Investigations of infiltration basins at the Vomb Water Plant – a study of possible causes of reduced infiltration capacity

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Contents

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Abstract: Artificial groundwater recharge is an important technology in water resources management and is nowadays one of the most common and rapidly spread world wide methods for increasing groundwater capacity. In many countries this technique has been employed for a long time, however in the others it is in progress. It has been used in Europe since the early 1900s, and is still a popular method municipal water supplies. The goal of this study was to give brief overview the mechanisms active in artificial recharge of groundwater and study different factors of reduced infiltration capacity in the Vomb Water Plant located in western Skåne in southern Sweden. The plant is owned and operated by Sydvatten that supplies large parts of the potable water for western Skåne. The focus was given on four infiltration basins, situated in different parts of this huge infiltration area to see if differences in the geology possibly could explain variations in the infiltration capacity. Two of them were selected whereas the sand had been removed (no. 13 and no. 211, called "new" basins) and replaced by washed sand to improve infiltration properties of the soils. However, the other two, where this procedure has not yet been required (no. 63 and no. 207, called "old" basins). Besides the selection of basins in different parts of the infiltration area samples from these basins have been subject to a range of various analyses: grain size and fine grain analysis to get the grain size distribution in the vertical profile of the filter material, spectrophotometer analysis to determine amount of iron, loss on ignition to get organic and inorganic carbon content. The obtained results indicate very homogenous sediments in the "new" and inhomogeneous in the "old" basins according to grain size analysis. Accumulation of fine grain material (less than 0.063 mm) is similar in "old" and "new" basins, especially the amount of clay (< 0.002 mm) occurs in value 30 %. Data of hydraulic conductivity display very small differences with depth. Anyhow, the content of organic and inorganic carbon is low and in all profiles does not show any clear patterns. The concentration of iron does not display any clear trends, as well.

Keywords: artificial groundwater recharge, infiltration basin, infiltration capacity, clogging, grain size analysis, effective diameter, iron content, organic and inorganic carbon content, hydraulic conductivity.

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Badania zbiorników infiltracyjnych terenu wodnego Vomb - oszacowanie przyczyn powodujących zmniejszoną pojemność infiltracyjną

URSZULA CZARNIECKA

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Abstract: Sztuczna infiltracja jest niezwykle ważną technologią stosowaną w zarządzaniu zasobami wodnymi. Jest jedną z najpopularniejszych i szybko rozprzestrzeniających się w zwiększeniu pojemności wsiąkającej wody podziemnej metod na świecie. W wielu krajach praktykowana jest już od dawna, zaś w innych jest dopiero powoli wdrażana. Powyższa technologia wykorzystywana była w Europie już od wczesnych lat 1900 i jest nadal najpopularniejszą metodą zaopatrywania w wodę ośrodki miejskie. Celem niniejszej pracy magisterskiej było przedstawienie aktywnych mechanizmów w sztucznym wzbogacaniu wody podziemnej oraz studiowanie różnych czynników powodujących zmniejszenie współczynnika infiltracji w poszczególnych zbiornikach infiltracyjnych. Badania obejmują teren wodny Vomb, którego właścicielem i operatorem jest firma Sydvatten. Sydvatten dostarcza ogromną część wody pitnej dla zachodniej Skåne, w południowej Szwecji. Niniejsza praca magisterska obejmuje cztery zbiorniki infiltracyjne, które mieszczą się w różnych częściach wielkiego terenu, by dowiedzieć się czy różnice podłoża geologicznego mogłyby wyjaśnić zmiany w pojemności infiltracyjnej. Dwa z nich zostały wyselekcjonowane na podstawie, gdzie materiał żwirowo-piaszczysty został usunięty (numer 13 i 211, zwane „nowymi" zbiornikami) i zastąpione „nowym", przemytym materiałem o tej samej genezie. Kolejne dwa zbiorniki, zwane „starymi" (numer 63 i 207), funkcjonują od samego początku, gdyż ta czynność nie była wymagana. W celu rozwiązania problemu z pojemnością infiltracyjną poszczególnych zbiorników, przeprowadzonych zostało wiele różnorodnych badań, takich jak: analiza sitowa i areometryczna do określenia składu granulometrycznego poszczególnych gruntów, analiza spektrometryczna, by określić zawartość żelaza w próbkach oraz oznaczenie zawartości substancji organicznej i nieorganicznej za pomocą strat prażenia. Uzyskane wyniki wskazują jednolity skład granulometryczny w „nowych" zbiornikach i niejednolity w „starych" według analizy granulometrycznej. Akumulacja cząstek mniejszych niż 0.063 mm jest podobna w "starych" i "nowch" zbiornikach infiltracyjnych, szczególnie zawartość iłu (0.002 mm), który osiąga przeciętnie 30 % (szacowany na podstawie analizy areometrycznej dla materiału < 0.063 mm). Współczynnik filtracji wykazuje nieznaczne różnice wraz ze wzrostem głębokości. Zawartość organicznej i nieorganicznej materii jest niska i nie wykazuje żadnych trendów. Zawartość żelaza również nie wykazuje wyraźnych trendów.

Słowa kluczowe: sztuczna infiltracja, zbiorniki infiltracyjne, średnica zastępcza ziarna (cząstki), analiza granulometryczna, zatykanie porów, zawartość żelaza, zawartość organicznego i nieorganicznego węgla, współczynnik filtracji.

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Undersökningar av infiltrationsbassängerna vid Vombs vattenverk - en studie av möjliga orsaker till begränsad infiltrationskapacitet

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Sammanfattning: Konstgjord grundvattenbildning är en viktig teknik i vattenhushållningssammanhang och är idag en av de vanligaste och mest utbredda metoderna i världen för att öka vår grundvattenkapacitet. I många länder har den här tekniken använts under lång tid medan den i andra är i framåtskridande. Tekniken har använts i Europa sedan början av 1900-talet och är fortfarande en vanlig metod för grundvattenförsörjning av många samhällen. Syftet med den här undersökningen har varit att ge en kortfattad översikt av olika mekanismer som föreligger vid konstgjord grundvattenbildning och att studera olika faktorer som leder till en reducerad infiltration vid Vombs vattenverk som ligger i västra Skåne. Vombs vattenverk ägs och sköts av Sydvatten, som förser stora delar av västra Skåne med dricksvatten. Undersökningen har koncentrerats på fyra infiltrationsbassänger som ligger inom olika delar av det stora infiltrationsområdet för att se om möjligen geologiska skillnader kan förklara skillnaderna. Två av bassängerna valdes där sanden hade bytts (nr. 13 och nr. 211, kallade ”nya ” bassänger) och ersatts med tvättad sand för att förbättra infiltrationensegenskaperna. De två andra valdes där denna procedur inte varit nödvändig (nr. 63 och mr.207, kallade ”gamla” bassänger). Förutom valet av bassänger inom olika delar av infiltrationsområdet har prover från flera profiler i varje bassäng analyserats med avseende på kornstorlek och speciellt med avseende på kornstorleksfördelningen av material <0.063mm, spektrofofometeranalyser för att bestämma järnhalten, glödförlust för att bestämma halten av organiskt och oorganiskt kol. Resultaten visar att sedimenten är homogena i de ”nya” bassängerna och inhomogena i den ”gamla” bassängerna. Andelen finkornigt material (<0.063 mm) är likartat i de ”gamla” och de ”nya ” bassängerna, speciellt mängden lerpartiklar ligger runt 30 % (räknat på material <0.063 mm). Den hydrauliska konduktiviteten visar små variationer mot djupet i de olika profilerna. Halterna av organiskt och oorganiskt kol är låga i alla profilerna och visar inga tydliga mönster.

Nyckelord: konstgjord grundvattenbildning, infiltrationsbassäng, igensättning, kornstorleksanalys, järnhalt, organisk och oorganisk kolhal, hydraulisk konduktivitet

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1 Introduction

1.1 Background

Vomb Water Plant owned and operated by Sydvatten, supplies large parts of the potable water for western Skåne in southern Sweden (Figs. 1 and 2). The plant was opened in 1948. Groundwater is produced by artificial recharge[1] of infiltration of water from nearby the Vomb Lake. Normally, approximately 1000 l/s is pumped out of the lake although 1500 l/s are allowed according to the water verdict.

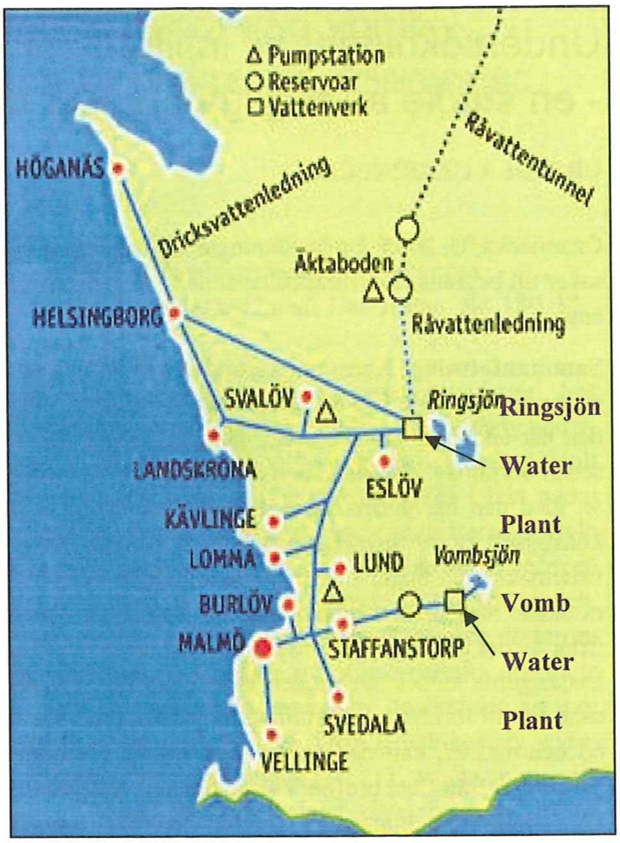

Fig. 1. (on the right) Map of western Skåne with the distribution net of potable water supplied by Sydvatten. At the Vomb Water Plant artificial ground water is produced based on water pumped out of Lake Vombsjön (which is dealt with in this thesis). At the Ringsjön Water Plant lake water is supplied from Lake Bolmen in Småland via a 80 km long tunnel (Råvattentunnel) and a 25 km long pipe-line (Råvattenledning). In special cases also raw water from Lake Ringsjön can is used. Drinking water from the Vomb Water Plant is mainly distributed to consumes in Lund, Malmö and Staffanstorp communes (http://www.sydvatten.se/page.php?sid=11).

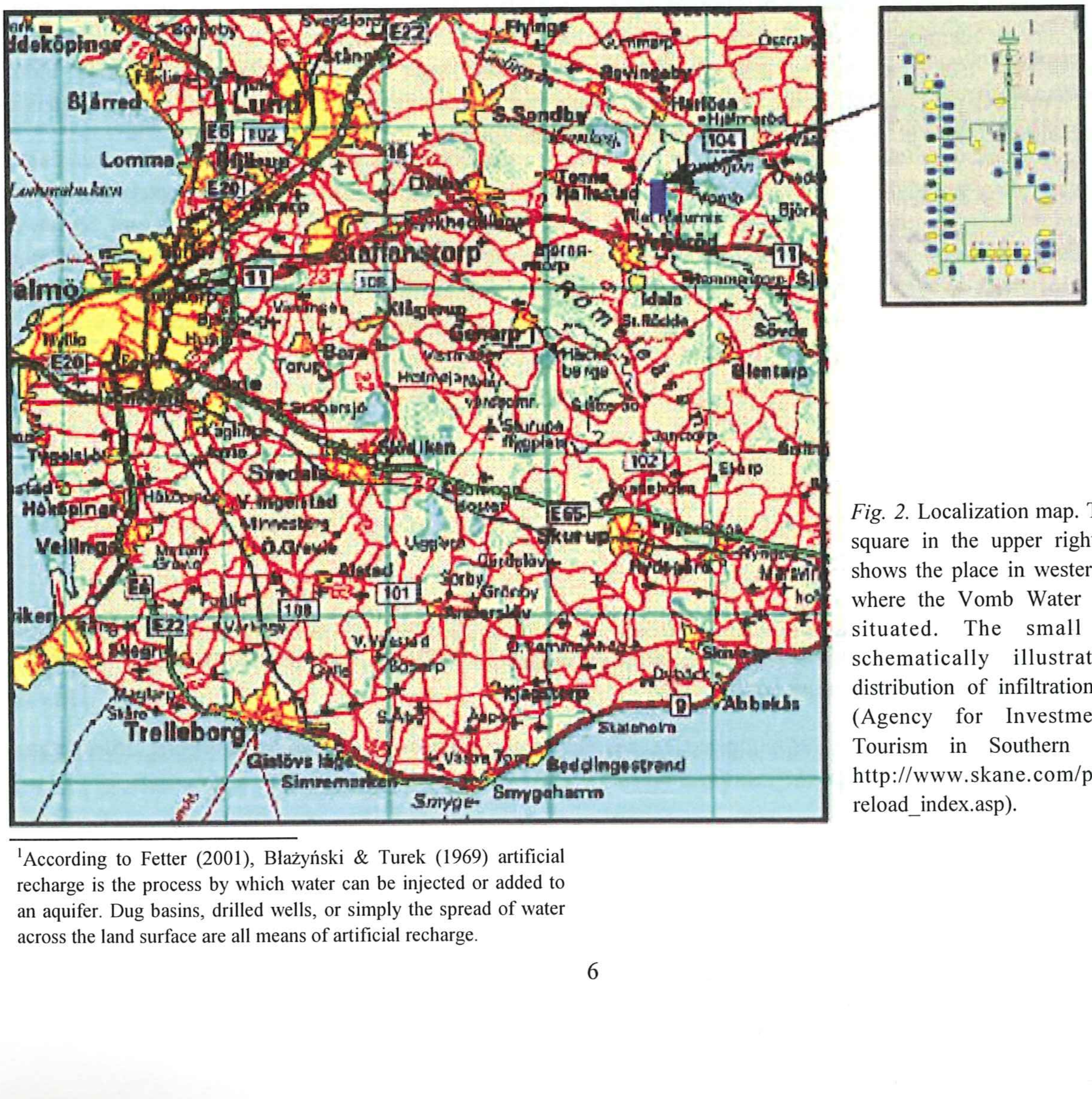

Fig. 2. Localization map. The blue square in the upper right corner shows the place in western Skåne where the Vomb Water Plant is situated. The small figure schematically illustrates the distribution of infiltration basins. (Agency for Investment and Tourism in Southern Sweden, http://www.skane.com/position/reload_index.asp).

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[1] According to Fetter (2001), Błażyński & Turek (1969) artificial recharge is the process by which water can be injected or added to an aquifer. Dug basins, drilled wells, or simply the spread of water across the land surface are all means of artificial recharge.

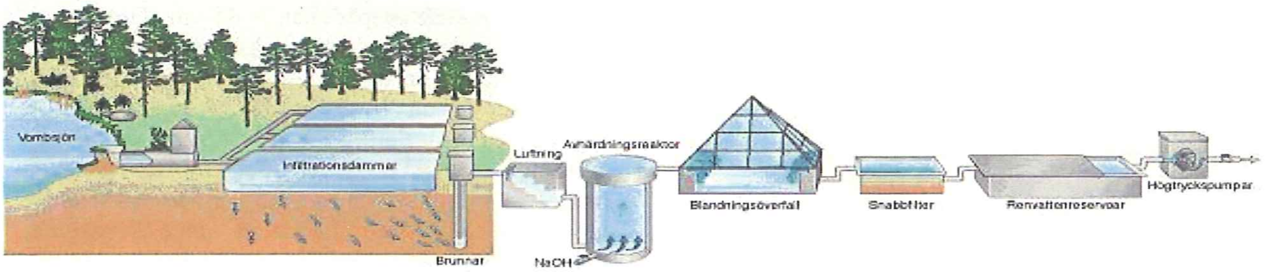

Fig. 3. Schematic scheme showing the production of drinking water at the Vomb Water Plant. Water is pumped out of the lake into some of the 54 infiltration basins (Infiltrations dammar), pumped out by 120 wells (Brunnar) into the water plant where the water is treated in different ways to get a high quality drinking water before it is pumped out to the consumers by high pressure pumps (Högtryckspumpar) (http://www.sydvatten.se/page.php?sid=22).

