Onderzoek naar besluitvorming rond aankoop infiltratie meetapparatuur

Een afstudeeropdracht van Van Hall Larenstein
In opdracht van Eijkelkamp Agrisearch Equipment
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Infiltratie, meetapparatuur, stroomschema.

Samenvatting

Eijkelkamp Agrisearch Equipment is een bedrijf dat apparatuur fabriceert en distribueert, waarmee allerhande zaken kunnen worden gemeten met betrekking tot water en bodem, waaronder infiltratiemeetapparatuur. Infiltratie is het proces waarbij water uit de atmosfeer de bodem binnendringt. Het vergt echter veel kennis om te bepalen welke methode het meest geschikt is om infiltratie te meten in een bepaalde situatie, en deze kennis is in de literatuur sterk gefragmenteerd. Daarom moet informatie gebundeld worden. Om dit te bereiken willen zij een stroomschema, voorzien van achterliggende informatie in de vorm van een rapport, waarmee iemand eenvoudig tot de juiste keuze zal kunnen komen.

Het is belangrijk om het stroomschema aan de juiste personen aan te bieden, daarom moet bekend zijn waar zij hun keuze op baseren en waar zij hun informatie vandaan halen. Om dit te onderzoeken, is een enquête opgesteld. Om de onderzoeksmethode verantwoord vorm te geven, is gekeken naar de methode van consumentenonderzoeken, er is gekozen voor een kwalitatief onderzoek.
Het doel van de uitgevoerde literatuurstudie was enerzijds het creëren van een naslagwerk waarin de meest relevante informatie te vinden is over de verschillende factoren en de verschillende apparatuur. Dit naslagwerk, dat de titel ‘Measuring infiltration by means of…?’ heeft gekregen, moest een toegankelijk, compleet en duidelijk overzicht geven voor de leek. Het tweede doel van de uitgevoerde literatuurstudie was om uit te vinden wat de belangrijkste factoren zijn die invloed hebben op het infiltratieproces. Deze informatie is gebruikt voor het opzetten van het stroomschema.

Nadat de enquête is uitgezet, zijn de resultaten geanalyseerd. Door 5 (van de 12) respondenten wordt gezegd dat hun beslissing van de klant af hangt, met andere woorden dat zij helemaal geen invloed hebben op de beslissing. De helft (8 van de 16) respondenten, verklaren zelf voldoende kennis in huis te hebben om hun beslissing te nemen. In ruim 45% van de gevallen blijkt dat de respondent zelf degene is die de beslissing neemt.

De eindgebruikers en doorverkopers, die op de site van Eijkelkamp kunnen worden verwacht, hebben weinig aan het stroomschema. De groep die de beslissing zelf neemt, en er wel iets aan heeft komt niet op de site omdat zij vaak zelf niet het apparaat kopen. Door het stroomschema op de website te plaatsen wordt de feitelijke doelgroep dus slechts zeer beperkt bereikt.
Een andere conclusie die kan worden getrokken uit de resultaten, is dat klanten die hulp of informatie zoeken om hun keuze op te baseren, blijkbaar niet in eerste instantie denken aan Eijkelkamp. De conclusie die kan worden getrokken uit het literatuuronderzoek, is dat de wensen van de klant weinig tot geen invloed hebben op de structuur van het stroomschema, aangezien fysische eigenschappen van de bodem en het doel van de meting vrijwel altijd doorslaggevend zijn.
Het probleem waar Eijkelkamp tegenaan zal lopen is dat de mensen die baat kunnen hebben bij een stroomschema over het algemeen weinig met Eijkelkamp te maken hebben. Met het plaatsen op de website alleen, zoals aanvankelijk de bedoeling was, wordt het potentiële voordeel van het stroomschema daarom niet volledig benut.

De volgende aanbevelingen worden gedaan: het stroomschema kan op de website van distributeurs worden geplaatst voor betere toegankelijkheid, het moet beschikbaar komen in verschillende talen, en het kan worden uitgebreid voor andere producten. Een mogelijkheid is verder om te zoeken naar andere manieren dan de website om het stroomschema te verspreiden. Een alternatieve mogelijkheid is echter om het intern te houden en zo klantcontact te stimuleren. Tenslotte kan het rapport ‘Measuring infiltration by means of…?’, onafhankelijk van het stroomschema, gebruikt worden als bijvoorbeeld relatiegeschenk.

Voorwoord

Het rapport dat voor u ligt is geschreven als een afstudeeropdracht voor Van Hall Larenstein. Voor het theoretische deel heb ik mij een weg gebaand door een schijnbaar eindeloze stroom theorie, waaruit het rapport in de bijlage 3 is voortgekomen. Daarnaast heb ik een enquête onderzoek gedaan, waarvan in dit rapport verslag is gedaan.

Het rapport is het resultaat van een afstudeerstage die ik heb gelopen bij Eijkelkamp Agrisearch Equipment, waar ik een fijne tijd heb gehad met mijn medestudenten van InnoCampus. Ik wil mijn begeleider Karlien van Oosterhout dan ook hartelijk danken voor het creëren van deze omgeving.

Ook aan Sara Eeman, mijn begeleider vanuit school, ben ik dank verschuldigd voor het geven van goede feedback. Verder wil ik mijn ouders bedanken, die mij een werkomgeving gaven waar ik minder werd afgeleid dan thuis, en die het eindresultaat aan enkele spellingscontroles hebben onderworpen.

Inhoudsopgave

1 Inleiding en probleemstelling

Eijkelkamp Agrisearch Equipment is een bedrijf dat apparatuur fabriceert en distribueert, waarmee allerhande zaken kunnen worden gemeten met betrekking tot water en bodem. De infiltratie-capaciteit van de bodem is een van de eigenschappen waarvoor Eijkelkamp diverse meetapparaten aanbiedt.

Infiltratie is het proces waarbij water uit de atmosfeer de bodem binnendringt. Dit proces is vaak van groot belang. Zo wordt er gebruik van gemaakt bij irrigatie, of wanneer men hemelwater wil afkoppelen van het rioolstelsel. De snelheid waarmee water infiltreert verschilt echter enorm, en is afhankelijk van vele factoren. Het is in gevallen waarbij men van het proces gebruik wil maken dan ook belangrijk de infiltratiecapaciteit van een bodem van te voren te bepalen.

Hiervoor zijn verschillende manieren: het kan berekend worden op basis van korrelgrootteverdeling, of in het lab bepaald met behulp van een ongestoord monster, of het kan gemeten worden in het veld. De verschillen tussen de methoden zijn groot. Het is echter niet zo dat sommige methoden beter zijn dan andere; ze zijn allemaal ontwikkeld met een specifiek doel in gedachten, en het hangt van de situatie af welke methode het meest geschikt is.

Het vergt echter veel kennis om te bepalen welke methode het meest geschikt is in een bepaalde situatie, deze kennis is niet altijd aanwezig. Het kan ook erg verwarrend zijn om dit uit te zoeken, omdat de nodige kennis in de literatuur erg gefragmenteerd is. De kennis die zij eventueel voor een bepaalde vraag opdoen, is specifiek en vaak vluchtig. Om het infiltratieproces inzichtelijk te maken, is er behoefte aan een naslagwerk waarin informatie gebundeld is.

Ook moet duidelijk worden, of in elk geval eenvoudig te bepalen, welk apparaat het beste toegepast kan worden door de klant in een bepaalde situatie. Om dit te bereiken willen zij een stroomschema, voorzien van achterliggende informatie, waarmee iemand eenvoudig tot de juiste keuze zal kunnen komen.

Het is belangrijk om het stroomschema aan de juiste personen aan te bieden, dat wil zeggen de personen die de keuze voor een infiltratiemeetapparaat moeten maken. Daarbij moet bekend zijn waar zij hun keuze op baseren en waar zij hun informatie vandaan halen.

1.1 Onderzoeksvragen

Het probleem van Eijkelkamp, de vraag naar verduidelijking over welk infiltratiemeetapparaat zou moeten worden gebruikt in een bepaalde situatie, kan met onderstaande onderzoeksvraag worden weergegeven:

> Wie zal er baat hebben bij het te ontwikkelen stroomschema, en welke informatie is er nodig voor de ontwikkeling?

Om tot een antwoord te komen, zijn de volgende deelvragen geformuleerd:

1. Waar wordt de keuze voor een bepaald infiltratiemeetapparaat op gebaseerd?
2. Wie maakt momenteel de keuze voor een bepaald infiltratiemeetapparaat?
3. Waar komt de nodige informatie vandaan om een infiltratiemeetapparaat te kiezen?
4. Welke fysische factoren zijn van belang bij het infiltratie proces?

1.2 Werkwijze

Om deelvragen 1 tot en met 3 te beantwoorden, is een online enquête opgesteld en verspreid onder klanten van Eijkelkamp.

Er moet ook onderzocht worden welke fysische processen in de bodem een rol spelen bij het infiltratieproces, om te weten welk apparaat het best functioneert in een bepaalde situatie. Om hier achter te komen, is deelvraag 4 geformuleerd. Om deze deelvraag te beantwoorden wordt een rapport geschreven, waarin een compleet overzicht wordt gegeven van verschillende apparaten, beïnvloedende factoren en theoretische onderbouwing. Ook het stroomschema wordt opgesteld op basis van de informatie uit de literatuurstudie.

1.3 Opbouw rapport

In dit hoofdstuk is de probleemstelling gegeven.
In hoofdstuk 2; "Methoden en materialen" is beschreven welke middelen zijn aangewend om dit probleem op te lossen. Hier worden de opbouw van de enquête, de literatuurstudie en het veldwerk beschreven.
Vervolgens wordt in hoofdstuk 3; "Producten en resultaten" de resultaten beschreven die uit de enquête gekomen zijn. In dit hoofdstuk wordt ook het resultaat van het literatuuronderzoek (het rapport 'Measuring infiltration by means of…?'), en het veldwerk beschreven.
In hoofdstuk 4 "Conclusies en aanbevelingen" worden de conclusies, gebaseerd op de gegevens van hoofdstuk 3, uiteen gezet.
In hoofdstuk 5 worden enkele discussiepunten besproken.
In het laatste hoofdstuk (6, literatuurlijst) is de geraadpleegde literatuur vermeld. Dit is gesplitst in geraadpleegde boeken, die bovenaan staan. Vervolgens is een lijst van algemene internetbronnen vermeld, en tenslotte een lijst voor figuurbronnen.

In bijlage 1 is de enquête opgenomen, waarvan de resultaten in bijlage 2 zijn opgenomen.
In bijlage 3 is het rapport 'Measuring infiltration by means of…?' te vinden. Dit rapport is het resultaat van de literatuurstudie.
In bijlage 4 is het stroomschema te vinden, waarmee de beslissing voor een bepaald infiltratiemeetapparaat kan worden gemaakt.

2 Methoden en materialen

In dit hoofdstuk wordt beschreven welke methoden en materialen, o.a. de apparatuur, gebruikt zijn om de antwoorden op de deelvragen te verkrijgen.

2.1 De online enquête

2.1.1 Inleiding

Het doel van de enquête was om te onderzoeken waarop diegene die de beslissing nam, deze baseerde. Daarnaast werd ook onderzocht, wie er besliste over de aankoop, en waar hij eventuele benodigde informatie vandaan haalde. De enquête is te vinden in bijlage 1, de complete resultaten zijn te vinden in bijlage 2.

Het stroomschema dat is ontworpen is erop gericht om het keuzeproces van de klant zoveel mogelijk te vereenvoudigen. Een aanname die is gedaan bij de start van het onderzoek, is dat degene die de apparatuur kiest ook de eindgebruiker is. Hiervan uitgaande, is besloten de enquête te verspreiden onder klanten van Eijkelkamp, en hen daarbij te vragen waar hun keuze op gebaseerd werd en waar zij eventuele extra informatie vandaan haalden. Het onderzoek is in het bijzonder gericht aan klanten die in recente jaren infiltratieapparatuur hebben aangeschaft. Het aantal klanten dat voor deelname in aanmerking kwam was echter, met circa 50 adressen, beperkt. Om die reden is het onderzoek uitgebreid naar potentiële klanten, zoals veldwerkers en adviseurs die (nog) geen apparatuur van Eijkelkamp hebben gekocht.

2.1.2 De enquête

Om de onderzoeksmethode verantwoord vorm te geven, is gekeken naar de methode van consumentenonderzoeken. Consumenten onderzoeken kunnen worden onderverdeeld in twee hoofdcategorieën: kwantitatief en kwalitatief onderzoek. Het verschil is dat een kwantitatief onderzoek als doel heeft iets te meten, en meestal de uitkomsten in procenten uitgedrukt worden. Bij een kwalitatief onderzoek wordt bepaald of een bepaalde factor bij het gedrag van de consument een rol speelt, zonder te weten in welke mate dat het geval is, het gaat hier meer om begrijpen dan om meten (Kooiker en v.d. Heuvel, 1992).
Kwalitatief onderzoek is meer gericht op het begrijpen van keuze- en/of beslissingsprocessen van potentiële klanten. Het doel van dit onderzoek is te begrijpen waar de klant zijn keuze op baseert, en waar hij zijn informatie vandaan haalt. Daarom is gekozen voor een kwalitatief onderzoek.

Voor de manier waarop het onderzoek wordt uitgevoerd, is in dit geval gekozen voor een enquête oftewel een vragenlijst.
De web survey, de online enquête, maakt een snelle opmars in de onderzoeksindustrie. De non – respons ligt veel lager dan bij traditionele methoden. Ook is de respons tijd erg kort; mensen die meedoen, doen dat meestal meteen. Ook is de respons inhoudelijker (dan die van bijvoorbeeld telefonisch onderzoek), aangezien men zelf bepaalt wanneer men meedoet, en daarom niet geïrriteerd is (Verhage, 2004).

Een nadeel van dit type onderzoek is dat het weinig flexibel is. Dit komt vooral tot uiting in het feit dat vragen niet kunnen worden aangepast naar aanleiding van antwoorden. Door gebruik van logische routes (zie hoofdstuk 2.1.3) kan de flexibiliteit echter sterk worden verbeterd.

Ondanks dit nadeel is toch gekozen voor een online enquête. Voor de gekozen methode waren de volgende redenen (Verhage, 2004):

- Online enquêtes kennen vaak een relatief hoge respons.
- Online enquête kost gemiddeld minder tijd dan interviews.
- Aantal respondenten heeft weinig invloed op de te besteden tijd.
- De antwoorden op open vragen zijn vaak inhoudelijker omdat de respondent de enquête op een zelf gekozen tijdstip invult en daardoor niet geïrriteerd zal zijn.

2.1.3 De vormgeving

In de volgende paragrafen zal dieper ingegaan worden op de vormgeving van de enquête.

De vragen

Voor de enquête is gekozen voor een half gestructureerde opzet, dus een combinatie van open en gesloten vragen. Waar mogelijk zijn de vragen gesloten om de classificatie zo eenvoudig mogelijk te houden. Bij bijvoorbeeld vraag 10 (Vindt u dat Eijkelkamp meer moet/kan doen om de klant bij zijn beslissing te helpen? Licht uw antwoord toe.) is echter een open vraag toegepast, aangezien open vragen meer informatie geven, en meer geschikt zijn als men wil weten wat de consument vindt (Kotler et al, 2000).

Figuur 1: gestructureerd versus ongestructureerd.

Soorten vragen verschillen dus in de hoeveelheid informatie die ze opleveren, maar ook in de moeite die de respondent moet doen om de vraag bevredigend te beantwoorden. In dit onderzoek wordt het type vraag gesteld dat hierin een balans vindt, dat wil zeggen de makkelijkst te beantwoorden soort die nog voldoende informatie biedt, is gekozen. De volgende soorten worden in dit onderzoek toegepast:

- Gesloten vragen
    - polair (ja/nee)
    - multiple response
    - multiple choice
    - Schaalwaardering
- Open vragen

Gesloten vragen:
Polaire of dichotome (Kooiker en Van Den Heuvel, 1992) vragen moeten worden beantwoord met een van twee antwoordmogelijkheden, bijvoorbeeld ‘ja’ dan wel ‘nee’. Dit soort vraag is over het algemeen kwantitatief van aard (Verhage 2004), aangezien bij de resultaten slechts kan worden gekeken naar een aantal mensen dat ‘ja’ antwoord ten opzichte van het aantal mensen dat ‘nee’ antwoord; er wordt niet naar een, kwalitatieve, onderbouwing gevraagd. Een voorbeeld van dit type vragen in dit onderzoek is vraag 3; Is er een vooronderzoek uitgevoerd naar de meetlocatie voorafgaand aan de meting?

Multiple response vragen zijn in feite meervoudige dichotome vragen, waarbij voor een serie antwoorden telkens ‘ja’ of ‘nee’ moet worden geantwoord.

Multiple choice vragen kunnen worden gebruikt als een polaire vraag niet genoeg informatie geeft. Het geeft de respondent de keus uit een rij verschillende antwoorden, waarvan er een kan worden gekozen. Hierbij wordt meer informatie verkregen dan bij een polaire vraag, maar er wordt niet naar een onderbouwing gevraagd. Wel is er meestal een optie ‘anders’, waar de respondent terecht kan als zijn antwoord niet in de rij voorkomt.

Als een respondent bij het lezen van een rij antwoorden een antwoordkeus tegenkomt die min of meer aansluit bij zijn mening, bestaat het gevaar dat hij dit antwoord invult zonder eerst de rest te lezen. Op deze manier zullen antwoorden die bovenaan in de rij staan mogelijk onterecht vaker worden gekozen dan de antwoorden die onderaan staan.

In deze enquête worden daarom de antwoorden van alle multiple choice en multiple response vragen in willekeurige volgorde weergegeven (bij polaire vragen is er vanuit gegaan dat dit van geen betekenis zou zijn). Een uitzondering vormt de optie ‘anders’, die altijd onderaan de lijst verschijnt. Als iemand deze optie invult, zal hij dus eerst alle ander opties bekeken hebben.

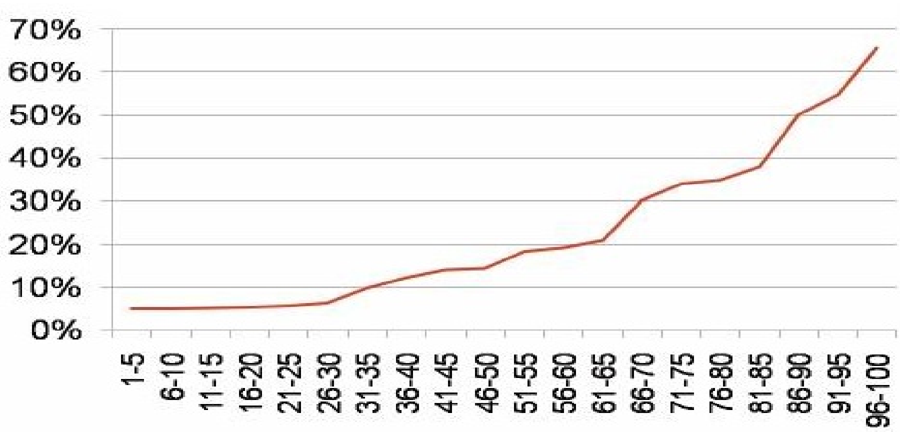
Het voordeel van gesloten vragen is dat de antwoorden erop makkelijk te categoriseren zijn (Principes van de Marketing, 2000). Door het categoriseren van de antwoorden, kunnen ook de respondenten verdeeld worden in groepen. Dit onderzoek start met enkele gesloten vragen om de respondenten op te splitsen in groepen, bijvoorbeeld respondenten die zelf voldoende kennis hebben om het juiste apparaat te kiezen en respondenten die kennis niet hebben.

De schaalwaardering is het vraagtype waarbij de respondent invult tot op welke hoogte hij het eens is met één stelling, van laag naar hoog. Dit is echter relatief, twee respondenten kunnen respectievelijk ‘een beetje’ en ‘heel erg’ invullen, en hier hetzelfde mee bedoelen.
In dit onderzoek is de schaalwaardering toegepast bij de vraag ‘zou u dit onderzoek (het vooronderzoek) beschrijven als… (uitgebreid – beperkt)’. Dit is besloten, omdat alleen de keuze tussen ‘uitgebreid’ en ‘beperkt’ niet genoeg informatie op zou leveren. Anderzijds zou een open antwoord op deze vraag moeilijk te geven en te classificeren zijn. Het doel van de vraag is om erachter te komen hoeveel informatie de respondent nodig denkt te hebben, voordat de beslissing voor een bepaald apparaat genomen wordt.

Open vragen
Open vragen zijn vragen die bedoeld zijn om meer informatie te verkrijgen dan met gesloten vragen mogelijk is. Het geeft de respondent de mogelijkheid het antwoord zelf te formuleren zonder beïnvloed te worden door van te voren bedachte keuzemogelijkheden. Er is een invoervak in de enquête waar de respondent kan uitweiden. Dit vraagtype heeft verreweg de grootste potentie voor informatie, maar er is ook het risico dat respondenten hem overslaan omdat de respondent de tijd moet nemen om hierover na te denken (referentie o.a. diverse algemene internetbronnen, zie literatuurlijst).

Lengte en volgorde van de enquête
"Irritatie is de natuurlijke vijand van het marktonderzoek." Het is belangrijk om te letten op details, en irritatie bij de respondent te voorkomen. Simpele dingen als de vraagvorm, hebben grote gevolgen voor de respons (Verhage, 2004).

Een groot deel van de personen die de enquête ontvangen hebben het druk, om de kans op een reactie te vergroten is het dan ook belangrijk de tijdsduur die de potentiële respondent nodig heeft beperkt te houden. Respondenten vinden het daarbij prettig als ze zicht hebben op de voortgang van de enquête (Verhage, 2004), er wordt daarom tijdens het invullen een voortgangsbalk weergegeven. Er is gekozen voor een enquête duur van ongeveer vijftien minuten, bij langere enquêtes wordt het risico op afhaken van respondenten snel groter. Het aantal vragen dat binnen dit tijdsbestek gesteld kan worden ligt aan de aard van de vragen, het duurt immers langer om een open vraag te beantwoorden dan een gesloten vraag.



Figuur 2: percentage respondenten dat afhaakt, afgezet tegen de duur van een enquête (in minuten).

Respondenten vinden het prettig als de volgorde van de vragen logisch is. Met de eerste vraag wordt hopelijk de belangstelling gewekt, persoonlijke vragen over opleiding en dergelijke komen aan het eind om te voorkomen dat de respondent defensief wordt (Kotler et al, 2000).

Incentive
Bij veel online enquêtes wordt een beloning in het vooruitzicht gesteld voor respondenten die reageren, je kunt dan bijvoorbeeld iets winnen. Dit wordt een incentive genoemd (Kooiker en v.d. Heuvel, 1992). Het idee achter een incentive is dat respondenten hierdoor worden verleid om mee te doen, waardoor de respons hoger wordt.

Er worden voor deze enquête echter met name bedrijven aangeschreven, wat betekent dat de respondent zelf waarschijnlijk niets aan de incentive heeft. Om deze reden zal het effect van een incentive waarschijnlijk klein zijn. Een belangijker nadeel is dat, in dit opzicht, een hogere respons kan leiden tot lagere kwaliteit van de antwoorden. Respondenten doen dan mogelijk mee om de prijs, en kunnen minder serieus omgaan met het beantwoorden van de vragen. In een kwalitatieve enquête als deze, met bijvoorbeeld veel open vragen, is het daarom van belang respondenten te overtuigen van het belang dat zij zelf hebben bij het verstrekken van deugdelijke antwoorden. Dat wil zeggen dat de begeleidende email, waarin kort wordt uitgelegd welk doel de enquête dient, de motivatie moet zijn en niet een incentive.

Het is daarmee een kwestie van kiezen tussen kwaliteit en kwantiteit; een incentive zorgt ervoor dat het aantal respondenten groter wordt, maar dat de kwaliteit van de antwoorden mogelijk verslechterd. Er is daarom besloten om voor dit onderzoek zonder incentive te werken.

Op deze manier kan ervan uit worden gegaan dat respondenten daadwerkelijk een duidelijke mening hebben en deze willen delen.

Logische verwijzingen
Als een respondent een vraag beantwoordt, kan zijn antwoord invloed hebben op de gewenste vervolgvragen. Met logische routes wordt een respondent, afhankelijk van zijn antwoord, doorgestuurd naar een volgende vraag. Dit vergroot de flexibiliteit van de enquête aanzienlijk, omdat vragenlijst aangepast wordt aan de respondent zonder dat hij overbodige vragen hoeft te beantwoorden. Op deze manier wordt de tijdsduur van de enquête beperkt gehouden en afhaken van de respondent voorkomen. Daarom zijn in deze enquête logische routes ingebouwd.

Verplichte antwoorden
Het is mogelijk om bij een vraag antwoorden verplicht te stellen. Zolang de respondent geen antwoord ingevuld heeft, kan hij niet verder met de enquête. Ook hier moet men eigenlijk kiezen tussen kwaliteit en kwantiteit. In dit onderzoek is besloten om antwoorden zo min mogelijk verplicht te stellen. Dit omdat het aannemelijk is dat, ook al wordt de vraag dan vaker beantwoord, de antwoorden minder betrouwbaar zijn. Er is zelfs het risico dat de respondent helemaal afhaakt.

Uitzonderingen hierbij zijn de vragen waar logische verwijzingen aan vastzitten. Bij deze vragen, die dus bepalen welke route de respondent volgt door de enquête, is antwoorden wel verplicht gesteld omdat hij anders totaal irrelevante vragen krijgt.

Weergave voortgang
Door middel van een voortgangsbalk, heeft de respondent inzicht in hoe ver hij is. Dit is vaak niet helemaal accuraat, aangezien door middel van logische verwijzingen vaak meerdere vragen worden overgeslagen, maar het geeft de respondent toch een idee. Het is niet raadzaam om de respondent (veel) langer bezig te houden dan toegezegd aangezien het risico op afhaken dan heel groot wordt. In dit onderzoek is er echter voor gezorgd dat het in veruit de meeste gevallen (ruim) binnen de beloofde tijd zal zijn afgerond. Om de respondent hier ook tijdens de enquête van te verzekeren, is besloten de voortgangsbalk toe te passen.

Surveymonkey
Er bestaan diverse websites die de mogelijkheid bieden om een professionele enquête te ontwerpen, te versturen en de resultaten te analyseren. Eijkelkamp heeft de beschikking over een account bij een dergelijke site, genaamd Surveymonkey, en er is besloten ook de enquête voor dit onderzoek hiermee uit te zetten.

2.2 Het rapport 'Measuring infiltration by means of …?'

2.2.1 Literatuurstudie

Het doel van de uitgevoerde literatuurstudie was enerzijds om uit te vinden wat de belangrijkste factoren zijn die invloed hebben op het infiltratieproces. Deze informatie is gebruikt voor het opzetten van het stroomschema (zie hoofdstuk 2.3 en bijlage 4).

Er is in de literatuur veel geschreven over het infiltratieproces, maar deze informatie is erg gefragmenteerd en vaak ontoegankelijk. Er zijn bijvoorbeeld veel stukken te vinden over de Wet van Darcy, maar die hebben vaak zo veel diepgang dat het voor de leek waarschijnlijk niet te volgen is, en vaak wordt bovendien de basis als bekend verondersteld.

Het tweede doel was het creëren van een naslagwerk waarin de meest relevante informatie te vinden is over de verschillende factoren en de verschillende apparatuur. Dit naslagwerk, dat de titel 'Measuring infiltration by means of… ?') heeft gekregen, moest een toegankelijk, compleet en duidelijk overzicht geven voor de leek. In het rapport is een balans gezocht tussen voldoende diepgang en compleetheid enerzijds, en leesbaarheid anderzijds. Een leek op het gebied van infiltratie moet het rapport kunnen volgen, maar wel zijn keuze kunnen maken en voldoende kunnen onderbouwen. Dit naslagwerk is te vinden in bijlage 3.

2.2.2 Veldwerk

De waarden die met infiltratiemeetapparatuur gemeten worden, geven niet direct de infiltratiecapaciteit weer. Het zijn peilveranderingen in het reservoir van het apparaat, waaruit de K-waarde berekend kan worden. De berekening waarmee uit dit debiet een infiltratiecapaciteit berekend kan worden is echter niet altijd eenvoudig. Er is daarom besloten om in het rapport 'Measuring infiltration by means of…?' bij een aantal apparaten voorbeeldberekeningen toe te voegen. Met deze apparaten, te weten de Ksat, de Tensio Infiltrometer, de Aardvark, de Dubbele Ring en de Rainfall Simulator, zijn metingen uitgevoerd in het veld om de voorbeeld-berekeningen op te baseren.

De metingen voor de voorbeeld berekeningen zijn uitgevoerd op het terrein van Helicon te Velp. Hiervoor is eerst een proefboring gezet, om te zien of er slecht doorlatende lagen aanwezig zijn. De bodem bleek hier voornamelijk te bestaan uit matig grof zand en leem. De scheiding tussen deze lagen was erg onduidelijk vanwege sterke vergraving. Vervolgens zijn infiltratiemetingen in situ uitgevoerd. Ook zijn op enkele centimeters afstand van het meetpunten vier ongestoorde monsters gestoken, die zijn geanalyseerd in een lab permeameter. De resultaten van de metingen zijn te vinden in het rapport 'Measuring infiltration by means of…?'.

2.3 Het stroomschema

De informatie die voor het rapport 'Measuring infiltration by means of…?' werd gebruikt, is ook gebruikt voor het opstellen van het stroomschema. Er is begonnen met een lijst apparaten, die vervolgens is gesplitst in steeds kleinere groepen op basis van fysische factoren en het doel van de meting, tot er uiteindelijk maar een overblijft. Uit de gevonden informatie is geconcludeerd welke vragen hiervoor gesteld moeten worden en in welke volgorde.

