

Cumulative rainfall collectors – A tool for assessing groundwater recharge

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Abstract

The great majority of Southern African aquifers depend on rainfall for their recharge. The accurate estimation of recharge remains one of the biggest challenges for groundwater investigators. Accurate recharge estimations are needed for proper groundwater management as this governs the estimation of sustainable exploitation. Current estimates of recharge to aquifers range between 0.2 and 3% of annual rainfall for the drier Karoo and Kalahari areas and up to 20% for the winter rainfall region of the Western Cape. Important input for determining recharge is knowledge of the chemical and isotopic composition of rainfall. This paper describes a simple, low-cost and low-maintenance tool, the cumulative rainfall collector (CRC), which provides a cumulative sample of rainfall which is unaffected by evaporation. The instrument is capable of collecting rainfall over periods of up to one year. The crucial aspect is to store sufficient rainfall, to eliminate evaporation by covering the water sample with silicon oil and to reduce interference by birds.

CRCs were installed at Struisbaai, the West Coast and the South Coast of the Western Cape Province. CRC data for Struisbaai indicate that recharge to the Table Mountain Group (TMG) Aquifer is 17.4% of mean annual rainfall. The West Coast transect includes two production wellfields. CRC data indicate that recharge is 9.7% to 13.5% for the Bredasdorp Formation of the Langebaan Road Wellfield. At Agter Witzenberg recharge estimations range from 24% to 46% to the Nardouw Formation of the TMG. The South Coast transect encompasses the Klein Karoo Rural Water Supply Scheme and CRC data indicate that recharge to the Peninsula Formation of the TMG is 5%.

Keywords: Groundwater recharge, rainfall quality, cumulative rainfall collectors, TMG aquifer, Bredasdorp aquifer, chloride mass balance, deuterium displacement

Introduction

The need for regular rainfall sampling has been known for many decades. The recognition that acid constituents in rain arising from air pollution present a danger to ecosystems and to humans has necessitated large rainfall sampling networks on global and regional scales in which the emphasis is on rainfall chemistry. The atmospheric nuclear weapon tests of the 1950s triggered a global network for the collection of rainfall samples for tritium and stable isotope analysis (see IAEA-GNIP website) that has become useful for many disciplines. Groundwater professionals have started to use chemical and isotopic properties of rainfall as input to the groundwater system. The data enable estimates of recharge to be made.

The standard rainfall sampling protocols require that rainfall be collected at least daily and the samples immediately analysed or stored for some sort of cumulating procedure. This is a time consuming manual effort and automation is quite expensive to make it reliable enough. Sophisticated samplers have been designed that collect separate rainfalls and also separate dry and wet deposition. These are expensive to purchase and maintain and require power. Groundwater professionals are usually interested in cumulative data (seasonal or annual) and prefer a spread of localities to identify regional effects. Using the standard sampling protocols when annual data are sufficient, is therefore superfluous and uneconomic. There is therefore a

need for a simple cumulating rainfall sampler that can operate for long periods without supervision.

Previous work

Friedman et al. (1992) collected integrated samples over a 7-year period in the south-east California desert at elevations ranging from below sea-level to 2 280 m. Their sample collectors were constructed from white polypropylene and rubber tubing. They were able to use the results to distinguish between the origin of winter and summer precipitation. The collector bottles had a layer of hydrocarbon oil to prevent evaporation of the water. A gelatinous third phase developed, resulting in an under-estimation of rain volume; however, analysis showed that this phase had the same deuterium value as the rain, and thus did not alter the deuterium content of the water. They did not carry out chloride analyses and did not do recharge calculations. This work is the first design of a rain collector that used an oil layer to reduce evaporation.

Scholl et al. (1996) used precipitation and groundwater isotope data to interpret the regional hydrology on Hawaii. They used CRCs to obtain the chloride and isotope signature of precipitation. Initially they used a 3 to 4 mm layer of oil but found that significant evaporation occurred from both indoor and field controls. Field controls showed weight losses of 0 to 33%, and $\delta^{18}\text{O}$ enrichment of 0.5 to 6.2‰. Later designs used 8 mm of oil, which resulted in ^{18}O enrichment of less than 0.6‰ over a six-month period.

Beekman and Sunguro (2002) installed triplicate sets of CRCs, farmers' rain-gauges and metal rain collectors. They found that the CRCs gave slightly elevated levels of chloride

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compared to the other two collectors despite corrections for evaporation. It is not clear from the report whether an oil layer was used. They also found significant variations of analytical results for chloride from three different laboratories.

Why use a cumulative rainfall collector?

The use of a CRC for collecting rain samples in order to determine chloride and isotopes in rain as an input for estimating groundwater recharge is extremely powerful due to the following advantages:

- It provides a direct estimate of total deposition
- The sample includes dry deposition
- It is time integrating
- It is inexpensive
- The collectors can be left unattended and thus have a low servicing cost
- The collectors do not need a power source.

Calculating recharge from the chloride content of rain

Chloride can be considered a conservative tracer as it is generally not adsorbed or desorbed during transport through soil. Chloride enters the soil as part of infiltrating rainfall and is subsequently concentrated by evaporation and transpiration. Recharge (R_c) (expressed as a percentage of mean annual rainfall) is thus the mean concentration of chloride in rain (which includes dry deposition), Cl_r , divided by concentration of chloride in groundwater (Cl_{gr}) $\times 100$.

$$R_c = Cl_r / Cl_{gr} \times 100 \%$$

This method is referred to as the chloride mass balance (CMB) method (Eriksson and Khunakasem, 1969). Various workers (Wood and Sanford, 1995; Bazuhair and Wood, 1996; Cook, 2003; Beekman and Xu, 2003; Sami, 2003 and Van Tonder and Bean, 2003) have used and described the CMB method with its variations, assumptions, applicability and accuracy.

