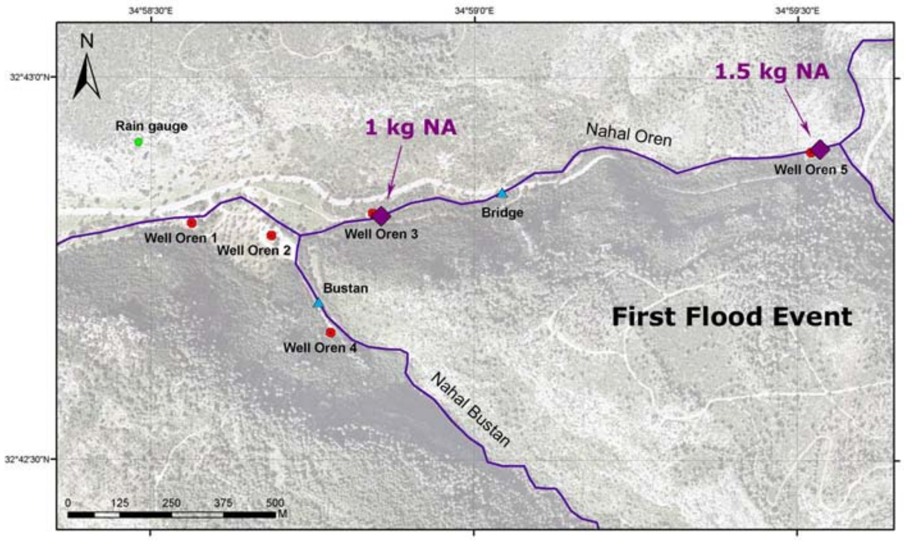


Figure 4.8: Experimental setting during First Flood Event on 26./27.01.06

For the FFE two pits have been dug along the wadi into the alluvium of the dry channel, near well Nahal Oren 3 and 5 (see above). Naphtionate is used for this first experiment for different reasons: the main concern is the potential coloration of drinking water if the hydraulic connection of the surface flow and the aquifer is high. Thus Naphtionate has been used rather than Uranine as its visibility threshold is much higher and the risk of colored drinking water in the Nahal Oren wells is reduced. Also NA shows low sorptivity rates and is well suitable in short distance experiments, it could therefore be immobile at the bottom of the alluvial riverbed. It has been used before in karstic aquifers, and has proven itself to be a good choice in lithologies with a high fraction of conduits and fissures (e.g. [Maloszewski et al, 1992])

NA was injected into both pits prior to the flood when high rainfall intensities could be expected within the next 24 hours. The NA grains were dissolved in deionised water, but only to its lower solubility threshold:

- 1.5 kg of NA was injected into Pit Oren 5 on the 25.01.06 just before the rainfall started and the pit was covered after the injection. As the water table at this location lies about 100 m below the surface, more NA was assumed to be appropriate.
- At Pit Oren 3 1 kg of NA was injected on the 25.01.06 just before the rainfall started and the pit was covered after the injection.

(a) Injection of 1.5 kg NA in Pit Oren 5 on 25.01.06

(b) Bridge runoff gauging station during FFE

Figure 4.9: First Flood Event

From the time the flood occurred (26.01.06 - 9:00) sampling started twice a day from Well Nahal Oren 3 and 5 because they were closest to the injection points, and because object of the experiment is the vertical movement of the tracer. Blind samples have been taken before the tracer was injected. For taking a sample from the wells, each well has to be in operation for at least 30-45 min in order not to sample stagnant water from the pipe and to make sure the drawdown cone is well established. The wells are usually not operating in winter for more than one hour per day as the demand of water is much less than in summer. Therefore the sampling schedule had to be arranged with Mekorot, the operator of the wells in the area. Each measurement, two bottles of 100 ml have been taken - one was sent to the Institute of Hydrology at the University of Freiburg (IHF), Germany for fluorescentic analysis, one for the Field Service Laboratory in Neve Yaa'r (FSL), Israel for analysing major ions.
Intense sampling went on until the 02.02., and changed to taking samples once a day until the 08.02.06. In total the reaction of the aquifer to the flood event was monitored for 14 days.

4.2.2 The Second Flood Event on 09./10.02.06

The experiment of the Second Flood Event (SFE) was more complex than the first one. During the FFE a reach of potential increased transmission losses between the Bridge gauging station and Well Nahal Oren 3 was observed. Therefore a different approach was set up: Uranine was used instead of Naphtionate as a tracer in the Nahal Oren reach, whereas another study reach was defined in Nahal Bustan for Naphtionate. Due to the fact that no water coloration could be detected during the sampling schedule of the FFE, it was agreed to use Uranine in appropriate amounts for this experiment. Thus the setup included the following:

- Five shallow pits were dug (about 40 cm deep) into the alluvial body upstream of Well Nahal Oren 3 in interspaces of about 40 m, this way covering a reach of about 200 m. 100 g of Uranine was injected in each of these small pits on the 08.02.06, just before the rainfall started. It was only in slightly dissolved condition and immediately covered with the alluvial soil. This way in total 500 g of UA were injected immobile.
- Another big pit was dug in Nahal Bustan near Well Nahal Oren 4 at a narrow cross section about 20 m upstream the well. The description of Pit Oren 4 is given above. 1 kg of NA was injected in slightly dissolved condition into the pit and covered on the 08.02.06.

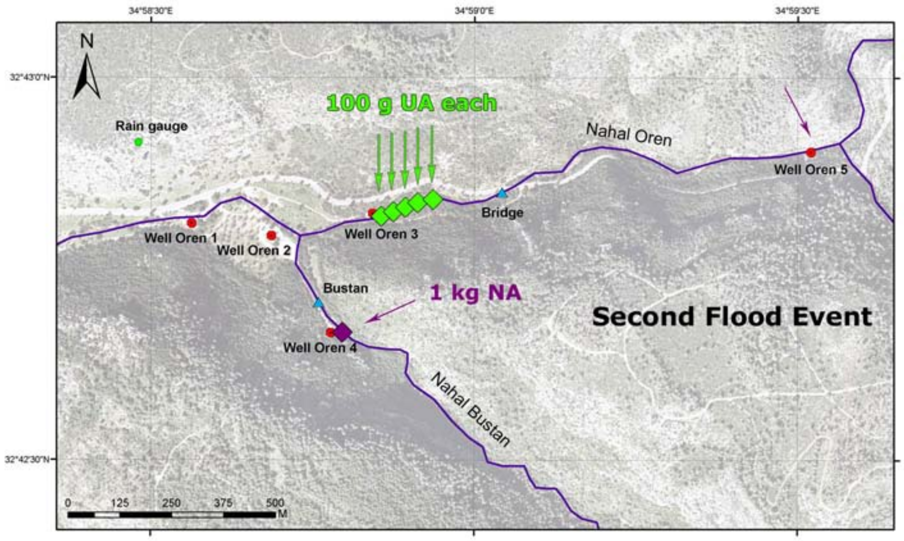


Figure 4.10: Experimental setting during Second Flood Event on 09./10.02.06

Heavy rainfalls in the night of the 08./09.02. induced a flood in the Nahal Oren and Nahal Bustan stream system which lasted approximately 1 day. The wadi started to flow on 09.02. at about 12:00 and ceased on 10.02. around 15:00. Also during this flood no runoff data could be recorded neither from the Bridge and the Bustan station due to the data logger malfunction mentioned before. From high water marks a peak discharge of about 1 m^3/s at the Bridge gauging station could be estimated, the flood duration was about 27 h. From historical data the same linear regression was used to calculate the flood volume to about 26,700 m^3.

Intensive sampling after the start of the SFE included collecting samples once to twice a day from wells Nahal Oren 1, 3 and 4 from 10.02. until 16.02.06. Well Nahal Oren 1 is taken into account during and after the SFE to cover the entire aquifer and potential lateral transportation of the tracer to the culmination along the assumed flow path. After 16.02. the interval was increased to once a day until the 25.02.06, and after that, time steps were raised as no flood or large rainfall event occurred, until the sampling schedule stopped on 22.03.06. Samples were taken in the same way than during the FFE, after the wells operated for at least 30-45 mins. Two bottles of 100 ml have been taken each time and each well - one was sent to the IHF, Germany, for fluorescentic analysis, one for the FSL, Israel, for analysing major ions.
Well Nahal Oren 5 could not be sampled during the period from 14.02. - 22.03.06 due to bacterial contamination of groundwater detected in mandatory water quality checks by Mekorot.

(a) Injection of 1 kg NA in Pit Oren 4 on 08.02.06

(b) Injection of 100 g UA in one of the small pits at the Bridge-Nahal Oren 3 reach

Figure 4.11: Second Flood Event

4.2.3 Additional Measurements

During both the FFE and the SFE water samples from the surface runoff were taken near the sampled wells to send them to the Field Service Laboratory in Neve Yaa'r for analysing major ions. The chemical data of rainfall is taken from records also used in [Arbel, not published]. Rainfall amounts are taken from the stations operated by the Israel Meteorological Survey and the Nature Reserve Authority, which take measurements on a daily basis, but in addition, rainfall intensities were measured and are available from January until April 2006 by a tipping bucket rain gauge above the Oren Caves (see above).

Water levels were monitored in 2 different ways:

- Manually with an electric line from 09.01. - 27.03.06 in all of the Nahal Oren wells (1-5). During the period of intense sampling during and after both flood events the static water level was measured in daily time steps. It had to be assured that the well to be measured did not operate for at least 8 hours before taking levels to establish a static condition in the aquifer. An oil layer on the groundwater surface at wells Nahal Oren 3 and 5 caused difficulties in the data acquisition. For this reason a measurement error of about +/- 2 cm has to be assumed.
- Automatically by installing a CTD-DIVER probe (*Schlumberger/Van Essen Instruments*) into the observation well Atlit 1 located 1150 m west of well Nahal Oren 1 in the coastal plains (see 3.2): the CTD-DIVER is able to measure water level, temperature and electrical conductivity continuously and save the data to an integrated logger. This way these parameters were measured continuously in time steps of 10 min from 05.01. - 05.04.06, with only a short gap between 22.-27.02.06 due to maintenance.

Initially all of the Nahal Oren wells should be equipped with CTD-DIVERs, but the observation pipes of the wells were clogged due to precipitation of calcite inside the pipes.

As already mentioned, more tracer experiments have been carried out to investigate groundwater recharge processes on the slope scale for the work of [Arbel, not published]: a combined tracer experiment using Uranine and Naphtionate at Ein Alon, a spring in the upper catchment, where the tracer was partly injected into soil pits above the spring and into surface runoff about 50 upstream the spring; and a tracer experiment using Uranine at the Oren Caves near the outlet of Nahal Oren, where the tracer was injected into soil pits above the caves and detected within days in cave drippings. More information about the implementation and the results will be given in [Arbel, not published].

4.2.4 Conclusion

Prior to the occurring floods in the Nahal Oren stream system three deep injection pits have been dug into the alluvium near the wells Nahal Oren 3, 4 and 5. Each pit has been described with respect to stratigraphy, infiltration capacities, texture and preflow moisture. All of the pits show an upper active layer and indicate increased infiltration capacities and preferential conditions for transmission losses. For each of the two occurring flood events during the period of investigation a tracer aided experiment could be prepared. The experimental setting and the sampling schedule provided an appropriate way to investigate groundwater recharge triggered by transmission losses on the Nahal Oren catchment scale. Both samples for fluorescentic analysis and major ions analysis have been taken during and after both flood events. Additional measurements included physical parameters, static water levels and rainfall intensities. Unfortunately no discharge data could be recorded due to data logger malfunction; runoff volumes and peak discharges could be estimated, but without a hydrograph most results have to be regarded as qualitative rather than quantitative.

(a) FFE at well Nahal Oren 5 (26.01.06, 12:00)

(b) FFE at well Nahal Oren 3 (26.01.06, 12:30)

Figure 4.12: First Flood Event at injection pits

Chapter 5

Results

5.1 Precipitation

Precipitation data is available from different rainfall stations in the Nahal Oren catchment and from adjacent catchments. On a daily basis the data from the stations Beit Oren, Shalala, Daliyat-al-Carmel, Nir Ezion, Atlit, Nahal Mearot, Carmel National Park Office, Hai-Bar and Haifa University have been collected by the respective operator. They can help defining single rainfall events and quantifying them, whereas the rainfall data from the Oren Caves station provides data for rainfall intensities and are used in interpreting water levels and the tracer data later on.

5.1.1 Rainfall Events

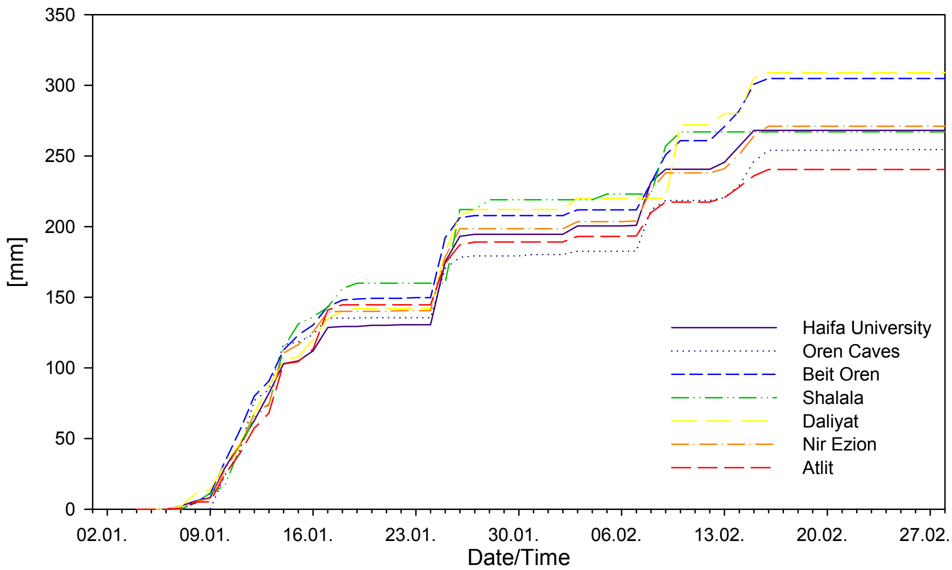


Figure 5.1: Cumulative rainfall for Jan/Feb from available rainfall gauging stations

To find a representative station for the Nahal Oren catchment from the above mentioned stations, a comparison the cumulative rainfall data for the period of January and February is done. The stations Nahal Mearot, Carmel National Park Office and Hai-Bar are disregarded because they are located in adjacent catchments to the north and south, respectively. The values of cumulated rainfall for the remaining stations range from 309 mm (Daliyat) to 240 mm (Atlit). Stations Shalala and Daliyat were regarded as not to be consistent due to gaps in daily values (e.g. after weekends cumulative values instead of daily values). Station Oren Caves has not been noted everyday, but was equipped with a data logger and a tipping technique, the cumulative value of 254.5 mm was calculated. Haifa University station is the most consistent of the stations, but the rainfall data can only be used by a correlation for the Nahal Oren catchment. Stations Beit Oren (304.8 mm) and Nir Ezion (271 mm) are both located on the watershed of the catchment, and can both be regarded as representative, with the Nir Ezion station showing a higher consistency and values of the same order as Oren Caves. Hence the latter is used to define rainfall events and amounts.

Daily values of rainfall at the Nir Ezion station are shown in Figure 5.2. From 01.01. - 31.03.06 a total rainfall amount of 276.0 mm was recorded. A rainfall event in this study

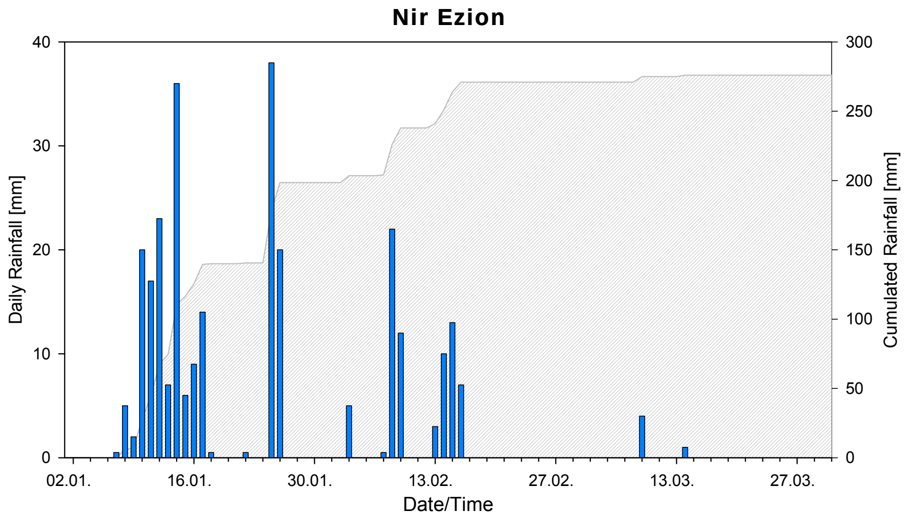


Figure 5.2: Rainfall at Nir Ezion station for Jan - Mar 2006

is defined as measured precipitation on consecutive days with more than 10 mm volume in total. There have been 4 rainfall events from 01.01. - 31.03.2006. An overview is given in Table 5.1.

Table 5.1: Rainfall Events in Nahal Oren catchment in Jan/Feb 2006

Nr	Date	Duration [d]	Volume [mm]
1	07.-18.01.	12	140.0
2	25./26.01.	2	58.0
3	07.-09.02	3	34.5
4	13.-16.02.	4	33.0

The first event lasted for 12 days and a total volume of 140.0 mm was recorded. Although [Wittenberg et al, 2004] state that already 45-50 mm are enough to induce a flood in the Nahal Oren river system, flood was only observed in the upper catchment during and after the days the rainfall occurred, but did not reach the lower catchment and the Nahal Oren wells. They also assume that even rainstorms of over 100 mm do not generate flow if they are scattered, like observed during this event. One can assume that rainfall intensities weren't high enough or the soils in the catchment were too dry to generate flow in the lower wadi. Probably this event started saturating the soils and alluvial layers to a high extent. As [Wittenberg et al, 2004] point out, flood generation occurs after preceding accumulated rainfall of 120-150 mm. This is why a flood could be expected for the next rainstorm.
The next rainstorm only lasted for 2 days, but with volumes of 38.0 and 20.0 mm for the single days. This intense rainfall triggered flow in the Nahal Oren river system which was object for the first experiment or FFE as it is called in this study.
The following rainfall event only had a volume of 34.5 mm at the Nir Ezion station, but was intense enough to induce the SFE (Second Flood Event) in Nahal Oren and Nahal Bustan streams which was the object of the second experiment.
Although only a few days later another rainfall of about the same order of volume (33.0 mm) occurred, it has not been intense enough to generate flow in Nahal Oren, only Nahal Bustan was flowing on 15./16.02.06.

5.1.2 Rainfall Intensities and Variations

In semi-arid regions where rainstorm are highly variable in spatial and temporal scale, it is recommended to use rainfall intensities for interpreting single flood events. Runoff is mostly generated by saturation excess in semi-arid areas and is strongly connected to rainfall intensity and infiltration processes ([Simmers, 2003]). The rainfall intensities have only been recorded at the Oren Caves station, and are shown in Figure 5.3. As no runoff data is available, only the approximate dates of the floods are shown in this and the following figures. Looking at the statistical analysis of the rainfall intensities recorded at the Oren Caves station one can interpret the occurrences of floods and their absence. The rainfall events 2 and 3 in the table above which induced flow in the catchment show the highest proportions in high intensities from 10-100 mm/h. This can explain the generation of flow although in rainfall event 3 only a volume of 34.5 mm could be recorded, whereas [Wittenberg et al, 2004] state that flow doesn't generate below 45-50 mm volume. The first rainfall event was too scattered to induce a flood but also shows a high proportion of higher rainfall intensities. Rainfall event 4 also shows high proportions in high intensities, but combined with the low total volume of 33.0 mm one can assume that a higher proportion of very high intensities would have been required to generate flow in the entire catchment.

An example for the high variation in rainfall amounts during the years can be taken from Figure 5.5. The sum amounts of January and February of each year is plotted with the total amount of each year for the Haifa University station. There is a certain correlation, but no trend could be observed in these data.

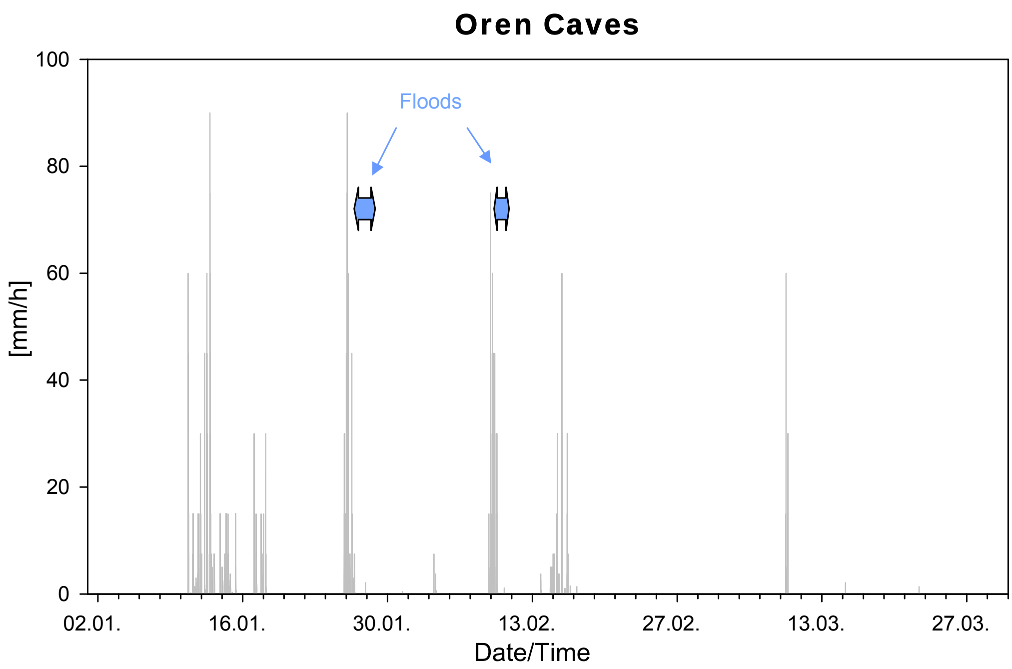


Figure 5.3: Rainfall Intensities at Oren Caves station for Jan - Mar 2006 and occurrence of floods

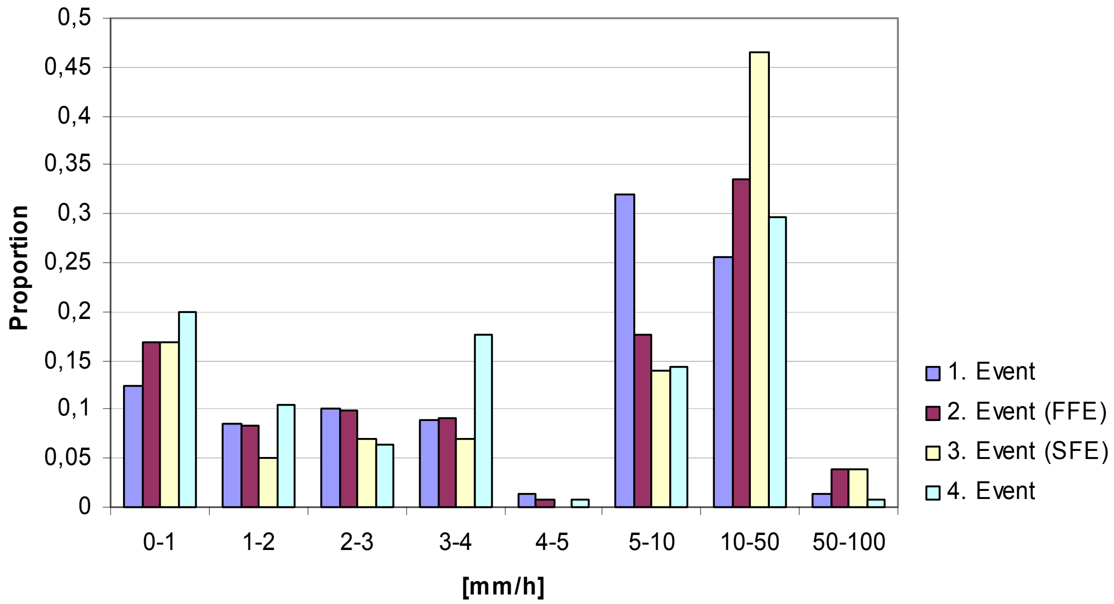


Figure 5.4: Histogram for Rainfall Intensities at Oren Caves station for Jan - Mar 2006

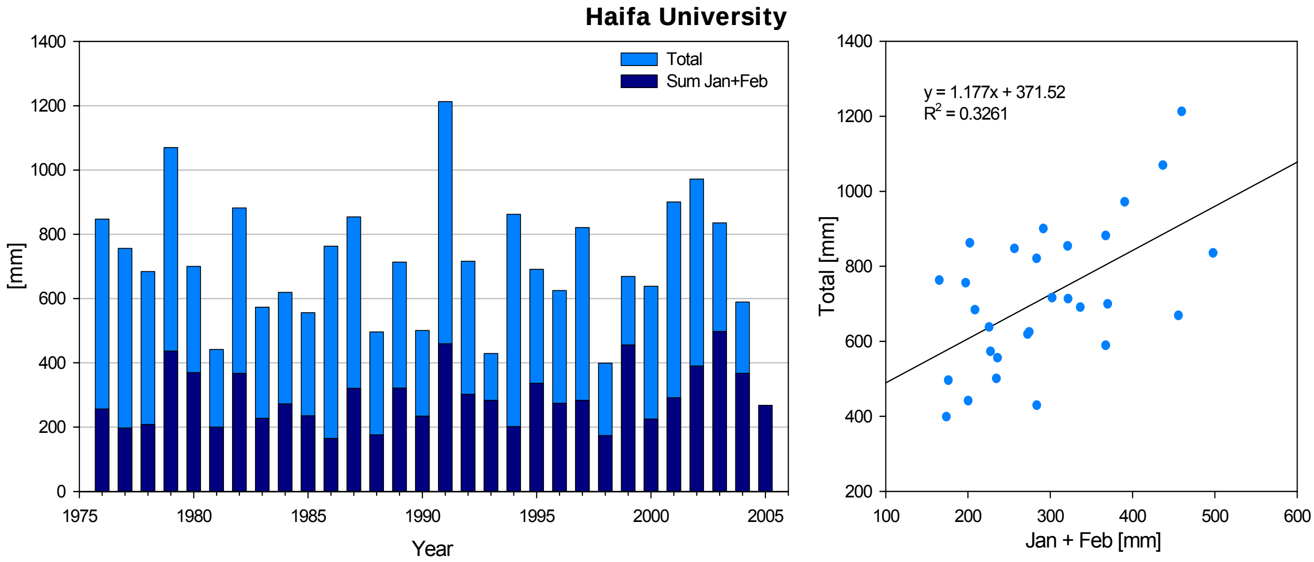


Figure 5.5: Rainfall amounts for Jan+Feb and correlation

5.1.3 Conclusion

Four rainfall events have been observed during the months of January to March 2006, which induced two flood events in the Nahal Oren stream system. The first rainfall event yielded amounts of precipitation of 140 mm, but was too scattered to generate flow. In return it saturated the soils and the alluvial layer to a high extent. The saturated soil provided the preconditions for the second rainfall event which was short and intense enough in addition to a volume of 58 mm to induce the FFE. Also the third rainfall event was short and intensities were high enough to generate flow although the volume of 34.5 mm was below the threshold given by [Wittenberg et al, 2004]. The fourth rainfall event was too scattered to induce a flood, although yielding a similar volume of precipitation.

5.2 Static Water Levels and Reaction of the Aquifer

Static water levels were monitored in the wells in the Nahal Oren catchment during the period of January to March 2006. Gaps in measurement data result from maintenance work at the wells or from problems caused by the oil layer mentioned in Subsection 4.2.3. The results of each well are described separately. Discharge volumes from the wells have been available, but not in a daily resolution. Therefore they are not considered in this section. The location of the wells is shown in Figure 4.1 on page 32.

