



Baseflow estimation using streamflow hydrograph data in South Africa

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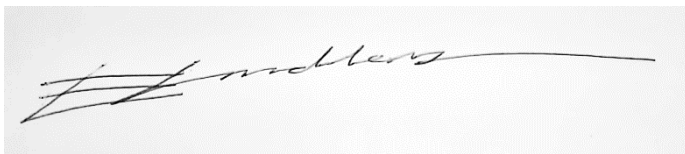
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Graduation: July 2024

Declaration

I, Eddie Landsberg, hereby declare that this dissertation titled “**Baseflow estimation using streamflow hydrograph data in South Africa**” is my own work and that the views and opinions expressed in this research study are my own. This includes all relevant literature references, as seen in the reference list.

Furthermore, all content of this research study will only be submitted for this qualification and not any other qualification at any other tertiary institution.

A handwritten signature in black ink, appearing to read 'E. Landsberg', with a long horizontal flourish extending to the right.

Eddie Landsberg

May 2024

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Abstract

Title:

Baseflow estimation using streamflow hydrograph data in South Africa

Keywords:

Baseflow, Streamflow, Hydrograph, Groundwater, HYSEP, RDF, Herold, RCD, Smakhtin.

The reason we have perennial rivers running all seasons of the year is mainly due to baseflow. Baseflow can be defined as a groundwater contributing factor that sustains perennial rivers. Baseflow can be estimated through various methods such as hydrograph separation (HYSEP), recursive digital filter (RDF), Herold, recession curve displacement (RCD), Smakhtin low flow, United Kingdom Institute of Hydrology (UKIH), and tracer tests. Baseflow is a very important factor in relation to environmental impact assessment (EIA) studies, hydrological sustainability, and ecological reserve, however its estimation is limited. Tracer tests are considered the most accurate estimation of baseflow, but are not used frequently due to the time, effort, and money involved. Due to the limited research on the applicability of the above methods in a South African context, this research study's objective was to establish an estimation method built from the advantages of existing methods with tracer test results as a benchmark.

Learning from these existing methods, a newly proposed baseflow estimation method, namely, the South African Baseflow Estimation Method (SABEM) is introduced in this dissertation. This method makes use of readily available hydrograph data from the Department of Water and Sanitation through a Python scripted data scraper. By leveraging the advantages of established methods and incorporating a foundation established through tracer studies, the parameters of the SABEM were calibrated with parameters identified by existing methods proven to have direct impact on baseflow. The designated study areas are adequately broad and tailored to cover various South African geohydrological regions. They are distinct enough to include diverse parameters, ensuring calibration extends across the spectrum of South Africa's geological and hydrological features. Therefore, specific parameters were identified for upper and lower spectrums emphasising the quality of parameters rather than quantity of case studies. Lastly, the areas also required existing studies of tracer tests on baseflow to be sufficient. Study areas across South Africa combining various and unique characteristics were selected at the following flow-gauging stations: G1H043, T3H009, V1H010, X2H008, X2H010, X2H022, and X2H031. For SABEM

to accurately and successfully estimate baseflow, it was crucial for the characteristics of all study areas to exhibit a directional linearity with SABEM parameters. This necessitated running all study areas in parallel through the SABEM calibration process to obtain equal baseflow estimations to that of the case study tracer results for baseflow, creating a directly proportional system to encompass all catchment characteristics across South Africa. Thus, the characteristics of South African catchments can serve as a basis for baseflow estimation, given that the parameters demonstrate directional proportionality with tracer results for baseflow. The tool underwent development and calibration through multiple iterations, ensuring the parameters became directly proportional to the catchment characteristics within these areas and aligned with the tracer study findings. Later, the tool was effectively applied in a test case within the verification catchment area, where tracer study results were absent, and the area wasn't among the initial study areas.

The outcomes indicated an accurately estimated baseflow, asserting the applicability of SABEM to diverse catchments with varying characteristics across South Africa (SA), yielding reliable results without the need for tracers. Catchments characteristics included catchment size, groundwater occurrence, and groundwater gradient towards rivers. This means that the SABEM is applicable to other catchment areas besides those used in the study. One of the four catchment parameters, namely, hydraulic conductivity, when calibrated to SABEM parameters was found be negligibly small (0.014 K). For this reason, hydraulic conductivity could not be calibrated completely linear to the parameters and therefore can be used in addition to SABEM according to user preference as it is found to be a very sensitive parameter for catchments. The SABEM estimation method can be utilised in a variety of South African contexts and can be incorporated into EIAs, hydrological and ecological reserve studies with confidence without requiring the use of tracer tests.

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List of acronyms

ASCII	American Standard Code for Information Interchange
BFI	Baseflow Index
CSV	Comma Separated Values
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
EMMA	Environmental Mitigation Management and Assessment
EWMA	Environmental Waste Management
HTML	Hyper Text Markup Language
HYMAS	Hydrological Modelling Application Software
HYSEP	Hydrograph Separation
IHACRES	Identification of Unit Hydrographs And Component flows from Rainfall and Streamflow data
MRC	Master Recession Curve
NGA	National Groundwater Database
RCD	Recession Curve Displacement
RDF	Recursive Digital Filtering
SABEM	South African Baseflow Estimation Method
SQL	Structured Query Language
UKIH	United Kingdom Institute of Hydrology
URL	Uniform Resource Locator
WATSTORE	Water Data Storage and Retrieval System Technology
WDM	Watershed Data Management



1.1 Background

One of the main contributing factors to river sustainability is baseflow, which in simple terms is the contribution which groundwater makes to streamflow. Baseflow estimation methods include a wide variety of algorithms, equations, and tracer studies. The accuracy of most baseflow methods has been tested using other well established baseflow methods to verify their findings. If both new and established methods are biased in the same way the comparison is sound, it's a principle of accuracy and precision (bias), hence comparison to alternative and different methods should be assessed. In comparison to streamflow data, observed baseflow data do not exist. Consequently, tracers are considered the most accurate to measure baseflow, but this method is not frequently used due to the time, effort, and costs involved (Brunner and Simmons, 2012; Chapman, 1999; Leopold *et al.*, 1995). The accuracy of the existing methods which are mostly mathematical approaches, are subjective in a sense that they are not incorrect in themselves but are not considerate of the nature and physical characteristics that define baseflow. However, to formulate a new equation, validation and verification are required from these well-established methods. In order to make the estimation of baseflow as accurate as possible, it should preferably be verified against tracer studies which incorporate accurate measurements (Alley and Leake, 2004; Boulton, 2003). Tracer studies provide the most realistic estimates of baseflow; therefore, this is arguably the most accurate form of measuring groundwater flow or in this case baseflow. To do that, concentration of a tracer over time is measured from a borehole to a downstream river mark to get a representation of baseflow. Thus, a newly proposed method from valuable insights of existing literature can be developed against accurate tracers and well-established methods for enhanced accuracy.

1.2 Problem statement

Numerous baseflow estimation methods exist worldwide. These methods generally aim to estimate baseflow from observed streamflow data, and each is unique in relation to a case or specific site. These methods have been compared and verified alongside each other in several studies, but no single method has been found to be suitable for all sites or studies. All these methods are different and relate to their own data inputs and graph selections which then influence the estimation (Smakhtin, 2001; Rouhani and Malekian, 2013).

Baseflow in South Africa is not yet tied to a single characteristic or estimation method. It is a dynamic concept due to the great variability of the country's hydrological characteristics pertaining to hydrology (Smakhtin and Toulouse, 1998). Existing methods range from complex numerical modelling to subjective curve-fitting methods that only require a hydrograph. A reliable baseflow method is necessary to accommodate South African catchments that will be acceptable from both a hydrological and geohydrological point of view. Hydrological variability, therefore, should be used as an advantage.

A baseflow estimation method suitable for South Africa needs to be implemented at a smaller, quaternary catchment scale. This method should be diverse and flexible enough to accurately capture the unique characteristics of each catchment and yield results proportional to them. Consequently, it becomes necessary to quantify the physical parameters associated with these catchments (Smakhtin and Watkins, 1997).

1.3 Research question

How can a South African-specific baseflow estimation method be developed by integrating insights from existing methodologies, leveraging verification of baseflow numbers through tracer studies, and integrating seamless observed streamflow data from the national hydrological database?

This dissertation aimed to address the challenge of estimating baseflow in South African catchments. By examining existing baseflow estimation methods and their applicability and strengths or advantages, the research sought to identify insights and best techniques. Additionally, the study aims to leverage the national hydrological database to access comprehensive sets of observed streamflow data for refinement of the newly developed methodology.

1.4 Aims and objectives

This study aimed to develop a baseflow estimation technique that is acceptable from both a hydrological and geohydrological perspective that will yield reliable results that are adapted to South African conditions.

The specific objectives for this study are as follows:

- Acquire observed streamflow data from hydrologically diverse catchments across South Africa to ensure comprehensive and representative analysis. Automated data scrapping into a personalised and filtered database to ensure ease of use and applicability of data gathered.

- Conduct a thorough review of existing baseflow estimation methods, summarizing their data requirements, complexity, advantages, and disadvantages to inform development of a new method.
- Formulate a new baseflow estimation method by integrating the strengths and insights derived from existing literature and methodologies, ensuring it is well-suited to the specific hydrological context found in South Africa.
- Integrate the developed database seamlessly into a toolkit or interface, allowing the proposed method to be applied to the collected streamflow data and visualise hydrographs of baseflow and streamflow.
- Test the newly developed methodology against range of established methodologies to verify its capability and reliability in estimating baseflow values, thereby ensuring its validity for practical application, test all researched and developed methodologies against existing tracer studies.
- Obtain a comprehensive collection of Tracer estimated baseflow studies across South African catchments, in order to perform a verification in percentage baseflow and comparison of the proposed and existing methods.

1.5 Hypotheses, limitations, and assumptions

Prior to conducting the study, several anticipated constraints, and assumptions regarding the proposed methodology have been hypothesised. These considerations highlight potential limitations, uncertainties, and simplifications that may impact the analysis. Additionally, the study limitations, which may affect the overall validity and value of the research, are included here.

- Streamflow and tracer test data mismatch: Due to different record-keeping periods, the streamflow data does not align with the tracer test data in all case studies. It is assumed that tracer study results are still valid regardless of timing and can be applied to similar hydrological cycles to conditions of the year it was taken.
- Short Duration of Tracer Studies: Tracer analyses are conducted over short periods (approximately one month or less). It is assumed that this short duration adequately represents the baseflow response of the catchment system.
- Hydraulic conductivity estimates: Hydraulic conductivity values are selected from South African-specific charts based on average geology within the catchment. These values may lack precision but are assumed to limit overall accuracy of the results until exact measured values can be obtained and used.

- Limited data availability: The scarcity of tracer studies limits the method's parameter alignment to the entire range South African catchments. However, the methodology remains robust and spans the majority of the catchment property spectrum so if linear proportionality can be achieved it would mean that the properties form a direct correlation and other properties can successfully be inferred thus expanding the applicability and validity of the proposed methodology with limited studies.
- Groundwater contribution assumptions: Parameters are assumed to accurately represent groundwater contributions to baseflow, as discussed in the literature review.
- Aquifer and groundwater flow: Groundwater movement is inferred from borehole yields available on hydrogeological maps of South Africa.
- Consistency of catchment characteristics: Catchment characteristics are assumed to remain consistent over time, allowing the use of streamflow data not matching the time series data of tracer studies.
- Borehole water levels: Groundwater slopes inferred from borehole water levels are assumed to be the catchment average.

This method shows great promise for practical implementation and compatibility within the South African context. While the identified limitations present challenges, addressing these constraints will enhance the overall validity and value of the research, further validating and refining the SABEM method is very much possible. If successful the data scrapping script hypothesised should be able, with slight alterations, to automate any web-based interaction or data scrapping approach other than its intentions for in this study, can be applied in future studies elsewhere.

1.6 Dissertation outline

Chapter 1 introduces the study, providing background information, a problem statement, and the research aims and objectives, thus establishing the context for the dissertation. Chapter 2 presents a literature review, covering fundamental hydrology concepts such as hydrographs and river systems, followed by the definition and key concepts of baseflow. It reviews existing and well-established baseflow estimation methods, including hydrograph separation (HYSEP), recursive digital filtering (RDF), the Herold method, recession curve displacement (RCD), the Smakhtin low flow method, and the United Kingdom Institute of Hydrology (UKIH) method. Summarises their respective requirements, complexity, advantages, and disadvantages informing the formulation of Chapter 3. Which details the study's methodology, including data collection and sampling techniques, with a focus on Python scripting for an automated data scrapping and collection function. It also evaluates

the available tracer studies and description of study areas available for development of the methodology. Chapter 4 discusses the proposed methodologies verification through tracer test percentages and literature review method. The significant finding of catchment parameter-proportionality to South African catchment characteristics are also discussed here followed by the study's limitations and assumptions and finally its validation. Chapter 5 concludes the dissertation by summarizing key findings, discussing their implications, and offering recommendations for future research and practical applications based on the study's outcomes.

Chapter 2 Literature review

2.1 Introduction

The literature review describes river systems and hydrographs, and the various definitions of baseflow. The focus is on the various baseflow separation methods, particularly the six most common or frequently used methods in order to have the necessary background before comparing them.

2.2 Rivers and hydrographs

Watercourses are a complex hierarchical system of streams converging to form rivers, combining into larger watercourses, ultimately draining towards oceans or lakes. Rivers are known to have three components, as described by Le Maitre and Colvin (2018): the geological and geomorphological components (baseflow); the climate and hydrological components (surface runoff and flow); and the biological component.

Rivers are commonly classified into two types, namely, perennial, and ephemeral. Perennial rivers are rivers that sustain their flow through dry periods or winter seasons. Ephemeral rivers quickly respond to rainfall, drying up when there is no precipitation because there is no sustained flow from groundwater, which diminishes as it is not being replenished (Smakhtin and Watkins, 1997).

Both government and private sector entities engage in the continuous surveillance of watercourses. This monitoring is conducted with a multifaceted focus on economic considerations, water resource management, quantitative and qualitative assessments, as well as the judicious allocation of water. To achieve these objectives, a suite of hydraulic structures such as weirs and dams, along with technologically advanced flow meters, are employed. These instruments facilitate meticulous monitoring on temporal scales ranging from monthly to daily and, in certain instances, even hourly intervals. This data is then recorded in a database, and flows (m^3/s) are plotted against time (y/m/d/h/s) to form

streamflow hydrographs that account for all surface water runoff from the catchment at a determined point. It is important to note that groundwater may extend beyond catchment boundaries in deeper-lying aquifers (Freeze and Cherry, 1979).

2.2.1 Background

Streamflow and hydrographs are two important concepts in the field of hydrology. Streamflow refers to the volume of water that moves through a particular section of a river or stream per unit time, and hydrographs are graphs that depict the variation in streamflow over time. However, it is important to note that hydrographs are not always linked to streamflow in the sense that they can depict flows other than streamflows of rivers, such as urban storm water drainage systems or even groundwater variations over time (Maidment, 1993; Singh, 1998).

Streamflow can be influenced by a variety of factors such as precipitation, soil moisture, vegetation cover and land use. The movement of water through a river is primarily driven by the forces of gravity which cause water to flow from higher elevations to lower elevations. The rate of streamflow can be measured using various techniques such as stream gauges which measure the water level in order to calculate the flow rate, or tracer studies, which involve adding a substance to the water and measuring its movement downstream. The tracer method can be applied to boreholes to measure groundwater flow as well (Chow *et al.*, 1988).

2.2.2 Hydrographs

Hydrographs are commonly used in hydrology to illustrate the response of a river or stream to precipitation or other changes in hydrologic conditions. Hydrographs typically display two main components: a rising limb indicating increase in streamflow in response to precipitation or other inputs, and a falling limb which represents the decline in streamflow as the system returns to its baseflow conditions (Han, 2010; National Oceanic and Atmospheric Administration, 2023), as illustrated in Figure 1 which shows a simplistic hydrograph.

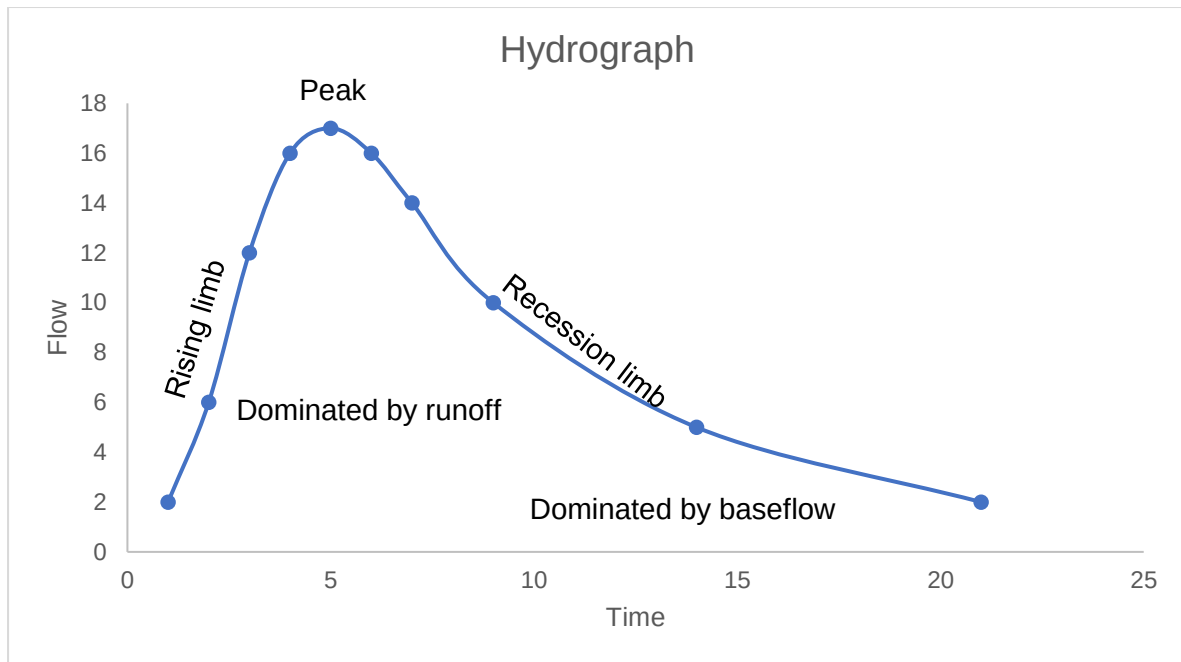


Figure 1: Simplistic streamflow hydrograph
Source: Han (2010)

Considerations regarding the streamflow data utilised for baseflow calculation include its reliability and quality, along with the presence of metadata explaining data quality. Additionally, it is important to inquire whether missing data or gaps in timeline are addressed through patching or interpolation, or if they are omitted entirely (Smakhtin and Watkins, 1997; Sloto and Crouse, 1996).

2.2.2.1 Flow Measurement Methods

One of the many flow measurements available for streamflow is that of a set structure built within a river, such as a weir structure. Weir structures can be calibrated to estimate the discharge or flow directly proportional to the rise in water level/stage relative to the weir structure. This can be manually read from the weir structure or electronic data loggers used to measure water levels. Data is simply recorded by hand or automated at the gauge plate or gauge weir, and a corresponding flow measurement in m^3/s or m^3/d is obtained from the weir structure rating table. An example of a stage discharge rating table is presented in Table 1. The rating table matrix in the given example indicates discharge in m^3 for 1 cm rise in water level. Discharge, in this case, is equal to the height of the measured water level parallel to the structure (cross-section) considering an exponent determined by the characteristics of the weir structure (already factored into the table) multiplied by a coefficient specific to the structure. Factors that can affect the rating table readings of streamflow discharge are as follows (Chow, 1959; Henderson, 1966; French, 2003):

1. The geometry of the structure such as shape, length, and crest elevation can influence the discharge relationship with the rating table by erosion of the structure or damage from floods etc.
2. Submergences of the weir structure, possibly due to floods where water level rises above the calibration point.
3. Accumulation of sediment or debris can easily affect the water level heights read from the weir structure and necessitates maintenance or adjustments to the rating table.
4. Temperature and viscosity can influence fluid dynamics at the weir structure.
5. Other factors such as instrumentation accuracy, conditions of the approach channels, and even alterations in channel morphology can affect discharge read from the structure using the rating table.

It is important to note these factors, as they could affect the data read from the calibrated conditions for the rating table. This could change because of one or multiple instances of these factors. Of course, weir structure integrity is kept at certain standards (Chow, 1959; Henderson, 1966; French, 2003).

Table 1: DWS Streamflow data rating table

STATION NO A2H014
DATE OF APPLICATION 1922-11-13
DT NO 7
DISCHARGE IN CUMEC FOR 1CM RISE IN WATER LEVEL

METRE	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.00	0.000000	0.0033	0.0083	0.0144	0.0213	0.0289	0.0371	0.0459	0.0553	0.0651
0.10	0.0754	0.0861	0.0971	0.1086	0.1204	0.1326	0.1451	0.1579	0.1710	0.1844
0.20	0.1981	0.2121	0.2263	0.2408	0.2556	0.2706	0.2859	0.3014	0.3173	0.3340
0.30	0.3509	0.3681	0.3856	0.4033	0.4213	0.4395	0.4580	0.4767	0.4956	0.5148
0.40	0.5343	0.5539	0.5738	0.5939	0.6142	0.6347	0.6555	0.6764	0.6976	0.7190
0.50	0.7406	0.7624	0.8167	0.8836	0.9545	1.030	1.109	1.193	1.282	1.376
0.60	1.475	1.580	1.689	1.805	1.927	2.054	2.188	2.329	2.475	2.593
0.70	2.715	2.841	2.971	3.104	3.242	3.384	3.531	3.681	3.836	3.996
0.80	4.160	4.328	4.502	4.680	4.862	5.050	5.242	5.440	5.643	5.850
0.90	6.063	6.282	6.505	6.505	6.505	6.505	6.505	6.505	6.505	6.505
1.00	6.505	6.505	6.505	6.505	6.505	6.505	6.505	6.505	6.505	6.505
1.10	6.505	6.505	6.505	6.505	6.505	6.505	6.505	6.505	6.505	6.505

Another form of flow measurement involves determining a 2D cross-sectional area perpendicular to the flow of a river. In this method, the area related to the wetted perimeter is calculated, and velocity is measured with a small handheld flow meter that determines the speed of rotation from its propeller design. Flow is then calculated in m³/s (Freeze and Cherry, 1979). This type of measurement using a cross section requires a different understanding of flow as it is not channelled through a weir structure and different aspects come into play. Surveying the river bottom perpendicular to the flow path allows for the determination of the cross-section required to measure centreline velocity, indicating the velocity of water at the channel's midpoint, and to calculate flow rates. This velocity profile is

essential for comprehending how flow dynamics alter the cross-section. Centreline velocity indicates that the highest velocities in rivers are typically found at the centreline due to the least resistance, contrasting with the lower velocities observed near the riverbanks where velocity gradients decrease. The cross section will indicate different structures which can also indicate altering velocities. Wide shallow rivers tend to have evenly distributed flow while narrow deep rivers tend to have numerous velocity gradients. Other factors like bed profiles (material type) can contribute to friction and turbulence which will affect velocity through the cross section (Henderson, 1966).

Another sophisticated method of measurement involves the use of an Acoustic Doppler Current Profiler (ADCP) and Acoustic Doppler Velocimeters (ADV). These instruments are utilised to gauge the flow or velocity of water across a water column or depth range. Operating on sound principles like sonar, they emit sound waves into the water, which bounce off particles or other features within the flow. By analysing the Doppler shift in the returned signals, these instruments can accurately determine water velocity at various depths, providing valuable insights into the flow dynamics of rivers and streams (Brumley *et al.*, 1991).

2.3 Baseflow

Baseflow, as defined previously, is the portion of streamflow that is sustained by groundwater inputs, while runoff is the portion that results from direct precipitation. The separation of these components can be complex and requires detailed hydrologic analysis but is critical for understanding the behaviour of rivers and streams under different conditions. These conditions can be modelled, and, if applied specifically to South Africa, can result in more accurate responses (Maidment, 1993; Singh, 1998; Chow *et al.*, 1988; San Diego State University, 2023).

Maliva (2014) describes two basic types of flow in an aquifer-spring-discharge-system, which are remarkably similar to types of flow we see on the surface, i.e., quickflow and baseflow. Maliva (2014) defines quickflow as the rapid response to rainfall events and baseflow as the delayed response of flow mainly from a storage source.

Maliva (2014) further explains that the shape of hydrographs can be quantitatively analysed to determine the contribution of quickflow and baseflow which are separated by a period of combined mixed flows (interflows) (Smakhtin and Watkins, 1997). A time-series event of streamflow shows multiple peak hydrographs and indicates the determinants for quickflow, interflow and baseflow. Steep gradients indicate quickflow, and the more gradual gradients

indicate baseflow. Maliva (2014) uses the gradient to determine both the storage and transmissivity properties of the aquifer (not a readily available property).

Baseflow is described by Han (2010) as the portion of streamflow that originates from groundwater. Han (2010) divides rainfall contributions to a river into four types, namely:

1. Overland surface runoff (quickflow)
 2. Interflow (subsurface runoff)
 3. Direct rainfall onto river channel
 4. Baseflow from groundwater
- Direct runoff

Based on hydrological cycle diagrams by Freeze and Cherry (1979) and Adrien (2004), the following diagram (Figure 2) is constructed and describes how baseflow fits into the hydrological cycle for the purpose of this study.

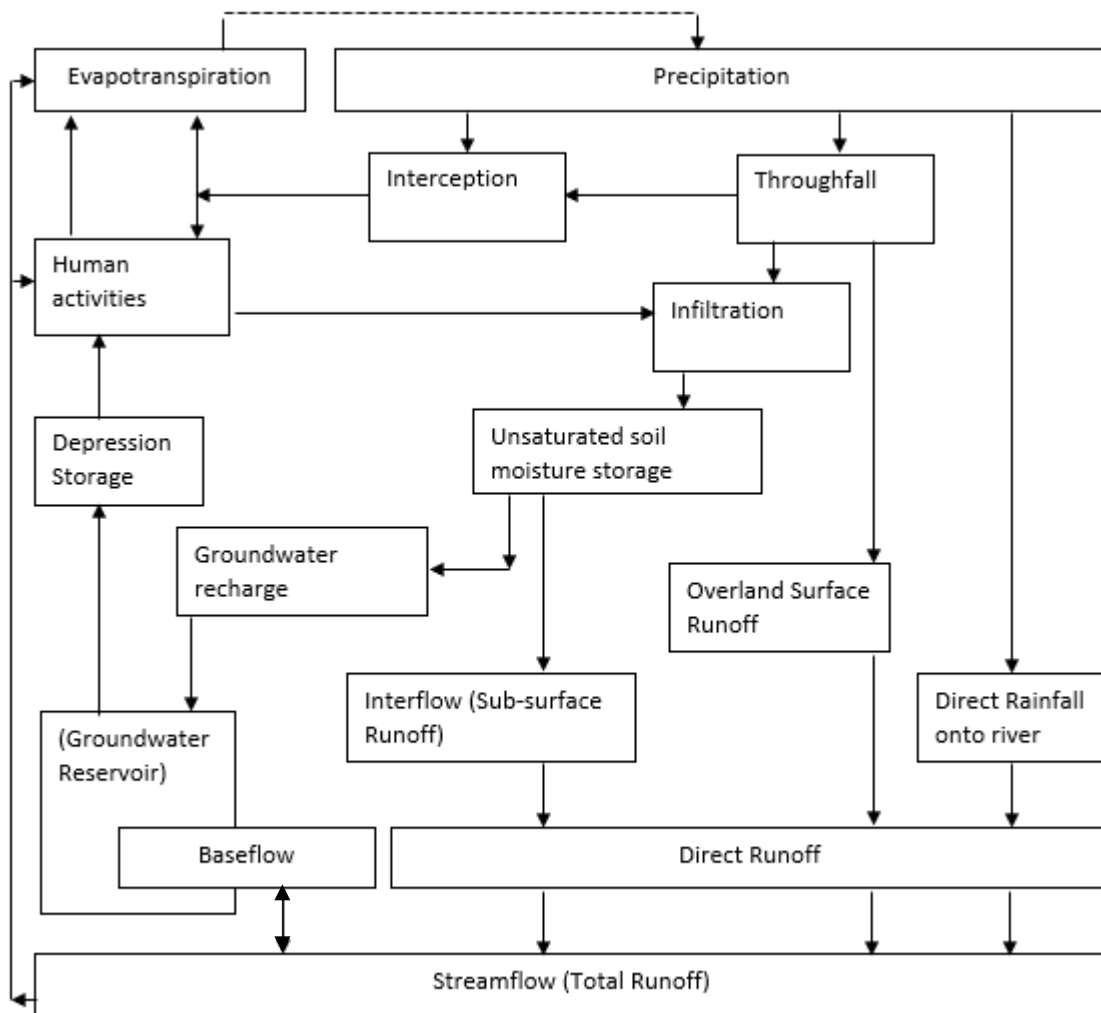


Figure 2: Hydrological cycle

Source: adapted from Freeze and Cherry (1979) and Adrien (2004)

Baseflow, as described by Adrien (2004), refers to a sustained discharge in a river that encompasses groundwater discharge and delayed subsurface discharge while excluding direct runoff from precipitation. It is sustained by drainage from natural storage in groundwater or natural water sources such as wetlands or lakes. Baseflow is typically determined from the measured hydrograph at a catchment, spring, or basin outlet. It can be estimated by assuming a constant and uniform distribution throughout precipitation events.

Smakhtin (2001) defines quickflow as the component of a hydrograph that is not related to groundwater storage. During dry seasons, a stream hydrograph primarily or entirely consists of baseflow, while during wet seasons, it includes both quickflow and baseflow. Nathan and McMahon (1990) distinguish quickflow from baseflow based on their frequency signals in hydrographs, with quickflow characterised by high-frequency signals.

According to Smakhtin (1997), gains in streamflow during low-flow periods are attributed to interactions between the river and the water table, influenced by factors such as hydraulic conductivity and gradient. Additionally, lateral movement through geological features, such as fractures, particularly in steeply sloping areas, contributes to prolonged groundwater contribution to baseflow. Bank storage, especially lateral movement after rainfall periods, also contributes to baseflow over extended periods. While storage of water in the soil is not considered part of true groundwater storage, there may be a direct connection between the two, referred to as subsurface flow, which contributes to direct runoff. Smakhtin emphasises the importance of identifying the relevance of these factors on a regional catchment as a crucial step in low-flow analysis.

Various terms for baseflow exist with similar definitions (Smakhtin, 2001; Nathan and McMahon, 1990; Adrien, 2004; Han, 2010; Freeze and Cherry, 1979; Maliva, 2014; Sloto and Crouse, 1996). For example, baseflow is alternatively known as dry flow (Han, 2010), although this term is infrequently used. Therefore, in the present study, the term baseflow will be substituted for each of the following terms: base flow, low-flow, dry weather flow, base runoff, delayed runoff, baseline flow (Han, 2010).

Some definitions such as groundwater flow (Han, 2010) (occasionally incorrectly used as baseflow) should not be substituted by the term baseflow, as groundwater flow is only a contributing factor to baseflow. Therefore, groundwater contribution to baseflow is not equal to baseflow. Groundwater contribution to baseflow can refer to other flows in aquifers as described by Maliva (2014). Adrien (2004) describes groundwater contribution to baseflow as the portion of precipitation that infiltrates the ground to the saturated zone and contributes to a surface stream baseflow. The depth of groundwater can be hundreds of metres deep

and reside in confined aquifers, not contributing to baseflow because it is disconnected from groundwater contributing to baseflow (Kovalevsky *et al.*, 2004). Interflow, also referred to as subsurface stormflow, should not be confused with baseflow. This is water infiltrating the ground but not reaching the saturation zone, leading to basin discharge. This is commonly referred to as the Horton overland flow concept, where interflow contributes to overland flow (quickflow), resulting in direct runoff (Kovalevsky *et al.*, 2004).

2.3.1 Importance of baseflow separation

The growing recognition that rivers receive groundwater has led to substantial consequences for river quality and quantity research into baseflow (Brodie and Hostetler, 2005). Analysis of groundwater contribution to rivers has critical implications on water supply, sustainability, allocation, trading, design of water storage infrastructure, hydroelectric power generation, ecosystems, wastewater treatment works, pollution, and mining industry (Brodie and Hostetler, 2005).

Baseflow is important to report for the purpose of environmental impact assessments (EIAs) in relation to water resource assessment, streamflow analysis, groundwater interaction and water quality assessment (Xu and Beekman, 2003). Hydrograph analyses are useful in various water resource investigations, specifically for baseflow estimation as well as flood analyses, flow regime and water availability assessments similar to EIAs (Sloto and Crouse, 1996).

Baseflow separation is also used in some cases to calculate groundwater recharge from precipitation. Therefore, baseflow separation plays a significant part in flood studies (Smakhtin and Toulouse, 1997). Han (2010) further describes the importance of baseflow separation in water balance calculations; although the division between direct runoff and baseflow is transitional and vague, baseflow separation remains important.

To ensure the conservation of flora and fauna, the South African government has designated and currently oversees areas known as protected areas or conservation reserves. Within these areas, the river flow regimes function as an important determining factor for surface water and the contributions from overland surface runoff, interflow, and groundwater contribution to baseflow, which are all equally important for the maintenance of the ecological reserve. As a minimum, regardless of individual characteristics, these flow regimes contribute to the determination of the ecological reserve across South Africa (Hughes, 2001) and baseflow plays an important aspect of the conservation.

South Africa has established one of the most comprehensive legal frameworks globally for safeguarding water resources; however, the challenge lies in the effective implementation and enforcement of this framework. The creation of an ecological water reserve is directly associated with the National Water Act (NWA) (Act 36 of 1998) in South Africa (South Africa, 1998), aiming to ensure the accounting of all water flows and contributions. Ecological reserves are necessary in order to set aside or reserve water to maintain all ecological functions for the long-term sustainability of the ecosystem. This means that all flows need to be accounted for, with groundwater being a major element and understanding the separation between groundwater contribution and surface runoff effects.

2.3.2 Streamflow and baseflow integration

In clarifying the data collection process and discerning the informational content summarised within the dataset, the subsequent explanation serves to inform the significance thereof.

Figure 2 depicts a detailed view of how rainfall and groundwater form streamflow with the aid of a simple water balance (Equation 1), where storage is considered as groundwater, rainfall as inflow, and streamflow as the outflow. When referring to multiple sub-catchments, the inflow component in Equation 1 will be the sum of rainfall and inflow from adjacent catchments.

$$\text{Change in Storage} = \text{Inflow} - \text{Outflow}. \quad [1]$$

This type of calculation has been computed for all drainage regions in South Africa by Alexander (1985), yielding an approximate value of only 8.6% of precipitation resulting in streamflow.

2.3.3 Factors affecting baseflow estimation

Numerous factors influence the estimation of baseflow irrespective of the chosen method. While these limitations may be conspicuous, they warrant record and acknowledgement during investigations, research endeavours, or baseflow estimation: Firstly, data quality as described previously under the hydrographs section. Secondly, activities residing within the catchment that could impact measured streamflow, for example if a catchment has a wastewater treatment plant that constantly discharges into a stream, such a discharge would impact the resulting baseflow (Sloto and Crouse, 1996). Constant discharges will result in higher baseflow values. A massive amount of water released from a dam could also alter hydrographs resulting in a variety of frequencies observed in the hydrographs (Smakhtin and Watkins, 1997; Sloto and Crouse, 1996).

Thirdly, the lack of climatological data and monitoring could also lead to errors in estimation if streamflow is available only from a wet or dry period. This will surely over or underestimate the baseflow, as climatology impacts the whole system. Therefore, the longest available periods of streamflow data are used to counter these effects (Sloto and Crouse, 1996).

2.3.4 Frequently used baseflow estimation methods

Various methods exist to estimate baseflow. The simplest methods are the graphical methods done by hand by connecting a straight line between a streamflow hydrograph's rising and falling limbs as seen in Figure 3 (Linsley *et al.*, 1958; Freeze and Cherry, 1979).

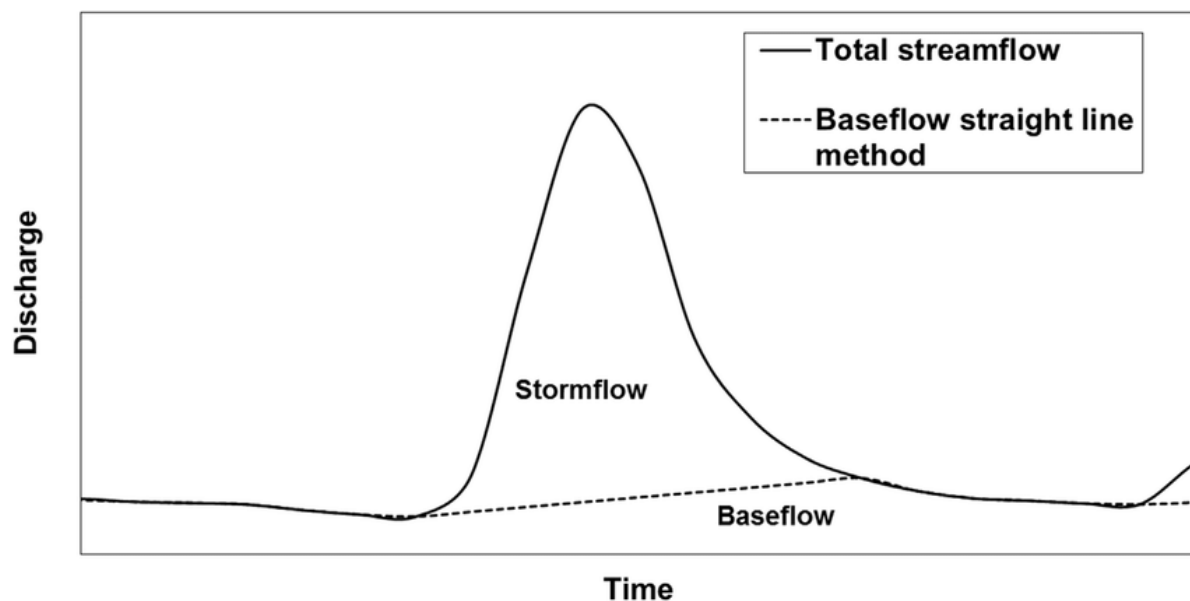


Figure 3: Graphical baseflow estimation
Source: Bosch *et al.* (2017)

Software and algorithms have replaced these methods to eliminate human error and to ultimately save time. Numerous methods have been developed, tried, and tested, of which only a few are discussed below, namely, HYSEP, recursive digital filter (RDF), Herold, RCD, Smakhtin low flow, and UKIH.

2.3.4.1 HYSEP

Hydrograph separation and analysis techniques were developed by Pettyjohn and Henning in 1979 (Sloto and Crouse, 1996). Subsequently, due to technological advances, HYSEP was further developed into a computer program by incorporating Pettyjohn and Henning's method in 1982. Henning developed HYSEP as a method which filters input-streamflow data into two components known as baseflow and surface runoff (quickflow). The duration of surface runoff is calculated from an empirical relation, where N is referred to as the number

of days after which direct runoff has stopped, and $2N$ the number of days for baseflow (Sloto and Crouse, 1996) (Equation 2):

$$N = A^{0.2} \quad [2]$$

N = Number of days after which surface runoff ceases

A = Drainage area (m^2)

Baseflow separation is determined by connecting low flow points of a stream hydrograph. These can be connected in various ways, which is why HYSEP is divided further into three different methods, each with its own unique algorithm (Sloto and Crouse, 1996).

- HYSEP 1: Fixed interval method.
- HYSEP 2: Sliding interval method.
- HYSEP 3: Local minimum method.

2.3.4.1.1 HYSEP 1

The fixed interval method assigns the lowest discharge value for each interval ($2N$) to all days in that interval. As seen in Figure 4, the first interval spans from day 1 to day 5 (obtained from equation $2N^*$ days wide) is combined as one value or a single bar graph and increases/decreases in volume until it reaches the lowest point of the streamflow hydrograph for the specified number of days N . In this case, for hydrograph separation, the $2N^*$ is calculated to the odd integer between 3 and 11 nearest to $2N$.

The volume for that single bar graph is then calculated, and the process is repeated calculating the lowest flows over a period in other words up to the lowest points of the hydrograph resulting in a low flow series of bar graphs. The volumes of the bar graphs are then added to give the baseflow value (Sloto and Crouse, 1996).