Zo blijkt bijvoorbeeld dat voor bepaalde bodemtypen (zoals zeer grof zand en grind) er maar één mogelijkheid is om de infiltratiecapaciteit te bepalen, namelijk de berekening op basis van korrelgrootteverdeling. Daarom is het eerste beslismoment in het stroomschema gebaseerd op de verwachte conductiviteit ('expected conductivity'). In de uitleg die hierbij gegeven wordt (bereikbaar via het '?' teken) is snel te vinden dat het gaat om een scheiding tussen een conductiviteit van meer of minder dan 10^4 meter per dag. Ook wordt kort uitgelegd in wat voor bodems (zeer grof) deze conductiviteit verwacht kan worden. Uitgebreidere uitleg hierover is te vinden in het rapport 'Measuring infiltration by means of…?'). Personen die op basis van deze uitleg kiezen voor extreem hoog, komen uit bij de korrelgrootte methode, personen die kiezen voor normaal gaan verder naar de volgende vraag.

Vervolgens wordt het onderscheid gemaakt tussen meten in het veld (in situ) of in het lab. Op deze manier wordt het aantal mogelijkheden steeds kleiner, zodat men uiteindelijk uitkomt bij het apparaat dat het best past bij de situatie waarin de klant zich bevindt.

3 Producten en resultaten

In dit hoofdstuk zijn de resultaten beschreven van de onderzoeken die zijn uitgevoerd zoals beschreven in hoofdstuk 2. Deze resultaten worden geanalyseerd, en in hoofdstuk 4 worden er vervolgens conclusies aan verbonden.

3.1 Resultaten van de online enquête

Nadat de enquête is uitgezet, zijn de resultaten geanalyseerd. De complete vragenlijst, en de complete resultaten zijn te vinden in de bijlages 1 en 2.
In dit hoofdstuk zijn de resultaten van enkele vragen in diagrammen weergegeven. Omdat de enquête in het Engels is opgezet, worden de vragen in deze figuren ook in het Engels weergegeven. In het bijschrift van de figuren zijn deze vragen vertaald.

In totaal zijn 22 respondenten de enquête gestart, dit is een respons van 44%. Het is echter wel zo dat 11 (50%) van de respondenten onderweg is afgehaakt.

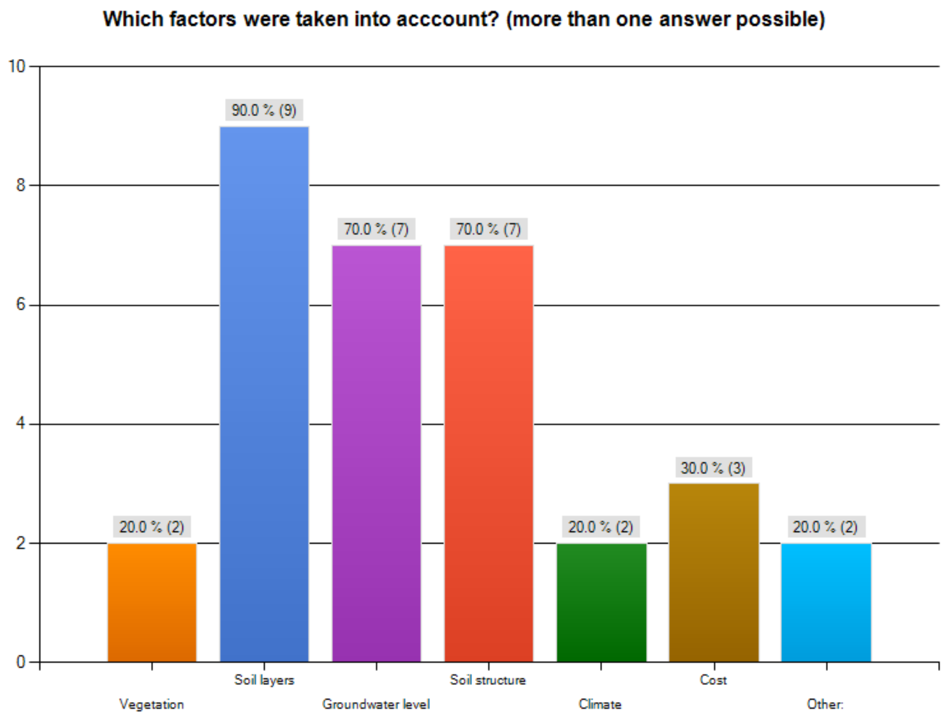
Het aantal respondenten per vraag varieert sterk, van nul tot honderd procent. De oorzaak van de grote variaties kan worden gezocht in twee dingen:

- niet elke respondent krijgt elke vraag voor zich, vanwege de logische routes die zijn ingebouwd (zie hoofdstuk 2.1.3).
- Sommige respondenten hebben uit eigen beweging vragen overgeslagen, vermoedelijk omdat zij geen mening hadden. Om te voorkomen dat zij afhaken, hebben ze de mogelijkheid om de vraag dan over te slaan (zie hoofdstuk 2.1.3).

Ondanks dit zijn uit de resultaten een aantal belangrijke conclusies te trekken, die uiteen worden gezet in hoofdstuk 4. In dit hoofdstuk worden de resultaten gepresenteerd. Hier wordt alleen in gegaan op de vragen die de meeste relevantie hebben. Dit zijn dan ook de vragen waar de conclusies op gebaseerd zijn. De overige vragen van de enquête bleken bij de analyse weinig relevantie te hebben en zijn daarom in dit hoofdstuk buiten beschouwing gelaten. Hier wordt in de discussie nog op teruggekomen.

Bij het kiezen van een infiltratiemeetapparaat is het van belang te kijken naar het doel van de meting en fysische eigenschappen van de bodem. Het is echter mogelijk dat, vooral wanneer een klant weinig kennis bezit over infiltratie, er meer naar andere zaken gekeken wordt, zoals de kosten. Om het stroomschema voor de klant optimaal in te richten, is het van belang te weten waar bij zijn beslissing zijn prioriteiten liggen. Er is daarom aan de respondenten gevraagd waarop zij hun beslissing hebben gebaseerd. Hiervoor zijn de respondenten opgedeeld in twee groepen (vraag 3): zij die geen vooronderzoek uitvoeren en zij die dat wel doen.

Tien van de achttien respondenten (56%) geeft aan dit wel te doen. Er wordt door deze groep altijd een profielboring gedaan, in 4 van de 10 gevallen (40%) word hier nog een literatuuronderzoek aan toegevoegd. Deze groep van achttien respondenten werd gevraagd waar bij dit vooronderzoek naar gekeken wordt, de resultaten hiervan zijn te zien in figuur 3. Bij de optie 'anders' werd de hoogteligging van de locatie nog door 1 respondent genoemd.



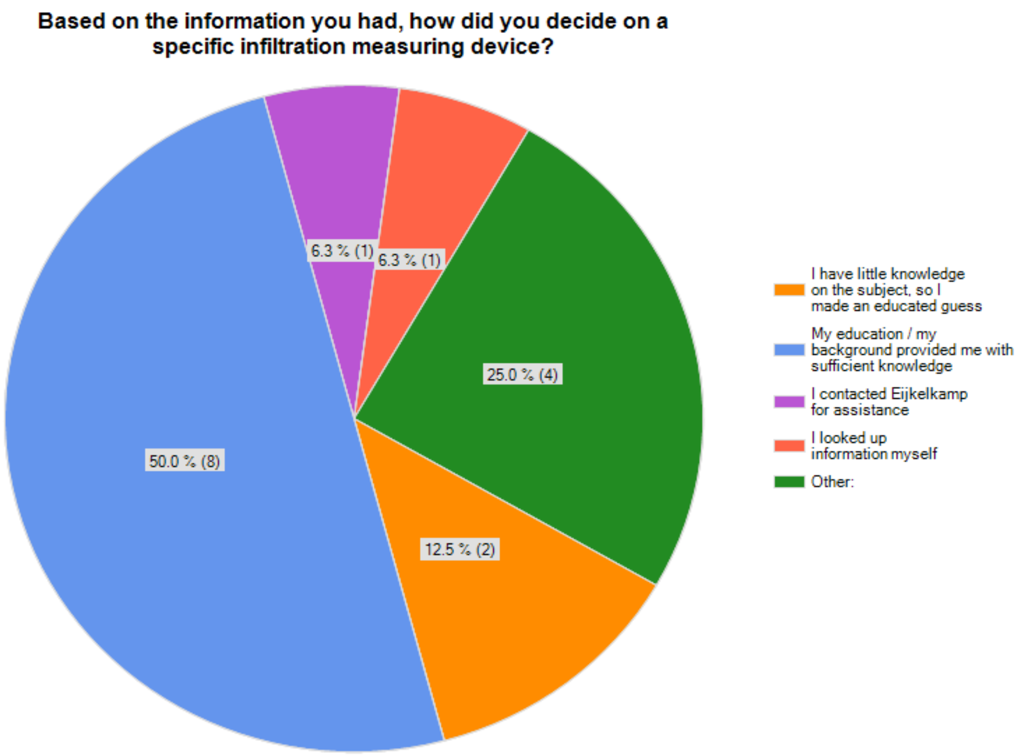
Figuur 3: factoren waar op gelet wordt bij een vooronderzoek.

Aan beide groepen werd vervolgens vraag 7 gesteld: Waar was uw beslissing op gebaseerd? Aan de respondenten die geen vooronderzoek doen, is dit gevraagd omdat zij hun beslissing blijkbaar ergens anders op baseren. Bij de andere groep kan er echter niet zonder meer van uit worden gegaan dat dit vooronderzoek het enige was waar zij op letten.

Er is gekozen voor een open vraag, om de respondent niet te leiden in zijn antwoord en hem de ruimte te geven om in zijn eigen woorden te antwoorden. Hierop werd door 5 (van de 12) respondenten geantwoord dat dit van de klant af hangt, met andere woorden dat zij helemaal geen invloed hebben op de beslissing, maar slechts een apparaat op bestelling leverden.
De bodemstructuur wordt 3 keer genoemd. Korrelgrootteverdeling, grondwaterniveau, kosten en het doel van de meting, waarvan verwacht zou worden dat het belangrijke criteria zijn, worden slechts eenmaal genoemd.
Later in de enquête (vraag 11) wordt gevraagd welke factoren er verder meewogen in de beslissing. Op deze vraag werd 10 keer gereageerd, waarbij de kosten de belangrijkste nevenfactor was die werd genoemd (door 4 respondenten), hoewel vaak in combinatie met andere factoren. Het doel van de meting, de wens van de klant en de scheiding tussen verzadigde en onverzadigde metingen werden ieder 3 maal genoemd. Door 2 respondenten werd ook op het bodemtype gelet.

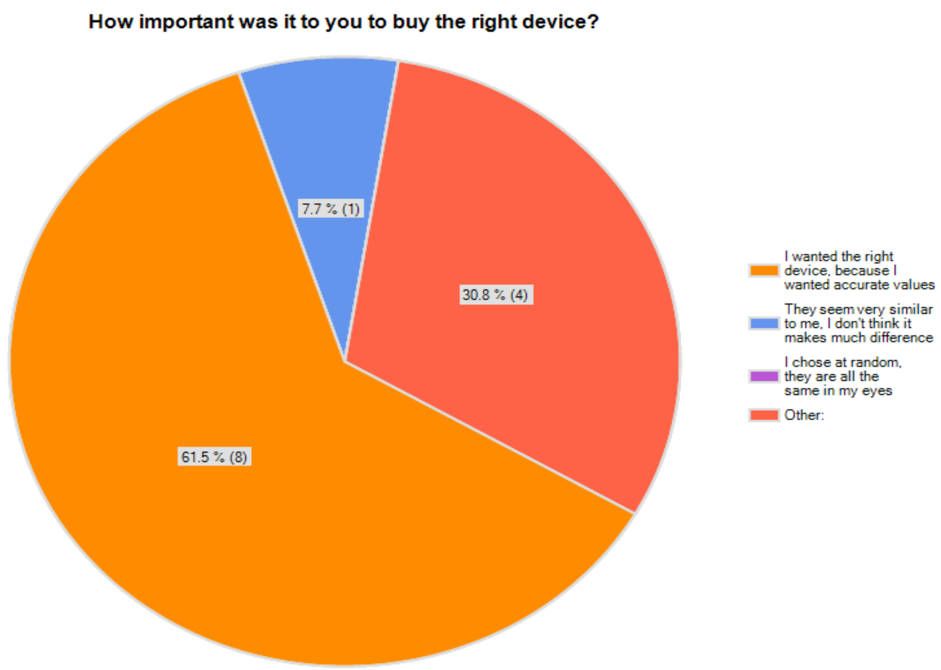
Ook interessant is waar de informatie, die nodig is voor het maken van de keuze, vandaan komt. Hierop heeft vraag 8 betrekking; Hoe is de beslissing genomen?
Aangezien deze vraag moeilijk te formuleren was, en open voor interpretatie, is ervoor gekozen om een multiple choice vraag toe te passen (met optie ‘anders’).
De helft (8 van de 16) respondenten die deze vraag hebben ingevuld, verklaren hiervoor zelf voldoende kennis in huis te hebben. Vier van de respondenten koos voor ‘anders’, en verklaarde hierbij (3 van de 4) dat de beslissing van hun klant al vast stond.
De overige vier hebben zelf informatie op moeten zoeken, of hebben de beslissing op gevoel genomen; slechts een ervan heeft contact gezocht met Eijkelkamp voor advies. De verdeling tussen de verschillende groepen is te zien in figuur 4.

In het getoonde taartdiagram is het blauwe veld de groep die de kennis zelf in huis heeft, terwijl het groene veld de groep weergeeft die zelf geen beslissing neemt. De overige velden (paars, roze en oranje) zijn allemaal groepen die op de een of andere manier informatie hebben moeten verzamelen om tot een verantwoorde keuze te komen, en zijn daarom de potentiële doelgroepen die baat kunnen hebben bij een stroomschema ter ondersteuning van hun keuze. Als de distributeurs van Eijkelkamp een meer adviserende rol gaan spelen, kan ook het groene vlak hier gedeeltelijk bij gerekend worden, waardoor het totaal zou uitkomen op ongeveer de helft van de klanten.



Figuur 4: waar komt de informatie vandaan?

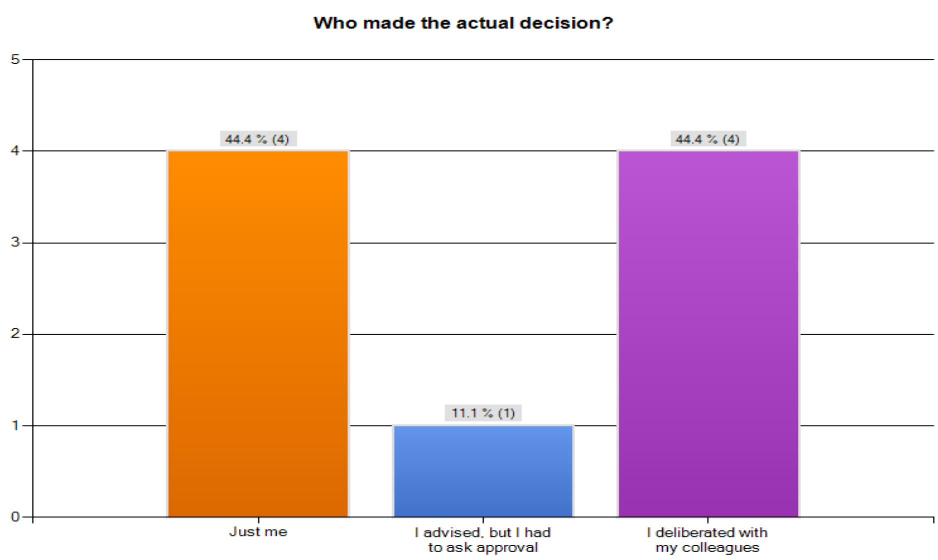
De helft van de klanten heeft zelf niet voldoende kennis in huis om het optimale apparaat te kiezen, dit blijkt uit figuur 4. Het is echter niet zo, dat de keuze over het algemeen als onbelangrijk word gezien. Dit blijkt uit figuur 5, waarin de resultaten van de vraag ‘hoe belangrijk was het om het juiste apparaat te kopen’ zijn samengevat in een taartdiagram:



Figuur 5: hoe belangrijk vindt u het om het juiste apparaat te kiezen?

In figuur 5 is te zien, dat bijna tweederde (62%) de keuze bewust maakt. Hierbij dient te worden opgemerkt, dat de groep die voor 'other' heeft gekozen, voornamelijk (75%) bestaat uit distributeurs die slechts aan de wensen van hun klanten willen voldoen.
De blauwe groep, die bijna 8% van de respondenten beslaat, gaat ervan uit dat de apparaten min of meer dezelfde functie hebben.

In figuur 4 is gezien, dat een groot deel van de respondenten niet de benodigde kennis heeft om een infiltratiemeetapparaat te kiezen. Het is daarom belangrijk te weten, of de respondenten ook degenen zijn die hier over gaan. Uit figuur 6 blijkt dit inderdaad vaak het geval te zijn:



Figuur 6: wie neemt de beslissing?

Aan de respondenten werd gevraagd, wie de uiteindelijke beslissing neemt. In 45% van de gevallen blijkt dat de respondent zelf te zijn, terwijl 11% niet de beslissing neemt maar wel een adviserende rol speelt. Er kan dus gesteld worden dat ruwweg de helft van de respondenten de eindbeslissing neemt, terwijl eerder gezien is dat tweederde hier niet voldoende kennis voor heeft.

Vraag 21 werd gesteld om een beeld te kunnen vormen van het gemiddelde opleidingsniveau van de respondenten. Uit de reacties is gebleken dat ruwweg de helft van de respondenten een universitaire achtergrond heeft, terwijl de andere helft een bachelor diploma heeft. Hieruit blijkt dat de respondenten over het algemeen goed tot zeer goed opgeleid zijn, hoewel (zie vraag 21, bijlage 1) niet altijd op het gebied van infiltratie.

Vragen 22 en 23 werden gesteld om een beeld te vormen van de instellingen die infiltratieapparaten afnemen. Hieruit blijkt dat dit naast distributeurs vooral kleinere adviesbureaus en veldwerkbureaus zijn, en onderwijsinstellingen.

3.2 Het rapport 'Measuring infiltration by means of...?'

Het rapport 'Measuring infiltration by means of…?' is het resultaat van de literatuurstudie die is uitgevoerd; en is te vinden in bijlage 3. Dit rapport is ook de bron van alle informatie die in het stroomschema is verwerkt.

3.3 Voorbeeld berekening veldwerk

De voorbeeldberekeningen zijn gebaseerd op het veldwerk dat is uitgevoerd. Deze voorbeeldberekeningen zijn ter verduidelijking bijgevoegd in het rapport 'Measuring infiltration by means of…?' aan het eind van de beschrijvingen van de respectievelijke apparaten.

3.4 Het stroomschema

Het stroomschema is opgezet op basis van het rapport 'Measuring infiltration by means of…?' en is te vinden in bijlage 4.

4 Conclusies en aanbevelingen

4.1 Conclusies

Waar wordt de keuze voor een bepaald infiltratiemeetapparaat op gebaseerd?
Iets meer dan de helft van de klanten voert een profielboring uit en baseert hier gedeeltelijk zijn keuze op, waarbij voornamelijk gelet word op de gelaagdheid van de bodem. Als een van de belangrijkste nevenfactoren worden de kosten genoemd.

Wat echter met name opvalt, is het aantal klanten dat blijkbaar helemaal geen invloed heeft op de keuze; bijna de helft van de klanten blijkt een apparaat slechts te kopen op verzoek van een klant. Dit geldt bijvoorbeeld voor veldwerkers, die een opdracht krijgen waar al uit blijkt welk apparaat gebruikt moet worden, en voor distributeurs die het apparaat niet gebruiken maar doorverkopen. Deze groep heeft dus niets aan het stroomschema, aangezien zij geen keuze maken.

Van de klanten die hulp nodig hebben bij het kiezen, komt slechts een kwart bij Eijkelkamp. In de overige gevallen zoeken ze zelf informatie op, of ze doen een beredeneerde schatting. Deze groep zou geholpen zijn met het stroomschema en/of het rapport, maar zoekt geen hulp bij Eijkelkamp. Blijkbaar word Eijkelkamp niet gezien als kenniscentrum.

Wie maakt momenteel de keuze voor een bepaald infiltratiemeetapparaat?
Bij het opstellen van de enquête is de aanname gedaan, dat degene die de apparatuur kiest ook de eindgebruiker is. Uit resultaten van de enquête is gebleken, dat deze aanname niet juist was. Een deel van de respondenten bleken distributeurs te zijn die puur aankochten wat hun klanten wensten zonder verdere navraag te doen over het waarom. Een ander deel (10%) bleken eindgebruikers te zijn, zoals veldwerkers, die geen invloed bleken te hebben op het beslisproces over de aanschaf van apparatuur.

De klanten, die de apparatuur kopen, blijken dus vaak niet dezelfde personen te zijn die ook de beslissing nemen. Bij het afnemen van interviews hebben we te maken met enerzijds mensen die de apparaten gebruiken of doorverkopen, zoals medewerkers van veldwerkbureaus of distributeurs. In deze gevallen worden de apparaten besteld om aan de wens van de klant te voldoen, en in hun opdrachten staat meestal het apparaat al vast. Anderzijds zijn er de mensen die wel de beslissing nemen, maar de apparaten niet gebruiken, zoals medewerkers van adviesbureaus.

Hoewel er overlap in deze groepen zit, levert dit toch problemen op bij de verspreiding van het stroomschema. De eerste groep (eindgebruikers en doorverkopers), die op de site van Eijkelkamp kan worden verwacht, heeft namelijk weinig aan het stroomschema, tenzij ze ervoor kiezen om ook een adviserende rol te spelen. De tweede groep (die de beslissing zelf neemt) die er wel iets aan heeft komt niet op de site omdat zij vaak zelf niet het apparaat kopen.
Aanvankelijk was het idee dat het stroomschema, inclusief het rapport, gepubliceerd zou worden op de website van Eijkelkamp. Blijkbaar wordt bij deze manier van verspreiding de feitelijke doelgroep slechts zeer beperkt bereikt.

Waar komt de nodige informatie vandaan om een infiltratiemeetapparaat te kiezen?
De helft van de ondervraagden (8 van de 16) zegt zelf voldoende kennis in huis te hebben om een apparaat te kiezen, dit is te zien aan de resultaten van vraag 8. De andere helft zal de keuze toch moeten maken, en zou geholpen zijn met het rapport ‘Measuring infiltration by means of…?’ en het stroomschema.

Een andere conclusie die kan worden getrokken uit de resultaten in figuur 4, is dat klanten die hulp of informatie zoeken om hun keuze op te baseren, blijkbaar niet in eerste instantie denken aan Eijkelkamp. Deze conclusie wordt gestaafd door het feit dat vraag 10 (Vindt u dat Eijkelkamp meer kan/zou moeten doen om klanten te helpen bij het maken van een keuze?) door geen enkele respondent is beantwoord.

Welke fysische factoren zijn van belang bij het infiltratie proces?
De conclusie die kan worden getrokken uit het literatuuronderzoek, is dat de wensen van de klant weinig tot geen invloed hebben op de structuur van het stroomschema, aangezien fysische eigenschappen van de bodem en het doel van de meting vrijwel altijd doorslaggevend zijn. Om het meest geschikte apparaat te kiezen, zou de beslissing moeten worden gebaseerd op kennis van processen in de bodem.

Wie zal er baat hebben bij het te ontwikkelen stroomschema, en welke informatie is er nodig voor de ontwikkeling?
De respondenten van de enquête zijn in vier groepen te verdelen:

- Groep 1 adviseert welk apparaat gebruikt wordt, maar voert geen metingen uit.
- Groep 2 adviseert welke meeting het meest geschikt is en voert de metingen zelf uit.
- Groep 3 gebruikt het apparaat op aangeven adviseur/opdrachtgever.
- Groep 4 zijn de distributeurs.

Het probleem waar Eijkelkamp tegenaan zal lopen is dat de mensen die baat kunnen hebben bij een stroomschema de groepen 1 en 2 zijn; mensen die beslissen of mensen die beslissen en kopen. Hun clientèle bestaat echter voornamelijk uit groepen 2 tot en met 4, mensen uit de eerste groep hebben weinig met Eijkelkamp te maken.
Er zit dus wel overlap in de doelgroep en de huidige klanten, maar vaak zijn het niet dezelfde personen. Hiermee moet rekening worden gehouden bij de verspreiding, deze moet zo breed mogelijk zijn. Met het plaatsen op de website alleen, zoals aanvankelijk de bedoeling was, wordt het potentiële voordeel van het stroomschema niet volledig benut.

De ontwikkeling van het stroomschema kon niet worden gebaseerd op de resultaten van de enquête, omdat fysische factoren bepalen welk apparaat het meest geschikt is. Derhalve is het stroomschema volledig gebaseerd op het resultaat van de literatuurstudie.

4.2 Aanbevelingen

Het oorspronkelijke plan van Eijkelkamp was om het stroomschema en het rapport 'Measuring infiltration by means of…?' te publiceren op de website van Eijkelkamp. In dit onderzoeksrapport is gekeken hoe de effectiviteit hiervan kan worden verbeterd, en de volgende aanbevelingen worden gedaan:

1. Stroomschema ook op de site van distributeurs voor betere toegankelijkheid.
   Uit de resultaten van de enquête is naar voren gekomen dat de doelgroep voor het stroomschema voor Eijkelkamp moeilijk te bereiken is, aangezien de mensen die de apparatuur kopen vaak niet degene zijn die beslissen welke apparatuur moet worden gebruikt. Dit geldt in het bijzonder voor de distributeurs, die voor een groot deel van de afname van infiltratiemeetapparatuur verantwoordelijk zijn.
   Het zou daarom de bereikbaarheid van het stroomschema zeker ten goede komen als het op de websites van verschillende distributeurs wordt geplaatst.

2. Stroomschema beschikbaar maken in andere talen.
   Eijkelkamp is een internationaal bedrijf, met klanten en distributeurs verspreid over de hele wereld. Het stroomschema en het rapport 'Measuring infiltration by means of…?' zijn in het Engels geschreven, om zoveel mogelijk relaties te kunnen bereiken. Het zou echter goed zijn om het te vertalen in bijvoorbeeld Spaans, Russisch en/of Chinees, zodat het beter beschikbaar wordt in grote potentiële afzetgebieden.

3. Stroomschema's opzetten voor ander productlijnen.
   Als het stroomschema goed ontvangen en gebruikt wordt, zijn er binnen het assortiment van Eijkelkamp nog andere productgroepen waarvoor een dergelijk schema nuttig kan zijn. Voorbeelden hiervan zijn bodemvochtsensoren en bemonsteringsapparatuur. Na verloop van tijd kan in principe het gehele assortiment in stroomschema's worden ondergebracht.

4. Navraag bij gebruikers over keuze traject , voor eventuele bijstelling van het stroomschema.
   Het is belangrijk om te weten of klanten baat hebben gehad bij het stroomschema. Dit mede vanwege aanbeveling 3; als het aantal stroomschema's sterk moet worden uitgebreid, is het belangrijk om te weten hoe het optimaal functioneert. Het verdient daarom aanbeveling om de klant bij elk gebruik van het stroomschema de mogelijkheid te geven om een reactie te plaatsen, zodat het in de loop van de tijd, indien gewenst, kan worden bijgesteld.

5. Het verdient aanbeveling om te zoeken naar andere manieren om het stroomschema te verspreiden. Er wordt gekeken naar een mogelijkheid om het stroomschema te vermelden in "Geijkt Nieuws", het tijdschrift van Eijkelkamp, dat regelmatig verspreid wordt onder klanten, op beurzen en dergelijke. Ook kan het stroomschema verspreid worden met social media, of rechtstreeks naar klanten worden gestuurd. Op deze manier kan het stroomschema onder de aandacht worden gebracht, zodat men het op de site zal weten te vinden. Uiteindelijk is het de bedoeling dat men het tegenkomt, zonder er naar te zoeken.

6. Het is voor Eijkelkamp wellicht niet de beste optie om de klant de keuze zelf te laten maken. Ze zien liever dat de klant naar hen toe komt met de vraag, zodat het klantcontact gestimuleerd wordt. Het verdient daarom aanbeveling om, als alternatief voor aanbeveling 5, het stroomschema intern te houden. Het zou dan alleen verspreid worden onder medewerkers van Eijkelkamp, in het bijzonder de verkoopafdeling, zodat vragen van klanten wel snel en doeltreffend beantwoord kunnen worden. In dit geval zou het alsnog onder distributeurs kunnen worden verspreid, maar niet op hun websites moeten worden geplaatst.

7. Het stroomschema en het rapport 'Measuring infiltration by means of…?' vullen elkaar aan, maar kunnen ook onafhankelijk van elkaar worden gebruikt. Ongeacht of het stroomschema wordt gepubliceerd, verdiend het aanbeveling om van het rapport een boekje te maken voor klanten die interesse tonen in het infiltratieproces. Het zou dan bijvoorbeeld als relatiegeschenk kunnen dienen.

5 Discussie

1. Beperkte populatie.
   De populatie waaronder de enquête verspreid kon worden is beperkt; er is slechts een beperkt aantal klanten dat in de afgelopen jaren infiltratiemeetapparatuur gekocht heeft bij Eijkelkamp, en deze zijn allemaal aangeschreven. Vanwege het beperkte aantal potentiële respondenten is de doelgroep uitgebreid. De enquête is ook ingevuld door potentiële klanten van Eijkelkamp, dat wil zeggen mensen die wel regelmatig beslissen over de aankoop van een infiltratiemeetapparaat, maar die deze (nog) niet bij Eijkelkamp gekocht hebben. Hiervoor zijn veldwerkers en adviseurs benaderd. Ook na het uitbreiden van de doelgroep kwam het totale aantal respondenten slechts op 22. Dit is te weinig om statistisch verantwoorde uitspraken te doen.