5.2.1 Well Nahal Oren 1

In **Well Nahal Oren 1** the water level shows reactions after both flood events. Water

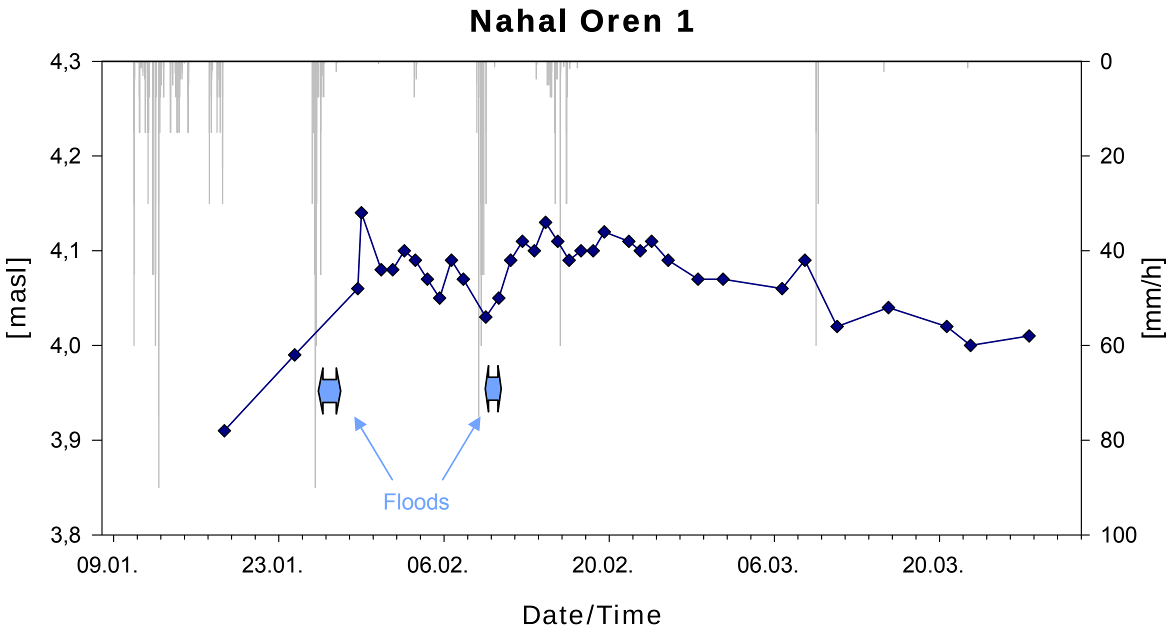


Figure 5.6: Static Water Levels and Rainfall Intensity at Well Nahal Oren 1

level started from 3.91 meters above sea level (masl) on 18.01. and rose to 4.14 masl 3 days after the FFE on 30.01.06, a total rise of 0.23 m. After that the water level decreased again to 4.03 masl on 09.02., the day the SFE started. 4 days after the SFE the water level was measured at 4.13 masl, representing a rise of 0.1 m. The water level showed another reaction to the rainfall event on 13.-16.02., but only a small rise of 0.03 m which could be due to the scattered character of rainfall intensities. But also this increase is in the order of measurement error (+/- 2 cm). The level decreased almost constantly to 4.01 masl on 27.03.06 when measurements stopped. Thus a rise during the entire observation period of 0.1 could be detected.

5.2.2 Well Nahal Oren 2

Well Nahal Oren 2 has been stated by [Guttman, 1998] to be a representative well for the entire region. Unfortunately it was subject to extended maintenance during the first months of 2006, therefore only water level measurements could be taken.

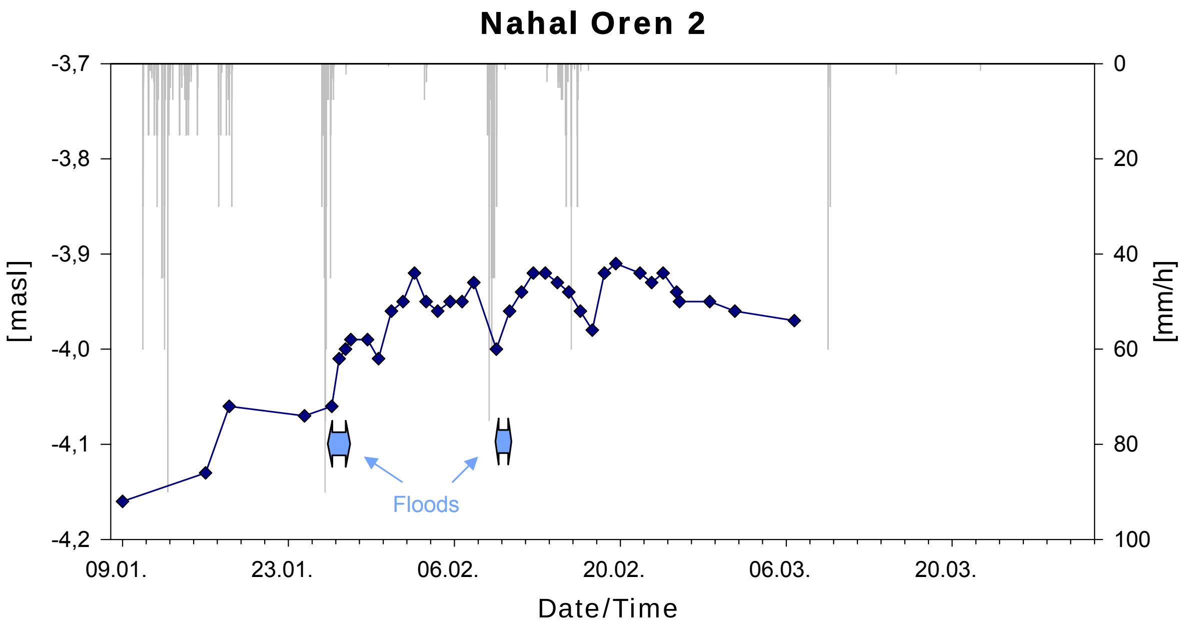


Figure 5.7: Static Water Levels and Rainfall Intensity at Well Nahal Oren 2

In the beginning of the monitoring schedule the water level was measured at -4.16 masl. It rose already during the long rainfall event in January to -4.06 masl on 18.01. It reacted very quickly to the FFE and increased to -3.92 masl on 02.02. with an interim decrease. During and after the SFE the water levels first increased within 3 days from -4.00 masl (09.02.) to -3.92 masl (12.02.), but also decreased again to -3.98 masl (17.02.) within the following 5 days. It reacted also to the scattered rainfall on 13.-16.02.: A rise of 0.07 m to -3.91 masl - the highest value during this period - could be detected. After that the water level decreased to -3.97 masl on 06.03.06 when measurements stopped due to ongoing problems with the electrical line. The fact that water levels in well Nahal Oren 2 are below the sea level leads to different assumptions: either the well exploits a different sub-aquifer than the others, which could not be found in the well's log (see Appendix); or it forms a local sink of water flow paths. Pipes are also found to be very old and their performance may be reduced. Anyhow, well Nahal Oren 2 should not be considered in the concept of groundwater flow directions on personal advise (oral communication, Guttman).

5.2.3 Well Nahal Oren 3

Well Nahal Oren 3 is the only well where water levels show a constant trend to decrease over the entire period of intensive observation. There have been problems due to the oil layer on the groundwater surface, and higher measurement errors need to be recognised.

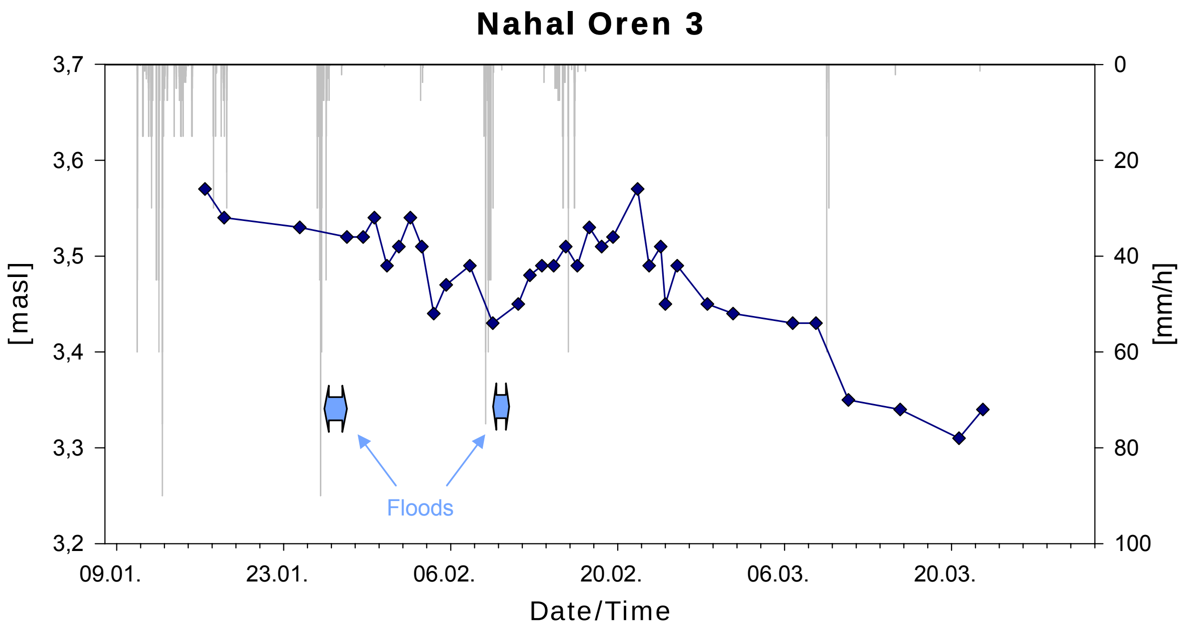


Figure 5.8: Static Water Levels and Rainfall Intensity at Well Nahal Oren 3

Starting from 3.57 masl on 16.01. it is probably effected by the precedent rainfalls in January. After the FFE water levels did not rise immediately, but did only fluctuate about 2-7 cm until it got to 3.43 masl on 09.02., the day the SFE started. Then the water level started rising and also influenced by the rainfalls on 13.-16.02. it reached a maximum value of 3.57 masl (a rise of 0.14 m) before it decreased again to 3.34 masl on 22.03.06 when measurements ended.

5.2.4 Well Nahal Oren 4

Well Nahal Oren 4 is the only well in the catchment which is located in the sub-basin of Nahal Bustan. Measurements during the FFE showed a rise from 3.96 masl (26.01.) to 4.14 masl (31.01.), an increase of 0.18 m within 5 days. It shows fluctuating level values in the following days. During the SFE the level rose from 4.11 masl (10.02.) to 4.19 masl on the next day. Dropping down to 4.08 masl on 17.02. the scattered rainfalls on 13.-16.02. and the concurrent flow in Nahal Bustan probably accounted for a rise to 4.18 masl until 19.02., before it decreased until the end of the monitoring period to 4.04 masl on 22.03.06. In total the water level did not alter (within measurement error).

5.2.5 Well Nahal Oren 5

In **Well Nahal Oren 5** a different order of magnitudes in water level changes could be observed. Whereas in the other Nahal Oren wells a total difference between minimum

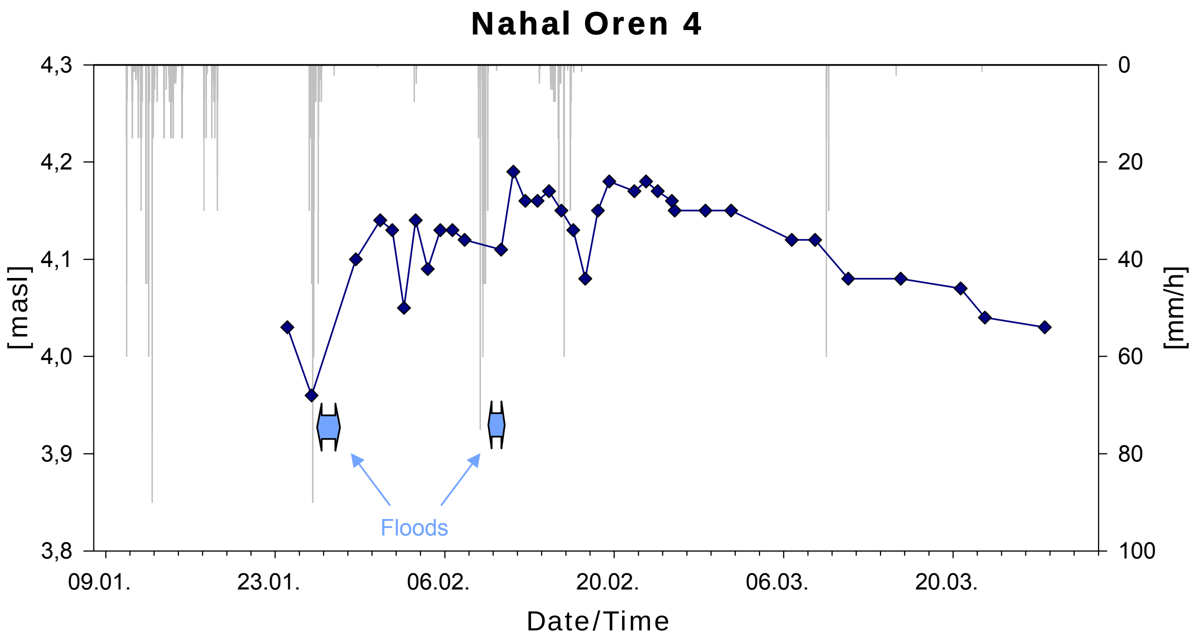


Figure 5.9: Static Water Levels and Rainfall Intensity at Well Nahal Oren 4

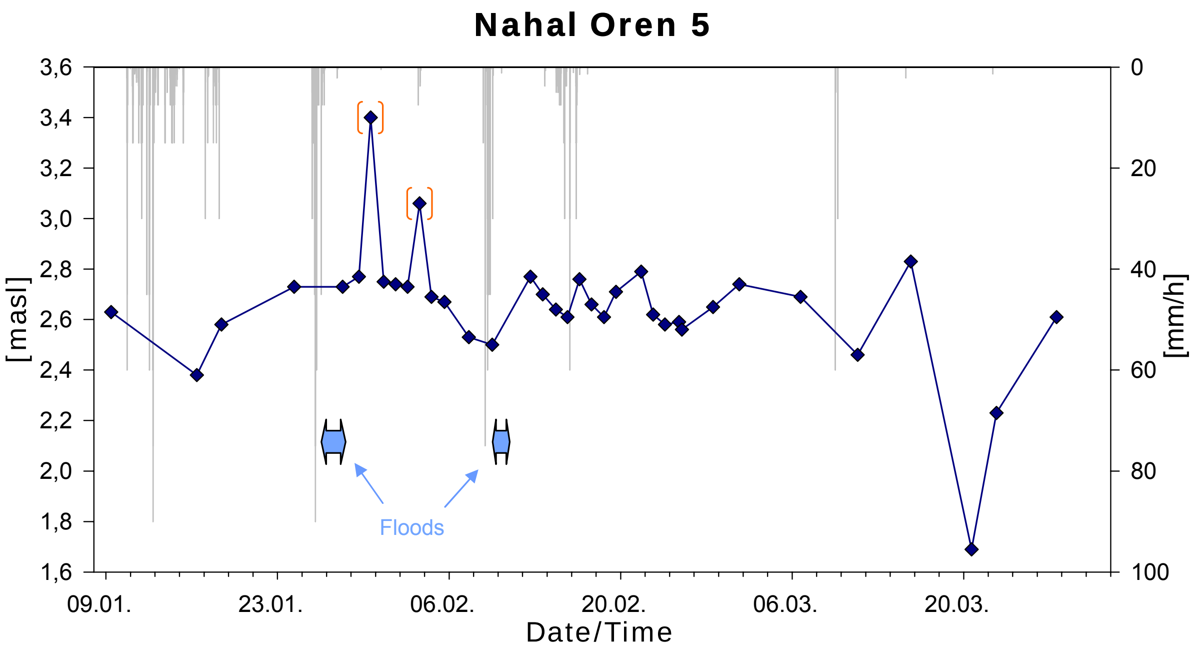


Figure 5.10: Static Water Levels and Rainfall Intensity at Well Nahal Oren 5

and maximum of 0.23-0.26 m could be detected, in Nahal Oren 5 there is a total difference of 1.71 m. One could assume a higher measurement error due to the oil layer on the groundwater surface which is most persistent in this well according to Mekorot staff.
Water levels rose after the first rainfalls in January from 2.38 masl (16.01.) to 2.73 masl on 24.01. just before the FFE. 3 days after the FFE ceased the water level increased up to 3.40 masl which could be interpreted as a very sharp increase of the water level due to an arriving front of infiltrating and percolating transmission losses contributing to recharge. But the fact that the next value measured is again at 2.75 masl one could also regard the rise as a measurement error. Then the total rise affected by the FFE would be neglectable. There is another doubtful increased value on 03.02. (3.06 masl), but the general trend until the SFE are decreasing water levels. During the SFE the water level rose from 2.50 masl (09.02.) to 2.77 masl 3 days later (12.02.), declining again until affected by the rainfalls of 13.-16.02.06. After that, water levels fluctuate severely and are hard to interpret. The values after 06.03. are questionable and the time intervals between the measurements are too high to draw any conclusions on the reaction of the aquifer.

5.2.6 Observation Well Atlit 1

Well Atlit 1 was the only well monitored in the present study which could be equipped with a CTD-DIVER probe explained above. This way, in addition to water levels electrical conductivity and temperature of the groundwater could be measured and the most consistent data of water levels could be recorded with the best temporal resolution. There was no significant change in the water temperature during the period of observation, the electrical conductivity is discussed later.

After installing the CTD-DIVER into the abandoned well, the values leveled off at about 3.60 masl. During the first rainfalls (07.-18.01.) the level started to rise, but not before 13.01., 5 days after the rainfall started. It reached values of about 3.80 masl on 23.01., before decreasing again until the start of the FFE. The FFE induced increasing values on the same day the flood started and the water level rose from about 3.77 masl to 3.90 masl (02.02.) within 7 days. Because of the accurate temporal resolution also reactions to a small rainstorm on 03.02. and the consequent rise in water levels could be detected. When the rainfalls leading to the SFE started the values still decreased, but as soon as the flood started, the water level increased from 3.82 masl (09.02.) to 3.92 masl 4 days later (13.02.). Also the rainfalls on 13.-16.02. induced a rise in water levels of about 5 cm, but the values did not increase before 17.02., 3 days after the rainfall started. After that values showed a general decreasing trend, with numerous fluctuations of +/- 5 cm which could not be explained by neither infiltrating rainfall nor floods. A potential connection of the Judea Group aquifer and the overlaying Coastal Aquifer could account for the changing levels, but the well log shows only penetration of the limestone layers. Also there are continuous undulations within one day which can only be explained by the sensitivity of the CTD-DIVER probe as there are not any sources of irritation around this well. It has to be questioned if the probe worked properly because of these fluctuation and the results of the electrical conductivity data (presented later).

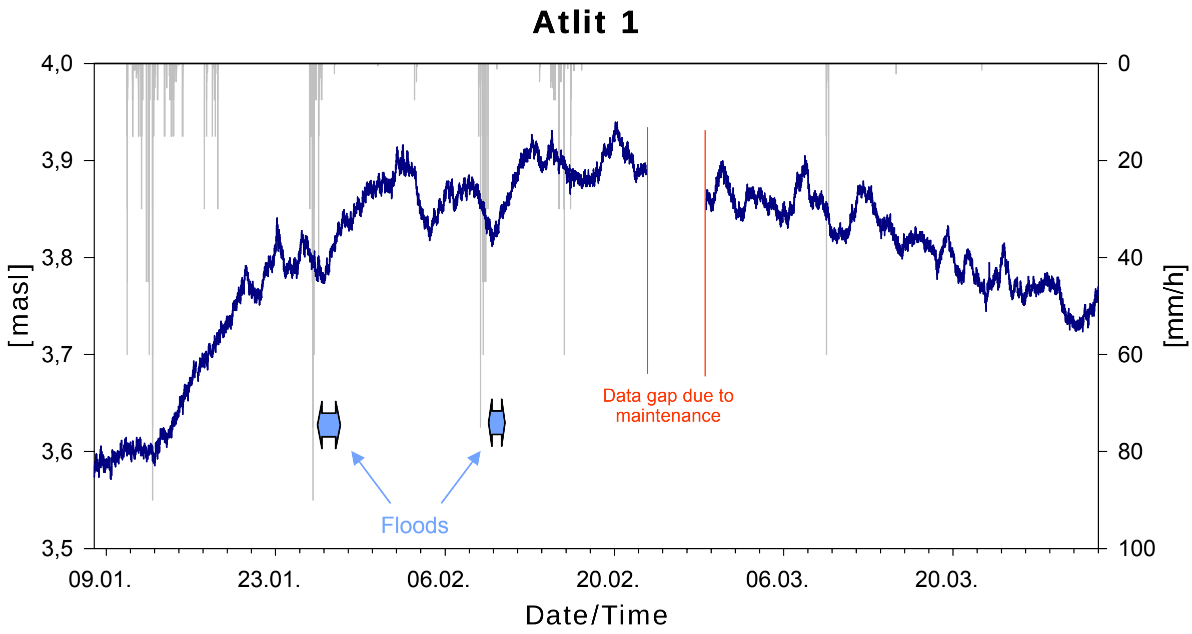


Figure 5.11: Static Water Levels and Rainfall Intensity at Well Atlit 1

5.2.7 Hydraulic Conditions in the Mt. Carmel Aquifer

Comparing water levels during the observation period similar patterns can be detected in the monitored wells: a general rise after the first scattered rainfall event, reaching the maximum after the SFE and the consequent rainfalls, and decreasing during March due to the absence of significant rainfall events >10 mm in volume. Nahal Oren 5 represents an exception unless one disregards the doubtful values after the FFE; taking into consideration that it showed the same trend in March.

The magnitude of water level changes is in the order in all of the monitored wells except for well Nahal Oren 5 where higher magnitudes can be observed. Partly this can be due to measurement errors (oil layer) or doubtful values. On the other hand this fact could prove that around well Nahal Oren 5 higher hydraulic conductivities can be assumed and recharge processes evolve quicker and more intense. This can be due to a higher proportion of fractures or fissures in the area or due to a detected major fault of Mt. Carmel nearby the well.

It is very remarkable that a reverse gradient of groundwater level is present. This fact can be taken from Figure 5.12. The groundwater seems to flow unexpectedly in an eastward direction, but was observed in previous studies to flow towards the coast. The highest water levels are observed in well Nahal Oren 4 (average at 4.12 masl) and values decrease towards well Nahal Oren 3 and 5 down to 2.65 masl average. Well Nahal Oren 1 and 4 seem to form an underground groundwater ridge and water flows generally towards the sea (Atlit 1 average 3.81 masl) and towards wells Nahal Oren 3 and 5. In [Guttman, 1998] it is noted that this reverse gradient can evolve during summer time when extraction from the wells exceeds the recharge in the area. It has been pointed out to happen only

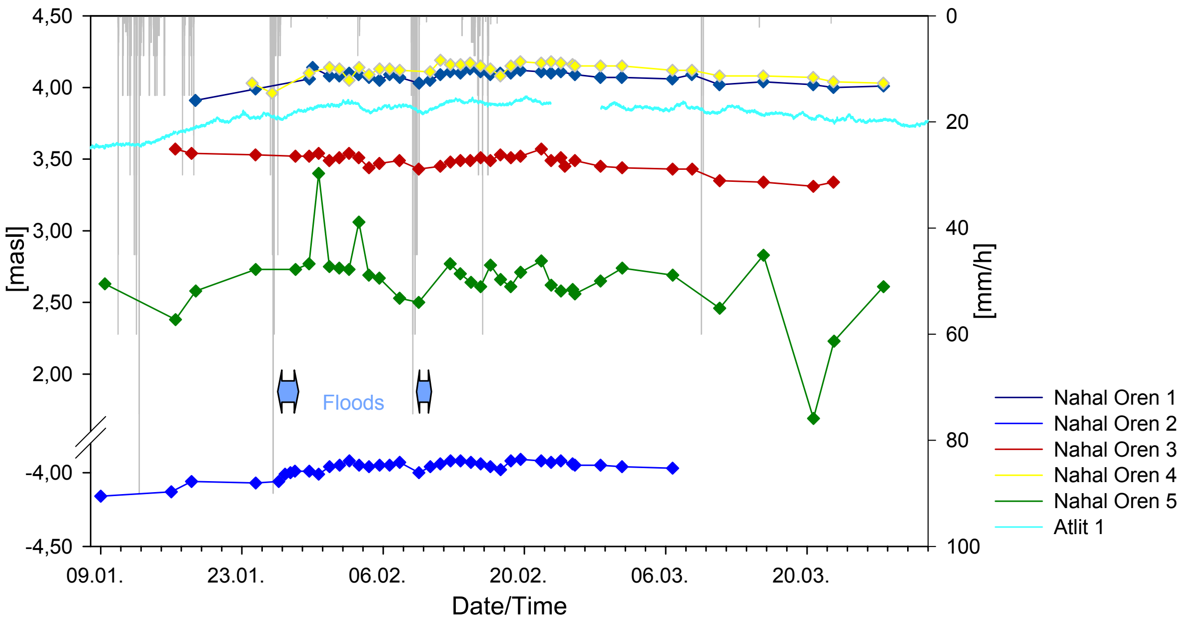


Figure 5.12: Static Water Levels in all wells in the Nahal Oren catchment

in times of increased abstraction of groundwater from the Judea Group aquifer, and two conceptual models have been constructed, for winter and summer conditions. In winter months, groundwater generally flows from well Nahal Oren 5 towards well Nahal Oren 1 and towards the sea, whereas in the summer months water is flowing from the Pleistocene aquifer into the Judea Group aquifer where hydraulic connection exists, thus deteriorating groundwater quality in the Judea Group ([Guttman, 1998]). Historical water levels are shown in Figure 5.13 and despite seasonal fluctuations resulting from the above mentioned increased extraction of groundwater during the summer and recovery during increased recharge in the winter months, the general gradient towards the Mediterranean Sea can be observed. Unfortunately there is a certain gap in data, especially in wells Nahal Oren 1, 2 and 3 during the last 20-30 years. When monitoring started again, well Nahal Oren 1 showed the highest water levels and Nahal Oren 2 fell below the sea level again. Reverse gradients can be determined in times when data from every well is available (see Figure 5.14). But measurements have been taken sporadic and these observations should be regarded with care. As there are no continuous data of water levels in the potential affected wells, no assumptions should be made about changing groundwater gradients throughout recent years.

[Mazor, 2004] points out that one can never deduce groundwater flow directions from water levels alone. Therefore the chemical composition of the groundwater extracted by the Nahal Oren wells during this study may gain more information.