Wood (1999) described some of the errors made when using CRCs for rain sample collection for CMB calculation. It is important to collect groundwater samples at the water table within the recharge zone of an aquifer for this comparison. Due to evapo-transpiration, or dissolution of chloride ions from the aquifer material, or mixing of higher chloride water from another aquifer zone, it is likely that groundwater from the discharge zone will have concentrations of chloride higher than freshly recharged water. Thus groundwater collected away from the recharge zone of an aquifer, near the discharge zone, could result in underestimation of the recharge percentage. One should also not place the CRCs near salt pans, as wind-blown dust will have excessively high chloride levels.

Calculating recharge from the stable isotope content of rain

Allison et al. (1994) introduced a method to estimate recharge by comparing the stable isotope content of rainwater and groundwater. The calculation is based on the displacement of the deuterium-¹⁸O relation from rainwater to groundwater. This phenomenon is interpreted as the result of mixing of infiltrating rainwater with soil moisture that has undergone evaporation in the unsaturated zone. The extent of this displacement is proportional to the

evaporative enrichment of infiltrating water in the upper layers of the soil and dilution by recharging groundwater. Recharge is given by the following equation (Allison et al., 1994):

$$\Delta\delta D = C/\sqrt{R}$$

where:

$\Delta\delta D$ is the displacement of δD

$C = 22$, constant determined for arid Australia

R = mean annual recharge in mm/a.

Recharge estimated by this method is only feasible in areas with low recharge, typically less than 10 mm/a (Selaolo, 1998) where the D displacement can be properly recognised. These are the arid areas. No local values of the constant, C , have been determined. The assumptions behind this method imply that it would only be applicable to recharge through un-vegetated soils. Nevertheless this method has given acceptable results in Botswana (Selaolo, 1998; DWA, 2002) and can be recommended for wider use (Van Tonder and Xu, 2000). Application of this method requires a good knowledge of the local meteoric water line (LMWL) applicable for the study site. Such lines should preferably be obtained over a number of years since significant differences are found from year to year (Selaolo, 1998; Meyer et al., 2001). Various data-sets of isotope analyses in rainfall exist from which a LMWL can be constructed (IAEA-GNIP website; Selaolo, 1998; Diamond and Harris, 1997) and more are being added regularly. The CRC is intended to expand the available data base to have more directly applicable data over longer time scales.

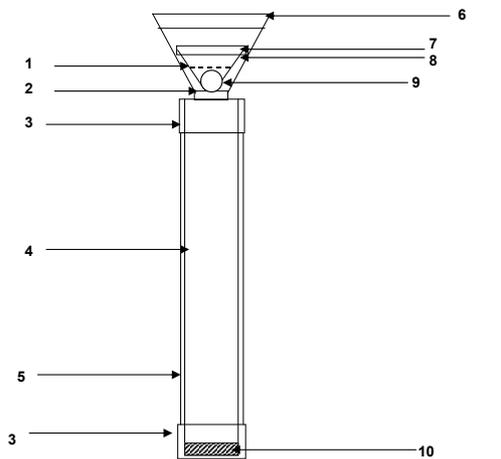
Design of the CRC

Early designs of CRCs (Weaver et al., 1999) were simple funnels glued to PVC tubes with a wire bird-chaser attached. A number of lessons have been learnt and the two current designs incorporate features developed from these early designs. CRC-V1 is an inexpensive simpler design, suitable for collecting samples for groundwater research projects.

Design and usage factors

The following are essential features of the CRC and are shown in Fig. 1:

- The funnel is a standard plastic rain-gauge funnel of 128.5 mm with bevelled edges available from all agricultural co-operative stores
- For this research we used 140 mm diameter class 12 uPVC tubing. The length of the PVC collector tube is sized according to the expected rainfall. The length of the tube should at least be equal to the expected rainfall amount. It would be prudent to add another 20 to 50% of length to accommodate high rainfall years
- The above design is quite adequate for areas close to the coast where chloride levels in rain are high. For inland areas where chloride levels are in the order of 0.4 to 1.0 mg/l and there is a possibility (however slight) of leaching of chloride from uPVC, a stainless steel insert is used as shown in Fig. 1, so that the rainfall sample is not in contact with uPVC.
- A circular 125 mm screen is glued with silicon sealant 20 mm from the top edge of the funnel. This prevents insects and leaves from falling into the collector and altering the



Legend

- 1 Stainless steel mesh screen
- 2 74 mm x 43 mm x 25 mm circular tapered flange
- 3 160 mm PVC flat-bottomed end cap
- 4 Stainless steel bucket inserts
- 5 160 mm Class 4 Duraflo PVC pipe (3.45 mm wall thickness)
- 6 Wire frame (bird distracter)
- 7 Standard "5 inch" rainfall measuring funnel
- 8 PVC household funnel 130 mm diameter
- 9 Table tennis ball
- 10 Silicon oil layer

Figure 1

Diagram showing the critical design elements of the cumulative rainfall collector

chemistry. The screen is 2 mm mesh stainless filter screen, obtainable from irrigation suppliers.