2. Kwaliteit enquête gezien de respons.
   De resultaten van de enquête geven enig inzicht in de vragen die gesteld worden. De respons was niet slecht, maar het aantal reacties is, ook met de uitgebreide doelgroep, te laag om hier statistisch verantwoorde uitspraken over te doen. Ook is de helft van de respondenten gedurende de enquête afgehaakt. De betrouwbaarheid van de resultaten wordt hierdoor verminderd.

3. Greep op de doelgroep
   Een nadeel van een enquête die via email wordt verstuurd, is de beperkte greep die de enquêteur heeft op de proefgroep; men heeft geen controle over wie op een bepaald adres het formulier uiteindelijk invult. Dit geldt ook voor het nu uitgevoerde onderzoek, omdat niet voldoende informatie beschikbaar was om de enquête aan een specifiek persoon te richten.

4. Opbouw van de enquête.
   Het doel van de enquête was om in beeld te brengen hoe de klant tot zijn beslissing voor een bepaald meetapparaat komt. Gaandeweg het onderzoek is echter de focus verlegd, waardoor een aantal van de vragen hun relevantie verloren hebben. Daarnaast hadden bepaalde vragen anders geformuleerd kunnen worden.
   Opvallend is, dat bij vraag 11 (Welke factoren hebben invloed gehad op uw beslissing?...) voorbeelden werden gegeven en dat de antwoorden hierdoor sterk lijken worden te beïnvloed. Bij vraag 7 die hier sterk op lijkt, maar waarbij geen voorbeelden werden gegeven, kwamen sterk verschillende antwoorden.

5. Bij succesvolle introductie bij infiltratie stroomschema's opzetten voor ander productlijnen.
   Als het stroomschema aanslaat, kan het worden uitgebreid met andere productgroepen. Als er meer producten in ondergebracht zijn, zal het aantrekkelijker worden en kan het beter worden verspreid. Hierdoor zal de kans groter worden dat het goed aanslaat. Men kan zich daarom afvragen wat eerst moet gebeuren; uitbreiding van het stroomschema of de verspreiding ervan.

6 Literatuurlijst

1 Bethlehem, J.G., Biffignandi, S., (2012); Handboek of Web Surveys.

2 Kooiker, R., Heuvel, T. van den, (1992); Marktonderzoek, Wolters Noordhof.

3 Kotler, P., Armstrong, G., Saunders, J., Wong, V., (2000); Principes van marketing, Academic Service.

4 Schoormans, J., Bont, C. de, (1995); Consumentenonderzoek in de productontwikkeling, Lemma BV.

5 Verhage, B., (2004); Grondslagen van de marketing, Stenfert Kroese.

6 Zwart, P.S., (1994); Methoden van marktonderzoek, Stenfert Kroese.

Internetbronnen

Algemeen:
http://www.multiscope.nl/download/rapportage-beleving-online-onderzoek.pdf
http://itknowledgebase.computable.nl/content/beleving-online-onderzoek/207326/
http://www.hulpbijonderzoek.nl/vragenlijst/
http://www.cbs.nl/NR/rdonlyres/8E7C1E1E-F6C8-4956-B993-3D58DE622B13/0/200905x37pub.pdf.

Bijlagen

Bijlage 1: Vragenlijst enquête

Deze enquete is volledig anoniem.

Let er alstublieft op dat degene die de gekochte apparaten gebruikt heeft, bij voorkeur ook degene is die deze enquete invult.

De resultaten zullen worden op 20 oktober worden verwerkt, zorg er alstublieft voor dat u voor die tijd reageert.

* 1. Waarom wilde u een infiltratiecapaciteit meten?

- ◯ Voor het ontwerpen van een irrigatiesysteem
- ◯ Om het risico op erosie te onderzoeken
- ◯ Om de haalbaarheid van hemelwaterinfiltratie te onderzoeken
- ◯ Overige (geef nadere toelichting)

2. Wist u welke irrigatiemethode zou worden gebruikt?

- ◯ Nee, dat hing van de meetresultaten af
- ◯ Ja, namelijk:

* 3. Is onderzoek uitgevoerd naar de meetlocatie voor de metingen werden gedaan?

- ◯ Nee
- ◯ Ja

4. Wat voor onderzoek was dit?

- ◯ Veldonderzoek (profielonderzoek)
- ◯ Literatuurstudie
- ◯ Beiden

5. U zou dit onderzoek omschrijven als...

Beperkt			Gemiddeld			Uitgebreid
◯	◯	◯	◯	◯	◯	◯

6. Met welke factoren is rekening gehouden? (meerdere antwoorden mogelijk)

- [ ] Klimaat
- [ ] Vegetatie
- [ ] Gelaagdheid van de bodem
- [ ] Structuur van de bodem
- [ ] Grondwaterniveau
- [ ] Kosten
- [ ] Overige (geef nadere toelichting)

7. Waar was uw beslissing op gebaseerd?

*8. Hoe koos u, gebaseerd op de informatie die u had, voor een bepaald infiltratie meetapparaat?

- ○ Ik heb contact opgenomen met Eijkelkamp voor advies
- ○ Op gevoel
- ○ Vanwege mijn opleiding / achtergrond had ik zelf voldoende kennis
- ○ Ik heb zelf informatie opgezocht
- ○ Overige (geef nadere toelichting)

9. Was dit advies voldoende van kwaliteit?

Ja, want:

Nee, want:

10. Vind u dat Eijkelkamp meer moet/kan doen om de klant bij zijn beslissing te helpen? Licht uw antwoord toe:

11. Welke factoren hebben invloed gehad op uw beslissing? Denk aan zaken als bodemsoort, verzadigd/onverzadigd, kosten, ect.

12. Welke van deze factoren waren het meest belangrijk?

13. Hoe belangrijk was het voor u om het juiste apparaat te kopen?

- ◯ Ik wilde het juiste apparaat hebben, want ik wilde nauwkeurige waarden
- ◯ Ze lijken volgens mij erg op elkaar, ik geloof niet dat het veel uitmaakt
- ◯ Het was willekeurig, voor mij zijn ze allemaal hetzelfde
- ◯ Overige (geef nadere toelichting)

14. Wie maakte de uiteindelijke beslissing?

- ◯ Ik gaf advies, maar moest wel toestemming vragen
- ◯ Ik
- ◯ Ik heb overlegd met mijn collega's

15. Had u vertrouwen in uw beslissing?

Ja, want:

Nee, want:

16. Waren de metingen succesvol?

- ◯ Nee, de waarden zijn onbetrouwbaar gebleken
- ◯ Ja, de waarden zijn betrouwbaar gebleken
- ◯ Het is nog niet bewezen

17. zou u, achteraf gezien, een ander apparaat hebben gekozen?

Ja, want: ____________________

Nee, want: ____________________

*18. Hoeveel verschillende soorten apparaten heeft u gekocht?

- ◯ Eén
- ◯ Meer dan één

19. Waarom heeft u meerdere soorten apparaten gekocht?

- ◯ Er moesten metingen verricht worden in verschillende situaties
- ◯ Het bleek dat ik het verkeerde apparaat had
- ◯ Anders (geef nadere toelichting)

____

20. Welk(e) appara(a)t(en) heeft/hebt u gekocht?

- ☐ Guelph
- ☐ Dubbele ring infiltrometer
- ☐ Tension infiltrometer
- ☐ K-sat
- ☐ Labtype permeameter

Overige (geef nadere toelichting)

____

21. Wat is uw hoogst afgeronde opleiding?

22. Voor wat voor soort instituut werkt u?

- Onderzoek
- Educatief
- Industrieel
- Overige (geef nadere toelichting)

23. Geef alstublieft een korte omschrijving van het instituut, en uw werk:

Bedankt dat u de tijd heeft genomen om onze vragen te beantwoorden!

Wij zijn ervan overtuigd dat we de antwoorden kunnen gebruiken om onze service te verbeteren.

Bijlage 2: Resultaten enquête

Infiltration devices

1. Why did you want to measure an infiltration capacity?

	Percentage reacties	Aantal reacties
To research the feasibility of rainwater infiltration	**45,5%**	**10**
For irrigation system design	22,7%	5
To research the risk of erosion	0,0%	0
Other:	31,8%	7
	beantwoorde vraag	**22**
	overgeslagen vraag	**0**

2. Did you know which method of irrigation was going to be used?

	Percentage reacties	Aantal reacties
No, it depended on the measurement	**80,0%**	**4**
Yes:	20,0%	1
	beantwoorde vraag	**5**
	overgeslagen vraag	**17**

3. Did you carry out any research to the site prior to the infiltration measurement?

	Percentage reacties	Aantal reacties
Yes	**55,6%**	**10**
No	44,4%	8
	beantwoorde vraag	**18**
	overgeslagen vraag	**4**

4. What kind of research?

		Percentage reacties	Aantal reacties
Field (profile) research		**60,0%**	**6**
Desk study		0,0%	0
Both		40,0%	4
		beantwoorde vraag	**10**
		overgeslagen vraag	**12**

5. Would you describe this research as...

	restricted			moderate			extensive	Gemiddeld waarderin
	0,0% (0)	20,0% (2)	30,0% (3)	**40,0% (4)**	0,0% (0)	0,0% (0)	10,0% (1)	3,6
								beantwoorde vraa
								overgeslagen vraa

6. Which factors were taken into acccount? (more than one answer possible)

	Percentage reacties	Aantal reacties
Vegetation	20,0%	2
Soil layers	**90,0%**	**9**
Groundwater level	70,0%	7
Soil structure	70,0%	7
Climate	20,0%	2
Cost	30,0%	3
Other:	20,0%	2
	beantwoorde vraag	**10**
	overgeslagen vraag	**12**

7. What was your decision based on?

	Aantal reacties
	12
beantwoorde vraag	**12**
overgeslagen vraag	**10**

8. Based on the information you had, how did you decide on a specific infiltration measuring device?

	Percentage reacties	Aantal reacties
I have little knowledge on the subject, so I made an educated guess	12,5%	2
My education / my background provided me with sufficient knowledge	**50,0%**	**8**
I contacted Eijkelkamp for assistance	6,3%	1
I looked up information myself	6,3%	1
Other:	25,0%	4
	beantwoorde vraag	**16**
	overgeslagen vraag	**6**

9. Was this assistance sufficient?

	Percentage reacties	Aantal reacties
Yes, because:	0,0%	0
No, because:	0,0%	0
	beantwoorde vraag	**0**
	overgeslagen vraag	**22**

10. Do you think Eijkelkamp should/could do more to help the customer with his decision? Please clarify:

	Aantal reacties
	0
beantwoorde vraag	**0**
overgeslagen vraag	**22**

11. Which factors were involved in your decision? Consider things such as soil type, saturated/unsaturated, cost, ect.

	Aantal reacties
	10
beantwoorde vraag	**10**
overgeslagen vraag	**12**

12. Which of these factors were most important?

	Aantal reacties
	7
beantwoorde vraag	**7**
overgeslagen vraag	**15**

13. How important was it to you to buy the right device?

	Percentage reacties	Aantal reacties
I wanted the right device, because I wanted accurate values	**61,5%**	**8**
They seem very similar to me, I don't think it makes much difference	7,7%	1
I chose at random, they are all the same in my eyes	0,0%	0
Other:	30,8%	4
	beantwoorde vraag	**13**
	overgeslagen vraag	**9**

14. Who made the actual decision?

	Percentage reacties	Aantal reacties
Just me	**44,4%**	**4**
I advised, but I had to ask approval	11,1%	1
I deliberated with my colleagues	**44,4%**	**4**
	beantwoorde vraag	**9**
	overgeslagen vraag	**13**

15. Where you confident about the decision you made?

	Percentage reacties	Aantal reacties
Yes, because:	**75,0%**	**6**
No, because:	25,0%	2
beantwoorde vraag		**8**
overgeslagen vraag		**14**

16. Where the measurements succesful?

	Percentage reacties	Aantal reacties
Yes, the values turned out to be reliable	**70,0%**	**7**
No, the values turned out to be unreliable	0,0%	0
It has not been proven either way	30,0%	3
beantwoorde vraag		**10**
overgeslagen vraag		**12**

17. In retrospect, would you have chosen a different device?

	Percentage reacties	Aantal reacties
Yes, because:	28,6%	2
No, because:	**71,4%**	**5**
beantwoorde vraag		**7**
overgeslagen vraag		**15**

18. How many different kinds of device did you buy?

	Percentage reacties	Aantal reacties
One	**53,8%**	**7**
More then one	46,2%	6
	beantwoorde vraag	**13**
	overgeslagen vraag	**9**

19. Why did you buy different kinds of devices?

	Percentage reacties	Aantal reacties
I had to take more measurements in a different situation	**66,7%**	**4**
It turns out I had the wrong device	0,0%	0
Other:	33,3%	2
	beantwoorde vraag	**6**
	overgeslagen vraag	**16**

20. Which device(s) did you buy?

	Percentage reacties	Aantal reacties
Double ring infiltrometer	**66,7%**	**8**
Guelph	41,7%	5
K-sat	8,3%	1
Tension infiltrometer	50,0%	6
Labtype permeameter	0,0%	0
Other:	8,3%	1
	beantwoorde vraag	**12**
	overgeslagen vraag	**10**

21. What is you highest finished education?

	Aantal reacties
	9
beantwoorde vraag	**9**
overgeslagen vraag	**13**

22. What kind of institution do you work for?

	Percentage reacties	Aantal reacties
Research	27,3%	3
Educational	18,2%	2
Industrial	0,0%	0
Other:	**54,5%**	**6**
	beantwoorde vraag	**11**
	overgeslagen vraag	**11**

23. Please give a short description of the institution, and your job:

	Aantal reacties
	10
beantwoorde vraag	**10**
overgeslagen vraag	**12**

Page 2, Q1. Why did you want to measure an infiltration capacity?		
1	All of the above	Dec 1, 2013 3:36 AM
2	Unknown, on assingment	Dec 1, 2013 3:24 AM
3	unknown, the customer doesnt always tell us	Dec 1, 2013 3:14 AM
4	We do not know because we are not the final user	Oct 18, 2013 4:59 AM
5	x	Oct 18, 2013 1:42 AM
6	Clients have different needs.	Oct 2, 2013 10:29 AM
7	I am the distributor, so this is for resale	Oct 2, 2013 6:06 AM

Page 3, Q2. Did you know which method of irrigation was going to be used?		
1	Sprinkler irrigation	Dec 1, 2013 2:57 AM

Page 7, Q6. Which factors were taken into acccount? (more than one answer possible)		
1	Literature study by customer	Dec 1, 2013 3:26 AM
2	Altitude	Dec 1, 2013 2:58 AM

Page 8, Q7. What was your decision based on?		
1	Information of the customer	Dec 1, 2013 3:37 AM
2	Choice is made by customer	Dec 1, 2013 3:27 AM
3	soil layers, groundwater level, other things only if the customer specifically asks for it.	Dec 1, 2013 3:15 AM
4	Situation and measuring infiltration or erosion	Dec 1, 2013 3:00 AM
5	I do not know we just sold the device ????? to our client	Oct 18, 2013 5:00 AM
6	x	Oct 18, 2013 1:42 AM
7	particle size distribution	Oct 17, 2013 6:53 AM
8	Soil structure&cost	Oct 7, 2013 1:26 AM
9	results	Oct 6, 2013 4:36 PM
10	Field research, analize of soil structure	Oct 4, 2013 5:47 AM
11	Usually our clients decide.	Oct 2, 2013 10:30 AM
12	N/A	Oct 2, 2013 6:07 AM

Page 9, Q8. Based on the information you had, how did you decide on a specific infiltration measuring device?		
1	X DG	Oct 21, 2013 6:05 AM
2	Just send our order to Eijkelkamp	Oct 18, 2013 5:00 AM
3	Usually they have the information needed.	Oct 2, 2013 10:30 AM
4	Client discussed with me for advise	Oct 2, 2013 6:07 AM

Page 12, Q11. Which factors were involved in your decision? Consider things such as soil type, saturated/unsaturated, cost, ect.		
1	Goal of the measurement	Dec 1, 2013 3:42 AM
2	Customers whishes	Dec 1, 2013 3:27 AM
3	the wish of the customer, the method is usually in the assignment	Dec 1, 2013 3:18 AM
4	Goal of the measurement and sat/unsat.	Dec 1, 2013 3:00 AM
5	Soil type, saturated conditions, objective of the work	Oct 21, 2013 7:40 AM
6	Dont know we are just the distributor	Oct 18, 2013 5:01 AM
7	cost	Oct 17, 2013 6:54 AM
8	soil type&cost	Oct 7, 2013 1:27 AM
9	Cost and competition.	Oct 2, 2013 10:31 AM
10	Cost, saturated conductivity	Oct 2, 2013 6:08 AM

Page 13, Q12. Which of these factors were most important?		
1	sometimes we advise on the reliability, the number of measuremetns,cost, ed	Dec 1, 2013 3:19 AM
2	Situation sat/unsat and costs	Dec 1, 2013 3:01 AM
3	Soil type	Oct 21, 2013 7:41 AM
4	delivery time for the devices	Oct 18, 2013 5:01 AM
5	cost	Oct 17, 2013 6:54 AM
6	Soil structure	Oct 7, 2013 1:27 AM
7	Costs	Oct 2, 2013 6:08 AM

Page 14, Q13. How important was it to you to buy the right device?		
1	There is only one good method	Dec 1, 2013 3:42 AM
2	Comply with customers request	Dec 1, 2013 3:29 AM
3	Customer decision	Oct 18, 2013 5:01 AM
4	Difficult to tell.	Oct 2, 2013 10:31 AM

Page 16, Q15. Where you confident about the decision you made?		
	Yes, because:	
1	Yes	Dec 1, 2013 3:42 AM
2	Yes	Dec 1, 2013 3:30 AM
3	we never get complaints about the results	Dec 1, 2013 3:20 AM
4	Yes	Dec 1, 2013 3:02 AM
6	partly	Oct 17, 2013 6:55 AM
8	Usually our clients are.	Oct 2, 2013 10:32 AM
	No, because:	
5	I do not know the exact use for the device	Oct 18, 2013 5:02 AM
7	No, decision is up to our clients	Oct 7, 2013 1:28 AM

Page 18, Q17. In retrospect, would you have chosen a different device?		
	Yes, because:	
4	shipment, delivery times to large	Oct 18, 2013 5:03 AM
5	additionally yes	Oct 17, 2013 6:56 AM
	No, because:	
1	It went well	Dec 1, 2013 3:30 AM
2	the customer is happy	Dec 1, 2013 3:21 AM
3	Satisfied with results	Dec 1, 2013 3:03 AM
6	No, I guess	Oct 7, 2013 1:29 AM
7	was ok	Oct 6, 2013 4:37 PM

Page 20, Q19. Why did you buy different kinds of devices?		
1	different customers	Dec 1, 2013 3:21 AM
2	Different clients	Oct 2, 2013 10:33 AM

Page 21, Q20. Which device(s) did you buy?		
1	Soil moisture equipment	Dec 1, 2013 3:33 AM

Page 21, Q20. Which device(s) did you buy?

Page 22, Q21. What is you highest finished education?

1	MBCS Land and watermanagement	Dec 1, 2013 3:43 AM
2	BCS	Dec 1, 2013 3:33 AM
3	MBCS IAHL, land en water management	Dec 1, 2013 3:22 AM
4	HBO Land&water management	Dec 1, 2013 3:04 AM
5	Phd	Oct 21, 2013 7:44 AM
6	University	Oct 18, 2013 5:04 AM
7	university msc	Oct 17, 2013 6:57 AM
8	Do not know	Oct 7, 2013 1:29 AM
9	PhD	Oct 2, 2013 10:34 AM

Page 23, Q22. What kind of institution do you work for?

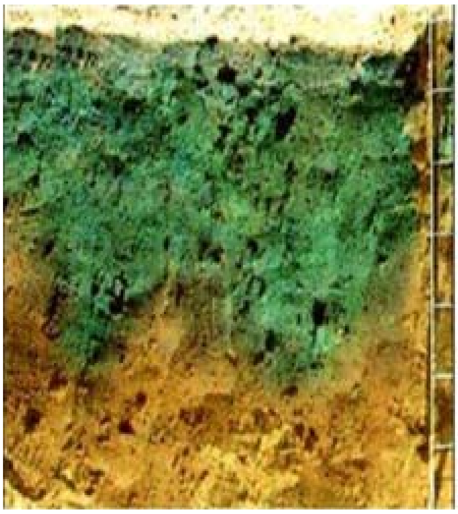
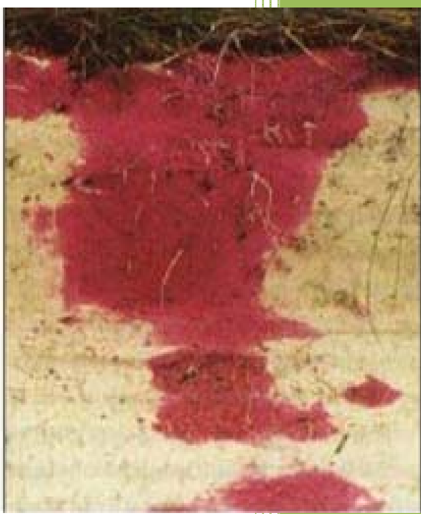
1	Advise centre	Dec 1, 2013 3:43 AM
2	field research, sometimes we give advice	Dec 1, 2013 3:22 AM
3	Service	Dec 1, 2013 3:04 AM
4	commercial distributor	Oct 18, 2013 5:04 AM
5	Equipment distributor	Oct 7, 2013 1:30 AM
6	Comercial	Oct 2, 2013 10:34 AM

Page 24, Q23. Please give a short description of the institution, and your job:		
1	Planning, coordination and fieldwork	Dec 1, 2013 3:44 AM
2	Owner, sometimes fieldwork	Dec 1, 2013 3:34 AM
3	field work	Dec 1, 2013 3:23 AM
4	Director	Dec 1, 2013 3:05 AM
5	I study the triggering mechanisms of shallow landslides in the Department of Earth and Environmental Sciences	Oct 21, 2013 7:45 AM
6	distributor for many foreign companies	Oct 18, 2013 5:05 AM
7	consultant (environmental)	Oct 17, 2013 6:58 AM
8	Eijkelkamp ditributor Manager	Oct 7, 2013 1:30 AM
9	We represent EAE	Oct 2, 2013 10:34 AM
10	I am the distributor in the USA	Oct 2, 2013 6:10 AM

Bijlage 3: Het rapport; Measuring infiltration by means of…?

2014

Measuring infiltration by means of…?


Jos van de Greef

A graduation assignment for Royal Eijkelkamp

6-1-2014

Management Summary

Infiltration is the process that occurs when water from the atmosphere enters into the soil. This report was written to create a reference work for those who want to gain knowledge on this subject.

A term that holds close relation to the infiltration capacity is the hydraulic conductivity (K). The hydraulic conductivity of a soil is a measure of the ease with which the water can flow through the soil, in any direction, horizontal or vertical. Hydraulic conductivity is an important factor for the infiltration capacity. An infiltrometer is a device used to measure the infiltration rate/capacity of a soil, whereas the permeameter is used to determine the hydraulic conductivity.
Soil is a three phase system, consisting of solids, liquids, and gasses. The presence and exchangeability of water and air depend primarily on porosity. The spaces between the soil particles are called pores. Pores are of considerable importance to a soil, since they allow movement of water and air through the soil. The pore size distribution (in part) determines the speed of water and air flow in the soil. The total volume of the pores is known as the porosity of a soil.
If the pores are filled exclusively with water, the soil is said to be saturated. When the soil is not saturated, there are several forces that keep water 'hanging' in the soil.
Another important factor for infiltration is the soil type, and the shape of the three different types of soil particles: silt, sand and clay. Clay particles are much smaller than silt and sand, and they are plate – shaped. This shape is, for a large part, responsible for the vast differences of K – values in horizontal and vertical direction.
The head or the pressure (in meters water column) is a measure of the amount of energy stored in water. If there is no head there is negative pressure or tension.
The difference in pressure between two points is called the hydraulic gradient. Soil water above the groundwater table has a negative pressure. The soil particles 'pull' at it over their entire surface area, so the water will be stretched around it causing a state of tension.
Water does not flow through air-filled pores. Any pore in the soil that is filled with air, must first be wetted before it can contribute to the flow of water through the soil. The groundwater level is no free surface of water, there is also water above it. The term 'ground water level' refers to the point where the groundwater pressure is zero.
Macropores are hollows in the soil, such as wormholes. When water is delivered to the soil at positive pressure, macropores will contribute enormously to the hydraulic conductivity.
When a lot (or most) of the water flows very rapidly down to the subsoil through macropores without wetting the topsoil, this is known as a 'short circuit'.
In many soils, certain compounds are present that will prevent water from wetting the soil. These soils are called Water Repellent Soils, usually this occurs only in the top 10 centimeters of the cultivated top layer. When water repellent soils are wetted, they form an unstable wetting front in which so – called 'fingers' occur.
Slaking is the process where the smaller soil particles will form a hard, dense layer on top of the soil called a crust, which has a big influence on the infiltration capacity.

The essence of any method of measuring infiltration, is the law of continuity which states, in its simplest form, that 'inflow – outflow = change in storage'. If water is delivered to the soil at negative pressure, the soil has to pull the water out. Infiltration measuring methods that use this principle are unsaturated, and they show how a soil reacts to rain or sprinklers much better than saturated methods. A Mariotte bottle is a container, from which water flows at a constant rate. This principle is used in many infiltrometers, in order to create a constant head.

In – hole tests for hydraulic conductivity can be roughly divided into two groups: by adding water or by extracting water. Depending on the goal of the measurement, and the expected hydraulic

conductivity some of these are more suitable than others. When measuring in the laboratory, samples have to be taken, that can be analyzed, in the field the sample is not taken out of its context.

The measured value is only an indication of the 'real' value, because soil is not homogenous. The number of measurements that should be carried out, is dependent on the expected magnitude of variation. The saturated hydraulic conductivity is equal to the infiltration capacity unless any limiting factors are present. It is a key parameter for all aspects of water movement in soils. To calculate the saturated hydraulic conductivity, Darcy's Law is commonly used.
When a crust has formed on the soil, pores will only fill themselves with water if they are able to 'pull' the water through the crust. To calculate the infiltration capacity of such a soil, Darcy's Law must first be applied to the crust itself.
The Green and Ampt equation also takes the initial soil moisture into account.
One equation that is appropriate for use in boreholes is Glover's formula, because it assumes saturated conditions and it takes into account the shape of a borehole. Glover's formula is:

The K-sat Constant Head Permeameter determines permeability of any layer <4 m, is meant for above the groundwater table, is a stable, compact and versatile instrument, and employs a steady state principle for optimum accuracy. The Aardvark determines permeability of any layer <15 m deep, does all calculations automatically and uses a constant head for optimal accuracy. The Tension Infiltrometer measures unsaturated infiltration capacity, is ideal for sprinkler irrigation advice and is insensitive for root tunnels and insect borings because of this, comes to an equilibrium quickly and causes very limited soil surface alteration. The Double Ring Infiltrometer is ideal for infiltration measurement of top soils but cannot be used in stony areas, is most suited for flood/furrow irrigation advice, and is low – tech and therefore very durable. The Single Ring Infiltrometer is ideal for infiltration measurement of top soils but cannot be used in stony areas, is most suited for flood/furrow irrigation advice, and is low – tech and therefore very durable but has low accuracy due to lateral flow. The Rainfall Simulator is not an infiltration measurement device, it measures run – off and erosion risk but can give an indication of the infiltration capacity, creates standardized shower to be used in the lab or in the field. The Guelph Permeameter is a versatile instrument that can measure both saturated and unsaturated, at surface or at depth, its calculations are rather complicated so it requires a skilled operator, it is very susceptible to wind and works in a bore hole but to a limited depth (<3 meters). The Labtype Permeameter can be used only in the lab, measures permeability from undisturbed samples, has both constant and falling head method options. Grain Size Analysis is the only way to determine K – values greater than 10^4 meters per day but is not very accurate.

Preface

This report was written as a reference work for those who want to know more about infiltration. Plenty of information about this subject can be found in literature, but it is very fragmented. Several books explain Darcy's Law, for example, but so thoroughly that the average person probably cannot follow it. And for another formula another book must be found. So my job was to find information on several subjects that have to do with infiltration, and bring it together in a single report that is readable for anyone.

The report that is now in front of you is the result of several months of searching, reading and typing. I hope that, if you have an interest in infiltration, this report will help you understand the process better.

I have several people to thank for this final report, which I think turned out nice particularly because of my father, Hans van de Greef, who tirelessly edited endless pieces of text. I would also like to thank my supervisor, Cor Verbruggen, for his enthusiasm on the subject that aroused my interest. I also owe thanks to Piet Peters from Wageningen University, for giving me a demonstration on the use of the Rainfall Simulator. To my girlfriend Jingwen I owe an apology more than thanks, since in the past weeks I have unfortunately had more time for this report than for her…

Table of contents

1 Introduction

1.1. Why measure infiltration?

When it rains, the water will seep into the soil, adding to the groundwater. Groundwater is present almost everywhere in the soil, at different depths. This can be seen when one digs a hole in the ground at any random location; eventually groundwater will start seeping in to it.
The process of water seeping into the soil is called infiltration. Precipitation can infiltrate either directly or indirectly (after first flowing into surface water).
The speed at which water can infiltrate into a soil is called the infiltration rate, and it depends heavily on the situation. A clay soil for example will seem reluctant to let the water infiltrate, and it will take a long time. In course sand it will go very fast.
And in both cases, it may not go on indefinitely – eventually the soil will be completely saturated, and water will have to find other places to go.