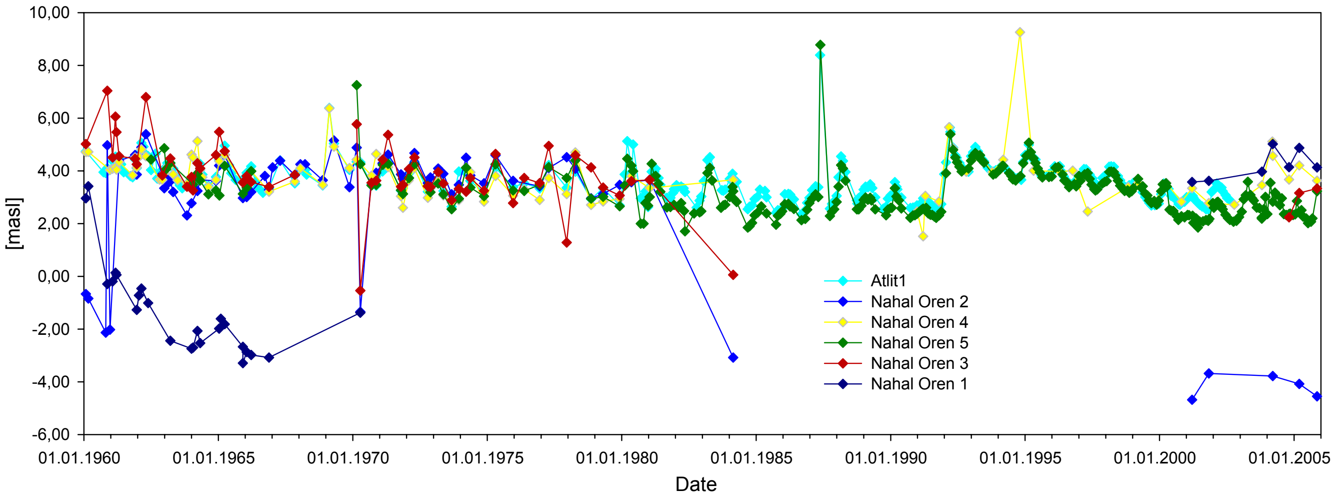


Figure 5.13: Historical Static Water Levels from 1960-2005

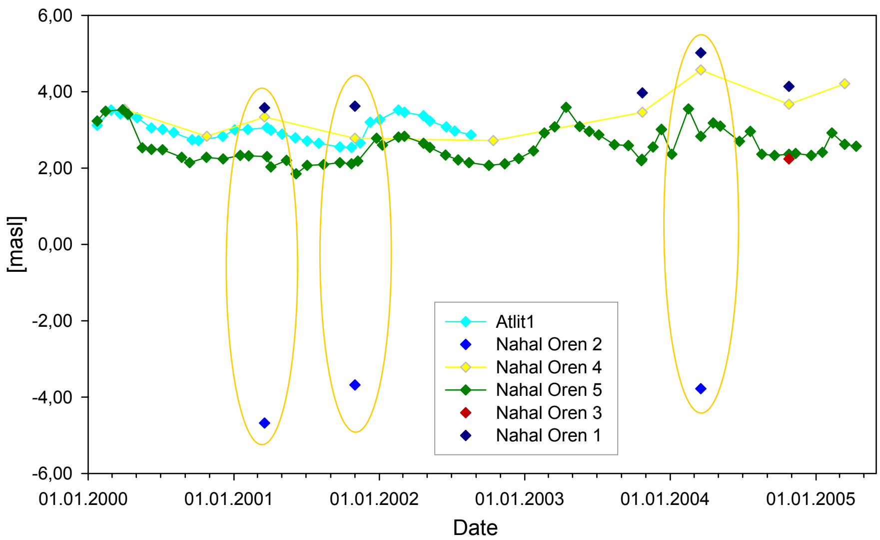


Figure 5.14: Water levels in recent years showing the *reverse gradient*

5.2.8 Conclusion

Water level changes are recorded in all of the monitored wells throughout the period of observation. Especially the change in water level after the flood events is significant and could be related to transmission losses and groundwater recharge processes. There may be a vertical connection from the surface to the underlying dolomite aquifer where the pipes of the wells are screened. The increasing water levels in the wells may also be influenced by piston flow effects where the dolomite aquifer is present in confined condition (wells Nahal Oren 1, 2, 3 and 4).

The detection of a reversed groundwater gradient does not verify the conceptual flow model described for the winter months by [Guttman, 1998]. A reverse gradient is assumed to evolve only in the summer months when extraction from the aquifer is highest. Historical data leads to the assumption that both conceptual models of flow directions have been present in the area over the last years and should be investigated by consulting the chemical composition of groundwater.

5.3 Fluorescentic Tracer Data

The analysis of the samples taken before, during and after the flood events in the Nahal Oren catchment from wells Nahal Oren 1, 3, 4 and 5 has been carried out at the Institute of Hydrology, Freiburg. A *Perkin Elmer* LS 50 B Luminescence Spectrometer is used and the syncroscan technique is applied to get the optimal detection sensitivity. Regarding the blind samples from the well and the resolution of the scan plots, the detection limit is defined to 0.005 ppm (Naphtionate) and 0.001 ppm (Uranine). The results are presented in the following.

5.3.1 Naphtionate Breakthrough at Well Nahal Oren 5

After the First Flood Event distinctive concentrations and a clear breakthrough curve of the injected Naphtionate could be detected in samples taken from well Nahal Oren 5 and is shown in Figure 5.15. Unfortunately no runoff data is available for the flood events, thus the start and the end of the FFE is determined to 26.01. / 9:00 and 27.01. / 22:00 respectively. Regarding the detection limit, there is a steep rise and fall in concentrations within 100 hours after the runoff generated. Concentrations in the samples rose up to about 152 $ppb = \mu g/l$. A slow recession of concentrations like in comparable tracer experiments in karstic terrains (e.g. [Maloszewski et al, 1992]) could not be observed. One sample does not fit into the breakthrough curve, but an analysis failure could be

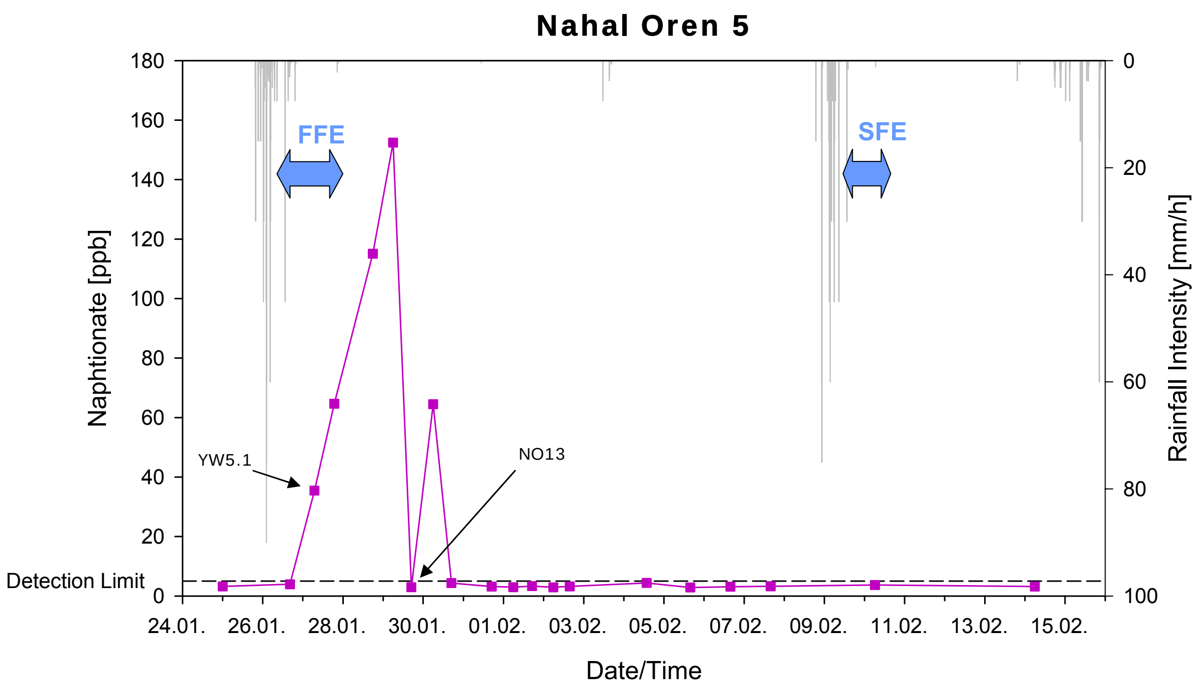


Figure 5.15: Naphtionate concentrations during FFE and SFE

excluded due to double-checks. Two exemplary scans of the spectra are presented in Figure 5.16, one sample containing 35 ppb of Naphtionate and the doubtful sample where no

Naphtionate could be detected.
During and after the Second Flood Event only two samples could be taken from well Nahal Oren 5 due to a shutdown of the well after encountering bacterial contamination of the water in a mandatory check by Mekorot. Naphtionate could not be detected in these samples, thus drawing the conclusion that the injected tracer could be diluted and transported completely by the FFE.
The very quick detection of Naphtionate in the well is rather notable because the water level is around 100 m below surface. The Yagur dolomite formation crops out at this location and the aquifer is considered to be unconfined. The quick detection would suggest either a high-developed karstic system with fractures and fissures and thus a high proportion of preferential flow. This positive result from the tracer experiment is a qualitative proof of a direct hydraulic connection between the surface and the underlying aquifer.

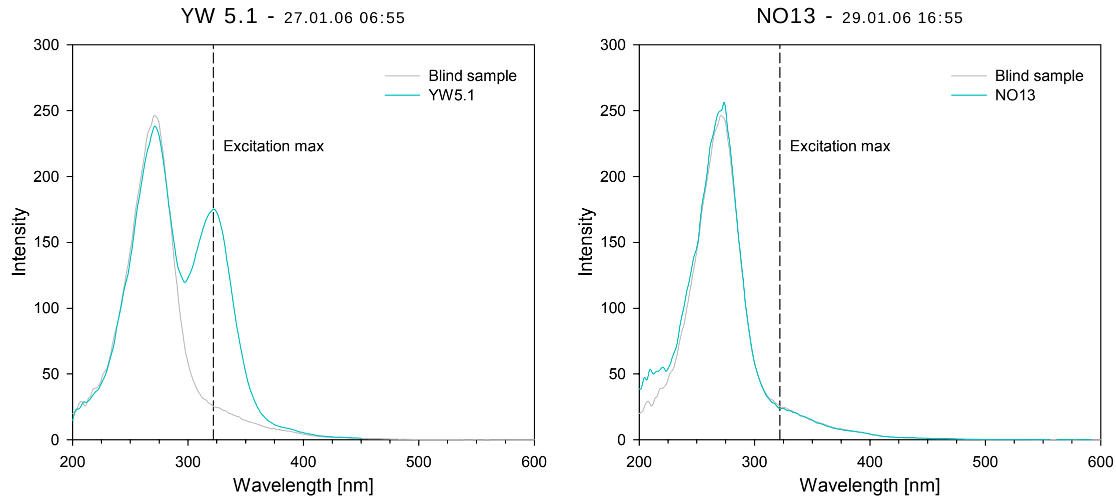


Figure 5.16: Scans of chosen samples from well Nahal Oren 5

5.3.1.1 Mathematical Modelling using the Multi Dispersion Model

To interpret the transport of Naphtionate through the unsaturated zone to the groundwater level, the Multi Dispersion Model by [Maloszewski et al, 1992] is applied. Due to the fact the tracer was injected in an immobile condition on the bedrock surface and was diluted in the percolating flood water, a Dirac pulse of the injection is assumed. A total recovery of 108,8 g of Naphtionate is calculated using the tracer concentration data and the pumping rates of well Nahal Oren 5 from the days after the FFE started. This leads to a restitution or recovery rate R of 7.25%. As the total recovery is smaller than the mass injected, the real recoveries R_i have to be used in equations (2.9) and (2.10) instead of M_i to solve the inverse problem ([Maloszewski et al, 1992]). In a step by step procedure 4 flow subsystems have been found to get the best fit of theoretical and measured breakthrough. The total mean discharge from the aquifer has been evaluated from volumes of groundwater abstracted by the well and the time interval when Naphtionate was detected. Equations (2.9) and (2.10) have been used to evaluate the theoretical passage. The best fit is presented in Figure 5.17. As the observed samples

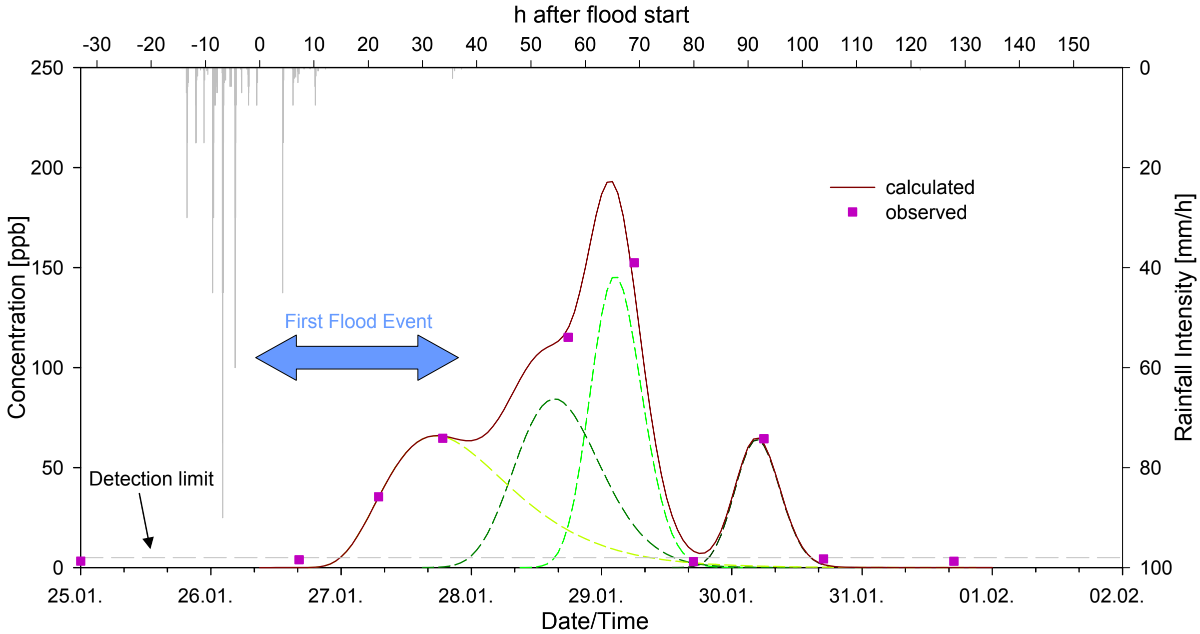


Figure 5.17: Best Fit of MDM and observed concentrations of Naphtionate in well Nahal Oren 5

show a large time interval, a lot of theoretical breakthrough curves are possible to fit and the results should be regarded censoriously. Like in the conceptual model, different flow paths are assumed and can be explained by preferential flow through fissures and faults in karstic lithologies. It is difficult to interpret the passage of the tracer in the abstracted groundwater without regarding the hydrograph of the runoff event. But as no data of the surface flow is available, the only data suitable are rainfall intensities of the preceding rainfall event.

The best fitted curve suggests that different subsystems contribute to the aquifer in the observed location. It is questionable if all of these flow paths really exist, but it is the best approach to the existing data. A very quick transportation with only short time lag is assumed in the calculated flow model. Hereby a high vulnerability of the aquifer may be assumed in this area due to a high hydraulic connection between surface and saturated zone. After the rainfalls ceased the concentrations of Naphtionate still increased. The peak of the tracer passage was not sampled according to the theoretical model, and the peak concentration is assumed to out-range the highest observed sample by about 40 ppb. This fact should be regarded critically as there is no observed sample proving the higher amount of Naphtionate. The second peak of the tracer passage, about 90 h after the FFE started, is modeled by another flow subsystem. It can be explained by a different flow path or remobilization by percolating rainfall through the unsaturated zone ([WGSHS, 2003]), but no other rain spell was recorded in the potential period of time before the detection.

The minimal transit time t_{min} is evaluated from the calculated breakthrough curve and determined to about 16 h. The peak transit time t_{Peak} is also taken from the breakthrough curve, calculated to about 66 h, but has no validation as there is no proof of an observed sample. The mean transit time of entire system t_0 or t_{mean} was calculated from

$$t_0 = V/Q = \sum_{i=1}^{N} V_i/Q = \sum_{i=1}^{N} (r_i \cdot t_{0i}) \tag{5.1}$$

where r_i are the ratios of i-th recovery to the total recovery R_i/R and t_{0i} are the mean transit times for the i-th flow path ([Maloszewski et al, 1992]). This way a mean transit time for the entire system could be computed to 58.2 h. Estimating flow volumes is not appropriate because values of Q used to calculate the theoretical transport are based on well discharge rates. Also flow velocities cannot be estimated adequately because of different unknown flow paths in karstic terrains and different unknown values for x_i.

5.3.1.2 Interpretation

The total restitution rate R is evaluated to about 7.25%, there are some reasons to cause a decrease as rates of almost 100% have been observed in karstic areas ([WGSHS, 2003]):

- no ideal tracer is used: Naphtionate is known to show irreversible sorption processes and is not the best choice for tracer tests in the unsaturated zone.
- no ideal test execution, remaining tracer deposits at injection site: There was no positive detection of Naphtionate after the SFE, so it may be assumed that there was no remaining tracer at the injection pit.
- parts of the injected tracer can flow past the sampling site: this is probably the main reason for the decrease in restitution rate, as the well cannot drain completely the injected tracer and fissures in karstic aquifers can be too developed to transport the tracer on a suggested flow path.

It is remarkable that the tracer could be detected in significant amounts within hours of the occurrence of flow in the ephemeral stream. This leads to the assumption that the aquifer system is vulnerable at this location and the quick transition should be noticed in damage and hazard scenarios. The very quick passage of the tracer without the characteristic tail may suggest that there are no significant sorption or desorption processes during the period of sampling. It is doubtful whether the "real first appearance" should be determined with a solute transport mode ([WGSHS, 2003]), but the qualitative proof of a connection between the surface flow and the groundwater in 100 m depth is a strong finding for further investigations. Still, it has to be noted that the tracer may have reached the pipe of the well already close to the surface by lateral flow in the unsaturated zone, as the well screen starts in 5 m below surface (see drilling log in Appendix). The application of a theoretical transport model should be regarded censoriously because a high temporal resolution of the observed breakthrough curve samples taken close together is not given ([Käss, 1998]).

Figure 5.18 shows the calculated transport model together with the concentrations of chloride in time. A clear distinction can be made between dilution of chloride concentration due to runoff infiltration processes (transmission losses) and other groundwater flow processes because of the simultaneous detection of Naphtionate. Therefore an approach of quantifying these transmission losses will be done later (see Section 5.4.4).

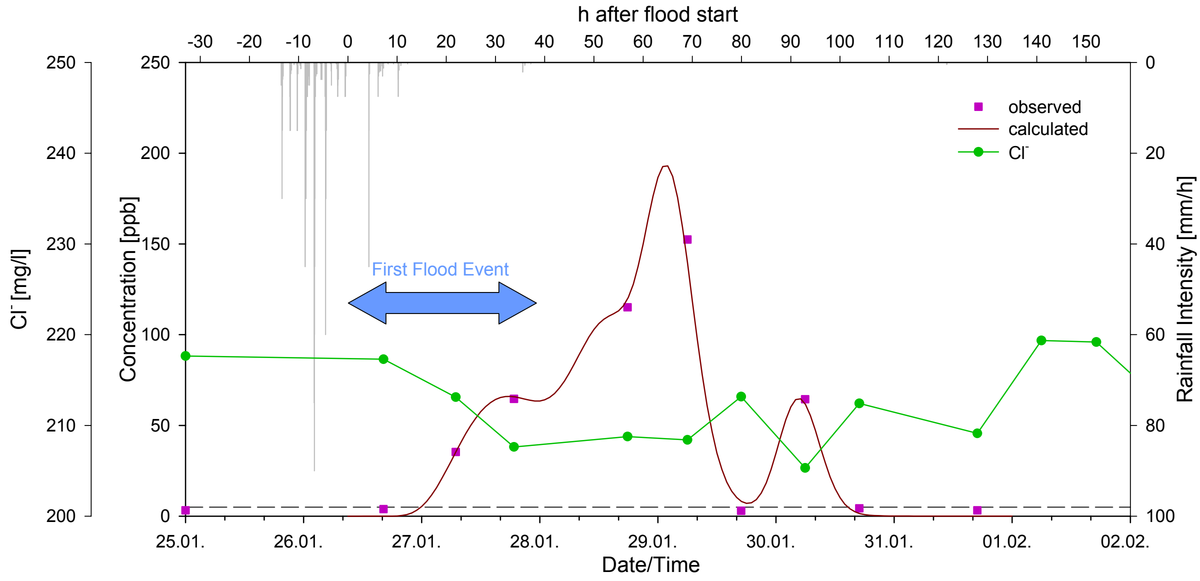


Figure 5.18: Cl^--concentrations compared to Naphtionate passage in Well Nahal Oren 5

5.3.2 Tracer Detection at Nahal Oren 1, 3 and 4

In opposition to the positive detection of Naphtionate at well Nahal Oren 5, there was no positive detection of any traces of the fluorescentic dyes in the other sampled wells. The results are given in the Appendix.

Uranine intensities are always in the order of the background noise in all the samples of wells Nahal Oren 3 and 1 which were supposed be situated along the same groundwater flow direction. But as already stated in the previous section, groundwater flow directions have been detected to follow an eastward gradient. One could assume to detect Uranine in an eastern sampling spot like in well Nahal Oren 5, but no samples were taken from this well after UA was injected into the alluvium in adequate time-spaces. Scans of UA are shown in Figure 5.19, where they are compared to the blind sample and to the calibration concentration of 1 ppb.

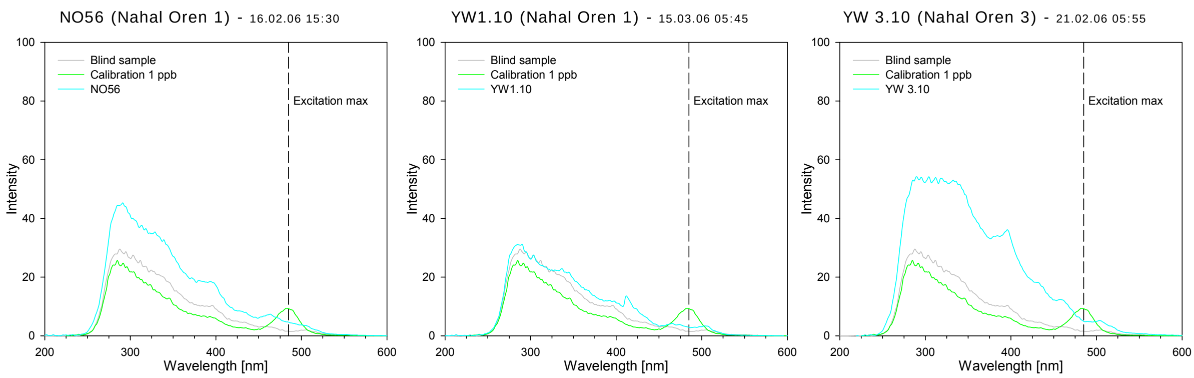


Figure 5.19: Scans of chosen samples from well Nahal Oren 1 and 3

Naphtionate detection also failed in well Nahal Oren 3 after the FFE, and in wells Nahal Oren 4 and 1 after the SFE. This fact may draw the conclusion that the alluvial layers are too thick in these locations to transport dye tracers without important sorption and absorption processes.

In the drilling logs of the wells (see Appendix) several layers of marls can be found above the well screens: this may also account for the failed detection of the tracer because marls act as an aquiclude in vertical water movement. Thus no vertical connection of the wadi and the dolomite aquifer could be proven in the given period of observation. The rather impervious layer found in the profile near well Nahal Oren 4 could prevent infiltration of runoff water to the saturated zone. If sampling downwards along a presumed groundwater gradient, geological faults have to be considered in the area (Figure 3.5 on Page 21). Transmissivities may increase or decrease when geological layers meet and the water may be forced to flow in another direction than assumed. The object of this tracer test is to discover vertical connections and movement of infiltrating runoff. Flow paths from other locations may be too deep and have transit times too long to be detected in the samples taken in this study. Furthermore the water level gradient provides a different concept of groundwater flow than previously assumed and may also account for the failed detection.

5.3.3 Conclusion

On the one hand, the positive detection of Naphtionate in well Nahal Oren 5 within hours indicates a vertical connection of the surface flow to the underlying aquifer which is unconfined at this location and therefore most likely represents an area of preferential recharge in the catchment. The Yagur dolomite crops out in this part of the catchment and is suggested to be vulnerable due to the very low transit times of infiltrating runoff. The application of the Multi Dispersion Model may be regarded with care, but the qualitative proof of short transit times over 100 m depth in the unsaturated zone is a strong finding for further investigations.

On the other hand, Uranine and Naphtionate are not detected in the sampled wells Nahal Oren 1, 3 and 4, but still the possibility of hydraulic connection between the surface flow and the underlying dolomite aquifer exists. The well screens are drilled into the Yagur formation which is confined in these locations and is overlain by marls which form an aquiclude in terms of hydraulic conductivities. The infiltrating water may undergo reversible and irreversible processes during percolation through the unsaturated zone; or flow paths may be too long and transit times to high to be detected in the period of observation conducted in this study. Due to the faulted character in geological terms flow paths may be altered along the hydraulic gradient. Groundwater gradients suggest a different flow direction than previously assumed.

5.4 Environmental Tracer Data

The analysis of environmental data has been conducted twice. The first set of samples has been analysed by the Field Service Laboratory in Neve Yaa'r, Israel. After obtaining both the environmental tracer data and the fluorescentic tracer data, a few selected samples have been rechecked at the Institute of Hydrology in Freiburg (IHF), Germany. Due to noticeable discrepancies in the environmental data of these critical samples, all of the samples sent to the IHF, Germany, have been analysed using the Ion Exchange Chromatography technique. An Ion Exchange Chromatograph DX500 by *Dionex Systems* has been used to analyse the major ions Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+} and Mg^{2+}. The sampling bottles were stored cool and dry at IHF, so that interactions with the environment and microbiological processes could be reduced to a minimum.

5.4.1 Comparison of Obtained Data

As the above mentioned discrepancies in the obtained data sets prohibited interpretation of the recharge processes in the study area, a comparison of the data has to be performed. The data from the Field Service Lab in Neve Yaa'r (FSL), Israel, provide consistent data of Cl^-, Ca^{2+} and Mg^{2+} concentrations, that is why data from these ions are compared with the data acquired in Freiburg.

The comparison is carried out by a two-sided approach: on one hand the data is compared graphically on a time scale regarding rainfall events and floods, on the other hand the data is analysed by descriptive statistical parameters: both series are regarded to be samples from the same population. The samples analysed in Israel and Germany yield estimators for the mean value $\overline{x_1}$ and $\overline{x_2}$ for the unknown true mean value μ. Both data series also yield estimators for standard deviations s_1 and s_2 and variances s_1^2 and s_2^2 for the unknown variance of the population, σ^2. Variances of two sample series can be compared by using an F-Test which tests the determined variances. The values F for the test are determined by $F = s_1^2/s_2^2$ where s_1^2 is usually the higher variance of both sample series, so that $F \geqslant 1$. A smaller variance indicates a better estimator for the same true μ ([Blobel & Lohrmann, 1998]). In addition, mean values are calculated within a 95% confidence interval.