- Bird droppings are a serious contamination threat. A bird-chaser of four wire uprights surrounding the funnel is attached. The points of the uprights have a hole drilled through and a cats-cradle of nylon is strung *loosely* around and across the funnel.
- The PVC fittings are all thoroughly cleaned and rinsed with distilled water.
- The thickness of the silicon oil layer must be at least 20 mm to prevent evaporation. Oil can be obtained from photocopying suppliers. Silicon oil sold under the brand name 'Nashua' has been shown to be chloride-free.
- A table-tennis ball is placed in the throat of the funnel to further reduce evaporation.
- Firmly fix the collector vertically to a pole in the open with no overhead trees, branches, scaffolding, roofs, etc within a 45° elevation. The rain funnel should be about 1.5 m above ground to prevent splashing into the funnel.
- Extreme care must be taken not to allow any contamination of the collector during the transport and installation, e.g. from sweaty hands or droplets of sweat from the foreheads of field personnel. Any added chloride will cause the recharge to be over-estimated.
- Leave for a year. Collect and measure the volume of the collected water to obtain the annual rainfall. Collect a sample for chemistry and isotope analysis.
- The sample collection bottles in which the samples are collected must be thoroughly cleaned, rinsed with distilled water and then with sample water.

- It is prudent to install pairs of CRCs, just in case one sample gets lost or is spoiled by bird droppings.
- It is very important that great care is taken not to add any chloride during the CRC installation, during sample collection or any other phase, as this will affect the eventual calculation of recharge.

CRC-V2

A variation on the theme is the CRC-V2, which also collects a rain sample in the same manner but has a millimetre sight-tube attached. The well-field management CRC-V2 has a sight tube attached, so that the cumulative rain at any stage can be recorded without having to open the collector. In order to provide a one-to-one reading where 1 mm of sight tube reading equals 1 mm of rainfall the inner area of the funnel must be equal to the inner area of the PVC tube plus the sight tube. The specification for the uPVC tube is ISO4422 Class 12 OD 140 mm and the sight-tube is 7.5 mm diameter (standard supply from laboratory suppliers). This combination will result in an under-reading of rainfall of 0.08%. This error is negligible and can be disregarded. The purpose of the sight-tube is that the cumulative rainfall quantity can also be recorded when measuring borehole water-levels, thus allowing a comparison of rainfall with the groundwater table through the course of the season. CRC-V2s were installed at two rural villages in the Eastern Cape and Mpumalanga and they have been valuable in demonstrating the relation between rain events and water-table fluctuations, i.e. recharge to the aquifer. CRC-V2 thus also serves as an education tool.

The silicon oil layer

An essential feature of a CRC is a layer of oil inside the collector, which prevents evaporation of the collected rainfall. This ensures that both the salinity and the isotope content of the water sample does not change due to evaporation during the year-long sampling period.

A controlled experiment to test the efficiency of the silicon layer was carried out. Two CRC's, one with a 13 mm silicon oil layer (220mm water height) and the other without oil (156mm water height) were placed on the roof at the CSIR laboratory in Stellenbosch. To prevent rain from entering, a "roof" was installed covering the funnel. Stellenbosch river water with added NaCl was used to fill the collectors. Samples were collected at two-month intervals for just over a year and, with control samples, were analysed for Cl and ¹⁸O (Table 1).

Some minor evaporation occurred from the CRC with oil, as is shown by the slight but steady increase of δ¹⁸O of 0.72‰. Chloride does not appear to change if compared to the analysis for the control samples. In comparison, the CRC without oil

Elapsed time (d)	Date	With oil		Without oil		Control	
		Cl (mg/ℓ)	δ ¹⁸ O ‰	Cl (mg/ℓ)	δ ¹⁸ O ‰	Cl (mg/ℓ)	δ ¹⁸ O ‰
Start	01.08.95	86	-3.98	86	-3.98	86	-3.98
66	12.10.95	83	-3.93	85	-3.78	86	-
118	01.12.95	85	-3.87	88	-3.29	85	-
180	01.02.96	86	-3.73	91	-2.80	86	-
261	22.04.96	83	-3.58	94	-2.07	83	-
389	28.08.96	83	-3.26	97	-1.71	82	-3.99

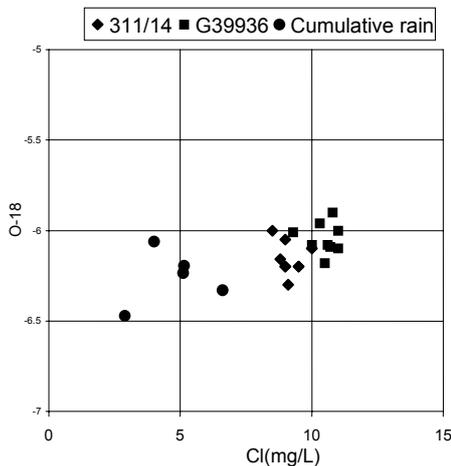


Figure 2
Chloride and $\delta^{18}\text{O}$ from CRCs and mountain boreholes G39936 and 311/14 in Agter Witzenberg

showed changes in both parameters: chloride increased by 13% and $\delta^{18}\text{O}$ changed by 2.3‰.

The layer of oil for the CRC in our experiment was 13 mm thick. This resulted in an enrichment of 0.25‰ over 6 months, which was during the hot dry Cape summer period. The second 6-month period resulted in an 0.47‰ shift. Scholl et al. (1996) used an 8 mm hydrocarbon oil layer in a similar CRC set-up and found no significant enrichment of $\delta^{18}\text{O}$ over a six-month period. The volume of water in the CRC also affects the effect of evaporation, i.e. the surface area is the same but with a smaller volume the effect on chloride and isotope composition is accentuated. Thus the following precautions should be taken to reduce the effects of evaporation:

- Have at least 20 mm of silicon oil, which floats on water. That amounts to 400 ml of oil in a standard CRC.
- Place a table tennis ball in the funnel mouth to reduce evaporation.
- If rain falls during one season, then install the CRCs at the start of the dry season and collect at the end of the rainy season, thus ensuring that dry deposition is also collected. Dry deposition is part of the total chloride input as recharge and can be equal to the wet deposition (Selaolo, 1998; Sami, 2003).
- Cover the PVC tube with silvered insulation to reduce temperature.