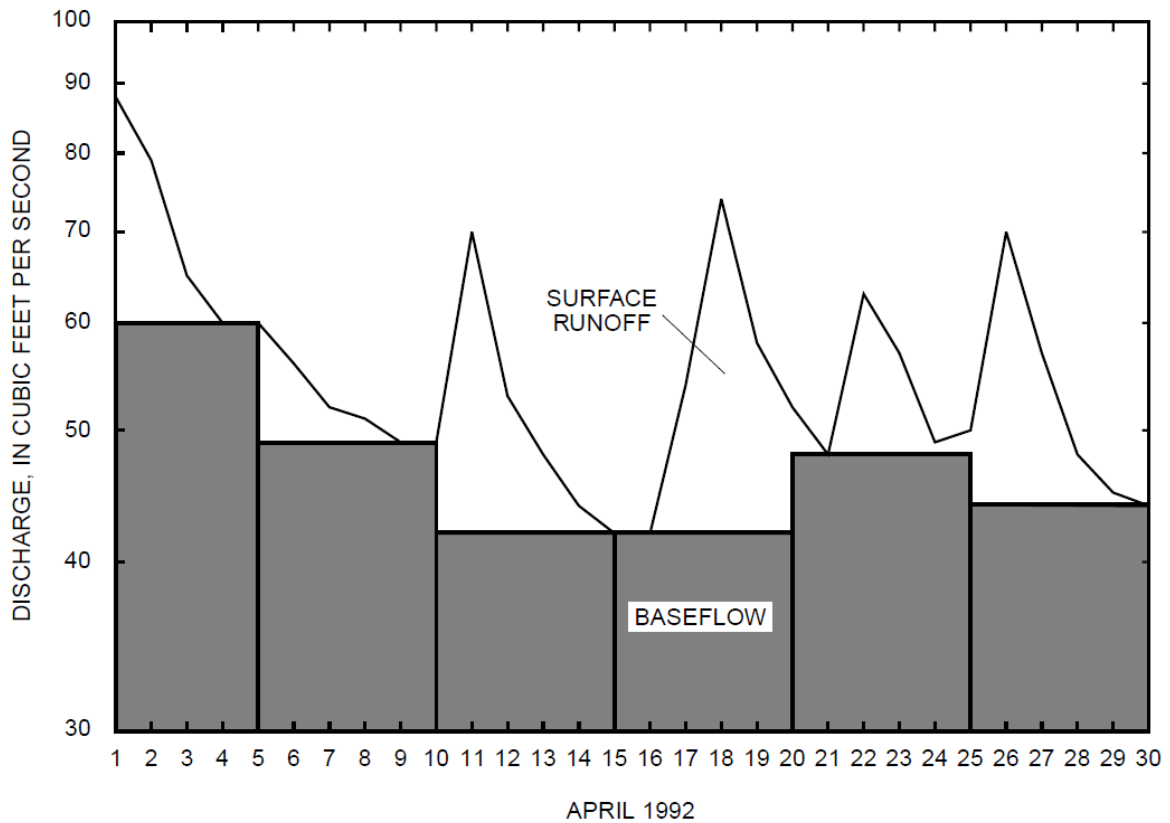


Figure 4: HYSEP 1
Source: Sloto and Crouse (1996)

2.3.4.1.2 HYSEP 2

This method utilises the sliding interval approach to determine the minimum discharge. This involves considering a time span of one-half of the interval, subtracting a day before and after the target day $[0.5(2N*-1)$ days] (refer to Figure 5 for a visual representation). In contrast to the fixed interval method, HYSEP2 employs a bar graph where each bar represents a 2N-day width, systematically increasing to create a hydrograph. The sliding interval method shifts one day at a time, and the median of the two adjacent days is used to form a line for each interval day. This distinctive approach enables HYSEP2 to generate a more detailed baseflow estimation compared to the HYSEP1 method (Sloto and Crouse, 1996).

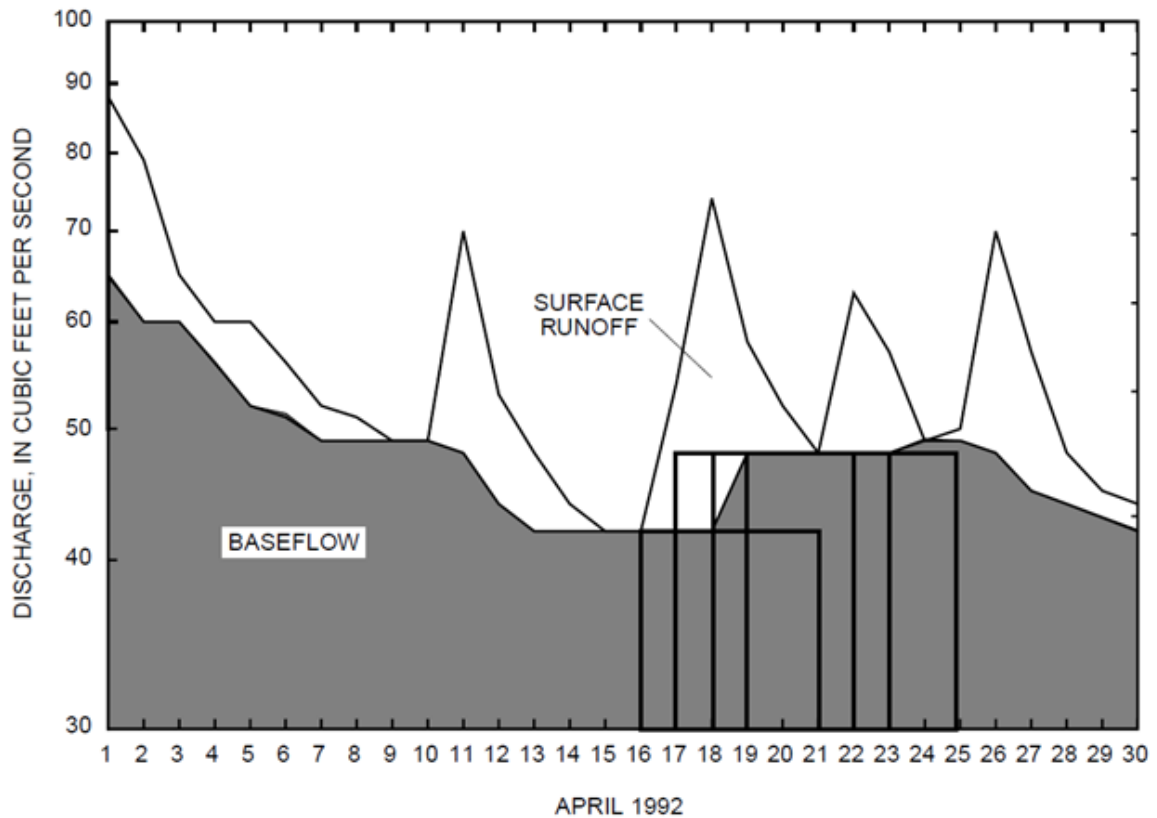


Figure 5: HYSEP 2
Source: Sloto and Crouse (1996)

2.3.4.1.3 HYSEP 3

The local minimum method verifies each day to determine if it is indeed the lowest point in one-half of the interval minus a day before and a day after, the considered calculated day $[0.5(2N*-1) \text{ days}]$, connecting all low flows with straight line rather than bar graphs as indicated in Figure 6. If the statement is true, then the point is taken as the local minimum and connected to its adjacent local minimum point, after which the process is repeated for the remaining days. The local minimums are connected by a linear interpolated line (Sloto and Crouse, 1996).

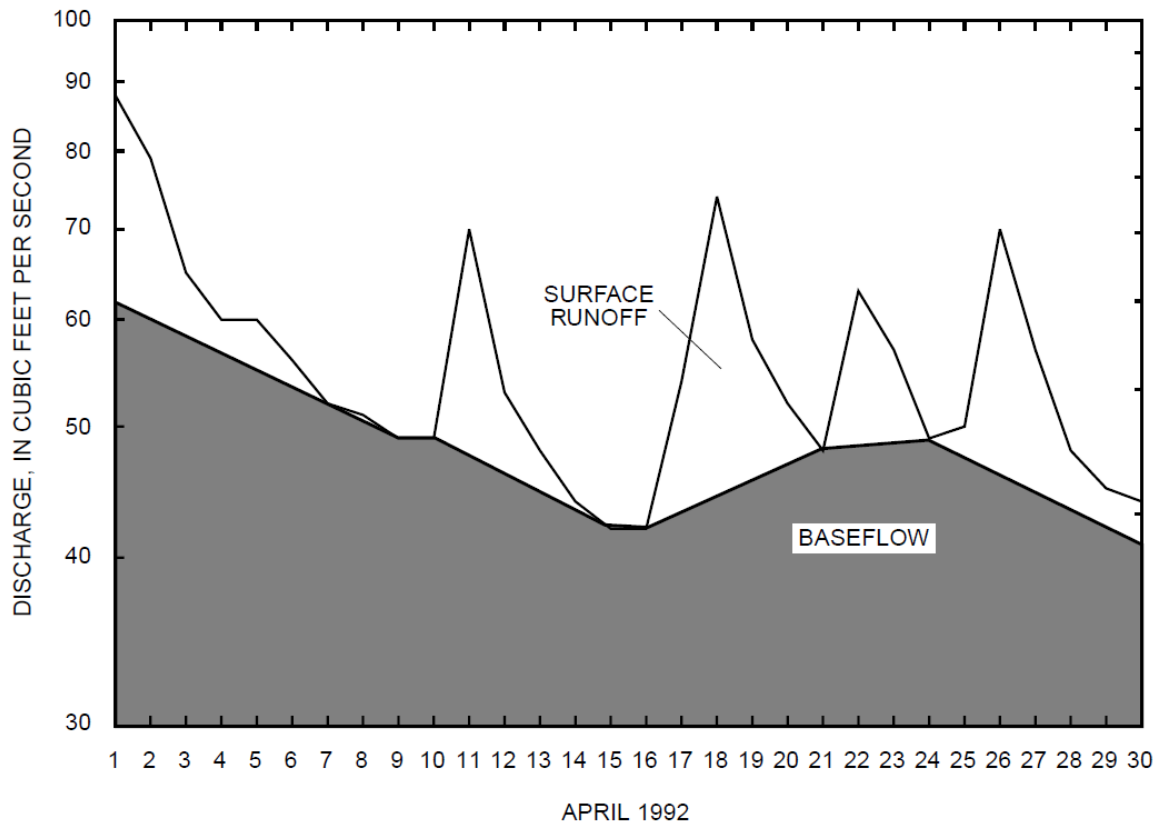


Figure 6: HYSEP 3
Source: Sloto and Crouse (1996)

2.3.4.1.4 HYSEP Advantages

The HYSEP program uses a graphical user interface separating streamflow hydrographs into baseflow and direct runoff while performing frequency analyses on both. The HYSEP method generally provides more reliable results from annual streamflow measurements than monthly or daily estimates. The method's accuracy depends on the period of record used in the analysis. The effectiveness of the data is the responsibility of the user (Sloto and Crouse, 1996).

The three methods of HYSEP each have their uniqueness as well as advantages and disadvantages. They are simplistic and easy to use but assume a fixed percentage of streamflow as baseflow. HYSEP2 considers a more nuanced approach to identify minimum discharge which results in a more intricate baseflow estimation whereas HYSEP3 shows enhanced adaptability to different conditions by employing a baseflow recession constant which can lead to more accuracy in diverse environments (Sloto and Crouse, 1996).

The program accepts daily mean streamflow data in the following two formats: firstly, standard United States Geological Survey National Water Drainage Storage and Retrieval System 80-character record in American Standard Code for Information Interchange (ASCII)

format. Secondly, the binary direct access Watershed Data Management (WDM) file format. The data from one station is further restricted to a minimum of one year and a maximum of 100 years of data in either format described above. The input of data can start on any given calendar year (not restricted to hydrological year inputs) (Sloto and Crouse, 1996).

The program can export data in tables, graphs, ASCII files, and WDM data, indicating missing values as -1.0. The program is designed to produce outputs in a series of one-year records for all data entered. The final output is a summarised table of the annual streamflow hydrograph indicating the percentage split between baseflow and streamflow as well as the estimated flow of each. The monthly summary is available if requested. The program can also produce frequency distributions of the mean annual streamflow, baseflow and runoff, as well as a cumulative probability distribution (Sloto and Crouse, 1996).

HYSEP claims to use a “very portable” and “usable” written software that can be used on multiple platforms that is user friendly. But all programs have a learning curve (Sloto and Crouse, 1996). The process steps shown in Figure 7 are executed once the program is instructed to execute the selected method on the provided streamflow data.

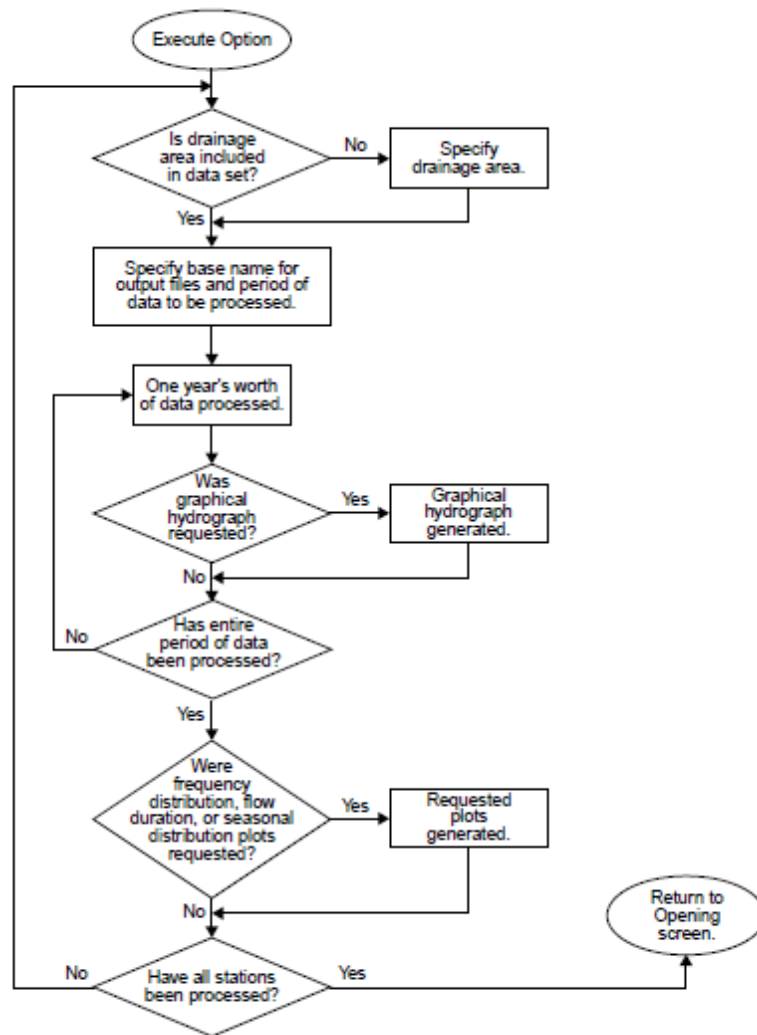


Figure 7: Process flow diagram HYSEP

Source: Sloto and Crouse (1996)

Major insights into HYSEP can be utilised and advantages can be taken from the method, such as steps in calculating the baseflow and output files. The program's general setup can be used to build a new and perhaps similar program for South Africa. However, the complexity of the program is quite intricate with a learning curve (Sloto and Crouse, 1996). Learning from HYSEP can be utilised in formulating a new method especially by identifying low flows from graphs which are easily calculated but can be optimised to incorporate catchment characteristics where baseflow is more intricate, meaning combining the three HYSEP methods and utilising them based on catchment characteristics where it will identify which calculations or parameters to use to inform the separation. This will aid in avoiding the disadvantages of the sensitivity, fixed percentage baseflows and input parameters of the HYSEP methods and avoid the linearity of the methods as the natural state of catchments is

very seldom linear. HYSEP also struggles with smaller catchments and temporal resolution thereof which can be improved on if approached correctly by utilising recursive digital filtering.

2.3.4.2 RDF

Recursive digital filters of hydrographs is a baseflow separation method developed by Lyne and Hollick (1979) and further developed by Eckhardt (2005). Eckhardt introduced modified versions providing enhanced baseflow separation results which addressed the limitations and sensitivity of the RDF methods (Eckhardt, 2005). By analysing a streamflow hydrograph, waves are obtained of high and low frequencies over time as rainfall events dictate the volume of runoff shaping high-frequency events and as baseflow shaping the long wave low-frequency events. Therefore, the streamflow hydrograph can be partitioned into both direct runoff and baseflow. After careful consideration the equation from Eckhardt showed more reliability and usability in catchments similar to South Africa. The following general formulation by Eckhardt (2005) can devolve into several of the commonly used one-parameter filters. Equation 3 describes the one-parameter RDF equation.

$$q_{b(i)} = \frac{(1 - BFI_{max})aq_{b(i-1)} + (1 - a)BFI_{max}q_i}{1 - aBFI_{max}} \quad [3]$$

i = Time-step

$q_{b(i)}$ = Baseflow at time step i

$q_{b(i-1)}$ = Baseflow at the previous time step $i-1$

q_i = Streamflow at step i

a = Recession constant

BFI_{max} = Maximum value of baseflow index that can be measured

A key assumption by Eckhart (2005) is that the one-parameter filter method concludes that the baseflow component of streamflow follows an exponential decay implying that direct runoff is inversely proportional to the storage, meaning that as storage (for example in soil moisture) increases the direct runoff decreases, indicating the recharge effect depending on conditions. Eckhart also explained that his method might be beneficial if some of the low-frequency content of the streamflow could be related to direct runoff. Therefore, the one-parameter equation must be upgraded to a two-parameter filter confirming parameter effects on the method which can be utilised in the newly proposed method (Eckhardt, 2005).

A recent study by Indarto *et al.* (2017) calibrated six RDF methods (one parameter, Boughton-two-parameter, identification of unit hydrographs and component flows from rainfall evaporation and streamflow data [IHACRES], Lyne and Hollick, exponentially weighted moving average [EWMA], and the Chapman algorithm) comparing the results for a specific case study. The study concluded that all six RDF methods are indeed applicable with similar results, with the IHACRES and EWMA filters performing the best for the specific study area. A key motivation for that study was the argument that RDF filtering performs best when developed for a specific area or case study which is why it could be argued that a method developed specifically for South Africa would yield better baseflow estimations.

Multiple RDF methods have been developed and used in baseflow studies, as summarised in Table 2 (Brodie and Hostetler, 2005).

Table 2: RDF methods

RDF Method	Equation	Source
Lyne and Hollick	$q_{f(i)} = \alpha q_{f(i-1)} + (q_{(i)} - q_{(i-1)}) \frac{1+\alpha}{2}, \text{ for } q_{f(i)} \geq 0$	Lyne and Hollick (1979)
Boughton-two-parameter	$q_{b(i)} = \frac{K}{1+C} q_{b(i-1)} + \frac{C}{1+C} q_{(i)}, \text{ for } q_{b(i)} \leq q_{(i)}$	Boughton (1993)
IHACRES-three-parameter	$q_{b(i)} = \frac{K}{1+C} q_{b(i-1)} + \frac{C}{1+C} (q_{(i)} + \alpha q_{(i-1)})$	Jakeman and Hornberger (1993)
One Parameter	$q_{b(i)} = \frac{K}{2-K} q_{b(i-1)} + \frac{1-k}{2-k} q_{(i)}, \text{ for } q_{b(i)} \leq q_{(i)}$	Chapman and Maxwell (1996)
Chapman Algorithm	$q_{f(i)} = \frac{3\alpha-1}{3-\alpha} q_{f(i-1)} + \frac{2}{3-\alpha} (q_{(i)} - \alpha q_{(i-1)})$	Chapman (1999)
Furey and Gupta Filter	$q_{f(i)} = (1-\gamma) q_{b(i-1)} + \gamma \frac{C_3}{C_1} (q_{(i-d-1)} - q_{b(i-d-1)})$	Furey and Gupta (2001)
Eckhardt	$q_{b(i)} = \frac{(1-BFI_{max})\alpha q_{b(i-1)} + (1-\alpha)BFI_{max}q_{(i)}}{1-\alpha BFI_{max}}$	Eckhardt (2005)
EWMA	$q_{b(i)} = \alpha q_{(i)} + (1+\alpha) q_{b(i-1)}$	Tularam and Illahee (2008)

$q_{(i)}$ = streamflow, $q_{b(i)}$ = filtered baseflow, $q_{f(i)}$ = filtered quickflow, K, α, C, γ = filter parameters.

Source: Brodie and Hostetler (2005), Indarto *et al.* (2017)

From Table 2, the Lyne and Hollick method holds the advantage of being simple and widely used but relies on fixed thresholds and may not capture all hydrological variations. The Boughton-two-parameters incorporates flexibility with two parameters but requires calibration and can be too sensitive. The IHACRES-three-parameter allows for even more flexibility, but the complexity may limit its applicability which can be seen as a disadvantage, but when developing a new method for a specific area such as South Africa its three-parameter approach can be utilised as an advantage. One parameter methods certainly hold simplicity as a major advantage with less calibration but may not capture the hydrological behaviour accurately. The Furey and Gupta method is suitable for long term data with frequency domain analysis but requires expertise and can be sensitive to parameter

selection. The Eckarht method is computationally efficient, but the parameters are sensitive, and the assumption of exponential decay must be considered. Reflecting recent changes in streamflow with moving averages, EWMA offers an interesting advantage in its method; however, it may not be suitable for all hydrological conditions unless combined with certain advantages found in the HYSEP method or Smakhtin low flow, as discussed in section 2.3.4.5. Furthermore, RDF methods are the most commonly used methods and are widely investigated due to their relative ease of use and implementation, making them quite efficient methods. The difficulty is finding the optimal RDF method to use and investigate because each method has small differences and thus various advantages and disadvantages, mostly making them specific for certain areas. In general, RDF methods are described to separate low frequencies from high frequencies with the assistance of a variety and combination of parameters. A study by Li *et al.* (2013) states that the most accurate means of baseflow calculation would be the use of an RDF method that uses a hydraulic mixing cell method in conjunction with an integrated surface water/groundwater model such as HydroGeoSphere. However, the complexity of this combined method is challenging, with various data requirements and calibration parameters required.

The RDF method is the most used method in the world due to its minimal input data requirements and simple, efficient implementation of the formulas on any datasheet software, and each RDF method is defined by its filter type as presented in Table 2.

Many studies have been conducted in an attempt to compare the performance of these RDF methods (for example: Chapman, 1999; Eckhardt, 2005; Li *et al.*, 2013; Nejadhashemi *et al.*, 2003; Partington *et al.*, 2012). The one advantage of the RDF might also be the one disadvantage of the method: RDFs only use input data of streamflow hydrographs without considering potential impacts of physical catchment characteristics. Li *et al.* (2013) further explain that the physical parameters of a catchment could significantly impact RDF methods. When dealing with hydrological modelling and baseflow separation methods, the selection of parameters is crucial. The higher the number of input parameters, the more degrees of freedom are introduced into the model. This increased flexibility can lead to a potential lack of uniqueness in the solution. Considering that the aim of a new method would be to target specific areas of the hydrograph per the parameter which they affect and to avoid the potential lack of uniqueness, this can be solved by performing calibrations of the observed data such as tracer studies and utilising the array of physical properties unique to South African catchments.

Methods for rainfall-discharge relationships demonstrate diverse responses and yield varying outcomes in each case study, posing challenges in identifying the most suitable approach.

Based on various RDF methods from various comparison studies using several RDF methods the conclusion is that more parameters give more reliable results, but this also depends on the type of parameters used. Eckhardt stated that his one-parameter filter has to be converted to a two-parameter filter because it yields more reliable results (Chapman, 1999; Eckhardt, 2005; Li *et al.*, 2013, 2009; Nejadhashemi *et al.*, 2003; Partington *et al.*, 2012).

Zhang *et al.* (2017) conducted a study on Australian catchments to compare the three RDF methods of Lyne and Hollick, Chapman-Maxwell and Eckhardt with the UKIH method. Zhang *et al.* (2017) stated that the RDF method is a major candidate for replacing the very time-consuming tracer test methods. The author chose the Lyne-Hollick method for its popularity, even though it is not recommended for ephemeral streams. Chapman (1999) developed a more suitable method for ephemeral streams. It is clear from the literature that the performance of various RDF methods vary from case study to case study and each method has its own advantages.

Zhang *et al.* (2017) found that the Eckhardt method assumes that outflow from an aquifer is directly proportional to the aquifer's storage. Various filter parameters have been identified for different characteristics, such that perennial streams with porous aquifers should have the BFI filter parameter set to 0.8 and ephemeral streams on the same aquifer set to 0.5, and 0.25 for hard rock aquifers. A relatively impermeable BFI of 0.25 should be set for a hard rock aquifer.

Zhang *et al.* (2017) found that the Lyne-Hollick method responds well to multiple passes (filtered again), but the Eckhardt and Chapman-Maxwell methods generated good results with a single pass. The Chapman-Maxwell method performed well in all catchments, while the Eckhardt and Lyne-Hollick methods were inconsistent throughout the catchment, yielding generally larger peaks of baseflow. The authors concluded that the Eckhardt method might be better situated for tropical catchments.

Zhang *et al.* (2017), similarly to Li *et al.* (2013), stated that many physical catchment factors can influence baseflow, such as the thickness of soil surface and geology above the water table and the catchment topography, and that some of these characteristics can be neglected with catchments larger than 200 km². Some anthropogenic characteristics such as irrigation, drainage, and urban areas also affect baseflow.

Recursive digital filter methods do not consider the physical attributes of a catchment responsible for the baseflow frequency because these methods are simply based on filter

parameter values. Therefore, recent studies have given attention to the physical attributes of a catchment and included surface and groundwater models with precipitation and evapotranspiration parameters as inputs to estimate baseflow using RDF methods in general (Indarto *et al.*, 2017; Zhang *et al.*, 2017).

2.3.4.3 Herold baseflow separation

The Herold method, although less recognised compared to baseflow separation techniques like HYSEP or RDF, is specifically designed for South African catchments. It offers a straightforward curve-fitting-graphical approach, where a constant flow across time is adjusted vertically on the y-axis until it aligns with a streamflow value, mimicking the shape of the streamflow hydrograph. Minor adjustments to baseflow peaks can be made by tweaking its three parameters, facilitating a baseflow fit (Figure 8).

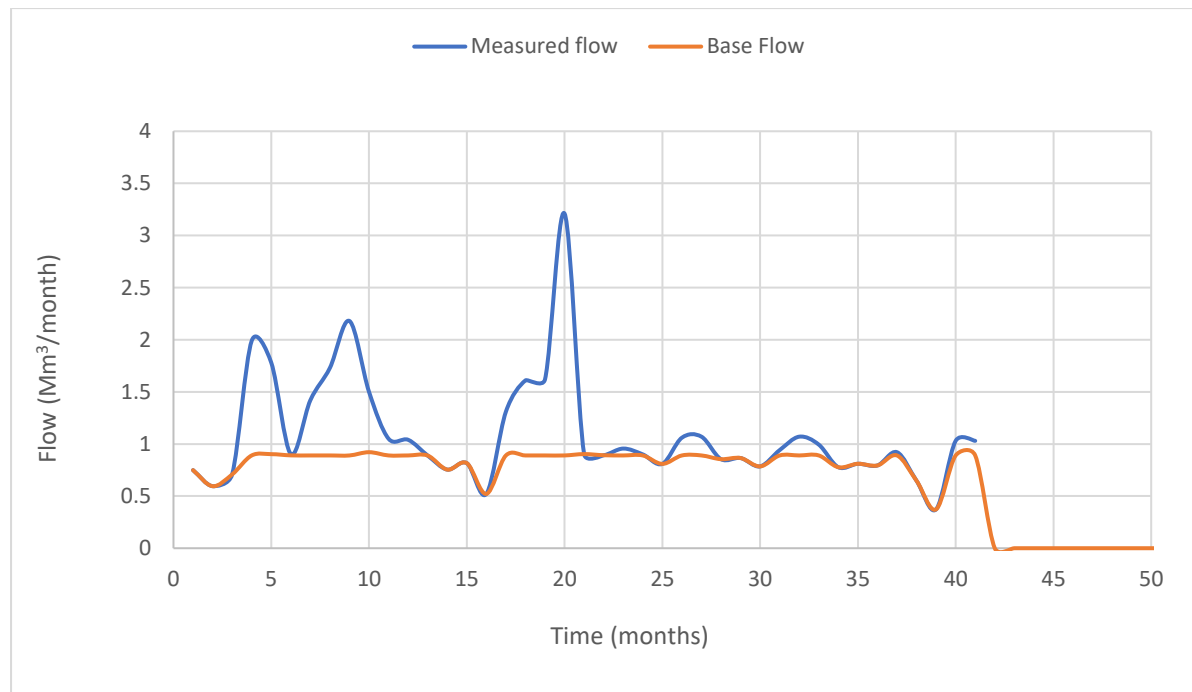


Figure 8: Herold baseflow example

The Herold method was developed in 1980 by Herold (Xu and Beekman, 2002). The total flow is presented in Equation 4 which is the sum of groundwater contribution and surface runoff (Xu and Beekman, 2003):

$$q_{(i)} = q_{gw(i)} + q_{s(i)} \quad [4]$$

$q_{(i)}$ = Total flow during month

$q_{g(i)}$ = Groundwater contribution

$qs_{(i)} = \text{Surface runoff}$

Equation 5 describes the surface runoff calculation represented by total flow minus groundwater flow.

$$qs_{(i)} = q_{(i)} - gg_{max}, \text{ for } q_{(i)} > qg_{max} \quad [5]$$

$$\text{or, } qs_{(i)} = 0, \text{ for } q_{(i)} \leq qg_{max}$$

$$\text{hence, } qs_{(i)} = q_{(i)} - qs_{(i)}$$

It is assumed that all flow below the value gg_{max} is considered groundwater flow (Xu and Beekman, 2003) and that gg_{max} may not be less than qg_{max} . Furthermore, the value gg_{max} is altered for every preceding month according to the qs from the previous month. This is further assumed to decay with time (Equation 6) (Xu and Beekman, 2003):

$$gg_{max(i)} = Decay * gg_{max(i-1)} + \frac{pg * qs_{(i-1)}}{100} \quad [6]$$

$Decay$ = Groundwater Decay Factor, with $0 < Decay < 1$.

pg = Groundwater growth factor, for $0 < pg < 100$.

The Herold method is conducted by adjusting the $Decay$, pg and qg_{max} values until a visually realistic split between baseflow and direct runoff is achieved meaning that it is a very subjective method. This method may be subjected to researcher or analyst experience and with the assistance of calibration (Xu and Beekman, 2003).

The Herold method is a useful baseflow estimation method for the experienced user because it relies on user input and understanding of the method. The Herold method is very easy to use with variable parameters selected on a type of sliding scale used to fit the baseflow to the input hydrograph. Employing a method such as this relies heavily on subjective judgement regarding its advantages, primarily based on how the results are justified. This approach can however effectively accommodate the wide range of situations encountered in South Africa (Vegter and Pitman 2003).

The main disadvantage of the method is inexperienced users not knowing how to apply the method properly; in general, the procedure is subjective, with different users obtaining different results for the same problem or case study. The Herold method estimates good baseflow volumes (litres of water) compared to baseflow curves that are visually correct or

regarded as visually correct by graphical method standards of baseflow curves fitted to hydrographs and its approach is easily adoptable into a new method.

Limited studies on this method exists and are currently only explored in a South African context. It has been previously quoted by Smakhtin (1997) and explained in relation to calculating baseflow percentages for South African water management areas (Herold, 1980; Vegter and Pitman 2003).

2.3.4.4 RCD

Multiple methods use the RCD principle, the basic method used for separating baseflow from streamflow in hydrograph analysis. The main idea behind this method is to displace the recession curve of streamflow during periods of low flow to estimate the baseflow component. The recession curve part of the method comes in where it is represented by the falling limb of a hydrograph (see Figure 2), which occurs after a rainfall event. During this period, streamflow decreases as water is gradually released from storage, including groundwater (see Figure 1). The displacement is then accomplished by identifying a point on the recession limb where the curve deviates from a straight line. This deviation is often associated with the depletion of surface runoff, leaving the remaining flow as baseflow.

Methods for rainfall-runoff characterisation are associated with several specific techniques such as:

1. The regionally estimated baseflow single basin computer program recession curve extraction for streamflow (RECESS) by Schaake (1989).
2. Rise and recession computer program routine for online recession analysis (RORA) proposed by Nathan and McMahon (1990).
3. Partitioning of rainfall into runoff and baseflow computer program PARTitioning (PART) developed by J. Dooge (Rutledge, 1998).

These applications can work in conjunction with each other. It is recommended to use the RECESS method first before moving on to either RORA or PART (Rutledge, 1998; Rutledge and Daniel, 1994; Smith and Schwartz, 2016).

The general RCD method consists of seven steps (Rutledge, 1998):

1. Determining recession constant K
2. Use of T_c to which streamflow recession will be extrapolated
3. Determining the groundwater recharge to the stream pre-event
4. Determining the groundwater recharge to the stream post-event
5. Application of Equation 7:

$$R = \frac{2(Q2 - Q1)K}{2.3026} \quad [7]$$

R = Volume of recharge (m^3/d)

$Q1$ = Groundwater discharge at a critical time from pre-event streamflow recession (m^3/d)

$Q2$ = Groundwater discharge at a critical time from post-event streamflow recession (m^3/d)

The RCD methods will be discussed in the following sub-sections, but they all take Equation 7 into consideration to determine baseflow. RCD takes a solely mathematical look at estimating baseflow from daily streamflow hydrograph data, meaning it is widely applicable but not specific. Comparison results by Rutledge (1998) correlated well with results from publications found by Rutledge with some outliers and differences in the computerised and manual application of time method. An RCD study of 157 streamflow gauging stations in the United States resulted in the RORA groundwater recharge program Rutledge (1998). Based on the difference in potential groundwater discharge, this method correlated well with the PART groundwater discharge method using a linear interpolation function to determine baseflow for periods that do not fit requirements based on recession. The methods assume that all or nearly all groundwater is discharged to a stream, except for what is lost to evapotranspiration, and neglects flow diversion (Rutledge, 1998).

2.3.4.4.1 RECESS

The RECESS method defines the master recession curve (MRC) from streamflow hydrographs during periods of only groundwater contribution and when the groundwater levels are nearly stable (Rutledge, 1998; Rutledge and Daniel, 1994). The method repeats the process of selecting several periods of recession and then determines a best-fit equation for the recession rate as a function of the logarithm of streamflow. The algorithm works in three steps, as depicted in Figure 9 (Rutledge, 1998 Rutledge and Daniel, 1994):

1. Image 9A: The selected recession segments are extrapolated from streamflow data and allow the user to select which segments to use (nearly straight segments).
2. Image 9B: Determine the best linear equation of time against the logarithm of flow where a K constant can be extrapolated (recession index K). Determine the best linear equation for K (best-fit line) as a function of the logarithm of flow.
3. Image 9C: Finally, the coefficient from the equation in step 2 can be used to obtain the MRC, which is considered a second-order polynomial expression for time against

the logarithm of flow. The MRC filter is applied recursively to successive rising and falling limbs of the hydrograph to refine the separation and identification of baseflow (Rutledge, 1998).

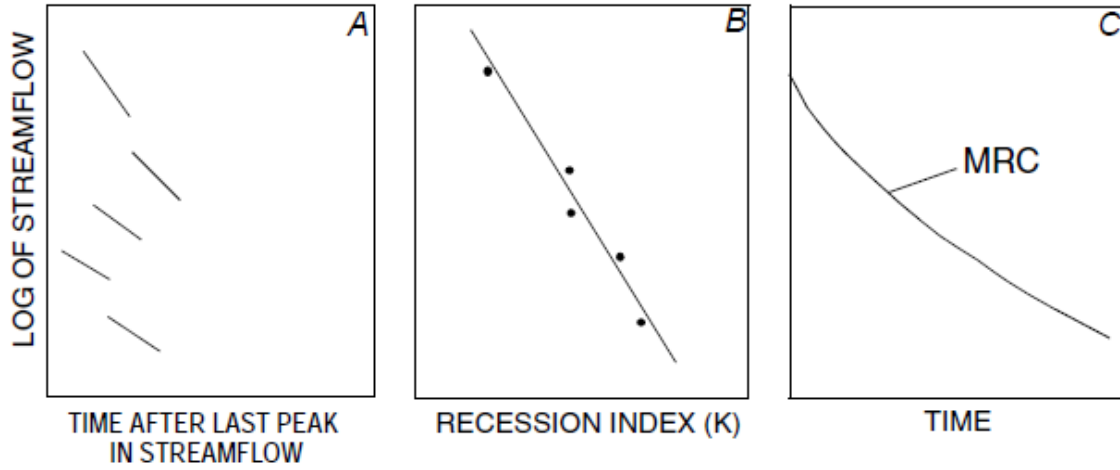


Figure 9: RECESS programs steps A-B

Source: Rutledge (1998) and Rutledge and Daniel (1994)

2.3.4.4.2 RORA

The RORA method uses the RCD method to estimate recharge for each peak in the streamflow hydrograph and results in an estimate of mean-rate groundwater recharge. A crucial aspect of this method is the use of the Equation 8 to extrapolate groundwater discharge from the groundwater recession (Rutledge, 1998; Rutledge and Daniel, 1994; Smith and Schwartz, 2016).

$$dQ = \frac{C}{\sqrt{dT}} \quad [8]$$

dQ = Difference between groundwater discharge and discharge with the absence of recharge (m^3/d)

C = Constant for the magnitude of a recharge event (m^3/d)

dT = Time after a recharge event (days)

The linear extrapolation is described by Equation 9.

$$Q = Q_o \times 10^{\frac{-dT}{K}} \quad [9]$$

Q = Groundwater discharge extrapolated to a time after the critical time (m^3/d)

Q_o = Groundwater discharge extrapolated to the critical time (m^3/d)

dT = Time period between critical time and day of interest (days)

2.3.4.4.3 PART

The PART method uses a one-dimensional array of daily mean streamflow which is then narrowed down for days that fit a preceding recession (Rutledge, 1998; Rutledge and Daniel, 1994). On each of these days, the baseflow is designated to be equal to streamflow at these low flow frequencies or the slow movement of water through the aquifer, not declining for more than 0.1 log cycle (meaning only long-term frequencies) and these are partitioned. This also implies that the method is quite useful for long terms (decades). The method searches the array again and linearly interpolates the days where the partitioning does not fit (high-frequency streamflow data), resulting in the separation of baseflow and direct runoff (Rutledge, 1998; Rutledge and Daniel, 1994). The process is carried out three times. Initially, it evaluates the conditions of the preceding recessions that are less than Equation 2 for N , and subsequently, it applies the procedure for the next two larger integers derived from Equation 2 for N . (Rutledge, 1998; Rutledge and Daniel, 1994). The method then constructs a second-order polynomial function for the groundwater discharge, and by using the streamflow partitioning, the method calculates the groundwater discharge for the exact result of Equation 2 from the polynomial function. Figure 10 describes the steps taken and applied by the method, where “ALLGW” refers to all groundwater and ALLGW=* refers to the partitioned groundwater volume (Rutledge, 1998; Rutledge and Daniel, 1994).