5.4.1.1 Major Ions Analysis

Cl^-:

Comparing the acquired data of chloride in the samples taken from the Nahal Oren wells it is noticeable that values from IHF are generally lower than values from Field Service Lab (see Figure 5.20). The range of the data series is much lower as well as fewer outliers can be noted. Basically, the data from FSL complicate the interpretation of water movement in the aquifer due to chloride fluctuations in the order of 10-20 mg/l. Both series show reactions and diluting processes (Nahal Oren 1, 3 and 5) after rainfall or flood events, but the FSL data also fluctuate when there is no significant change in the data from IHF and

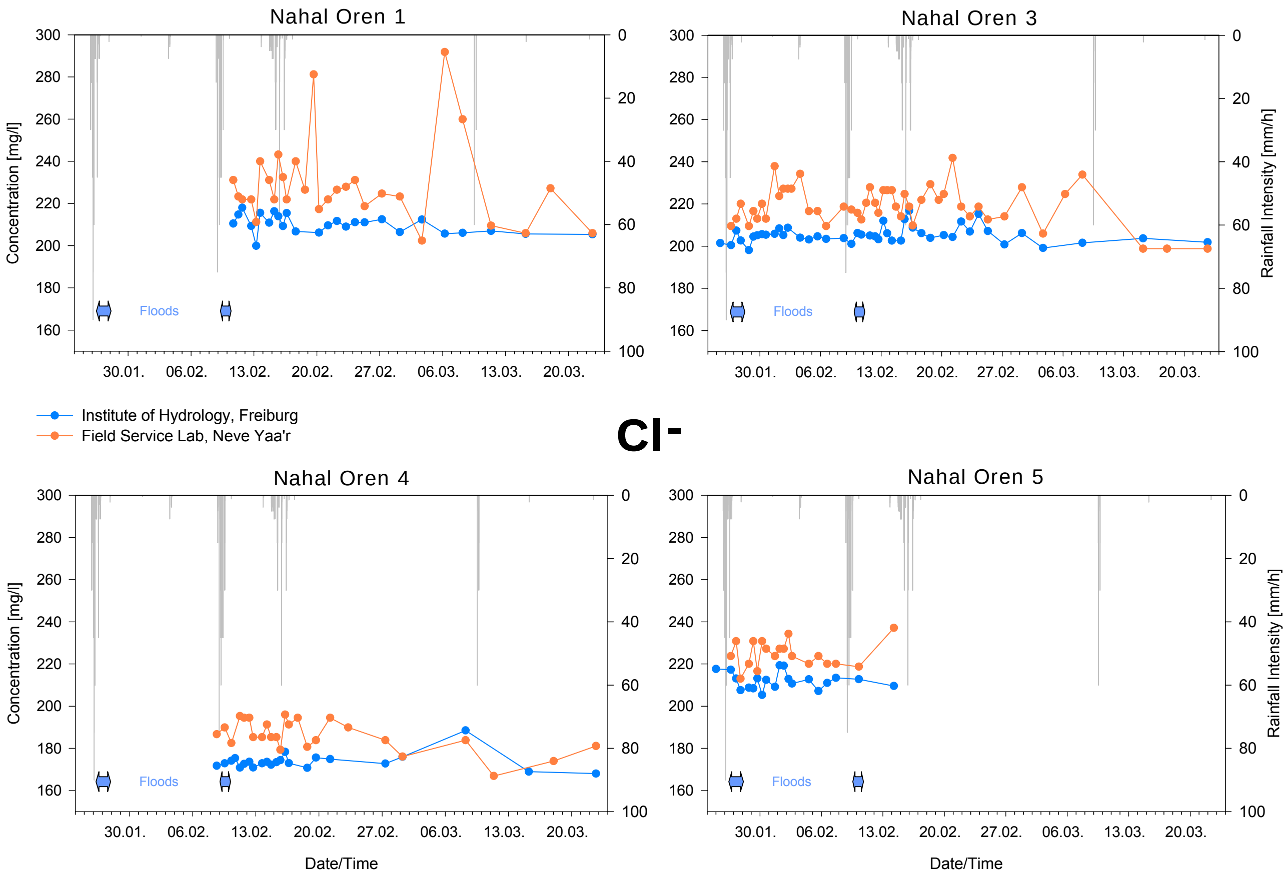


Figure 5.20: Comparison of Cl^{-} data from IHF and FSL

during dry spells. Suspicious values, e.g. towards the end of the series in Nahal Oren 1, could only be explained by mixing with a very saline water type and cannot be proven right by the acquired data from IHF.

As already seen in Figure 5.20, also the statistical parameters show better results from the IHF data and are presented in Table 5.2. The data series sizes from the IHF is often lower due to broken sampling bottles during the transportation to Germany. The variances show big differences with values for F ranging from 22.5 - 2.5, making it impossible for the data from FSL to pass an F-Test. Standard deviations are much lower in the IHF data, but also the mean values are about 12-19 mg/l below the FSL mean values ranging from about 174 mg/l at Nahal Oren 4 to 225 mg/l at Nahal Oren 5. Therefore the IHF chloride data will be used for further analysis of recharge processes and are discussed later.

Mg^{2+}:

The Mg^{2+} data acquired from IHF and FSL is shown in Figure 5.21 and point out more fluctuations in the FSL data compared to IHF data. Mg^{2+} values are fluctuating to a higher degree than are hydrogeologically explainable in the data from FSL, and cannot be used for interpretation. Values from IHF more or less stay the same over the period

Table 5.2: Statistical Analysis of Cl^- Data

Cl^- [mg/l]	Nahal Oren 1		Nahal Oren 3		Nahal Oren 4		Nahal Oren 5	
	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r
Size	26	29	45	50	23	25	20	19
Min	199.95	202.40	198.12	198.80	168.03	166.90	205.32	213.00
Max	217.98	291.80	216.84	241.80	188.49	196.00	219.36	237.10
Range	18.03	89.40	18.72	43.00	20.46	29.10	14.04	24.10
Mean	210.02	229.02	205.31	219.12	173.72	186.08	212.09	224.68
Variance	17.75	398.57	14.92	85.00	15.57	53.90	15.75	39.08
Std.Dev	4.21	19.96	3.86	9.22	3.95	7.34	3.97	6.25
Std.Err	0.83	3.71	0.58	1.30	0.82	1.47	0.89	1.43
95% Conf	1.70	7.59	1.16	2.62	1.71	3.03	1.86	3.01
	210.02 ± 1.70	229.02 ± 7.59	205.31 ± 1.16	219.12 ± 2.62	173.72 ± 1.71	186.08 ± 3.03	212.09 ± 1.86	224.68 ± 3.01

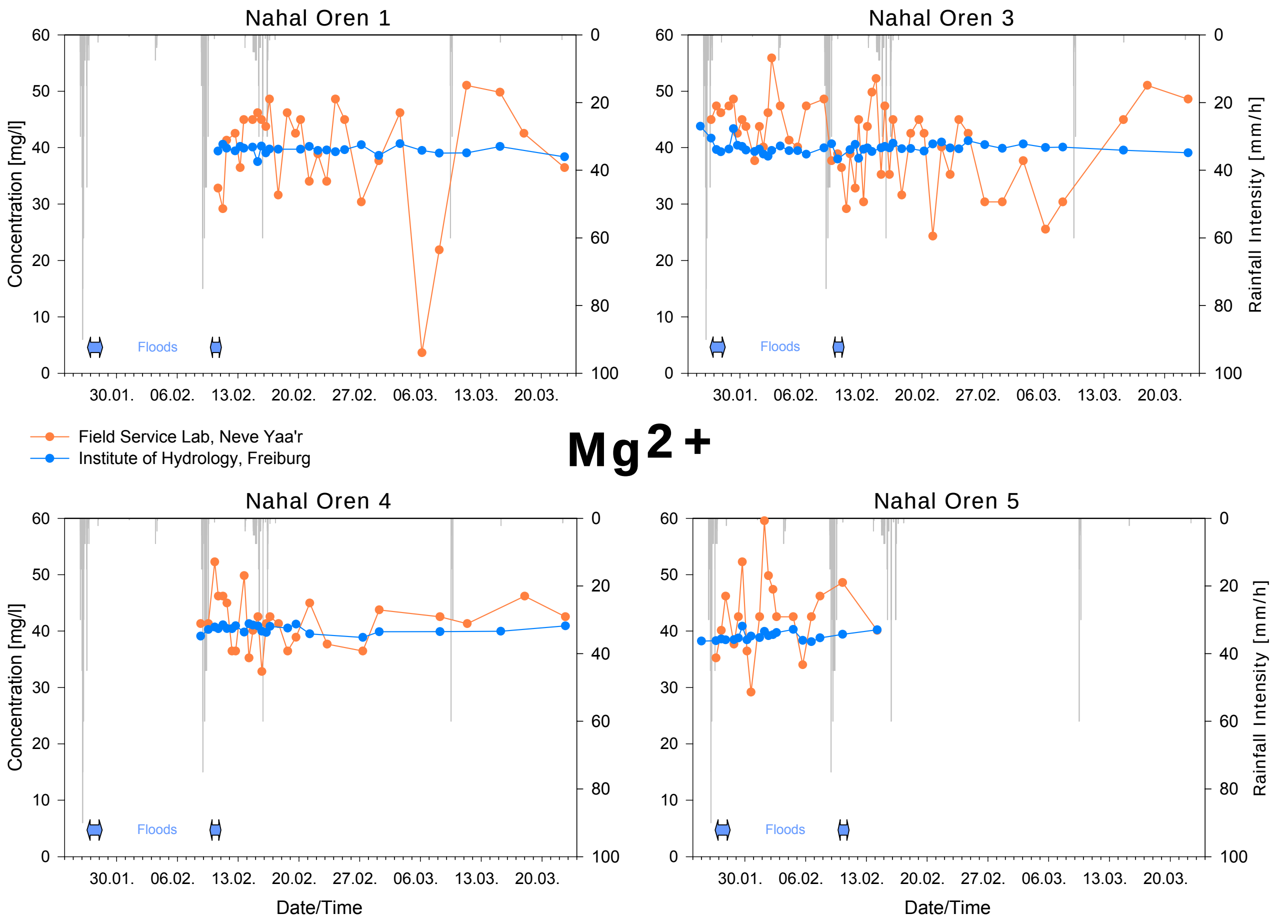


Figure 5.21: Comparison of Mg^{2+} data from IHF and FSL

of observation and only seem to react in Nahal Oren 3 after the First Flood Event.

Table 5.3: Statistical Analysis of Mg^{2+} Data

	Nahal Oren 1		Nahal Oren 3		Nahal Oren 4		Nahal Oren 5	
Mg^{2+} [mg/l]	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r
Size	26	29	46	50	23	26	20	19
Min	37.53	3.65	37.98	24.31	38.88	32.81	38.10	29.17
Max	40.71	51.04	43.80	55.90	41.28	52.26	40.86	59.55
Range	3.18	47.39	5.82	31.60	2.40	19.44	2.76	30.38
Mean	39.60	39.35	39.99	41.20	40.34	41.60	39.06	42.92
Variance	0.52	96.88	1.13	51.61	0.45	20.95	0.63	49.89
Std.Dev	0.72	9.84	1.06	7.18	0.67	4.58	0.79	7.06
Std.Err	0.14	1.83	0.16	1.02	0.14	0.90	0.18	1.62
95% Conf	0.29	3.74	0.32	2.04	0.29	1.85	0.37	3.40
	39.69 ± 0.29	39.35 ± 3.74	39.99 ± 0.32	41.20 ± 2.04	40.34 ± 0.29	41.60 ± 1.85	39.06 ± 0.37	42.92 ± 3.40

Also the statistical parameters in Table 5.3 with values for F from 188 - 46 state that there are too many outliers in the data series. Mean values are very similar regarding standard errors and 95% confident intervals, but the variations in time show that the Mg^{2+} data from FSE have to be discarded, but also Mg^{2+} data from IHF is not used to interpret hydrological processes.

Ca^{2+}:

Comparing the acquired Ca^{2+} data from IHF and FSL one can see in Figure 5.22 that both sample series on each well fluctuate to a certain extend. There are certain dilutions which can be observed for example at Well Nahal Oren 3 during and after the First Flood Event. Outliers can be noted in data from Well Nahal Oren 1 towards the end and from Well Nahal Oren 5 after the FFE. In total there are fewer discrepancies in the data of Well Nahal Oren 4 and 5. Hence also the F-Test only fails at data from Well Nahal Oren 4

Table 5.4: Statistical Analysis of Ca^{2+} Data

	Nahal Oren 1		Nahal Oren 3		Nahal Oren 4		Nahal Oren 5	
Ca^{2+} [mg/l]	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r
Size	25	29	46	50	22	26	20	19
Min	89.19	106.21	85.17	96.19	94.26	98.20	80.82	104.21
Max	124.62	164.33	122.34	136.27	116.07	112.22	124.86	124.25
Range	35.43	58.12	37.17	40.08	21.81	14.03	44.04	20.04
Mean	107.29	118.24	105.67	110.34	111.28	105.36	118.46	111.70
Variance	130.36	168.67	129.61	93.01	36.34	14.83	99.09	28.04
Std.Dev	11.42	12.99	11.38	9.64	6.03	3.85	9.95	5.30
Std.Err	2.28	2.41	1.68	1.36	1.29	0.76	2.23	1.21
95% Conf	4.71	4.94	3.38	2.74	2.67	1.56	4.66	2.55
	107.29 ± 4.71	118.24 ± 4.94	105.67 ± 3.38	110.34 ± 2.74	111.28 ± 2.67	105.36 ± 1.56	118.46 ± 4.66	111.70 ± 2.55

and 5, but with better data and lower variances from FSL. At Well Nahal Oren 1 and 3 the variances are significantly similar, thus are of the same quality. Mean values are more or less of the same order, and 95% confidence intervals are relatively high. But with

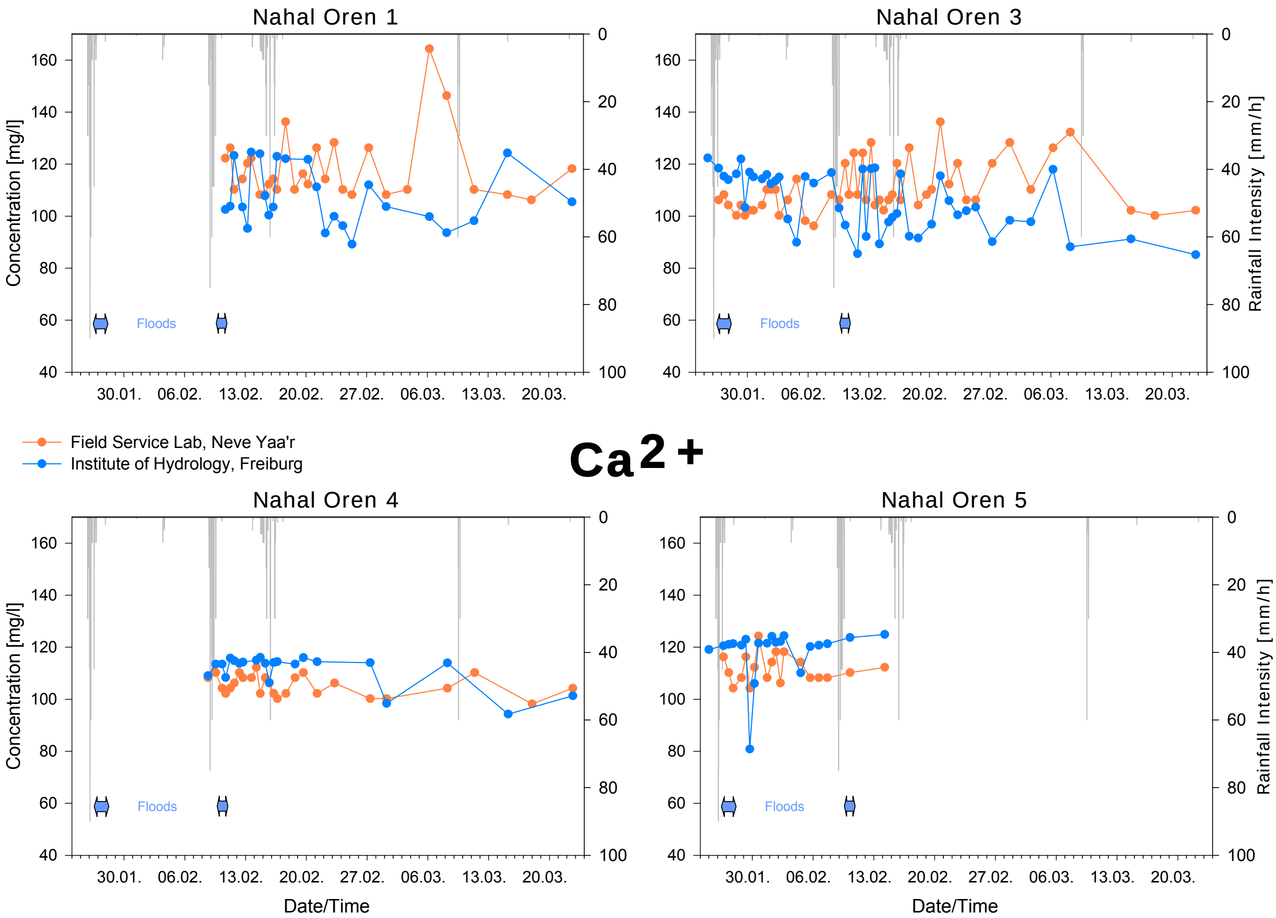


Figure 5.22: Comparison of Ca^{2+} data from IHF and FSL

regard of using the data from IHF for further investigation, also Ca^{2+} is taken from the data analysed at IHF.

5.4.1.2 Electrical Conductivity

Electrical Conductivity (EC) is a parameter which is usually taken on-site when sampling water in the field with the aid of a portable conductivity measurement equipment. It is based on the fact that the ability of water to conduct electrical currents increase with a higher concentration of dissolved ions. All the samples taken from the Nahal Oren wells were measured instantaneously and their electrical conductivities are shown in Figure 5.23. There have been some problems due to malfunctions and calibrations, this is why all the samples have been rechecked at IHF about 15 weeks after the samples have been taken. All samples have been stored cool after being sent to Germany. The parameter which was measured was the specific electrical conductivity calculated to a reference temperature of 25℃.

Comparing both data series in Figure 5.23 one can see that data from IHF show generally higher values in EC than values taken in situ and less fluctuations. Similar changes after

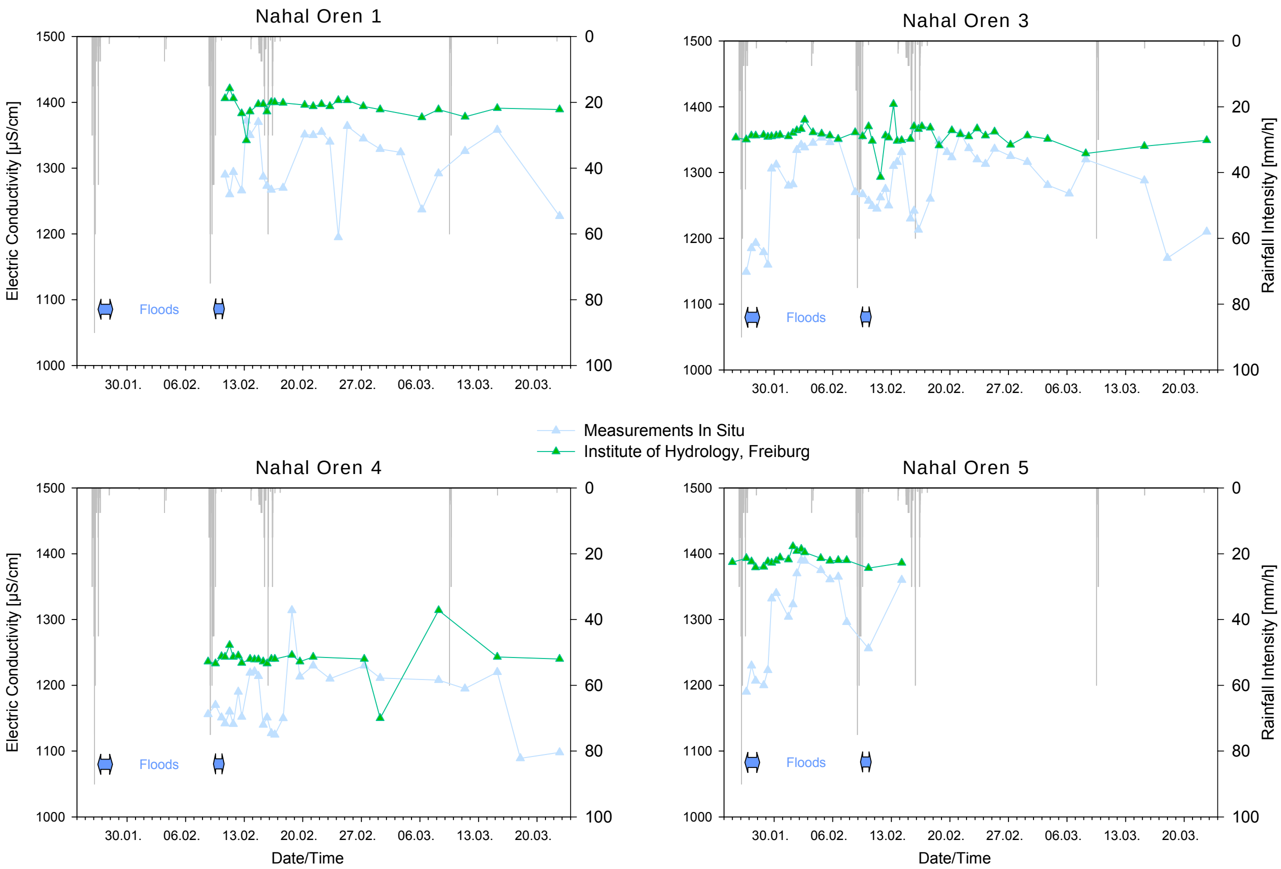


Figure 5.23: Comparison of Electrical Conductivity data from IHF and FSL

or during flood events in different wells (e.g. SFE at Well Nahal Oren 1, 3 and 4) can be observed in the immediate measurements. But a change in EC cannot prove hydrological processes like an infiltrating water front as EC result mainly from the presence of bivalent ions and not only from one chemical element. In total, also the statistical analysis of this

Table 5.5: Statistical Analysis of Electrical Conductivity Data

Electric Conductivity [µS/cm]	**Nahal Oren 1**		**Nahal Oren 3**		**Nahal Oren 4**		**Nahal Oren 5**	
	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r	Institute of Hydrology, Freiburg	Field Lab Service Neve Yaa'r
Size	25	25	46	47	23	27	20	18
Min	1342	1195	1293	1149	1150	1089	1378	1190
Max	1421	1372	1404	1360	1314	1314	1411	1390
Range	79	177	111	211	164	225	33	200
Mean	1393	1308	1356	1282	1240	1179	1391	1306
Variance	202	2441	220	3331	651	2415	78	4947
Std.Dev	14	49	15	58	26	49	9	70
Std.Err	3	10	2	8	5	9	2	17
95% Conf	6	20	4	17	11	19	4	35
	1393 ± 6	1308 ± 20	1356 ± 4	1282 ± 17	1240 ± 11	1179 ± 19	1391 ± 4	1306 ± 35

parameter in Table 5.5 shows the higher EC values rechecked at IHF with much lower variances. In this case this cannot be a proof of a better quality of the data, because EC should always be measured instantaneously and both storage and chemical reactions with the sampling bottles can change the chemical composition of the sample.

Water temperature measurements have also been conducted with the same portable measurement equipment on site. They also show the same fluctuations in values as the EC data which seem to be more related to malfunctions of the equipment than to processes of infiltrating surface water.

5.4.1.3 Conclusion

Data series of different sources for the same chemical parameter or environmental tracer have been compared with regard to their consistency and suitability for further interpretation. The data is obtained from in situ measurements, Field Service Lab in Neve Yaa'r and the Insitute for Hydrology, Freiburg. In total the are discrepancies in the comparison of Cl^-, Mg^{2+} and EC data, relating to statistical analysis and time series. Different values, but of about the same quality is found in Ca^{2+} data. Therefore data from IHF is used in further investigations in this study due to a higher consistency.

5.4.2 Environmental Tracers

5.4.2.1 Chemical Composition

A Piper diagram is generated using the AquaChem software by *Waterloo Hydrogeologic* for representative samples taken from the Nahal Oren wells during the period of observation and analysed for major ions at IHF, Germany. It should be noted that HCO_3^- has been calculated by closing the major ion balance and is not measured in the Ion Chromatography procedure. The result is presented in Figure 5.24. The samples from the different

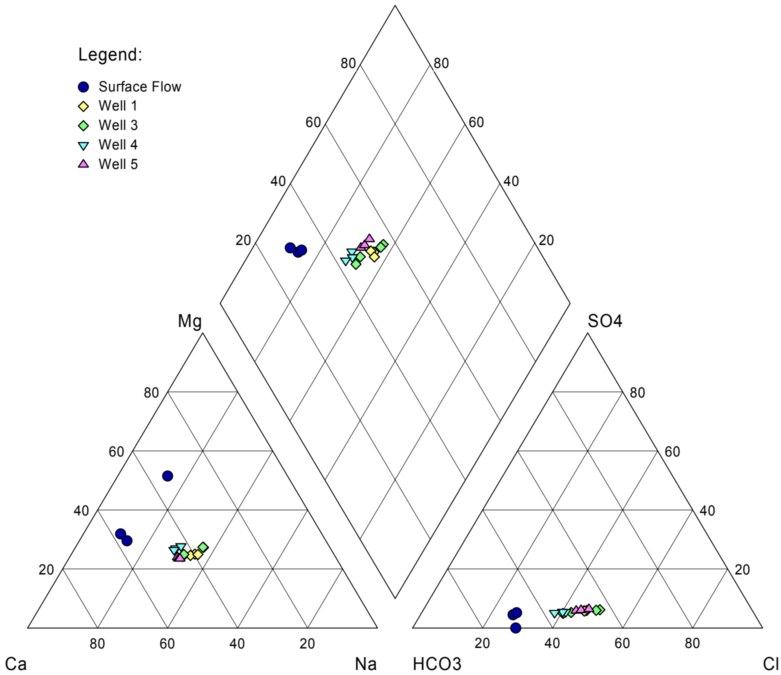


Figure 5.24: Piper Diagram of the chemical analysis of the Nahal Oren wells

wells are of a Ca-Na-Mg-HCO_3 water type and no mixing line along an assumed flow path can be observed. A cluster of water samples indicates that wells penetrate the same aquifer and can help in verifying water level gradients and deduce groundwater flow directions ([Mazor, 2004]). Compared to the Piper diagram derived from historical records (see Figure 3.9 on Page 27) the water in the area seems to be homogenized and does not undergo alterations along the suggested flow path. This could lead to the assumption that groundwater flow is reversed more often than presumed, not only in summer time during extended pumping.

Another way to provide a description of the relative abundance pattern of the dissolved ions and the relative salinity is the fingerprint diagram by Schoeller. For representative samples of the study site during the period of observation a fingerprint diagram is generated and is presented in Figure 5.25. All of the samples show the same type of water from most likely interconnected wells, indicated by clustered lines in the diagram for the wells' samples. Parallel lines indicate that dilution occurs. Fan shaped lines can

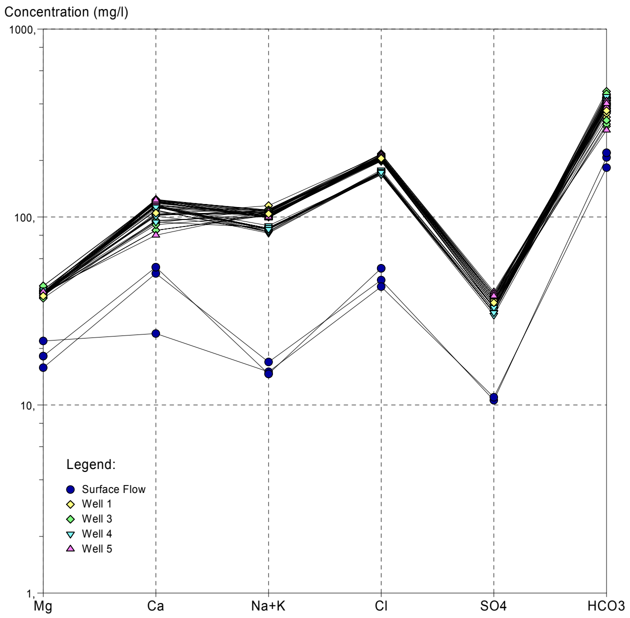


Figure 5.25: Fingerprint Diagram of the chemical analysis of the Nahal Oren wells

be observed only with the concentrations of Ca^{2+}-ions and indicate that mixing occurs ([Mazor, 2004]).

Composition diagrams have been created from the major ions data acquired from the Ion Chromatography conducted at IHF, Germany, and from the chemical analysis of the flood water from FSL, Israel. Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, Na^+, K^+, Ca^{2+} and Mg^{2+} are plotted against TDI in x-y-diagrams and are shown in Figure 5.26. A positive correlation can be observed in the Ca^{2+} concentrations, indicating mixing: the line extrapolates to the TDI axis, indicating that the fresh end member contains significant ions other than Ca^{2+}. The HCO_3^- concentrations also show a positive correlation, but it should be noted that HCO_3^- is calculated by closing the major ion balance and not measured. It may be that the water is not saturated with respect to calcite and therefore a positive correlation of Ca^{2+} and HCO_3^- with TDI is found. The other elements show clustering, indicating that only one type of water is involved and the wells are draining the same aquifer, thus are most likely to be interconnected. This fact may help verifying the water level gradients.