Results of CRC field studies

A number of studies by the authors demonstrate the use of CRCs in hydrogeological studies. These were done in the Western Cape region and compared CMB recharge data with recharge data determined by other methods. Since this locality is far from arid, it is not suitable for using the D-displacement method.

Agter-Witzenberg, W Cape

Weaver et al. (1999) carried out an investigation of geochemistry and isotopes in the fractured rock aquifers of the quartzites of the Table Mountain Group (TMG). Five pairs of CRCs were installed over a 4 km profile stretching from the relatively flat

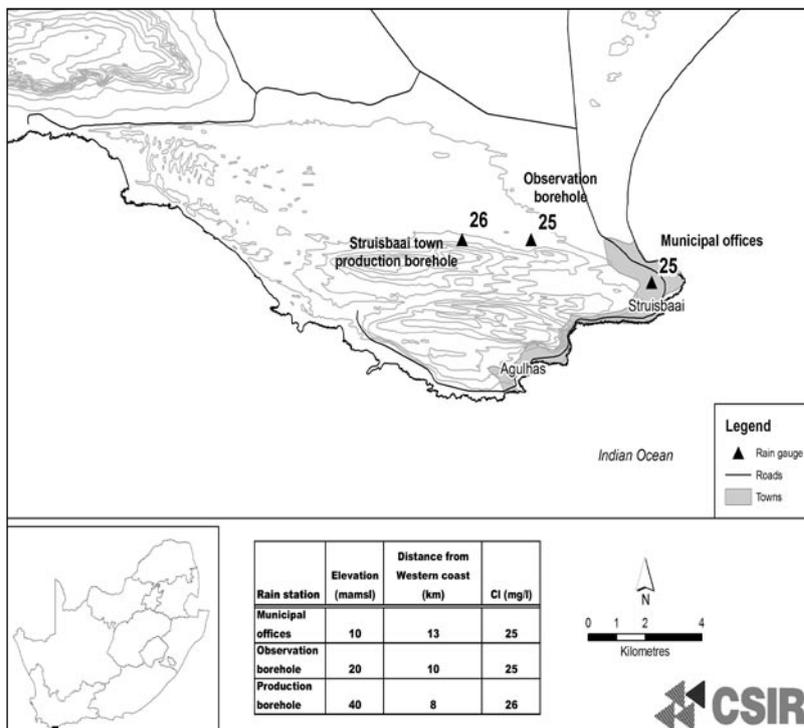
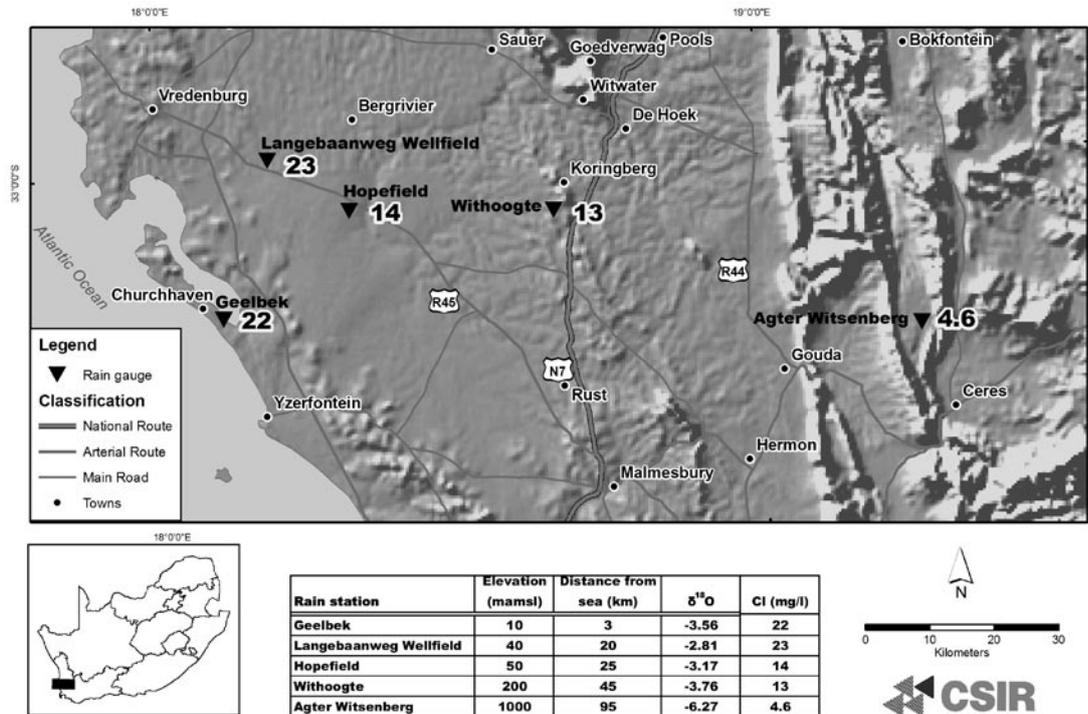