There are many cases in which it is desirable to know how fast water can infiltrate into the soil, and how much water can infiltrate in total.
If more water is applied than can infiltrate, it will form run off which means there is a risk of erosion, especially in sloped areas. But if the amount of water the soil can store is known, run off – and therefore erosion – can be prevented. When designing an irrigation system, it is of vital importance to know how much water will infiltrate into a soil, in order to get exactly the right amount to the crops. And in many urban areas, rainwater is collected into infiltrating facilities in the ground to reduce the pressure for the sewage system.
So, if a farmer or a city planner has any plans like the examples above, they need a way to measure the infiltration capacity. There are several methods to do this, each designed for their own circumstances. So which one to use?

1.2. Why this report was written

The infiltration capacity of a soil depends on many factors. Measuring the infiltration capacity of a soil can be done in many ways. The different existing methods differ from each other to a greater or lesser extent, however all were designed with a specific purpose.

There are also many factors that determine which device or method is best in a certain situation. The people who have to make the decision do not always have the knowledge that is necessary for this choice. There has been done a lot of research on this subject, however for people who have no knowledge about infiltration it can be very difficult to find the information required to make the decision.

In order to make this decision easier Eijkelkamp Agrisearch Equipment has developed a flowchart. This flowchart shows the most important factors the decision for a certain infiltration measuring device should be based on, and following this flow chart the decision can be made easily. Those who want to know the details of what makes a device the most suitable, can find a lot of relevant information gathered in this report. The process of infiltration is described here, accessible and in detail. It is meant for those people, who have had little or no education on the subject but need or want to know what happens in the soil.

1.3. Structure

In the following chapter the soil is investigated to see what it is made of and how infiltrating water reacts to it.
Chapter 3 deals with the most important principles on which infiltration measuring devices work.
In chapter 4 the theory behind the infiltration process is described with different equations.
In chapter 5 the used devices are introduced, their basic construction and applications are described. When available, a calculating example is also included.

2 Factors that have an influence on infiltration

This chapter explains what happens in the soil when water is applied on it. It starts out with the more common factors that always have an influence, such as porosity or grain size. Later on more specific issues, which occur more rarely, such as water repellence will be explored.

Infiltration is defined as the process by which water from the atmosphere enters into the soil. This happens at a certain speed, the infiltration rate. When a large plot is wetted at the same time (because of precipitation or irrigation for example) this movement is vertical. When measuring infiltration, the only interesting movement is the vertical one. During a measurement, however, the soil is wetted locally, and water will flow horizontally as well. This is called lateral flow, which will be discussed later in this chapter.

This movement is always vertical. The ability of a soil to take in water is a very important factor. When growing crops, for example, it is vital to know how fast water can infiltrate and how much water can infiltrate at one time. This is called the infiltration capacity (which is the maximum infiltration rate), and measuring it is what this report is about.

When ponded water is infiltrating the soil, three distinct zones can be distinguished in the soil column (Hillel 1980):

- the saturated zone
- the transivity zone
- humidification zone

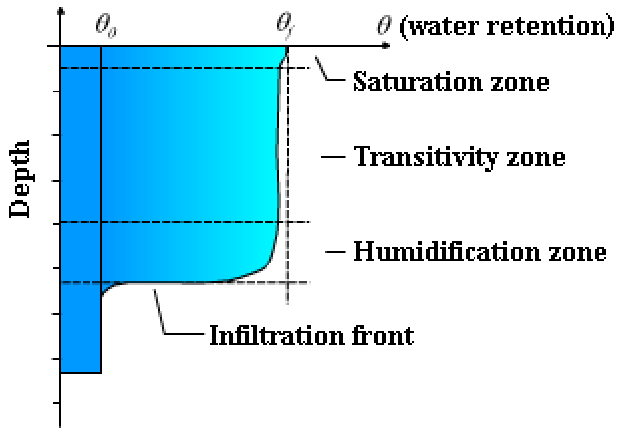


Figure 1: saturation zones during infiltration[1].

The saturated zone is the zone directly under the soils surface, in which the pore space is completely filled with water.

The transition zone below that (not in the picture) forms the transition between the saturated zone and the transitivity zone. In the transition zone the water content decreases quite rapidly with depth.

[1] http://echo2.epfl.ch/VICAIRE/mod_1a/chapt_5/main.htm

The transitivity zone is the zone in which the most water is moved since it gets longer over time (this is much less obvious for the other zones). Also, it shows little change in water content with depth, being almost saturated from the top to the bottom. Movement of water in the transitivity zone happens mostly under influence of gravity.

The humidification zone (wetting zone), is the zone in which the soil initially gets wetted. It therefore shows a sharp decrease in moisture content, from almost saturated to the initial water content of the soil. The wetting zone does not get larger with time, but it moves down into the soil as the transitivity zone becomes longer. Water movement in the wetting zone happens mainly under influence of soil tension.
The wetting zone is bordered at the underside by the wetting front, which is the border between wetted and unwetted soil[2].

The speed at which all this happens, depends on many factors. Water that moves through a soil encounters resistance, just like it does in pipes – in fact, the pores in the soil could be viewed as a very complex system of extremely narrow, bendy, interconnecting pipelines. The 'ease' with which water will move through this system, is called the hydraulic conductivity, and it is dependent on many factors, some of which are:

- Water content. The more water the soil contains, the greater the cross-sectional area of water filled pores through which water can flow. Air filled pores have to be wetted first, before they can add to the flow.
- Tortuosity of the pore system. The water cannot travel in a straight line, and the more convoluted the pore system is, the longer the route the water has to take. This tortuosity increases as the water level decreases, as the water has to move around air-filled pores.
- Size of water filled pores. A water molecule at the surface of a soil particle is stuck to it and therefore virtually stationary. Further away from the soil particle the flow goes faster, much like the water in the middle of a river flows faster than close to the banks. The bigger the pore, the higher the speed in the middle.

Now, let's take the example of a single ring infiltrometer where a portion of a field is flooded in about 10 centimetres of water. How it will infiltrate (if it does at all) is heavily dependent on several factors.

If the soil is completely saturated, as has been said, the water cannot infiltrate. The water level in the ring will drop, but the outflow will be lateral (horizontal). If the soil was at field capacity, with the groundwater table out of the way, things would go different. Field capacity is the 'natural' water content of a soil, the maximal amount the soil tension can hold before if flows down under influence of gravity (see chapter 2.4). If more water is applied to it gravity will pull it down. Initially the water will move straight down, and form a wetting front that is more or less flat at the bottom.

However, when the wetting front comes lower than the edge of the ring, its shape will change. Inside the ring the soil can be assumed saturated, but below it is still at field capacity, with negative pressure.
The path of least resistance is now to flow horizontal. This is called lateral flow, and it will cause the shape of the wetting front to become bulb-like.
With the double ring infiltrometer, this also happens, but the water for the lateral flow is provided by the outer ring. The level in the inner ring will therefore drop slower, and give a more accurate value for the infiltration rate (see figure 2).

[2] http://www.epa.gov/ada/csmos/ninflmod.html

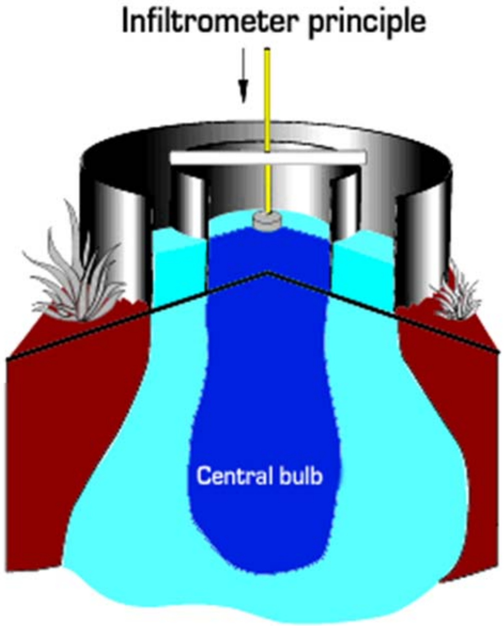


Figure 2: bulb-like wetting front that occurs below a double ring infiltrometer [3].

This presents a difficulty: the infiltration capacity is the value we are ultimately interested in, but due to lateral flow this is usually not the rate at which the water level drops in the ring.
As described above, lateral (horizontal) flow also plays a role and will likely make the water level drop faster for which the measured infiltration capacity has to be corrected.

Eventually the pressure inside the ring will decrease as the water level drops and the soil nears saturation, and infiltration will start to go slower. The infiltration capacity of a soil gives the maximum amount of water that can infiltrate in a soil per unit of time, and is therefore dependent on the infiltration rate. Once the water is in the soil, further downward movement is referred to as percolation. This is a different process, and it will not be investigated further in this report.

Another term that holds close relation to the infiltration capacity is the hydraulic conductivity. The hydraulic conductivity of a soil is a measure of the ease with which the water can flow through the soil, in any direction, horizontal or vertical. This means that it is also important when describing deep ground water systems – infiltration capacity is not. Hydraulic conductivity is therefore an important factor for the infiltration capacity. Likewise, the term infiltrometer is not to be confused with permeameter. An infiltrometer is a device used to measure the infiltration rate/capacity of a soil, whereas the permeameter is used to determine the hydraulic conductivity.

2.1. Porosity/soil water content

Water in the soil is essential for plant growth. Water also strongly influences the soil itself. Many physical, chemical and biological processes in the soil only occur in the presence of enough moisture. Locher and Broekhuizen (1990) also make note that the soil is a three phase system, consisting of solids (the mineral part of the soil, and organic matter), liquids (water, or rather soil moisture since it usually contains dissolved minerals), and gasses (air).
The presence and exchangeability of water and air depend primarily on a property of the soil known as porosity.

[3] http://www.usyd.edu.au/agric/web04/double%20ring%20final.htm

Soil is made up of particles that may differ enormously in size and shape, from coarse gravel to fine silt or clay. In figure 3 we see a schematic view (the shape of the particles has been left out of consideration) of the comparative sizes of different soil particles, if the clay particle was the size of a pencil point (in reality it is no bigger than 2 µm). The spaces between these particles are called pores.

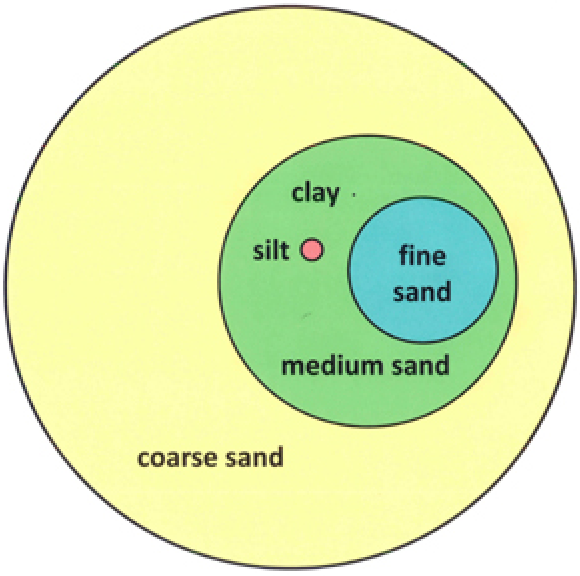


Figure 3: comparative sizes of soil particles[4].

Soil structure can be measured in a number of ways, but according to Danielson and Sutherland (1986) , it may be most meaningfully evaluated through some knowledge of the amount, size, configuration, or distribution of soil pores.

Pores are of considerable importance to a soil, since they allow movement of water and air through the soil. This is dependent on the shape and size of the pores. Though they may be big or small, they may be poorly connected and have a highly irregular shape. Precise quantification of these characteristics of soil pores is essentially impossible, due to their extremely complicated nature. However, by making certain assumptions, the size distribution of pores can be made with at least useful accuracy for both laboratory and field purposes.

Locher and Broekhuizen (1990) describe a fairly simple, but effective method to determine the total porosity of a soil. A sample of the soil is dried at 105 degrees for 24 hours, and then weighed. This weight is then divided by the volume of the sample when it was taken, to obtain the 'dry mass' of the sample. If it is now saturated with water and weighed again, the volume of water in the sample can be calculated.

With this method however, the porosity is determined only as a volumetric portion of the soil. Locher and Broekhuizen (1990) themselves make note: "A sandy soil with a porosity of 0.40 may be sufficiently conductive for air and water and penetrable for plant roots, whereas a clay layer with a porosity of 0.55 may considerably hinder flow of water." This is because, if porosity is determined in this way, no information is gained on the shape and distribution of the pores.

[4] http://www.ext.colostate.edu/mg/gardennotes/213.html

Danielson and Sutherland (1986) describe a more elaborate method that yields more information. They start with a saturated soil sample, and then proceed to drain it in steps, and measure the volume of water that is removed between each step. Then, if the size-range of pores that are drained in each step, the pore size distribution can be determined. In theory, the larger pores should drain first, however, the drainage of the pore will actually be determined by the largest 'opening' of that pore to the next one.

The frequency of occurrence of pores with certain sizes can be expressed in a value known as the pore size distribution. Pore size distribution (in part) determines the speed of water and air flow in the soil. The total volume of the pores is known as the porosity of a soil, which is given in percent.

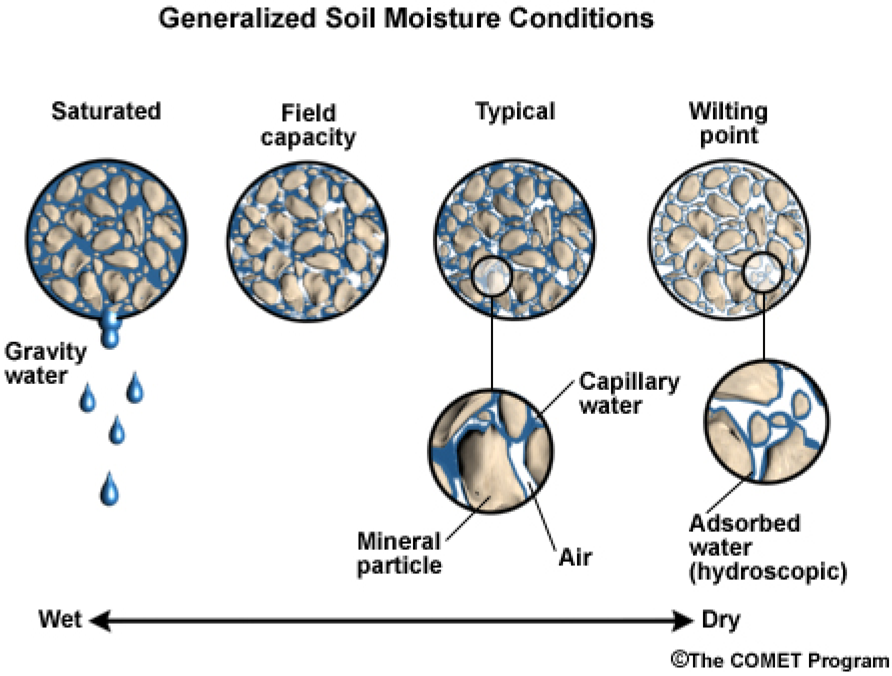


Figure 4: generalized soil moisture conditions[5].

If the pores are filled exclusively with water, the soil is said to be saturated. In the field, this happens only when the groundwater table rises from below. When infiltrating rainwater causes the groundwater level to rise, air is trapped and some bubbles often remain. The maximal amount of water that can be stored in a soil is therefore easily determined by the porosity of the soil.

In the field, the amount of pores that is filled with water will usually differ greatly over time. When all pores are filled entirely with water, the volume of water is typically between 40 and 60 per cent (see figure 9), and no air is present. A soil in this state is said to be saturated (see chapter 2.5). When the rain stops, the water will be drained away over time into rivers and canals and such, and the groundwater level will drop under the influence of gravity. Not all water will flow out of the soil by itself though, there are several forces at work that keep water 'hanging' in the soil.

One of such forces is capillarity (see figure 5). Due to its molecular structure (H2O, two hydrogen and one oxygen) each water molecule has a slight positive charge. Most soil particles are made up of none-metal elements, and therefore have a negative charge. This causes the two to stick together, and so a film of water will be maintained around each soil particle. In a glass of water the same effect can be seen, when the water stands up against the edge.

[5] http://stream2.cma.gov.cn/pub/comet/HydrologyFlooding/UnderstandingtheHydrologicCycleInternationalEdition/comet/hydro/basic_int/hydrologic_cycle/navmenu.php_tab_1_page_4.3.0.htm

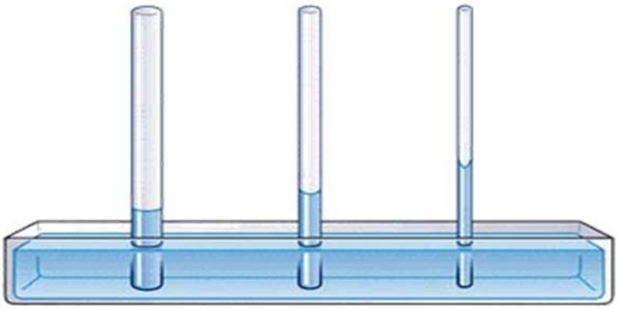


Figure 5: capillary rise in different glass tubes[6].

The smaller the pore (or, in the example above, the glass tube) is, the more water relatively comes into contact with it. Hence, the smaller the pore, the larger the capillary force. However, small pores do offer more resistance to the movement of water. In coarse soils, such as course sand, the capillary rise will be small but established quickly. In fine silt, for example, the capillary rise will be high (see figure 6) but it may take weeks to fully develop.

Table II.1.B Typical Height of Capillary Fringe

Material	Grain size (mm)[a]	Pore radius (cm)[b]	Capillary rise (cm)	
Coarse gravel		0.4		0.38[b]
Fine gravel	5–2		2.5[a]	
Very coarse sand	2–1		6.5[a]	
Coarse sand	1–0.5	0.05	13.5[a]	3.0[b]
Medium sand	0.5–0.2		24.6[a]	
Fine sand	0.2–0.1	0.02	42.8[a]	7.7[b]
Silt	0.1–0.05	0.001	105.5[a]	150[b]
Silt	0.05–0.02		200[a]	
Clay		0.0005		300[b]

[a] Reid, R. C., Prausnitz, J. M., and Poling, B. F., *The Properties of Liquids and Gases*, 4th ed., McGraw-Hill, New York, 1987. With permission.

[b] Fetter, C. W., Jr., *Applied Hydrogeology*, Charles E. Merrill Publishing, Columbus, OH, 1980. With permission.

Figure 6: capillary rise in different soil types, (Kuo 1999).

Another important force of nature that works in the soil is osmosis, the force that makes solutes strive for the lowest possible concentration. The films of water directly around the soil particles have many dissolved minerals in them. When (pure) rain water comes down into the soil, with a osmotic value close to zero, this water will tend to stick to the particles as well, in order to relieve the high concentrations of solvents in the soil moisture.

When the water level drops, leaving only capillary water as described above, the soil is said to be at field capacity. This means typically between 10 and 55 per cent of the water is still present. Water that is retained in this way will not drain away under the influence of gravity.

[6] http://www2.mcdaniel.edu/Biology/botf99/xylemweb/xyflow2.html

The water content can still be reduced by plant transpiration, however. Roots of plants will ingest water for as long as they can before the tension in the water becomes too great, which happens between 5 and 35 percent water content. This is called the permanent wilting point.

Further drying now occurs only by evaporation until the so called air dry state is reached. Water content can drop to around 8 percent in heavy clays, and almost to zero in sandy soils. In this air dry state, most of the pores will be filled with air.

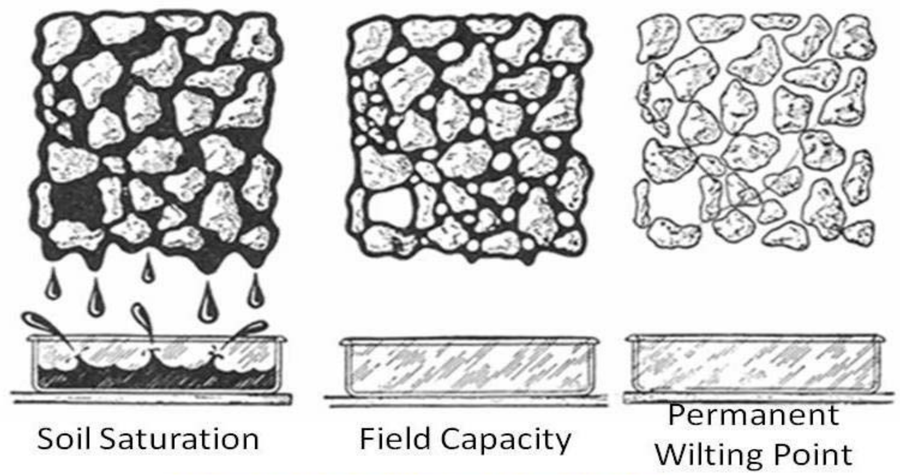


Figure 7: different levels of saturation[7].

2.2. *Soil type*

The porosity of a soil is mainly dependent on the size of the particles. Another important factor for infiltration is their shape, which also determines for an important part the soil type. Soil consists basically of three types of particles: silt, sand and clay, in different combinations (see figure 8). The difference between sand and silt is only in size. Silt is much smaller, and therefore also has smaller pores, but both are basically small rocks. Clay particles are different; they are much smaller still, and they are plate – shaped.

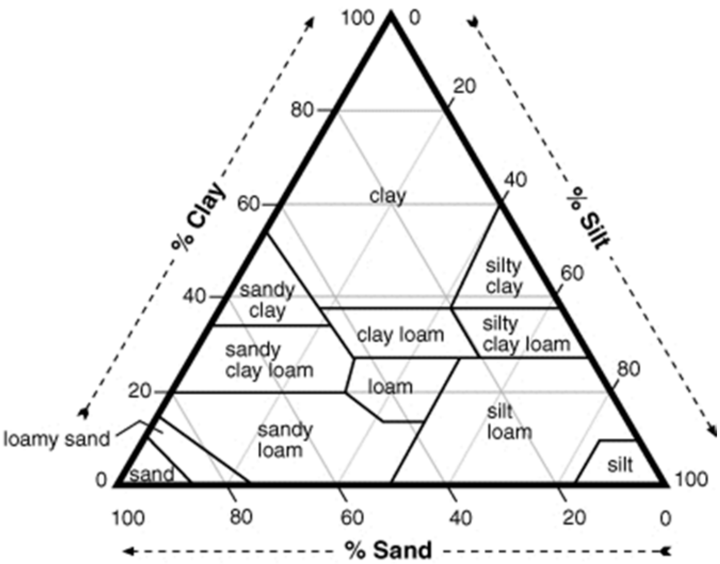


Figure 8: different soil types[8].

[7] http://thealmonddoctor.com/general/irrigation-scheduling-part-2-determining-water-holding-capacity/

This shape is, for a large part, responsible for the vast differences of K – values in horizontal and vertical direction. They are usually positioned 'flat', which means that lateral flow can pass through them, while vertically flowing (infiltrating) water has to go around. In figure 9, some typical infiltration rates for different soil types are shown.

	(Saxton and Rawls 2005)[1]		(Rawls *et al.* 1998)		(Clapp and Hornberger 1978)	
USDA Soil Textural Class	K_{sat} (ft/h)	Porosity (m^3/m^3)	K_{sat} (ft/h)	Porosity (m^3/m^3)	K_{sat} (ft/h)	Porosity (m^3/m^3)
Sand	0.5091–0.3058	0.48–0.46	0.5965–0.3000	0.44–0.39	0.9732	0.40
Loamy Sand	0.4464–0.1638	0.47–0.44	0.4039–0.1358	0.45–0.37	0.4783	0.44
Sandy Loam	0.3553–0.0744	0.47–0.42	0.1831–0.0425	0.47–0.37	0.1453	0.44
Loam	0.0271–0.1538	0.48–0.46	0.0130–0.0201	0.47–0.39	0.0331	0.45
Silt Loam	0.0402–0.2126	0.48–0.46	0.0472–0.0106	0.49-0.39	0.0083	0.49
Silt	0.0425–0.1068	0.49–0.47	-	-	-	-
Sandy Clay Loam	0.0128–0.0653	0.45–0.42	0.0248–0.0094	0.44–0.37	0.0296	0.42
Clay Loam	0.0122–0.0256	0.50–0.45	0.0142–0.0024	0.48–0.40	0.0083	0.48
Silty Clay Loam	0.0183–0.0252	0.53–0.49	0.0118–0.0165	0.50-0.43	0.0024	0.48
Sandy Clay	0.0003–0.0088	0.46–0.43	0.0035	0.39	0.0035	0.43
Silty Clay	0.0115-0.0118	0.55–0.50	0.0059	0.53	0.0012	0.49
Clay	0.0103–0.0056	0.56–0.46	0.0071–0.0060	0.48-0.40	0.0071	0.48

[1] Assuming 2.5% organic matter content and normal compaction

Figure 9: table with different soil types and their approximate infiltration values, according to different experts[9] (1 ft = 30.5 cm).

It can be seen, in the table, that the infiltration capacity decreases gradually as the particle size decreases. However, when the soil includes a considerable amount of clay, the infiltration rate drops dramatically.

2.3. Head

The head or pressure (in meters), is a measure of the amount of energy stored in water. When water is ponded on the surface of the soil, the head is the thickness of the layer of water. For example, in the double ring infiltrometer the head should be about 0.10 meters, in other words there should be about 10 centimetres of water in the rings.

When there is a head, there is also pressure, which means the water is infiltrating under saturated conditions. The pressure forces the water into the soil; the higher the pressure, the faster it will infiltrate (Bouwma, 1990). If there is no head, for instance when it is raining, there is negative pressure or tension (see chapter 2.4). The difference in pressure between two points is called the hydraulic gradient. When the hydraulic gradient is 'steep', that is, when the difference is large, the water will have a strong tendency to move from one place another.

The head is a very important variable. No matter what the soil conditions are, the higher the head, the faster the water will infiltrate. The relation between head (cm) and hydraulic conductivity, can be show in a so – called conductivity curve (see figure 10), with conductivity (K – value) on one axel and head (h) on the other:

[8] http://www.extension.umn.edu/distribution/cropsystems/components/7399_02.html
[9] http://stormwaterbook.safl.umn.edu/content/capacity-testing-bio-enhanced

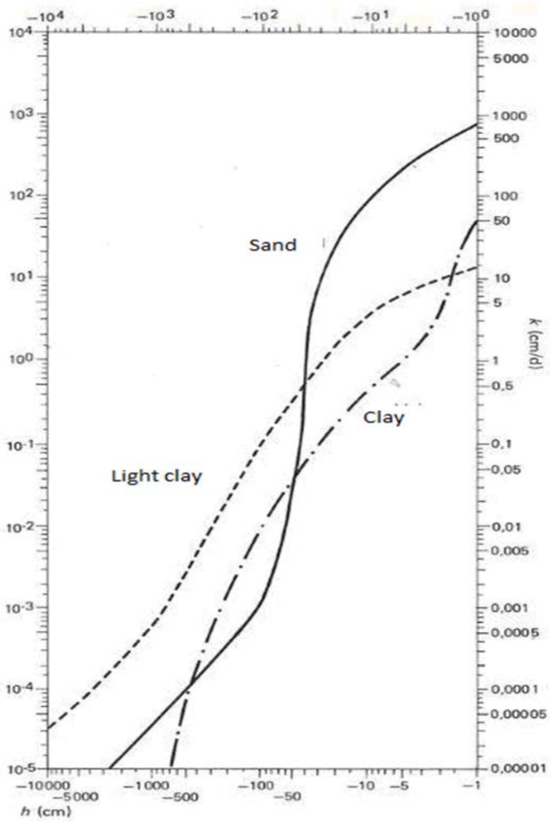


Figure 10: conductivity curves of sand, clay and silt (Bouwma, 1990).

The conductivity curve is unique for every soil, although approximate curves for many soil types can be found in literature. It typically shows an ‘s’ – like shape, like in the picture. A conductivity curve contains information necessary to calculate how much moisture a soil can provide to a crop under a certain capillarity (van der Sluijs, 1990), and also for determining the effect of a crust on the infiltration capacity (see chapters 2.8 and 5.1.4).

2.4. Soil water tension

Infiltrating water moves primarily under influence of gravity; it will flow to the point with the lowest pressure, following the path of least resistance. In groundwater, gravity causes pressure that increases with depth. The water pressure at the groundwater level is equal to the atmospheric pressure.
Soil water above the groundwater table has a negative pressure. The negatively charged soil particles ‘pull’ at it over their entire surface area because of the positive charge of the water molecules (see chapter 2.1). The water will be stretched around it causing a state of tension, leading to the term soil water tension.

This is demonstrated when a drop of water at atmospheric pressure is brought into contact with a soil sample that has moisture contents just below field capacity. It will be sucked into the soil by the water tension, and the surface tension as well as the concentration of dissolved substances will go down. If more water is added to the soil eventually the water pressure will become greater than zero, and water will start flowing down under the influence of gravity.

2.5. Saturated/unsaturated

The most important distinction that should be made (concerning moisture level) when choosing a method to measure infiltration capacity, is that between saturated and unsaturated measuring methods. The division between saturated and unsaturated infiltration is mainly important in respect to macropores.

Aside from grain size distribution and pressure gradient, the amount of moisture already present in a soil is also a very important factor for the hydraulic conductivity of a soil (and, therefore, the infiltration capacity).

The reason that the soil moisture content is so important to the infiltration capacity is that water does not flow through air-filled pores (Locher and Broekhuizen, 1990). Any pore in the soil that is filled with air, must first be wetted before it can contribute to the flow of water through the soil.