Comparing with historical data, a different composition is observed. [Guttman, 1998] noted that Na^+, Mg^{2+}, Cl^- and SO_4^{2-}, which form very soluble salts, increase with increasing TDI, the main source of these ions being mainly from sea spray aerosols. On the other hand he found a poor correlation between Ca^{2+} and HCO_3^- and TDI, which he stated could result from carbonate saturation determined in the area. This is an observation in opposition to the present results. This could be explained by a change in water type over the last decade, and altered generation processes. In addition, this change in water type could be related to the occurring change in groundwater flow directions and the appearance of the reverse gradient. A recent water sample from Atlit 1 could not be taken during the period of investigations, but historical data could be helpful in interpreting the current situation.

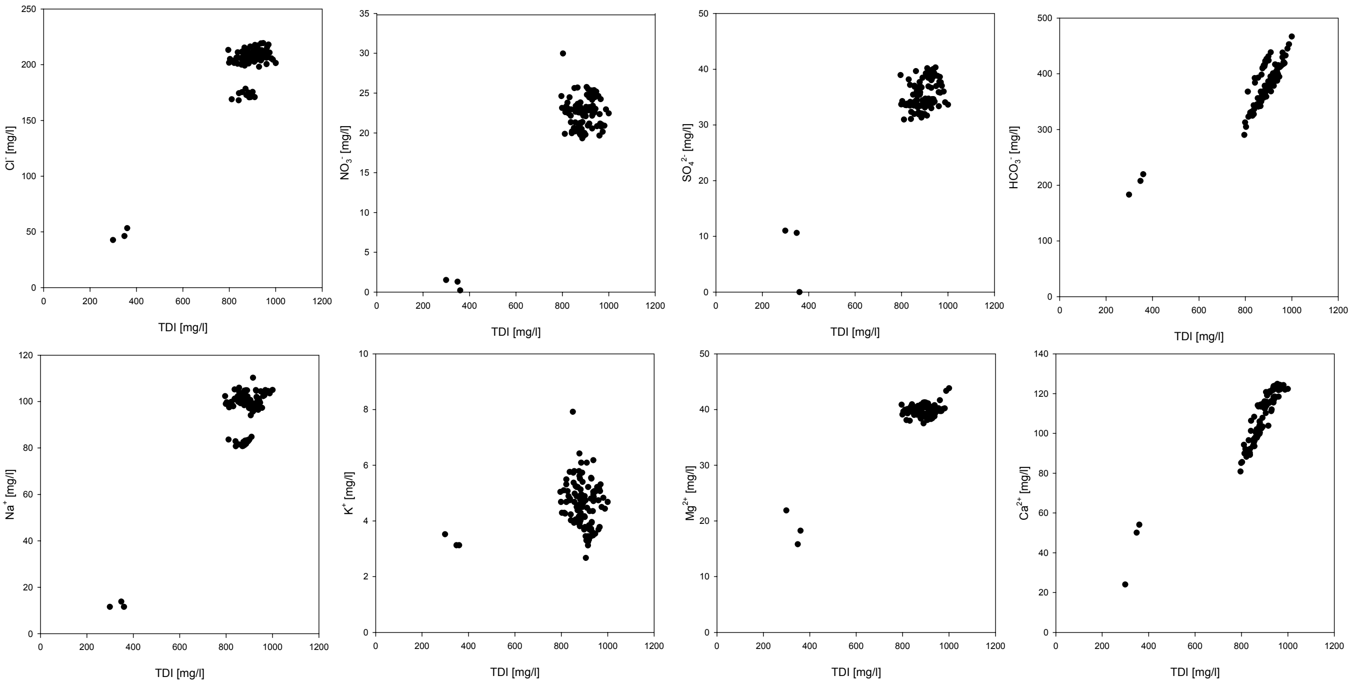


Figure 5.26: Composition diagram of the groundwater in the Nahal Oren catchment and the flood water

5.4.2.2 Chloride

Chloride is a conservative tracer, and once it enters the groundwater, the concentration can only be altered by mixing of different water types, if there are no lithological units known to release chloride ([Mazor, 2004]). Figure 5.27 shows the chloride concentrations of the samples taken from wells Nahal Oren 1, 3, 4 and 5 for the period of 25.01.-23.03.06.

There are significant differences in the average chloride concentration of the groundwater. The water from well Nahal Oren 5 shows the highest values (mean 212 mg/l), the water from well Nahal Oren 4 the lowest values (mean 174 mg/l). The water from well Nahal Oren 3 could result from a mixture of water from wells Nahal Oren 1 and 4. Also the observed water levels in these wells (see Section 5.2) could confirm this mixture as water levels in well Nahal Oren 3 are lower than in wells Nahal Oren 1 and 4. In Well Nahal Oren 5 the detection of Naphtionate proves a hydraulic connection to the surface: therefore chloride concentrations could be expected to be lower than observed due to vertical recharge processes. On the other hand, water levels are lowest at well Nahal Oren 5 and would support the conceptual flow model of a reverse gradient, hence explaining the higher concentrations of chloride.
It is questionable to interpret dilution and changes in chloride concentrations due to different processes playing a role in the area. It could be possible to relate changes to occurring floods, but only in well Nahal Oren 5 a concurrent detection of Naphtionate allows to determine the arrival of the infiltrating water front, altering the concentration of chloride.

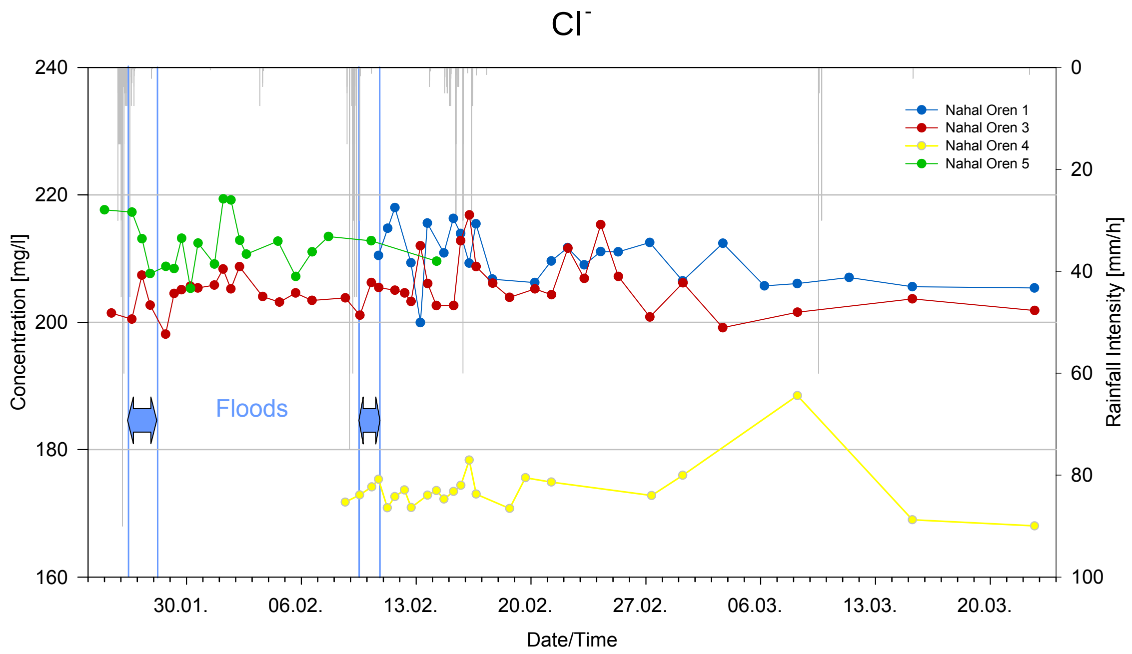


Figure 5.27: Cl⁻-concentrations in wells Nahal Oren 1, 3, 4 and 5

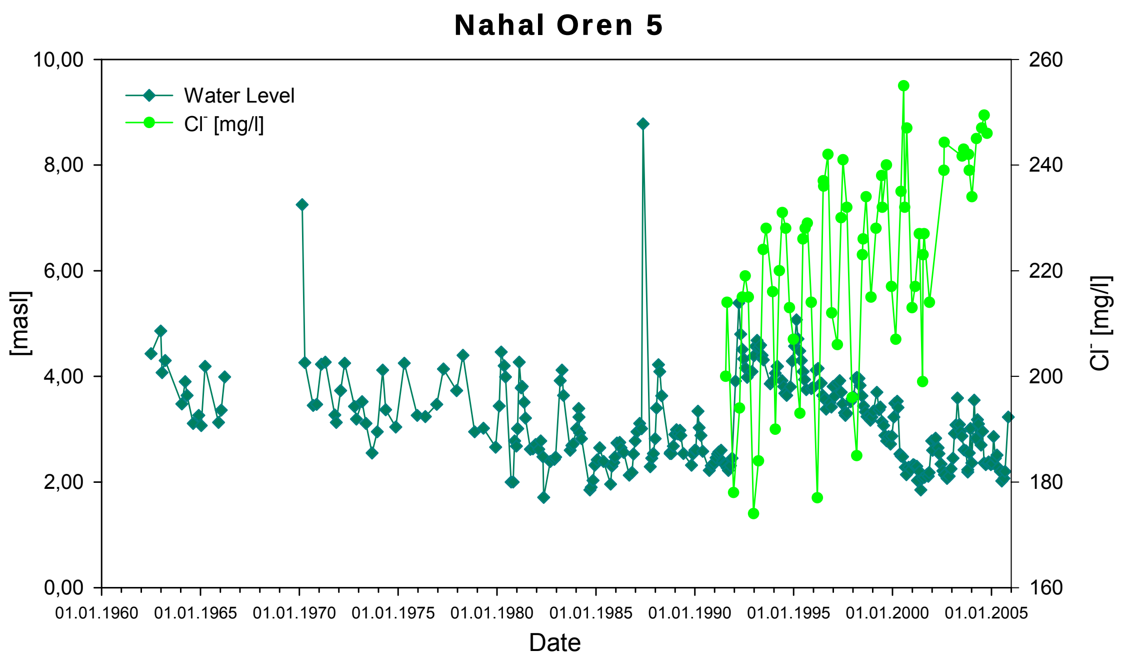


Figure 5.28: Historical data from well Nahal Oren 5 showing increasing chloride concentrations and decreasing water levels

[Guttman, 1998] noted a rise in chloride concentrations in the Judea Group aquifer over the last 40 years of pumping. Historical data provided by Mekorot from well Nahal Oren 5 (Figure 5.28) show the rise of chloride concentrations and the concurrent decrease in water levels. By the time [Guttman, 1998] noted two conceptual flow models for winter and summer for this region. This trend could already be found in data from this well, but since 1998 chloride concentrations are still found to rise, whereas water levels seem to have stabilised at about 2-3 masl.

5.4.2.3 Electrical Conductivity

The electrical conductivity has been rechecked at IHF and the results are presented in Figure 5.29 for the wells Nahal Oren 1, 3, 4 and 5. There are significant differences in the

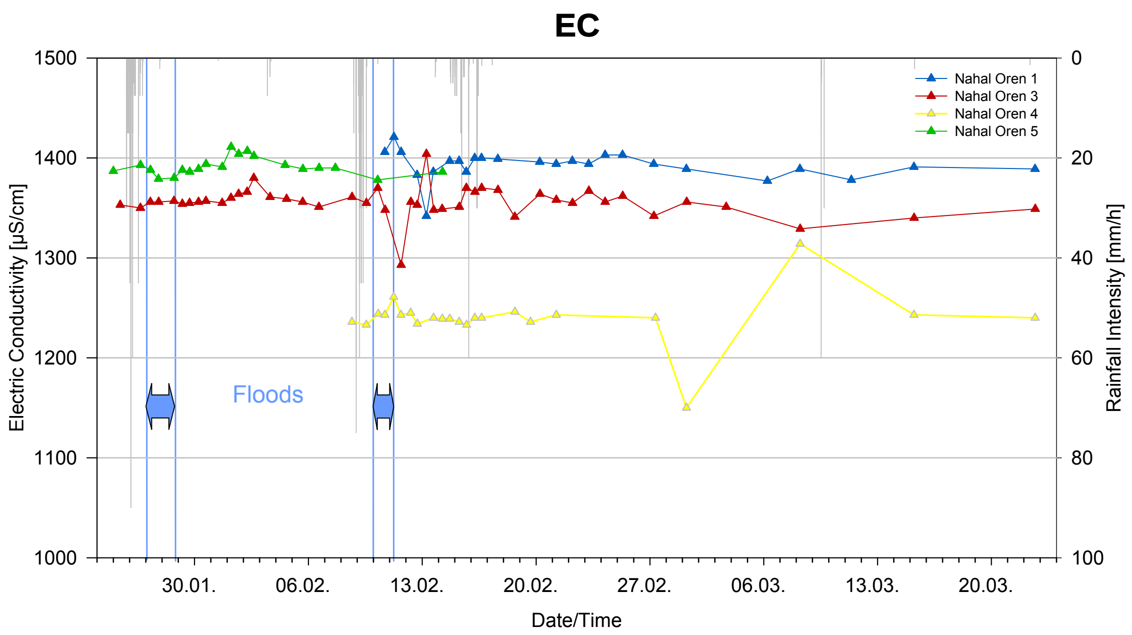


Figure 5.29: Electrical Conductivity in wells Nahal Oren 1, 3, 4 and 5

average electrical conductivity found in the samples from the wells. Wells Nahal Oren 5 and 1 show the highest values (1389 and 1379 μS/cm average respectively), whereas the water from well Nahal Oren 4 yields the lowest values (1240 μS/cm average). The water from well Nahal Oren 3 (average 1363 μS/cm) could result from a mixture of water from wells Nahal Oren 1 and 4, like suggested in the chloride section. The same assumption can be made for electrical conductivity and chloride (see above): Well Nahal Oren 5 is the only location where vertical hydraulic connection can be proven by the detection of Naphtionate, and water from this well should be more diluted from infiltrating precipitation and runoff. On the other hand, the conceptual flow model of a reversed hydraulic gradient observed during this study could account for the highest values at this location. Well Nahal Oren 1 could be mixed with water infiltrating from the Pleistocene aquifer when static water levels in the Judea Group aquifer fall beneath the more saline water from the coast. But according to water levels from Atlit 1, water is flowing both in a westward and eastward direction from Nahal Oren 1.

The electrical conductivity in Atlit 1 was measured by a CTD-DIVER in addition to water level and temperature; the results can be seen in Figure 5.30. Unlike temperature, the

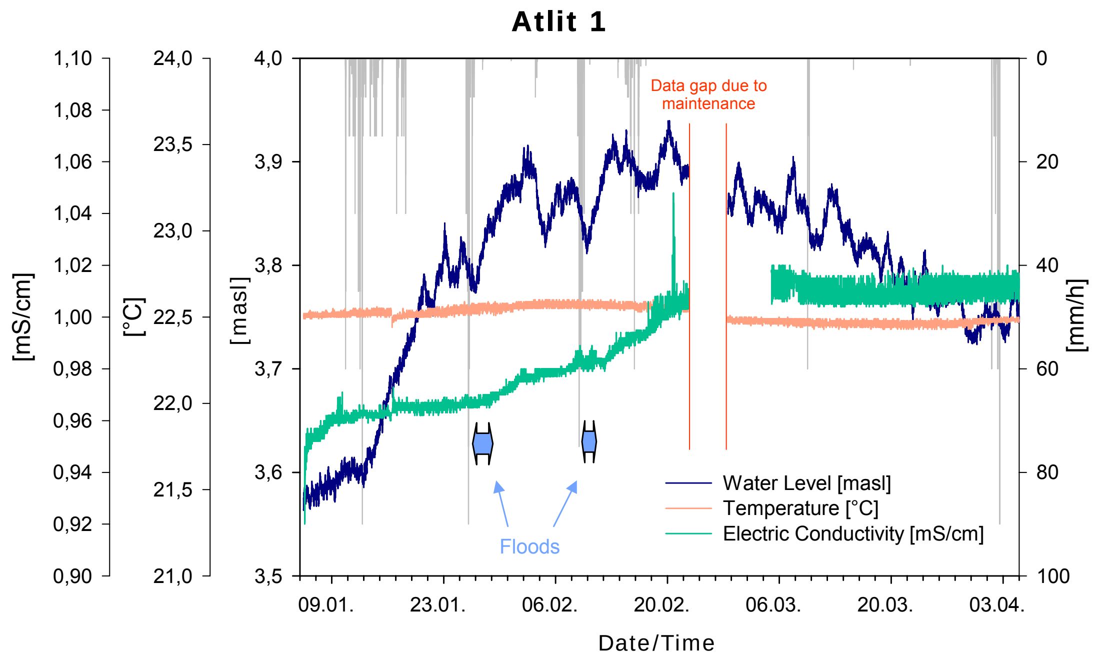


Figure 5.30: Water Levels, Electrical Conductivity and Temperature in observation well Atlit 1

electrical conductivity increased during the period of observation, from about 950 μS/cm to about 1010 μS/cm after both floods have passed. It is found to be generally lower than in the Nahal Oren wells, where all the samples show values of more than 1100 μS/cm. The well used to drain the Isafiya chalk and limestone formation according to the drilling log (see Appendix), unlike the other wells which are drilled into the Yagur dolomite formation. There might be a hydraulic connection between these conductive layers along the flow path from Nahal Oren 1 towards the sea. The water levels in Atlit 1 are lower than in Nahal Oren 1 which shows the highest levels in the study area (see Section 5.2). Therefore the water in Atlit 1 could be a mixture of water from the limestone formation and the dolomite formation yielding a higher conductivity and therefore increasing the electrical conductivity with a time lag. Comparing the results from the CTD-DIVER with historical data provided by Mekorot and the Hydrology Service in the Israel National Infrastructure Ministry, the water from Atlit 1 is supposed to show much higher values in electrical conductivity, resulting from a higher concentration of all major ions than in water from the Nahal Oren wells. EC was taken last on 10.08.2000 in this well and the value of 2750 μS/cm varies from the recent values nearly to 280%.

5.4.2.4 Conclusion

The chemical composition, chloride concentrations and electrical conductivity allow a characterization of the water types in the catchment and potential conceptual flow models in the area. The water in all of the Nahal Oren wells is mainly of a Ca-Na-Mg-HCO_3 water type, with only minimal alteration between them. The wells are therefore assumed to tap the same aquifer and to be interconnected. The reverse groundwater flow model can be validated from static water levels. Two conceptual flow models have been determined by [Guttman, 1998] and are presented in Figure 5.4.2.4. The data from chloride concentrations and electrical conductivity support the following assumption: Water from well Nahal Oren 1 shows the highest concentrations of chloride and values of conductivity, well Nahal Oren 4 the lowest. The water from well Nahal Oren 3 could evolve from a mixture of wells Nahal Oren 1 and 4. Well Nahal Oren 5 shows also very high values in chloride concentration and salinity and may support the flow model deduced from the static water levels, but also shows the only location with an assumed quick recharge from runoff events (see Section 5.3).
In total these conditions are suggested to exist only during the summer (see Figure 5.31), [Guttman, 1998]), but are now assumed to also exist in the winter season.

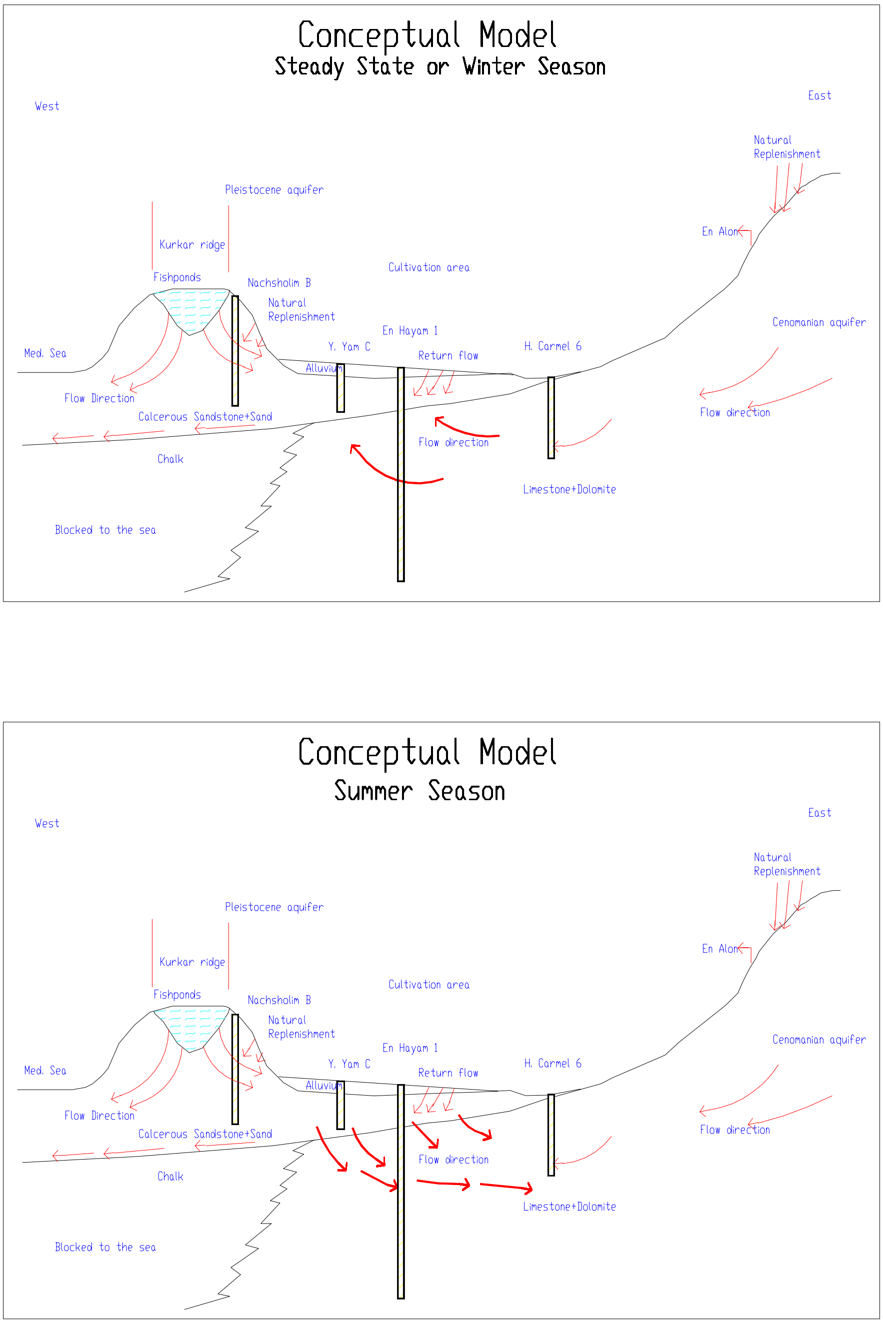


Figure 5.31: Conceptual Flow Models for the region in summer and winter season (from [Guttman, 1998]): The actual wells are different in this figures, but the concept of changing groundwater gradients is shown with wells drilling into the Judea Group and the Pleistocene aquifer; the figures also show the reason why the theory of seawater intrusion is disregarded in the area: infiltrating water from fishponds is creating an artificial barrier.

5.4.3 Chloride Method

5.4.3.1 Application

For verification of the other approaches, the chloride method is applied. It is assumed to be adequate as the climate is semi-arid and there are no lithological units in the Nahal Oren catchment that are known to release chloride. Water that is in contact with halite dissolves it rapidly, reaching a chloride concentration of more than 180,000 mg/l ([Mazor, 2004]. The water in the Nahal Oren area contains chloride in concentrations in the range of about 160-300 mg/l throughout the years.
In addition, as the catchment lies within the Mt. Carmel National Park, there is no additional input from fertilizers around the sampled wells. Intrusion of sea water can be excluded, because [Guttman, 1998] shows that fishponds in the coastal plain form a local groundwater ridge and prohibit sea water to drain towards Mt. Carmel (see also Figure 5.31). There is fertilization and other agricultural practices being carried out on the coastal plain, and the water from the Pleistocene aquifer can flow into the Judea Group aquifer when the groundwater flow direction is reversed during increased summer exploitation of the Judea Group ([Guttman, 1998]). This phenomena cannot only happen during summer time, as shown above, but also during time when the groundwater flow was assumed to drain towards the sea. It can alter the chloride concentration and therefore the estimation of groundwater recharge.

There is runoff known to exist in the area, taking away potential input of chloride, thus overestimating recharge. But due to the high infiltration capacity in the area, also a certain proportion of the runoff infiltrates and contributes to recharge. The chloride method usually is applied in soil profiles or in groundwater directly below the zero-flux-plane ([Allison & Hughes, 1978]). It can be applied in shallow groundwater, noting that chloride concentration not only result from vertical movement, but also from mixing with groundwater flowing laterally from other locations.
The recharge rates calculated may not represent the recharge rates at the sampling location, but an average recharge rate between the point where the water entered the saturated zone and the point the sample was taken (Harrington et al., 2002 in [Brunner et al, 2004]). To reduce this error, one could calculate recharge in boreholes or wells along the watershed or in the upper part of the catchment. The Nahal Oren wells are located in the lower part of the catchment, therefore recharged water is probably mixed with lateral transported water and biases the true recharge concentration of chloride. Thus the use of the chloride method in this study is just a rough estimation, and should be regarded with care.

Rainfall data is taken from Haifa University and by using a linear regression (given in [Wittenberg et al, 2004]) the annual rainfall for Beit Oren station and the mean rainfall for the period 1991-2004 can be estimated. As there are no monitoring stations for dry deposition flux of chloride known to exist in the area, it is neglected in the calculations. Chloride in rainfall is known to vary to a high extent in catchments close to the sea. The mean chloride content in rainfall in the Nahal Oren catchment is taken from data provided by [Arbel, not published] and is used as the input concentration. The mean chloride concentration is taken from data provided by Mekorot for each well for the years 1991-2004. Well Nahal Oren 2 is neglected as groundwater levels are below sea level. The annual mean racharge rates are calculated using equation 2.14 and are presented in Table 5.7.

Table 5.6: Application of the Chloride Method

1991 - 2004	Mean Rainfall Beit Oren [mm]	Mean Cl⁻ rainfall [mg/l]	Mean Cl⁻ groundwater [mg/l]	Groundwater Recharge [mm]	Groundwater Recharge [MCM]
Well Nahal Oren 1	709.5	19.73	262.3	53.4	1.87
Well Nahal Oren 3			243.2	57.6	2.01
Well Nahal Oren 4			182.4	76.8	2.69
Well Nahal Oren 5			222.3	63.0	2.20
			Average:	**62.7**	**2.19**

Considering the discussion above, a mean annual recharge rate of 62.7 mm or 2.19 MCM can be computed. This would be about 8.9% of the mean annual rainfall at Beit Oren and may be understated for the karstic area. On the other hand, if extraction from the wells are about the order of last year's (2.48 MCM, see Chapter 3), it would support the assumption that extraction exceeds recharge in the area and could account for more frequent reverse groundwater flow gradients. Extraction volumes are available for the years 1991-2004 and are presented in Table 5.7; they are found to be higher than the calculated recharge rate for each year.

Table 5.7: Annual discharge volumes of the Nahal Oren wells for the period 1991-2004

Year	MCM
1991	2.33
1992	3.01
1993	3.46
1994	4.07
1995	3.01
1996	4.04
1997	3.11
1998	2.27
1999	3.88
2000	2.89
2001	2.85
2002	3.38
2003	3.04
2004	3.45

The system does not represent steady-state conditions as seen from the chloride data above. Chloride accumulates and shows a positive trend. That is why the recharge rates should not be overrated. Measurement errors and especially chloride concentrations in rainfall are highly variable close to the coast and can vary results to a high extent.