Figure 3
Map showing rain collector stations and chloride values for seasons September 1999 to September 2000 in Struisbaai

valley floor (elevation 900 m a.m.s.l.) eastwards into the mountain pass (elevation 1 070 m a.m.s.l.). Chloride and ^{18}O in the rainfall correlated well with each other, showing little effect of topography. Rain volumes were very similar, being 600 to 700 mm for the 1995 winter. Chloride value ranged from 2.5 mg/l to 6.6 mg/l, with the median being 4.2 mg/l. One outlier of 11 mg/l had other indicators of contamination and was excluded. A shallow borehole (G39936) was drilled at the summit of the pass and groundwater obtained from this borehole was regarded as newly recharged water. This borehole was sampled 10 times over a period of 37 months, and the measured chloride ranged from 8.5 mg/l to 10.0 mg/l with the average being 9.2 mg/l. A second borehole (311/14 of Fig. 2) at the base of the mountains was also sampled. This borehole was sampled 9 times over a period of 27 months, and the chloride content ranged from 9.3 mg/l to 11.0 mg/l, the average being 10.5 mg/l. Comparing this groundwater to CRC rainwater (Fig. 2) it is seen that little evaporation prior to recharge has occurred as $\delta^{18}\text{O}$ has been enriched by 0.23‰.

The chloride level increased from 4.6 mg/l in the rain to 10.5 mg/l in groundwater at the base of the mountain. This suggests groundwater recharge of 44% of mean annual rainfall at this locality. If one uses the median rainfall chloride of 4.2 mg/l the recharge could be 40% to 46%. Of the 10 CRCs, the lowest chloride at 2.5 mg/l, is from one of the pair of CRCs at the top of the mountain. Using this value the recharge is calculated to be 24% to 27%. For groundwater resource evaluation this is an important number. Hartnady and Hay (2002), using GIS modelling techniques applied to the Citrusdal area to the north of Agter-Witzenberg, have speculated that recharge to TMG quartzites in areas with elevations above 1 500 m a.m.s.l. could be in the range of 30% to 40%. These values should be regarded with caution, and should be taken to be upper maximum values. There

Figure 4
Map showing rain collector stations and chloride values for the season January 1999 to January 2000 in the West Coast, Langebaan transect



are two mechanisms that could be applied to explain such high values. The TMG quartzites are fractured with a thin coarse sand cover and the low groundwater chloride could be attributed to rapid recharge along these fractures. Another mechanism could be rapid recharge followed by equally rapid discharge via shallower pathways, and thus loss of the recharged water to surface flow, resulting in a lower effective recharge.

Values of 15 to 20% for recharge are generally used for TMG resource evaluation. This means that the delineation of high and low recharge areas needs to be done thoroughly in order to ensure that sustainable resources in the TMG are correctly estimated. This case example is a good demonstration of the need to carry out an independent estimation of recharge and not rely solely on one method.

Struisbaai, W Cape

Three collectors were installed in Struisbaai in 1999 (Fig. 3). The consistent chloride results obtained are an indication of the reproducibility of the CRCs. The prevailing winter rains are from the west, which might explain the slightly higher value for the most westerly CRC, i.e. some rain-out has occurred. However, the difference of chloride value is so small that it can be ignored.

During a previous investigation, Weaver (1998) had installed two large-volume rain collectors. Samples had been planned for collection after each rainstorm, but this was not satisfactorily done. The samples that were collected were analysed for major determinants and the concentration was related and weighted to recorded amounts of rainfall. Chloride was calculated to be 31 mg/l and 23.1 mg/l for these two collectors, averaging 27 mg/l. This value is very close to the 25.3 mg/l average of the three CRCs that were installed later.

Regular sampling (5 times over a period of 14 months) of the two main production boreholes (P2 and P3) gave chloride values ranging from 138 to 153 mg/l, average 144 mg/l. Relating the chloride in rain from the CRCs to the groundwater gives a recharge percentage of 17.4%.

West Coast: Langebaan towards Agter-Witzenberg

Four CRCs were installed along a 50 km transect from Langebaan on the West Coast eastwards to Moorreesburg (Fig. 4). Data from Agter-Witzenberg (100 km further inland) can be used for comparison. The data show a decrease of chloride from 22 mg/l at the coast, through 14 mg/l at the Langebaan Road Wellfield (LRW), 13 mg/l at Withoogte to 4.6 mg/l at Agter-Witzenberg (Table 2). Note also the reasonably similar ^{18}O values for the flat coastal area, a slight depletion inland at Withoogte, and a significant depletion at Agter-Witzenberg. This area receives winter rainfall, with cold fronts arriving from a westerly direction from the Atlantic Ocean. Both chloride and ^{18}O show the rain-out and continental effect.

The Langebaan Road Wellfield (LRW: 20 km inland of Langebaan) is currently delivering 50 l/s for 24 h/d (4 320 m³/d) (Weaver and Fraser, 1998). The siting of the wellfield was based on the extensive exploration of the regional area carried out by DWAF (Timmerman, 1985a; 1985b). Recharge was not determined during this study. Timmerman used a figure of 16% recharge, which had been estimated for the Atlantis Aquifer, a similar aquifer about 75 km to the south. Du Toit and Weaver (1995) conducted a groundwater investigation at the Saldanha Steel Plant, about 10 km north of Saldanha. They calculated a recharge of 8% from water level data from boreholes on the adjacent property, Namaqua Sands. At Saldanha Steel, using reverse modelling techniques, they calculated 12% for recharge.

The hydrogeology at LRW consists of an upper unconfined aquifer and a lower confined aquifer. The current conceptual model has the recharge zone for the upper aquifer being local, and for the lower confined aquifer it is a zone about 10 to 20 km in a south-easterly direction towards Hopefield (Timmerman, 1985a;b; Weaver and Fraser, 1998). Two sampling runs have been made of monitoring boreholes and both chemistry and isotopes have been measured (Weaver and Talma, 2000). Table 2 shows the relevant chloride and ^{18}O data. Using this data, recharge in this area is estimated at 9.7% to 13.5% using the CMB method.

