6. CONCLUSION

6.1. Synthesis

The regional hydraulic characterisation study in combination with the recharge investigation together with the isotope and hydrochemical analysis formed the basis of the conceptual hydrogeological model. The Limpopo basement rocks can be characterised by a generally thin regolith (≈20 m) and groundwater aquifers are primarily structurally controlled. Although the weathered zone is capable of storing water and transmitting it to the fractured bedrock, the general lack of recharge (≈2 % of MAP) implies an important circulation in the underlying fractured zone of the bedrock which is recharged along vertical to sub-vertical fractures with lateral flow along horizontal to sub-horizontal fracture systems. The groundwater table reflects topography showing an overall gradient towards the catchment (basin) outlet. Locally, however, groundwater flow directions are controlled by fracture orientation. On a regional scale the aquifer can be regarded as (semi-)confined and capable of receiving diffuse recharge, but its water supply potential is primarily dependent on groundwater flow in discrete fractures in the weathered-fractured bedrock which are hydraulically connected. Due to the irregular groundwater flow pattern which is determined by the fracture system, groundwater is mostly a mixture of waters with different ages.

These composite weathered-fractured aquifer systems do not satisfy the underlying assumptions for porous media, and the inherent heterogeneity needs to be considered in groundwater investigations. A commonly encountered problem in crystalline aquifers is how to conceptualize their hydrogeological behaviour in order to determine long term abstraction rates and estimate aquifer properties. Advances in hydrogeological well test interpretation software over the last few years, such as derivative plots, flow regime tools and automatic curve fitting of a range of analytical solutions, have made the interpretation of pumping test data easier. But the applicability of a certain model (i.e. leaky, double porosity) to an observed dataset especially in fractured bedrock aquifers still requires a clear understanding of the fundamental principles and assumptions governing the analytical solution. This thesis proposes modern methods for the analysis of pumping test data in crystalline basement aquifers and highlights the importance of diagnostic plots, especially derivatives, for the detection of flow regimes and the choice of the correct 'theoretical' model. The analysis of drawdown responses showed that all typical conceptual models can occur in the weather-fractured basement rocks and can be related to the physical parameters that control them at the specific scale of interest (i.e. fractured aquifer behaves in some instances identically to an unconsolidated medium).

Several geological and geomorphologic factors including structural features have been identified as most suitable targets for further groundwater exploration and an improved conceptual understanding for groundwater occurrence in the basement aquifers of the Limpopo Province was developed. The most obvious variation in borehole yield and transmissivity can be related to different lithologies and rock types. Although it is expected that a thicker regolith should enhance borehole productivity, the poor correlation between borehole yield and weathering thickness suggests that high yields are predominantly related to a geological structure at depth as reflected by the average waters strike depth of 30 m. While the metamorphic aureoles of the granite batholiths present good conditions regarding groundwater supply, the granitic body itself can be considered as a poor target. Alluvial deposits, mainly composed of permeable material have high groundwater supply potential but may be limited in extent and are vulnerable to pollution. Favourable drilling targets are also along major rivers and topographic lows (i.e. valleys). Dykes are generally considered barriers to groundwater flow and in some instances can be regarded as part of the host rock with no difference in permeability. These magnetic anomalies may present overrated targets for groundwater exploration with often disappointing results unless their strike direction and geological setting is considered.

Specific lineament orientations have been identified which may provide above average yields and transmissivities. However, further intrusive investigations are needed to confirm whether these identified lineament orientations do indeed offer higher groundwater potential. Due to the complex geological history of the area, it is difficult to link these open discontinuities to a distinct recent or past tectonic event. The regional stress field data, as in this case, may not account for local, possibly highly significant, stress field variations.

It can be concluded, as in so many other basement aquifer investigations (i.e. Wright, 1992), that despite the apparent influence of regional factors on groundwater occurrence, the complexity of the weathered-fractured aquifer system suggests an over-riding influence of local features, which results in significant variations in yield and response to abstraction.

6.2. Recommendations and suggestions for future investigations

It has been shown that the recommended ‘sustainable’ borehole yields can exceed the annual recharge, which emphasises the fact that simply recommending a borehole yield without considering the cumulative influence it may have on the environment can be to the long-term detriment of the system (i.e. decrease discharges). In this regard there is also a need to accurately identify and quantify potential groundwater discharge zones. A recommended long term basin yield should be based on recharge (including rainfall variability) and baseflow studies, pumping test interpretation, and numerical models.

In terms of pumping tests, proper planning and execution of a test will yield reliable data and enable the user to estimate realistic parameter values along with ‘sustainable’ yields. Observation boreholes are often monitored haphazardly by contractors without understanding the importance of the observed results. The following procedure is recommended: A step drawdown test (minimum 4 steps of 1 hour each) to locate the depth of the main water strike as well as to determine a suitable abstraction rate for the constant discharge test and to determine well loss.

- The constant discharge rate should ideally reach 80-90% of the available drawdown after one or two days and maintain it for another day if the drawdown stabilises in order to stress the aquifer sufficiently. Otherwise the test should continue until failure of the borehole.

- At least one observation borehole at a distance of 20 to 50 m from the abstraction borehole should be installed and monitored at regular intervals to determine the spatial extent of drawdown. The confidence of determined hydraulic parameters increases significantly as the monitoring borehole allows the direct determination of storativity values.
- A sound conceptual model for the aquifer including locations and distances to potential flow boundaries needs to be developed and applied for the interpretation of the test. The model will determine the choice of analytical solution employed for the interpretation of the test.

Despite a number of site-specific studies within this thesis, the focus was mainly on a regional scale. It is hoped that in future more site specific studies will be undertaken to enhance the understanding of both aquifer behaviour and the occurrence of groundwater. This relates mostly to:

- A better understanding of the hydraulic connection between the regolith and the underlying fractured bedrock,
- the origins of (high) nitrates in the Limpopo basement aquifers, with special reference to nitrogen isotopes,
- expand on the knowledge of groundwater ages and mixing by using common isotopes as well as recent tracers such as CFCs and $^{3}H/^{3}He$,
- with this in mind the occurrence of deep-seated groundwater should be investigated with the purpose of proving or disproving the presence of deep, more regional groundwater flow systems,
- delineation of aquifer system and resource units,
- in order to better identify the structural controls on groundwater more intensive site-specific studies be conducted with a comprehensive drilling program, and
- the following questions should also be addressed in future research: how much water is available and exploitable?, and what are the needs for water (i.e. development and ecological Reserve)?

6.2.1. Groundwater management

Water management issues differ from place to place, depending on various factors but generally upon the overall availability of water and water demand. In South Africa, despite the new national water Act (1998) which includes excellent general protection measures, the challenge lies in the implementation of the available approaches and instruments. Perhaps one of the biggest weights lies on water service providers to convey the value of groundwater to the communities. Groundwater resource management has to deal with balancing the exploitation of a complex resource (in terms of quantity and quality) with the increasing demands of water and land users (who can pose a threat to the resource availability and quality).