Before, the raw water is infiltrated it passes through a mesh to get rid of macro particles. The infiltration basins are built in sandy and gravelly sediment of glaciofluvial origin, which characterize major parts of Vomb plain. The artificially produced groundwater is then pumped out of 120 wells and treated in the plant before distributed to the consumers (Fig. 3, above). Altogether, there are 54 infiltration basins covering an area 380 000 m^2 (the small figure in Fig. 2). Problem with infiltration has existed for a long time in that the infiltration capacity[2] of the sandy/gravelly beds in some of the basins is considerably reduced after some time. In solving this long lasting problem Sydvatten has used a simple method, which consists of scraping of 5 cm of the uppermost layer. After many years when a basin gets too deep, there will be a problem with the microbiologic activity and the basin has to be refilled with new sand. The old and contaminated sand is washed in a special plant within the area. By this process organic contaminants and fine grained particles are removed. A "clean" layer of sand is put back in the infiltration basin. When the infiltration tends to slow down again another 5 cm of the top layer is removed (called re-cultivation) and a new "cycle" begins. The problem with reduced infiltration capacity varies a lot in the area. The reason for this is not known.

1.2 Objectives

The removal, washing and replacing the upper sand layer to overcome the problem with reduced infiltration capacity is a costly and time-consuming procedure. The aim of this thesis is therefore to study a number of parameters to try to explain variations between "new" and "old" basins in the infiltration capacity.

2 Mechanisms leading to reduced infiltration capacity

2.1 Purification mechanisms of the water

Artificial infiltration influences on the composition of the infiltrated water as well as the properties of the soils (Frycklund, 1992). The raw water source consists of suspended solids, some large particles such as algae and vegetative debris (Haarhoff & Cleasby, 1991), coloids, microorganisms, viruses, soluble substances and bacteria (Hendricks & Bellamy, 1991) which can be captured by the soil. According to Huisman & Olsthoorn (1983) several purification mechanisms of the water have been distinguished:

1) Mechanical straining causes filtering of the soils. It is a result of the size distribution of the suspended solids relative to the pore size distribution of the soil (Frycklund, 1992). This removes those particles of suspended matter that are too large to pass through the pores of the formation. All particles with bigger than 20 % d_{10}[3], transported with infiltrating water, will retain (Huisman & Olsthoorn, 1983).

2) *Sedimentation* results in the retention of the suspended solids smaller than those retained by mechanical straining (Frycklund, 1992).

3) Adsorption is probably the most important purification process during percolation and also infiltration, due to attaching suspended and colloidal matter to the surface of the sand grains and retained by chemical/electrical forces (Frycklund, 1992).

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[2] Infiltration capacity is the maximum rate at which infiltration can occur under specific conditions of soil moisture (Fetter, 2001).

[3] d_{10} – the effective grain size defined as value where 10 per cent of the particles are finer and 90 per cent coarser in mm (Craig, 2001).

4) *The bacterial and biochemical activity* affects transformation of iron and manganese compounds, decomposition of organic matter, and also adsorbed organic substance (Frycklund, 1992).

2.2 Causes of reduced infiltration capacity

The infiltration capacity of basins is initially high and then declines as recharge progresses, due to surface clogging by fine sediments and biological growths in the uppermost few centimeters of the soil (Fetter, 2001). A number of factors that can lead to reduced infiltration capacity have been described in the literature, of which the most important are:

Bubbles of air
The ability of infiltration will be reduced if air is occupying part of the effective pore system. Thus, the infiltration will increase when blocked air bubbles are dissolved by the infiltrating water (Hedström, 1997).

Clogging
Infiltration basins for artificial recharge are prone to clogging. Clogging processes occur at different depths and can be caused by several factors:

1. *Biological activity*
Effects of biological activity are restrained to the top few centimeters of the basin floor. On the surface of the filterbed a thin layer of organic material (filterskin) is produced. Aerobic bacteria are highly connected to the presence of fine grained sediments. This bacteria population, which develops in the filtermaterial, produces and causes an accumulation of gases and other remaining products, which tend to block and plug the pores in the sediment (Hanson, 2000).

2. *Mechanical processes*
Suspended material (both organic and inorganic) will get stuck in the filtermaterial and accumulate in the pores spaces between the sand grains reducing the infiltration (Goss et al., 1973).

3. *Chemical processes*
Chemical interactions of the infiltrating water and the material results in precipitation of iron and manganese oxides, and also calcium carbonates leading to cementation of the soil particles (Hanson, 2000).

According to Ripley & Saleem (1973) clogging of type 1 (*Biological activity*) occurs in the uppermost layer of the basin floor, wherever type 2 (*Mechanical processes*) occurs over a greater depth, from the surface to the depth of 48-123 centimeters. Further, clogging of type 2 depends on the grain size of the suspended material related to the size of the pores. If there are large-open pores at the surface of the basin floor, more than 50 % of suspended solids have been found to be transported deeper than > 45 cm (Goss et al, 1973) than if the pores are closed where, more than 90 % was retained on the surface in the filter material. Referring to Schuh (1990), deep plugging (down to 38 cm) was built up during the first 19-75 hours of the infiltration. However further clogging occurs at the surface where silt particles form a filter which intercepted the clay in the infiltrating water (Frycklund, 1992).

Algae or microbiological growth
In fact, algae and microorganisms can cause decreased infiltration capacity. They can form aggregates that plug emitters (Haman, 1987c). In addition, algae can be transported into the irrigation system from the raw water and create conditions that may promote the formation of aggregates. On the other hand, an optimal growth of algae is necessary for cleaning of water and plays an important role in the elimination of dangerous substances. It is also important for the straining of suspended material (Hedström, 1997).

Effect of temperature
The hydraulic conductivity depends on the kinematic viscosity of the water. The equations below (1 and 2) express the relation between hydraulic conductivity, K (m/s), and kinematic viscosity, n (m^2/s):

$$K = \frac{C \times d^2 \times g}{v} \qquad (1)$$

$$v = \frac{497 \times 10^{-6}}{[T+42.5]^{1.5}} \qquad (2),$$

where:
K is hydraulic conductivity (m/s)
C is proportionality constant for the soil (-),
d is the grain or pore diameter (m),
q is the constant gravitational acceleration (~ 9.81 m/s^2)
T is the water temperature (°C) (Frycklund, 1992).

The kinematic viscosity is higher for lower temperatures and therefore water at lower temperatures is more resistant to movement (Huisman & Olsthoorn, 1983).

3 Geological Setting

3.1 Site description

The Vomb water plant is situated on the Vomb plain, approximately 20 km southeast of Lund (Fig. 2).

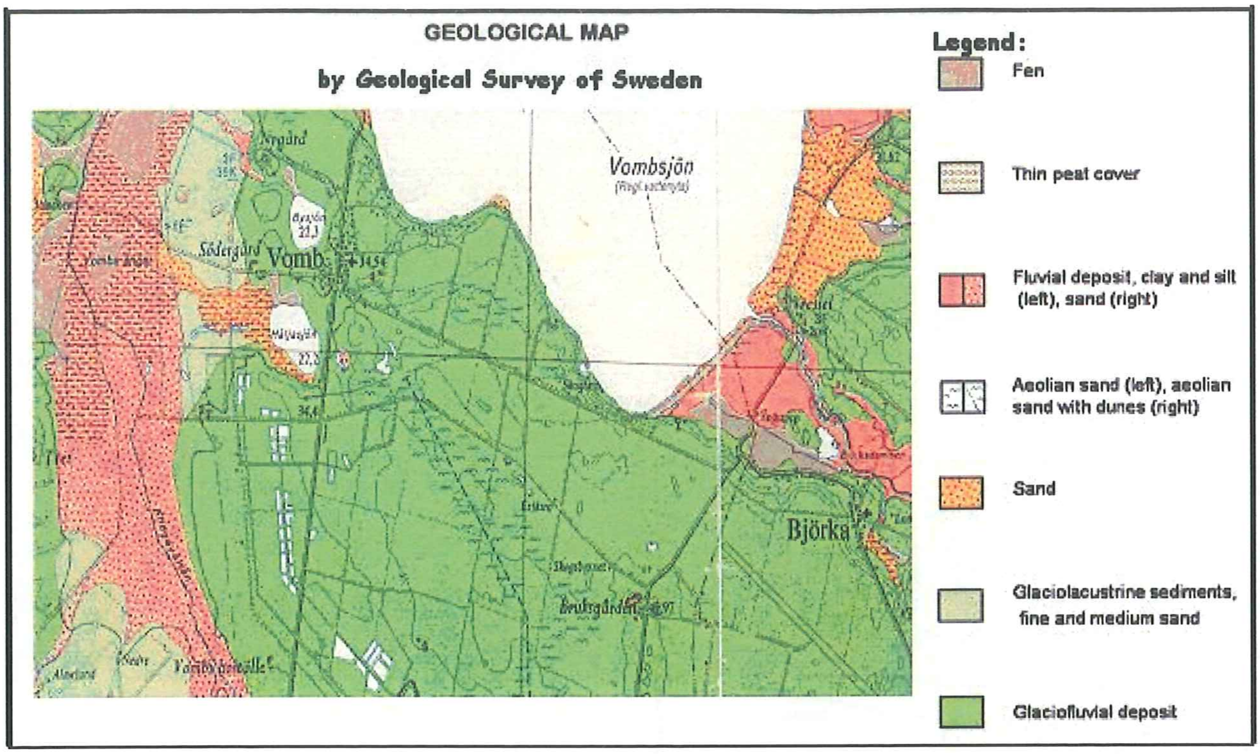


Fig. 4. Map of the Quaternary deposits around the Vomb Water Plant. Since this map was produced additional infiltration basins have been dug out east of the local road to Vomb village (Daniel, 1992).

3.2 Geology of the Vomb plain

The entire Vomb plain is covered by Quaternary deposits to depths ranging between 30 and 90 m. The underlying bedrock consists of lime and sandstones of older Cretaceous and younger Terteriy age. The Cretaceous deposits can in parts of the Vomb plain reach almost 1000 m (Daniel, 1992). Figure 4 presents a map of the Quaternary deposits around the water plant.

The Vomb plain is covered by extensive glaciofluvial and glaciolacustrine sediments that make up completely plain surfaces at various levels. Till occurs most subordinate but can be found within a few areas. The stratigraphy of the Quaternary deposits has been investigated by Gustavsson (1969). Till covered sediments have often been found a connection with drillings.

The water plant is situated in a very flat area with glaciofluvial deposits (Fig. 4). Towards the Vomb Lake and the Björkaå River these are delimited by steep, sometimes up to 20 m high slopes whereas the transition to the lower sediment plains in the west is very gradual.

The western part of these glaciofluvial deposits, in which the water plant is situated, range between 25 and 35 m a.s.l. (Fig. 5). The sediments generally consist of sand and gravelly sand, occasionally stones can also be found. Eolian dunes cover parts of the deposit. Large-scale through-cross-bedding indicates that the sediment was deposited as a sandur plain in relatively shallow water (Daniel, 1992).

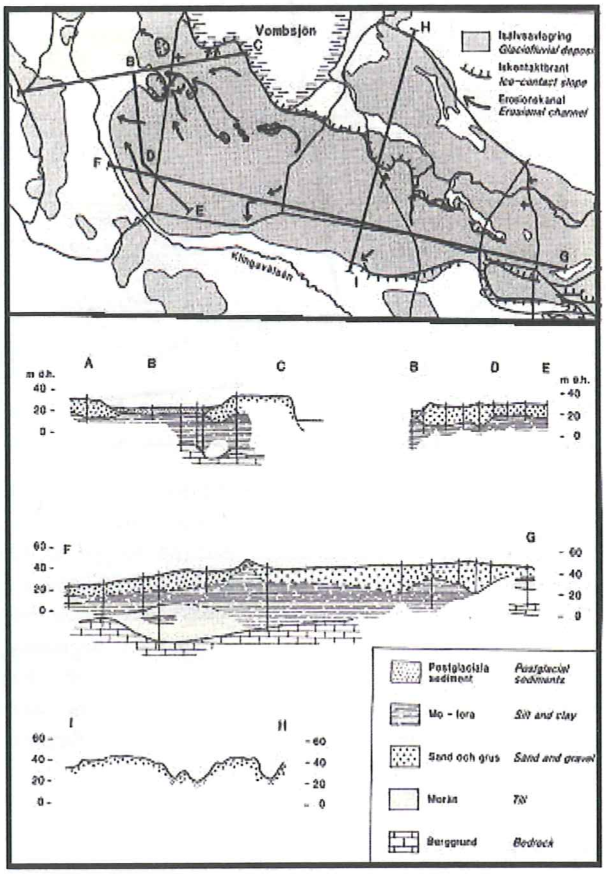


Fig. 5. Overview of the glaciofluvial deposits on the Vomb plain in which the Vomb water plant is situated (Upper figure). Sections through the glaciofluvial deposits based on groundwater drillings and a number of corings performed in connection with investigations around the water plant (lower figure) (Daniel, 1992).

4 Methodology

Of the 54 basins four were chosen for this study (Fig. 6). They are situated in different parts of this huge area to see if differences in the geology possibly could explain variations in the infiltration capacity. In these two areas two basins were selected where the sand had been removed (no. 13 and no. 211, called "new" basins) and replaced by washed sand and the other two where this procedure has not yet been required (no. 63 and no. 207, called "old" basins), because they are working in the same cycle from the beginning without any problems with infiltration capacity.

Fig. 7. Digging of profile C in basin no. 207.

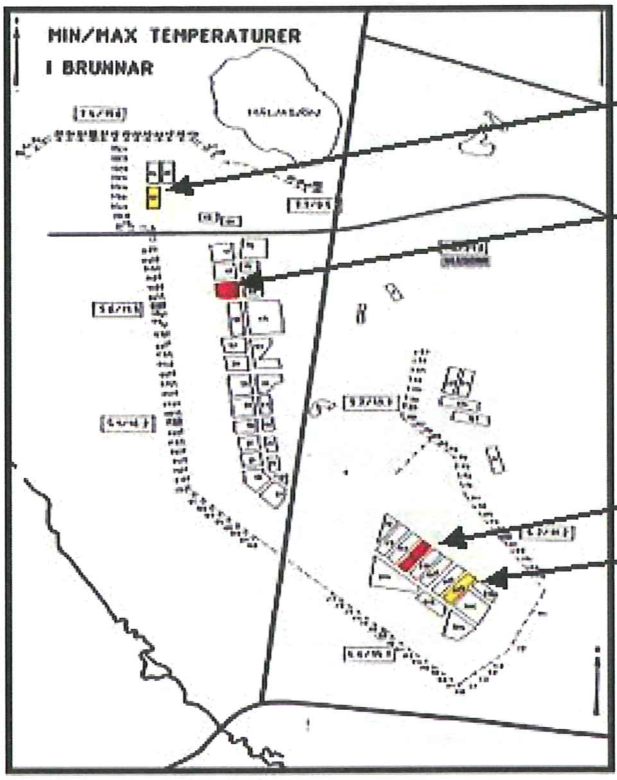
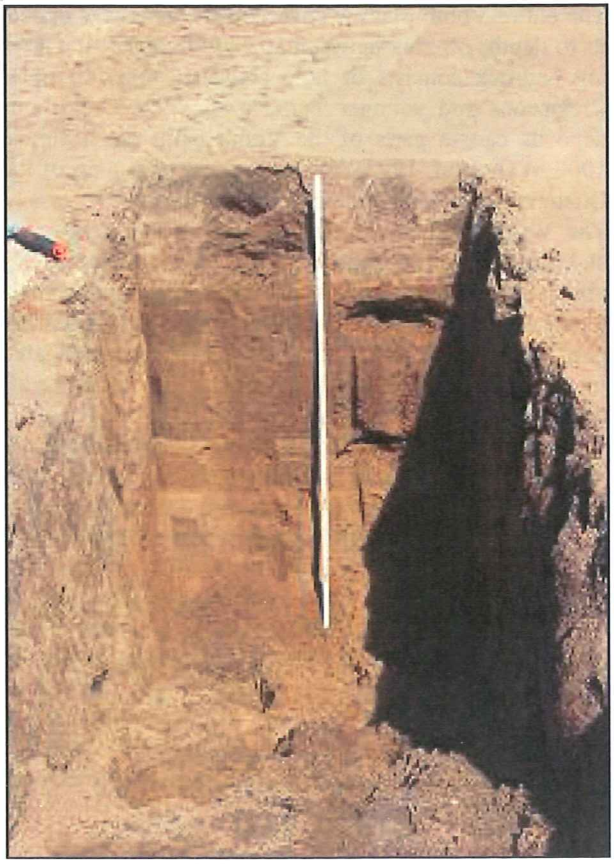


Fig. 6. Schematic plan of Vomb water plant (AB Sydvatten Vombverket, KM Kjessler & Mannerstråle AB, 1989-06-08). Two basins in the northwestern part (no. 63 and no. 13 were chosen and two in the southeaster part (no. 207 and no. 211). Yellow color indicates "old" basins, which means that they are working in the same cycle from the beginning without any problems with infiltration capacity and red color indicates "new" with washed and changed sand. The sand has been removed and replaced due to decreased infiltration capacity to improve infiltration properties of the soils.