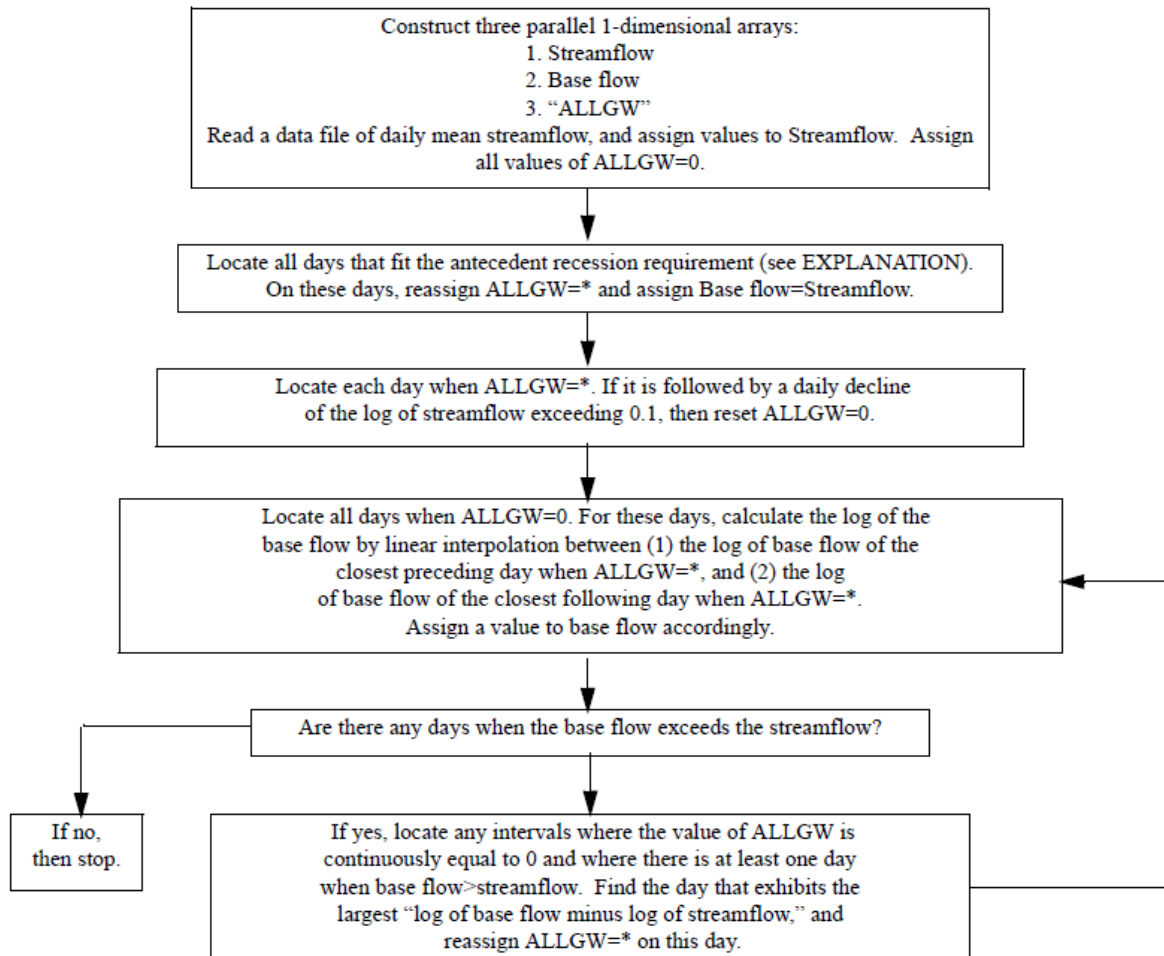


Figure 10: Flow diagram of PART programme steps
Source: Rutledge (1998) and Rutledge and Daniel (1994)

2.3.4.5 Smakhtin low flow

Low flow estimation in South Africa by Smakhtin and Watkins (1997) is a comprehensive and thoroughly investigated topic. Only the baseflow separation section will be investigated for the purpose of this study, which is incorporated in the hydrological modelling application software (HYMAS) program. The HYMAS package includes multiple methods such as (Smakhtin and Watkins, 1997):

- Flow duration curve construction (extracting low-flow indices).
- Analysis of frequency magnitude and duration of low flow events.
- Baseflow separation procedures.
- Calculation of recession properties of a stream.
- Low flow frequency analyses.

Two baseflow separation techniques are incorporated into HYMAS, namely, an RDF and a rational method with examples shown in Figure 11.

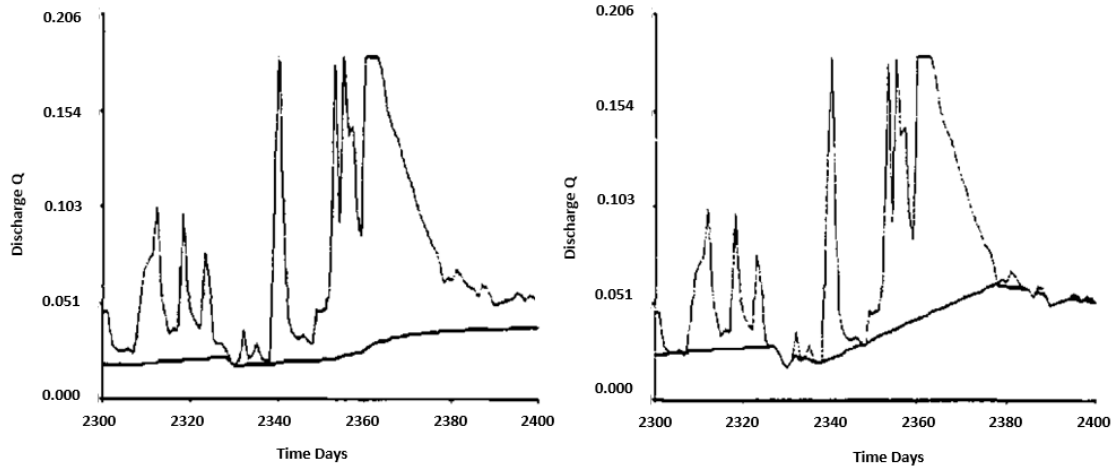


Figure 11: Left Method 1, Right Method 2
Source: Smakhtin and Watkins (1997)

As previously discussed, method 1 uses an RDF method separating high frequency and low-frequency components on the streamflow hydrograph. The calculation for this specific method is presented in Equation 10 (Smakhtin and Watkins, 1997).

$$q_{b(i)} = \alpha q_{(i)} + (1 + \alpha)q_{b(i-1)} \quad [10]$$

q = Monthly flows (cubic metres per second)

I = Time step (month)

α = Filter parameter

q_b = Part of the flow contributing to baseflow (cubic metres per second)

Method 2, labelled 'rational method' at the time (Smakhtin and Watkins, 1997), is based on the results from a recession analysis. This analysis provides method 2 with a set of nodal points in the hydrograph, which are the ends of recession periods where quickflow is assumed to be zero. Flat areas (low flow frequencies) are also assumed to comprise baseflow. A line is then interpolated between the nodes, forming the split between direct runoff and baseflow, while also constraining the data not to exceed the original streamflow hydrograph (Smakhtin and Watkins, 1997).

The Smakhtin HYMAS package is characterised as a user-friendly system that operates entirely through a menu-driven interface. The methods have been applied to catchments across South Africa and has been updated and enhanced throughout the course of various projects. The results showed that South African catchments characteristics exhibit a very

high variability and that low flow frequencies should be addressed at a fine resolution on the quaternary scale or smaller (Smakhtin and Watkins, 1997).

The HYMAS software has been developed to be applicable to different data sets, i.e., observed and simulated, with time resolution of daily and monthly flows, which is especially the case for the South African Department of Water and Sanitation (DWS) hydrological data pertaining to daily and monthly flows. The methods were applied to 240 streamflow gauging stations across South Africa. The results showed that South African catchments characteristics exhibited a very high variability and that low flow characteristics depended on physiographic factors and should be addressed at a fine resolution (quaternary or smaller) (Smakhtin and Watkins, 1997). In most cases, the method proved successful for basin-wide analysis of low flow across South Africa but was limited in terms of data quality, limited rainfall data and knowledge of characteristics of the catchments. Other complications included abstractions from rivers, inter-basin transfers, sewage plants, and farm dams. The application of the software is also time-consuming (Smakhtin and Watkins, 1997).

Strong groundwater components in many circumstances result in high baseflow values and the converse holds true. Therefore, groundwater components strongly indicate the estimated or expected baseflow value for a catchment. Proposing a baseflow estimation method in South Africa should thus include adequate and flexible characteristics of the catchment to estimate a realistic baseflow value relative to the catchment (Smakhtin and Watkins, 1997).

2.3.4.6 UKIH

The UKIH method is based on the interpolation of so-called turning points within streamflow data. Turning points are identified by the days where observed flow is assumed to be equal to baseflow. In order to calculate these points, segments of five consecutive days are proportioned, and the minimum value within each segment is selected as a candidate and compared to previous and following segments. Candidate turning points are then analysed by means of Equation 11 (Piggott *et al.*, 2005) with typical results shown in Figure 12,

$$0.9y_i < \min(y_{i-1}, y_{i+1}) \quad [11]$$

y = Minimum turning points of 5-day segments

i = Time step (days)

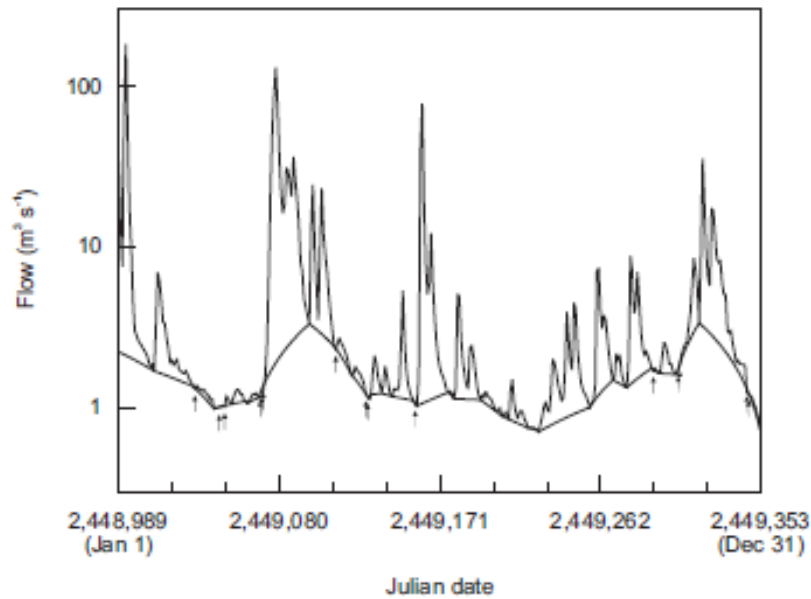


Figure 12: UKIH method
Source: Piggott *et al.* (2005)

This process results in a sequence of turning points which are then linearly linked through interpolation, which in turn forms the baseflow section of the hydrograph. This method holds some conditional rules: it cannot calculate baseflow if fewer than two turning points are defined; the baseflow cannot be calculated outside of the turning points resulting in a calculated value gap at the start and end of the streamflow hydrograph (Piggott *et al.*, 2005).

The UKIH method is constantly reviewed and evolved (with the latest method referenced being version 3.2.1.1 UKIH [2008]), and aspects are changed to fine-tune the method for optimal results. Constraints are removed so that the calculated values do not exceed the observed values which eliminates the dependence on 5-day segmentation. This allows for a more precise interpolation so therefore improved result (Piggott *et al.*, 2005) (Figure 13).

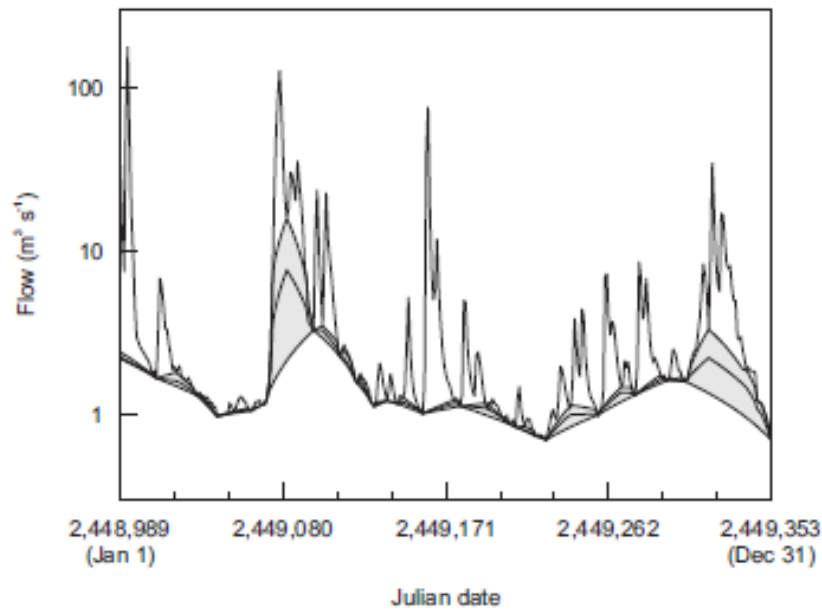


Figure 13: UKIH revised method

Source: Piggott *et al.* (2005)

Piggott *et al.* (2005) compared and combined the UKIH with the RDF method resulting in higher baseflow estimates. The UKIH simply connects consecutive turning points by linear interpolation resulting in sharp peaks and the method is therefore used in conjunction with RDF to filter the data twice (once through each of the methods). The UKIH method ultimately behaves as a straight-line graphical method where daily flows are linearly interpreted between high-frequency events. Combining the two methods resulted in what is considered a realistic result (Aksoy *et al.*, 2009).

2.3.4.7 Tracer test

Tracer tests serve as a fundamental technique in hydrological and geohydrological investigations, involving the deliberate introduction of a known chemical or isotope, such as deuterium (^2H), oxygen-18 (^{18}O) or salts, into a designated upstream water source, river, or borehole (Camacho *et al.*, 2015). Boreholes are aimed at baseflow estimations as the tracer needs to move through ground to the river downstream. The subsequent monitoring of concentrations and the time it takes for the tracer to traverse to a downstream location enables the determination of various hydrogeological parameters within the study area, including baseflow, porosity, pollution plumes, and aquifer characteristics. This methodology enables quantifying both the timing and magnitude of groundwater contributions to rivers. The concentration time curve obtained through tracer studies can then be used to determine a percentage split of baseflow from streamflow similar to calculating baseflow index which is baseflow divided by total streamflow.

In the context of South African catchments, the literature on tracer tests is relatively scarce, reflecting the inherent challenges associated with the temporal, financial, and labour-intensive nature of such studies. Despite these constraints, the value of tracer tests in advancing our understanding of hydrological systems are worthwhile considering (Mekiso and Ochieng, 2014; Turnadge and Smerdon, 2014).

Tracers are broadly categorised into two types: environmental and artificial. Within the artificial category, fluorescent and salt tracers are notable, characterised by their detectability through radioactive emissions. Environmental tracers, on the other hand, encompass isotopes that remain stable during their application but can be activated to emit radioactivity for subsequent analysis. The ideal groundwater tracer is expected to be conservative, seamlessly tracking water flow without significant losses to adjacent rock types, such as adsorbing sediments. Additionally, it should be non-toxic, easily detectable with high sensitivity, and amenable to accurate measurement. Cost considerations, both in terms of tracer procurement and subsequent analysis, further contribute to the selection of an ideal tracer (Turnadge and Smerdon, 2014).

Advantages of tracer studies on baseflow include their ability to provide insights into groundwater dynamics, quantify groundwater contributions to surface water bodies, and delineate aquifer characteristics. Tracer tests offer a unique window into understanding the movement and interaction of water within a hydrological system. However, the methodology is not without its challenges. Disadvantages include the financial and logistical demands associated with conducting tracer tests, potential environmental impacts of the chosen tracer, and the need for careful interpretation of results, considering the complex nature of subsurface flow pathways. Additionally, the accuracy of tracer studies is contingent upon the choice of an appropriate tracer and the meticulous execution of the experimental setup and analysis (Mekiso and Ochieng, 2014).

2.4 Advantages and disadvantages

These methods were not tested in this study and were only analysed from literature to understand the advantages and disadvantages from a user perspective and gain more insight into the methods. Many methods offer the advantage of being integrated into software computer programs, which significantly reduces calculation time. However, this convenience comes with the trade-off of needing to overcome a learning curve to effectively operate the program. Hand methods, on the other hand, are time-consuming when processing large amounts of data. This is possible for a single hydrograph event, but it is prone to human errors. A physical method such as tracer tests is also time-consuming and costly and requires

experience and know-how to obtain trustworthy results; however, this method yields the most accurate results because tracer concentrations do not change over time and space and are therefore ideal to track flows (Mutema and Chaplot, 2018; Schulze *et al.*, 2005; Gonzales *et al.*, 2009).

Various baseflow estimation methods have been employed, each with its set of advantages and disadvantages. The HYSEP stands out for its widespread use and systematic approach, but its dependency on substantial streamflow data can be a limiting factor unless seamless data entry can be obtained. Similarly, the RDF method offers simplicity and visual interpretability but is subjective in its application, particularly in catchments with intricate hydrological behaviours. Its mathematical side makes adaptation easy and also easily applicable in order to incorporate catchment specific characteristics in terms of parameters (Gonzales *et al.*, 2009).

The Herold baseflow separation technique provides an intuitive means of estimation. However, the reliance on user interpretation and potential imprecision, especially in data-scarce regions, raises concerns. RCF methods (including PART, RORA, and RECESS) focus on the recession limb of the hydrograph, capturing essential baseflow characteristics. However, despite their suitability for diverse hydrological behaviours, these methods often necessitate parameter calibration and might be sensitive to data quality. These methodologies are not as efficiently practical to apply as RDF, but they hold interesting interpretations.

For low-flow conditions, the Smakhtin low flow method, HYMAS, is valuable, particularly in parched regions such as South Africa. Its consideration of predecessor conditions enhances accuracy, yet it demands a sufficient dataset for reliable performance. As previously discussed, HYMAS provides valuable insight into key catchment characteristics that affect baseflow, which can be easily obtained and incorporated into easily applied methods such as RDF or Herold. Characteristics like hydraulic gradient, hydraulic conductivity, and groundwater yield are essential. The UKIH method, tailored for UK catchments, is as a systematic approach considering geology and land use. However, its applicability in regions with different hydrogeological characteristics may require adjustments.

Considering South Africa's hydrological landscape, characterised by diverse hydrogeological conditions, dynamic land use patterns, and variable precipitation, creating a tailored baseflow estimation method becomes imperative. Diversity in data, including a broad range of variables or factors, can lead to a more comprehensive understanding of the studied system. It allows for capturing various aspects, providing a holistic view. Integrating tracer studies

into the methodology can enhance accuracy by accounting for groundwater contributions, a crucial factor in regions with varying hydrological contexts.

Table 3 provides a broad overview of various baseflow estimation methods, detailing their respective advantages, disadvantages, complexity ratings, required data inputs, and parameters. Each method offers distinct advantages, such as established methodologies or consideration of spatial variability, alongside inherent limitations, such as data requirements or the need for calibration. The complexity ratings reflect the level of difficulty in understanding and implementing each method from my own perspective and research, while the listed parameters highlight the key variables necessary for their application.

Table 3: Comparative analysis of baseflow estimation methods: Advantages, disadvantages, and requirements

Method	Advantages	Disadvantages	Complexity	Data Inputs	Parameters Required
HYSEP	Well-established method	Assumptions may not hold in all conditions	Medium	Streamflow data	Watershed area (e.g., km ²)
RDF	Effective in separating baseflow from runoff, number of parameters affects estimation	May require calibration	Medium	Streamflow data	Filter parameters, watershed area (e.g., km ²)
Eckhardt and Lynne Method	Suitable for analysing long-term trends	Calibration may be necessary	Medium	Streamflow data	Watershed area (e.g., km ²)
Herold Baseflow Estimation	Considers spatial variability in baseflow	Data requirements makes sense from hydrological point of view	Low	Streamflow data	Watershed area, land use, soil type, etc.
RCD	Conceptually straightforward	Data availability may limit applicability	Medium	Streamflow data	Watershed area (e.g., km ²)
RORA	Incorporates soil moisture dynamics	May require extensive secondary data	High	Streamflow and soil moisture data	Watershed area, soil properties, vegetation type, etc.
Smakhtin Low Flow	Suitable for low flow analysis and noteworthy insights into parameters affecting baseflow	May not be applicable in all hydrological conditions	Medium	Streamflow data	Watershed area (e.g., km ²)
UKIH	Well-established method	May require calibration	Medium	Streamflow data	Watershed area (e.g., km ²)
Tracer Studies	Provides direct measurement of groundwater contributions	Resource intensive	High	Tracer data, hydrological data	Tracer type, injection rate, injection duration, etc.

In summary, the literature review has provided a comprehensive understanding of fundamental hydrology concepts, the definition, and key principles of baseflow, and a critical evaluation of existing baseflow estimation methods, including hydrograph separation (HYSEP), recursive digital filtering (RDF), the Herold method, recession curve displacement (RCD), the Smakhtin low flow method, and the United Kingdom Institute of Hydrology (UKIH) method. This foundation sets the stage for developing a novel baseflow estimation technique tailored to South African conditions. Building on these insights, Chapter 3 will outline the methodology employed in this study, detailing the data collection process, study areas and the analytical methods used, including the application of Python scripting. This chapter will also discuss the rationale behind the chosen methods and how they address the gaps identified in the existing literature.

Chapter 3 Methodology

This chapter describes the database setup and automated data collection of streamflow data from the DWS hydrological database, followed by the collection of additional catchment characteristic data used in the process of developing a new baseflow estimation method from the insights of the literature.

3.1 Hydrograph data collection

All available gauge station data across SA was obtained from the verified hydrological streamflow data at the DWS (Department of Water and Sanitation, 2022) website (<https://www.dws.gov.za/Hydrology/Verified/>) as shown in Figure 14. The data was extracted from the site using software known as Selenium, which linked the data to a MySQL database and sorted it to make it more user friendly to ultimately view and use in Excel.

The daily average and/or monthly flow data were recorded and stored in the DWS online database, accessible by selecting the appropriate flow gauge. To streamline the process of obtaining all flow gauge data on the website (essentially creating a copy of the database), a Python script was employed to automate data extraction from each flow gauge. As an integral component of the proposed method, the database will be incorporated into the comprehensive product, which currently houses all available flow gauge stations derived from the website (server database). Users can access these stations with a simple click of a button, and the database continually updates as new data becomes available. As an integral component of the proposed method, the database will be incorporated into the comprehensive product, which currently houses all available flow gauge stations. However, in the current study only selected data was used which aligned with the tracer studies on the baseflow and the availability of reliable streamflow data. These restricted stations are highlighted in red in Figure 14, with their respective locations detailed in Table 4.

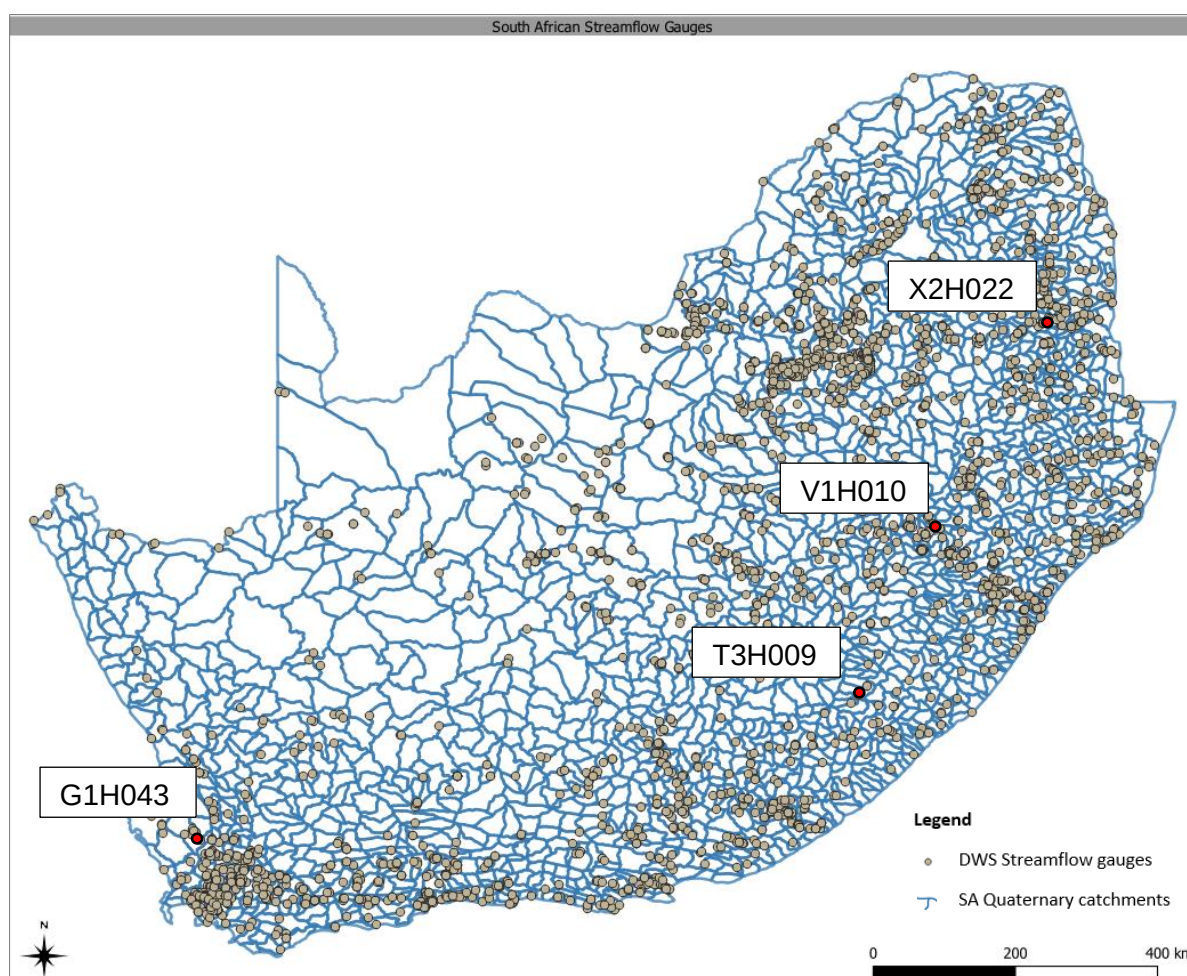


Figure 14: South African quaternary catchments and selected streamflow gauge stations.

Source: <https://www.dws.gov.za/Hydrology/Verified/>

Table 4 shows the stations which were selected based on tracer study availability in South Africa, with their respective coordinates and data availability dates further discussed in Chapter 3.4.

Table 4: Gauge stations used in study.

Station	Latitude	Longitude	Start Date	End Date
G1H043	-33.16111	18.89222	4/10/1996	10/6/1997
T3H009	-31.07166	28.35361	3/11/1934	16/12/1955
V1H010	-28.81813	29.54505	10/1/1977	9/1/1978
X2H008	-25.78602	30.92433	6/1/1966	9/1/1967
X2H022	-25.54322	31.31669	9/10/1973	10/11/1974
X2H010	-25.61111	30.87491	10/1/1962	9/1/1963
X2H031	-25.73025	30.97838	10/1/1984	8/1/1985

DWS verified hydrological data was assigned a quality code, allowing for the identification of "good quality" data. Additionally, certain aspects of the data were hand-picked to address any inaccuracies or inconsistencies, further enhancing the reliability of the dataset. This

meticulous approach guaranteed that only accurate and reliable information was incorporated into the analysis, and quality codes created an easy form of filtering out bad data maintaining the integrity of the data quality process. Examples of filtered out data were duplicate flow values over multiple days or monthly values allocated to daily data sheets and averaging of data across time periods – these were also demarcated with a quality code.

3.1.1 Establishment of streamflow database

Connecting to the online DWS database and retrieving the flow gauge data requires human input to manually select a gauge station and meticulously download a set of data by clicking some dropdowns and functions on the DWS database interface. The intelligence of the script is that in order to automate this download process a looped script replicates the actions of a user by “clicking” on flow gauge station and downloading the data sets then converting them to excel with an automated update function. Essentially this script can access (with permissions) any online website and function as a “human” and interact with the website with some minor adjustments. In the current study this functionality allowed the use and collection of data to be seamless and immediate and forms a crucial part of the proposed method discussed in section 3.5 to allow a user of the method to seamlessly pull any flow gauge and apply the proposed method. The particulars of how this was done is described as follows: a Python script prompts Google to open a URL, namely ‘DWS verified hydrograph data’ (Department of Water and Sanitation, 2022), a direct link to the South African Streamflow database. The Python script then prompts the use of the website HTML coding, and from there, the script prompts certain selections to export the monthly and daily flow values from every stream gauging station. The script is set up to loop through every station available, check the data availability, and then download the data. The data is then linked to an Azure SQL package database by using a URL that links the two and stores all tables and data extracted by the script. The script dictates how the data is stored by using fields for dates, flow, and data quality codes. Local CSV files are saved to ensure the integrity of cloud and local storage data.

3.2 Borehole data

Borehole data was collected from the National Groundwater Archive (NGA) for South Africa (Appendix A). Only water level data was extracted for the study areas. This data was then used to extrapolate the hydraulic gradient, as discussed in Chapter 3.7.4, utilising the insights from Maliva (2014) and as described by Smakhtin and Watkins (1997), where research and evidence indicates hydraulic gradients do in fact change the balance between quick flow and baseflow if utilised for low flow frequencies and build-up of events.

3.3 Hydrogeological data

Hydrogeological maps on the 1:500 000 scale collected from the DWS website for groundwater resources (Barnard and Baran, 1999). This data was used to extrapolate the groundwater occurrence of the catchments, as discussed in the methodology. This data is readily available and gives great insight into groundwater and geohydrological conditions if used with catchment size.

3.4 Study areas

Several case studies across South Africa were used where baseflow was estimated through tracer tests by means of a percentage groundwater contribution to stream flow. This percentage baseflow obtained from each study was subjective to the specific study and scientist. The study areas identified/obtained were geographically adequate and widespread across South Africa improving the proposed baseflow estimation and thus being as relevant as possible for South African catchments. Figure 14 highlights the study areas pertinent to tracer studies and high-quality streamflow data. Further details concerning gauge stations necessary for additional information are listed and described.

3.4.1 T3H009

Streamflow station T3H009 is situated on the Mooi River at Maclear with a catchment size of 307 km². The geohydrological aquifer types consist of intergranular ultramafic material and hornblende (d3). There is an average groundwater slope to river of 0.018.

Case study situated in Unzimbubu Basin in Eastern Cape with streamflow station T3H009 (Figure 15). This station is located on the Mooi River south of the town of Maclear (Wenninger *et al.* 2008). Wenninger *et al.* (2008) conducted hydrometric measurements and electrical resistivity surveys with tracer sampling utilising dissolved silica (Si), chloride (Cl) and electrical conductivity, with analytical errors of $\pm 0.2\%$ for oxygen-18 and $\pm 1\%$ for deuterium.

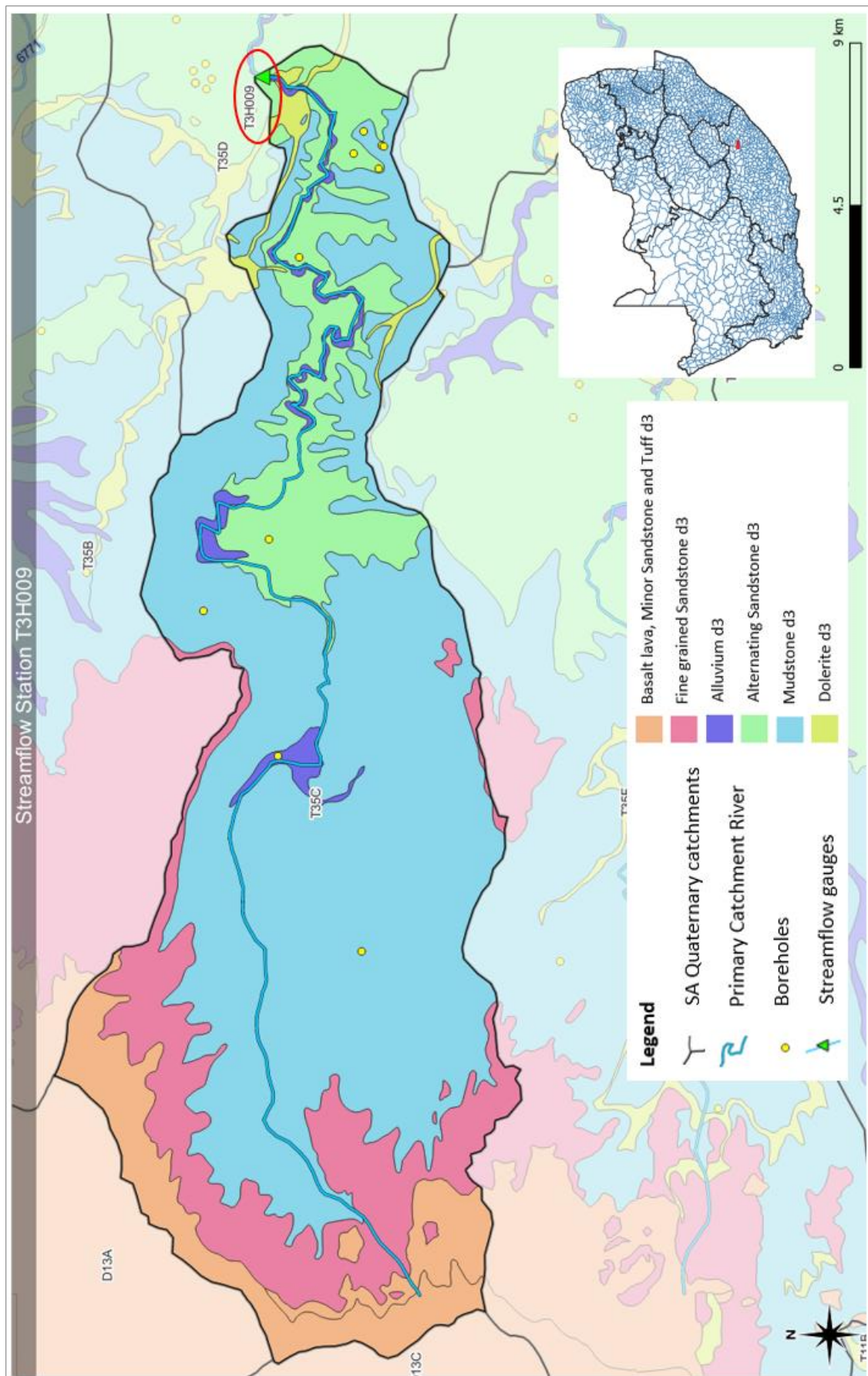


Figure 15: Study area map for streamflow gauge T3H009

3.4.2 G1H043

Streamflow station G1H043 is situated on the Sand Spruit river at Vrisgewaagd with a catchment size of 151 km². The geohydrological aquifer types consist of mostly fractured rock of sandstone and mudstone (aquifer rating b3 and b2 see section 3.9.3). Average groundwater slope to river is 0.031.

Damons's (2018) study had some shortcomings in terms of tracer data but is still noteworthy. The study on the Berg River at gauge station G1H043 resulted in a 33% groundwater contribution and concluded that too little data was sampled to verify this value. Damons's study on the gauge station stretched from the 16th of July to the 26th of July in 2014. A study by Bugar *et al.* (2012) used the water balance method to conclude that the overland contribution to streamflow was 4.92%. In order to get good coverage across South Africa, the proposed method was tested on this catchment with the 33% groundwater contribution using monthly flow data similar to Damons's results. According to Bugar's data, groundwater levels increased as more rainfall occurred, and the groundwater contribution had increased from 1.4% to 33.4% in just two rainfall events. A longer investigation with more data could have concluded a more precise calculation. The result, nonetheless, is used to get a clear understanding of the proposed baseflow estimation method. The streamflow station G1H043 catchment is depicted in Figure 16.

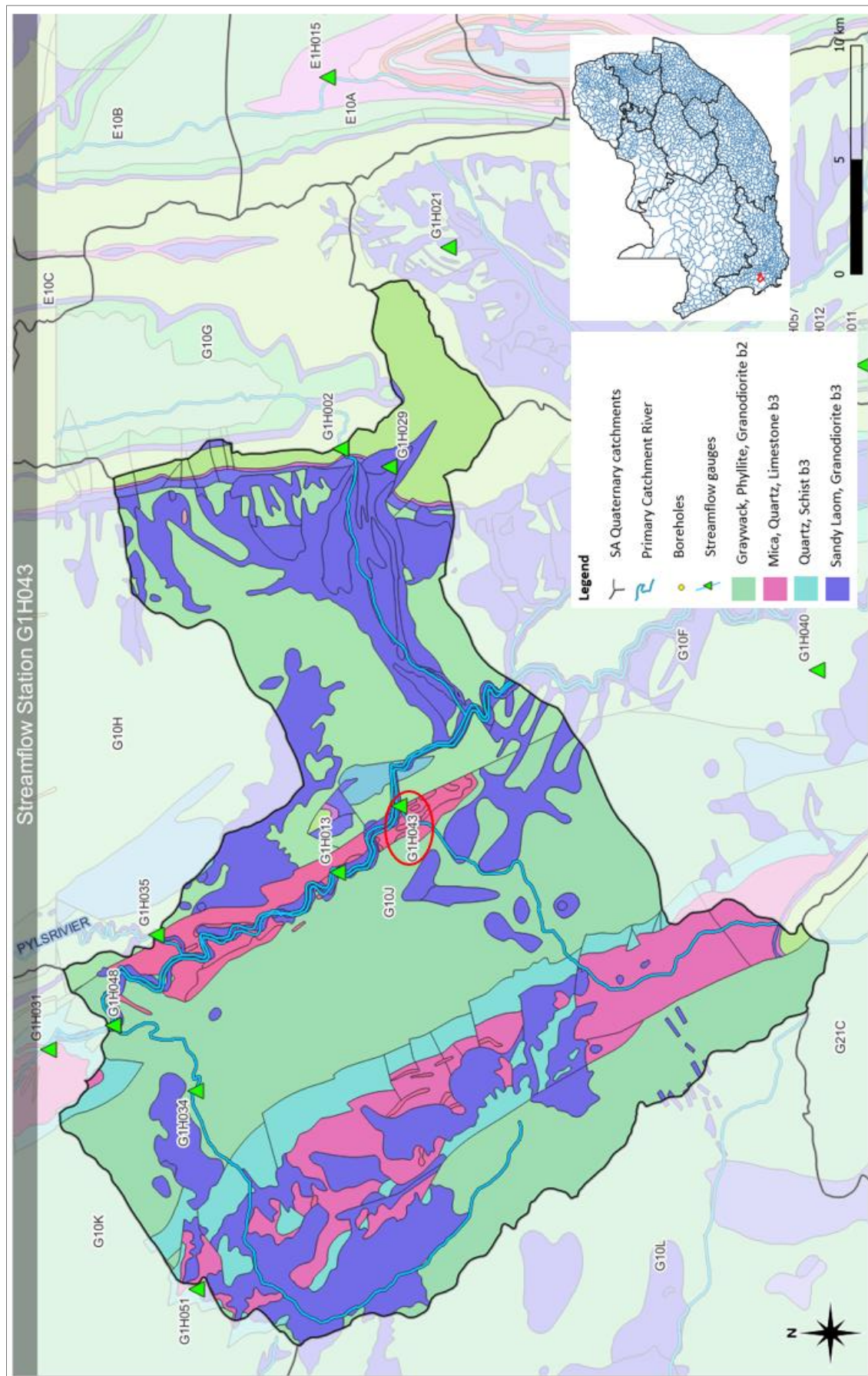


Figure 16: Study area map for streamflow gauge G1H043

3.4.3 X2H008

Streamflow station X2H008 is situated on the Queens River at Sassenheim with a catchment size of 180 km². The geohydrological aquifer types consist of intergranular Sandstone material (d3) with an average groundwater slope towards the river of 0.026.

The study conducted by Okello *et al.* (2018) on the Kaap River catchments used the tried and tested method of electrical conductivity as a tracer to conclude baseflow contributions on gauge stations X2H008, X2H010, X2H022 and X2H031. The period spanned from 1997 to 2005. The authors found a groundwater contribution of 90% during dry seasons and 50% during wet seasons for an estimated average split between the seasons of 70%. The streamflow station X2H008 catchment is depicted in Figure 17.

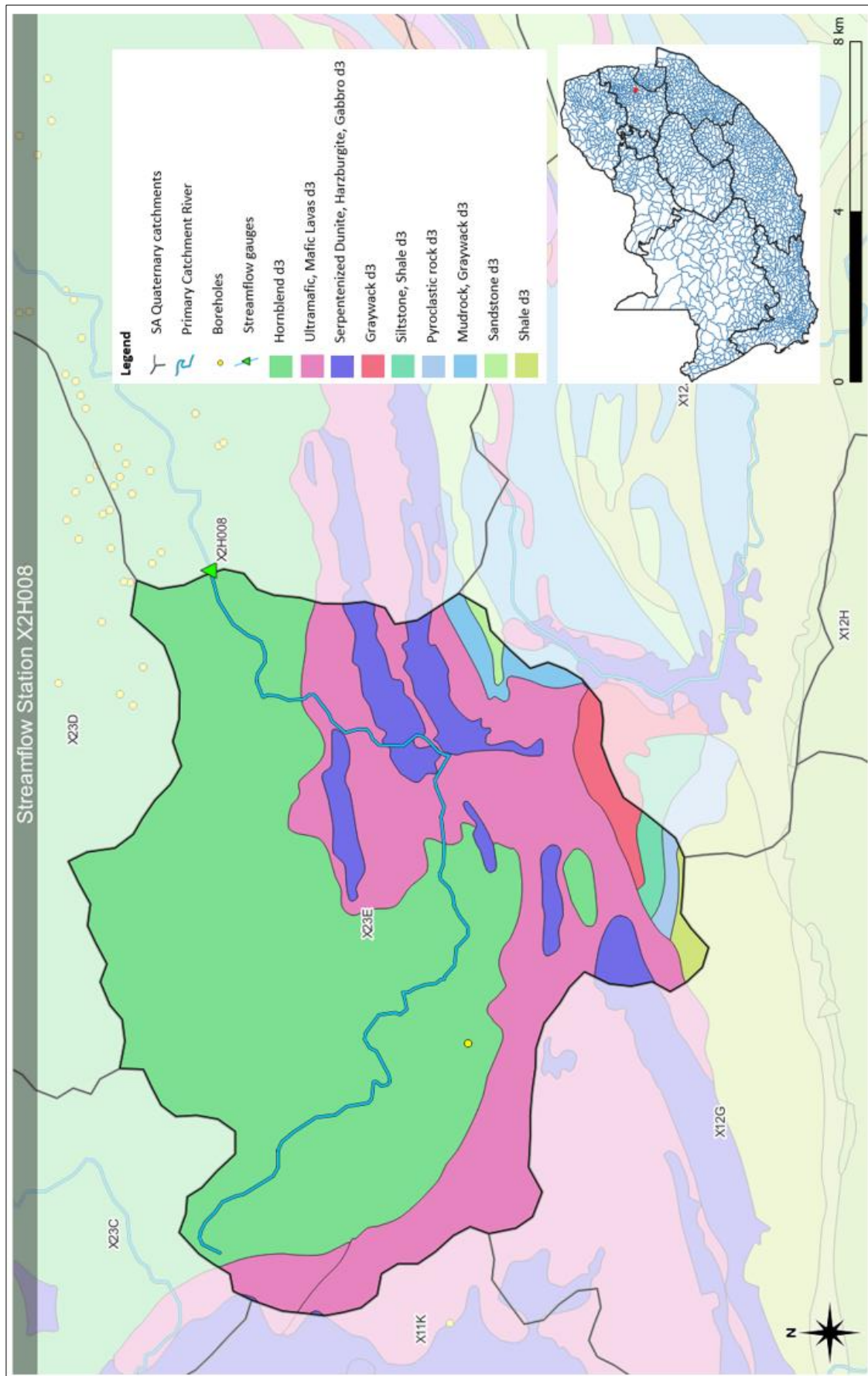


Figure 17: Study area map for streamflow gauge for X2H008

3.4.4 X2H010

Streamflow station X2H010 is situated on Noordkaap River at Bellevue with a catchment size of 126 km². The geohydrological aquifer types consists of intergranular and karst Hornblende and Dolomite material (d3, c4 and d4) and an average groundwater slope towards the river of 0.022.