If an amount of ponded water is maintained on the soil surface, all pores will be filled with water quickly, forcing the air out. The soil is then saturated. Its hydraulic conductivity is now at its maximum level, as water can flow through any pore.
Saturated is a clearly defined term, it means 100 percent of the pore-volume is filled with water. However, this rarely occurs in the field. When an area is temporarily flooded, and even when the soil is below the groundwater table, some trapped bubbles of air remain but these are considered negligible (Rowell, 1994).

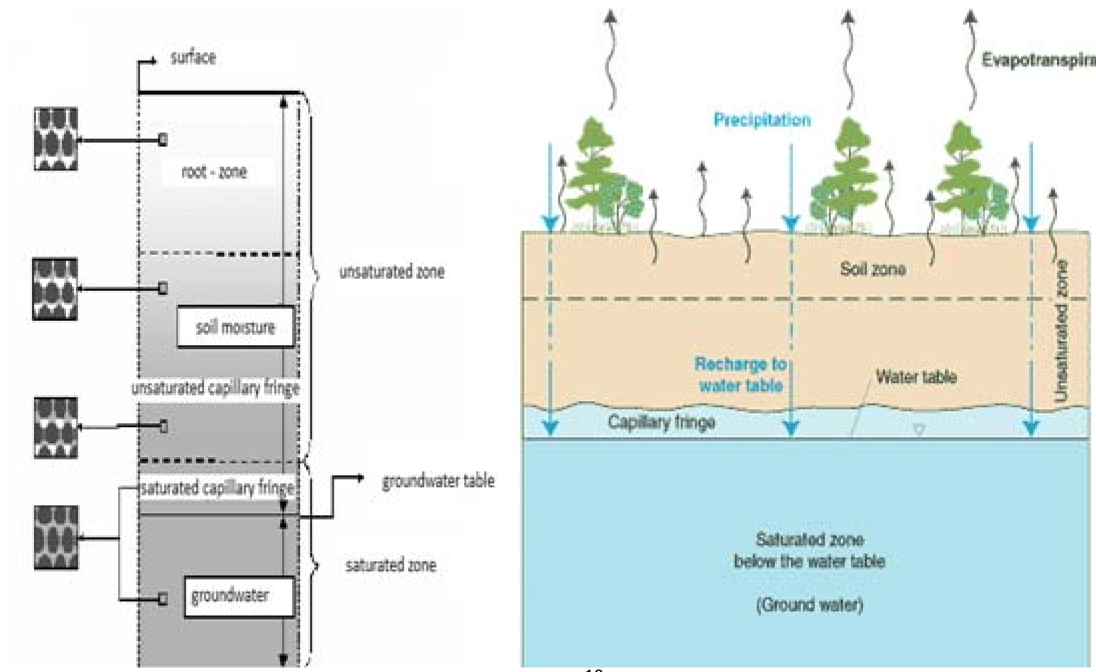


Figure 11: two different takes on the capillary fringe[10], can you spot the difference?

Under the groundwater level the soil is always saturated, however, it is a common misconception that the saturated zone ends there. The groundwater level is no free surface of water, there is also water above it.

[10] http://pubs.usgs.gov/circ/circ1186/html/gen_facts.html

The term 'ground water level' refers to the point where the groundwater pressure is zero. Above that, the water pressure will be negative, because the same forces described in chapter 2.4. also act on soil and water above and below the groundwater level: the water will tend to form a layer over every soil particle. This area is called the capillary fringe.
At the bottom of the capillary fringe, so close to the groundwater table plenty of water is available for capillary rise, and a portion of the soil will be saturated above the groundwater table.
At the top the capillary fringe is unsaturated, however a film of water is still around every particle. This division in two parts (saturated and unsaturated) of the capillary fringe is rarely recognized; in most literature the two are considered one, or the groundwater level is considered to be at the top of the saturated capillary fringe.

Many plants rely on capillary rise to supply them with water. An important note with this is that the maximal height the water can reach in this way, as well as the time it takes varies per soil type. The smaller the soil particles, the slower it goes (since the pore resistance is great), but the higher it eventually gets (since the capillary forces are greatest in small pores).

2.6. Macropores

When a single drop of rain water hits the ground, it will immediately wets the soil. It will form layers of water around nearby soil particles, and a tension (negative pressure) occurs. As long as the rain intensity is lower than the infiltration capacity, infiltrating water will behave in this way and only small pores will be filled.
If the rain intensity is higher than the infiltration capacity, the water cannot infiltrate fast enough and soon ponding will occur at the surface. The water pressure now becomes positive, which means it wants to move down and will do so through much bigger pores. This is how the soil becomes saturated, and the infiltration capacity is now at its highest.

When water is delivered to the soil at positive pressure (e.g. heavy shower or ponding irrigation), macropores will contribute enormously to the hydraulic conductivity. The smaller pores are filled with air, and will not conduct any water.
Conversely, if the rain has a low intensity, the water will be delivered at negative pressure. In this case, smaller pores will conduct water whereas the macropores will only fill when no more micro pores are available. This slows down the process considerably, since water will have to take a detour through small pores.

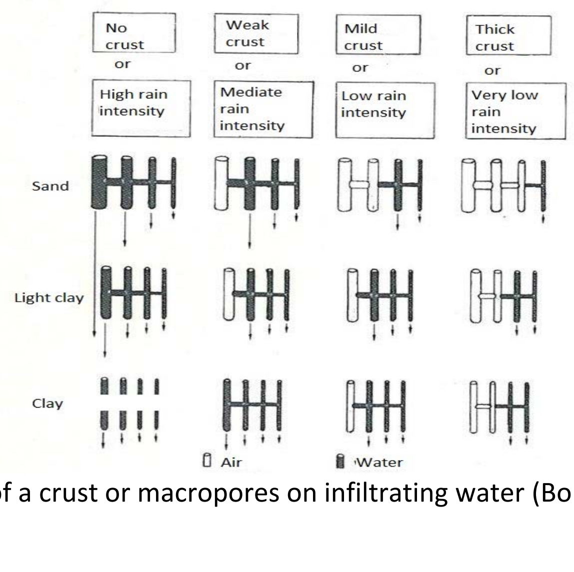


Figure 12: the effect of a crust or macropores on infiltrating water (Bouwma, 1990).

When water is applied at positive pressure to a soil that has macropores however, such as cracks, these cracks present the 'path of least resistance' that water is always looking for. In this way, a lot (if not most) of the water will flow very rapidly down to the subsoil, circumventing the root zone of the crop entirely. This process can be so severe, that part of the water can even escape before the soil matrix is saturated (Ietswaard, 1990). This process is known as a 'short circuit', and it can be very harmful for several reasons:

- It takes a lot of water to irrigate a field, since most cannot be used.
- In many areas it is common practice for farmers to mix their fertilizer with the water in order to deliver it to the root zone. In this way, considerable amounts end up in the deep groundwater, with the risk of severe pollution.
- Unwanted substances may be present in the finer pores, and those will not be leached out to the groundwater.

In case of short circuits only a small portion of the potentially available adsorption- and infiltration capacities are made use of. In situations where good-quality water is of short supply, this state of affairs is simply unacceptable (Bakker, 1990).

Figure 13: wormholes make great macro pores[11].

When many macropores are (expected to be) present in a soil, this can present a problem for measuring the infiltration capacity. If a ponding method is used, the water will drain at a very high rate through the cracks and root-holes and a very high infiltration capacity might be concluded falsely.

Thus, if a farmer measures the infiltration of a field with macropores using a saturated method (such as the double ring infiltrometer), a very high value for infiltration capacity may be found. And if he then, based on these measurements, designs a ponding infiltration system, the field will indeed be able to facilitate a lot of water. However, due to drainage through macropores circumventing the root zone of the crop entirely, the crops may still wilt and die.

In a case like this, the farmer may be better advised using an unsaturated method of infiltration measurement and irrigation. The macropores in the soil would not add to the infiltration capacity then, and the found value would be much lower, but the root zone would probably be wetted much better, because the soil tension would prevent the water from draining right away. This is also the reason unsaturated measuring methods show how a soil reacts to rain or sprinklers much better than saturated methods.

[11] http://www.gaiabodem.nl/Kenniscentrum%20teelten/Akkerbouw%20loess/

Care should be taken with this, however, since the method with witch the measurement is carried out, and the method used for irrigation, should be adjusted to each other. In this case, if the farmer decides to use the same amount of water for drip irrigation as he did for ponding irrigation, it will be too much.

If plants are given too much water in a soil without macropores, ponding will occur and the farmer may decide to give less water. In a soil with macropores, water will still be drained, and ponding will be prevented even though the soil is saturated. His plants will now die because the roots have no access to air in a constantly saturated environment.

Figure 14: drip irrigation in action[12].

It is better, in this case, to measure the unsaturated hydraulic conductivity (an example of this is the disk permeameter, see chapter 6.3). These make use of tension to keep the water in the reservoir, and prevent it from flowing out freely. The soil will have to 'pull' the water out of the device, much like what happens in drip irrigation. The infiltration rate will be much lower than the infiltration capacity, but much more suitable to the situation.

2.7. Water Repellency

In chapter 2.6, it is shown that soils with macropores tend to suffer from preferential flow ('short circuits'). However, when a soil shows preferential flow patterns, this is not always due to macropores. Preferential flow may also occur due to differences in wettability[13]. A drop of water that is placed on the surface of the soil, will not always enter the soil spontaneously. In many soils, certain compounds are present that will prevent water from infiltrating. These soils are called Water Repellent Soils, and they repel water mainly due to a number of hydrophobic compounds, although surface roughness also plays a role (Ritsema en Dekker 2003).

[12] http://environment.nationalgeographic.com/environment/photos/water-infrastructure/#/dams03-drip-irrigation-israel_13203_600x450.jpg
[13] http://www.agric.wa.gov.au/PC_92461.html?s=1127038737

Water repellency in soils is caused by complex organic acids that are produced during the decomposition of organic matter. They are wax like substances, that form a coating over the soil particles[14]. The exact nature of these compounds, however, is beyond the scope of this report. The fact that water repellency is caused by organic matter means that it is mainly found on the surface, since in the deep soil there is little organic matter present that can cause water repellency. Usually water repellency exists only in the top 10 centimeters cultivated top layer.

Soils which have hydrophobic properties (also called water repellent soils) can resist or retard surface water infiltration. Clearly, this poses problems in many fields, such as irrigation for agriculture.

Methods to measure the water-entry value (quote: Ritsema en Dekker 2003).

To measure the extent to which a soil is water repellent, the simplest and most common method used is the water drop penetration time (WDPT) test. Three drops of distilled water from a standard medicine dropper are placed on the smoothed surface of a soil sample, and the time that elapses before the drops are adsorbed is determined. For a soil to be called wettable, this can take no more than five seconds. But in extremely repellent soils, this process may take over one hour to complete. When designing a drip-irrigation system, for example, an extremely repellent soil clearly presents a problem, as most of the water would evaporate before it ever got to the root zone.
Luckily, by imposing a hydraulic pressure (which can be done by adding more water) *on the top of the soil, and slowly increasing this pressure, a critical value can be found at which instantaneous breakdown of the repellency occurs and infiltration begins. This point, known as the 'water-entry value', can be found for any water repellent soil.*

Figure 15: drops on water repellent soils (left[15] highly, right[16] moderate).

When a 'normal' soil (e.g. a soil that is not water repellent) is wetted, the wetting front will be more or less stable. That is, the wetting zone will be level at the bottom, dry below, and saturated above. In these soils, the depth to which an amount of water will infiltrate is relatively easy to predict.

Soil is always heterogeneous to some extent, which means that the water repellency will never be exactly equal over a certain plot, because the presence of hydrophobic compounds will not occur in the exact same amounts everywhere. The water will therefore find those particles that are slightly less repellent then adjacent particles, and these will be wetted first. Previously wetted soil is easier to wet then dry soil. This is why, when water repellent soils are wetted, they form an unstable wetting front in which so – called 'fingers' occur. Fingers are protuberances that are thin and go deep, thereby actually wetting only a small portion of the soil.

[14] http://www2.dpi.qld.gov.au/extra/pdf/hort/water_repellency.pdf
[15] http://plantsinaction.science.uq.edu.au/edition1//?q=figure_view/761
[16] http://geography.swansea.ac.uk/hydrophobicity/soil_hydrophobicity.htm

When these fingers occur, preferential flow patterns can be observed. The water runs down though them at relatively high speeds, getting any irrigation water to the groundwater very fast, leaving the surrounding soil dry. So, although the cause is different, the effect is essentially the same as that of a short – circuit. This effect can be made visible by adding a tracer to the infiltrating water, in the form of colorant (see figure 16).

Figure 16: preferential flow patterns with increasing complexity form left to right, indicated by a tracer[17].

Several methods to negate the effect of water repellency have been developed, with varying levels of success. One of the more successful methods is 'claying' the soil.
Water repellency is mostly found in soils that hold 1% or less clay particles. This is because clay particles, with their small size a great surface area, so that they will be wetted by water much more easily. Mixing the top soil with a highly clayey soil type, to increase the clay particle level to about 3 or 4 percent, will therefore have positive effect for many years. Other methods of negating water repellency exist, but will not be discussed here.

A soil can only be water repellent to a certain extent. A single drop may take so long to infiltrate, that is has evaporated before it gets a chance to wet the soil. But even if it doesn't (as mentioned above) the process may take hours.
However, if a column of water is placed on top of a soil, water will infiltrate immediately, provided the pressure is high enough. For any water repellent soil, the pressure at which this happens can be found, and is called the water – entry value.

In the lab, this can be done using samples from the field. In the field it can be done with a double ring infiltrometer. One simply increases the ponding depth on top of the sample until the critical value at which water starts to infiltrate is found. The water-entry value is indicative of the water repellency of a soil.

The water-entry value can also be found the other way around, using tension (see chapter 2.4) In the above method, a positive pressure is increased. But alternatively, a negative pressure can be used, that is slowly released until the water entry value is found.
For this, a tension-pressure infiltrometer (see chapter 6.3) can be used to determine the water-entry value.

[17] http://geography.swansea.ac.uk/hydrophobicity/soil_hydrophobicity.htm

2.8. *Slaking*

In some soils, small and large particles tend to stick together and form clumps, that appear as larger particles. These ‘particles’ are called aggregates. When these aggregates are relatively unstable, the impact of rain drops can break them apart, and the parts are splashed upward.
Under the influence of gravity, the bigger particles will come down first, and the smaller ones (>2-5 mm) will fall on top of the surface. If this process continues over time, the small particles will form a hard, dense layer on top of the soil called a crust.

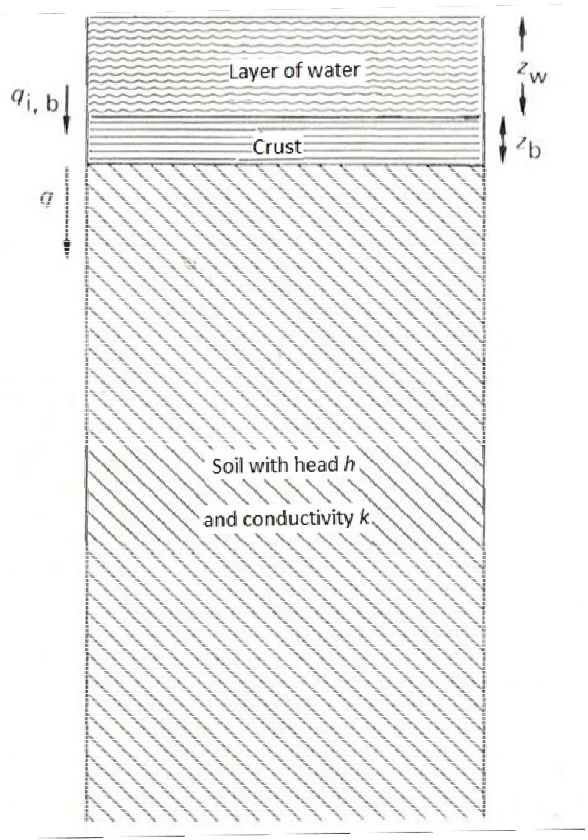


Figure 17: a crust (Bouwma, 1990).

A crust on top of the soil typically has a big influence on the infiltration capacity, since the crust itself, although thin, has a very poor conductivity and forms a rather strong barrier for infiltrating water. Also the exchange of air, which is just as important for plant growth as water, can be hindered by a crust.

3 Principles

While every infiltration measuring device is different, they work on certain principles that are often the same. An understanding of these principles can help understanding the devices, and this also plays a role in the situations they should be used in.
In this chapter, the most important of these principles are explained.

3.1. Law of continuity

The essence of any method of measuring infiltration, is the law of continuity which states, in its simplest form, that ‘inflow – outflow = change in storage’ (US Army Corps, 1994):

$$(1) \qquad I - O = \left(\frac{dS}{dt}\right)$$

Where I is the inflow, O is the outflow, and (dS / dt) is the change rate of the amount of stored water.

This means that, if the inflow is smaller than the outflow, the water level will drop. And conversely, if the inflow is bigger than the outflow the water will be stored or in other words; the water level will rise.
In infiltration testing this is useful because if the head is kept constant, the inflow needed to keep it constant is known, and equal to the outflow. Conversely, if varying head methods are used it is known that inflow is zero, and the change in head can be used to calculate outflow.

3.2 Steady state

when a saturated infiltration measurement is carried out in dry soil, the soil has to be wetted first because air filled pores do not contribute to the infiltration process (see chapter 2.5). At the start of the measurement, water will flow into the soil at a high rate because water is used to fill the pores. After a while, when the soil is wet, the rate will go down and reach ‘steady state’, meaning it becomes constant over time. At this time, the actual infiltration capacity of the soil can be observed. The infiltration value can only be measured in steady sate.

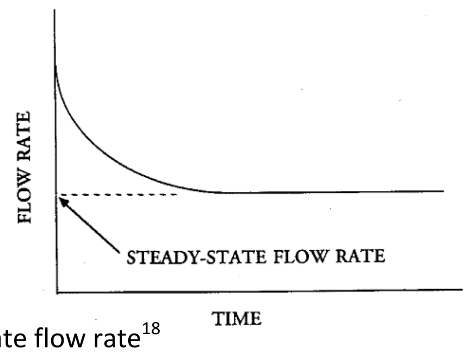


Figure 18: the steady state flow rate[18]

[18] pkd.eijkelkamp.com/Portals/2/Eijkelkamp/Files/Manuals/M1-0911e-scan.pdf

3.3. Tensio

As described earlier, the tensio is a negative pressure in the soil which causes water to be pulled in all directions. When using saturated measuring methods, this is a problem because it causes lateral outflow.

However, this principle can also be made use of when the unsaturated infiltration capacity must be measured. If water is delivered to the soil at negative pressure, the soil has to pull the water out. The water will then stick closely to the soil particles, leaving larger pores filled with air. Methods like this are unsaturated, and they show how a soil reacts to rain or sprinklers much better then saturated methods such as the double ring infiltrometer.

3.4. Mariotte principle

A Mariotte bottle[19] is a container of water with a tap at the bottom, from which water flows at a constant rate. This principle is used in many infiltrometers, in order to create a constant head. The advantage of a constant head when measuring infiltration, is mainly an improvement in accuracy. The double ring infiltrometer, for example, is a so – called falling head method: a column of water is placed on top of the soil, and infiltrates, thereby lowering the head.

As the head falls, the pressure decreases, which influences the infiltration rate (Bouwma, 1990). (It could be noted that it is possible to equip a double ring infiltrometer with a Mariotte bottle to keep the head constant, but since the double ring's most important virtue is its simplicity, this is not often done). Values that have been found using a constant head, can therefore be seen as more reliable.

Normally, when water flows out of its container, the pressure head will decrease as the water level drops, and the flow rate will gradually decrease from maximum to zero. In a Mariotte bottle, this process is counteracted. This very ingenious device was invented by the French physicist Edme Mariotte (1620 – 1684), and its working will be explained below.

Figure 19: Edme Mariotte (1620 – 1684), the motion of fluids was only one of his many fields of study[20].

[19] http://web.physics.ucsb.edu/~lecturedemonstrations/Composer/Pages/36.07
[20] http://www.nndb.com/people/112/000095824/

A Mariotte bottle is closed off at the top, except for an air inlet tube that goes down into the bottle, to an adjustable height (although for it to work properly, the bottom of the tube must be under the water level in the container), and an outlet tap for the water.

When starting a test with the Mariotte bottle the air inlet tube must be closed off at the top with a stopper. The tap, which is at the same level as the bottom of the tube, can then be opened.
A vacuum will now form in the top of the bottle, as well as in the top of the air inlet tube (in which the water level is the same). The negative pressure will increase downward, and reach atmospheric pressure at the open tap. This is the same as the pressure outside, hence there will be no water flow.

When the air inlet tube is now opened, however, the vacuum in the tube is released, and there is a difference in head (pressure) between the water level in the tube (at the top of the reservoir), and the tap level. There is now a pressure behind the tap, that can be calculated with the following equation:

(2) $$P = \rho * g * h$$

In which P (Pa) is the water pressure, ρ (kg/l) is the density of the water (generally assumed to be 1 kg/l), g (m/s^2) is the gravitational acceleration and h (m) is the height of the water column.

Due to this pressure, water will start flowing out of the tap, and the water level in the air inlet tube will drop (the level in the rest of the container will stay the same, since there is still a vacuum in the top), until the water level is at the bottom of the tube.
An air bubble will now be visible at the bottom of the tube, and a drop of water will hang from the tap, and the pressure will again be equal at both points. Hence the flow of water will stop. The amount of water that has flowed out will be equal to what was inside the air inlet tube before.

If now the air inlet tube is raised above the level of the tap, a hydraulic head (h) is created, and water will start to flow out of the tap. The pressure at the bottom of the tube is still atmospheric, but the pressure at the tap exceeds that by $\rho * g * h$.

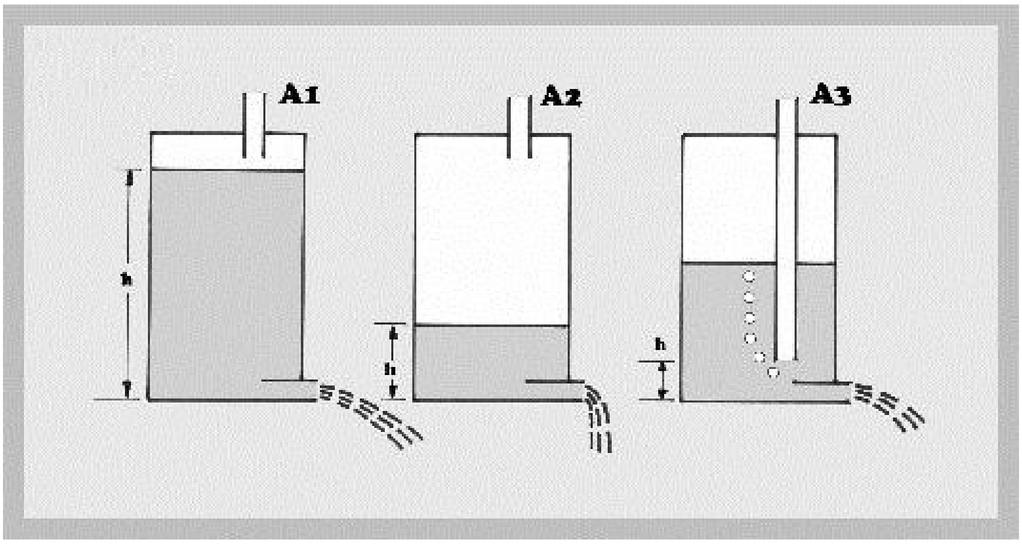


Figure 20: the hydraulic head in a Mariotte Bottle is always the same since it does not depend on the actual water level[21].

[21] http://www.clacro.de/Seite_tankD.htm

As water flows out, the pressure inside the bottle decreases and air bubbles will now be pulled through the air inlet tube, releasing the negative pressure at the top of the container. In this way, the hydraulic head will remain the same as long as the water level inside the bottle is higher than the air inlet tube, and the water will keep flowing at a constant rate that is proportional to the hydraulic head.
In this way the flow of water can be regulated quite accurately, by adjusting the height of the bubbling tube. The higher the tube, the greater $\rho * g * h$, the bigger the discharge. It is therefore important that the tube is set at the right level before starting the test, since adjusting the tube results in a change in discharge, which will influence the result.

An important disadvantage of the Mariotte bottle, is that it cannot be refilled during operation, since that would mean opening the bottle and breaking the vacuum. When the Mariotte bottle was just invented, it found much application in laboratories, but those have long since been replaced by more advanced technologies for just that reason. However, in infiltration measuring devices, where only a limited amount of water is needed and simplicity and durability is important, it is still commonly used.

3.5. In – hole testing

Since the inflow of water in a borehole is known, and the water level can be measured, the law of continuity can be used to determine the outflow.

In – hole tests for hydraulic conductivity can be roughly divided into two groups: by adding water of by extracting water. Depending on the goal of the measurement, and the expected hydraulic conductivity some of these are more suitable than others.

Adding water (can also be done at the surface)

1. Adding water at a varying discharge, to keep the water level at a constant height, until equilibrium is reached. When this equilibrium is found, it is known that inflow = outflow.
2. Adding water at constant discharge, until equilibrium is reached. When this equilibrium is found, it is known that inflow = outflow.
3. One-time heightening of the water level, after which inflow = 0 and the water level varies (drops).

Extracting water

4. Extracting water at a varying discharge, to keep the water level at a constant height, until equilibrium is reached. When this equilibrium is found, it is known that inflow = outflow.
5. Extracting water at constant discharge, until equilibrium is reached. When this equilibrium is found, it is known that inflow = outflow.
6. One-time lowering of the water level, after which outflow = 0 and the water level varies (rises).

The above mentioned tests can be carried out with different measuring instruments. For example, the Ksat and the Aardvark both use a constant head, by adding water at constant rate (1).The onetime heightening of the water level (3) is mostly used in a borehole, without a specialized device.

The methods for which water must be extracted are used for measuring hydraulic conductivity. A hole must be augured to below the groundwater table, and water is extracted. The speed with which the water fills the hole back up, can be used to calculate the hydraulic conductivity. The flow that is established here, is primarily horizontal, which is why this method is not suitable for measuring infiltration capacity.

The methods for which water is added can be carried out in drier soil, above the groundwater table. These are better suited for infiltration tests, although the bulb – like shape of the wetting front must be taken into account when calculating the results.

When the head in the borehole rises or lowers, the pressure gradient changes, which has an influence on the infiltration rate. If the head – and therefore the pressure gradient – is kept constant, the test will therefore be more accurate.
The methods that employ a variable head (rising or falling, 3 and 6) can be used as well, but only when the time it takes to fill or empty the hole is considerably shorter than the time needed for the test itself. In soils with large grain sizes (and good hydraulic conductivity), the water level in the hole may have returned to its natural state before a good measurement can be done. In soils with smaller grain sizes, the variation in water level during the filling or emptying of the hole may be considered negligible. Tests 3 and 6 are therefore most suited for soils with a hydraulic conductivity between 0.0001 en 0.10 m/day.

Use of methods 2 and 5 is fairly limited, since in many cases the borehole would either be dry or overflowing before equilibrium is found. These tests can therefore only be done in somewhat course soils, with a hydraulic conductivity above 0.10 m/day.

Methods 1 and 4 employ a constant head, which makes them generally more accurate. Also, with a constant head the test is less reliable on the hydraulic conductivity of the soil. This gives these methods a rather large area of application: hydraulic conductivity between 1.0*10^-2 en 10 m/day.

3.6. Measuring in the lab or in the field

Soil characteristics can be measured in the field or in the laboratory. When measuring in the laboratory, samples have to be taken and analyzed. In some cases, laboratory measurements or calculation methods for determining the hydraulic conductivity may be satisfactory. However, in situ measurements are usually preferred, as long as the site is suitable for this (that is, sufficiently accessible, the ground not to stony, etc.). A larger area of measurement and preservation of field structure are inherent advantages of field methods over laboratory methods (Green et al, 1986).

4 The results of the measurement

The infiltration capacity of a soil can be measured, with modern devices, very accurately, in millimetres if necessary. And often, when the measurement has been done in millimetres, the results from the calculation will also be in millimeters, and those are often assumed to be the correct value for the entire plot. However, it should always be remembered that the measured value is only an indication of the 'real' value. Measuring the infiltration capacity at a certain spot in an area, is much like taking a sample from that spot (the infiltration capacity may even be measured from a sample). Unfortunately, there is usually no way to assess the accuracy of the results. The measurement may represent the site very well, or it may not, any confidence in the results must rest entirely on faith in the samplers judgement (Petersen and Calvin, 1986).

Soil is not homogenous, it is a heterogeneous body of material (methods of soil analysis). Due to the way in which soils are formed, it differs wildly from one location to the next, with often no sharp boundary between them but rather a gradual transition. Sometimes large areas may be found that consist of relatively homogenous material, whereas in other areas great variety is present over a very short distance. It is therefore important to closely observe, on the surface, how much variation can be expected. This can be seen by looking at the soil itself, but factors like vegetation can have large influence, even if the parent material is the same. The number of measurements that should be carried out, is dependent on the expected magnitude of variation.

Also in a vertical direction the soil will often change from one layer to the next. Various soil layers can consist of entirely different soil types, and the groundwater table may vary from one location to the next. So all of the factors that are described in chapter 2 can be very different in different soil layers, so it's evident that the infiltration capacity of a soil can vary wildly with depth (this will be discussed with more detail in chapter 5.1). Any poorly conducting layers at a certain depth from the measured point should be known. This why the layered profile of a soil should always be researched before an infiltration measurement, as close to the measurement site as possible. This can be done by digging a test pit, but usually it is more convenient to use an auger. The soil profile should be investigated to a depth of 120 centimeters or the groundwater table (Locher and De Bakker, 1990).