Fig. 8. Profile C in the "old" basin no. 207. Note inhomogeneous stratigraphy consisting of slightly gravelly and silty sand to the depth of 20 cm, diamict on the depth of 50-60 cm and gravelly sand. The ruler is 100 cm long.



4.1 Field work

In basins no. 63, 207 and 211, three approximately 1 m deep profiles were dug with an excavator (see Figs. 7, 8 and 9). Two of the profiles in each basin were situated at the end of a diagonal across the basin while the third one was dug in the centre. In each profile the

Fig. 9. Infiltration basin no. 63 ("old"). The position of the three profiles A, B and C is marked with an arrow.

stratigraphy was documented and samples were collected from various levels for different laboratory analyses. From the forth basin (no. 13), samples had previously been collected (in a similar way as in the other three basin but only at two locations) and were provided by Sydvatten. The stratigraphy documented in the field of all the profiles (apart from the one that was subsampled by Sydvatten) shown in appendix 1.

4.2 Laboratory analyses

All samples have been subject to the following analyses:

- Grain size analysis (20-0.063 mm)
- Fine grain analysis (0.063-0.001 mm)
- Determination of iron content
- Determination of organic (C_{org}) and inorganic (C_{inorg}) carbon content

4.2.1 Grain size analysis (20-0.063 mm)

Grain size analysis, also known as sieving test is the most basic sedimentology technique to characterize the sediments. The grain size distribution of the material between 20 and 0.063 mm was determined by sieving test according to standard procedures described e.g. by Talme & Almen (1975). The particle size analysis of the soil samples involved determination of the percentage of particles within different size ranges based on the size of the sieves in the ϕ phi-system but the samples are labeled according to the system in Table 1. The logarithmic ϕ (phi) scale is one useful and commonly used way to represent grain size information for a sediment distribution. The sediments were sieved for 15 minutes using a sieving machine. The material that has been remained in each sieve was weighed and the resulting values were used for the construction of cumulative curves on a semilogarithmic plot (see section 5.1, Figs. 14-17).

Table 1. Fractions used in the thesis (according to Enligt 1953 års jordartsnomenklaturkommitténs förslag Ranges of the soil fractions, from Talme & Almen, 1975).

Fraction	Subfraction	Range (mm)
Boulder	-	> 200
Stone	-	20-200
Gravel	Coarse	6-20
	Fine	2-6
Sand	Coarse	0.6-2
	Medium	0.2-0.6
	Fine	0.06-0.2
Silt	Coarse	0.02-0.06
	Medium	0.006-0.02
	Fine	0.002-0.006
Clay	-	< 0.002

4.2.2 Fine grain analysis (0.063-0.002 mm)

The grain size distribution of the material in the range from 0.063 to 0.002 mm was determined by using a Micromeritics SediGraph 5120 Particle Size Analysis System (Fig. 10). The SediGraph utilize the principle of measuring the gravity-induced settling rates of different size particles in a liquid of known properties. It uses a collimated beam of X-rays to sense the sedimentation speed of suspended particles with time (Micromeritics©: MasterTech and SediGraph operations manual #512-42801-01, 2004). The fine grain size distribution data is presented as cumulative percentages of several fractions: coarse silt (20-60 µm), medium silt (6-20 µm), fine silt (2-6 µm) and clay (< 2 µm) (see appendix 4).

Fig. 10. SediGraph 5120 Particle Size Analysis System, Micromeritics used for the determination of the grain size distribution between 0.063 and 0.001 mm.

4.2.3 Organic (C_{org}) and inorganic (C_{inorg}) carbon content

In the present study the organic (C_{org}) and inorganic carbon content (C_{inorg}) was determined by loss on ignition (Fig. 11.). The method is fast, inexpensive thus it is a commonly used to estimate sediment properties (Maher, 1998). The carbon emitted between 105 and of 550°C is inferred as the content of organic carbon of the samples. The inorganic carbon content has been calculated as the loss on ignition between 550 and 925°C. The weight differences divided by the initial soil weight was used to determine organic (C_{org}) and inorganic (C_{inorg}) carbon content (calculated according to formula from Myślińska, 2001). The results are shown in appendix 8. Fig. 12. presents as an example source of organic matter, which is formed on top of the sediment in the basins.

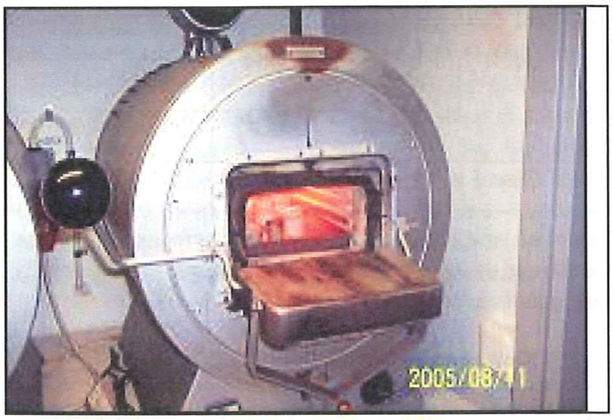


Fig. 11. The oven used to determine organic and inorganic carbon content by loss on ignition.

Fig. 12. Close up of the 2 cm thick organic layer formed on top of the sediment in the "new" basin no. 211.

4.2.4 Iron content

For the determination of the iron content a Spectrophotometer Analysis according to standard no. 28129 of Swedish Standards Institute (SIS) has been used. A spectrophotometer technique is based on the amount of light absorbed at wavelength by a sample. It measures the intensity of the light transmitted through a transparent sample at a given wavelength and converts this number to an absorbance value (http://www.chem.queensu.ca/PROGRAMS/UG/Firstyearlabs/112&116/labman/manual/lab6/). The iron concentration was determined by adding 15 ml of distilled water, 1 ml ascorbic acid and 0.5 ml sulphated acid to 1g of sand to form a colored complex. After boiling the sample was treated with a NaOH buffer (TPTZ)[4]. Thereafter the absorbance of the complex was measured at 594 nm on a spectrophotometer. Finally, the iron content has been computed as a g/kg of sand. The obtained results of iron content are shown in appendix 6. The accumulation of iron in the sediments can appear as sand lens is seen in Fig. 13.

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[4] TPTZ is a ferrous sulfate solution; $C_3N_3(C_5H_4N)_3$; 2,4,6-Tri-2-pyridyl-1,3,5-triazi (SIS no. 28129).

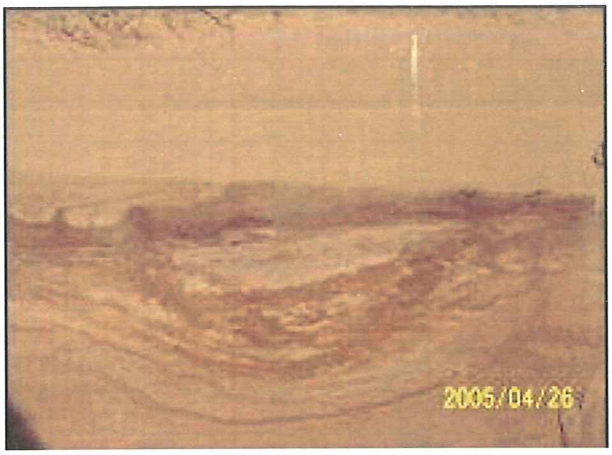


Fig. 13. The sand lens is reddish brown colour. The colour is due to the formation of basic iron (III) compounds (profile C in basin no. 63).

4.3 Hydraulic conductivity

Hydraulic conductivity is a measure of the capability of a medium to transmit water. This is an important parameter, which is useful in determining the volume of water passing through a given soil cross section. Hydraulic conductivity can be measured in a couple of ways. In practice, the most common methods are: empirical, field and laboratory tests. Doubtless, field investigations like field-permeability tests provide the most reliable results, because they characterize conditions over a larger part of the aquifer. On the other hand, laboratory methods (e. g. pumping tests) provide only a rough estimation of the coefficient. Empirical correlations relate to various properties of a porous medium, for instance grain size and porosity. They are definitely the simplest methods, but unfortunately they do not reflect the natural properties of an aquifer which have also some impact on filtration, such as pressure and packing of grains. Thus, they provide only a rough calculation of the hydraulic coefficient. Nevertheless, these correlations are commonly used during preliminary hydrogeological site investigations in order to estimate general situation of the infiltration and soil permeability (Fetter, 2001; Pazdro, 1990). Hazen formula (1911) is commonly used world-wide, because it gives a good estimation and reliable results of the hydraulic conductivity. On the other hand, it gives only idealized theoretical results, because it does not involve parameters as precipitations and organic material (Farag, http://www.hbrc.edu.eg/ehbrc/journal/SG34.pdf). Hazen's method directly relates the coefficient of permeability K, to the effective diameter, d_{10}, which can be obtained from grain size distribution curves. Equation (3) is applicable to sorted sandy sediments where the effective grain size (d_{10}) is between approximately 0.1 and 3.0 mm (Fetter, 2001) and on conditions that the ratio between 60 and 10 per cent of the finest grains in a sample, $\left(\frac{d_{60}}{d_{10}}\right)$, (in mm), does not exceed 5 (Craig, 2001).

$$\mathbf{K = 10^{-2} * (d_{10})^2} \qquad (3),$$

Where:

K - Hydraulic conductivity (m/s),
d_{10}- the effective grain size defined as value where 10 per cent of the particles are finer and 90 per cent coarser in mm (Craig, 2001).

Calculations of hydraulic conductivity are presented in appendix 7.

5 Results

All appendixes give a summary of the results for the laboratory researches at all sediments of infiltration basins. Moreover, the stratigraphy description done in situ (appendix 1) was comparable with the laboratory method- sieving test (appendix 2). In present thesis the emphasis has been put on the fine grain material which is the most important for this study, thus figure 14 gives an overview of this deliberations and investigations.

5.1 Grain size analysis (20-0.063 mm)

5.1.1 "old" basins

The two "old" basins (no. 63 and no. 207) are situated in different parts of the area (Fig. 6). They display quite similar grain size composition according to the grain size analysis. The three profiles in basin no. 63 display some inter-basin variations (Fig. 15). Profile A has very little amount of gravel (typically less than 0.2 %, with exception 9.8 % in the lowermost layer) and silt (ranging from 0.2 to 1.6 %), while the other two profiles (B and C) have somewhat different characteristics. Profile B has a considerably higher contribution of silt and thus in the majority of the samples have been classified as well sorted silty sand with a silt content ranging between 1 and 14 %. The lowermost layer has a very high silt content and is classified as a sandy silt with a silt content reaching almost 60 %. The sediment in profile C is also sandy but has on the contrary a coarser grain size assemblage with a higher contribution of gravel grains. In basin no. 207 also very small the inter basin fluctuations have been documented (Fig. 16). All profiles consist of sand ranging between 93 and 99 %; 48 and 93 %; 79 and 94 %, respectively. The sediments is generally classified as slightly gravely, gravely or just sand.

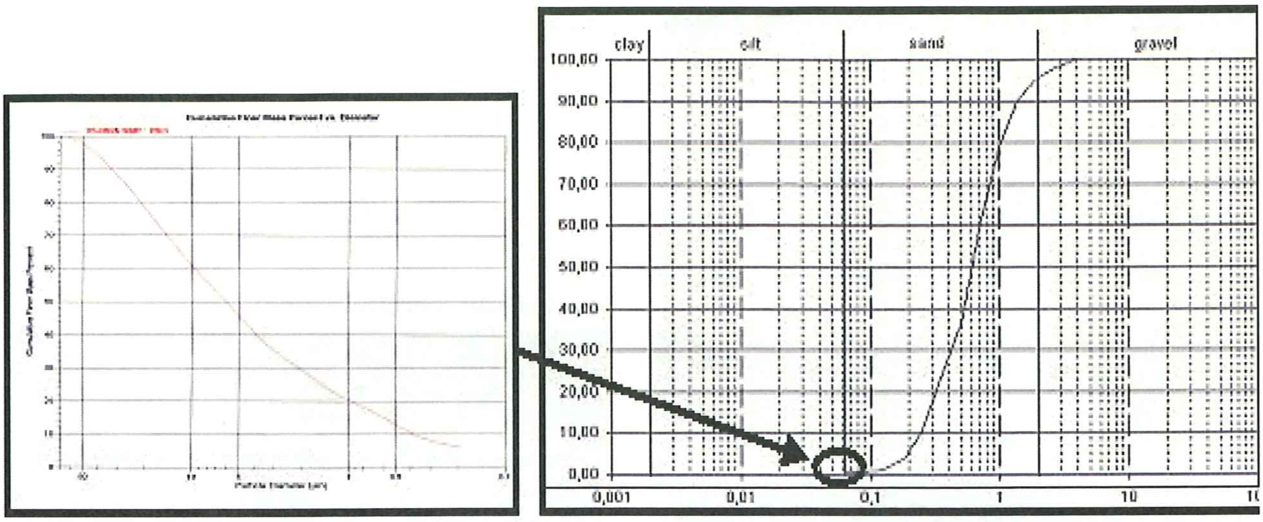


Fig. 14 .Plot on the right shows results of grain size analysis. The marked area shows the place the most important for this study (0.063 mm), thus on the left the fine grain plot is shown.

The contribution of gravel grains in profile B and C is considerable higher than in A, ranging between 6 and 51 %, 3 and 50 %, respectively (according to appendix 2). The amount of silt grains is generally very small ca. 1.5 % and is mostly observed in the uppermost layers of profile C. Investigation has noted diamict on the depth of 50-60 cm in profile C of basin no. 207.

5.1.2 "new" basins

The results of sieving analysis from the no. 13 and 211 show homogenous grain size contribution but anyhow some small differences can be distinguished (Figs. 17 and 18). All analyzed samples in single profile of basin no. 13 are extremely homogeneous (classified as well-sorted, slightly gravely sand) with a sand content typically 95 % and gravel content in a range between 3 and 7 %. The contribution of fine grains in the silt range is very small (rarely exceeds 1 %). No downward or upward trends can be noted.

Different statistical parameters are presented in appendix 2, which indicates that in basin no. 211 sand is ranging between 79 and 98 %. In a profile A on the depth of 100 cm diamict has been noted. Generally, the gravel content displays downward trend. The stratygraphy characteristic of other profiles B and C is similar with an greater amount of coarser grains and silt content in profile C.