The streamflow station X2H010 catchment is depicted in Figure 18. It is clear that the limited number of boreholes are isolated however the aquifer yield is consistent and covers the majority of the catchment.

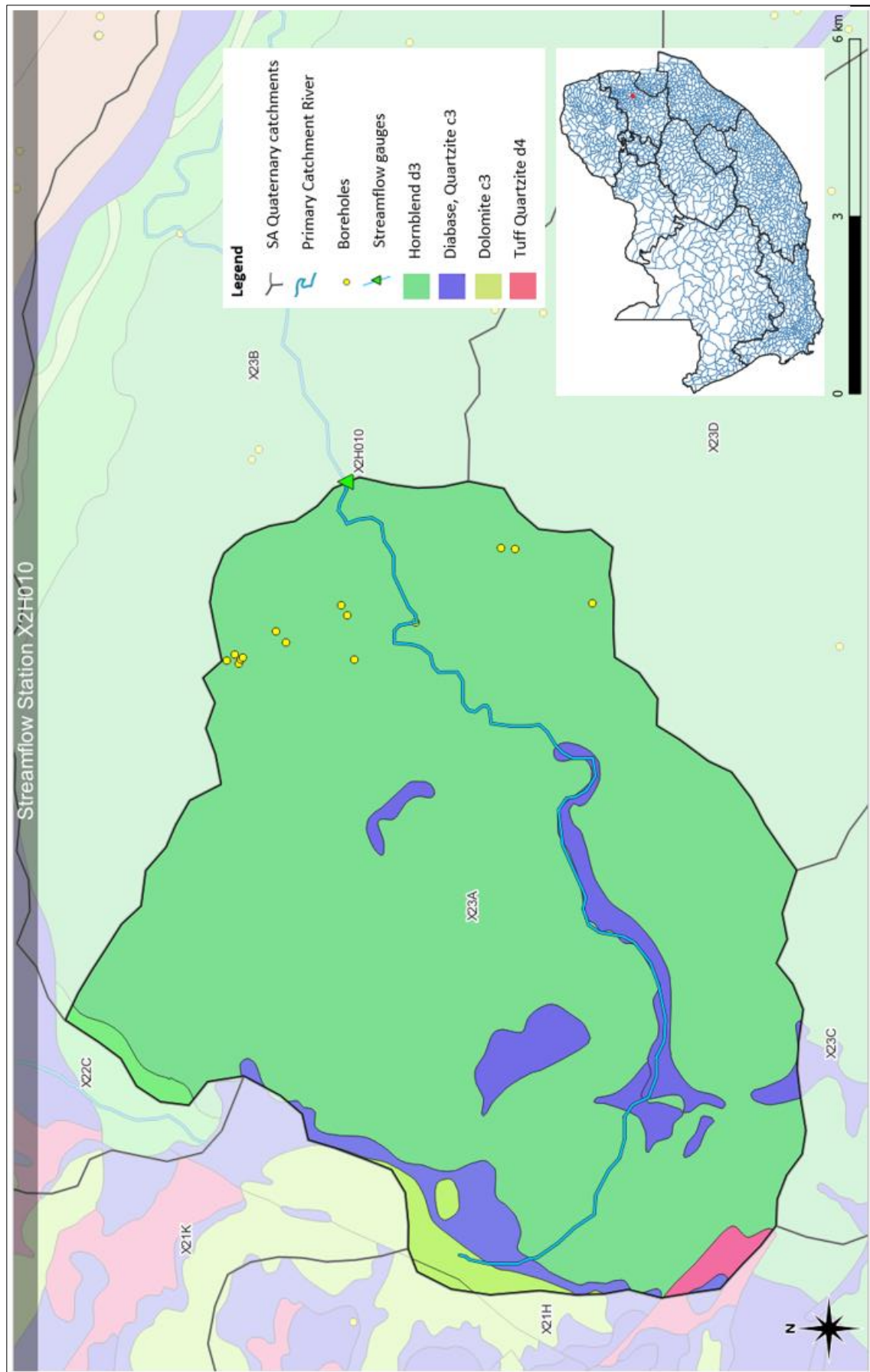


Figure 18: Study area map for streamflow gauge for X2H010

3.4.5 X2H031

X2H031 streamflow station is situated on Suidkaap River at Bornmans Drift with a catchment size of 262 km². The geohydrological aquifer types consisting of intergranular Hornblende material (d3 and d4). Average groundwater slope towards river of 0.024.

The streamflow station X2H031 catchment is depicted in Figure 19. This catchment is south of the X2H010 catchment and has similar catchment characteristics but with a higher number of boreholes covering the area.

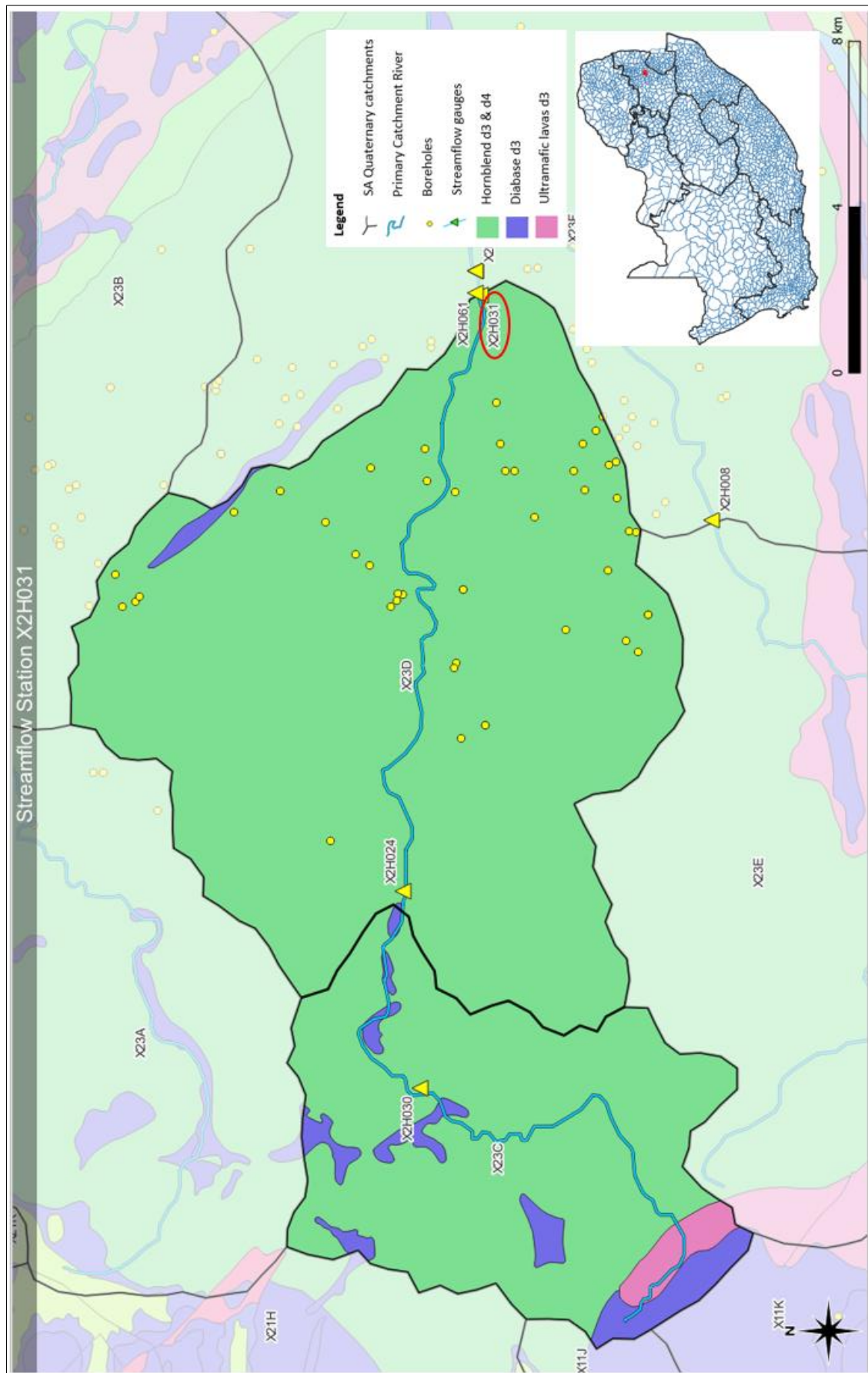
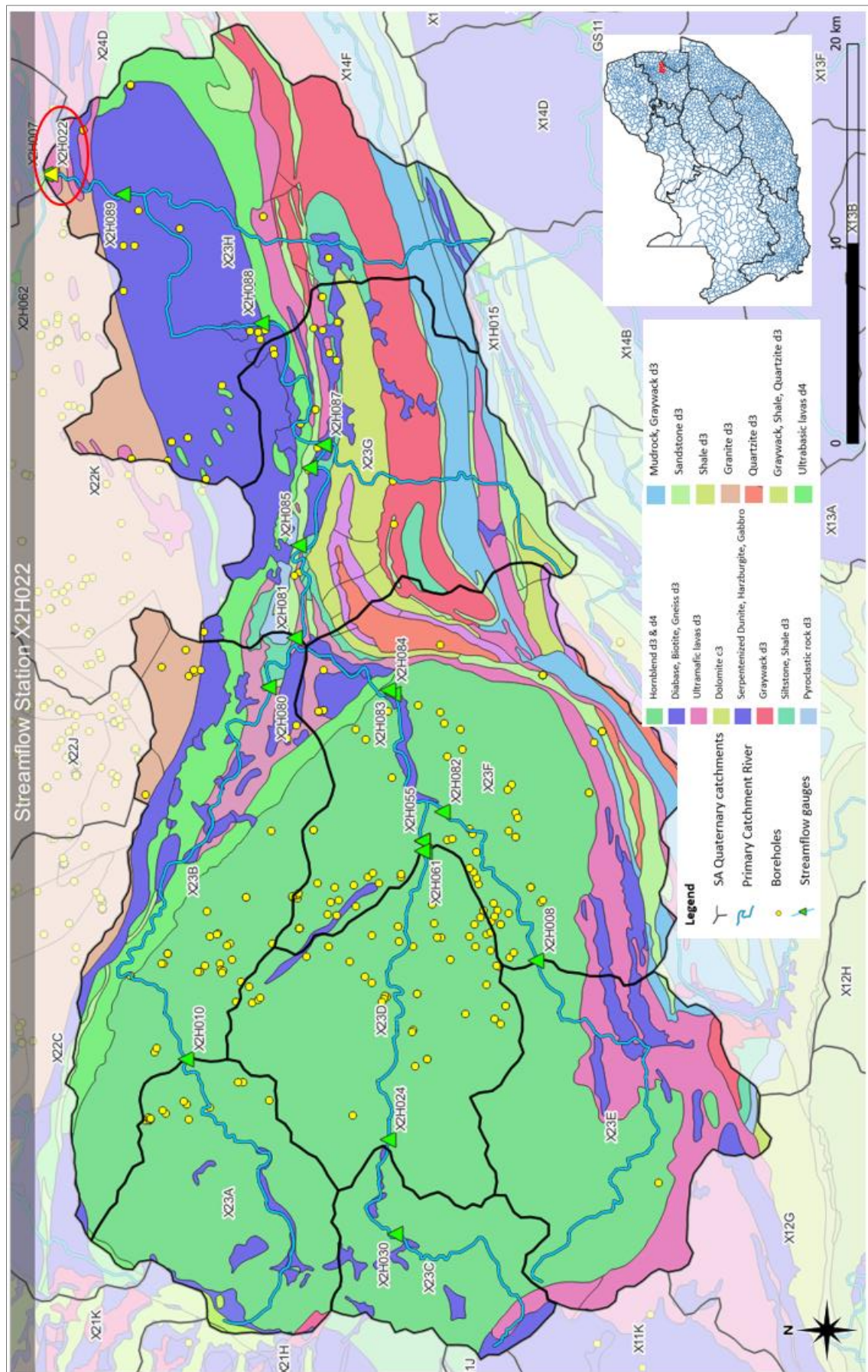


Figure 19: Study area map for streamflow gauge for X2H031

3.4.6 X2H022

X2H022 streamflow station is situated at Kaap River at Dolton with a catchment size of 1639 km². The geohydrological aquifer types consisting of intergranular Hornblende material (d3 and d4). Average groundwater slope towards the river of 0.029.

The streamflow station X2H022 catchment is depicted in Figure 20. This catchment encompassed all the previous X2H streamflow stations and some additional catchments as a comparison to larger networks or secondary catchments.



3.4.7 V1H010

V1H010 streamflow station is situated on the Little-Tugela River at Winterton with a catchment size of 782 km². The geohydrological aquifer types consisting of intergranular Sandstone material (d3 and d2). Average groundwater slope towards the river of 0.011.

Mutema and Chaplot (2018) conducted a study in the Tugela River Basin with gauge station V1H010 and multiple quaternary catchments within the basin and reached a different conclusion compared to the previous studies. A total of 40% overland runoff contributed to streamflow on a catchment scale and 67% on basin-scale when using End Member Mixing Analysis (EMMA) with sodium (Na) and silica (Si) as tracers. The study data covered the period spanning from the 1st of September 2012 to the 30th of April 2013. The comparison of baseflow methods is shown in Figure 21.

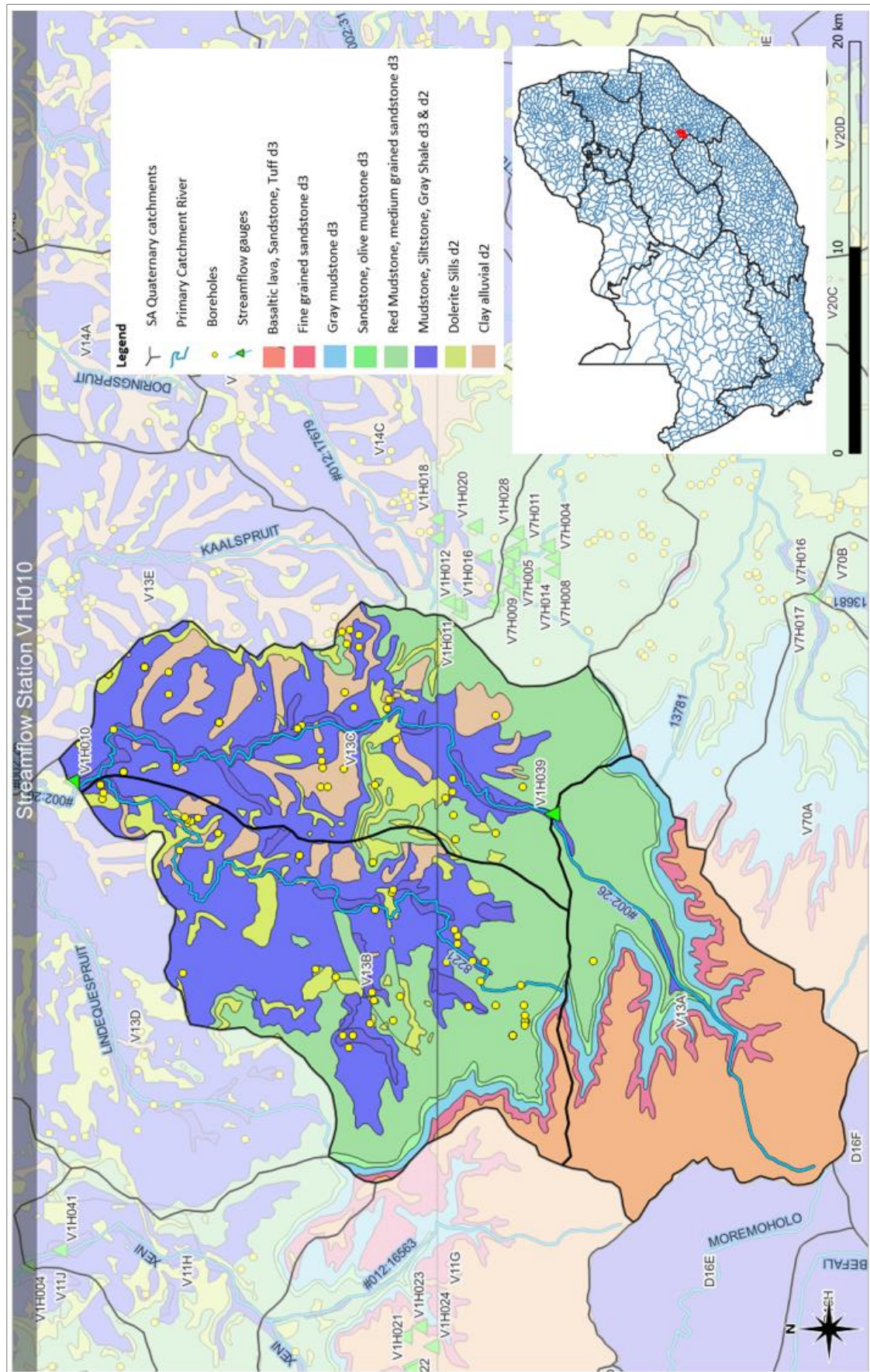


Figure 21: Study area map for streamflow gauge for V1H01

3.5 Developing the proposed estimation method

A new method was developed around the strengths of the main estimation methods found in the literature review and applied to verified tracer studies (baseflow percentages) in order to replicate the tracer baseflow percentages using the newly developed baseflow estimation method. The proposed method used catchment characteristics identified in literature with strong representation of the findings by Smakhtin and Watkins (1997) on catchment characteristics related to baseflow. The following assumption were made:

- The catchment characteristics (parameters) for these study areas are directly proportional to the tracer baseflow percentages, for example, the entire spectrum of catchment characteristic is assigned a sliding interval parameter (for instance the catchment size, bigger catchment sizes equal to bigger parameters). The assumption is that the tracer can be used to obtain the required parameters.
- Parameters denote individual characteristics or factors deliberately manipulated by the researcher to influence the method's outcome, thereby establishing a range of parameters. When calibrated or proportionate, they can be applied to any other catchment characteristic within the spectrum. Alternatively, they function as transferable or scaled parameters (scaling factor), enabling the estimation of unknown parameters based on known catchment characteristics. This implies that if a parameter maintains direct proportionality with known catchment characteristics across all study areas, it can be applied elsewhere without the need for tracer studies or prior knowledge of baseflow, solely based on the established catchment characteristics. It is important to note the diverse range of South African catchment characteristics covered in the study areas, addressing each parameter comprehensively (refer to Section 3.7 for detailed discussions on each parameter).

This allowed for a method to be built/proposed using the catchment characteristics and the proposed baseflow estimation method by simultaneously applying scaled parameters to each study area until a directly proportional straight-line graph was obtained for each characteristic. The same parameters were applied to all catchments (duplicated for all three parameters, namely: aquifer yield, average slope, hydraulic conductivity). The initial estimation of baseflow percentages was performed using the default input parameters specific to each case study being examined. Subsequently, these input parameters underwent calibration until they demonstrated a satisfactory level of agreement with the tracer-based baseflow estimates. In other words, the parameters fed to the proposed estimation method were applied repeatedly as sliding filters to try and calculate the same baseflow percentage as calculated by the tracer study for all study areas simultaneously.

This process was repeated until a straight line (directly proportional) parameter was found for each of the three parameters and catchments that resulted in the exact same baseflow percentage as the tracer test results for all catchments. All of this was done simultaneously and meticulously repeated until all parameters were “calibrated”, and the method could successfully calculate the same baseflow percentage as the tracer test with its given catchment characteristics. This implies that for unknown parameters at a unique catchment the characteristics can simply be applied to the linear graph and the corresponding parameter can then be read from the graph slotted into the newly proposed method and estimate a baseflow unique to the catchment characteristics associated with the baseflow.

Using the tracer baseflow and calibrating South African specific parameters of a catchment allowed for the estimation method to be applied without the need for physically undertaking tracer studies. The aim was to develop a method that can be applied to any catchment across South Africa with catchment parameters that mimic baseflow characteristics.

By using the tracer studies at the exact same flow gauge along with the related catchment characteristics, the parameters were calibrated for all selected studies at once. The relationship between catchment characteristics and parameters allows the proposed baseflow estimation method to be applied to any other catchment. It should be noted that the fieldwork of the studies that the current study drew data from was conducted at weir structures or by hand, which means that the dates or timelines used in these studies may not have matched the data availability of DWS. Nevertheless, the focus in the current study was on the catchment characteristics, and timelines of the studies were picked as close to each other as possible, or in a similar time of the hydrological year. This means that the method will hold true for the catchment characteristics for the time it was captured.

3.6 Algorithm

Most baseflow estimation methods are based purely on a mathematical approach to determine baseflow (not linked to any physical characteristics of the catchment). However, this study used a more direct approach with simple percentage-based equations with basic calculations, using only the streamflow data and catchment parameters as inputs.

As explained and retrieved from the literature on substantial low flow studies from Smakhtin and Watkins (1997), a baseflow estimation method for South Africa has to be able to be applied on a small scale due to large variability found in catchments and be diverse and flexible enough to capture the characteristics of the catchment, which means that these physical parameters need to be quantified.

Referring to the literature and conclusions by Smakhtin and Watkins (1997), the proposed method uses the following physical parameters: hydraulic conductivity, hydraulic gradient or slope, and geological groundwater aspects. The data is prepared using available data from the catchment on a weighted average basis subject to data availability.

3.7 SABEM

The baseflow estimation method arising from this study and proposed for South Africa is referred to as the South African Baseflow Estimation Method (SABEM). SABEM was developed by leveraging the strengths identified in existing baseflow methods described in the literature while incorporating strategies to overcome the limitations associated with those methods.

SABEM aims to make use of the diversity in South African catchments and diverse data which can lead to a more comprehensive understanding of the baseflow in South Africa by allowing various aspects to be captured providing a holistic view. Patterns, relationships, and trends can be revealed that are not immediately apparent when analysing limited sets of variables.

By capitalising on the advantages found in previous research explained in more detail to follow, SABEM aims to enhance the accuracy and reliability of baseflow estimation specifically tailored to the South African context. It carefully considers the shortcomings observed in existing methods, ensuring that these drawbacks are addressed and mitigated effectively.

Through this approach, SABEM seeks to optimise the estimation of baseflow by incorporating the most relevant and appropriate techniques. This ensures that SABEM is tailored to capture the unique characteristics and challenges posed by South African catchments, resulting in a more robust and reliable baseflow estimation based on the following:

- Using multiple parameter inputs instead of only one or two parameter calculations as discussed previously.
- Using catchment specific characteristics in the estimation.
- A purpose-built estimation tool for South African catchments using South African available data.
- An automated tool that is easily applied and verified using tracer test data instead of using other methods to verify the accuracy of SABEM.
- Use of groundwater contribution to baseflow parameters as inputs to define SABEM.

- Calibration of parameters so as to obtain the tracer indicated baseflow percentage.

The SABEM method is not tackled purely as a mathematical problem; instead, it is viewed as a catchment characteristic problem. The focus lies on understanding the catchment's features and determining how to effectively apply these characteristics to extract a baseflow value from the input streamflow data. SABEM equations are defined through a series of IF-statements. This closely resembles the averaging and straight-line advantages found in using the Herold method for South African catchments, where a series of parameters are combined with limits to define a mathematical and visually acceptable method of estimating baseflow.

Parameters defined by Smakhtin and Watkins (1997) such as 'gains to streamflow' namely, hydraulic conductivity, hydraulic gradient, and the hydrogeological aspect of South African catchment characteristics, were used as inputs to SABEM. This data was also selected as it is relatively available from a desktop study point of view in order to define the parameters required by the proposed SABEM methodology.

The following sections describe each parameter used in SABEM and conclude how they link to each other to estimate the final baseflow value for visual and value-based purposes.

3.7.1 SABEM equation

Baseflow separation is performed for flows higher than the average (Q_a) and flows lower than the average (Q_b) using the average flow for the entire streamflow period in Equation 12. The parameters c , d and f (relating to aquifer, hydraulic gradient and hydraulic conductivity respectively, also discussed below) are then applied separately, but on both Q_a and Q_b , this allows the parameters to define high frequency flows differently than low frequency flows by separating them with an adjustable average cut-off (advantage from Herold method and RCD). The parameters and calculations used for high and low flows are the same and averaged for the Q_a and Q_b combined parameters. If one component is increased, the other must decrease in order for the averaged parameter of the two flows (Q_a and Q_b) to represent the parameter associated with the catchment. The baseflow calculations are applied to Q_a and Q_b , respectively, and the separated flows are then added to calculate the baseflow for the given streamflow data Equations 12 & 13.

$$bz_{t3} = Q_{t2} - Q_{t1} \quad [12]$$

$$by = bz_{t3} \times c$$

$$bx_{t1} = d + (Q_{t1} \times 0.7)$$

$$bx_{t2} = by + (bx_{t1} \times f)$$

$$b_t = by + (b_{t-1} \times f) \quad [13]$$

bz = Baseflow at 1st stage.

by = Baseflow at 2nd stage.

bx = Final baseflow calculation for Qa and Qb.

tn = Time interval of streamflow data, (ex. Q_{t3} = flow at day 3)

c = Aquifer type parameter

d = Hydraulic gradient parameter

f = Hydraulic conductivity parameter

Due to the emphasis on parameter determination where Smakhtin and Watkins (1997) indicated physical catchment characteristics affecting baseflow subsequently linking parameters to the catchment was also highlighted by RDF literature such as Eckhardt, which is an essential advantage that can be utilised for baseflow estimation. SABEM has been developed with a focus on simplifying the problem. This is achieved by formulating separate equations and incorporating IF-statements within SABEM.

The calibration process of SABEM involved iteratively inputting parameters and adjusting them until directly proportional parameters were obtained as described in methodology sections 3.7.1 to 3.7.5, effectively capturing the characteristic features of the catchment. This iterative approach allowed for fine-tuning the parameters to establish a proportional relationship that accurately represented the catchments' behaviour and hydrological responses.

By using separate equations and IF statements to break down the calculations, SABEM aimed to streamline the parameter determination process and simplify the complexity associated with baseflow estimation. This approach facilitated a more efficient calibration process, enabling the identification of parameter values that exhibited a direct relationship with the catchment characteristics.

Through the repetitive input and adjustment of parameters, SABEM sought to refine the estimation method to ensure that it accurately reflected the behaviour of the specific catchment under consideration. The goal was to obtain directly proportional parameters that aligned with the catchment's unique hydrological characteristics, thus enhancing the

reliability and accuracy of baseflow estimation using SABEM and its applicability to the unknown. See verification steps applied to verify this in section 4.2.

The parameters were entered simultaneously for each case study, with changes in one parameter affecting the others. Multiple iterations of entering and modifying the parameters were performed until a linear relationship could be established for each parameter (c, d, and f). The baseflow percentage required, and the catchment characteristics are known and that leaves the parameters as the unknown, meaning the characteristics and baseflow could be used to obtain the parameters for all the study areas but had to be done simultaneously, a classic example known in mathematics as linear relationship. When graphed, the parameters form a straight line and create a sliding scale. When the catchment characteristic changes so do the parameter linked to it. A linear straight line or directly proportional line indicates high precision and accuracy of a proportionally constant factor. In other words, if all study area parameters and characteristics are found to be directly proportional it can be applied to any other area where the parameter is not known through a tracer validation step.

3.7.2 Catchment size

A useful method found in the literature is the use of catchment sizes and the delayed response of the flow thereto. A simplistic approach was formulated by taking the catchment sizes across South Africa, excluding basin sized catchments larger than 1650 km². These were then ordered in descending order depicted in the histogram seen in Figure 22, where catchments were automatically populated with bin sizes of 150 km² to try and obtain a representative figure for the parameter and to achieve a consistent impact of the parameters on SABEM. Most methods discussed in literature use some form of catchment size affect. In other words, smaller catchments or unequal bin sizes would result in an uneven distribution of catchment sizes across South Africa for this specific parameter.

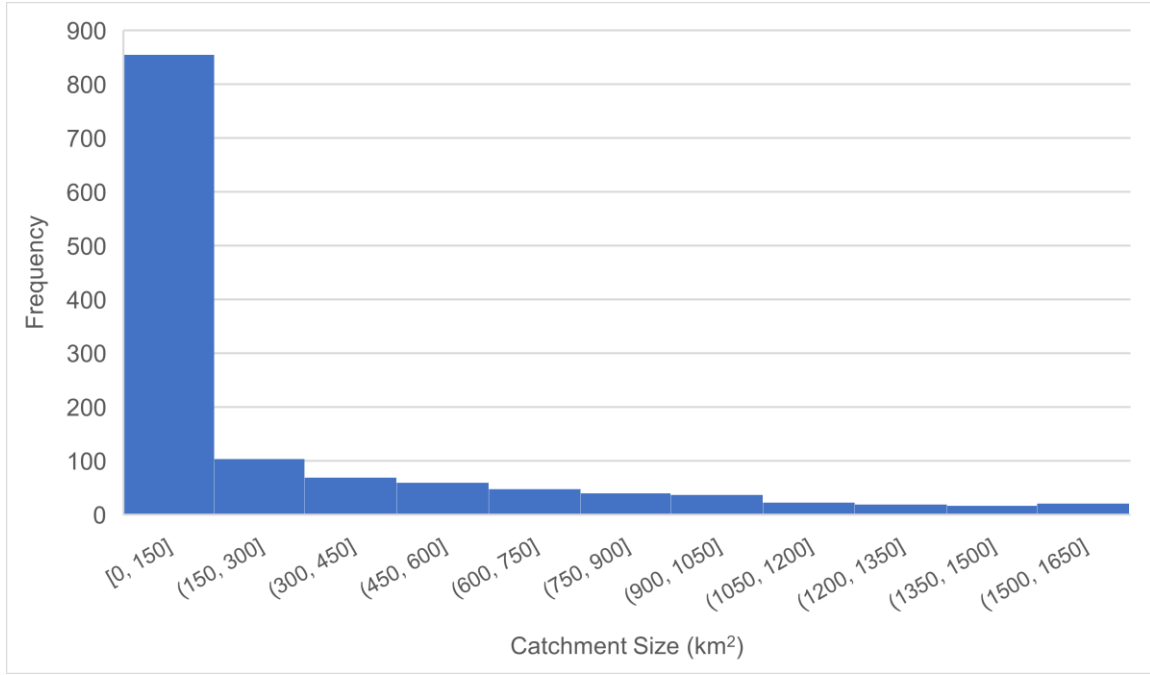


Figure 22: Histogram of catchment size frequency.

Based on this observation, the delayed time parameter was calibrated in direct proportion to each catchment size. This is similar to the UKIH method, which calculates a delayed response. These advantageous characteristics were integrated into a parameter value specific to South Africa by making use of every catchment. This customised value accurately matched the study areas.

A delayed time parameter was used in SABEM by applying the following procedure. Firstly, falling limb flows were extracted by “IF” statements to represent recession limbs of hydrographs and based on these extracted flows a certain amount of them would account for baseflow. Equation 14 describes the process in which the falling limb was identified, and the value extracted when the flow was less than the minimum value from the previous n-days of flow. A larger time parameter results in a later time response which means that a larger catchment will have a delayed response, similar to the HYSEP method.

$$Q_t < MinQ_{t-n} \quad [14]$$

Q = Daily streamflow at time step t

$MinQ$ = Minimum streamflow value from previous n days (time steps).

For example, if the parameter chosen is based on a catchment size of 600 km², it will result in a parameter with the value of 4, and this will prompt an IF statement to extract flows only

from the 4th day after the hydrograph peak. This represents delayed responses from catchment to streamflow gauge.

3.7.3 Groundwater occurrence

Using the DWS verified hydrogeological groundwater occurrence maps at 1:500 000 scale with a legend for borehole yield per aquifer type, a representative value can be extracted for the parameter c in Equation 13. Figure 23 shows the groundwater occurrence legend for relating DWS maps.

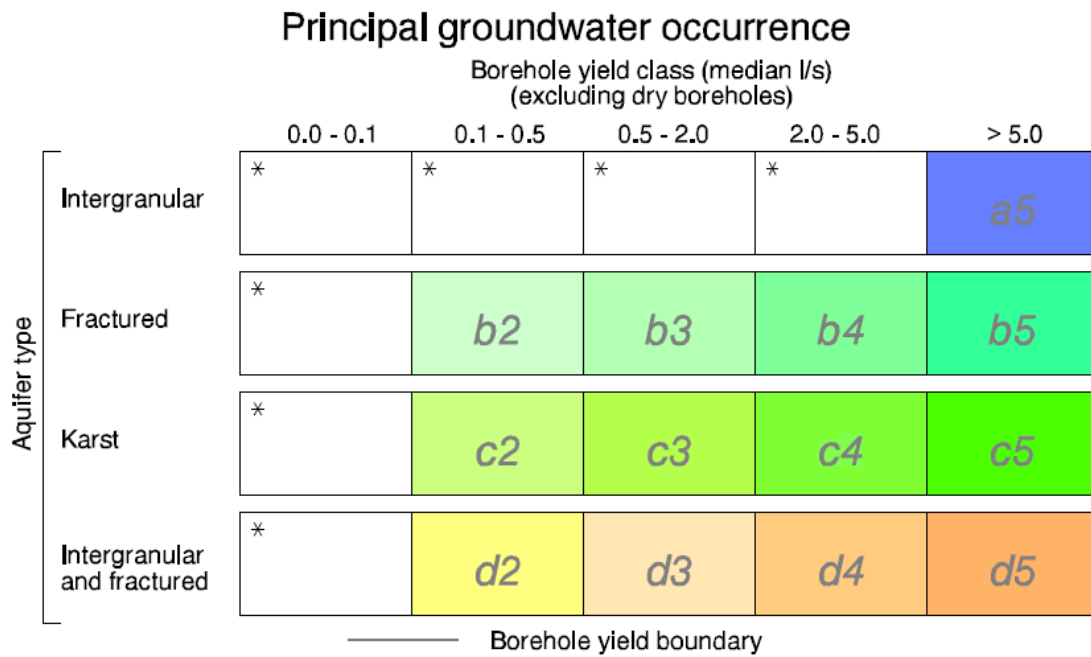


Figure 23 Principal groundwater occurrence.
Source: Barnard and Baran (1999)

Firstly, a weighted average of the aquifer type present in the catchment was calculated on median yield. The catchment groundwater occurrence characteristic was kept the same but the parameter for the equation was recalculated for each study area until a directly proportionate and representative parameter was obtained. Baseflow at a specified time step was calculated and parameter c was then applied to calculate the baseflow at the next time stage using Equation 15.

$$bz_{t3} = Q_{t-1} - Q_{t-2} \quad [15]$$

$$by = bz \times c$$

bz = Baseflow at stage z for time step t .

b_y = Baseflow at stage y , normalised value of b_z by parameter c .

Q = Streamflow at time step t .

c = Groundwater occurrence parameter.

3.7.4 Hydraulic gradient

The hydraulic gradient was calculated by simply taking water elevation data for boreholes in the catchment and the water elevation of the nearest perpendicular downstream river to obtain a representative slope (i), calculated by dividing the height (elevation change from borehole to river) in metres with the distance to the river in metres. Moreover, assigning a linear and directly proportional parameter.

$$i = \frac{h}{d} \quad [15]$$

i = Slope.

h = Difference in height, metres.

d = Distance in metres.

For the SABEM to read the catchment slope, a representative parameter was calibrated to represent catchment slopes in m/m.

The slope was only applied to the first streamflow reading Q on day one by multiplying the Q_1 value with 70% (percentage can be used as variable, 70% had a good fit with all the catchments).

$$bx_{t1} = d + (Q_{t1} \times 0.7) \quad [16]$$

bx_{t1} = Baseflow representative for parameter d

Q_{t1} = Initial streamflow value at day 1.

d = Slope parameter.

3.7.5 Hydraulic conductivity

Hydraulic conductivity was extracted from known geology and aquifer types and plotted against a representative catchment parameter. Unfortunately, no true or substantial data

could be obtained on exact hydraulic conductivity for each catchment, and a relative value was selected from Figure 24 and calibrated for all study catchments.

Based on the hydraulic conductivity of the geology for the study areas, a parameter was calibrated for each catchment simultaneously by re-entering the respective parameter values until a proportional function could be obtained; this parameter of SABEM is very sensitive and a poor response was obtained due to the irregularities of hydraulic conductivity and the lack of good representative data. Using the table is only recommended as a last resort – calculated hydraulic conductivity would be more precise. Using Figure 24 can be justified looking at the nature and properties at hand as the problem is complex and due to lack of accurate data it will still allow the estimation of trends and key parameters without relying on precise numerical values if they are not available. It provides a good sense of scale and the option of optimising SABEM is there when quality data does become available. It focuses the attention on the more significant aspect of parameters.

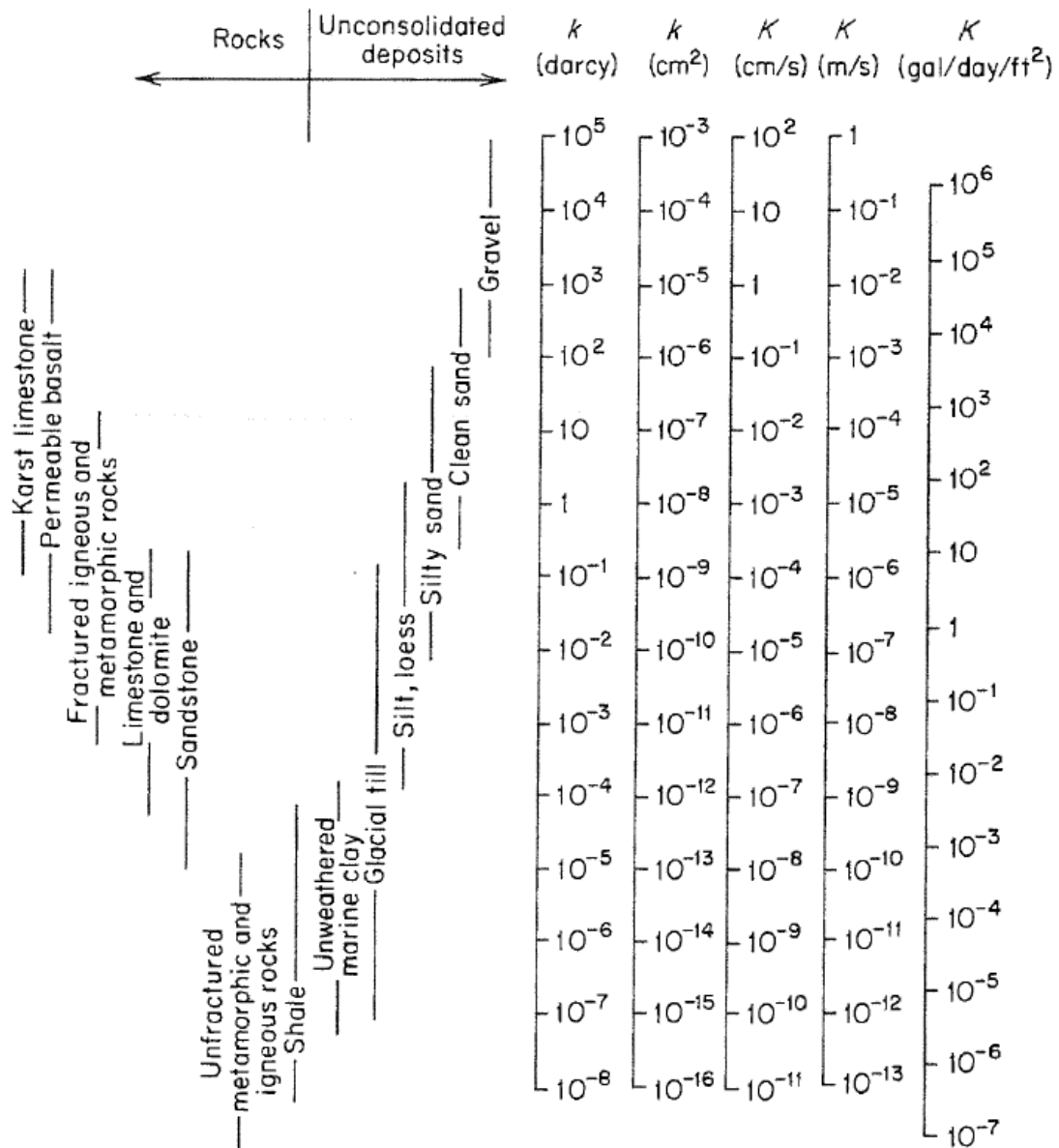


Figure 24: Hydraulic conductivity.
Source: Freeze and Cherry (1979)

Reading hydraulic conductivity K in m/s and based on the geology of the catchment, Figure 24 was compiled with a calibrated f parameter to K value relative to the catchment.