The double ring infiltrometer comes in sets of three, that is three outer and three inner rings, with which three measurements can be carried out simultaneously. Even if these rings are placed only a few meters away from each other, the values found will probably be different. This shows that the exact location that is chosen (usually arbitrary to some extend) has great influence on the values found. Although taking the average value of the three is common practice, and makes sense, no standard way of measuring in order to get a representative value exists. If the variations are unexpectedly big, more measurements should be carried out.

An example of how large variation can be in a soil can be found in chapter 6.8, where conductivities of 4 samples are shown. These samples where all taken at a few centimetres from each other, at the same depth. However, the terrain where they were taken (Helicon, Velp, the Netherlands), has been heavily disturbed, as there has been a lot of digging and boring over the years. In the past, there may have been a clear boundary between the loam layer and the sand layer, but now they are mixed, which explains the extreme variations between the samples.

5 The theory of infiltration

Previous chapters have attempted to explain what happens within the soil when water infiltrates in a rather practical sense. This is important, because the ability to visualize what happens helps understanding of the process.
However, when someone has to design an infiltration facility (for example), understanding and knowledge of general principles is not good enough. In order to draw reliable conclusions, accurate values are necessary, and these will have to be calculated.
These calculations are in turn based on measurements, taken either in the field or in the lab. When interpreting the results of an infiltration test, for example, any poorly conducting layers that are present at shallow depth must be taken into account, as well as the groundwater table.
In this chapter the formulas that are used to calculate values such as hydraulic conductivity , grain/pore size distribution, and moisture level are described and explained.

5.1. Darcy's Law

As we have seen in chapter 2, one of the most important factors in the process of infiltration is the hydraulic conductivity. In fact, the saturated hydraulic conductivity is equal to the infiltration capacity unless any limiting factors are present (such as poorly conducting layers, or unsaturated soil). It is a key parameter for all aspects of water movement (Amoozegar and Warrick, 1986). To calculate the saturated hydraulic conductivity, Darcy's Law is commonly used. The equation will be further explained below, but it looks like this:

$$(3) \qquad Q = k * A * \frac{dH}{S}$$

As we have also seen in chapter 2, water flow through the sample is only possible through interconnecting pores. However, to calculate the size and flow for every pore individually would be an impossible task, so we will consider a portion of soil as if water flows through the entire cross section and will encounter equal resistance everywhere. The calculated flow is then effectively the average velocity of the water in all pores.

The volume that comes through this portion of soil is the discharge (Q), given in units of volume per time (e.g. cubic meter per day).

However, instead of a discharge Q, given in units of volume per time (e.g. cubic meter per day), Darcy made use of a quantity known as the flux density q in distance per time, which means the cross sectional area A (in m2) can be left out of equation 2. In formula:

$$(4) \qquad q = \frac{Q}{A}$$

The flux density is an imaginary speed, which can be considered as the thickness of a disk of water that moves through the soil per unit of time.
For example, let us take a portion of soil with a cross sectional area of 2 m^2, and for convenience, a discharge of 1 m^3 a day. Flux density is then:

q = Q / A → q = 1/2 = 0.5 m/day

Since the flux density is equal to the infiltration capacity, the same symbol can be used:

Flux density = infiltration capacity = q = hydraulic conductivity

Note that this is *only* applies when using Darcy's Law in saturated conditions, since infiltration capacity also depends on soil moisture that is already present in the soil. The hydraulic conductivity does not.

Figure 21 shows the experimental setup, which Henri Darcy published in 1856. The goal he had with it was to determine the hydraulic conductivity of a soil sample. He created a difference in hydraulic head (in the figure this is the difference between h_1 and h_2). This head difference, over a certain distance, creates a hydraulic pressure gradient that forces water through the sample.
All quantities in the equation are indicated: the surface area of the cross section of the soil sample A, the hydraulic head difference dH (which equals $h_1 - h_2$), the distance over which this difference occurs S (note that only the length of the soil sample is taken into account, the resistance of the tubes is considered negligible), and the discharge Q. The values for dH and S are known, and the discharge is measured. The hydraulic conductivity of the soil sample can then be calculated according to Darcy's Law.

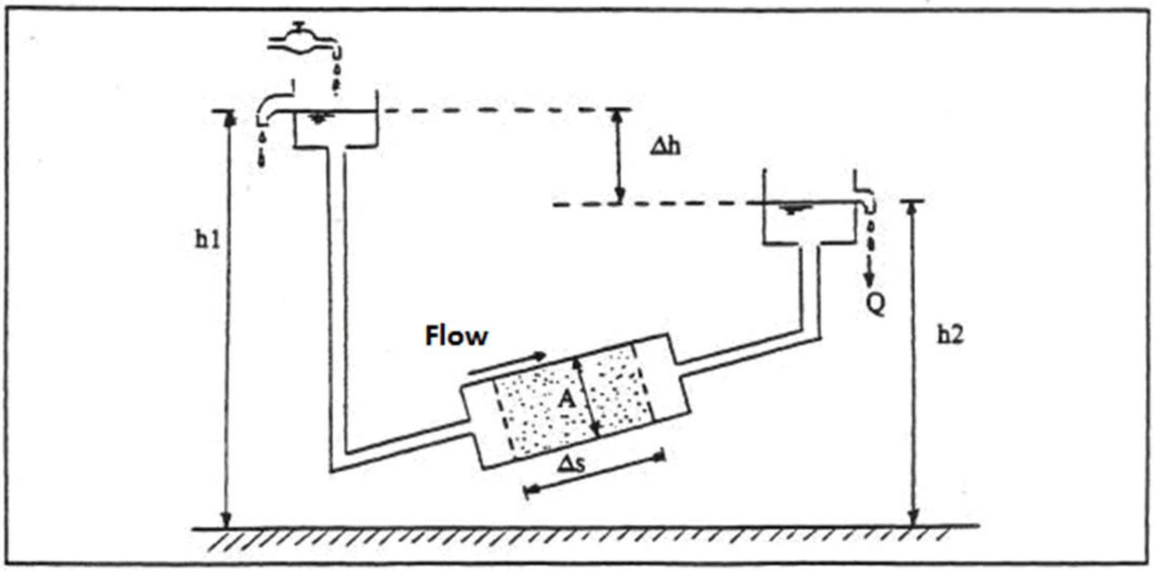


Figure 21: Experimental set up Darcy's Law[22].

Darcy's Law can be written as follows:

(5) $$Q = k * A * \frac{dH}{S}$$

Or, after substituting formula 1 in 2, in a slightly simpler form:

(6) $$q = -k * \frac{dH}{S}$$

The k in this equation is the hydraulic conductivity, in meters per day.

22 http://www.jeroenb.nl/Water/grootscherm/darcy.htm

The difference in hydraulic head (dH) is what gives the water the energy that forces it through the soil. The larger this value is, the higher the discharge will be.
Combined with the distance over which this difference occurs (S), the hydraulic gradient (dH/S) is found. The larger this distance, the smaller the 'slope' of the hydraulic gradient, and the lower the discharge will be.
Finally, the - symbol in the formula indicates that the resistance increases as the hydraulic gradient (dH/S) decreases.

5.1.1. Deep, homogenous soils

We will first consider a soil that is both homogenous and deep. Homogenous means unchanging, the consistency of the soil is the same at any point in the cross section. Deep in this context, means the groundwater table is very deep. In a soil like this, rare as they may be, the water flows under influence of gravity and is held back only by the resistance of the soil itself. A constant hydraulic head will form, which means the dH/S – part of Darcy's Law equals 1/1 = 1. In a case like this, the flux density equals the hydraulic conductivity, in other words, q = -k.

5.1.2. Groundwater table

Unfortunately, most soils in nature are not that straightforward. In more complex soils, the infiltration process also becomes more complex. We will now see what happens when a groundwater table is present.
The ground water has influence already above the groundwater level. How high depends mostly on the type of soil; as we have seen in chapter 2.4, capillary rise is stronger in some soils then others.

The pressure of the infiltrating water in the soil will be negative, due to the suction of the soil (see chapter 2.4). However, at the groundwater table this pressure is zero. It depends on the soil type how high above the groundwater level, Hn, the presence of groundwater starts to have influence. The pressure in the infiltrating water will therefore gradually increase as it moves down, and the soil around it gets wetter. This gradient can be calculated with an integrated form of Darcy's Law:

(7) $$Zn = -\int_{h_0}^{h_n} dh/(1 + q/k)$$

Where Zn is the vertical distance between a point in the soil with pressure Hn, and a reference point with pressure Ho (the groundwater table).
The value for q is positive when flow is upward, or negative for downward flow.

Solving this equation is a complicated task, since K (meters per day) depends on H (meters). Solving it should be done in small steps, starting at the groundwater table then working upwards. For K, the average value of K between H_n and H_o should be used, this value can be found in literature (for examples, see figure 9, page 16).

5.1.3. Layered soils

The above is based on homogenous soils, because these are easiest to understand. In nature, however, they are very rare; a soil usually consists of layers that differ to some extent. The change between two layers may be gradual, or sharp, and the difference between layers can be big or small. Consider, for example, fine sand that gradually changes into medium grained sand, as opposed to a coarse sand on top of a layer of heavy clay.

When the wetting front, that moves down through a relatively highly conducting layer, reaches a poorly conducting layer, the water pressure will build until it is high enough to force water down further. Conversely, when water moves down through a poorly conducting layer and reaches a highly conducting layer, tension will build.

This effect can be made use of when constructing sport fields. These should have a top layer of sand, mixed with organic matter and everything that makes it perfect for growth of grass. Below that, a layer of gravel should be placed about ten centimetres thick. The tension in the sand is much stronger than that in the gravel, due to the smaller size of the pores. Water will therefore fill up the pore spaces in the sand, and only seep through when it is saturated. When no more water is applied, the water will form a perched water table just above the gravel, so that a field like this is considerably more water efficient then a field without the gravel layer.

The effect of a relatively poorly conducting layer is comparable to that of a groundwater table, in that the presence of groundwater increases resistance for infiltrating water. The infiltration capacity per soil layer can therefore be calculated with formula (7) that is also used when correcting for the presence of groundwater.

The calculation should be done one layer at a time, starting at the bottom of the system which is preferably at the groundwater table where h = 0. At the groundwater table Z = 0 as well.

5.1.4. Crust

A crust on top of the soil can have a strong influence on the infiltration capacity. As discussed in chapter 2.5, water only moves through pores that are filled with water.
When a crust has formed on the soil, pores will only fill themselves with water if they are able to ‘pull’ the water through the crust. Smaller pores have higher tension, so the smaller the pores, the less influence the crust will have. The influence of a crust will therefore be stronger in a sandy soil then in a clay soil, for example.

To calculate the infiltration capacity of such a soil, Darcy’s Law must first be applied to the crust itself:

$$q_{(i,b)} = -K_b\left(Z_b + Z_w - \frac{h}{Z_b}\right) = -\left(\frac{1}{R_b}\right) * (Z_b + Z_w - h) \qquad (8)$$

where qi stands for infiltration capacity (q being the flux) in meters per day. The b stands for ‘barrier’, indicating the crust. The q_{ib} is therefore the infiltration capacity, while Z_b (Z being a thickness) is the thickness of the crust, and Z_w the thickness of the layer of water that forms on top of the crust.
The R_b in the third expression of the equation is called the hydraulic resistance of the crust (see below).

In essence it is the same equation, only slightly adapted. The expression dH (the water pressure head) has been replaced by $Z_b + Z_w - h$, in which Z_b stands for the thickness of the crust, Z_w the water depth at the surface and h is the pressure (or tension) in the soil immediately below the crust. Likewise, the S has been replaced with Z_b, the thickness of the crust.

The hydraulic resistance of the crust is called Rb:

$$R_b = \frac{Z_b}{K_b} \quad (9)$$

When flow though a crust is constant, the following equation applies:

$$R_b * K = Z_b + Z_w - h \quad (10)$$

When values are filled out for R_b, Z_b and Z_w, the resulting curve (on a double logarithmic scale) represents which combinations of K and h are allowed through the crust. If this graph is combined with the 'conductivity curve', the curves will intersect at a certain value for h. The pressure under the crust will, during infiltration, become stable at this value.

The graph in figure 22 shows a graph, the x – axel gives the head and at the y – axel the hydraulic conductivity is given. Several graphs have been combined: those that start at the bottom represent the relation of the two for a silt, a clay and a sand respectively. The line that curves up from the y – axel represents the effect of a crust, under variable head.
The intersections between the lines show which combinations of K and h will be allowed through the crust into the soil below.

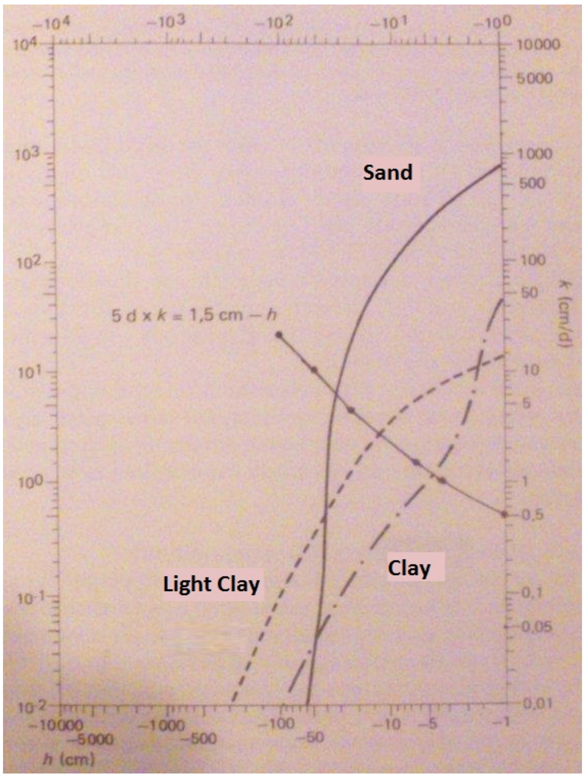


Figure 22: graph showing the combinations of K and h for different soil types (Bouwma, 1990).

5.2 Green and Ampt equation

Darcy's Law is the most used equation to calculate K. It is somewhat generalized, and therefore applicable in many situations. However, it takes into account a very limited number of factors. One thing it does not account for, for example, is the initial soil moisture content. When applying the equation to deep aquifers this is not a problem, since these can often be assumed to be always saturated. When dealing with infiltration, however, the soil can be anywhere between saturated and completely dry and the soil moisture content at the start of the measurement becomes an important factor. One equation that does take this into account, is that of Green and Ampt.

For this equation, the soil is assumed to be relatively dry at the start, so that the soil moisture level increases over time. As the soil moisture level changes, the conductivity changes too. Therefore, in the Green and Ampt equation, K varies over time and is called Kt.

The Green and Ampt equation (Turner, 2006) assumes the water to infiltrate the soil as a 'sharp' front, meaning that the front is perfectly level, dry below and saturated above. In reality this is not always the case, as preferential flow will to some extend occur in most soils and the soil above the wetting front may not saturate entirely. The situation that Green and Ampt assume (see figure 23) is therefore somewhat simplified.

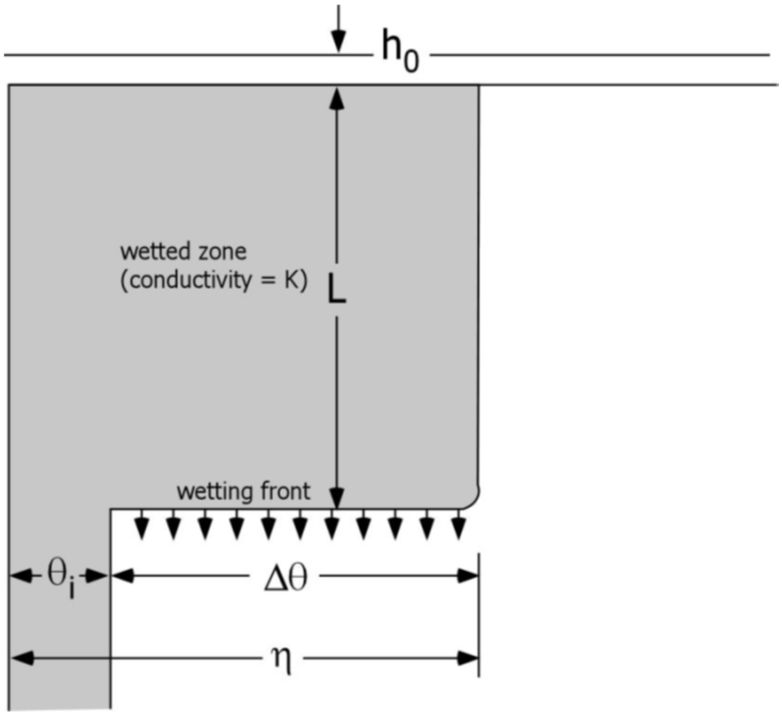


Figure 23: Wetting front according to Green Ampt[23].

In the column of soil in figure 23, the initial moisture content is called θ_i. This moisture takes up a portion of the total porosity (η) of the soil, that is not available for the infiltrating water. The wetting front is sharp, which means that below it the soil moisture content is equal to θ_i, and above it the soil is saturated (in reality this changes more gradually).

[23] http://www.personal.kent.edu/~amoore5/Hydro_L_12.pdf

The maximum amount of water that can be added to the soil is Δθ, which is the difference between $θ_i$ and complete saturation. L is the depth of the wetting front. The ponding depth h_0 is assumed to be negligible (note that this is likely in a storm, but not when applying ponding irrigation).

Calculating the amount of water that got added to the soil (F at time t) is now relatively simple:

$$(11) \qquad F(t) = L(\eta - \theta_i)$$

Where (η −θ *i*) is equal to Δθ.

In this equation, however, an important factor is missing: the capillary suction or tension of the soil (see chapter 2.4). So Green and Ampt went on, and came up with the following equation:

$$(12) \qquad K_t = F(t) - \psi\Delta\theta \ln\left(1 + \frac{F(t)}{\psi\Delta\theta}\right)$$

Where Ψ is the capillary suction.

This is the Green and Ampt equation. The problem with this is that it is what mathematics call a 'non-linear' equation, which makes it difficult to solve. It can be 'made' linear though, but only if one is willing to assume that the (F(t) / Ψ * Δθ) part of the equation is very small, in which case we are left with ln (1) = 0, and the equation becomes:

$$(13) \qquad F(t) = K_t.$$

The other option to solve it, is to put F on both sides. It can then be solved by iteration. Make an educated guess for F (Kt is a good starting point) to get a new F and so on.

In the past this was the reason that this equation was not commonly used: it is a good equation, but it is difficult to work with. However, in the days of computer simulation it is making a comeback.

5.3 Glovers formula

The only way to measure the hydraulic conductivity at any depth, is by using one of the several existing borehole methods (see chapter 3.5). These methods have in common that a hole is augured into the soil to the desired depth, and usually water is added.

The addition of an amount of water that creates a hydraulic head inside the hole, means that the water will be infiltrating under saturated conditions. Therefore, borehole methods should be combined with a calculating method that assumes saturated flow. Also, the flow is not entirely vertical. The water will infiltrate through the bottom of the hole, but also lateral (horizontally) through the sides. When calculating the saturated conductivity, this will have to be taken into account.

A number of models exist for this, each with their own limitations. Discussion of these is beyond the scope of this report. One equation that is appropriate for use in boreholes is Glover's formula, which will be discussed here (K-sat Eijkelkamp manual). It is suitable for use combined with borehole methods because it assumes saturated conditions, and it takes into account the shape of the borehole.

The bottom of the hole is disregarded in Glover's Formula, it includes only the outflow through the sides between the bottom and the water surface (Stephens et. al., 1983). The flow region is assumed to be sharply bordered by the 'free surface' (see figure 24). This is a streamline along which there is no flow, and an isobar along which the pressure is atmospheric everywhere. The soil within this line is saturated. The outside is dry, and not part of the flow region.

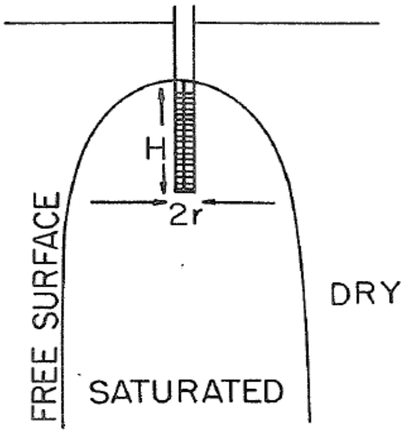


Figure 24: the shape of the 'free surface'.

Glover's formula is:

(14) $$K_s = \frac{Q_s}{rH} * \frac{1}{C_u}$$

Where Qs is the steady state infiltration rate, r is the borehole radius and H is the height of water in the borehole. Cu is a constant value to that accounts for the shape of the free surface, and it can be calculated with:

(15) $$C_u = \frac{2\pi H}{r} * \left(\sin^{-1}\left(\frac{H}{r}\right) - 1\right)^{-1}$$

The biggest advantage of Glover's formula, is its lack of complex variables. The only unknown factor is Ks as Cu can be calculated by formula 15. There is no need to obtain an unknown value by estimation or by using an independent method related to the unsaturated flow around the auger hole.

Glover's formula also has its limitations: it does not account for the unconfined nature of the flow and it disregards outflow from the bottom of the borehole. According to Glover (1953), if all the boundary conditions are exactly accounted for, the Cu value as defined in equation 14 will be exceeded by 25 percent when H/r = 6 and by 8 percent when H/r = 8. From this, he concluded that equation 14 is reasonably accurate as long as H/r >10.

6 The instruments

As has been said before, the infiltration rate/infiltration capacity can be measured in a number of different ways, using different instruments, depending on the situation.
The best instrument to use in a situation, depends on the reason the infiltration capacity has to be measured, as well as the layered structure and nature of the soil, and desired accuracy of the measurement.

In the next paragraphs different instruments will be described by:
Summary description
Applications
Design
Remarks

(Part of the paragraphs about the pro's and contra's will be gained by interviewing user of the different types of instruments).

The systems described are:

- Compact Constant Head Permeameter (Ksat)
- The Aardvark
- The Tension Infiltrometer
- The Double Ring Infiltrometer
- The Single Ring Infiltrometer
- The Rain simulator
- The Guelph
- The Laboratory analyzer

6.1 *The Compact Constant Head Permeameter (also known as Amoozemeter or Ksat)*

Summary description

- Determines permeability of any layer <4 m
- Meant for above the groundwater table
- Stable, compact and versatile instrument
- Steady state principle for optimum accuracy

Figure 25: Ksat[24].

Applications

The Amoozemeter is used to measure saturated hydraulic conductivity of the vadose zone (i.e. the zone above the groundwater) of the soil, through a two-step process. Firstly, the steady-state rate at which water flows into the soil from a cylindrical (auger) hole is measured. Then the Ksat can be calculated using the Glover Solution, which is an adapted form of Darcy's Law specified to use for the Ksat (see chapter 5.3). It can measure the Ksat of any layer (that is thick enough) to a depth of up to two meters (four meters with extension). To do this, a testing pit is not necessary, a borehole is big enough.

Design

Once a hole is bored down to the desired depth, water is allowed to flow into the hole by means of a water dissipating unit. The hole is filled up to a certain depth, and the soil around it is wetted. As the water flows into the soil, more water flows into the hole to keep the water level the same.

The water comes, in soils with small pore sizes, from the 1 liter flow measuring unit. This is a cylinder with a calibration on the side to measure the amount of water flowing out per time unit.

In soils with large pore sizes, the water will flow considerably faster. To solve this problem, the 4 liter main reservoir can also be opened, so that a total of 5 liters is available to the test.

[24] http://www.advison.be/nl/infiltratieproeven

To make sure the water in the hole stays at the desired depth, the Amoozemeter is equipped with a system of bubbling tubes. There is one in the flow measuring unit which makes use of the Mariotte-principle. However, the vacuum has to correspond to the depth of the desired water level in the hole. This is why there are four bubbling tubes at the side of the device. When the water level in the measuring unit drops, air is forced to travel through these tubes (the total distance is to be determined by the user) before it gets into the measuring unit.

Remarks

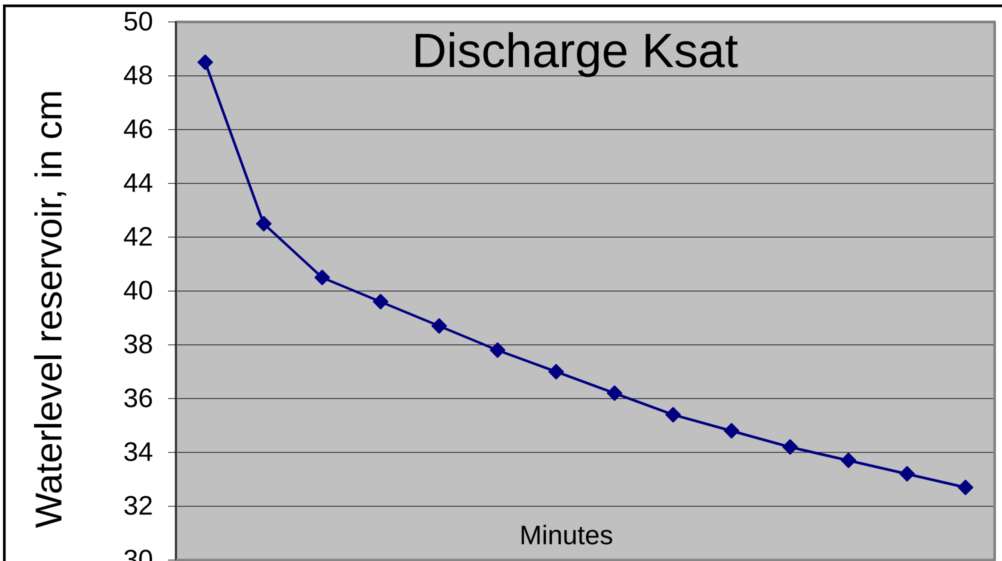
It is the responsibility of the user to determine if climatic and soil conditions allow use of the Amoozemeter. It requires a skilled person to operate, since it has some limitations. For example it cannot be used directly above the groundwater table (i.e. capillary fringe) because the near-saturated conditions will hinder water movement from the hole. Also, it is unsuited for measuring the Ksat of a layer or horizon that is less than 10 cm thick.
In order to use the Amoozemeter, a pre study must be carried out. For example, the ground water level and any poorly conducting layers must be known in order to carry out the correct calculations.

Example

Before measuring the saturated conductivity with the Ksat Constant Head Permeameter, a profile research must be carried out: a hole must be augured to the groundwater table so that the soil can be checked for any poorly conducting layers.
For this measurement, the following profile was found:

0 – 60	cm	fairly coarse sand, high organic matter content (dark)
60 – 80	cm	fairly coarse sand, no organic matter (yellow)
80 – 150	cm	sandy clay, wet
150 -	cm	groundwater level

The sand is expected to be relatively highly conductive due to its large grain size. The clay is expected to be very poorly conductive, not only because it is clay but also due to its high moisture level. The measurement was carried out in the dark sand, at a depth of 46 centimetres, with 19 centimetres of water in the hole. The following values have been found:



	0	2	4	6	8	10	12	14	16	18	20	22	24	26
Waterlevel	48,5	42,5	40,5	39,6	38,7	37,8	37	36,2	35,4	34,8	34,2	33,7	33,2	32,7

Figure 26: values found

The clay layer can, especially because of its high moisture content, be considered an (almost) impermeable layer.
The distance between the bottom of the hole and the top of the poorly conducting layer is 34 centimetres which is <2H (2 * 19 = 38), so the following formula should be used:

(16) $K_{sat} = B * Q$

Q must be calculated from the data in figure 26. After reaching steady state, the difference in reading is 0.25 centimetres per minute. Due to the (expected) high conductivity of the sand, both reservoirs where used, so the volume can be calculated with conversion factor 105 cm2:

$$0.25 * 105 = 26.25 \text{ cm}^3\text{/minute}$$

The B can be calculated with the following formula:

(17) $$B = \left\{ \frac{3 \ln\left(\frac{H}{r}\right)}{\pi H(3H + 2s)} \right\}$$

Where H is the height of water in the hole, r is the radius of the hole, and s is the measured or estimated distance between the bottom of the hole and the impermeable layer. In this case

- H = 19 centimetres
- r = 3 centimetres
- s = 34 centimetres

Substituting these parameters in formula (17) gives:

B = (3ln (19/3)) / (π * 19 (3 * 19 + 2 * 34))

B = (3ln6.33) / (59.69 (57 + 68))

B = 5.54 / 7461.25 = 0.00074

Then we fill out formula 16:

$K_{sat} = B * Q$

$K_{sat} = 0.00074 * 26.25 = 0.019$ cm / minute, or 0.28 m/day

6.2 The Aardvark

Summary description

- Determines permeability of any layer <15 m
- Does all calculations automatically
- Constant head for optimal accuracy
- Very susceptible to wind

Figure 27: Aardvark[25].

Applications

The Aardvark is used to determine the saturated infiltration capacity of any layer up to four meters deep. After setup, it works almost entirely independent, so that multiple measurements can be carried out by one person at the same time.
The head difference should be constant, to ensure accuracy.

Design

The Aardvark consists of a water reservoir on top of a weighing scale and a flow regulating unit, and has to be connected to a laptop with the proper software installed.
The flow regulating unit is lowered into a borehole, and water is allowed to flow from the reservoir into the hole. When the water in the hole reaches a specific depth, a floatation device in the flow regulator closes a valve, stopping the flow of water. When water infiltrates, and the level drops, more water will be allowed to flow into the hole. In this way, a constant head is ensured (although it should be checked regularly during measurements).
The scale constantly keeps track of the weight of the reservoir which reduces as water flows out. This scale is connected to a laptop.
The software that comes with the Aardvark allows the user to set up the measurement, by having the computer taking a measurement at fixed intervals. The infiltration capacity is fully automatically determined after the steady state is reached. The steady state can be defined by the user, by specifying how much variation in the values is allowed.