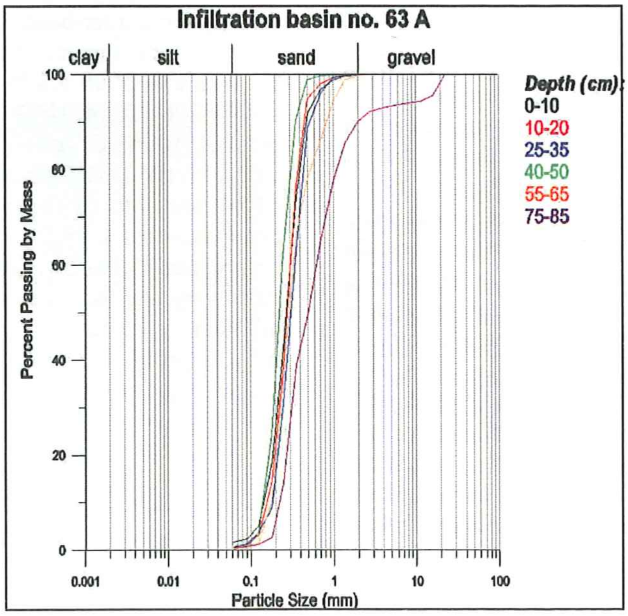
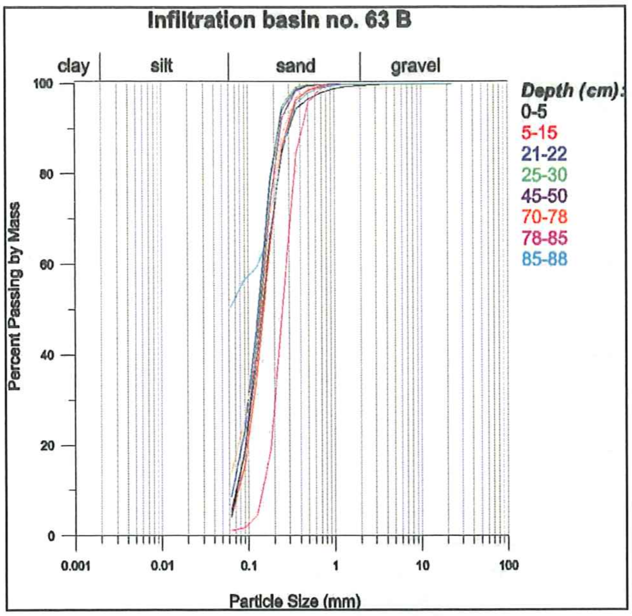
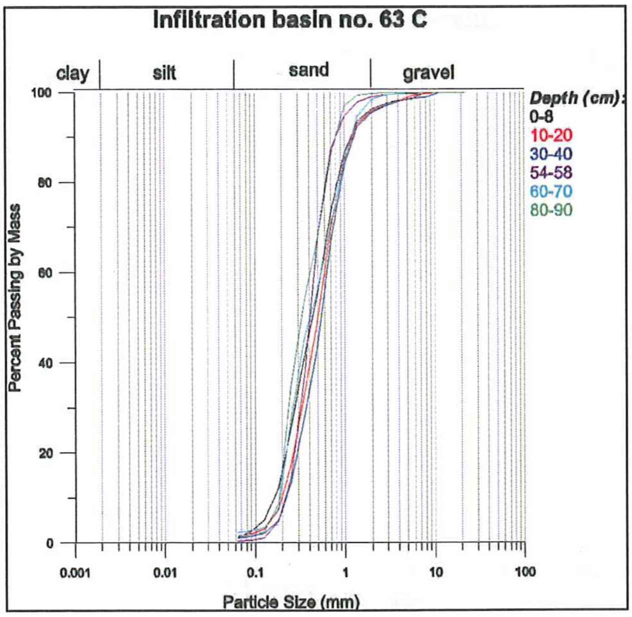


Fig. 15. Grain size plots from basin no. 63 (profile: A, B and C).





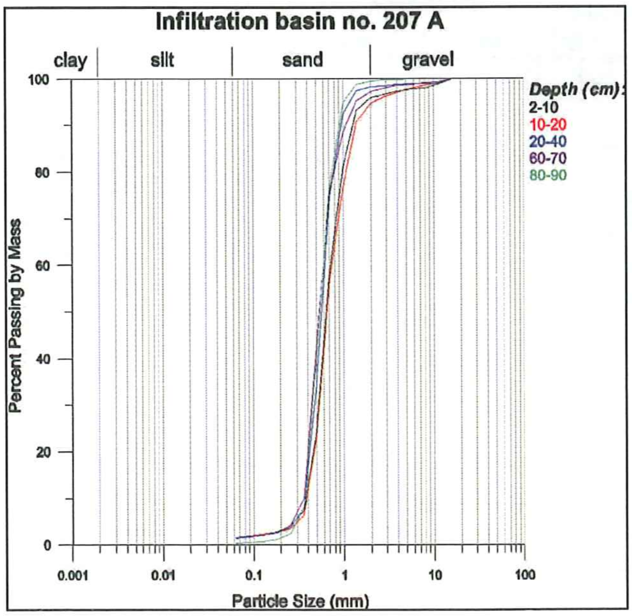


Fig. 16. Grain size plots for basin no. 207 (profile A, B and C).

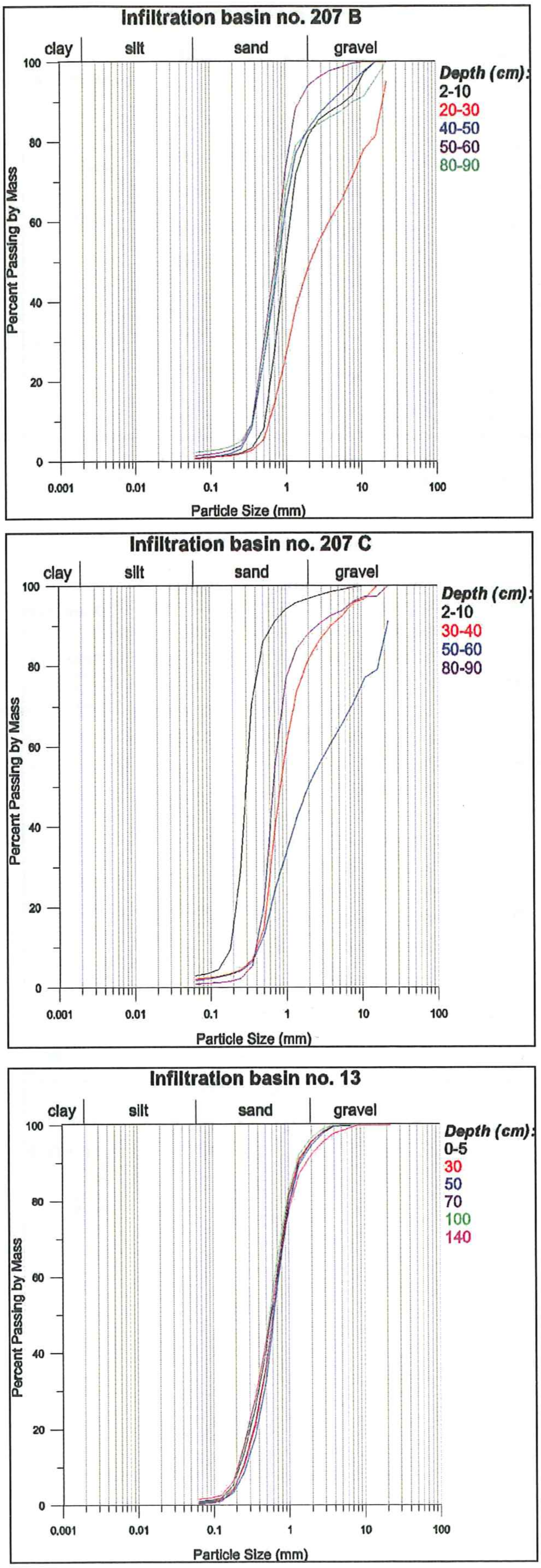


Fig. 17. Grain size plots for basin no. 13.

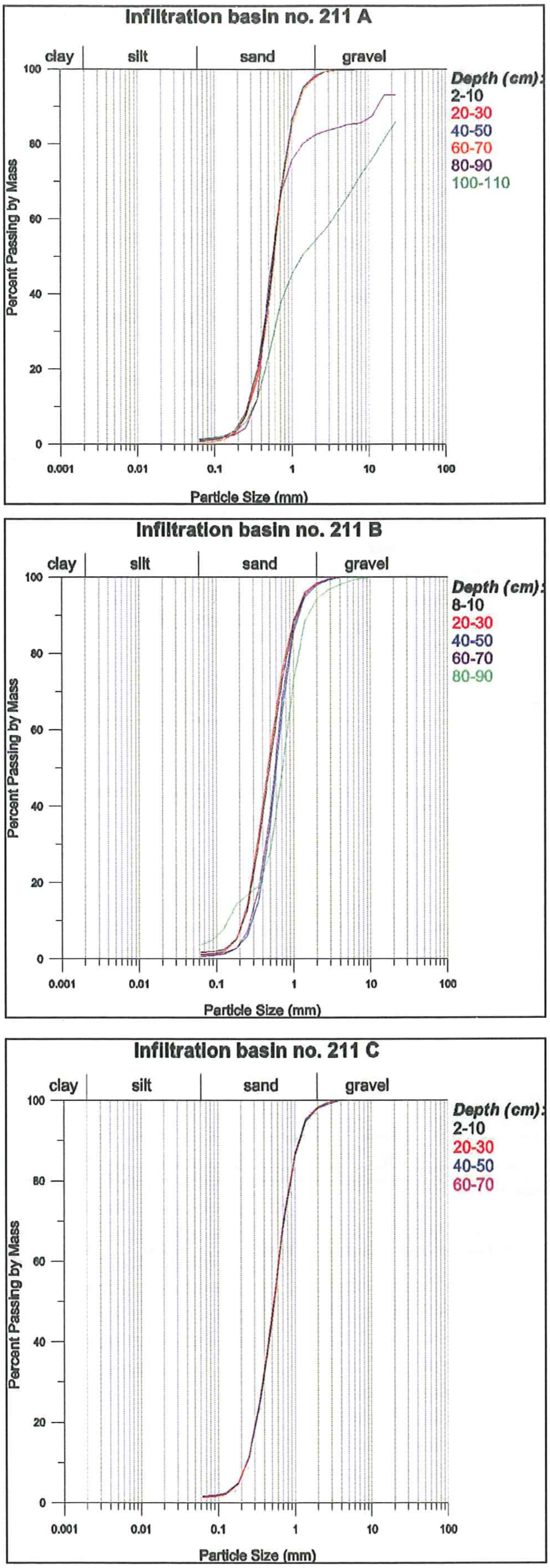


Fig. 18. Grain size plots for basin no. 211 (profile A, B and C).

5.2 Fine grain analysis

To facilitate a comparison between the grain size distributions of the fine material, which possibly could be an important factor influencing the infiltration, the analyzed amount of this analysis has been set to 100 %. The results of fine grain analysis are shown in plots as a cumulative percentages of several fractions: coarse silt (60-50 µm; 50-40 µm; 40-30 µm; 30-20 µm), medium silt (20-10 µm; 10-5 µm), fine silt (2-5 µm) and clay (< 2 µm). The results are compiled in appendix 5.

5.2.1 “old” basins

With the exception of the samples at the coring point B in basin 63 the total percentage of grains < 0.063 mm is generally 4 % or less (Fig. 19). The amount of clay in profiles A, B and C reaches average 30 %. In all the three profiles of basin 207 the clay content (i.e. particles < 2 µm) is also very consistent around 30 %, whereas there is a considerably higher degree of variation in basin 63 especially in profile B where the amount of clay ranges between 10.8 and 71.0 %.

Fine silt (2-5 µm) typically is varies between ca. 13 and 20 % in basin 207 while a range of samples specifically in profile B and C in basin 63 have very low values. Basin 63 has a generally coarser grain size assemblage compared to basin 207 in that the amount of coarse silt (20-60 µm) is in general higher in profile 63 while the medium silt (5-20 µm) is higher in profile 207.

5.2.2 “new” basins

The clay content in the two “new” basins is in a value around 33 %. In the 140 cm deep profile in basin no. 13, only four samples could be analyzed due to enough amount of the material < 0.063 mm.

In both basins fine silt (2-5 µm) typically varies between 15 and 21 %. The small differences are seen in coarse silt content (20-60 µm), where in basin no. 13 the value is a bit higher, approximately 24 % than in basin no. 211 (profile A: 16 %, B: 20 % and C: 21 %, respectively).

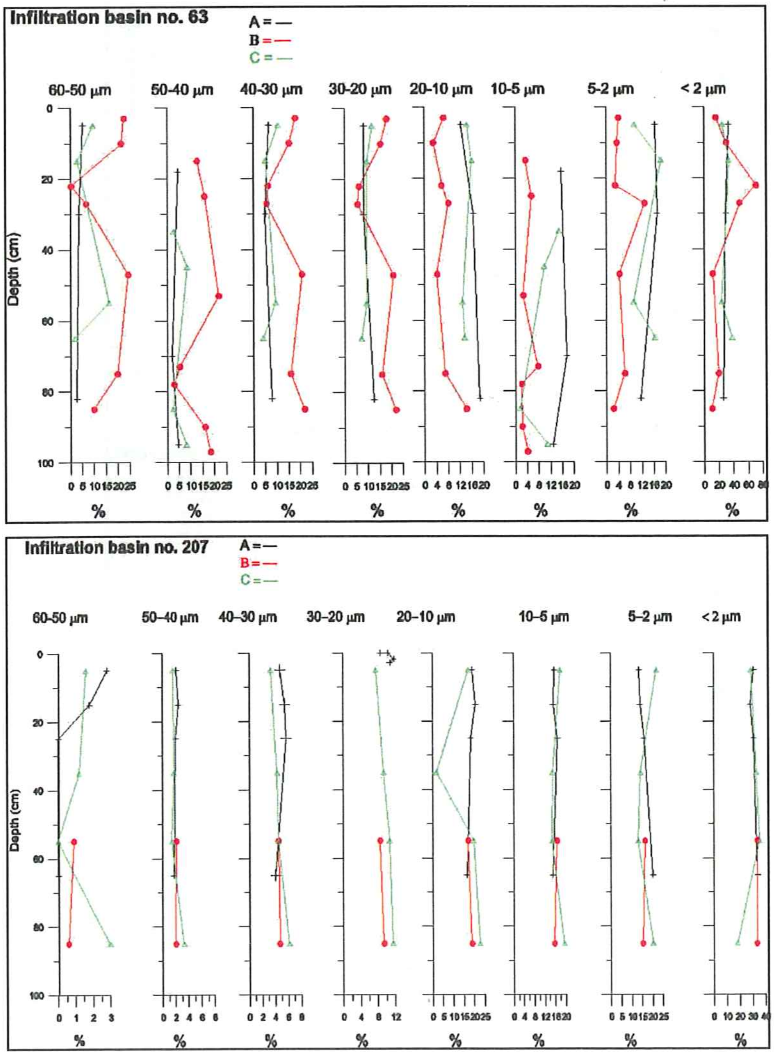


Fig. 19. Fine grain plots for basin no. 63. and 207.

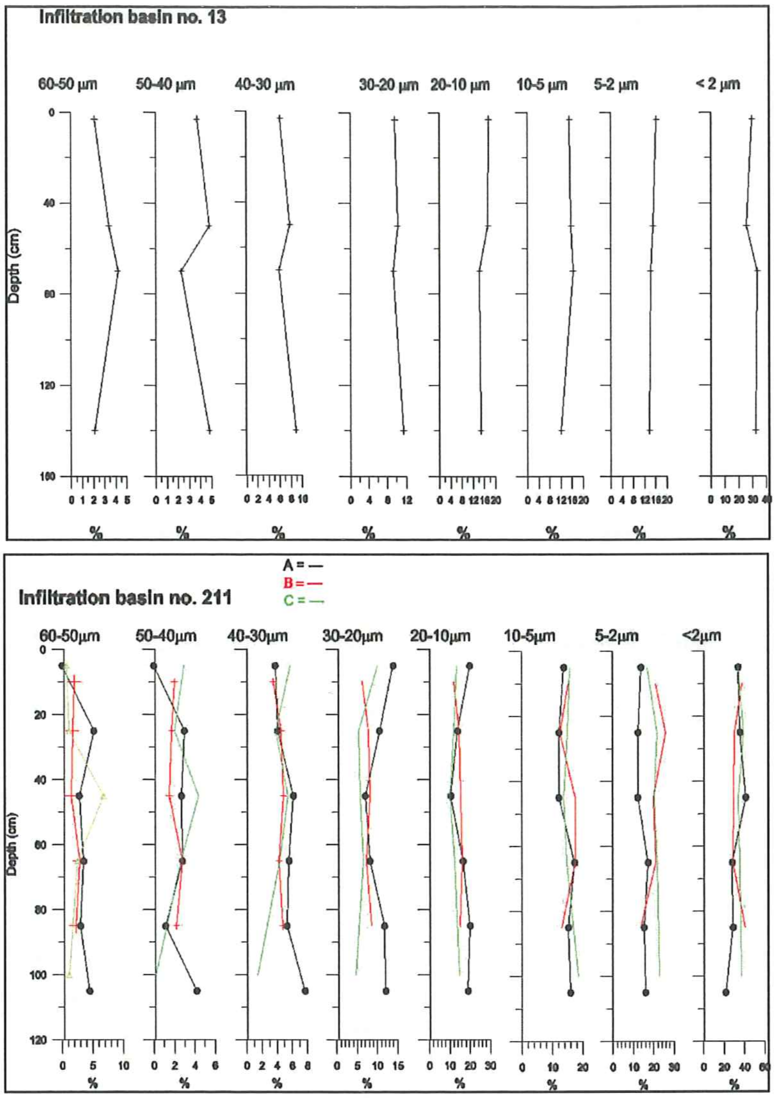


Fig. 20. Fine grain plots for basin no. 13 and 211.