3.7.6 Implementation and development of the toolkit

A specialised Excel toolkit was created to facilitate the loading and transformation of data from an SQL database. This toolkit serves multiple purposes, including importing the data, performing baseflow calculations using SABEM equations, and calibrating the delayed time parameters along with the c , d , and f parameters. For detailed instructions on the Python

scripting for SABEM, please refer to Appendix B. Additionally, the Excel toolkit can be utilised to calculate baseflow using SABEM, providing a practical and replicable solution.

Benchmarking against tracer studies is valuable and a specific approach but it is beneficial to complement SABEM with benchmarking against other methods discussed in the literature review to provide a more comprehensive and robust assessment to obtain methodological diversity cross validation and validation of tracer studies, as described in Chapter 4. Eckhardt, Herold and HYSEP sliding interval baseflow estimation were also used in tandem with SABEM as verification and justification methods to confirm the accuracy and applicable use of the SABEM method. See Appendix C for exported baseflow data from SABEM.

Chapter 4 Results and Discussion

4.1 SABEM

This chapter presents the results and discussion of the SABEM and the subsequent discussion of the validation. Typically, baseflow methods are compared to each other to ensure their validity and reliability; it is a common practice to rely on existing methods that are well-established, widely accepted, and rigorously tested. These established methods serve as a reasonable benchmark for verification purposes similar to studies identified in the literature.

Figure 25 shows the consistent correlation achieved during the calibration and alignment process which involved multiple runs with each of the parameters. This led to the establishment of a direct proportional relationship between the catchment characteristics and the parameters for all the case studies. Consequently, it was possible to input any catchment size and derive the corresponding parameter using this linear function or graph. This relation indicates that the desired baseflow could be attained using the catchment size as a parameter.



Figure 25: Catchment size and delayed time parameter.

Figure 26 shows that aquifer yield data (parameter c) produced a perfectly calibrated parameter which was directly proportional, evidently covering the majority of the aquifer yield range. The linear regression obtained provides great confidence in this parameter. With the

points indicated showing the case studies respective data and the variety and proportions of the parameters of the method together forming a straight-line function.

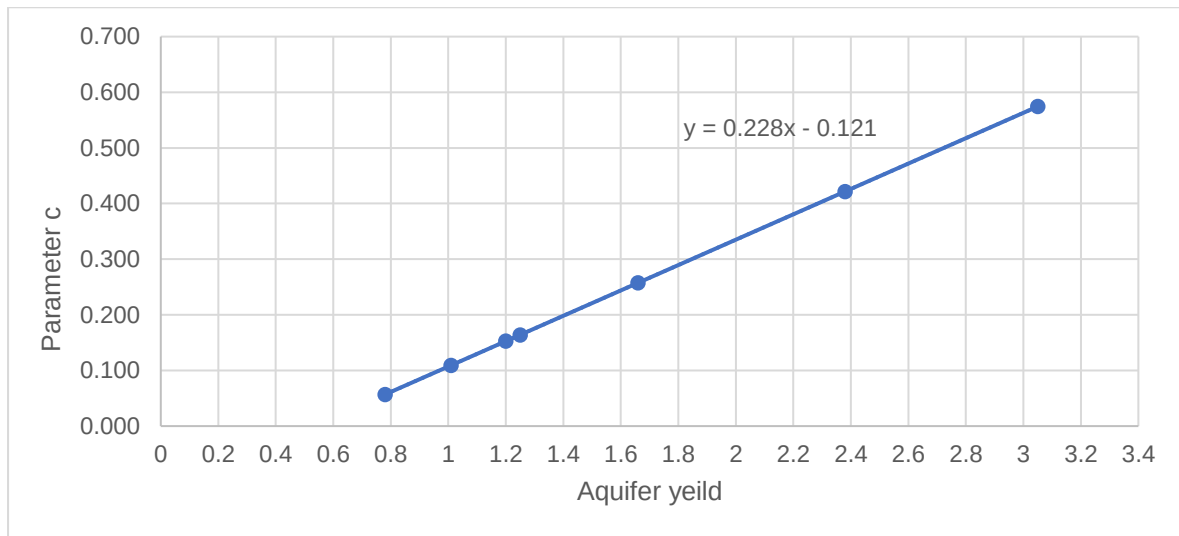


Figure 26: Aquifer type, parameter c

Similar to aquifer yield, perfect alignment was also obtained with parameter d (hydraulic gradient). This also produced a directly proportional linear regression line between hydraulic gradient and parameter d . Unlike the limited range of the aquifer yield, hydraulic gradients can vary and extend beyond the verification range, as depicted in Figure 27, in which case extension of the linear line should be applied as an assumption based on the extent of the data available from the case studies.

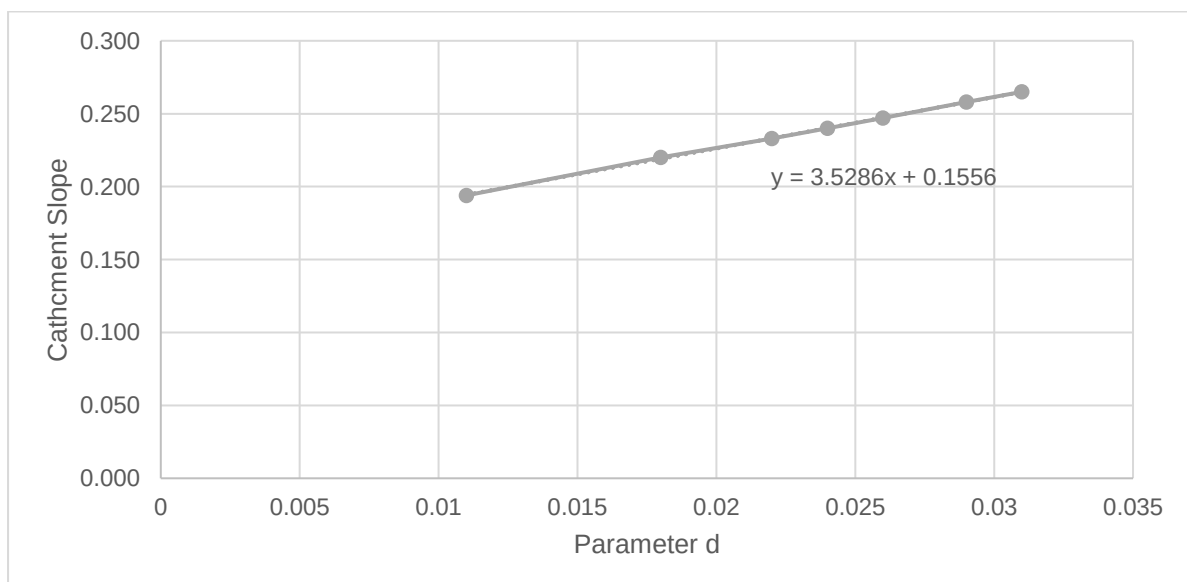


Figure 27: Hydraulic gradient, parameter d

The reason behind the challenge in calibrating parameter f lay in its broad and minuscule nature. Relating this parameter to the catchment characteristics proved to be difficult due to the significant geological diversity observed in the study areas. Parameter f can be used for achieving a better fit between the baseflow estimation and the catchment behaviour (Figure 28). The standard deviation applied was 4.8×10^{-3} .

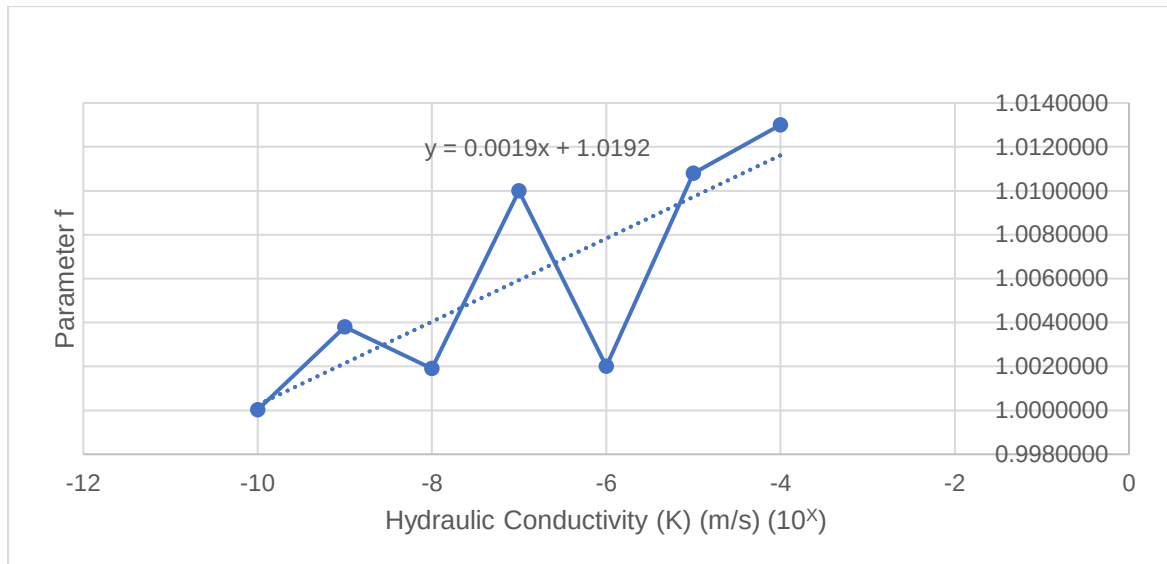


Figure 28: Hydraulic conductivity parameter f

At some gauge sites it was clear that the maximum peak discharge value was exceeded and inevitably would affect the averages that SABEM used. Preference for average values over median values was considered but median values did not work well with linear relationships.

When the peak discharge value is exceeded, this signifies that the flow-gauging site experienced a flow event beyond the instruments' designed capacity to accurately measure. This poses a challenge in accurately capturing the extreme high flow values, potentially skewing the calculated averages for the SABEM.

To address this problem, several strategies were employed not by the SABEM but from the data point of view. One approach involved implementing data quality control measures to identify and flag the data points that exceeded the maximum peak discharge value. These flagged data points were then subjected to further inspection and possible adjustments. The outcome of SABEM is, therefore, as with any other method, a result of the quality and accuracy of the inputs.

In terms of preference for average values over median values, the choice was driven by the need to capture the overall central tendency of the dataset. Averages provide a measure of the typical performance of data, reflecting the mean value across all observations. This

choice may be useful in understanding the general flow patterns and characteristics of the gauging site, despite the occasional extreme events that exceed the rating.

On the other hand, median values represent the middle observation in a dataset, which can be more robust to extreme values or outliers. However, in this context, the preference for average values indicated a desire to capture the overall flow management and to characterise the sites' typical flow conditions, even with occasional extreme events.

4.2 SABEM verification

The ideal verification of the proposed baseflow estimation would be to compare it to tracer tests from various catchments with diverse characteristics across South Africa. This would give insight into how baseflow naturally flows and contributes to rivers. Therefore, tracer test studies were identified across South Africa, particularly regarding baseflow contributions to streamflow. Limited studies have been done on this topic, and fewer have attained conclusive results. Unfortunately, DWS streamflow data specifically corresponding to the same timeline of tracer studies could not be found, therefore streamflow data of different timelines (for a single hydrological year with good quality data and similar rainfall) was used as catchment characteristics should still be applicable for the given time periods, as the effect of rainfall on the same medium (catchment characteristics) should remain the same.

4.2.1 T3H009

The daily streamflow data used in the tracer study was collected from 29th January 2004 to 26th February 2004, a one-month daily investigation with a total of 8 high-frequency events due to rainfall in this period. The researcher captured the streamflow data on-site and was not obtained from DWS. The results obtained showed that even during high-frequency events, the direct runoff did not exceed 38% of the total runoff and the groundwater contributions led to highs of 90% of total runoff. The average groundwater contribution for the monitored period was roughly 70% of the total runoff, with 16% subsurface runoff. Using RDF methods and Wenninger's (2008) own tracer data to calibrate, Wenninger concluded a baseflow percentage of 88% of the total runoff derived for the 2004 hydrological year. This is a very conclusive and well-investigated study with results that could verify the newly proposed baseflow estimation method with confidence (Wenninger, 2008).

Data from DWS in this study was not readily available for the same time period, and DWS streamflow data was therefore obtained for the latest hydrological year with good quality data. The average baseflow percentage from Wenninger (2008) could be obtained using the proposed method and visually reflects the resulting streamflow and baseflow graphs.

SABEM indicated a very late rise of baseflow as expected and intended as it conformed to the geohydrological characteristics of the sedimentary formations across the catchment receiving more water as the rainfall increases, saturating the catchment, and resulting in more baseflow at a later stage in time. Similarities can be seen between the Eckhardt method and the SABEM in terms of high frequency events, the difference being that the SABEM builds up to these events whereas Eckhardt indicates these high frequency events throughout the hydrological cycle. It is clear that there are some sensitivities to hydrological conditions in the Eckhardt method that SABEM seeks to answer in a more realistic fashion, in terms of saturation build-up increasing baseflow over time. Performance of the SABEM is restricted to a single hydrological cycle in this case study in order to conform to the tracer test. No data restrictions were evident as a complete cycle with good data was identified, given the shortcomings of this catchment. Comparison of methods are indicated in Figure 29, with SABEM fit to streamflow data indicated in Figure 30.

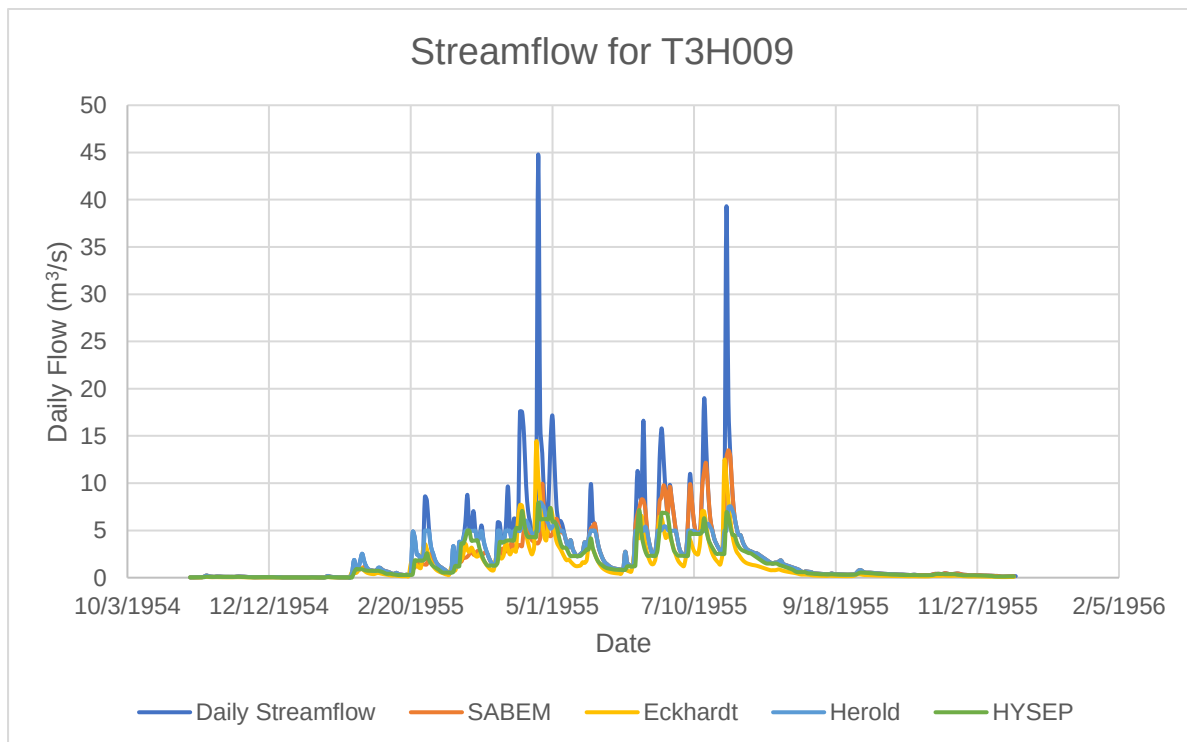


Figure 29: Streamflow data with SABEM, Eckhardt, Herold and HYSEP baseflow methods for T3H009.

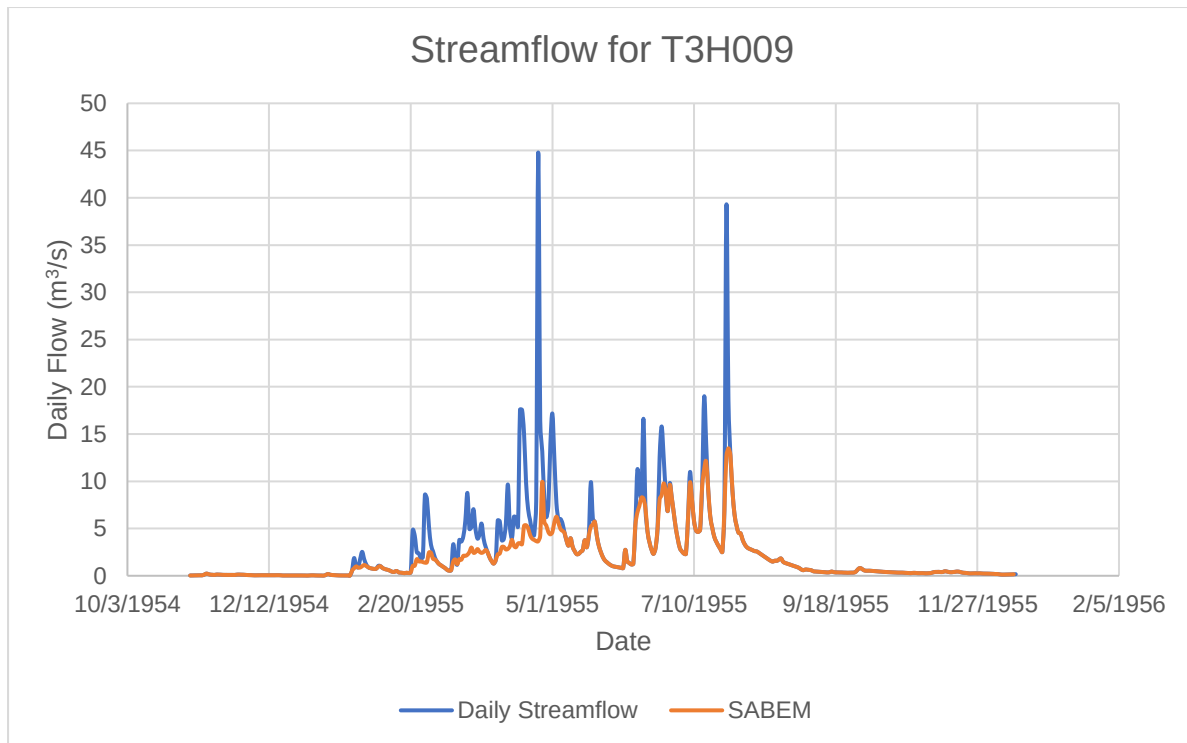


Figure 30: Streamflow and SABEM for T3H009.

Table 5 indicates the selected parameters and resulting baseflow percentage for T3H009 from each of the indicated baseflow estimation methods presented in Figure 29. Parameters entered to obtain the same runoff percentage with other models are also indicated for the benefit of future research implementation and comparison. All methods except HYSEP were able to obtain the tracer baseflow percentage. This shows the favourable robustness of SABEM to allow for catchment characteristics to be implemented whereas the HYSEP method is restricted by the use of only two parameters from attaining or replicating the tracer results for this specific area.

Table 5: Table of parameters for T3H009

Method	T3H009 Parameters										Percentage Baseflow of total runoff
	f	c	d	a	BFI	QGMAX	PG	Decay	A	2N*	
Tracer											70%
SABEM	1.013	0.153	0.220								70%
Eckhardt				0.920	0.710						70%
Herold						4.96	9	0.88			70%
HYSEP									307	5	57%

4.2.2 G1H043

It is clear from Figures 31 and 32 that the magnitudes of methods differed with temporal distributions. The Eckhardt method indicated high frequency peaks unlike the other methods, being a clear outlier in this case study. The SABEM indicated very low flow of events similar to the HYSEP and Herold methods. This indicated the ability of the SABEM to replicate other methods in different scenarios while being sensitive to the conditions of the catchments. This case study makes a strong argument for the practical and robustness that the SABEM has to offer. The data showed a completely different hydrograph shape and rainfall events regarding its location with high intensity rainfall or subsequent streamflow events with clear low flow periods in between, allowing the SABEM to clearly indicate the low flow events of baseflow unlike the T3H009 catchment which created a build-up of groundwater contribution.

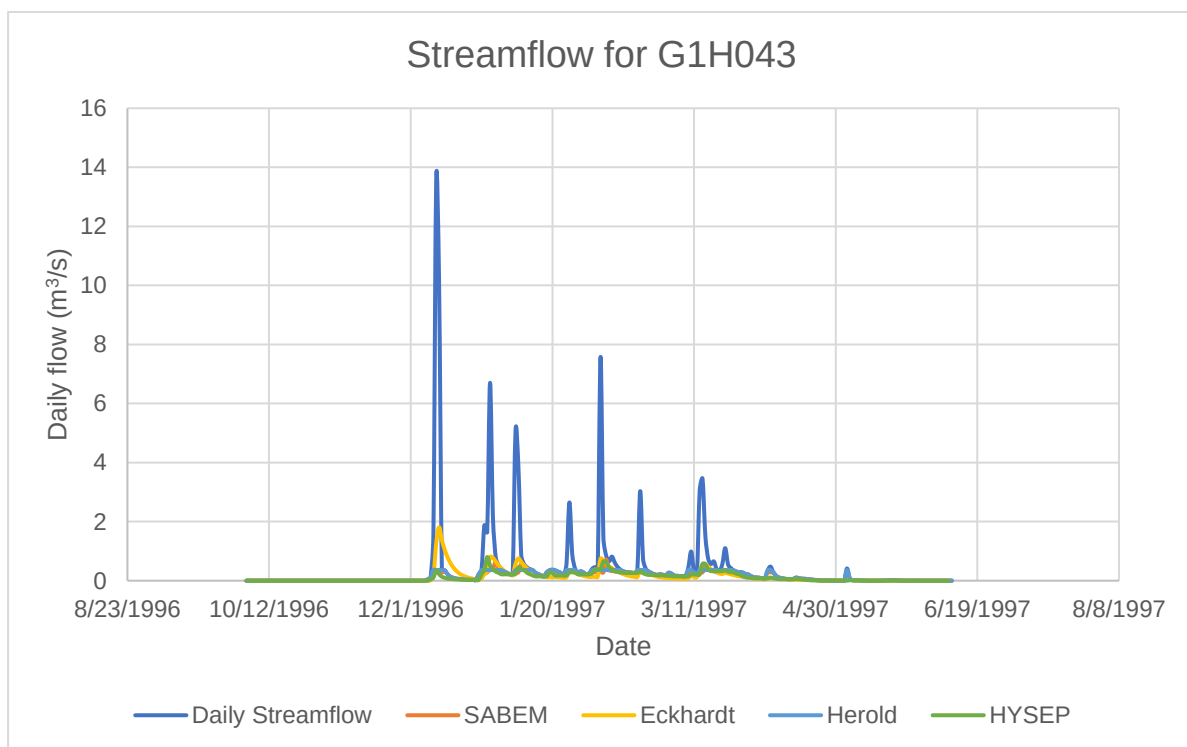


Figure 31: Streamflow data with SABEM, Eckhardt, Herold and HYSEP baseflow methods for G1H043.

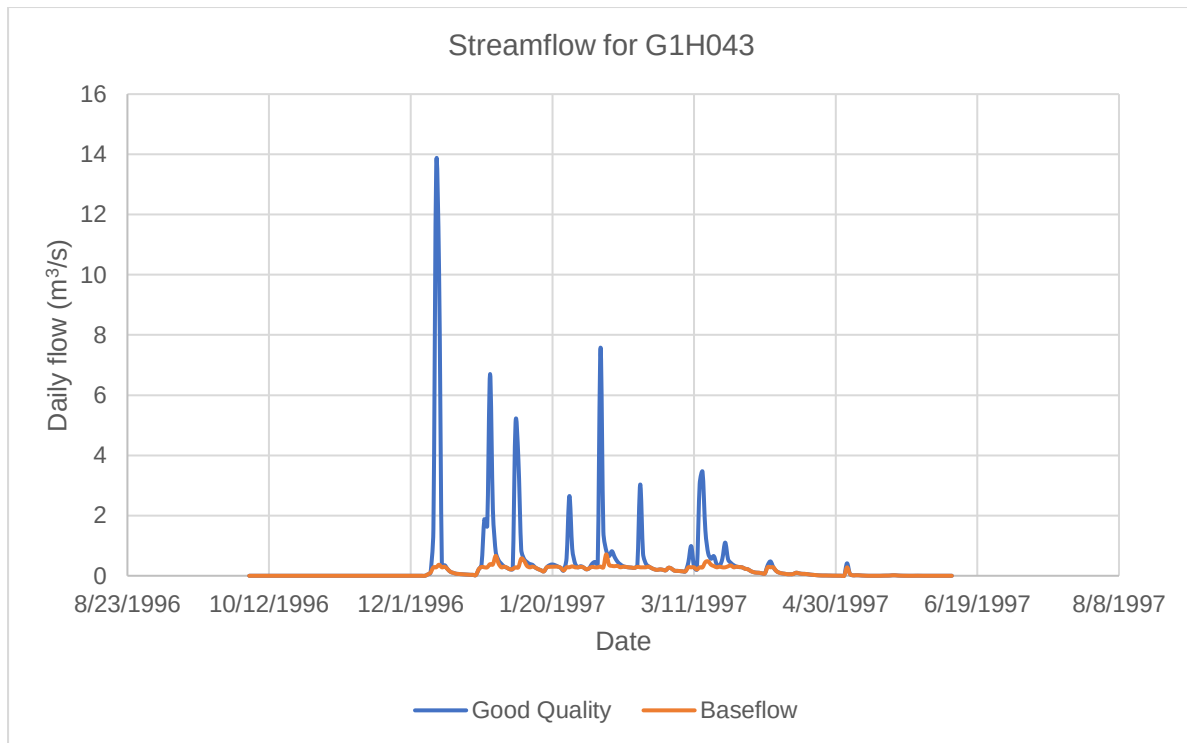


Figure 32: Streamflow and SABEM for G1H043.

Table 6 indicates the selected parameters and resulting baseflow percentage for G1H043 from each of the indicated baseflow estimation methods. Even though the Eckhardt method resulted in high frequency events on a visual assessment, it was still able to replicate and match the tracer test unlike the HYSEP method which was again limited but only slightly below target with this smaller catchment. Catchment G1H034 had some clear distinguishing geological features such as sedimentary and igneous rocks with various faults resulting in lower baseflow percentages than T3H009 which the SABEM was able to use to predict the baseflow percentage while the other methods were able to reach the same value by their required parameters by simply being identified in the table.

Table 6: Table of parameters for G1H043

Method	G1H043 Parameters										Percentage Baseflow of total runoff
	f	c	d	a	BFI	QGMAX	PG	Decay	A	2N*	
Tracer											33%
SABEM	1	0.057	0.280								33%
Eckhardt				0.81	0.33						33%
Herold						0.36	0.6	0.05			33%
HYSEP									151	5	27%

4.2.3 X2H008

Figures 33 and 34 indicate the shortcomings of other methods like the HYSEP method where it is represented by similar rainfall trends of recurring events but presenting different parameters allowing it to replicate the high frequency events of the Eckhardt and the SABEM, which was not possible in the case study of T3H009. The SABEM interpreted the consistent high frequency events allowing for a build-up of groundwater and groundwater contributing to the baseflow clearly seen in the higher peaks as the events built-up but could be exaggerated in lateral portions of the graph.

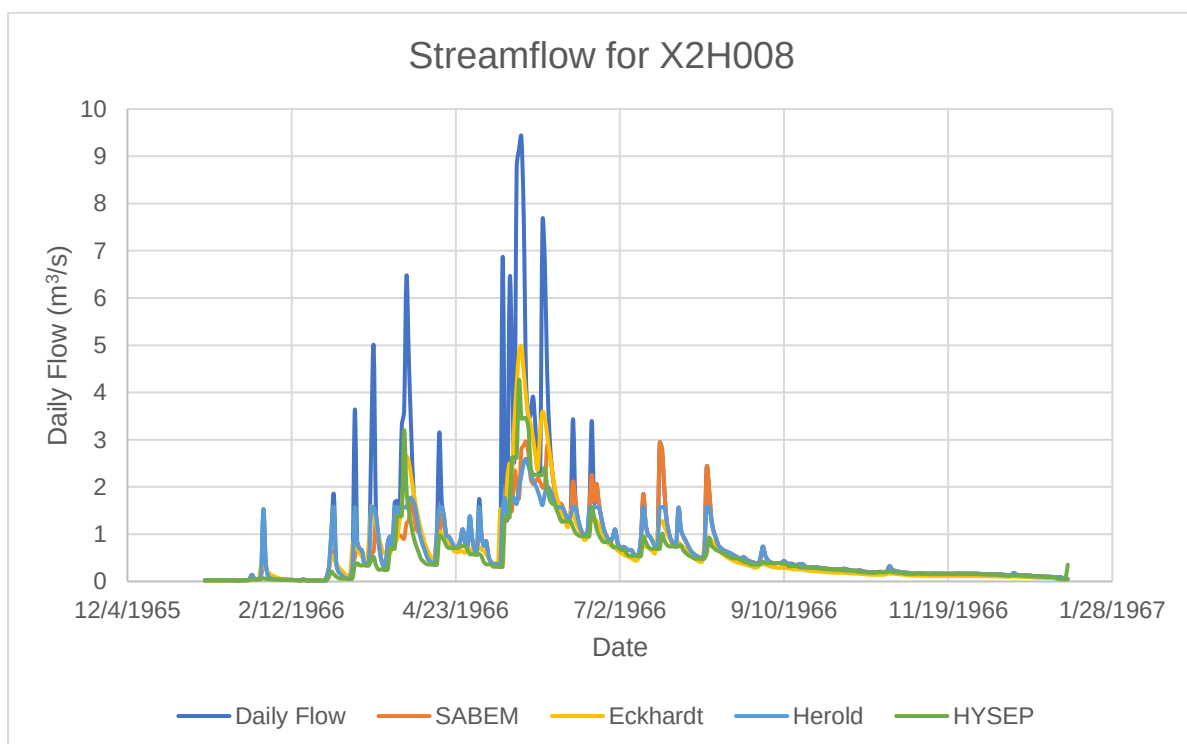


Figure 33: Streamflow data with SABEM, Eckhardt, Herold and HYSEP baseflow methods for X2H008.

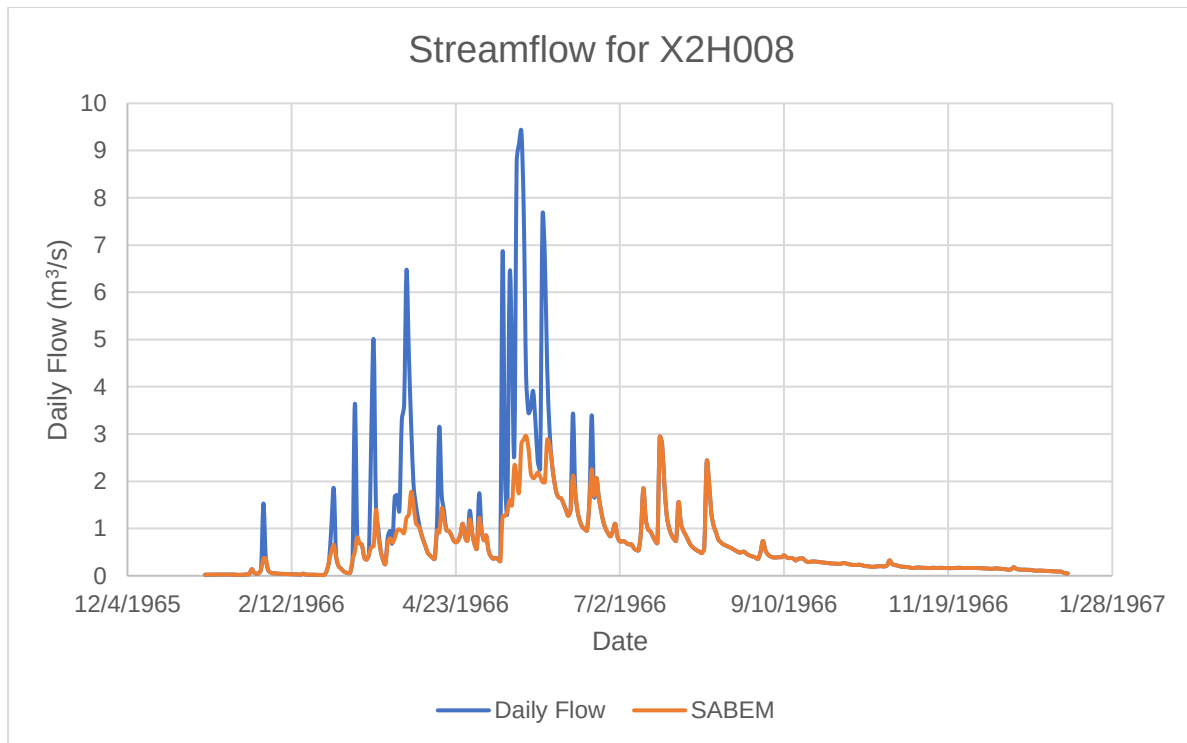


Figure 34: Streamflow and SABEM for X2H008.

Table 7 indicates the selected parameters and resulting baseflow percentage for X2H008 from each of the indicated baseflow estimation methods. As discussed with Figure 33, the HYSEP method is able to perform better in a smaller catchment with a similar percentage to a target tracer percentage and similar to that of the SABEM estimated tracer value.

Table 7: Table of parameters for XH2008

Method	X2H008 Parameters										Percentage Baseflow of total runoff
	f	c	d	a	BFI	QGMAX	PG	Decay	A	2N*	
Tracer											70%
SABEM	1.013	0.153	0.220								70%
Eckhardt				0.900	0.700						70%
Herold						1.57	6.7	0.9			70%
HYSEP									180	5	62%

4.2.4 X2H010

All methods indicated in Figure 35 are consistent or as expected, with the Herold method indicating a straight-line approach, and high frequency events plotting similarly, with the SABEM indicating higher frequency events later in the cycle (Figure 36).

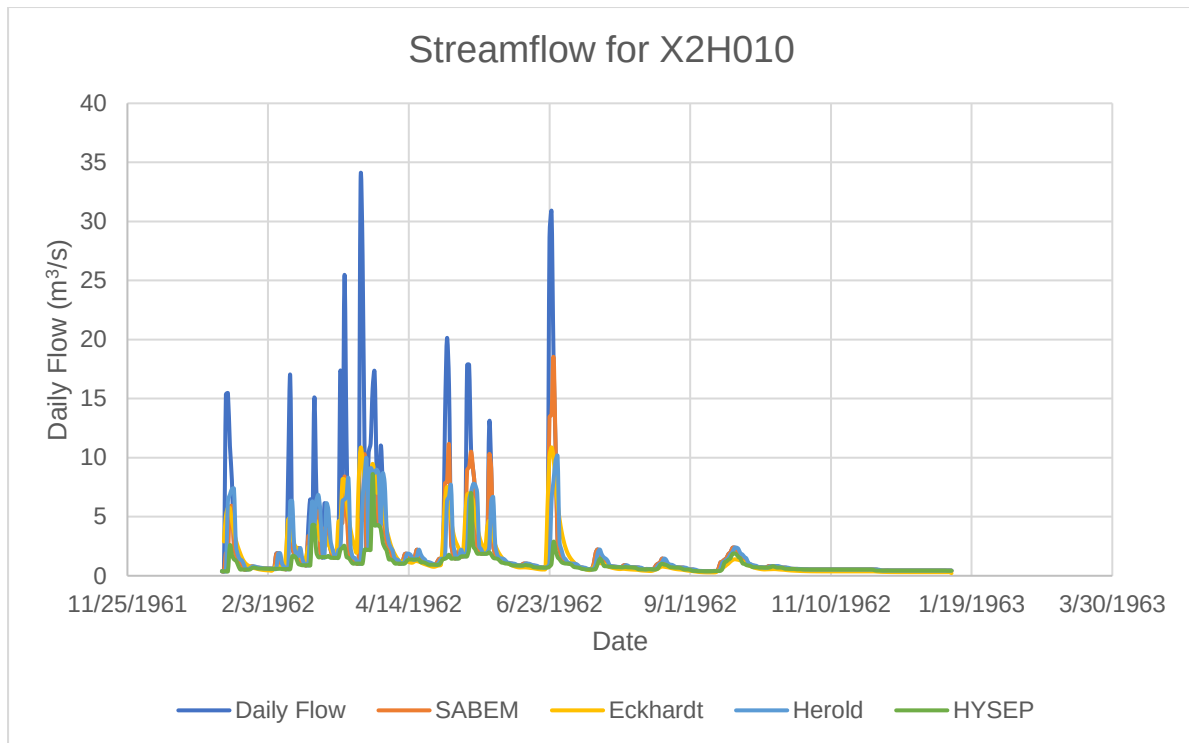


Figure 35: Streamflow data with SABEM, Eckhardt, Herold and HYSEP baseflow methods for X2H010.

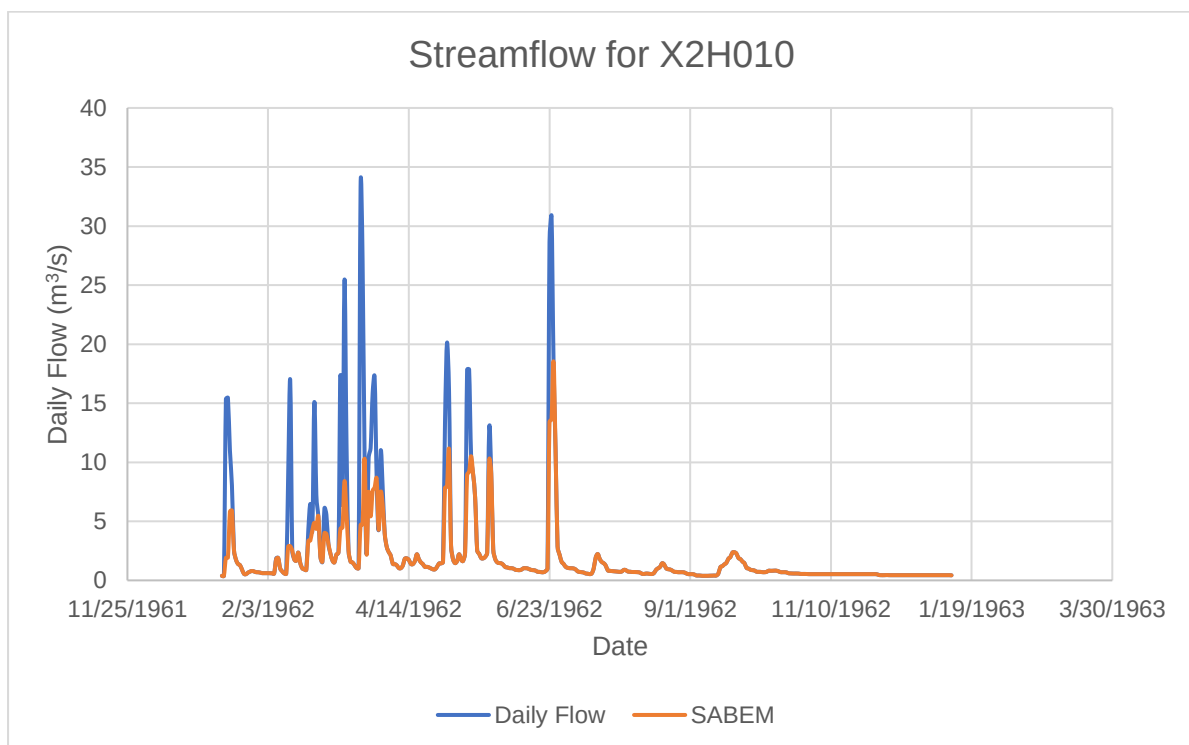


Figure 36: Streamflow and SABEM for X2H010.