[25] http://www.soilmoisture.com/prod_details.asp?prod_id=1451&cat_id=18

Remarks
The greatest advantage of the Aardvark, is that it works almost fully automatic. Once the measurement has started, it will do all the work itself, and the operator can simply walk away. It is otherwise very similar to the K – sat, except it can go much deeper, namely up to 15 meters. It is, however, not very easy to move around, since it comes in two large suitcases (one for the scale, and one for the reservoir), and it also requires a laptop to operate.
A disadvantage of the Aardvark is its very sensitive scale, which may produce corrupt measurements when influenced by wind.

Example
A measurement has been carried out with the Aardvark of which the results are shown in figure 28 to 31. The software that comes with the Aardvark does all the calculations automatically and can be exported all at once. The resulting list of tables, the graph and the K-value can be found here.

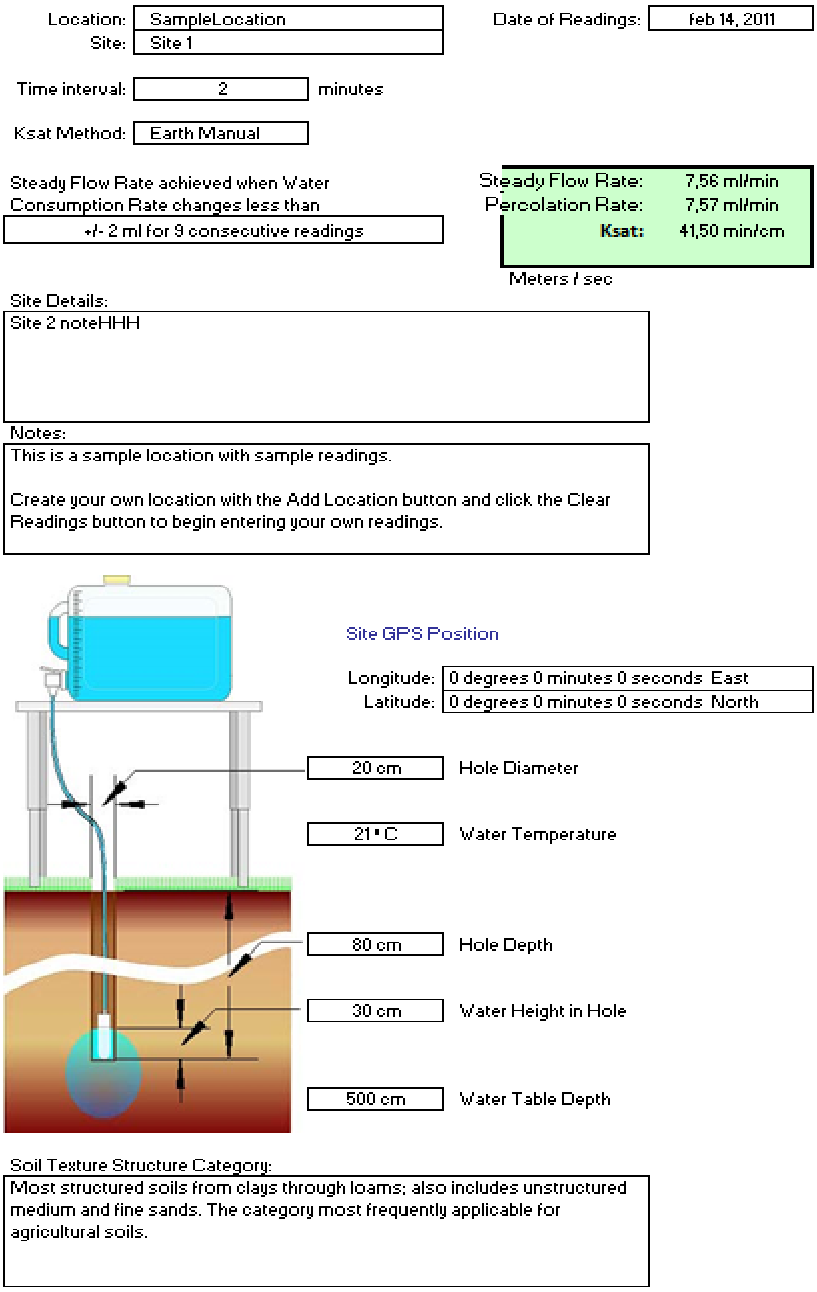


Figure 28: screenshot Aarvar

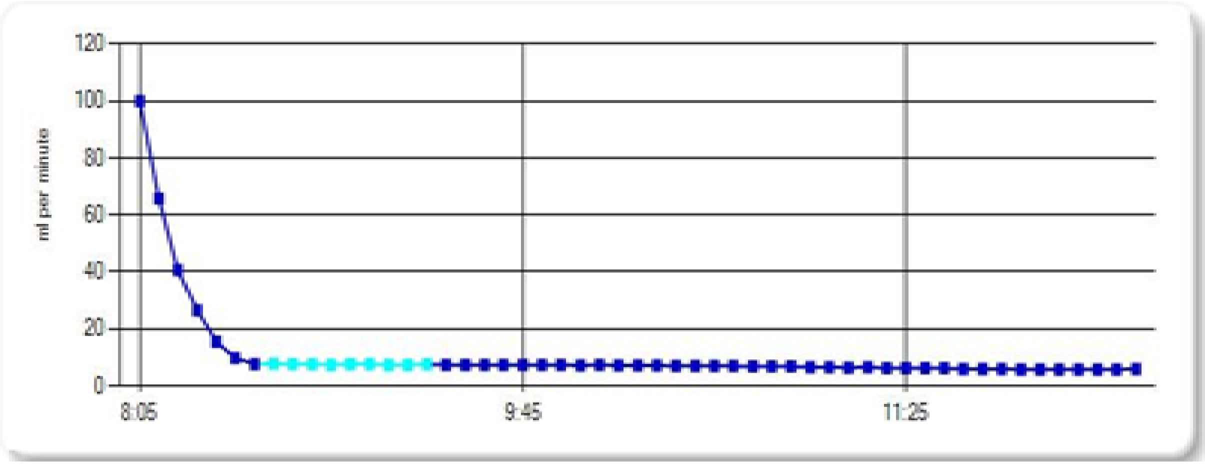


Figure 29: water consumption rate.

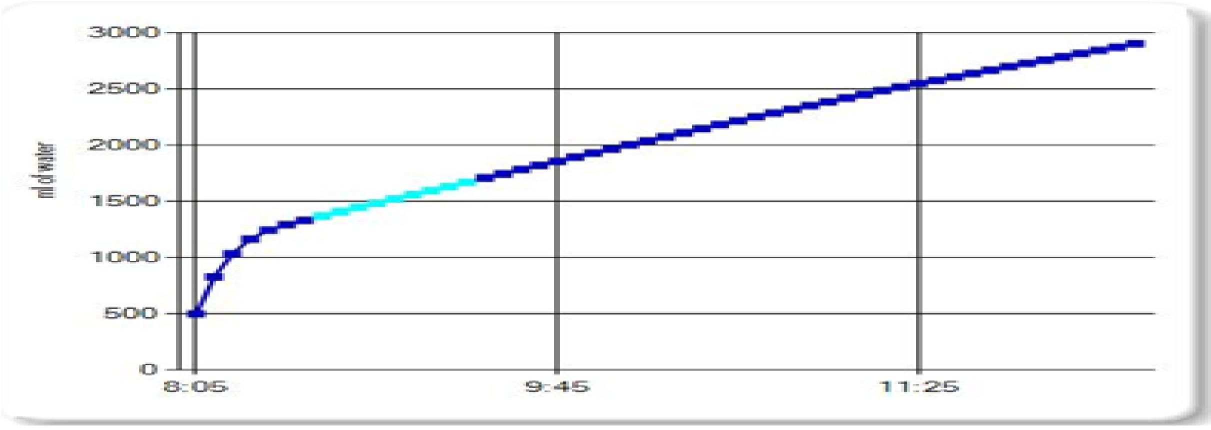


Figure 30: total water consumed.

Time	Reservoir Water Level (ml)	Elapsed Time Interval (minutes)	Interval Water Consumed (ml)	Total Water Consumed (ml)	Water Consumption Rate (ml / min)	Ignore this Reading?
8:00:00	-738	0				
8:05:00	-1238	5	500	500	100	
8:10:00	-1567	5	329	829	65,8	
8:15:00	-1770	5	203	1032	40,6	
8:20:00	-1903	5	133	1165	26,6	
8:25:00	-1981	5	78	1243	15,6	
8:30:00	-2030	5	49	1292	9,8	
8:35:00	-2068	5	38	1330	7,6	
8:40:00	-2107	5	39	1369	7,8	
8:45:00	-2145	5	38	1407	7,6	
8:50:00	-2183	5	38	1445	7,6	
8:55:00	-2220	5	37	1482	7,4	
9:00:00	-2258	5	38	1520	7,6	
9:05:00	-2296	5	38	1558	7,6	
9:10:00	-2333	5	37	1595	7,4	
9:15:00	-2370	5	37	1632	7,4	
9:20:00	-2408	5	38	1670	7,6	
9:25:00	-2445	5	37	1707	7,4	
9:30:00	-2482	5	37	1744	7,4	
9:35:00	-2519	5	37	1781	7,4	
9:40:00	-2556	5	37	1818	7,4	
9:45:00	-2593	5	37	1855	7,4	
9:50:00	-2630	5	37	1892	7,4	
9:55:00	-2667	5	37	1929	7,4	

Figure 31: Aardvark table.

6.3 The Tension Infiltrometer

Summary description

- measures unsaturated infiltration capacity
- ideal for sprinkler irrigation advice
- insensitive for root tunnels, insect borings
- comes to an equilibrium quickly
- intermediate sand for optimal soil contact
- very limited soil surface alteration

Figure 32: Tensio infiltrometer[26].

Applications

The Tension infiltrometer measures the unsaturated infiltration capacity of a soil. It does this by creating a vacuum, so that the soil actually has to 'pull' the water out of the device. The smaller the pores in the soil, the more capillary force they can exert on the water in the infiltration disk. Thus, the water is pulled into pores, and tends to flow into the soil as capillary water. Macropores, such as root tunnels and insect borings, and cracks, are circumvented entirely and do not play a role in the measurement. This makes the tension infiltrometer especially fit for sprinkler irrigation advice, and any other situation in which macropores are to be left out of the equation.

Because of the vacuum principle, the tension infiltrometer does not rely on wetting of the soil to measure an accurate value. Therefore, it reaches equilibrium quickly. Also, the extend to witch the soil surface is disturbed is very limited.

Design

The tension infiltrometer has been designed to operate in one of two modes. In mode one the infiltration disk is separated from the water tower. This mode is advantageous when operating under windy conditions. In this mode the infiltrometer is somewhat unstable, and a slight movement (caused by wind or accidental touching) may interfere with the measurement.

[26] http://people.fsv.cvut.cz/~dusekjar/pesticides.htm

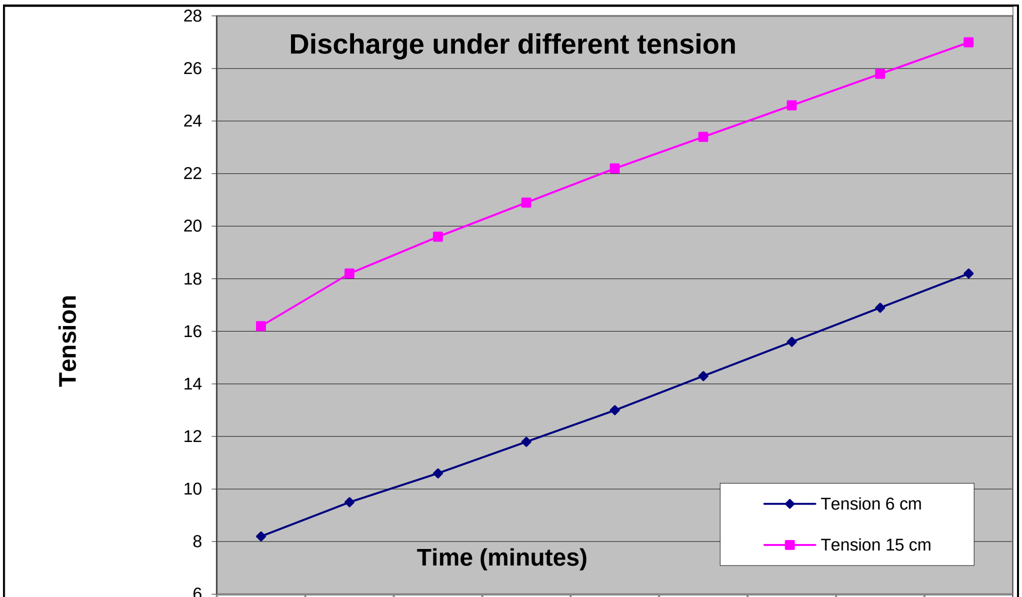
Another advantage of having the parts separated, is that the weight resting on the disk will remain constant throughout the measurement.
Mode two (with the water tower attached to the infiltration disk) is advantageous when space is limited, such as in a testing pit.

The most notable parts of the tension infiltrometer are: the infiltration disk, the water reservoir, and the bubbling tower complete with adjustable air entry tube.
The infiltration disk is what provides the interface between water and soil. Due to the design of the device, water will not spontaneously start to flow because the water pressure in the disk is negative. Only when a soil has sufficient capillary suction, it will be wetted and a flow will occur.

The water reservoir provides the water necessary to carry out the measurement. From here, the water flows through the disk and into the soil. At the top of the reservoir, the air-pressure at the inside can be measured. For every centimeter the water level drops, so does the pressure (it is always negative). This way, the rate at which the water drops can be monitored.
The bubbling tower is the part that creates the vacuum the device employs. It does this by forcing air to displace water as it moves down through the adjustable air tube, as the force required for this is the same as the force required for water in the reservoir to go down.

Remarks
The tension infiltrometer is used at the soil surface. Measurements at a certain depth are possible, but they will have to be carried out in a testing pit. The device requires a skilled person to operate, and calculations are rather complicated.

Example
Two measurements have been carried out in the field, on a loam soil (loam is a mixture of sand, silt and clay, see figure 29) at tensions of 6 and 15 centimetres. The values that have been observed can be seen below:



	0	2	4	6	8	10	12	14	16
Tension 6 cm	8,2	9,5	10,6	11,8	13	14,3	15,6	16,9	18,2
Tension 15 cm	16,2	18,2	19,6	20,9	22,2	23,4	24,6	25,8	27

Figure 33: discharge under different tension.

As can be seen in the graph and table, both reach their steady state after about ten minutes. The values above represent the lowering of the water level in the reservoir, these first have to be converted into a discharge that flows into the soil. Discharge can be calculated with the following formula:

(18) $$Q = \frac{v}{t}$$

The inside of the supply tube is 4.45 centimetres across, its radius is 4.45/2 = 2.225 centimetres. The cross sectional area is:

(19) $A = \pi * r^2$

$A = \pi * 2.225^2 = 15.55$ cm2

And the volume of water that enters the soil per time unit equals the difference in water height in the reservoir which at h_1 is 1.3 / 2 = 0.65 centimetres per minute in steady state, multiplied with the cross sectional area A:

$Q_1 = 15.55 * 0.65 = 10.11$ cm^3 / minute or 606.56 cm^3 / hour

At h2 the water level in the reservoir drops at 1.2 / 2 = 0.60 centimetres per minute, so Q_2 is:

$Q_2 = 15.55 * 0.60 = 9.33$ cm3 / minute or 559.90 cm^3/hour

The relation between Q and K is given by the formulas 20 and 21:

(20) $$Q\ (h_1) = \pi r^2 * Ksat * e^{\alpha h_1}\left[1 + \frac{4}{\pi r \alpha}\right]$$

(21) $$Q(h_2) = \pi r^2 * Ksat * e^{\alpha h_2}\left[1 + \frac{4}{\pi r \alpha}\right]$$

However, to calculate K, first α must be known. To do this, we can now divide the formulas 20 and 21, resulting in formula 22:

(22) $$\alpha = \frac{\ln[Q(h_2)/Q(h_1)]}{(h_2 - h_1)}$$

This is why at least two measurements must be taken; to get values for h_1 and h_2. In this case, measurements have been carried out at tensions of 6 and 15 centimetres, so:

$h_2 - h_1 = -15 - (-6) = -9$

and the discharges calculated above are:

$Q_2 / Q_1 = 559.90/606.56 = 0.92$

So:

$\alpha = (\ln 0.92) / -9 = -0.083 / -9 = 0.0093$

With α known, we can now go back to formula 20:

$$Q\ (h_1) = \pi r^2 * Ksat * e^{\alpha h_1}\left[1 + \frac{4}{\pi r \alpha}\right] \tag{20}$$

606.56 = π * 10^2 * Ksat *$e^{(0.0093 * -6)}$ * (1 + 4 / π * 10 * 0.0093)

606.56 = 314.15 * Ksat * $e^{(-0.056)}$ * 14.69

606.56 = 314.15 * Ksat * 0.94 *14.69

Ksat = 606.56 / (314.15 * 0.94 * 14.69) = 0.14 cm/h

6.4 The Double Ring Infiltrometer

Summary description

- ideal for infiltration measurement of top soils
- cannot be used in stony areas
- suited for flood/furrow irrigation advice
- triple rings to get a representative average
- low – tech, very durable

Figure 34: Double ring infiltrometer[27].

Applications

The double ring infiltrometer is a low-tech, relatively easy to use device, ideal for measuring the saturated infiltration capacity at the soil surface.
It does this by simply ponding a layer of water onto the soil (much like in flood irrigation), and measuring how fast it infiltrates. In this way, a number of hydrological features can be determined: infiltration capacity, near-saturated hydraulic conductivity, infiltration curve, and cumulative infiltration over a certain period.
It can be used on virtually any type of soil, with the exception of severely stony soils (to prevent damaging the rings) or soils on a steep incline.

Design

The double ring infiltrometer comes in a set of three double rings, which can be employed simultaneously. It consists of two metal rings, an inner ring and an outer ring. Both rings are inserted in the soil to a sufficient depth to prevent leakage. When the rings cannot be inserted deep enough, bentonite can be used at the edges of the ring to prevent leakage.
The water level in the inner ring will drop as water infiltrates. The difference in water level over a certain time is measured.
The outer ring is meant to reduce lateral flow; as the water moves down into the soil, the water from the inner ring cannot go to the sides.

[27] http://www.archimil.nl/bodem/hemelwaterinfiltratie.html

Remarks
The double ring infiltrometer is a rather simple device, but accuracy may suffer for this. It has no constant-head function, unless a Mariotte bottle is added, so the user may have to refill the rings several times during a measurement. As the water level changes, so does the pressure and therefore the infiltration speed. The head can be kept almost constant, however, by refilling it very often. Also, additional profile investigation is always necessary. A crust on the top of the soil for example may cause insecurities about the values found. Also, cracks and macropores will influence the measurement, although with the rather large surface area of the three rings combined this is not a problem (since macropores will also play a role in actual infiltration).

Example
A measurement has been carried out with the double ring Infiltrometer, for the results see figure 35. As can be seen in row 4, the water level started at 10 centimetres. The rings were refilled after every reading, to approximate a constant head.
The last two readings are the same, which means steady state was reached after an hour and 20 minutes. The infiltration capacity (rf K-value) is 27 mm/hour, or 64.8 cm per day.

DATA SHEET: INFILTRATION RATE

Site location: EXAMPLE   Soil type: Loam   Test date: 5 DEC 1987

1 Reading on the clock (hr min sec)	2 Time difference (min)	3 Cumulative time (min)	4 Water level readings before filling (mm)	4 Water level readings after filling (mm)	5 Infiltration (mm)	6 Infiltration rate (mm/min)	7 Infiltration rate (mm/hour)	8 Cumulative infiltration (mm)
14 05 0	start = 0	start = 0		100				start = 0
14 07 0	2	(0+2) 2	92	100	(100-92) 8	(8/2) 4.00	240	(0+8) 8
14 10 0	3	(2+3) 5	93	99	(100-93) 7	(7/3) 2.33	140	(8+7) 15
14 15 0	5	(5+5) 10	89	101	(99-89) 10	(10/5) 2.00	120	(15+10) 25
14 25 0	10	(10+10) 20	84	100	(101-84) 17	(17/10) 1.70	102	(25+17) 42
14 35 0	10	(20+10) 30	89	102	(100-89) 11	(11/10) 1.10	66	(42+11) 53
14 45 0	10	(30+10) 40	95	101	(102-95) 7	(7/10) 0.70	42	(53+7) 60
15 05 0	20	(40+20) 60	92	100	(101-92) 9	(9/20) 0.45	27 *	(60+9) 69
15 25 0	20	(60+20) 80	91		(100-91) 9	(9/20) 0.45	27 *	(69+9) 78

* basic infiltration rate

Figure 35: data sheet Double Ring Infiltrometer.

6.5 The Single Ring Infiltrometer

Summary description

- ideal for infiltration measurement of top soils
- cannot be used in stony areas
- suited for flood/furrow irrigation advice
- low accuracy due to lateral flow
- low – tech, very durable

Figure 36: Single ring[28].

Applications

The single ring infiltrometer is a low-tech, relatively easy to use device, ideal for measuring the saturated infiltration capacity at the soil surface.
It does this by simply ponding a layer of water onto the soil (much like in flood irrigation), and measuring how fast it infiltrates. In this way, a number of hydrological features can be determined: infiltration capacity, near-saturated hydraulic conductivity, infiltration curve, and cumulative infiltration over a certain period.
It can be used on virtually any type of soil, with the exception of severely stony soils (to prevent damaging the ring) or soils on a steep incline.

Design

The single ring is 20 centimeters across and 17 centimeters in height. The ring is inserted into the soil and filled with about 2 liters of water.
It is essentially the same as the double ring infiltrometer, except it does not have an outer ring. The single ring is therefore much less accurate then the double ring.

Remarks

The single ring infiltrometer is arguably the simplest infiltration measuring device, but accuracy suffers for this. It has no constant-head function, unless a Mariotte bottle is added, so the user may have to refill the rings several times during a measurement. As the water level changes, so does the pressure and therefore the infiltration speed. Also, lateral outflow is a problem, since it has no outer ring.
Additional profile investigation is always necessary. A crust on the top of the soil for example may cause insecurities about the values found. Also, cracks and macropores will influence the measurement, so it is advisable to repeat the measurement several times in different locations.

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[28] http://www.usyd.edu.au/agric/web04/Single%20ring%20final.htm

6.6 The Rainfall Simulator

Summary description

- not an infiltration measurement device but can give an indication
- measures run – off and erosion risk
- creates standardized shower
- can be used in the lab or in the field

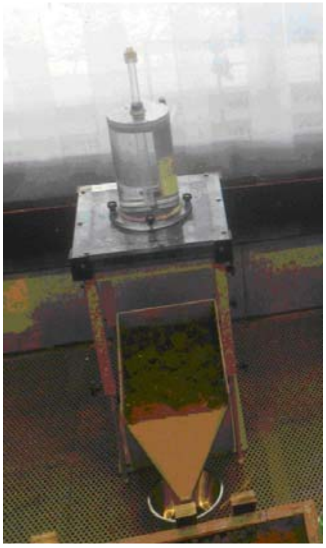

Figure 37: Rainfall simulator.

Applications

The rainfall simulator is a device used in the lab or in the field, to produce a shower of artificial rain in order to observe what happens to the soil, primarily in terms of erosion.
In order to do this, it has to produce a standard shower, that is comparable to a natural shower.

Design

The water is released from a container, under standard pressure, through a distributor that makes the drops standard as well. In this way, the intensity of the shower is always reliable, and reproducible no matter where the measurement is preformed (although temperature should be taken into account).

The intensity of rain the rainfall simulator produces is about 360 mm/hour. In comparison to a natural shower, this is extreme – almost half of annual rainfall in the Netherlands. However, intensity is not really what matters. The important thing is the impact a drop has on the soil.

In a natural shower, the drops fall down from a very high altitude, so that is comes down at the maximum speed, which is reached after about 10 meters. The average mass of a single drop is about 0.004 grams. We can now calculate the kinetic energy of the drop with the following equation:

$$KE_{drop} = m * g * h \quad (23)$$

Where KE_{drop} is the kinetic energy of the drop, m is its mass in grams, g the gravitational pull and h the falling height in meters. For the average drop, as described above and using formula 23, the kinetic energy is:

0.004 * 9.81 * 10 = 0.39 J

So, to reliably simulate a shower, the drops should have about this kinetic energy. However, the 10 meter fall height is not realistic, as that would be a rather cumbersome device. The only other variable that can be changed is the mass of the drops, which can be calculated using formula 23 after rephrasing to formula 24:

$$(24) \qquad m = \frac{KE}{g * h}$$

The fall height from the rainfall simulator is 0.4 meters, so:

0.39 / (9.81 * 0.4) = 0.1 gr

So, a drop with a mass of 0.1 grams that falls from the rainfall simulator, has the same kinetic energy as a natural raindrop. However, it is about 25 times as heavy, which explains the high volume of water that goes through.

Remarks
The rainfall simulator is not an infiltration measuring device, it is primarily meant to determine the risk of erosion. The fact that the amount of infiltrating water can also be measured, is merely incidental. This device is not suitable for calculating accurate infiltration curves.

Example
In order to show how the rainfall simulator works, a demonstration was set up. The experiment was to test the effect of different kinds of soil cover on erosion.

Three test plots have been prepared. The soil type, which is löss, is the same in all of them, but the surface cover is different.
On plot one (the setup on the left in figure 33) is the control test, a bare soil.
On plot two, the soil is covered in straw (which is a common measure against erosion).
On plot three there is grass, which is hypothesized to prevent erosion very effectively.
All tree plots have been placed outside for the past 48 hours, so they are assumed to have the same moisture level (close to field capacity).


Figure 38: three test plots.

The reservoirs at the top are all filled up to 2300 ml. When the stopper is removed from the air-supply tubes at the top, water is free to drop out the bottom. The intensity may vary per test, since the vacuum tube is adjustable, so the water level is measured every minute. However, during these test the three tubes were set at the same height, so the three simulations had the same intensity. The test runs for four minutes, and the following numbers have been found:

Time (min)	Water level (ml)
Start	2350
1	2050
2	1750
3	1450
4	1150

So the intensity throughout the test has been 300 ml/minute. This means that 300 * 4 = 1200 ml has fallen. For every drop there are now two options: either it runs off over the surface, or it infiltrates. The infiltrating water goes out through a drain at the bottom the run off is collected.

Figure 39: run off samples from left to right: bare soil, straw cover and grass cover.

It is obvious that the bare soil sample has the most run off (410 ml), and the run of has collected the most particles.
The straw cover has helped. The run off is less than half (160 ml) and the layer of sand at the bottom is clearly smaller.
The grass acts like a sponge by opening pores in the soil. The grass leaves also get wet themselves, and there has been no run off.
For more detailed analysis the samples may be sent to a lab, where grain sizes etcetera can be measured.

The water that came out of the rainfall simulator, but didn't run off, must have infiltrated. For each plot this amount is:

Cover	Precipitation	Run off	Infiltrated
Bare	1200	410	790
Straw	1200	160	1040
Grass	1200	0	1200

The ability to measure the infiltration capacity like this is coincidental, and not particularly accurate. The rainfall simulator is built to research the sensitivity to erosion for a particular soil, not for measuring infiltration capacity.

6.7 The Guelph Permeameter (Guelph pressure infiltrometer)

Summary description

- versatile instrument, can measure both saturated and unsaturated, at surface or at depth
- calculations are rather complicated, requires skilled operator
- very susceptible to wind
- works at limited depth (<3 meters)

Figure 40: Guelph infiltrometer[29].

Applications

Measurements with the Guelph are carried out in the vadose (unsaturated) zone, above the water table and the capillary fringe.
After the measurement is started and steady state occurs, a small bulb shaped saturated zone is quickly established, and around that a larger wetted, but unsaturated zone will form. Hence, the Guelph causes combined saturated and unsaturated flow to occur (see figure 36).
it is a versatile instrument, because it can measure saturated and unsaturated, and it can be used on the surface or in a borehole, although its operating depth is limited.

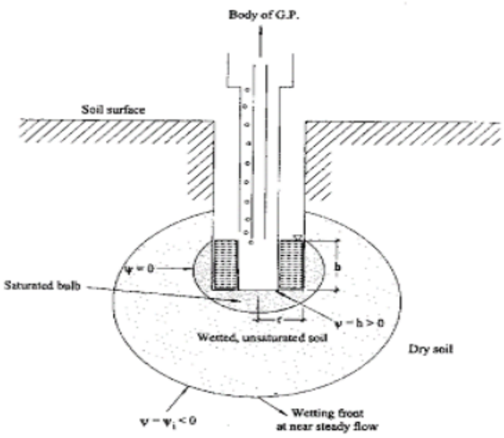

Figure 41: the saturated bulb surrounded by a wetted but unsaturated zone[30].

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[29] http://www.hilbec.com/STORMWATER.htm#thumb
[30] http://www.robertsongeoconsultants.com/hydromine/topics/Permeability_Testing/Guelph_Permeameter.html

Design

The Guelph permeameter is essentially a Mariotte bottle that can be set up in a borehole, With it, the hydraulic conductivity, sorptivity and matrix flux potential of any soil can be measured quickly and easily. It uses little water, and with the necessary attachments it can be used to a depth of up to three meters. It also has the possibility of adding a tension adapter, with which it can be used as a tensio infiltrometer that can measure at depth.