5.3 Organic (C_{org}) and inorganic (C_{inorg}) carbon content

5.3.1 Organic Carbon (C_{org})

The accumulation of organic material in all analysed sediments shows rather unclear patterns. In all basins the amount of organic carbon is very low, predominantly less than 1 %. The values fluctuate in all profiles, thus the greater amount of organic content has been reported on different depths. Somewhat, occasional some variations have been observed. All data are shown in appendix 8 attached to the paper.

5.3.1.1 "old" basins

In the two "old" basins no. 63 and 207 organic carbon values are generally very low, around 0.5-0.75 % (Fig.21). The outliers (at 50-60 cm in basin no. 207 B and at 21-22 and 45-50 cm in basin no. 63 B) reaching values between 2 and 2.5% most probably are erroneous or in case basin no. 63, the fine fraction (< 0.063 mm) is present in a greater value what is closely followed by a rise in extra weight-loss due to structural water. Aside from these values no significant upward or downward trends can be noted.

5.3.1.2 "new" basins

Organic carbon values are also very low in all the profiles of the two "new" basins, typically < 0.75 % (Fig. 22). Like for the "old" basins no clear trends can be seen. The consistency of the result is indicated by the duplicate samples at many levels in profile basin no. 13 where values are almost identical in the two samples at the same level. Possibly the relatively very high value in the lowermost sample in profile A in basin no. 211 can be due to a measurement or weighing error.

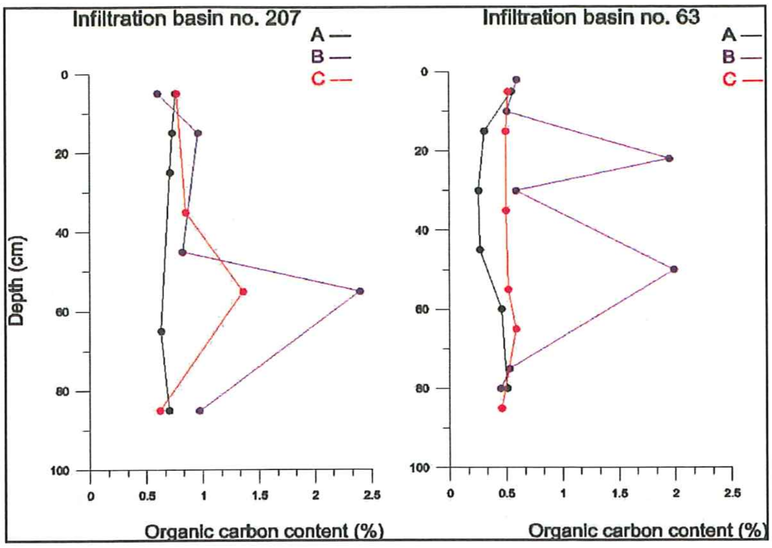


Fig. 21. Organic carbon content with depth ("old" basins).

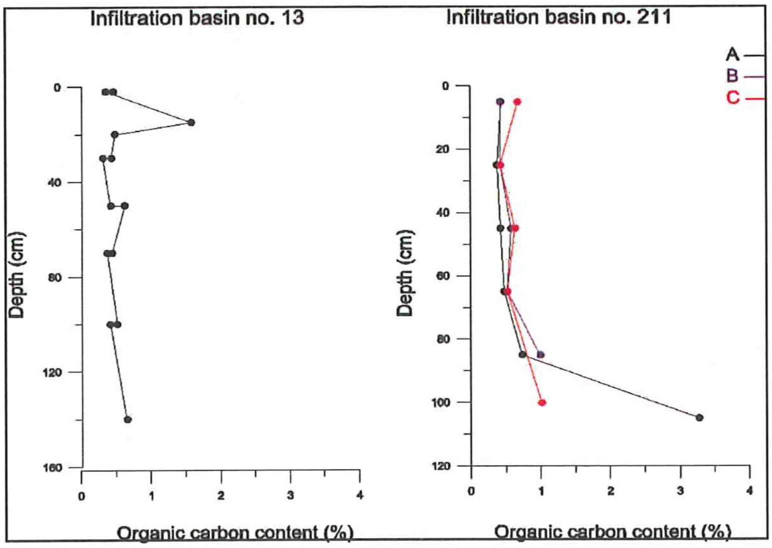


Fig. 22. Organic carbon content with depth ("new" basins). Note that duplicate samples have been analyzed at several levels in basin 13.

5.3.2 Inorganic Carbon (C_{inorg})

The amount of inorganic matter does not show clear trend. Both in "new" and "old" infiltration basins the inorganic carbon matter displays many fluctuations. Practically, the inorganic carbon content is usually higher than 1 % especially in „old" basins and appears in greater values than organic matter. In many samples the amount of it exceeds 3, 4 or even 5 %. To notice this dependence better see appendix 8 which contains the results of organic and inorganic matter.

5.3.2.1 "old" basins

In both "old" basins values of inorganic carbon range between practically 0.1 and 5.6 %. Two of the profiles (A and C) in basin no. 207 show downward increasing values while the reverse holds for profile B. There is a higher degree of consistency between the three profiles in basin no. 63 with an apparent peak in concentrations between ca. 30 and 60 cm possibly representing a uniform stratigraphic unit across the entire basin.

5.3.2.2 "new" basins

In the two "new" basins inorganic carbon values are in general very low, with exception of two lowermost samples in profile A in basin no. 211 with values of 2.5 and 5 %, respectively. Again the representatively of duplicate analyzed samples is evident from basin no.13 in Fig. 24.

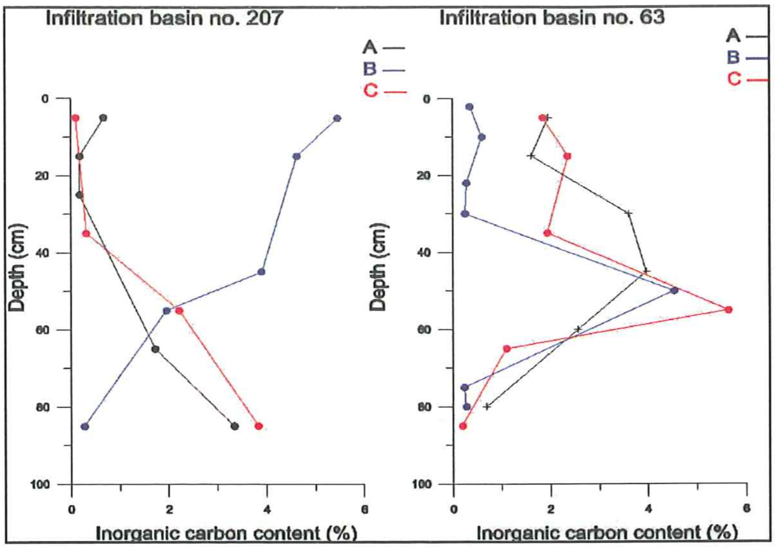


Fig. 23. Inorganic carbon content with depth ("old" basins).

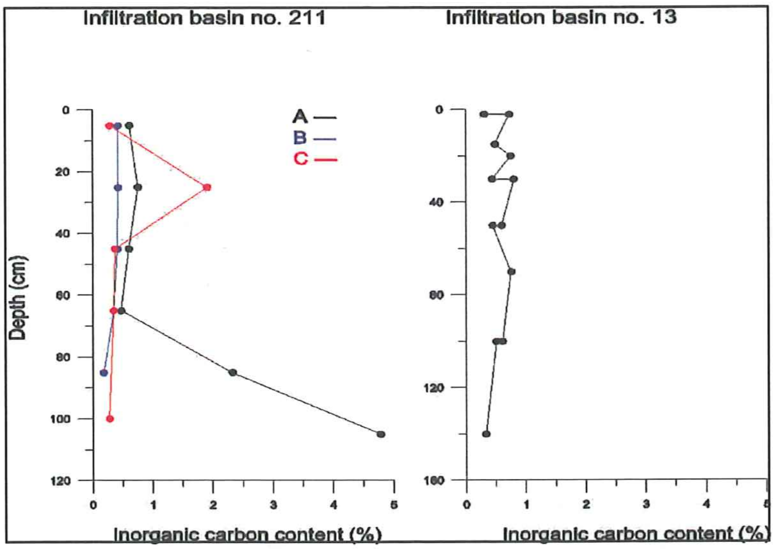


Fig. 24. Inorganic carbon content with depth ("new" basins).

5.4 Iron content

The amount of iron content in all profiles displays no clear patterns.

5.4.1 "old" basins

In the two old basins the iron content varies between 10 and 72 g/kg with no consistent pattern neither with respect to inter or intra basin correlations (Fig. 25).

5.4.2 "new" basins

In basin no. 211 in which samples from three profiles were analyzed there is very little inter profile variation (Fig. 26). Down to the depth of ca. 70 cm values in all the three profiles are very consistent around 30-40 g/kg with increasing values down profile. In the single profile approximately around 25 g/kg when the result of the duplicate samples at many levels are taken into account. This value is only slightly lower than the values in basin no. 211 down to ca. 80 cm.

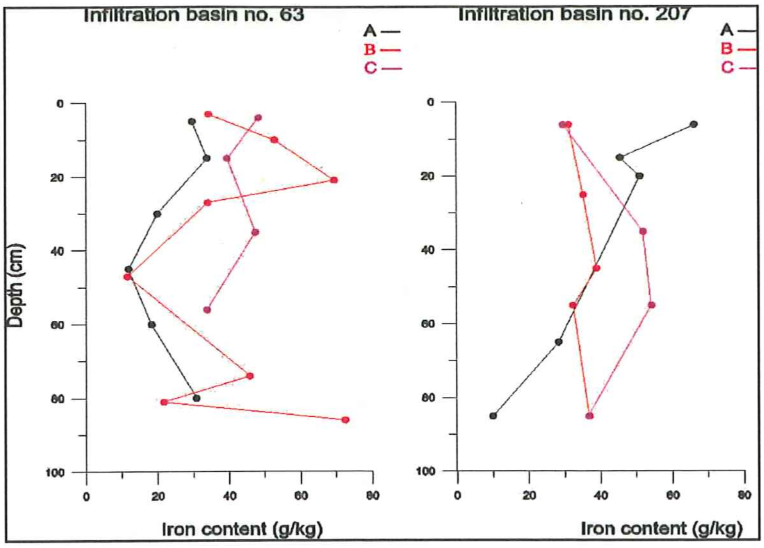


Fig. 25. Iron content with depth ("old" basins).

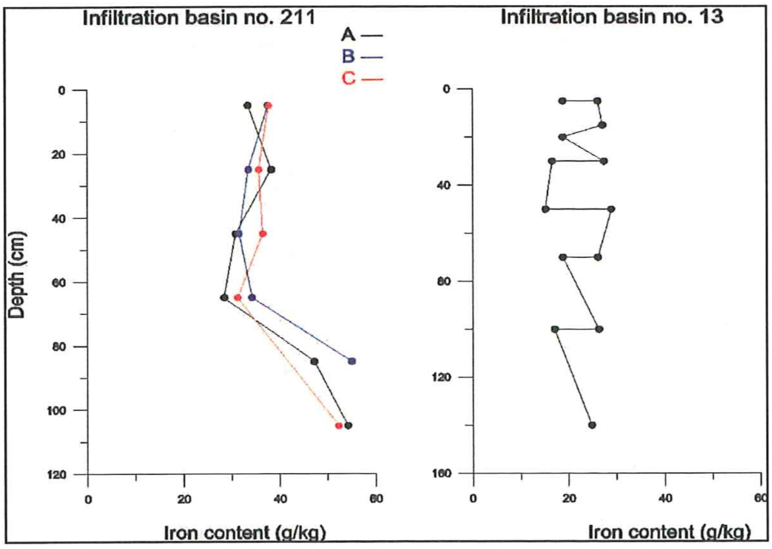


Fig. 26. Iron content with depth ("new" basins).

5.5 Hydraulic conductivity

The values of hydraulic coefficient in all profiles are quite different and range between $1 * 10^{-3}$ and $4 * 10^{-5}$ m/s. The results are presented in appendix 7. In table 2 all obtained data have been compared with general values of permeability coefficient, and as a result almost all sediments in both "old" and "new" basins are well-sorted sands and gravel mixtures. The only exception is in profile B of basin no. 63, where fraction is fine and the values indicate very fine sand, silt and clayey silt.

5.5.1 "old" basins

In the two old basins K values as expressed by Hazen formula are different but quite constant with depth, with values ranging practically between $1 * 10^{-3}$ and $4 * 10^{-5}$ m/s. The lowest results of K fluctuate between $4 * 10^{-4}$ and $4 * 10^{-5}$ m/s and have been noted in basin no. 63 B because of a significant amount of silt and clay. The highest values are observed in basin no. 207 (mainly $1\text{-}3 * 10^{-3}$ m/s), probably due to coarser grains size. At two depths in profile B: 20-30 cm (sandy gravel) and in profile C: 50-60 cm (diamict) the coefficient has not been calculated because $\left(\frac{d_{60}}{d_{10}}\right) > 5$.

5.5.2 "new" basins

The 140 cm deep profile in basin no. 13 has quite constant values with coefficient ranging between 3 and $6 * 10^{-4}$ m/s. In addition, no upward and downward trend has been observed. The composition of hydraulic conductivity values in basin no. 211 is quite homogenous as well, ca. 3 and 6 * 10^{-4} m/s. At the depth of 80-90 cm (slightly gravely and silty sand) in profile B and 100-110 cm (diamict) in profile A the hydraulic coefficient has not been calculated, because

of $\left(\frac{d_{60}}{d_{10}}\right) > 5$.

Table 2. Coefficient of permeability (m/s) (BS 8004:1986, from Craig, 2001).

Material	**Hydraulic conductivity (m/s)**
Unfissured clays and clay-silts	10^{-10}-10^{-7}
Very fine sands, silts and clay-silt laminate	10^{-7}-10^{-4}
Clean sands and sand-gravel mixtures	10^{-4}-10^{-2}
Clean gravel	10^{-2}-1

6 Discussion

Sand filters can be highly effective natural filters in removing several common pollutants from the raw water, such as suspended material, colloids, microorganisms, viruses, soluble substances and bacteria (Hendricks & Bellamy, 1991) as they adsorb to the sand grains. The top layer of the sand is always the main contaminant because of this process. However, the removals efficiencies are functionally dependent on variables processes like thickness of the filter bed, grain size, temperature, hydraulic loading rate etc. (Hendricks & Bellamy, 1991).

Artificial infiltration is a good and still new method for increasing groundwater capacity in water treatment, which has been proved in many facilities around the world. The analyzed sediments which have been studied in the present thesis have been characterized by grain size variations, organic/inorganic carbon and iron content. In the discussion they have been correlated with other properties of the soils.

6.1 Grain size analysis

Within geology accurate sieving analyses are required for petrophysical studies which relate sand texture to porosity and permeability. Thus, particle size distribution is a fundamental property of loose sediments because it is related to many other properties. Knowledge about the texture of a soil gives an idea about its other properties (Buckley & Cranston, 1991). The analyzed sediments are of glaciofluvial origin and represent altogether sand or gravely sand. However, in some samples gravely pebbles, silt and clay content appear in significant or very small amount. In the "old" basins some intra-basin variations occur, because basin no. 63 has considerably amount of finer grains (e.g. sandy silt), what is clearly seen especially in profile B whereas infiltration basin no. 207 is characterized more by coarser grains. The "new" basins (no. 13 and 211) are more homogeneous and consist of mainly gravely sand or just sand. Sorting coefficient shows that almost all deposits are well sorted, what is connected to hydraulic conductivity, which is good in most of profiles. In consideration of reduced infiltration capacity some problems with it might occur in profile B in basin no. 63.