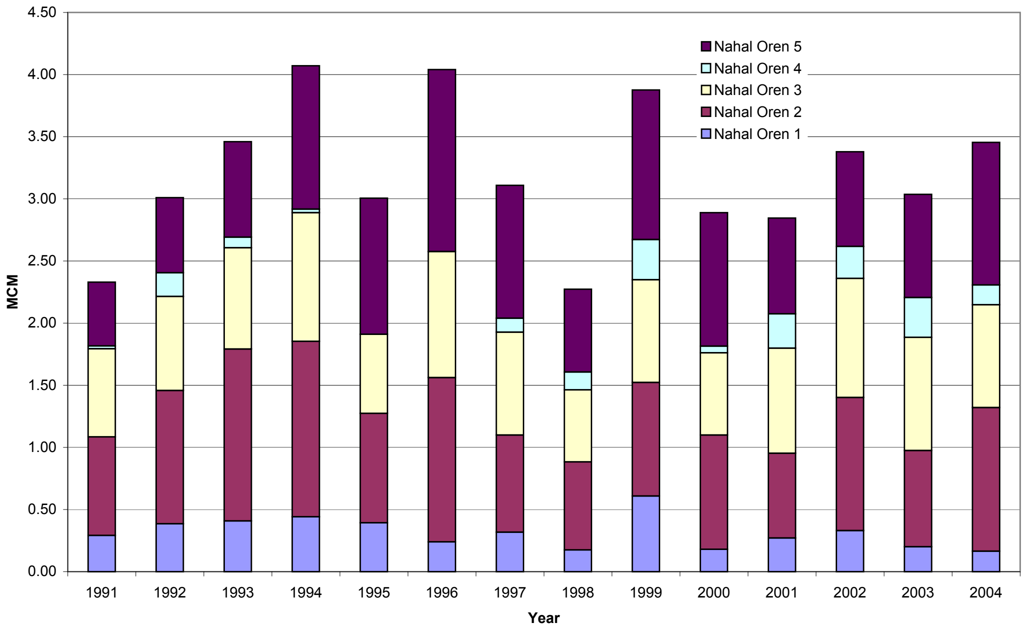


Figure 5.32: Annual extraction of groundwater from the Nahal Oren wells for the period 1991-2004

5.4.3.2 Conclusion

The chloride method allows to calculate groundwater recharge rates in long average terms. Under the given conditions and concerning limitations and presumptions valid in the area, a recharge rate of 62.7 mm or 2.19 MCM can be computed.

Extraction from the wells exceed this recharge rates in the years of 1991-2004, but parameters used in the recharge calculation are highly sensitive and input concentration in rainfall varies to a high extent in catchments close to the sea and should not be overrated.

5.4.4 End Member Mixing Analysis

The detection of the flourescentic dye tracer described in Section 5.3 allows to distinguish sources of observed dilution in chloride and sulfate concentrations in the samples of well Nahal Oren 5. During the FFE a rather swift detection of Naphtionate could be recorded. Simultaneously chloride and sulfate concentrations decreased from the value before the flood started and rose back after the tracer has passed and could not be detected any more. This way the dilution of groundwater can be related to infiltrating runoff and be connected with the detection of Naphtionate. All the other dilution and fluctuation effects observed in samples from wells Nahal Oren 1, 3, 4 and 5 are hard to allocate to different processes and an end member mixing analysis would be arguable. But for the period of the positive tracer detection in combination with the FFE an end member mixing analysis can be applied.

5.4.4.1 Application

For the runoff event on the 26./27.01.06 the chloride and sulfate concentrations are taken to apply a mixing analysis. Only one environmental tracer is required to distinguish two fractions of total discharge ([Ogunkoya & Jenkins, 1993]). Chloride is taken due to its conservative nature: the concentration of chloride is altered only by mixing once it enters the groundwater. Two end members are determined with significantly different concentrations of chloride: surface runoff from the FFE and groundwater from Nahal Oren 5 prior to the flood. Neither runoff data of the flood nor flow rates of the aquifer are available, this way only fractions of the components can be computed, not absolute discharge values. The results are shown in Figure 5.33.

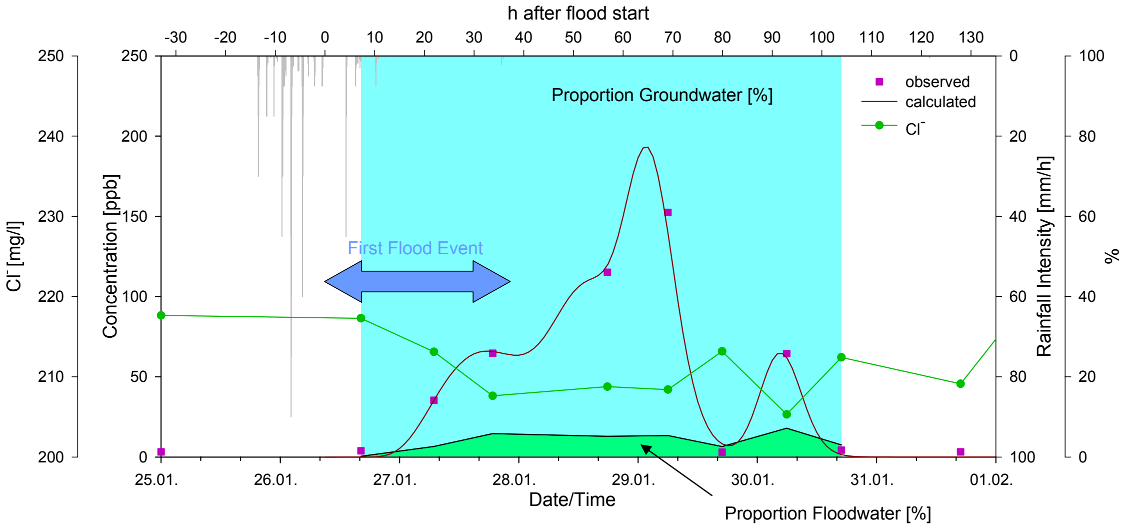


Figure 5.33: Proportions of groundwater and surface water in the discharge of well Nahal Oren 5 calculated using EMMA for chloride

It is assumed that transmission losses take place until the Naphtionate concentrations decrease to background values (from 27.01.06, 0:00 - 30.01.06, 15:00), after that the dilution in chloride concentrations is triggered by other processes. Equations (2.18) and (2.19) are used to calculate the fractions of both end members (Q_1/Q_T and Q_2/Q_T) in the water extracted from the well. Thus for the days during and after the FFE the contribution of infiltrating runoff to the total discharge of the well rises up to 7.2%. The weighted mean fraction of transmission losses is calculated to 3.1% of the total discharge. The total amount of groundwater extracted during these days can be estimated from the daily records, and is determined to about 4100 m^3. Taking this value leads to an absolute amount of about 127 m^3 extracted water from surface runoff origin. Further, the total runoff of the FFE is estimated in Chapter 4 to about 16,000 m^3 . Thus, a fraction of 0.8% of the total runoff of the FFE can be regarded as infiltrating runoff or transmission losses and as a contribution to groundwater recharge at this location.

The same method can be applied for SO_4^{2-}, because of its conservative nature in the study region. There is no positive correlation found in the composition diagram of SO_4^{2-} with TDI. It also shows clearly distinguishable concentrations in both end members, surface runoff from the FFE and groundwater from Nahal Oren 5 prior to the flood. The results of the application of the EMMA using sulfate is presented in Figure 5.34. Similar proportions

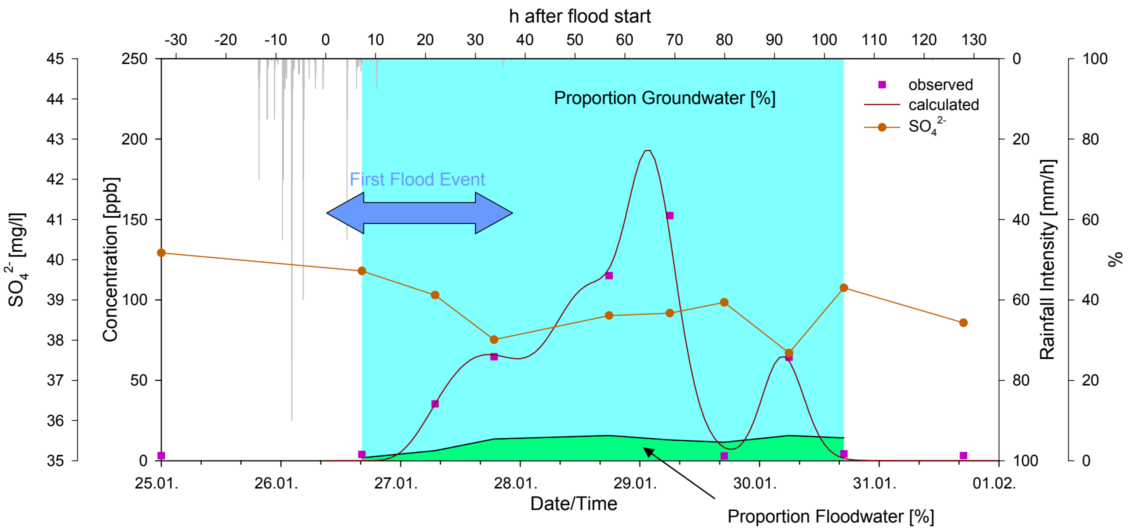


Figure 5.34: Proportions of groundwater and surface water in the discharge of well Nahal Oren 5 calculated using EMMA for sulfate

can be found, like in the application of chloride before: the maximum contribution of infiltrating runoff to the well discharge is calculated to 6.3%, the weighted mean during and after the FFE to 3.9%. This leads to an absolute amount of 160 m^3 extracted water from surface runoff origin and a fraction of 1% of the total runoff from the FFE.

It should be noted, that the value of 0.8% and 1%, respectively, is assumed to be a minimal value as only a fraction of the infiltrating and percolating water is extracted from the well, the other fraction may percolate and flow laterally. Hence groundwater recharge from transmission losses are assumed to be >0.8% for this runoff event.

5.4.4.2 Conclusion

An End Member Mixing Analysis is carried out only for the period following the First Flood Event at well Nahal Oren 5. Due to the detection of Naphtionate the dilution of chloride and sulfate can be connected to an infiltrating water front from transmission losses. Other dilution observed in other events or wells cannot be determined or allocated and are therefore neglected.
The use of chloride and sulfate as tracers result in minimal values of 127 and 160 m^3 total recharge, respectively, or in proportions, 0.8 and 1% of the total runoff. These are minimal values because discharge from the wells is just a fraction of recharged groundwater, others fractions may flow laterally.

5.4.5 Conclusion

The environmental tracer data have been analysed twice. The data acquired at FSL and IHF is compared and due to a higher consistency the major ions data from IHF is taken for the methods applied in this study.
The chemical composition, chloride concentrations and electrical conductivity allow a characterisation of the water types in the catchment and potential conceptual flow models in the area. Compared to historical data, the groundwater system seems to be altered and the suggested conceptual flow model for the winter season cannot be verified.
The application of the chloride method must be considered with care due to limitations and conditions in the area. A mean annual recharge of 62.7 mm = 219 MCM can be estimated. The annual extraction of groundwater from the Nahal Oren wells exceeded this value in the period of 1991-2004.
The End Member Mixing Analysis can be applied to the location Nahal Oren 5 where a positive detection of Naphtionate allows to connect infiltrating runoff water to dilution effects in chloride and sulfate concentrations. A minimal value of transmission losses contributing to groundwater recharge of 127 m^3 or, in proportions, 0.8% of the FFE can be assumed.

Chapter 6

Discussion

Integrating the results of the applied methods in this study, different conclusions can be drawn regarding the current understanding of the groundwater system in the Nahal Oren catchment.

Indirect recharge takes place, as seen by the positive proof of hydraulic connection of the surface to groundwater at well Nahal Oren 5 where Naphtionate could be detected in extracted water within a day after flow in the wadi generated. On one hand, this qualitative proof of transmission losses may indicate a high vulnerability of the aquifer at this location, on the other hand it may indicate a preferential recharge area as the Yagur formation crops out at this part of the catchment. There is a definitive vertical connection between the ephemeral stream and the underlying aquifer. But the calculated transportation model (MDM) should be regarded critically because there are not enough observed samples proving the calculated passage through the unsaturated zone. Also a hydrograph is crucial in interpreting the results of the tracer experiment and is missing in this study. Due to the very quick detection in a rather great depth it should be considered to take samples in smaller time steps in future investigations.

There was no proof of direct hydraulic vertical connection at the other locations investigated in this study (wells Nahal Oren 1, 3 and 4). These wells are screened in the Yagur dolomite formation like well Nahal Oren 5, but are covered with limestone and marl layers. Marl layers act as aquicludes and flow in the deep dolomite facies could exhibit longer flow paths and transit times. Therefore transmission losses may be contributing to groundwater recharge, but in a larger time-scale than expected due to longer flow paths.

Concerning future tracer experiments it should be noted that the tracer may still be present in the system and potential contamination of the site could be a problem. Sorption and desorption processes may still take place in the unsaturated zone and along potential flow paths in a larger time-scale, thus tracer could be detected in future water samples. Future tracer experiments should be conducted using substances other than Uranine and Naphtionate, and only be carried out in preliminary well investigated areas.

Water levels show a hydraulic gradient in a reverse direction than assumed for the groundwater flow conditions during the winter months, when rainfall and recharge rates are supposed to be highest. Disregarding well Nahal Oren 2, the observed gradient would suggest an eastward flow from well Nahal Oren 1 to Nahal Oren 5 and a westward flow from well Nahal Oren 1 to Atlit 1. This reverse gradient was recorded when groundwater extraction from the wells is at a maximum in the dry summer months, and when water levels in the Judea Group aquifer fall beneath water levels in the Pleistocene aquifer. As already investigated before, this could lead to infiltration of water from the Pleistocene into the Judea Group aquifer, thus to a deterioration of groundwater quality and a rise in chloride concentrations. If these conditions are assumed to be also present during winter time, the groundwater gradient and flow direction may not recover to its natural state. A comprehensive and more continuous observation of static water levels in the affected wells is suggested to review this assumption.

The chemical composition of the present groundwater types show a cluster in the illustration of a Piper diagram, therefore suggesting to be of the same water type and tapping the same aquifer. In composition diagrams they also show a cluster in most of the major ions, suggesting saturation of major ions except Ca^{2+}. Comparing with the same illustration for historical data, the water type is found to have changed over the last 40 years. In a previous study ([Guttman, 1998]), the water types show a mixing line in the Piper diagram and a positive correlation in the composition diagrams. The flow path could be reconstructed from the recharge area in the upper catchment towards the sea, with intermixing with water from the Pleistocene aquifer during the summer months, when the groundwater flow direction is reversed. Now, the water from the Nahal Oren wells seems to be of the same water type, and does not show a clear mixing line. This could happen when the groundwater gradient would not recover in the winter months, meaning: if recharge would be too low to compensate groundwater extraction throughout the year. But the chemical composition has been recorded only over a rather small period of observation in this study and should therefore be monitored on a larger time-scale to allow more assumptions on water type generation.

The chloride method is applied in consideration of different limitations and should just allow to estimate an order of long term average recharge rates. The result of 63 mm (= 2.19 MCM) is below the annual discharge rates of the Nahal Oren wells during the last 15 years. This may lead to the assumption of overstraining groundwater resources in the area. Predominant flow conditions may not be able to recover due to extraction exceeding recharge of groundwater in the Nahal Oren catchment. But the exact value of groundwater recharge is hard to determine using the chloride method: input concentration may vary in proximity to the Mediterranean Sea and also dry deposition should not be neglected.

The application of the End Member Mixing Analysis allows to calculate a minimal value for groundwater recharge at the location of well Nahal Oren 5. The qualitative proof of hydraulic connection to the surface and the quantitative analysis of Naphtionate support the connection between the dilution of water with respect to chloride and sulfate and indirect groundwater recharge. For this event, the groundwater recharge is calculated to >0.8% of the total runoff volume. There is no runoff data available for both runoff events when the experiments have been carried out, therefore even this minimal value should be considered with care.

For future studies it is suggested to examine the predominant flow directions and investigate changes in groundwater gradients during the year. There are indications for an altered groundwater system with respect to flow directions and dynamics as well as chemical compositions in the Nahal Oren catchment. The rise in chloride concentrations could be another object to future research in this area. The use of fluorescentic dye tracers should be regarded carefully because the aquifer may be contaminated with respect to Uranine and Naphtionate for an unknown period of time, furthermore it is important to know about the predominant flow paths.