Table 8 indicates the selected parameters and resulting baseflow percentage for X2H010 in terms of each of the indicated baseflow estimation methods. Contrary to the previous studies, the HYSEP method struggled to attain the target percentage tracer baseflow even with a

smaller catchment, which could indicate inconsistency in the method, limited parameter range, or tracer study variances and inconsistencies. The SABEM was able to attain the target tracer baseflow as calibrated; visually very high frequency runoff events are plotted and could be a reflection of the fairly steep and rocky gradients picked up by the SABEM.

Table 8: Table of parameters for XH2010

Method	X2H010 Parameters										Percentage Baseflow of total runoff
	f	c	d	a	BFI	QGMAX	PG	Decay	A	2N*	
Tracer											70%
SABEM	1.013	0.153	0.220								70%
Eckhardt				0.900	0.700						70%
Herold						6.31	8.9	0.96			70%
HYSEP									126	5	42%

4.2.5 X2H031

The streamflow hydrograph (Figure 37) shows that a single high frequency event occurred during this rainfall season which tapered off as baseflow decreased without rainfall. This plot is a very good example of the SABEM and its abilities. All methods are able to indicate the high frequency event with the Eckhardt method indicating the highest peak as expected. Figure 38 reveals why this is a good example plot for the SABEM because this method is able to identify the smaller rainfall streamflow events as well as the high frequency events. What is noticeable too is the intended negative baseflow or bank storage abilities of SABEM which can be seen just before the high frequency event occurs; it creates a negative influx indicating the sudden infiltration of rainfall which was recharging the groundwater rather than supplying the river with baseflow. This is more of a contribution to groundwater – graphically it is minuscule but noteworthy, and ultimately a good indicator of the SABEM’s robustness.

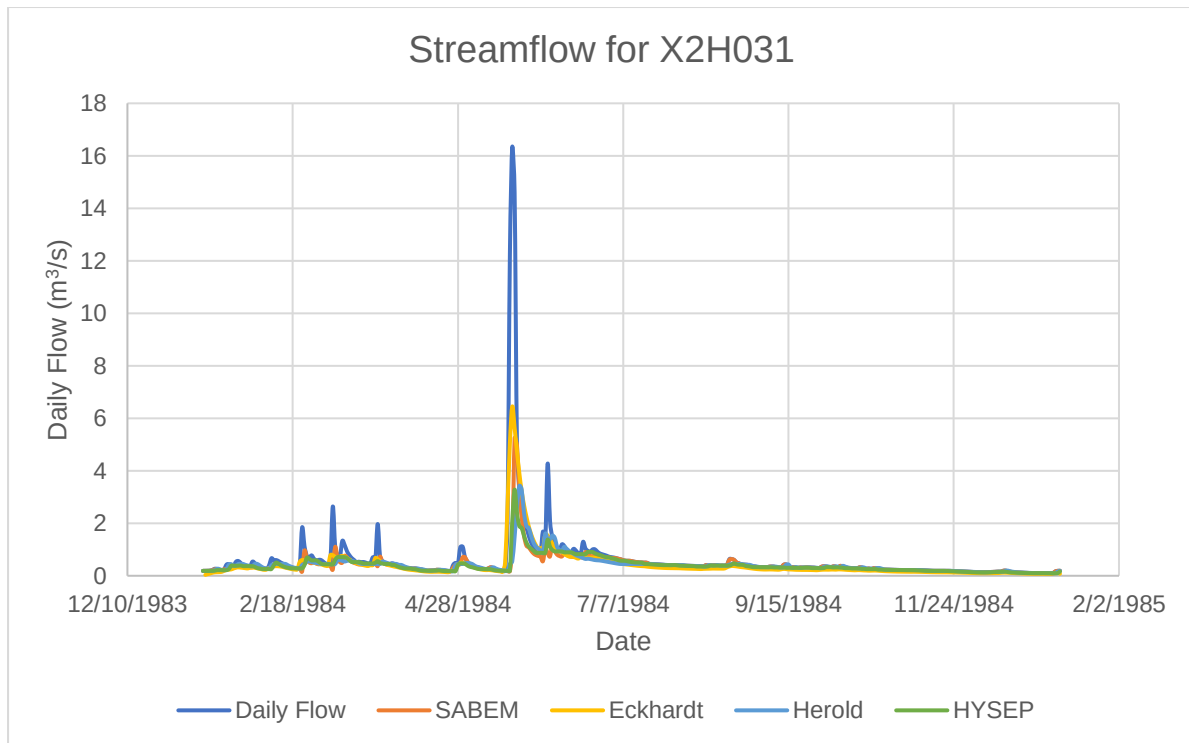


Figure 37: Streamflow data with SABEM, Eckhardt, Herold and HYSEP baseflow methods for X2H031.

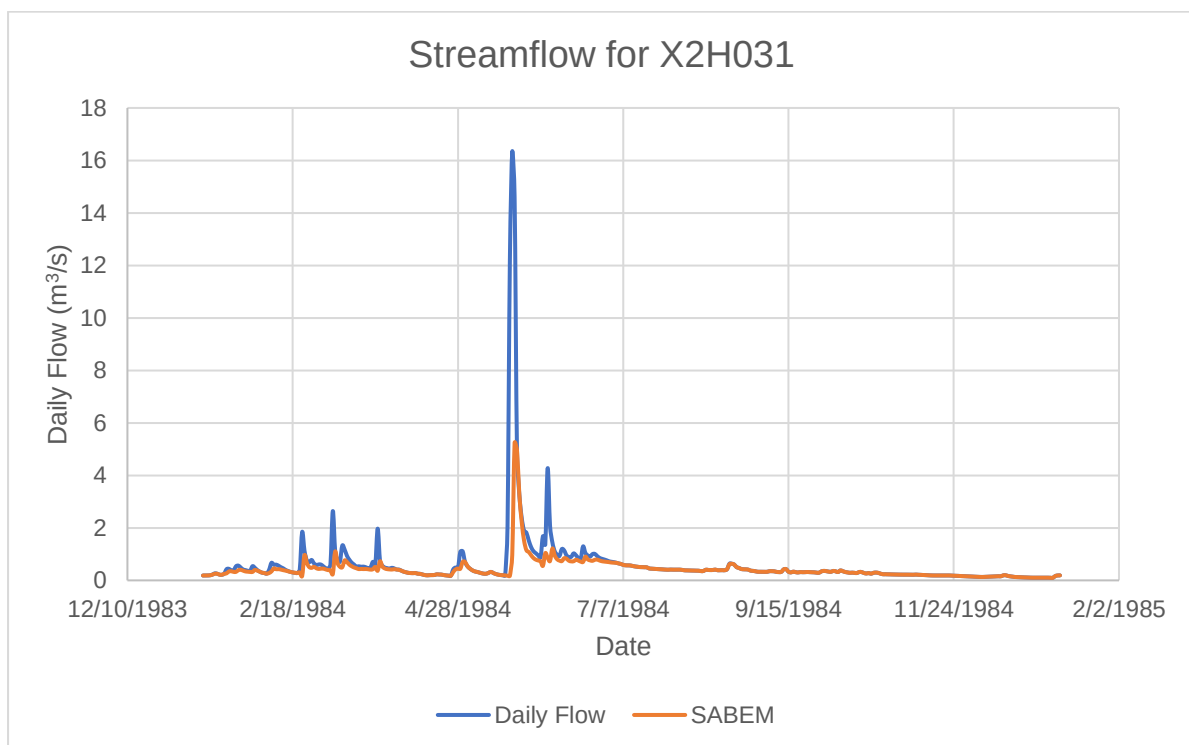


Figure 38: Streamflow and SABEM for X2H031.

Table 9 indicates the selected parameters and resulting baseflow percentage for X2H031 from each of the indicated baseflow estimation methods. Larger catchments result in better performance for the HYSEP method, but all methods performed well which could be because

of its lack of geological complexity and rocky gradients with good results being obtained from all methods (Sloto and Crouse, 1996).

Table 9: Table of parameters for XH2031

Method	X2H031 Parameters										Percentage Baseflow of total runoff
	f	c	d	a	BFI	QGMAX	PG	Decay	A	2N*	
Tracer											70%
SABEM	1.013	0.153	0.220								70%
Eckhardt				0.900	0.700						70%
Herold						0.45	8.3	0.93			70%
HYSEP									262	5	71%

4.2.6 X2H022

What is evident in Figure 39 and Figure 40 is that the baseflow methods performed adequately with some higher and lower frequency peaks identified, including lower frequency plots seen from the HYSEP.

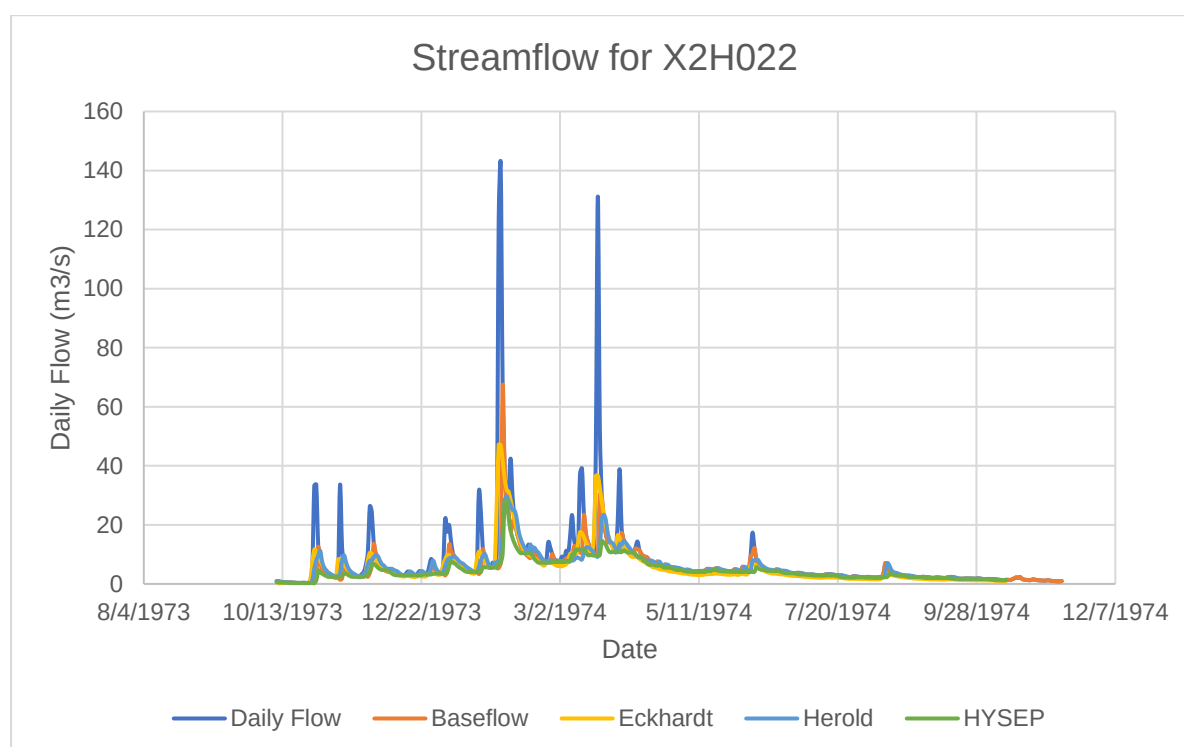


Figure 39: Streamflow data with SABEM, Eckhardt, Herold and HYSEP baseflow methods for X2H022.

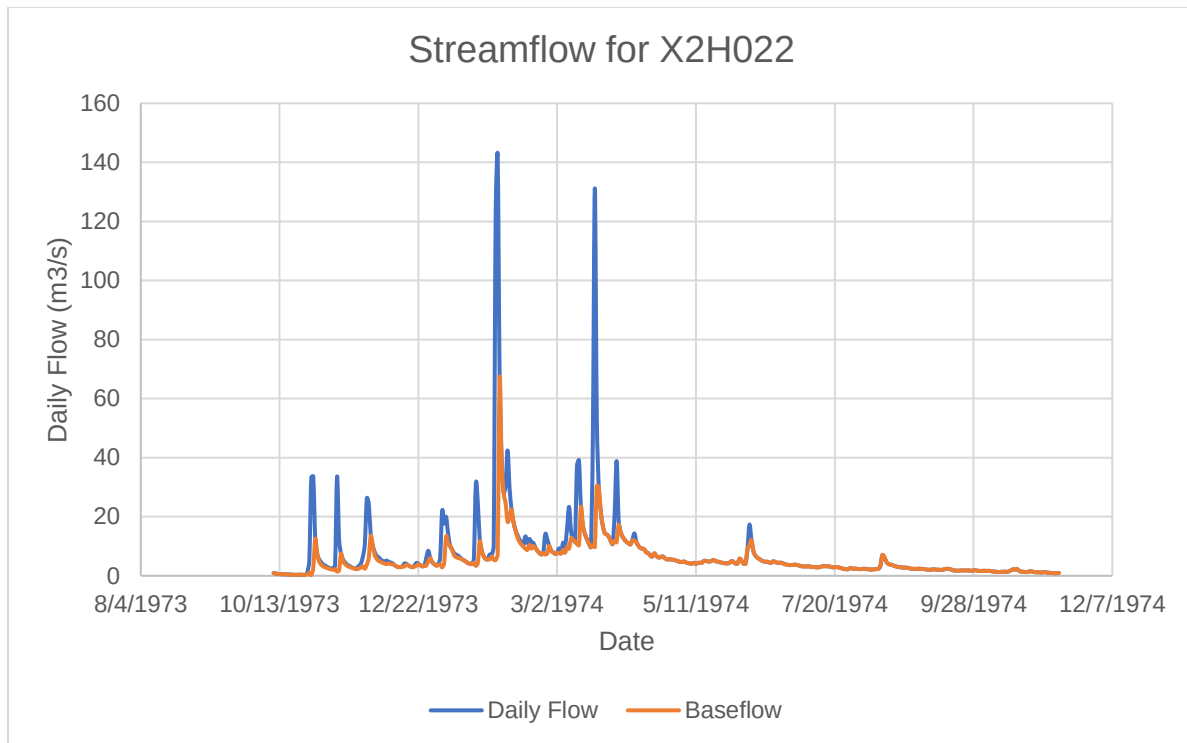


Figure 40: Streamflow and SABEM for X2H022.

Table 10 indicates the selected parameters and resulting baseflow percentage for X2H022 from each of the indicated baseflow estimation methods. With this much larger catchment, the HYSEP model performed below the target tracer study with the Herold, Eckhardt and SABE-M able to replicate the tracer study indicated percentage of baseflow.

Table 10: Table of parameters for XH2022

Method	X2H022 Parameters										Percentage Baseflow of total runoff
	f	c	d	a	BFI	QGMAX	PG	Decay	A	2N*	
Tracer											70%
SABEM	1.013	0.153	0.220								70%
Eckhardt				0.900	0.700						70%
Herold						7.89	9.2	0.93			70%
HYSEP									1639	7	57%

4.2.7 V1H010

Figure 41 shows some questionable baseflow plots; visually they do not conform to the previous studies, although HYSEP will conform to any streamflow plot because of the way the methodology is set up. The Herold and Eckhardt methods performed the poorest as they did not recognise the low frequency events or the falling limbs as baseflow, as their plots are well below streamflow events long after the falling limb of the hydrographs. The SABEM on

the other hand was able to match the low flow as seen in Figure 42. These figures show that high volumes of water were constantly flowing through this streamflow station with strong falling limbs, bearing in mind that the methods were applied to match the tracer study, so visually the parameters could be adjusted to be more aesthetically pleasing. It is clear that there are many rainfall and streamflow events that build on each other with a quick falling limb receding to a constant baseflow or low flow. This is seen as an outlier as it depicts very steep gradients in the catchment meaning that surface runoff will be dominant in this area, confirmed by the streamflow hydrograph. SABEM also indicates steep negative baseflow trends meaning that either the area has weak recharge ability and majority of streamflow is purely runoff, not recharging into the ground or allowing baseflow to contribute as much. It can also be conjectured that the tracer study conducted had more baseflow than what was measured (Mutema and Chaplot, 2018).

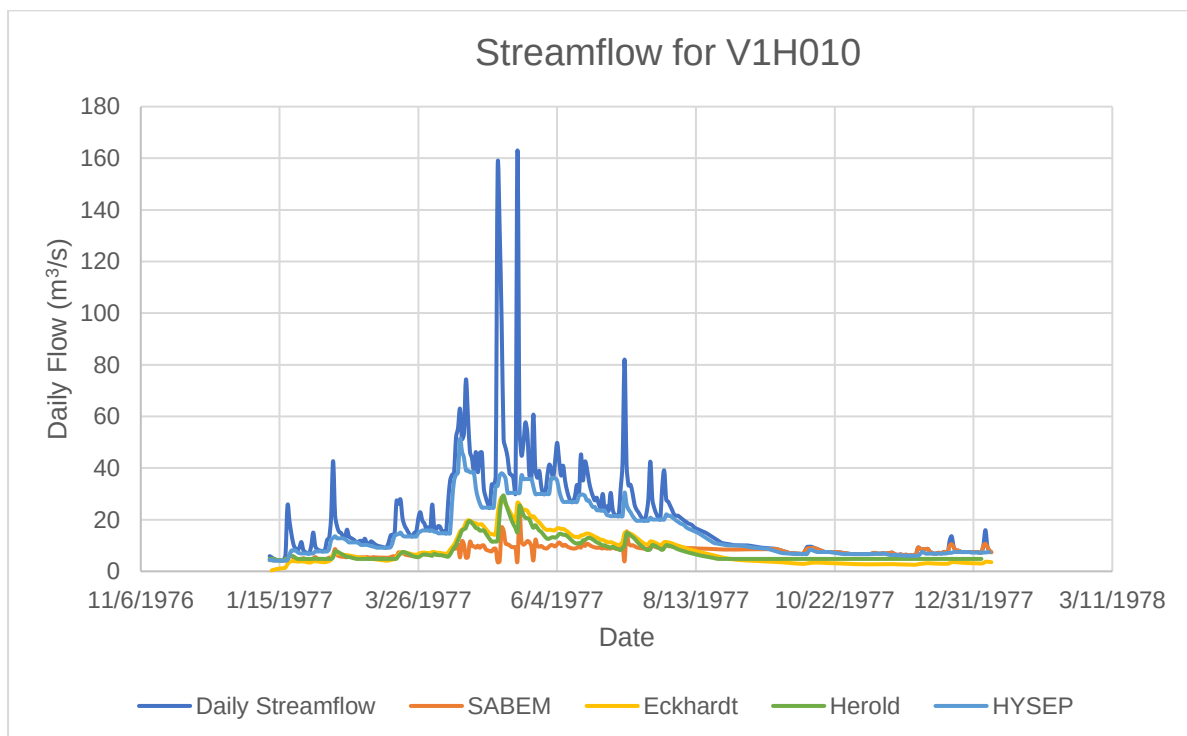


Figure 41: Streamflow data with SABEM, Eckhardt, Herold and HYSEP baseflow methods for V1H010.

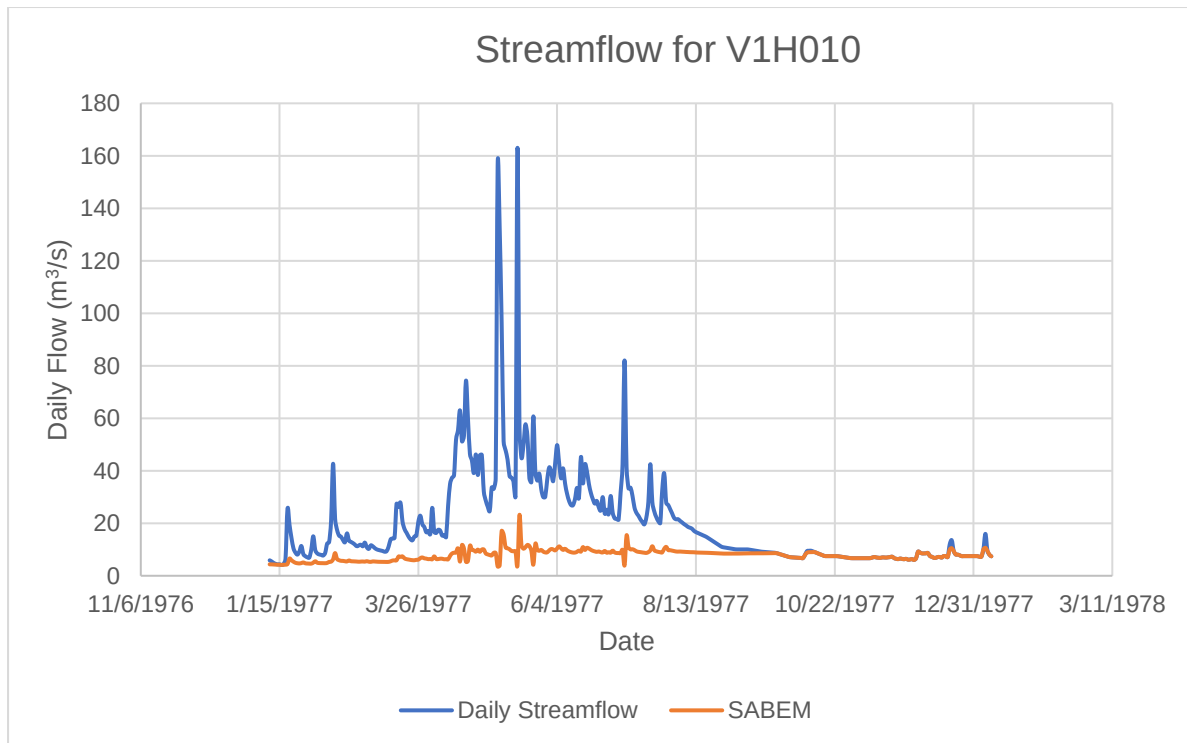


Figure 42: Streamflow and SABEM for V1H010.

Table 11 shows the selected parameters and resulting baseflow percentage for V1H010 from each of the indicated baseflow estimation methods. It is clear that the catchment characteristics applied to HYSEP indicated a much larger baseflow percentage than what the tracer tests indicated, so it is possible that either that method was not applicable, or that the tracer study conducted did not observe the same amount of baseflow. In terms of the tracer tests, the methods were able to match the results in terms of percentage but visually were difficult to attain a realistic baseflow graph, constrained by tracer not abilities of the methods.

Table 11: Table of parameters for V1H010

Method	V1H010 Parameters										Percentage Baseflow of total runoff
	f	c	d	a	BFI	QGMAX	PG	Decay	A	2N*	
Tracer											40%
SABEM	1.0019	0.109	0.233								40%
Eckhardt				0.9	0.4						40%
Herold						4.82	8.5	0.84			40%
HYSEP									782	7	76%

4.3 Limitations and assumptions

Distinguishing limitations and assumptions allow for a comprehensive understanding of the boundaries and potential biases inherent in the findings and conclusions. This allows the researcher to evaluate the robustness and applicability of the SABEM's results.

The following section presents a comprehensive list of the limitations and assumptions associated with the SABEM in this study. These considerations highlight the potential constraints, uncertainties, and simplifications that impact the analysis. Limitations indicate potential weaknesses in the study and assumptions are statements accepted as true.

- Streamflow data periods do not match those of the tracer tests conducted because the periods of record-keeping by the DWS did not match the period when the tracer test was conducted. The assumption is therefore made that tracer studies of ground or baseflow are true to the catchment regardless of time and can be applied to a similar hydrological cycle or portion of the cycle. Considering that the study takes physical properties approach it can be argued that rainfall over the same medium should react in the same way unless disturbed or changed.
- Tracer analyses studies are carried out for short periods, roughly one month. This limitation can only be improved through funding and long exposure tracer studies. Thus, in the current study, one month's tracer test data represented the entire hydrological response of the system in question.
- Hydraulic conductivity that could not be clearly defined is selected from South African specific charts based on average geology within the catchment. This will only impact the precision, not the accuracy of the results.
- Streamflow data abundance and tracer studies for baseflow purposes are limited which limits the alignment of the method to the physical properties and therefore the parameters. However, the methodology or approach is robust and will stay the same as more tracer data becomes available.
- The parameters identified and calibrated are assumed to represent the whole of South Africa even though the calibration is done with selected catchments as per directly proportional results obtained and for as long as the math holds true.
- Parameters chosen are assumed to represent the groundwater contribution to baseflow as discussed in the literature review regarding the characteristics which affect the groundwater contribution to baseflow as identified by previous researchers.

- Aquifer water movement or groundwater flow is assumed from available borehole yields (available from hydrogeological maps of South Africa).
- Catchment characteristics are regarded as consistent and do not change over time, which is why time series data do not influence timely catchment characteristics. This allows for the use of streamflow data that does not match the tracer studies' time series data.

Future research identification that could affect the outcomes are longer time periods and case specific tracer studies which will identify additional parameter sensitivities and refinement to enhance accuracy and reliability. SABEM indicates good practical considerations for implementation and compatibility with existing methods.

4.4 Summary

Gathering streamflow hydrograph data from the case studies as well as a diverse variety of surface water catchments throughout South Africa was accomplished relatively easily using Python scraper script. The entire collection of South African stream gauge data was successfully extracted, stored, and utilised.

Existing baseflow estimation methods were conducted and discussed in detail, and their respective data requirements, complexity, advantages, and disadvantages were carefully evaluated and incorporated into the SABEM with some limitations to keep the method simple. The wide range of studies was advantageous, with recommendations from the studies playing an important role in the formulation of the method, with physical characteristics of the catchment being the most important insights gathered as they proved to be directly proportional to the tracer studies and form a strong basis of the SABEM.

The proposed SABEM is unique to South African catchments, yet the limited availability of tracer data sources underscores the need for continued data collection to refine its parameters and enhance its precision. Precision will be improved if identical streamflow data can be obtained for the exact period of the tracer test. Notably, the Baseflow Index (BFI) values were very similar to the results from both the tracer studies and SABEM, indicating a strong correlation and supporting the method's validity. This strong alignment suggests that SABEM can provide accurate baseflow estimations and highlights its potential for practical implementation in the South African context with its ability to apply proportionally catchment characteristics to estimate catchment without tracers.

The SABEM underwent alignment and successfully estimated the baseflow percentage in the tracer studies, despite facing limitations and time frame differences. The SABEM

demonstrated a strong alignment with all existing methods, while certain of the existing methods fell short of reaching the tracer study benchmarks. The accuracy or degree of uncertainty therefore relies on the outcomes of these tracer studies. The baseflow percentages shown indicate the total streamflow contributed by baseflow calculated by related studies.

Accuracy of tracer tests are situational to the catchment and the field scientists that conducted the studies. Whether the test results are accurate to their professional standards and are a true reflection of groundwater contribution to baseflow. The effect of these studies has a big effect on the proposed baseflow estimation method (SABEM) as the graphical interpretation of baseflow is calculated to match the results of the tracer studies only. More data can lead to better precision, but the existing tracer study data was sufficient to be able to accurately estimate the given values only slightly lacking precision. Recalibration of the parameters will be possible as more data becomes available which will enhance precision.

Utilising an average predicted value of 60.43% baseflow from the case studies and a standard error of 0.7% evident from the poor proportionality of hydraulic conductivity, arguably the only degree of uncertainty given the assumptions. Standard 95% confidence interval is used to quantify the uncertainty surrounding the predictions. The margin of error, computed as 0.98%, was added and subtracted from the average predicted value to determine the upper and lower bounds of the confidence interval. Consequently, it was established that the 95% confidence interval for the average predicted value ranges from approximately 60.92% to 59.94%. This interval provides valuable insights into the precision and reliability of the prediction, allowing for the communication of uncertainty associated with the estimate with confidence.

4.5 Validation

As an initial proof of concept when introducing a new method to assess its viability and potential, a single case study can provide valuable insights into the methods used in terms of performance and feasibility. A case study approach helps researchers understand the fundamental principles. The case study presented in this section of the dissertation to validate the proposed method (SABEM) is therefore a unique and representative case unlike any of the scenarios used in the method's calibration and development process. It represents extreme events and low flows and completely different geological aspects. This approach allowed for standardisation and control of parameters as designed and was intended to determine the method's performance.

In order to validate the SABEM it was applied to the Hennops River area which lies in an urban area between Pretoria and Johannesburg. Quaternary catchments A21B and A21A with streamflow station A2H014 had sufficient hydrograph data. The area is surrounded by dolomitic aquifers with drained boreholes and is prone to flooding due to the urban surroundings. The geology is mostly dolomite with some sandstone and well populated urban areas as well as wastewater treatment works. The river stream and well populated borehole area lies north of Johannesburg and just south of Pretoria. The Rietvlei dam splits the two catchments (Lowies, 2014).

Delayed time parameter

The delayed time parameter entered into SABEM was calculated to be 7, with an overall catchment size of 1007 km².

Parameter c

With major dolomitic aquifer types and quite diverse geological karst and intergranular rock types, the dominating aquifer types are taken as c5 (70%) d3 (10%) b3 (10%) and d2 (10%) which resulted in an average aquifer yield of 3.78 and corresponding parameter c value of 0.74. Above and below average values for the SABEM were split to 0.57 and 0.95 parameter values (averaging out at 0.74).

Parameter d

The borehole data in this area had significant borehole abstraction rates and negative slopes towards the river, with an average slope of -0.0401 which resulted in a parameter value of 0.014.

Parameter f

The hydraulic conductivity for the area was estimated to be between 0.1×10^{-6} and 0.1×10^{-9} . Therefore, the parameter f value was estimated to be 1.00192.

Results

These parameters for the SABEM resulted in a baseflow percentage of 71% (applying standard deviation results in 70% to 75%) and was plotted as shown in Figure 43. The results showed a good estimated baseflow percentage, confirming that SABEM can be applied to other catchments besides those calibrated. Other studies (Lowies, 2014; Leketa *et al.*, 2018)

in this area calculated the runoff as 8.5% and 7.1%, confirming the high baseflow percentages in this area, as found by the SABEM.

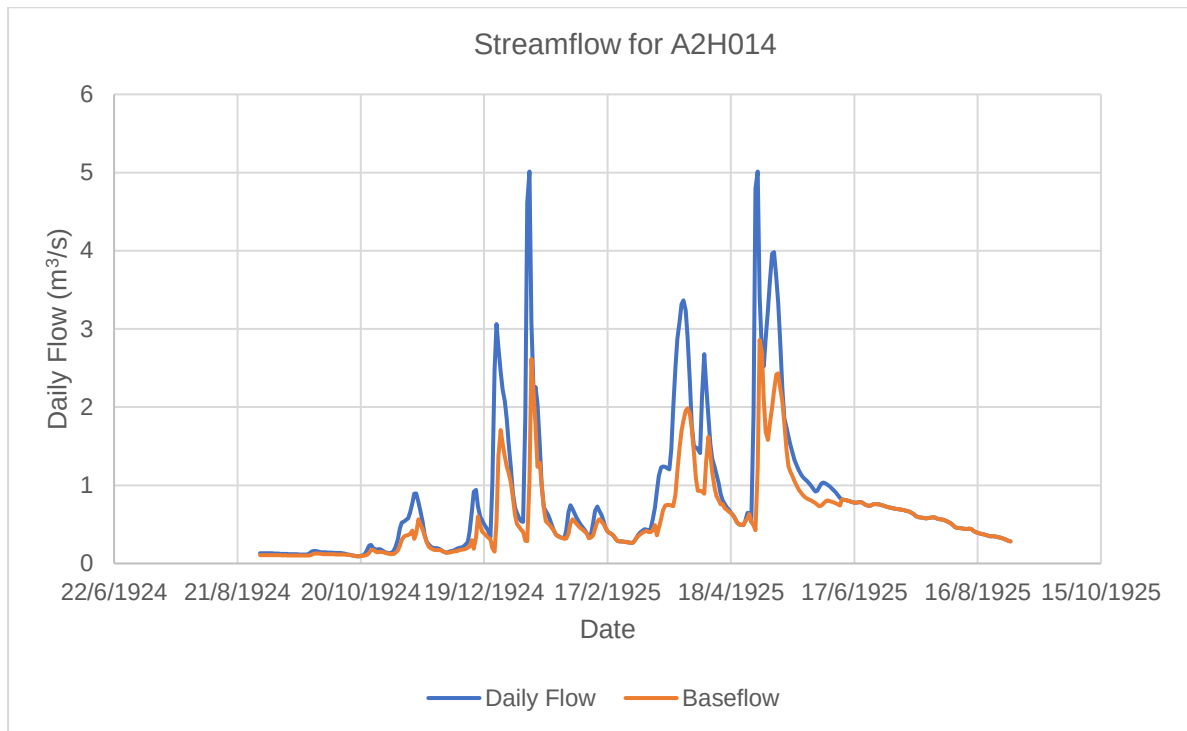


Figure 43: A2H014 Streamflow station hydrograph.

Additional verification to obtain a percentage error was accomplished by removing tracer studies from the calibration process and looking at the predicted tracer results versus the SABEM when the study area is removed, repeating the process for each study area, and found that on average of 0.5% standard error was seen across the study areas.

Chapter 5 Conclusion and recommendations

The accuracy of the newly proposed South African Baseflow Estimation Method (SABEM) which includes hydrograph data specific to South African catchments has been tested and analysed using tracer test studies as a benchmark. Based on this study, it can be concluded that SABEM offers a successful method for estimating baseflow by leveraging the advantages and strengths of other established methodologies identified in the existing literature. The method is successful both graphically and numerically.

The calibration process of SABEM revealed that certain parameters are directly linked to catchment characteristics. This discovery highlights the accuracy and practicality of SABEM in calculating baseflow, as these proportional relationships allow for precise estimations based on the unique features of the catchment. By acquiring observed streamflow data from hydrologically diverse catchments across South Africa, the study ensured a comprehensive and representative analysis, fulfilling the objective of a broad data collection. A thorough review of existing baseflow estimation methods provided valuable insights into their characteristics. This review summarised the data requirements, complexity, advantages, and disadvantages, informing the development of a new method, as outlined in the study objectives. Utilising found insights and workflows, a new methodology was developed, integrating the strengths of established approaches. The successful validation of the SABEM against existing studies affirmed its reliability and potential applicability, marking a significant contribution to the field of hydrology and enhancing our understanding of baseflow dynamics in South African catchments.

This study made use of unique and comprehensive data sets as per the aims and objectives, encompassing hydrological, hydrogeological, geological, borehole, and hydraulic conductivity information which are specifically relevant to South African catchments. The seamless integration of the developed scrapper database into a toolkit allowed for the proposed method to be applied to the collected streamflow data and visualized hydrographs, achieving another key objective. The application of these data sets using the proposed SABEM baseflow estimation method yielded successful outcomes along with limitations that were identified and addressed.

During the verification process, certain limitations of SABEM were identified and addressed as part of the normal verification process. For instance, the averaging performed by SABEM assumes that peak discharges are reliable readings of good quality. Additionally, tracer baseflow data is seldom utilised for calibrating parameters specific to a particular catchment

for baseflow estimation. However, in order to cover the diverse characteristics of South African catchments, the parameters of SABEM were calibrated to encompass a wide range of features, making the method more diverse and applicable.

Implementation of SABEM can be facilitated through using the SABEM integrated Excel toolkit outlined in Appendix B. However, certain constraints should be considered, such as the careful application of hydraulic conductivity estimates due to their broad nature, and the associated standard deviation.

Practical recommendations include using the provided script in Appendix B and setting up an SQL database to run and manage the script. It should be noted that any modifications to the Department of Water and Sanitation (DWS) website may affect the usability of the script.

While this study relied on seven unique case studies to verify and validate SABEM, its refinement and further improvement can be achieved through additional, more precise, and specified tracer studies aligning with dates of streamflow data. This aligns with the objective to obtain a comprehensive collection of tracer-estimated baseflow studies for verification and comparison of the proposed and existing methods. Re-calibration of SABEM will then be possible which will rule out some of the assumptions in this study.

SABEM has, therefore been successfully developed, applied, verified and validated on the conducted case studies concerning South Africa as a whole. Its continued utilisation and application in future studies will ensure ongoing refinement and increased accuracy through recurring calibration. Thus, it can be confidently concluded that SABEM represents a viable and acceptable method for estimating baseflow in the South African context.