TABLE 2
Langebaan Road Wellfield - Comparison of chloride and ¹⁸O data for rain and groundwater and calculation of recharge percentages using the CMB method

Site	Chloride (mg/l)	δ ¹⁸ O (‰)	Recharge (%)
CRC – LRW	23	-2.8	-
CRC – Hopefield	14	-3.2	-
LRW – Upper aquifer	237	-3.5	9.7
LRW – Lower aquifer	125	-3.7	11.2
LRW- Hopefield recharge zone – upper aquifer	104	-3.6	13.5
LRW- Hopefield recharge zone – lower aquifer	122	-3.6	11.5

TABLE 3
Vermaaks River Wellfield - Comparison of chloride and ¹⁸O data for rainfall and groundwater and calculation of recharge percentage

Site	Chloride (mg/l)	δ ¹⁸ O (‰)	Recharge (%)
CRC – Wildebeesvlakte (Recharge zone)	1	-6.6	-
CRC – Vermaaks River wellfield (discharge zone)	1	-5.3	-
Boreholes VR 6, 7, 8 & 11	19-23	-7.2	5%
CMB method: Kotze (2000) cited by Parson (2002)	-	-	11.1%

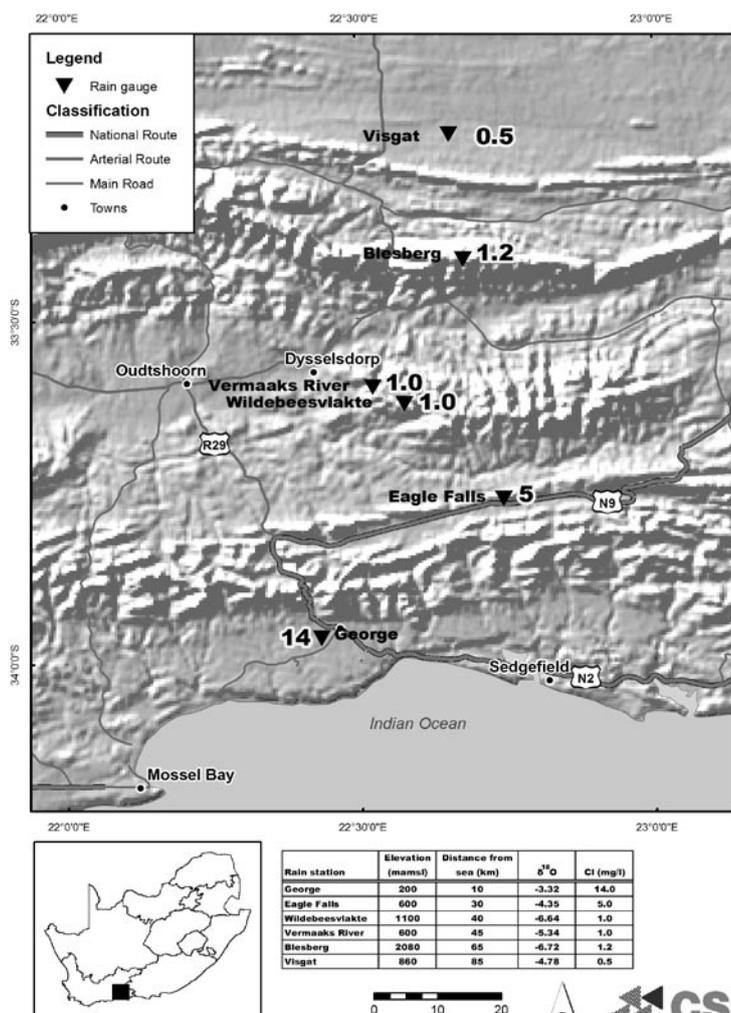


Figure 5

Map showing rain collector stations, ¹⁸O and chloride values for the seasons April 1999 to April 2000 along the South Coast, George to Dysveldorp transect

It has been postulated that groundwater in the lower aquifer at LRW is recharged from groundwater deriving in the high mountains of the TMG further inland. This water would then flow westwards via deep circulation towards the Atlantic coast and leak upwards into the coastal aquifers. If this were so, the ¹⁸O signal of this deep-circulation water would reflect rain from the recharge zone. Agter-Witzenberg rain would be representative of these high mountains and has δ¹⁸O of -6.3‰ (Weaver et al., 1999) while LRW groundwater is -3.6‰ (Weaver and Talma, 2000). The similarity of ¹⁸O in LRW aquifer (both upper and lower aquifers) to local rain, collected in the CRCs, and the large ¹⁸O difference between mountain and coastal rain leads one to reject this TMG recharge hypothesis.

South Coast: George to Swartberg Mountains

Six CRCs were installed along a transect from George along the South Coast to the Vermaaks River wellfield of the Klein Karoo and into the Groot Karoo at Visgat (Fig. 5). This transect shows high chloride of 14 mg/l close to the coast, at a monitoring site 30 km inland, decreasing to 5 mg/l, and low values further inland. The continental and elevation depletion effects of ¹⁸O can also be seen, with -3.3‰ at the coast (200m a.m.s.l.) to -4.8‰ at Visgat (80 km inland at 860m a.m.s.l.) and the low values of -6.6‰ and -6.7‰ for the two collectors installed at the top of high mountains, Wildebeesvlakte (1 100 m a.m.s.l.) and Blesberg (2 080 m a.m.s.l.).