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Drilling Logs

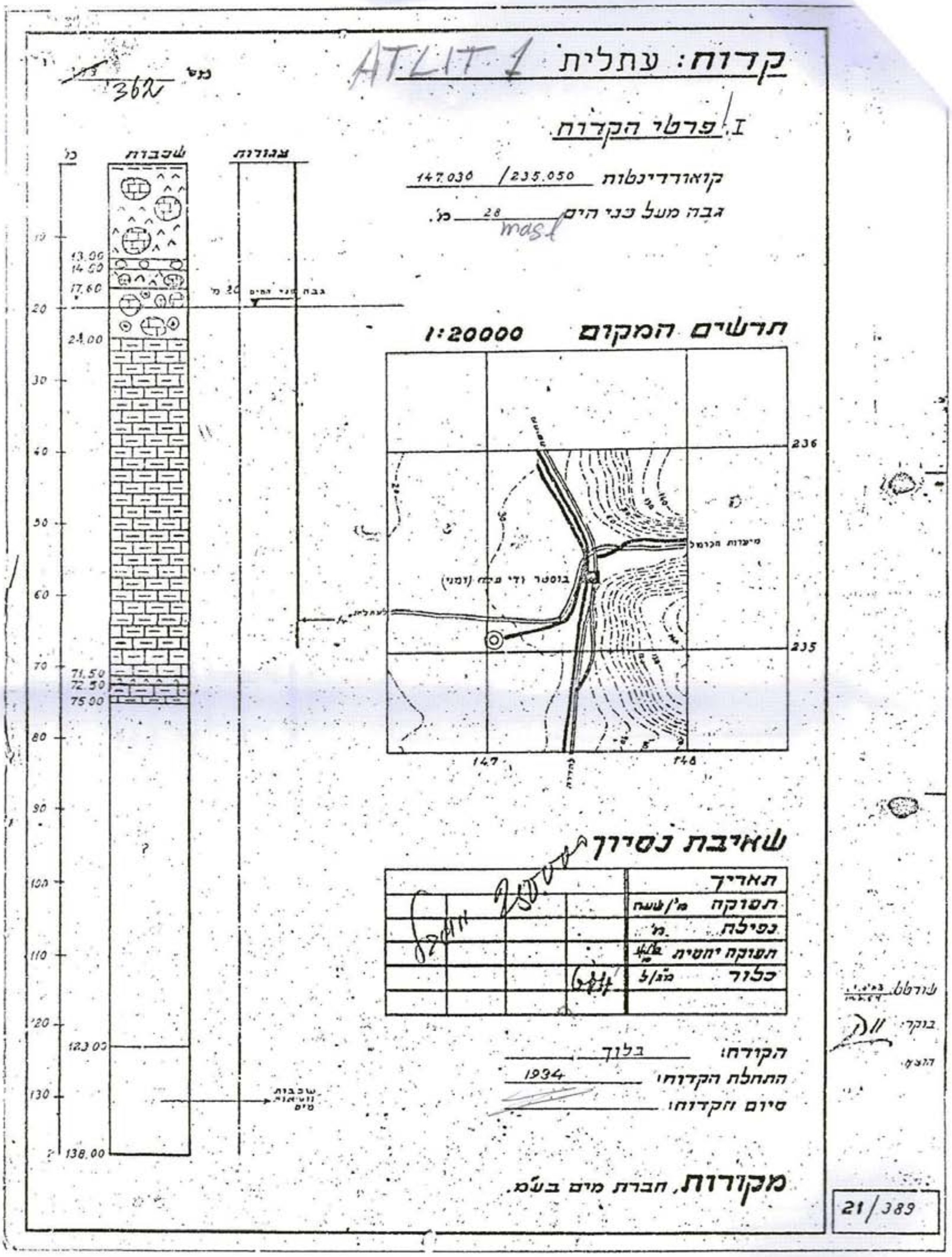

Figure 1: Drilling Log of Atlit 1

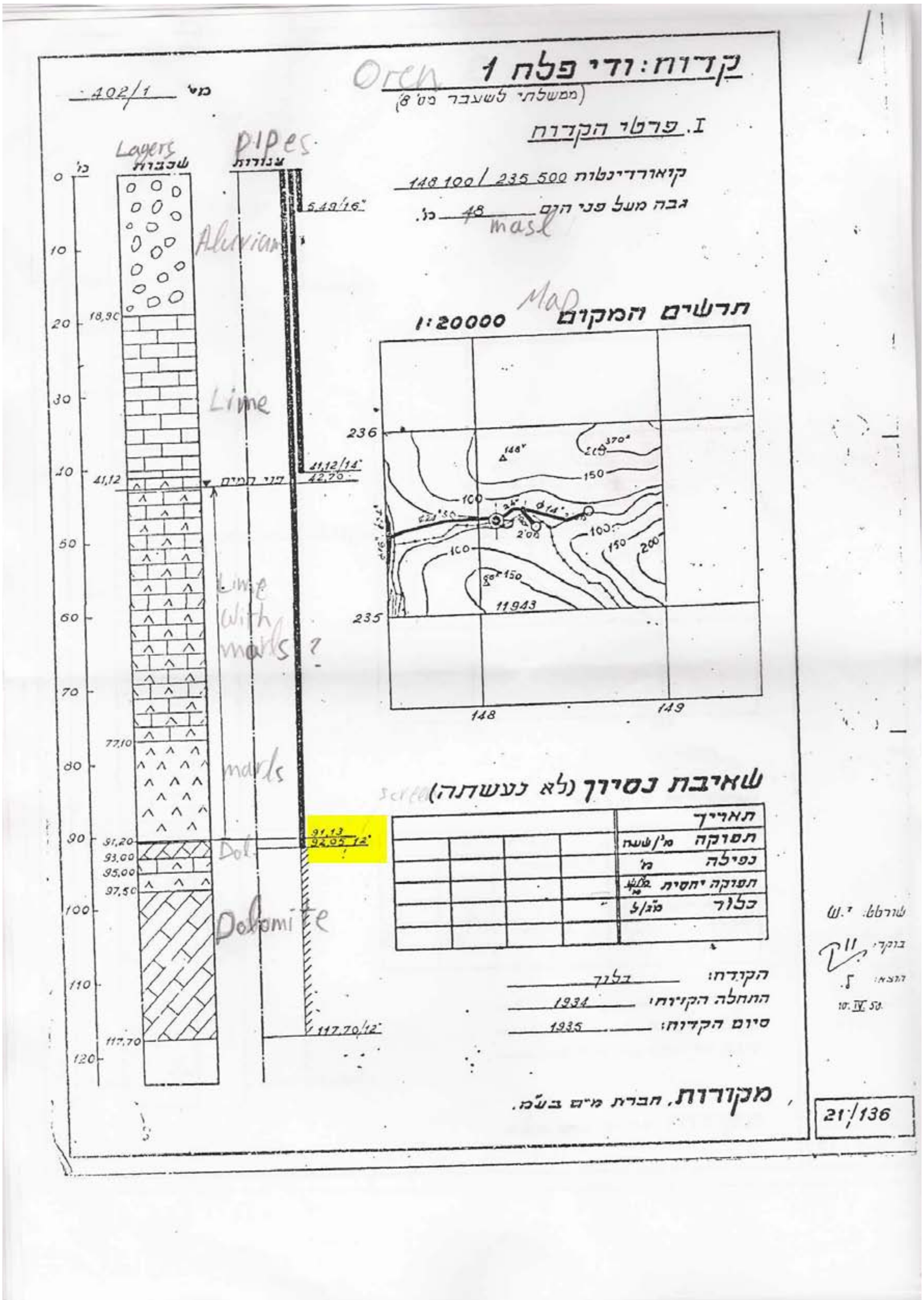

Figure 2: Drilling Log of Nahal Oren 1

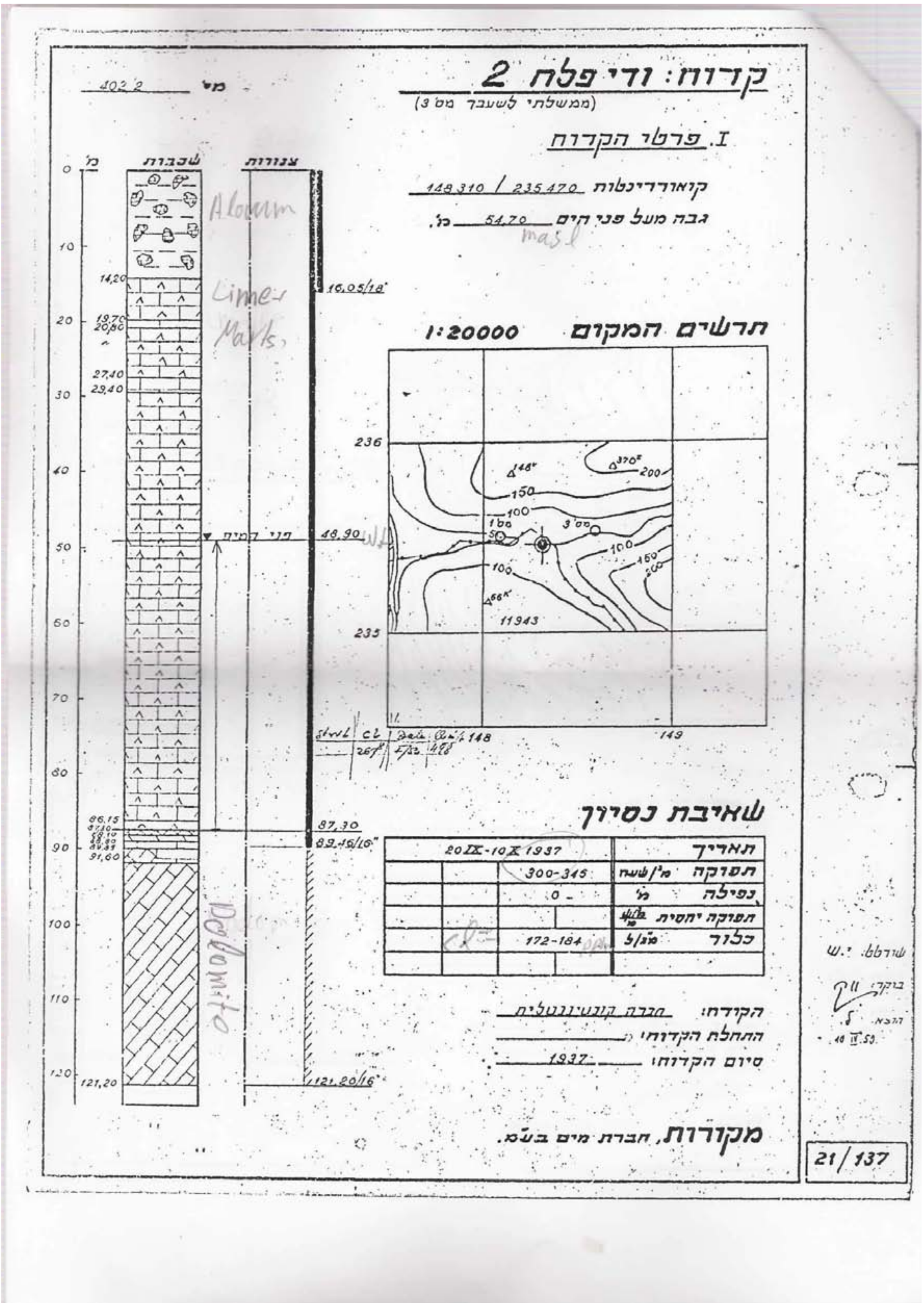

Figure 3: Drilling Log of Nahal Oren 2

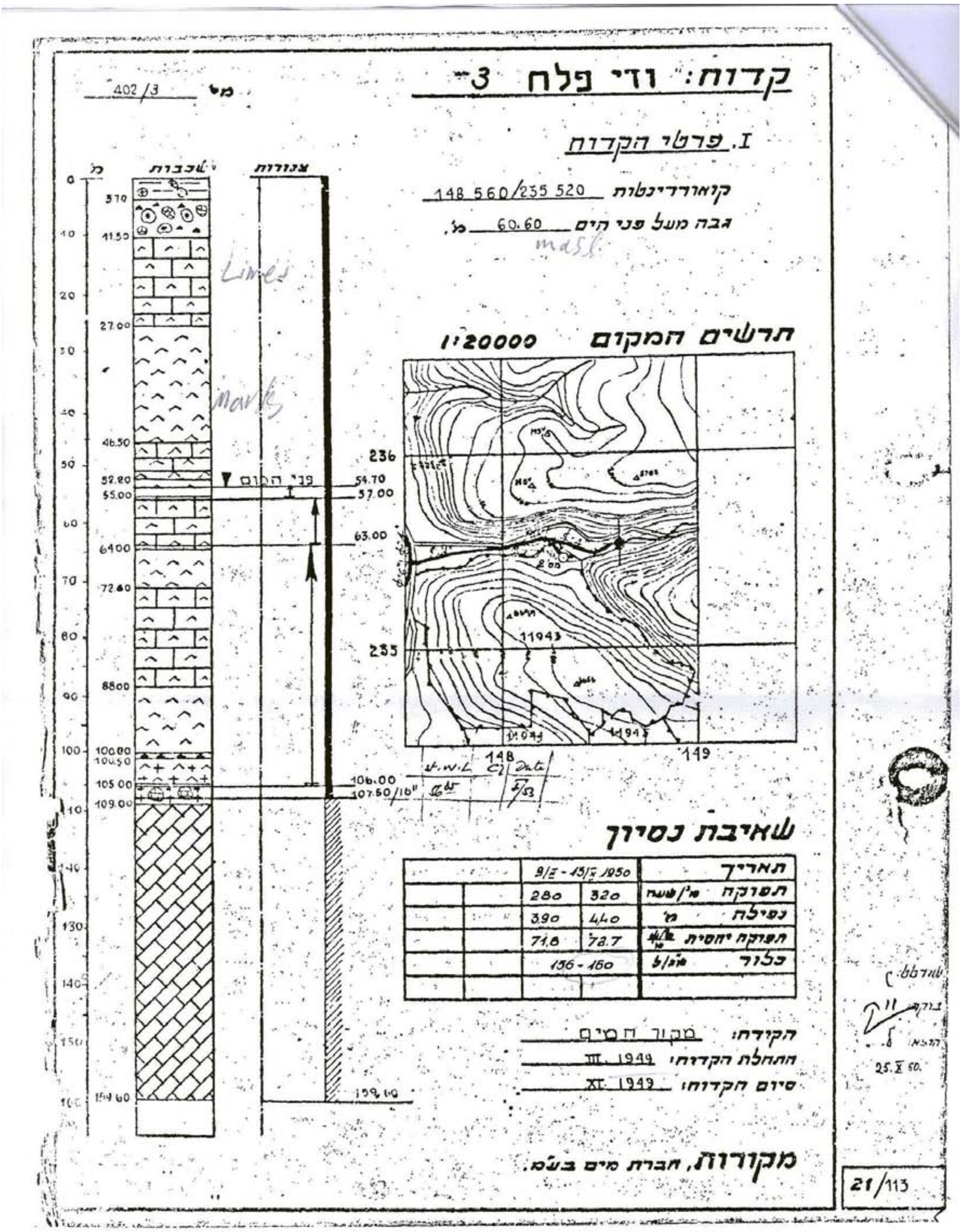

Figure 4: Drilling Log of Nahal Oren 3

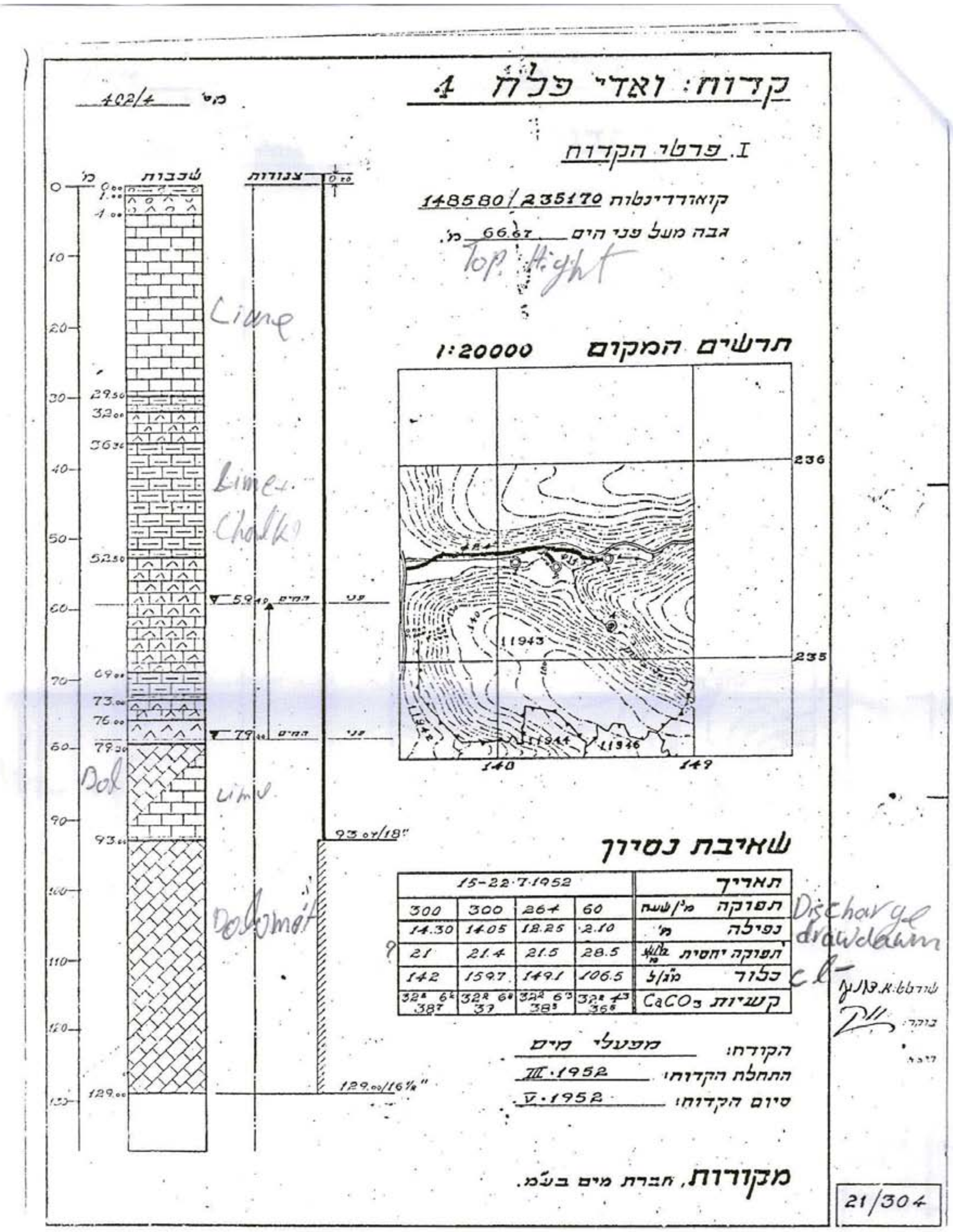

Figure 5: Drilling Log of Nahal Oren 4

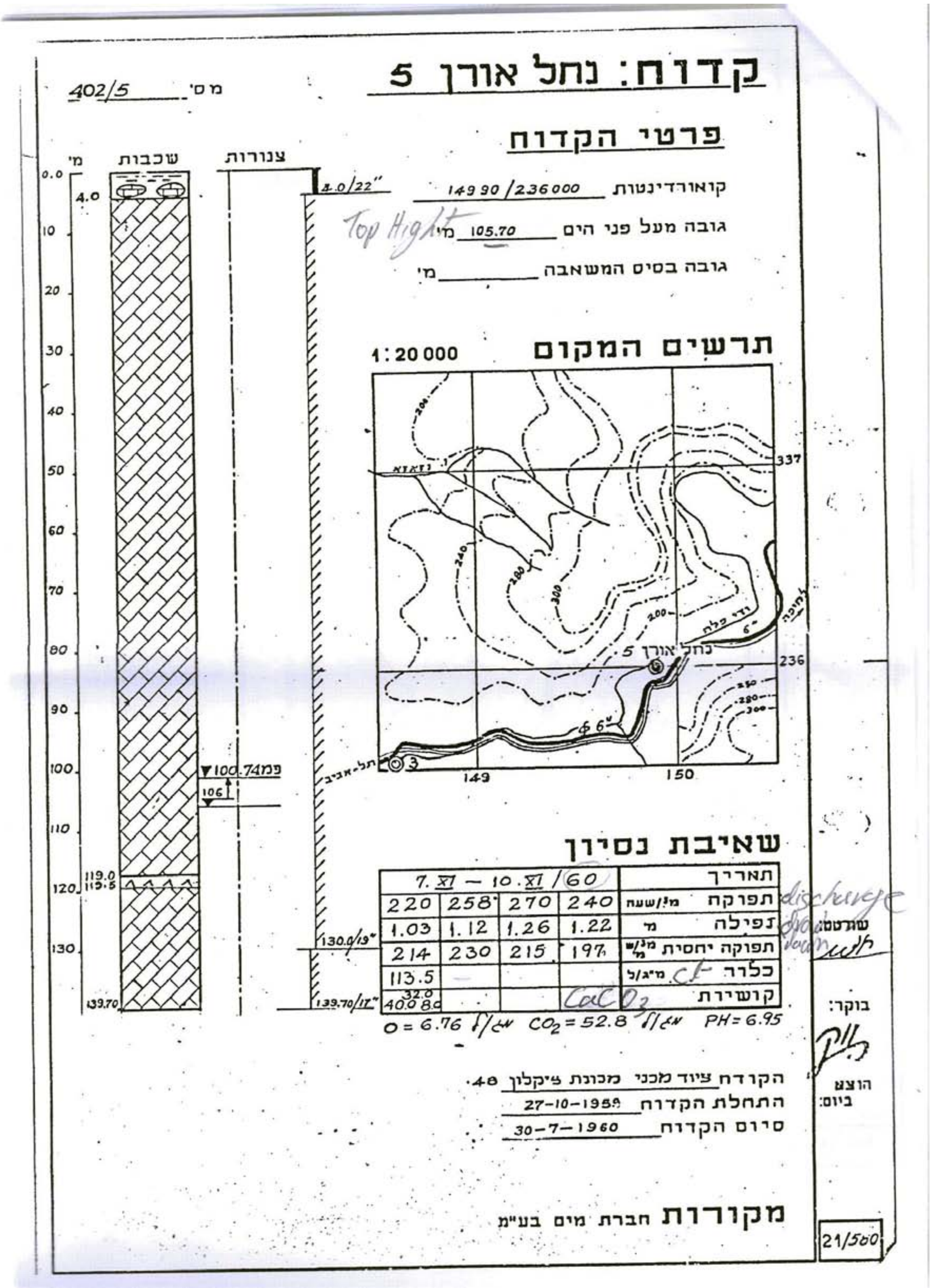

Figure 6: Drilling Log of Nahal Oren 5

Obtained Data

Table 1: Obtained Data during the Measurement campaign and from chemical analysis: Temperature, pH and electrical conductivity have been taken in the field, grey fields indicate malfunction of measurement equipment or doubtful data; Major Ions have been analysed by Field Service Lab, Neve Yaa'r, empty fields indicate not analysed ions.

Table 2: Static Water Levels from the Nahal Oren wells have been taken manually using an electric line, and are calculated from the aperture and the height of the measurement point; red entries indicate arguable values due to problems with measurement equipment or measurements influenced by the present oil layer.

Table 3: Data obtained at the Institute of Hydrology, Freiburg: Electrical Conductivity has been rechecked, Major Ions have been analysed using a *Dionex Systems* Ion Chromatograph, Fluorescentic Dyes have been detected by a *Perkin Elmer* Spectrofluorimeter. Grey fields indicate problems in acquisition, dark grey fields indicate samples where Uranine was not used during the experiment, orange highlighted fields indicate doubtful values and potential outliers.

Table 1

Location	Date/Time	Sample ID	pH	EC [µS/cm]	Tempe-rature [°C]	HCO3 [meq/l]	SO4 [mg/l]	NO3 [mg/l]	Cl [mg/l]	Mg [meq/l]	Ca [meq/l]	Na [meq/l]	K [meq/l]
			in situ			Field Service Lab, Neve Yaa'r							
Nahal Oren 1	10.02.2006 16:50	A-112	7.4	1290	21.2	6.6	46.7	4.7	231.1	2.7	6.1	4.7	0.08
Nahal Oren 1	11.02.2006 06:15	YW1.1	7.6	1260	18.1		47.8	4.9	223.3	2.4	6.3		
Nahal Oren 1	11.02.2006 16:50	A-117	7.5	1294	21.1		46.1	4.8	221.9	3.4	5.5		
Nahal Oren 1	12.02.2006 16:25	NO35		1266	20.9		27.7	4.6	221.9	3.5	5.7		
Nahal Oren 1	13.02.2006 06:05	YW1.3	7.8	1372	20.2	6.6	40.8	5.2	211.2	3.0	6.0	4.2	0.08
Nahal Oren 1	13.02.2006 16:25	NO38	7.8	1350	21.0		44.7	4.7	240.0	3.7	6.1		
Nahal Oren 1	14.02.2006 16:30	NO44	7.5	1370	21.1		44.7	4.7	231.1	3.7	5.4		
Nahal Oren 1	15.02.2006 06:25	NO47		1287	20.6		44.5	4.7	221.9	3.8	5.4		
Nahal Oren 1	15.02.2006 17:00	NO50	7.7	1273	20.3		23.6	4.8	243.2	3.7	5.6		
Nahal Oren 1	16.02.2006 05:25	NO53	7.4	1267	20.6				232.5	3.6	5.7		
Nahal Oren 1	16.02.2006 15:30	NO56	7.4						221.9	4.0	5.5		
Nahal Oren 1	17.02.2006 15:30	YW1.5	7.3	1270	22.0				240.0	2.6	6.8		
Nahal Oren 1	18.02.2006 16:25	NO59	7.3	1368	20.8				226.5	3.8	5.5		
Nahal Oren 1	19.02.2006 15:30	NO62	6.9	1366	20.4				281.2	3.5	5.8		
Nahal Oren 1	20.02.2006 05:30	NO65	7.1	1351	19.9				217.3	3.7	5.6		
Nahal Oren 1	21.02.2006 05:40	YW1.6		1350	20.6				221.9	2.8	6.3		
Nahal Oren 1	22.02.2006 05:30	NO67		1355	20.3				226.5	3.2	5.7		
Nahal Oren 1	23.02.2006 05:45	YW1.7	6.7	1340	19.8				227.9	2.8	6.4		
Nahal Oren 1	24.02.2006 05:55	A-124		1195	19.6				231.1	4.0	5.5		
Nahal Oren 1	25.02.2006 07:35	A-129		1364	20.3				218.7	3.7	5.4		
Nahal Oren 1	27.02.2006 05:40	YW1.8		1345	20.0				224.7	2.5	6.3		
Nahal Oren 1	01.03.2006 05:50	NO69	8.0	1329	20.1				223.3	3.1	5.4		
Nahal Oren 1	03.03.2006 16:45	A-140	7.0	1324	21.2				202.4	3.8	5.5		
Nahal Oren 1	06.03.2006 05:30	NO72	7.2	1237	19.8				291.8	0.3	8.2		
Nahal Oren 1	08.03.2006 05:25	NO74	6.7	1292	20.6				259.9	1.8	7.3		
Nahal Oren 1	11.03.2006 09:20	A-148	7.1	1326	20.3				209.5	4.2	5.5		
Nahal Oren 1	15.03.2006 05:45	YW1.10	7.1	1358	20.0				205.9	4.1	5.4		
Nahal Oren 1	18.03.2006 00:00	A-167		1213					227.2	3.5	5.3		
Nahal Oren 1	22.03.2006 16:30	NO77	7.1	1227	21.6				205.9	3.0	5.9		
Nahal Oren 1	25.04.2006 00:30	Y241	7.0	1285	20.8				220.1	4.4	5.5		
Nahal Oren 3	25.01.2006 10:15	OW3											
Nahal Oren 3	26.01.2006 16:00	NO1		1149	20.9	6.4	32.0	5.2	209.5	3.7	5.3	5.0	0.08
Nahal Oren 3	27.01.2006 06:45	YW3.1		1185	18.4		43.1	5.2	213.0	3.9	5.4		
Nahal Oren 3	27.01.2006 19:00	NO6		1193	18.7		42.6	5.2	220.1	3.8	5.2		
Nahal Oren 3	28.01.2006 17:30	NO8		1179	18.8		40.2	5.2	209.5	3.9	5.0		
Nahal Oren 3	29.01.2006 06:00	YW3.2		1160	18.3		47.4	5.2	216.6	4.0	5.2		
Nahal Oren 3	29.01.2006 16:40	NO12		1306	19.7	6.6	39.7	5.3	213.0	3.5	5.0	4.8	0.08
Nahal Oren 3	30.01.2006 05:45	YW3.3	7.5	1312	18.6		45.3	5.2	220.1	3.7	5.1		
Nahal Oren 3	30.01.2006 16:40	YW3.4					32.8	5.2	213.0	3.6	5.1		
Nahal Oren 3	31.01.2006 16:45	NO16		1280	21.5		43.6	5.3	237.9	3.1	5.2		
Nahal Oren 3	01.02.2006 05:40	NO18		1282	20.3		40.7	5.3	223.7	3.6	5.5		
Nahal Oren 3	01.02.2006 16:55	NO20		1334	21.3		36.4	5.2	227.2	3.3	5.5		
Nahal Oren 3	02.02.2006 05:35	NO22		1342	20.0		44.9	5.3	227.2	3.8	5.5		
Nahal Oren 3	02.02.2006 15:30	NO24	7.0	1338	20.8		45.2	5.3	227.2	4.6	5.0		
Nahal Oren 3	03.02.2006 15:30	A-87	8.2	1345	20.4		41.2	5.2	234.3	3.9	5.3		
Nahal Oren 3	04.02.2006 15:55	A-92	9.0	1353	21.2		34.5	5.3	216.6	3.4	5.7		
Nahal Oren 3	05.02.2006 15:35	NO26		1346	21.3		40.4	5.2	216.6	3.3	4.9		
Nahal Oren 3	06.02.2006 15:35	NO28		1350	21.3		43.2	5.3	209.5	3.9	4.8		
Nahal Oren 3	08.02.2006 16:20	NO32		1270	20.0	6.6	36.7	5.2	218.7	4.0	5.4	4.4	0.08
Nahal Oren 3	09.02.2006 13:35	NO34		1267	19.6		41.5	5.2	217.3	3.1	5.3		
Nahal Oren 3	10.02.2006 06:30	A-96	7.5	1257	19.3		45.3	5.6	215.8	3.2	6.0		
Nahal Oren 3	10.02.2006 17:10	A-114	7.5	1249	20.4		36.4	5.3	212.6	3.0	5.4		
Nahal Oren 3	11.02.2006 06:30	YW3.6		1245	19.5		36.4	5.3	220.5	2.4	6.2		
Nahal Oren 3	11.02.2006 16:55	A-118	7.6	1262	21.0		41.5	6.4	227.9	3.2	5.4		
Nahal Oren 3	12.02.2006 07:15	YW3.7		1275	19.5		30.0	5.3	220.5	2.7	6.2		
Nahal Oren 3	12.02.2006 16:35	NO36		1250	21.0		31.2	5.3	215.8	3.7	5.3		
Nahal Oren 3	13.02.2006 06:10	YW3.8	7.9	1310	20.2				226.5	2.5	6.4		
Nahal Oren 3	13.02.2006 16:50	NO40	8.0	1316	20.1				226.5	3.6	5.2		
Nahal Oren 3	14.02.2006 05:30	NO41	7.7	1331	19.7				226.5	4.1	5.3		
Nahal Oren 3	14.02.2006 16:55	NO46	7.4						218.7	4.3	5.1		
Nahal Oren 3	15.02.2006 06:50	NO49		1230	19.5				214.1	2.9	5.3		
Nahal Oren 3	15.02.2006 17:05	NO51	7.5	1242	20.0				224.7	3.9	5.4		
Nahal Oren 3	16.02.2006 05:55	NO55	7.7	1213	19.5				218.7	2.9	6.0		
Nahal Oren 3	16.02.2006 15:40	NO57	7.4						209.8	3.7	5.3		
Nahal Oren 3	17.02.2006 15:50	YW3.9	7.4	1260	21.0				221.9	2.6	6.3		
Nahal Oren 3	18.02.2006 16:35	NO60	7.4	1348	20.3				229.3	3.5	5.2		
Nahal Oren 3	19.02.2006 15:40	NO63	7.0	1331	20.3				221.9	3.7	5.4		
Nahal Oren 3	20.02.2006 05:45	NO66	7.1	1323	17.8				224.7	3.5	5.5		
Nahal Oren 3	21.02.2006 05:55	YW3.10		1360	20.0				241.8	2.0	6.8		
Nahal Oren 3	22.02.2006 05:55	NO68		1337	19.3				218.7	3.3	5.6		
Nahal Oren 3	23.02.2006 05:55	YW3.11	6.8	1320	19.3				214.1	2.9	6.0		

Location	Date/Time	Sample ID	pH	EC [µS/cm]	Tempe-rature [°C]	HCO3 [meq/l]	SO4 [mg/l]	NO3 [mg/l]	Cl [mg/l]	Mg [meq/l]	Ca [meq/l]	Na [meq/l]	K [meq/l]
			in situ			Field Service Lab, Neve Yaa'r							
Nahal Oren 3	24.02.2006 06:00	A-125		1313	19.0				218.7	3.7	5.3		
Nahal Oren 3	25.02.2006 07:50	A-130		1336	20.1				212.6	3.5	5.3		
Nahal Oren 3	27.02.2006 05:50	YW3.12		1325	19.5				214.1	2.5	6.0		
Nahal Oren 3	01.03.2006 06:15	NO71	7.9	1316	19.1				227.9	2.5	6.4		
Nahal Oren 3	03.03.2006 16:35	A-139	7.1	1281	21.0				205.9	3.1	5.5		
Nahal Oren 3	06.03.2006 05:55	NO73		1268	18.6				224.7	2.1	6.3		
Nahal Oren 3	08.03.2006 05:50	NO76	6.7	1320	20.3				233.9	2.5	6.6		
Nahal Oren 3	15.03.2006 05:55	YW3.15	7.2	1288	19.6				198.8	3.7	5.1		
Nahal Oren 3	18.03.2006 00:00	A-168		1170					198.8	4.2	5.0		
Nahal Oren 3	22.03.2006 16:45	NO79	7.1	1210	20.6				198.8	4.0	5.1		
Nahal Oren 3	25.04.2006 00:50	A244		1235	19.8				202.4	3.7	5.3		
Nahal Oren 4	08.02.2006 16:10	NO31		1156	20.3	6.6	39.4	4.6	186.7	3.4	5.4	3.8	0.08
Nahal Oren 4	09.02.2006 13:25	NO33		1170	19.9		20.3	4.6	189.9	3.4	5.5		
Nahal Oren 4	10.02.2006 07:00	A-97	7.4	1151	20.3		30.1	4.6	182.5	4.3	5.2		
Nahal Oren 4	10.02.2006 16:55	A-113	7.4	1142	21.2		38.6	4.8	121.6	3.8	5.1		
Nahal Oren 4	11.02.2006 05:55	YW4.1	7.7	1160	19.4				195.3	3.8	5.2		
Nahal Oren 4	11.02.2006 16:40	A-116	7.5	1141	21.8		38.6	4.7	194.5	3.7	5.3		
Nahal Oren 4	12.02.2006 06:55	YW4.2	7.7	1190	19.8		38.6	4.6	194.5	3.0	5.5		
Nahal Oren 4	12.02.2006 16:45	NO37		1152	21.1		33.5	4.6	185.3	3.0	5.4		
Nahal Oren 4	13.02.2006 16:40	NO39	7.8	1219	20.7	6.6	39.8	4.9	185.3	4.1	5.4	3.7	0.08
Nahal Oren 4	14.02.2006 05:40	NO42	7.5	1221	19.9		35.9	4.5	191.3	2.9	5.6		
Nahal Oren 4	14.02.2006 16:45	NO45	7.4	1214	20.8		30.4	4.5	185.3	3.3	5.1		
Nahal Oren 4	15.02.2006 06:40	NO48		1140	20.1				185.3	3.5	5.4		
Nahal Oren 4	15.02.2006 17:20	NO52		1151	19.5				179.3	2.7	5.3		
Nahal Oren 4	16.02.2006 05:40	NO54	7.5	1127	20.1				196.0	3.4	5.1		
Nahal Oren 4	16.02.2006 15:45	NO58	7.4	1125	20.7				191.3	3.5	5.0		
Nahal Oren 4	17.02.2006 15:40	YW4.5	7.6	1150	21.4				194.5	3.4	5.1		
Nahal Oren 4	18.02.2006 16:45	NO61	7.4	1314	20.0				180.7	3.0	5.4		
Nahal Oren 4	19.02.2006 15:50	NO64	6.9	1213	20.4				183.9	3.2	5.5		
Nahal Oren 4	21.02.2006 05:50	YW4.6		1230	19.9				194.5	3.7	5.1		
Nahal Oren 4	23.02.2006 05:50	YW4.7	6.7	1210	18.8				189.9	3.1	5.3		
Nahal Oren 4	27.02.2006 08:25	YW4.8	7.6	1230	20.6				183.9	3.0	5.0		
Nahal Oren 4	01.03.2006 06:00	NO70	7.9	1211	19.4				176.1	3.6	5.0		
Nahal Oren 4	08.03.2006 05:40	NO75	6.8	1208	20.6				183.9	3.5	5.2		
Nahal Oren 4	11.03.2006 09:05	A-147	7.1	1195	21.1				166.9	3.4	5.5		
Nahal Oren 4	15.03.2006 05:50	YW4.10	7.3	1220	20.3								
Nahal Oren 4	18.03.2006 00:00	A-169		1089					174.0	3.8	4.9		
Nahal Oren 4	22.03.2006 16:35	NO78	7.2	1098	21.2				181.1	3.5	5.2		
Nahal Oren 4	25.04.2006 00:55	Y242	7.0	1148	19.9				174	3.8	5.2		
Nahal Oren 5	25.01.2006 00:00	OW5											
Nahal Oren 5	26.01.2006 16:15	NO2		1190	20.7	6.4	44.0	5.6	223.7	2.9	5.8	5.0	0.08
Nahal Oren 5	27.01.2006 06:55	YW5.1		1230	19.3		49.8	5.6	230.8	3.3	5.5		
Nahal Oren 5	27.01.2006 18:45	NO5		1207	19.2		48.7	5.6	213.0	3.8	5.2		
Nahal Oren 5	28.01.2006 17:50	NO9		1200	18.4		48.9	5.6	220.1	3.1	5.4		
Nahal Oren 5	29.01.2006 06:00	YW5.2		1223	18.9		48.2	5.7	230.8	3.5	5.8		
Nahal Oren 5	29.01.2006 16:55	NO13		1332	19.5	6.6	51.1	5.7	216.6	4.3	5.2	5.0	0.08
Nahal Oren 5	30.01.2006 05:55	YW5.3	7.5	1340	18.9		48.3	5.7	230.8	3.0	5.6		
Nahal Oren 5	30.01.2006 16:55	YW5.4					49.4	5.8	227.2	2.4	6.2		
Nahal Oren 5	31.01.2006 16:55	NO17		1304	21.2		47.2	5.7	223.7	3.5	5.4		
Nahal Oren 5	01.02.2006 05:55	NO19		1323	20.2		50.2	5.6	227.2	4.9	5.7		
Nahal Oren 5	01.02.2006 17:05	NO21		1370	20.6		53.0	5.6	227.2	4.1	5.9		
Nahal Oren 5	02.02.2006 05:50	NO23		1390	19.8		53.3	5.7	234.3	3.9	5.3		
Nahal Oren 5	02.02.2006 15:40	NO25	7.0	1389	20.3		47.8	5.6	223.7	3.5	5.9		
Nahal Oren 5	04.02.2006 13:40	A-93	8.8	1375	20.7		45.4	5.7	220.1	3.5	5.7		
Nahal Oren 5	05.02.2006 15:50	NO27		1361	20.1		44.9	5.7	223.7	2.8	5.4		
Nahal Oren 5	06.02.2006 15:50	NO29		1365	20.0		50.2	5.7	220.1	3.5	5.4		
Nahal Oren 5	07.02.2006 15:50	NO30		1296	20.0		48.9	5.7	220.1	3.8	5.4		
Nahal Oren 5	10.02.2006 06:15	A-94	7.5	1256	19.8	6.4	47.3	5.6	218.7	4.0	5.5	4.2	0.07
Nahal Oren 5	14.02.2006 05:55	NO43	7.6	1360	19.8	6.6	49.4	5.6	237.1	3.3	5.6	4.4	0.08
Nahal Oren 5		YW5.5							195.3	3.6	5.5		
Nahal Oren 5	25.04.2006 00:55	Y243	7.0	1320	20.2				230.8	3.6	6.0		
Runoff Oren 3	26.01.2006 10:35	S2		345	14.8	3.6	0.0	0.2	53.3	1.5	2.7	0.5	0.08
Runoff Oren 3	26.01.2006 15:45	S3		260	14.5		0.3	0.8	63.9	1.2	2.0		
Runoff Oren 3	27.01.2006 06:45	YS3		326	11.6		17.2	1.4	42.6	1.4	2.2		
Runoff Oren 3	27.01.2006 19:00	S8		366	12.3		6.7	0.8	35.5	1.0	2.7		
Runoff Oren 3	09.02.2006 12:45	S10		455	13.0		2.7	1.4	42.6	4.1	1.2		
Runoff Oren 3	10.02.2006 07:30	A-99	8.5	348	12.1		9.6	8.0	34.8	1.4	2.3		
Runoff Oren 4	09.02.2006 13:15	S11		308	11.0	3.0	11.0	1.5	42.6	1.8	1.2	0.5	0.09
Runoff Oren 4	10.02.2006 07:15	A-98	8.7	377	11.9		22.4	1.5	51.8	0.7	2.7		
Runoff Oren 4	10.02.2006 16:30	A-111	7.8	488	14.2		20.8	0.4	33.4	0.7	3.6		
Runoff Oren 4	15.02.2006 17:15	S12		433	11.5		31.2	1.1	30.5	2.8	0.9		
Runoff Oren 4	16.02.2006 05:40	S13		348	11.5		19.9	1.0	44.0	2.1	1.2		
Runoff Oren 4	16.02.2006 14:50	S14		429	11.7		28.8	1.2	44.0	2.2	1.2		
Runoff Oren 4	17.02.2006 09:00	SB	8.2	620	10.2		36.6	2.9	56.1	2.1	1.6		
Runoff Oren 5	26.01.2006 10:25	S1		308	15.5	3.4	10.6	1.3	46.2	1.3	2.5	0.6	0.08
Runoff Oren 5	26.01.2006 16:20	S4		260	13.6		0.0	0.9	49.7	1.4	2.2		
Runoff Oren 5	27.01.2006 06:45	YS4		341	11.0		10.7	1.5	42.6	1.6	2.4		
Runoff Oren 5	27.01.2006 18:35	S7		346	11.8		16.1	1.2	28.4	1.5	2.4		
Runoff Oren 5	09.02.2006 12:30	S9		403	10.8		14.6	2.3	51.8	3.0	1.5		
Runoff Oren 5	10.02.2006 06:20	A-95	8.7	332	11.7		7.8	1.4	48.6	1.5	2.3		