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Appendix A – Borehole data

Borehole Data NGA 2008 Database

T3H009	Zcoord	Avg Water Level m	wl	river height	H	distance	Slope
3128AA00002	1390	37.5	1352.5	1350	2.5	150	0.0167
3128AA00004	1340	10.79	1329.21	1309	20.21	1000	0.0202
							0.0184

G1H043	Zcoord	Avg Water Level m	wl	river height	H	distance	Slope
3318BA00069	220	1.52	218.48		218.48	150	
3318BA00070	220	13.72	206.28		206.28		
3318BB00001	140	3	137		137		
3318BB00004	160	15.7	144.3		144.3		
3318BB00006	80	15.24	64.76	69	-4.24	2480	-0.0017
3318BB00007	80	12.19	67.81	69	-1.19	2480	-0.0005
3318BD00016	120	15.24	104.76		104.76		
3318BD00017	120	1.52	118.48	60	58.48	700	0.0835
3318BD00018	120	4.57	115.43	56	59.43	500	0.1189
3318BD00019	120	5.49	114.51		114.51		
3318BD00020	120	10.67	109.33	71	38.33	2500	0.0153
3318BD00021	120	24	96	85	11	4000	0.0028
3318BD00022	120	25	95	85	10	4000	0.0025
3318BD00037	180	20	160		160		
3318BD00041	180	30	150		150		
3318BD00043	180	5	175		175		
3318BD00045	180	7.62	172.38		172.38		
3318BD00046	180	2.44	177.56		177.56		
3318BD00047	200	7.62	192.38		192.38		
3318BD00048	200	7.62	192.38		192.38		
3318BD00049	200	6.1	193.9		193.9		
3318BD00050	200	3.66	196.34		196.34		
3318BD00051	200	17.07	182.93		182.93		
3318BD00055	200	20.72	179.28		179.28		
3318BD00057	200	4.57	195.43		195.43		
3318BD00058	200	2.44	197.56		197.56		
3318BD00062	180	13.11	166.89		166.89		
3318BD00064	180	9.14	170.86		170.86		
3318BD00067	180	0.01	179.99		179.99		
3318BD00073	180	0.01	179.99		179.99		
3318BD00075	180	12.19	167.81		167.81		
3318BD00076	180	10.97	169.03		169.03		

3318BD00077	180	4.57	175.43		175.43		
3318BD00078	180	0.91	179.09		179.09		
3318BD00079	180	13	167		167		
3318BD00094	200	1.52	198.48		198.48		
3318BD00171	210	2.18	207.82		207.82		
							0.0315

X2H010	Zcoord	Avg Water Level m	wl	river height	H	distance	Slope
2530DB00237	920	66	854	850	4	2300	0.0017
2530DB00239	980	20	960	855	105	3000	0.0350
2530DB00240	980	40	940	855	85	3000	0.0283
							0.0217

X2H008	Zcoord	Avg Water Level m	wl	river height	H	distance	Slope
2530DD00002	1380	21.43	1358.57	1312	46.57	1800	0.0259
							0.0259

X2H031	Zcoord	Avg Water Level m	wl	river height	H	distance	Slope
2530DB00003	820	16.9	803.1	744	59.1	3000	0.0197
2530DB00009	740	7.62	732.38	702	30.38	2900	0.0105
2530DB00017	784	21.64	762.36	722	40.36	814	0.0496
2530DB00030	760	14.33	745.67	689	56.67	2300	0.0246
2530DD00006	820	1.22	818.78		818.78		
2530DD00007	820	9.75	810.25	686	124.25	6400	0.0194
							0.0248

x2h0022	Zcoord	Avg Water Level m	wl	river height	H	distance	Slope
2531CA00012	920	30	890		890		
2531CA00013	920	30	890		890		
2531CA00034	740	14.63	725.37		725.37		
2531CA00423	480	26	454		454		
2531CA00425	780	7.6	772.4		772.4		
2531CA00448	500	7	493		493		
2531CA00464	480	3.65	476.35		476.35		
2531CA00478	820	14	806		806		
2531CB00002	480	28.04	451.96	431	20.96	1000	0.0210
2531CB00019	400	9.14	390.86	373	17.86	619	0.0289
2531CB00020	400	12.19	387.81		387.81		
2531CB00021	560	15.24	544.76		544.76		
2531CB00022	560	9.14	550.86		550.86		
2531CB00024	560	11.58	548.42		548.42		
2531CB00030	440	9	431	361	70	2540	0.0276

2531CB00033	440	30.5	409.5	361	48.5	2540	0.0191
2531CB00040	580	60	520	373	147	2700	0.0544
2531CB00069	400	6	394	373	21	840	0.0250
2731CB00014	400	6.1	393.9		393.9		
							0.0293

v1h010	Zcoord	Avg Water Level m	wl	river height	H	distance	Slope
2829CD00024	1140	21.33	1118.67		1118.67		
2829CD00025	1140	4.57	1135.43		1135.43		
2829DC00001	1170	40	1130		1130		
2829DC00011	1057	9	1048	1028	20	800	0.0250
2829DC00012	1057	9	1048	1028	20	800	0.0250
2829DC00013	1057	18	1039	1028	11	800	0.0138
2829DC00014	1040	20	1020	1020	0	800	0.0000
2829DC00029	1060	9.14	1050.86		1050.86		
2829DC00042	1040	4.57	1035.43	1033	2.43	113	0.0215
2829DC00049	1100	16.76	1083.24		1083.24		
2829DC00050	1160	11.58	1148.42		1148.42		
2829DC00051	1160	12.49	1147.51		1147.51		
2829DC00073	1040	4.87	1035.13	1028	7.13	800	0.0089
2829DC00074	1040	3	1037	1028	9	800	0.0113
2829DC00102	1060	13.71	1046.29		1046.29		
2829DC00103	1060	9.75	1050.25		1050.25		
2829DC00105	1060	9.14	1050.86		1050.86		
2829DC00107	1060	12.8	1047.2		1047.2		
2829DC00108	1060	0.91	1059.09		1059.09		
2829DC00109	1060	12.19	1047.81		1047.81		
2829DC00110	1060	15.24	1044.76		1044.76		
2829DC00111	1060	14.63	1045.37		1045.37		
2829DC00112	1069	12.19	1056.81	1046	10.81	1700	0.0064
2829DC00114	1069	3.04	1065.96	1046	19.96	1700	0.0117
2829DC00116	1060	6.09	1053.91		1053.91		
2829DC00117	1069	12.19	1056.81	1046	10.81	1700	0.0064
2829DC00120	1100	9.14	1090.86		1090.86		
2829DC00121	1100	13.41	1086.59		1086.59		
2829DC00122	1100	12.19	1087.81		1087.81		
2829DC00123	1100	2.13	1097.87		1097.87		
2829DC00125	1100	13.41	1086.59		1086.59		
2829DC00150	1056	25	1031	1032	-1	300	-0.0033
2829DC00173	1080	30	1050		1050		
2829DC00179	1260	40	1220		1220		
2829DC00198	1100	60	1040		1040		
2829DC00200	1130	90	1040		1040		
2829DC00201	1120	27	1093		1093		

2829DC00206	1160	60	1100		1100		
2829DC00207	1170	60	1110		1110		
2829DC00215	1360	2.57	1357.43		1357.43		
							0.0115

Appendix B – SABEM

SABEM integrated Excel Toolkit

Software

Software products to be used in this study include Microsoft Excel, Python and Azure SQL. They will interact with each other, and the Excel toolkit will be the main form of interaction. The following packages and versions are installed to run the Python Script:

- pyodbc=4.0.30
- selenium=3.141.0
- urllib3=1.25.10

Data Scraper

The Python script labelled as a scraper can be described below as follows:

```
1  from selenium import webdriver
2  from selenium.webdriver.support.ui import Select
3  from datetime import datetime, timedelta
4  import urllib.parse as urlparse
5  from urllib.parse import parse_qs
6  import pyodbc
7
8  conn = pyodbc.connect("Driver={ODBC Driver 17 for SQL
   Server};Server=tcp:drainage-region-stations.database.windows.net,1433;Database=Streamflow;
   Uid=ArsenalAdmin;Pwd=Arsenal1;Encrypt=yes;TrustServerCertificate=no;Connection
   Timeout=30;")
9
10 def createTableStationInfo(conn=conn):
16
17 def createTableStationDataMonthly(conn=conn):
23
24 def createTableStationDataDaily(conn=conn):
30
31 def getAllData(conn=conn):
130
131 def getStationData(driver):
192
193
194     getAllData()
195
196     # createTableStationInfo()
197     # createTableStationDataMonthly()
198     # createTableStationDataDaily()
199
```

```

1 from selenium import webdriver
2 from selenium.webdriver.support.ui import Select
3 from datetime import datetime, timedelta
4 import urllib.parse as urlparse
5 from urllib.parse import parse_qs
6 import pyodbc
7
8 conn = pyodbc.connect("Driver={ODBC Driver 17 for SQL
Server};Server=tcp:drainage-region-stations.database.windows.net,1433;Database=Streamflo
w;Uid=ArsenalAdmin;Pwd=Arsenal1;Encrypt=yes;TrustServerCertificate=no;Connection
Timeout=30;")
9
10 def createTableStationInfo(conn=conn):
11     cursor = conn.cursor()
12     table_name = "StationInfo"
13     query = 'CREATE TABLE ' + table_name + ' (StationId INT NOT NULL IDENTITY (1,1)
PRIMARY KEY, StationName VARCHAR(255) NOT NULL, StationPlace VARCHAR(255),
CatchmentArea DECIMAL(18,5), Latitude DECIMAL(9,6), Longitude DECIMAL(9,6),
DateStart DATE, DateEnd DATE, URL VARCHAR(8000));'
14     cursor.execute(query)
15     cursor.commit()
16
17 def createTableStationDataMonthly(conn=conn):
18     cursor = conn.cursor()
19     table_name = "StationDataMonthly"
20     query = 'CREATE TABLE ' + table_name + ' (StationId INT NOT NULL, DateRecorded
DATE NOT NULL, Volume DECIMAL(31,6), QualityCode INT);'
21     cursor.execute(query)
22     cursor.commit()
23
24 def createTableStationDataDaily(conn=conn):
25     cursor = conn.cursor()
26     table_name = "StationDataDaily"
27     query = 'CREATE TABLE ' + table_name + ' (StationId INT NOT NULL, DateRecorded
DATE NOT NULL, AverageFlow DECIMAL(31,6), QualityCode INT);'
28     cursor.execute(query)
29     cursor.commit()

```

SQL database link

```

30
31 def getAllData(conn=conn):
32     url = "http://www.dwa.gov.za/Hydrology/Verified/hvmain.aspx"
33     driver = webdriver.Chrome()
34     driver.get(url)
35
36     # Region list search
37     region_select = Select(driver.find_element_by_name("cbRegion"))
38
39     # loop through all regions
40     # start at index 1, because "-Stations in drainage region-" is at index 0
41     for i in range(1, len(region_select.options)):
42         region_select = Select(driver.find_element_by_name("cbRegion"))
43         region_button = driver.find_element_by_name("btnRegion")
44
45         region_select.select_by_index(i)
46         region_button.click()
47
48         stations = driver.find_elements_by_xpath("//table[@id='tableStations']//tr")
49         stations = stations[2:]
50         station_names = []
51         station_places = []
52         station_catchment_areas = []
53         station_latitudes = []
54         station_longitudes = []
55         station_start_dates = []
56         station_end_dates = []
57         station_urls = []
58         for station in stations:
59             station_names.append(station.find_elements_by_xpath("./td")[0].text)
60             station_places.append(station.find_elements_by_xpath("./td")[1].text)
61             station_catchment_areas.append(station.find_elements_by_xpath("./td")[2].
text)
62             station_latitudes.append(station.find_elements_by_xpath("./td")[3].text)
63             station_longitudes.append(station.find_elements_by_xpath("./td")[4].text)
64             station_date_range = station.find_elements_by_xpath("./td")[5].text
65             station_start_dates.append(station_date_range.split()[0])
66             station_end_dates.append(station_date_range.split()[2])
67             station_urls.append(station.find_element_by_xpath("./a[@href]").
get_attribute('href'))

```

Collection of general
station information

```

68
69
70 cur = conn.cursor()
71 for station_name, station_place, station_catchment_area, station_latitude,
station_longitude, station_start_date, station_end_date, station_url in \
zip(station_names, station_places, station_catchment_areas,
station_latitudes, station_longitudes, station_start_dates,
station_end_dates, station_urls):
72
73     station_query = 'SELECT * FROM StationInfo WHERE StationName=?;'
74     cur.execute(station_query, (station_name))
75     station_db = cur.fetchone()
76     if station_db is None:
77         if len(station_catchment_area) == 0:
78             station_catchment_area = None
79             query_insert_station = 'INSERT INTO StationInfo
(StationName,StationPlace,CatchmentArea,Latitude,Longitude,URL)
VALUES(?,?,?, ?, ?, ?)'
80             cur.execute(query_insert_station, (station_name, station_place,
station_catchment_area, station_latitude, station_longitude,
station_url))
81             cur.commit()
82     else:
83         # continue
84         if station_db.DateStart is not None and station_db.DateEnd is not None:
85             # station data already up to date
86             continue
87
88         # if str(station_db.DateStart) == station_start_date and \
89         # str(station_db.DateEnd) == station_end_date:
90         #     # station data already up to date
91         #     continue
92         # else:
93         #     # station data outdated
94         #     pass
95
96     driver.get(station_url)
97
98     if "Invalid station number" in driver.page_source:
99         print("Invalid station number:", station_name)
100         continue

```

```

101
102     # get monthly data
103     driver.find_element_by_name("cbNew").click()
104     month_button = driver.find_element_by_name("btnMnth_0")
105     month_button.click()
106     getStationData(driver)
107
108     # get daily data
109     driver.back()
110     daily_button = driver.find_element_by_name("btnDay_0")
111     daily_button.click()
112     getStationData(driver)
113
114     query_station_id = 'SELECT StationId FROM StationInfo WHERE StationName=?;'
115     cur.execute(query_station_id, (station_name))
116     station_id = cur.fetchone()
117     station_date_query = 'SELECT MIN(DateRecorded) AS StartDate,
118     MAX(DateRecorded) AS EndDate FROM StationDataDaily WHERE StationId=?;'
119     cur.execute(station_date_query, (station_id))
120     date = cur.fetchone()
121     if date.StartDate is not None and date.EndDate is not None:
122         # date_start_date = date.StartDate
123         # date_end_date = date.EndDate + timedelta(days=1)
124         query_update_dates = 'UPDATE StationInfo SET DateStart=?, DateEnd=?
125         WHERE StationName=?'
126         cur.execute(query_update_dates, (date.StartDate, date.EndDate,
127         station_name))
128         cur.commit()
129
130     driver.get(url)
131
132     driver.close()
133
134 def getStationData(driver):
135     parsed = urlparse.urlparse(driver.current_url)
136     station_name = parse_qs(parsed.query)['Station'][0][:6]
137     station_data_type = parse_qs(parsed.query)['DataType'][0]
138     station_start_date = parse_qs(parsed.query)['StartDT'][0]
139     station_end_date = parse_qs(parsed.query)['EndDT'][0]
140
141     if "No data for requested period" in driver.page_source:
142         print("No " + station_data_type + " data for station " + station_name + " for
143         requested period " + station_start_date + " to " + station_end_date)
144         return
145     elif "Unknown SQL type - 0" in driver.page_source:
146         print("Error:\\"Unknown SQL type - 0\\" for " + station_data_type + " data for
147         station " + station_name + " for requested period " + station_start_date + "
148         to " + station_end_date)
149         return
150
151     try:
152         station_data = driver.find_element_by_xpath("//pre").text.splitlines()
153     except Exception as e:
154         print("Error: ", e)
155         print(driver.page_source)
156         return
157
158     data_start = [i for i, s in enumerate(station_data) if 'DATE' in s][0]
159     station_data = station_data[data_start + 1:]
160
161     cur = conn.cursor()
162     query_station_id = 'SELECT StationId FROM StationInfo WHERE StationName=?;'
163     cur.execute(query_station_id, (station_name))
164     station_id = cur.fetchone()
165
166     if station_data_type == "Monthly":
167         query_insert_monthly = 'IF NOT EXISTS (SELECT * FROM StationDataMonthly WHERE
168         StationId=? AND DateRecorded=?) INSERT INTO StationDataMonthly (StationId,
169         DateRecorded, Volume, QualityCode) VALUES(?,?,?,?)'
170         # query_insert_monthly = 'INSERT INTO StationDataMonthly (StationId,
171         DateRecorded, Volume, QualityCode) VALUES(?,?,?,?)'
172         for row in station_data:
173             if len(row) == 24:
174                 date = row[0:6]
175                 volume = row[9:18].strip()
176                 code = row[19:24].strip()
177                 if len(volume) == 0:
178                     volume = None
179                 date = str(datetime.strptime(date, '%Y%m').strftime('%Y-%m-%d'))

```

Looping though the
daily and monthly
stations extracting
data one by one

```

171
172         cur.execute(query_insert_monthly, (station_id, date, volume, code))
173     else:
174         break
175 elif station_data_type == "Daily":
176     query_insert_daily = 'IF NOT EXISTS (SELECT * FROM StationDataDaily WHERE
    StationId=? AND DateRecorded=?) INSERT INTO StationDataDaily (StationId,
    DateRecorded, AverageFlow, QualityCode) VALUES(?,?,?,?)'
177     # query_insert_daily = 'INSERT INTO StationDataDaily (StationId, DateRecorded,
    AverageFlow, QualityCode) VALUES(?,?,?,?)'
178     for row in station_data:
179         if len(row) == 24:
180             date = row[0:8]
181             average_flow = row[9:18].strip()
182             code = row[19:24].strip()
183             if len(average_flow) == 0:
184                 average_flow = None
185             date = str(datetime.strptime(date, '%Y%m%d').strftime('%Y-%m-%d'))
186             cur.execute(query_insert_daily, (station_id, date, average_flow, code))
187         else:
188             break
189
190
191     cur.commit()
192
193
194     getAllData()
195
196     # createTableStationInfo()
197     # createTableStationDataMonthly()
198     # createTableStationDataDaily()
199

```

HTML streamflow data represented by a single line element and data extracted based on the row number the data or flow starts and ends

Python Data Scraper Script

Developing a toolkit

One of the objectives of this study was to create a toolkit that would incorporate the entire SQL database and the proposed baseflow estimation method by means of Microsoft Excel. The toolkit allows minor inputs and buttons to automate most basic functions usually done by hand. The toolkit searches and extracts streamflow data for a specific flow gauge or station. Once entered or selected, dates are defined, and the data is imported to Excel by clicking a button which begins the baseflow estimation of the data. The toolkit makes use of Excel VLOOKUP functions to extract general information related to the flow gauge or station.

It should be noted that the DWS database is not completely accurate and dates given on the site are not necessarily the dates found when the data is extracted. The scraper will automate this task by extracting the specific timeline of each data set so that it will not be confused with the data set defined on the site itself. Data quality is also of concern and is mitigated by using the quality data codes of the data and using an IF statement to extract certain types of data before use.

The accompanying Excel toolkit incorporates both the Python scraper code and the SABEM method with input parameters. Excel extracts or imports data as requested from the SQL database.

Sheets on excel:

- Baseflow estimation (main user interface)
- Station info (basic info used for VLOOKUP)
- Quality codes (for convenience)

SABEM

Step 1: Select Flow Station and Data Type

Blue cells indicate dropdown lists to select the required data.

1. Click on blue cell under **Station** and scroll down until you find a familiar streamflow station or specific station required, then select it.
2. Click on blue cell under **Data Type** and select between Daily streamflow data or Monthly streamflow data.
3. Additional data on the selected streamflow gauge is then displayed below which is simply a Vlookup indicating the location's GPS coordinates and catchment size for convenience.

Step 2: Select Chronologically Correct Time Frame:

There are two ways the dates can be entered in the blue cells.

1. The first and most simple method is to click on the **Use Available Dates** button. This will prompt the **Date Start** cell and **Date End** cell to automatically use the dates that are available from the very first entry to the last entry for that specific station.
2. The second method is to manually enter the required dates in the blue cells under **Date Start** and **Date End** cells.

Note the small box indicating the available time frame for the selected station.

The cells will turn red if the dates are not within the available time frame for the streamflow data or when the dates are not in chronological order i.e., start date is after end date etc.

These dates are not the dates that the Department used to indicate the stations available time frame, these dates are derived from the data itself so that there are no gaps or incorrect start and end dates not correlating to the data.

Step 3: Retrieving the data

Click on the **Load Data** button.

This will prompt Excel to connect to the SQL database and retrieve the data requested. Please note that Excel is not frozen or lagging as it takes a while for the SQL to run and retrieve the data because it updates the data to see if any new entries are available and then it fine tunes the data putting it in the correct format and does all the hard work usually done by hand. The data is then displayed in Excel, so this process takes a couple of seconds to minutes to complete – just wait for it to complete.

Note that sometimes the graph does not display because the series Y data shifts one column to the right and should just be reverted back to the “Good Quality” column.

If the formula in the Good Quality column is not working or has #REF error, the correct formula should look like this: =IF([@QualityCode]<7,[@AverageFlow],#N/A)

Note that here you can specify which quality data should be extracted using the quality codes sheet. It is currently set at all codes below 7.

Step 4: Estimate baseflow

Copy the imported data into the indicated columns for Date and Flow (Quality not required once desired data is extracted).

Calculate the catchment parameters and use the directly proportional SABEM parameter and fine tune the parameters for high and low frequency flows.

Appendix C – Streamflow data SABEM results

Streamflow Data collected with resulting baseflow estimation using SABEM

G1H043	Flo w	baseflo w	V1H010	Flo w	baseflo w	T3H009	Flo w	baseflo w	X2H008	Flo w	baseflo w	X2H010	Flo w	baseflo w	X2H031	Flo w	baseflo w	X2H022	Flo w	baseflo w
10/4/1996	0	0.000	1/10/197 7	5.9	4.361	11/3/1954	0.03	0.031	1/6/1966	0.02	0.022	1/10/196 2	0.39	0.385	1/10/198 4	0.18	0.184	10/9/1973	0.94	0.916
10/5/1996	0	0.000	1/11/197 7	5.46	4.339	11/4/1954	0.03	0.034	1/7/1966	0.02	0.023	1/11/196 2	0.39	0.385	1/11/198 4	0.19	0.186	10/10/197 3	0.93	0.862
10/6/1996	0	0.000	1/12/197 7	4.91	4.299	11/5/1954	0.04	0.039	1/8/1966	0.02	0.024	1/12/196 2	0.39	0.385	1/12/198 4	0.19	0.187	10/11/197 3	0.81	0.807
10/7/1996	0	0.000	1/13/197 7	4.55	4.247	11/6/1954	0.04	0.043	1/9/1966	0.03	0.025	1/13/196 2	15.3	1.920	1/13/198 4	0.19	0.189	10/12/197 3	0.63	0.631
10/8/1996	0	0.000	1/14/197 7	4.35	4.217	11/7/1954	0.05	0.047	1/10/196 6	0.03	0.025	1/14/196 2	15.5	1.939	1/14/198 4	0.2	0.195	10/13/197 3	0.55	0.554
10/9/1996	0	0.000	1/15/197 7	4.36	4.203	11/8/1954	0.05	0.051	1/11/196 6	0.03	0.026	1/15/196 2	11	5.810	1/15/198 4	0.22	0.219	10/14/197 3	0.53	0.528
10/10/199 6	0	0.000	1/16/197 7	4.14	4.135	11/9/1954	0.06	0.055	1/12/196 6	0.03	0.026	1/16/196 2	8.04	5.901	1/16/198 4	0.27	0.250	10/15/197 3	0.47	0.467
10/11/199 6	0	0.000	1/17/197 7	4.39	4.195	11/10/195 4	0.12	0.124	1/13/196 6	0.03	0.026	1/17/196 2	2.57	2.570	1/17/198 4	0.25	0.254	10/16/197 3	0.48	0.479
10/12/199 6	0	0.000	1/18/197 7	6.47	4.230	11/11/195 4	0.23	0.231	1/14/196 6	0.03	0.026	1/18/196 2	1.76	1.762	1/18/198 4	0.22	0.219	10/17/197 3	0.45	0.449
10/13/199 6	0	0.000	1/19/197 7	25.5	4.466	11/12/195 4	0.17	0.174	1/15/196 6	0.03	0.026	1/19/196 2	1.4	1.395	1/19/198 4	0.21	0.214	10/18/197 3	0.41	0.412
10/14/199 6	0	0.000	1/20/197 7	19.5	6.555	11/13/195 4	0.12	0.122	1/16/196 6	0.03	0.026	1/20/196 2	1.29	1.288	1/20/198 4	0.26	0.250	10/19/197 3	0.38	0.378
10/15/199 6	0	0.000	1/21/197 7	14.4	5.915	11/14/195 4	0.1	0.104	1/17/196 6	0.03	0.026	1/21/196 2	0.92	0.919	1/21/198 4	0.43	0.268	10/20/197 3	0.33	0.334
10/16/199 6	0	0.000	1/22/197 7	10.5	5.370	11/15/195 4	0.09	0.091	1/18/196 6	0.03	0.026	1/22/196 2	0.55	0.550	1/22/198 4	0.44	0.341	10/21/197 3	0.33	0.326
10/17/199 6	0	0.000	1/23/197 7	8.85	4.947	11/16/195 4	0.13	0.126	1/19/196 6	0.02	0.023	1/23/196 2	0.53	0.528	1/23/198 4	0.38	0.347	10/22/197 3	0.33	0.333
10/18/199 6	0	0.000	1/24/197 7	8.06	4.778	11/17/195 4	0.12	0.124	1/20/196 6	0.02	0.020	1/24/196 2	0.66	0.657	1/24/198 4	0.38	0.323	10/23/197 3	0.36	0.360
10/19/199 6	0	0.000	1/25/197 7	9.23	4.701	11/18/195 4	0.12	0.115	1/21/196 6	0.02	0.019	1/25/196 2	0.74	0.743	1/25/198 4	0.54	0.324	10/24/197 3	0.35	0.351
10/20/199 6	0	0.000	1/26/197 7	11.4	4.838	11/19/195 4	0.1	0.100	1/22/196 6	0.02	0.023	1/26/196 2	0.8	0.797	1/26/198 4	0.56	0.390	10/25/197 3	0.31	0.306
10/21/199 6	0	0.000	1/27/197 7	8.21	5.079	11/20/195 4	0.09	0.093	1/23/196 6	0.02	0.023	1/27/196 2	0.76	0.756	1/27/198 4	0.49	0.401	10/26/197 3	0.33	0.328
10/22/199 6	0	0.000	1/28/197 7	7.47	4.745	11/21/195 4	0.09	0.092	1/24/196 6	0.03	0.032	1/28/196 2	0.7	0.696	1/28/198 4	0.41	0.371	10/27/197 3	1.14	0.553

10/23/199	6	0	0.000	1/29/197	7	7.04	4.673	11/22/195	4	0.09	0.091	1/25/196	6	0.04	0.035	1/29/196	2	0.69	0.688	1/29/198	4	0.39	0.340	10/28/197	3	5.21	1.018	
10/24/199	6	0	0.000	1/30/197	7	6.93	4.635	11/23/195	4	0.09	0.090	1/26/196	6	0.14	0.140	1/30/196	2	0.66	0.660	1/30/198	4	0.37	0.331	10/29/197	3	33.2	0.255	
10/25/199	6	0	0.000	1/31/197	7	10	4.632	11/24/195	4	0.09	0.090	1/27/196	6	0.07	0.069	1/31/196	2	0.61	0.614	1/31/198	4	0.37	0.322	10/30/197	3	33.7	2.598	
10/26/199	6	0	0.000	2/1/1977	15	4.976		11/25/195	4	0.09	0.088	1/28/196	6	0.05	0.046	2/1/1962	0.61	0.611	2/1/1984	0.54	0.322		10/31/197	3	12.5	12.492		
10/27/199	6	0	0.000	2/2/1977	9.76	5.537		11/26/195	4	0.12	0.117	1/29/196	6	0.05	0.054	2/2/1962	0.61	0.611	2/2/1984	0.48	0.397		11/1/1973	7.4	7.396			
10/28/199	6	0	0.000	2/3/1977	8.53	4.970		11/27/195	4	0.13	0.128	1/30/196	6	0.14	0.137	2/3/1962	0.61	0.611	2/3/1984	0.4	0.370		11/2/1973	5.53	4.810			
10/29/199	6	0	0.000	2/4/1977	8.13	4.845		11/28/195	4	0.12	0.119	1/31/196	6	1.53	0.363	2/4/1962	0.61	0.607	2/4/1984	0.33	0.334		11/3/1973	4.54	3.754			
10/30/199	6	0	0.000	2/5/1977	7.94	4.811		11/29/195	4	0.11	0.112	2/1/1966	0.36	0.362	2/5/1962	0.59	0.594	2/5/1984	0.29	0.294		11/4/1973	3.84	3.204				
10/31/199	6	0	0.000	2/6/1977	7.71	4.799		11/30/195	4	0.1	0.100	2/2/1966	0.12	0.119	2/6/1962	0.58	0.584	2/6/1984	0.28	0.279		11/5/1973	3.45	2.811				
11/1/1996	0	0.000		2/7/1977	8.68	4.783		12/1/1954	0.08	0.083	2/3/1966	0.07	0.070	2/7/1962	1.85	1.791	2/7/1984	0.26	0.257		11/6/1973	3.04	2.596					
11/2/1996	0	0.000		2/8/1977	12.3	4.898		12/2/1954	0.07	0.073	2/4/1966	0.05	0.053	2/8/1962	1.9	1.896	2/8/1984	0.4	0.281		11/7/1973	2.67	2.370					
11/3/1996	0	0.000		2/9/1977	12.9	5.299		12/3/1954	0.07	0.068	2/5/1966	0.05	0.052	2/9/1962	1.01	1.014	2/9/1984	0.67	0.341		11/8/1973	2.4	2.171					
11/4/1996	0	0.000		2/10/197	7	21	5.377	12/4/1954	0.06	0.057	2/6/1966	0.05	0.046	2/10/196	2	0.76	0.764	2/10/198	4	0.6	0.454	11/9/1973	2.71	2.025				
11/5/1996	0	0.000		2/11/197	7	42.7	6.274	12/5/1954	0.05	0.049	2/7/1966	0.04	0.041	2/11/196	2	0.59	0.594	2/11/198	4	0.6	0.425	11/10/197	3	3.35	2.210			
11/6/1996	0	0.000		2/12/197	7	21.8	8.656	12/6/1954	0.05	0.052	2/8/1966	0.04	0.041	2/12/196	2	0.57	0.565	2/12/198	4	0.56	0.428	11/11/197	3	33.7	1.409			
11/7/1996	0	0.000		2/13/197	7	17.5	6.394	12/7/1954	0.06	0.055	2/9/1966	0.04	0.039	2/13/196	2	9.1	2.871	2/13/198	4	0.5	0.412	11/12/197	3	12.5	1.782			
11/8/1996	0	0.000		2/14/197	7	15.3	5.930	12/8/1954	0.06	0.058	2/10/196	6	0.04	0.037	2/14/196	2	16.9	2.892	2/14/198	4	0.46	0.389	11/13/197	3	7.4	7.396		
11/9/1996	0	0.000		2/15/197	7	14.9	5.705	12/9/1954	0.06	0.058	2/11/196	6	0.04	0.035	2/15/196	2	2.53	2.526	2/15/198	4	0.4	0.371	11/14/197	3	5.53	5.024		
11/10/199	6	0	0.000	2/16/197	7	13.6	5.667	12/10/195	4	0.06	0.058	2/12/196	6	0.03	0.033	2/16/196	2	1.78	1.781	2/16/198	4	0.36	0.346	11/15/197	3	4.54	3.969	
11/11/199	6	0	0.000	2/17/197	7	12.8	5.538	12/11/195	4	0.06	0.058	2/13/196	6	0.03	0.031	2/17/196	2	1.66	1.663	2/17/198	4	0.32	0.324	11/16/197	3	3.84	3.420	
11/12/199	6	0	0.000	2/18/197	7	16.2	5.461	12/12/195	4	0.06	0.058	2/14/196	6	0.03	0.029	2/18/196	2	2.36	2.359	2/18/198	4	0.3	0.304	11/17/197	3	3.45	3.028	
11/13/199	6	0	0.000	2/19/197	7	13.5	5.839	12/13/195	4	0.06	0.058	2/15/196	6	0.03	0.027	2/19/196	2	1.46	1.460	2/19/198	4	0.29	0.288	11/18/197	3	3.04	2.814	
11/14/199	6	0	0.000	2/20/197	7	12.9	5.554	12/14/195	4	0.06	0.058	2/16/196	6	0.03	0.025	2/20/196	2	1.02	1.021	2/20/198	4	0.28	0.283	11/19/197	3	2.67	2.589	
11/15/199	6	0	0.000	2/21/197	7	12.5	5.506	12/15/195	4	0.06	0.058	2/17/196	6	0.05	0.045	2/21/196	2	0.93	0.932	2/21/198	4	0.41	0.301	11/20/197	3	2.4	2.390	
11/16/199	6	0	0.000	2/22/197	7	11.9	5.467	12/16/195	4	0.06	0.060	2/18/196	6	0.03	0.027	2/22/196	2	0.89	0.890	2/22/198	4	1.84	0.162	11/21/197	3	2.71	2.245	

11/17/1996	0	0.000	2/23/1977	11.2	5.414	12/17/1954	0.06	0.060	2/19/1966	0.02	0.023	2/23/1962	4.29	3.346	2/23/1984	1.13	0.959	11/22/1973	3.35	2.431
11/18/1996	0	0.000	2/24/1977	11.6	5.352	12/18/1954	0.04	0.044	2/20/1966	0.02	0.023	2/24/1962	6.48	3.369	2/24/1984	0.76	0.661	11/23/1973	4.1	2.809
11/19/1996	0	0.000	2/25/1977	11.8	5.402	12/19/1954	0.03	0.030	2/21/1966	0.02	0.022	2/25/1962	4.28	4.276	2/25/1984	0.69	0.507	11/24/1973	6.44	3.250
11/20/1996	0	0.000	2/26/1977	11.2	5.441	12/20/1954	0.03	0.030	2/22/1966	0.02	0.021	2/26/1962	15.1	4.883	2/26/1984	0.78	0.478	11/25/1973	10.7	2.404
11/21/1996	0	0.000	2/27/1977	12.6	5.385	12/21/1954	0.03	0.030	2/23/1966	0.02	0.019	2/27/1962	7.23	4.366	2/27/1984	0.65	0.517	11/26/1973	26.2	3.754
11/22/1996	0	0.000	2/28/1977	10.9	5.549	12/22/1954	0.03	0.030	2/24/1966	0.02	0.017	2/28/1962	5.41	5.411	2/28/1984	0.59	0.463	11/27/1973	24.4	6.203
11/23/1996	0	0.000	3/1/1977	10.2	5.365	12/23/1954	0.03	0.030	2/25/1966	0.02	0.018	3/1/1962	2	2.004	2/29/1984	0.61	0.437	11/28/1973	13.5	13.515
11/24/1996	0	0.000	3/2/1977	11.6	5.307	12/24/1954	0.03	0.030	2/26/1966	0.02	0.020	3/2/1962	1.58	1.582	3/1/1984	0.6	0.447	11/29/1973	10.2	10.189
11/25/1996	0	0.000	3/3/1977	11.2	5.463	12/25/1954	0.03	0.030	2/27/1966	0.11	0.108	3/3/1962	6.08	3.997	3/2/1984	0.53	0.445	11/30/1973	8.04	6.953
11/26/1996	0	0.000	3/4/1977	10.6	5.436	12/26/1954	0.03	0.030	2/28/1966	0.31	0.312	3/4/1962	5.56	3.928	3/3/1984	0.47	0.418	12/1/1973	6.77	5.743
11/27/1996	0	0.000	3/5/1977	10.1	5.373	12/27/1954	0.03	0.030	3/1/1966	1.07	0.523	3/5/1962	3.08	3.076	3/4/1984	0.44	0.391	12/2/1973	6.26	5.036
11/28/1996	0	0.000	3/6/1977	9.82	5.329	12/28/1954	0.03	0.030	3/2/1966	1.85	0.653	3/6/1962	2.26	2.262	3/5/1984	0.61	0.379	12/3/1973	5.53	4.765
11/29/1996	0	0.000	3/7/1977	9.62	5.312	12/29/1954	0.03	0.029	3/3/1966	0.41	0.409	3/7/1962	1.68	1.681	3/6/1984	2.64	0.236	12/4/1973	5.04	4.364
11/30/1996	0	0.000	3/8/1977	9.44	5.301	12/30/1954	0.03	0.026	3/4/1966	0.21	0.209	3/8/1962	1.53	1.525	3/7/1984	1.1	1.099	12/5/1973	4.73	4.098
12/1/1996	0	0.000	3/9/1977	9.16	5.291	12/31/1954	0.02	0.022	3/5/1966	0.15	0.154	3/9/1962	2.2	2.198	3/8/1984	0.76	0.662	12/6/1973	5.16	3.934
12/2/1996	0	0.000	3/10/1977	9.38	5.271	1/1/1955	0.04	0.035	3/6/1966	0.1	0.104	3/10/1962	2.36	2.361	3/9/1984	0.71	0.519	12/7/1973	4.74	4.197
12/3/1996	0	0.000	3/11/1977	11.1	5.304	1/2/1955	0.05	0.045	3/7/1966	0.07	0.073	3/11/1962	17.4	4.399	3/10/1984	1.32	0.500	12/8/1973	4.51	3.970
12/4/1996	0	0.000	3/12/1977	13.9	5.504	1/3/1955	0.04	0.044	3/8/1966	0.06	0.060	3/12/1962	6.46	4.485	3/11/1984	1.17	0.760	12/9/1973	4.2	3.854
12/5/1996	0	0.000	3/13/1977	14.2	5.813	1/4/1955	0.04	0.035	3/9/1966	0.07	0.066	3/13/1962	25.5	8.398	3/12/1984	0.94	0.698	12/10/1973	3.61	3.613
12/6/1996	0	0.000	3/14/1977	14.4	5.864	1/5/1955	0.03	0.029	3/10/1966	0.35	0.345	3/14/1962	11.5	5.668	3/13/1984	0.79	0.599	12/11/1973	3.17	3.167
12/7/1996	0.04	0.044	3/15/1977	27.4	5.901	1/6/1955	0.03	0.026	3/11/1966	3.64	0.514	3/15/1962	2.52	2.522	3/14/1984	0.68	0.538	12/12/1973	2.95	2.954
12/8/1996	0.11	0.107	3/16/1977	26.1	7.324	1/7/1955	0.02	0.024	3/12/1966	0.81	0.812	3/16/1962	1.6	1.598	3/15/1984	0.6	0.492	12/13/1973	2.95	2.949
12/9/1996	1.55	0.280	3/17/1977	27.8	7.204	1/8/1955	0.02	0.021	3/13/1966	0.69	0.685	3/17/1962	1.52	1.517	3/16/1984	0.52	0.462	12/14/1973	3.22	3.023
12/10/1996	13.6	0.280	3/18/1977	20.7	7.400	1/9/1955	0.08	0.081	3/14/1966	0.65	0.653	3/18/1962	1.29	1.285	3/17/1984	0.54	0.430	12/15/1973	4.17	3.193
12/11/1996	10.2	0.368	3/19/1977	17.8	6.640	1/10/1955	0.19	0.187	3/15/1966	0.39	0.385	3/19/1962	1.05	1.045	3/18/1984	0.52	0.436	12/16/1973	4.03	3.748

12/12/199	6	0.35	0.280	3/20/197	7	16.5	6.338	1/11/1955	0.12	0.124	3/16/196	6	0.34	0.341	3/20/196	2	1.03	1.033	3/19/198	4	0.52	0.430	12/17/197	3	3.49	3.486
12/13/199	6	0.35	0.300	3/21/197	7	15	6.197	1/12/1955	0.09	0.085	3/17/196	6	0.45	0.453	3/21/196	2	33.3	4.700	3/20/198	4	0.5	0.433	12/18/197	3	3.11	3.108
12/14/199	6	0.22	0.221	3/22/197	7	13.9	6.052	1/13/1955	0.07	0.070	3/18/196	6	3.02	0.610	3/22/196	2	27.1	4.743	3/21/198	4	0.47	0.423	12/19/197	3	2.92	2.919
12/15/199	6	0.13	0.133	3/23/197	7	13.5	5.946	1/14/1955	0.06	0.057	3/19/196	6	4.98	0.635	3/23/196	2	10.3	10.303	3/22/198	4	0.5	0.411	12/20/197	3	3.41	3.083
12/16/199	6	0.1	0.098	3/24/197	7	14.9	5.910	1/15/1955	0.05	0.045	3/20/196	6	1.4	1.397	3/24/196	2	2.2	2.203	3/23/198	4	0.71	0.425	12/21/197	3	4.34	3.378
12/17/199	6	0.07	0.069	3/25/197	7	15.3	6.078	1/16/1955	0.04	0.036	3/21/196	6	0.98	0.851	3/25/196	2	10.3	7.425	3/24/198	4	0.61	0.514	12/22/197	3	4.12	3.924
12/18/199	6	0.06	0.060	3/26/197	7	20.6	6.134	1/17/1955	0.03	0.034	3/22/196	6	0.53	0.525	3/26/196	2	11.2	5.414	3/25/198	4	1.97	0.366	12/23/197	3	3.57	3.565
12/19/199	6	0.05	0.052	3/27/197	7	22.9	6.721	1/18/1955	0.03	0.031	3/23/196	6	0.34	0.341	3/27/196	2	15.8	7.562	3/26/198	4	0.73	0.729	12/24/197	3	3.2	3.203
12/20/199	6	0.05	0.045	3/28/197	7	19.6	6.983	1/19/1955	0.03	0.030	3/24/196	6	0.25	0.253	3/28/196	2	17.2	7.859	3/27/198	4	0.56	0.527	12/25/197	3	3.44	3.313
12/21/199	6	0.04	0.039	3/29/197	7	18.6	6.639	1/20/1955	0.03	0.032	3/25/196	6	0.81	0.697	3/29/196	2	8.62	8.615	3/28/198	4	0.49	0.456	12/26/197	3	6.08	3.460
12/22/199	6	0.03	0.033	3/30/197	7	16.6	6.540	1/21/1955	0.03	0.034	3/26/196	6	0.95	0.796	3/30/196	2	4.28	4.276	3/29/198	4	0.47	0.428	12/27/197	3	8.47	4.990
12/23/199	6	0.03	0.031	3/31/197	7	17	6.331	1/22/1955	0.55	0.550	3/27/196	6	0.7	0.700	3/31/196	2	10.9	7.460	3/30/198	4	0.45	0.419	12/28/197	3	5.94	5.935
12/24/199	6	0.03	0.025	4/1/1977	15.8	6.392	1/23/1955	1.88	0.780	3/28/196	6	1.67	0.795	4/1/1962	7.83	6.418	3/31/198	4	0.48	0.413	12/29/197	3	4.64	4.641		
12/25/199	6	0.22	0.217	4/2/1977	25.9	6.273	1/24/1955	1.01	0.993	3/29/196	6	1.71	0.963	4/2/1962	3.99	3.985	4/1/1984	0.46	0.425	12/30/197	3	3.97	3.968			
12/26/199	6	0.38	0.293	4/3/1977	16.7	7.385	1/25/1955	0.9	0.874	3/30/196	6	1.39	0.979	4/3/1962	2.84	2.843	4/2/1984	0.41	0.413	12/31/197	3	3.48	3.484			
12/27/199	6	1.88	0.280	4/4/1977	16.3	6.399	1/26/1955	1.77	0.868	3/31/196	6	3.3	0.948	4/4/1962	2.4	2.401	4/3/1984	0.41	0.400	1/1/1974	3.88	3.593				
12/28/199	6	1.65	0.281	4/5/1977	17.5	6.363	1/27/1955	2.54	1.012	4/1/1966	3.62	0.906	4/5/1962	2.1	2.100	4/4/1984	0.37	0.372	1/2/1974	6.08	3.835					
12/29/199	6	6.7	0.387	4/6/1977	17.2	6.509	1/28/1955	1.75	1.142	4/2/1966	6.47	1.229	4/6/1962	1.41	1.406	4/5/1984	0.33	0.333	1/3/1974	22	2.855					
12/30/199	6	2.2	0.374	4/7/1977	15.3	6.487	1/29/1955	1.2	1.037	4/3/1966	4.72	1.296	4/7/1962	1.38	1.375	4/6/1984	0.31	0.309	1/4/1974	17.7	4.130					
12/31/199	6	0.8	0.661	4/8/1977	15.5	6.293	1/30/1955	0.9	0.900	4/4/1966	3.2	1.776	4/8/1962	1.28	1.278	4/7/1984	0.29	0.287	1/5/1974	20	13.272					
1/1/1997	0.52	0.406	4/9/1977	14.7	6.325	1/31/1955	0.81	0.808	4/5/1966	1.94	1.508	4/9/1962	1.04	1.043	4/8/1984	0.28	0.279	1/6/1974	14.2	10.863						
1/2/1997	0.4	0.281	4/10/197	7	26.7	6.254	2/1/1955	0.76	0.757	4/6/1966	1.5	1.116	4/10/196	2	1.03	1.031	4/9/1984	0.28	0.276	1/7/1974	10.2	10.163				
1/3/1997	0.31	0.303	4/11/197	7	35	7.567	2/2/1955	0.73	0.727	4/7/1966	1.19	1.057	4/11/196	2	1.26	1.255	4/10/198	4	0.28	0.279	1/8/1974	8.87	8.874			
1/4/1997	0.27	0.266	4/12/197	7	37.4	8.496	2/3/1955	0.76	0.757	4/8/1966	0.95	0.949	4/12/196	2	1.83	1.829	4/11/198	4	0.26	0.255	1/9/1974	7.74	6.953			
1/5/1997	0.22	0.215	4/13/197	7	38.3	8.769	2/4/1955	1.05	0.960	4/9/1966	0.78	0.775	4/13/196	2	1.86	1.863	4/12/198	4	0.25	0.248	1/10/1974	7.17	6.326			