6.2 Fine grain analysis

According to Schuh (1990), in general the infiltration water consists of 60 mg/l of suspended solids, of which 60 % are clay and 40 % silt, thus fine grain analysis is a very important part of this study, because the finest particles have a great influence on clogging and the reduction of infiltration capacity. When considering the fine grain content some small differences in both "old" and "new" basins have been observed. In basins with a natural sequence and unwashed sediments the results from sieving analysis shows that the contribution of fine grains (< 0.063 mm) in all samples, practically in each profile, is significantly higher than in "new" basins, for instance 50.6 % (profile B in the "old" basin no. 63). However, even in the "new" basins, where the cleaning procedure of sand has been required, material < 0.063 mm still exists, but it does not exceed 4 %. Generally, the concentration of clay particles (< 0.002 mm) has constant values in both the "old" and "new" basins and reaches approximately 30-33 %. Occasionally it is greater and reaches as much as 71 % e.g. in basin no. 63 (B). The basin consists of natural, unchanged sand with a variety of different fractions of the soil. It is well known that high silt and clay content might cause reduction of the infiltration capacity due to their special structural properties. Normally, the hydraulic conductivity of these sediments range between 10^{-7} and 10^{-10} m/s (Craig, 2001), so all silty and clayey additions in the soil can cause that the infiltrating water can be kept in retain, thus the best filters are sandy or gravely, because the spaces between porous are greater and is easier to pass for the infiltration water, even where other factors causing clogging occur.

6.3 Organic (C_{org}) and Inorganic (C_{inorg}) Carbon Content

The loss on ignition is a good tool to determine organic and inorganic content. The method is accurate if the fine fraction is present in low percentages. The precision of organic carbon determination can be disturbed by different factors. It has been shown that the results can be overestimated because of various factors, due to the loss of e.g. volatile salts, organic compounds (Bengtsson & Enell, 1986), structural water (Dean, 1974), sulphide oxidation (Ramrath et al., 1999) or inorganic carbon. In the soils organic matter helps to create and stabilize aggregates of the grains of salt, silt, and clay. These complexes have relatively large spaces between them, permitting more rapid water movement (Huddleston, 1996). According to Schumacher (2002) the content of organic matter in a soil also has a positive effect on available water capacity, water infiltration, and soil organism activity.

Based on the obtained results is difficult to say if organic or inorganic carbon has some positive or negative influence on infiltration capacity of the studied infiltration basins. In general, the amount of organic/inorganic carbon has determined by loss on ignition is quite low to gain appropriate estimation. In consideration of C_{org} no pattern, both in "old" and "new" basins are seen. Albeit, the outliers at 50-60 cm in basin no. 207 B and at 21-22 and 45-50 cm in basin no. 63 B have been observed are reaching values between 2 and 2.5 % the most probably they are erroneous or in case "old" basin (63 B) another explanation is possible. There the fine fraction is present in a greater value what is closely followed by a rise in extra weight-loss due to structural water. Anyhow in the "new" basin no. 211 at the depth of 80 cm the accumulation of C_{org} is the greatest in all profiles. It might be because of decrease of oxygen content and decomposition of organic compounds by oxygen consumers and that organic matter causes seal of the pores, thus retains the oxygen movement with depth (Wood & Basset, 1975). Only in one "old" basin (no. 207) inorganic carbon content displays clear downward (profile A and C) and upward trends (profile B). The values are low but still higher than organic carbon.

The presence of organic and inorganic carbon is very low in studied profiles and is thought to have minor influences on infiltration capacity and unwanted plugging.

6.4 Iron content

The precipitation of iron is influenced by several cooperating factors, such as pH of the soil, temperature of the water, bacteria, content of carbon and others. The results from the four studied basins show very different values. The standards and expected iron value in a sandy and gravely sediment is ca. 38 g/kg. Concerning iron content the presence of organic matter is some kind of advantage, because it allows iron to be dissolved and transported with the water (Schumacher, 2002). Proves from literature are seen in "new" basin no. 211, where the greatest concentration (30-40 g/kg) of iron occurs down from the depth of 80 cm. It is worth pointing out that in the same sediments and at the same depths the organic carbon content is considerably higher (1-3 %). The facts above show that iron compound can pass through the filter sand and accumulate at deeper levels. At greater depths in the "new" basin no. 211 the presence of iron might be due to transition between filter bed and underlying natural soil sequence. In this case, the concentration of iron can cause clogging of the pores in the soils and retain infiltration water. The grain size of the soils is important for extending iron precipitation, as well. The dependence is found in studied sediments, for example in profile B (basin no. 63) enormous amount of iron (72.5 g/kg) in sandy silt has been noted thus unwanted clogging is very possible.

6.5 Hydraulic conductivity

Hazen's formula (1911) is commonly used in the whole world, because it gives approximately reliable results of hydraulic conductivity. It gives only idealized theoretical results, because it does not involve parameters as precipitations and organic material (Farag, http://www.hbrc.edu.eg/ehbrc/journal/SG34.pdf). As seen from the results, there is some variation in this parameter. In fact, most values are quite constant with depth in the "old" basins. The lowest values can be observed in profile B in basin no. 63, where K fluctuates between $4 * 10^{-4}$ and $4 * 10^{-5}$ m/s. Here, the sediments generally consist of silty sand and the amount of fine material (< 0.063 mm) is quite high (4-51 % according to sieving analysis). The highest values are documented in basin no. 207 (generally $1 * 10^{-3}$ and $3 * 10^{-4}$ m/s). The most probably reason for that is a coarser grain size (mainly gravely sand and sandy gravel), so in this case clogging ought to not take place. In the "new" basins the hydraulic conductivity reaches values ranging between 3 and $6 * 10^{-4}$ m/s and they are less constant with depth compared to the "old" basins. In addition, no upward and downward trend has been observed. To conclude, almost all sediments in "old" (no. 63 and 207) and all in "new" (no. 13 and 211) basins are well-sorted sands, clean sands and gravel mixtures according to Table 2 (see section 5.5.2) with good hydraulic conductivity, thus generally the infiltration capacity should not be reduced. The only exception is profile B in basin no. 63, where fraction is fine and the values indicate very fine sands, silt and clayey silt (also Table 2). In this case deterioration of infiltration capacity is very plausible.

7 Conclusions

The conclusions based on the aforementioned analysis and results can be presented in following order:

(1) Data from grain size analysis show homogeneous sediments in the "new" basins and inhomogeneous in

origin and represent altogether sand with a small addition of finer and coarser grains. The clear dependence is well seen that in facilities, where sand has been washed and changed the amount of fine material (< 0.063 mm) is considerably smaller than in "old" basins with unchanged sand.

(2) Accumulation of fine grain content (< 0.063 mm) is definitely higher in "old" basins; however the amount of clay (< 0.002 mm) occurs in great values ca. 30 % in both "old" and "new" basins. What is worth pointing out the great differences in silt and clay content with depth have not been observed. Generally the contribution of clay content is quite constant with depth.

(3) The precipitation of iron occurs in different parts of the profiles both in "old" and "new" basins. In "old" basins no clear pattern is reported. However, in "new" facility no. 211 the iron content is observed on the greater depths. From the depth of 80 cm can be seen the transition between filter bed and underlying sediments with natural sequence of the soils, thus the infiltrate water might be kept in retain.

(4) The sediments are characterized by very low organic carbon content plausible cause by low organic productivity of microorganisms in the Vomb Lake or on the other hand could be a result of dissolution of organic matter by mineral matter. Distinct trend in organic and inorganic carbon content is not observed.

(5) It is difficult in this study to notice some direct connection between iron, organic and inorganic content and also hydraulic conductivity, thus other parameters and dependences should be given accurate researches.

(6) Differences in the geology can explain partly the variations in the infiltration capacity.

In a summary, while a couple of analysis have been done to find out what causes reduce infiltration capacity in particular basins at Vomb Water Plant, some conclusive discussion has been done to assume this process. The importance of factors cause clogging is well-demonstrated, but obtained parameters do not show clear influences on it, so they are still not well-understood.
To sum up, in the four infiltration basins in Vomb Water Plant some differences in all parameters and also geology are distinguished, but they do not give enough explanation connected to reduced infiltration capacity of basins. My suggestion is checking the washing sand machine if it works in proper way. Moreover, scraping the filter to improve infiltration capacity in basins where this procedure has not been required can even deteriorate efficiency of filter to a deteriorate degree. The effect of scraping will not be meaningful if the filter bed is mature, thus before analyze of the bed maturity should be done.

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List of Figures:

List of Tables:

APPENDIXES

List of Appendixes:

1 Field stratigraphic description.
2 Results of sieving analyses (20-0.063 µm) in %.
3 Statistical parameters.
4 Example of the result of the fine grain analysis of a sample from basin no. 207A at 2 to 10 cm.
5 Results of the fine grain analysis (0.063-0.002 mm).
6 Results of iron content determination.
7 Hydraulic conductivity according to Hazen formula.
8 Results of the organic (C_{org}) and inorganic (C_{inorg}).

Appendix 1

Field stratigraphic description

A) "old" basins (no. 207 and 63)

Basin	Depth (cm)	Name of the soil	Symbol of the soil[1]	Color
207A	0-2	Organic layer	-	-
	2-25	Medium sand	Sa	Yellow-brown
	25-70	Gravelly sand	grSa	Yellow- brown
	70-100+	Coarse sand	Sa	Yellow- brown
207B	0-2	Organic layer	-	-
	2-16	Coarse sand	Sa	Yellow-brown
	16-35	Sandy gravel	saGr	Yellow-brown
	35-48	Medium sand	Sa	Yellow-brown
	48-105+	Coarse sand	Sa	Yellow-brown
207C	0-2	Organic layer	-	-
	2-25	Gravelly sand	grSa	Yellow-brown
	25-100	Medium-coarse sand	Sa	Yellow-brown
63A	0-12	Fine-medium sand	Sa	Yellow-brown
	12-23	Fine-medium sand	Sa	Yellow-brown
	23-56	Medium-fine sand	Sa	Yellow-brown
	56-66	Medium sand	Sa	Yellow-brown
	66-80	Medium sand	Sa	Yellow-brown
	80+	Coarse sand	Sa	Yellow-brown
63B	0-8	Fine sand	siSa	Yellow-brown
	8-18	Fine sand	siSa	Grey-yellow
	18-21	Fine sand	siSa	Yellow-brown
	21-22	Silt	Si	Reddish
	22-78	Fine sand	siSa	Yellow-brown
	78-85	Medium sand	Sa	Yellow-brown
	85-88	Silt	Si	Reddish
	88+	Medium sand	Sa	Yellow-brown
63C	0-8	Medium sand	Sa	Yellow-brown
	8-54	Medium-coarse sand	Sa	Brown
	54-58	Medium sand	Sa	Bright yellow
	58-78	Medium-coarse sand	Sa	Yellow-brown
	78-100	Medium sand	Sa	Brown-yellow
	100+	Fine to medium sand	Sa	Yellow-brown

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[1] According to ISO/CEN:Gr-gravel, Sa-sand, Si- silt, Cl- clay, gr- gravelly, sa-sandy, si- silty, ci-clayey (Eurocode No 7: Geotechnics, Commission of the European Communities, 1992; from Myślińska, 2001).

B) “new” basin (no. 211)

Basin	**Depth (cm)**	**Name of the soil**	**Symbol of the soil**	**Color**
211A	0-2	Organic layer	-	-
	2-100	Medium sand	Sa	Dark brown
	100+	Coarse-gravelly sand	grSa	Dark brown
211B	0-2	Organic layer	-	-
	2-77	Medium-coarse sand	Sa	Dark brown
	77+	Gravelly sand	grSa	Dark brown
211C	0-1	Organic layer	-	-
	1-85	Medium-coarse sand	Sa	Dark brown
	85-115+	Gravelly sand	grSa	Dark brown

Appendix 2

Results of sieving analyses (20-0.063 µm) in %

A) “old” basins

Infiltration basin no. 63

Basin	Depth [cm]	Gravel	Sand	Silt	Clay	Name of the soil
63A	1	2	3	4	5	
	0-10	0.10	98.26	1.64	0.00	Well-sorted, slightly silty sand
	10-20	0.03	99.27	0.70	0.00	Well-sorted sand
	25-35	0.04	99.54	0.42	0.00	Well-sorted sand
	40-50	0.00	99.80	0.20	0.00	Well-sorted sand
	55-65	0.17	99.47	0.37	0.00	Well-sorted sand
	75-85	9.83	89.63	0.53	0.00	Well-sorted, gravelly sand
63B	1	2	3	4	5	
	0-5	0.40	93.87	5.73	0.00	Well-sorted, silty sand
	5-15	0.03	95.66	4.31	0.00	Well-sorted, silty sand
	21-22	0.00	91.39	8.61	0.00	Well-sorted, silty sand
	25-30	0.00	95.97	4.03	0.00	Well-sorted, silty sand
	45-50	0.00	95.45	4.55	0.00	Well-sorted, silty sand
	70-78	0.06	86.08	13.86	0.00	Well-sorted, silty sand
	78-85	0.00	98.90	1.10	0.00	Well-sorted, sand
	85-88	0.00	49.41	50.59	0.00	Well-sorted sandy silt
63C	1	2	3	4	5	
	0-8	3.73	95.15	1.12	0.00	Well-sorted, slightly gravelly sand
	10-20	4.19	94.34	1.47	0.00	Well-sorted, slightly gravelly sand
	30-40	4.42	94.38	1.20	0.00	Well-sorted, slightly gravelly sand
	54-58	1.05	98.55	0.40	0.00	Well-sorted sand
	60-70	1.55	96.08	2.37	0.00	Well-sorted, slightly silty sand
	80-90	0.24	98.33	1.43	0.00	Well-sorted sand

Infiltration basin no. 207

Basin	Depth [cm]	Gravel	Sand	Silt	Clay	Name of the soil
207A	1	2	3	4	5	
	2-10	4.18	94.38	1.44	0.00	Well-sorted, slightly gravelly sand
	10-20	5.24	93.20	1.56	0.00	Well-sorted, slightly gravelly sand
	20-40	1.77	96.62	1.62	0.00	Well-sorted sand
	60-70	2.80	95.83	1.37	0.00	Well-sorted, slightly gravelly sand
	80-90	0.51	99.15	0.34	0.00	Well-sorted sand
207B	1	2	3	4	5	
	2-10	18.64	80.56	0.80	0.00	Well-sorted, gravelly sand
	20-30	51.13	48.28	0.59	0.00	Well-sorted, sandy gravel
	40-50	16.87	82.35	0.79	0.00	Well-sorted, gravelly sand
	50-60	6.06	92.56	1.37	0.00	Well-sorted, slightly gravelly sand
	80-90	17.41	80.49	2.10	0.00	Well-sorted, gravelly sand
207C	1	2	3	4	5	
	2-10	3.18	93.92	2.90	0.00	Well-sorted, slightly gravelly and silty sand
	30-40	18.40	79.40	2.05	0.00	Well-sorted, gravelly sand
	50-60	49.65	48.69	1.66	0.00	Unsorted diamict
	80-90	11.96	87.09	0.95	0.00	Well-sorted, gravelly sand

B) “new” basins (no 13 and 211)

Depth [cm]	**Sample**	**Gravel**	**Sand**	**Silt**	**Clay**	**Name of the soil**
13		1	2	3	4	5
0-5	P7/28	4.25	94.72	1.03	0.00	Well-sorted, slightly gravelly sand
0-5	P6/3	5.03	93.60	1.37	0.00	Well-sorted, slightly gravelly sand
15	P1/22	5.35	94.01	0.64	0.00	Well-sorted, slightly gravelly sand
20	P8/29	3.33	96.21	0.46	0.00	Well-sorted, slightly gravelly sand
30	P2/23	4.20	95.09	0.71	0.00	Well-sorted, slightly gravelly sand
50	P10/12	4.40	95.03	0.57	0.00	Well-sorted, slightly gravelly sand
30	P9/4	3.06	96.52	0.42	0.00	Well-sorted, slightly gravelly sand
50	P3/24	5.38	93.98	0.64	0.00	Well-sorted, slightly gravelly sand
70	P4/32	5.26	94.02	0.72	0.00	Well-sorted, slightly gravelly sand
70	P11/27	4.42	95.21	0.37	0.00	Well-sorted, slightly gravelly sand
100	P5/4	5.90	93.32	0.78	0.00	Well-sorted, slightly gravelly sand
100	P12/27	3.37	96.18	0.45	0.00	Well-sorted, slightly gravelly sand
140	P13/24	7.63	90.78	1.59	0.00	Well-sorted, slightly gravelly sand