Table 2

Date/Time	**Nahal Oren 1** Measuring Point: 48.56 masl		**Nahal Oren 2** Measuring Point: 55.09 masl		**Nahal Oren 3** Measuring Point: 60.66 masl		**Nahal Oren 4** Measuring Point: 66.22 masl		**Nahal Oren 5** Measuring Point: 109.58 masl	
	Aperture [m]	Water Level [masl]	Aperture [m]	Water Level [masl]	Aperture [m]	Water Level [masl]	Aperture [m]	Water Level [masl]	Aperture [m]	Water Level [masl]
09.01.2006	44.40	4.16	59.25	-4.16	57.65	3.01	61.68	4.54	106.95	2.63
10.01.2006										
11.01.2006										
12.01.2006										
13.01.2006										
14.01.2006										
15.01.2006										
16.01.2006	44.45	4.11	59.22	-4.13	57.09	3.57			107.20	2.38
17.01.2006										
18.01.2006	44.65	3.91	59.15	-4.06	57.12	3.54	62.23	3.99	107.00	2.58
19.01.2006										
20.01.2006										
21.01.2006										
22.01.2006							62.03	4.19		
23.01.2006										
24.01.2006	44.57	3.99	59.16	-4.07	57.13	3.53	62.19	4.03	106.85	2.73
25.01.2006										
26.01.2006			59.15	-4.06			62.26	3.96		
27.01.2006			59.09	-4.00						
28.01.2006			59.08	-3.99	57.14	3.52			106.85	2.73
29.01.2006	44.50	4.06	59.08	-3.99	57.14	3.52	62.12	4.10	106.81	2.77
30.01.2006	44.42	4.14	59.10	-4.01	57.12	3.54			106.18	3.40
31.01.2006	44.48	4.08	59.05	-3.96	57.17	3.49	62.08	4.14	106.83	2.75
01.02.2006	44.48	4.08	59.04	-3.95	57.15	3.51	62.09	4.13	106.84	2.74
02.02.2006	44.46	4.10	59.01	-3.92	57.12	3.54	62.17	4.05	106.85	2.73
03.02.2006	44.47	4.09	59.04	-3.95	57.15	3.51	62.08	4.14	106.52	3.06
04.02.2006	44.49	4.07	59.05	-3.96	57.22	3.44	62.13	4.09	106.89	2.69
05.02.2006	44.51	4.05	59.04	-3.95	57.19	3.47	62.09	4.13	106.91	2.67
06.02.2006	44.47	4.09	59.04	-3.95			62.09	4.13		
07.02.2006	44.49	4.07	59.02	-3.93	57.17	3.49	62.10	4.12	107.05	2.53
08.02.2006										
09.02.2006	44.53	4.03	59.09	-4.00	57.23	3.43			107.08	2.50
10.02.2006	44.51	4.05	59.05	-3.96	58.21	2.45	62.11	4.11		
11.02.2006	44.47	4.09	59.03	-3.94	57.21	3.45	62.03	4.19		
12.02.2006	44.45	4.11	59.01	-3.92	57.18	3.48	62.06	4.16	106.81	2.77
13.02.2006	44.46	4.10	59.01	-3.92	57.17	3.49	62.06	4.16	106.88	2.70
14.02.2006	44.43	4.13	59.02	-3.93	57.17	3.49	62.05	4.17	106.94	2.64
15.02.2006	44.45	4.11	59.03	-3.94	57.15	3.51	62.07	4.15	106.97	2.61
16.02.2006	44.47	4.09	59.05	-3.96	57.17	3.49	62.09	4.13	106.82	2.76
17.02.2006	44.46	4.10	59.07	-3.98	57.13	3.53	62.14	4.08	106.92	2.66
18.02.2006	44.46	4.10	59.01	-3.92	57.15	3.51	62.07	4.15	106.97	2.61
19.02.2006	44.44	4.12	59.00	-3.91	57.14	3.52	62.04	4.18	106.87	2.71
20.02.2006										
21.02.2006	44.45	4.11	59.01	-3.92	57.09	3.57	62.05	4.17	106.79	2.79
22.02.2006	44.46	4.10	59.02	-3.93	57.17	3.49	62.04	4.18	106.96	2.62
23.02.2006	44.45	4.11	59.01	-3.92	57.15	3.51	62.05	4.17	107.00	2.58
24.02.2006	44.77	3.79	59.03	-3.94	57.21	3.45	62.06	4.16	106.99	2.59
25.02.2006	44.47	4.09	59.04	-3.95	57.17	3.49	62.07	4.15	107.02	2.56
26.02.2006										
27.02.2006	44.49	4.07	59.04	-3.95	57.21	3.45	62.07	4.15	106.93	2.65
28.02.2006										
01.03.2006	44.49	4.07	59.05	-3.96	57.22	3.44	62.07	4.15	106.84	2.74
02.03.2006										
03.03.2006										
04.03.2006										
05.03.2006										
06.03.2006	44.50	4.06	59.06	-3.97	57.23	3.43	62.10	4.12	106.89	2.69
07.03.2006										
08.03.2006	44.47	4.09			57.23	3.43	62.10	4.12		
09.03.2006										
10.03.2006										
11.03.2006	44.54	4.02			57.31	3.35	62.14	4.08	107.12	2.46
12.03.2006										
13.03.2006										
14.03.2006										
15.03.2006	44.52	4.04			57.32	3.34	62.14	4.08	106.75	2.83
16.03.2006										
17.03.2006										
18.03.2006										
19.03.2006										
20.03.2006	44.54	4.02			57.35	3.31	62.15	4.07	107.89	1.69
21.03.2006										
22.03.2006	44.56	4.00			57.32	3.34	62.18	4.04	107.35	2.23
23.03.2006										
24.03.2006										
25.03.2006										
26.03.2006										
27.03.2006	44.55	4.01					62.19	4.03	106.97	2.61

Table 3

Location	Date/Time	Sample ID	EC rechecked [µS/cm]	SO4 [mg/l]	NO3 [mg/l]	Cl [mg/l]	Mg [mg/l]	Ca [mg/l]	Na [mg/l]	K [mg/l]	Concentration Naphtionate [ppb]	Concentration Uranine [ppb]
			Institute of Hydrology, Freiburg									
Nahal Oren 1	10.02.2006 16:50	A-112	1406	36.72	21.36	210.48	39.39	102.54	104.85	4.95	3.45	-0.69
Nahal Oren 1	11.02.2006 06:15	YW1.1	1421	36.90	21.15	214.74	40.59	103.80	110.22	5.22	-0.02	-0.77
Nahal Oren 1	11.02.2006 16:50	A-117	1406	37.65	21.03	217.98	39.90	123.30	104.91	5.31	3.13	-0.73
Nahal Oren 1	12.02.2006 16:25	NO35	1383	35.85	20.40	209.34	39.42	103.47	101.40	5.52	2.18	-0.65
Nahal Oren 1	13.02.2006 06:05	YW1.3	1342	33.45	22.89	199.95	40.20	95.19	99.96	5.37	2.27	-0.72
Nahal Oren 1	13.02.2006 16:25	NO38	1386	37.56	0.45	215.55	39.90	124.62	104.82	5.31	2.14	-0.74
Nahal Oren 1	14.02.2006 16:30	NO44	1397	37.02	20.13	210.87	40.08	123.96	104.31	4.50	2.38	-0.73
Nahal Oren 1	15.02.2006 06:25	NO47	1397	38.46	22.14	216.30	37.53	107.76	104.76	4.62	2.06	-0.75
Nahal Oren 1	15.02.2006 17:00	NO50	1386	37.02	21.18	213.93	40.26	100.35	104.70	4.83	2.76	-0.56
Nahal Oren 1	16.02.2006 05:25	NO53	1400	36.54	20.52	209.28	39.06	103.47	103.05	3.81	2.50	-0.72
Nahal Oren 1	16.02.2006 15:30	NO56	1400	37.74	21.15	215.46	39.75	122.97	103.59	5.16	3.90	-0.30
Nahal Oren 1	17.02.2006 15:30	YW1.5	1399	35.79	20.79	206.76	39.72	122.07	103.86	5.07	2.79	-0.71
Nahal Oren 1	18.02.2006 16:25	NO59	broken									
Nahal Oren 1	19.02.2006 15:30	NO62	broken									
Nahal Oren 1	20.02.2006 05:30	NO65	1396	35.88	19.65	206.22	39.72	121.77	102.39	4.74	2.29	-0.70
Nahal Oren 1	21.02.2006 05:40	YW1.6	1394	36.66	20.55	209.61	40.20	111.18	104.94	5.55	2.65	-0.71
Nahal Oren 1	22.02.2006 05:30	NO67	1397	37.02	21.30	211.71	39.51	93.48	105.96	5.79	2.21	-0.75
Nahal Oren 1	23.02.2006 05:45	YW1.7	1394	36.42	21.24	209.01	39.57	99.90	103.89	5.79	4.14	-0.68
Nahal Oren 1	24.02.2006 05:55	A-124	1403	36.84	22.65	211.08	39.27	96.30	104.04	4.68	3.12	-0.26
Nahal Oren 1	25.02.2006 07:35	A-129	1403	37.17	21.33	211.05	39.63	89.19	105.21	5.76	2.54	-0.71
Nahal Oren 1	27.02.2006 05:40	YW1.8	1394	38.13	22.44	212.52	40.50	111.99	104.61	5.52	2.17	-0.76
Nahal Oren 1	01.03.2006 05:50	NO69	1389	36.06	23.25	206.49	38.61	103.65	102.12	4.17	2.52	-0.62
Nahal Oren 1	03.03.2006 16:45	A-140	1032	36.87	22.02	212.40	40.71	40.02	105.54	4.59	3.18	-0.73
Nahal Oren 1	06.03.2006 05:30	NO72	1377	35.43	19.74	205.71	39.51	99.78	104.04	5.61	2.33	-0.54
Nahal Oren 1	08.03.2006 05:25	NO74	1389	35.43	20.61	206.07	39.03	93.63	102.18	7.92	2.47	-0.66
Nahal Oren 1	11.03.2006 09:20	A-148	1378	39.63	20.55	207.03	39.06	98.19	102.81	5.25	2.23	-0.74
Nahal Oren 1	15.03.2006 05:45	YW1.10	1391	35.97	20.88	205.59	40.20	124.26	104.52	4.83	3.86	-0.51
Nahal Oren 1	22.03.2006 16:30	NO77	1389	35.52	21.18	205.38	38.37	105.45	100.56	4.59	3.24	-0.68
Nahal Oren 3	25.01.2006 10:15	OW3	1353	33.63	22.44	201.45	43.80	122.34	105.00	4.68	2.61	
Nahal Oren 3	26.01.2006 16:00	NO1	1350	33.36	22.35	200.49	41.67	118.44	102.42	3.69	2.92	
Nahal Oren 3	27.01.2006 06:45	YW3.1	1356	34.71	23.22	207.39	39.66	115.32	98.70	3.45	0.31	
Nahal Oren 3	27.01.2006 19:00	NO6	1356	33.39	22.80	202.68	39.27	113.97	97.74	3.30	1.19	
Nahal Oren 3	28.01.2006 17:30	NO8	1357	33.00	22.14	198.12	39.75	116.22	98.91	3.45	0.28	
Nahal Oren 3	29.01.2006 06:00	YW3.2	1354	34.05	22.95	204.51	43.35	121.98	103.53	4.44	0.32	
Nahal Oren 3	29.01.2006 16:40	NO12	1355	34.11	22.83	205.11	40.41	103.32	102.21	5.40	0.34	
Nahal Oren 3	30.01.2006 05:45	YW3.3	1356	34.32	22.95	205.65	40.20	116.85	101.22	4.86	0.30	
Nahal Oren 3	30.01.2006 16:40	YW3.4	1357	34.38	22.89	205.38	39.57	115.08	98.49	3.12	0.41	
Nahal Oren 3	31.01.2006 16:45	NO16	1355	34.38	23.19	205.83	39.30	114.33	96.93	3.45	0.50	
Nahal Oren 3	01.02.2006 05:40	NO18	1360	34.62	23.40	208.35	39.72	115.95	101.94	3.96	0.40	
Nahal Oren 3	01.02.2006 16:55	NO20	1364	34.14	22.74	205.23	38.85	112.41	98.28	4.14		
Nahal Oren 3	02.02.2006 05:35	NO22	1366	34.71	23.25	208.71	38.49	113.55	98.85	3.78	1.27	
Nahal Oren 3	02.02.2006 15:30	NO24	1380	20.94	14.04	131.94	39.51	114.99	101.97	6.00	2.75	
Nahal Oren 3	03.02.2006 15:30	A-87	1361	33.57	22.56	204.03	40.29	98.85	101.49	5.22	1.30	-0.68
Nahal Oren 3	04.02.2006 15:55	A-92	1359	33.66	22.59	203.16	39.45	89.91	97.53	4.29	0.59	-0.77
Nahal Oren 3	05.02.2006 15:35	NO26	1356	33.78	22.86	204.60	39.45	115.23	99.15	3.84	2.80	
Nahal Oren 3	06.02.2006 15:35	NO28	1351	33.87	22.62	203.43	38.82	112.68	97.20	3.69		
Nahal Oren 3	08.02.2006 16:20	NO32	1361	33.96	22.50	203.82	39.96	116.70	100.68	4.35	1.62	
Nahal Oren 3	09.02.2006 13:35	NO34	1355	33.42	22.47	201.09	40.68	103.11	99.06	5.13	0.93	-0.75
Nahal Oren 3	10.02.2006 06:30	A-96	1370	38.16	24.45	206.22	37.98	96.51	97.95	4.89	3.38	-0.73
Nahal Oren 3	10.02.2006 17:10	A-114	1348	34.98	24.24	205.44	225.60	236.61	234.93	240.18	0.73	-0.75
Nahal Oren 3	11.02.2006 06:30	YW3.6	broken									
Nahal Oren 3	11.02.2006 16:55	A-118	1293	34.26	29.97	205.02	39.63	85.53	99.66	4.29	0.95	-0.74
Nahal Oren 3	12.02.2006 07:15	YW3.7	1356	34.17	22.71	204.60	40.56	118.08	98.52	4.95	0.89	-0.75
Nahal Oren 3	12.02.2006 16:35	NO36	1353	33.57	23.31	203.25	38.10	92.13	98.28	4.26	1.50	-0.75
Nahal Oren 3	13.02.2006 06:10	YW3.8	1404	36.96	20.82	212.01	39.72	118.23	104.40	5.07	2.50	-0.74
Nahal Oren 3	13.02.2006 16:50	NO40	1348	34.17	23.01	206.07	39.93	118.53	100.47	5.07	1.01	-0.74

Location	Date/Time	Sample ID	EC rechecked [µS/cm]	SO4 [mg/l]	NO3 [mg/l]	Cl [mg/l]	Mg [mg/l]	Ca [mg/l]	Na [mg/l]	K [mg/l]	Concentration Naphtionate [ppb]	Concentration Uranine [ppb]
			Institute of Hydrology, Freiburg									
Nahal Oren 3	14.02.2006 05:30	NO41	1349	33.60	23.79	202.62	39.30	89.31	99.81	5.49	1.93	-0.75
Nahal Oren 3	14.02.2006 16:55	NO46	broken									
Nahal Oren 3	15.02.2006 06:50	NO49	1351	33.87	23.37	202.62	39.96	97.71	99.63	4.98	2.74	-0.60
Nahal Oren 3	15.02.2006 17:05	NO51	1370	35.19	23.40	212.79	40.20	99.45	102.63	4.53	0.88	-0.75
Nahal Oren 3	16.02.2006 05:55	NO55	1366	36.00	0.27	216.84	39.96	100.95	101.01	5.52	0.69	-0.75
Nahal Oren 3	16.02.2006 15:40	NO57	1370	34.62	22.89	208.74	40.77	116.19	100.86	5.04	0.85	-0.76
Nahal Oren 3	17.02.2006 15:50	YW3.9	1368	34.11	22.95	206.13	39.81	92.22	101.22	4.80	0.65	-0.75
Nahal Oren 3	18.02.2006 16:35	NO60	1341	33.81	22.44	203.91	39.84	91.53	98.37	5.07	0.34	-0.77
Nahal Oren 3	19.02.2006 15:40	NO63	broken									
Nahal Oren 3	20.02.2006 05:45	NO66	1364	34.05	25.62	205.23	39.39	96.87	99.96	5.73	0.60	-0.77
Nahal Oren 3	21.02.2006 05:55	YW3.10	1358	34.14	22.74	204.33	40.65	115.47	100.32	6.18	5.70	-0.25
Nahal Oren 3	22.02.2006 05:55	NO68	1355	35.13	0.39	211.62	40.98	105.90	101.73	5.46	0.90	-0.76
Nahal Oren 3	23.02.2006 05:55	YW3.11	1367	34.35	23.25	206.88	39.93	100.47	99.27	4.05	0.69	-0.77
Nahal Oren 3	24.02.2006 06:00	A-125	1356	35.97	25.68	215.31	39.78	102.06	99.99	4.89	0.77	-0.75
Nahal Oren 3	25.02.2006 07:50	A-130	1362	34.41	22.89	207.18	41.22	103.41	100.44	5.73	0.63	-0.76
Nahal Oren 3	27.02.2006 05:50	YW3.12	1342	33.45	22.14	200.82	40.53	90.15	100.89	4.74	1.17	-0.74
Nahal Oren 3	01.03.2006 06:15	NO71	1356	34.44	23.64	206.19	39.87	98.37	102.54	4.50	0.50	-0.76
Nahal Oren 3	03.03.2006 16:35	A-139	1351	33.30	22.62	199.14	40.65	97.80	99.90	5.22	0.71	-0.75
Nahal Oren 3	06.03.2006 05:55	NO73	1694	33.63	23.82	298.80	40.02	117.96	100.44	103.77	3.78	-0.44
Nahal Oren 3	08.03.2006 05:50	NO76	1329	33.51	22.86	201.57	40.08	88.20	99.57	5.31	0.97	-0.73
Nahal Oren 3	15.03.2006 05:55	YW3.15	1340	33.75	23.10	203.67	39.54	91.20	98.07	4.68	1.48	-0.73
Nahal Oren 3	22.03.2006 16:45	NO79	1349	33.66	23.13	201.84	39.09	85.17	98.94	4.68	0.97	-0.71
Nahal Oren 4	08.02.2006 16:10	NO31	1236	31.86	20.04	171.75	39.09	109.02	79.56	3.51		
Nahal Oren 4	09.02.2006 13:25	NO33	1233	32.22	20.52	172.89	40.26	113.46	80.85	3.93	2.62	
Nahal Oren 4	10.02.2006 07:00	A-97	1244	31.71	20.49	174.15	40.71	113.46	82.65	4.29	0.14	
Nahal Oren 4	10.02.2006 16:55	A-113	1243	31.95	20.19	175.35	40.41	108.33	81.54	3.93	0.34	
Nahal Oren 4	11.02.2006 05:55	YW4.1	1261	31.65	20.91	170.88	41.10	115.77	84.75	6.09	4.95	
Nahal Oren 4	11.02.2006 16:40	A-116	1243	31.95	19.92	172.62	40.44	114.78	83.28	4.62	0.44	
Nahal Oren 4	12.02.2006 06:55	YW4.2	1245	31.89	19.98	173.67	40.41	113.73	82.98	4.02	0.51	
Nahal Oren 4	12.02.2006 16:45	NO37	1234	31.65	19.59	170.91	40.95	114.21	82.86	4.50	1.92	
Nahal Oren 4	13.02.2006 16:40	NO39	1240	31.56	21.90	172.86	39.81	40.20	83.04	4.80	2.26	
Nahal Oren 4	14.02.2006 05:40	NO42	1239	31.86	19.98	173.58	41.28	114.99	82.89	4.65	2.09	
Nahal Oren 4	14.02.2006 16:45	NO45	1239	31.95	19.77	172.23	41.04	116.07	83.46	4.17	2.07	
Nahal Oren 4	15.02.2006 06:40	NO48	1236	31.80	19.89	173.43	40.89	113.79	81.21	3.93	1.86	
Nahal Oren 4	15.02.2006 17:20	NO52	1233	32.34	20.16	174.39	39.96	106.35	80.70	4.02	2.71	
Nahal Oren 4	16.02.2006 05:40	NO54	1240	33.15	21.09	178.35	39.75	114.09	80.73	4.38	2.09	
Nahal Oren 4	16.02.2006 15:45	NO58	1240	32.04	19.92	173.01	40.83	114.42	82.02	4.50	1.93	
Nahal Oren 4	17.02.2006 15:40	YW4.5	broken									
Nahal Oren 4	18.02.2006 16:45	NO61	1246	31.32	19.32	170.76	40.53	113.46	81.72	6.09	2.22	
Nahal Oren 4	19.02.2006 15:50	NO64	1236	33.09	22.08	175.59	41.22	115.98	83.70	4.89	1.94	
Nahal Oren 4	21.02.2006 05:50	YW4.6	1243	32.04	20.10	174.90	39.51	114.42	83.13	4.77	1.48	
Nahal Oren 4	23.02.2006 05:50	YW4.7	broken									
Nahal Oren 4	27.02.2006 08:25	YW4.8	1240	31.86	19.89	172.80	38.88	114.03	82.56	4.14	0.56	
Nahal Oren 4	01.03.2006 06:00	NO70	1150	32.58	20.94	175.98	39.87	98.37	102.54	4.50	2.41	
Nahal Oren 4	08.03.2006 05:40	NO75	1314	31.80	20.52	188.49	39.90	113.94	81.93	23.37	2.73	
Nahal Oren 4	11.03.2006 09:05	A-147	broken									
Nahal Oren 4	15.03.2006 05:50	YW4.10	1243	30.96	19.86	168.99	39.96	94.26	83.58	5.10	0.77	
Nahal Oren 4	18.03.2006 00:00	A-169	broken									
Nahal Oren 4	22.03.2006 16:35	NO78	1240	31.05	19.95	168.03	40.92	101.28	82.89	4.23	2.16	
Nahal Oren 5	25.01.2006 00:00	OW5	1387	40.17	25.53	217.65	38.22	119.07	97.14	4.47	3.24	
Nahal Oren 5	26.01.2006 16:15	NO2	1393	39.72	25.14	217.29	38.28	120.54	98.52	4.35	3.92	
Nahal Oren 5	27.01.2006 06:55	YW5.1	1388	39.12	24.81	213.12	38.58	121.08	96.87	3.69	35.41	
Nahal Oren 5	27.01.2006 18:45	NO5	1379	38.01	24.15	207.63	38.43	121.35	97.50	3.72	64.65	
Nahal Oren 5	28.01.2006 17:50	NO9	1380	38.61	24.87	208.77	38.46	120.78	96.09	3.33	115.12	
Nahal Oren 5	29.01.2006 06:00	YW5.2	1388	38.67	24.48	208.41	38.76	123.00	97.86	3.57	152.46	
Nahal Oren 5	29.01.2006 16:55	NO13	1386	38.94	24.60	213.18	40.86	80.82	102.30	5.04	2.99	
Nahal Oren 5	30.01.2006 05:55	YW5.3	1389	37.68	23.82	205.32	38.43	106.02	98.40	6.42	64.47	
Nahal Oren 5	30.01.2006 16:55	YW5.4	1394	39.30	24.54	212.43	39.09	121.53	97.86	3.93	4.35	
Nahal Oren 5	31.01.2006 16:55	NO17	1391	38.43	24.33	209.13	38.82	121.47	97.77	3.63	3.18	
Nahal Oren 5	01.02.2006 05:55	NO19	1411	40.32	25.17	219.36	39.93	124.11	99.48	3.54	2.97	
Nahal Oren 5	01.02.2006 17:05	NO21	1404	40.02	25.35	219.18	39.18	121.83	100.74	3.48	3.32	
Nahal Oren 5	02.02.2006 05:50	NO23	1407	39.30	24.48	212.88	39.36	122.16	99.69	3.54	2.92	
Nahal Oren 5	02.02.2006 15:40	NO25	1402	38.61	24.24	210.69	39.72	124.41	102.63	3.78	3.24	
Nahal Oren 5	04.02.2006 13:40	A-93	1393	39.24	25.74	212.73	40.29	110.13	100.68	4.74	4.39	
Nahal Oren 5	05.02.2006 15:50	NO27	1389	38.43	24.45	207.18	38.34	120.21	95.64	3.24	2.86	
Nahal Oren 5	06.02.2006 15:50	NO29	1390	38.91	24.78	211.05	38.10	120.75	94.05	2.67	3.11	
Nahal Oren 5	07.02.2006 15:50	NO30	1390	39.81	25.32	213.45	38.79	121.32	97.17	4.80	3.28	
Nahal Oren 5	10.02.2006 06:15	A-94	1378	39.21	25.05	212.79	39.42	123.72	96.42	4.71	3.69	
Nahal Oren 5	14.02.2006 05:55	NO43	1386	38.79	24.63	209.58	40.23	124.86	97.29	5.22	3.16	

Ehrenwörtliche Erklärung

Hiermit erkläre ich, dass ich die Arbeit selbständig und nur unter Verwendung der angegebenen Hilfsmittel angefertigt habe.

Ort, Datum, Unterschrift