A number of boreholes have been drilled in and around the Vermaaks River, which provide water for the Klein Karoo Rural Water Scheme. Kotze (2000) and Kotze et al. (2000) investigated recharge in the Kamanassie Mountains in order to develop a management model for the wellfield in the Vermaaks

River. Six methods were used to estimate recharge to the Peninsula Formation giving recharge values ranging from 23.9% to 11.1%. The chloride mass balance method used by Kotze (2000) gave 11.1%.

Weaver and Talma (1999) carried out isotope, chlorofluorocarbon (CFC) and chemistry sampling in the Vermaak's River Wellfield. Four boreholes in the Peninsula Formation were sampled and the results are compared to the CRC data in Table 3.

Woodford (2000) used data from KKRWS and compared "safe-yields" from borehole aquifer tests with other methods of calculating sustainable yields. Kotze (2000) had calculated the yield to be 452 600 m³/a using 14% recharge. Woodford (2000) using GIS methods (not fully described) obtained 250 000 to 450 000 m³/a. The data from these CRCs indicate 5% recharge to the Peninsula Formation, and suggest that further long-term monitoring is needed to gain more confidence regarding the sustainable yield.

Conclusion and recommendations

- The cumulative rainfall collector (CRC) is an inexpensive tool capable of yielding valuable information for groundwater investigations regarding the chemical and isotopic signature of rainfall and thus the recharge rates to our aquifers.
- CRCs need to be installed on a national network to obtain the isotopic and chemical rainfall signature country-wide.
- We recommend that a formal and official database be maintained centrally, preferably by DWAF. Until such time as this has been established, we request producers of rainfall chemistry and isotope data to send them to the database established at the University of the Western Cape wherefrom the data will be available to all researchers. Users are requested to provide the following information: Collector and institution, latitude, longitude and elevation, period of monitoring, total rainfall measured over the monitoring period, chloride, deuterium and ¹⁸O results. Laboratory name, instrument used for analysis and detection limits for chloride should also be supplied.
- The collectors used in the above experiments were constructed from uPVC (UV-light protected polyvinyl chloride). uPVC has the potential to leach chloride (Adams, 2002). A small increase in the chloride level measured in the rain sample will lead to an over-estimation of recharge, especially in low-chloride environments typically found inland. Our current design uses a length of stainless steel pipe inserted inside the PVC. This method will be effective in preventing contact of the collected rain with PVC. However, the cost, at R2 500 per collector, is substantially higher than the R600 for the original design. The authors have made arrangements with a manufacturer in Stellenbosch who can produce CRCs with the stainless steel inserts.
- This design could be improved upon in order to reduce production costs. More research is needed in order to identify a suitable material which will not add to the chloride in the collected rain sample and which is inexpensive.
- A proper handling and installation protocol must be adhered to in order to prevent inadvertent contamination that will lead to elevated chloride in the collected rainwater and thus overestimated recharge.
- Most water analytical laboratories are not set up to accurately determine chloride below 5 mg/l or with a precision of less than 0.5 mg/l routinely. The researcher must therefore ensure that the laboratory chosen to carry out the analyses is both able and willing to analyse to below 0.5 mg/l with

an accuracy of at least 0.1 mg/l. Beekman and Sunguro (2002) recommend sending duplicate samples to at least two reputable laboratories, and that the detection limit should be less than 0.05 mg/l. We currently use the Air Quality Laboratory at the CSIR in Pretoria (Shirley McCormick). They are able to determine chloride reliably and accurately to 0.05 mg/l.

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References

- ADAMS S (2002) Bulk rainfall samplers and groundwater recharge. In: *Tales of a Hidden Treasure. Proc. Conf. Geol. Soc. S. Afr.* Western Cape Branch, Groundwater Division, Geological Society of South Africa, 16 September 2002.
- ALLISON GB, GEE GW and TYLER SW (1994) Vadose-zone techniques for estimating groundwater recharge in arid and semi-arid regions. *Soil Sci. Soc. Am. J.* **58** 6-14.
- BAZUHAIR AS and WOOD WW (1996) Chloride mass-balance method for estimating ground water recharge in arid areas: examples from western Saudi Arabia. *J. Hydrol.* **186** 153-159
- BEEKMAN HE and SUNGURO S (2002) Groundwater recharge estimation – Suitability and reliability of three types of rain gauges for monitoring chloride deposition. In: *Tales of a Hidden Treasure. Proc. Conf. Geol. Soc. S. Afr.* Western Cape Branch, Groundwater Division, Geological Society of South Africa. 16 September 2002.
- BEEKMAN HE and XU Y (2003) Review of groundwater recharge estimation in arid and semi-arid Southern Africa. In: Xu Y and Beekman HE (eds.) *Groundwater Recharge Estimation in Southern Africa*. UNESCO IHP Series No. 64. 207 pp.
- COOK PG (2003) *A Guide to Regional Groundwater Flow in Fractured Rock Aquifers*. CSIRO-Seaview Press, South Australia. ISBN 1740082338. 108 pp..
- DIAMOND RE and HARRIS C (1997) Oxygen and hydrogen isotope composition of Western Cape meteoric water. *S Afr. J. Sci.* **93** (8) 371-374.
- DWA (2002) Tsabong Groundwater Resources Investigation, Assessment and Development, Technical Report 6: Hydrochemistry and Isotopes. Report TB10/3/24/98-99 to the Department of Water Affairs, Gaborone, Botswana.
- DU TOIT IM and WEAVER JMC (1995) Saldanha Steel Project: Groundwater Investigations. Consulting Report to Saldanha Steel and Bechtel-LTA. CSIR Report No 27/95 WF034, CSIR, Stellenbosch.
- ERIKSSON E and KHUNAKASEM V (1969) Chloride concentration in groundwater, recharge rate and rate of deposition of chloride in the Israel coastal plain. *J. Hydrol.* **7** 178-197.
- FRIEDMAN I, SMITH GI, GLEASON JD, WARDEN A and HARRIS JM (1992) Stable isotope composition of waters in south-eastern California: 1 Modern precipitation. *J. Geophys. Res.* **97** (D5) 5795-5812.
- HARTNADY CJH and HAY ER (2002) Towards "map-centric" simulation modelling of Table Mountain Recharge. In: Pietersen K and Parsons R (eds.) *A Synthesis of the Hydrogeology of the Table Mountain Group*. WRC Report No TT 158/01, Water Research Commission.