Basin	**Depth [cm]**	**Gravel**	**Sand**	**Silt**	**Clay**	**Name of the soil**
211A	1	2	3	4	5	
	2-10	1.88	97.24	0.89	0.00	Well-sorted sand
	20-30	1.86	97.70	0.44	0.00	Well- sorted sand
	40-50	1.64	97.91	0.45	0.00	Well-sorted sand
	60-70	2.14	97.38	0.49	0.00	Well-sorted, slightly gravelly sand
	80-90	17.60	81.22	1.18	0.00	Well-sorted, gravelly sand
	100-110	45.80	52.87	1.33	0.00	Unsorted, Diamict
211B	1	2	3	4	5	
	8-10	1.76	96.51	1.73	0.00	Well- sorted sand
	20-30	1.52	97.28	1.20	0.00	Well- sorted sand
	40-50	2.10	96.86	1.04	0.00	Well- sorted sand
	60-70	1.74	97.52	0.75	0.00	Well-sorted sand
	80-90	5.70	90.57	3.73	0.00	Well-sorted, slightly gavelly and silty sand
211C	1	2	3	4	5	
	2-10	1.97	96.47	1.56	0.00	Well- sorted sand
	20-30	1.78	96.88	1.34	0.00	Well- sorted sand
	40-50	1.69	96.62	1.69	0.00	Well- sorted sand
	60-70	1.99	96.53	1.48	0.00	Well- sorted sand
	100	17.40	79.20	3.40	0.00	Well-sorted, gravelly and slightly silty sand

Appendix 3 Statistical parameters

A) “old” basins (no. 63 and 207)

Basin	Depth (cm)	Avarage grain size $(d_{25}+d_{50}+d_{75})/3$	Sorting $\sqrt{(d_{75}/d_{25})}$	Sorting coefficient		
				< 2.5 well sorted	2.5 – 3.5 not well sorted	> 3.5 unsorted
63A	1	2	3	4	5	6
	0-10	0.27	1.31	+	-	-
	10-20	0.27	1.25	+	-	-
	25-35	0.31	1.34	+	-	-
	40-50	0.23	1.26	+	-	-
	55-65	0.32	1.44	+	-	-
	75-85	0.58	1.80	+	-	-
63 B	1	2	3	4	5	6
	0-5	0.15	1.45	+	-	-
	5-15	0.15	1.42	+	-	-
	21-22	0.13	1.37	+	-	-
	25-30	0.14	1.33	+	-	-
	45-50	0.14	1.37	+	-	-
	70-78	0.14	1.50	+	-	-
	78-85	0.25	1.27	+	-	-
	85-88	0.56	1.28	+	-	-
63 C	1	2	3	4	5	6
	0-8	0.47	1.72			
	10-20	0.53	1.66	+	-	-
	30-40	0.57	1.63	+	-	-
	54-58	0.42	1.41	+	-	-
	60-70	0.48	1.82	+	-	-
	80-90	0.37	1.61	+	-	-
207 A	1	2	3	4	5	6
	2-10	0.69	1.35	+	-	-
	10-20	0.72	1.38	+	-	-
	20-40	0.58	1.27	+	-	-
	60-70	0.56	1.31	+	-	-
	80-90	0.56	1.29	+	-	-
207 B	1	2	3	4	5	6
	2-10	1.08	1.53	+	-	-
	20-30	4.23	3.16	-	+	-
	40-50	0.88	1.64	+	-	-
	50-60	0.75	1.50	+	-	-
	80-90	0.84	1.59	+	-	-
207 C	1	2	3	4	5	6
	2-10	0.31	1.28	+	-	-
	30-40	0.98	1.60	+	-	-
	50-60	4.26	3.75	-	-	+
	80-90	0.73	1.36	+	-	-

B) “new” basins (no. 211 and 13)

Basin	**Depth (cm)**	**Avarage grain size $(d_{25}+d_{50}+d_{75})/3$**	**Sorting $\sqrt{(d_{75}/d_{25})}$**	**Sorting coefficient**		
				< 2.5 well sorted	**2.5 – 3.5 not well sorted**	**> 3.5 unsorted**
211 A	1	2	3	4	5	6
	2-10	0.60	1.48	+	-	-
	20-30	0.61	1.43	+	-	-
	40-50	0.60	1.46	+	-	-
	60-70	0.62	1.47	+	-	-
	80-90	0.65	1.55	+	-	-
	100-110	4.07	4.46	-	-	+
211 B	1	2	3	4	5	6
	8-10	0.52	1.56	+	-	-
	20-30	0.49	1.53	+	-	-
	40-50	0.62	1.44	+	-	-
	60-70	0.60	1.45	+	-	-
	80-90	0.73	1.55	+	-	-
211 C	1	2	3	4	5	6
	2-10	0.56	1.57	+	-	-
	20-30	0.56	1.56	+	-	-
	40-50	0.56	1.56	+	-	-
	60-70	0.55	1.56	+	-	-
	100	0.76	1.98	+	-	-
13	1	2	3	4	5	6
P7/28	*0-5*	0.61	1.65	+	-	-
P6/3	*0-5*	0.66	1.53	+	-	-
P1/22	*15*	0.65	1.57	+	-	-
P8/29	*20*	0.57	1.68	+	-	-
P2/23	*30*	0.64	1.56	+	-	-
P10/12	*50*	0.64	1.59	+	-	-
P9/4	*30*	0.54	1.70	+	-	-
P3/24	*50*	0.67	1.52	+	-	-
P4/32	*70*	0.67	1.53	+	-	-
P11/27	*70*	0.64	1.60	+	-	-
P5/4	*100*	0.68	1.53	+	-	-
P12/27	*100*	0.58	1.66	+	-	-
P13/24	*140*	0.62	1.75	+	-	-

Appendix 4

Example of the result of the fine grain analysis of a sample from basin no. 207A at 2 to 10 cm

(size table, cumulative finer mass percent vs. diameter and
mass frequency vs. diameter plots)

A) Size table

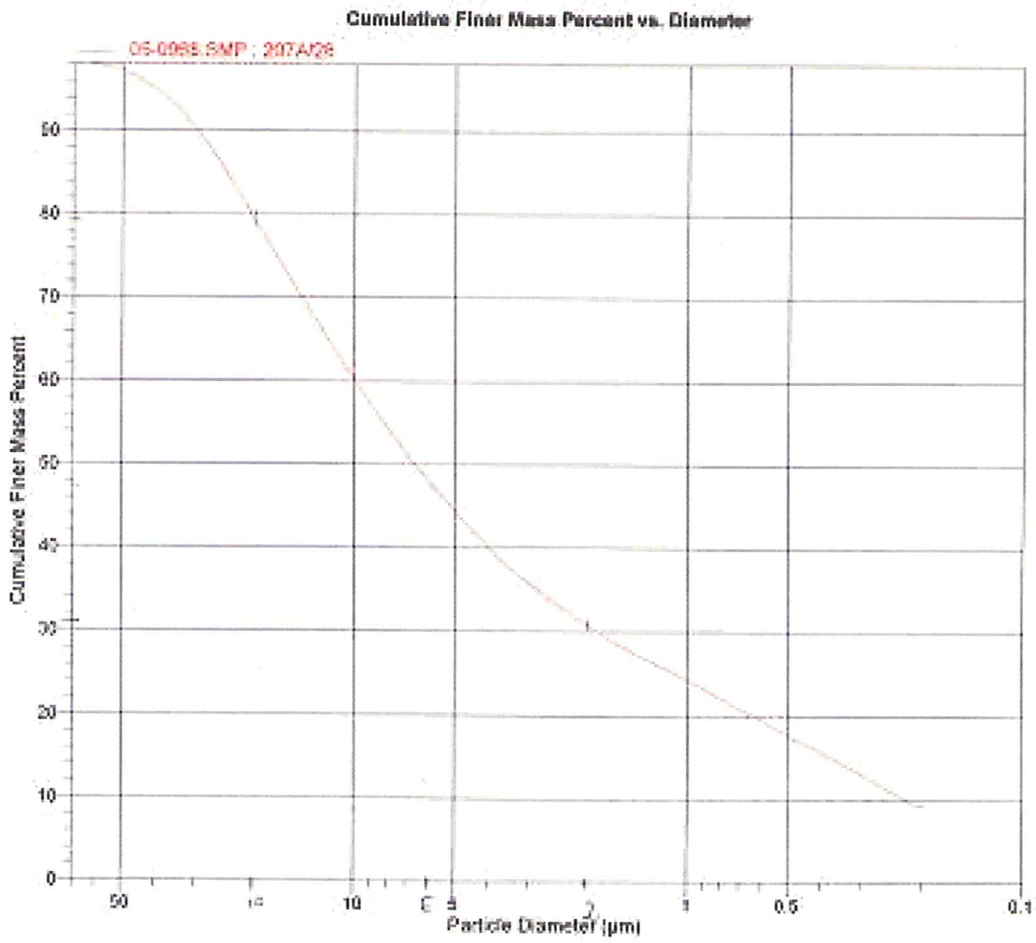
Test Number: 1
Analyzed: 2005-06-20 13:05:26
Reported: 2005-06-20 13:34:45
Liquid Visc: 0.7232 mPa·s
Analysis Temp: 35.0 °C
Full Scale Mass: 100.0 %

Analysis Type: High Speed(Adj)
Run Time: 0:25 hrs:min
Sample Density: 2.650 g/cm³
Liquid Density: 0.9941 g/cm³
Base/Full Scale: 130 / 75 kCnts/s
Reynolds Number: 0.37

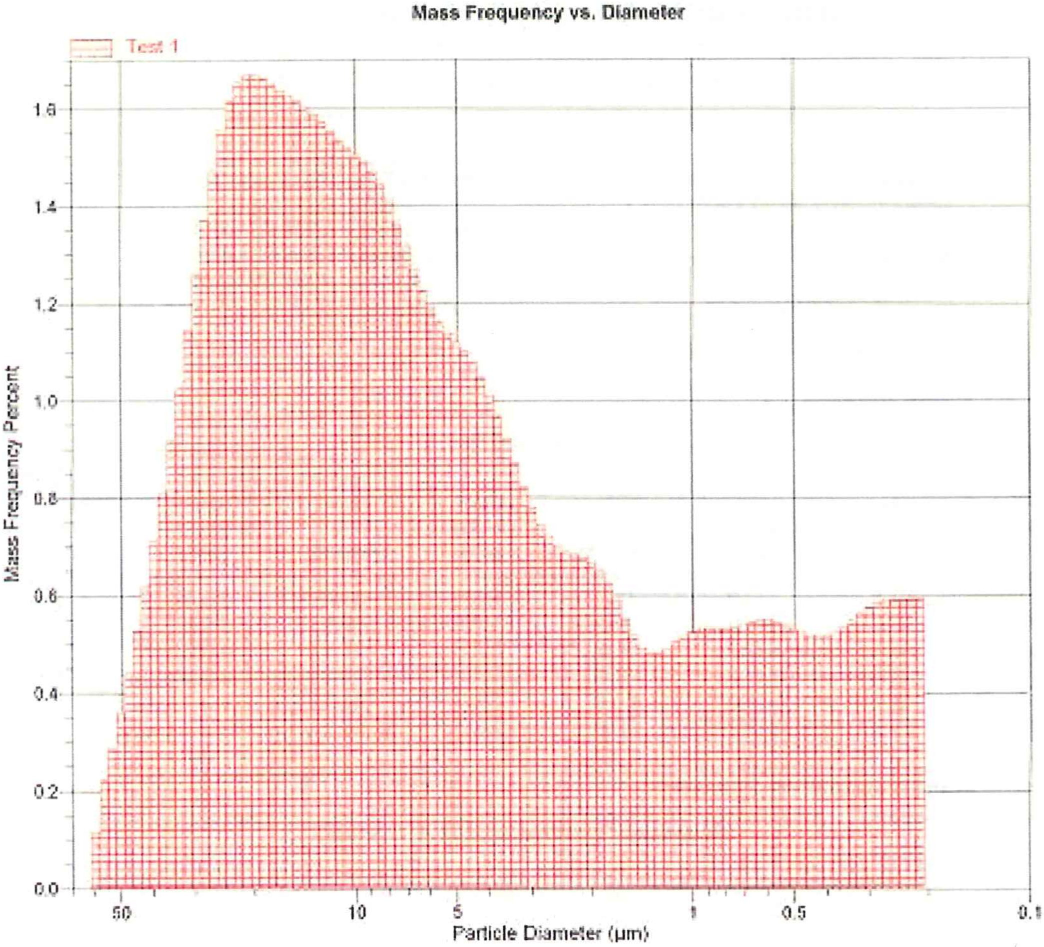
Report by Size Table

Low Diameter (µm)	Cumulative Mass Finer (Percent)	Low Diameter (µm)	Cumulative Mass Finer (Percent)	Low Diameter (µm)	Cumulative Mass Finer (Percent)	Low Diameter (µm)	Cumulative Mass Finer (Percent)
60.00	97.9	15.00	71.2	3.000	35.7	0.500	17.8
50.00	97.2	10.00	60.2	2.000	30.8	0.400	15.7
40.00	95.1	8.000	54.5	1.500	27.8	0.300	13.0
30.00	90.3	6.000	48.0	1.000	24.2	0.200	9.2
25.00	85.8	5.000	44.4	0.800	22.2		
20.00	79.4	4.000	40.2	0.600	19.5		

B) Cumulative finer mass percent vs. diameter



C) Mass frequency vs. diameter



Appendix 5 **Results of the fine grain analysis (0.063-0.002 mm)**

The results are compiled in two tables for each basin. First, it is a sum of percentage of classes set to 100 %, which are distinguish in the material less than 0.063 mm. However, the second table is different and presents data given also in %, but they constitute some % of the total amount of fine grain according to sieving analysis, thus they are not computed to 100 %.

A) "old" basins **Infiltration basin no. 63**

Basin	**Depth (cm)**	**Fine grain according to sieving test (%)**	**Classes of fine grain analysis (µm)**							
			Silt (%)							**Clay (%)**
			Coarse				**Medium**		**Fine**	
			60-50	***50-40***	***40-30***	***30-20***	***20-10***	***10-5***	***5-2***	***< 2***
63 A	*0-10*	1.64	5.3	4.6	6.5	8.2	12.4	12.8	16.6	33.6
	25-35	0.42	3.6	1.9	5.1	8.3	16.7	17.6	17.2	29.6
	75-88	0.53	2.7	4.6	7.9	12.5	18.8	15.7	11.6	26.2
63 B	*0-5*	5.73	22.7	18.4	18.0	9.8	6.5	4.2	4.1	16.3
	5-15	4.31	21.5	16.1	15.4	7.5	3.0	2.4	3.5	30.6
	21-22	8.61	0.4	2.9	6.3	8.3	5.8	2.3	3.0	71.0
	25-30	4.03	6.8	5.3	5.7	4.8	8.1	7.8	13.0	48.5
	45-50	4.55	24.5	21.9	20.8	9.3	4.2	2.8	4.4	12.1
	70-78	13.86	19.9	15.9	15.9	9.6	6.9	5.6	6.2	20.0
	85-88	50.59	10.0	12.8	21.9	24.4	14.2	3.6	2.3	10.8
63 C	*0-8*	1.12	9.5	8.2	10.6	11.7	14.5	11.1	9.4	25.0
	10-20	1.47	3.1	2.5	5.3	9.6	16.2	1.6	18.5	34.2
	54-58	0.40	16.2	8.6	9.4	9.6	13.0	9.9	9.2	24.1
	60-70	2.37	2.1	2.6	4.2	7.2	13.8	14.9	16.5	38.7

Basin	**Depth (cm)**	**Fine grain according to sieving test (%)**	**% of fine grain set to value from sieving test**			
			Silt (%)			**Clay (%)**
			Coarse (60-20 µm)	**Medium** (20-5 µm)	**Fine** (5-2 µm)	**< 2 µm**
63 A	*0-10*	1.64	0.41	0.41	0.27	0.55
	25-35	0.42	0.08	0.14	0.07	0.13
	75-88	0.53	0.15	0.18	0.06	0.14
63 B	*0-5*	5.73	3.95	0.61	0.23	0.93
	5-15	4.31	2.61	0.23	0.15	1.32
	21-22	8.61	1.54	0.70	0.26	6.11
	25-30	4.03	0.91	0.64	0.52	1.95
	45-50	4.55	3.48	0.32	0.20	0.55
	70-78	13.86	8.50	1.73	0.86	2.77
	85-88	50.59	34.96	9.0	1.16	5.46
63 C	*0-8*	1.12	0.45	0.29	0.10	0.28
	10-20	1.47	0.30	0.26	0.27	0.50
	54-58	0.40	0.18	0.09	0.04	0.10
	60-70	2.37	0.38	0.68	0.39	0.92