1/6/1997	0.23	0.227	4/14/1977	51.8	8.890	2/5/1955	1.03	1.017	4/10/1966	0.64	0.642	4/14/1962	1.74	1.740	4/13/1984	0.22	0.224	1/11/1974	6.87	6.025
1/7/1997	5.09	0.281	4/15/1977	55.5	10.378	2/6/1955	0.83	0.833	4/11/1966	0.5	0.496	4/15/1962	1.4	1.395	4/14/1984	0.2	0.202	1/12/1974	6.22	5.872
1/8/1997	3.87	0.281	4/16/1977	63	5.384	2/7/1955	0.73	0.730	4/12/1966	0.43	0.432	4/16/1962	1.38	1.375	4/15/1984	0.19	0.193	1/13/1974	5.67	5.522
1/9/1997	0.87	0.570	4/17/1977	51.2	11.643	2/8/1955	0.66	0.661	4/13/1966	0.39	0.387	4/17/1962	1.63	1.628	4/16/1984	0.2	0.199	1/14/1974	5.22	5.220
1/10/1997	0.56	0.501	4/18/1977	53.4	10.379	2/9/1955	0.61	0.605	4/14/1966	0.36	0.359	4/18/1962	2.21	2.210	4/17/1984	0.2	0.202	1/15/1974	4.79	4.786
1/11/1997	0.46	0.330	4/19/1977	74.3	5.356	2/10/1955	0.51	0.510	4/15/1966	1.07	0.954	4/19/1962	1.8	1.800	4/18/1984	0.21	0.205	1/16/1974	4.28	4.275
1/12/1997	0.39	0.281	4/20/1977	60.2	5.600	2/11/1955	0.42	0.416	4/16/1966	3.15	0.917	4/20/1962	1.53	1.525	4/19/1984	0.23	0.229	1/17/1974	4.1	4.104
1/13/1997	0.36	0.303	4/21/1977	46.5	11.429	2/12/1955	0.42	0.420	4/17/1966	1.73	1.433	4/21/1962	1.38	1.380	4/20/1984	0.22	0.224	1/18/1974	4.03	4.025
1/14/1997	0.27	0.271	4/22/1977	44	9.948	2/13/1955	0.52	0.517	4/18/1966	1.37	1.215	4/22/1962	1.14	1.142	4/21/1984	0.22	0.220	1/19/1974	5.78	4.375
1/15/1997	0.22	0.221	4/23/1977	39.1	9.690	2/14/1955	0.36	0.362	4/19/1966	0.97	0.969	4/23/1962	1.15	1.146	4/22/1984	0.2	0.203	1/20/1974	31.1	3.330
1/16/1997	0.18	0.183	4/24/1977	46.2	9.180	2/15/1955	0.33	0.333	4/20/1966	0.95	0.949	4/24/1962	1.1	1.097	4/23/1984	0.19	0.190	1/21/1974	24.6	4.352
1/17/1997	0.15	0.145	4/25/1977	38.4	9.974	2/16/1955	0.3	0.304	4/21/1966	0.87	0.873	4/25/1962	1.01	1.013	4/24/1984	0.18	0.181	1/22/1974	11.7	11.710
1/18/1997	0.28	0.280	4/26/1977	45.9	9.135	2/17/1955	0.28	0.280	4/22/1966	0.76	0.758	4/26/1962	0.93	0.934	4/25/1984	0.18	0.179	1/23/1974	8.37	8.368
1/19/1997	0.35	0.297	4/27/1977	46	9.970	2/18/1955	0.32	0.319	4/23/1966	0.71	0.709	4/27/1962	0.93	0.934	4/26/1984	0.42	0.317	1/24/1974	6.6	6.600
1/20/1997	0.38	0.301	4/28/1977	32.2	10.008	2/19/1955	0.29	0.290	4/24/1966	0.75	0.746	4/28/1962	1.13	1.134	4/27/1984	0.49	0.418	1/25/1974	5.63	5.633
1/21/1997	0.35	0.302	4/29/1977	28.7	8.514	2/20/1955	0.36	0.359	4/25/1966	0.87	0.872	4/29/1962	1.42	1.424	4/28/1984	0.47	0.450	1/26/1974	5.61	5.558
1/22/1997	0.31	0.300	4/30/1977	26.3	8.144	2/21/1955	4.82	1.045	4/26/1966	1.1	1.103	4/30/1962	1.44	1.440	4/29/1984	1.09	0.442	1/27/1974	7.22	5.563
1/23/1997	0.26	0.261	5/1/1977	24.7	7.902	2/22/1955	4.23	1.069	4/27/1966	0.82	0.819	5/1/1962	1.55	1.548	4/30/1984	1.11	0.702	1/28/1974	7.08	6.511
1/24/1997	0.18	0.177	5/2/1977	33.6	7.741	2/23/1955	2.49	1.757	4/28/1966	0.75	0.747	5/2/1962	13.4	7.821	5/1/1984	0.7	0.704	1/29/1974	10.2	5.430
1/25/1997	0.58	0.281	5/3/1977	33.1	8.732	2/24/1955	2.38	1.515	4/29/1966	1.38	1.192	5/3/1962	20.1	7.927	5/2/1984	0.54	0.542	1/30/1974	123	5.370
1/26/1997	2.65	0.281	5/4/1977	37	8.687	2/25/1955	1.81	1.517	4/30/1966	0.91	0.913	5/4/1962	16	11.050	5/3/1984	0.45	0.454	1/31/1974	143	7.185
1/27/1997	0.9	0.314	5/5/1977	156	3.509	2/26/1955	1.98	1.451	5/1/1966	0.68	0.675	5/5/1962	2.97	2.970	5/4/1984	0.39	0.390	2/1/1974	66.8	66.770
1/28/1997	0.41	0.281	5/6/1977	133	3.949	2/27/1955	8.56	1.388	5/2/1966	0.58	0.577	5/6/1962	1.79	1.785	5/5/1984	0.35	0.346	2/2/1974	39.1	39.109
1/29/1997	0.28	0.281	5/7/1977	96.7	16.989	2/28/1955	8.16	1.432	5/3/1966	1.74	1.218	5/7/1962	1.46	1.460	5/6/1984	0.32	0.324	2/3/1974	28.1	28.100
1/30/1997	0.32	0.297	5/8/1977	51.3	15.756	3/1/1955	5.23	2.454	5/4/1966	0.97	0.967	5/8/1962	1.63	1.631	5/7/1984	0.3	0.300	2/4/1974	30.5	24.559

1/31/1997	0.28	0.276	5/9/1977	47.8	10.820	3/2/1955	3.28	2.426	5/5/1966	0.75	0.752	5/9/1962	2.21	2.210	5/8/1984	0.27	0.273	2/5/1974	42.4	18.329				
2/1/1997	0.21	0.214	5/10/197	7	44.2	10.461	3/3/1955	2.6	1.805	5/6/1966	0.85	0.852	5/10/196	2	1.76	1.762	5/9/1984	0.26	0.255	2/6/1974	29.7	19.753		
			5/11/197	7	38	10.091	3/4/1955	1.9	1.724	5/7/1966	0.53	0.533	5/11/196	2	1.65	1.648	5/10/198	4	0.26	0.255	2/7/1974	22.5	22.490	
2/2/1997	0.25	0.251	5/12/197	7	37.4	9.428	3/5/1955	1.5	1.499	5/8/1966	0.41	0.410	5/12/196	2	2.34	2.340	5/11/198	4	0.29	0.288	2/8/1974	18.1	18.085	
2/3/1997	0.4	0.295	5/13/197	7	35.8	9.377	3/6/1955	1.24	1.242	5/9/1966	0.36	0.363	5/13/196	2	17.8	8.913	5/12/198	4	0.32	0.324	2/9/1974	15.5	15.427	
			5/14/197	7	30.4	9.226	3/7/1955	1.1	1.102	5/10/196	6	0.38	0.375	5/14/196	2	17.9	9.180	5/13/198	4	0.28	0.279	2/10/1974	13.7	12.956
2/5/1997	0.39	0.281	5/15/197	7	163	3.950	3/8/1955	0.95	0.949	5/11/196	6	0.36	0.356	5/15/196	2	10.5	10.513	5/14/198	4	0.24	0.244	2/11/1974	12.3	11.530
			5/16/197	7	56.3	23.166	3/9/1955	0.81	0.810	5/12/196	6	0.31	0.313	5/16/196	2	8.97	8.967	5/15/198	4	0.22	0.219	2/12/1974	11.2	10.555
2/7/1997	1.47	0.281	5/17/197	7	44.9	11.540	3/10/1955	0.62	0.624	5/13/196	6	6.85	1.259	5/17/196	2	7.01	7.014	5/16/198	4	0.2	0.204	2/13/1974	10.4	9.772
			5/18/197	7	49.7	10.319	3/11/1955	0.54	0.537	5/14/196	6	2.14	1.266	5/18/196	2	2.54	2.539	5/17/198	4	0.2	0.197	2/14/1974	13.4	9.199
2/9/1997	0.65	0.364	5/19/197	7	57.7	10.865	3/12/1955	0.6	0.599	5/15/196	6	1.36	1.360	5/19/196	2	2.25	2.253	5/18/198	4	0.19	0.190	2/15/1974	11	8.765
			5/20/197	7	53.3	11.757	3/13/1955	3.33	1.502	5/16/196	6	6.35	1.605	5/20/196	2	1.89	1.885	5/19/198	4	2.06	0.178	2/16/1974	12.5	10.474
2/11/1997	0.62	0.318	5/21/197	7	37.2	11.294	3/14/1955	1.74	1.737	5/17/196	6	4.75	1.494	5/21/196	2	1.86	1.863	5/20/198	4	12.2	0.175	2/17/1974	11.3	9.191
			5/22/197	7	35.8	9.557	3/15/1955	1.23	1.225	5/18/196	6	2.62	2.328	5/22/196	2	1.99	1.993	5/21/198	4	16.3	0.965	2/18/1974	11.1	10.061
2/13/1997	0.38	0.281	5/23/197	7	60.7	4.200	3/16/1955	3.78	1.750	5/19/196	6	8.76	2.090	5/23/196	2	2.36	2.361	5/22/198	4	14.6	5.236	2/19/1974	9.6	9.405
2/14/1997	0.32	0.302	5/24/197	7	39.4	12.171	3/17/1955	3.61	1.695	5/20/196	6	9.14	1.764	5/24/196	2	12.9	10.188	5/23/198	4	4.97	4.974	2/20/1974	8.49	8.485
2/15/1997	0.29	0.293	5/25/197	7	36.2	9.856	3/18/1955	4.18	2.106	5/21/196	6	9.41	2.791	5/25/196	2	9.05	9.051	5/24/198	4	3.28	3.278	2/21/1974	7.79	7.787
2/16/1997	0.28	0.279	5/26/197	7	38.9	9.535	3/19/1955	5.86	2.107	5/22/196	6	7.72	2.883	5/26/196	2	2.61	2.611	5/25/198	4	2.39	2.232	2/22/1974	7.2	7.201
			5/27/197	7	32.9	9.842	3/20/1955	8.78	2.222	5/23/196	6	4.26	2.958	5/27/196	2	1.8	1.800	5/26/198	4	1.9	1.521	2/23/1974	7.7	7.702
2/18/1997	0.26	0.262	5/28/197	7	30	9.202	3/21/1955	4.97	2.507	5/24/196	6	3.45	2.713	5/28/196	2	1.53	1.525	5/27/198	4	1.82	1.149	2/24/1974	14.1	7.217
2/19/1997	0.35	0.296	5/29/197	7	30.1	8.903	3/22/1955	5.17	2.985	5/25/196	6	3.56	2.174	5/29/196	2	1.47	1.468	5/28/198	4	1.52	1.081	2/25/1974	12.4	7.533
2/20/1997	3.03	0.281	5/30/197	7	36.8	8.931	3/23/1955	7.05	2.442	5/26/196	6	3.91	2.066	5/30/196	2	1.44	1.443	5/29/198	4	1.27	0.957	2/26/1974	10.1	10.114
2/21/1997	0.74	0.281	5/31/197	7	41.3	9.679	3/24/1955	4.95	2.505	5/27/196	6	3.26	2.106	5/31/196	2	1.31	1.314	5/30/198	4	1.11	0.852	2/27/1974	8.49	8.486
2/22/1997	0.4	0.281	6/1/1977	39.6	10.191	3/25/1955	3.93	2.825	5/28/196	6	2.41	2.186	6/1/1962	1.13	1.127	6/1/1984	0.95	0.757	2/28/1974	8	7.995			
2/23/1997	0.31	0.304				3/26/1955	4.38	2.540	5/29/196	6	2.26	2.102	6/2/1962	1.1	1.096				3/1/1974	7.42	7.416			
2/24/1997	0.26	0.256	6/2/1977	36.1	10.024	3/26/1955	4.38	2.540	5/29/196	6	2.26	2.102	6/2/1962	1.1	1.096	6/1/1984	0.95	0.757	3/1/1974	7.42	7.416			

2/25/1997	0.22	0.215	6/3/1977	43	9.660	3/27/1955	5.53	2.419	5/30/1966	7.59	1.986	6/3/1962	1.04	1.037	6/2/1984	0.87	0.725	3/2/1974	7.78	7.781
2/26/1997	0.2	0.196	6/4/1977	49.8	10.435	3/28/1955	3.94	2.518	5/31/1966	6.76	1.983	6/4/1962	1.03	1.031	6/3/1984	1.69	0.555	3/3/1974	9.31	7.574
2/27/1997	0.21	0.212	6/5/1977	42.9	11.199	3/29/1955	3.08	2.727	6/1/1966	4.41	2.878	6/5/1962	1	0.997	6/4/1984	1.38	1.037	3/4/1974	7.58	7.575
2/28/1997	0.2	0.198	6/6/1977	37.1	10.469	3/30/1955	2.48	2.484	6/2/1966	3.11	2.774	6/6/1962	0.9	0.900	6/5/1984	4.27	0.867	3/5/1974	11.2	8.717
3/1/1997	0.18	0.180	6/7/1977	40.9	9.851	3/31/1955	1.93	1.925	6/3/1966	2.4	2.401	6/7/1962	0.88	0.877	6/6/1984	2.09	0.738	3/6/1974	9.95	7.757
3/2/1997	0.27	0.266	6/8/1977	35.1	10.292	4/1/1955	1.54	1.538	6/4/1966	2.01	2.013	6/8/1962	0.86	0.864	6/7/1984	1.45	1.215	3/7/1974	16.1	9.868
3/3/1997	0.24	0.241	6/9/1977	31.3	9.674	4/2/1955	1.29	1.285	6/5/1966	1.75	1.747	6/9/1962	0.91	0.905	6/8/1984	1.11	0.947	3/8/1974	23.3	9.185
3/4/1997	0.17	0.172	6/10/1977	7	28.5	4/3/1955	1.66	1.655	6/6/1966	1.66	1.655	6/10/1962	2	1.02	6/9/1984	0.98	0.805	3/9/1974	15.1	12.743
3/5/1997	0.16	0.163	6/11/1977	7	27	4/4/1955	5.85	2.269	6/7/1966	1.64	1.636	6/11/1962	2	1.03	6/10/1984	4	0.93	3/10/1974	12.3	12.284
3/6/1997	0.16	0.157	6/12/1977	7	26.9	4/5/1955	5.77	2.355	6/8/1966	1.52	1.520	6/12/1962	2	1.01	6/11/1984	4	1.19	3/11/1974	11.6	11.597
3/7/1997	0.15	0.146	6/13/1977	7	29.2	4/6/1955	3.76	3.026	6/9/1966	1.4	1.395	6/13/1962	2	0.94	6/12/1984	4	1.14	3/12/1974	37.1	10.723
3/8/1997	0.15	0.151	6/14/1977	7	33.5	4/7/1955	3.89	3.052	6/10/1966	6	1.27	6/14/1962	2	0.88	6/13/1984	4	0.95	3/13/1974	39.1	10.369
3/9/1997	0.45	0.281	6/15/1977	7	29.7	4/8/1955	5.48	2.786	6/11/1966	6	1.4	6/15/1962	2	0.86	6/14/1984	4	0.89	3/14/1974	23.3	23.306
3/10/1997	0.99	0.281	6/16/1977	7	45.3	4/9/1955	9.67	2.842	6/12/1966	6	3.44	6/16/1962	2	0.83	6/15/1984	4	0.9	3/15/1974	17	17.007
3/11/1997	0.29	0.281	6/17/1977	7	35.2	4/10/1955	5.18	3.121	6/13/1966	6	1.76	6/17/1962	2	0.73	6/16/1984	4	1.03	3/16/1974	14.2	14.170
3/12/1997	0.21	0.210	6/18/1977	7	42.5	4/11/1955	3.95	3.801	6/14/1966	6	1.35	6/18/1962	2	0.72	6/17/1984	4	0.96	3/17/1974	12.4	12.429
3/13/1997	3.05	0.281	6/19/1977	7	39.9	4/12/1955	6.24	3.165	6/15/1966	6	1.15	6/19/1962	2	0.69	6/18/1984	4	0.86	3/18/1974	10.9	10.949
3/14/1997	3.46	0.281	6/20/1977	7	35	4/13/1955	6.15	3.019	6/16/1966	6	1.03	6/20/1962	2	0.69	6/19/1984	4	0.82	3/19/1974	9.74	9.742
3/15/1997	1.51	0.454	6/21/1977	7	31.6	4/14/1955	5.23	3.408	6/17/1966	6	0.99	6/21/1962	2	0.78	6/20/1984	4	1.3	3/20/1974	45.6	10.439
3/16/1997	0.74	0.477	6/22/1977	7	29.2	4/15/1955	17.6	3.439	6/18/1966	6	0.96	6/22/1962	2	1.02	6/21/1984	4	1.04	3/21/1974	131	9.785
3/17/1997	0.57	0.367	6/23/1977	7	27.5	4/16/1955	17.6	3.343	6/19/1966	6	1.56	6/23/1962	2	28.7	6/22/1984	4	0.95	3/22/1974	53.6	30.440
3/18/1997	0.65	0.323	6/24/1977	7	28.5	4/17/1955	15.1	5.271	6/20/1966	6	3.4	6/24/1962	2	30.9	6/23/1984	4	0.91	3/23/1974	30	30.002
3/19/1997	0.38	0.281	6/25/1977	7	26.1	4/18/1955	9.87	5.338	6/21/1966	6	1.69	6/25/1962	2	18.5	6/24/1984	4	1	3/24/1974	21.8	21.797
3/20/1997	0.32	0.303	6/26/1977	7	24.9	4/19/1955	7.06	5.024	6/22/1966	6	2.07	6/26/1962	2	11.1	6/25/1984	4	1.01	3/25/1974	17	17.046
3/21/1997	0.57	0.281	6/27/1977	7	30	4/20/1955	5.88	4.297	6/23/1966	6	1.67	6/27/1962	2	2.87	6/26/1984	4	0.92	3/26/1974	14.5	14.465

3/22/1997	1.1	0.281	6/28/1977	23.7	9.456	4/21/1955	4.69	3.925	6/24/1966	1.37	1.373	6/28/1962	2.18	2.180	6/27/1984	0.86	0.756	3/27/1974	14	13.971
3/23/1997	0.55	0.313	6/29/1977	25.2	8.786	4/22/1955	4.3	3.795	6/25/1966	1.13	1.133	6/29/1962	1.58	1.580	6/28/1984	0.82	0.729	3/28/1974	13.3	13.292
3/24/1997	0.43	0.344	6/30/1977	23.5	8.966	4/23/1955	7.91	3.663	6/26/1966	0.99	0.991	6/30/1962	1.39	1.393	6/29/1984	0.79	0.716	3/29/1974	11.8	11.765
3/25/1997	0.35	0.281	7/1/1977	30.4	8.799	4/24/1955	44.8	3.651	6/27/1966	0.9	0.897	7/1/1962	1.15	1.151	6/30/1984	0.76	0.706	3/30/1974	10.8	10.776
3/26/1997	0.31	0.301	7/2/1977	24.1	9.573	4/25/1955	16.4	4.249	6/28/1966	0.84	0.836	7/2/1962	1.07	1.068	7/1/1984	0.73	0.694	3/31/1974	20.8	11.892
3/27/1997	0.29	0.289	7/3/1977	21.9	8.896	4/26/1955	13.2	9.934	6/29/1966	0.94	0.944	7/3/1962	1.03	1.032	7/2/1984	0.71	0.680	4/1/1974	38.9	11.369
3/28/1997	0.28	0.280	7/4/1977	21.7	8.678	4/27/1955	8.22	5.730	6/30/1966	1.1	1.101	7/4/1962	1.03	1.027	7/3/1984	0.7	0.674	4/2/1974	18.9	17.196
3/29/1997	0.23	0.233	7/5/1977	21.4	8.666	4/28/1955	6.2	5.311	7/1/1966	0.82	0.821	7/5/1962	1.01	1.006	7/4/1984	0.67	0.669	4/3/1974	14.9	14.871
3/30/1997	0.22	0.216	7/6/1977	31.7	8.653	4/29/1955	7.4	4.625	7/2/1966	0.73	0.727	7/6/1962	0.92	0.924	7/5/1984	0.65	0.647	4/4/1974	13.2	13.229
3/31/1997	0.16	0.158	7/7/1977	42.5	9.795	4/30/1955	13.9	4.376	7/3/1966	0.73	0.730	7/7/1962	0.76	0.760	7/6/1984	0.63	0.626	4/5/1974	12.2	12.237
4/1/1997	0.12	0.121	7/8/1977	82	3.949	5/1/1955	17.2	4.616	7/4/1966	0.73	0.727	7/8/1962	0.72	0.718	7/7/1984	0.59	0.592	4/6/1974	11.4	11.436
4/2/1997	0.1	0.104	7/9/1977	41.4	15.338	5/2/1955	12.3	5.671	7/5/1966	0.68	0.681	7/9/1962	0.69	0.693	7/8/1984	0.58	0.575	4/7/1974	11	11.029
4/3/1997	0.1	0.099	7/10/1977	33.3	10.927	5/3/1955	7.69	6.239	7/6/1966	0.66	0.664	7/10/1962	0.66	0.664	7/9/1984	0.57	0.572	4/8/1974	10.6	10.624
4/4/1997	0.08	0.081	7/11/1977	33.6	10.060	5/4/1955	5.95	5.584	7/7/1966	0.66	0.663	7/11/1962	0.58	0.584	7/10/1984	0.57	0.568	4/9/1974	12.3	11.987
4/5/1997	0.08	0.077	7/12/1977	30.4	10.111	5/5/1955	6.02	4.948	7/8/1966	0.58	0.583	7/12/1962	0.57	0.567	7/11/1984	0.55	0.549	4/10/1974	14.4	11.800
4/6/1997	0.35	0.285	7/13/1977	26	9.786	5/6/1955	5.54	4.747	7/9/1966	0.55	0.546	7/13/1962	0.53	0.531	7/12/1984	0.53	0.531	4/11/1974	11.4	11.380
4/7/1997	0.48	0.281	7/14/1977	24	9.320	5/7/1955	4.55	4.545	7/10/1966	0.54	0.543	7/14/1962	0.59	0.586	7/13/1984	0.52	0.519	4/12/1974	10.1	10.141
4/8/1997	0.28	0.280	7/15/1977	22.9	9.115	5/8/1955	3.7	3.703	7/11/1966	0.94	0.939	7/15/1962	1.03	1.026	7/14/1984	0.51	0.508	4/13/1974	9.4	9.398
4/9/1997	0.16	0.161	7/16/1977	21.5	9.015	5/9/1955	3.19	3.187	7/12/1966	1.85	1.850	7/16/1962	1.95	1.946	7/15/1984	0.51	0.505	4/14/1974	9.21	9.211
4/10/1997	0.11	0.106	7/17/1977	20.5	8.879	5/10/1955	3.98	3.981	7/13/1966	1.22	1.216	7/17/1962	2.23	2.230	7/16/1984	0.5	0.501	4/15/1974	8.92	8.920
4/11/1997	0.08	0.081	7/18/1977	19.6	8.783	5/11/1955	3.07	3.068	7/14/1966	0.99	0.988	7/18/1962	1.81	1.812	7/17/1984	0.5	0.496	4/16/1974	7.88	7.880
4/12/1997	0.07	0.067	7/19/1977	22.2	8.708	5/12/1955	2.62	2.620	7/15/1966	0.94	0.941	7/19/1962	1.56	1.558	7/18/1984	0.46	0.455	4/17/1974	7.66	7.660
4/13/1997	0.05	0.052	7/20/1977	28.1	9.011	5/13/1955	2.29	2.286	7/16/1966	0.84	0.842	7/20/1962	1.45	1.447	7/19/1984	0.45	0.446	4/18/1974	6.85	6.848
4/14/1997	0.05	0.051	7/21/1977	42.5	9.672	5/14/1955	2.32	2.317	7/17/1966	0.75	0.745	7/21/1962	1.24	1.241	7/20/1984	0.44	0.440	4/19/1974	6.49	6.493
4/15/1997	0.06	0.057	7/22/1977	28.1	11.263	5/15/1955	2.54	2.539	7/18/1966	0.69	0.694	7/22/1962	0.85	0.847	7/21/1984	0.43	0.434	4/20/1974	7.58	7.581

4/16/1997	0.1	0.102	7/23/1977	24.5	9.708	5/16/1955	2.72	2.724	7/19/1966	2.93	2.933	7/23/1962	0.81	0.807	7/22/1984	0.43	0.428	4/21/1974	6.75	6.754
4/17/1997	0.08	0.083	7/24/1977	22.3	9.331	5/17/1955	3.77	3.772	7/20/1966	2.8	2.796	7/24/1962	0.79	0.790	7/23/1984	0.42	0.422	4/22/1974	6.22	6.219
4/18/1997	0.07	0.066	7/25/1977	20.8	9.116	5/18/1955	3.01	3.007	7/21/1966	1.92	1.919	7/25/1962	0.77	0.772	7/24/1984	0.42	0.416	4/23/1974	6.26	6.257
4/19/1997	0.06	0.063	7/26/1977	20.1	8.966	5/19/1955	4.26	4.260	7/22/1966	1.27	1.268	7/26/1962	0.76	0.755	7/25/1984	0.41	0.410	4/24/1974	6.59	6.592
4/20/1997	0.05	0.054	7/27/1977	32.7	8.904	5/20/1955	9.92	5.174	7/23/1966	1.01	1.011	7/27/1962	0.74	0.739	7/26/1984	0.41	0.406	4/25/1974	6.16	6.155
4/21/1997	0.04	0.040	7/28/1977	39.1	10.299	5/21/1955	6.06	5.432	7/24/1966	0.87	0.868	7/28/1962	0.72	0.722	7/27/1984	0.41	0.411	4/26/1974	5.62	5.623
4/22/1997	0.03	0.031	7/29/1977	27.8	11.013	5/22/1955	5.7	5.698	7/25/1966	0.78	0.781	7/29/1962	0.76	0.757	7/28/1984	0.41	0.409	4/27/1974	5.51	5.511
4/23/1997	0.02	0.022	7/30/1977	27	9.806	5/23/1955	4.17	4.173	7/26/1966	0.74	0.742	7/30/1962	0.89	0.891	7/29/1984	0.41	0.408	4/28/1974	5.6	5.600
4/24/1997	0.01	0.014	7/31/1977	25.4	9.735	5/24/1955	3.14	3.142	7/27/1966	1.56	1.558	7/31/1962	0.86	0.859	7/30/1984	0.41	0.408	4/29/1974	5.44	5.440
4/25/1997	0.01	0.010	8/1/1977	23.7	9.575	5/25/1955	2.48	2.479	7/28/1966	1.11	1.114	8/1/1962	0.75	0.749	7/31/1984	0.41	0.408	4/30/1974	5.4	5.404
4/26/1997	0.01	0.009	8/2/1977	22	9.415	5/26/1955	1.95	1.954	7/29/1966	0.96	0.960	8/2/1962	0.73	0.734	8/1/1984	0.4	0.398	5/1/1974	5.15	5.149
4/27/1997	0.01	0.008	8/3/1977	21.5	9.246	5/27/1955	1.62	1.615	7/30/1966	0.87	0.867	8/3/1962	0.71	0.710	8/2/1984	0.38	0.384	5/2/1974	4.93	4.925
4/28/1997	0.01	0.006	8/4/1977	21.6	9.208	5/28/1955	1.42	1.424	7/31/1966	0.77	0.765	8/4/1962	0.71	0.709	8/3/1984	0.38	0.381	5/3/1974	4.7	4.702
4/29/1997	0	0.004	8/5/1977	20.9	9.230	5/29/1955	1.24	1.243	8/1/1966	0.67	0.666	8/5/1962	0.7	0.704	8/4/1984	0.38	0.378	5/4/1974	4.71	4.707
4/30/1997	0	0.003	8/6/1977	20.3	9.176	5/30/1955	1.1	1.100	8/2/1966	0.61	0.607	8/6/1962	0.69	0.693	8/5/1984	0.38	0.375	5/5/1974	4.82	4.822
5/1/1997	0	0.002	8/7/1977	19.7	9.132	5/31/1955	1.01	1.006	8/3/1966	0.57	0.566	8/7/1962	0.66	0.660	8/6/1984	0.37	0.373	5/6/1974	4.52	4.519
5/2/1997	0	0.002	8/8/1977	19.2	9.079	6/1/1955	0.96	0.959	8/4/1966	0.53	0.532	8/8/1962	0.56	0.561	8/7/1984	0.37	0.370	5/7/1974	4.3	4.295
5/3/1997	0	0.001	8/9/1977	18.6	9.043	6/2/1955	0.92	0.919	8/5/1966	0.51	0.510	8/9/1962	0.54	0.543	8/8/1984	0.37	0.367	5/8/1974	4.18	4.176
5/4/1997	0.42	0.281	8/10/1977	18.3	8.995	6/3/1955	0.88	0.880	8/6/1966	0.48	0.481	8/10/1962	0.58	0.577	8/9/1984	0.35	0.353	5/9/1974	4.13	4.130
5/5/1997	0.07	0.066	8/11/1977	17.9	8.979	6/4/1955	0.85	0.845	8/7/1966	0.59	0.591	8/11/1962	0.57	0.571	8/10/1984	0.36	0.358	5/10/1974	4.4	4.398
5/6/1997	0.02	0.016	8/12/1977	17.1	8.955	6/5/1955	0.83	0.832	8/8/1966	2.39	2.394	8/12/1962	0.55	0.545	8/11/1984	0.41	0.405	5/11/1974	4.07	4.066
5/7/1997	0.02	0.017	8/13/1977	16.6	8.884	6/6/1955	2.74	2.739	8/9/1966	2	1.997	8/13/1962	0.54	0.544	8/12/1984	0.4	0.397	5/12/1974	4.33	4.332
5/8/1997	0.02	0.017	8/14/1977	16.3	8.847	6/7/1955	1.54	1.543	8/10/1966	1.32	1.323	8/14/1962	0.62	0.624	8/13/1984	0.39	0.393	5/13/1974	4.43	4.429
5/9/1997	0.01	0.010	8/15/1977	15.9	8.826	6/8/1955	1.35	1.354	8/11/1966	1.06	1.060	8/15/1962	0.89	0.892	8/14/1984	0.4	0.396	5/14/1974	4.36	4.363
5/10/1997	0.01	0.005	8/16/1977	15.6	8.806	6/9/1955	1.2	1.197	8/12/1966	0.92	0.919	8/16/1962	1.02	1.023	8/15/1984	0.41	0.409	5/15/1974	5.06	5.063

5/11/1997	0	0.002	8/17/1977	15.3	8.785	6/10/1955	1.28	1.276	8/13/1966	0.77	0.765	8/17/1962	1.14	1.140	8/16/1984	0.39	0.387	5/16/1974	5.01	5.010
5/12/1997	0	0.000	8/18/1977	14.9	8.764	6/11/1955	5.35	5.354	8/14/1966	0.71	0.713	8/18/1962	1.45	1.447	8/17/1984	0.39	0.387	5/17/1974	4.85	4.853
5/13/1997	0	0.000	8/19/1977	14.5	8.743	6/12/1955	11.2	6.681	8/15/1966	0.67	0.667	8/19/1962	1.36	1.356	8/18/1984	0.39	0.389	5/18/1974	4.82	4.816
5/14/1997	0	0.000	8/20/1977	14	8.710	6/13/1955	9.01	7.390	8/16/1966	0.65	0.645	8/20/1962	1.03	1.027	8/19/1984	0.39	0.387	5/19/1974	5.08	5.084
5/15/1997	0	0.000	8/21/1977	13.5	8.672	6/14/1955	8.28	8.283	8/17/1966	0.62	0.621	8/21/1962	0.95	0.945	8/20/1984	0.43	0.428	5/20/1974	5.35	5.354
5/16/1997	0	0.001	8/22/1977	13	8.635	6/15/1955	16.6	8.153	8/18/1966	0.6	0.599	8/22/1962	0.92	0.921	8/21/1984	0.64	0.614	5/21/1974	4.9	4.901
5/17/1997	0	0.004	8/23/1977	12.5	8.597	6/16/1955	7.15	7.148	8/19/1966	0.57	0.573	8/23/1962	0.83	0.832	8/22/1984	0.63	0.633	5/22/1974	4.82	4.816
5/18/1997	0.01	0.005	8/24/1977	12	8.559	6/17/1955	4.7	4.704	8/20/1966	0.54	0.542	8/24/1962	0.73	0.731	8/23/1984	0.6	0.603	5/23/1974	4.59	4.590
5/19/1997	0.01	0.007	8/25/1977	11.5	8.522	6/18/1955	3.53	3.528	8/21/1966	0.52	0.518	8/25/1962	0.72	0.717	8/24/1984	0.51	0.506	5/24/1974	4.46	4.458
5/20/1997	0.02	0.015	8/26/1977	11	8.484	6/19/1955	2.75	2.754	8/22/1966	0.49	0.490	8/26/1962	0.69	0.693	8/25/1984	0.48	0.475	5/25/1974	4.27	4.271
5/21/1997	0.02	0.015	8/27/1977	10.8	8.449	6/20/1955	2.32	2.317	8/23/1966	0.5	0.501	8/27/1962	0.69	0.692	8/26/1984	0.43	0.434	5/26/1974	4.24	4.238
5/22/1997	0.01	0.008	8/28/1977	10.7	8.444	6/21/1955	2.95	2.948	8/24/1966	0.51	0.511	8/28/1962	0.69	0.692	8/27/1984	0.42	0.422	5/27/1974	4.19	4.191
5/23/1997	0	0.004	8/29/1977	10.6	8.446	6/22/1955	5.07	5.068	8/25/1966	0.47	0.466	8/29/1962	0.67	0.672	8/28/1984	0.42	0.419	5/28/1974	4.41	4.409
5/24/1997	0	0.002	8/30/1977	10.5	8.448	6/23/1955	12.6	8.081	8/26/1966	0.44	0.437	8/30/1962	0.59	0.594	8/29/1984	0.41	0.408	5/29/1974	4.98	4.975
5/25/1997	0	0.001	8/31/1977	10.3	8.450	6/24/1955	15.8	8.509	8/27/1966	0.42	0.416	8/31/1962	0.53	0.532	8/30/1984	0.37	0.370	5/30/1974	4.65	4.649
5/26/1997	0	0.000	9/1/1977	10.2	8.452	6/25/1955	12.5	9.765	8/28/1966	0.4	0.402	9/1/1962	0.53	0.528	8/31/1984	0.36	0.362	5/31/1974	4.1	4.103
5/27/1997	0	0.000	9/2/1977	10.1	8.454	6/26/1955	8.88	8.882	8/29/1966	0.38	0.380	9/2/1962	0.53	0.528	9/1/1984	0.35	0.346	6/1/1974	4.15	4.146
5/28/1997	0	0.001	9/3/1977	10	8.457	6/27/1955	6.84	6.844	8/30/1966	0.36	0.360	9/3/1962	0.5	0.499	9/2/1984	0.33	0.329	6/2/1974	5.78	5.784
5/29/1997	0	0.002	9/4/1977	10	8.470	6/28/1955	9.79	9.594	8/31/1966	0.51	0.506	9/4/1962	0.42	0.417	9/3/1984	0.33	0.328	6/3/1974	5.19	5.193
5/30/1997	0	0.001	9/5/1977	10	8.486	6/29/1955	8.27	8.268	9/1/1966	0.74	0.738	9/5/1962	0.41	0.412	9/4/1984	0.33	0.327	6/4/1974	4.09	4.086
5/31/1997	0	0.000	9/6/1977	10	8.502	6/30/1955	6.64	6.635	9/2/1966	0.55	0.551	9/6/1962	0.41	0.405	9/5/1984	0.33	0.326	6/5/1974	4.11	4.110
6/1/1997	0	0.000	9/7/1977	10	8.518	7/1/1955	5.04	5.040	9/3/1966	0.46	0.457	9/7/1962	0.39	0.386	9/6/1984	0.33	0.328	6/6/1974	9.05	9.050
6/2/1997	0	0.000	9/8/1977	10	8.534	7/2/1955	3.86	3.856	9/4/1966	0.42	0.416	9/8/1962	0.39	0.385	9/7/1984	0.35	0.350	6/7/1974	17.3	10.315
6/3/1997	0	0.000	9/9/1977	9.94	8.550	7/3/1955	2.92	2.915	9/5/1966	0.39	0.393	9/9/1962	0.39	0.385	9/8/1984	0.35	0.350	6/8/1974	12.1	12.123
6/4/1997	0	0.000	9/10/1977	9.82	8.556	7/4/1955	2.59	2.589	9/6/1966	0.39	0.386	9/10/1962	0.39	0.388	9/9/1984	0.34	0.344	6/9/1974	8.25	8.249

6/5/1997	0	0.000	9/11/1977	9.69	8.558	7/5/1955	2.35	2.347	9/7/1966	0.39	0.389	9/11/1962	0.4	0.398	9/10/1984	0.32	0.323	6/10/1974	6.81	6.812
6/6/1997	0	0.000	9/12/1977	9.57	8.561	7/6/1955	2.32	2.321	9/8/1966	0.39	0.393	9/12/1962	0.4	0.401	9/11/1984	0.32	0.316	6/11/1974	6.14	6.137
6/7/1997	0	0.000	9/13/1977	9.44	8.563	7/7/1955	5.94	5.943	9/9/1966	0.39	0.394	9/13/1962	0.41	0.411	9/12/1984	0.33	0.326	6/12/1974	5.65	5.649
6/8/1997	0	0.000	9/14/1977	9.31	8.566	7/8/1955	11	9.851	9/10/1966	0.43	0.432	9/14/1962	0.41	0.412	9/13/1984	0.42	0.420	6/13/1974	5.22	5.224
6/9/1997	0	0.000	9/15/1977	9.19	8.568	7/9/1955	8.05	8.053	9/11/1966	0.39	0.393	9/15/1962	0.58	0.578	9/14/1984	0.43	0.428	6/14/1974	4.89	4.894
6/10/1997	0	0.000	9/16/1977	9.12	8.571	7/10/1955	5.8	5.797	9/12/1966	0.37	0.373	9/16/1962	1.12	1.117	9/15/1984	0.33	0.331	6/15/1974	4.75	4.752