- IAEA-GNIP (2004) *Global Network of Isotopes in Precipitation*. International Atomic Energy Agency, Vienna. URL: <http://isohis.iaea.org/>. Accessed in October 2004.
- KOTZE JC (2000) Hydrogeology of the Table Mountain Group aquifer in the Little Karoo. Unpublished Ph.D. Thesis, University of Orange Free State.
- KOTZE JC, VERHAGEN BTh and BUTLER MJ (2000) An aquifer model based on chemistry, isotopes and lineament mapping: Little Karoo, South Africa. In: Sililo O (ed.) *Proc. IAH Conf. Cape Town*. Nov 2000. 539-544.
- MEYER R, TALMA AS, DUVENHAGE AWA, EGLINGTON BM, TALJAARD J, BOTHA JF, VERWEY J and VAN DER VOORT I (2001) Geohydrological Investigation and Evaluation of the Zululand Coastal Aquifer. WRC Report No 221/1/01. Water Research Commission, Pretoria. 51 pp.
- PARSONS R (2002) Recharge of Table Mountain Group Aquifer systems. In: K Pietersen and R Parsons (eds.) *A Synthesis of the Hydrogeology of the TMG*. WRC Report No TT 158/01, Water Research Commission.
- SAMI K (2003) A comparison of recharge estimates in a Karoo aquifer from a chloride mass balance in groundwater and an integrated surface-subsurface model. In: Xu Y and Beekman HE (eds.) *Groundwater Recharge Estimation in Southern Africa*. UNESCO IHP Series No. 64. 207 pp.
- SCHOLL MA, INGEBRITSEN SE, JANIK CJ and KAUAHIKUAU JP (1996) Use of precipitation and groundwater isotopes to interpret regional hydrology on a tropical volcanic island: Kilauea Volcano area, Hawaii. *Water Resour. Res.* **32** (12) 3523-3537.
- SELAOLO ET (1998) Tracer Studies and Groundwater Recharge Assessment in the Eastern Fringe of the Botswana Kalahari – The Lethlakeng-Botlapatlou Area. Unpublished Ph.D. Thesis, Free University, Amsterdam. 224 pp.
- TIMMERMAN L (1985a) Preliminary Report on the Geohydrology of the Langebaan Road and Elandsfontein Aquifer Units in the Lower Berg River Region. Report GH3374, Department of Water Affairs, South Africa.
- TIMMERMAN L (1985b) Regional Hydrogeological Study of the Lower Berg River Area, Cape Province, South Africa. Ph.D. Thesis, State University of Ghent, Belgium.
- VAN TONDER GJ and XU Y (2000) *Recharge – Excel-Based Software to Quantify Recharge*. Dept of Water Affairs and Forestry, Pretoria, Unpublished software.
- VAN TONDER GJ and BEAN J (2003) Challenges in estimating groundwater recharge. In Xu Y and Beekman HE (eds.) *Groundwater Recharge Estimation in Southern Africa*. UNESCO IHP Series No. 64. 207 pp.
- WEAVER JMC (1998) Salinity in the Struisbaai Aquifer. M.Sc. Thesis, University of the Orange Free State. Also reproduced in Weaver et al. (1999), cited below.
- WEAVER JMC, TALMA AS and CAVÈ LC (1999) Geochemistry and Isotopes for Resource Evaluation in the Fractured Rock Aquifers of the Table Mountain Group. WRC Report No 481/1/99, Water Research Commission, Pretoria, South Africa.
- WEAVER JMC and TALMA AS (1999) Field Studies of Chlorofluorocarbons (CFCs) as a Groundwater Dating Tool in Fractured Rock Aquifers. WRC Report No 731/1/99, Water Research Commission, Pretoria.
- WEAVER JMC and TALMA AS (2000) Langebaan Road Wellfield: Isotope data from the new boreholes: CSIR report to Geohydrology. Department of Water Affairs and Forestry. Report No ENV-S-C 2000-082, CSIR, Stellenbosch.
- WEAVER JMC and FRASER L (1998) Drilling and Testing of a New Wellfield. Consulting report to West-Coast District Council. CSIR Report No ENV-S-C 98-042, CSIR, Stellenbosch.
- WOOD WW (1999) Use and misuse of the chloride mass balance method in estimating groundwater recharge. *Ground Water* **37** (1) 2-3.
- WOOD WW and SANFORD WE (1995) Chemical and isotopic methods for quantifying groundwater recharge in a regional semi-arid environment. *Ground Water* **33** (3) 458-468.
- WOODFORD A (2000) Interpretation and applicability of pumping-tests in the Table Mountain Group aquifers. In: Pietersen K and Parsons R (eds.) *A Synthesis of the Hydrogeology of the TMG*. WRC Report No TT 158/01, Water Research Commission.