The Mariotte principle ensures that a constant depth of water is maintained in the hole. Using the values of water height and discharge, the hydraulic conductivity and the matrix flux potential can now be calculated with the following equation 25:

(25)
$$Q = \left[\frac{2\alpha H^2}{C} + \pi\alpha^2\right] K_{f_s} + \left(\frac{2\pi H}{C}\right) \text{Ø}_m$$

$$= A * K_{f_s} + B\text{Ø}_m$$

Where Q (m^3/d) is the discharge, H (m) is the water depth in the hole and a (m) is the hole diameter, and K is the hydraulic conductivity (m/d). The f_s behind the K stand for field and saturated, so the Kfs is the field saturated conductivity. The matrix flux potential (m^2/d) is represented by Φ_m. The C (-) is a constant, that depends on H, a, and α* (cm^{-1}), which is a value that corresponds to the soil type (see figure 37). It is a complex calculation, which is usually done with software.

The Guelph permeameter measures the hydraulic conductivity of the soil, which means the capacity of the soil to conduct the water, and the matrix flux potential, which means the capacity of the soil to absorb the water. If these two are added up, they form the total discharge Q from the device. The flow is combined saturated and unsaturated, now the first term of the equation represents the pushing factor of the hydraulic head, while the second term represents the pulling of the capillary action in the soil.

Soil Texture-Structure Category	$\alpha^*(cm^{-1})$	Shape Factor
Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01	$C_1 = \left(\frac{H_1/a}{2.102 + 0.118(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{2.102 + 0.118(H_2/a)}\right)^{0.683}$
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04	$C_1 = \left(\frac{H_1/a}{1.992 + 0.091(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{1.992 + 0.091(H_2/a)}\right)^{0.683}$
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$
Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macro pores, etc.	0.36	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$

Figure 42: table with calculations for C, depending on soil type α*[31].

Remarks

The Guelph is a very versatile device, since it can measure both at the surface and at depth, and both saturated and unsaturated. It also uses little water.

The depth it goes to is limited, however, and it takes a skilled person to operate, particularly when measuring unsaturated conditions.

[31] http://pkd.eijkelkamp.com/Portals/2/Eijkelkamp/Files/Manuals/M1-0907e%20Guelph%20permea.pdf

6.8 The Labtype permeameter

Summary description

- used only in the lab
- measures permeability from undisturbed samples
- both constant and falling head method options

Figure 43: Labtype permeameter [32].

Applications

When measuring in – situ is not possible, the lab type permeameter can be used to analyze undisturbed samples. For conductivities between 10^4 and 10^{-2} meters per day, the constant head method can be used. These conductivities are generally found in gravel to fine sand.
For conductivities lower than that, the falling head method should be used, for conductivities up to 10^{-5} meters per day. If the conductivity is lower than that, it can be considered negligible.

Design

The Lab type Permeameter consists mainly of a large tank, in which a constant water level is maintained. To measure the conductivity with the constant head method, an undisturbed soil sample is placed in the tank, below the water level. The water will then flow up, through the sample to its top, where it will be siphoned off. In this way, a constant difference in head is created and water will continuously flow through the sample. By measuring the amount of water that is siphoned off, the hydraulic conductivity can be calculated.

With samples that have a very low conductivity (see figure 39) the falling head method should be used. For this, a layer of water is placed on top of the sample, and the lowering of the level after a certain time is measured.

Remarks

The lab type permeameter can measure at high accuracy, both with a falling head and a constant head method. The sample has to be taken out of its context, however, which means the values found are less reliable.

[32] http://www.usyd.edu.au/agric/ACSS/sphysic/waterlab/waterlab.htm

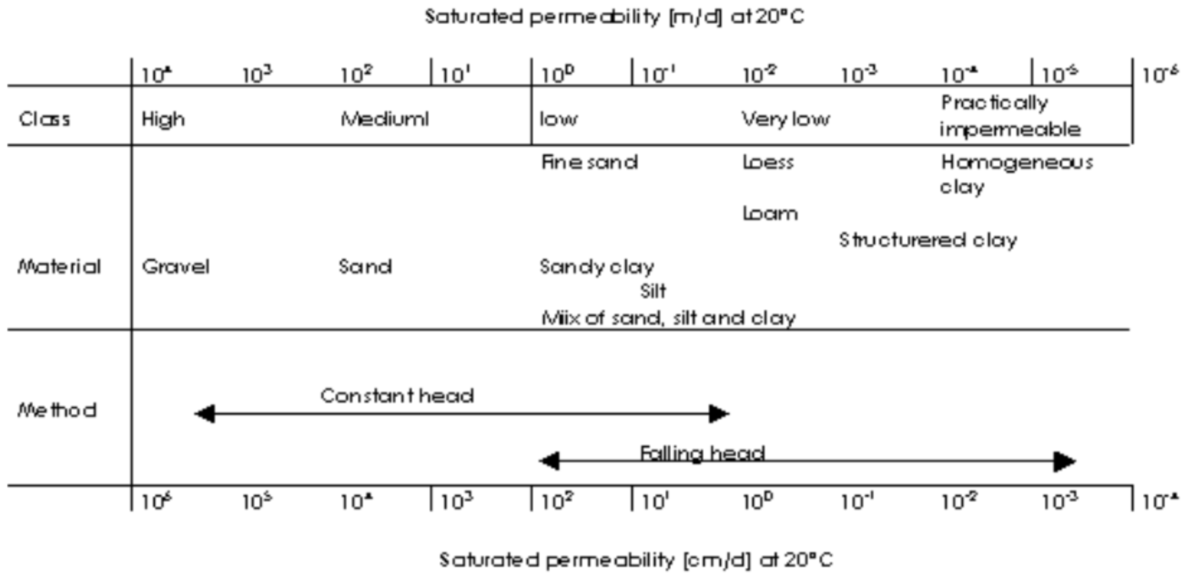


Figure 44: showing the method that should be used for certain K – values, and the soil types they should be expected in (Klute and Dirksen 1986).

Example
Four undisturbed samples have been taken, in the same location where also the Ksat (see chapter 6.1) and the Tension Infiltrometer (see chapter 6.3) have been tested. The conductivity is therefore expected to be similar, so the constant head method has been used.

Before the measurement can start, the samples have to be saturated. They are placed in a container of water (with the water level just below the edge of the sample) for 24 hours. After that, they are placed in the permeameter.

This experimental setup is much like Darcy's experiment (that has been discussed in detail in chapter 5.1), except the soil sample is placed vertically with the water flowing from the bottom to the top of the sample. at the top of the sample the water is siphoned off and collected. Before the experiment starts, the water level above the sample has to be constant, this takes some time. The water level inside and outside of the sample has to be measured, to calculate the head. The results can be seen in figure 45:

sample	level inside sample (cm)	level outside sample (cm)	head (cm)
1	-	1,6	-
2	4,4	1,6	2,8
3	4,0	1,6	2,4
4	5,0	1,6	3,4

Figure 45: head for different samples.

The measurement is then carried out by measuring how long it takes for the glass tubes at the front of the device to fill up from 0 to 40 ml. The measurement was not carried out for sample 1, since no water was flowing (we will get back to this later).

For samples 2 to 3, the results can be seen in figure 46:

sample 2		sample 3		sample 4	
measurement	time (sec)	measurement	time (sec)	measurement	time (sec)
1	328	1	25	1	1680
2	384	2	25	2	1647
3	354	3	25	3	1798
average:	369		25		1708

Figure 46: time values to determine discharge.

For the calculations of the K value, an adapted form of Darcy's Law is used:

$$K = \frac{Q * L}{h * A} \qquad (26)$$

In this formula, h (cm) is the head which can be found in table 45. Q (cm^3/s) is the discharge that flows through the sample. The L (cm) and A (cm) are constants that depend on the used sampling ring. The L is the height of the sampling ring which is 5 cm. The diameter of the sampling rings used is also 5 cm, so its radius is 2.5 cm. This means the cross sectional area (A) is 19.63 cm^2:

$\pi * 2.5^2 = 19.63\ cm^2$

The discharge is calculated from the data in table 46. For example, with sample to it takes on average 369 seconds for 40 ml (or cm^3) of water to flow through. This means a discharge of:

$40/369 = 0.11\ cm^3/s * 60 = 6.50\ cm^3/minute$

The K value for sample 2 can then be calculated with formula 26:

K = 6.57*5 / 2.8*19.63
K = 32.52 / 54.96 = 0.59 cm/min or 8.52 m/day

The values for all samples are listed below:

sample	K value (m/d)
1	-
2	8.52
3	146,71
4	1.54
average	53.44

Figure 47: K values found.

The variety in these results is clearly too big for the average value to be reliable. Before the measurement is carried out there is no way to tell what exactly is in it, since they have to be undisturbed. When discarding the samples however, the contents where visually inspected. Since the samples were taken at the same depth as the measurement with the Ksat was carried out, at only a few centimetres distance, the soil type was assumed to be similar. This was not the case. Sample number one consisted of only heavy loam, and sample number 4 was a mixture of loam and sand, and both contained many rocks. Sample number 2 was about half loam, half sand. The only sample that consisted only of sand was number 3.

6.9 Grain size analysis

Summary description

- only way to determine K – values greater than 10^4 meters per day
- not very accurate

Figure 48: Grain size analysis[33].

Applications

In some cases which extremely coarse soils, the hydraulic conductivity may be so high that an in-situ measurement is not practical or not even possible, because the reservoir of any device will be drained too fast to make accurate observations. This is the case when the estimated hydraulic conductivity exceeds 10^4 meters per day.
In these cases, the grain size distribution can be analyzed, and the hydraulic conductivity can roughly be calculated from it.

Method

For grain size analysis, a sample (preferably more than one) is needed. Any components of the soil that will make particles stick together (mainly organic matter, water and iron) will be removed. After this, the sample goes through a series of sieves with different mesh sized from great to small. Either the volume or weight of the soil that remains in each sieve is then measured, and calculated into percentages.

Remarks

Grain size analysis is not a very reliable method, since the sample has to be disturbed. It should only be used when it is the only possible option, which is in extremely conductive soils where field measurements would be unreliable.

[33] http://courses.washington.edu/uwtoce06/methods.html

Literature list

1	Amoozegar, A., Warrick, A.W., (1986); Methods of Soil Analysis, Ch. Hydraulic Conductivity of Saturated Soils: Field methods, pp. 735-769, Madison Wisconsin
2	Bakker, H.de, (1990); Bodemkunde van Nederland, Ch. 3 Het bodemprofiel, pp. 39-55, Malmberg Den Bosch
3	Bouwma, J., (1990); Bodemkunde van Nederland, Ch. 10 Stroming van water, pp. 147-165, Malmberg Den Bosch
4	Cuenca, R.H., (1989); Irrigation system design - An engineering approach, Prentice Hall
5	Danielson, R.E., Sutherland, P.P., (1986); Methods of Soil Analysis, Ch. Porosity, pp. 443-461, Madison Wisconsin
6	Ietswaard, H., (1990); Bepalen van bodemparameters met een discpermeameter, Student report
7	Green, R.E., et.al.,(1986); Methods of Soil Analysis, Ch. 30 Hydraulic Conductivity, Diffusivity, and Sorptivity of Unsaturated Soils: Field Methods, pp. 771-798, Madison Wisconsin
8	Hillel, D., (1980); Applications of Soil Physics, Academic Press
9	Kuo, J., (1999); Practical Design Calculations - for Groundwater and Soil Remediation, CrC Press LLC
10	Klute, A., Dirksen, C., (1986); Methods of Soil Analysis, Ch. 28 Hydraulic Conductivity and Diffusivity: Laboratory Methods, pp. 687-732, Madison Wisconsin
11	Locher, W.P., Broekhuizen, J., (1990); Bodemkunde van Nederland, Ch. 4 Grond als driefasig systeem, pp. 57-69, Malmberg Den Bosch
12	Petersen, R.G., Calvin, L.D., (1986); Methods of Soil Analysis, Ch. 2 Sampling, pp. 33-51, Madison Wisconsin
13	Ritsema, C.J., Dekker, L.W., (2003); Soil water repellency – occurrence, consequences, and amelioration, Monograph
14	Rowell, D.L.,(1994); Soil Science – Methods & Applications, Longman Scientific&Technical
15	Sluis, P. van der, (1990); Bodemkunde van Nederland, Ch. 8 Vochtlevering door de grond, pp. 269-284, Malmberg Den Bosch
16	Stephens, D.B., et. al., (1983);Insitu Determination of Hydraulic Conductivity in the Vadose Zone using Borehole Infiltration Tests, University of Arizona
17	Turner, E.R., (2006); Comparison of Infiltration Equations and their Field validation with Rainfall Simulation, University of Maryland
18	US Army Corps, (1994); Engineering and Design – Flood Run-off Analysis (EM 1110-2-1417)

Bijlage 4: Het stroomschema

Flowchart infiltration measuring devices

With this flowchart the decision for an infiltration measuring device* is made easy. For additional information, see the report: "Measuring infiltration by means of...?", which is available on www.eijkelkamp.com or you can click *here*.

= Device

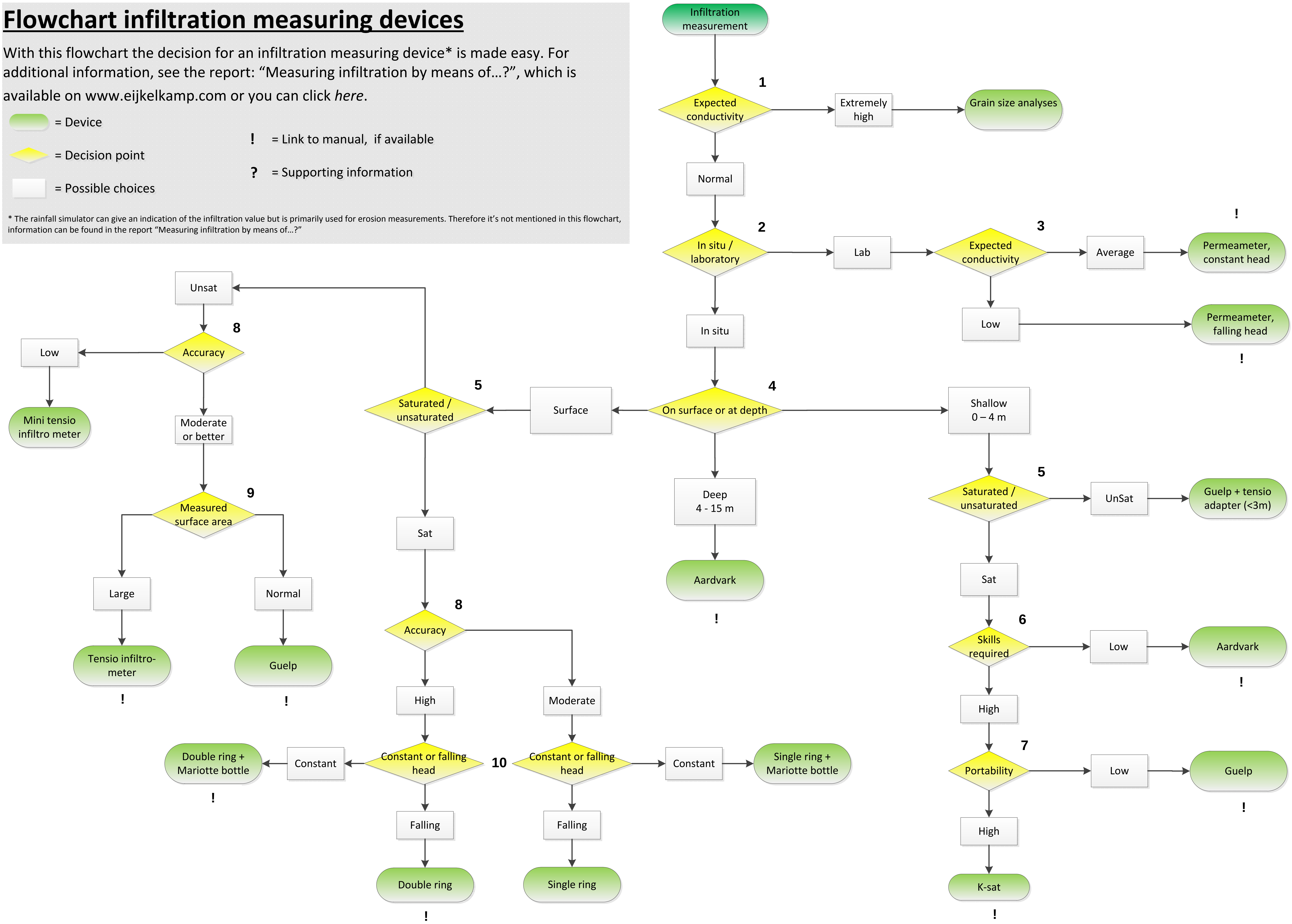
= Decision point

= Possible choices

! = Link to manual, if available

? = Supporting information

* The rainfall simulator can give an indication of the infiltration value but is primarily used for erosion measurements. Therefore it's not mentioned in this flowchart, information can be found in the report "Measuring infiltration by means of...?"



Flowchart support

1 Expected conductivity, grain size analysis

In some cases whit extremely coarse soils, the hydraulic conductivity may be so high that an in-situ measurement is not practical or not even possible, because the reservoir of any device will be drained too fast to make accurate observations. This is the case when the estimated hydraulic conductivity exceeds 10^4 meters per day.

In these cases, the grain size distribution can be analyzed, and the hydraulic conductivity can roughly be calculated from it.
Grain size analysis is not a very reliable method, since the sample has to be disturbed. It should only be used when it is the only possible option, which is in extremely conductive soils where field measurements would be unreliable.

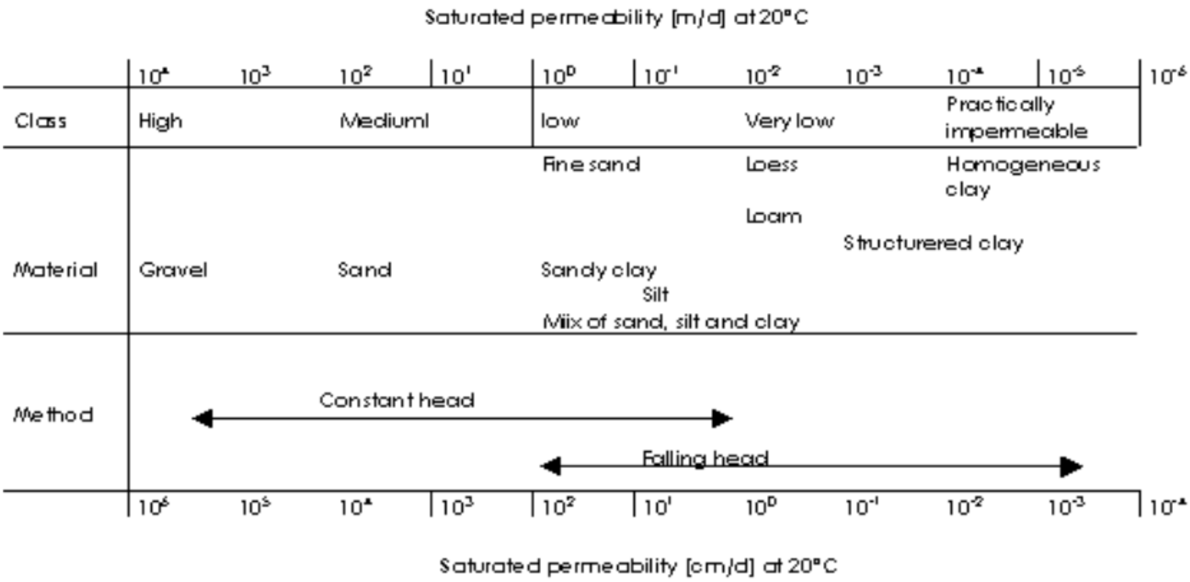


Figure 1: The relation between the conductivity and the method that should be used.

2 In-situ or Laboratorium

Soil characteristics can be measured in one of two ways: in the field or in the laboratory.

When measuring in the laboratory, samples have to be taken, that can be analyzed.

Measuring in the field (in – situ) has a number of advantages: the sample is not taken out of its context and sources of error are avoided.

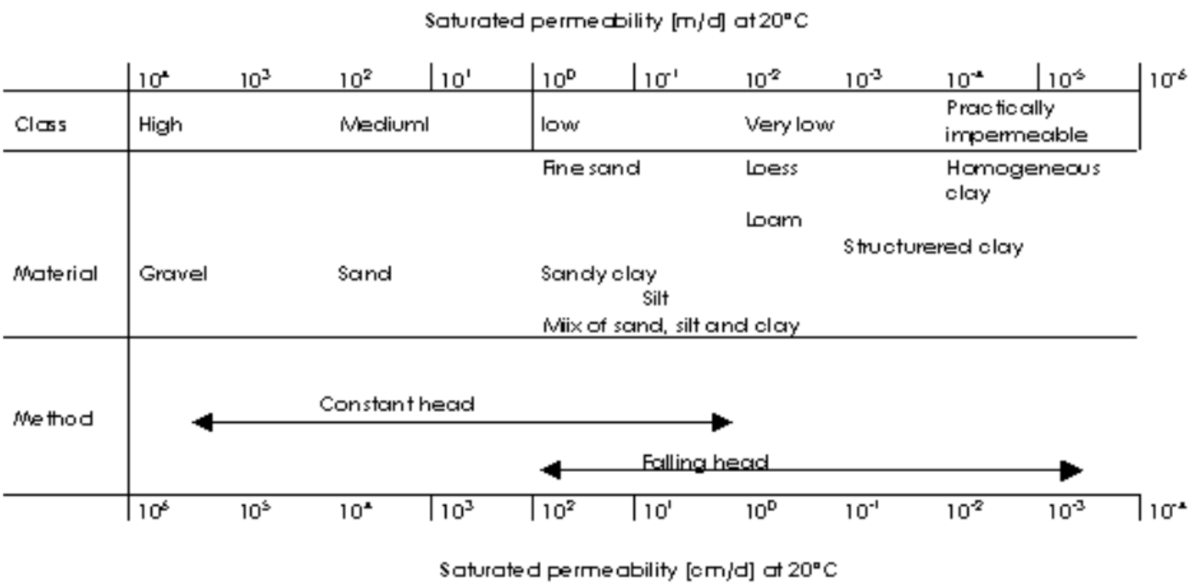
However, measuring in the field is usually more difficult than simply taking a sample, since the measuring device will have to be transported to the site which may be quite remote.

3 Expected conductivity, falling or constant head

The labtype permeameter can be used to analyze undisturbed samples. The sample has to be taken out of its context, however, which means the values found are less reliable. It can measure at high accuracy, both with a falling head and a constant head method.

Conductivities between 10^{4} and 10^{-2} meters per day can be considered very high to low. They cover most soil types, from gravel to fine sand. For these, the constant head method can be used.

Conductivities lower than that, the falling head method should be used. This is possible for conductivities up to 10^{-5} meters per day, which should be considered very low. If the conductivity is lower than that, it can be considered negligible.



The relation between the conductivity and the method that should be used.

4 On the surface or at depth

When designing, for example, an infiltration facility that is going to be two meters deep, the infiltration capacity at the surface – which can be very different – is of no interest. The infiltration capacity should therefore be measured at the same depth as where the water is actually going to infiltrate.

<u>At the surface</u>
Methods that measure at the surface (the double rings) also take into account the vegetation, and a possible crust. If these methods are to be used at depth, a testing pit must be dug.

<u>0 – 4 meters</u>
This offers the most possibilities, since these methods work in a bore hole, which means they can be carried out at depth without digging a test pit. The maximum depth is however, even with extensions, limited.

0 – 15

The only device that works this deep is the Aardvark. If another method is to be used, it would have to be traditional methods such as Hooghoudt where water is added in a borehole and the change in water level over time is measured.

5 Saturated/unsaturated

The most important distinction that should be made when choosing a method to measure infiltration capacity, is that between saturated and unsaturated. The division between saturated and unsaturated infiltration is mainly important in respect to macropores, and to the method of application.

Aside from grain size distribution and pressure gradient, the amount of moisture already present in a soil is also a very important factor for the hydraulic conductivity of a soil (and, therefore, the infiltration capacity).

The reason that the soil moisture content is so important to the infiltration capacity is that water does not flow through air-filled pores (Locher and de Bakker, 1990). Any pore in the soil that is filled with air, must first be wetted before it can contribute to the flow of water through the soil.
If an amount of ponded water is maintained on the soil surface, all pores will be filled with water quickly, forcing the air out. The soil is then saturated. Its hydraulic conductivity is now at its maximum level, as water can flow through any pore.
Saturated is a clearly defined term, it means 100 percent of the pore-volume is filled with water. However, this rarely occurs in the field. When an area is temporarily flooded, and even when the soil is below the groundwater table, some trapped bubbles of air remain but these are considered negligible. (Rowell 1994).

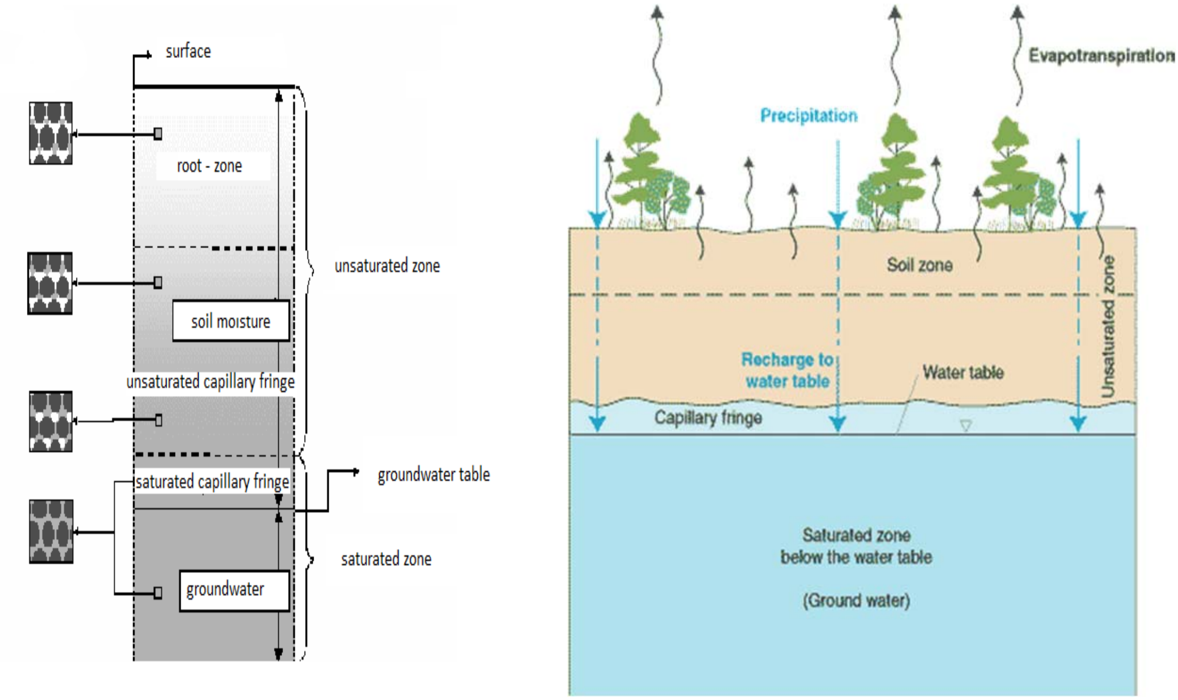


Figure 1: two different takes on the capillary fringe, can you spot the difference?
http://pubs.usgs.gov/circ/circ1186/html/gen_facts.html

Infiltrating water moves primarily under influence of gravity; it will flow to the point with the lowest pressure, following the path of least resistance. In groundwater, gravity causes pressure that increases with depth. The water pressure at the groundwater level is equal to the atmospheric pressure.
Soil water above the groundwater table has a negative pressure. The soil particles ‘pull’ at it over their entire surface area, so the water will be stretched around it causing a state of tension, leading to the term soil water tension.

This is demonstrated when a drop of water at atmospheric pressure is brought into contact with a soil sample that is relatively dry. It will be sucked into the soil by the water tension, and the surface tension and the concentration of dissolved substances will go down. Keep adding drops in this way, and eventually the water pressure will become greater than zero, and water will start flowing down.

When the water is applied under unsaturated conditions, such as sprinkler irrigation, the measurement must also be done under unsaturated conditions, and vice versa.

6 Skills required

One thing that clearly separates the Aardvark from the others, is its level of automation. Once it is set up, the operator can simply walk away and do something else. The software will perform measurements according to the set up, and calculate the K – value automatically.

Because of this, the level of skill required from the operator is also much lower than with most other devices.

7 Portability

While the portability of a device has no influence on the measurement itself, it can make a great difference to the person who does the measuring, especially in remote areas.

Most devices come in big suitcases, but the K – sat has a strap that makes it easy to carry like a backpack.

8 Accuracy

Some devices come in two varieties, of which the one is usually cheaper or more easily carried and the other more accurate.

This may be due to the construction of the device, or a smaller measured area, or both. In any case, the less accurate the device is, the more measurements have to be carried out in order to get a comparable reliability in the results.

9 Measured surface area

Usually more than one measurement is carried out, and the average value will be taken as the value found. The results of the separate measurements will rarely be the same. This is due to the heterogeneity in every soil, no two square meters of soil are the same.

This is why the size of the measured area, the 'footprint' of the device, also plays a role; a single measurement on one point can be seen as the average value of that location, since even within the footprint there will be variations. The larger this footprint is, the more representative the results will be.

10 Constant or falling head

The head (in meters) is a measure of the amount of energy stored in water, or the pressure. When water is ponded on the surface of the soil, the head is the thickness of the layer of water.
As the head is falling, the pressure gradient decreases, which influences the rate of the infiltrating water. This makes the measurement less accurate.

Separate Mariotte bottles are available that can make a double or single ring infiltrometer (which normally are falling head methods) into a constant head device. This improves its accuracy.
Another advantage of constant head methods is they generally use less water than falling head methods, which also improves portability of a device.