Infiltration basin no. 207

Basin	Depth (cm)	Fine grain according to sieving test (%)	Classes of fine grain analysis (µm)							
			Silt (%)							Clay
			Coarse				Medium		Fine	(%)
			60-50	50-40	40-30	30-20	20-10	10-5	5-2	< 2
207 A	*2-10*	4.18	2.8	2.1	4.8	10.9	19.2	15.8	13.6	30.8
	10-20	5.24	1.8	2.4	5.5	11.8	20.7	15.3	14.1	28.4
	20-40	1.77	0	2.0	5.7	10.4	18.4	16.9	15.9	30.7
	60-70	2.80	0	1.7	4.1	8.6	16.5	15.1	20.2	33.8
207 B	*50-60*	6.06	0.9	2.1	4.5	8.5	17.1	16.7	16.4	33.8
	80-90	17.41	0.6	2.0	4.7	9.4	18.9	15.7	15.3	33.4
207 C	*2-10*	3.18	1.6	1.6	3.3	7.5	17.3	17.9	22.1	28.7
	30-40	18.4	1.2	1.7	4.3	9.4	1.8	15.0	14.3	33.0
	50-60	49.65	0	1.4	4.5	10.7	19.8	14.9	13.3	35.4
	80-90	11.96	3.0	3.3	6.2	11.5	22.9	19.5	20.3	18.3

Basin	Depth (cm)	Fine grain according to sieving test (%)	% of fine grain set to value from sieving test			
			Silt (%)			Clay (%) < 2 µm
			Coarse (60-20 µm)	Medium (20-5 µm)	Fine (5-2 µm)	
207 A	*2-10*	4.18	0.86	1.46	0.57	1.29
	10-20	5.24	1.13	1.89	0.74	1.49
	20-40	1.77	0.32	0.62	0.28	0.54
	60-70	2.80	0.40	0.88	0.56	0.95
207 B	*50-60*	6.06	0.97	2.05	0.99	2.05
	80-90	17.41	2.91	6.02	2.66	5.81
207 C	*2-10*	3.18	0.44	1.11	6.95	0.93
	30-40	18.4	3.05	3.09	2.60	6.07
	50-60	49.65	8.24	17.23	6.60	17.58
	80-90	11.96	2.87	5.07	2.43	2.19

B) "new" basins

Infiltration basin no. 13

Basin	Depth (cm)	Fine grain according to sieving test (%)	Classes of fine grain analysis (µm)							
			Silt (%)							Clay
			Coarse				Medium		Fine	(%)
			60-50	50-40	40-30	30-20	20-10	10-5	5-2	< 2
13	*0-5(P6)*	1.37	2.1	3.7	6.0	9.6	17.6	15.2	16.3	29.5
	50(P10)	0.57	3.4	4.8	7.8	10.2	17.4	15.8	15.1	25.5
	70(P4)	0.72	4.2	2.3	5.8	9.3	14.4	16.4	14.2	33.4
	140(P13)	1.59	2.1	4.8	8.8	11.4	14.7	12.2	13.8	32.2

Basin	Depth (cm)	Fine grain according to sieving test (%)	% of fine grain set to value from sieving test			
			Silt (%)			Clay (%) < 2 µm
			Coarse (60-20 µm)	Medium (20-5 µm)	Fine (5-2 µm)	
13	*0-5(P6)*	1.37	0.29	0.45	0.22	0.40
	50(P10)	0.57	0.15	0.19	0.09	0.15
	70(P4)	0.72	0.16	0.22	0.10	0.24
	140(P13)	1.59	0.43	0.43	0.22	0.51

Infiltration basin no. 211

Basin	Depth (cm)	Fine grain according to sieving test (%)	Classes of fine grain analysis (µm)							
			Silt (%)							Clay (%)
			Coarse				Medium		Fine	
			60-50	50-40	40-30	30-20	20-10	10-5	5-2	< 2
211 A	*2-10*	0.89	0	0	3.8	14.0	20.0	13.9	14.3	34.0
	20-30	0.44	5.2	3.0	4.1	10.6	14.0	12.3	15.1	35.7
	40-50	0.45	2.8	2.7	6.2	7.1	10.7	12.2	16.9	41.4
	60-70	0.49	3.5	2.8	5.6	8.2	16.6	17.4	17.8	28.1
	80-90	1.18	3.0	1.1	5.3	11.8	20.1	15.3	14.6	28.8
	100-110	1.33	4.5	4.2	7.7	12.1	19.0	16.0	15.0	21.5
211 B	*8-10*	1.73	2.0	1.8	3.5	6.3	12.2	15.3	21.2	37.7
	20-30	1.20	1.7	2.5	4.5	7.8	14.6	12.5	26.0	30.4
	40-50	1.04	1.5	2.4	4.8	8.3	15.4	17.6	20.0	29.5
	60-70	0.75	2.8	1.9	4.2	7.3	16.1	17.7	21.2	28.8
	80-90	3.73	2.2	2.5	4.7	8.7	14.9	13.0	13.3	40.7
211 C	*2-10*	1.56	0.7	2.9	5.8	10.1	13.7	15.9	17.0	33.9
	20-30	1.34	1.1	2.0	3.8	5.4	12.0	15.0	21.7	39.0
	40-50	1.69	6.8	4.4	5.5	5.7	10.0	13.7	20.4	33.5
	60-70	1.48	2.5	2.6	4.3	6.5	12.4	14.8	21.8	35.1
	100	3.40	1.1	0.1	1.4	4.6	14.6	18.5	22.8	36.9

Basin	**Depth (cm)**	**Fine grain according to sieving test (%)**	**% of fine grain set to value from sieving test**			
			Silt (%)			**Clay (%) < 2 µm**
			Coarse (60-20 µm)	**Medium (20-5 µm)**	**Fine (5-2 µm)**	
211 A	*2-10*	0.89	0.16	0.30	0.13	0.30
	20-30	0.44	0.10	0.12	0.07	0.16
	40-50	0.45	0.08	0.10	0.08	0.19
	60-70	0.49	0.10	0.17	0.09	0.14
	80-90	1.18	0.25	0.42	0.17	0.34
	100-110	1.33	0.38	0.47	0.20	0.29
211 B	*8-10*	1.73	0.24	0.48	0.37	0.65
	20-30	1.20	0.20	0.33	0.31	0.36
	40-50	1.04	0.18	0.34	0.21	0.31
	60-70	0.75	0.12	0.25	0.16	0.22
	80-90	3.73	0.68	1.06	0.50	1.52
211 C	*2-10*	1.56	0.30	0.46	0.27	0.53
	20-30	1.34	0.16	0.36	0.29	0.52
	40-50	1.69	0.38	0.40	0.34	0.57
	60-70	1.48	0.24	0.40	0.32	0.52
	100	3.40	0.24	1.12	0.78	1.25

Appendix 6

Results of iron content determination

"old" basins (no. 63 and 207)

Basin	Depth (cm)	Iron content (g/kg)
63A	0-10	29.7
	10-20	33.8
	25-35	19.9
	40-50	11.9
	55-65	18.3
	75-85	30.8
63B	0-5	34.3
	5-15	52.8
	21-22	69.5
	25-30	34.0
	45-50	11.6
	70-78	45.8
	78-85	21.7
	85-88	72.5
63C	0-8	48.3
	10-20	39.5
	30-40	47.4
	54-58	33.8
	60-70	36.3
	80-90	36.3
207A	2-10	66.2
	10-20	45.5
	30-40	51.0
	60-70	28.3
	80-90	9.95
207B	2-10	31.2
	20-30	35.2
	40-50	38.9
	50-60	32.3
	80-90	36.9
207C	2-10	29.6
	30-40	51.9
	50-60	54.2
	80-90	36.7

„new" basins (no. 211 and 13)

Basin	Depth (cm)	Iron content (g/kg)
211 A	2-10	33,4
	20-30	38,3
	40-50	30,8
	60-70	28,4
	80-90	47,2
	100-110	54,2
211 B	8-10	37,6
	20-30	33,5
	40-50	31,5
	60-70	34,2
	80-90	55,0
211 C	2-10	37,8
	20-30	35,7
	40-50	36,5
	60-70	31,2
	100-110	52.3
13		
P7/28	0-5	18,8
P6/3	0-5	26,1
P1/22	15	27,1
P8/29	20	18,8
P2/23	30	27,4
P10/12	50	15,2
P9/4	30	16,6
P3/24	50	28,9
P4/32	70	26,1
P11/27	70	18,8
P5/4	100	26,3
P12/27	100	17,1
P13/24	140	24,8

Appendix 7

Hydraulic conductivity according to Hazen formula

A) “old” basins

Infiltration basin no. 63

Basin	Depth (cm)	d_{10} (mm)	Hydraulic conductivity according to Hazen formula* (m/s)
63A	**1**	**2**	**3**
	0-10	0.125	$2 * 10^{-4}$
	10-20	0.125	$2 * 10^{-4}$
	25-35	0.18	$3 * 10^{-4}$
	40-50	0.125	$2 * 10^{-4}$
	55-65	0.18	$3 * 10^{-4}$
	75-85	0.18	$3 * 10^{-4}$
63B	**1**	**2**	**3**
	0-5	0.063	$4 * 10^{-5}$
	5-15	0.063	$4 * 10^{-5}$
	21-22	0.063	$4 * 10^{-5}$
	25-30	0.063	$4 * 10^{-5}$
	45-50	0.063	$4 * 10^{-5}$
	70-78	-	-
	78-85	0.125	$2 * 10^{-4}$
	85-88	-	-
63C	**1**	**2**	**3**
	0-8	0.125	$2 * 10^{-4}$
	10-20	0.18	$3 * 10^{-4}$
	30-40	0.18	$3 * 10^{-4}$
	54-58	0.18	$3 * 10^{-4}$
	60-70	0.18	$3 * 10^{-4}$
	80-90	0.18	$3 * 10^{-4}$

Infiltration basin no. 207

Basin	**Depth (cm)**	**d_{10} (mm)**	**Hydraulic conductivity according to Hazen formula* (m/s)**
207A	**1**	**2**	**3**
	2-10	0.335	$1 * 10^{-3}$
	10-20	0.335	$1 * 10^{-3}$
	20-40	0.335	$1 * 10^{-3}$
	60-70	0.335	$1 * 10^{-3}$
	80-90	0.335	$1 * 10^{-3}$
207B	**1**	**2**	**3**
	2-10	0.5	$3 * 10^{-3}$
	20-30	0.5	$(d_{60}/d_{10}>5)$
	40-50	0.335	$1 * 10^{-3}$
	50-60	0.335	$1 * 10^{-3}$
	80-90	0.335	$1 * 10^{-3}$
207C	**1**	**2**	**3**
	2-10	0.18	$3 * 10^{-4}$
	30-40	0.335	$1 * 10^{-3}$
	50-60	0.335	$(d_{60}/d_{10}>5)$
	80-90	0.335	$1 * 10^{-3}$

B) “new” basins

Infiltration basin no. 13

Basin	**Depth (cm)**	**d_{10} (mm)**	**Hydraulic conductivity according to Hazen formula*** *(m/s)*
P7/28	*0-5*	0.18	$3 * 10^{-4}$
P6/3	*0-5*	0.25	$6 * 10^{-4}$
P1/22	*15*	0.25	$6 * 10^{-4}$
P8/29	*20*	0.18	$3 * 10^{-4}$
P2/23	*30*	0.25	$6 * 10^{-4}$
P10/12	*50*	0.25	$6 * 10^{-4}$
P9/4	*30*	0.18	$3 * 10^{-4}$
P3/24	*50*	0.25	$6 * 10^{-4}$
P4/32	*70*	0.25	$6 * 10^{-4}$
P11/27	*70*	0.25	$6 * 10^{-4}$
P5/4	*100*	0.25	$6 * 10^{-4}$
P12/27	*100*	0.18	$3 * 10^{-4}$
P13/24	*140*	0.18	$3 * 10^{-4}$

Infiltration basin no. 211

Basin	Depth (cm)	d_{10} (mm)	Hydraulic conductivity according to Hazen formula* (m/s)
211A	1	2	3
	2-10	0.25	$6 * 10^{-4}$
	20-30	0.25	$6 * 10^{-4}$
	40-50	0.25	$6 * 10^{-4}$
	60-70	0.25	$6 * 10^{-4}$
	80-90	0.25	$6 * 10^{-4}$
	100-110	0.25	$(d_{60}/d_{10}>5)$
211B	1	2	3
	8-10	0.18	$3 * 10^{-4}$
	20-30	0.18	$3 * 10^{-4}$
	40-50	0.25	$6 * 10^{-4}$
	60-70	0.25	$6 * 10^{-4}$
	80-90	0.125	$(d_{60}/d_{10}>5)$
211C	1	2	3
	2-10	0.25	$6 * 10^{-4}$
	20-30	0.25	$6 * 10^{-4}$
	40-50	0.25	$6 * 10^{-4}$
	60-70	0.25	$6 * 10^{-4}$
	100-110	0.18	$3 * 10^{-4}$

* $K = 10^{-2} * d^{2}_{10}$ (Craig, 2001)

Appendix 8

Results of the organic (C_{org}) and inorganic (C_{inorg}) carbon determination

A) "old" basins

Infiltration basin no. 63

Basin	**Depth (cm)**	**C_{org} (%)**	**C_{inorg} (%)**
63A	1	2	3
	0-10	0.55	1.96
	10-20	0.31	1.61
	25-35	0.26	3.60
	40-50	0.27	3.97
	55-65	0.46	2.57
	75-85	0.51	0.69
average		**0.39**	**2.40**
63B	1	2	3
	0-5	0.60	0.35
	5-15	0.51	0.60
	21-22	1.95	0.28
	25-30	0.59	0.25
	45-50	1.99	4.53
	70-78	0.53	0.23
	78-85	0.45	0.27
	85-88	-	-
average		**0.95**	**0.93**
63C	1	2	3
	0-8	0.52	1.85
	10-20	0.50	2.36
	30-40	0.50	1.94
	54-58	0.52	5.63
	60-70	0.59	1.10
average		**0.52**	**2.18**

Infiltration basin no. 207

Basin	Depth (cm)	C_{org}(%)	C_{inorg}(%)
207A	1	2	3
	2-10	0.76	0.67
	10-20	0.73	0.18
	20-40	0.71	0.18
	60-70	0.63	1.72
	80-90	0.70	3.34
average		**0.71**	**1.22**
207B	1	2	3
	2-10	0.60	5.46
	20-30	0.96	4.63
	40-50	0.82	3.90
	50-60	2.40	1.95
	80-90	0.97	0.27
average		**1.15**	**3.24**
207C	1	2	3
	2-10	0.77	0.10
	30-40	0.85	0.31
	50-60	1.36	2.21
	80-90	0.62	3.83
		0.90	**1.61**

B) "new" basins

Infiltration basin no. 13

Basin	Depth (cm)	C_{org} (%)	C_{inorg} (%)
13	1	2	3
P7/28	0-5	0.47	0.31
P6/3	0-5	0.36	0.73
P1/22	15	1.59	0.49
P8/29	20	0.49	0.75
P2/23	30	0.44	0.44
P10/12	50	0.43	0.60
P9/4	30	0.32	0.80
P3/24	50	0.63	0.45
P4/32	70	0.45	0.45
P11/27	70	0.38	0.76
P5/4	100	0.52	0.61
P12/27	100	0.42	0.51
P13/24	140	0.66	0.33
average		**0.55**	**0.56**

Infiltration basin no. 211

Basin	Depth (cm)	C_{org} (%)	C_{inorg} (%)
211A	1	2	3
	2-10	0.44	0.62
	20-30	0.38	0.76
	40-50	0.43	0.61
	60-70	0.48	0.48
	80-90	0.74	2.33
	100-110	3.28	4.79
average		**0.96**	**1.60**
211B	1	2	3
	2-10	0.43	0.43
	20-30	0.43	0.43
	40-50	0.58	0.42
	60-70	0.53	0.35
	80-90	1.00	0.18
average		**0.59**	**0.36**
211C	1	2	3
	2-10	0.68	0.29
	20-30	0.43	1.91
	40-50	0.64	0.37
	60-70	0.53	0.35
	100	1.02	0.28
average		**0.66**	**0.64**

Source: Myślińska, E., 2001. Laboratoryjne badania gruntów, PWN.

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